Attachment 1

W3F1-2015-0056

Report WCAP-17969-NP, Revision 0, dated April 2015, "Analysis of Capsule 83° from the Entergy Operations, Inc. Waterford Unit 3 Reactor Vessel Radiation Surveillance Program"

(255 pages)

WCAP-17969-NP
Revision 0

April 2015

Analysis of Capsule 83° from the Entergy Operations, Inc. Waterford Unit 3 Reactor Vessel Radiation Surveillance Program

Westinghouse

WCAP-17969-NP
Revision 0

Analysis of Capsule 83° from the Entergy Operations, Inc. Waterford Unit 3 Reactor Vessel Radiation Surveillance Program

Benjamin A. Rosier*
Materials Center of Excellence

Arzu Alpan*
Radiation Engineering and Analysis

April 2015

Verifiers: Elliot J. Long*
Materials Center of Excellence

Eugene T. Hayes*
Radiation Engineering and Analysis

Approved: Frank C. Gift*, Manager
Materials Center of Excellence

Laurent P. Houssay*, Manager
Radiation Engineering and Analysis

Westinghouse Electric Company LLC
1000 Westinghouse Drive
Cranberry Township, PA 16066, USA

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The purpose of this report is to document the testing results of surveillance Capsule 83° from Waterford Unit 3. Capsule 83° was removed at 24.66 EFPY and post-irradiation mechanical tests of the Charpy V-notch and tensile specimens were performed. A fluence evaluation utilizing the neutron transport and dosimetry cross-section libraries was derived from the ENDF/B-VI database. Capsule 83° received a fluence of 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV) after irradiation to 24.66 EFPY. The peak clad/base metal interface vessel fluence after 24.66 EFPY of plant operation was 2.02 x 10^{19} n/cm^2 (E > 1.0 MeV).

This evaluation led to the following conclusions: 1) The measured percent decreases in upper-shelf energy for the surveillance plate and weld materials contained in Waterford Unit 3 Capsule 83° are less than the Regulatory Guide 1.99, Revision 2 [Ref. 1] predictions. 2) The Waterford Unit 3 surveillance plate data are judged to be non-credible. The Waterford Unit 3 surveillance weld (Heat # 88114) data are judged to be credible. This credibility evaluation can be found in Appendix D. 3) With consideration of surveillance data, all beltline materials exhibit adequate upper-shelf energy levels for continued safe plant operation and are predicted to maintain an upper-shelf energy greater than 50 ft-lb through end-of-license (32 EFPY) as required by 10 CFR 50, Appendix G [Ref. 2]. The upper-shelf energy evaluation is presented in Appendix E.

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 83°, the third capsule removed and tested from the Waterford Unit 3 reactor pressure vessel, led to the following conclusions:

- Charpy V-notch test data were plotted using a symmetric hyperbolic tangent curve-fitting program. Appendix C presents the CVGRAPH, Version 6.0, Charpy V-notch plots for Capsule 83° and previous capsules, along with the program input data.

- Capsule 83° received an average fast neutron fluence (E > 1.0 MeV) of 2.42 x 10^{19} n/cm^2 after 24.66 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel Lower Shell Plate M-1004-2 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 0.1°F and an irradiated 50 ft-lb transition temperature of 35.3°F. This results in a 30 ft-lb transition temperature increase of 13.6°F and a 50 ft-lb transition temperature increase of 23.6°F for the longitudinally oriented specimens.

- Irradiation of the reactor vessel Lower Shell Plate M-1004-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), resulted in an irradiated 30 ft-lb transition temperature of 0.8°F and an irradiated 50 ft-lb transition temperature of 37.4°F. This results in a 30 ft-lb transition temperature increase of 25.3°F and a 50 ft-lb transition temperature increase of 34.6°F for the transversely oriented specimens.

- Irradiation of the Surveillance Program Weld Material (Heat # 88114) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -65.4°F and an irradiated 50 ft-lb transition temperature of -44.0°F. This results in a 30 ft-lb transition temperature increase of 19.0°F and a 50 ft-lb transition temperature increase of 21.0°F.

- Irradiation of the Heat Affected Zone (HAZ) Material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -84.3°F and an irradiated 50 ft-lb transition temperature of -37.5°F. This results in a 30 ft-lb transition temperature increase of 32.7°F and a 50 ft-lb transition temperature increase of 52.6°F.

- The average upper-shelf energy of Lower Shell Plate M-1004-2 (longitudinal orientation) resulted in an average energy decrease of 12 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 158 ft-lb for the longitudinally oriented specimens.

- The average upper-shelf energy of Lower Shell Plate M-1004-2 (transverse orientation) resulted in an average energy decrease of 3 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 138 ft-lb for the transversely oriented specimens.

- The average upper-shelf energy of the Surveillance Program Weld Material (Heat # 88114) Charpy specimens resulted in an average energy decrease of 23 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 133 ft-lb for the weld metal specimens.

- The average upper-shelf energy of the HAZ Material Charpy specimens resulted in an average energy decrease of 12 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 158 ft-lb for the HAZ Material.

- Comparisons of the measured 30 ft-lb shift in transition temperature values and upper-shelf energy decreases to those predicted by Regulatory Guide 1.99, Revision 2 [Ref. 1] for the Waterford Unit 3 reactor vessel surveillance materials are presented in Table 5-10.

  Standard Reference Material (SRM) HSST 01 Charpy specimens were not included in the Waterford Unit 3 Capsule 83°. However, the SRM HSST 01 Charpy specimens were reanalyzed in this report. The SRM HSST 01 material was contained in Capsule 263°, which was irradiated to a neutron fluence of 1.45 x 10^{19} n/cm^2 (E > 1.0 MeV). The results of the SRM HSST 01 reanalysis will be included in Table 5-10 and shown in Figures 5-13 through 5-15.

  - Irradiation of the SRM HSST 01 Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 185.0°F and an irradiated 50 ft-lb transition temperature of 211.4°F. This results in a 30 ft-lb transition temperature increase of 150.5°F and a 50 ft-lb transition temperature increase of 151.3°F.

  - The average upper-shelf energy of the SRM HSST 01 Charpy specimens resulted in an average energy decrease of 20 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 113 ft-lb.

- Based on the credibility evaluation presented in Appendix D, the Waterford Unit 3 surveillance plate data is non-credible, and the surveillance weld (Heat # 88114) data is credible.

- Based on the upper-shelf energy evaluation in Appendix E, all beltline materials contained in the Waterford Unit 3 reactor vessel exhibit adequate upper-shelf energy levels for continued safe plant operation and are predicted to maintain an upper-shelf energy greater than 50 ft-lb through end-of-license (32 EFPY) as required by 10 CFR 50, Appendix G [Ref. 2].

- The maximum calculated 32 EFPY (end-of-license) neutron fluence (E > 1.0 MeV) for the Waterford Unit 3 reactor vessel beltline using the Regulatory Guide 1.99, Revision 2 attenuation formula (i.e., Equation #3 in the Guide) is as follows:

  Calculated (32 EFPY): Vessel clad/base metal interface fluence* = 2.57 x 10^{19} n/cm^2
  Vessel 1/4 thickness fluence = 1.53 x 10^{19} n/cm^2

  *This fluence value is documented in Table 6-6

2 INTRODUCTION

This report presents the results of the examination of Capsule 83°, the third capsule removed and tested in the continuing surveillance program, which monitors the effects of neutron irradiation on the Entergy Operations, Inc. Waterford Unit 3 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Waterford Unit 3 reactor pressure vessel materials was designed and recommended by Combustion Engineering, Inc. A detailed description of the surveillance program is contained in TR-C-MCS-001 [Ref. 3], "Summary Report on Manufacture of Test Specimens and Assembly of Capsules for Irradiation Surveillance of Waterford-Unit 3 Reactor Vessel Materials." The pre-irradiation mechanical properties of the reactor vessel materials are presented in TR-C-MCS-002 [Ref. 4]. The surveillance program is generally described in C-NLM-003, Revision 1 [Ref. 5]. It was originally planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-73 [Ref. 6], "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels." Capsule 83° was removed from the reactor after 24.66 EFPY of exposure and shipped to the Westinghouse Materials Center of Excellence 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 and post-irradiation data obtained from surveillance Capsule 83° removed from the Waterford Unit 3 reactor vessel and discusses the analysis of the data.

3 BACKGROUND

The ability of the large steel pressure vessel containing the reactor core and its primary coolant to resist fracture constitutes an important factor in ensuring safety in the nuclear industry. The beltline region of the reactor pressure vessel is the most critical region of the vessel because it is subjected to significant fast neutron bombardment. The overall effects of fast neutron irradiation on the mechanical properties of low-alloy, ferritic pressure vessel steels such as SA533 Grade B Class 1 (base material of the Waterford 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 [Ref. 7]. 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 E208 [Ref. 8]) 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 Section XI of the ASME Code [Ref. 7]. 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 Waterford Unit 3 reactor vessel radiation surveillance program, in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens are 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 (initial RT_{NDT} + M + ΔRT_{NDT}) is used to index the material to the K_{Ic} curve and, in turn, to set operating limits for the nuclear power plant that take into account the effects of irradiation on the reactor vessel materials.

4 DESCRIPTION OF PROGRAM

Six surveillance capsules for monitoring the effects of neutron exposure on the Waterford Unit 3 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant startup. The six capsules were positioned in the reactor vessel, as shown in Figure 4-1, between the core barrel and the vessel wall, at various azimuthal locations. The vertical center of the capsules is opposite the vertical center of the core. The capsules contain specimens made from the following:

- Lower Shell Plate M-1004-2 (longitudinal orientation)
- Lower Shell Plate M-1004-2 (transverse orientation)
- Weld metal fabricated with weld wire Heat Number 88114, Linde Type 0091 flux, which is equivalent to the heat number and Flux Type used in the actual fabrication of the intermediate shell to lower shell circumferential weld seam
- Weld heat affected zone (HAZ) material of Lower Shell Plate M-1004-2
- Standard Reference Material (SRM) Heavy-Section Steel Technology (HSST)-01MY Plate

Test material obtained from the lower shell plate (after thermal heat treatment and forming of the plate) was taken at least one plate thickness from the quenched edges of the plate. All test specimens were machined from the ¼ thickness location of the plate after performing a simulated post-weld stress-relieving treatment on the test material. Weld test specimens were removed from the weld metal of a stress-relieved weldment joining Lower Shell Plate M-1004-1 and adjacent Lower Shell Plate M-1004-3. All heat affected zone specimens were obtained from the weld heat affected zone of Lower Shell Plate M-1004-2.

Charpy V-notch impact specimens from Lower Shell Plate M-1004-2 were machined in the longitudinal orientation (longitudinal axis of the specimen parallel to the major rolling direction) and also in the transverse orientation (longitudinal axis of the specimen perpendicular to the major rolling direction). The core-region weld Charpy impact specimens were machined from the weldment such that the long dimension of each Charpy specimen was perpendicular (normal) 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 Lower Shell Plate M-1004-2 were machined in the transverse orientation only. Tensile specimens from the weld metal were oriented perpendicular to the welding direction.

Some of the Waterford Unit 3 capsules, specifically the previously tested Capsule 263° and also Capsule 104°, which is still in the reactor vessel, contain SRM, which was supplied by the Oak Ridge National Laboratory, from plate materials used in the HSST Program. The material for the Waterford Unit 3 Capsules was obtained from an A533, Grade B Class 1 plate labeled HSST 01. The plate was produced by the Lukens Steel Company and heat treated by Combustion Engineering, Inc.

All six capsules contain flux monitor assemblies that include sulfur pellets, iron wire, titanium wire, nickel wire *(cadmium-shielded)*, aluminum-cobalt wire *(cadmium-shielded and unshielded)*, copper wire *(cadmium-shielded)* and uranium foil *(cadmium-shielded and unshielded)*.

The capsules contain (12 total) thermal monitors made from four low-melting-point eutectic alloys, which were sealed in glass tubes. These thermal monitors were located in three different positions in the capsule. These thermal monitors are used to define the maximum temperature attained by the test specimens during irradiation. The composition of the four eutectic alloys and their melting points are as follows:

80.0% Au, 20.0% Sn	Melting Point: 536°F (280°C)
5.0% Ag, 5.0% Sn, 90.0% Pb	Melting Point: 558°F (292°C)
2.5% Ag, 97.5% Pb	Melting Point: 580°F (304°C)
1.75% Ag, 0.75% Sn, 97.5% Pb	Melting Point: 590°F (310°C)

The chemical composition and the arrangement of the various mechanical specimens in Capsule 83° are presented in Tables 4-1 and 4-2, respectively. The data in Tables 4-1 and 4-2 was obtained from the original surveillance program report, TR-C-MCS-001 [Ref. 3], Tables III and XX.

Capsule 83° was removed after 24.66 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch and tensile specimens, dosimeters, and thermal monitors. Figures 4-1 through 4-4 detail the arrangement of the surveillance capsules, an example of an original program surveillance capsule, a close-up of the Charpy impact specimen compartment, and the tensile and flux-monitor compartment assembly in the Waterford Unit 3 reactor vessel. Capsules 83°, 97°, 263° and 277° are radiologically equivalent to the 7° azimuth, while Capsules 104° and 284° are radiologically equivalent to the 14° azimuth.

Table 4-1 Chemical Composition (wt. %) of the Waterford Unit 3 Reactor Vessel Surveillance Materials (Unirradiated)

Element	Lower Shell Plate M-1004-2[a]	Standard Reference Material HSST 01MY Plate[b]	Surveillance Weld Material	
			Original CE Analysis[c]	Best-Estimate Analysis[d]
C	0.23	---	0.23	---
Mn	1.38	---	1.35	---
P	0.005	---	0.008	---
S	0.005	---	0.006	---
Si	0.23	---	0.16	---
Ni	**0.58**	**0.66**	**0.22**	**0.16**
Mo	0.57	---	0.57	---
Cr	0.01	---	0.05	---
Cu	**0.03**	**0.18**	**0.04**	**0.05**
Al	0.016	---	0.016	---
Co	0.009	---	0.007	---
Pb	<0.001	---	<0.001	---
W	<0.01	---	<0.01	---
Ti	<0.01	---	<0.01	---
Zr	<0.001	---	<0.001	---
V	0.002	---	0.005	---
Sn	0.002	---	0.001	---
As	0.018	---	0.001	---
Cb	<0.01	---	<0.01	---
Sb	0.0015	---	0.0011	---
N_2	0.009	---	0.009	---
B	<0.001	---	<0.001	---

Notes:

(a) Data obtained from TR-C-MCS-001, Table III [Ref. 3]

(b) Data obtained from NUREG/CR-6413 [Ref. 9].

(c) Data obtained from TR-C-MCS-001, Table III [Ref. 3]. Weld Wire Heat Number 88114, Flux Type Linde 0091.

(d) Best-Estimate Cu and Ni wt. % values were taken from WCAP-16088-NP, Revision 2 [Ref. 10].

Table 4-2 Arrangement of Encapsulated Test Specimens within Waterford Unit 3 Capsule 83°

Compartment Position[(a)]	Compartment Number (Specimen Type and Material)[(a)]	Specimen Numbers[(a)]
1	E114 (Tensile HAZ Specimens)	4J3, 4KB, 4JC
2	E124 (Charpy Impact HAZ Specimens)	47M, 454, 42E, 41Y, 45A, 472, 44K, 45U, 43J, 45L, 457, 46K
3	E131 (Charpy Impact Longitudinal Plate Specimens)	14E, 115, 15L, 12B, 116, 15M, 145, 11C, 14J, 114, 12U, 13P
4	E142 (Tensile Transverse Plate Specimens)	2J3, 2L7, 2K4
5	E152 (Charpy Impact Transverse Plate Specimens)	225, 261, 25Y, 23T, 21A, 226, 25L, 231, 22K, 24L, 21Y, 222
6	E163 (Charpy Impact Weld Specimens)	325, 3A2, 37B, 337, 312, 347, 31L, 35P, 371, 31P, 334, 34P
7	E173 (Tensile Weld Specimens)	3K5, 3KD, 3L3

Note:

(a) Data obtained from TR-C-MCS-001, Table XIX and/or Table XX [Ref. 3].

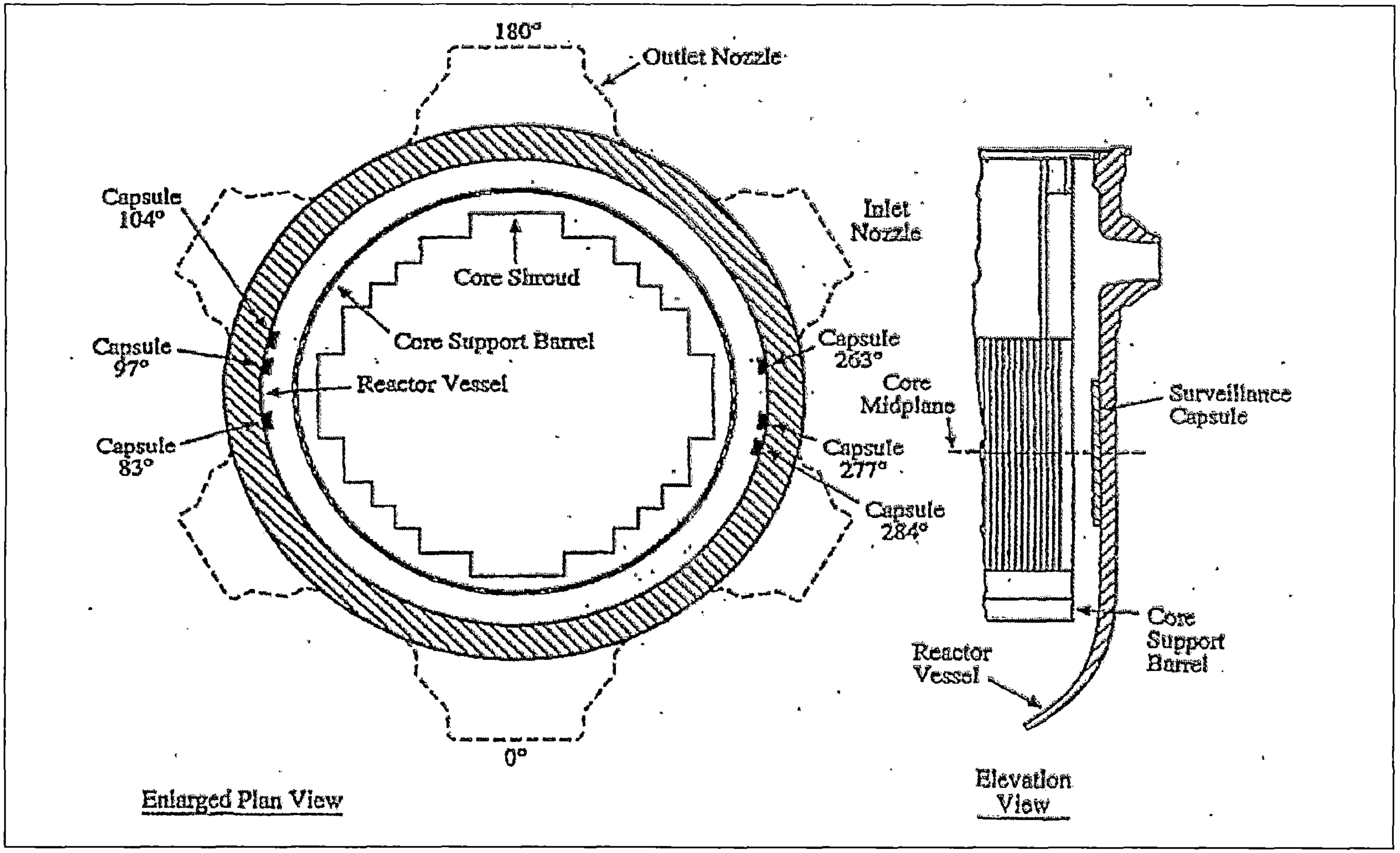


Figure 4-1 Arrangement of Surveillance Capsules in the Waterford Unit 3 Reactor Vessel

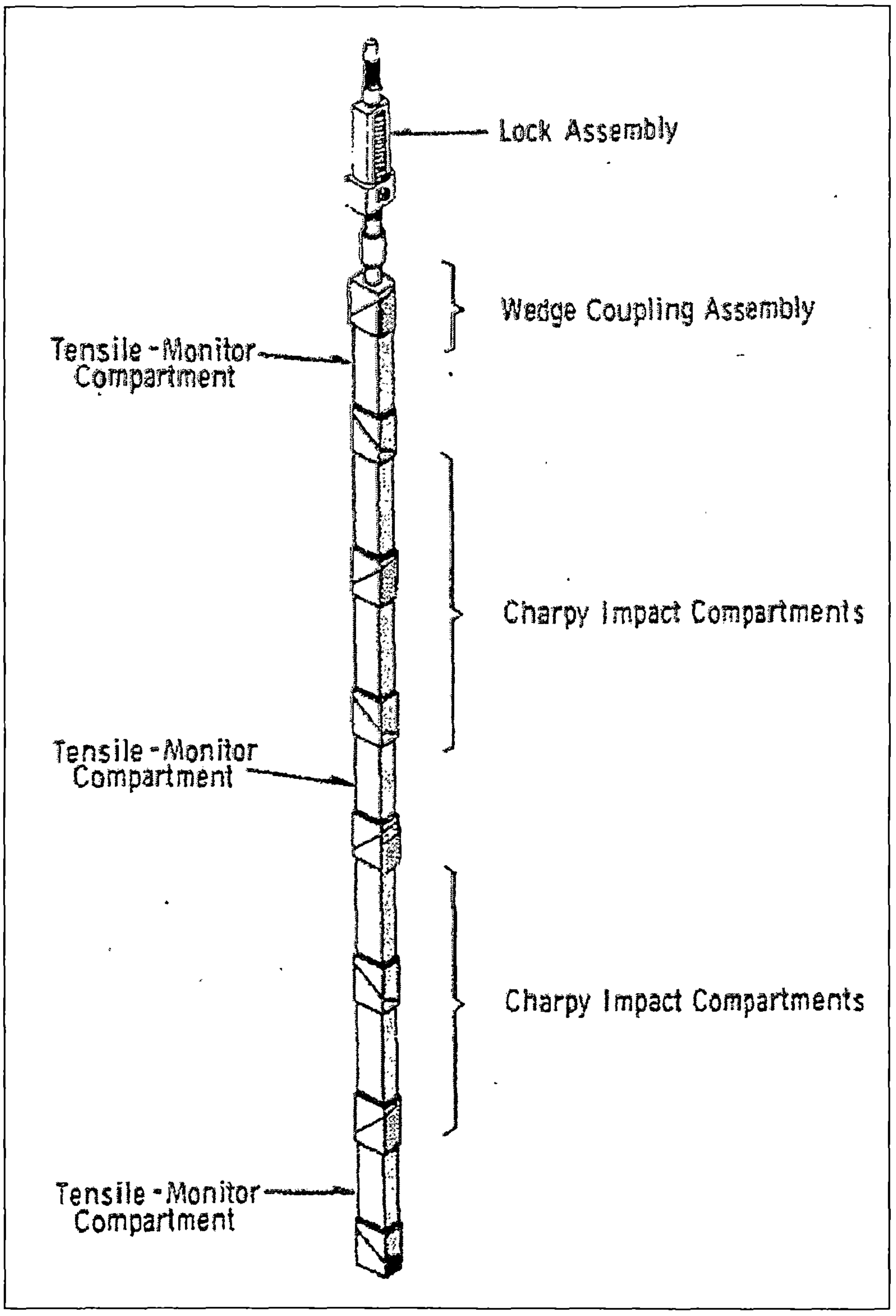


Figure 4-2 Original Surveillance Program Capsule in the Waterford Unit 3 Reactor Vessel

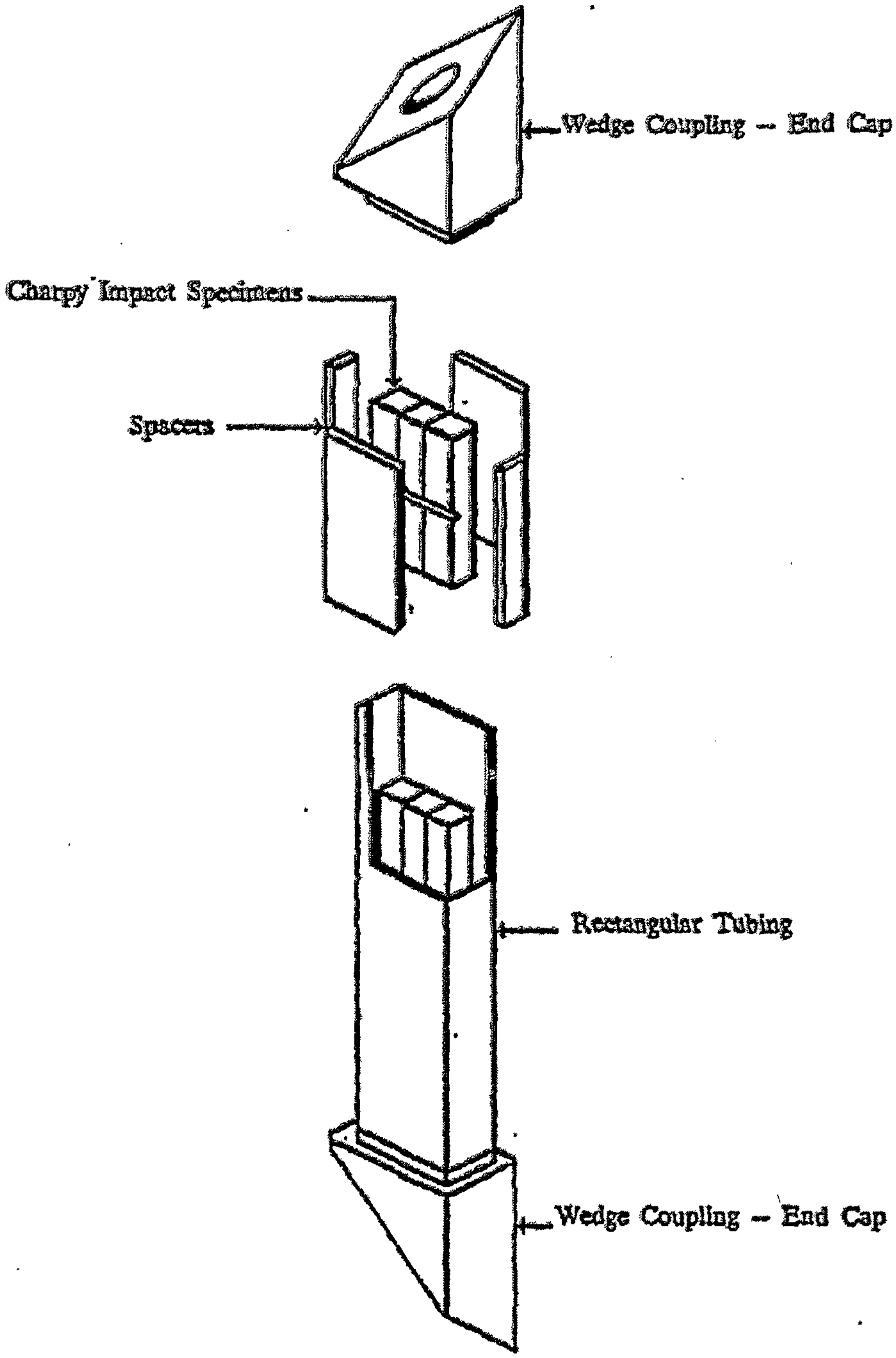


Figure 4-3 Surveillance Capsule Charpy Impact Specimen Compartment Assembly in the Waterford Unit 3 Reactor Vessel

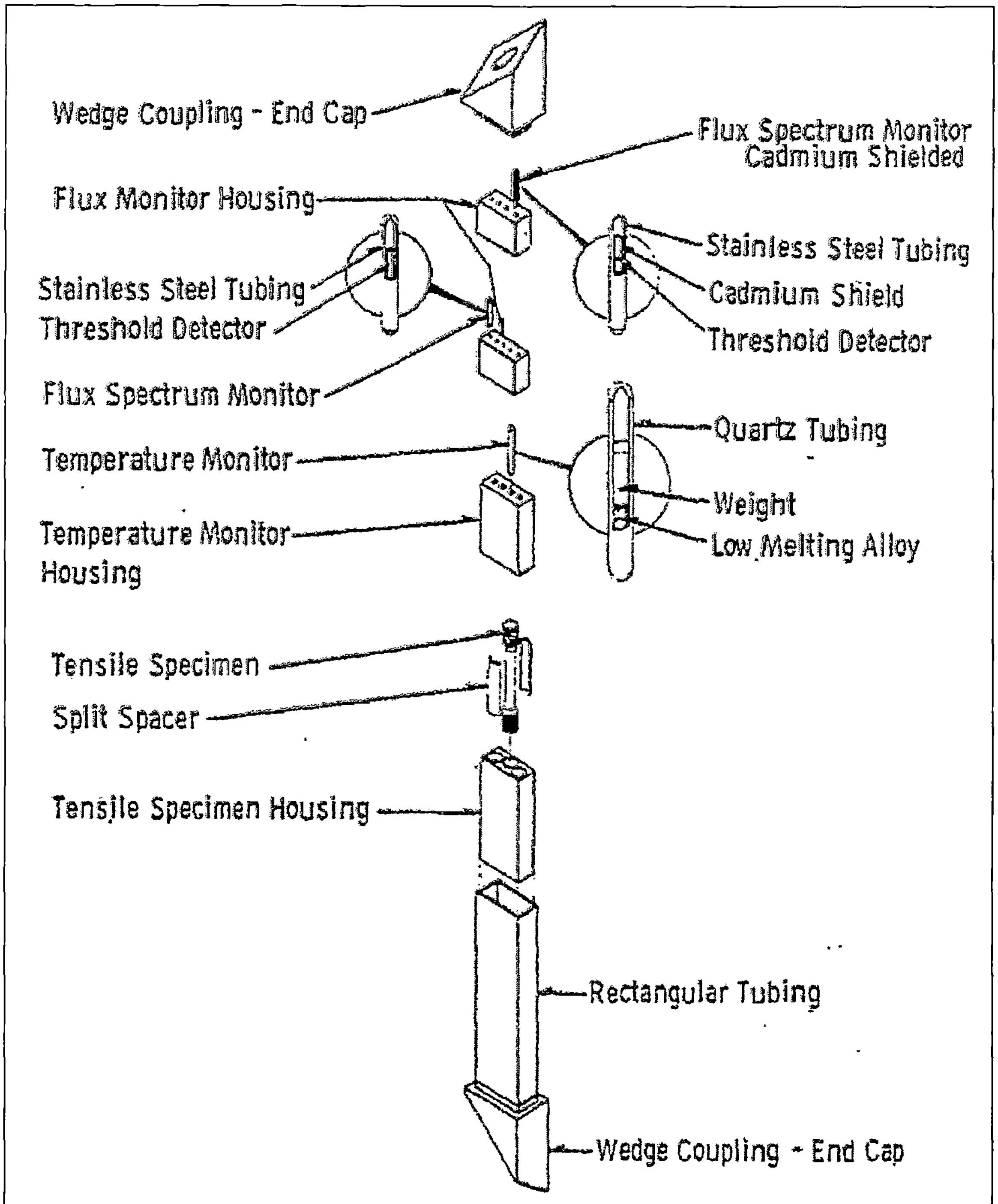


Figure 4-4 Surveillance Capsule Tensile and Flux-Monitor Compartment Assembly in the Waterford Unit 3 Reactor Vessel

5 TESTING OF SPECIMENS FROM CAPSULE 83°

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed at the Westinghouse Materials Center of Excellence Hot Cell Facility. Testing was performed in accordance with 10 CFR 50, Appendix H [Ref. 2] and ASTM Specification E185-82 [Ref. 11].

Capsule 83° was opened upon receipt at the hot cell laboratory. The specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in TR-C-MCS-001 [Ref. 3]. All of the items were in their proper locations.

Examination of the thermal monitors indicated that 6 of the 12 temperature monitors had melted, as described below:

- Capsule compartment E114, the 536°F (280°C) and 558°F (292°C) temperature monitors melted
- Capsule compartment E142, the 536°F (280°C) and 558°F (292°C) temperature monitors melted
- Capsule compartment E173, the 536°F (280°C) and 558°F (292°C) temperature monitors melted

Based on this examination, the maximum temperature to which the specimens were exposed was less than 580°F (304°C), but greater than 558°F (292°C).

The Charpy impact tests were performed per ASTM Specification E185-82 [Ref. 11] and E23-12c [Ref. 12] on a Tinius-Olsen Model 74, 358J machine. The Charpy machine striker was instrumented with an Instron Impulse system. Instrumented testing and calibration were performed to ASTM E2298-13a [Ref. 13]. The temperature requirements in ASTM E23-12c [Ref. 12] were met.

The instrumented striker load signal data acquisition rate was 819 kHz with data acquired for 10 ms. From the load-time curve, the load of general yielding (F_{gy}), the maximum load (F_m) and the time to maximum load were 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 brittle fracture load (F_{bf}). The termination load after the fast load drop is identified as the arrest load (F_a). F_{gy}, F_m, F_{bf}, and F_a were determined per the guidance in ASTM Standard E2298-13a [Ref. 13].

The energy at maximum load (W_m) was determined by integrating the load-time record to the maximum load point. 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 (W_P) is the difference between the total energy (W_t) and the energy at maximum load (W_m). W_t is compared to the dial energy (KV). W_t derived from the instrumented striker were all within 25% of the calibrated dial energy values as required in ASTM E2298-13a [Ref. 13].

Percent shear was determined from post-fracture photographs using the ratio-of-areas method in compliance with ASTM E23-12c [Ref. 12] and A370-13 [Ref. 14]. The lateral expansion was measured using a dial gage rig similar to that shown in the same specifications.

Tensile tests were performed on a 250 KN Instron screw driven tensile machine (Model 5985) per ASTM E185-82 [Ref. 11]. Testing met ASTM Specifications E8/E8M-13a [Ref. 15] for room temperature or E21-09 [Ref. 16] for elevated temperatures. Load was applied through a threaded connection. Strain measurements were made using an extensometer, which was attached to the 1.00 inch gage section of the tensile specimen. The strain rate obtained met the requirements of ASTM E8/E8M-13a [Ref. 15] and ASTM E21-09 [Ref. 16].

Elevated test temperatures were obtained with a three-zone electric resistance split-tube furnace with an 11-inch hot zone. Tensile specimens were soaked at temperature (±5°F) for a minimum of 20 minutes before testing. All tests were conducted in air.

The tensile specimens were 3.00 inches long with a 1.00 inch gage section and a reduced section of 1.50 inches long by 0.250 inch in diameter, as documented in Figure 5 (Drawing CND-B-3654 Rev 2) of TR-C-MCS-001 [Ref. 3]. The yield load, ultimate load, fracture load, uniform elongation and elongation at fracture were determined directly from the load-extension curve. The yield strength (0.2% offset method), ultimate tensile strength and fracture strength were calculated using the original cross-sectional area. Yield point elongation (YPE) was calculated as the difference in strain between the upper yield strength and the onset of uniform strain hardening using the methodology described in E8/E8M-13a [Ref. 15]. The final diameter and final gage length were determined from post-fracture photographs. This final diameter measurement was used to calculate the fracture stress (true stress at fracture) and the percent reduction in area. The final and original gage lengths were used to calculate total elongation after fracture.

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 83°, which received a fluence of 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV) in 24.66 EFPY of operation, are presented in Tables 5-1 through 5-8 and are compared with the unirradiated and previously withdrawn capsule results as shown in Figures 5-1 through 5-12. The unirradiated and previously withdrawn capsule results were taken from TR-C-MCS-002, Revision 0 [Ref. 4], BAW-2177, Revision 01 [Ref. 17] and WCAP-16002, Revision 0 [Ref. 18]. The previous capsules, along with the original program unirradiated material input data, were updated using CVGRAPH, Version 6.0 from the hand-drawn plots presented in the earliest reports. This accounts for the differences in measured values of 30 ft-lb and 50 ft-lb transition temperature between the results documented in this report and those shown in prior Waterford Unit 3 capsule reports.

The transition temperature increases and changes in upper-shelf energies for the Capsule 83° materials are summarized in Table 5-9 and led to the following results:

- Irradiation of the reactor vessel Lower Shell Plate M-1004-2 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 0.1°F and an irradiated 50 ft-lb transition

temperature of 35.3°F. This results in a 30 ft-lb transition temperature increase of 13.6°F and a 50 ft-lb transition temperature increase of 23.6°F for the longitudinally oriented specimens.

- Irradiation of the reactor vessel Lower Shell Plate M-1004-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), resulted in an irradiated 30 ft-lb transition temperature of 0.8°F and an irradiated 50 ft-lb transition temperature of 37.4°F. This results in a 30 ft-lb transition temperature increase of 25.3°F and a 50 ft-lb transition temperature increase of 34.6°F for the transversely oriented specimens.

- Irradiation of the Surveillance Program Weld Material (Heat # 88114) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -65.4°F and an irradiated 50 ft-lb transition temperature of -44.0°F. This results in a 30 ft-lb transition temperature increase of 19.0°F and a 50 ft-lb transition temperature increase of 21.0°F.

- Irradiation of the Heat Affected Zone (HAZ) Material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -84.3°F and an irradiated 50 ft-lb transition temperature of -37.5°F. This results in a 30 ft-lb transition temperature increase of 32.7°F and a 50 ft-lb transition temperature increase of 52.6°F.

- The irradiated upper-shelf energy of Lower Shell Plate M-1004-2 (longitudinal orientation) resulted in an average energy decrease of 12 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 158 ft-lb for the longitudinally oriented specimens.

- The average upper-shelf energy of Lower Shell Plate M-1004-2 (transverse orientation) resulted in an average energy decrease of 3 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 138 ft-lb for the transversely oriented specimens.

- The average upper-shelf energy of the Surveillance Program Weld Material (Heat # 88114) Charpy specimens resulted in an average energy decrease of 23 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 133 ft-lb for the weld metal specimens.

- The average upper-shelf energy of the HAZ Material Charpy specimens resulted in an average energy decrease of 12 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 158 ft-lb for the HAZ Material.

- Comparisons of the measured 30 ft-lb shift in transition temperature values and upper-shelf energy decreases to those predicted by Regulatory Guide 1.99, Revision 2 [Ref. 1] for the Waterford Unit 3 reactor vessel surveillance materials are presented in Table 5-10.

  Standard Reference Material (SRM) HSST 01 Charpy specimens were not included in the Waterford Unit 3 Capsule 83°. However, the SRM HSST 01 Charpy specimens were reanalyzed in this report. The SRM HSST 01 material was contained in Capsule 263°, which was irradiated to a neutron fluence of 1.45 x 10^{19} n/cm^2 (E > 1.0 MeV). The results of the SRM HSST 01 reanalysis will be included in Table 5-10 and shown in Figures 5-13 through 5-15.

- Irradiation of the SRM HSST 01 Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 185.0°F and an irradiated 50 ft-lb transition temperature of 211.4°F. This results in a 30 ft-lb transition temperature increase of 150.5°F and a 50 ft-lb transition temperature increase of 151.3°F.

- The average upper-shelf energy of the SRM HSST 01 Charpy specimens resulted in an average energy decrease of 20 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 113 ft-lb.

The fracture appearance of each irradiated Charpy specimen from the various materials is shown in Figures 5-16 through 5-19. The fractures show an increasingly ductile or tougher appearance with increasing test temperature. Load-time records for the individual instrumented Charpy specimens are contained in Appendix B.

With consideration of the surveillance data, all beltline materials exhibit adequate upper-shelf energy levels for continued safe plant operation and are predicted to maintain an upper-shelf energy greater than 50 ft-lb through end-of-license (32 EFPY) as required by 10 CFR 50, Appendix G [Ref. 2]. This evaluation can be found in Appendix E.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in Capsule 83° irradiated to 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV) are presented in Table 5-11 and are compared with unirradiated results as shown in Figures 5-20 through 5-22.

The results of the tensile tests performed on the Lower Shell Plate M-1004-2 (transverse orientation) indicated that irradiation to 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV) caused increases (except in one instance there was a slight decrease) in the 0.2 percent offset yield strength, and consistently caused increases in the ultimate tensile strength when compared to unirradiated data [Ref. 4]. See Figure 5-20 and Table 5-11.

The results of the tensile tests performed on the Surveillance Program Weld Material (Heat # 88114) indicated that irradiation to 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV) caused increases (except in one instance there was a decrease) in the 0.2 percent offset yield strength, and caused an increase in the ultimate tensile strength for the single available data point when compared to unirradiated data [Ref. 4]. See Figure 5-21 and Table 5-11.

The results of the tensile tests performed on the Heat Affected Zone Material indicated that irradiation to 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV) caused increases in the 0.2 percent offset yield strength and the ultimate tensile strength when compared to unirradiated data [Ref. 4]. See Figure 5-22 and Table 5-11.

The fractured tensile specimens for the Lower Shell Plate M-1004-2 (transverse orientation) material are shown in Figure 5-23, the fractured tensile specimens for the Surveillance Program Weld Material (Heat # 88114) are shown in Figure 5-24, and the fractured tensile specimens for the Heat Affected Zone Material are shown in Figure 5-25. The engineering stress-strain curves for the tensile tests are shown in Figures 5-26 through 5-31.

Table 5-1 Charpy V-notch Data for the Waterford Unit 3 Lower Shell Plate M-1004-2 Irradiated to a Fluence of 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV) (Longitudinal Orientation)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	°F	°C	ft-lbs	Joules	mils	mm	%
145	-25	-32	11	15	7	0.18	5
15M	0	-18	13	18	13	0.33	15
15L	5	-15	32	43	27	0.69	20
14E	10	-12	35	47	25	0.64	20
13P	20	-7	43	58	33	0.84	20
12B	30	-1	53	72	38	0.97	20
12U	40	4	62	84	45	1.14	25
114	100	38	104	141	74	1.88	60
14J	200	93	121	164	84	2.13	85
11C	230	110	154	209	89	2.26	100
116	250	121	162	220	87	2.21	100
115	300	149	158	214	93	2.36	100

Table 5-2 Charpy V-notch Data for the Waterford Unit 3 Lower Shell Plate M-1004-2 Irradiated to a Fluence of 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV) (Transverse Orientation)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	°F	°C	ft-lbs	Joules	mils	mm	%
231	-50	-46	18	24	15	0.38	5
21Y	-25	-32	19	26	17	0.43	5
22K	-10	-23	13	18	12	0.30	10
25L	0	-18	33	45	29	0.74	20
24L	10	-12	33	45	26	0.66	20
25Y	25	-4	44	60	36	0.91	20
23T	40	4	62	84	46	1.17	25
261	100	38	84	114	67	1.70	50
222	150	66	120	163	82	2.08	85
21A	200	93	124	168	81	2.06	100
225	250	121	145	197	71	1.80	100
226	300	149	145	197	91	2.31	100

Table 5-3 Charpy V-notch Data for the Waterford Unit 3 Surveillance Program Weld Material (Heat # 88114) Irradiated to a Fluence of 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	°F	°C	ft-lbs	Joules	mils	mm	%
337	-90	-68	10	14	13	0.33	10
3A2	-70	-57	28	38	20	0.51	25
31L	-65	-54	29	39	21	0.53	20
31P	-60	-51	28	38	23	0.58	30
34P	-55	-48	41	56	33	0.84	35
325	-50	-46	48	65	35	0.89	40
334	-30	-34	70	95	54	1.37	50
35P	0	-18	96	130	66	1.68	60
347	69	21	117	159	84	2.13	95
371	100	38	137	186	90	2.29	98
37B	150	66	140	190	97	2.46	100
312	200	93	136	184	90	2.29	100

Table 5-4 Charpy V-notch Data for the Waterford Unit 3 Heat Affected Zone (HAZ) Material Irradiated to a Fluence of 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	°F	°C	ft-lbs	Joules	mils	mm	%
47M	-125	-87	21	28	13	0.33	5
44K	-90	-68	23	31	13	0.33	10
42E	-80	-62	14	19	10	0.25	15
45U	-75	-59	31	42	23	0.58	15
454	-70	-57	39	53	29	0.74	25
45L	-60	-51	49	66	34	0.86	35
45A	-50	-46	59	80	36	0.91	45
41Y	0	-18	71	96	53	1.35	65
43J	69	21	99	134	66	1.68	70
46K	150	66	131	178	84	2.13	100
457	200	93	163	221	88	2.24	100
472	250	121	179	243	85	2.16	100

Table 5-5 Instrumented Charpy Impact Test Results for the Waterford Unit 3 Lower Shell Plate M-1004-2 Irradiated to a Fluence of 2.42×10^{19} n/cm^2 (E > 1.0 MeV) (Longitudinal Orientation)

Sample Number	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, $(KV-W_t)/KV$ (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
145	-25	11	10	9	4.3	4400	0.11	3400	3700	0
15M	0	13	11	15	3.5	4000	0.09	3400	3700	0
15L	5	32	30	6	27.8	4200	0.48	3200	4200	0
14E	10	35	31	11	29.1	4200	0.50	3200	4100	0
13P	20	43	39	9	35.5	4400	0.60	3100	4300	500
12B	30	53	47	11	45.5	4300	0.76	3200	4300	500
12U	40	62	56	10	51.8	4300	0.87	3000	4100	600
114	100	104	103	1	44.0	4200	0.77	3000	3200	2100
14J	200	121	118	3	43.1	4000	0.79	2700	2900	2000
11C	230	154	148	4	51.5	4000	0.95	2600	0	0
116	250	162	157	3	44.0	4200	0.83	2600	0	0
115	300	158	153	3	51.6	3900	0.95	2500	0	0

Table 5-6 Instrumented Charpy Impact Test Results for the Waterford Unit 3 Lower Shell Plate M-1004-2 Irradiated to a Fluence of 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV) (Transverse Orientation)

Sample Number	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, $(KV-W_t)/KV$ (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
231	-50	18	18	0	16.2	4100	0.29	3500	4100	0
21Y	-25	19	18	5	3.1	4200	0.09	3300	4000	0
22K	-10	13	11	15	3.5	4100	0.09	3300	3700	0
25L	0	33	31	6	29.6	4200	0.51	3300	4200	0
24L	10	33	30*	9	24.3	4100	0.43	3200	4000	300
25Y	25	44	39	11	35	4200	0.61	3200	4100	400
23T	40	62	58	7	36.2	4300	0.62	3200	4200	300
261	100	84	80	5	33.2	4100	0.60	2900	3300	1600
222	150	120	117	3	43.1	4000	0.79	2700	2400	1600
21A	200	124	121	2	32	4000	0.60	2800	0	0
225	250	145	140	3	52.6	4000	0.94	2600	0	0
226	300	145	140	3	42.1	4000	0.80	2800	0	0

*Note: In accordance with Reference 13, an adjustment was made to this value to include additional absorbed energy after the load crossed zero.

Table 5-7 Instrumented Charpy Impact Test Results for the Waterford Unit 3 Surveillance Program Weld Material (Heat # 88114) Irradiated to a Fluence of 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample Number	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, $(KV-W_t)/KV$ (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
337	-90	10	10	0	4.5	5200	0.12	3800	3900	0
3A2	-70	28	25	11	5.1	4400	0.11	3900	4100	300
31L	-65	29	27	7	3.5	4600	0.09	3500	4400	0
31P	-60	28	25	11	4.4	5100	0.12	3900	4600	400
34P	-55	41	36	12	3.5	4500	0.09	3400	4200	700
325	-50	48	43	10	3.7	4600	0.09	3800	4400	1400
334	-30	70	65	7	38.0	4400	0.60	3700	4200	1900
35P	0	96	93	3	37.2	4400	0.60	3500	3500	1700
347	69	117	116	1	35.0	4200	0.60	3200	2800	2600
371	100	137	133	3	34.5	4200	0.60	3200	2300	2000
37B	150	140	136	3	34.7	4100	0.63	3100	0	0
312	200	136	134	2	34.9	4100	0.63	3000	0	0

Table 5-8 Instrumented Charpy Impact Test Results for the Waterford Unit 3 Heat Affected Zone (HAZ) Material Irradiated to a Fluence of 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample Number	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, $(KV-W_t)/KV$ (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
47M	-125	21	21	0	4.8	5200	0.11	4300	4900	0
44K	-90	23	23	0	3.8	4600	0.09	3500	4500	0
42E	-80	14	12	14	3.8	4600	0.09	4100	4300	0
45U	-75	31	31	0	3.9	4800	0.09	3800	4500	0
454	-70	39	36	8	32.3	4600	0.50	3600	4400	0
45L	-60	49	47	4	40.4	4600	0.61	3700	4500	0
45A	-50	59	54	9	3.7	4600	0.09	3700	4400	600
41Y	0	71	70	1	30.5	4400	0.50	3600	4200	2500
43J	69	99	93	6	36.4	4400	0.61	3300	3300	2200
46K	150	131	128	2	4.0	4900	0.13	3200	0	0
457	200	163	159	3	45.5	4200	0.79	3100	0	0
472	250	179	174	3	56.0	4200	0.95	3000	0	0

Table 5-9 Effect of Irradiation to 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV) on the Charpy V-Notch Toughness Properties of the Waterford Unit 3 Reactor Vessel Surveillance Capsule 83° Materials

Material	Average 30 ft-lb Transition Temperature[a] (°F)			Average 35 mil Lateral Expansion Temperature[a] (°F)			Average 50 ft-lb Transition Temperature[a] (°F)			Average Energy Absorption at Full Shear[a] (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Lower Shell Plate M-1004-2 (Longitudinal)	-13.5	0.1	13.6	5.3	26.6	21.3	11.7	35.3	23.6	170	158	-12
Lower Shell Plate M-1004-2 (Transverse)	-24.5	0.8	25.3	-6.7	23	29.7	2.8	37.4	34.6	141	138	-3
Surveillance Weld Material (Heat # 88114)	-84.4	-65.4	19.0	-68.2	-48.1	20.1	-65.0	-44.0	21.0	156	133	-23
Heat Affected Zone Material	-117.0	-84.3	32.7	-89.7	-40.5	49.2	-90.1	-37.5	52.6	170	158	-12

Note:
(a) Average value is determined by CVGRAPH, Version 6.0 (see Appendix C).

Table 5-10 Comparison of the Waterford 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	Capsule Fluence ($x10^{19}$ n/cm^2, E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		Upper-Shelf Energy Decrease	
			Predicted[(a)] (°F)	Measured[(b)] (°F)	Predicted[(a)] (%)	Measured[(b)] (%)
Lower Shell Plate M-1004-2 (Longitudinal)	97°	0.631	17.4	6.1	17	9
	83°	2.42	24.8	13.6	23	7
Lower Shell Plate M-1004-2 (Transverse)	97°	0.631	17.4	28.0	17	12
	263°	1.45	22.1	-9.1	21	7
	83°	2.42	24.8	25.3	23	2
Surveillance Weld Material (Heat # 88114)	97°	0.631	38.7	23.5	17	1
	263°	1.45	49.0	6.6	21	7
	83°	2.42	55.0	19.0	23	15
Heat Affected Zone Material	97°	0.631	---	13.5	---	8
	263°	1.45	---	25.8	---	4
	83°	2.42	---	32.7	---	7
Standard Reference Material	263°	1.45	---	150.5	---	15

Notes:

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

(b) Calculated by CVGRAPH, Version 6.0 using measured Charpy data (See Appendix C).

Table 5-11 Tensile Properties of the Waterford Unit 3 Capsule 83° Reactor Vessel Surveillance Materials Irradiated to 2.42×10^{19} n/cm^2 (E > 1.0 MeV)

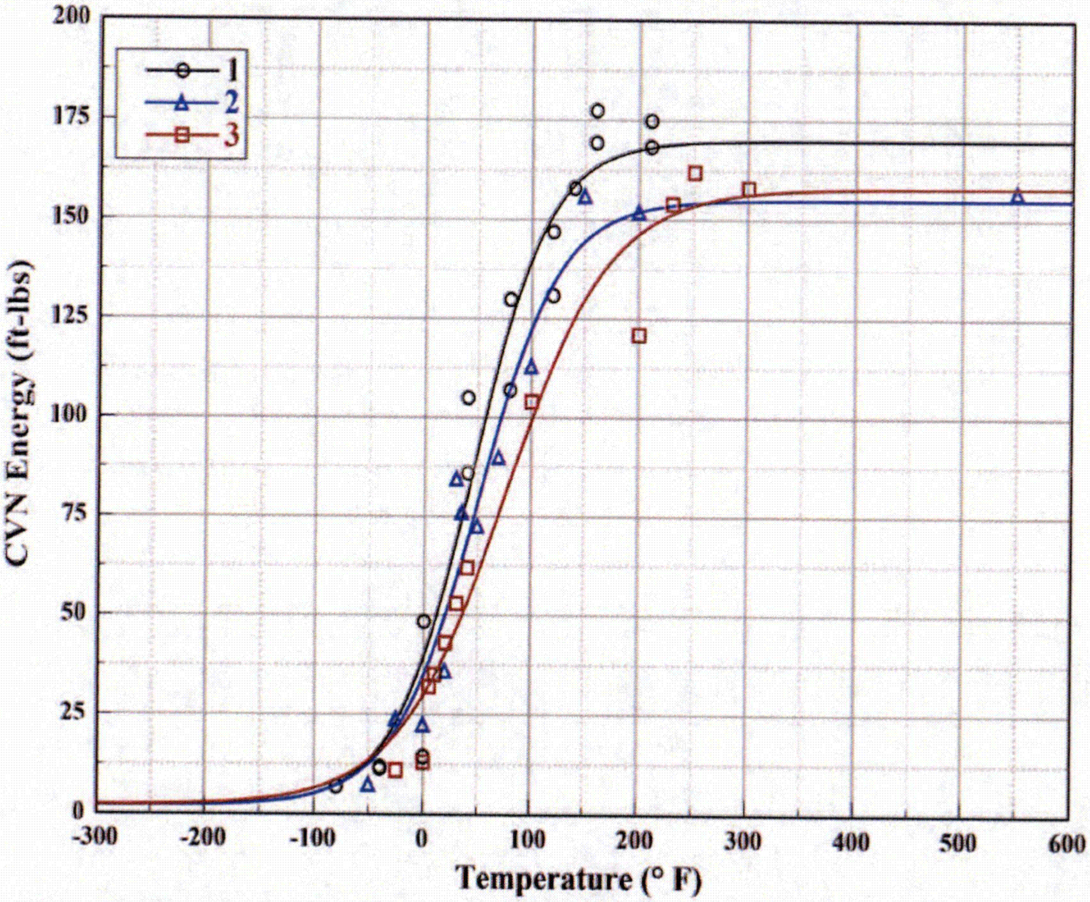
Material	Sample Number	Test Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Strength (ksi)	Fracture True Stress (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
Lower Shell Plate M-1004-2 (Transverse)	2J3	69	74.7	94.6	3.11	63.3	188	11.9	26.5	66
	2L7	250	68.2	86.7	2.74	55.9	161	9.7	23.7	65
	2K4	550	64.4	89.3	3.15	64.2	147	9.9	19.8	56
Surveillance Weld Material (Heat # 88114)	3K5	71	85.4	*	*	*	*	*	*	*
	3KD	250	76.4	89.5	2.71	55.3	179	8.1	21.4	69
	3L3	550	76.2	*	*	*	*	*	*	*
Heat Affected Zone Material	4J3	71	73.3	96.6	2.92	59.4	184	7.1	19.9	68
	4KB	250	67.4	88.5	2.73	55.7	203	5.2	18.0	73
	4JC	550	69.7	90.9	3.05	62.1	339	4.9	15.8	82

*Note: For specimens 3K5 and 3L3, the specimens broke outside of the gage section; as a result, the tensile results may not reflect the weld behavior and are therefore not reported.

Lower Shell Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:14 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	LT	NR 57 286-1
2	Waterford 3	97°	SA533B1	LT	NR 57 286-1
3	Waterford 3	83°	SA533B1	LT	NR 57 286-1



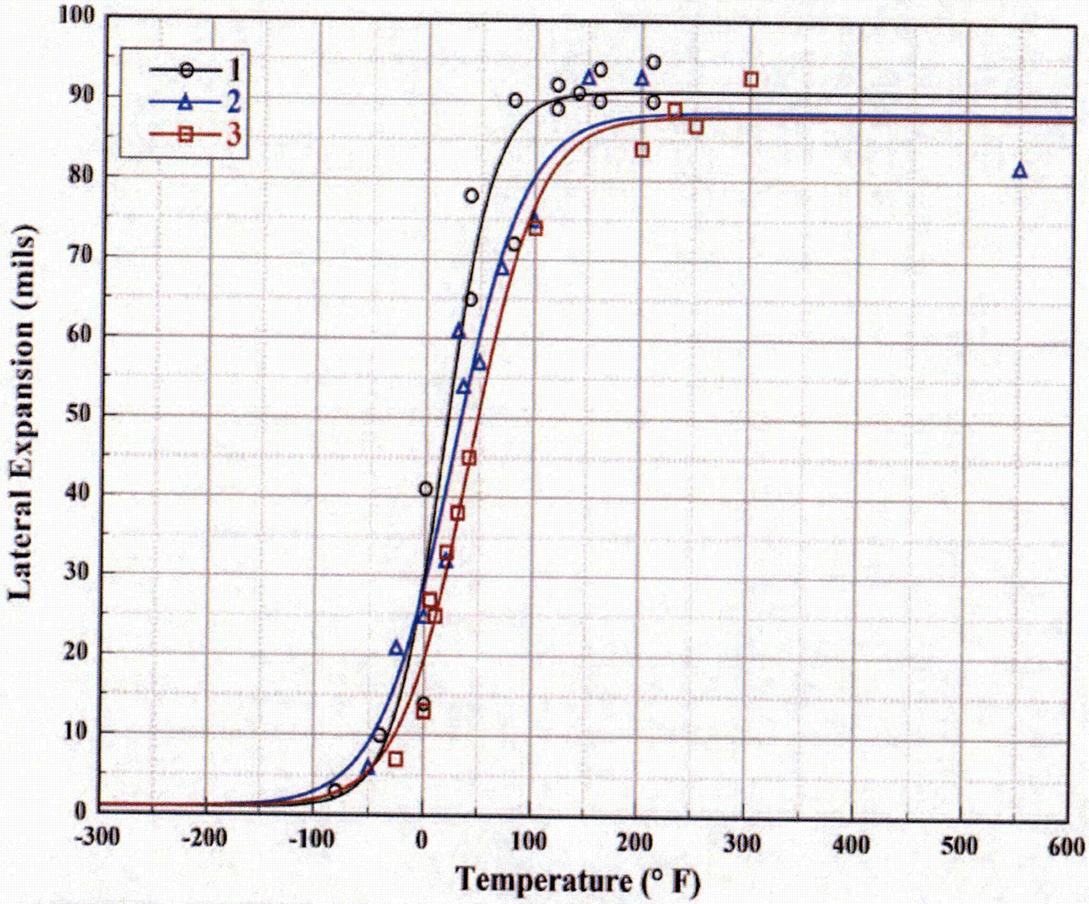
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	170	0	-13.5	0	11.7	0
2		2.2	155	-15	-7.4	6.1	20.2	8.5
3		2.2	158	-12	0.1	13.6	35.3	23.6

Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Longitudinal Orientation)

Lower Shell Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:19 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	LT	NR 57 286-1
2	Waterford 3	97°	SA533B1	LT	NR 57 286-1
3	Waterford 3	83°	SA533B1	LT	NR 57 286-1



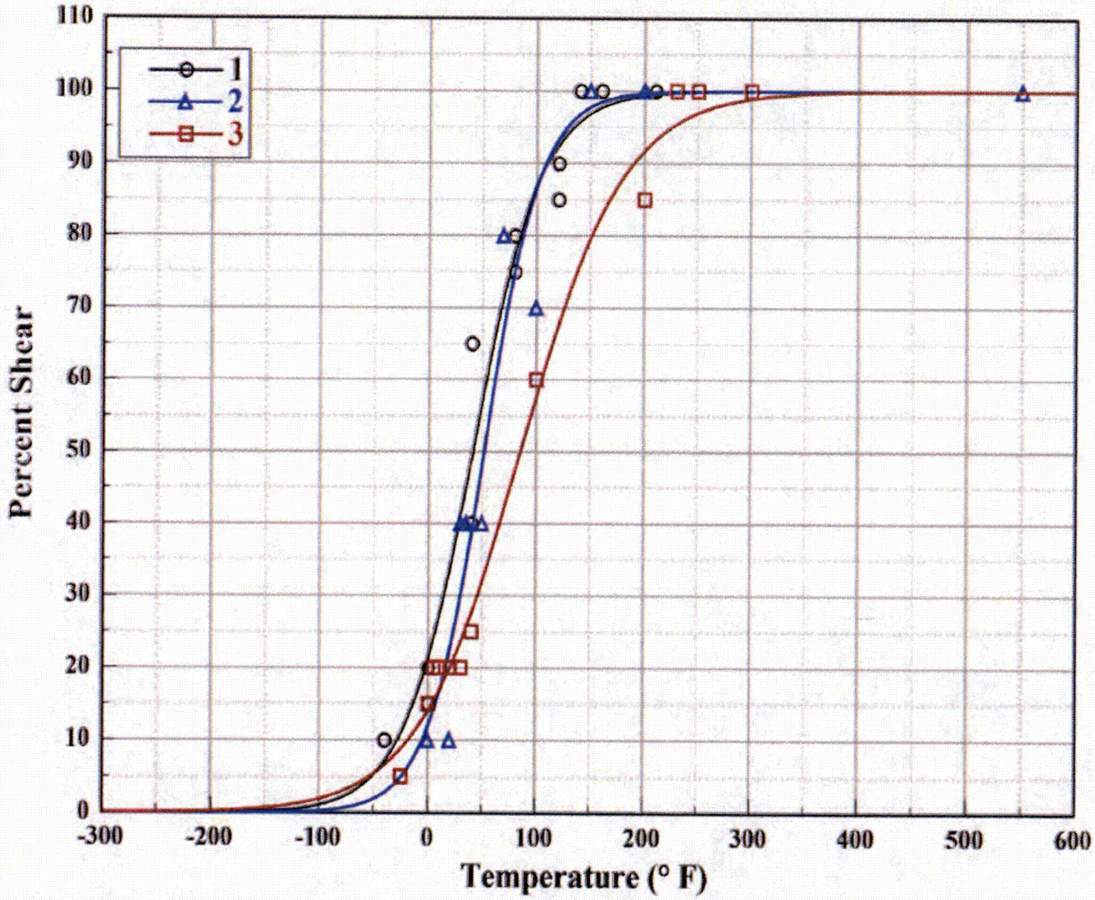
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1	91.07	0	5.3	0
2		1	88.56	-2.51	10.5	5.2
3		1	88.05	-3.02	26.6	21.3

Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Longitudinal Orientation)

Lower Shell Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:21 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	LT	NR 57 286-1
2	Waterford 3	97°	SA533B1	LT	NR 57 286-1
3	Waterford 3	83°	SA533B1	LT	NR 57 286-1



Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		0	100	0	40.8	0
2		0	100	0	52.2	11.4
3		0	100	0	85.6	44.8

Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Longitudinal Orientation)

Lower Shell Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:36 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	TL	NR 57 286-1
2	Waterford 3	97°	SA533B1	TL	NR 57 286-1
3	Waterford 3	263°	SA533B1	TL	NR 57 286-1
4	Waterford 3	83°	SA533B1	TL	NR 57 286-1

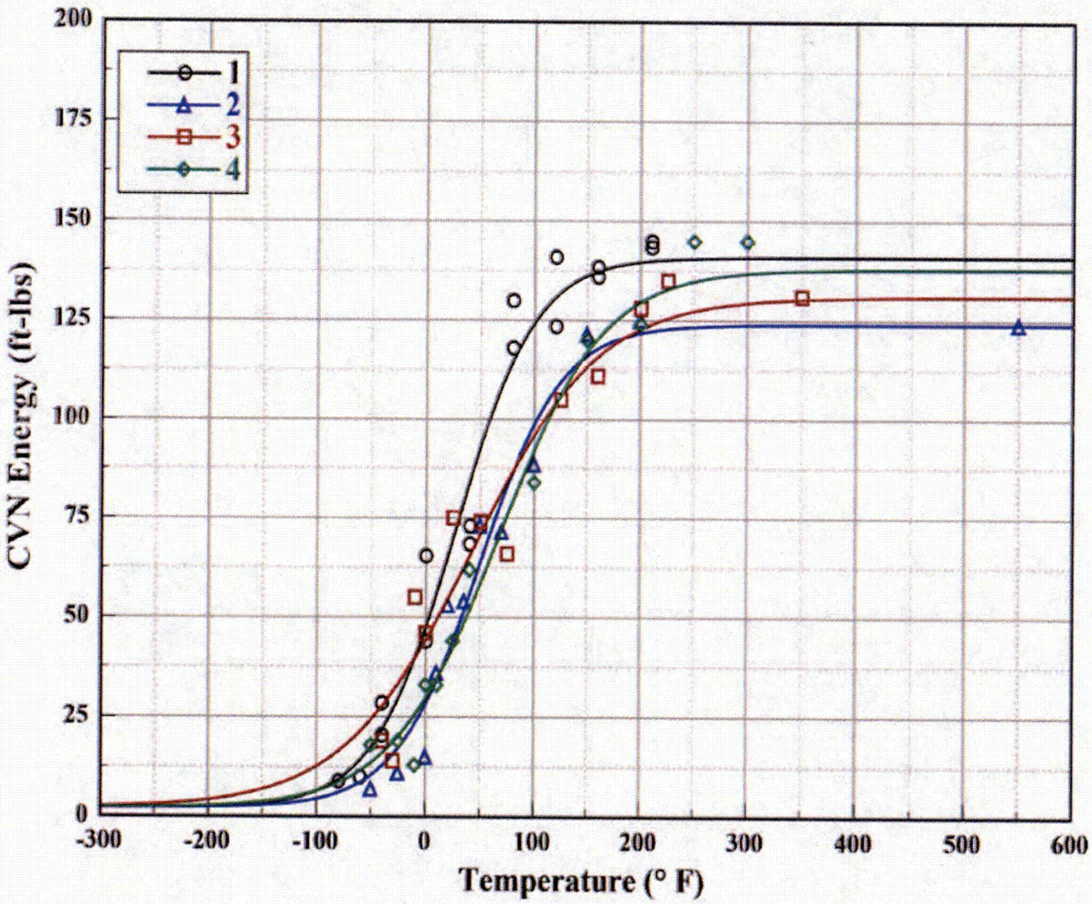


Figure 5-4 **Charpy V-Notch Impact Energy vs. Temperature for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Transverse Orientation)**

Lower Shell Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:36 PM

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	141	0	-24.5	0	2.8	0
2		2.2	124	-17	3.5	28	33.1	30.3
3		2.2	131	-10	-33.6	-9.1	11.1	8.3
4		2.2	138	-3	0.8	25.3	37.4	34.6

Figure 5-4(a) Charpy V-Notch Impact Energy vs. Temperature for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Transverse Orientation) – Continued

Lower Shell Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:39 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	TL	NR 57 286-1
2	Waterford 3	97°	SA533B1	TL	NR 57 286-1
3	Waterford 3	263°	SA533B1	TL	NR 57 286-1
4	Waterford 3	83°	SA533B1	TL	NR 57 286-1

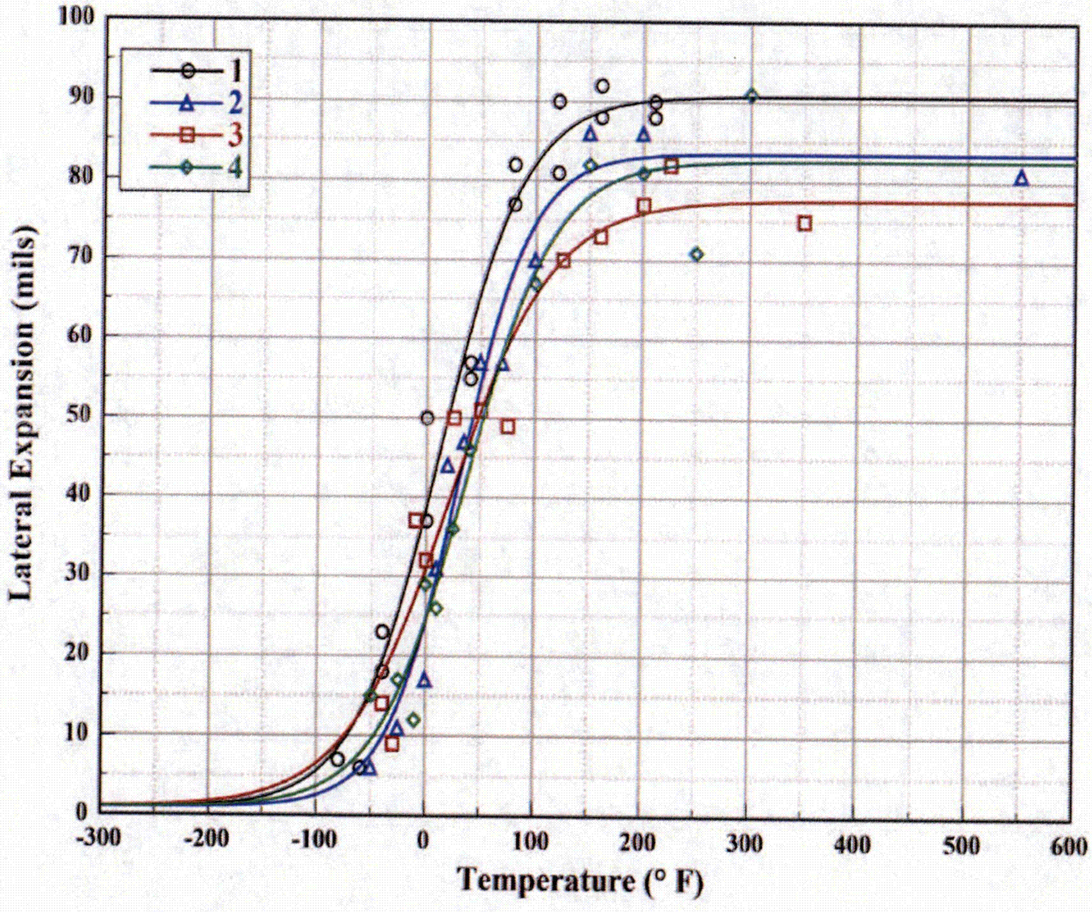


Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Transverse Orientation)

Lower Shell Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:39 PM

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1	90.72	0	-6.7	0
2		1	83.47	-7.25	19.1	25.8
3		1	77.6	-13.12	9.9	16.6
4		1	82.58	-8.14	23	29.7

Figure 5-5(a) Charpy V-Notch Lateral Expansion vs. Temperature for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Transverse Orientation) – Continued

Lower Shell Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:41 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	TL	NR 57 286-1
2	Waterford 3	97°	SA533B1	TL	NR 57 286-1
3	Waterford 3	263°	SA533B1	TL	NR 57 286-1
4	Waterford 3	83°	SA533B1	TL	NR 57 286-1

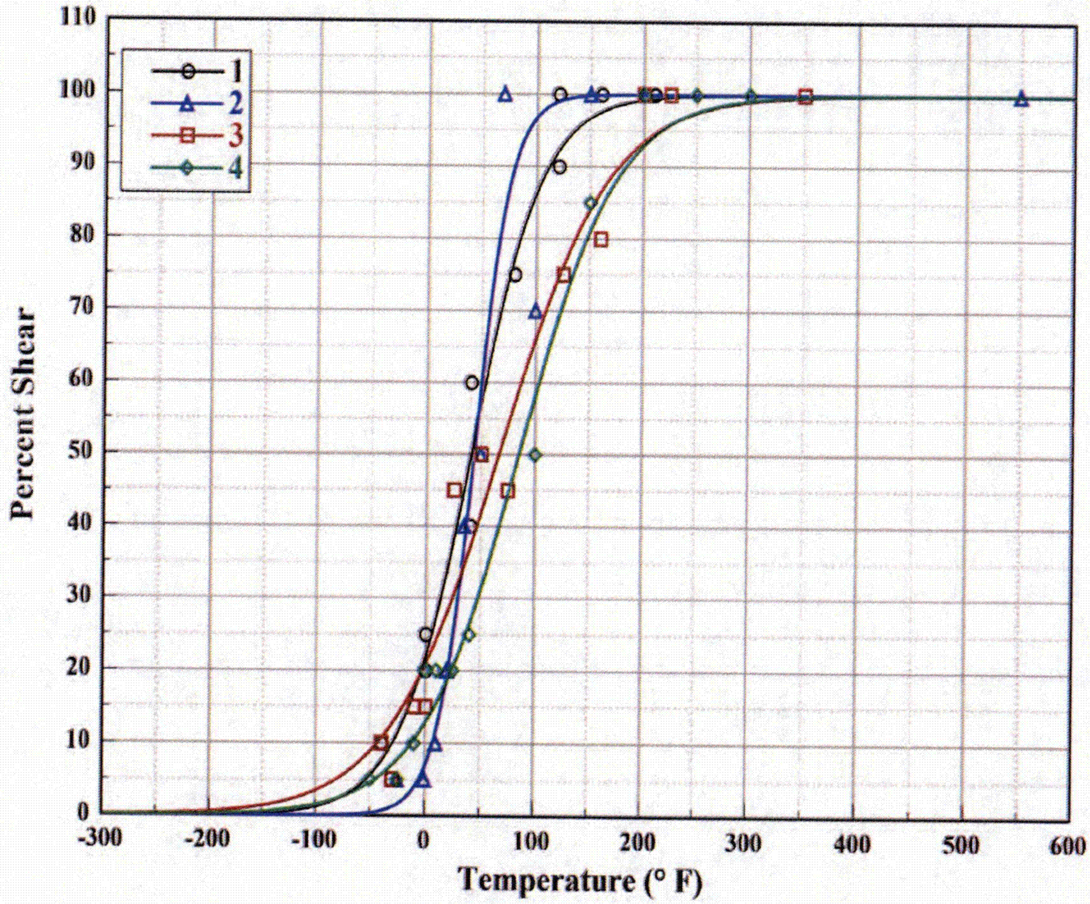


Figure 5-6 **Charpy V-Notch Percent Shear vs. Temperature for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Transverse Orientation)**

Lower Shell Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:41 PM

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		0	100	0	40.4	0
2		0	100	0	43.9	3.5
3		0	100	0	66.5	26.1
4		0	100	0	85.5	45.1

Figure 5-6(a) Charpy V-Notch Percent Shear vs. Temperature for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Transverse Orientation) – Continued

Surveillance Program Weld Metal

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:45 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SAW	NA	88114
2	Waterford 3	97°	SAW	NA	88114
3	Waterford 3	263°	SAW	NA	88114
4	Waterford 3	83°	SAW	NA	88114

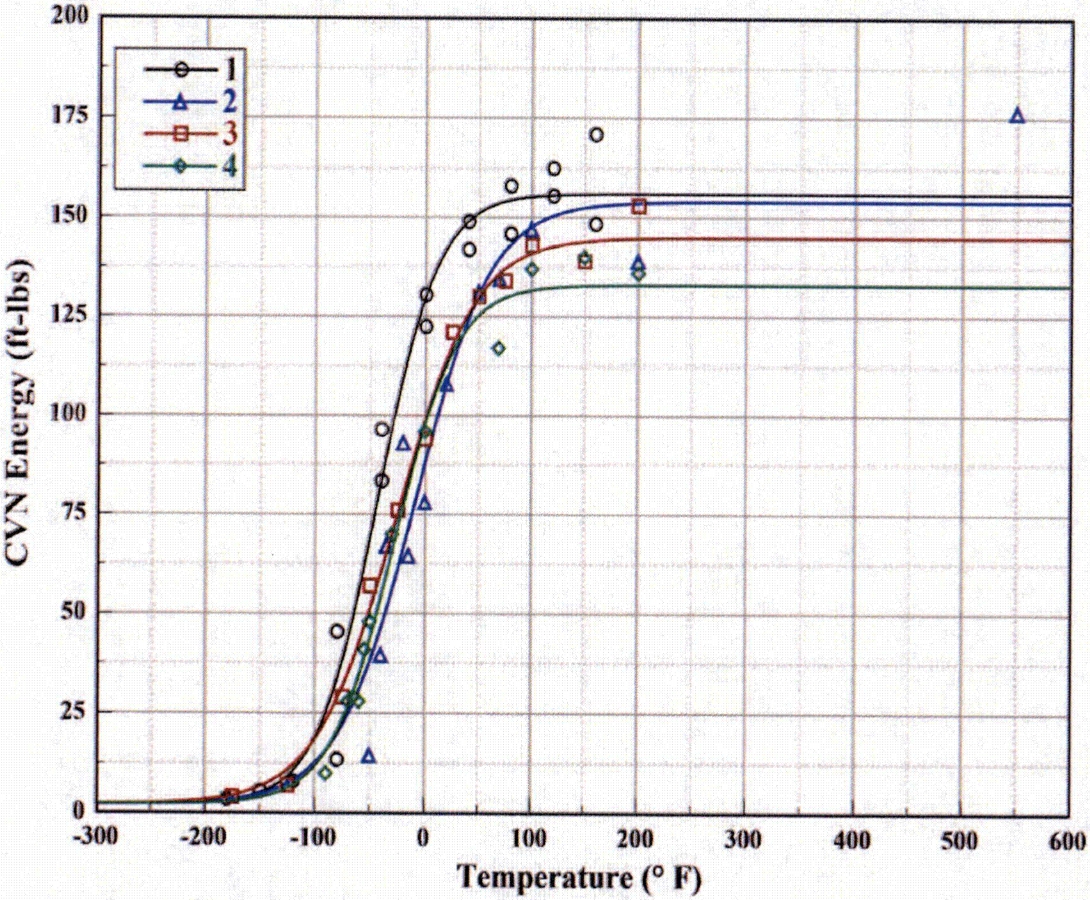


Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for the Waterford Unit 3 Reactor Vessel Surveillance Program Weld Material (Heat # 88114)

Surveillance Program Weld Metal

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:45 PM

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	156	0	-84.4	0	-65	0
2		2.2	154	-2	-60.9	23.5	-35.9	29.1
3		2.2	145	-11	-77.8	6.60	-51.4	13.6
4		2.2	133	-23	-65.4	19	-44	21

Figure 5-7(a) Charpy V-Notch Impact Energy vs. Temperature for the Waterford Unit 3 Reactor Vessel Surveillance Program Weld Material (Heat # 88114) – Continued

Surveillance Program Weld Metal

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:52 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SAW	NA	88114
2	Waterford 3	97°	SAW	NA	88114
3	Waterford 3	263°	SAW	NA	88114
4	Waterford 3	83°	SAW	NA	88114

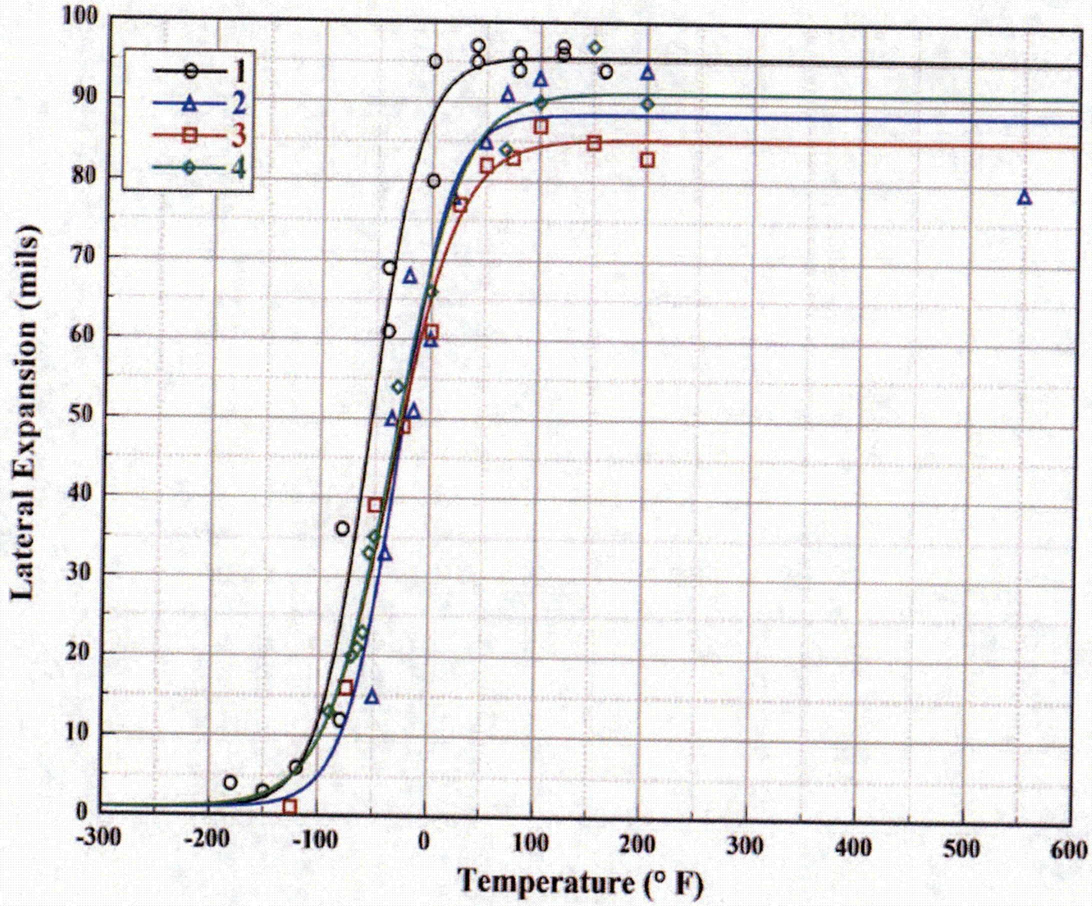


Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for the Waterford Unit 3 Reactor Vessel Surveillance Program Weld Material (Heat # 88114)

Surveillance Program Weld Metal

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:52 PM

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1	95.53	0	-68.2	0
2		1	88.46	-7.07	-39.8	28.4
3		1	85.31	-10.22	-46.7	21.5
4		1	91.19	-4.34	-48.1	20.1

Figure 5-8(a) Charpy V-Notch Lateral Expansion vs. Temperature for the Waterford Unit 3 Reactor Vessel Surveillance Program Weld Material (Heat # 88114) – Continued

Surveillance Program Weld Metal

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:54 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SAW	NA	88114
2	Waterford 3	97°	SAW	NA	88114
3	Waterford 3	263°	SAW	NA	88114
4	Waterford 3	83°	SAW	NA	88114

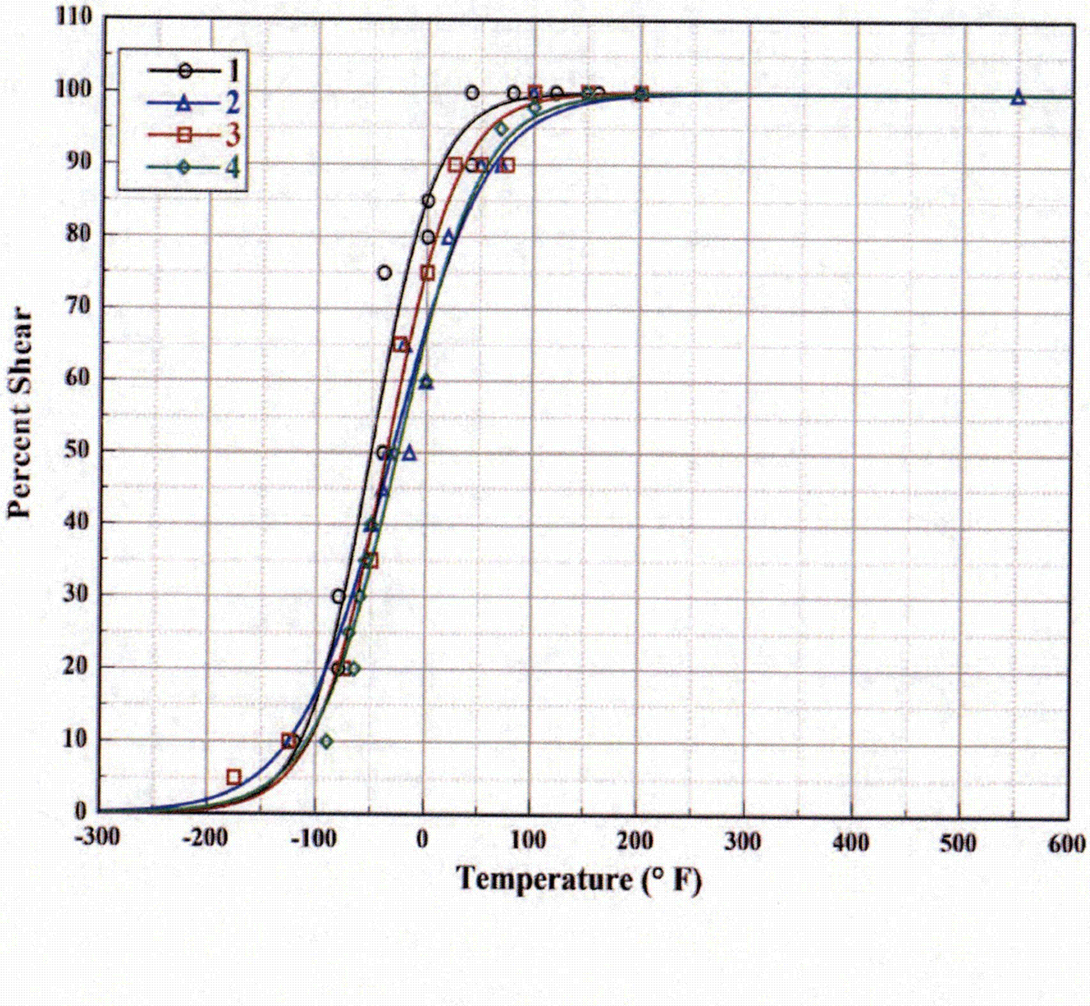


Figure 5-9 Charpy V-Notch Percent Shear vs. Temperature for the Waterford Unit 3 Reactor Vessel Surveillance Program Weld Material (Heat # 88114)

Surveillance Program Weld Metal

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:54 PM

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		0	100	0	-51	0
2		0	100	0	-31.1	19.9
3		0	100	0	-36.2	14.8
4		0	100	0	-26	25

Figure 5-9(a) Charpy V-Notch Percent Shear vs. Temperature for the Waterford Unit 3 Reactor Vessel Surveillance Program Weld Material (Heat # 88114) – Continued

Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:58 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	NA	NR 57 286-1
2	Waterford 3	97°	SA533B1	NA	NR 57 286-1
3	Waterford 3	263°	SA533B1	NA	NR 57 286-1
4	Waterford 3	83°	SA533B1	NA	NR 57 286-1

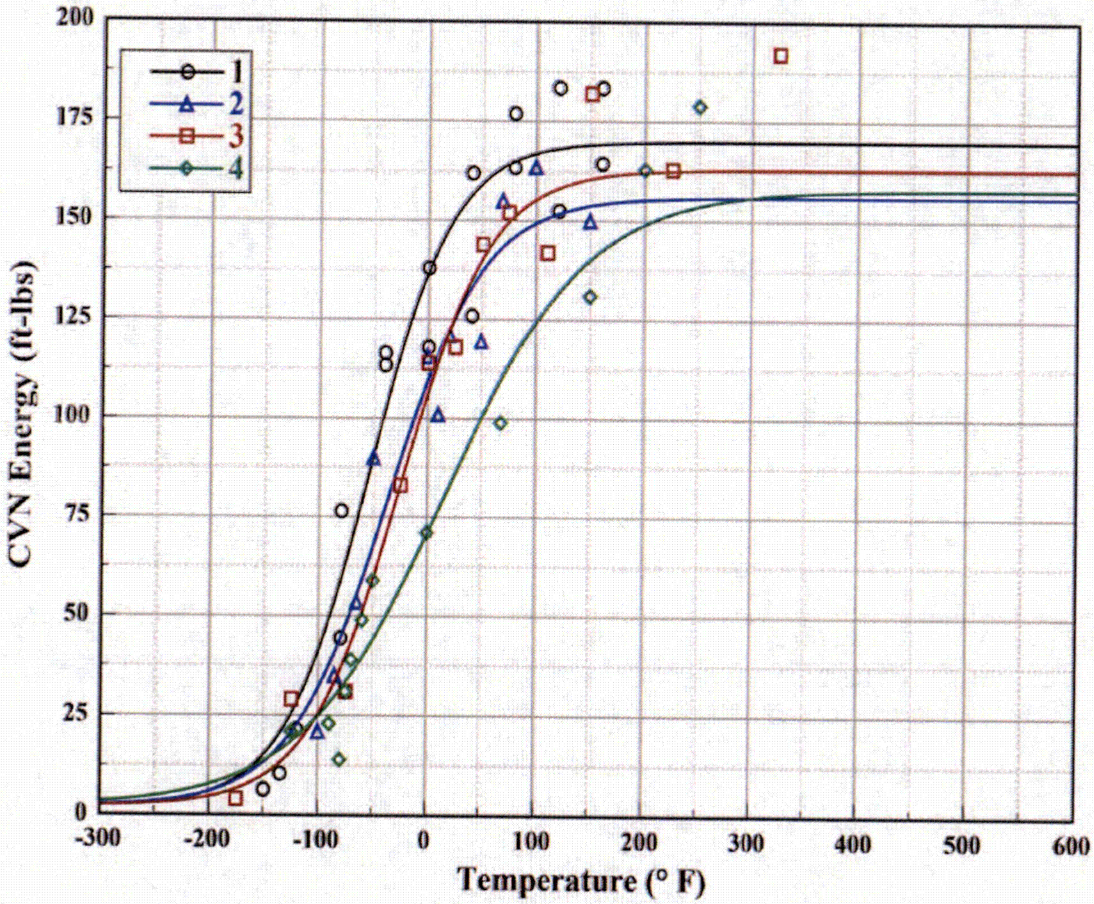


Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for the Waterford Unit 3 Reactor Vessel Heat Affected Zone Material

Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 1:58 PM

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	170	0	-117	0	-90.1	0
2		2.2	156	-14	-103.5	13.5	-71.9	18.2
3		2.2	163	-7	-91.2	25.8	-61.7	28.4
4		2.2	158	-12	-84.3	32.7	-37.5	52.6

Figure 5-10(a) Charpy V-Notch Impact Energy vs. Temperature for the Waterford Unit 3 Reactor Vessel Heat Affected Zone Material – Continued

Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 2:01 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	NA	NR 57 286-1
2	Waterford 3	97°	SA533B1	NA	NR 57 286-1
3	Waterford 3	263°	SA533B1	NA	NR 57 286-1
4	Waterford 3	83°	SA533B1	NA	NR 57 286-1

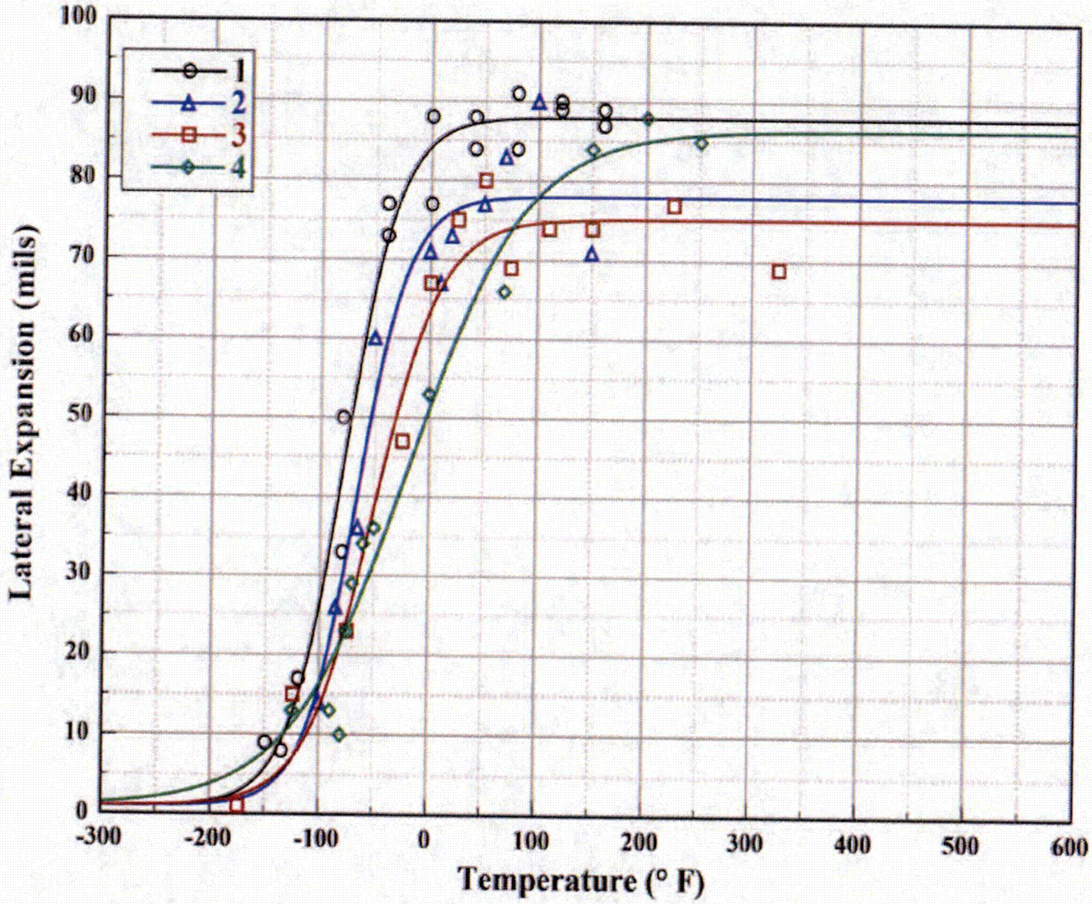


Figure 5-11 **Charpy V-Notch Lateral Expansion vs. Temperature for the Waterford Unit 3 Reactor Vessel Heat Affected Zone Material**

Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 2:01 PM

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1	87.92	0	-89.7	0
2		1	77.96	-9.96	-71.8	17.9
3		1	75.15	-12.77	-56.4	33.3
4		1	86.43	-1.49	-40.5	49.2

Figure 5-11(a) Charpy V-Notch Lateral Expansion vs. Temperature for the Waterford Unit 3 Reactor Vessel Heat Affected Zone Material – Continued

Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 2:15 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	NA	NR 57 286-1
2	Waterford 3	97°	SA533B1	NA	NR 57 286-1
3	Waterford 3	263°	SA533B1	NA	NR 57 286-1
4	Waterford 3	83°	SA533B1	NA	NR 57 286-1

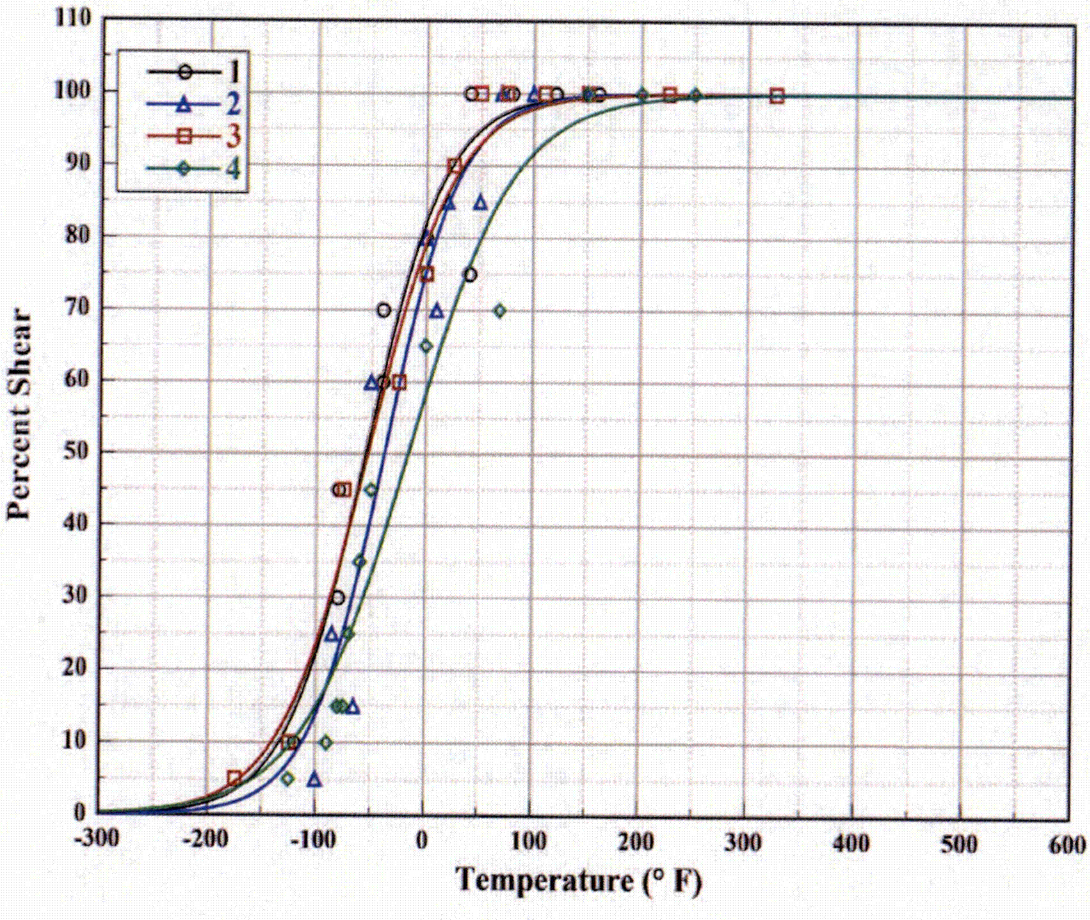


Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for the Waterford Unit 3 Reactor Vessel Heat Affected Zone Material

Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 2:15 PM

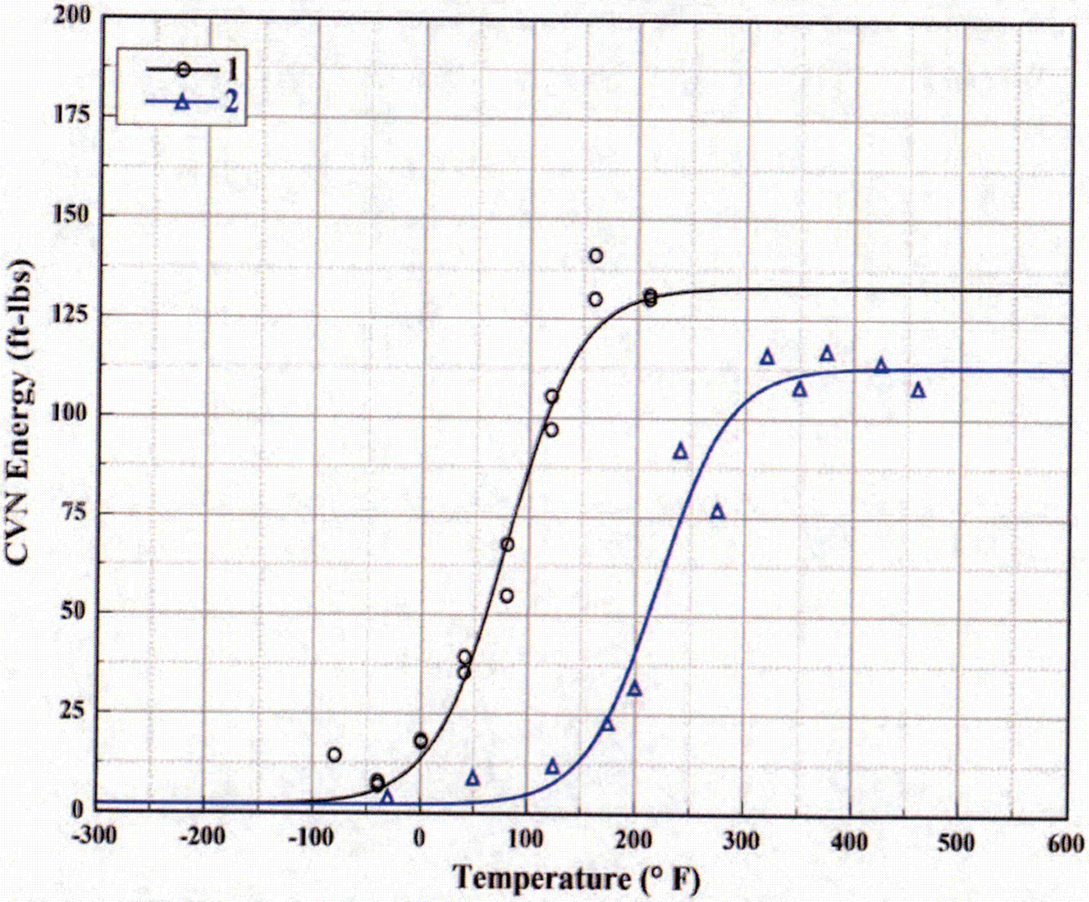
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		0	100	0	-55.4	0
2		0	100	0	-37.6	17.8
3		0	100	0	-53.4	2
4		0	100	0	-15.9	39.5

Figure 5-12(a) Charpy V-Notch Percent Shear vs. Temperature for the Waterford Unit 3 Reactor Vessel Heat Affected Zone Material – Continued

Standard Reference Material

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 2:19 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	LT	HSST-01MY
2	Waterford 3	263°	SA533B1	LT	HSST-01MY



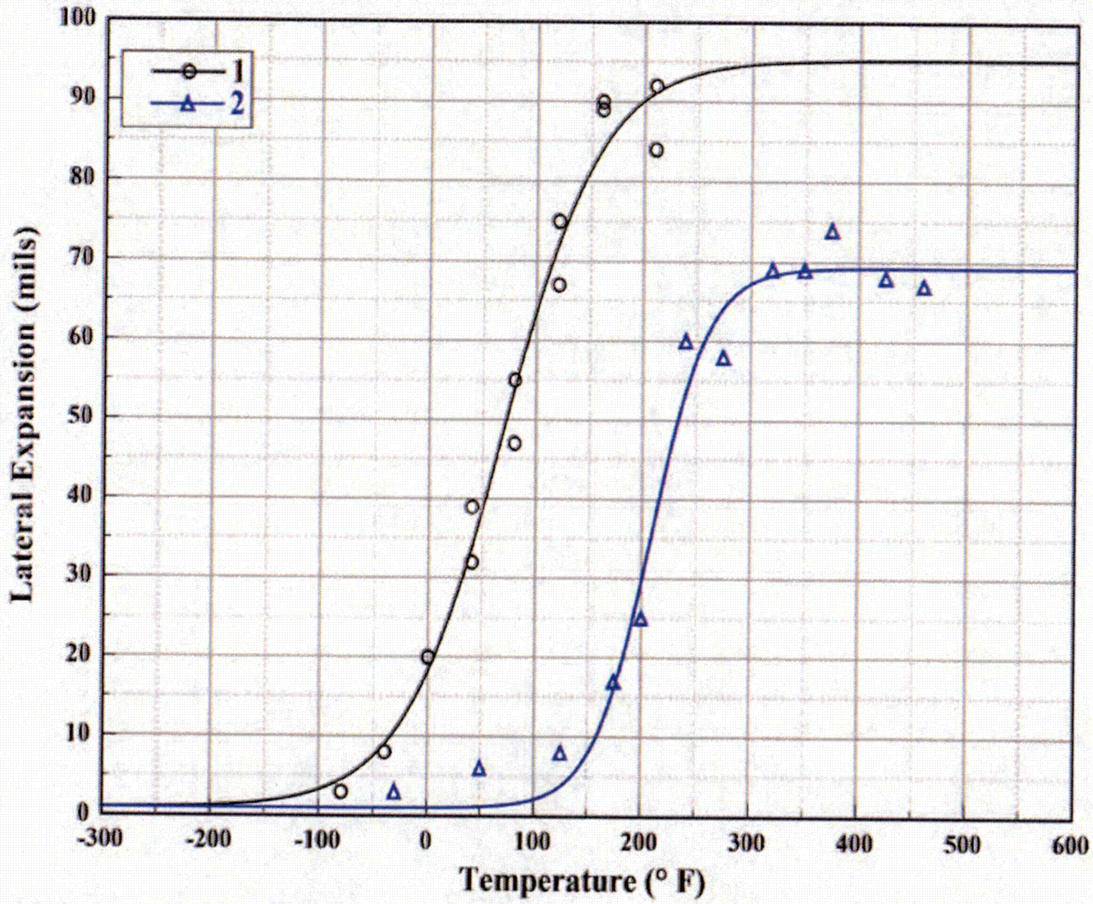
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	133	0	34.5	0	60.1	0
2		2.2	113	-20	185	150.5	211.4	151.3

Figure 5-13 Charpy V-Notch Impact Energy vs. Temperature for the Waterford Unit 3 Reactor Vessel Standard Reference Material

Standard Reference Material

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 2:23 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	LT	HSST-01MY
2	Waterford 3	263°	SA533B1	LT	HSST-01MY



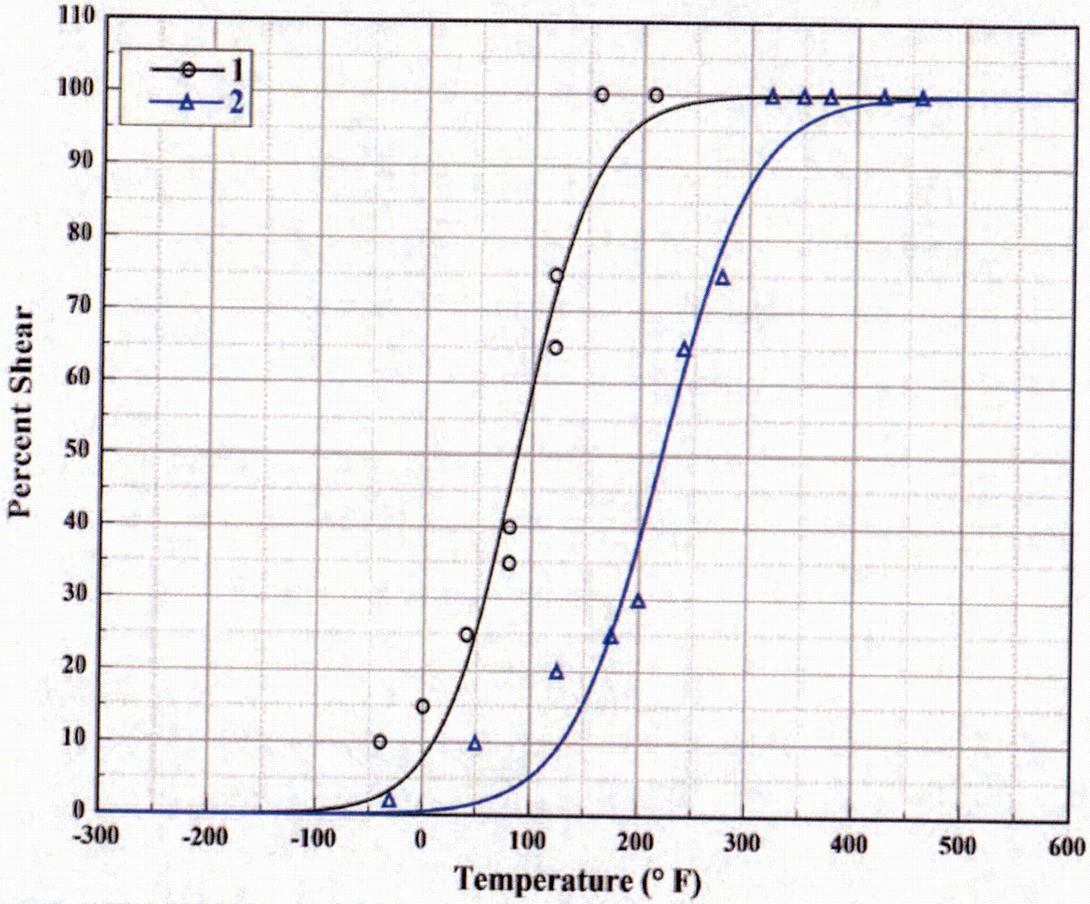
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1	95.28	0	42.3	0
2		1	69.27	-26.01	208.4	166.1

Figure 5-14 Charpy V-Notch Lateral Expansion vs. Temperature for the Waterford Unit 3 Reactor Vessel Standard Reference Material

Standard Reference Material

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 2:24 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Waterford 3	Unirrad	SA533B1	LT	HSST-01MY
2	Waterford 3	263°	SA533B1	LT	HSST-01MY



Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		0	100	0	86.6	0
2		0	100	0	220.1	133.5

Figure 5-15 Charpy V-Notch Percent Shear vs. Temperature for the Waterford Unit 3 Reactor Vessel Standard Reference Material

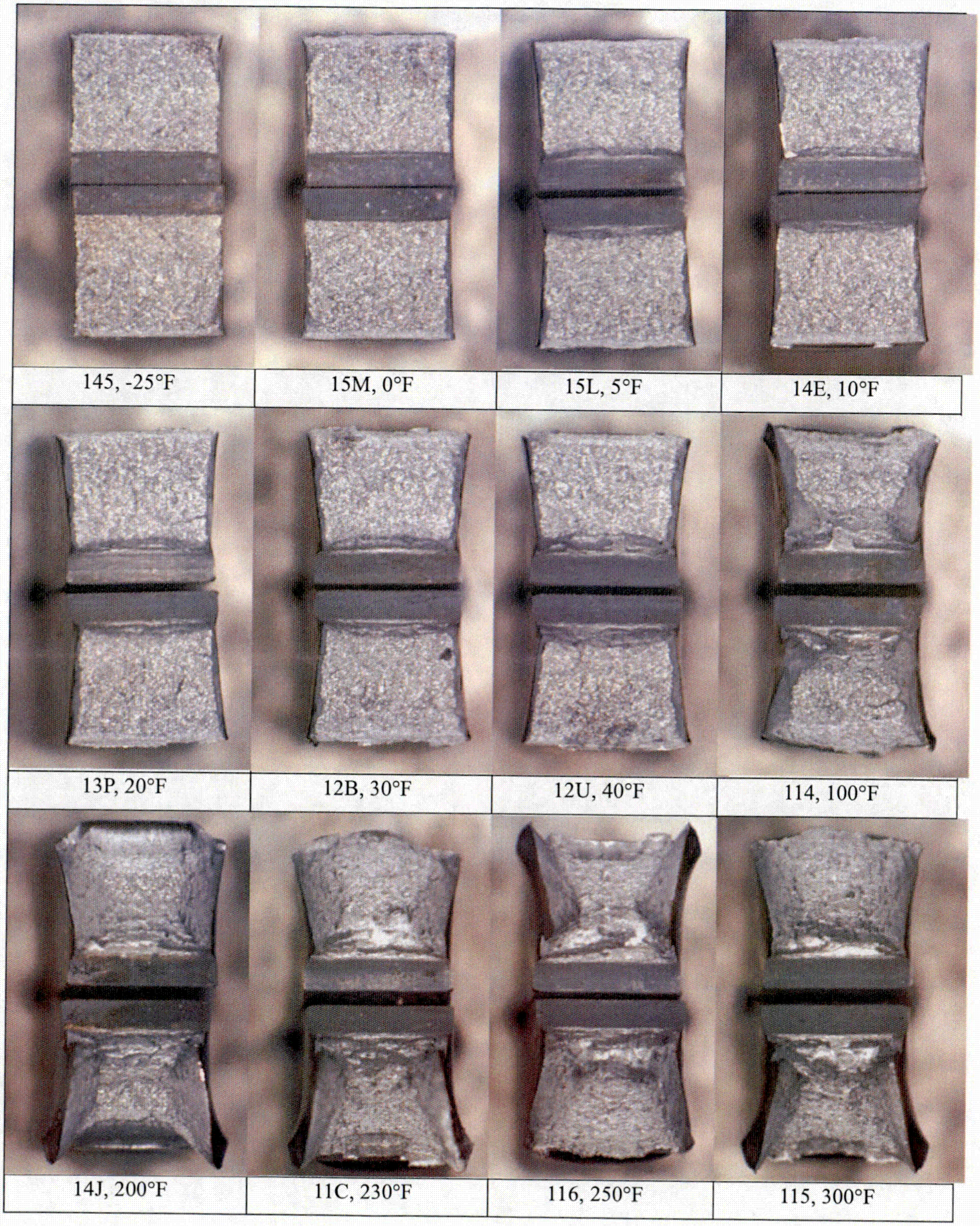


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Longitudinal Orientation)

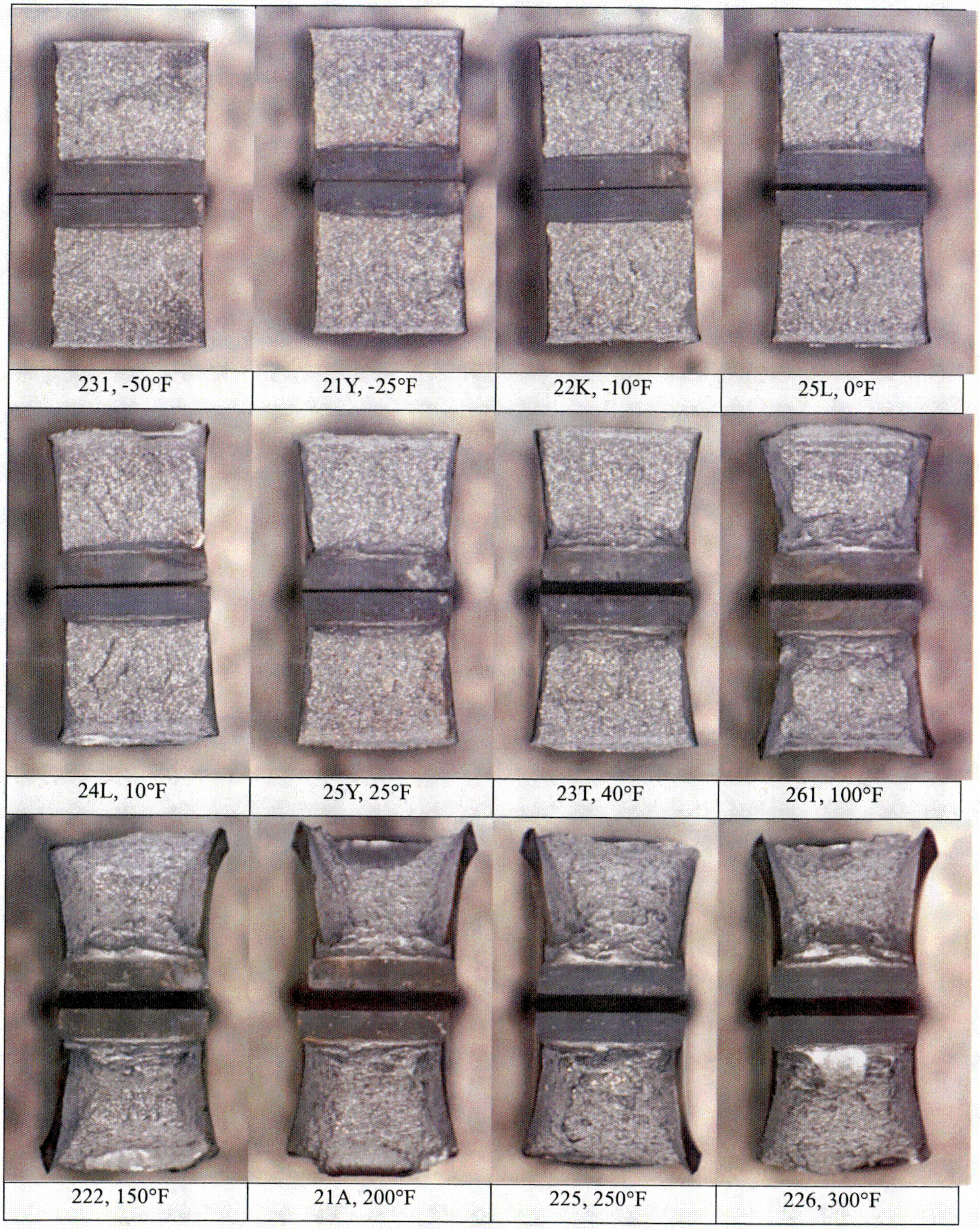


Figure 5-17 Charpy Impact Specimen Fracture Surfaces for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Transverse Orientation)

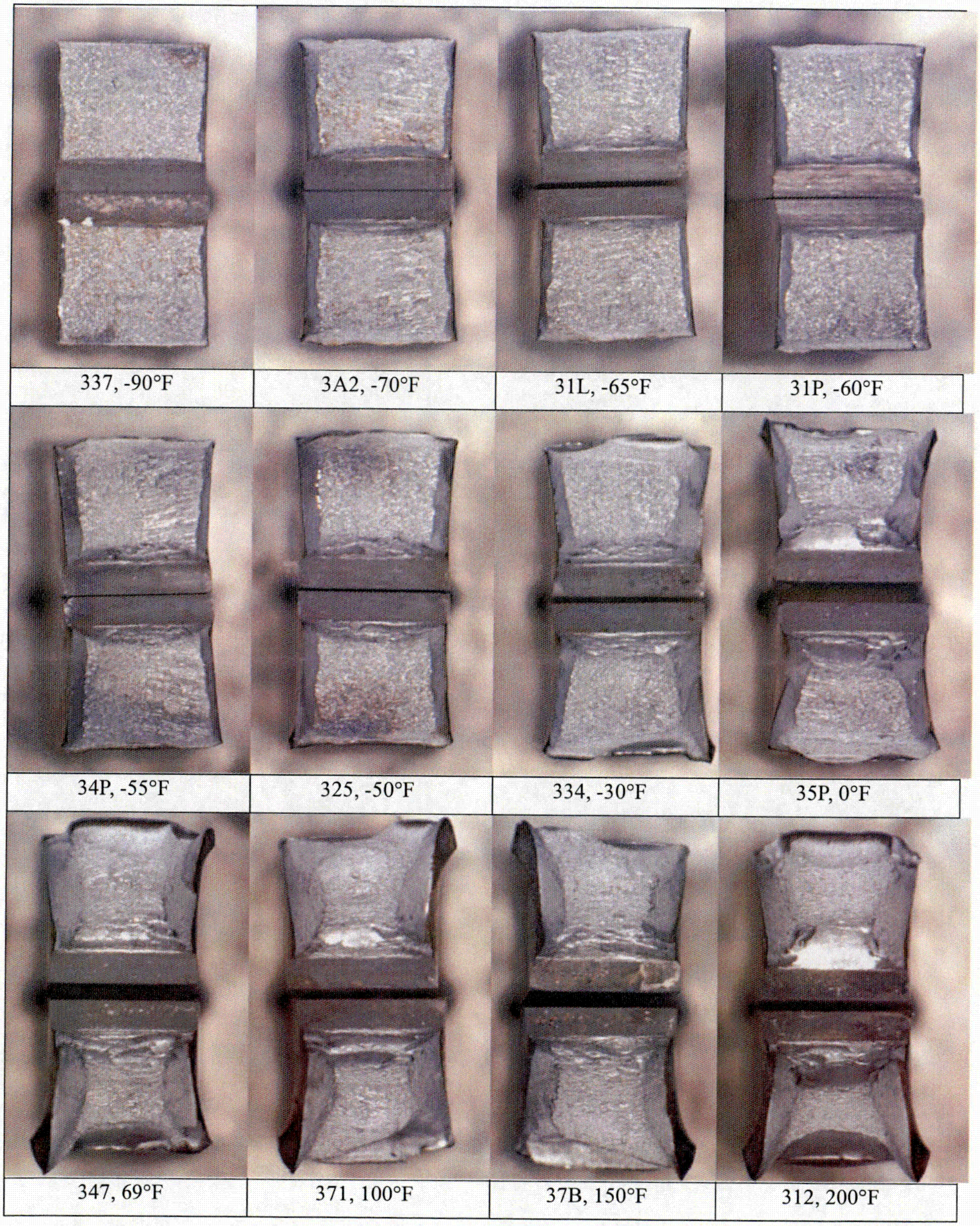


Figure 5-18 Charpy Impact Specimen Fracture Surfaces for the Waterford Unit 3 Reactor Vessel Surveillance Program Weld Material (Heat # 88114)

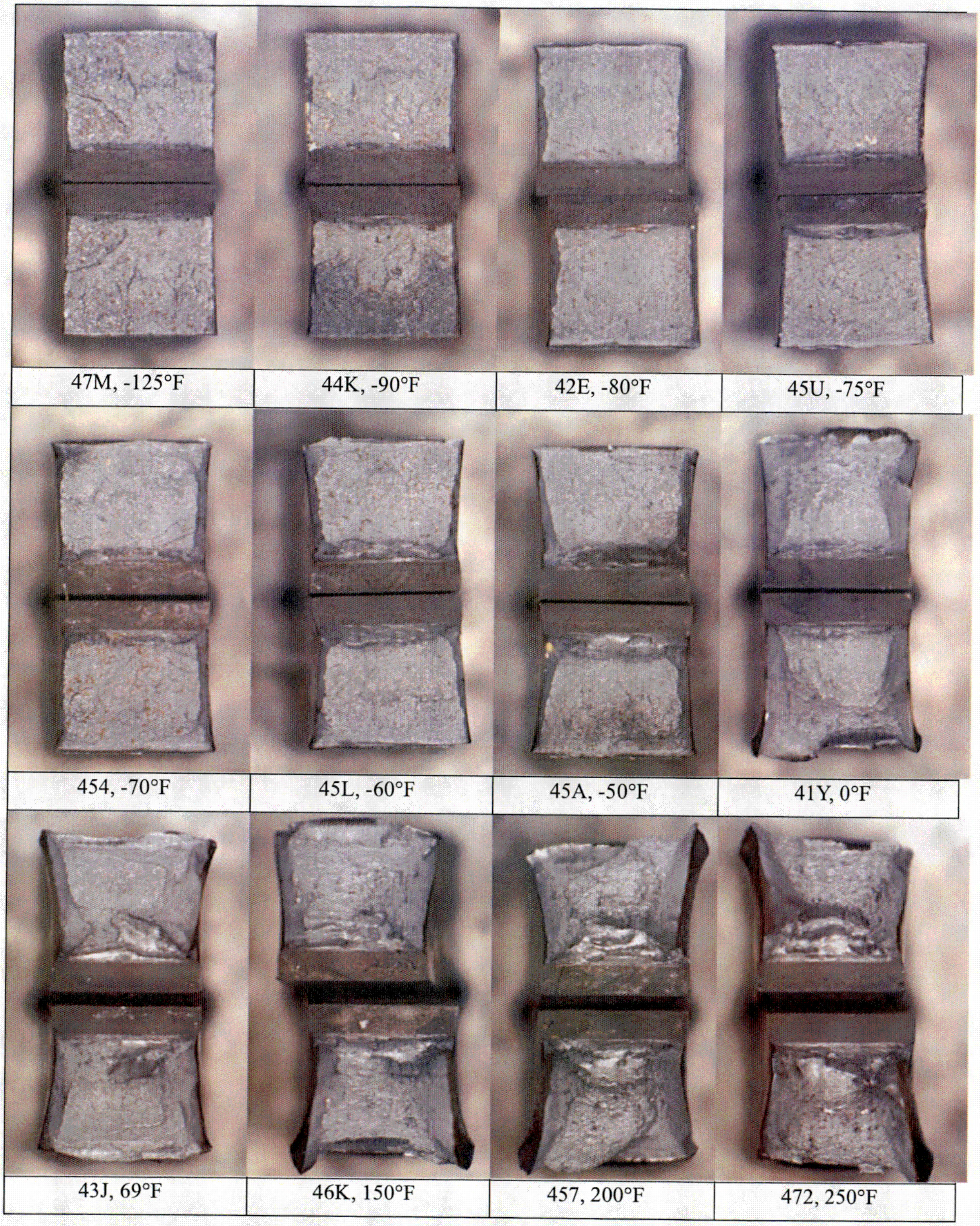
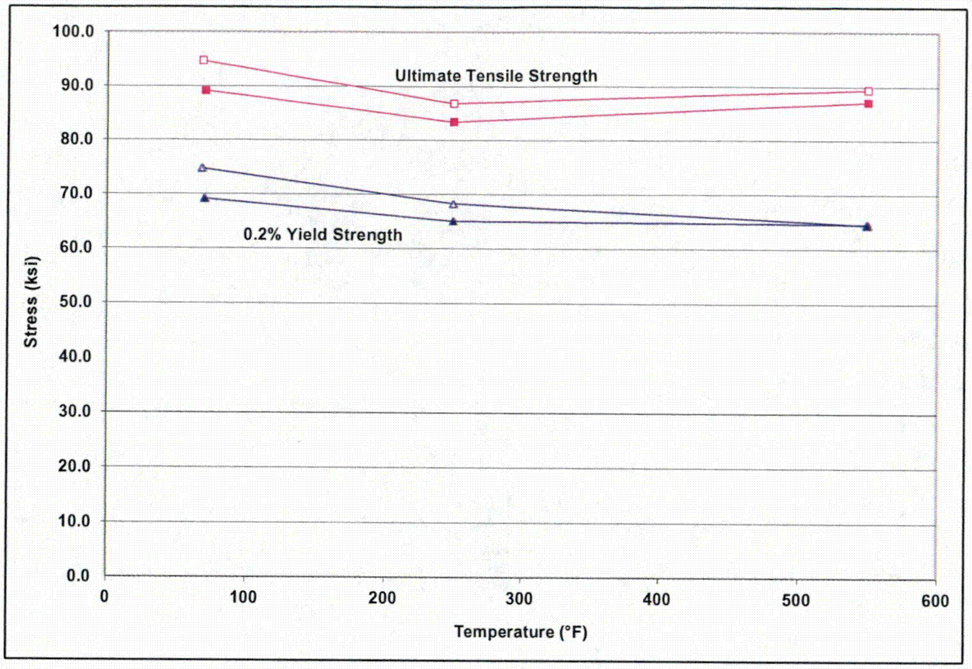


Figure 5-19 Charpy Impact Specimen Fracture Surfaces for the Waterford Unit 3 Reactor Vessel Heat Affected Zone Material



Legend: ▲ and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV)

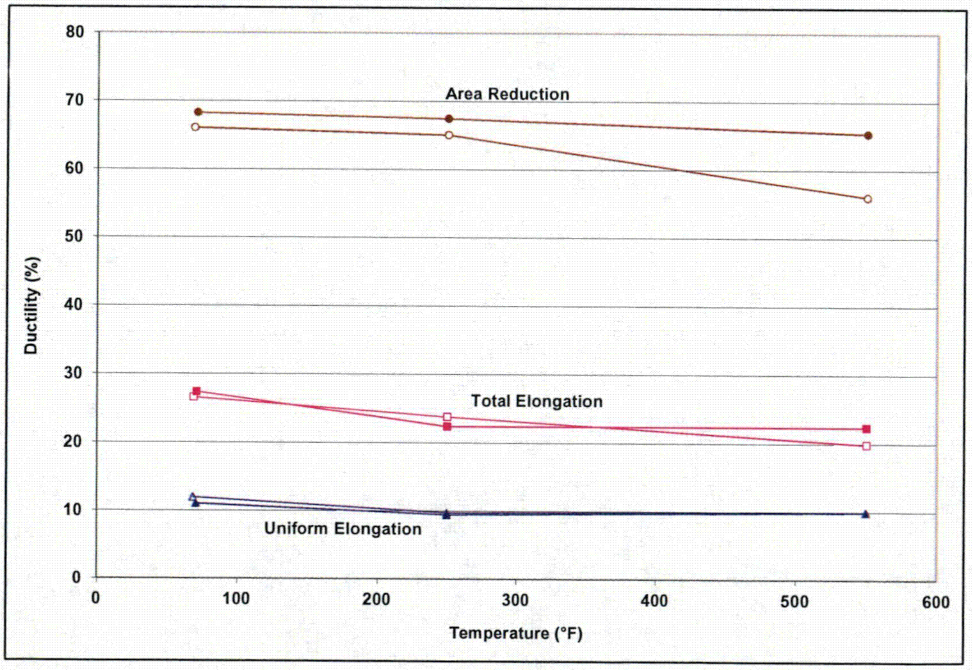
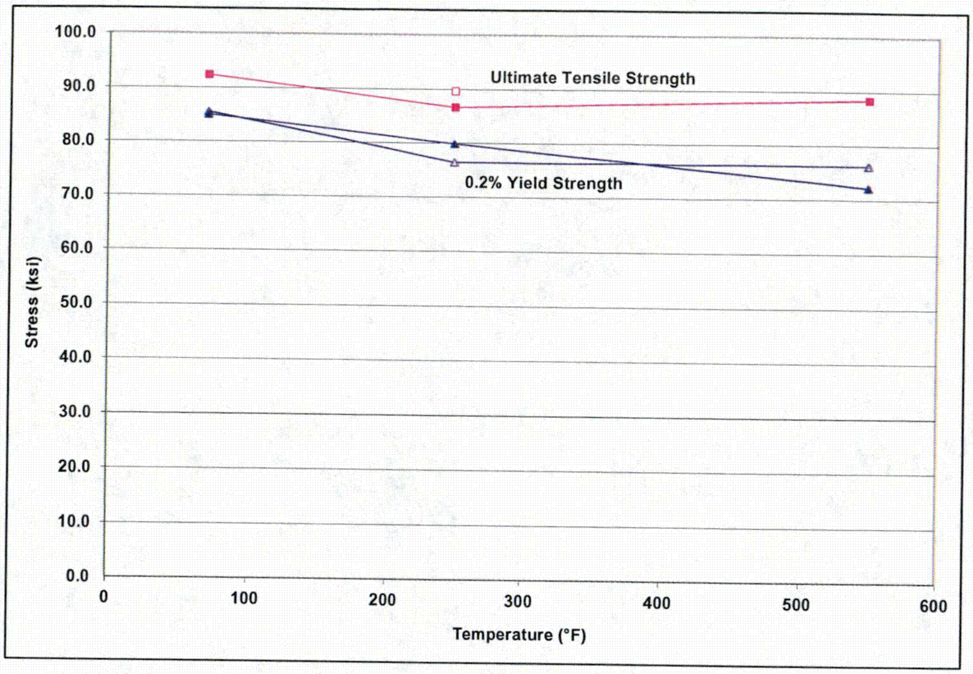
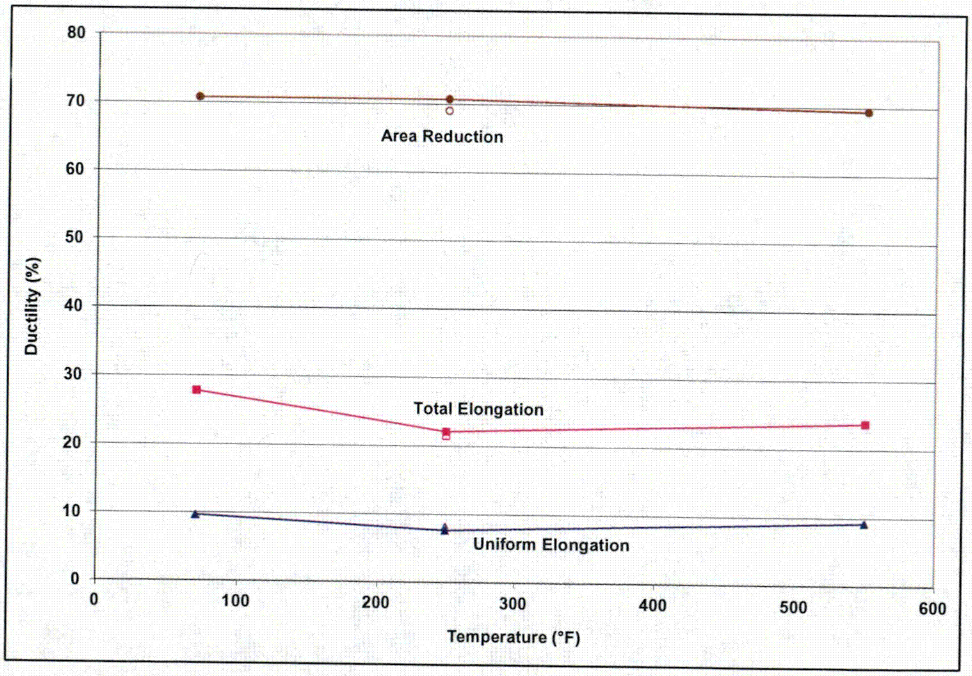


Figure 5-20 Tensile Properties for Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Transverse Orientation)

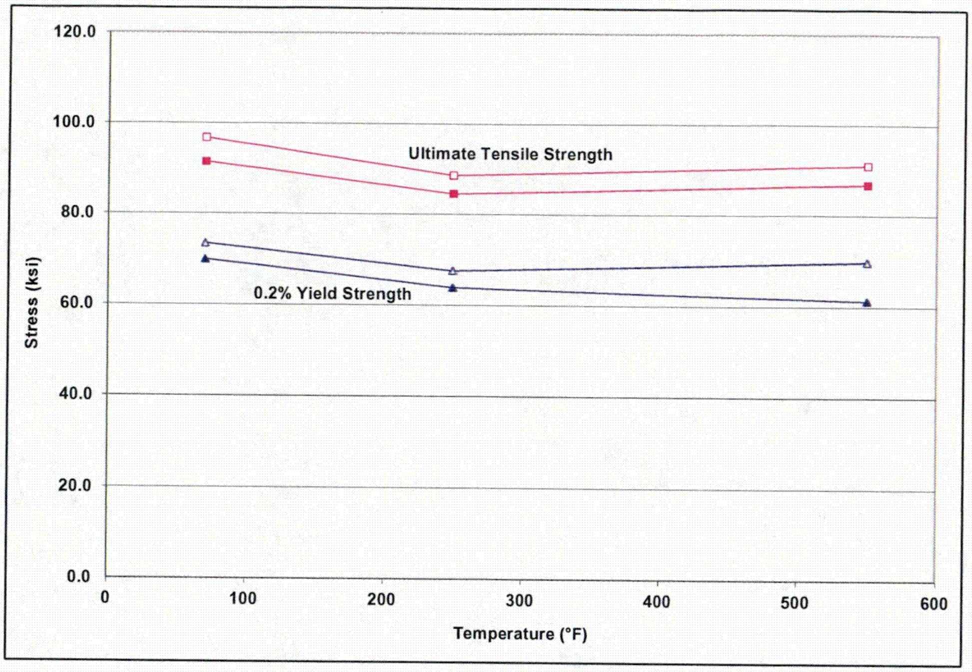


Legend: ▲and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 2.42×10^{19} n/cm^2 (E > 1.0 MeV)



*Note: Irradiated weld specimens 3K5 and 3L3 broke outside of the gage section. Thus, limited data is available for these specimens as seen in the plots above. See Table 5-11 for more information.

Figure 5-21 Tensile Properties for the Waterford Unit 3 Reactor Vessel Surveillance Program Weld Material (Heat # 88114)



Legend: ▲ and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 2.42 x 10^{19} n/cm^2 (E > 1.0 MeV)

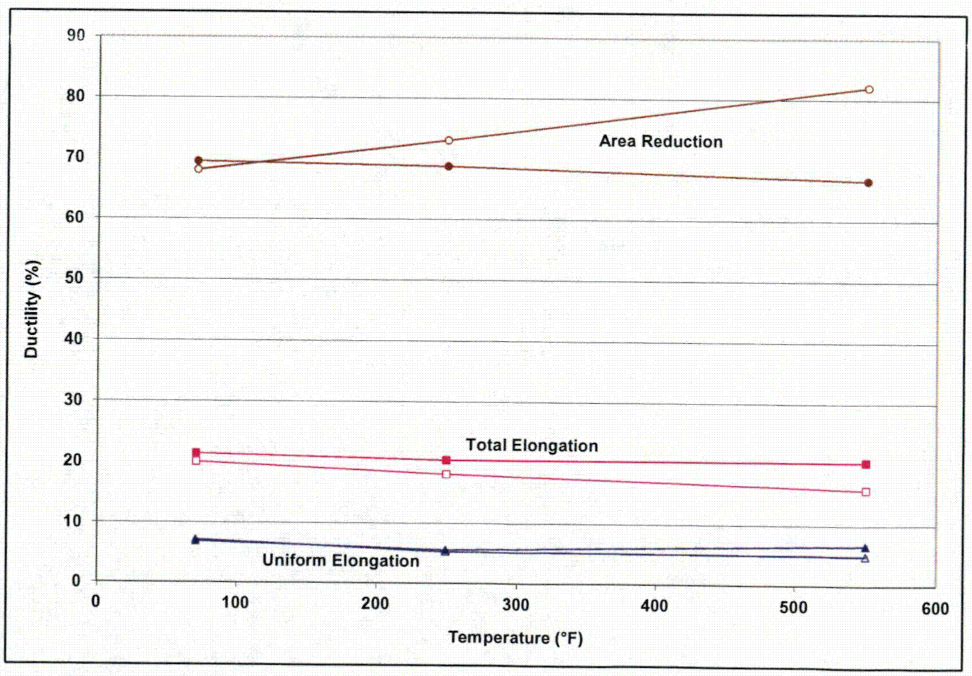
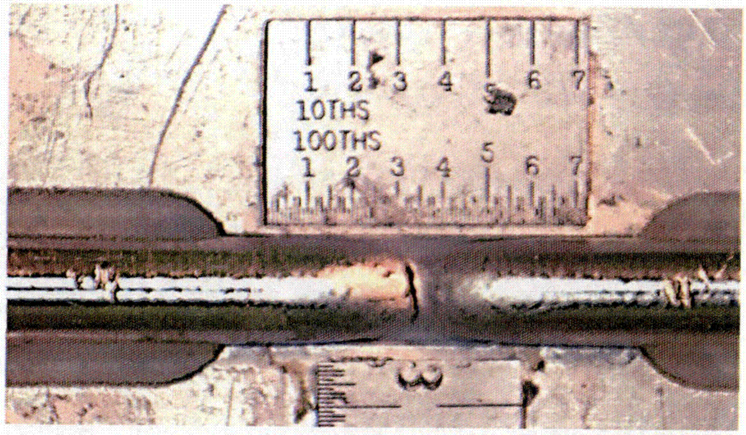
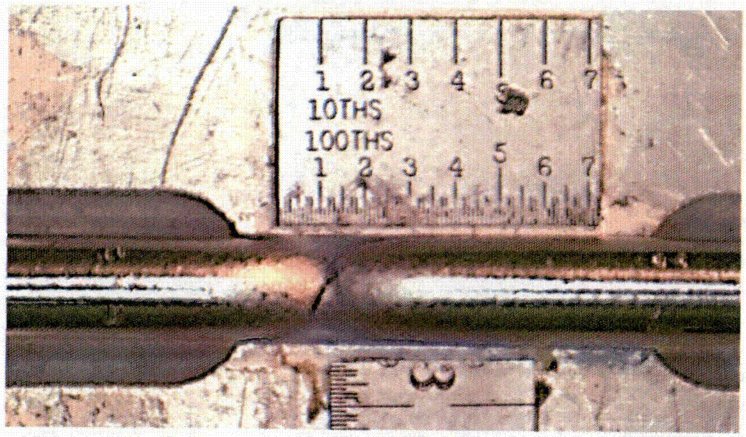


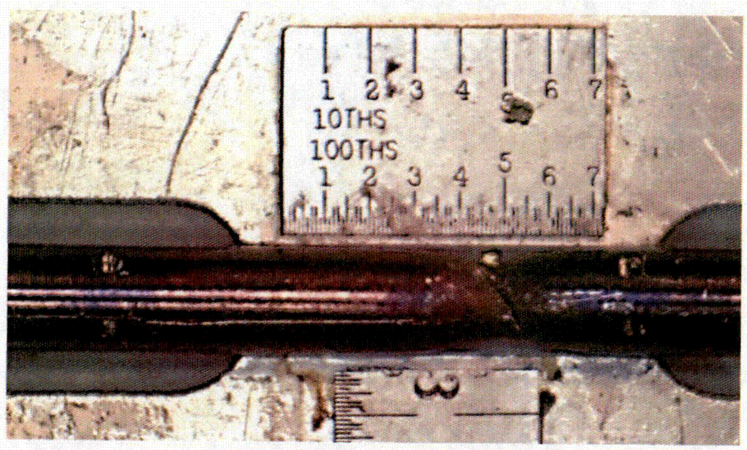
Figure 5-22 Tensile Properties for the Waterford Unit 3 Reactor Vessel Heat Affected Zone Material



2J3 – Tested at 69°F

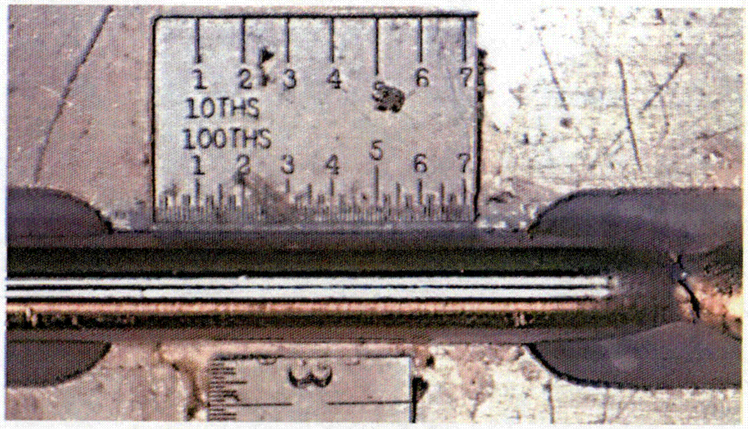


2L7 – Tested at 250°F

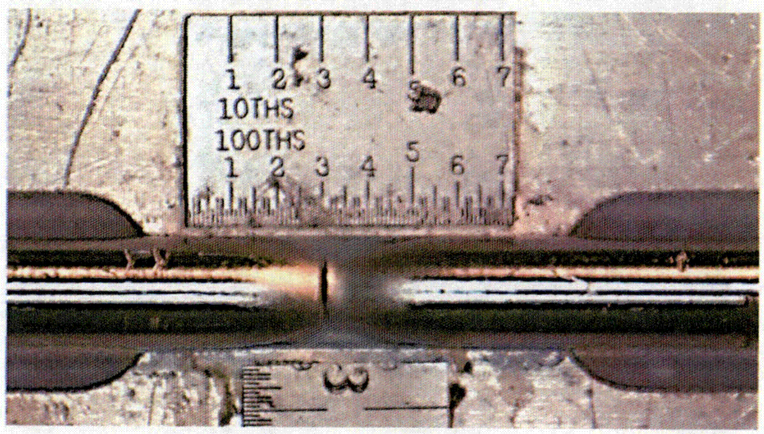


2K4 – Tested at 550°F

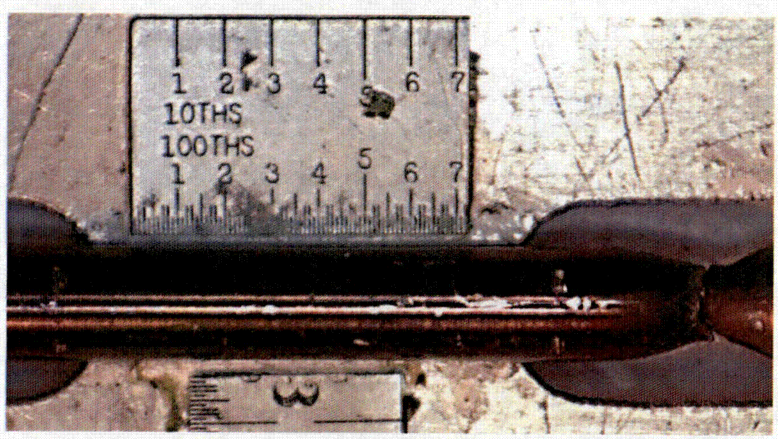
Figure 5-23 Fractured Tensile Specimens from Waterford Unit 3 Reactor Vessel Lower Shell Plate M-1004-2 (Transverse Orientation)



3K5 – Tested at 71°F

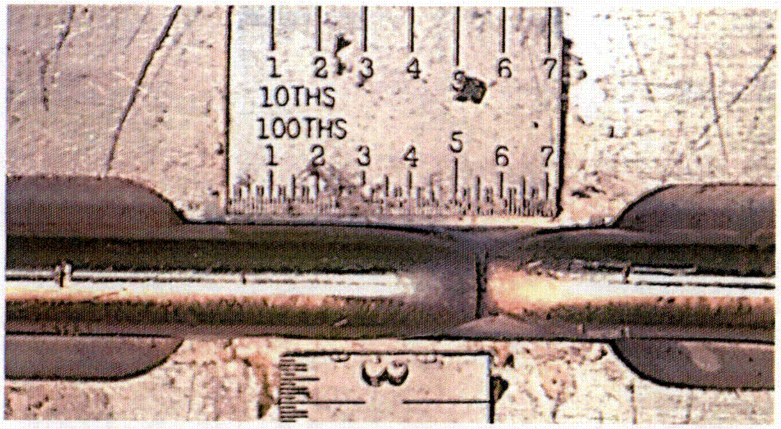


3KD – Tested at 250°F

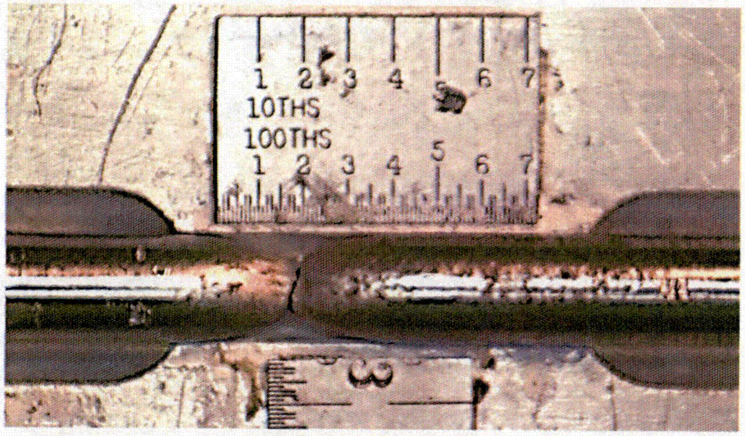


3L3 – Tested at 550°F

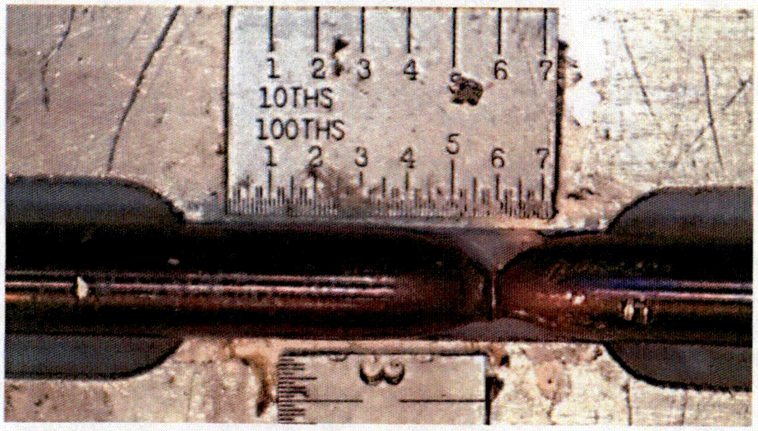
Figure 5-24 Fractured Tensile Specimens from the Waterford Unit 3 Reactor Vessel Surveillance Program Weld Material (Heat # 88114)



4J3 – Tested at 71°F

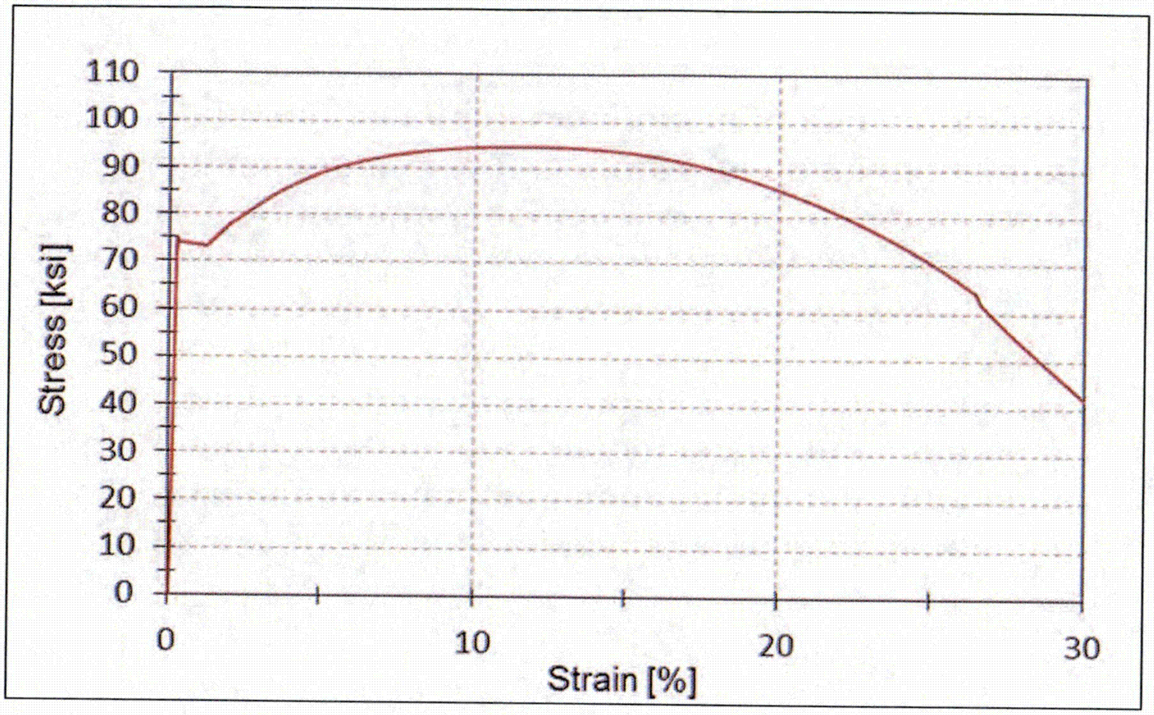


4KB – Tested at 250°F

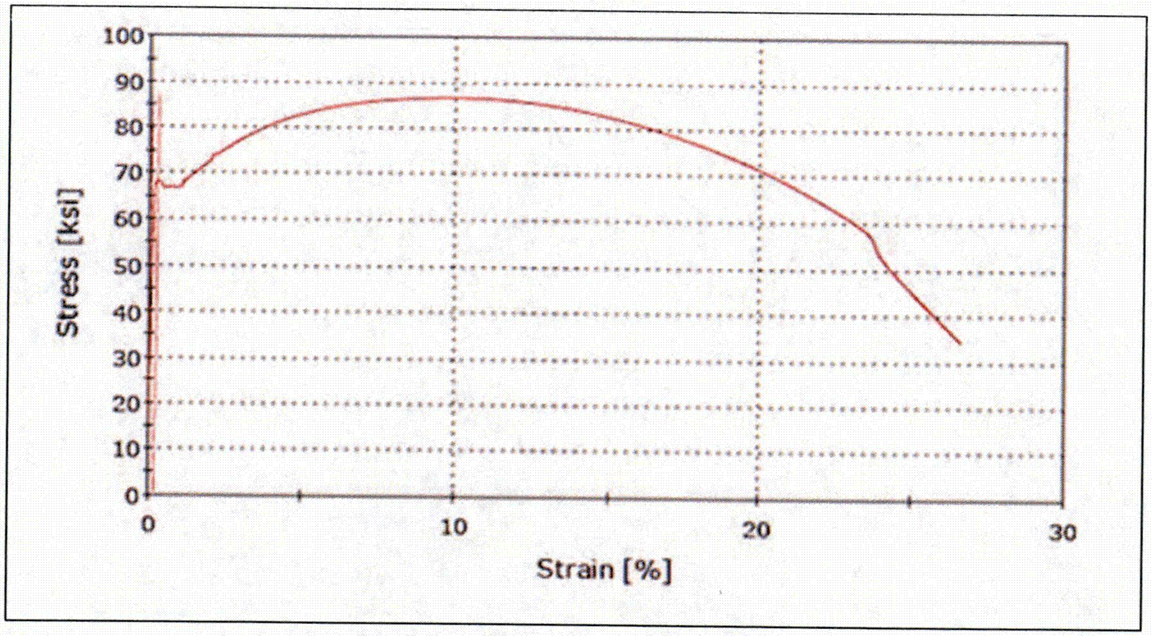


4JC – Tested at 550°F

Figure 5-25 Fractured Tensile Specimens from the Waterford Unit 3 Reactor Vessel Heat Affected Zone Material

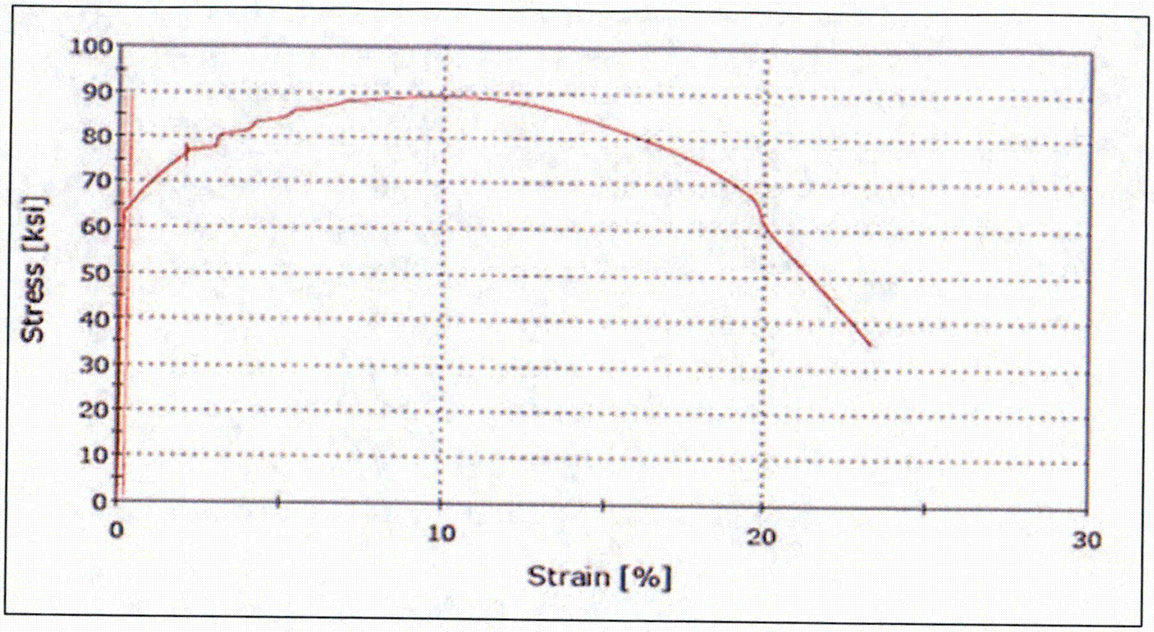


Tensile Specimen 2J3 Tested at 69°F



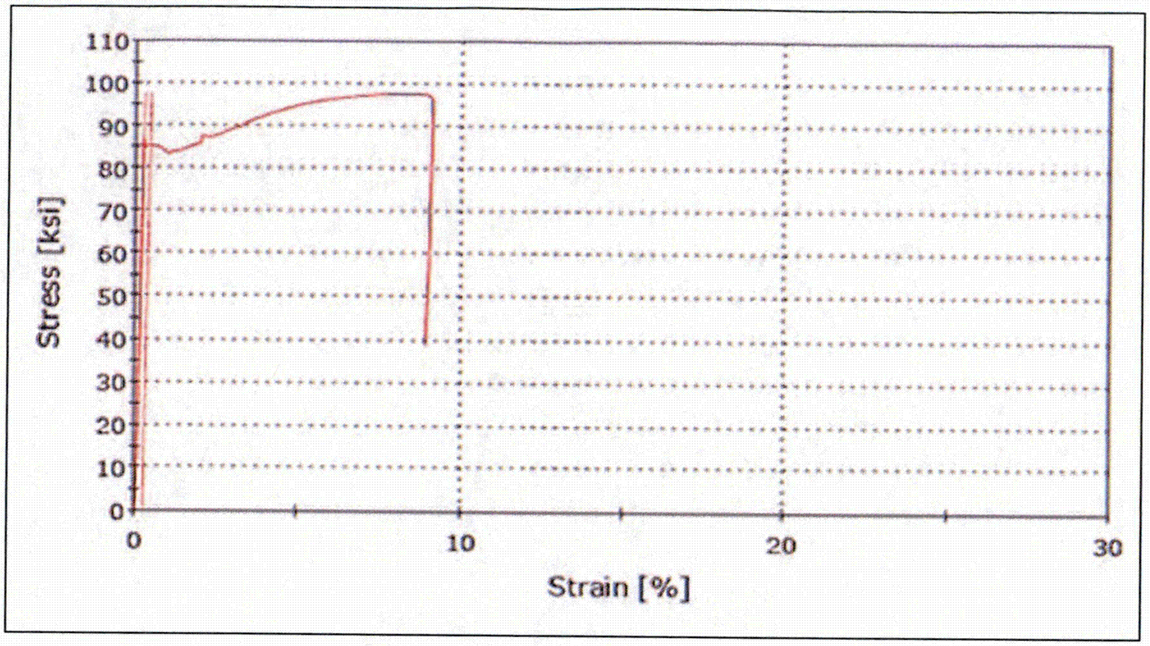
Tensile Specimen 2L7 Tested at 250°F

Figure 5-26 Engineering Stress-Strain Curves for Waterford Unit 3 Lower Shell Plate M-1004-2 Tensile Specimens 2J3 and 2L7 (Transverse Orientation)



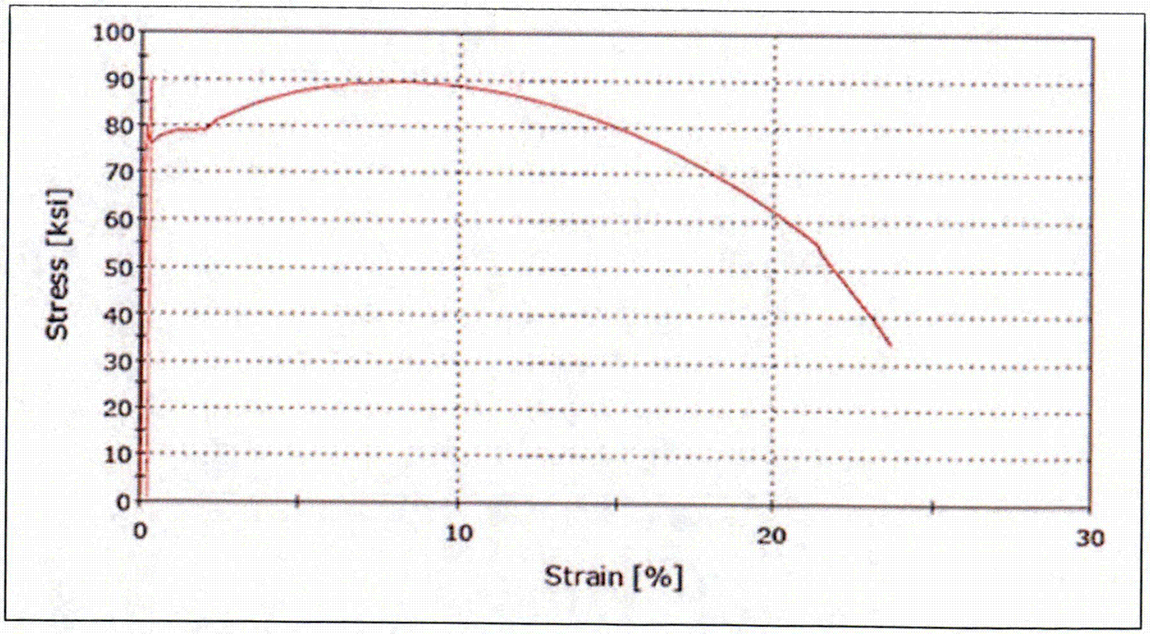
Tensile Specimen 2K4 Tested at 550°F

Figure 5-27 Engineering Stress-Strain Curve for Waterford Unit 3 Lower Shell Plate M-1004-2 Tensile Specimen 2K4 (Transverse Orientation)



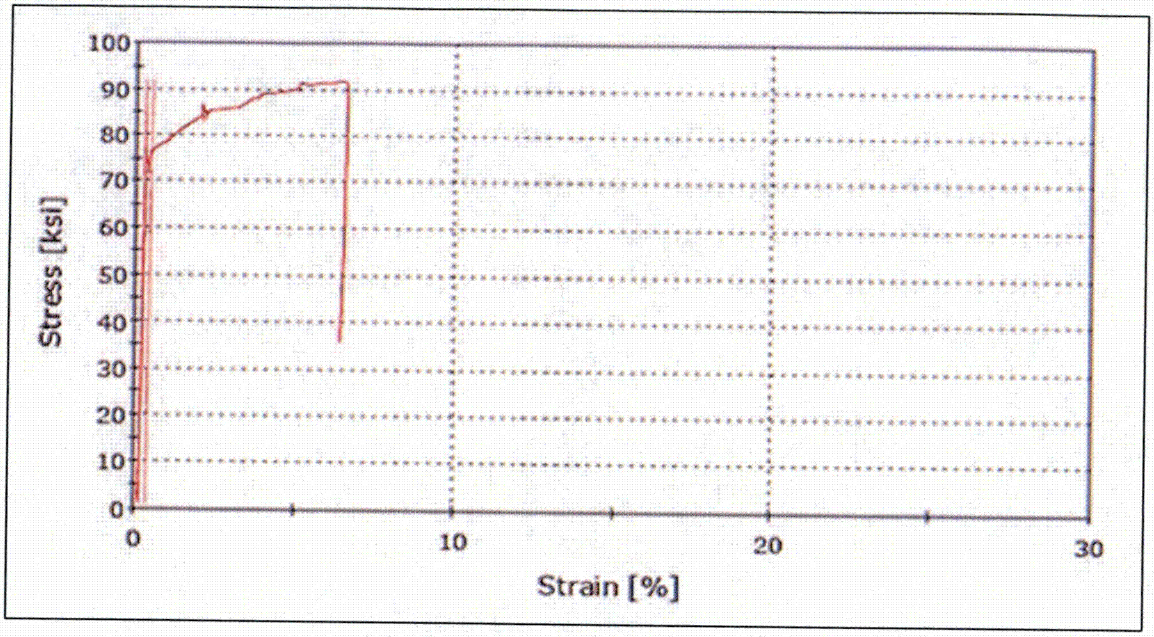
Tensile Specimen 3K5 Tested at 71°F

*Note: Irradiated weld specimen 3K5 broke outside of the gage section. As a result, the stress-strain curve is atypical and may not reflect the weld behavior.



Tensile Specimen 3KD Tested at 250°F

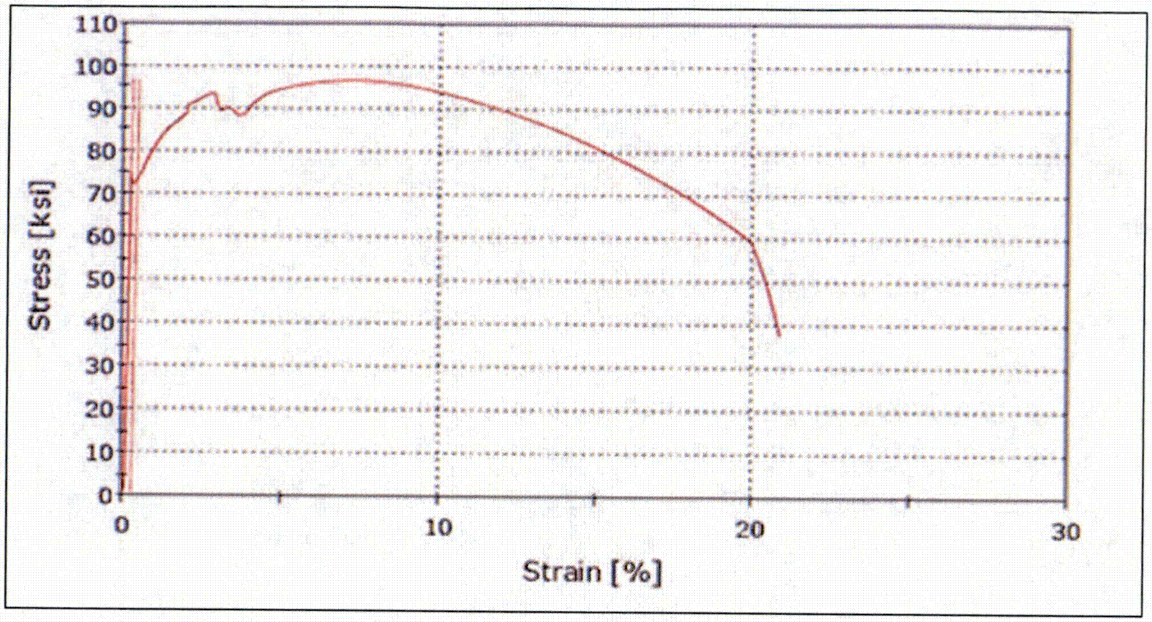
Figure 5-28 Engineering Stress-Strain Curves for Waterford Unit 3 Surveillance Program Weld Material (Heat # 88114) Tensile Specimens 3K5 and 3KD



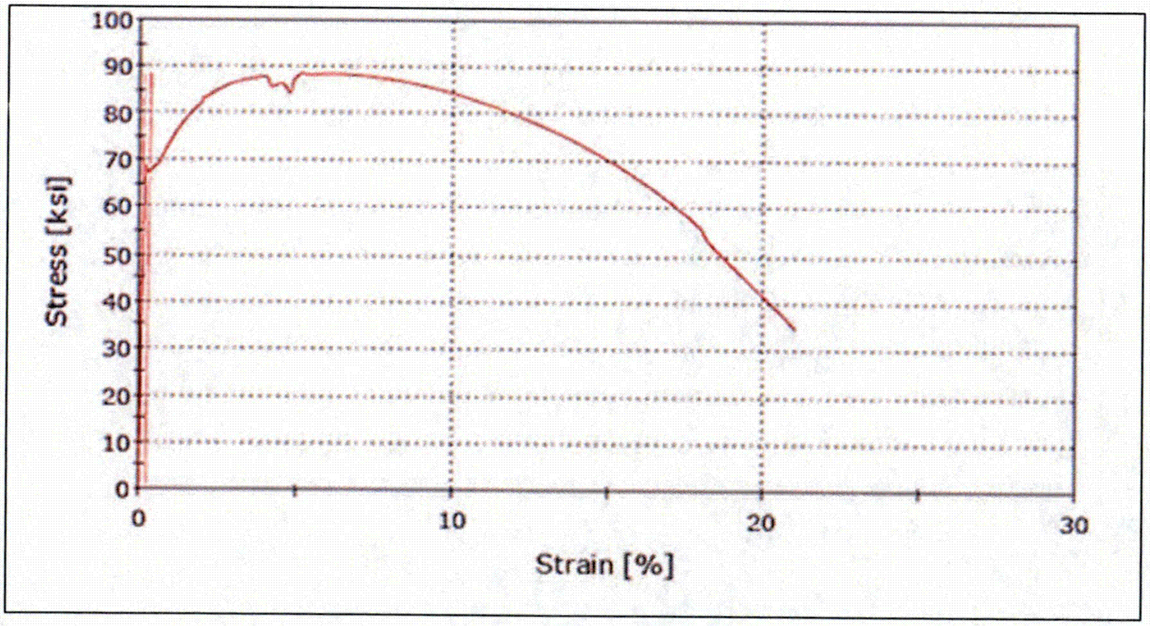
Tensile Specimen 3L3 Tested at 550°F

*Note: Irradiated weld specimen 3L3 broke outside of the gage section. As a result, the stress-strain curve is atypical and may not reflect the weld behavior.

Figure 5-29 Engineering Stress-Strain Curve for Waterford Unit 3 Surveillance Program Weld Material (Heat # 88114) Tensile Specimen 3L3

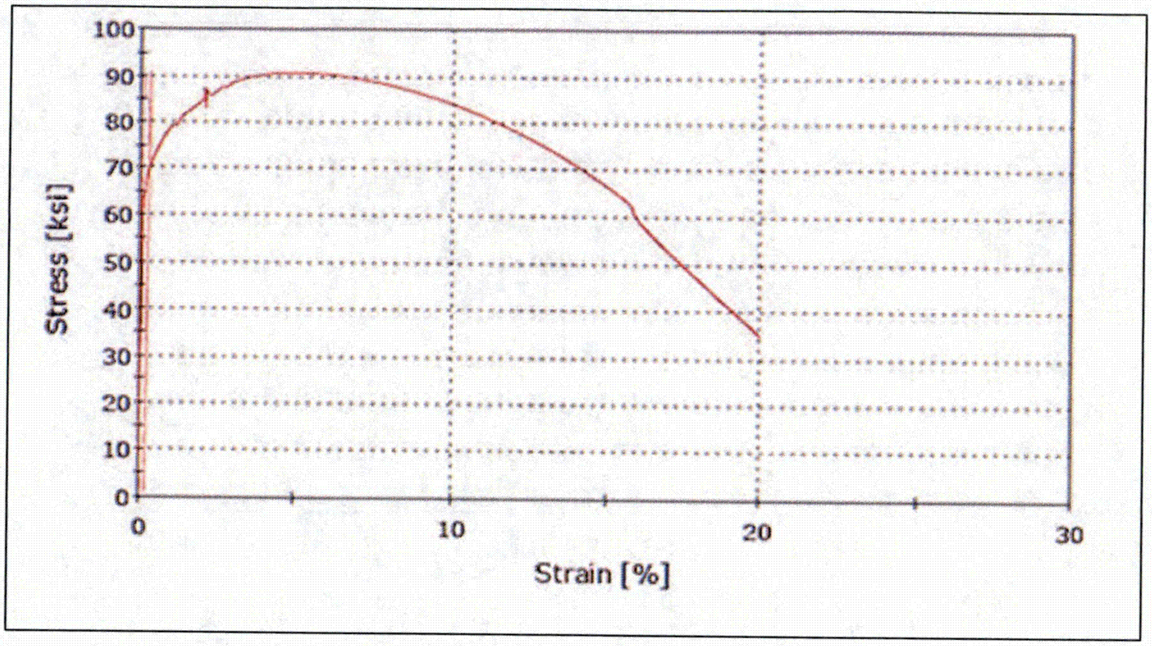


Tensile Specimen 4J3 Tested at 71°F



Tensile Specimen 4KB Tested at 250°F

Figure 5-30 Engineering Stress-Strain Curves for Waterford Unit 3 Heat Affected Zone Material Tensile Specimens 4J3 and 4KB



Tensile Specimen 4JC Tested at 550°F

Figure 5-31 Engineering Stress-Strain Curve for Waterford Unit 3 Heat Affected Zone Material Tensile Specimen 4JC

6 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION

This section describes a discrete ordinates (S_n) transport analysis performed for the Waterford 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 83°, withdrawn at the end of the nineteenth plant operating cycle, is provided. In addition, the sensor sets from the previously withdrawn capsules (97° and 263°) are presented. 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 form the basis for projections of the neutron exposure of the reactor pressure vessel for operating periods extending to 60 effective full-power years (EFPY) at 3716 MWt.

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. However, in recent years, 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 E853-13, "Standard Practice for Analysis and Interpretation of Light-Water Reactor Surveillance Results," [Ref. 19] recommends reporting displacements per iron atom 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 E693-94, "Standard Practice for Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements per Atom" [Ref. 20]. The application of the dpa parameter to the assessment of embrittlement gradients through the thickness of the reactor vessel wall has already been promulgated in Revision 2 to Regulatory Guide 1.99, "Radiation Embrittlement of Reactor Vessel Materials" [Ref. 1].

All of the calculations and dosimetry evaluations described in this section and in Appendix A were based on nuclear cross-section data derived from ENDF/B-VI and used 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" [Ref. 21]. Additionally, the methods used to develop the calculated pressure vessel fluence are consistent with the NRC-approved methodology described in WCAP-14040-A, Revision 4, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves," May 2004 [Ref. 22]. As an improvement, instead of the fluence rate synthesis technique, three-dimensional transport calculations were performed.

6.2 DISCRETE ORDINATES ANALYSIS

The arrangement of the surveillance capsules in the Waterford Unit 3 reactor vessel is shown in Figure 4-1. Six irradiation capsules attached to the pressure vessel inside wall are included in the reactor design that constitutes the reactor vessel surveillance program. The capsules are located at azimuthal angles of 83°, 97°, 104°, 263°, 277°, and 284° as shown in Figure 4-1. These full-core positions correspond to the following octant symmetric locations represented in Figure 6-1: 7° from the core cardinal axes (for the 83°, 97°, 263° and 277° capsules) and 14° from the core cardinal axes (for the 104° and 284° capsules). The stainless steel specimen containers are 1.402-inch by 0.652-inch and are approximately 98 inches in height. The containers are positioned axially such that the test specimens are centered 6.25 inches above the core midplane, thus spanning the approximate central eight feet of the 12.5-foot-high reactor core.

From a neutronic standpoint, the surveillance capsules and capsule holders are significant. The presence of these materials has a significant effect on both the spatial distribution of neutron fluence rate and the neutron spectrum in the vicinity of the capsules. However, the capsules are far enough apart that they do not interfere with one another. 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 Waterford Unit 3 reactor vessel and surveillance capsules, a series of fuel-cycle-specific forward transport calculations were carried out using a three-dimensional geometrical reactor model. For the Waterford Unit 3 transport calculations, the r,θ,z models depicted (given as r,θ plan view) in Figures 6-1 and 6-2 were utilized since, with the exception of the capsules, the reactor is octant symmetric. The r,z section view depicted in Figure 6-3 shows the model having an axial span from an elevation 5.5 feet below the bottom of the active fuel to 5 feet above the top of the active fuel. These r,θ,z models include the core, the reactor internals, the surveillance capsules, the pressure vessel cladding and vessel wall, the insulation external to the pressure vessel, and the primary biological shield wall. These models formed the basis for the calculated results and enabled making comparisons to the surveillance capsule dosimetry evaluations. In developing these analytical models, nominal design dimensions were employed for the various structural components with a few exceptions. The radius to the center of the surveillance capsule holder and the radius to the pressure vessel were taken from as-built drawings for the Waterford Unit 3 reactor for key differences between the nominal and as-built dimensions. For the reactor pressure vessel, the minimum vessel thickness was used. 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,z reactor models consisted of 160 radial by 121 azimuthal by 247 axial intervals. Mesh sizes were chosen to ensure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration fluence rate convergence criterion utilized in the r,θ,z calculations was set at a value of 0.001.

The core power distributions used in the plant-specific transport analysis for each of the first 19 fuel cycles at Waterford Unit 3 included cycle-dependent fuel assembly initial enrichments, burnups, and axial power distributions. This information was used to develop spatial- and energy-dependent core source distributions averaged over each individual fuel cycle. Therefore, the results from the neutron transport

calculations provided data in terms of fuel-cycle-averaged neutron fluence rate, which when multiplied by the appropriate fuel cycle length, generated the incremental fast neutron exposure for each fuel cycle. In constructing these core source distributions, the energy distribution of the source was based on an appropriate fission split for uranium and plutonium isotopes based on the initial enrichment and burnup history of individual fuel assemblies. From these assembly-dependent fission splits, composite values of energy release per fission, neutron yield per fission, and fission spectrum were determined.

All of the transport calculations supporting this analysis were carried out using the RAPTOR-M3G discrete ordinates code [Ref. 23] and the BUGLE-96 cross-section library [Ref. 24]. The BUGLE-96 library provides a coupled 47-neutron, 20-gamma-group cross-section data set produced specifically for light-water reactor (LWR) applications. In these analyses, anisotropic scattering was treated with a P_5 Legendre expansion, and angular discretization was modeled with an S_{16} order of angular quadrature. Energy- and space-dependent core power distributions, as well as system operating temperatures, were treated on a fuel-cycle-specific basis.

Selected results from the neutron transport analyses are provided in Tables 6-1 through 6-10. In Tables 6-1 and 6-3, the calculated exposure rates and integral exposures expressed in terms of fast neutron fluence rate (E > 1.0 MeV) and fast neutron fluence (E > 1.0 MeV), and iron atom displacement rate (dpa/s) and iron atom displacements, respectively, are given at the radial and azimuthal center of the octant symmetric surveillance capsule positions, i.e., for the 7° capsule and 14° capsule. In Tables 6-2 and 6-4, the calculated integral exposures expressed for future projections, in terms of fast neutron fluence (E > 1.0 MeV) and iron atom displacements, respectively, are given at the radial and azimuthal center of the octant symmetric surveillance capsule positions, i.e., for the 7° capsule and 14° capsule. These results, representative of the average axial exposure of the material specimens, establish the calculated exposure of the surveillance capsules withdrawn to date as well as projections into the future.

Similar information, in terms of calculated fast neutron fluence rate (E > 1.0 MeV), fast neutron fluence (E > 1.0 MeV), dpa/s, and dpa, are provided in Tables 6-5 through 6-8, for the reactor vessel inner radius at four azimuthal locations, as well as the maximum exposure observed within in the octant. The vessel data given in Tables 6-5 through 6-8 were taken at the clad/base metal interface and represent maximum calculated exposure levels on the vessel. From the data provided in Table 6-6, it is noted that the peak clad/base metal interface vessel fluence (E > 1.0 MeV) at the end of the nineteenth fuel cycle (i.e., after 24.66 EFPY at 3716 MWt of plant operation) was 2.02E+19 n/cm^2.

These data tabulations include both plant- and fuel-cycle-specific calculated neutron exposures at the end of the nineteenth fuel cycle, as well as future projections to 32, 36, 40, 48, 55, and 60 EFPY at 3716 MWt. The calculations account for uprates from 3390 MWt to 3441 MWt that occurred prior to Cycle 12, and from 3441 MWt to 3716 MWt that occurred prior to Cycle 14. The projections are based on the assumption that the core power distributions and associated plant operating characteristics from Cycles 17, 18, and 19 are representative of future plant operation. The future projections are based on the current reactor power level of 3716 MWt and include a 5% positive bias applied to the power generated in the peripheral fuel assemblies.

The calculated fast neutron exposures for the three surveillance capsules withdrawn from the Waterford Unit 3 reactor are provided in Table 6-9. These neutron exposure levels are based on the plant- and fuel-cycle-specific neutron transport calculations performed for the Waterford Unit 3 reactor. From the data

provided in Table 6-9, Capsule 83° received a fluence (E > 1.0 MeV) of 2.42E+19 n/cm^2 after exposure through the end of the nineteenth fuel cycle (i.e., after 24.66 EFPY).

Updated lead factors for the Waterford Unit 3 surveillance capsules are provided in Table 6-10. The capsule lead factor is defined as the ratio of the calculated fluence (E > 1.0 MeV) at the geometric radial and azimuthal center of the surveillance capsule to the corresponding maximum calculated fluence at the pressure vessel clad/base metal interface. In Table 6-10, the lead factors for capsules that have been withdrawn from the reactor (97°, 263°, and 83°) 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 (104°, 277°, and 284°), the lead factor corresponds to the calculated fluence values at the end of Cycle 19, the last completed fuel cycle for Waterford 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 serve 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 83°, which was withdrawn from Waterford Unit 3 at the end of the nineteenth fuel cycle, is summarized below.

Reaction	Reaction Rate (rps/atom)		M/C
	Measured (M)	Calculated (C)	
Cu-63(n,α)Co-60	4.85E-17	4.60E-17	1.05
Ti-46(n,p)Sc-46	8.55E-16	7.19E-16	1.19
Fe-54(n,p)Mn-54	4.50E-15	4.07E-15	1.10
Ni-58(n,p)Co-58	6.24E-15	5.32E-15	1.17
Average			1.13
% standard deviation			5.7

The measured-to-calculated (M/C) reaction rate ratios for the Capsule 83° threshold reactions range from 1.05 to 1.19, and the average M/C ratio is 1.13 ± 5.7% (1σ). This direct comparison falls within the ± 20% criterion specified in Regulatory Guide 1.190. This comparison validates the current analytical results described in Section 6.2; therefore, the calculations are deemed applicable for Waterford Unit 3.

6.4 CALCULATIONAL UNCERTAINTIES

The uncertainty associated with the calculated neutron exposure of the Waterford 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:

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

The fourth phase of the uncertainty assessment (comparisons with Waterford 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 Waterford 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 23.

Description	Capsule and Vessel IR
PCA Comparisons	3%
H. B. Robinson Comparisons	3%
Analytical Sensitivity Studies	11%
Additional Uncertainty for Factors not Explicitly	5%
Net Calculational Uncertainty	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 Waterford Unit 3.

Table 6-1 Calculated Fast Neutron Fluence Rate and Fluence (E > 1.0 MeV) at the Surveillance Capsule Center at Core Midplane for Cycles 1 Through 19

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	Fluence Rate (n/cm²-s)		Fluence (n/cm²)	
			7-Degree	14-Degree	7-Degree	14-Degree
1	1.04	1.04	5.63E+10	3.92E+10	1.85E+18	1.28E+18
2	1.01	2.05	4.41E+10	3.04E+10	3.25E+18	2.25E+18
3	1.15	3.20	4.38E+10	2.92E+10	4.84E+18	3.31E+18
4	1.21	4.41	3.84E+10	2.64E+10	6.31E+18	4.32E+18
5	1.25	5.66	3.98E+10	2.74E+10	7.87E+18	5.40E+18
6	1.30	6.95	3.90E+10	2.31E+10	9.47E+18	6.35E+18
7	1.35	8.30	2.13E+10	1.65E+10	1.04E+19	7.05E+18
8	1.35	9.66	2.65E+10	1.82E+10	1.15E+19	7.83E+18
9	1.44	11.10	2.55E+10	1.88E+10	1.27E+19	8.68E+18
10	1.40	12.50	2.39E+10	1.78E+10	1.37E+19	9.47E+18
11	1.33	13.83	1.87E+10	1.35E+10	1.45E+19	1.00E+19
12	1.48	15.31	2.43E+10	1.72E+10	1.56E+19	1.08E+19
13	1.40	16.70	2.56E+10	1.89E+10	1.68E+19	1.17E+19
14	1.40	18.10	3.20E+10	2.20E+10	1.82E+19	1.26E+19
15	1.29	19.39	3.26E+10	2.16E+10	1.95E+19	1.35E+19
16	1.35	20.74	2.99E+10	2.05E+10	2.08E+19	1.44E+19
17	1.31	22.05	2.80E+10	1.92E+10	2.19E+19	1.52E+19
18	1.40	23.46	3.15E+10	2.12E+10	2.33E+19	1.61E+19
19	1.20	24.66	2.26E+10	1.77E+10	2.42E+19	1.68E+19

Table 6-2 Calculated Fast Neutron Fluence (E > 1.0 MeV) at the Surveillance Capsule Center at Core Midplane for Future Projections

Total Time (EFPY)	Fluence (n/cm²)	
	7-Degree	14-Degree
32.00	3.08E+19	2.15E+19
36.00	3.44E+19	2.40E+19
40.00	3.80E+19	2.66E+19
48.00	4.51E+19	3.16E+19
55.00	5.14E+19	3.61E+19
60.00	5.59E+19	3.93E+19

Table 6-3 Calculated Iron Atom Displacement Rate and Iron Atom Displacements at the Surveillance Capsule Center at Core Midplane for Cycles 1 Through 19

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	dpa/s		dpa	
			7-Degree	14-Degree	7-Degree	14-Degree
1	1.04	1.04	8.21E-11	5.74E-11	2.69E-03	1.88E-03
2	1.01	2.05	6.44E-11	4.46E-11	4.74E-03	3.30E-03
3	1.15	3.20	6.39E-11	4.29E-11	7.07E-03	4.87E-03
4	1.21	4.41	5.61E-11	3.89E-11	9.21E-03	6.35E-03
5	1.25	5.66	5.82E-11	4.03E-11	1.15E-02	7.93E-03
6	1.30	6.95	5.70E-11	3.40E-11	1.38E-02	9.33E-03
7	1.35	8.30	3.11E-11	2.42E-11	1.52E-02	1.04E-02
8	1.35	9.66	3.87E-11	2.67E-11	1.68E-02	1.15E-02
9	1.44	11.10	3.73E-11	2.76E-11	1.85E-02	1.28E-02
10	1.40	12.50	3.50E-11	2.63E-11	2.01E-02	1.39E-02
11	1.33	13.83	2.73E-11	1.98E-11	2.12E-02	1.48E-02
12	1.48	15.31	3.56E-11	2.54E-11	2.29E-02	1.59E-02
13	1.40	16.70	3.74E-11	2.77E-11	2.45E-02	1.72E-02
14	1.40	18.10	4.67E-11	3.24E-11	2.66E-02	1.86E-02
15	1.29	19.39	4.77E-11	3.18E-11	2.85E-02	1.99E-02
16	1.35	20.74	4.38E-11	3.01E-11	3.04E-02	2.12E-02
17	1.31	22.05	4.10E-11	2.83E-11	3.21E-02	2.23E-02
18	1.40	23.46	4.60E-11	3.12E-11	3.41E-02	2.37E-02
19	1.20	24.66	3.31E-11	2.60E-11	3.54E-02	2.47E-02

Table 6-4 Calculated Iron Atom Displacements at the Surveillance Capsule Center at Core Midplane for Future Projections

Total Time (EFPY)	dpa	
	7-Degree	14-Degree
32.00	4.50E-02	3.16E-02
36.00	5.03E-02	3.53E-02
40.00	5.55E-02	3.91E-02
48.00	6.60E-02	4.66E-02
55.00	7.52E-02	5.31E-02
60.00	8.18E-02	5.78E-02

Table 6-5 Calculated Azimuthal Variation of Maximum Fast Neutron Fluence Rates (E > 1.0 MeV) at the Reactor Vessel Clad/Base Metal Interface

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	Fluence Rate (n/cm^2-s)				
			0-Degree	15-Degree	30-Degree	45-Degree	Maximum
1	1.04	1.04	4.49E+10	2.76E+10	2.40E+10	1.80E+10	4.49E+10
2	1.01	2.05	3.80E+10	2.24E+10	2.06E+10	1.44E+10	3.80E+10
3	1.15	3.20	3.79E+10	2.12E+10	1.75E+10	1.22E+10	3.79E+10
4	1.21	4.41	3.34E+10	1.95E+10	1.78E+10	1.28E+10	3.34E+10
5	1.25	5.66	3.43E+10	2.00E+10	1.73E+10	1.26E+10	3.43E+10
6	1.30	6.95	3.48E+10	1.63E+10	1.16E+10	9.84E+09	3.48E+10
7	1.35	8.30	1.71E+10	1.21E+10	1.25E+10	9.59E+09	1.71E+10
8	1.35	9.66	2.22E+10	1.31E+10	1.05E+10	8.87E+09	2.22E+10
9	1.44	11.10	2.05E+10	1.36E+10	1.04E+10	7.32E+09	2.05E+10
10	1.40	12.50	1.91E+10	1.29E+10	1.24E+10	9.59E+09	1.91E+10
11	1.33	13.83	1.54E+10	9.78E+09	9.18E+09	8.10E+09	1.54E+10
12	1.48	15.31	2.00E+10	1.25E+10	1.05E+10	8.26E+09	2.00E+10
13	1.40	16.70	2.04E+10	1.36E+10	1.07E+10	8.52E+09	2.04E+10
14	1.40	18.10	2.66E+10	1.58E+10	1.31E+10	1.00E+10	2.66E+10
15	1.29	19.39	2.80E+10	1.56E+10	1.41E+10	1.20E+10	2.80E+10
16	1.35	20.74	2.59E+10	1.52E+10	1.46E+10	1.38E+10	2.59E+10
17	1.31	22.05	2.52E+10	1.48E+10	1.56E+10	1.22E+10	2.52E+10
18	1.40	23.46	2.76E+10	1.58E+10	1.54E+10	1.15E+10	2.76E+10
19	1.20	24.66	1.86E+10	1.34E+10	1.66E+10	1.47E+10	1.86E+10

Table 6-6 Calculated Azimuthal Variation of Maximum Fast Neutron Fluence (E > 1.0 MeV) at the Reactor Vessel Clad/Base Metal Interface

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	Fluence (n/cm^2)				
			0-Degree	15-Degree	30-Degree	45-Degree	Maximum
1	1.04	1.04	1.47E+18	9.04E+17	7.88E+17	5.89E+17	1.47E+18
2	1.01	2.05	2.66E+18	1.60E+18	1.43E+18	1.04E+18	2.66E+18
3	1.15	3.20	4.04E+18	2.38E+18	2.07E+18	1.48E+18	4.04E+18
4	1.21	4.41	5.32E+18	3.12E+18	2.75E+18	1.97E+18	5.32E+18
5	1.25	5.66	6.66E+18	3.91E+18	3.42E+18	2.47E+18	6.66E+18
6	1.30	6.95	8.09E+18	4.57E+18	3.90E+18	2.87E+18	8.09E+18
7	1.35	8.30	8.82E+18	5.09E+18	4.43E+18	3.28E+18	8.82E+18
8	1.35	9.66	9.76E+18	5.65E+18	4.88E+18	3.66E+18	9.76E+18
9	1.44	11.10	1.07E+19	6.27E+18	5.35E+18	3.99E+18	1.07E+19
10	1.40	12.50	1.15E+19	6.84E+18	5.90E+18	4.41E+18	1.15E+19
11	1.33	13.83	1.22E+19	7.25E+18	6.29E+18	4.75E+18	1.22E+19
12	1.48	15.31	1.31E+19	7.82E+18	6.77E+18	5.13E+18	1.31E+19
13	1.40	16.70	1.40E+19	8.43E+18	7.24E+18	5.51E+18	1.40E+19
14	1.40	18.10	1.52E+19	9.12E+18	7.82E+18	5.95E+18	1.52E+19
15	1.29	19.39	1.63E+19	9.76E+18	8.39E+18	6.44E+18	1.63E+19
16	1.35	20.74	1.74E+19	1.04E+19	9.00E+18	7.01E+18	1.74E+19
17	1.31	22.05	1.84E+19	1.10E+19	9.60E+18	7.48E+18	1.84E+19
18	1.40	23.46	1.95E+19	1.16E+19	1.03E+19	7.98E+18	1.96E+19
19	1.20	24.66	2.02E+19	1.21E+19	1.09E+19	8.52E+18	2.02E+19
Future		32.00	2.57E+19	1.55E+19	1.46E+19	1.15E+19	2.57E+19
Future		36.00	2.86E+19	1.73E+19	1.66E+19	1.32E+19	2.86E+19
Future		40.00	3.16E+19	1.92E+19	1.87E+19	1.49E+19	3.16E+19
Future		48.00	3.78E+19	2.30E+19	2.29E+19	1.83E+19	3.78E+19
Future		55.00	4.32E+19	2.63E+19	2.65E+19	2.12E+19	4.32E+19
Future		60.00	4.70E+19	2.87E+19	2.92E+19	2.34E+19	4.70E+19

Table 6-7 Calculated Azimuthal Variation of Maximum Iron Atom Displacement Rates at the Reactor Vessel Clad/Base Metal Interface

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	dpa/s				
			0-Degree	15-Degree	30-Degree	45-Degree	Maximum
1	1.04	1.04	6.84E-11	4.24E-11	3.67E-11	2.76E-11	6.84E-11
2	1.01	2.05	5.78E-11	3.45E-11	3.14E-11	2.22E-11	5.78E-11
3	1.15	3.20	5.77E-11	3.26E-11	2.67E-11	1.88E-11	5.77E-11
4	1.21	4.41	5.08E-11	3.00E-11	2.71E-11	1.98E-11	5.08E-11
5	1.25	5.66	5.21E-11	3.09E-11	2.64E-11	1.94E-11	5.21E-11
6	1.30	6.95	5.28E-11	2.51E-11	1.78E-11	1.52E-11	5.28E-11
7	1.35	8.30	2.62E-11	1.87E-11	1.92E-11	1.48E-11	2.62E-11
8	1.35	9.66	3.38E-11	2.02E-11	1.60E-11	1.37E-11	3.38E-11
9	1.44	11.10	3.13E-11	2.09E-11	1.59E-11	1.13E-11	3.13E-11
10	1.40	12.50	2.93E-11	2.00E-11	1.91E-11	1.48E-11	2.93E-11
11	1.33	13.83	2.35E-11	1.51E-11	1.41E-11	1.25E-11	2.35E-11
12	1.48	15.31	3.06E-11	1.92E-11	1.61E-11	1.28E-11	3.06E-11
13	1.40	16.70	3.11E-11	2.10E-11	1.64E-11	1.32E-11	3.11E-11
14	1.40	18.10	4.05E-11	2.44E-11	2.01E-11	1.55E-11	4.05E-11
15	1.29	19.39	4.27E-11	2.40E-11	2.15E-11	1.85E-11	4.27E-11
16	1.35	20.74	3.95E-11	2.34E-11	2.24E-11	2.13E-11	3.95E-11
17	1.31	22.05	3.85E-11	2.29E-11	2.39E-11	1.88E-11	3.85E-11
18	1.40	23.46	4.20E-11	2.44E-11	2.35E-11	1.78E-11	4.20E-11
19	1.20	24.66	2.84E-11	2.07E-11	2.53E-11	2.26E-11	2.84E-11

Table 6-8 Calculated Azimuthal Variation of Maximum Iron Atom Displacements at the Reactor Vessel Clad/Base Metal Interface

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	dpa				
			0-Degree	15-Degree	30-Degree	45-Degree	Maximum
1	1.04	1.04	2.24E-03	1.39E-03	1.20E-03	9.06E-04	2.24E-03
2	1.01	2.05	4.05E-03	2.47E-03	2.19E-03	1.60E-03	4.05E-03
3	1.15	3.20	6.15E-03	3.65E-03	3.16E-03	2.29E-03	6.15E-03
4	1.21	4.41	8.09E-03	4.80E-03	4.19E-03	3.04E-03	8.09E-03
5	1.25	5.66	1.01E-02	6.01E-03	5.23E-03	3.80E-03	1.01E-02
6	1.30	6.95	1.23E-02	7.04E-03	5.96E-03	4.42E-03	1.23E-02
7	1.35	8.30	1.34E-02	7.84E-03	6.78E-03	5.05E-03	1.34E-02
8	1.35	9.66	1.49E-02	8.70E-03	7.46E-03	5.64E-03	1.49E-02
9	1.44	11.10	1.63E-02	9.65E-03	8.19E-03	6.15E-03	1.63E-02
10	1.40	12.50	1.76E-02	1.05E-02	9.03E-03	6.81E-03	1.76E-02
11	1.33	13.83	1.86E-02	1.12E-02	9.62E-03	7.33E-03	1.86E-02
12	1.48	15.31	2.00E-02	1.20E-02	1.04E-02	7.92E-03	2.00E-02
13	1.40	16.70	2.13E-02	1.30E-02	1.11E-02	8.50E-03	2.13E-02
14	1.40	18.10	2.31E-02	1.40E-02	1.20E-02	9.18E-03	2.31E-02
15	1.29	19.39	2.49E-02	1.50E-02	1.28E-02	9.93E-03	2.49E-02
16	1.35	20.74	2.65E-02	1.60E-02	1.38E-02	1.08E-02	2.65E-02
17	1.31	22.05	2.80E-02	1.69E-02	1.47E-02	1.15E-02	2.80E-02
18	1.40	23.46	2.98E-02	1.79E-02	1.57E-02	1.23E-02	2.98E-02
19	1.20	24.66	3.08E-02	1.87E-02	1.66E-02	1.31E-02	3.08E-02
Future		32.00	3.91E-02	2.39E-02	2.23E-02	1.78E-02	3.91E-02
Future		36.00	4.37E-02	2.67E-02	2.54E-02	2.03E-02	4.37E-02
Future		40.00	4.82E-02	2.96E-02	2.86E-02	2.29E-02	4.82E-02
Future		48.00	5.76E-02	3.55E-02	3.50E-02	2.82E-02	5.76E-02
Future		55.00	6.58E-02	4.06E-02	4.06E-02	3.27E-02	6.58E-02
Future		60.00	7.17E-02	4.43E-02	4.46E-02	3.60E-02	7.17E-02

Table 6-9 Calculated Fast Neutron Exposure of Surveillance Capsules Withdrawn from Waterford Unit 3

Capsule	Irradiation Cycles	Irradiation Time (EFPY)	Fluence (E > 1.0 MeV) (n/cm^2)	Iron Atom Displacements (dpa)
97°	1-4	4.41	6.31E+18	9.21E-03
263°	1-11	13.83	1.45E+19	2.12E-02
83°	1-19	24.66	2.42E+19	3.54E-02

Table 6-10 Calculated Surveillance Capsule Lead Factors

Capsule Location	Status	Lead Factor
97°	Withdrawn EOC 4	1.19
263°	Withdrawn EOC 11	1.19
83°	Withdrawn EOC 19	1.20
104°	In Reactor(1)	0.83
277°	In Reactor(1)	1.20
284°	In Reactor(1)	0.83

Note:
1. Lead factors are based on the cumulative exposures from Cycles 1 through 19.

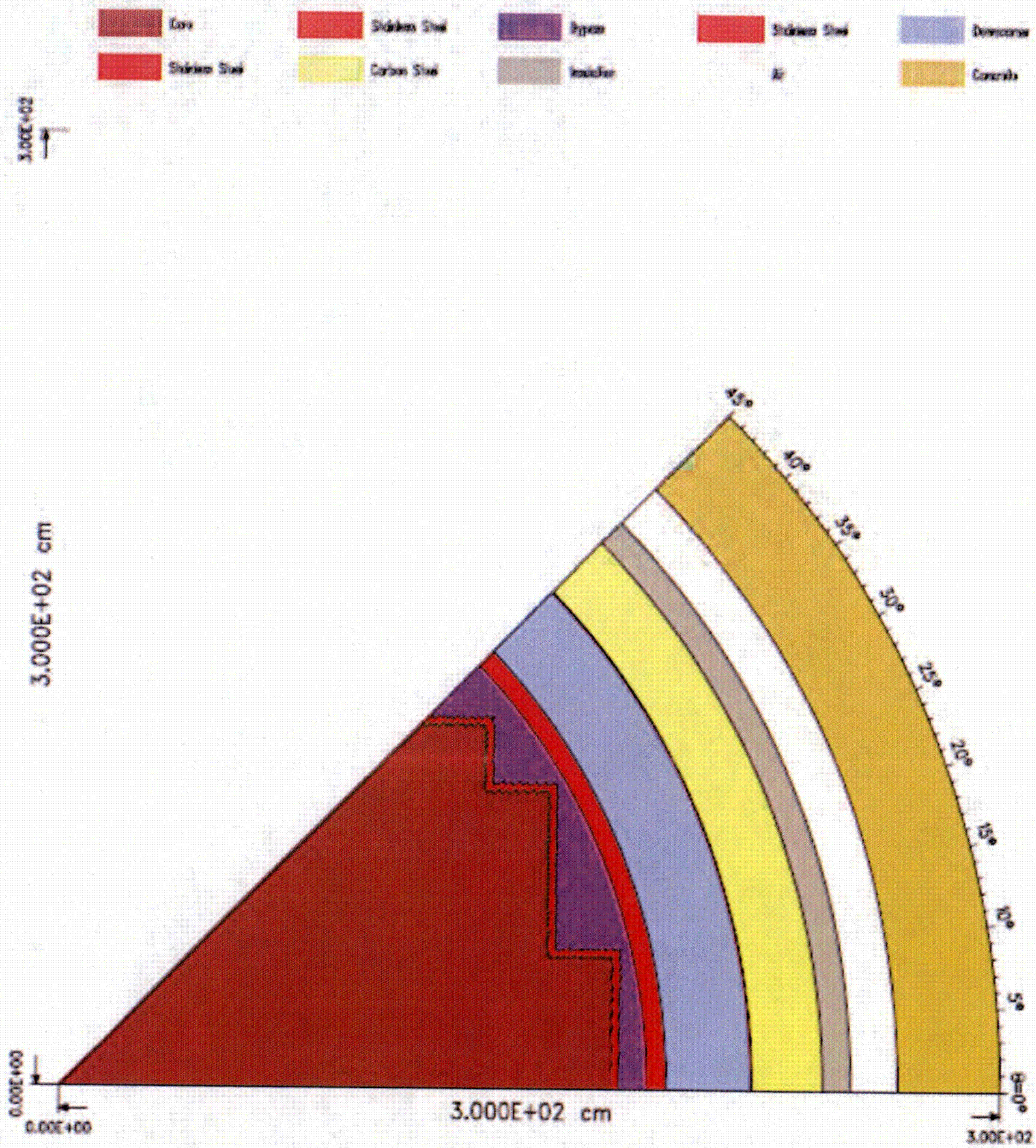


Figure 6-1 Waterford Unit 3 r,θ,z Reactor Geometry Plan View at the Core Midplane without Surveillance Capsules

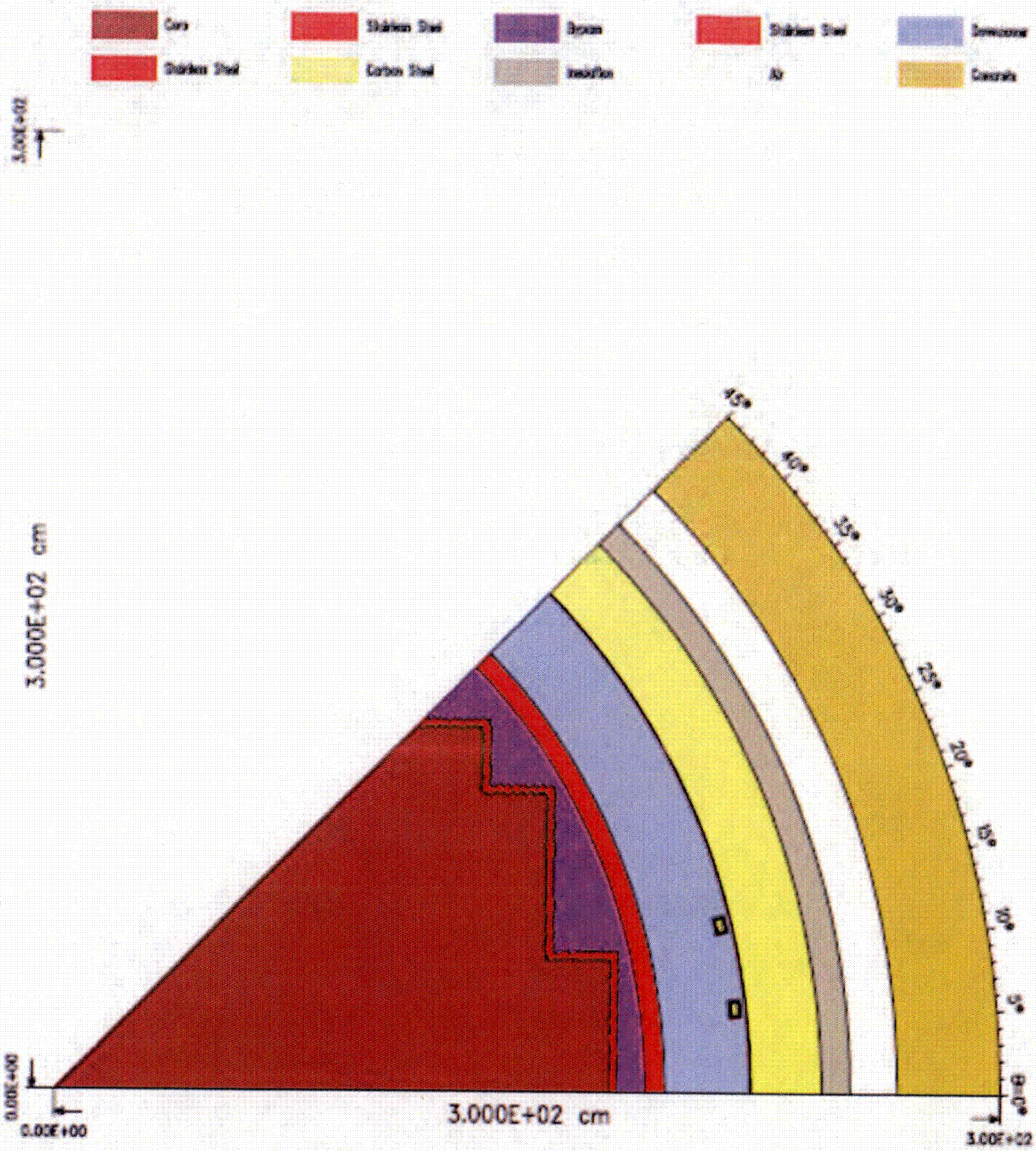


Figure 6-2 Waterford Unit 3 r,θ,z Reactor Geometry Plan View at the Core Midplane with 7° and 14° Surveillance Capsules

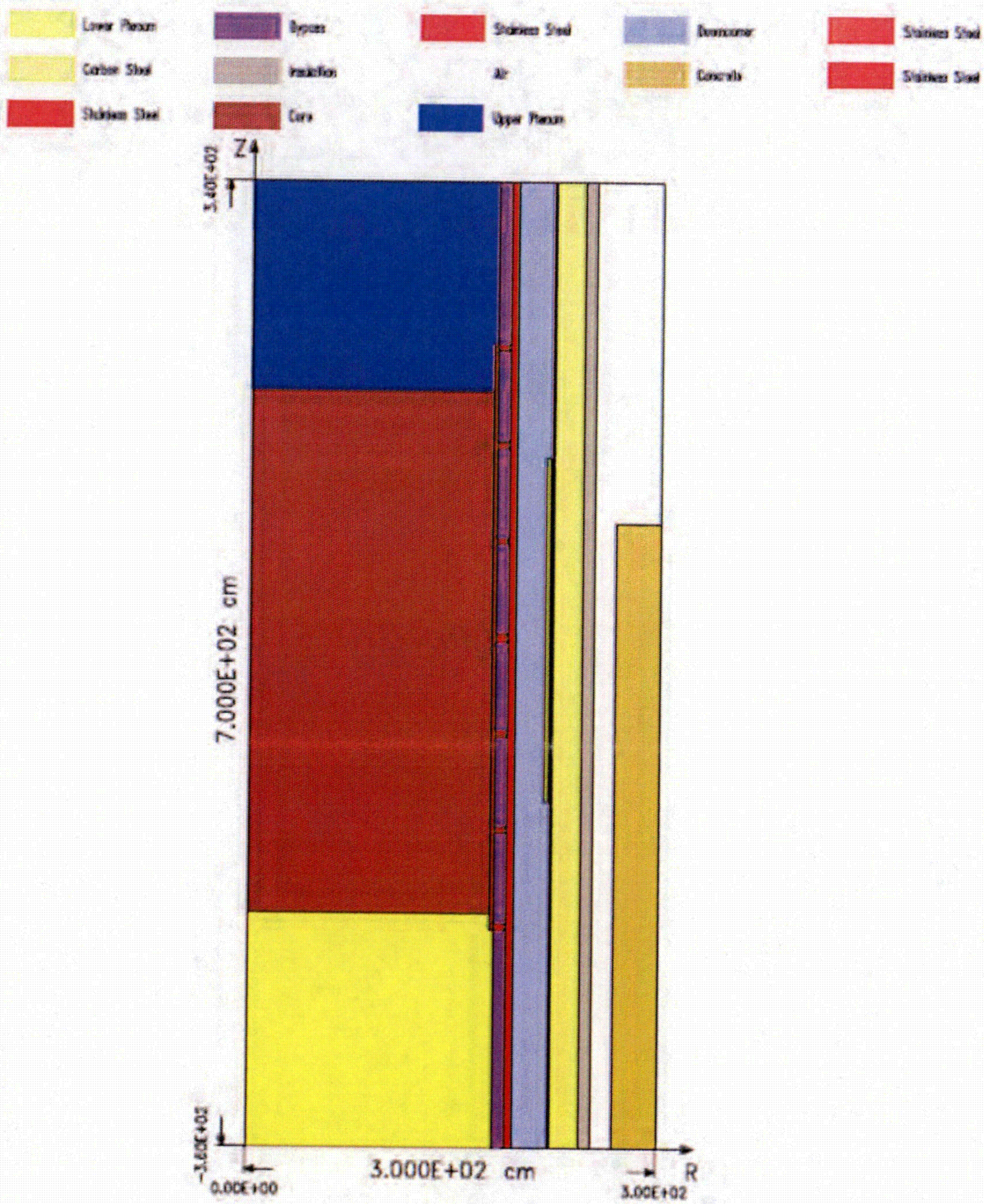


Figure 6-3 Waterford Unit 3 r,θ,z Reactor Geometry Section View at 7° Azimuthal Angle

7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following surveillance capsule removal schedule (Table 7-1) meets the requirements of ASTM E185-82 [Ref. 11]. Note that it is recommended for future capsule(s) to be removed from the Waterford Unit 3 reactor vessel.

Table 7-1 Surveillance Capsule Withdrawal Schedule

Capsule ID and Location	Status[(a)]	Capsule Lead Factor[(a)]	Withdrawal EFPY[(b, c)]	Capsule Fluence (n/cm^2, E > 1.0 MeV)[(c)]
97°	Withdrawn (EOC 4)	1.19	4.41	6.31E+18
263°	Withdrawn (EOC 11)	1.19	13.83	1.45E+19
83°	Withdrawn (EOC 19)	1.20	24.66	2.42E+19
277°	In Reactor	1.20	48[(d)]	4.51E+19[(d)]
104°	In Reactor	0.83	(e)	(e)
284°	In Reactor	0.83	(e)	(e)

Notes:

(a) Updated in Capsule 83° dosimetry analysis; see Table 6-10.

(b) EFPY from plant startup.

(c) Updated in Capsule 83° dosimetry analysis; see Table 6-9.

(d) Capsule 277° should be withdrawn at the vessel refueling outage nearest to 48 EFPY of plant operation, which is when the fluence on the capsule will have reached the projected 60-year (55 EFPY) peak vessel fluence.

(e) Capsules 104° and 284° currently have a lead factor of less than one. If additional metallurgical data is needed for Waterford Unit 3, such as in support of a second license renewal to 80 total years of operation, relocation of one or both of these capsules to a higher lead factor location will be required. Since it is not known when or if Waterford Unit 3 will apply for a second license extension, and given that many cycles of irradiation will be required for Capsules 104° and 284° to accumulate fluence greater than the 80-year vessel wall fluence, it is suggested that a potential relocation decision be implemented prior to 40 total years of operation.

8 REFERENCES

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

2. 10 CFR 50, Appendix G, *Fracture Toughness Requirements*, and Appendix H, *Reactor Vessel Material Surveillance Program Requirements*, Federal Register, Volume 60, No. 243, December 19, 1995.

3. TR-C-MCS-001, Revision 0, *Summary Report on Manufacture of Test Specimens and Assembly of Capsules for Irradiation Surveillance of Waterford-Unit 3 Reactor Vessel Materials*, December 1977.

4. TR-C-MCS-002, Revision 0, *Louisiana Power & Light Waterford Steam Electric Station Unit No. 3 Evaluation of Baseline Specimens Reactor Vessel Materials Irradiation Surveillance Program*, October 1977.

5. C-NLM-003, Revision 1, *Program for Irradiation Surveillance of Waterford Unit Three Reactor Vessel Materials*, October 1974.

6. ASTM E185-73, *Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels*, ASTM, 1973.

7. Appendix G of the ASME Boiler and Pressure Vessel (B&PV) Code, Section XI, Division 1, *Fracture Toughness Criteria for Protection Against Failure.*

8. ASTM E208, *Standard Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels*, ASTM.

9. NUREG/CR-6413; ORNL/TM-13133, *Analysis of the Irradiation Data for A302B and A533B Correlation Monitor Materials*, April 1996.

10. WCAP-16088-NP, Revision 2, *Waterford Unit 3 Reactor Vessel Heatup and Cooldown Limit Curves for Normal Operation*, June 2012.

11. ASTM E185-82, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels, E706 (IF)*, ASTM, 1982.

12. ASTM E23-12c, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*, ASTM, 2012.

13. ASTM E2298-13a, *Standard Test Method for Instrumented Impact Testing of Metallic Materials*, ASTM, 2013.

14. ASTM A370-13, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, ASTM, 2013.

15. ASTM E8/E8M-13a, *Standard Test Methods for Tension Testing of Metallic Materials*, ASTM, 2013.

16. ASTM E21-09, *Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials*, ASTM, 2009.

17. BAW-2177, Revision 01, *Analysis of Capsule W-97 Entergy Operations, Inc. Waterford Generating Station, Unit No. 3*, February 2004.

18. WCAP-16002, Revision 0, *Analysis of Capsule 263° from the Entergy Operations Waterford Unit 3 Reactor Vessel Radiation Surveillance Program*, March 2003.

19. ASTM E853-13, *Standard Practice for Analysis and Interpretation of Light-Water Reactor Surveillance Results*, ASTM, 2013

20. ASTM E693-94, *Standard Practice for Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements Per Atom (DPA), E706 (ID)*, ASTM, 1994.

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

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

23. WCAP-16083-NP, Revision 1, *Benchmark Testing of the FERRET Code for Least Squares Evaluation of Light Water Reactor Dosimetry*, April 2013.

24. 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 and analyzed to date at Waterford 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" [Ref. A-1]. One of the main purposes for presenting this material is to demonstrate that the overall measurements agree with the calculated and least-squares adjusted values to within ±20% as specified by Regulatory Guide 1.190, thus serving to validate the calculated neutron exposures previously reported in Section 6.2 of this report.

A.1.1 Sensor Reaction Rate Determinations

In this section, the results of the evaluations of the three surveillance capsules analyzed to date as part of the Waterford 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 Azimuthal Location	Withdrawal Time	Irradiation Time (EFPY)
97°	End of Cycle 4	4.41
263°	End of Cycle 11	13.83
83°	End of Cycle 19	24.66

The passive neutron sensors included in the evaluations of surveillance Capsules 97°, 263°, and 83° are summarized as follows:

Sensor Material	Reaction Of Interest	Capsule 97°	Capsule 263°	Capsule 83°
Copper (Cd)	$^{63}Cu(n,\alpha)^{60}Co$	X	X	X
Titanium	$^{46}Ti(n,p)^{46}Sc$	X	X	X
Iron	$^{54}Fe(n,p)^{54}Mn$	X	X	X
Nickel (Cd)	$^{58}Ni(n,p)^{58}Co$	X	X	X
Uranium-238*	$^{238}U(n,f)FP$	X	X	X
Cobalt-Aluminum*	$^{59}Co(n,\gamma)^{60}Co$	X	X	X

Note:
* The cobalt-aluminum and uranium monitors for this plant include both bare and cadmium-covered sensors.

The capsules also contained sulfur monitors, which were not analyzed because of the short half-life of the activation product isotope (^{32}P, 14.3 days). Pertinent physical and nuclear characteristics of the passive neutron sensors analyzed are listed in Table A-1 for Capsule 97°, and Table A-2 for Capsules 263° and 83°.

The use of passive monitors such as those listed above do not yield a direct measure of the energy-dependent neutron fluence rate 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 fluence rate has on the target material over the course of the irradiation period. An accurate assessment of the average neutron fluence rate 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 sensors from Capsule 83° was carried out by Pace Analytical Services, Inc. The radiometric counting followed established ASTM procedures.

The irradiation history of the reactor over the irradiation periods experienced by Capsules 97°, 263°, and 83° was based on the monthly power generation of Waterford 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 97°, 263°, and 83° is given in Table A-3.

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:

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

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/g).
N_0	=	Number of target element atoms per gram of sensor.

F	=	Atom fraction of the target isotope in the target element.
Y	=	Number of product atoms produced per reaction.
P_j	=	Average core power level during irradiation period j (MW).
P_{ref}	=	Maximum or reference power level of the reactor (MW).
C_j	=	Calculated ratio of $\phi(E > 1.0\ MeV)$ during irradiation period j to the time weighted average $\phi(E > 1.0\ MeV)$ over the entire irradiation period.
λ	=	Decay constant of the product isotope (1/sec).
t_j	=	Length of irradiation period j (sec).
$t_{d,j}$	=	Decay time following irradiation period j (sec).

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 fluence rate 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, the additional C_j term should be employed. The impact of changing fluence rate 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 fluence rates and the computed values for C_j are listed in Tables A-4 and A-5, respectively, for Capsules 97° and 83°. These fluence rates represent the capsule- and cycle-dependent results at the radial and azimuthal center of the respective capsules at core midplane. For Capsule 263°, which was removed at the conclusion of Cycle 11, it was noticed that the peripheral assembly closest to the cardinal axis for Cycle 11 had an average relative power significantly lower compared to the other cycles. It was decided to split Cycle 11 into beginning-of-cycle (BOC), middle-of-cycle (MOC), and end-of-cycle (EOC) segments. This has an impact on the calculations performed via the Cj ratios that account for changes in the sensor reaction rates due to variations in the flux level induced by changes in the spatial power distribution. The Cj terms were based on the individual reaction rates determined from Cycles 1 though the end of Cycle 11 at the 263° surveillance capsule location. Reaction rates in the 263° capsule location, and the Cj terms from Cycles 1 through 11 are given in Tables A-6 and A-7, respectively. These reaction rates represent the capsule- and cycle-dependent results at the radial and azimuthal center of the respective capsules at core midplane.

Prior to using the measured reaction rates in the least-squares evaluations of the dosimetry sensor sets, additional corrections were made to the ^{238}U cadmium-covered 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 sensor reaction rates to account for gamma-ray-induced fission reactions that occurred over the course of the capsule irradiations. The correction factors corresponding to the Waterford Unit 3 fission sensor reaction rates are summarized as follows:

Correction	Capsule 97°	Capsule 263°	Capsule 83°
^{235}U Impurity/Pu Build-in	0.8599	0.8273	0.7955
$^{238}U(\gamma,f)$	0.8705	0.8739	0.8745
Net ^{238}U Correction	0.7485	0.7230	0.6957

The correction factors for Capsules 97°, 263° and 83° were applied in a multiplicative fashion to the decay-corrected cadmium-covered uranium fission sensor reaction rates.

Results of the sensor reaction rate determinations for Capsules 97°, 263°, and 83°, are given in Tables A-8 through A-10. In Tables A-8 through A-10, the measured specific activities, decay-corrected saturated specific activities, and computed reaction rates for each sensor are listed. The cadmium-covered 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 fluence rate (E > 1.0 MeV) or dpa/s along with their uncertainties are then easily obtained from the adjusted spectrum. In general, the least-squares methods, as applied to surveillance capsule dosimetry evaluations, act to reconcile the measured sensor reaction rate data, dosimetry reaction cross sections, and the calculated neutron energy spectrum within their respective uncertainties. For example,

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

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

For the least-squares evaluation of the Waterford Unit 3 surveillance capsule dosimetry, the FERRET code [Ref. A-2] was employed to combine the results of the plant-specific neutron transport calculations

and sensor set reaction rate measurements to determine best-estimate values of exposure parameters (fluence rate (E > 1.0 MeV) and dpa) along with associated uncertainties for the three in-vessel capsules analyzed 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 Waterford 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 [Ref. A-3].

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 E944, "Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance" [Ref. A-4].

The following provides a summary of the uncertainties associated with the least-squares evaluation of the Waterford 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 ensured 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%
$^{46}Ti(n,p)^{46}Sc$	5%
$^{54}Fe(n,p)^{54}Mn$	5%
$^{58}Ni(n,p)^{58}Co$	5%
$^{238}U(n,f)FP$	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 recent cross-section evaluations, and they have been tested for 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 Waterford 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%
$^{46}Ti(n,p)^{46}Sc$	4.50-4.87%
$^{54}Fe(n,p)^{54}Mn$	3.05-3.11%
$^{58}Ni(n,p)^{58}Co$	4.49-4.56%
$^{238}U(n,f)^{137}Cs$	0.54-0.64%
$^{59}Co(n,\gamma)^{60}Co$	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 inputs to the least-squares adjustment procedure were obtained directly from the results of plant-specific transport calculations for each surveillance capsule irradiation period and location. The spectrum for each capsule was input in an absolute sense (rather than as simply a relative

spectral shape). Therefore, within the constraints of the assigned uncertainties, the calculated data were treated equally with the measurements.

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

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

where R_n specifies an overall fractional normalization uncertainty and the fractional uncertainties R_g and $R_{g'}$ specify additional random groupwise uncertainties that are correlated with a correlation matrix given by:

$$P_{gg'} = [1 - \theta]\delta_{gg'} + \theta\, e^{-H}$$

where

$$H = \frac{(g-g')^2}{2\gamma^2}$$

The first term in the correlation matrix equation specifies purely random uncertainties, while the second term describes the short-range correlations over a group range γ (θ specifies the strength of the latter term). The value of δ is 1.0 when $g = g'$, and is 0.0 otherwise.

The set of parameters defining the input covariance matrix for the Waterford Unit 3 calculated spectra was as follows:

Fluence Rate Normalization Uncertainty (R_n)	15%
Fluence Rate Group Uncertainties (R_g, $R_{g'}$)	
(E > 0.0055 MeV)	15%
(0.68 eV < E < 0.0055 MeV)	25%
(E < 0.68 eV)	50%
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
Fluence Rate Group Correlation Range (γ)	

(E > 0.0055 MeV)	6
(0.68 eV < E < 0.0055 MeV)	3
(E < 0.68 eV)	2

A.1.3 Comparisons of Measurements and Calculations

Results of the least-squares evaluations of the dosimetry from the Waterford Unit 3 surveillance capsules withdrawn to date are provided in Tables A-11, A-12, and A-13 for Capsules 97°, 263°, and 83°, respectively. In these tables, measured, calculated, and best-estimate values for sensor reaction rates are given for each capsule. Also provided in these tabulations 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. Additionally, comparisons of the calculated and best-estimate values of neutron fluence rate (E > 1.0 MeV) and iron atom displacement rate are tabulated along with the BE/C ratios observed for each of the capsules.

For Capsule 97°, the titanium monitor was discarded. For all three capsules, both bare and cadmium-covered uranium monitors were discarded. These dosimetry data were discarded because they were outside the expected values.

The data comparisons provided in Tables A-11 through A-13 show that the adjustments to the calculated spectra are relatively small and 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, the calculational uncertainty is specified as 13% at the 1σ level.

Further comparisons of the measurement results with calculations are given in Tables A-14 and A-15. These comparisons are given on two levels. In Table A-14, 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-15, calculations of fast neutron exposure rates in terms of fluence rate (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 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, for the individual threshold foils considered in the least-squares analysis, the average M/C comparisons for fast neutron reactions range from 1.07 to 1.17 in the data set. The overall average M/C ratio for the entire set of Waterford Unit 3 data is 1.11 with an associated standard deviation of 7.0%.

In the comparisons of best-estimate and calculated fast neutron exposure parameters, the corresponding BE/C comparisons for the capsule data sets range from 1.04 to 1.12 for neutron fluence rate (E > 1.0 MeV) and from 1.05 to 1.11 for iron atom displacement rate. The overall average BE/C ratios

for neutron fluence rate (E > 1.0 MeV) and iron atom displacement rate are 1.08 with a standard deviation of 3.7% and 1.08 with a standard deviation of 2.8%, 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 Waterford Unit 3 reactor pressure vessel.

Table A-1 Nuclear Parameters Used in the Evaluation of Neutron Sensors of Surveillance Capsule 97°

Reaction of Interest	Atomic Weight (g/g-atom)	Target Atom Fraction	Product Half-life (days)	Fission Yield (%)	90% Response Range[a] (MeV)
^{63}Cu (n,α) ^{60}Co	62.9296	1.0	1925.5	n/a	5.0 – 12.0
^{46}Ti (n,p) ^{46}Sc	45.9526	1.0	83.79	n/a	4.1 – 10.5
^{54}Fe (n,p) ^{54}Mn	53.9396	1.0	312.11	n/a	2.4 – 8.8
^{58}Ni (n,p) ^{58}Co	57.9353	1.0	70.82	n/a	2.1 – 8.7
^{238}U (n,f) ^{137}Cs	238.051	1.0	10983.07	6.02	1.5 – 7.9
^{59}Co (n,γ) ^{60}Co	58.933	1.0	1925.5	n/a	non-threshold

Note:

(a) The 90% response range is defined such that, in the neutron spectrum characteristic of the Waterford 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 Nuclear Parameters Used in the Evaluation of Neutron Sensors of Surveillance Capsules 263° and 83°

Reaction of Interest	Atomic Weight (g/g-atom)	Target Atom Fraction	Product Half-life (days)	Fission Yield (%)	90% Response Range[a] (MeV)
^{63}Cu (n,α) ^{60}Co	63.546	0.6917	1925.5	n/a	5.0 – 12.0
^{46}Ti (n,p) ^{46}Sc	47.867	0.0825	83.79	n/a	4.1 – 10.5
^{54}Fe (n,p) ^{54}Mn	55.845	0.05845	312.11	n/a	2.4 – 8.8
^{58}Ni (n,p) ^{58}Co	58.693	0.68077	70.82	n/a	2.1 – 8.8
^{238}U (n,f) ^{137}Cs	238.051	1.0	10983.07	6.02	1.5 – 8.0
^{59}Co (n,γ) ^{60}Co	58.933	0.0017	1925.5	n/a	non-threshold

Note:

(a) The 90% response range is defined such that, in the neutron spectrum characteristic of the Waterford 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-3 Monthly Thermal Generation during the First 19 Fuel Cycles of the Waterford Unit 3 Reactor

Cycle 1		Cycle 2		Cycle 3		Cycle 4	
Month	MWt-h	Month	MWt-h	Month	MWt-h	Month	MWt-h
Mar-85	42830	Dec-86	0	May-88	3254	Oct-89	0
Apr-85	613673	Jan-87	0	Jun-88	1934985	Nov-89	640027
May-85	809488	Feb-87	1379459	Jul-88	2304929	Dec-89	2444128
Jun-85	198642	Mar-87	2149043	Aug-88	2509305	Jan-90	1787064
Jul-85	846176	Apr-87	2257170	Sep-88	2107712	Feb-90	1612051
Aug-85	0	May-87	2278405	Oct-88	1509724	Mar-90	2271449
Sep-85	317589	Jun-87	2426725	Nov-88	1052050	Apr-90	2433315
Oct-85	1581557	Jul-87	2489860	Dec-88	2282880	May-90	2499444
Nov-85	2319818	Aug-87	2332754	Jan-89	2231876	Jun-90	2434503
Dec-85	1423475	Sep-87	1406064	Feb-89	2264143	Jul-90	2508532
Jan-86	2313146	Oct-87	1734107	Mar-89	2458113	Aug-90	2333299
Feb-86	2236098	Nov-87	2418833	Apr-89	2418581	Sep-90	2363915
Mar-86	551214	Dec-87	2224789	May-89	2509484	Oct-90	1728843
Apr-86	2380512	Jan-88	2143917	Jun-89	2390707	Nov-90	2433754
May-86	2337147	Feb-88	2339100	Jul-89	2292538	Dec-90	2516099
Jun-86	2345202	Mar-88	2298501	Aug-89	2249799	Jan-91	2515171
Jul-86	1646157	Apr-88	76267	Sep-89	1783533	Feb-91	2211690
Aug-86	2497833					Mar-91	1196293
Sep-86	2198347						
Oct-86	2206239						
Nov-86	2009429						

Table A-3 (Continued) Monthly Thermal Generation during the First 19 Fuel Cycles of the Waterford Unit 3 Reactor

Cycle 5		Cycle 6		Cycle 7		Cycle 8	
Month	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**
Apr-91	0	Oct-92	0	Apr-94	433275	Oct-95	0
May-91	163566	Nov-92	1581907	May-94	2515334	Nov-95	1929688
Jun-91	2275493	Dec-92	2505327	Jun-94	2306353	Dec-95	2517767
Jul-91	2453834	Jan-93	2514707	Jul-94	2518426	Jan-96	2517086
Aug-91	2389958	Feb-93	2271376	Aug-94	2514659	Feb-96	2357937
Sep-91	2435284	Mar-93	2373995	Sep-94	2430858	Mar-96	2516925
Oct-91	2522290	Apr-93	2433762	Oct-94	2518011	Apr-96	2436647
Nov-91	2256967	May-93	2518857	Nov-94	2439425	May-96	2326692
Dec-91	2500136	Jun-93	2310136	Dec-94	2515464	Jun-96	2440018
Jan-92	2517213	Jul-93	2513308	Jan-95	2517937	Jul-96	1247706
Feb-92	1649550	Aug-93	2517897	Feb-95	2273361	Aug-96	2105079
Mar-92	2284044	Sep-93	2431720	Mar-95	2516977	Sep-96	2396700
Apr-92	2429922	Oct-93	2519890	Apr-95	2436285	Oct-96	2471709
May-92	2418613	Nov-93	2437790	May-95	2518637	Nov-96	2295324
Jun-92	2436179	Dec-93	2517986	Jun-95	839448	Dec-96	2449101
Jul-92	2400380	Jan-94	2517230	Jul-95	2521005	Jan-97	2520469
Aug-92	2476631	Feb-94	2273776	Aug-95	2521249	Feb-97	2273932
Sep-92	1417812	Mar-94	318321	Sep-95	1774478	Mar-97	2520600
						Apr-97	886717

Table A-3 (Continued) Monthly Thermal Generation during the First 19 Fuel Cycles of the Waterford Unit 3 Reactor

Cycle 9		Cycle 10		Cycle 11		Cycle 12	
Month	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**
May-97	0	Mar-99	0	Nov-00	1030289	Apr-02	980490
Jun-97	0	Apr-99	2183602	Dec-00	2517757	May-02	2508388
Jul-97	99594	May-99	2513051	Jan-01	2521026	Jun-02	2475037
Aug-97	2505653	Jun-99	2244073	Feb-01	2121310	Jul-02	2554918
Sep-97	2439155	Jul-99	2521175	Mar-01	2520656	Aug-02	2558472
Oct-97	2523657	Aug-99	1808465	Apr-01	2436332	Sep-02	2472369
Nov-97	2433511	Sep-99	880564	May-01	2518333	Oct-02	2561743
Dec-97	2433511	Oct-99	2524076	Jun-01	2367725	Nov-02	2471286
Jan-98	2513765	Nov-99	2080135	Jul-01	2521008	Dec-02	2554752
Feb-98	2276816	Dec-99	2370546	Aug-01	2521122	Jan-03	2556532
Mar-98	2520985	Jan-00	2513887	Sep-01	2434974	Feb-03	1972402
Apr-98	2436390	Feb-00	2358614	Oct-01	2520999	Mar-03	2558500
May-98	2503708	Mar-00	2346459	Nov-01	2439796	Apr-03	2470264
Jun-98	2439738	Apr-00	2436564	Dec-01	2520997	May-03	2558445
Jul-98	2283997	May-00	2521322	Jan-02	2518017	Jun-03	2470519
Aug-98	2521163	Jun-00	1873406	Feb-02	2277045	Jul-03	2558736
Sep-98	1029804	Jul-00	2521097	Mar-02	1704398	Aug-03	2558749
Oct-98	2456652	Aug-00	2521192			Sep-03	2406613
Nov-98	1396144	Sep-00	2436861			Oct-03	1282988
Dec-98	2262325	Oct-00	1051538				
Jan-99	2486638						
Feb-99	1291559						

Table A-3 (Continued) Monthly Thermal Generation during the First 19 Fuel Cycles of the Waterford Unit 3 Reactor

Cycle 13		Cycle 14		Cycle 15		Cycle 16	
Month	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**
Nov-03	680404	May-05	0	Dec-06	306512	May-08	0
Dec-03	2558425	Jun-05	1636426	Jan-07	2762347	Jun-08	2504571
Jan-04	2558662	Jul-05	2762118	Feb-07	2494923	Jul-08	2760325
Feb-04	2346194	Aug-05	2450061	Mar-07	2758724	Aug-08	2752042
Mar-04	2558479	Sep-05	1517824	Apr-07	2673470	Sep-08	1805293
Apr-04	2472647	Oct-05	2766811	May-07	2762294	Oct-08	2762806
May-04	2556502	Nov-05	2409150	Jun-07	2673734	Nov-08	2677040
Jun-04	2476175	Dec-05	2762652	Jul-07	2762850	Dec-08	2761940
Jul-04	2558700	Jan-06	2755253	Aug-07	2762946	Jan-09	2762120
Aug-04	2558734	Feb-06	2490376	Sep-07	2673647	Feb-09	2489307
Sep-04	2474747	Mar-06	2762655	Oct-07	1484298	Mar-09	2757710
Oct-04	2561708	Apr-06	2669816	Nov-07	2674092	Apr-09	2673058
Nov-04	2474159	May-06	2759553	Dec-07	2761656	May-09	2761585
Dec-04	2558590	Jun-06	2673604	Jan-08	2762651	Jun-09	2673378
Jan-05	2558462	Jul-06	2762880	Feb-08	2584461	Jul-09	2762385
Feb-05	2309099	Aug-06	2736791	Mar-08	2758941	Aug-09	2762163
Mar-05	2558504	Sep-06	2675386	Apr-08	2314440	Sep-09	2664994
Apr-05	1316652	Oct-06	2766864			Oct-09	1624218
		Nov-06	2211054				

Table A-3 (Continued) Monthly Thermal Generation during the First 19 Fuel Cycles of the Waterford Unit 3 Reactor

Cycle 17		Cycle 18		Cycle 19	
Month	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**
Nov-09	0	May-11	1577376	Nov-12	0
Dec-09	2384615	Jun-11	2673136	Dec-12	0
Jan-10	2762121	Jul-11	2762028	Jan-13	838638
Feb-10	2495012	Aug-11	2760555	Feb-13	2493392
Mar-10	2758464	Sep-11	2672753	Mar-13	2759429
Apr-10	2673197	Oct-11	2762209	Apr-13	2319009
May-10	2759349	Nov-11	2676675	May-13	2557806
Jun-10	2672667	Dec-11	2760601	Jun-13	2673766
Jul-10	2762032	Jan-12	2651616	Jul-13	2753495
Aug-10	2761860	Feb-12	2582768	Aug-13	2761633
Sep-10	2672841	Mar-12	2754454	Sep-13	2666734
Oct-10	2762116	Apr-12	2626514	Oct-13	2754529
Nov-10	2676410	May-12	2761137	Nov-13	2675437
Dec-10	2760245	Jun-12	2659648	Dec-13	2759168
Jan-11	2762027	Jul-12	2761798	Jan-14	2764348
Feb-11	2377290	Aug-12	2422281	Feb-14	2494353
Mar-11	2350801	Sep-12	2413466	Mar-14	2757639
Apr-11	378111	Oct-12	1403317	Apr-14	1067533

Table A-4 Surveillance Capsule 97° and 83° Fluence Rates for Cj Calculation, Core Midplane Elevation

Fuel Cycle	Cycle Length (EFPY)	Flux (E > 1.0 MeV) [n/cm²-s]	
		Capsule 97°	Capsule 83°
1	1.04	5.63E+10	5.63E+10
2	1.01	4.41E+10	4.41E+10
3	1.15	4.38E+10	4.38E+10
4	1.21	3.84E+10	3.84E+10
5	1.25		3.98E+10
6	1.30		3.90E+10
7	1.35		2.13E+10
8	1.35		2.65E+10
9	1.44		2.55E+10
10	1.40		2.39E+10
11	1.33		1.87E+10
12	1.48		2.43E+10
13	1.40		2.56E+10
14	1.40		3.20E+10
15	1.29		3.26E+10
16	1.35		2.99E+10
17	1.31		2.80E+10
18	1.40		3.15E+10
19	1.20		2.26E+10
Average	-	4.53E+10	3.11E+10

Table A-5 Surveillance Capsule 97° and 83° Cj Factors, Core Midplane Elevation

Fuel Cycle	Cycle Length (EFPY)	C_j	
		Capsule 97°	Capsule 83°
1	1.04	1.24	1.81
2	1.01	0.97	1.42
3	1.15	0.97	1.41
4	1.21	0.85	1.24
5	1.25		1.28
6	1.30		1.25
7	1.35		0.68
8	1.35		0.85
9	1.44		0.82
10	1.40		0.77
11	1.33		0.60
12	1.48		0.78
13	1.40		0.82
14	1.40		1.03
15	1.29		1.05
16	1.35		0.96
17	1.31		0.90
18	1.40		1.01
19	1.20		0.73

Table A-6 Surveillance Capsule 263° Reaction Rates for Cj Calculation, Core Midplane Elevation

Cycle	Reaction Rate (rps/atom)						
	^{63}Cu(n,α)	^{46}Ti(n,p)	^{54}Fe(n,p)	^{58}Ni(n,p)	^{238}U(n,f)	^{59}Co(n,γ)	^{59}Co(Cd)(n,γ)
1	7.75E+07	1.31E+09	7.16E+09	9.36E+09	2.49E+10	3.02E+12	6.22E+11
2	6.26E+07	1.05E+09	5.69E+09	7.42E+09	1.96E+10	2.32E+12	4.82E+11
3	6.24E+07	1.05E+09	5.65E+09	7.37E+09	1.95E+10	2.30E+12	4.78E+11
4	5.50E+07	9.23E+08	4.97E+09	6.48E+09	1.71E+10	2.01E+12	4.19E+11
5	5.69E+07	9.56E+08	5.15E+09	6.72E+09	1.77E+10	2.09E+12	4.35E+11
6	5.62E+07	9.43E+08	5.07E+09	6.61E+09	1.74E+10	2.02E+12	4.21E+11
7	3.25E+07	5.37E+08	2.83E+09	3.68E+09	9.54E+09	1.07E+12	2.25E+11
8	4.00E+07	6.63E+08	3.50E+09	4.57E+09	1.19E+10	1.34E+12	2.81E+11
9	3.90E+07	6.45E+08	3.39E+09	4.42E+09	1.14E+10	1.28E+12	2.70E+11
10	3.69E+07	6.09E+08	3.20E+09	4.16E+09	1.07E+10	1.20E+12	2.52E+11
11 BOC	2.78E+07	4.58E+08	2.40E+09	3.12E+09	8.04E+09	8.91E+11	1.88E+11
11	2.90E+07	4.77E+08	2.50E+09	3.25E+09	8.39E+09	9.33E+11	1.97E+11
11 EOC	3.28E+07	5.40E+08	2.84E+09	3.70E+09	9.56E+09	1.07E+12	2.25E+11
Average	4.68E+07	7.82E+08	4.18E+09	5.45E+09	1.43E+10	1.66E+12	3.46E+11

Table A-7 Surveillance Capsule 263° Cj Factors, Core Midplane Elevation

Cycle	C_j						
	^{63}Cu(n,α)	^{46}Ti(n,p)	^{54}Fe(n,p)	^{58}Ni(n,p)	^{238}U(n,f)	^{59}Co(n,γ)	^{59}Co(Cd)(n,γ)
1	1.66	1.68	1.71	1.72	1.74	1.82	1.80
2	1.34	1.35	1.36	1.36	1.37	1.40	1.40
3	1.33	1.34	1.35	1.35	1.36	1.39	1.38
4	1.18	1.18	1.19	1.19	1.20	1.21	1.21
5	1.22	1.22	1.23	1.23	1.24	1.26	1.26
6	1.20	1.21	1.21	1.21	1.22	1.22	1.22
7	0.69	0.69	0.68	0.68	0.67	0.65	0.65
8	0.85	0.85	0.84	0.84	0.83	0.81	0.81
9	0.83	0.82	0.81	0.81	0.80	0.77	0.78
10	0.79	0.78	0.76	0.76	0.75	0.72	0.73
11 BOC	0.59	0.59	0.57	0.57	0.56	0.54	0.54
11	0.62	0.61	0.60	0.60	0.59	0.56	0.57
11 EOC	0.70	0.69	0.68	0.68	0.67	0.64	0.65
Average	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table A-8 Measured Sensor Activities and Reaction Rates for Surveillance Capsule 97°

Target Isotope	Product Isotope	Measured Activity (dps/g)[1]	Radially Corrected Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)	Corrected Average Reaction Rate (rps/atom)
Cu-63	Co-60	3.15E+05	7.77E+05	8.12E-17		
Cu-63	Co-60	2.93E+05	7.23E+05	7.55E-17		
Cu-63	Co-60	3.22E+05	7.94E+05	8.30E-17	7.99E-17	7.99E-17
Ti-46	Sc-46	1.23E+07	1.53E+07	1.17E-15		
Ti-46	Sc-46	1.31E+07	1.63E+07	1.24E-15		
Ti-46	Sc-46	1.52E+07	1.89E+07	1.44E-15	1.28E-15	1.28E-15
Fe-54	Mn-54	5.41E+07	7.15E+07	6.40E-15		
Fe-54	Mn-54	5.08E+07	6.71E+07	6.01E-15		
Fe-54	Mn-54	5.35E+07	7.07E+07	6.33E-15	6.25E-15	6.25E-15
Ni-58	Co-58	6.69E+07	8.26E+07	7.95E-15		
Ni-58	Co-58	6.54E+07	8.08E+07	7.77E-15		
Ni-58	Co-58	7.14E+07	8.82E+07	8.48E-15	8.07E-15	8.07E-15
U-238	Cs-137	2.94E+05	3.09E+06	2.03E-14		
U-238	Cs-137	2.94E+05	3.09E+06	2.03E-14		
U-238	Cs-137	3.12E+05	3.28E+06	2.15E-14	2.07E-14	1.55E-14
Co-59	Co-60	1.61E+10	3.97E+10	3.89E-12		
Co-59	Co-60	1.81E+10	4.47E+10	4.37E-12		
Co-59	Co-60	1.44E+10	3.55E+10	3.48E-12	3.91E-12	3.91E-12
Co-59(Cd)	Co-60	1.91E+09	4.71E+09	4.61E-13		
Co-59(Cd)	Co-60	1.64E+09	4.05E+09	3.96E-13		
Co-59(Cd)	Co-60	1.84E+09	4.54E+09	4.44E-13	4.34E-13	4.34E-13

Note:
1. Measured activity decay corrected to March 15, 1991

Table A-9 Measured Sensor Activities and Reaction Rates for Surveillance Capsule 263°

Target Isotope	Product Isotope	Measured Activity (dps/g)[1]	Radially Corrected Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)	Corrected Average Reaction Rate (rps/atom)
Cu-63	Co-60	2.36E+05	3.66E+05	5.58E-17		
Cu-63	Co-60	1.69E+05	2.62E+05	4.00E-17		
Cu-63	Co-60	1.98E+05	3.07E+05	4.68E-17	4.76E-17	4.76E-17
Ti-46	Sc-46	2.22E+05	9.43E+05	9.08E-16		
Ti-46	Sc-46	2.12E+05	9.00E+05	8.67E-16		
Ti-46	Sc-46	2.06E+05	8.75E+05	8.43E-16	8.73E-16	8.73E-16
Fe-54	Mn-54	1.42E+06	2.98E+06	4.73E-15		
Fe-54	Mn-54	1.36E+06	2.86E+06	4.53E-15		
Fe-54	Mn-54	1.33E+06	2.79E+06	4.43E-15	4.56E-15	4.56E-15
Ni-58	Co-58	8.83E+06	4.57E+07	6.55E-15		
Ni-58	Co-58	8.27E+06	4.28E+07	6.13E-15		
Ni-58	Co-58	8.31E+06	4.30E+07	6.16E-15	6.28E-15	6.28E-15
U-238	Cs-137	2.45E+05	9.21E+05	6.05E-15		
U-238	Cs-137	6.76E+04	2.54E+05	1.67E-15		
U-238	Cs-137	1.28E+05	4.81E+05	3.16E-15	3.63E-15	2.62E-15
Co-59	Co-60	2.45E+07	3.93E+07	2.26E-12		
Co-59	Co-60	2.41E+07	3.87E+07	2.23E-12		
Co-59	Co-60	1.96E+07	3.14E+07	1.81E-12	2.10E-12	2.10E-12
Co-59(Cd)	Co-60	3.04E+06	4.85E+06	2.79E-13		
Co-59(Cd)	Co-60	3.11E+06	4.97E+06	2.86E-13		
Co-59(Cd)	Co-60	3.04E+06	4.85E+06	2.79E-13	2.82E-13	2.82E-13

Note:
1. Measured activity decay corrected to July 25, 2002

Table A-10 Measured Sensor Activities and Reaction Rates for Surveillance Capsule 83°

Target Isotope	Product Isotope	Measured Activity (dps/g)[1]	Radially Corrected Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)	Corrected Average Reaction Rate (rps/atom)
Cu-63	Co-60	2.21E+05	3.08E+05	4.70E-17		
Cu-63	Co-60	2.00E+05	2.79E+05	4.25E-17		
Cu-63	Co-60	2.63E+05	3.67E+05	5.59E-17	4.85E-17	4.85E-17
Ti-46	Sc-46	8.70E+04	9.37E+05	9.03E-16		
Ti-46	Sc-46	7.85E+04	8.46E+05	8.15E-16		
Ti-46	Sc-46	8.17E+04	8.80E+05	8.48E-16	8.55E-16	8.55E-16
Fe-54	Mn-54	1.25E+06	2.97E+06	4.71E-15		
Fe-54	Mn-54	1.14E+06	2.71E+06	4.30E-15		
Fe-54	Mn-54	1.19E+06	2.83E+06	4.49E-15	4.50E-15	4.50E-15
Ni-58	Co-58	2.90E+06	4.52E+07	6.47E-15		
Ni-58	Co-58	2.66E+06	4.15E+07	5.94E-15		
Ni-58	Co-58	2.83E+06	4.41E+07	6.32E-15	6.24E-15	6.24E-15
U-238	Cs-137	6.82E+05	1.70E+06	1.12E-14		
U-238	Cs-137	1.63E+06	4.07E+06	2.67E-14		
U-238	Cs-137	5.14E+05	1.28E+06	8.42E-15	1.54E-14	1.07E-14
Co-59	Co-60	2.61E+07	3.64E+07	2.10E-12		
Co-59	Co-60	2.34E+07	3.26E+07	1.88E-12		
Co-59	Co-60	1.99E+07	2.77E+07	1.60E-12	1.86E-12	1.86E-12
Co-59(Cd)	Co-60	3.09E+06	4.31E+06	2.48E-13		
Co-59(Cd)	Co-60	3.24E+06	4.52E+06	2.60E-13		
Co-59(Cd)	Co-60	3.18E+06	4.43E+06	2.55E-13	2.54E-13	2.54E-13

Notes:
1. Measured activity decay corrected to December 15, 2014

Table A-11 Least-Squares Evaluation of Dosimetry in Surveillance Capsule 97° (7-Degree Azimuth, Core Midplane) Cycles 1 Through 4 Irradiation

Reaction	Reaction Rate (rps/atom)			M/C	M/BE	BE/C
	Measured (M)	Calculated (C)	Best-Estimate (BE)			
Cu-63(n,α)Co-60	7.99E-17	6.40E-17	7.61E-17	1.25	1.05	1.19
Fe-54(n,p)Mn-54	6.25E-15	5.82E-15	6.36E-15	1.07	0.98	1.09
Ni-58(n,p)Co-58	8.07E-15	7.61E-15	8.26E-15	1.06	0.98	1.09
Co-59(n,γ)Co-60	3.91E-12	2.74E-12	3.89E-12	1.42	1.00	1.42
Co-59(Cd)(n,γ)Co-60	4.34E-13	4.74E-13	4.37E-13	0.91	0.99	0.92
Average				1.13	1.00	1.12
% standard deviation				9.5	4.0	5.1
Integral Quantity	**Calculated (C)**	**% Unc.**	**Best-Estimate (BE)**	**% Unc.**	**BE/C**	
Fluence rate E > 1.0 MeV (n/cm^2-s)	4.53E+10	13	4.74E+10	7	1.04	
Fluence rate E > 0.1 MeV (n/cm^2-s)	8.64E+10	-	8.91E+10	9	1.03	
dpa/s	6.54E-11	13	6.92E-11	6	1.05	

Table A-12 Least-Squares Evaluation of Dosimetry in Surveillance Capsule 263° (7-Degree Azimuth, Core Midplane) Cycles 1 Through 11 Irradiation

Reaction	Reaction Rate (rps/atom)			M/C	M/BE	BE/C
	Measured (M)	Calculated (C)	Best-Estimate (BE)			
Cu-63(n,α)Co-60	4.75E-17	4.85E-17	4.99E-17	0.98	1.05	1.03
Ti-46(n,p)Sc-46	8.73E-16	7.60E-16	8.30E-16	1.15	0.95	1.09
Fe-54(n,p)Mn-54	4.56E-15	4.33E-15	4.65E-15	1.05	1.02	1.07
Ni-58(n,p)Co-58	6.28E-15	5.65E-15	6.15E-15	1.11	0.98	1.09
Co-59(n,γ)Co-60	2.10E-12	1.97E-12	2.10E-12	1.06	1.00	1.06
Co-59(Cd)(n,γ)Co-60	2.81E-13	3.43E-13	2.84E-13	0.82	1.01	0.83
Average				1.07	1.00	1.07
% standard deviation				6.9	4.4	2.6
Integral Quantity	**Calculated (C)**	**% Unc.**	**Best-Estimate (BE)**	**% Unc.**	**BE/C**	
Fluence rate E > 1.0 MeV (n/cm^2-s)	3.32E+10	13	3.60E+10	7	1.08	
Fluence rate E > 0.1 MeV (n/cm^2-s)	6.31E+10	-	6.70E+10	9	1.06	
dpa/s	4.80E-11	13	5.16E-11	6	1.07	

Table A-13 Least-Squares Evaluation of Dosimetry in Surveillance Capsule 83° (7-Degree Azimuth, Core Midplane) Cycles 1 Through 19 Irradiation

Reaction	Reaction Rate (rps/atom) Measured (M)	Calculated (C)	Best-Estimate (BE)	M/C	M/BE	BE/C
Cu-63(n,α)Co-60	4.85E-17	4.60E-17	5.02E-17	1.05	0.96	1.09
Ti-46(n,p)Sc-46	8.55E-16	7.19E-16	8.22E-16	1.19	1.04	1.14
Fe-54(n,p)Mn-54	4.50E-15	4.07E-15	4.59E-15	1.10	0.98	1.13
Ni-58(n,p)Co-58	6.24E-15	5.32E-15	6.08E-15	1.17	1.03	1.14
Co-59(n,γ)Co-60	1.86E-12	1.83E-12	1.86E-12	1.02	1.00	1.02
Co-59(Cd)(n,γ)Co-60	2.54E-13	3.19E-13	2.57E-13	0.80	0.99	0.81
Average				1.13	1.00	1.13
% standard deviation				5.7	3.9	2.1
Integral Quantity	**Calculated (C)**	**% Unc.**	**Best-Estimate (BE)**	**% Unc.**	**BE/C**	
Fluence rate E > 1.0 MeV (n/cm^2-s)	3.11E+10	13	3.50E+10	7	1.12	
Fluence rate E > 0.1 MeV (n/cm^2-s)	5.89E+10	-	6.46E+10	9	1.09	
dpa/s	4.49E-11	13	5.02E-11	6	1.11	

Table A-14 Comparison of Measured/Calculated (M/C) Sensor Reaction Rate Ratios for Fast Neutron Threshold Reactions

Capsule	M/C				
	$^{63}Cu(n,\alpha)$	$^{46}Ti(n,p)$	$^{54}Fe(n,p)$	$^{58}Ni(n,p)$	$^{238}U(n,f)$
97°	1.25	-	1.07	1.06	-
263°	0.98	1.15	1.05	1.11	-
83°	1.05	1.19	1.10	1.17	-
Average	1.09	1.17	1.07	1.11	-
% Standard Deviation	12.8	2.4	2.3	4.9	-
Average	1.11				
% Standard Deviation	7.0				

Table A-15 Comparison of Best-Estimate/Calculated (BE/C) Exposure Rate Ratios

Capsule	BE/C	
	Neutron Fluence Rate (E > 1.0 MeV)	Iron Atom Displacement Rate
97°	1.04	1.05
263°	1.08	1.07
83°	1.12	1.11
Average	1.08	1.08
% Standard deviation	3.7	2.8

A.1 REFERENCES

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

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

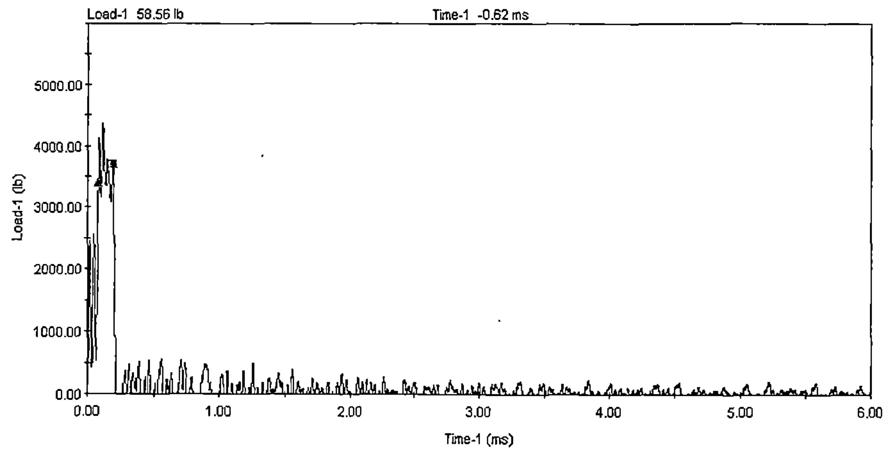
A-3 RSICC Data Library Collection DLC-178, *SNLRML Recommended Dosimetry Cross-Section Compendium*, July 1994.

A-4 ASTM Standard E944-13, *Standard Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance*, E 706 (IIA), 2013.

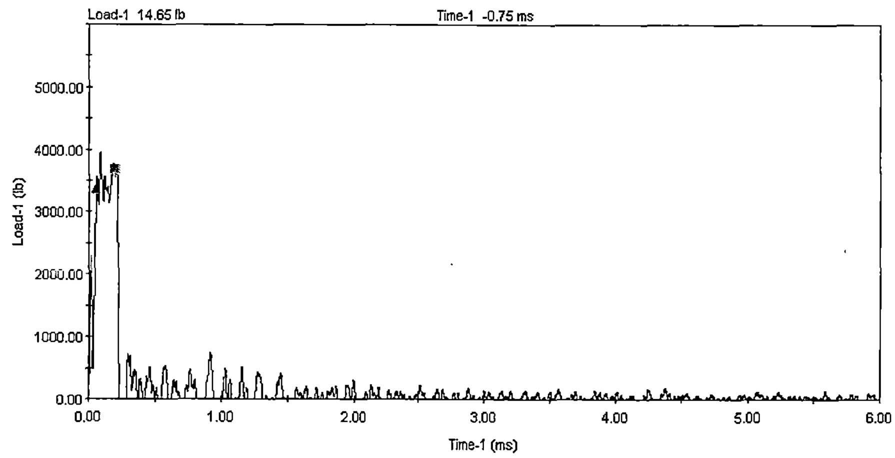
APPENDIX B LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

- "1XX" denotes Lower Shell Plate M-1004-2, longitudinal orientation
- "2XX" denotes Lower Shell Plate M-1004-2, transverse orientation
- "3XX" denotes weld material
- "4XX" denotes heat affected zone material

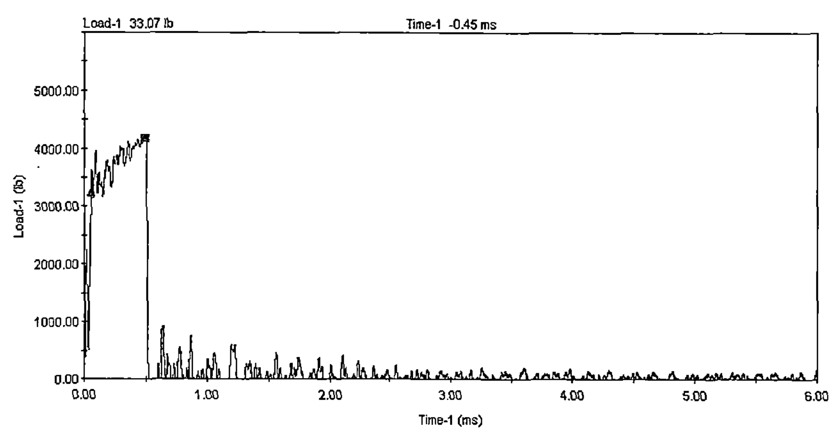
Note that the instrumented Charpy data is not required per ASTM Standards E185-82 or E23-12c.



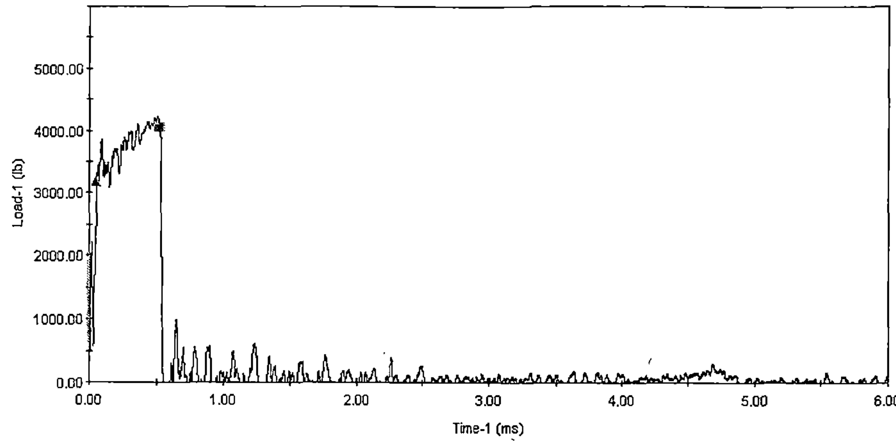
145: Tested at -25°F



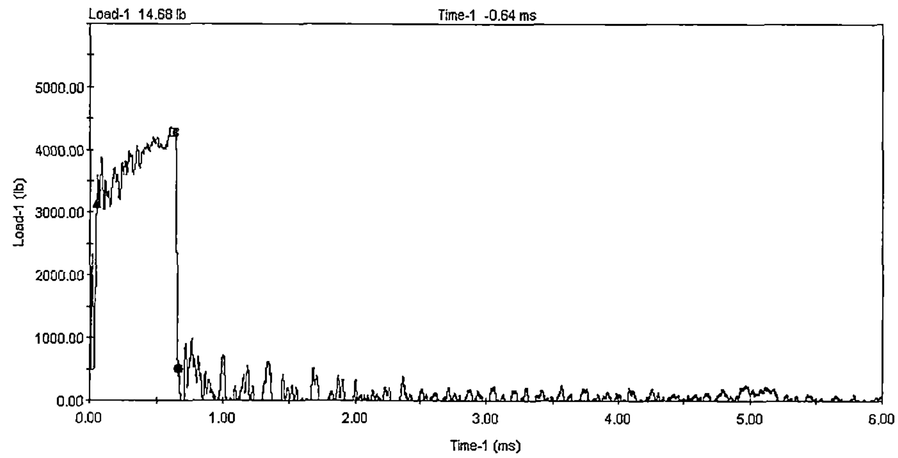
15M: Tested at 0°F



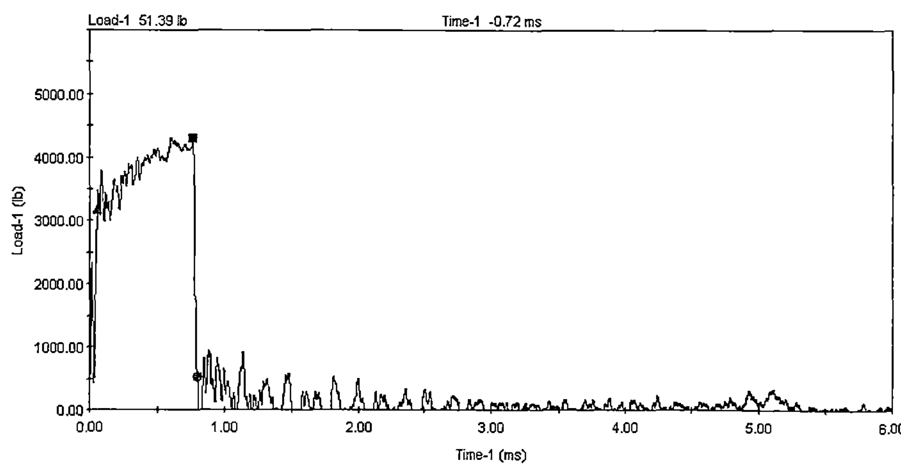
15L: Tested at 5°F



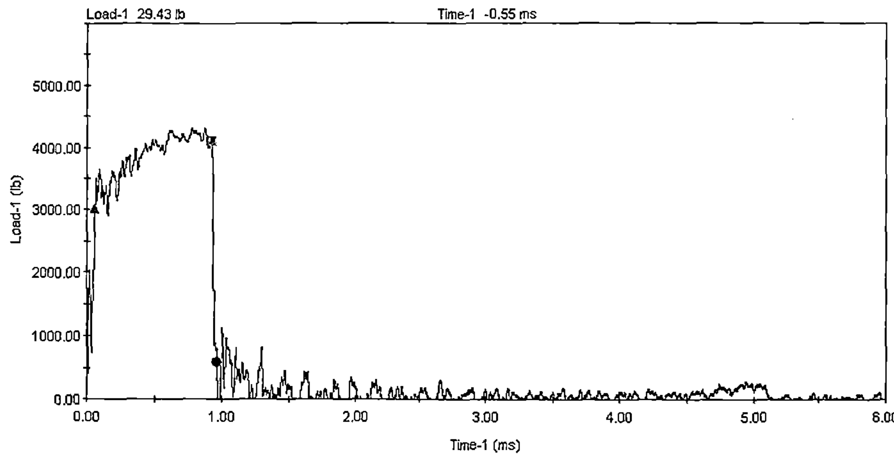
14E: Tested at 10°F



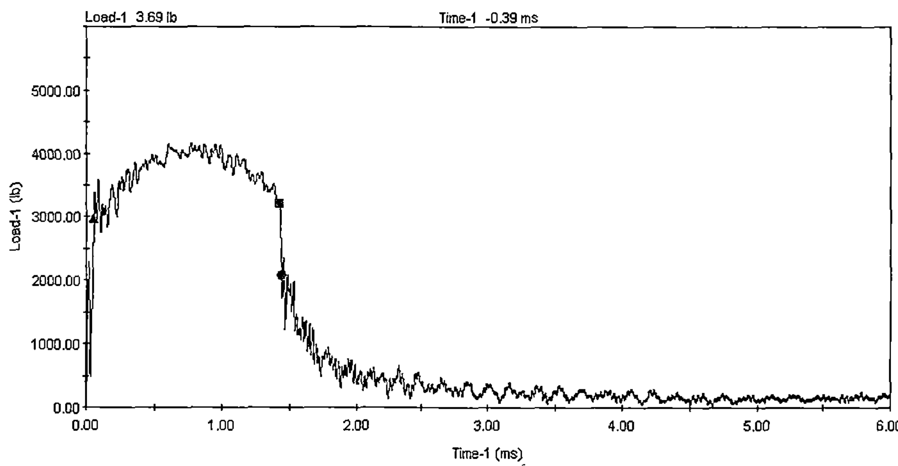
13P: Tested at 20°F



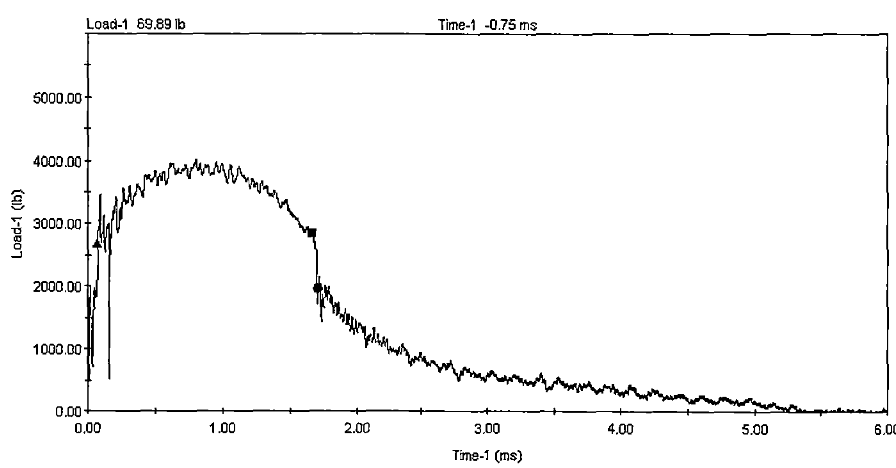
12B: Tested at 30°F



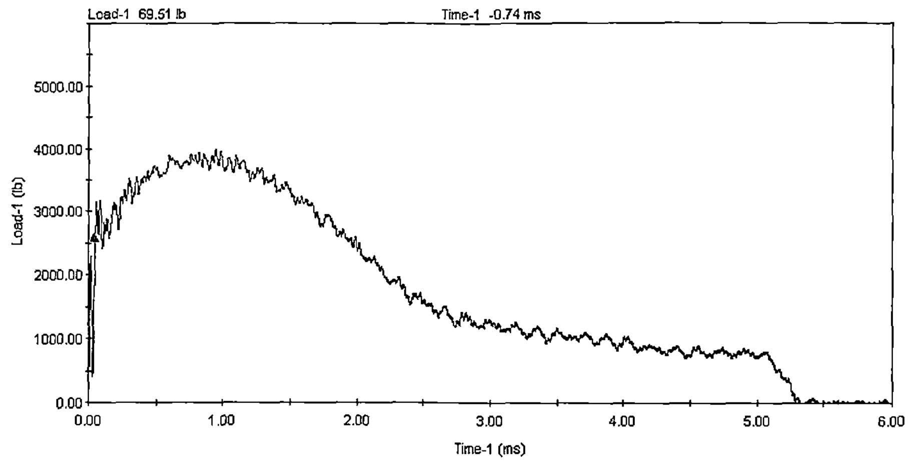
12U: Tested at 40°F



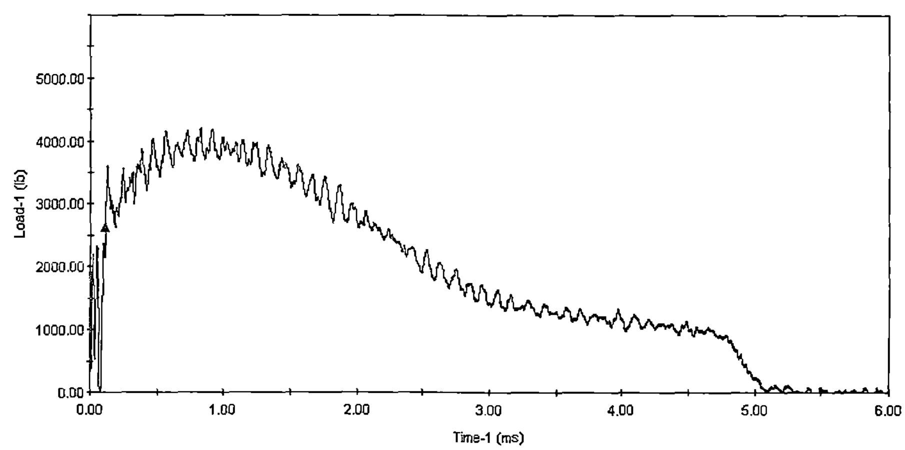
114: Tested at 100°F



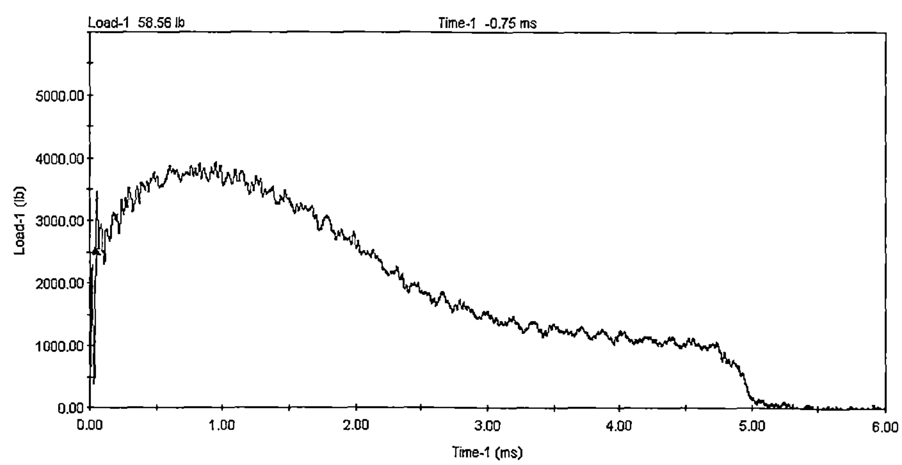
14J: Tested at 200°F



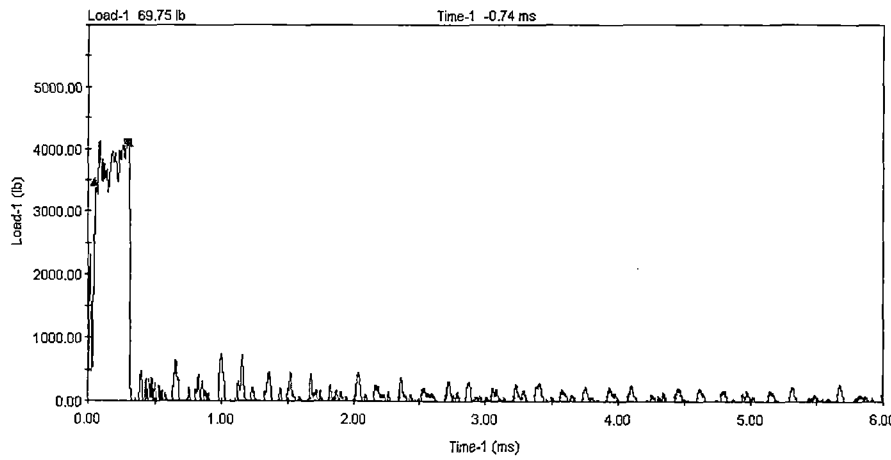
11C: Tested at 230°F



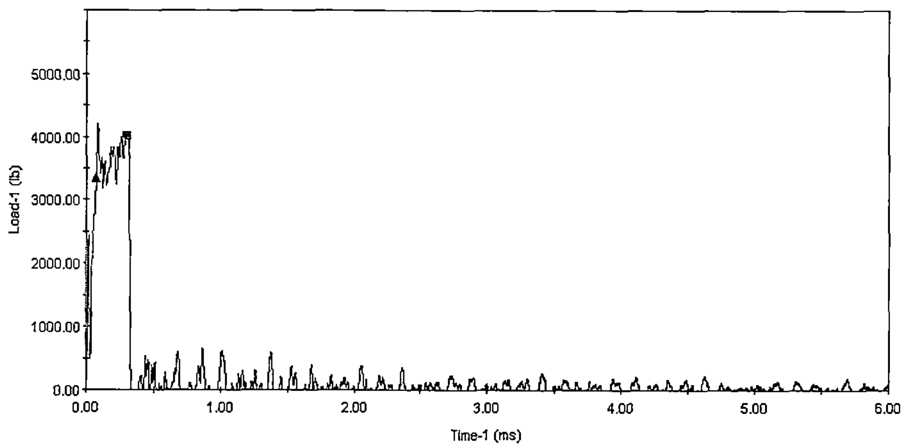
116: Tested at 250°F



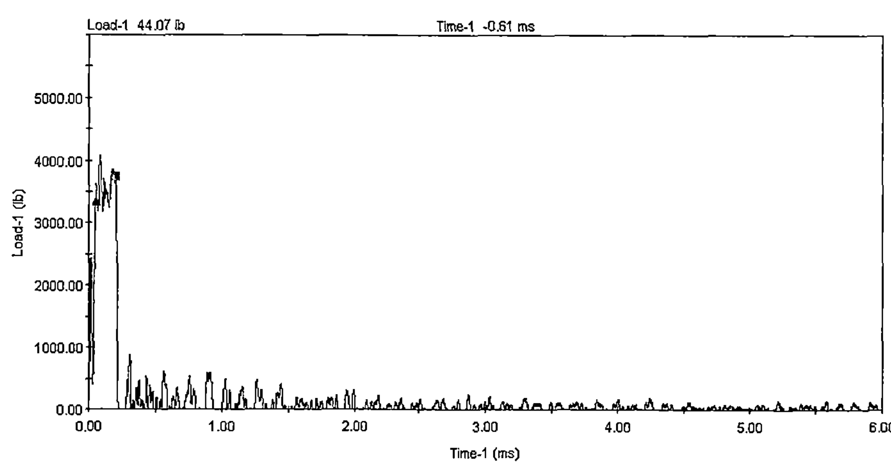
115: Tested at 300°F



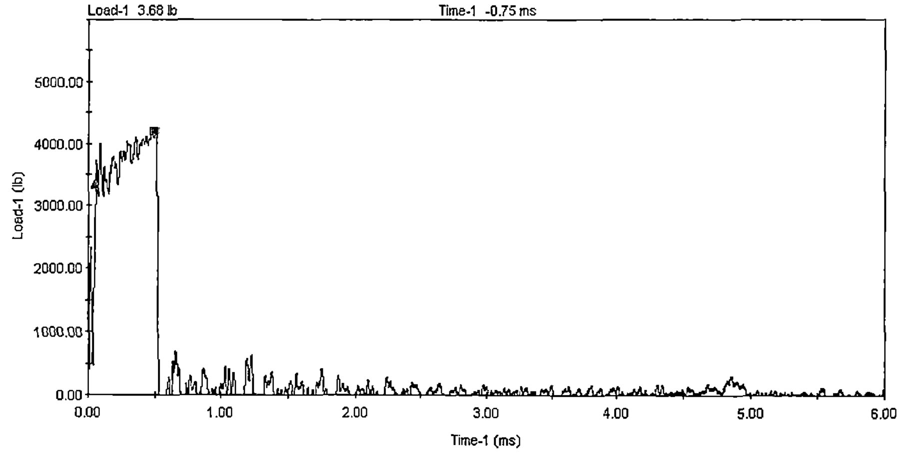
231: Tested at -50°F



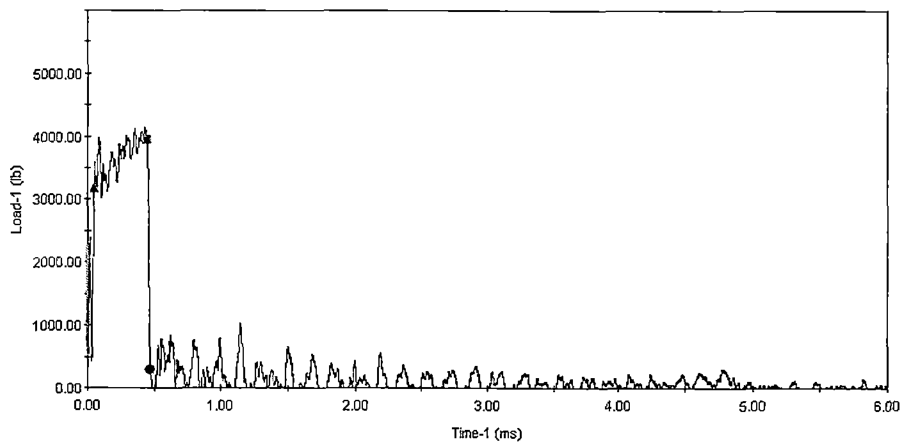
21Y: Tested at -25°F



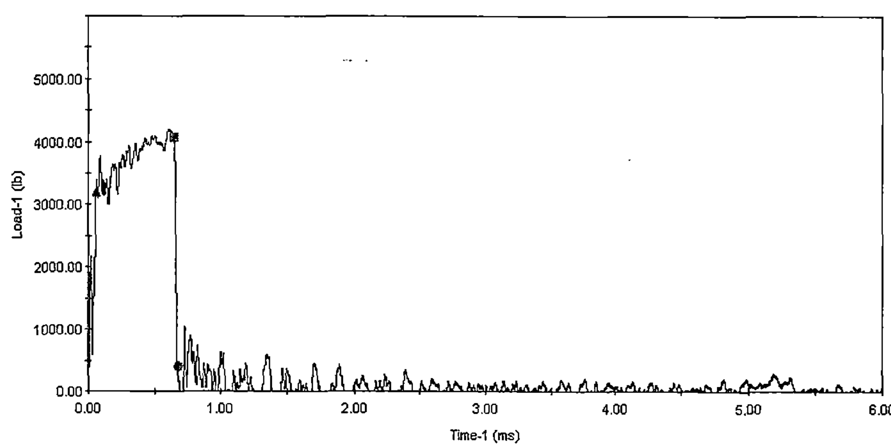
22K: Tested at -10°F



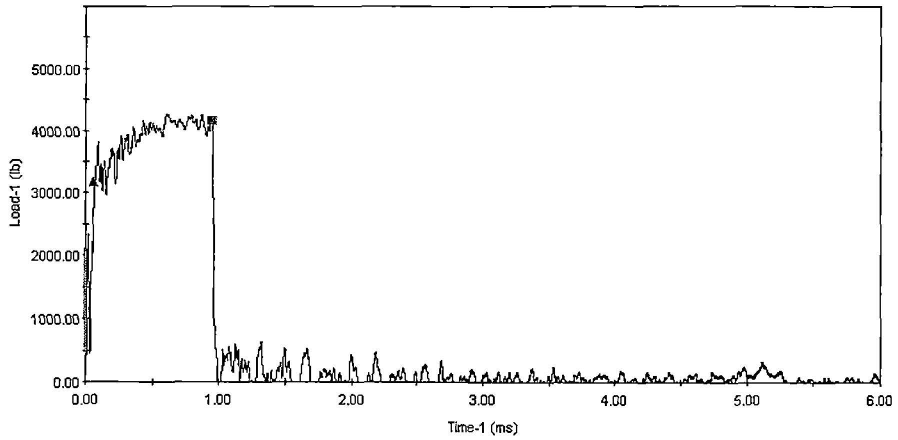
25L: Tested at 0°F



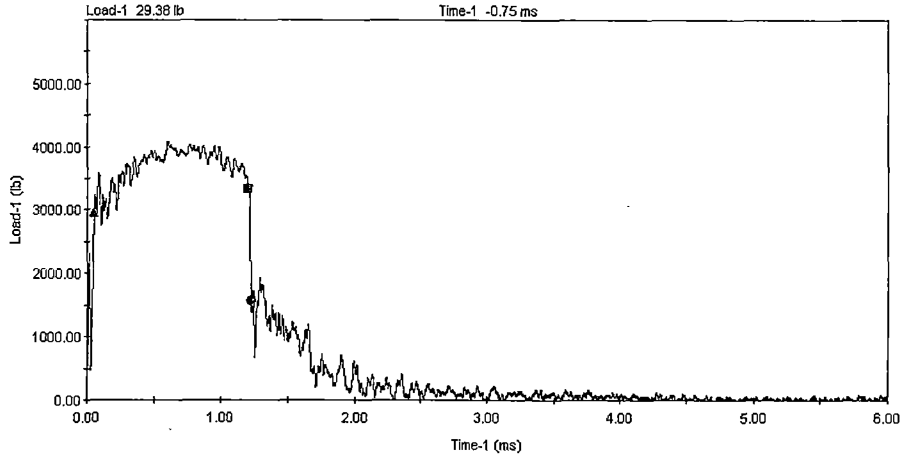
24L: Tested at 10°F



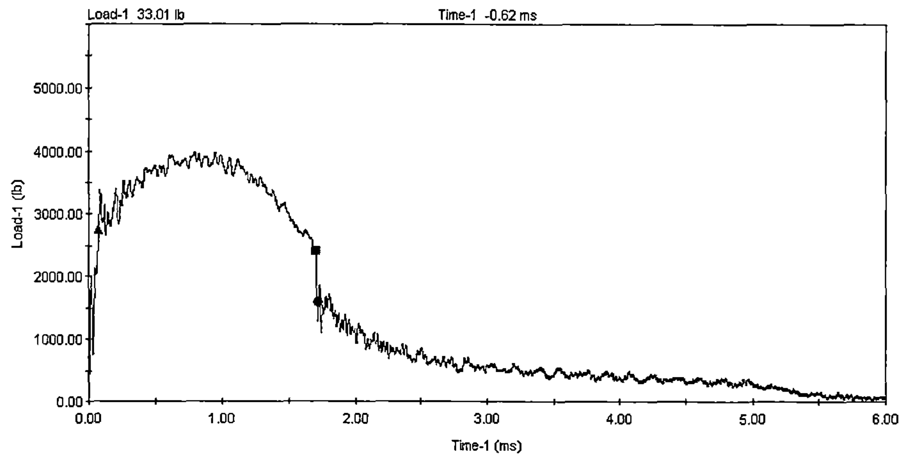
25Y: Tested at 25°F



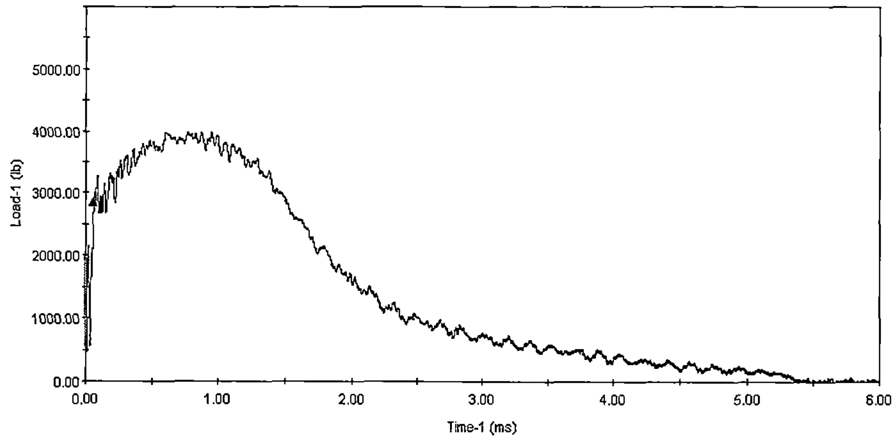
23T: Tested at 40°F



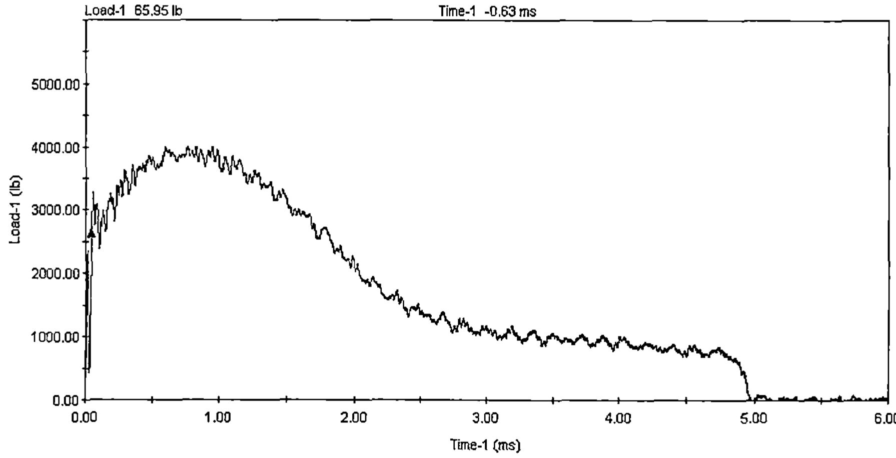
261: Tested at 100°F



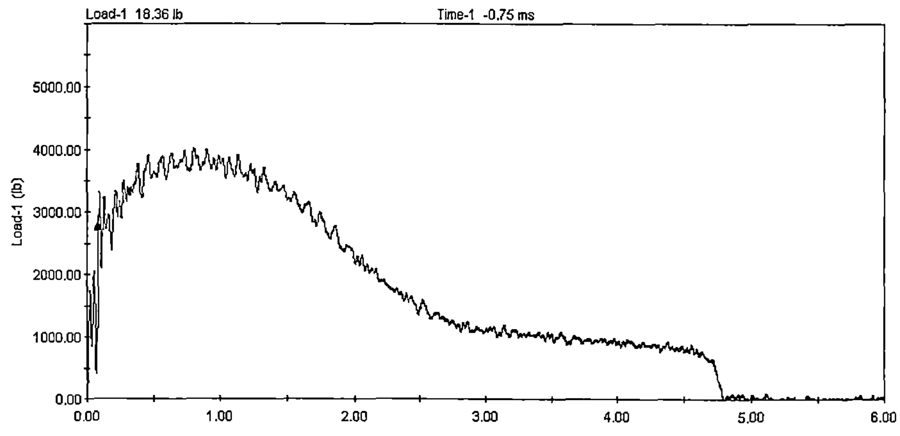
222: Tested at 150°F



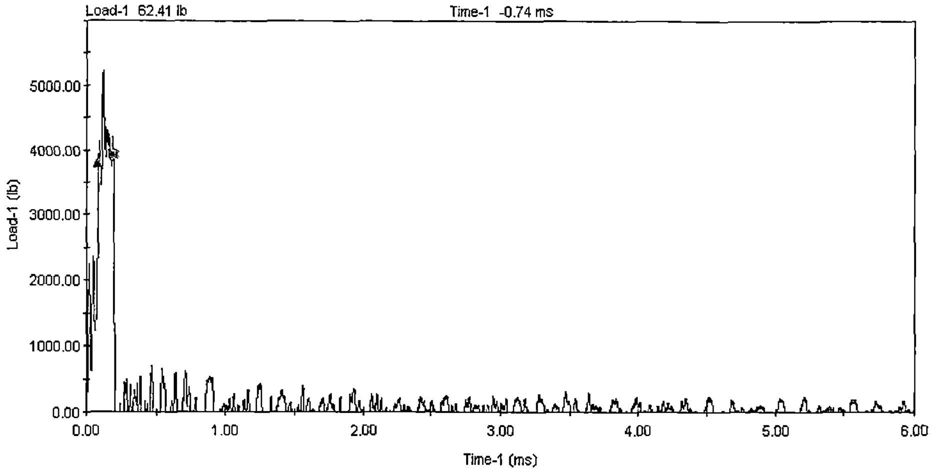
21A: Tested at 200°F



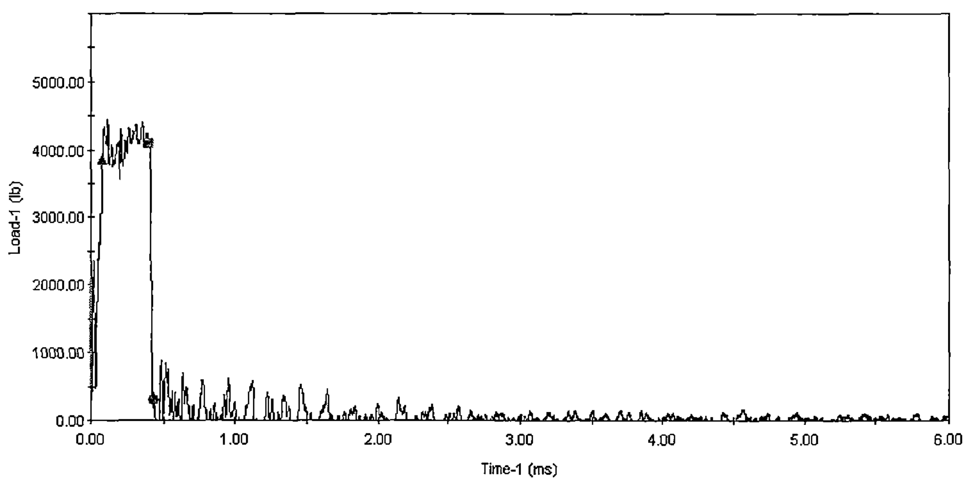
225: Tested at 250°F



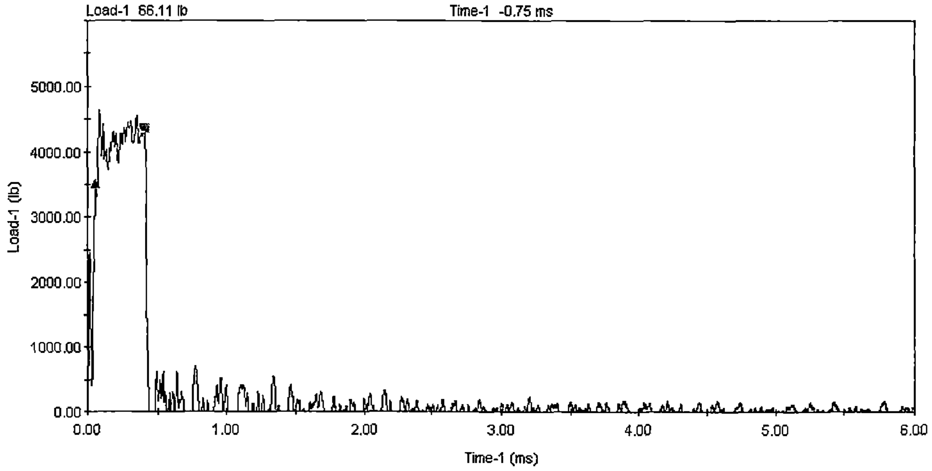
226: Tested at 300°F



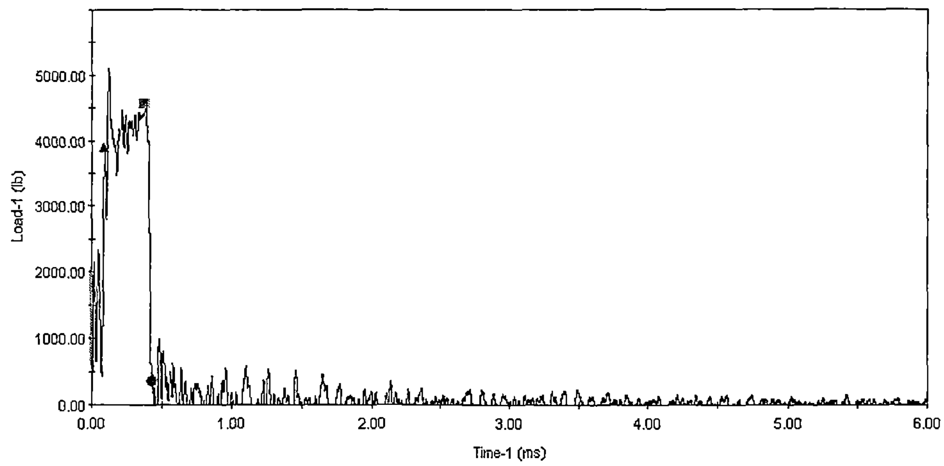
337: Tested at -90°F



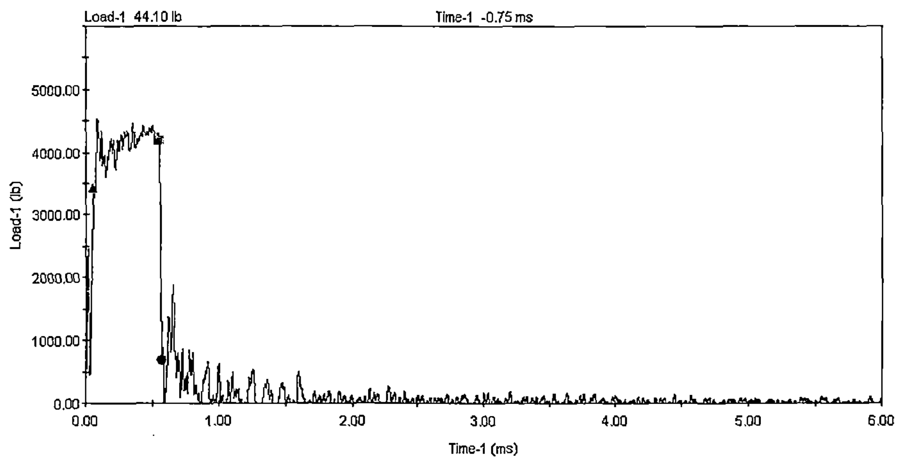
3A2: Tested at -70°F



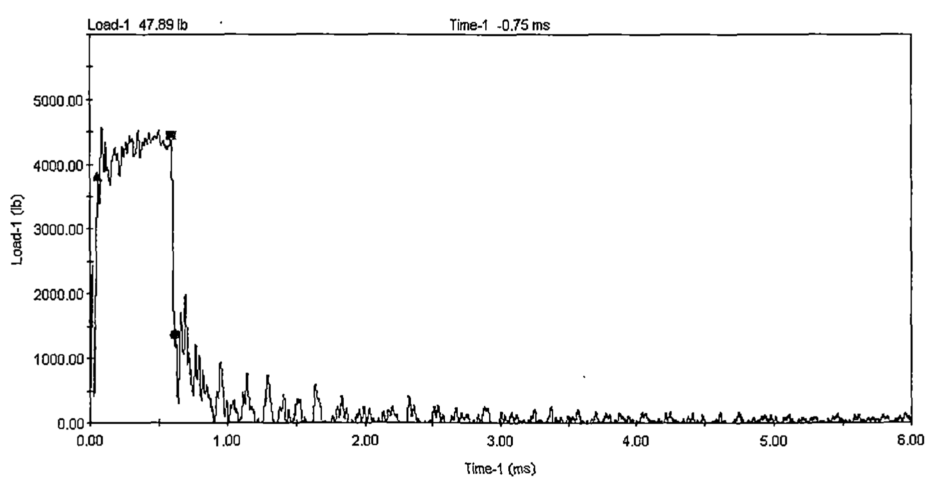
31L: Tested at -65°F



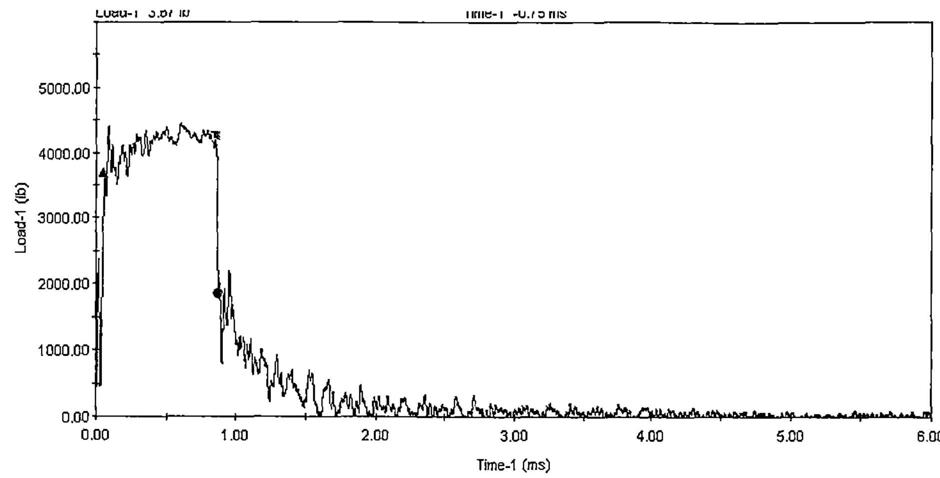
31P: Tested at -60°F



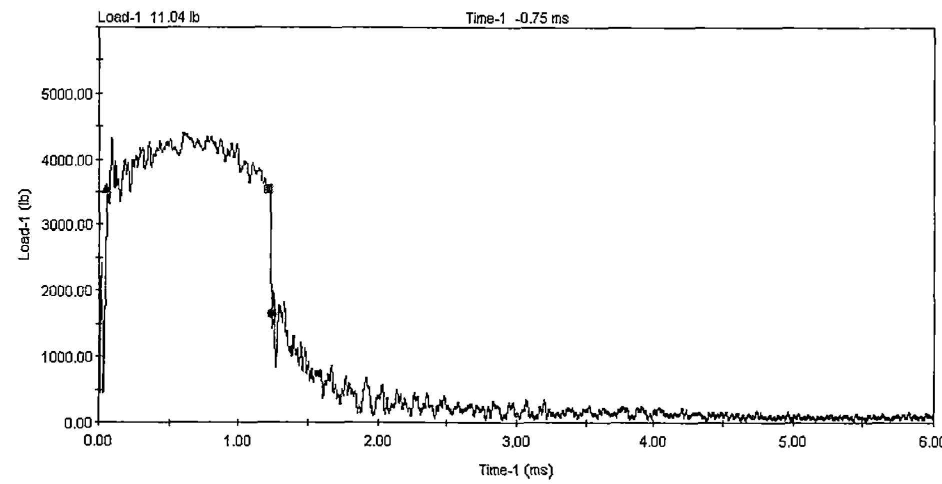
34P: Tested at -55°F



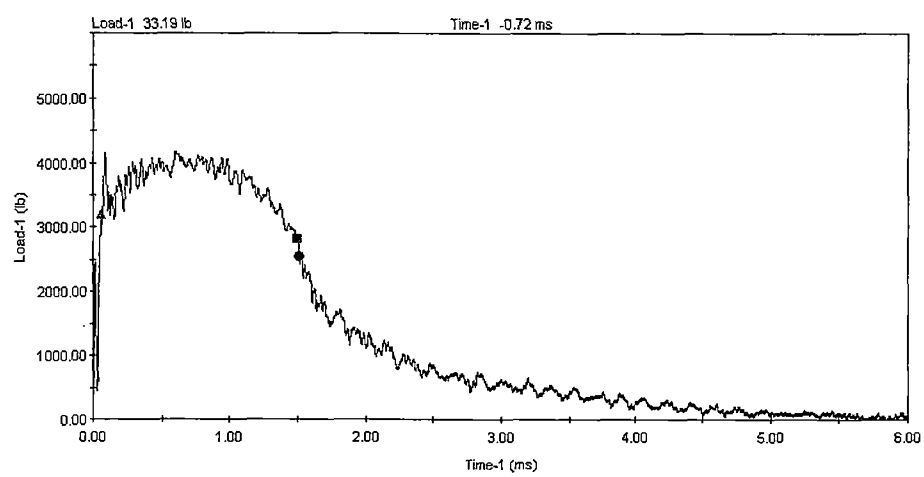
325: Tested at -50°F



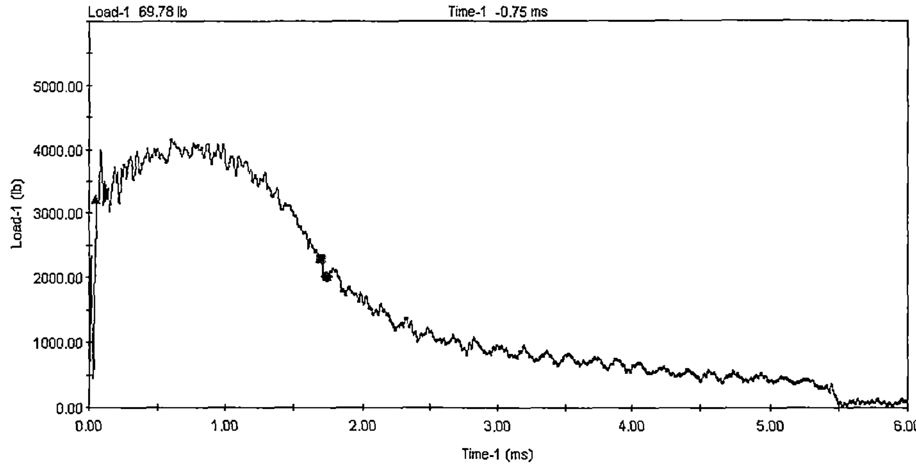
334: Tested at -30°F



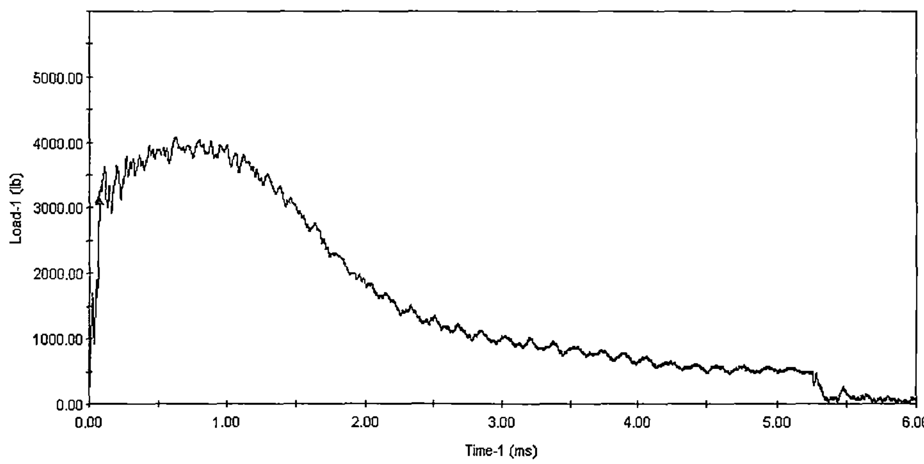
35P: Tested at 0°F



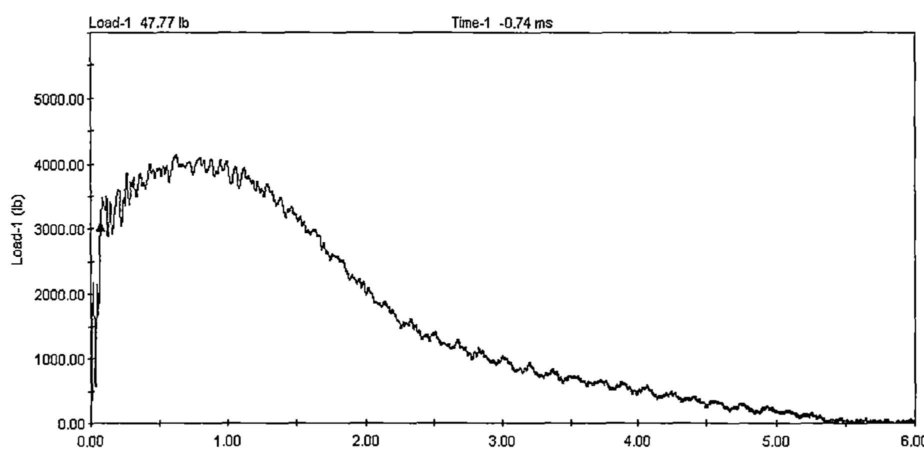
347: Tested at 69°F



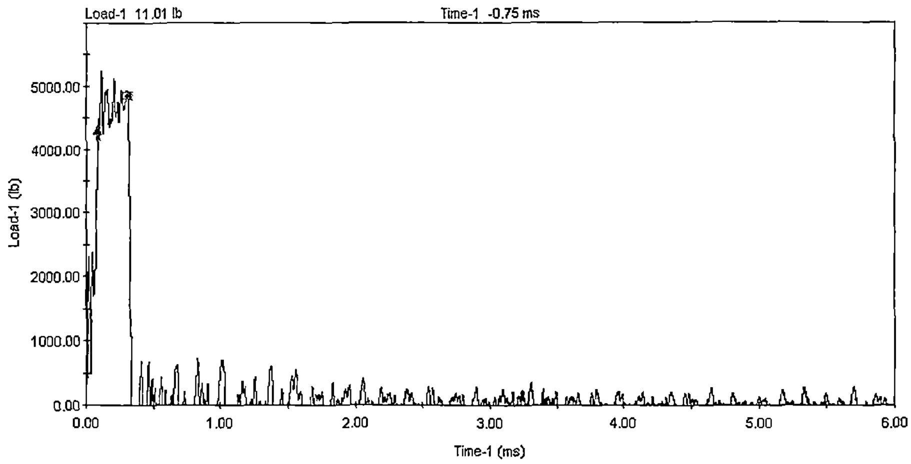
371: Tested at 100°F



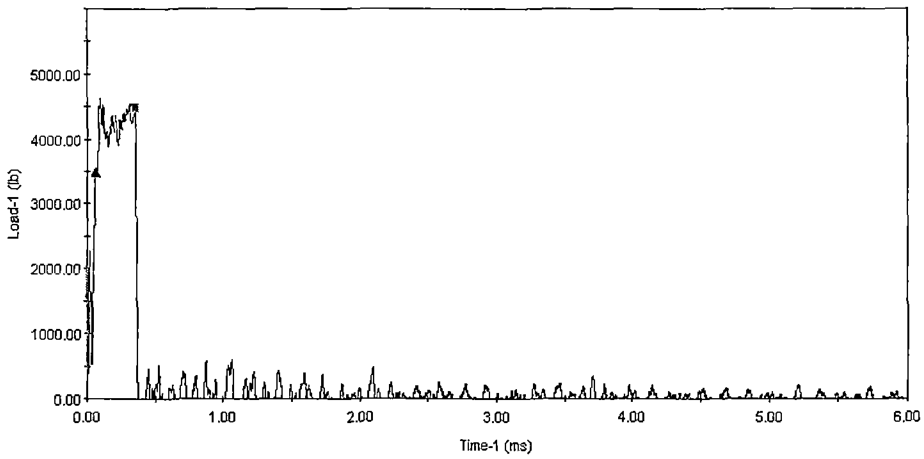
37B: Tested at 150°F



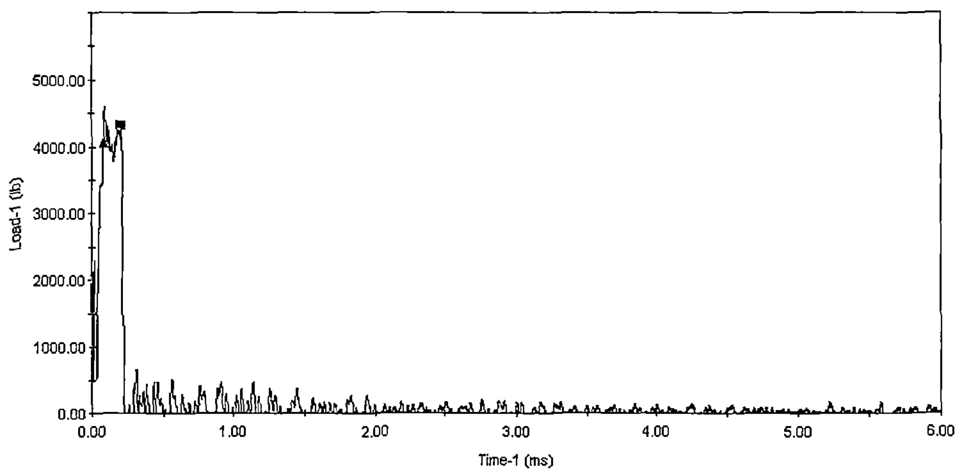
312: Tested at 200°F



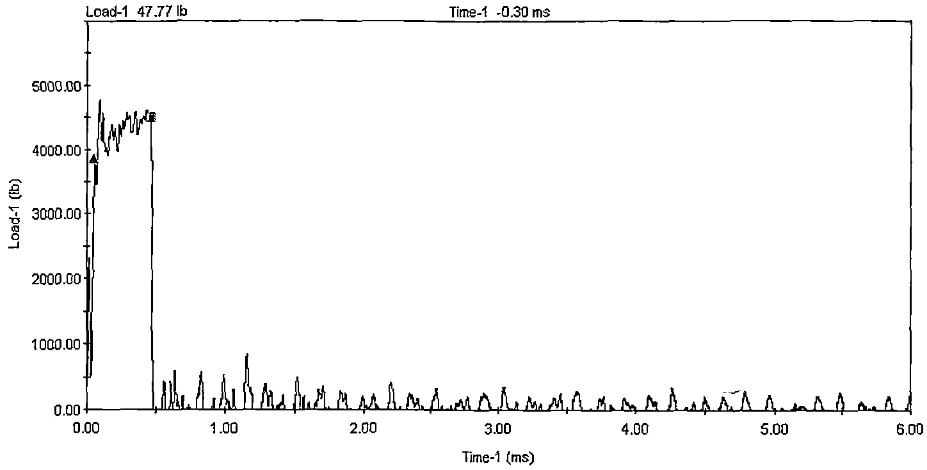
47M: Tested at -125°F



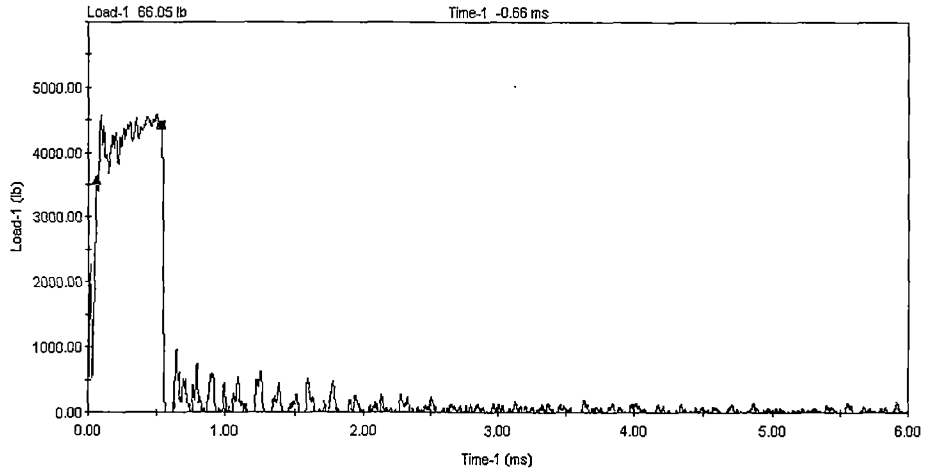
44K: Tested at -90°F



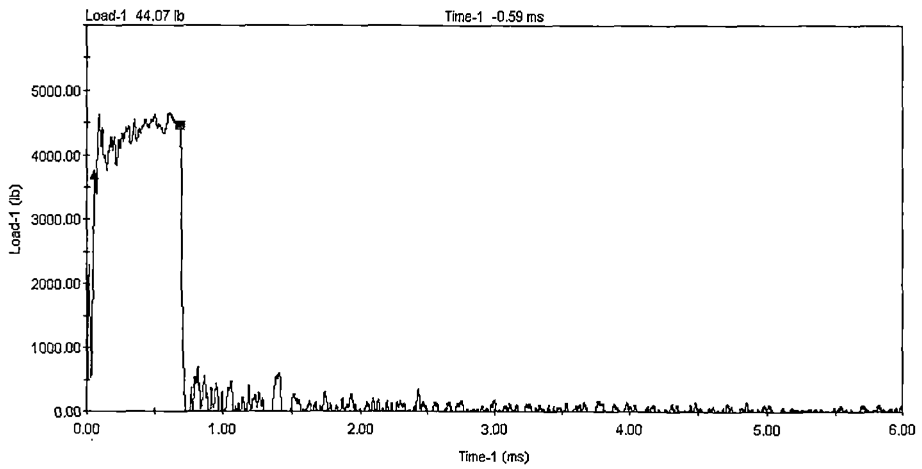
42E: Tested at -80°F



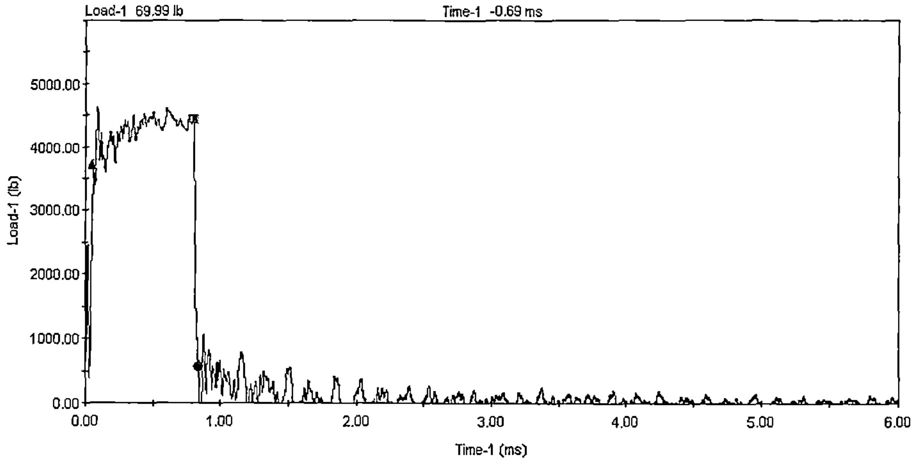
45U: Tested at -75°F



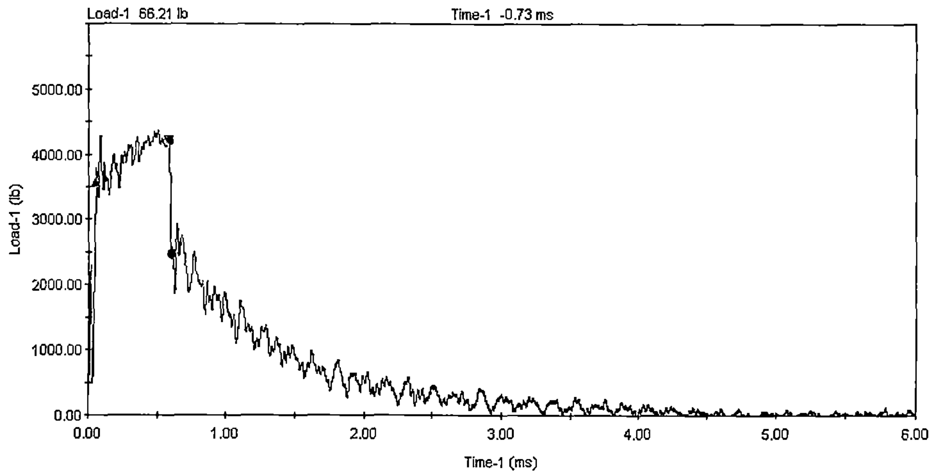
454: Tested at -70°F



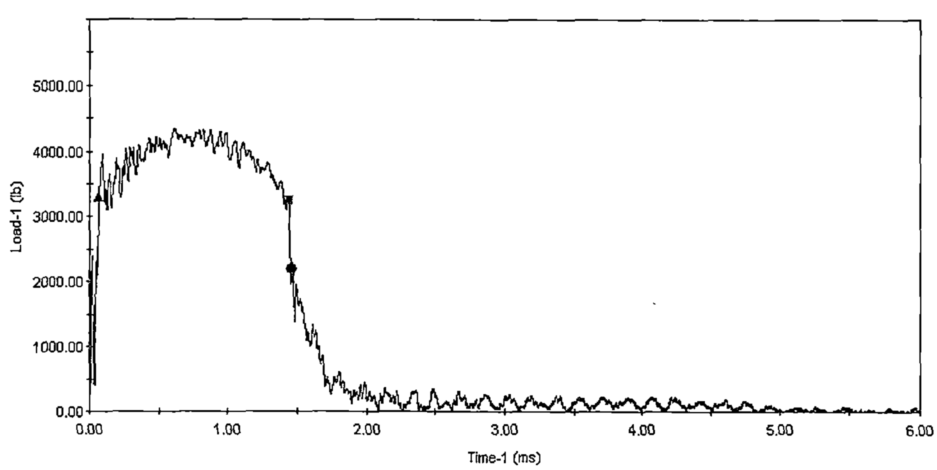
45L: Tested at -60°F



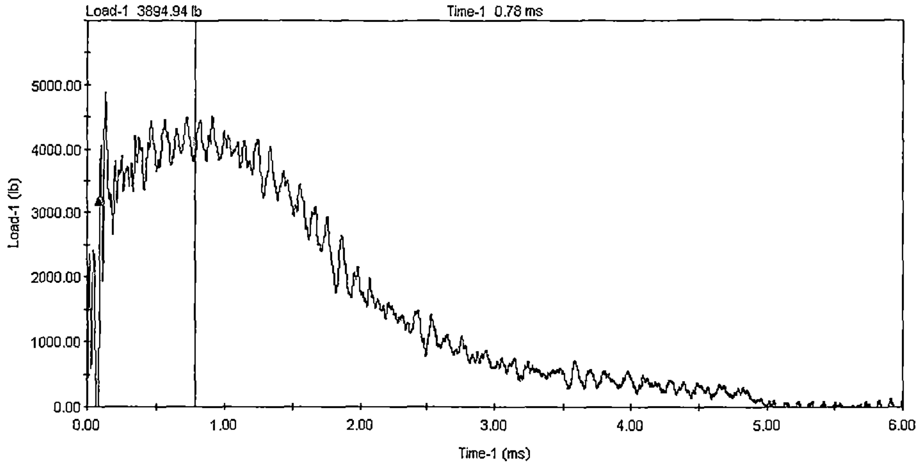
45A: Tested at -50°F



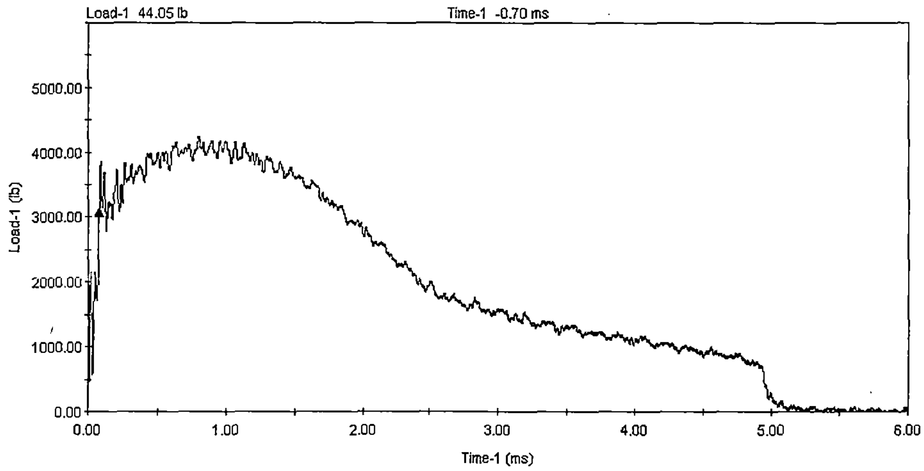
41Y: Tested at 0°F



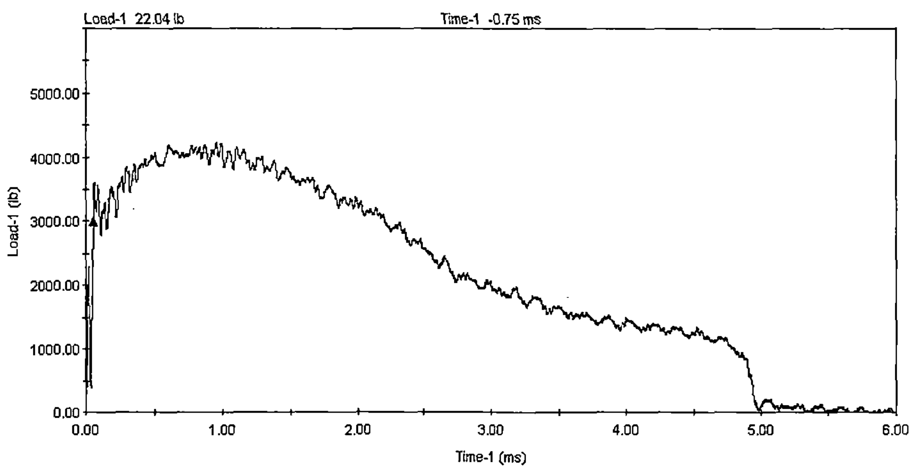
43J: Tested at 69°F



46K: Tested at 150°F



457: Tested at 200°F



472: Tested at 250°F

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

C.1 METHODOLOGY

Contained in Table C-1 are the upper-shelf energy (USE) values that are used as input for the generation of the Charpy V-notch plots using CVGRAPH, Version 6.0. The definition for USE is given in ASTM E185-82 [Ref. C-1], Section 4.18, and reads as follows:

> "*upper shelf energy level* – the average energy value for all Charpy specimens (normally three) whose test temperature is above the upper end of the transition region. For specimens tested in sets of three at each test temperature, the set having the highest average may be regarded as defining the upper shelf energy."

Westinghouse reports the average of all Charpy data with ≥ 95% shear as the USE, excluding any values that are deemed outliers using engineering judgment. Hence, the Capsule 83° USE values reported in Table C-1 were determined by applying this methodology to the Charpy data tabulated in Tables 5-1 through 5-4 of this report. USE values documented in Table C-1 for the unirradiated material, as well as Capsules 97° and 263°, were also determined by applying the methodology described above to the Charpy impact data reported in TR-C-MCS-002, Revision 0 [Ref. C-2], BAW-2177, Revision 01 [Ref. C-3] and WCAP-16002, Revision 0 [Ref. C-4]. The USE values reported in Table C-1 were used in generation of the Charpy V-notch curves.

The lower-shelf energy values were fixed at 2.2 ft-lb for all cases. The lower-shelf lateral expansion values were fixed at 1.0 mils in order to be consistent with the previous capsule analysis [Ref. C-4].

Table C-1 Upper-Shelf Energy Values (ft-lb) Fixed in CVGRAPH

Material	Capsule			
	Unirradiated	97°	263°	83°
Lower Shell Plate M-1004-2 Longitudinal Orientation	170	155	---	158
Lower Shell Plate M-1004-2 Transverse Orientation	141	124	131	138
Surveillance Program Weld Material (Heat # 88114)	156	154	145	133
Heat Affected Zone (HAZ) Material	170	156	163	158
Standard Reference Material (SRM)	133	---	113	---

CVGRAPH, Version 6.0 plots of all surveillance data are provided in this appendix, on the pages following the reference list.

C.2 REFERENCES

C-1 ASTM E185-82, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels, E706(IF)*, ASTM, 1982.

C-2 TR-C-MCS-002, Revision 0, *Louisiana Power & Light Waterford Steam Electric Station Unit No. 3 Evaluation of Baseline Specimens Reactor Vessel Materials Irradiation Surveillance Program*, October 1977.

C-3 BAW-2177, Revision 01, *Analysis of Capsule W-97 Entergy Operations, Inc. Waterford Generating Station, Unit No. 3*, February 2004.

C-4 WCAP-16002, Revision 0, *Analysis of Capsule 263° from the Entergy Operations Waterford Unit 3 Reactor Vessel Radiation Surveillance Program*, March 2003.

C.3 CVGRAPH VERSION 6.0 INDIVIDUAL PLOTS

Unirradiated Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 11:24 AM

A = 86.10 B = 83.90 C = 72.28 T0 = 44.89 D = 0.00

Correlation Coefficient = 0.981

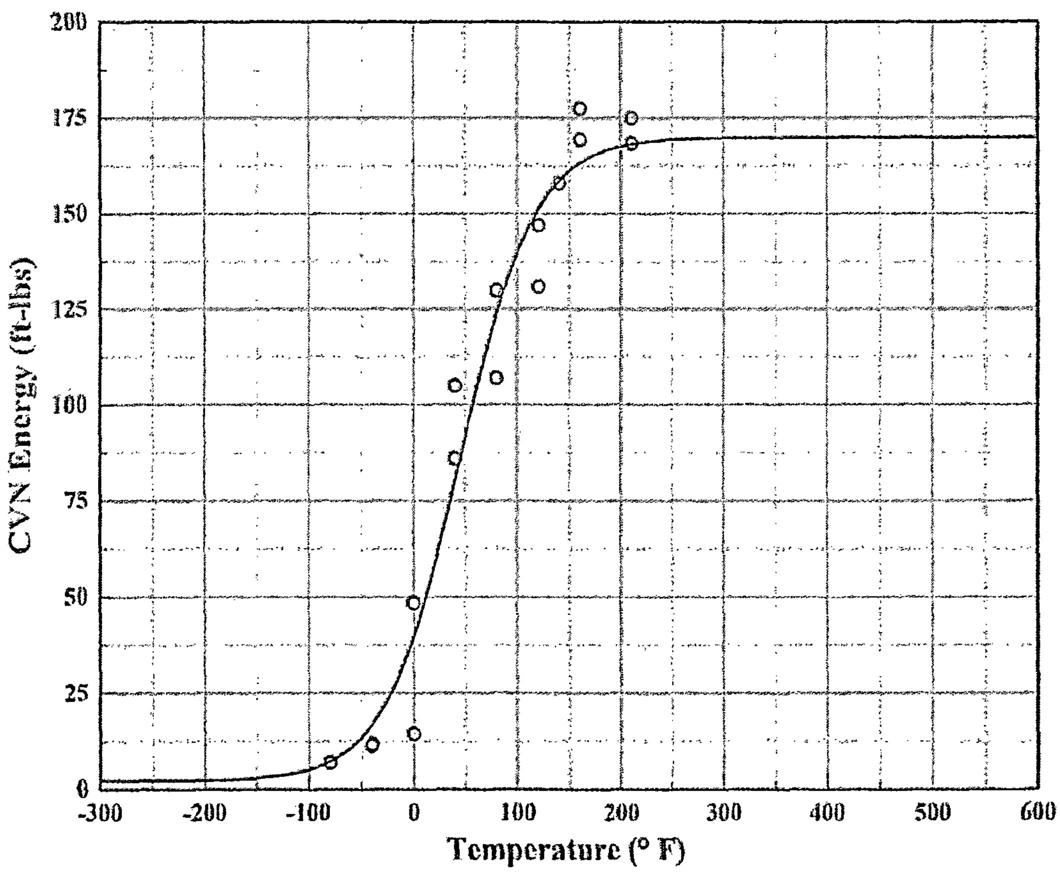
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 170.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-13.50° F Temp@35 ft-lbs= -6.20° F Temp@50 ft-lbs= 11.70° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: LT Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: LT | Capsule: Unirrad | Fluence:

Unirradiated Plate M-1004-2 (Longitudinal)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-80	7.0	7.3	-0.33
-40	12.0	16.8	-4.82
-40	11.5	16.8	-5.32
0	14.5	39.8	-25.30
0	48.5	39.8	8.70
40	86.0	80.4	5.57
40	105.0	80.4	24.57
80	107.0	123.9	-16.92
80	130.0	123.9	6.08
120	131.0	151.3	-20.34
120	147.0	151.3	-4.34
140	158.0	158.7	-0.74
160	169.5	163.3	6.17
160	177.5	163.3	14.17
210	168.5	168.3	0.22
210	175.0	168.3	6.72

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 11:27 AM

A = 46.04 B = 45.04 C = 44.56 T0 = 16.37 D = 0.00

Correlation Coefficient = 0.980

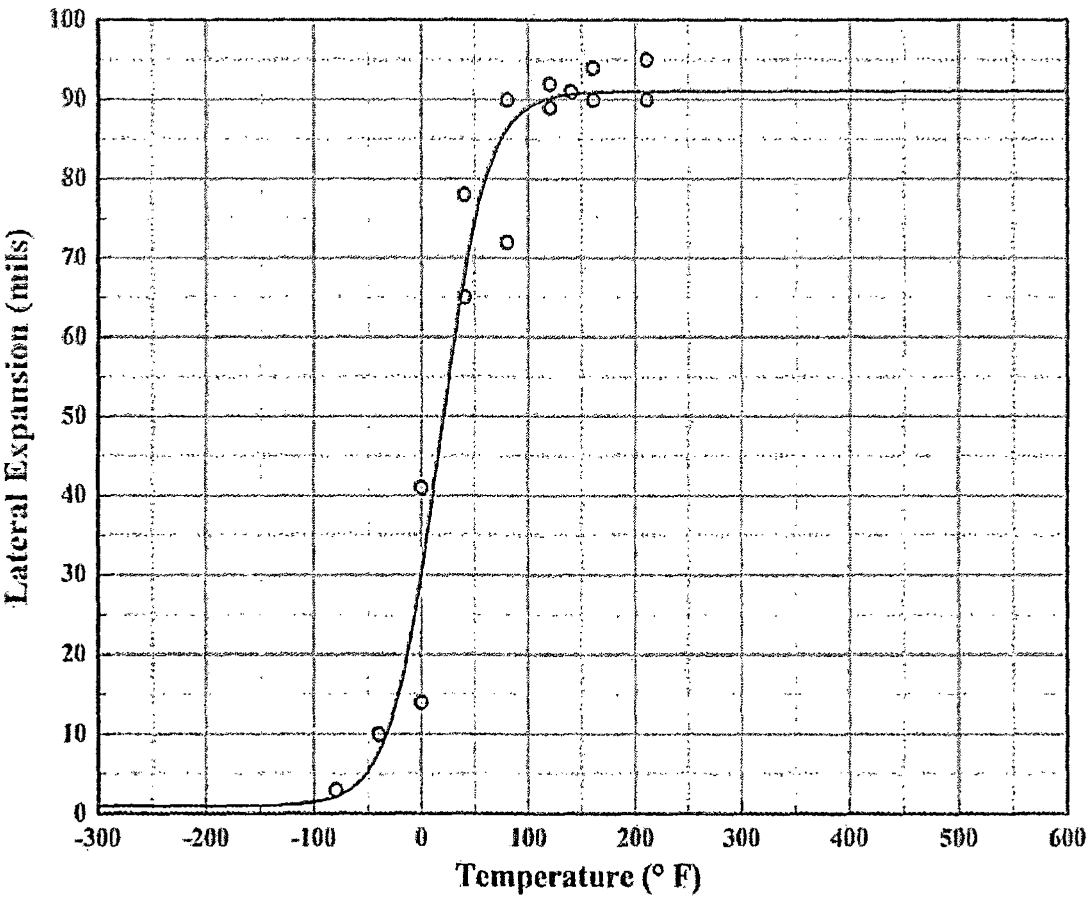
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 91.07 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 5.30° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: LT Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: LT | Capsule: Unirrad | Fluence:

Unirradiated Plate M-1004-2 (Longitudinal)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-80	3.0	2.2	0.82
-40	10.0	7.6	2.35
-40	10.0	7.6	2.35
0	14.0	30.2	-16.20
0	41.0	30.2	10.80
40	65.0	67.9	-2.91
40	78.0	67.9	10.09
80	72.0	86.2	-14.18
80	90.0	86.2	3.82
120	89.0	90.2	-1.22
120	92.0	90.2	1.78
140	91.0	90.7	0.28
160	94.0	90.9	3.07
160	90.0	90.9	-0.93
210	95.0	91.1	3.94
210	90.0	91.1	-1.06

CVGraph 6.0 | 01/29/2015 | Page 2/2

Unirradiated Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 11:29 AM

A = 50.00 B = 50.00 C = 63.00 T0 = 40.71 D = 0.00

Correlation Coefficient = 0.989

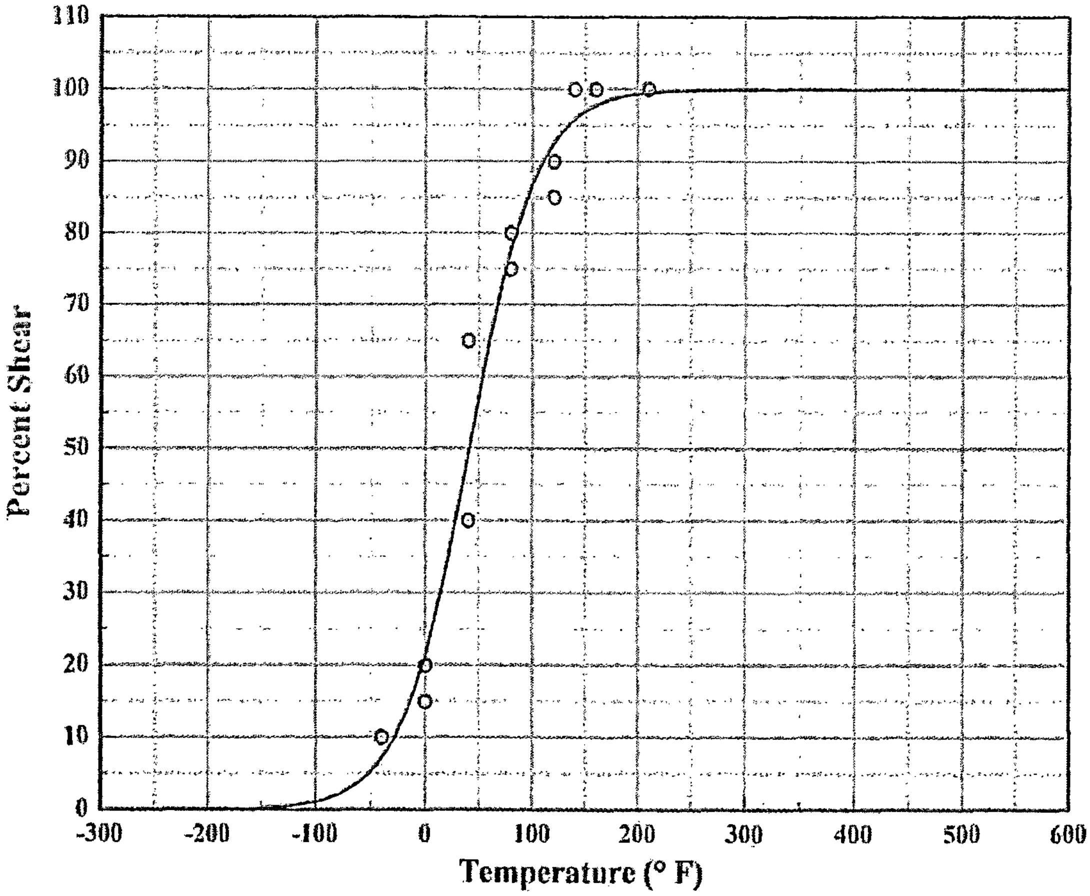
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = 40.80

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: LT Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: LT Capsule: Unirrad Fluence:

Unirradiated Plate M-1004-2 (Longitudinal)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-80	0.0	2.1	-2.12
-40	10.0	7.2	2.84
-40	10.0	7.2	2.84
0	15.0	21.5	-6.55
0	20.0	21.5	-1.55
40	40.0	49.4	-9.44
40	65.0	49.4	15.56
80	75.0	77.7	-2.68
80	80.0	77.7	2.32
120	85.0	92.5	-7.53
120	90.0	92.5	-2.53
140	100.0	95.9	4.10
160	100.0	97.8	2.22
160	100.0	97.8	2.22
210	100.0	99.5	0.46
210	100.0	99.5	0.46

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 12:59 PM

A = 71.60 B = 69.40 C = 73.71 T0 = 26.48 D = 0.00

Correlation Coefficient = 0.986

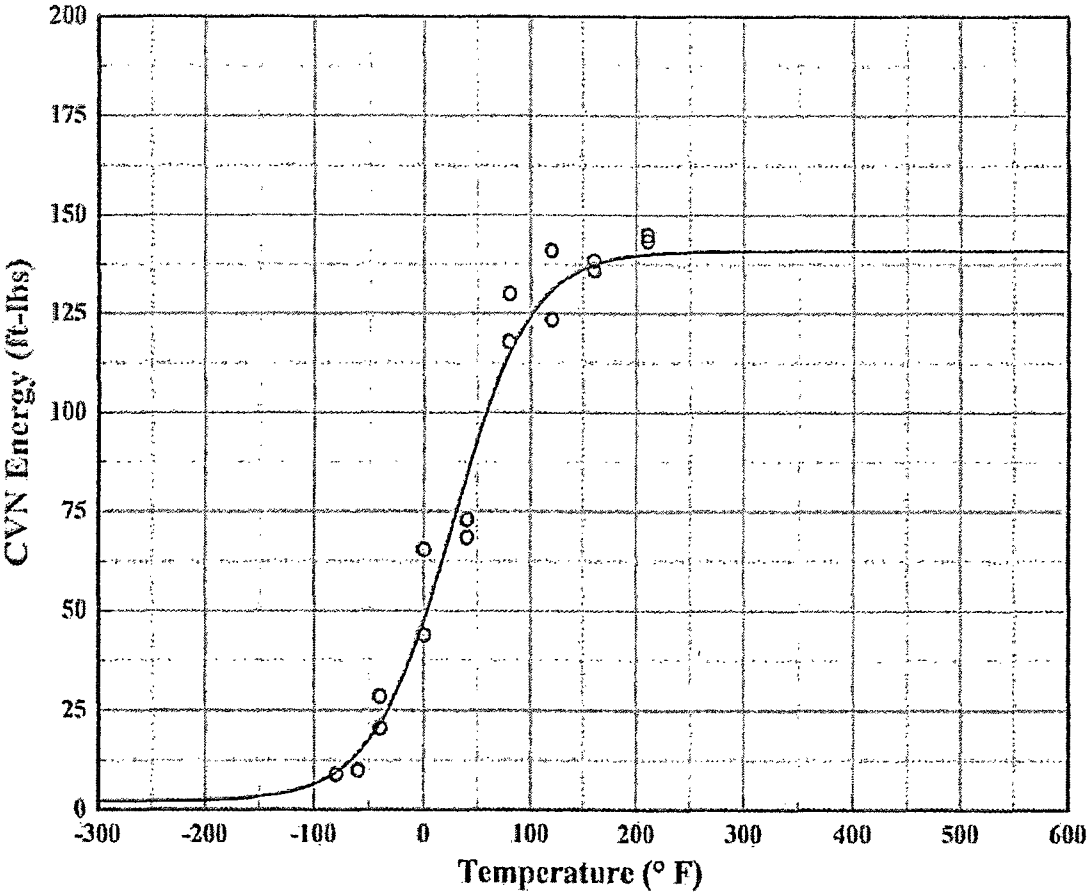
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 141.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-24.50° F Temp@35 ft-lbs=-16.70° F Temp@50 ft-lbs= 2.80° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: TL Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: TL Capsule: Unirrad Fluence:

Unirradiated Plate M-1004-2 (Transverse)

Charpy V-Notch Data

Temperature (°F)	Input CVN	Computed CVN	Differential
-80	9.0	9.5	-0.51
-60	10.0	14.3	-4.32
-40	20.5	21.8	-1.32
-40	28.5	21.8	6.68
0	44.0	47.7	-3.69
0	65.5	47.7	17.81
40	68.5	84.2	-15.69
40	73.0	84.2	-11.19
80	118.0	114.7	3.32
80	130.0	114.7	15.32
120	123.5	130.8	-7.33
120	141.0	130.8	10.17
160	136.0	137.4	-1.39
160	138.5	137.4	1.11
210	143.5	140.1	3.45
210	145.0	140.1	4.95

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 1:01 PM

A = 45.86 B = 44.86 C = 77.44 T0 = 12.38 D = 0.00

Correlation Coefficient = 0.989

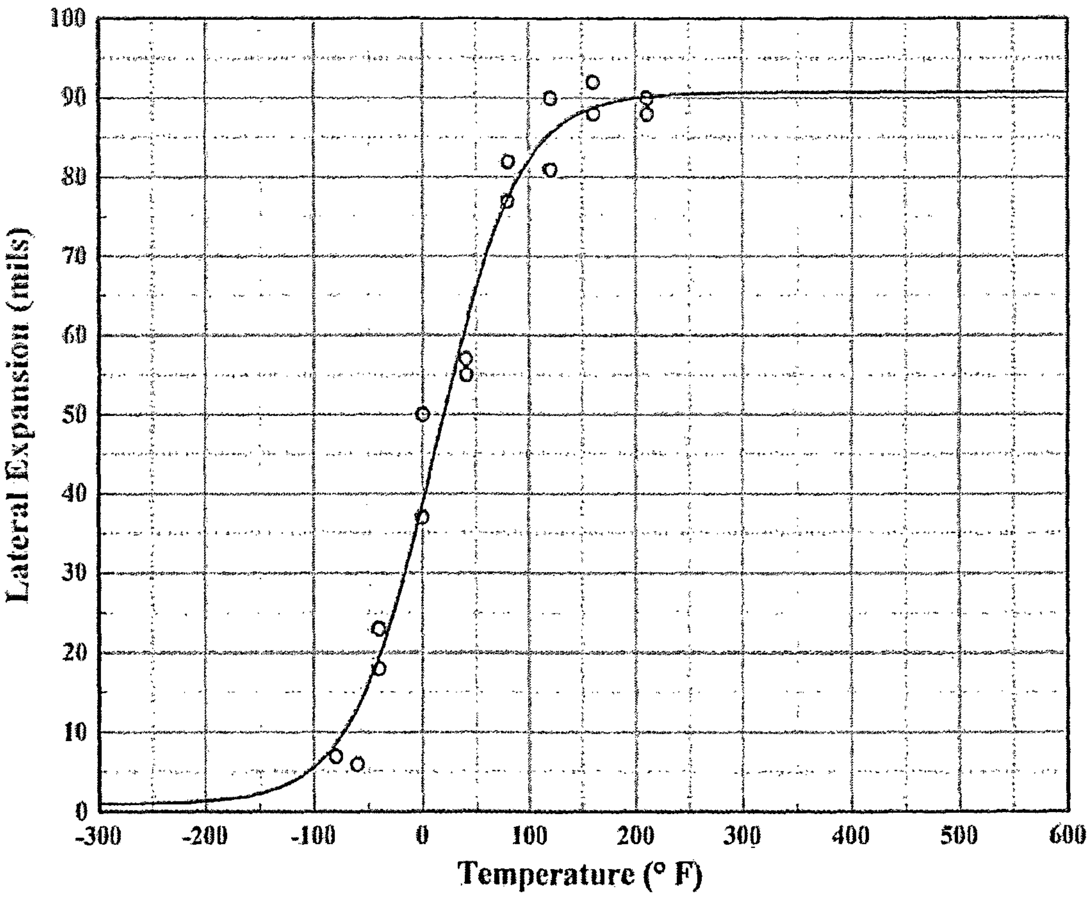
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 90.72   Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= -6.70° F

Plant: Waterford 3   Material: SA533B1   Heat: NR 57 286-1

Orientation: TL   Capsule: Unirrad   Fluence:



CVGraph 6.0   01/29/2015   Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: TL Capsule: Unirrad Fluence:

Unirradiated Plate M-1004-2 (Transverse)

Charpy V-Notch Data

Temperature (°F)	Input L. E.	Computed L. E.	Differential
-80	7.0	8.6	-1.56
-60	6.0	13.0	-6.99
-40	18.0	19.4	-1.43
-40	23.0	19.4	3.57
0	37.0	38.8	-1.75
0	50.0	38.8	11.25
40	55.0	61.2	-6.22
40	57.0	61.2	-4.22
80	82.0	77.4	4.60
80	77.0	77.4	-0.40
120	81.0	85.5	-4.48
120	90.0	85.5	4.52
160	88.0	88.8	-0.78
160	92.0	88.8	3.22
210	88.0	90.2	-2.18
210	90.0	90.2	-0.18

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 1:03 PM

A = 50.00 B = 50.00 C = 64.14 T0 = 40.33 D = 0.00

Correlation Coefficient = 0.993

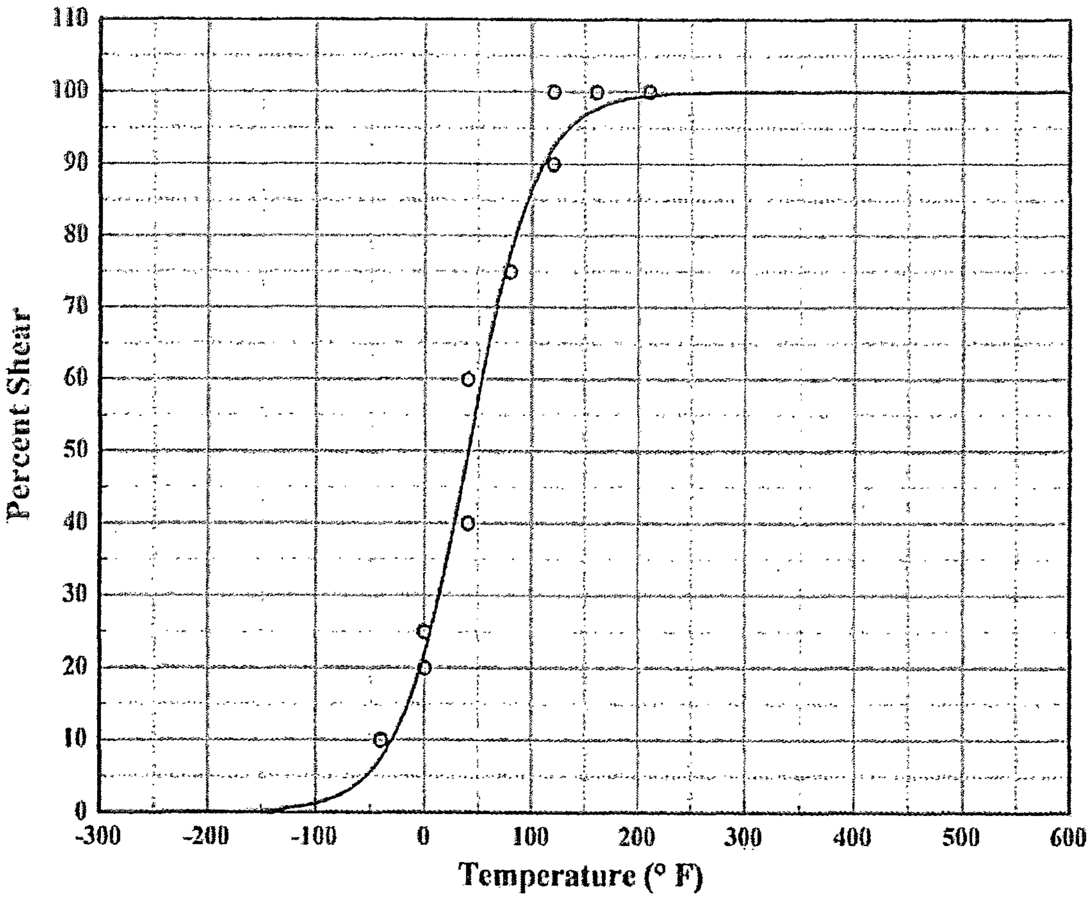
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed)   Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = 40.40

Plant: Waterford 3   Material: SA533B1   Heat: NR 57 286-1

Orientation: TL   Capsule: Unirrad   Fluence:



CVGraph 6.0   01/29/2015   Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: TL Capsule: Unirrad Fluence:

Unirradiated Plate M-1004-2 (Transverse)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-80	0.0	2.3	-2.29
-60	0.0	4.2	-4.19
-40	10.0	7.5	2.45
-40	10.0	7.5	2.45
0	20.0	22.1	-2.14
0	25.0	22.1	2.86
40	40.0	49.7	-9.74
40	60.0	49.7	10.26
80	75.0	77.5	-2.50
80	75.0	77.5	-2.50
120	90.0	92.3	-2.30
120	100.0	92.3	7.70
160	100.0	97.7	2.34
160	100.0	97.7	2.34
210	100.0	99.5	0.50
210	100.0	99.5	0.50

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 1:10 PM

A = 79.10 B = 76.90 C = 54.24 T0 = -43.47 D = 0.00

Correlation Coefficient = 0.990

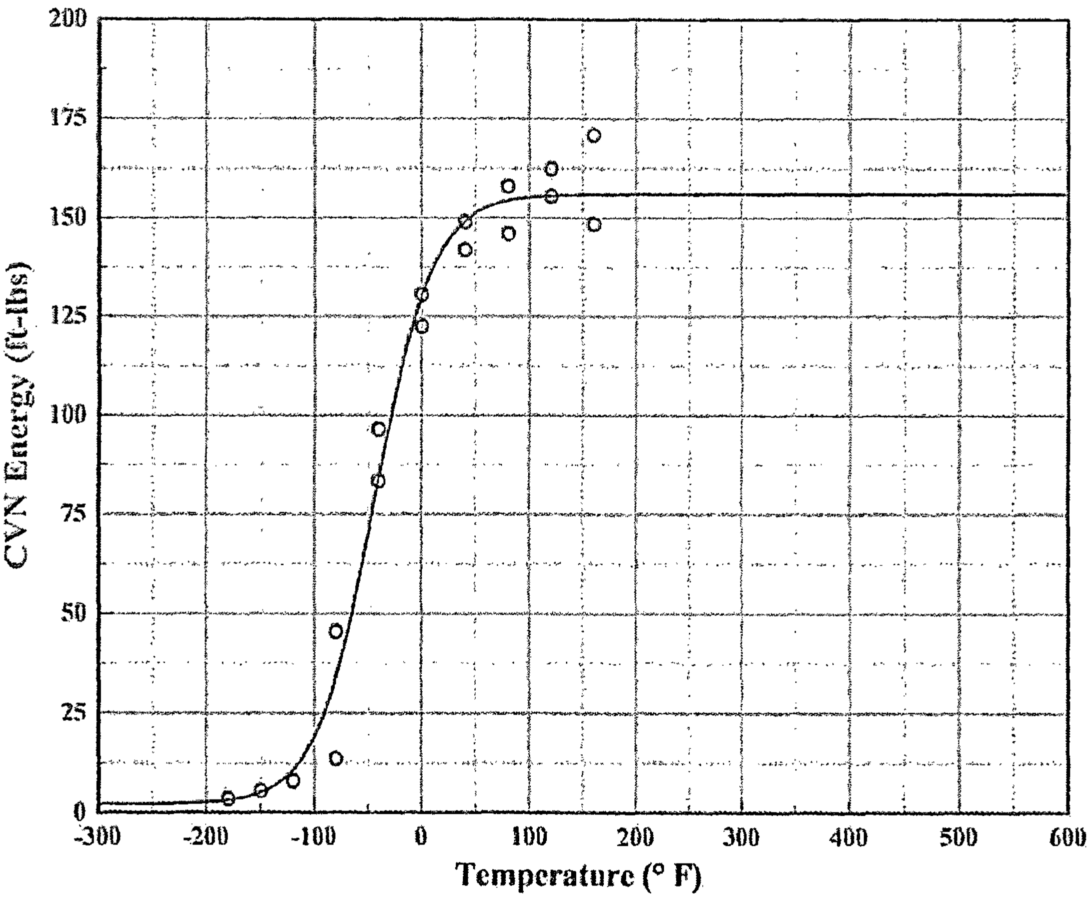
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 156.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-84.40° F Temp@35 ft-lbs=-78.80° F Temp@50 ft-lbs=-65.00° F

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 | Material: SAW | Heat: 88114
Orientation: NA | Capsule: Unirrad | Fluence:

Unirradiated Weld

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-180	3.5	3.2	0.31
-150	5.5	5.2	0.33
-120	8.0	10.8	-2.84
-80	13.5	33.9	-20.44
-80	45.5	33.9	11.56
-40	83.5	84.0	-0.52
-40	96.5	84.0	12.48
0	122.5	130.2	-7.73
0	130.5	130.2	0.27
40	142.0	149.2	-7.23
40	149.0	149.2	-0.23
80	146.0	154.4	-8.40
80	158.0	154.4	3.60
120	155.5	155.6	-0.13
120	162.5	155.6	6.87
160	148.5	155.9	-7.42
160	171.0	155.9	15.08

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 1:13 PM

A = 48.27 B = 47.27 C = 43.82 T0 = -55.65 D = 0.00

Correlation Coefficient = 0.990

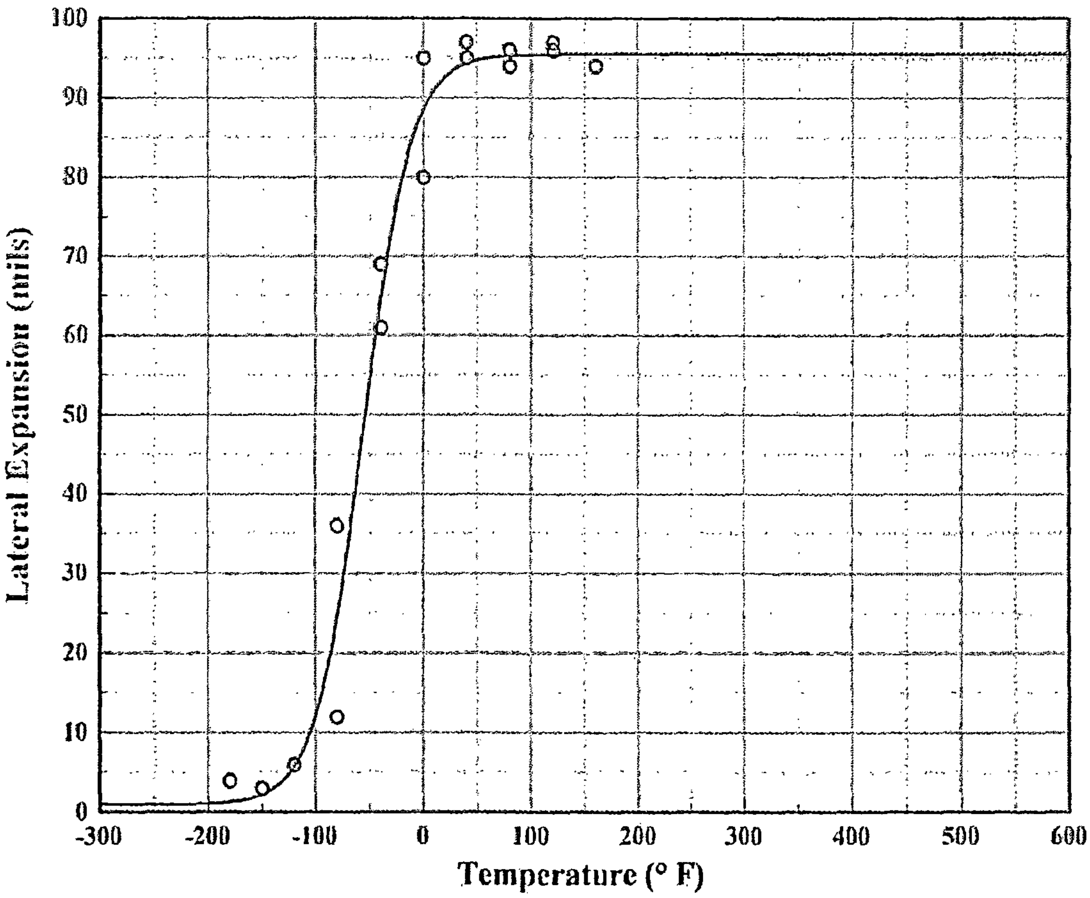
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 95.53 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-68.20° F

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 | Material: SAW | Heat: 88114
Orientation: NA | Capsule: Unirrad | Fluence:

Unirradiated Weld

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-180	4.0	1.3	2.68
-150	3.0	2.3	0.74
-120	6.0	5.8	0.24
-80	12.0	24.4	-12.41
-80	36.0	24.4	11.59
-40	61.0	64.5	-3.47
-40	69.0	64.5	4.53
0	80.0	88.6	-8.62
0	95.0	88.6	6.38
40	95.0	94.3	0.65
40	97.0	94.3	2.65
80	94.0	95.3	-1.34
80	96.0	95.3	0.66
120	96.0	95.5	0.50
120	97.0	95.5	1.50
160	94.0	95.5	-1.53
160	94.0	95.5	-1.53

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 1:15 PM

A = 50.00 B = 50.00 C = 57.79 T0 = -51.03 D = 0.00

Correlation Coefficient = 0.990

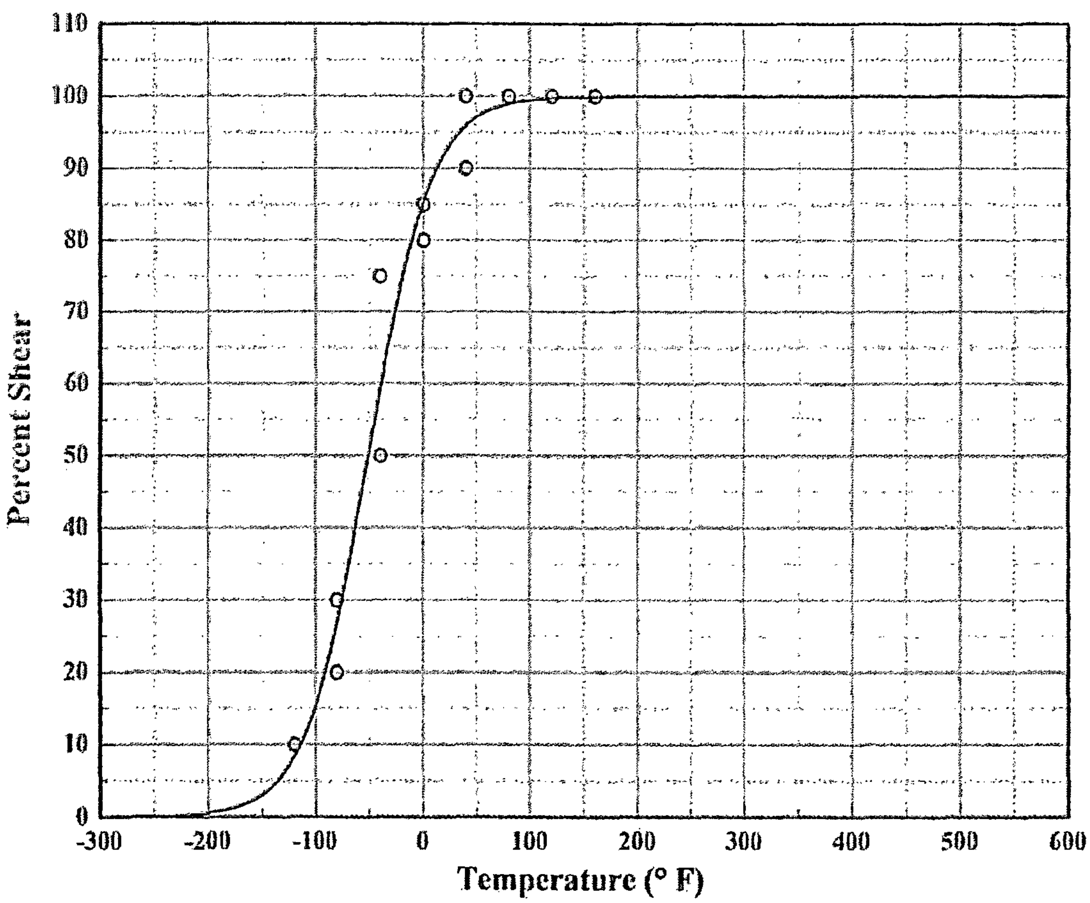
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed)   Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = -51.00

Plant: Waterford 3   Material: SAW   Heat: 88114

Orientation: NA   Capsule: Unirrad   Fluence:



CVGraph 6.0   01/29/2015   Page 1/2

Plant: Waterford 3 | Material: SAW | Heat: 88114
Orientation: NA | Capsule: Unirrad | Fluence:

Unirradiated Weld

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-180	0.0	1.1	-1.14
-150	0.0	3.2	-3.15
-120	10.0	8.4	1.58
-80	20.0	26.8	-6.84
-80	30.0	26.8	3.16
-40	50.0	59.4	-9.43
-40	75.0	59.4	15.57
0	80.0	85.4	-5.40
0	85.0	85.4	-0.40
40	90.0	95.9	-5.89
40	100.0	95.9	4.11
80	100.0	98.9	1.06
80	100.0	98.9	1.06
120	100.0	99.7	0.27
120	100.0	99.7	0.27
160	100.0	99.9	0.07
160	100.0	99.9	0.07

CVGraph 6.0 | 01/29/2015 | Page 2/2

Unirradiated Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 3:08 PM

A = 86.10 B = 83.90 C = 77.38 T0 = -54.53 D = 0.00

Correlation Coefficient = 0.973

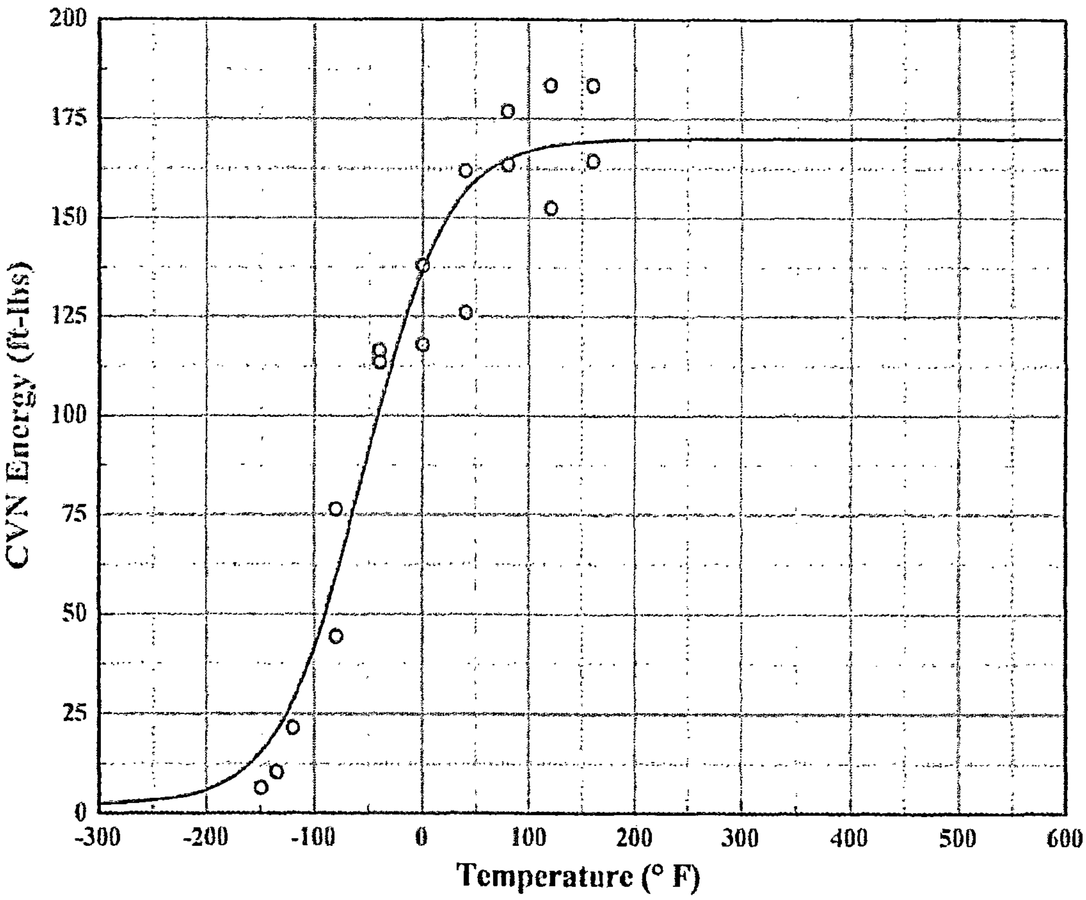
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 170.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-117.00° F Temp@35 ft-lbs=-109.20° F Temp@50 ft-lbs=-90.10° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: NA Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: NA Capsule: Unirrad Fluence:

Unirradiated Heat Affected Zone

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-150	6.5	15.3	-8.81
-135	10.5	20.8	-10.34
-120	21.5	28.3	-6.79
-80	44.5	59.4	-14.94
-80	76.5	59.4	17.06
-40	113.5	101.7	11.83
-40	116.5	101.7	14.83
0	118.0	137.1	-19.05
0	138.0	137.1	0.95
40	126.0	156.6	-30.59
40	162.0	156.6	5.41
80	163.5	165.0	-1.47
80	177.0	165.0	12.03
120	152.5	168.2	-15.68
120	183.5	168.2	15.32
160	164.5	169.3	-4.85
160	183.5	169.3	14.15

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 3:10 PM

A = 44.46 B = 43.46 C = 80.35 T0 = -78.61 D = 0.00

Correlation Coefficient = 0.990

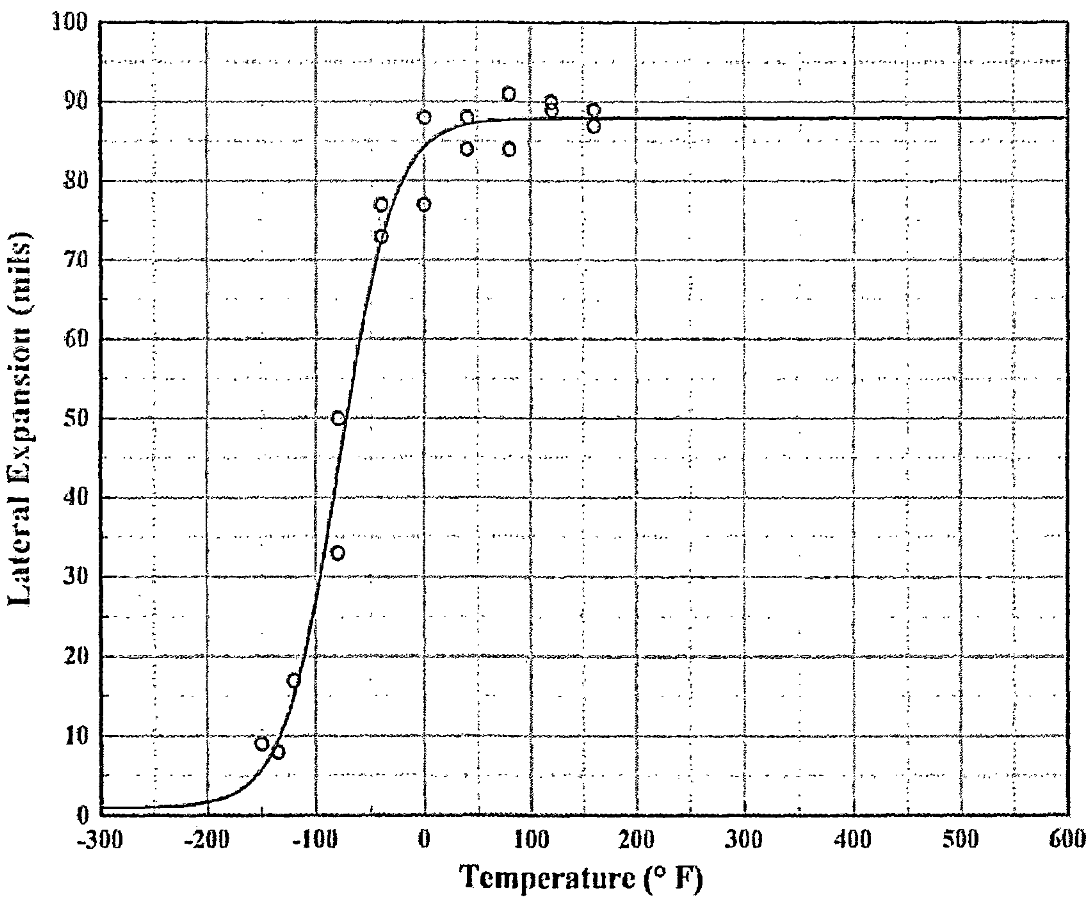
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 87.92 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-89.70° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 87 286-1

Orientation: NA Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: NA | Capsule: Unirrad | Fluence:

Unirradiated Heat Affected Zone

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-150	9.0	5.8	3.18
-135	8.0	9.4	-1.36
-120	17.0	15.1	1.93
-80	33.0	43.3	-10.26
-80	50.0	43.3	6.74
-40	73.0	72.5	0.51
-40	77.0	72.5	4.51
0	77.0	84.3	-7.25
0	88.0	84.3	3.75
40	84.0	87.1	-3.15
40	88.0	87.1	0.85
80	91.0	87.8	3.24
80	84.0	87.8	-3.76
120	90.0	87.9	2.11
120	89.0	87.9	1.11
160	87.0	87.9	-0.92
160	89.0	87.9	1.08

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 3:11 PM

A = 50.00 B = 50.00 C = 71.89 T0 = -55.47 D = 0.00

Correlation Coefficient = 0.982

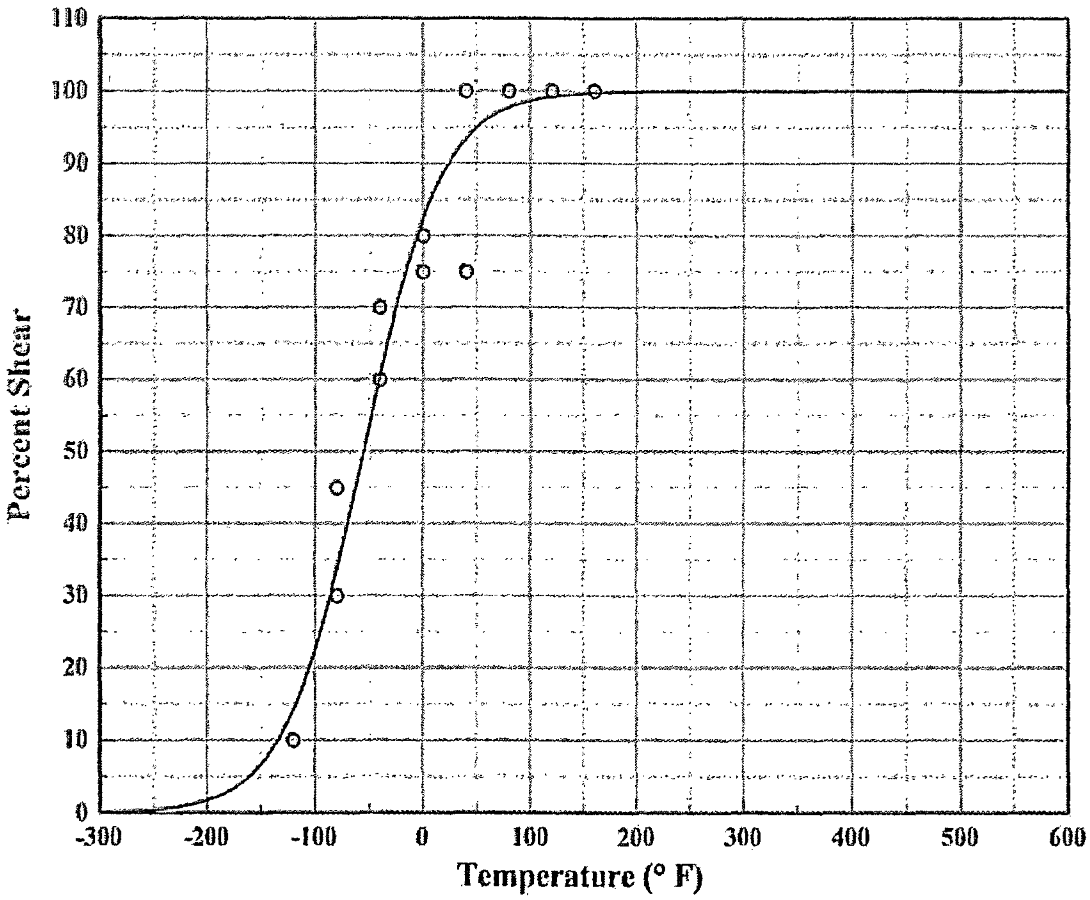
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = -55.40

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: NA Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: NA | Capsule: Unirrad | Fluence:

Unirradiated Heat Affected Zone

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-150	0.0	6.7	-6.72
-135	0.0	9.9	-9.86
-120	10.0	14.2	-4.24
-80	30.0	33.6	-3.57
-80	45.0	33.6	11.43
-40	70.0	60.6	9.40
-40	60.0	60.6	-0.60
0	75.0	82.4	-7.40
0	80.0	82.4	-2.40
40	75.0	93.4	-18.44
40	100.0	93.4	6.56
80	100.0	97.7	2.26
80	100.0	97.7	2.26
120	100.0	99.2	0.75
120	100.0	99.2	0.75
160	100.0	99.8	0.25
160	100.0	99.8	0.25

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Standard Reference Material

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 3:57 PM

A = 67.60 B = 65.40 C = 67.73 T0 = 78.76 D = 0.00

Correlation Coefficient = 0.990

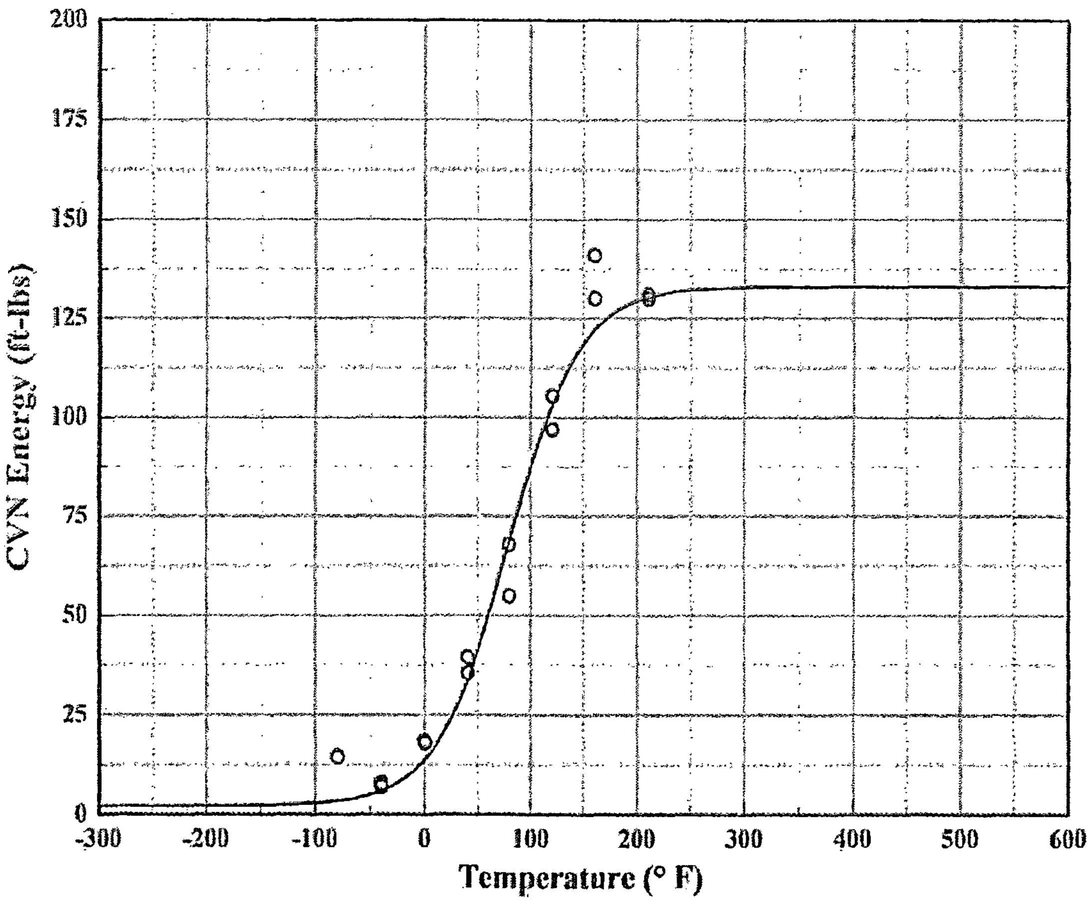
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 133.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= 34.50° F Temp@35 ft-lbs= 41.70° F Temp@50 ft-lbs= 60.10° F

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY

Orientation: LT Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: Unirrad Fluence:

Unirradiated Standard Reference Material

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-80	14.5	3.4	11.11
-40	7.0	6.0	0.99
-40	8.0	6.0	1.99
0	18.0	13.8	4.16
0	18.5	13.8	4.66
40	35.5	33.8	1.71
40	39.5	33.8	5.71
80	55.0	68.8	-13.80
80	68.0	68.8	-0.80
120	105.5	103.1	2.37
120	97.0	103.1	-6.13
160	130.0	122.1	7.89
160	141.0	122.1	18.89
210	130.0	130.3	-0.34
210	131.0	130.3	0.66

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Standard Reference Material

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 3:59 PM

A = 48.14 B = 47.14 C = 91.64 T0 = 68.53 D = 0.00

Correlation Coefficient = 0.992

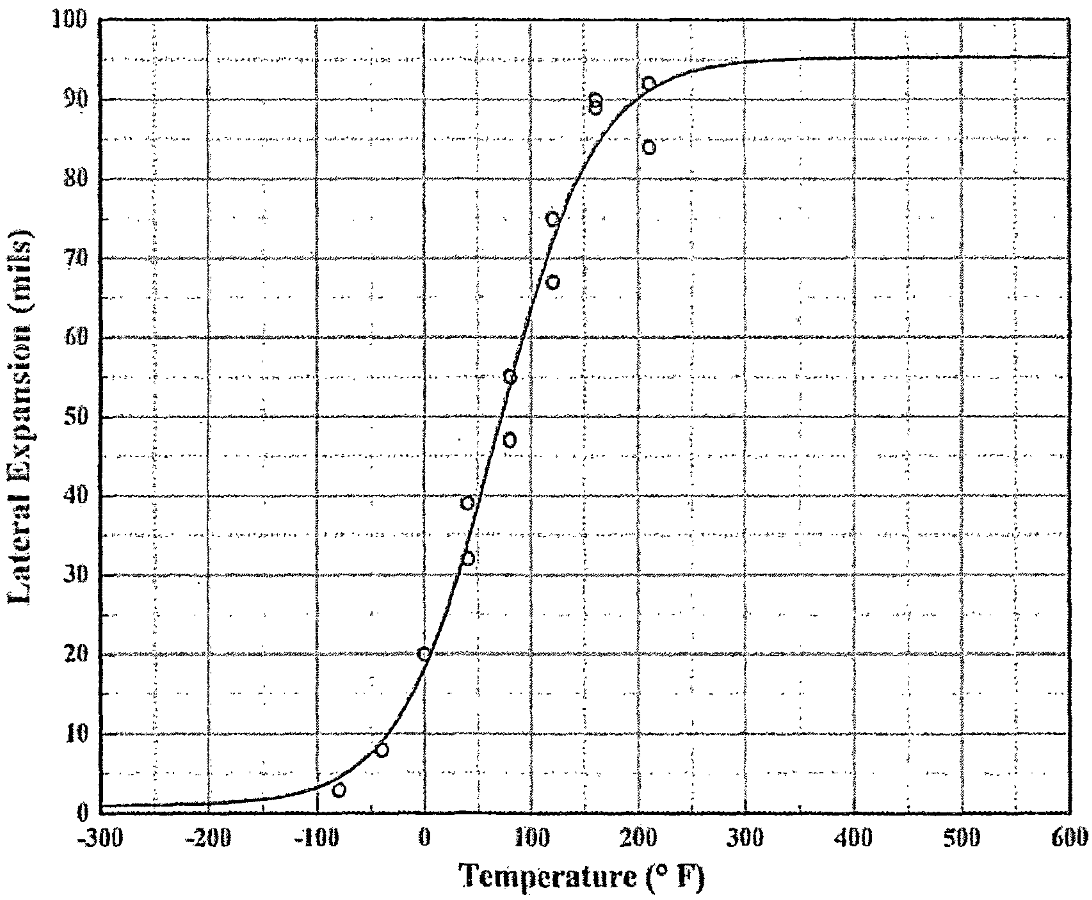
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 95.28 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 42.30° F

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY

Orientation: LT Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: Unirrad Fluence:

Unirradiated Standard Reference Material

Charpy V-Notch Data

Temperature (°F)	Input L. E.	Computed L. E.	Differential
-80	3.0	4.5	-1.55
-40	8.0	9.1	-1.07
-40	8.0	9.1	-1.07
0	20.0	18.3	1.74
0	20.0	18.3	1.74
40	32.0	33.9	-1.92
40	39.0	33.9	5.08
80	47.0	54.0	-7.01
80	55.0	54.0	0.99
120	75.0	72.1	2.85
120	67.0	72.1	-5.15
160	90.0	84.0	5.99
160	89.0	84.0	4.99
210	92.0	91.2	0.83
210	84.0	91.2	-7.17

CVGraph 6.0 01/29/2015 Page 2/2

Unirradiated Standard Reference Material

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 1/29/2015 4:01 PM

A = 50.00 B = 50.00 C = 69.75 T0 = 86.57 D = 0.00

Correlation Coefficient = 0.987

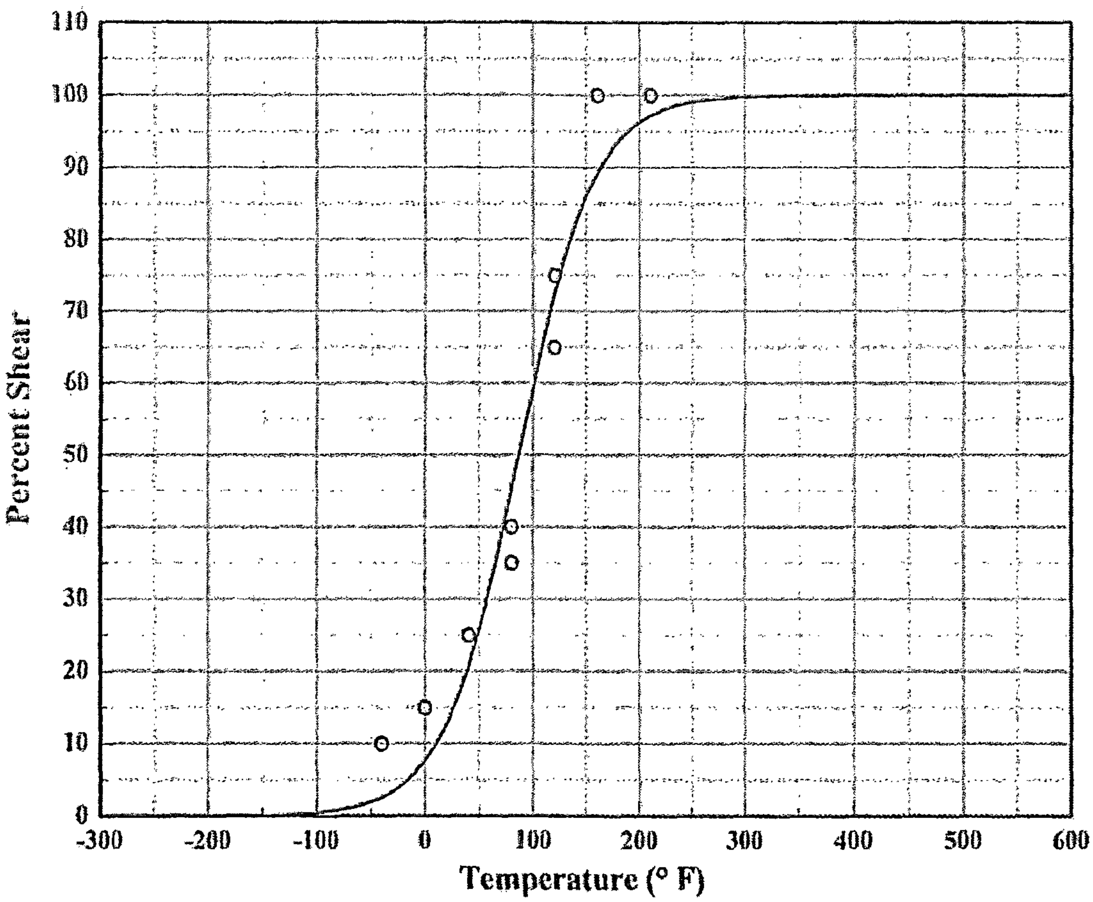
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = 86.60

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY

Orientation: LT Capsule: Unirrad Fluence:



CVGraph 6.0 01/29/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: Unirrad Fluence:

Unirradiated Standard Reference Material

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-80	0.0	0.8	-0.84
-40	0.0	2.6	-2.58
-40	10.0	2.6	7.42
0	15.0	7.7	7.29
0	15.0	7.7	7.29
40	25.0	20.8	4.17
40	25.0	20.8	4.17
80	35.0	45.3	-10.30
80	40.0	45.3	-5.30
120	75.0	72.3	2.71
120	65.0	72.3	-7.29
160	100.0	89.1	10.85
160	100.0	89.1	10.85
210	100.0	97.2	2.82
210	100.0	97.2	2.82

CVGraph 6.0 01/29/2015 Page 2/2

Capsule 97° Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 8:10 AM

A = 78.60 B = 76.40 C = 76.98 T0 = 50.42 D = 0.00

Correlation Coefficient = 0.976

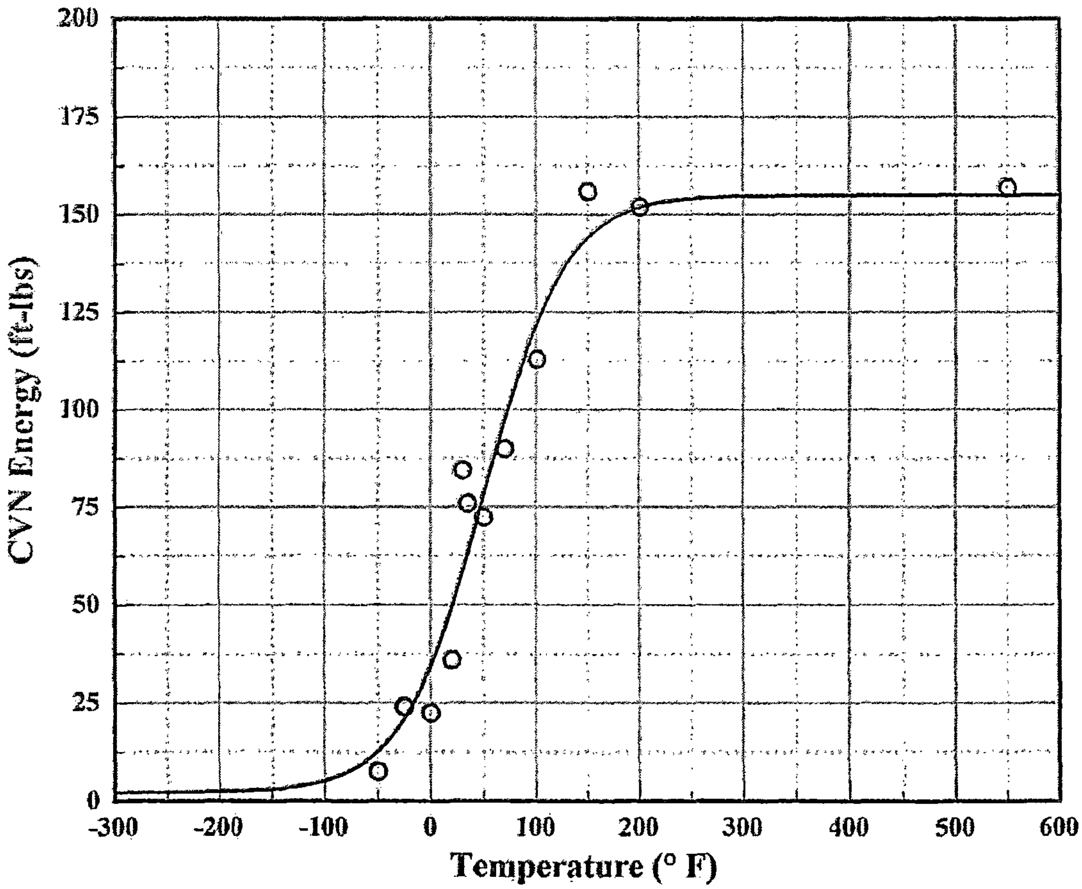
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 155.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= -7.40° F Temp@35 ft-lbs= 0.50° F Temp@50 ft-lbs= 20.20° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: LT Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: LT Capsule: 97° Fluence:

Capsule 97° Plate M-1004-2 (Longitudinal)
Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-50	7.5	12.7	-5.17
-25	24.0	21.1	2.93
0	22.5	34.7	-12.17
20	36.0	49.9	-13.89
30	84.5	58.8	25.70
35	76.0	63.5	12.50
50	72.5	78.2	-5.68
70	90.0	97.6	-7.63
100	113.0	122.0	-8.97
150	156.0	144.3	11.69
200	152.0	151.9	0.07
550	157.0	155.0	2.00

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 8:24 AM

A = 44.78 B = 43.78 C = 65.98 T0 = 25.41 D = 0.00

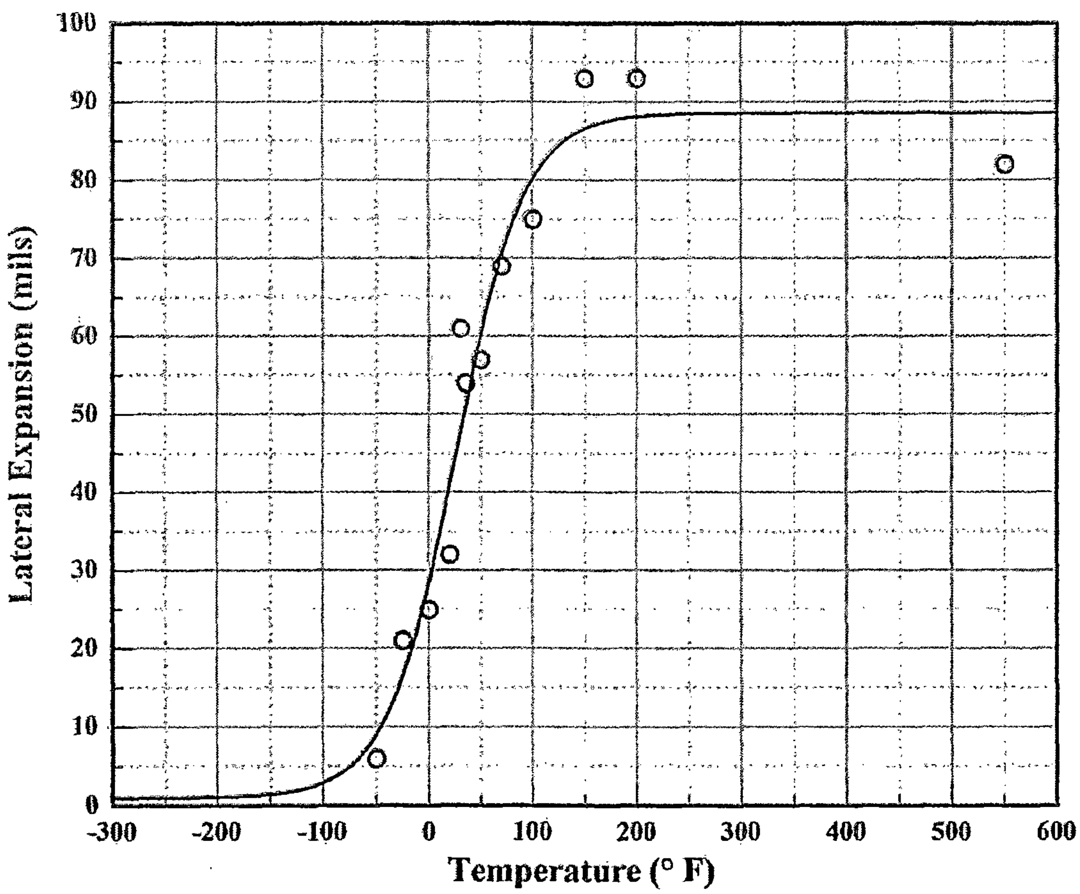
Correlation Coefficient = 0.975

Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 88.56   Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 10.50° F

Plant: Waterford 3	Material: SA533B1	Heat: NR 57 286-1
Orientation: LT	Capsule: 97°	Fluence:



CVGraph 6.0   02/09/2015   Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: LT Capsule: 97° Fluence:

Capsule 97° Plate M-1004-2 (Longitudinal)
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-50	6.0	9.1	-3.08
-25	21.0	16.6	4.39
0	25.0	28.7	-3.71
20	32.0	41.2	-9.20
30	61.0	47.8	13.17
35	54.0	51.1	2.90
50	57.0	60.4	-3.39
70	69.0	70.6	-1.56
100	75.0	80.3	-5.30
150	93.0	86.6	6.40
200	93.0	88.1	4.87
550	82.0	88.6	-6.56

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 8:27 AM

A = 50.00 B = 50.00 C = 51.80 T0 = 52.15 D = 0.00

Correlation Coefficient = 0.976

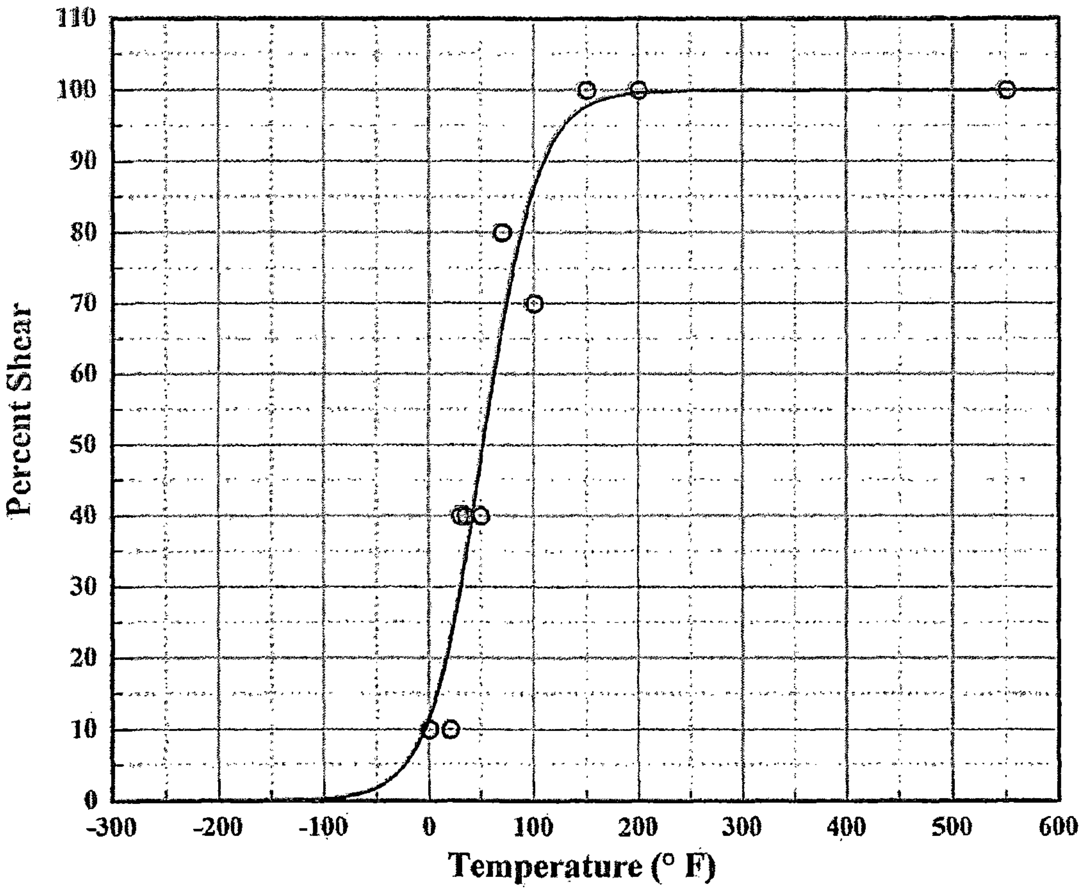
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = 52.20

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: LT Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: LT | Capsule: 97° | Fluence:

Capsule 97° Plate M-1004-2 (Longitudinal)
Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-50	0.0	1.9	-1.90
-25	0.0	4.8	-4.84
0	10.0	11.8	-1.78
20	10.0	22.4	-12.42
30	40.0	29.8	10.17
35	40.0	34.0	5.98
50	40.0	47.9	-7.92
70	80.0	66.6	13.42
100	70.0	86.4	-16.38
150	100.0	97.8	2.24
200	100.0	99.7	0.33
550	100.0	100.0	0.00

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 8:30 AM

A = 63.10 B = 60.90 C = 75.84 T0 = 49.60 D = 0.00

Correlation Coefficient = 0.984

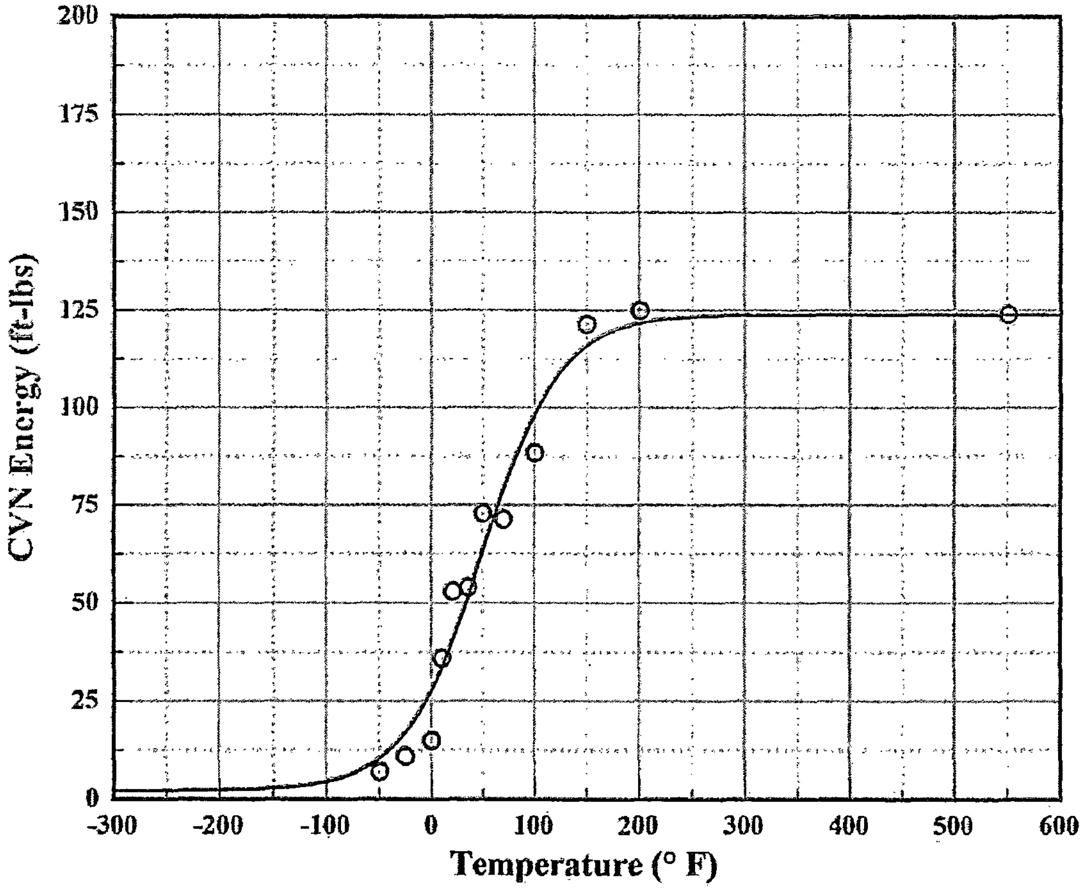
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 124.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= 3.50° F Temp@35 ft-lbs= 11.80° F Temp@50 ft-lbs= 33.10° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: TL Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: TL | Capsule: 97° | Fluence:

Capsule 97° Plate M-1004-2 (Transverse)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-50	7.0	10.4	-3.42
-25	11.0	17.1	-6.14
0	15.0	28.1	-13.12
10	36.0	33.9	2.09
20	53.0	40.5	12.53
35	54.0	51.5	2.48
50	73.0	63.4	9.58
70	71.5	79.1	-7.60
100	88.5	98.5	-10.00
150	121.5	115.9	5.56
200	125.0	121.7	3.27
550	124.0	124.0	0.00

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 8:32 AM

A = 42.23 B = 41.23 C = 66.00 T0 = 30.72 D = 0.00

Correlation Coefficient = 0.986

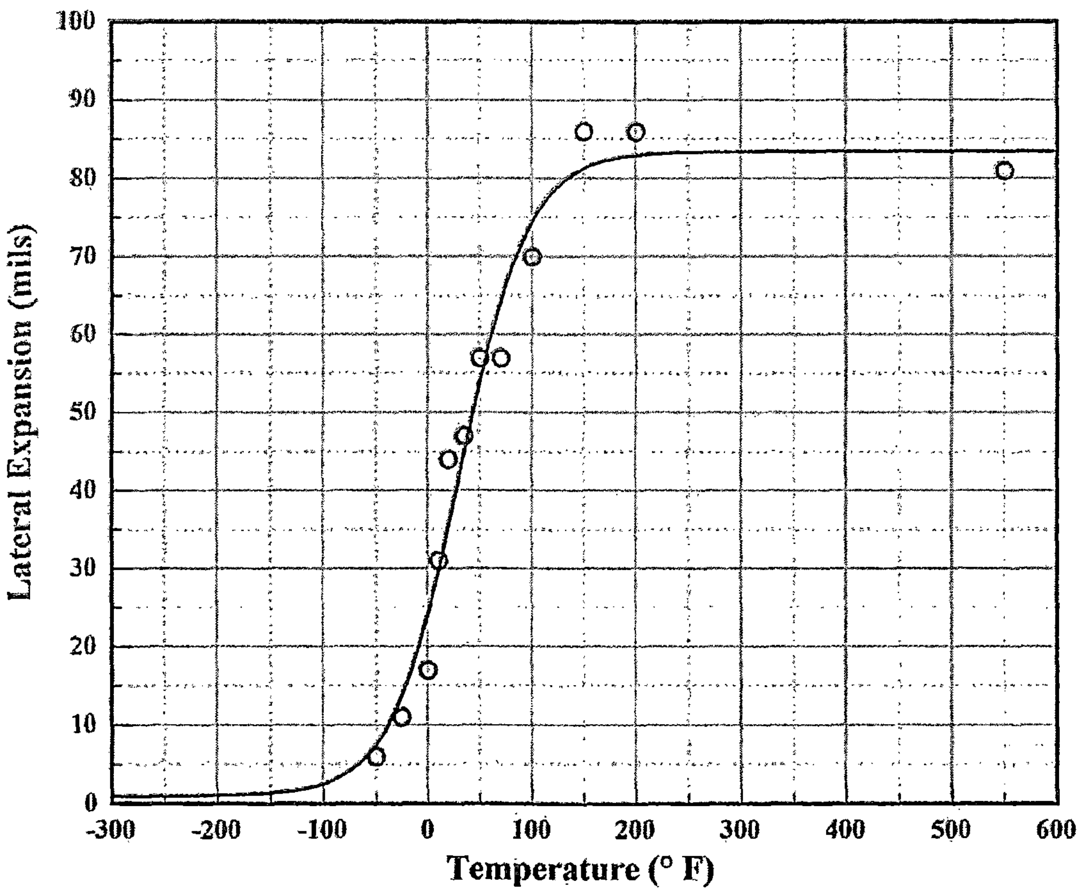
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 83.47 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 19.10° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: TL Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: TL | Capsule: 97° | Fluence:

Capsule 97° Plate M-1004-2 (Transverse)
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-50	6.0	7.6	-1.57
-25	11.0	13.9	-2.86
0	17.0	24.3	-7.32
10	31.0	29.7	1.30
20	44.0	35.6	8.41
35	47.0	44.9	2.10
50	57.0	53.9	3.05
70	57.0	64.2	-7.23
100	70.0	74.5	-4.46
150	86.0	81.3	4.70
200	86.0	83.0	3.02
550	81.0	83.5	-2.47

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 8:34 AM

A = 50.00 B = 50.00 C = 33.27 T0 = 43.86 D = 0.00

Correlation Coefficient = 0.972

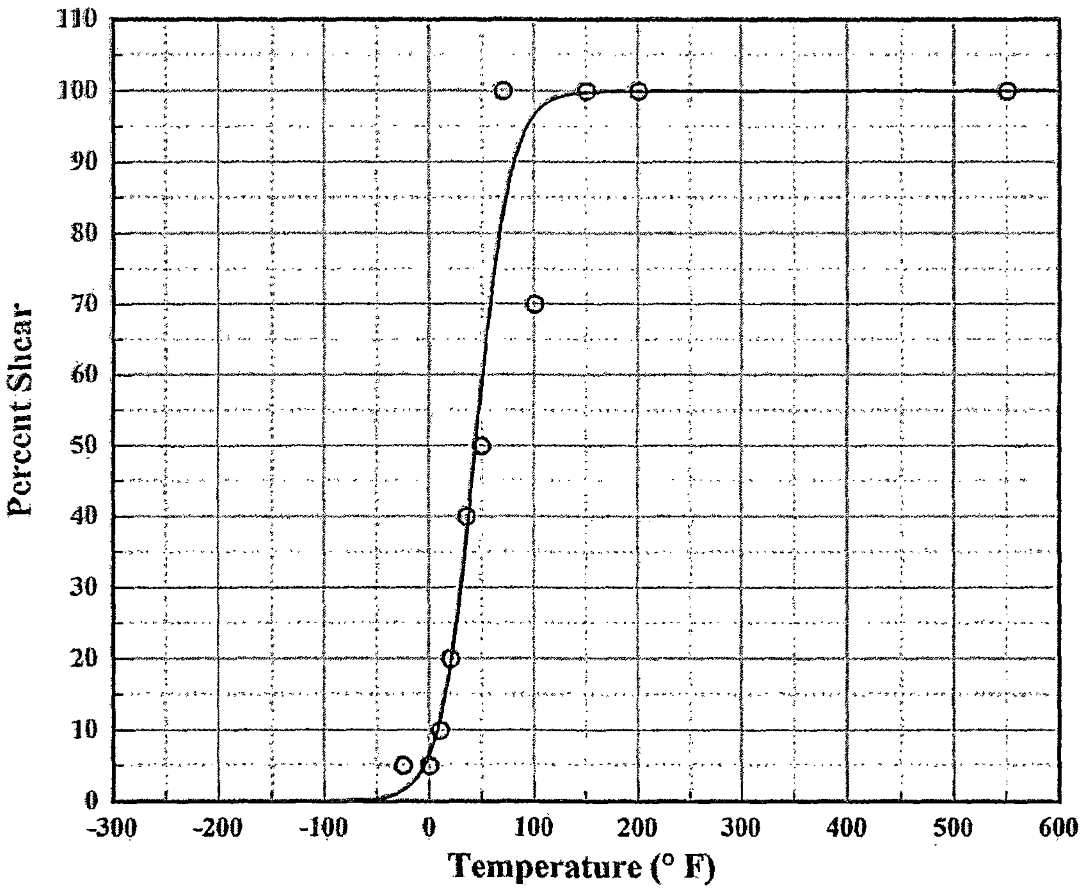
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = 43.90

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: TL Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: TL Capsule: 97° Fluence:

Capsule 97° Plate M-1004-2 (Transverse)
Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-50	0.0	0.4	-0.35
-25	5.0	1.6	3.43
0	5.0	6.7	-1.68
10	10.0	11.6	-1.55
20	20.0	19.2	0.76
35	40.0	37.0	3.01
50	50.0	59.1	-9.12
70	100.0	82.8	17.20
100	70.0	96.7	-26.69
150	100.0	99.8	0.17
200	100.0	100.0	0.01
550	100.0	100.0	0.00

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:02 AM

A = 78.10 B = 75.90 C = 69.61 T0 = -8.86 D = 0.00

Correlation Coefficient = 0.951

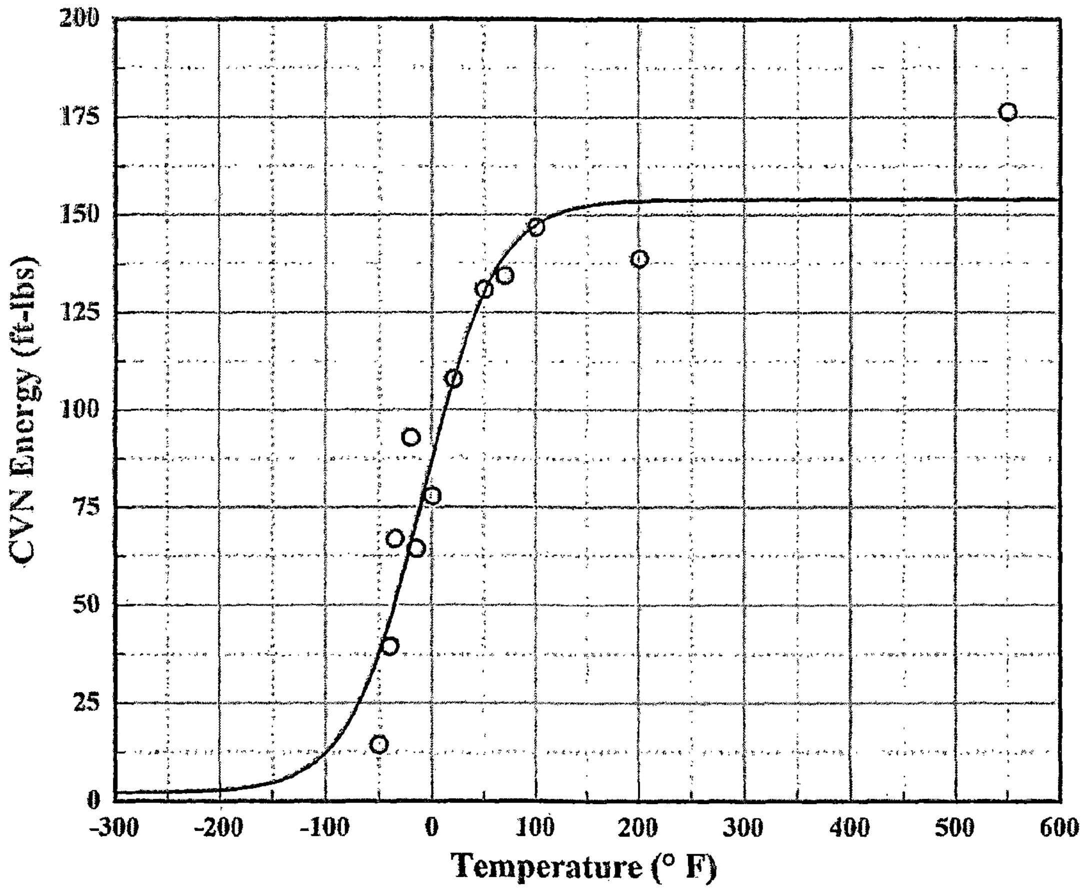
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 154.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-60.90° F Temp@35 ft-lbs=-53.70° F Temp@50 ft-lbs=-35.90° F

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 | Material: SAW | Heat: 88114
Orientation: NA | Capsule: 97° | Fluence:

Capsule 97° Weld

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-50	14.5	37.8	-23.32
-40	39.5	46.2	-6.74
-35	67.0	50.9	16.14
-20	93.0	66.1	26.95
-15	64.5	71.4	-6.92
0	78.0	87.7	-9.71
20	108.0	107.9	0.12
50	131.0	130.4	0.62
70	134.5	139.7	-5.23
100	147.0	147.6	-0.63
200	139.0	153.6	-14.63
550	176.5	154.0	22.50

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:05 AM

A = 44.73 B = 43.73 C = 46.01 T0 = -29.43 D = 0.00

Correlation Coefficient = 0.945

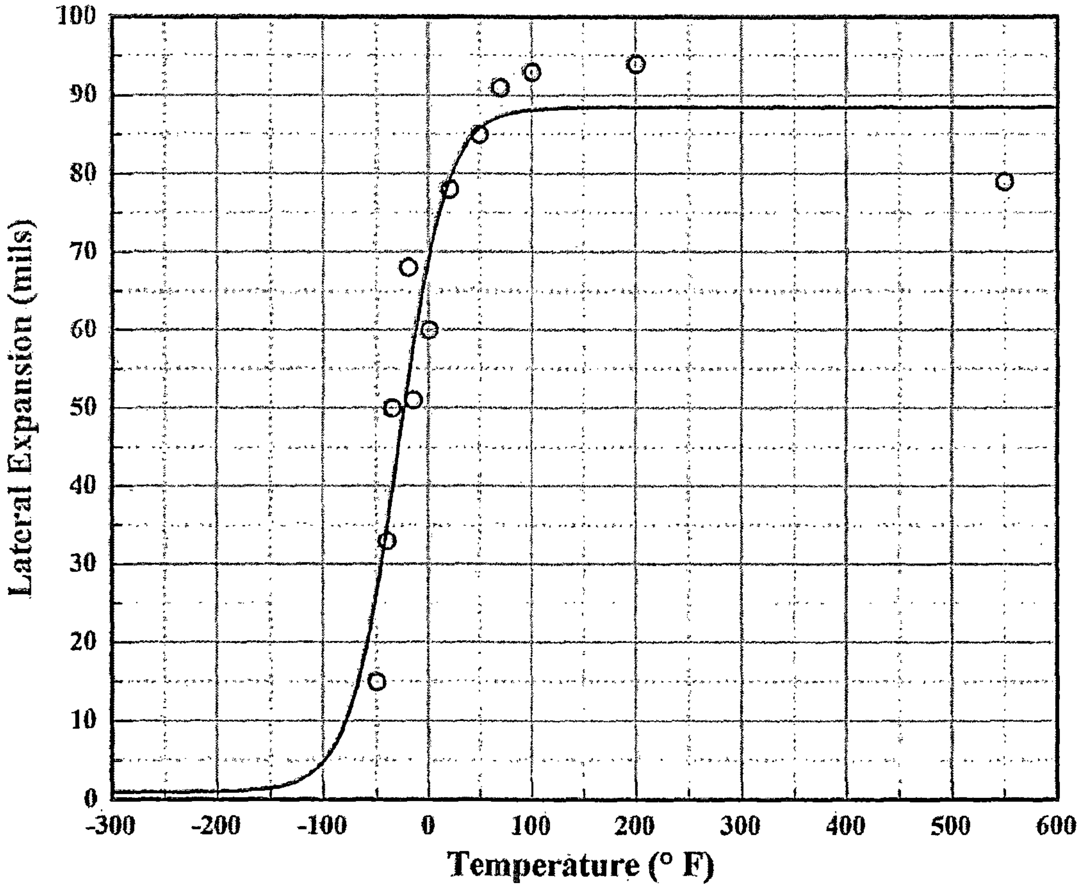
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 88.46 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-39.80° F

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SAW Heat: 88114
Orientation: NA Capsule: 97° Fluence:

Capsule 97° Weld
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-50	15.0	26.4	-11.38
-40	33.0	34.9	-1.85
-35	50.0	39.5	10.54
-20	68.0	53.6	14.44
-15	51.0	58.0	-7.01
0	60.0	69.4	-9.42
20	78.0	79.3	-1.32
50	85.0	85.8	-0.77
70	91.0	87.3	3.69
100	93.0	88.1	4.86
200	94.0	88.5	5.55
550	79.0	88.5	-9.46

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:06 AM

A = 50.00 B = 50.00 C = 85.42 T0 = -31.14 D = 0.00

Correlation Coefficient = 0.978

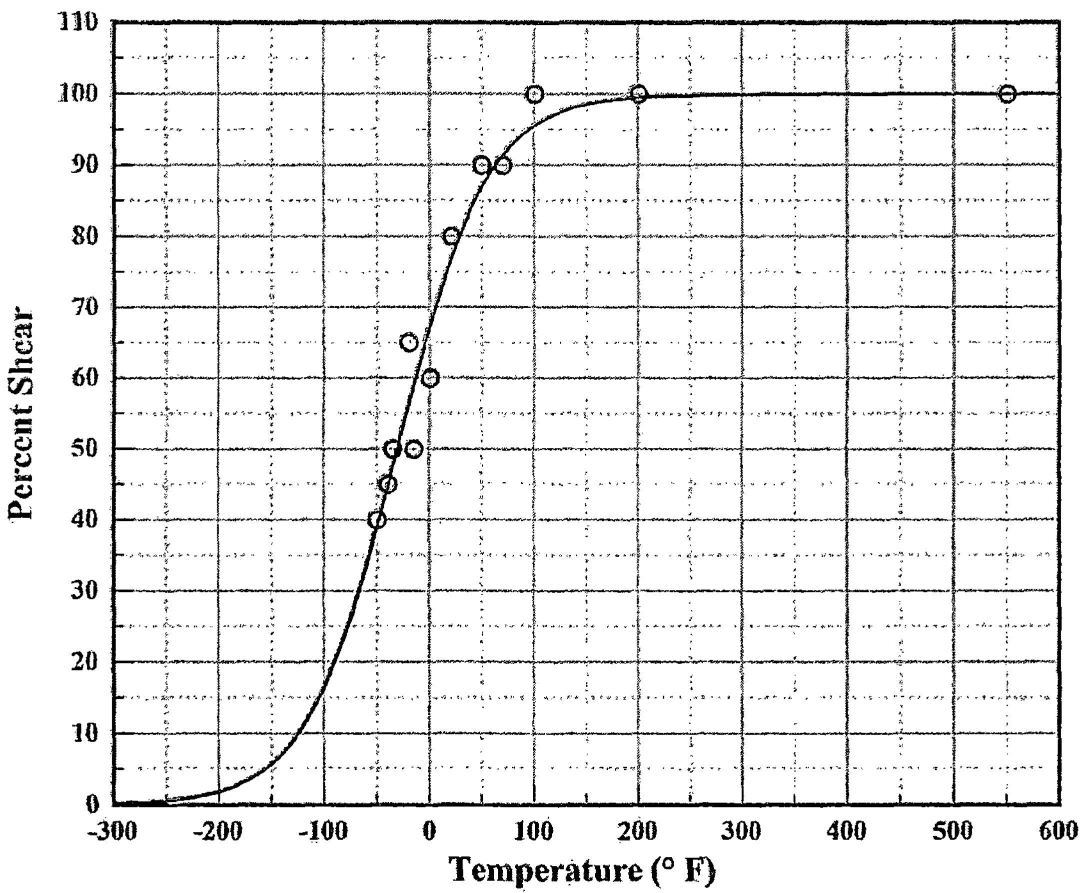
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = -31.10

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SAW Heat: 88114
Orientation: NA Capsule: 97° Fluence:

Capsule 97° Weld
Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-50	40.0	39.1	0.86
-40	45.0	44.8	0.17
-35	50.0	47.7	2.26
-20	65.0	56.5	8.52
-15	50.0	59.3	-9.34
0	60.0	67.5	-7.46
20	80.0	76.8	3.19
50	90.0	87.0	3.01
70	90.0	91.4	-1.44
100	100.0	95.6	4.43
200	100.0	99.6	0.44
550	100.0	100.0	0.00

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:09 AM

A = 79.10 B = 76.90 C = 88.63 T0 = -36.61 D = 0.00

Correlation Coefficient = 0.966

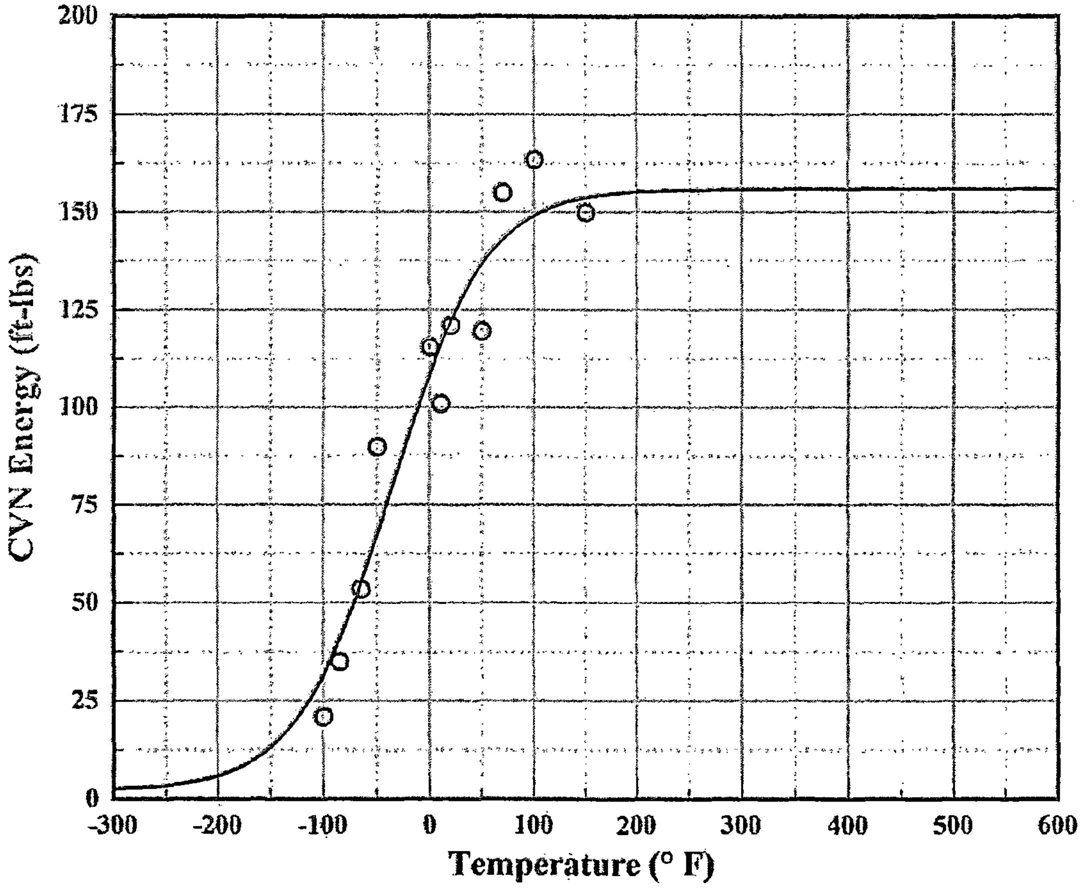
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 156.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-103.50° F Temp@35 ft-lbs=-94.40° F Temp@50 ft-lbs=-71.90° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: NA Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3
Orientation: NA

Material: SA533B1
Capsule: 97°

Heat: NR 57 286-1
Fluence:

Capsule 97° Heat Affected Zone Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-100	21.0	31.9	-10.89
-85	35.0	40.8	-5.84
-65	53.5	55.3	-1.78
-50	90.0	67.6	22.43
0	115.5	109.2	6.33
10	101.0	116.2	-15.18
20	121.0	122.5	-1.47
50	119.5	136.9	-17.42
70	155.0	143.3	11.73
100	163.5	149.3	14.24
150	150.0	153.8	-3.75

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:11 AM

A = 39.48 B = 38.48 C = 47.71 T0 = -66.30 D = 0.00

Correlation Coefficient = 0.967

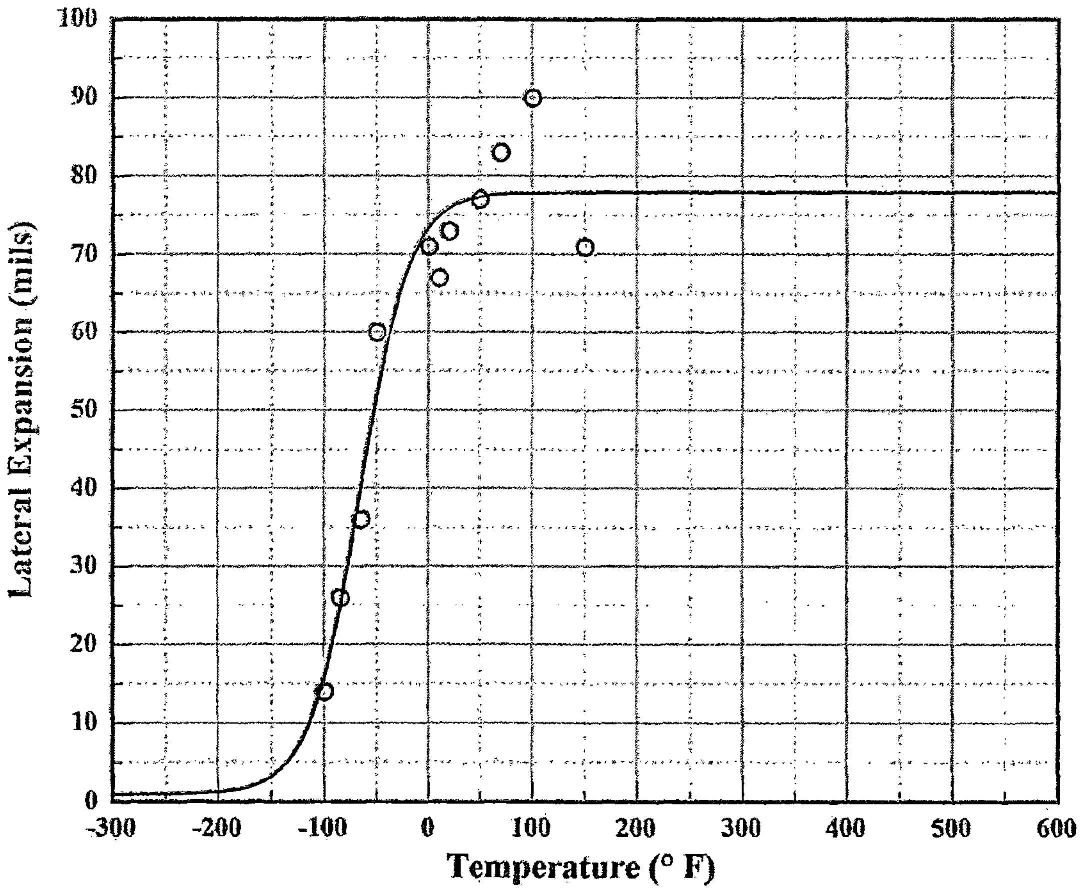
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 77.96 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-71.80° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: NA Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: NA Capsule: 97° Fluence:

Capsule 97° Heat Affected Zone
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-100	14.0	16.1	-2.07
-85	26.0	25.1	0.88
-65	36.0	40.5	-4.53
-50	60.0	52.1	7.86
0	71.0	73.5	-2.46
10	67.0	74.9	-7.94
20	73.0	75.9	-2.95
50	77.0	77.4	-0.38
70	83.0	77.7	5.29
100	90.0	77.9	12.11
150	71.0	78.0	-6.95

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 97° Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:13 AM

A = 50.00 B = 50.00 C = 68.09 T0 = -37.61 D = 0.00

Correlation Coefficient = 0.962

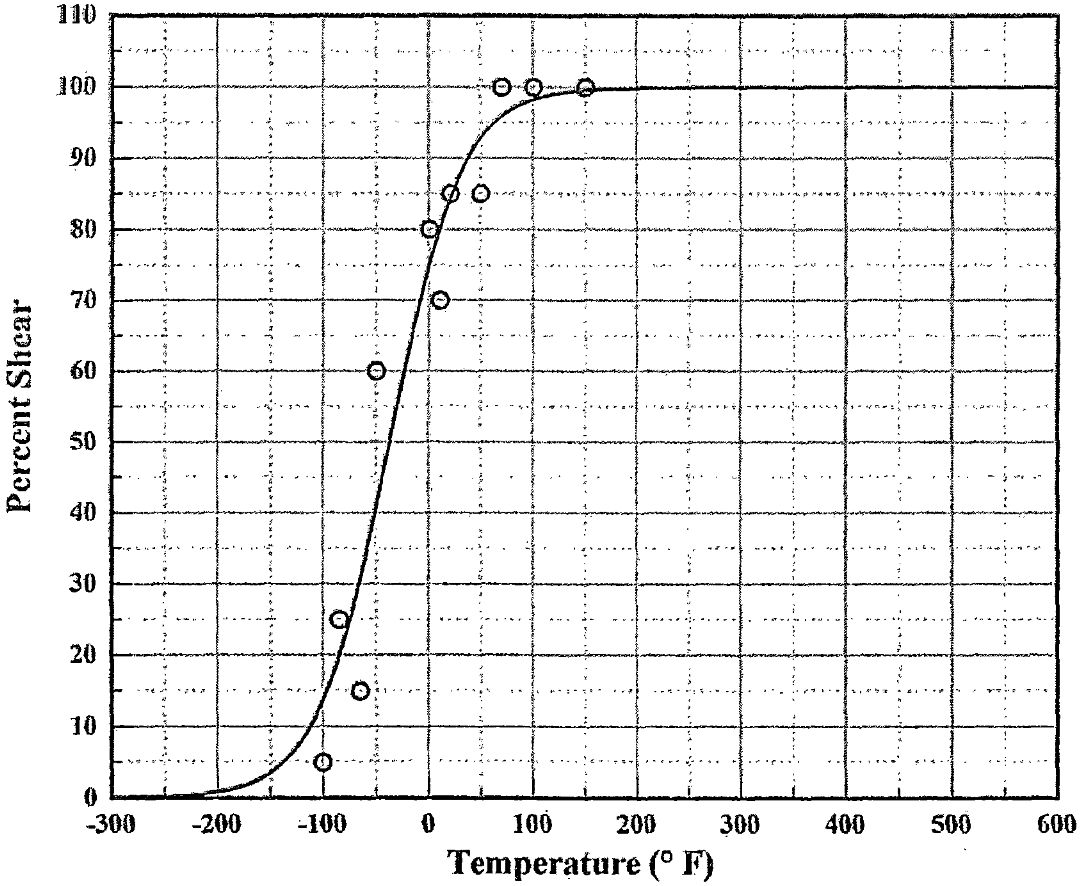
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = -37.60

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: NA Capsule: 97° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3
Orientation: NA

Material: SA533B1
Capsule: 97°

Heat: NR 57 286-1
Fluence:

Capsule 97° Heat Affected Zone Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-100	5.0	13.8	-8.79
-85	25.0	19.9	5.09
-65	15.0	30.9	-15.91
-50	60.0	41.0	19.00
0	80.0	75.1	4.88
10	70.0	80.2	-10.19
20	85.0	84.5	0.55
50	85.0	92.9	-7.91
70	100.0	95.9	4.07
100	100.0	98.3	1.73
150	100.0	99.6	0.40

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:23 AM

A = 66.60 B = 64.40 C = 117.40 T0 = 42.05 D = 0.00

Correlation Coefficient = 0.964

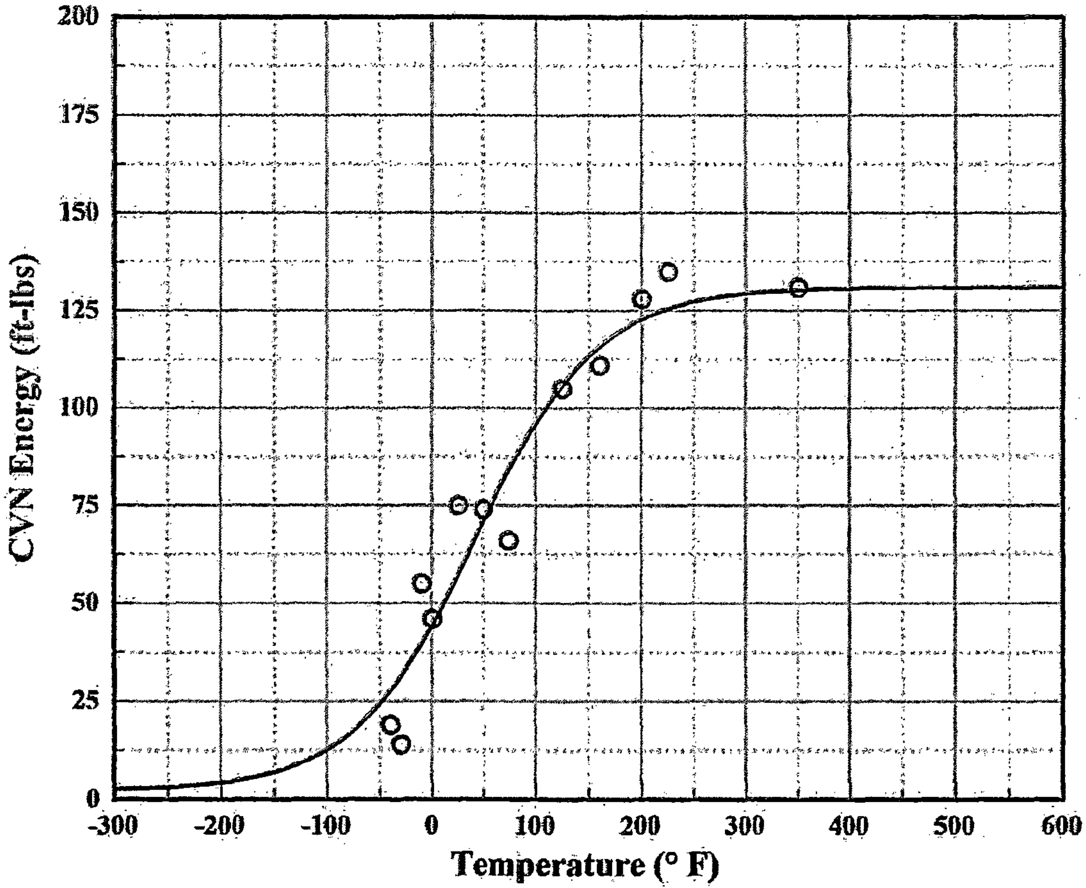
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 131.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-33.60° F Temp@35 ft-lbs=-20.90° F Temp@50 ft-lbs= 11.10° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: TL Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: TL Capsule: 263° Fluence:

Capsule 263° Plate M-1004-2 (Transverse)
Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-40	19.0	27.7	-8.72
-30	14.0	31.4	-17.39
-10	55.0	39.8	15.22
0	46.0	44.5	1.53
25	75.0	57.3	17.69
50	74.0	71.0	3.05
75	66.0	84.2	-18.21
125	105.0	105.8	-0.79
160	111.0	115.8	-4.77
200	128.0	122.8	5.18
225	135.0	125.5	9.46
350	131.0	130.3	0.68

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:27 AM

A = 39.30 B = 38.30 C = 94.58 T0 = 20.53 D = 0.00

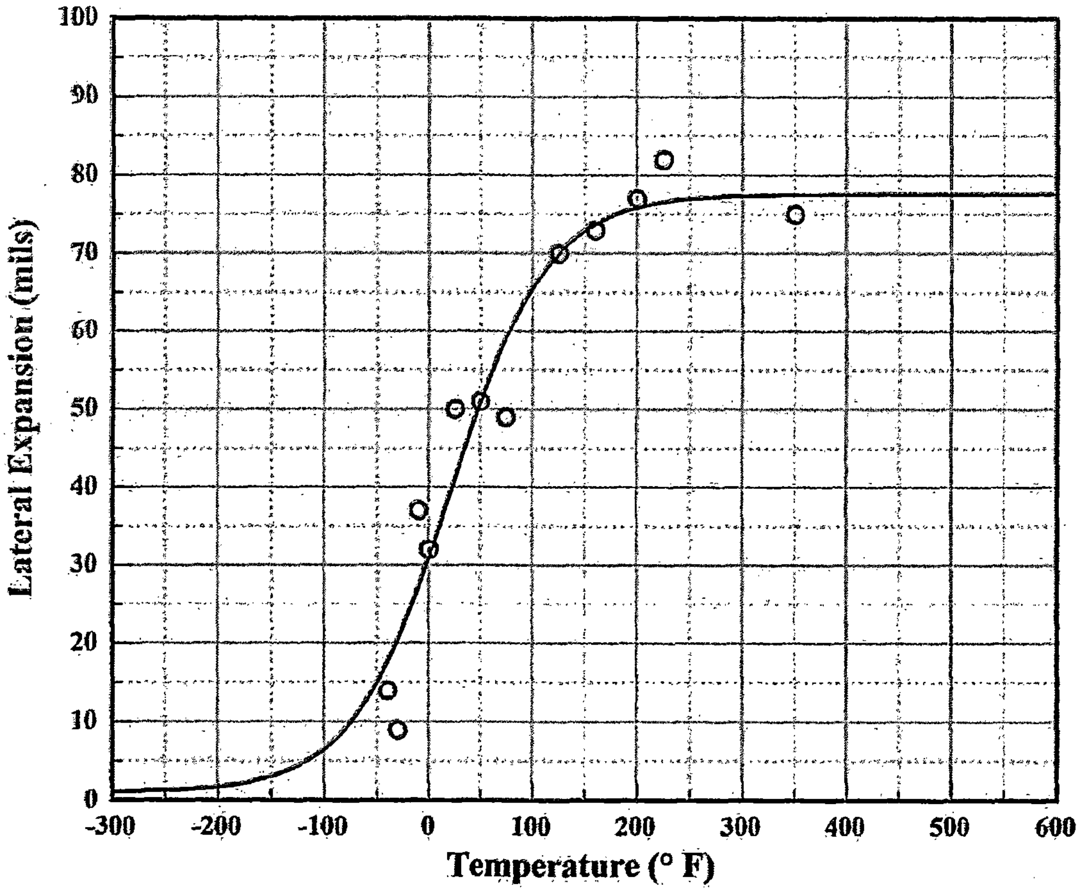
Correlation Coefficient = 0.965

Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 77.60 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 9.90° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: TL Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: TL | Capsule: 263° | Fluence:

Capsule 263° Plate M-1004-2 (Transverse)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-40	14.0	17.7	-3.66
-30	9.0	20.6	-11.59
-10	37.0	27.3	9.65
0	32.0	31.1	0.89
25	50.0	41.1	8.89
50	51.0	50.9	0.14
75	49.0	59.2	-10.20
125	70.0	70.0	-0.02
160	73.0	73.8	-0.79
200	77.0	75.9	1.08
225	82.0	76.6	5.40
350	75.0	77.5	-2.53

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:29 AM

A = 50.00 B = 50.00 C = 100.20 T0 = 66.47 D = 0.00

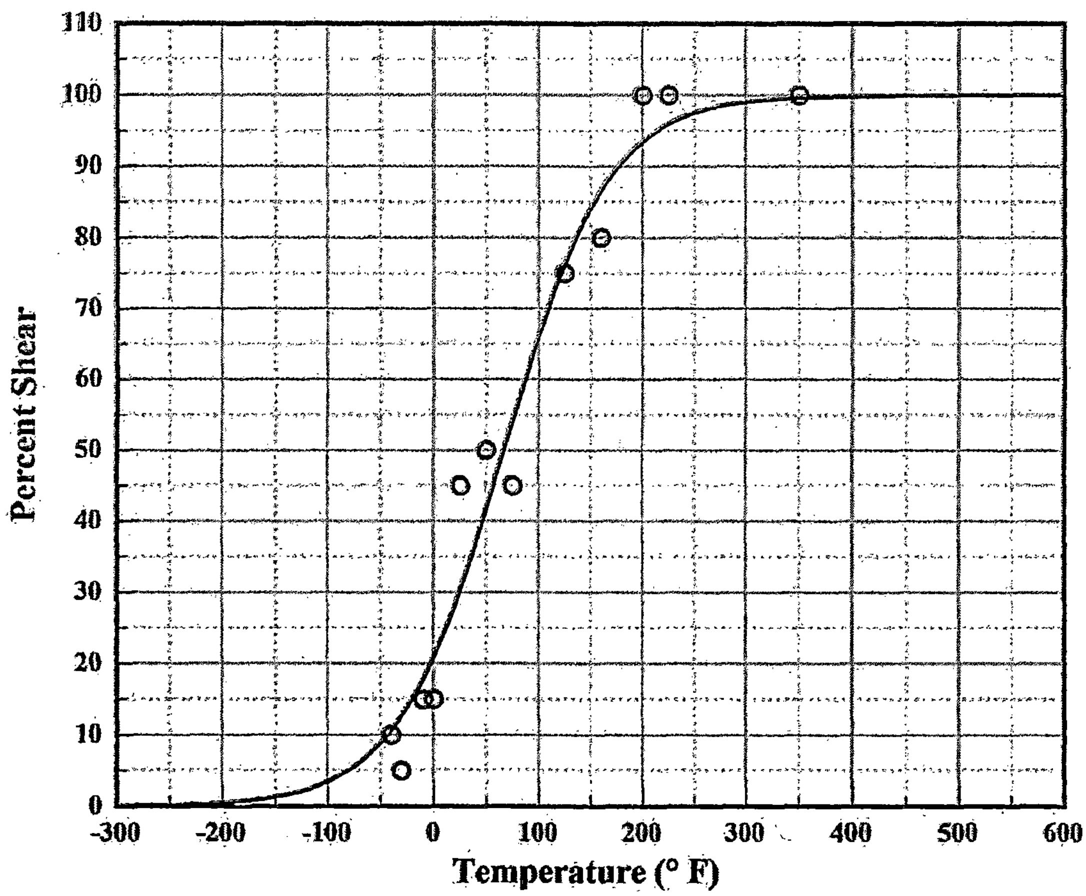
Correlation Coefficient = 0.981

Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = 66.50

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: TL Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: TL | Capsule: 263° | Fluence:

Capsule 263° Plate M-1004-2 (Transverse)
Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-40	10.0	10.7	-0.67
-30	5.0	12.7	-7.73
-10	15.0	17.9	-2.85
0	15.0	21.0	-5.97
25	45.0	30.4	14.59
50	50.0	41.9	8.14
75	45.0	54.2	-9.25
125	75.0	76.3	-1.28
160	80.0	86.6	-6.61
200	100.0	93.5	6.51
225	100.0	95.9	4.05
350	100.0	99.7	0.35

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:31 AM

A = 73.60 B = 71.40 C = 71.80 T0 = -26.84 D = 0.00

Correlation Coefficient = 0.997

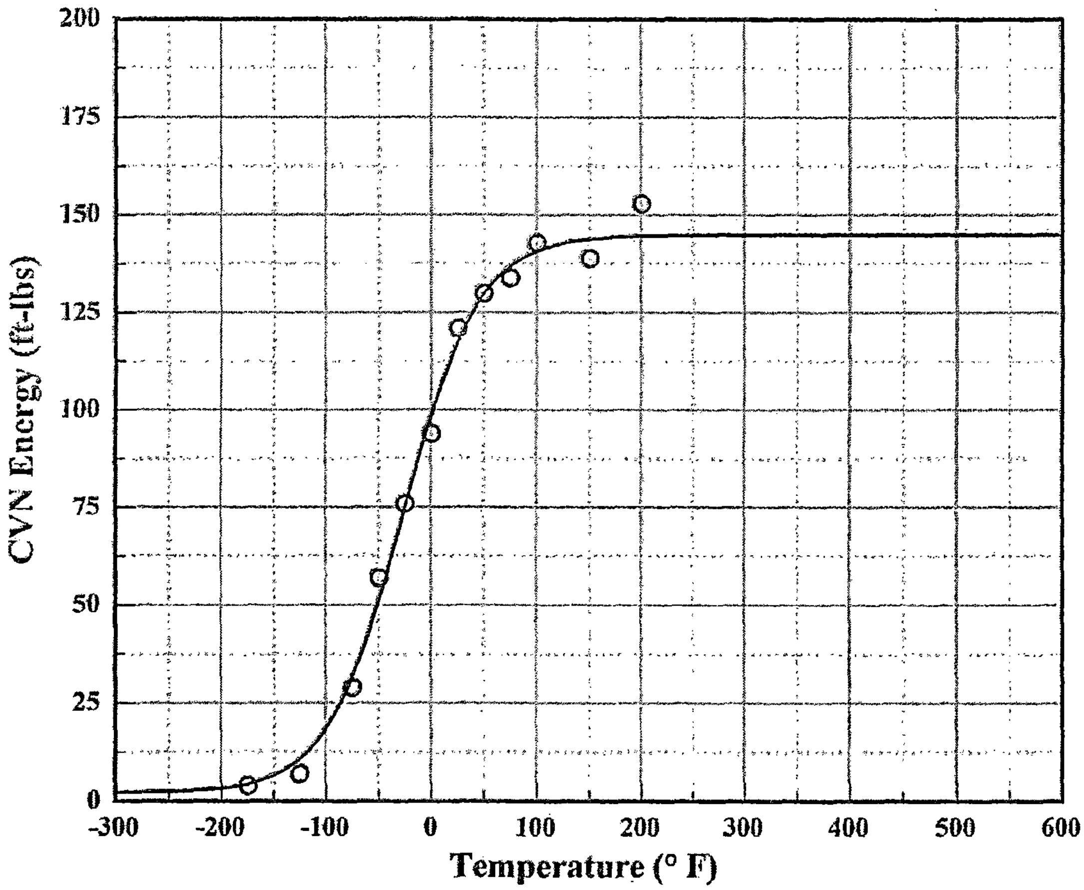
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 145.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-77.80° F Temp@35 ft-lbs=-70.20° F Temp@50 ft-lbs=-51.40° F

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 | Material: SAW | Heat: 88114
Orientation: NA | Capsule: 263° | Fluence:

Capsule 263° Weld
Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-175	4.0	4.5	-0.47
-125	7.0	10.9	-3.91
-75	29.0	31.8	-2.79
-50	57.0	51.3	5.67
-25	76.0	75.4	0.57
0	94.0	99.1	-5.11
25	121.0	117.7	3.27
50	130.0	130.0	0.03
75	134.0	137.1	-3.09
100	143.0	140.9	2.05
150	139.0	144.0	-4.97
200	153.0	144.7	8.26

CVGraph 6.0 | 02/09/2015 | Page 2/2

Capsule 263° Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:33 AM

A = 43.15 B = 42.15 C = 59.61 T0 = -35.09 D = 0.00

Correlation Coefficient = 0.996

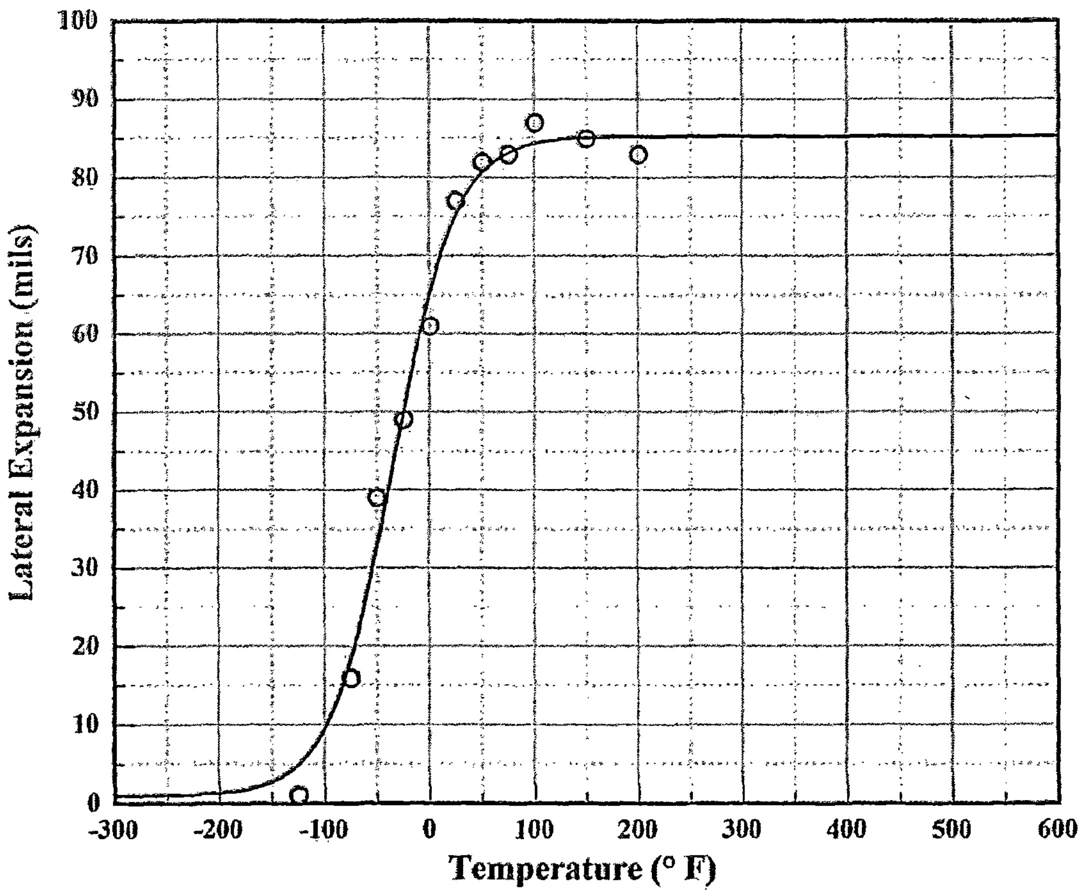
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 85.31 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-46.70° F

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SAW Heat: 88114
Orientation: NA Capsule: 263° Fluence:

Capsule 263° Weld
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-175	0.0	1.8	-1.76
-125	1.0	4.9	-3.94
-75	16.0	18.5	-2.51
-50	39.0	32.8	6.17
-25	49.0	50.2	-1.22
0	61.0	65.5	-4.45
25	77.0	75.4	1.60
50	82.0	80.7	1.28
75	83.0	83.3	-0.26
100	87.0	84.4	2.59
150	85.0	85.1	-0.14
200	83.0	85.3	-2.28

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:35 AM

A = 50.00 B = 50.00 C = 63.80 T0 = -36.28 D = 0.00

Correlation Coefficient = 0.995

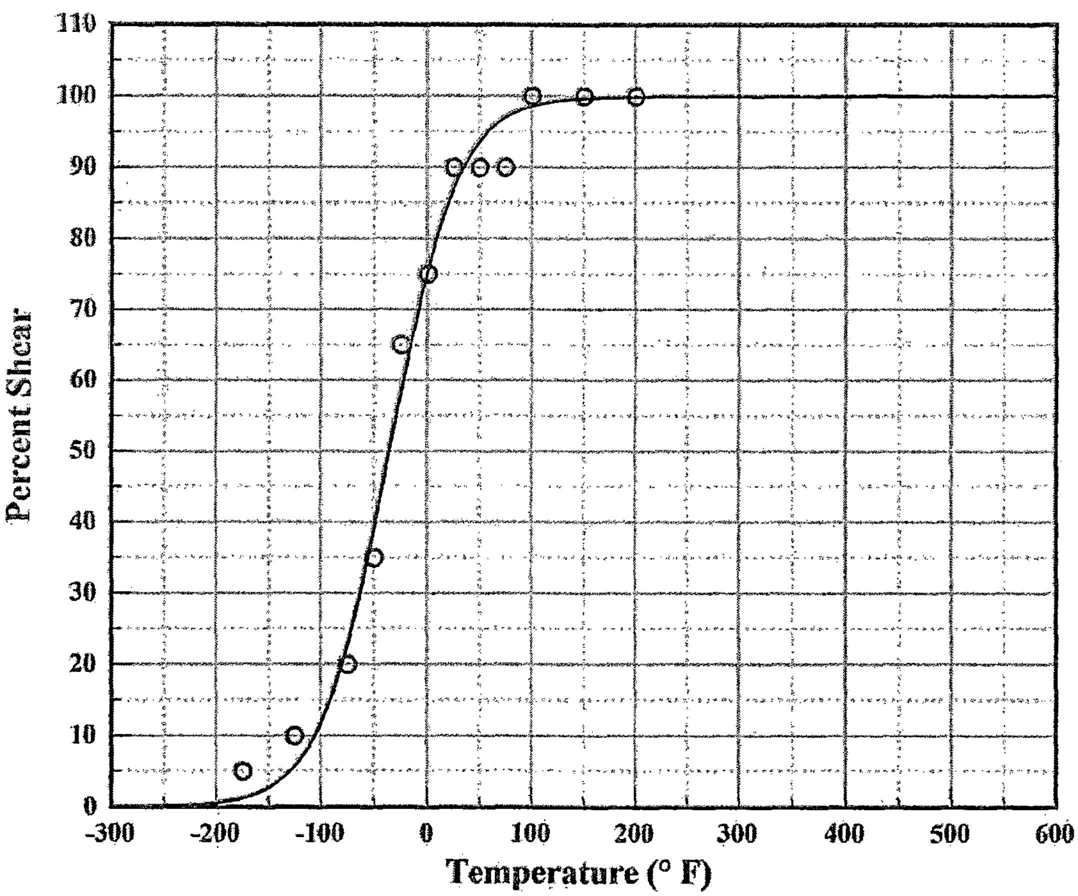
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = -36.20

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SAW Heat: 88114
Orientation: NA Capsule: 263° Fluence:

Capsule 263° Weld
Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-175	5.0	1.3	3.72
-125	10.0	5.8	4.17
-75	20.0	22.9	-2.90
-50	35.0	39.4	-4.41
-25	65.0	58.7	6.25
0	75.0	75.7	-0.72
25	90.0	87.2	2.77
50	90.0	93.7	-3.73
75	90.0	97.0	-7.04
100	100.0	98.6	1.38
150	100.0	99.7	0.29
200	100.0	99.9	0.06

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:38 AM

A = 82.60 B = 80.40 C = 83.91 T0 = -25.62 D = 0.00

Correlation Coefficient = 0.980

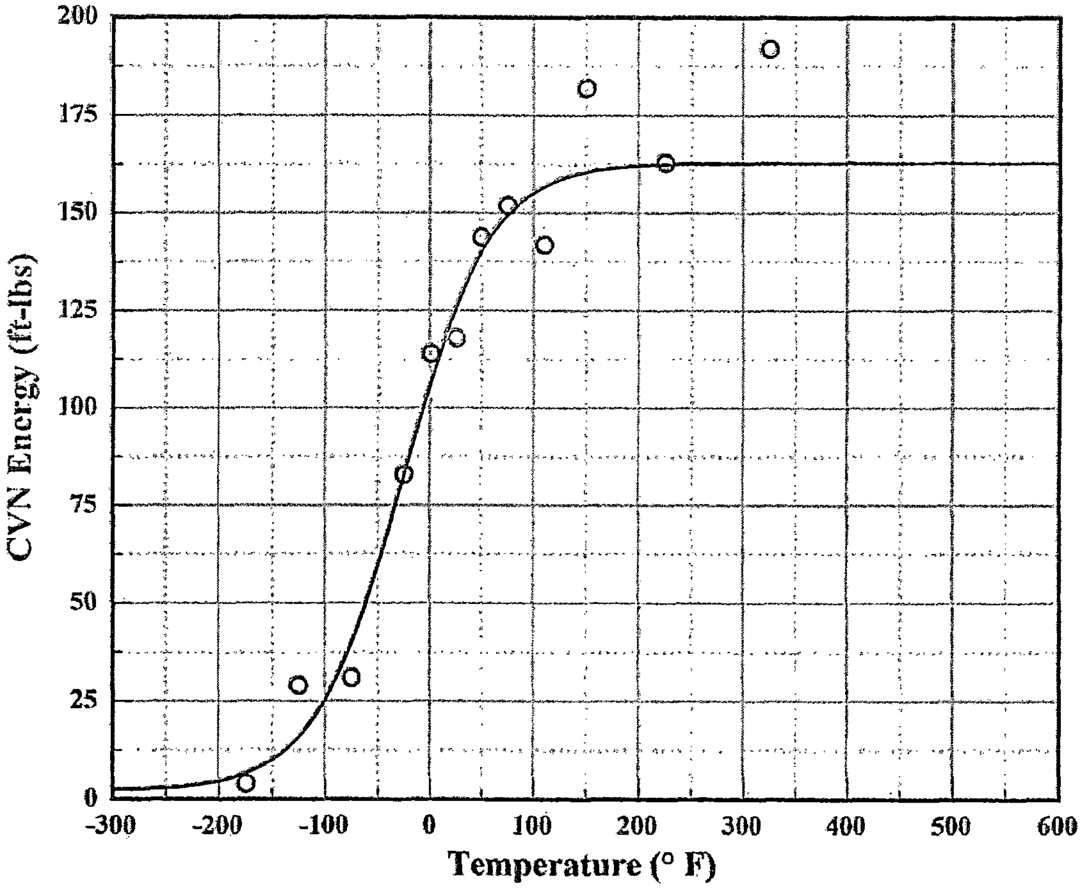
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 163.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-91.20° F Temp@35 ft-lbs=-82.70° F Temp@50 ft-lbs=-61.70° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: NA Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: NA Capsule: 263° Fluence:

Capsule 263° Heat Affected Zone
Charpy V-Notch Data

Temperature (°F)	Input CVN	Computed CVN	Differential
-175	4.0	6.6	-2.64
-125	29.0	16.0	13.04
-75	31.0	40.1	-9.08
-25	83.0	83.2	-0.20
0	114.0	106.4	7.58
25	118.0	126.0	-7.97
50	144.0	140.2	3.76
75	152.0	149.6	2.39
110	142.0	156.9	-14.90
150	182.0	160.6	21.41
225	163.0	162.6	0.41
325	192.0	163.0	29.04

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:39 AM

A = 38.08 B = 37.08 C = 61.12 T0 = -51.37 D = 0.00

Correlation Coefficient = 0.984

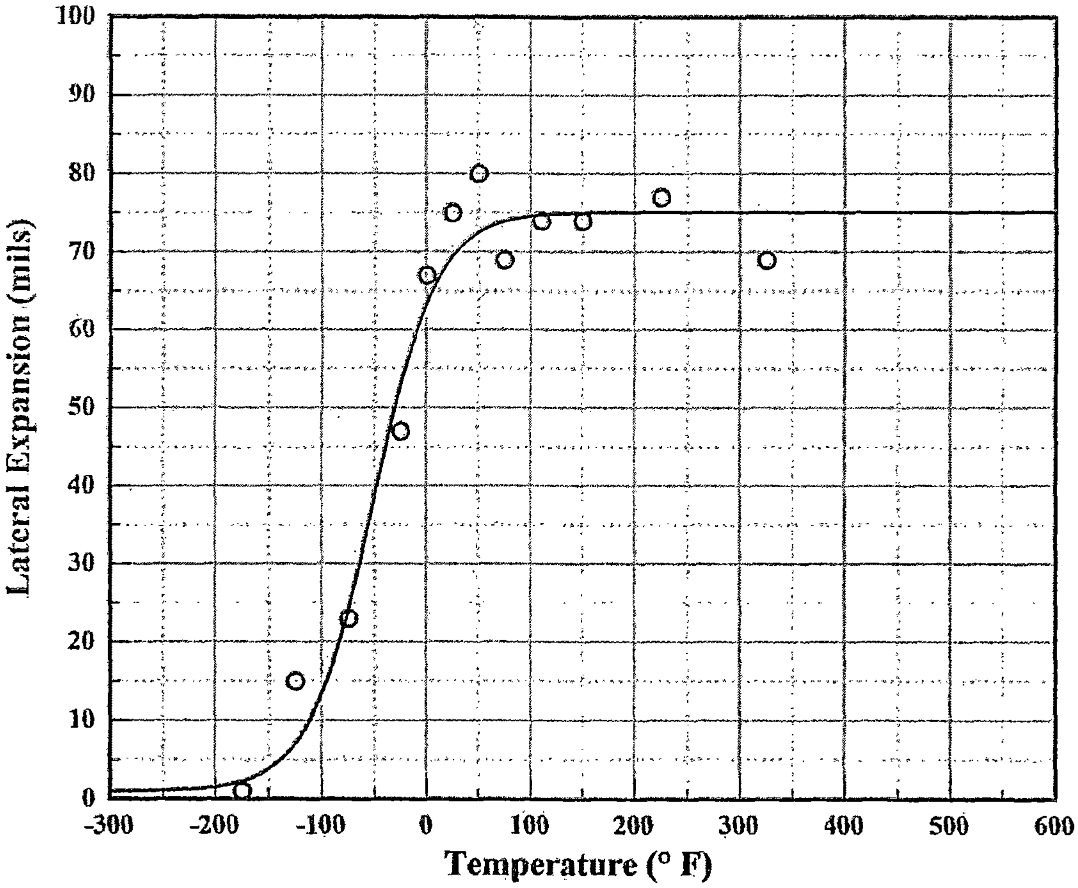
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 75.15   Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-56.40° F

Plant: Waterford 3   Material: SA533B1   Heat: NR 57 286-1

Orientation: NA   Capsule: 263°   Fluence:



CVGraph 6.0   02/09/2015   Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: NA Capsule: 263° Fluence:

Capsule 263° Heat Affected Zone
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-175	1.0	2.3	-1.28
-125	15.0	7.1	7.88
-75	23.0	24.4	-1.42
-25	47.0	53.1	-6.15
0	67.0	63.5	3.49
25	75.0	69.5	5.48
50	80.0	72.6	7.44
75	69.0	74.0	-4.99
110	74.0	74.8	-0.78
150	74.0	75.1	-1.05
225	77.0	75.1	1.85
325	69.0	75.2	-6.15

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:41 AM

A = 50.00 B = 50.00 C = 79.72 T0 = -53.45 D = 0.00

Correlation Coefficient = 0.992

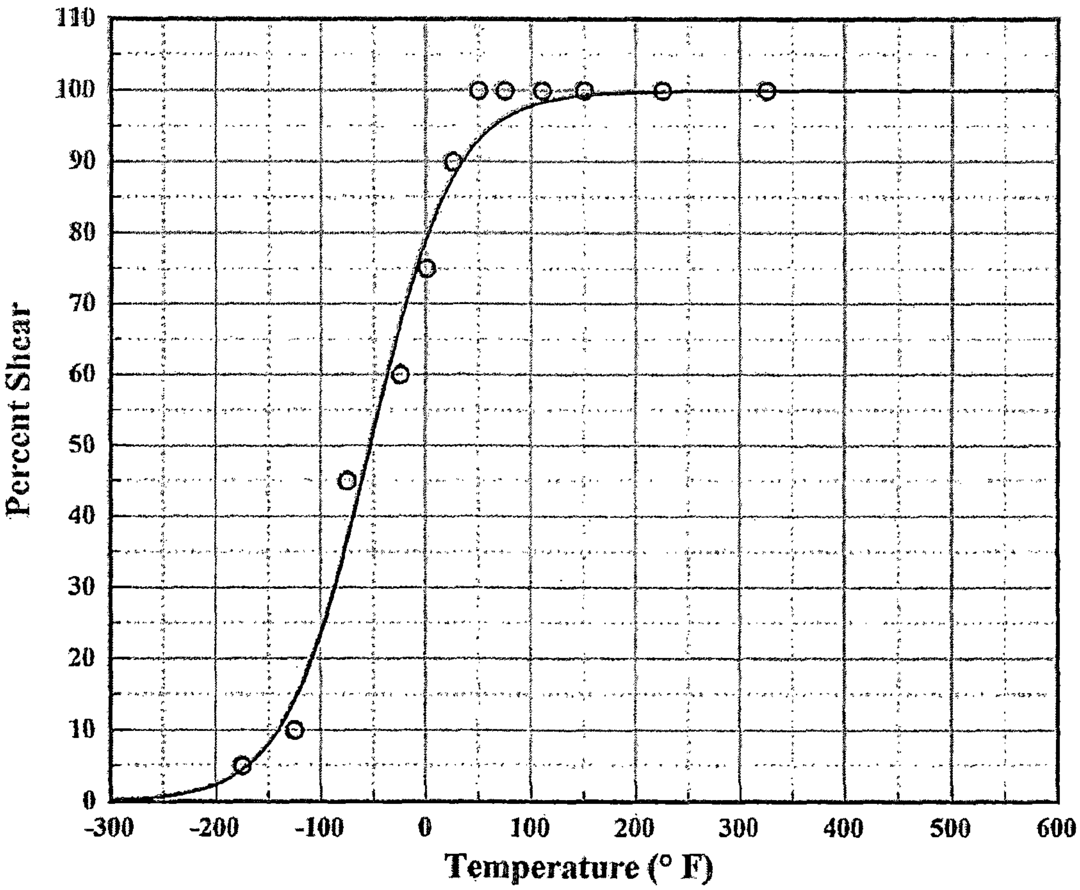
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = -53.40

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: NA Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: NA | Capsule: 263° | Fluence:

Capsule 263° Heat Affected Zone
Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-175	5.0	4.5	0.48
-125	10.0	14.2	-4.24
-75	45.0	36.8	8.20
-25	60.0	67.1	-7.12
0	75.0	79.3	-4.26
25	90.0	87.7	2.26
50	100.0	93.1	6.94
75	100.0	96.2	3.83
110	100.0	98.4	1.63
150	100.0	99.4	0.60
225	100.0	99.9	0.09
325	100.0	100.0	0.01

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Standard Reference Material

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:44 AM

A = 57.60 B = 55.40 C = 64.48 T0 = 220.22 D = 0.00

Correlation Coefficient = 0.981

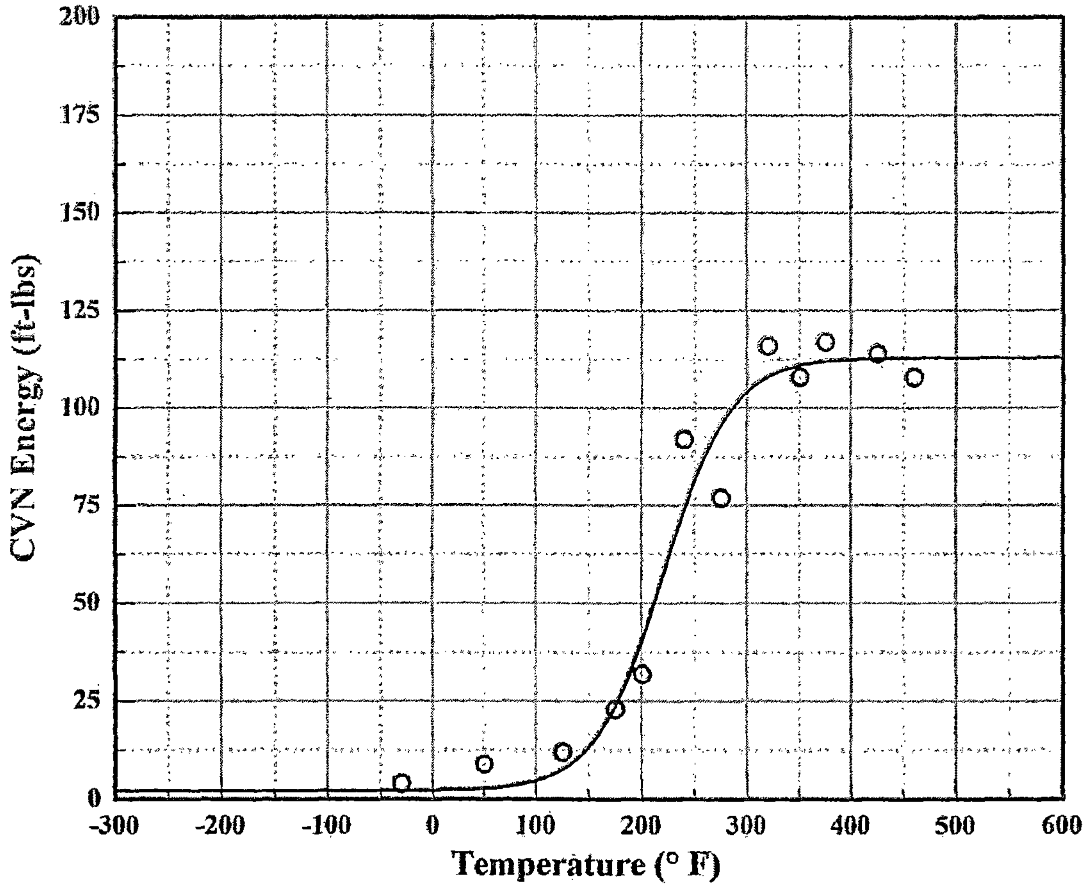
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 113.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=185.00° F Temp@35 ft-lbs=192.30° F Temp@50 ft-lbs=211.40° F

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY

Orientation: LT Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 263° Fluence:

Capsule 263° Standard Reference Material
Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-30	4.0	2.2	1.75
50	9.0	2.8	6.24
125	12.0	7.7	4.31
175	23.0	24.1	-1.07
200	32.0	40.8	-8.77
240	92.0	74.1	17.92
275	77.0	95.9	-18.87
320	116.0	108.2	7.80
350	108.0	111.1	-3.06
375	117.0	112.1	4.90
425	114.0	112.8	1.19
460	108.0	112.9	-4.93

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Standard Reference Material

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:45 AM

A = 35.13 B = 34.13 C = 52.92 T0 = 208.55 D = 0.00

Correlation Coefficient = 0.992

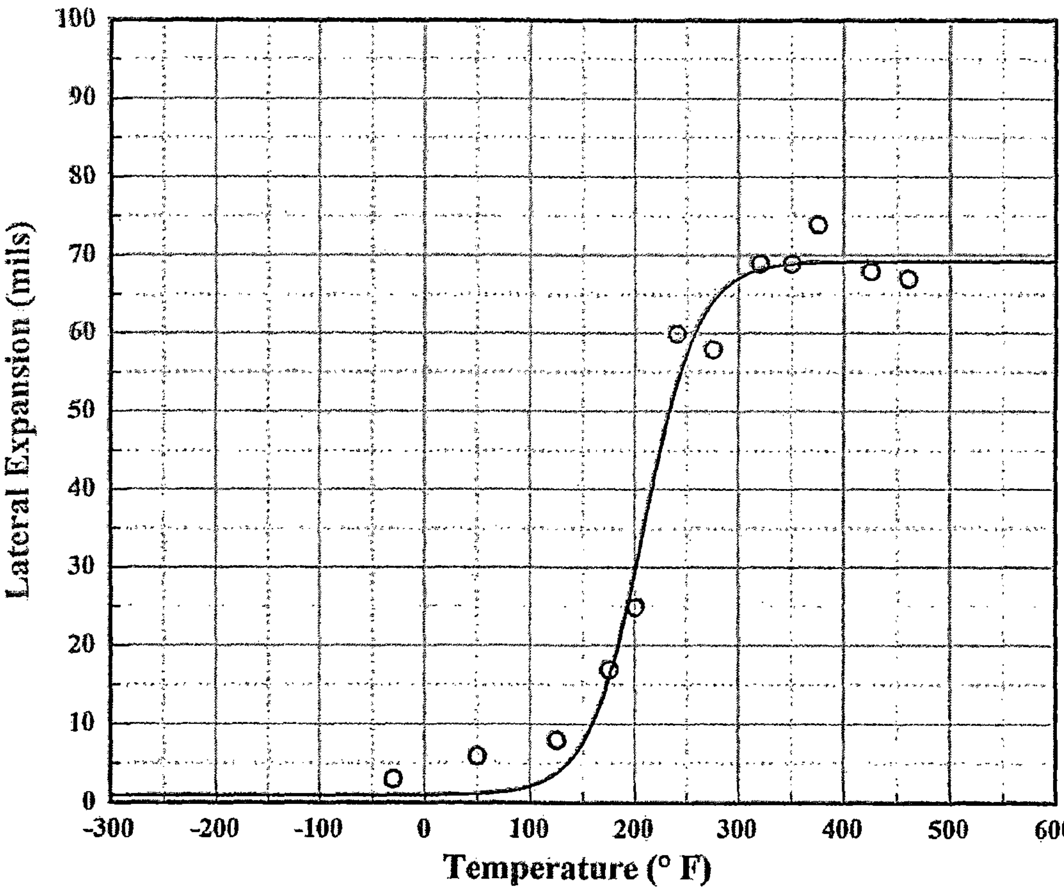
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 69.27 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=208.40° F

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY

Orientation: LT Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 263° Fluence:

Capsule 263° Standard Reference Material
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-30	3.0	1.0	1.99
50	6.0	1.2	4.83
125	8.0	3.8	4.21
175	17.0	16.0	1.01
200	25.0	29.7	-4.67
240	60.0	53.3	6.68
275	58.0	64.1	-6.14
320	69.0	68.3	0.73
350	69.0	68.9	0.06
375	74.0	69.1	4.86
425	68.0	69.2	-1.25
460	67.0	69.3	-2.26

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 263° Standard Reference Material

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/9/2015 9:47 AM

A = 50.00 B = 50.00 C = 82.66 T0 = 220.04 D = 0.00

Correlation Coefficient = 0.992

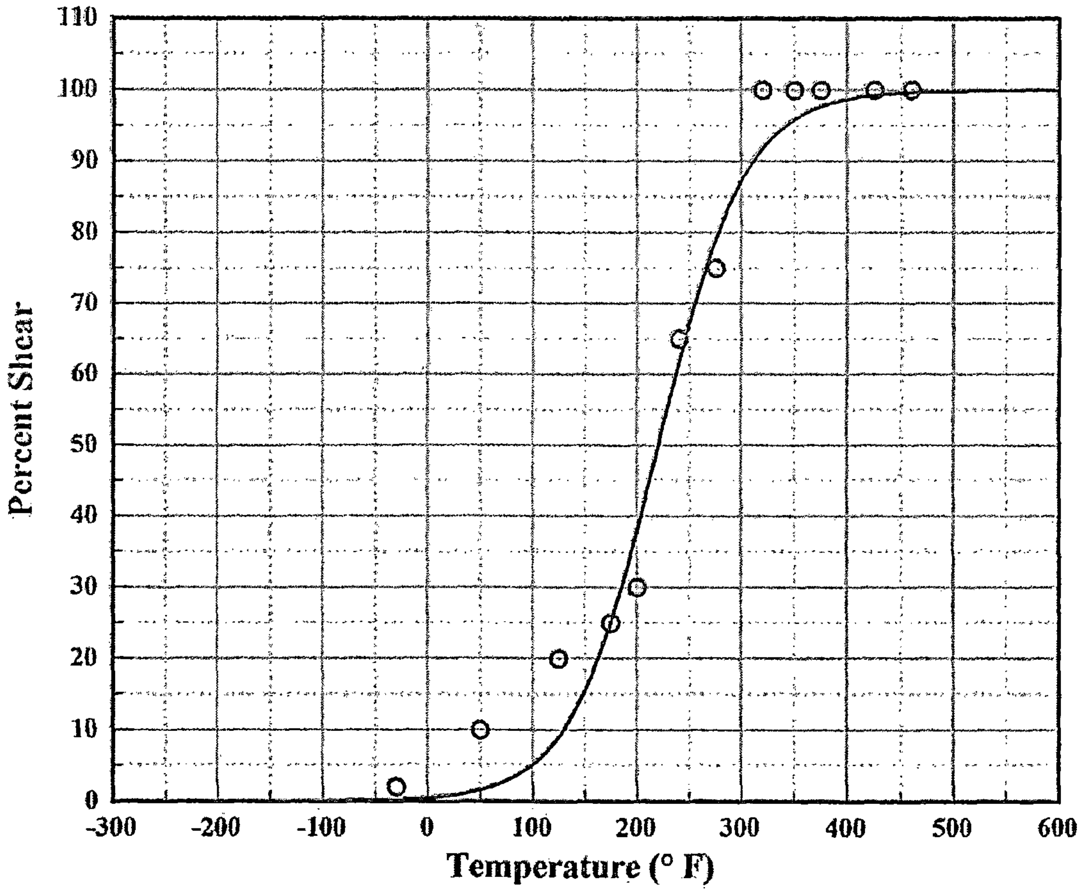
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = 220.10

Plant: Waterford 3 Material: SA533B1 Heat: HSST-01MY

Orientation: LT Capsule: 263° Fluence:



CVGraph 6.0 02/09/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: HSST-01MY
Orientation: LT | Capsule: 263° | Fluence:

Capsule 263° Standard Reference Material
Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-30	2.0	0.2	1.76
50	10.0	1.6	8.39
125	20.0	9.1	10.89
175	25.0	25.2	-0.16
200	30.0	38.1	-8.11
240	65.0	61.8	3.16
275	75.0	79.1	-4.08
320	100.0	91.8	8.18
350	100.0	95.9	4.13
375	100.0	97.7	2.30
425	100.0	99.3	0.70
460	100.0	99.7	0.30

CVGraph 6.0 02/09/2015 Page 2/2

Capsule 83° Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 10:51 AM

A = 80.10 B = 77.90 C = 98.64 T0 = 75.41 D = 0.00

Correlation Coefficient = 0.983

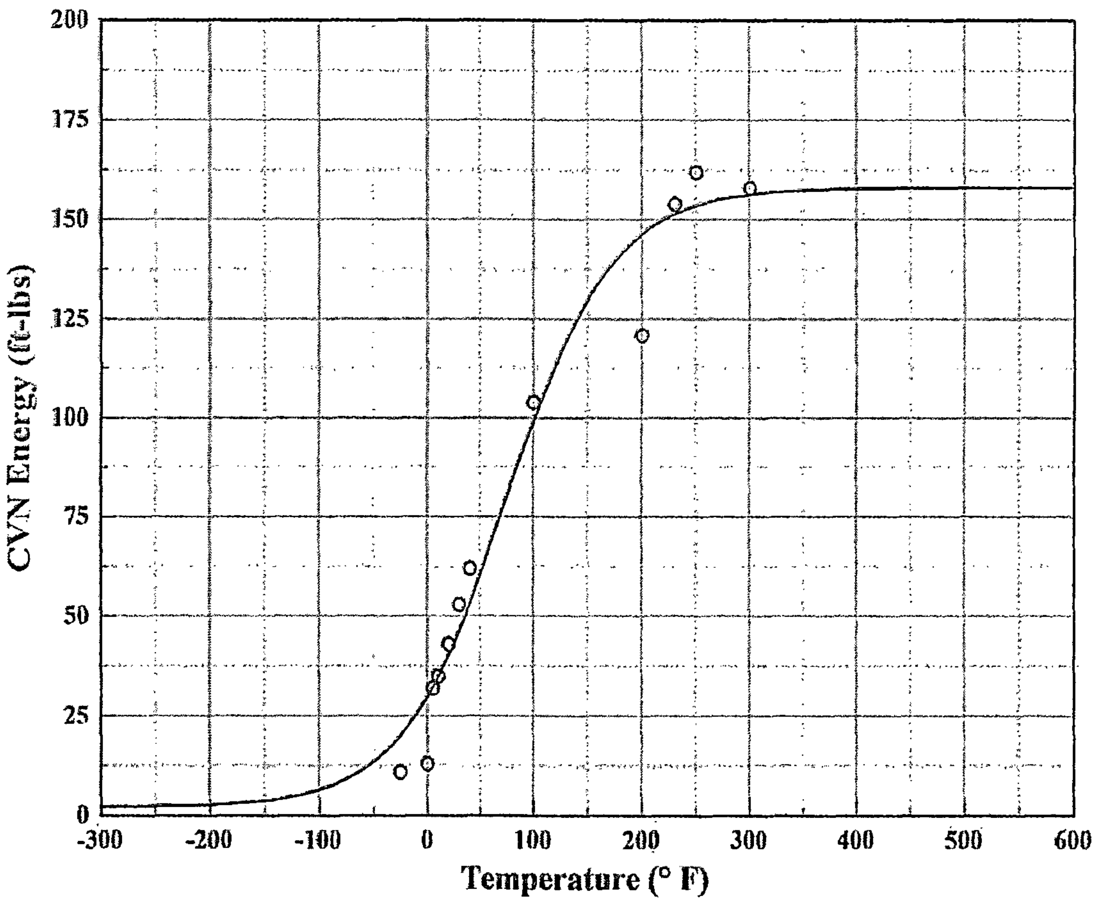
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 158.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= 0.10° F Temp@35 ft-lbs= 10.30° F Temp@50 ft-lbs= 35.30° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: LT Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: LT | Capsule: 83° | Fluence:

Capsule 83° Plate M-1004-2 (Longitudinal)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-25	11.0	20.2	-9.19
0	13.0	30.0	-16.95
5	32.0	32.3	-0.34
10	35.0	34.9	0.12
20	43.0	40.4	2.57
30	53.0	46.6	6.43
40	62.0	53.3	8.72
100	104.0	99.1	4.88
200	121.0	146.5	-25.46
230	154.0	151.5	2.50
250	162.0	153.6	8.39
300	158.0	156.4	1.62

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 10:56 AM

A = 44.52 B = 43.52 C = 62.15 T0 = 40.38 D = 0.00

Correlation Coefficient = 0.994

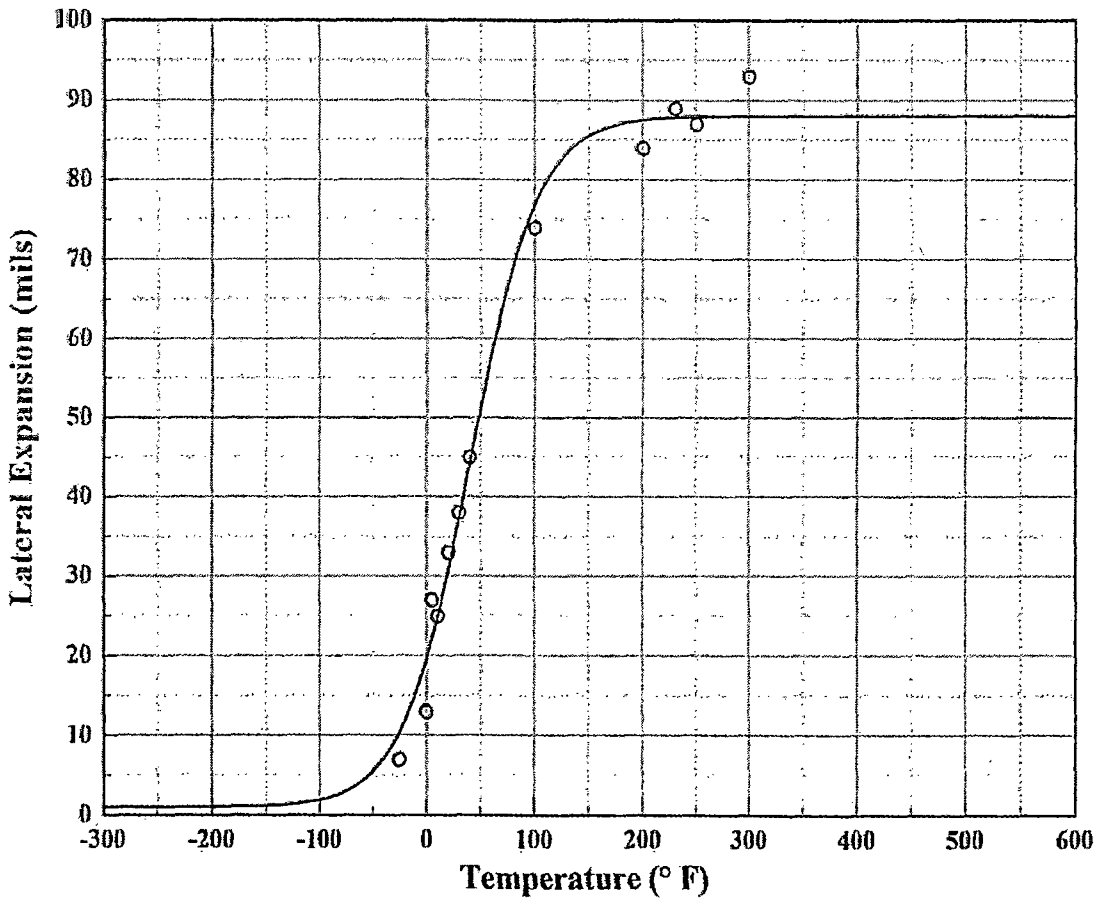
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 88.05 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 26.60° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: LT Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: LT Capsule: 83° Fluence:

Capsule 83° Plate M-1004-2 (Longitudinal)
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-25	7.0	10.5	-3.46
0	13.0	19.7	-6.65
5	27.0	22.1	4.88
10	25.0	24.8	0.20
20	33.0	30.7	2.26
30	38.0	37.3	0.68
40	45.0	44.3	0.74
100	74.0	76.9	-2.90
200	84.0	87.5	-3.54
230	89.0	87.9	1.15
250	87.0	87.9	-0.94
300	93.0	88.0	4.98

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Plate M-1004-2 (Longitudinal)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 10:59 AM

A = 50.00 B = 50.00 C = 94.69 T0 = 85.50 D = 0.00

Correlation Coefficient = 0.995

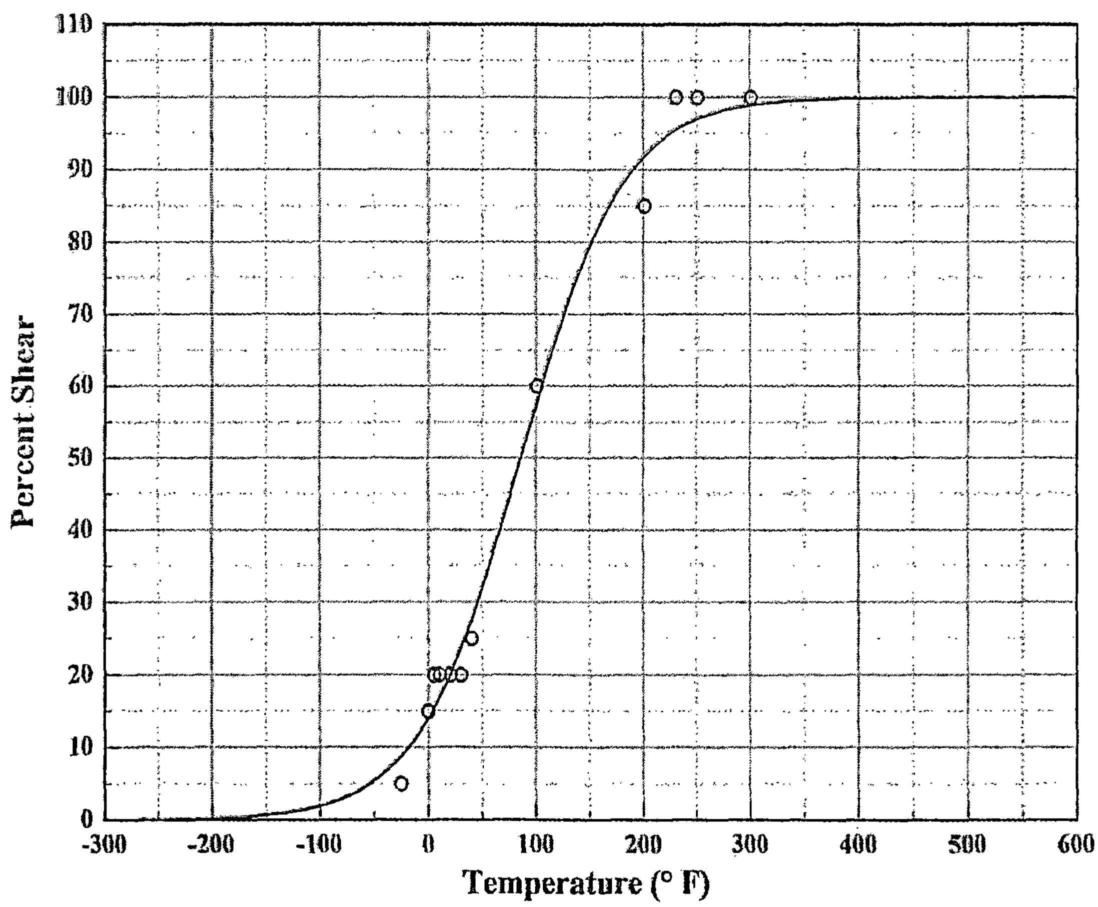
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = 85.60

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: LT Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: LT | Capsule: 83° | Fluence:

Capsule 83° Plate M-1004-2 (Longitudinal)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-25	5.0	8.8	-3.84
0	15.0	14.1	0.89
5	20.0	15.4	4.56
10	20.0	16.9	3.13
20	20.0	20.0	-0.05
30	20.0	23.6	-3.65
40	25.0	27.7	-2.67
100	60.0	57.6	2.40
200	85.0	91.8	-6.82
230	100.0	95.5	4.51
250	100.0	97.0	3.00
300	100.0	98.9	1.07

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 11:02 AM

A = 70.10 B = 67.90 C = 97.93 T0 = 67.19 D = 0.00

Correlation Coefficient = 0.991

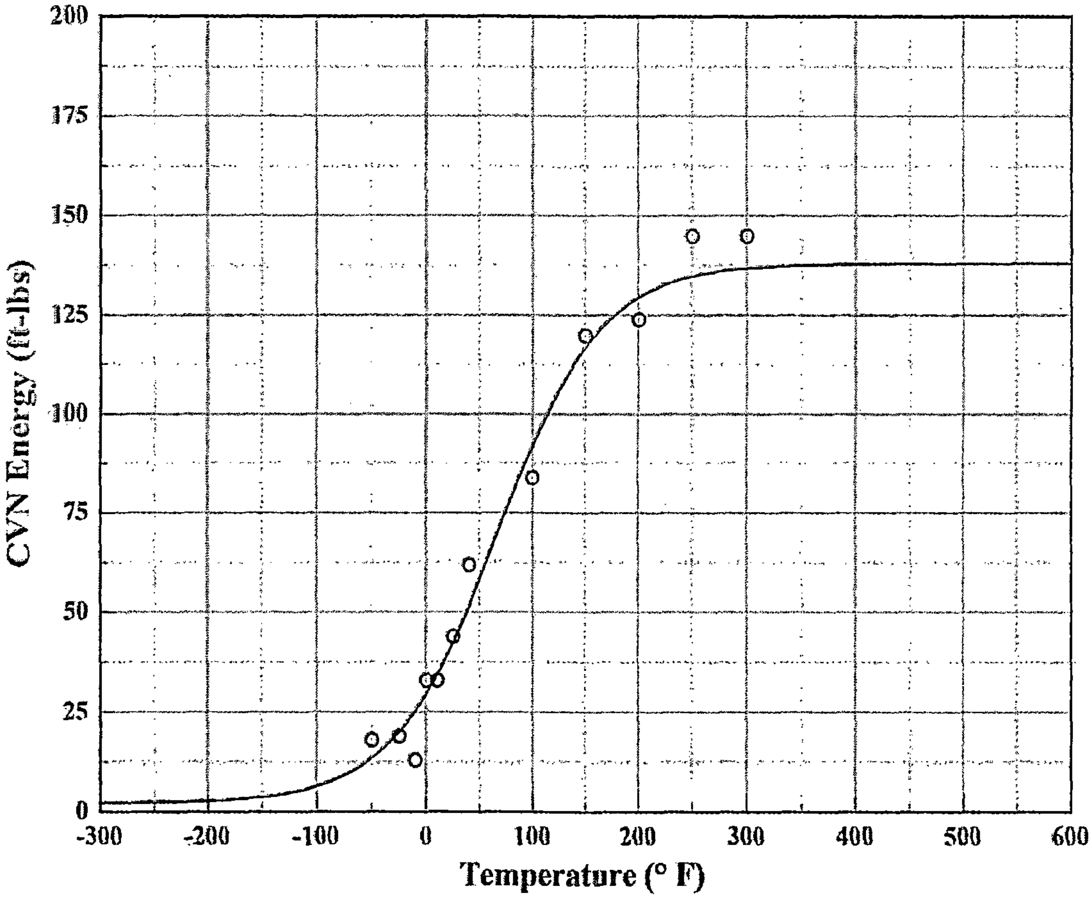
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 138.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= 0.80° F Temp@35 ft-lbs= 11.20° F Temp@50 ft-lbs= 37.40° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: TL Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: TL | Capsule: 83° | Fluence:

Capsule 83° Plate M-1004-2 (Transverse)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-50	18.0	13.6	4.44
-25	19.0	20.1	-1.14
-10	13.0	25.5	-12.46
0	33.0	29.7	3.33
10	33.0	34.4	-1.41
25	44.0	42.5	1.47
40	62.0	51.7	10.28
100	84.0	92.0	-8.04
150	120.0	116.9	3.13
200	124.0	129.5	-5.55
250	145.0	134.8	10.17
300	145.0	136.8	8.16

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 11:05 AM

A = 41.79 B = 40.79 C = 80.42 T0 = 36.47 D = 0.00

Correlation Coefficient = 0.981

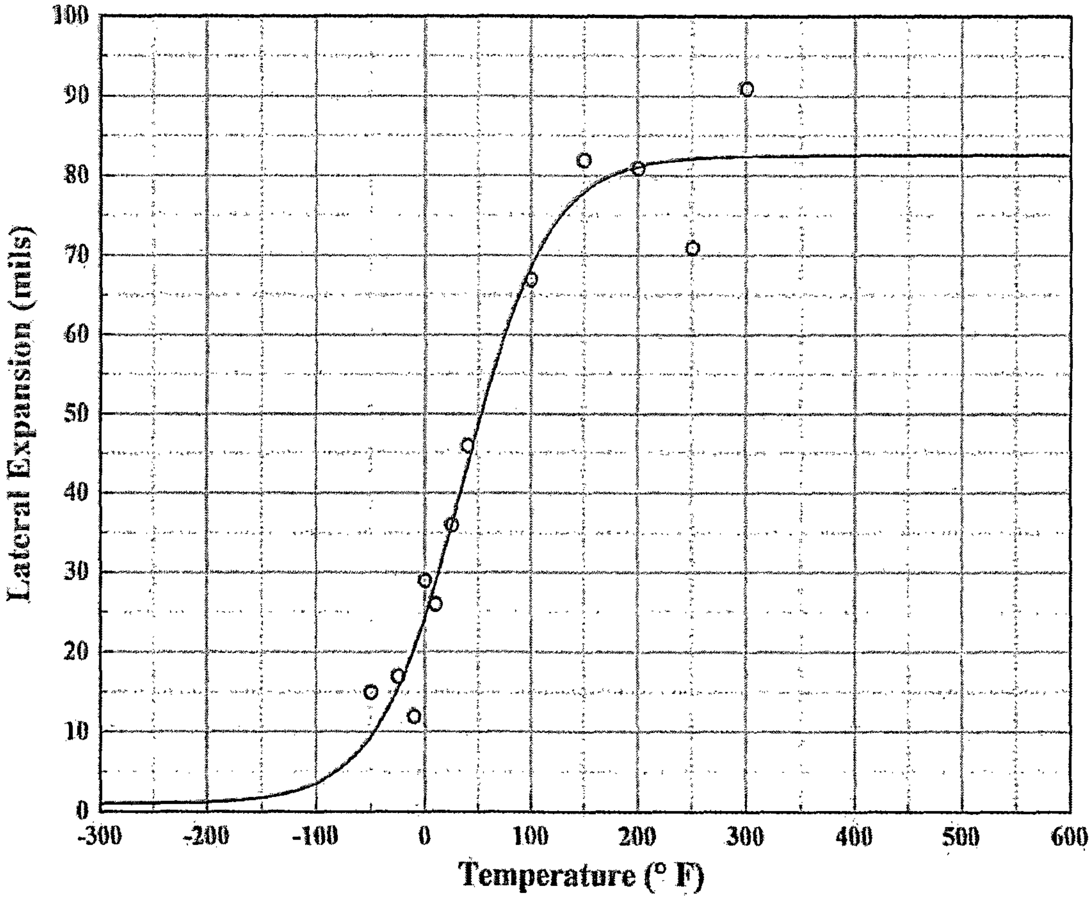
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 82.58 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 23.00° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: TL Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3 | Material: SA533B1 | Heat: NR 57 286-1
Orientation: TL | Capsule: 83° | Fluence:

Capsule 83° Plate M-1004-2 (Transverse)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-50	15.0	9.5	5.49
-25	17.0	15.5	1.46
-10	12.0	20.5	-8.54
0	29.0	24.5	4.54
10	26.0	28.8	-2.83
25	36.0	36.0	-0.01
40	46.0	43.6	2.42
100	67.0	68.6	-1.64
150	82.0	78.0	4.00
200	81.0	81.2	-0.20
250	71.0	82.2	-11.18
300	91.0	82.5	8.54

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Plate M-1004-2 (Transverse)

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 11:07 AM

A = 50.00 B = 50.00 C = 88.88 T0 = 85.46 D = 0.00

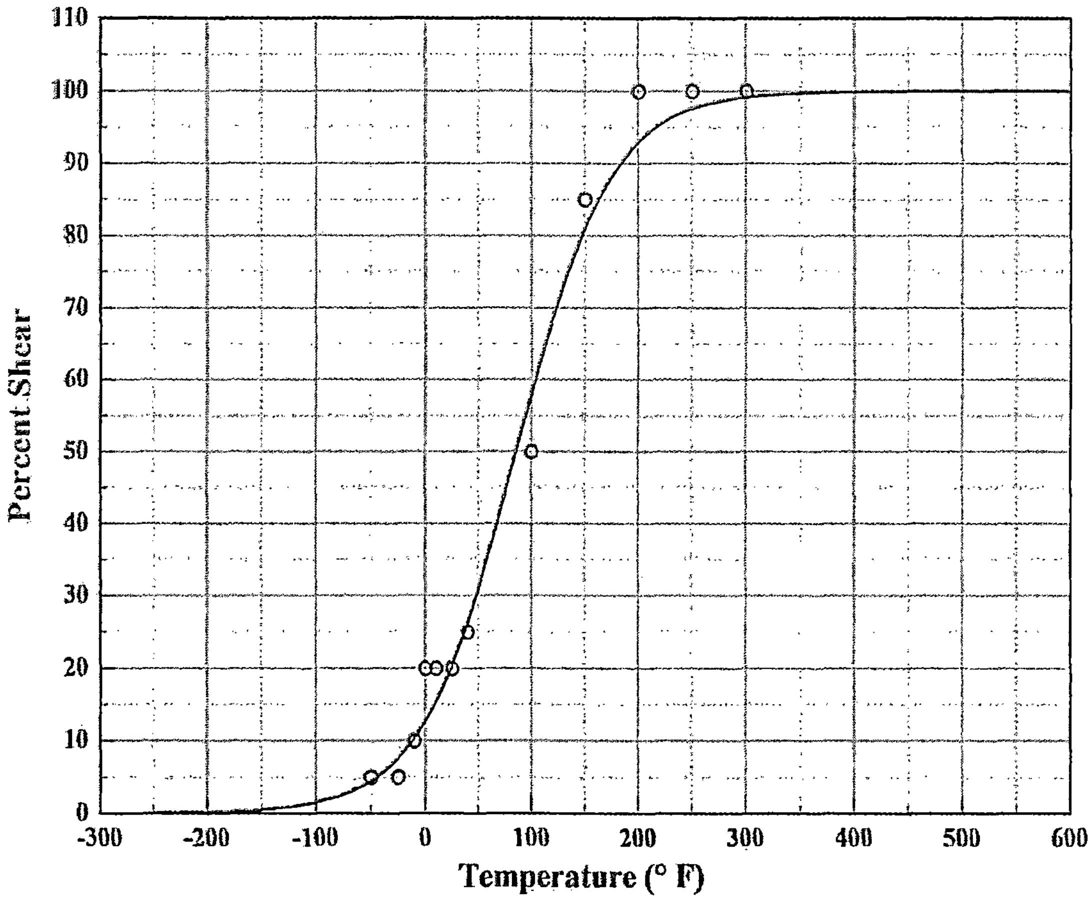
Correlation Coefficient = 0.994

Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = 85.50

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: TL Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3
Orientation: TL

Material: SA533B1
Capsule: 83°

Heat: NR 57 286-1
Fluence:

Capsule 83° Plate M-1004-2 (Transverse)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-50	5.0	4.5	0.47
-25	5.0	7.7	-2.69
-10	10.0	10.5	-0.45
0	20.0	12.8	7.25
10	20.0	15.5	4.53
25	20.0	20.4	-0.42
40	25.0	26.4	-1.44
100	50.0	58.1	-8.11
150	85.0	81.0	3.97
200	100.0	92.9	7.06
250	100.0	97.6	2.41
300	100.0	99.2	0.79

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 11:10 AM

A = 67.60 B = 65.40 C = 56.55 T0 = -28.41 D = 0.00

Correlation Coefficient = 0.994

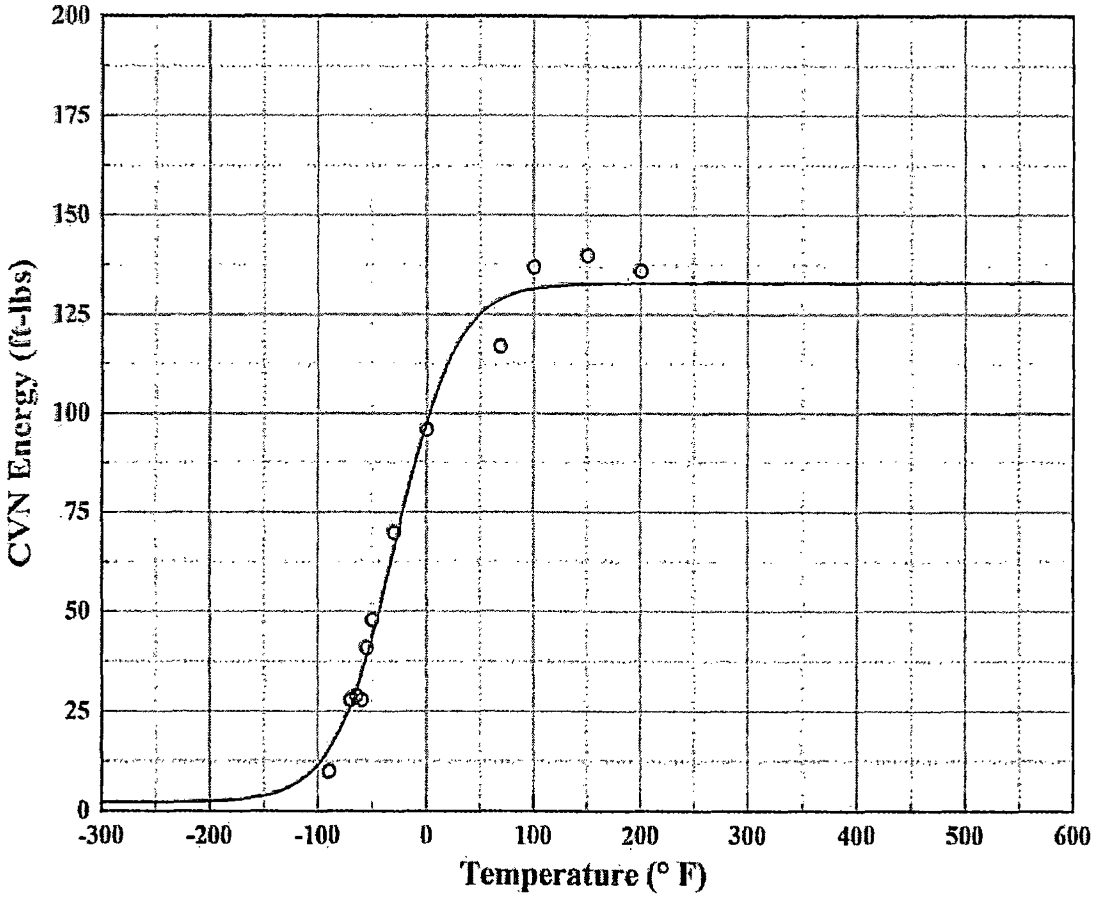
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 133.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-65.40° F Temp@35 ft-lbs=-59.30° F Temp@50 ft-lbs=-44.00° F

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3 | Material: SAW | Heat: 88114
Orientation: NA | Capsule: 83° | Fluence:

Capsule 83° Weld
Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-90	10.0	15.5	-5.51
-70	28.0	26.6	1.36
-65	29.0	30.3	-1.35
-60	28.0	34.4	-6.45
-55	41.0	38.9	2.07
-50	48.0	43.8	4.22
-30	70.0	65.8	4.24
0	96.0	97.9	-1.95
69	117.0	129.0	-11.96
100	137.0	131.6	5.38
150	140.0	132.8	7.24
200	136.0	133.0	3.04

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 12:28 PM

A = 46.10 B = 45.10 C = 59.07 T0 = -33.31 D = 0.00

Correlation Coefficient = 0.994

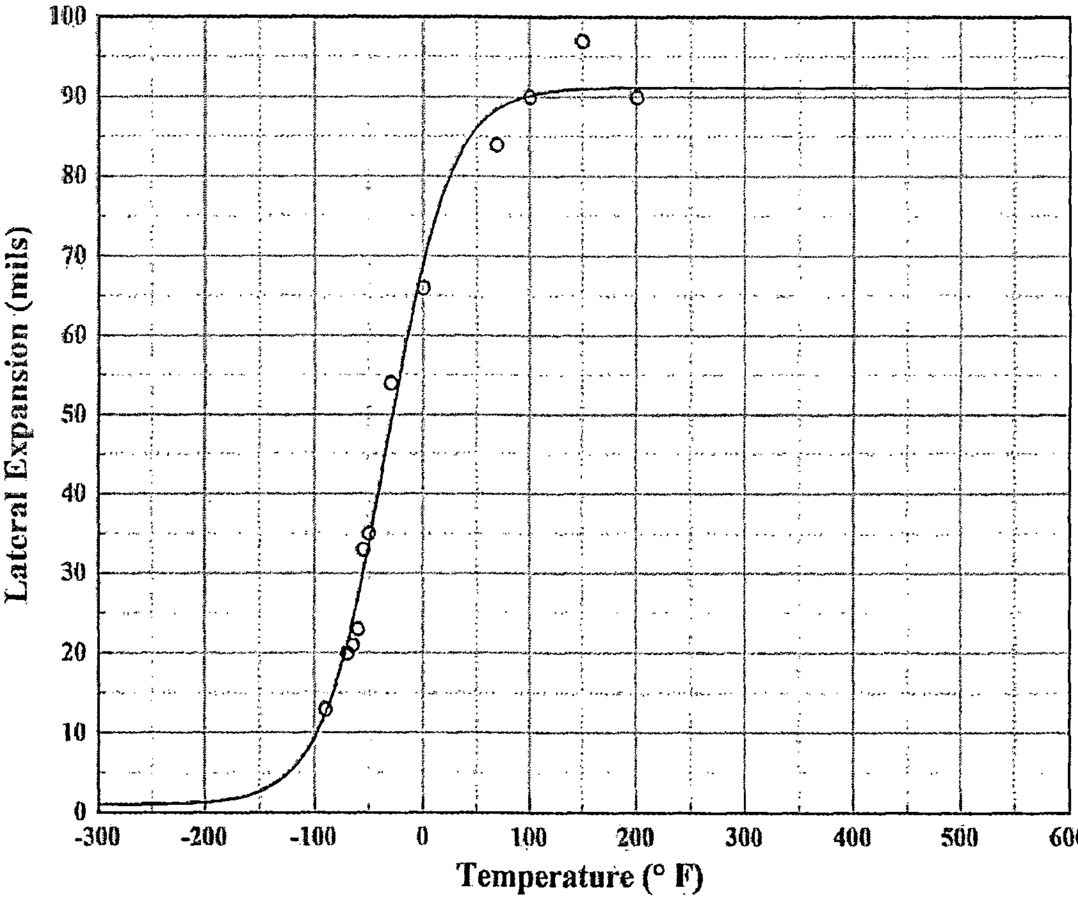
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 91.19 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-48.10° F

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3 | Material: SAW | Heat: 88114
Orientation: NA | Capsule: 83° | Fluence:

Capsule 83° Weld
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-90	13.0	12.5	0.46
-70	20.0	21.2	-1.21
-65	21.0	24.0	-2.99
-60	23.0	27.0	-4.00
-55	33.0	30.2	2.76
-50	35.0	33.7	1.32
-30	54.0	48.6	5.38
0	66.0	69.1	-3.14
69	84.0	88.5	-4.45
100	90.0	90.2	-0.21
150	97.0	91.0	5.99
200	90.0	91.2	-1.16

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Weld

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 12:32 PM

A = 50.00 B = 50.00 C = 74.91 T0 = -26.02 D = 0.00

Correlation Coefficient = 0.994

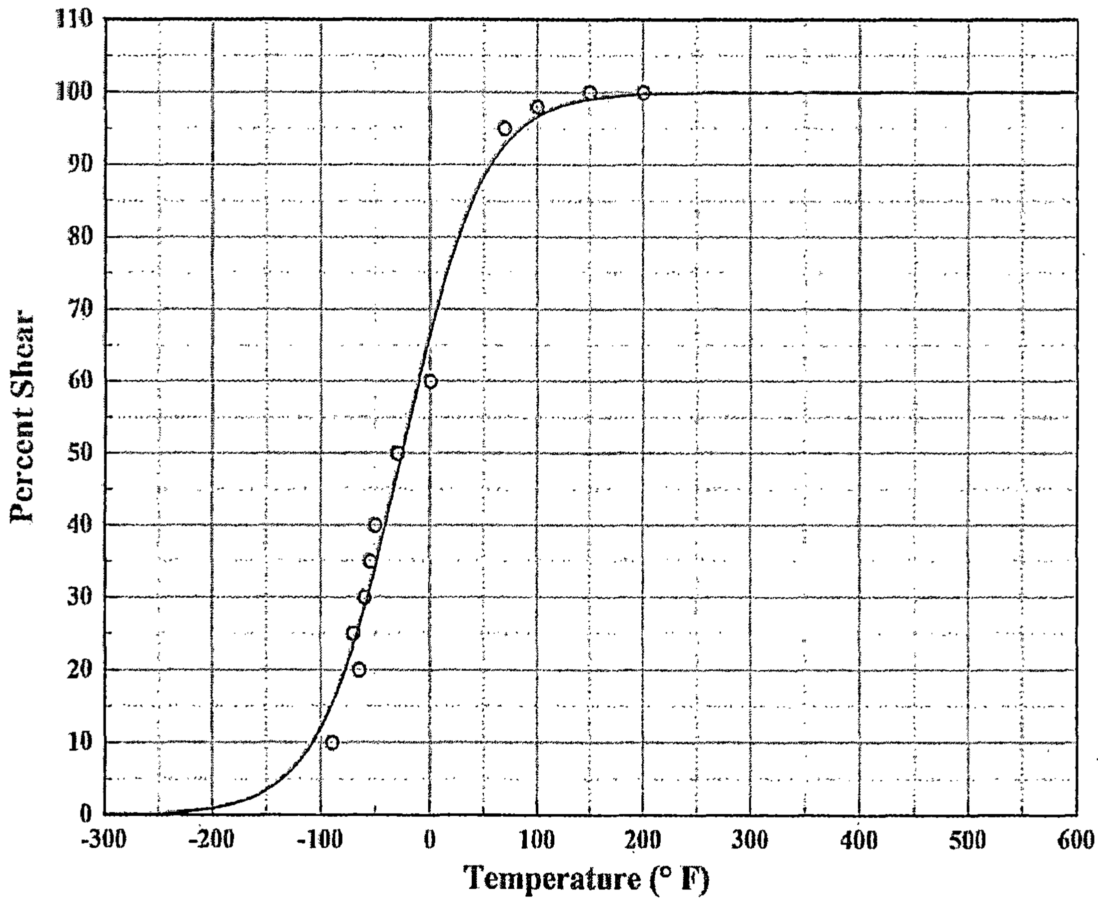
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = -26.00

Plant: Waterford 3 Material: SAW Heat: 88114

Orientation: NA Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3
Orientation: NA

Material: SAW
Capsule: 83°

Heat: 88114
Fluence:

Capsule 83° Weld
Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-90	10.0	15.3	-5.34
-70	25.0	23.6	1.39
-65	20.0	26.1	-6.10
-60	30.0	28.8	1.24
-55	35.0	31.6	3.43
-50	40.0	34.5	5.48
-30	50.0	47.3	2.65
0	60.0	66.7	-6.70
69	95.0	92.7	2.33
100	98.0	96.7	1.34
150	100.0	99.1	0.90
200	100.0	99.8	0.24

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 12:35 PM

A = 80.10 B = 77.90 C = 131.27 T0 = 15.92 D = 0.00

Correlation Coefficient = 0.979

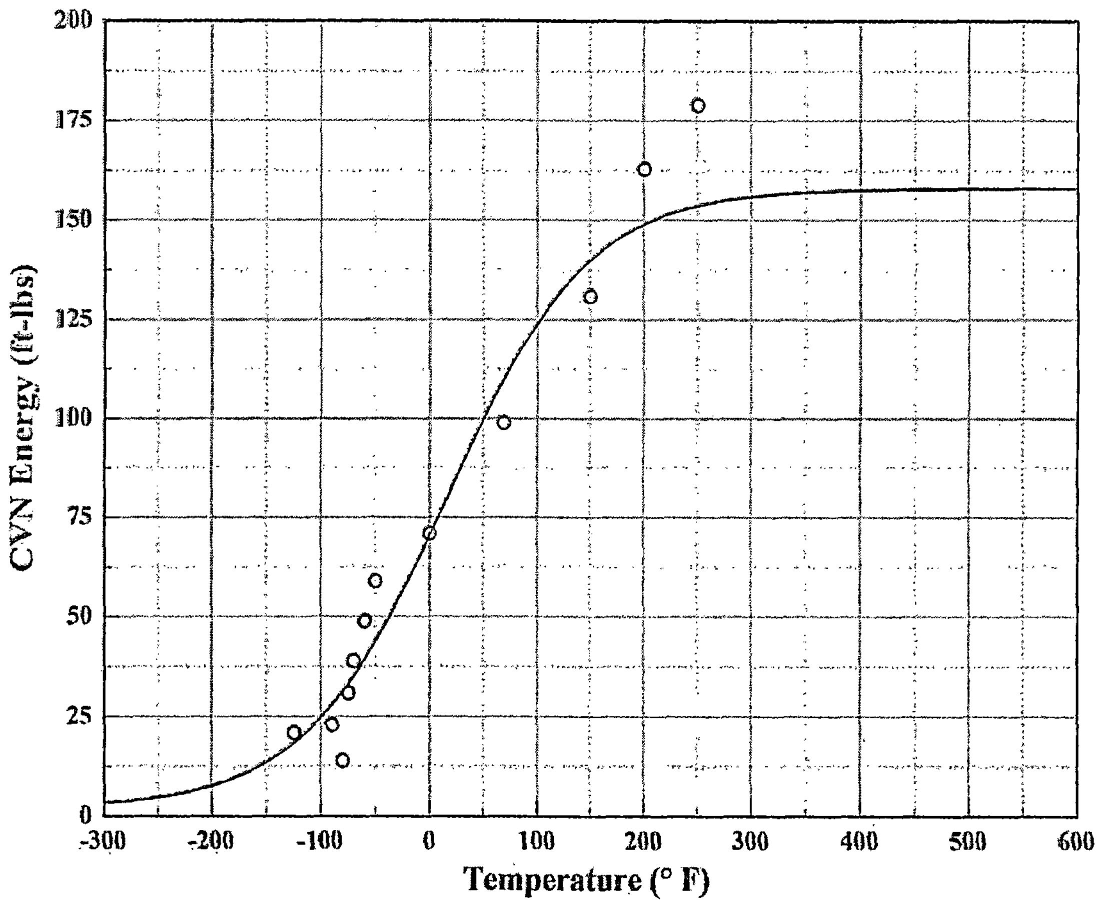
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 158.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-84.30° F Temp@35 ft-lbs=-70.80° F Temp@50 ft-lbs=-37.50° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: NA Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: NA Capsule: 83° Fluence:

Capsule 83° Heat Affected Zone

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-125	21.0	18.5	2.50
-90	23.0	28.1	-5.07
-80	14.0	31.5	-17.53
-75	31.0	33.4	-2.38
-70	39.0	35.3	3.67
-60	49.0	39.5	9.52
-50	59.0	44.0	15.03
0	71.0	70.7	0.30
69	99.0	110.0	-10.99
150	131.0	140.1	-9.12
200	163.0	149.1	13.89
250	179.0	153.7	25.28

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 12:56 PM

A = 43.71 B = 42.71 C = 107.56 T0 = -18.35 D = 0.00

Correlation Coefficient = 0.984

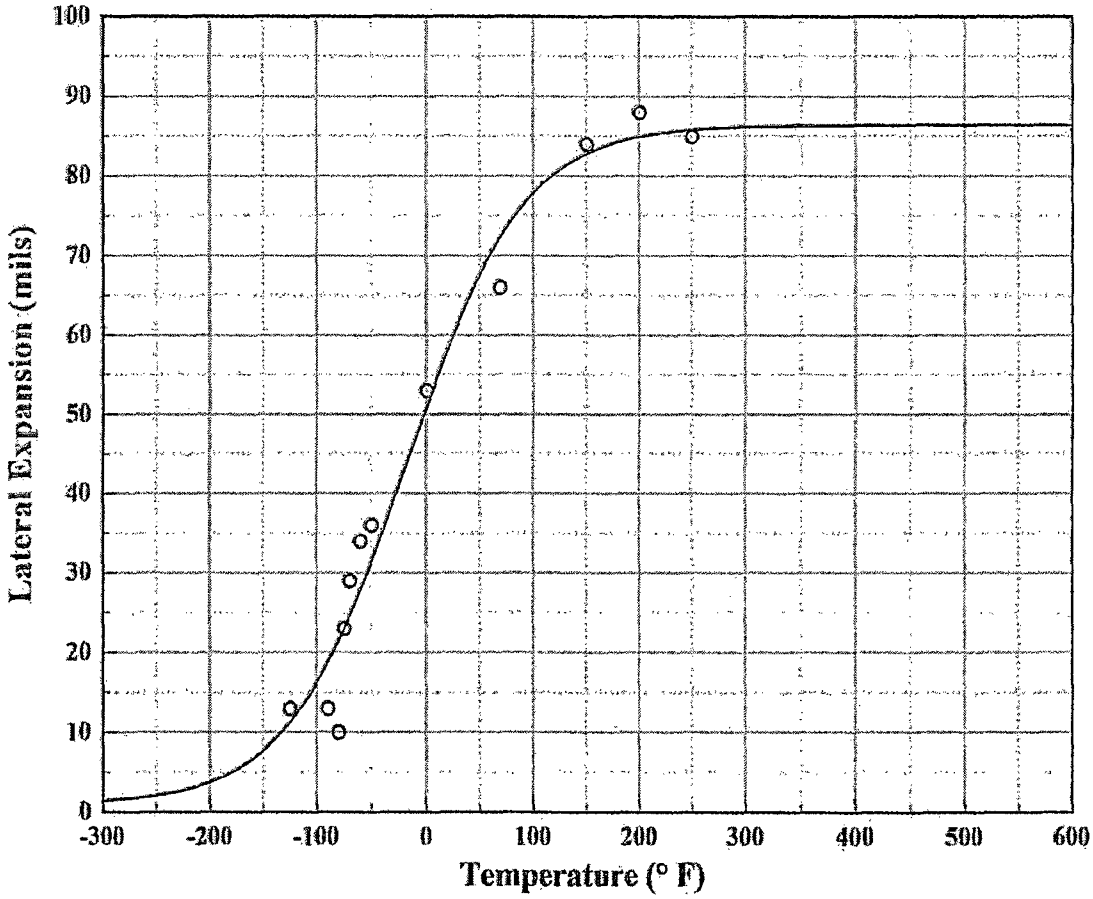
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 86.43 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-40.50° F

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: NA Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: NA Capsule: 83° Fluence:

Capsule 83° Heat Affected Zone
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-125	13.0	11.3	1.66
-90	13.0	18.8	-5.84
-80	10.0	21.6	-11.60
-75	23.0	23.1	-0.09
-70	29.0	24.6	4.35
-60	34.0	28.0	6.04
-50	36.0	31.5	4.50
0	53.0	50.9	2.07
69	66.0	72.4	-6.36
150	84.0	82.9	1.15
200	88.0	85.0	3.02
250	85.0	85.8	-0.85

CVGraph 6.0 02/26/2015 Page 2/2

Capsule 83° Heat Affected Zone

CVGraph 6.0: Hyperbolic Tangent Curve Printed on 2/26/2015 12:59 PM

A = 50.00 B = 50.00 C = 96.55 T0 = -15.95 D = 0.00

Correlation Coefficient = 0.979

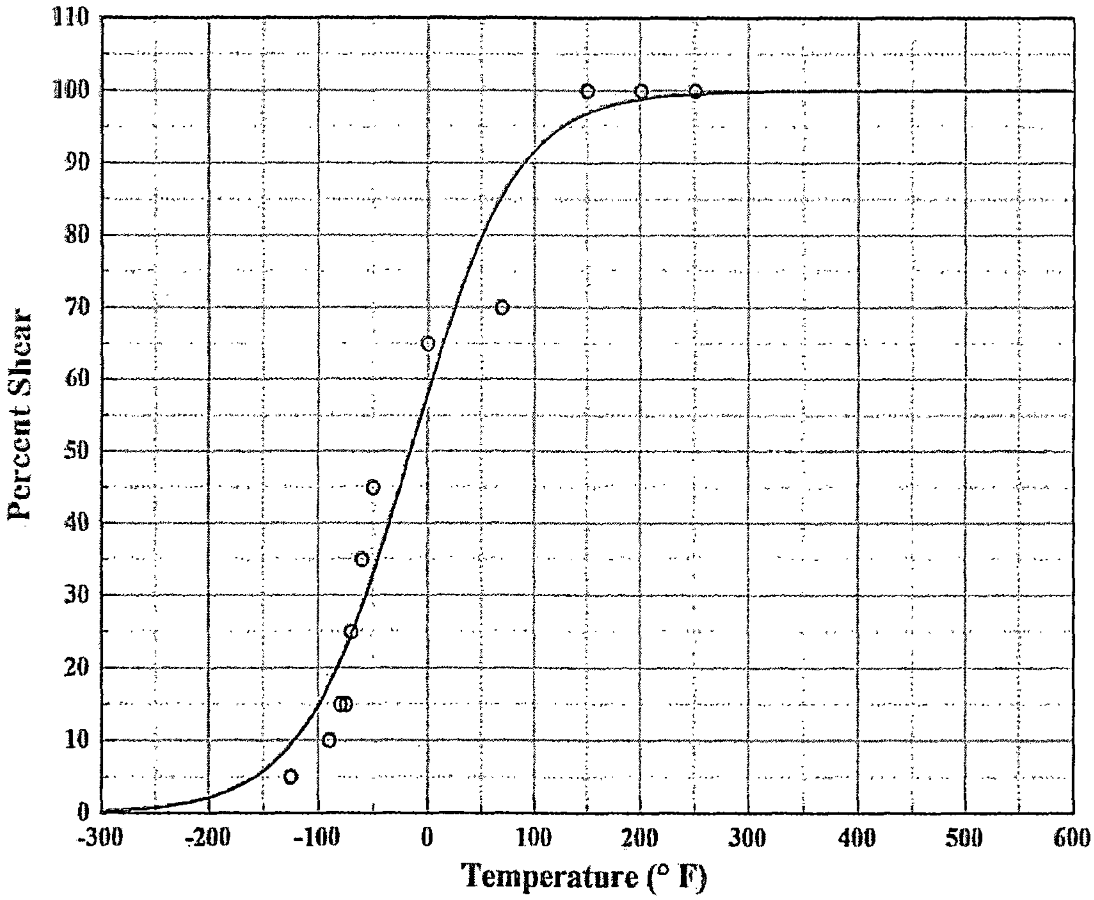
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf %Shear = 100.00 (Fixed) Lower Shelf %Shear = 0.00 (Fixed)

Temperature at 50% Shear = -15.90

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1

Orientation: NA Capsule: 83° Fluence:



CVGraph 6.0 02/26/2015 Page 1/2

Plant: Waterford 3 Material: SA533B1 Heat: NR 57 286-1
Orientation: NA Capsule: 83° Fluence:

Capsule 83° Heat Affected Zone
Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-125	5.0	9.5	-4.46
-90	10.0	17.7	-7.74
-80	15.0	21.0	-5.97
-75	15.0	22.7	-7.74
-70	25.0	24.6	0.39
-60	35.0	28.6	6.35
-50	45.0	33.1	11.94
0	65.0	58.2	6.82
69	70.0	85.3	-15.32
150	100.0	96.9	3.11
200	100.0	98.9	1.13
250	100.0	99.6	0.40

CVGraph 6.0 02/26/2015 Page 2/2

APPENDIX D WATERFORD UNIT 3 SURVEILLANCE PROGRAM CREDIBILITY EVALUATION

D.1 INTRODUCTION

Regulatory Guide 1.99, Revision 2 [Ref. D-1] 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. Positions 2.1 and 2.2 of Regulatory Guide 1.99, Revision 2, describe 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 Positions 2.1 and 2.2 can only be applied when two or more credible surveillance data sets become available from the reactor in question.

To date there have been three surveillance capsules removed and tested from the Waterford Unit 3 reactor vessel. To use these surveillance data sets, they must be shown to be credible. In accordance with Regulatory Guide 1.99, Revision 2, the credibility of the surveillance data will be judged based on five criteria.

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

D.2 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" [Ref. D-2], as follows:

> *"the region of 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 Waterford Unit 3 reactor vessel beltline region consists of the following materials:

1. Intermediate Shell Plates M-1003-1, 2, and 3
2. Lower Shell Plates M-1004-1, 2, and 3
3. Intermediate Shell Longitudinal Welds (Heat # BOLA & HODA)
4. Lower Shell Longitudinal Welds (Heat # 83653, Flux Type Linde 0091)
5. Intermediate to Lower Shell Circumferential Weld (Heat # 88114, Flux Type Linde 0091)

Per WCAP-16002, Revision 0 [Ref. D-3], the Waterford Unit 3 surveillance program was developed to the requirements of ASTM E185-73. At the time of the surveillance program development, all of the beltline plates were considered in terms of irradiation embrittlement through end of life. Of all the beltline plates, Lower Shell Plate M-1004-2 was foreseen to be the most limiting plate. This is largely due to its initial RT_{NDT} that is significantly greater than the other beltline plates. The chemistry values (Cu and Ni weight percent) and initial upper-shelf energy values for the beltline plates are relatively consistent. No plate is clearly differentiated from the rest by its high copper or nickel content or low upper-shelf energy. Therefore, Lower Shell Plate M-1004-2 was selected as the plate material for the surveillance program.

The beltline welds all have low copper content. Since Intermediate to Lower Shell Circumferential Weld 101-171 (Heat # 88114, Flux Type Linde 0091) has the highest copper content in comparison to the other beltline welds, it was selected for the surveillance program. Lastly, selection of the beltline circumferential weld is consistent with the general practice for Combustion Engineering surveillance programs because it was considered representative material.

Based on the discussion above, Criterion 1 is met for the Waterford Unit 3 surveillance program.

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

Based on engineering judgment, the scatter in the data presented in these plots is small enough to permit the determination of the 30 ft-lb temperature and the USE of the Waterford Unit 3 surveillance materials unambiguously.

Hence, Criterion 2 is met for the Waterford Unit 3 surveillance program.

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 should normally 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 USE if the upper shelf can be clearly determined, following the definition given in ASTM E185-82 [Ref. D-4].

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. In addition, the recommended NRC methods for determining credibility will be followed. The NRC methods were presented to industry at a meeting held by the NRC on February 12 and 13, 1998 [Ref. D-5]. At this meeting, the NRC presented five cases. Of the five cases, Case 1 ("Surveillance data available from plant but no other source") most closely represents the situation for the Waterford Unit 3 surveillance plate and weld material.

Case 1: Lower Shell Plate M-1004-2 and Weld Heat # 88114

Following the NRC Case 1 guidelines, the Waterford Unit 3 surveillance plate and weld metal (Heat # 88114) will be evaluated using the Waterford Unit 3 data. This evaluation is contained in Table D-1. Note that when evaluating the credibility of the surveillance weld data, the measured ΔRT_{NDT} values for the surveillance weld material do not include the adjustment ratio procedure of Regulatory Guide 1.99, Revision 2, Position 2.1, since this calculation is based on the actual surveillance weld material measured shift values. In addition, only Waterford Unit 3 data is being considered; therefore, no temperature adjustment is required.

Table D-1 Calculation of Interim Chemistry Factors for the Credibility Evaluation using Waterford Unit 3 Surveillance Capsule Data

Material	Capsule	Capsule Fluence ($x\ 10^{19}$ n/cm², E > 1.0 MeV)	FF	ΔRT_{NDT} (°F)	FF*ΔRT_{NDT} (°F)	FF^2
Lower Shell Plate M-1004-2 (Longitudinal)	97°	0.631	0.871	6.1	5.31	0.759
	83°	2.42	1.238	13.6	16.84	1.533
Lower Shell Plate M-1004-2 (Transverse)	97°	0.631	0.871	28.0	24.39	0.759
	263°	1.45	1.103	-9.1[(a)]	-10.04	1.217
	83°	2.42	1.238	25.3	31.32	1.533
				SUM:	67.82	5.799
	$CF_{M\text{-}1004\text{-}2} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (67.82) \div (5.799) =$ **11.7°F**					
Surveillance Weld Material (Heat # 88114)	97°	0.631	0.871	23.5	20.47	0.759
	263°	1.45	1.103	6.6	7.28	1.217
	83°	2.42	1.238	19.0	23.52	1.533
				SUM:	51.27	3.508
	$CF_{Surv.\ Weld} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (51.27) \div (3.508) =$ **14.6°F**					

Note for Table D-1:

(a) Even though a reduction should not occur, using the negative measured ΔRT_{NDT} value produces the most conservative results for this credibility evaluation (See Table D-2).

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 Waterford Unit 3 Surveillance Capsule Data Scatter about the Best-Fit Line

Material	Capsule	CF (Slope$_{best-fit}$) (°F)	Capsule Fluence (x 10^{19} n/cm^2)	FF	Measured ΔRT_{NDT} (°F)	Predicted ΔRT_{NDT} (°F)	Scatter ΔRT_{NDT} (°F)	<17°F (Base Metal) <28°F (Weld)
Lower Shell Plate M-1004-2 (Longitudinal)	97°	11.7	0.631	0.871	6.1	10.2	4.1	Yes
	83°	11.7	2.42	1.238	13.6	14.5	0.9	Yes
Lower Shell Plate M-1004-2 (Transverse)	97°	11.7	0.631	0.871	28.0	10.2	17.8	No
	263°	11.7	1.45	1.103	-9.1	12.9	22.0	No
	83°	11.7	2.42	1.238	25.3	14.5	10.8	Yes
Surveillance Weld Material (Heat # 88114)	97°	14.6	0.631	0.871	23.5	12.7	10.8	Yes
	263°	14.6	1.45	1.103	6.6	16.1	9.5	Yes
	83°	14.6	2.42	1.238	19.0	18.1	0.9	Yes

From a statistical point of view, +/- 1σ would be expected to encompass 68% of the data. Table D-2 indicates that only three of the five surveillance data points fall inside the +/- 1σ of 17°F scatter band for surveillance base metals; therefore, the plate data is deemed "non-credible" per the third criterion.

Table D-2 indicates that three of the three surveillance data points fall inside the +/- 1σ of 28°F scatter band for surveillance weld materials; therefore, the surveillance weld 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 surveillance materials are contained in capsules positioned near the reactor vessel inside wall so that the irradiation conditions (fluence, flux spectrum, temperature) of the test specimens resemble, as closely as possible, the irradiation conditions of the reactor vessel. The capsules are bisected by the midplane of the core and are placed in capsule holders positioned circumferentially about the core at locations near the regions of maximum flux. 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, Criterion 4 is met for the Waterford Unit 3 surveillance program.

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 Waterford Unit 3 surveillance program does contain Standard Reference Material (SRM). The material was obtained from an A533 Grade B, Class 1 plate (HSST Plate 01). NUREG/CR-6413, ORNL/TM-13133 [Ref. D-6] contains a plot of Residual vs. Fast Fluence for the SRM (Figure 11 in the report). This Figure shows a 2σ uncertainty of 50°F. The data used for this plot is contained in Table 14 in the report. However, the NUREG Report does not consider the recalculated fluence and ΔRT_{NDT} values for Capsule 263°. Thus, Table D-3 contains an updated calculation of Residual vs. Fast Fluence, considering the recalculated capsule fluence and ΔRT_{NDT} values for Capsule 263°.

Table D-3 Calculation of Residual vs. Fast Fluence for Waterford Unit 3

Capsule	Capsule f ($x10^{19}$ n/cm^2, E > 1.0 MeV)	FF	Measured Shift(a) (°F)	RG 1.99, Rev. 2 Shift(b) (°F)	Residual(c) (°F)
263°	1.45	1.103	150.5	150.1	0.4

Notes for Table D-3:

(a) Measured ΔT_{30} value for the SRM was taken from Figure 5-13 of this report.

(b) Per NUREG/CR-6413, ORNL/TM-13133, the Cu and Ni values for the SRM (HSST Plate 01) are 0.18 and 0.66, respectively. This equates to a chemistry factor value of 136.1°F based on Regulatory Guide 1.99, Revision 2, Position 1.1. The calculated shift is thus equal to CF * FF.

(c) Residual = Absolute Value [Measured Shift – RG 1.99 Shift].

Table D-3 shows a 2σ uncertainty of less than 50°F, which is the allowable scatter in NUREG/CR-6413, ORNL/TM-13133.

Hence, Criterion 5 is met for the Waterford Unit 3 surveillance program.

D.3 CONCLUSION

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B:

- The Waterford Unit 3 surveillance plate data are deemed "non-credible"
- The Waterford Unit 3 surveillance weld data are deemed "credible"

D.4 REFERENCES

D-1 Regulatory Guide 1.99, Revision 2, *Radiation Embrittlement of Reactor Vessel Materials*, U.S. Nuclear Regulatory Commission, May 1998.

D-2 10 CFR 50, Appendix G, *Fracture Toughness Requirements*, Federal Register, Volume 60, No. 243, December 19, 1995.

D-3 Westinghouse Report WCAP-16002, Revision 0, *Analysis of Capsule 263° from the Entergy Operations Waterford Unit 3 Reactor Vessel Radiation Surveillance Program*, March 2003.

D-4 ASTM E185-82, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels*, ASTM, 1982.

D-5 K. Wichman, M. Mitchell, and A. Hiser, USNRC, Generic Letter 92-01 and RPV Integrity Assessment Workshop Handouts, *NRC/Industry Workshop on RPV Integrity Issues*, February 12, 1998.

D-6 NUREG/CR-6413; ORNL/TM-13133, *Analysis of the Irradiation Data for A302B and A533B Correlation Monitor Materials*, J. A. Wang, Oak Ridge National Laboratory, Oak Ridge, TN, April 1996.

APPENDIX E WATERFORD UNIT 3 UPPER-SHELF ENERGY EVALUATION

E.1 EVALUATION

Per Regulatory Guide 1.99, Revision 2 [Ref. E-1], the Charpy upper-shelf energy (USE) is assumed to decrease as a function of fluence and copper content as indicated in Figure 2 of the Guide (Figure E-1 of this appendix) when surveillance data is not used. Linear interpolation is permitted. In addition, if surveillance data is to be used, the decrease in upper-shelf energy may be obtained by plotting the reduced plant surveillance data on Figure 2 of the Guide (Figure E-1 of this appendix) and fitting the data with a line drawn parallel to the existing lines as the upper bound of all the data. This line should be used in preference to the existing graph.

The 32 EFPY (end-of-license) upper-shelf energy of the vessel materials can be predicted using the corresponding 1/4T fluence projection, the copper content of the beltline materials and/or the results of the capsules tested to date using Figure 2 in Regulatory Guide 1.99, Revision 2. The maximum vessel clad/base metal interface fluence value was used to determine the corresponding 1/4T fluence value at 32 EFPY.

The Waterford Unit 3 reactor vessel beltline region minimum thickness is 8.625 inches. Calculation of the 1/4T vessel fluence values at 32 EFPY for the beltline materials is shown as follows:

$$\text{Maximum Vessel Fluence @ 32 EFPY} = 2.57 \times 10^{19}\ \text{n/cm}^2\ (E > 1.0\ \text{MeV})$$

$$\text{1/4T Fluence @ 32 EFPY} = (2.57 \times 10^{19}\ \text{n/cm}^2) * e^{(-0.24 * (8.625/4))}$$

$$= 1.53 \times 10^{19}\ \text{n/cm}^2\ (E > 1.0\ \text{MeV})$$

The following pages present the Waterford Unit 3 upper-shelf energy evaluation. Figure E-1, as indicated above, is used in making predictions in accordance with Regulatory Guide 1.99, Revision 2. Table E-1 provides the predicted upper-shelf energy values for 32 EFPY (EOL).

Finally, the initial USE values have been updated in this report from the values documented in WCAP-16088-NP, Revision 2 [Ref. E-2], which were based on longitudinal Charpy data reduced by 65%. The updated values herein reflect actual measured transverse Charpy data for each of the five, non-surveillance, reactor vessel beltline plate materials. The initial USE values for the surveillance plate material, Lower Shell Plate M-1004-2, and all of the reactor vessel beltline weld materials remain unchanged from those documented in WCAP-16088-NP, Revision 2. This change was undertaken to better reflect the actual Charpy test results of the Waterford Unit 3 reactor vessel beltline plate materials.

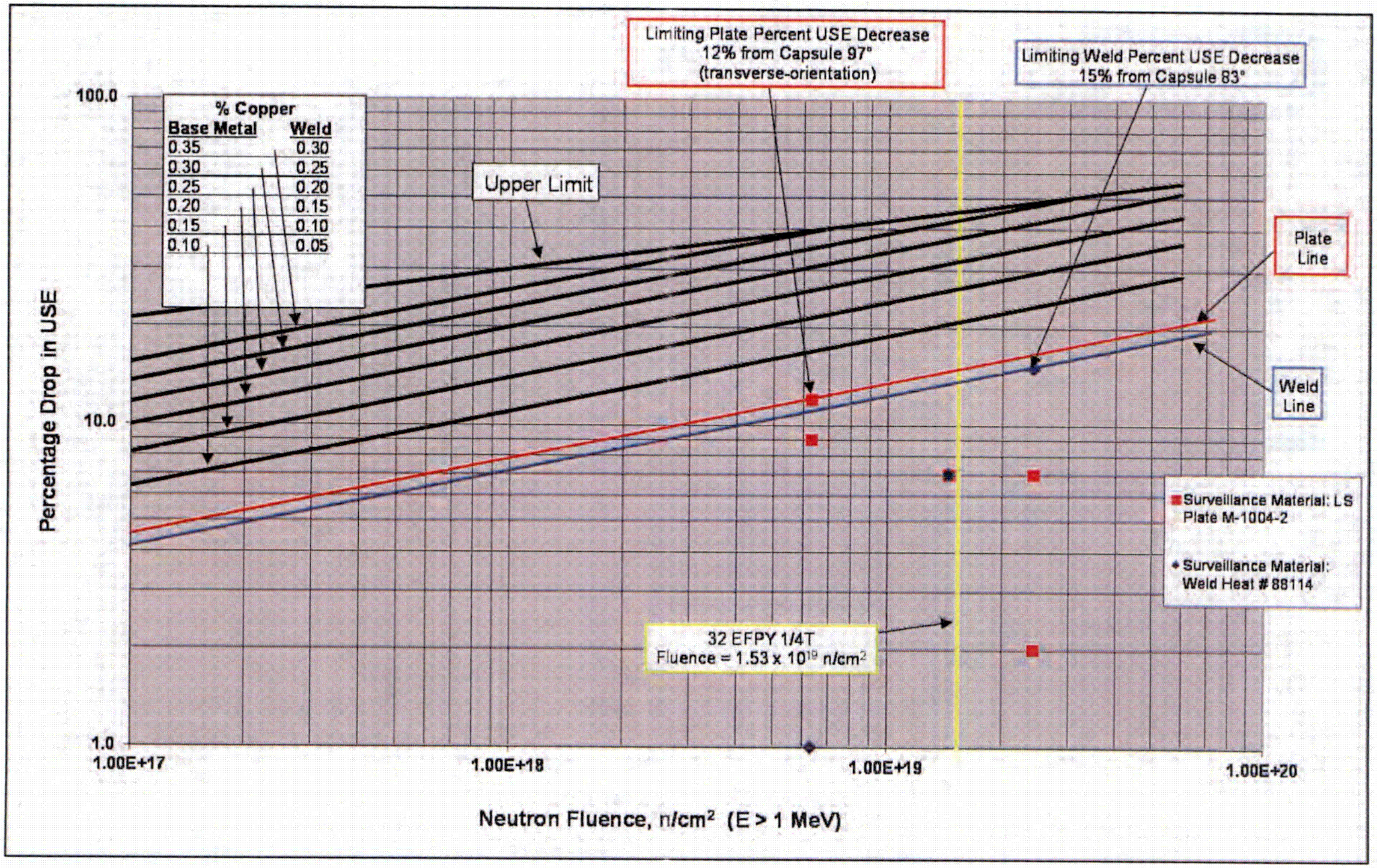


Figure E-1 **Regulatory Guide 1.99, Revision 2 Predicted Decrease in Upper-Shelf Energy as a Function of Copper and Fluence**

Table E-1 Predicted Positions 1.2 and 2.2 Upper-Shelf Energy Values at 32 EFPY

Material	Wt % Cu	1/4T EOL Fluence ($x10^{19}$ n/cm^2, E > 1.0 MeV)	Unirradiated USE (ft-lb)	Projected USE Decrease (%)	Projected EOL USE[c] (ft-lb)
Position 1.2[a]					
Intermediate Shell Plate M-1003-1	0.02	1.53	108	21	85
Intermediate Shell Plate M-1003-2	0.02	1.53	132	21	104
Intermediate Shell Plate M-1003-3	0.02	1.53	111	21	88
Lower Shell Plate M-1004-1	0.03	1.53	135	21	107
Lower Shell Plate M-1004-2	0.03	1.53	141	21	111
Lower Shell Plate M-1004-3	0.03	1.53	118	21	93
Intermediate Shell Longitudinal Weld 101-124A (Heat # BOLA & HODA)	0.02	1.53	106	21	84
Intermediate Shell Longitudinal Welds 101-124B & C (Heat # HODA)	0.02	1.53	131	21	103
Lower Shell Longitudinal Welds 101-142A, B & C (Heat # 83653)	0.03	1.53	129	21	102
Intermediate to Lower Shell Circumferential Weld 101-171 (Heat # 88114)	0.05	1.53	156	21	123
Position 2.2[b]					
Lower Shell Plate M-1004-2	0.03	1.53	141	16	118
Intermediate to Lower Shell Circumferential Weld 101-171 (Heat # 88114)	0.05	1.53	156	14	134

Notes:

(a) Calculated using the Cu wt. % value and 1/4T fluence value for each material and Regulatory Guide 1.99, Revision 2, Position 1.2. In calculating the Position 1.2 percent USE decreases, the base metal and weld Cu weight percentages were conservatively rounded up to the lowest line (Cu weight % of 0.10 for base metal, and 0.05 for weld) in Regulatory Guide 1.99, Revision 2, Figure 2.

(b) Calculated using surveillance capsule measured percent decrease in USE from Table 5-10 and Regulatory Guide 1.99, Revision 2, Position 2.2; see Figure E-1.

(c) The initial USE values for the five non-surveillance reactor vessel beltline plate materials have been updated from those documented in WCAP-16088-NP, Revision 2, which were based on longitudinal Charpy data reduced by 65%. The updated values herein reflect actual measured transverse Charpy data. The initial USE values for the surveillance plate material, Lower Shell Plate M-1004-2, and all of the reactor vessel beltline weld materials remain unchanged from those documented in WCAP-16088-NP, Revision 2.

USE Conclusion

As shown in Table E-1, all of the Waterford Unit 3 reactor vessel beltline materials are projected to remain above the USE screening criterion of 50 ft-lbs (per 10 CFR 50, Appendix G) at 32 EFPY.

E.2 REFERENCES

E-1 Regulatory Guide 1.99, Revision 2, *Radiation Embrittlement of Reactor Vessel Materials*, U.S. Nuclear Regulatory Commission, May 1998.

E-2 Westinghouse Report WCAP-16088-NP, Revision 2, *Waterford Unit 3 Reactor Vessel Heatup and Cooldown Limit Curves for Normal Operation*, June 2012.

Attachment 2

W3F1-2015-0056

List of Regulatory Commitments

(1 page)

List of Regulatory Commitments

The following table identifies those actions committed to by Entergy in this document. Any other statements in this submittal are provided for information purposes and are not considered to be regulatory commitments.

COMMITMENT	TYPE (Check One)		SCHEDULED COMPLETION DATE (If Required)
	ONE-TIME ACTION	CONTINUING COMPLIANCE	
Submit a LAR to the NRC by April 30, 2019 to request approval of a change to the existing TS 3.4.8.1 Figures 3.4-2 and 3.4-3 to incorporate the Capsule 83° test results as documented in report WCAP-17969-NP to allow operation past 32 EFPY.	X		April 30, 2019