Calvert Cliffs Nuclear Power Plant

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Lusby, Maryland 20657

CENG[SM]

a joint venture of

Constellation Energy

eDF

CALVERT CLIFFS
NUCLEAR POWER PLANT

March 29, 2011

U. S. Nuclear Regulatory Commission
Washington, DC 20555

ATTENTION: Document Control Desk

SUBJECT: Calvert Cliffs Nuclear Power Plant
Unit No. 1; Docket No. 50-317
Transmittal of Unit 1 Reactor Vessel Surveillance Capsule Report

In accordance with 10 CFR Part 50, Appendix H IV.A, Calvert Cliffs hereby submits Westinghouse Report WCAP-17365-NP, "Analysis of Capsule 284° from the Calvert Cliffs Unit No. 1 Reactor Vessel Radiation Surveillance Program," Revision 0 (Attachment 1). This report presents the analysis of the test results from the Unit 1 284° capsule. The 284° capsule test results were used to evaluate reactor vessel material properties following 26.17 effective full power years of plant operation. Based on this analysis, properties of the reactor beltline materials are predicted to remain more than adequate for the continued safe operation of Unit 1 through the end of the renewed license period. There are no changes to the pressure temperature limits associated with the Technical Specifications or to the operating procedures required to meet the limits in this report.

Should you have questions regarding this matter, please contact Mr. Douglas E. Lauver at (410) 495-5219.

Very truly yours,

James J. Stanley
Manager-Engineering Services

JJS/PSF/bjd

Attachment: (1) WCAP-17365-NP, Analysis of Capsule 284° from the Calvert Cliffs Unit No. 1 Reactor Vessel Radiation Surveillance Program

A008
NRR

cc: **(Without Attachment)**
D. V. Pickett, NRC
W. M. Dean, NRC
Resident Inspector, NRC
S. Gray, DNR

ATTACHMENT (1)

WCAP-17365-NP, ANALYSIS OF CAPSULE 284° FROM THE CALVERT CLIFFS UNIT NO. 1 REACTOR VESSEL RADIATION SURVEILLANCE PROGRAM

Westinghouse Non-Proprietary Class 3

WCAP-17365-NP
Revision 0

March 2011

Analysis of Capsule 284° from the Calvert Cliffs Unit No. 1 Reactor Vessel Radiation Surveillance Program

Westinghouse

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-17365-NP
Revision 0

Analysis of Capsule 284° from the Calvert Cliffs Unit No. 1 Reactor Vessel Radiation Surveillance Program

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March 2011

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EXECUTIVE SUMMARY

The purpose of this report is to document the testing results of surveillance Capsule 284° from Calvert Cliffs Unit 1. Capsule 284° was removed at 26.53 Effective Full Power Years, EFPY, (at 2700 MWt, the licensed rated thermal power at the time of capsule removal) or equivalently 26.17 EFPY (at 2737 MWt, the rated thermal power after Appendix K uprate) 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. In this document, EFPYs are expressed in terms of 2737 MWt, the reference power of the analysis, except in the case of exposure cumulative parameters Tables for which EFPY at 2700 MWt for the first nineteen cycles are also included for the purpose of direct comparison with previous documents. Capsule 284° received a fluence of 2.33 x 10^{19} n/cm^2 (E > 1.0 MeV) after irradiation to 26.17 EFPY. The peak clad/base metal interface vessel fluence after 26.17 EFPY of plant operation was 2.32 x 10^{19} n/cm^2 (E > 1.0 MeV).

This evaluation led to the following conclusions: 1) The measured percent decrease in upper-shelf energy for all the surveillance materials contained in Calvert Cliffs Unit 1 Capsule 284° are less than the Regulatory Guide 1.99, Revision 2 [Reference 1] predictions. 2) The Calvert Cliffs Unit 1 surveillance plate and weld data is judged to be credible. This credibility evaluation can be found in Appendix D. 3) All beltline materials exhibit a more than adequate upper-shelf energy level for continued safe plant operation and are predicted to maintain an upper-shelf energy greater than 50 ft-lb throughout the current license (32 EFPY) and license extension (48 EFPY) as required by 10 CFR 50, Appendix G [Reference 2]. The upper-shelf energy evaluation is presented in Appendix E. 4) All the surveillance capsule materials are predicted to meet the Pressurized Thermal Shock (PTS) screening criteria throughout the current license (32 EFPY) and license extension (48 EFPY) as required by 10 CFR 50.61 [Reference 3]. The PTS evaluation is presented in Appendix F. 5) The Capsule 284° evaluations, material properties and fluence, did not affect the applicability of the current Calvert Cliffs Unit 1 pressure-temperature (P-T) limit curves. The current Calvert Cliffs Unit 1 P-T limit curves are now applicable through license extension (48 EFPY). The applicability evaluation is presented in Appendix G.

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 284°, the third capsule removed and tested from the Calvert Cliffs Unit 1 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 5.3, Charpy V-notch plots for Capsule 284°. The previous capsules, along with the original program unirradiated material input data, were updated using CVGRAPH, Version 5.3, from the hand-drawn plots presented in earlier 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 the previous Calvert Cliffs Unit 1 capsule reports.

- Capsule 284° received an average fast neutron fluence (E > 1.0 MeV) of 2.33 x 10^{19} n/cm^2 after 26.17 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel Intermediate Shell Plate D-7206-3 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (longitudinal orientation), resulted in an irradiated 30 ft-lb transition temperature of 104.8°F and an irradiated 50 ft-lb transition temperature of 147.5°F. This results in a 30 ft-lb transition temperature increase of 98.6°F and a 50 ft-lb transition temperature increase of 111.6°F for the longitudinally oriented specimens.

- Irradiation of the reactor vessel Intermediate Shell Plate D-7206-3 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), resulted in an irradiated 30 ft-lb transition temperature of 149.6°F and an irradiated 50 ft-lb transition temperature of 182.9°F. This results in a 30 ft-lb transition temperature increase of 127.0°F and a 50 ft-lb transition temperature increase of 128.1°F for the transversely oriented specimens.

- Irradiation of the Surveillance Program Weld Metal (Heat # 33A277) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 16.7°F and an irradiated 50 ft-lb transition temperature of 60.7°F. This results in a 30 ft-lb transition temperature increase of 78.0°F and a 50 ft-lb transition temperature increase of 99.2°F.

- Irradiation of the Heat-Affected-Zone (HAZ) Material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 28.8°F and an irradiated 50 ft-lb transition temperature of 82.3°F. This results in a 30 ft-lb transition temperature increase of 137.3°F and a 50 ft-lb transition temperature increase of 147.1°F.

- The average upper-shelf energy of Intermediate Shell Plate D-7206-3 (longitudinal orientation) resulted in an average energy decrease of 34.1 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 103.3 ft-lb for the longitudinally oriented specimens.

- The average upper-shelf energy of Intermediate Shell Plate D-7206-3 (transverse orientation) resulted in an average energy decrease of 19.8 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 87.7 ft-lb for the transversely oriented specimens.

- The average upper-shelf energy of the Surveillance Program Weld Metal Charpy specimens resulted in an average energy decrease of 43.8 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 108.0 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 14.6 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 113.7 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 [Reference 1], for the Calvert Cliffs Unit 1 reactor vessel surveillance materials are presented in Table 5-10.

  Standard Reference Material (SRM) specimens were not included in the Calvert Cliffs Capsule 284°. However, the SRM unirradiated and previously withdrawn capsule results were reanalyzed in this report. The SRM was contained in Capsule 263°, which was irradiated to a neutron fluence of 5.05 x 10^{18} n/cm^2 (E > 1.0 MeV). The results of the SRM reanalysis will be included in Table 5-10 and shown in Figures 5-13 through 5-15.

  - Irradiation of the Standard Reference Material HSST 01 Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 132.0°F and an irradiated 50 ft-lb transition temperature of 167.0°F. This results in a 30 ft-lb transition temperature increase of 99.8°F and a 50 ft-lb transition temperature increase of 112.1°F.

  - The average upper-shelf energy of the Standard Reference Material HSST 01 Charpy specimens resulted in an average energy decrease of 26.1 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 109.4 ft-lb for the SRM.

- Based on the credibility evaluation presented in Appendix D, the Calvert Cliffs Unit 1 surveillance plate and weld data is credible.

- Based on the upper-shelf energy evaluation in Appendix E, all beltline materials exhibit a more than adequate upper-shelf energy level for continued safe plant operation and are predicted to maintain an upper-shelf energy greater than 50 ft-lb throughout the end of the current license (32 EFPY) and license extension (48 EFPY) as required by 10 CFR 50, Appendix G [Reference 2].

- Based on the Pressurized Thermal Shock (PTS) evaluation in Appendix F, all the surveillance capsule materials are predicted to meet the 10 CFR 50.61 [Reference 3] screening criteria throughout the current license (32 EFPY) and license extension (48 EFPY).

- Based on the Pressure-Temperature (P-T) limit curve applicability check in Appendix G, the Capsule 284° evaluations, material properties and fluence did not affect the applicability of the current Calvert

Cliffs Unit 1 P-T limit curves. The current Calvert Cliffs Unit 1 P-T limit curves are now applicable through license extension (48 EFPY).

- The calculated 48 EFPY (end-of-life-extension) neutron fluence values (E > 1.0 MeV) at the core mid-plane for the Calvert Cliffs Unit 1 reactor vessel using the Regulatory Guide 1.99, Revision 2, attenuation formula (i.e., Equation # 3 in the guide) are as follows:

  Calculated (48 EFPY): Vessel inner radius* = 3.86×10^{19} n/cm^2 (Taken from Table 6-2)

  Vessel 1/4 thickness = 2.301×10^{19} n/cm^2

  Vessel 3/4 thickness = 0.817×10^{19} n/cm^2

  * Clad/base metal interface

- All of the calculations and dosimetry evaluations described in this present analysis were based on nuclear cross-section data derived from ENDF/B-VI and made use of the latest available calculational tools. Furthermore, the neutron transport and dosimetry evaluation methodologies follow the guidance of Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence" [Reference 25]. 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 [Reference 26].

- With the methodology of the present analysis, the calculated peak neutron fluence (E > 1.0 MeV) at the clad/base metal interface (CBMI) for the Calvert Cliffs Unit 1 reactor vessel at the End-of-Cycle (EOC) 10 is 1.44×10^{19} n/cm^2. The last reported [Reference 22, Table 6-2] calculated peak neutron fluence (E > 1.0 MeV) at the CBMI for the Calvert Cliffs Unit 1 reactor vessel at the EOC 10 was 1.96×10^{19} n/cm^2. The difference in calculated fluences is attributed to the following:

  - The present analysis uses the average of as-built pressure vessel inside radius measurements (86.915 inches) while Reference 22 used the minimum reference inside diameter (ID) (172 inches). In other words, the present analysis positions the CBMI 0.915 inches radially outward compared to the last report [Reference 22, Figure 6-2].

  - The present analysis uses the BUGLE 96 [Reference 28] cross section library which is based on ENDF/B-VI while Reference 22 used the CASK (DCL-23F) cross section library which is based on ENDF/B-V. Notice that Regulatory Guide 1.190 indicates in page 2 footnote:

    "It should be noted that in many applications the ENDF/B-IV and the first three MODs of the ENDF/B-V iron cross-sections result in as much as ~20% underprediction of the vessel inner-wall fluence and ~35% underprediction of the cavity fluence (Refs. 5-7). Updated ENDF/B-VI iron cross-section data (Ref. 8) have been demonstrated to provide a more accurate determination of the flux attenuation through iron (Refs. 5, 6) and are strongly recommended. These new iron data are included in ENDF/B-VI."

- For Capsule 97°, the present analysis provides a calculated capsule axial-span-average fast neutron fluence (E > 1 MeV) of 1.94 x 10^{19} n/cm^2. The last report summary, Reference 22, indicated that the capsule received an average fast fluence of 2.64 x 10^{19} n/cm^2 (E > 1 MeV). The difference in calculated fluences is attributed to the following:

  - The present analysis uses the average as-built pressure vessel inside radius (86.915 inches) while Reference 22 used the minimum reference inner diameter (ID) (172 inches).

  - The present analysis uses the average of as-built capsule center radius measurements (85.445 inches) while Reference 22 (Figure 6-2) used the design reference inner diameter (ID) to the center of the capsule (169.362 inches).

  - Reference 22 Table 6-2 indicated that 2.64 x 10^{19} n/cm^2 is the capsules' peak fast neutron fluence (E > 1.0 MeV) and Reference 22 page 6-9 last paragraph indicated the calculation included a 3% bias factor.

  - The present analysis uses the BUGLE 96 [Reference 28] cross section library which is based on ENDF/B-VI while Reference 22 used the CASK [Reference 31] cross section library which is based on ENDF/B-V.

- For Capsule 97°, the present analysis provides a best-estimate least-squares average fast neutron fluence (E > 1 MeV) of 1.98 x 10^{19} n/cm^2. The last report [Reference 22 page 6-9 last paragraph], indicated that the fast neutron flux (E > 1 MeV) interpreted from the measurements were 6.92, 6.45 and 6.50 (x 10^{10} n/cm^2-s) for the top, middle and bottom compartments (where the seconds are in term of 2700 MWt). Thus, the corresponding fluence values were 2.42, 2.25 and 2.27 (x 10^{19} n/cm^2), respectively. The difference in calculated fluences is attributed to the following:

  - The present analysis uses the Iron, Nickel and Cobalt (bare and Cadmium-shielded) measurements as the input to the least-squares analysis for Capsule 97°. The Titanium and Uranium (Cadmium-shielded) monitors were discarded:

    1. The Titanium measurements were found to be +4.5σ from a database distribution of six similar plants capsules Titanium monitors measurements. Deviations of less than ±3σ are considered acceptable. Additionally, for Capsule 263°, "the titanium results were 20 to 30 percent higher, and were not considered valid due to the condition of the postirradiated wires. They were very brittle and a copper color which was assumed to be titanium nitride" [Reference 21].

    2. The Uranium measurements were found to be -2.3σ from a database distribution of four similar plants capsules Uranium cadmium-shielded monitors measurements. However, the Uranium cadmium-shielded monitors tend to melt with the cover providing poor specimens [Reference 21].

  In the last report [Reference 22] the interpretation of measured flux was performed "using four of the fast neutron dosimeters (Iron, Nickel, U-238 and Titanium)." Reference 22 states that "the corrections for the photofission in U-238 are not applied to the "best-estimate" fast neutron fluxes derived from the U-238 dosimeters because there is little or no measurement data currently available to confirm the gamma ray flux levels calculated at the dosimeter position." In the present analysis, the photofission correction for Capsule 97° is calculated to be 0.8450 which is defined as the neutron fission activity divided by the total activity.

- The present analysis uses SNLRML "Recommended Dosimetry Cross Section Compendium" [Reference 29] while the last report [Reference 22] used DOSDAM 81-82 "Multigroup Cross Section in SAND II Format for Spectral, Integral, and Damage Analysis" [Reference 30].

- Because the dosimetry cross sections are collapsed with the capsule best-estimate spectrum in the case of the present analysis, and the calculated spectrum in the case of Reference 22, all the reasons that determine the difference in calculated fluxes in Capsule 97° also affect the interpretation of the fluxes from measurements.

2 INTRODUCTION

This report presents the results of the examination of Capsule 284°, the third capsule removed and tested in the continuing surveillance program, which monitors the effects of neutron irradiation on the Constellation Energy Calvert Cliffs Unit 1 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Calvert Cliffs Unit 1 reactor pressure vessel materials was designed and recommended by Combustion Engineering, Inc. A description of the surveillance program and the pre-irradiation mechanical properties of the reactor vessel materials is presented in TR-ESS-001 [Reference 4], "Testing and Evaluation of Calvert Cliffs, Units 1 and 2 Reactor Vessel Materials Irradiation Surveillance Program Baseline Samples for the Baltimore Gas & Electric Co." and CENPD-34 [Reference 5], "Summary Report on Manufacture of Test Specimens and Assembly of Capsules for Irradiation Surveillance of Calvert Cliffs – Unit 1 Reactor Vessel Materials." The original surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-70 [Reference 6], "Recommended Practice Surveillance Tests on Structural Materials in Nuclear Reactors." The Comprehensive Reactor Vessel Surveillance Program (CRVSP), Revision 5 [Reference 7] documents the current surveillance capsule and reactor vessel integrity programs for Calvert Cliffs Unit 1.

Capsule 284° was removed from the reactor after 26.17 EFPY of exposure and shipped to the Westinghouse Research and Technology Unit (RTU) Hot Cell Facility, where the post-irradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

This report summarizes the testing of the post-irradiation data obtained from surveillance Capsule 284° removed from the Calvert Cliffs Unit 1 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 Calvert Cliffs Unit 1 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 [Reference 8]. The method uses fracture mechanics concepts and is based on the reference nil-ductility transition temperature (RT_{NDT}).

RT_{NDT} is defined as the greater of either the drop-weight nil-ductility transition temperature (NDTT per ASTM E208 [Reference 9]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (transverse) to the major 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 [Reference 8]. The K_{Ic} curve is a lower bound of static fracture toughness results obtained from several heats of pressure vessel steel. When a given material is indexed to the K_{Ic} curve, allowable stress intensity factors can be obtained for this material as a function of temperature. Allowable operating limits can then be determined using these allowable stress intensity factors.

RT_{NDT} and, in turn, the operating limits of nuclear power plants can be adjusted to account for the effects of radiation on the reactor vessel material properties. The changes in mechanical properties of a given reactor pressure vessel steel, due to irradiation, can be monitored by a reactor vessel surveillance program, such as the Calvert Cliffs Unit 1 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 Calvert Cliffs Unit 1 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant startup. The six surveillance capsules were positioned adjacent to the reactor vessel inside wall so that the irradiation conditions are very similar to those of the reactor vessel. The six surveillance capsules are bisected by the core mid-plane and are positioned in capsule holders at azimuthal locations near the regions of maximum neutron flux. The capsules contain specimens made from the following:

- Intermediate Shell Plate D-7206-3 (longitudinal orientation)
- Intermediate Shell Plate D-7206-3 (transverse orientation)
- Weld metal fabricated by a submerged arc process with Mil B-4 weld filler wire, Heat Number 33A277 Linde Type 1092 flux, Lot Number 3922, which is identical in Heat Number and flux type to that used in the actual fabrication of the intermediate to lower shell circumferential weld seam 9-203
- Weld heat-affected-zone (HAZ) material of Intermediate Shell Plates D-7206-1 and D-7206-3
- Heavy-Section Steel Technology (HSST) 01 Standard Reference Material (SRM)

Test material obtained from the intermediate shell course 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 and ¾ thickness locations of the plate after performing a simulated post-weld stress-relieving treatment on the test material. Test specimens were also removed from weld and heat-affected-zone metal of stress-relieved weldments joining Intermediate Shell Plate D-7206-1 and adjacent Intermediate Shell Plate D-7206-2, and Intermediate Shell Plate D-7206-1 and adjacent Intermediate Shell Plate D-7206-3, respectively.

Charpy V-notch impact specimens from Intermediate Shell Plate D-7206-3 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 Intermediate Shell Plate D-7206-3 were machined in both the longitudinal and transverse orientations. Tensile specimens from the weld metal were oriented perpendicular to the welding direction.

Some of the capsules in the Calvert Cliffs Unit 1 surveillance program contain Standard Reference Material, which was supplied by the Oak Ridge National Laboratory, from plate material used in the Heavy-Section Steel Technology (HSST) Program. The material for the Calvert Cliffs Unit 1 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 contained flux monitor assemblies made from 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 contained (12 total) thermal monitors made from four low-melting-point eutectic alloys, which were sealed in glass tubes. The thermal monitors were located in three different positions in the capsule. These thermal monitors were 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:

2.5% Ag, 5.0% Sn, 92.5% Pb	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 heat treatment of the unirradiated surveillance materials are presented in Tables 4-1 through 4-4. The arrangement of the various mechanical specimens in Capsule 284° is shown in Table 4-5. The data in Tables 4-1 through 4-5 was obtained from the unirradiated surveillance program report, TR-ESS-001 [Reference 4], Table I, the manufacture of Calvert Cliffs Unit 1 test specimens report, CENPD-34 [Reference 5], Tables III, XIX and XX, and the CRVSP, Revision 5 [Reference 7], Table 3-7.

Capsule 284° was removed after 26.17 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 on the Charpy impact specimen compartment and the tensile and flux-monitor compartment assembly in the Calvert Cliffs Unit 1 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 Calvert Cliffs Unit 1 Surveillance Test Materials – Intermediate Shell Plates (Unirradiated)

Element	Intermediate Shell Plate D-7206-1	Intermediate Shell Plate D-7206-2	Intermediate Shell Plate D-7206-3[(b)]
	Combustion Engineering Analysis[(a)]		
Si	0.21	0.24	0.24
S	0.014	0.014	0.016
P	0.011	0.011	0.011
Mn	1.31	1.28	1.29
C	0.25	0.26	0.26
Cr	0.09	0.08	0.08
Ni	**0.55**	**0.64**	**0.64**
Mo	0.58	0.67	0.69
V	0.002	0.001	0.001
Cb	0.01	0.01	0.01
B	0.0002	0.0003	0.0004
Co	0.010	0.008	0.008
N	0.007	0.008	0.008
Cu	**0.11**	**0.12**	**0.12**
Al	0.027	0.028	0.022
W	0.01	0.01	0.01
Ti	0.01	0.01	0.01
As	0.01	0.01	0.01
Sn	0.002	0.005	0.005
Zr	0.002	0.001	0.001

Notes:

(a) Data obtained from CENPD-34 [Reference 5].
(b) Surveillance program test plate.

Table 4-2 Chemical Composition (wt %) of the Calvert Cliffs Unit 1 Surveillance Test Materials – Lower Shell Plates (Unirradiated)

Element	Lower Shell Plate D-7207-1	Lower Shell Plate D-7207-2	Lower Shell Plate D-7207-3
	Combustion Engineering Analysis[(a)]		
Si	0.24	0.22	0.22
S	0.016	0.014	0.014
P	0.010	0.009	0.008
Mn	1.29	1.31	1.26
C	0.23	0.25	0.22
Cr	0.11	0.12	0.12
Ni	**0.54**	**0.56**	**0.53**
Mo	0.57	0.55	0.54
V	0.002	0.001	0.001
Cb	0.01	0.01	0.01
B	0.0003	0.0002	0.0002
Co	0.011	0.010	0.010
N	0.008	0.010	0.007
Cu	**0.13**	**0.11**	**0.11**
Al	0.034	0.016	0.020
W	0.01	0.01	0.01
Ti	0.01	0.01	0.01
As	0.01	0.01	0.01
Sn	0.002	0.002	0.001
Zr	0.002	0.002	0.002

Note:
(a) Data obtained from CENPD-34 [Reference 5].

Table 4-3 Chemical Composition (wt %) of the Calvert Cliffs Unit 1 Surveillance Test Materials – Weld and HAZ (Unirradiated)

Element	Intermediate to Lower Shell Girth Weld 9-203 (Heat # 33A277/Linde 1092) [D-7206-1/D-7206-2][(b)]	HAZ Material [D-7206-1/D-7206-3][(c)]
	Combustion Engineering Analysis[(a)]	
Si	0.20	0.18
S	0.013	0.013
P	0.014	0.014
Mn	1.05	1.20
C	0.15	0.15
Cr	0.06	0.06
Ni	**0.16**[(d)]	**0.19**
Mo	0.55	0.56
V	0.003	0.003
Cb	0.01	0.01
B	0.0001	0.0002
Co	0.003	0.003
N	0.008	0.008
Cu	**0.18**[(d)]	**0.18**
Al	0.002	0.001
W	0.01	0.01
Ti	0.01	0.01
As	0.01	0.01
Sn	0.002	0.002
Zr	0.001	0.001

Notes:

(a) Data obtained from CENPD-34 [Reference 5], unless otherwise noted.
(b) Surveillance program weld material.
(c) Surveillance program HAZ material.
(d) Data obtained from CRVSP, Revision 5 [Reference 7]. These best-estimate average values were determined using information from various sources.

Table 4-4 Heat Treatment History of the Calvert Cliffs Unit 1 Surveillance Test Materials

Material[a]	Temperature[a] (°F)	Time[a] (hours)	Cooling[a]
Intermediate Shell Plates D-7206-1, D-7206-2 and D-7206-3	Austenitized @ 1600 ± 25 (871°C)	4.00	Water-Quenched
	Tempered @ 1225 ± 25 (663°C)	4.00	Air-Cooled
	Stress Relieved @ 1150 ± 25 (621°C)	40.00	Furnace-Cooled to 600°F (316°C)
Lower Shell Plates D-7207-1, D-7207-2 and D-7207-3	Austenitized @ 1600 ± 25 (871°C)	4.00	Water-Quenched
	Tempered @ 1225 ± 25 (663°C)	4.00	Air-Cooled
	Stress Relieved @ 1150 ± 25 (621°C)	40.00	Furnace-Cooled to 600°F (316°C)
Surveillance Weld Metal (Heat # 33A277/Linde 1092)	Stress Relieved @ 1125 ± 25 (607°C)	0.25	See note (b)
	Stress Relieved @ 1150 (621°C)	40.00	Furnace-Cooled to 600°F (316°C)

Notes:

(a) Data obtained from TR-ESS-001 [Reference 4].
(b) Interstage stress relief was performed at 1125 ± 25°F for 0.25 hours followed by final stress relief at 1150°F for 40.00 hours. Furnace cooling was performed following the final stress relief.

Table 4-5 Arrangement of Encapsulated Test Specimens within Calvert Cliffs Unit 1 Capsule 284°

Compartment Position[a]	Compartment Number (Specimen Type and Material)[a]	Specimen Numbers[a]
1	4614 (Tensile HAZ Specimens)	4KJ, 4KK, 4KE
2	4624 (Charpy Impact HAZ Specimens)	464, 462, 45L, 46C, 46D, 463, 46B, 46E, 45U, 45T, 461, 45M
3	4632 (Charpy Impact Transverse Plate Specimens)	24D, 23Y, 24J, 254, 23U, 252, 242, 241, 253, 251, 24E, 24K
4	4641 (Tensile Longitudinal Plate Specimens)	1K4, 1JB, 1KY
5	4651 (Charpy Impact Longitudinal Plate Specimens)	16A, 16D, 15E, 165, 16C, 16B, 16E, 15D, 15J, 166, 167, 164
6	4663 (Charpy Impact Weld Specimens)	36L, 36P, 35U, 36E, 36U, 36J, 36T, 36D, 36M, 371, 36Y, 36K
7	4673 (Tensile Weld Specimens)	3KT, 3L3, 3L1

Note:
(a) Data obtained from CENPD-34 [Reference 5].

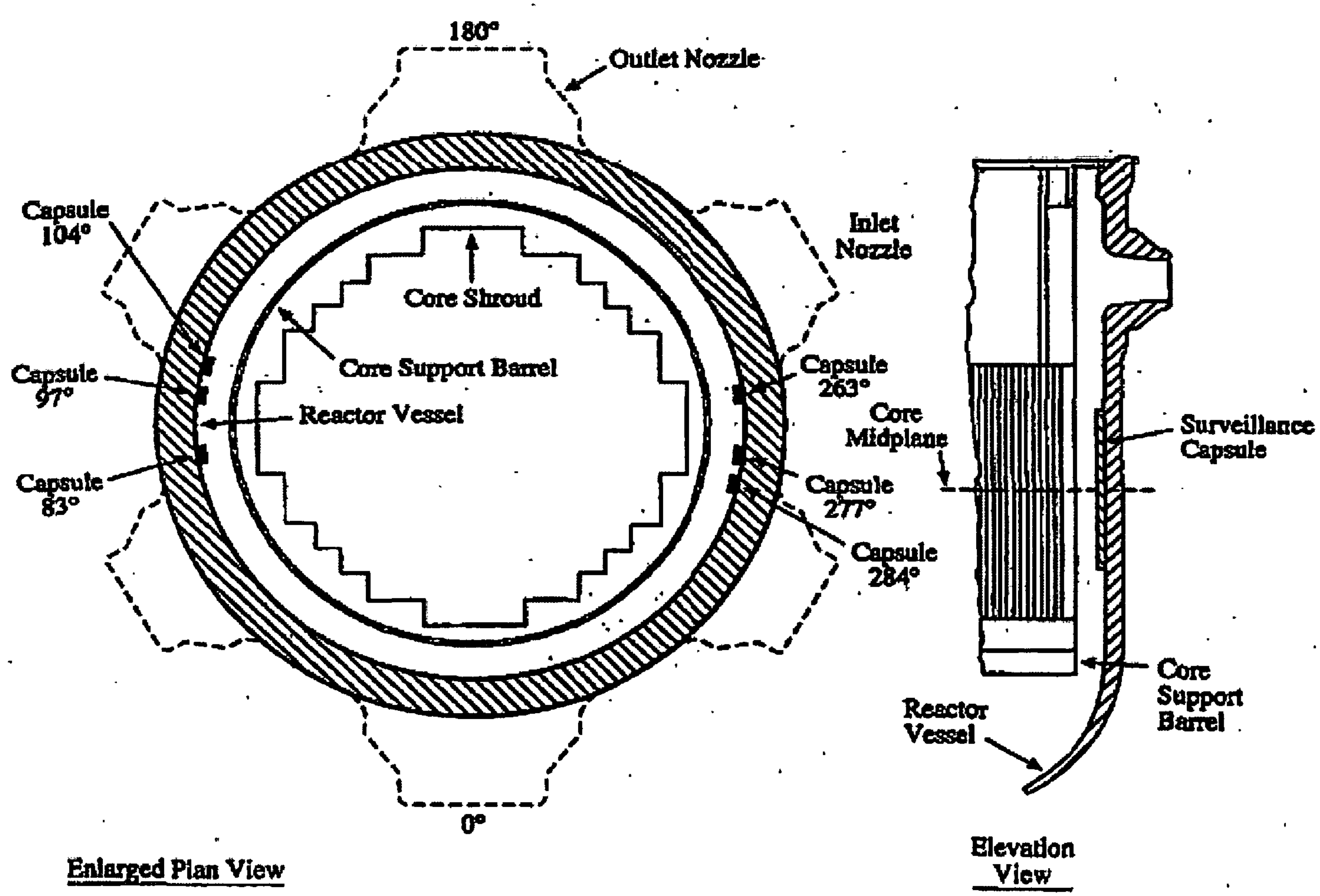


Figure 4-1 Arrangement of Surveillance Capsules in the Calvert Cliffs Unit 1 Reactor Vessel

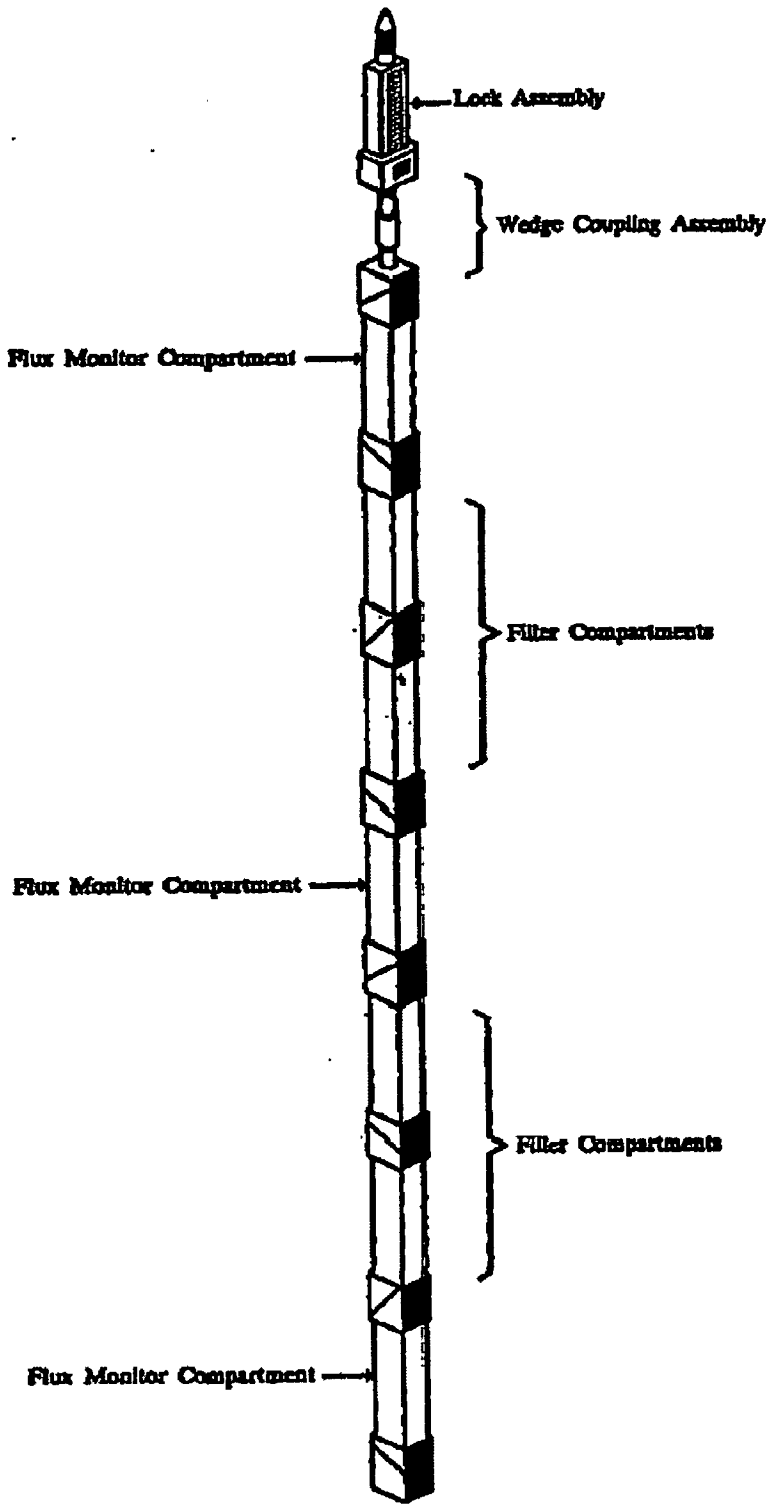


Figure 4-2 Original Surveillance Program Capsule in the Calvert Cliffs Unit 1 Reactor Vessel

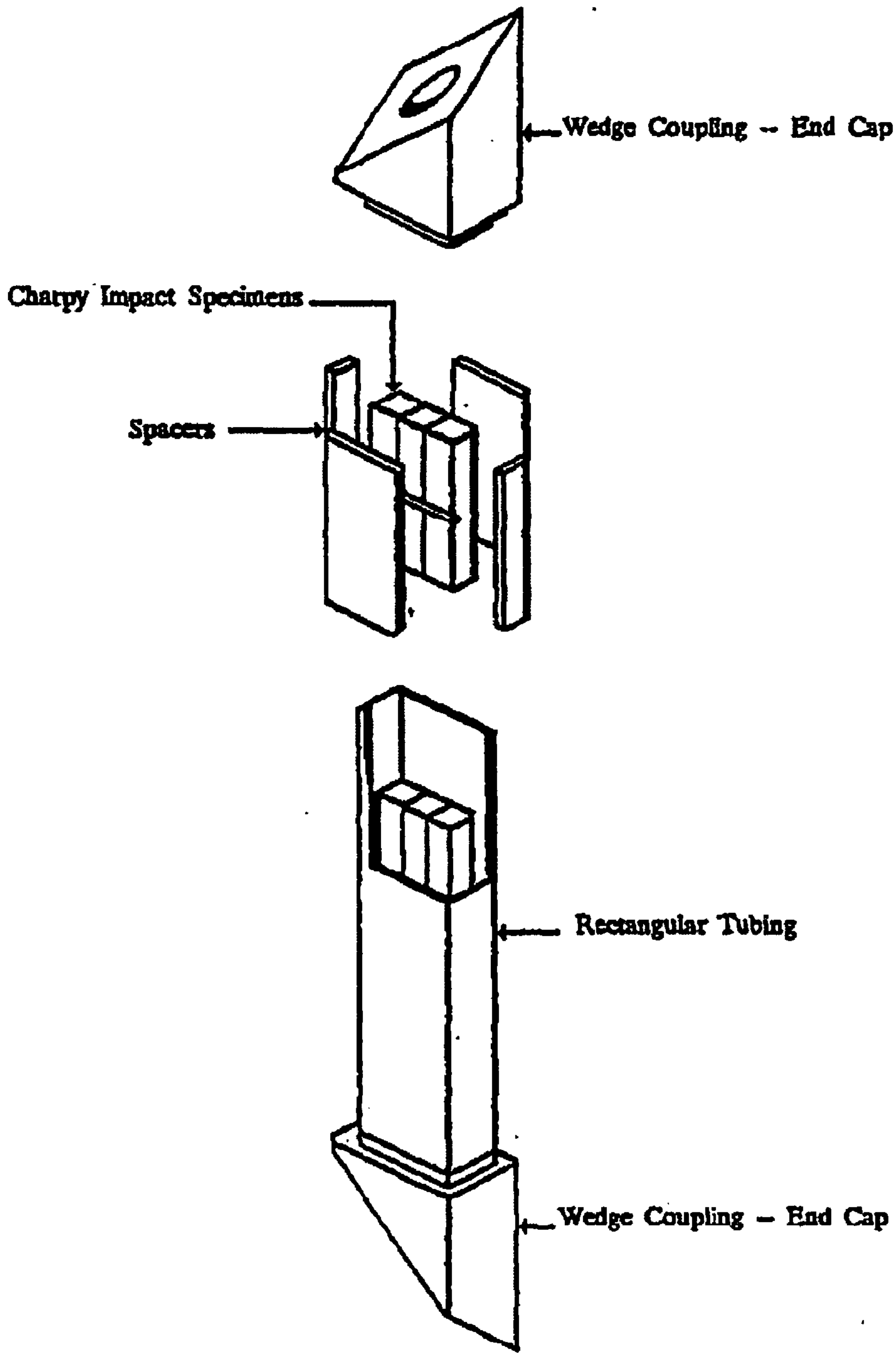


Figure 4-3 Surveillance Capsule Charpy Impact Specimen Compartment Assembly in the Calvert Cliffs Unit 1 Reactor Vessel

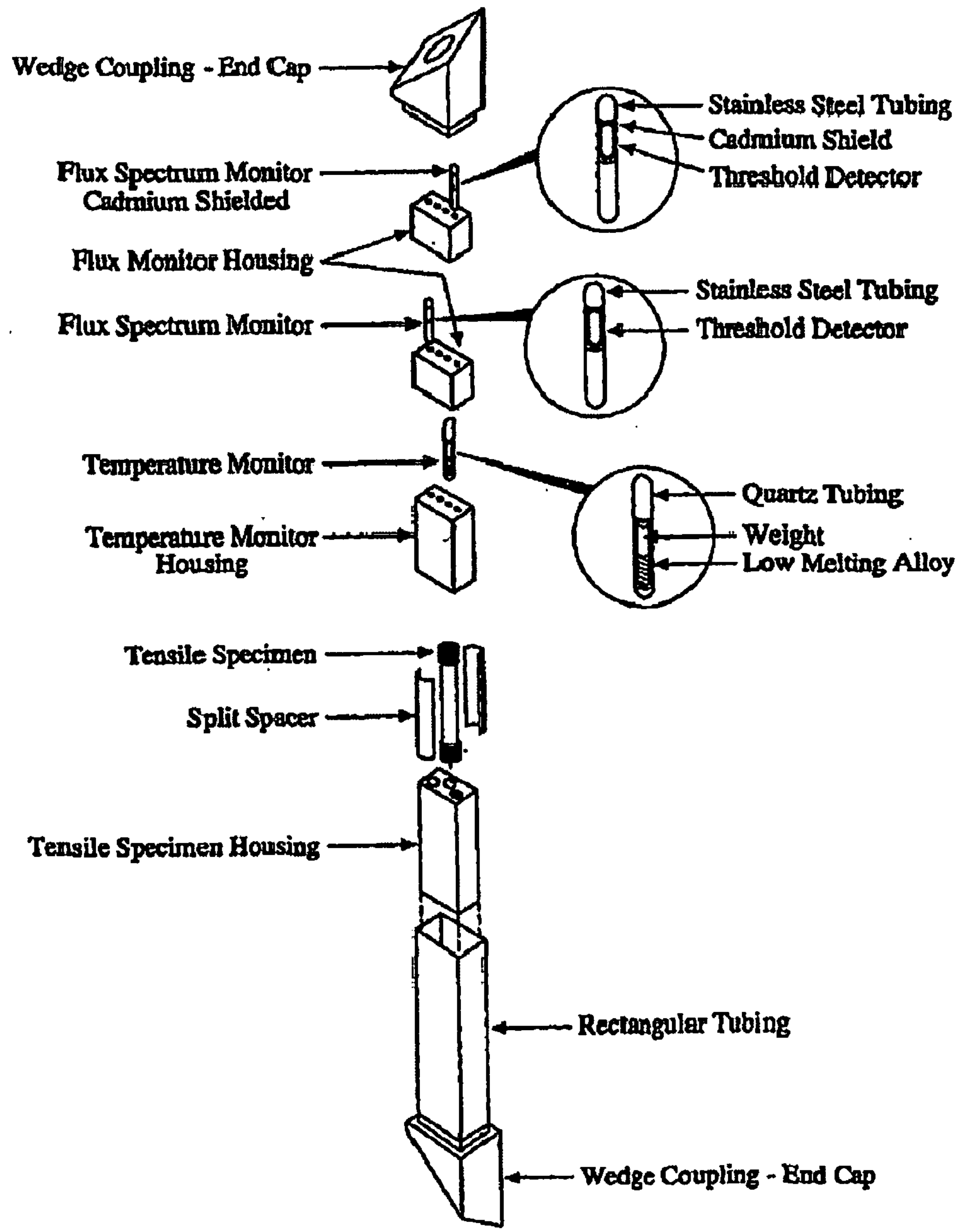


Figure 4-4 Surveillance Capsule Tensile and Flux-Monitor Compartment Assembly in the Calvert Cliffs Unit 1 Reactor Vessel

5 TESTING OF SPECIMENS FROM CAPSULE 284°

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed at the Hot Cell Facility at the Westinghouse Research and Technology Unit (RTU). Testing was performed in accordance with 10 CFR 50, Appendices G and H [Reference 2], ASTM Specification E185-82 [Reference 10], and Westinghouse Procedure RMF 8402, Revision 3 [Reference 11], as detailed by Westinghouse RMF Procedures 8102, Revision 3 [Reference 12], and 8103, Revision 2 [Reference 13].

The capsule was opened upon receipt at the hot cell laboratory per Procedure RMF 8804, Revision 3 [Reference 14]. The specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in CENPD-34 [Reference 5]. All items were in their proper locations.

Examination of the thermal monitors indicated that six of the twelve thermal monitors had 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 E23-07a [Reference 15] and Procedure RMF 8103 on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy machine is instrumented with an Instron Impulse instrumentation system, feeding information into a computer. Note that the instrumented Charpy data is for information only. The Instron Impulse system has not been calibrated to ASTM Standard E2298-09 [Reference 16], so the instrumented energy, load, time and stress data are considered for information only. With this system, load-time and energy-time signals can be recorded in addition to the standard dial measurement of Charpy energy. The 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 time to general yielding, the maximum load (F_m) and the time to maximum load can be determined. Under some test conditions, a sharp drop in load indicative of fast fracture was observed. The load at which fast fracture was initiated is identified as brittle fracture load (F_{bf}). The termination of 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 E2298-09. Note that some of the signals were filtered, which is not recommended by ASTM Standard E2298-09.

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 to fracture (W_t) and the energy at maximum load (W_m).

The yield stress (σ_Y) was calculated from the three-point bend formula having the following expression [Reference 17]:

$$\sigma_Y = F_{GY} \frac{L}{B(W-a)^2 C} \qquad \text{(Eqn. 5-1)}$$

where L = distance between the specimen supports in the impact testing machine; B = the width of the specimen measured parallel to the notch; W = height of the specimen, measured perpendicularly to the notch; a = notch depth. The constant C is dependent on the notch flank angle (φ), notch root radius (ρ) and the type of loading (i.e., pure bending or three-point bending). In three-point bending, for a Charpy specimen in which φ = 45° and ρ = 0.010 in., Equation 5-1 is valid with C = 1.21.

Therefore, (for L = 4W),

$$\sigma_Y = F_{GY} \frac{L}{B(W-a)^2\,1.21} = \frac{3.305\,F_{GY} W}{B(W-a)^2} \qquad \text{(Eqn. 5-2)}$$

For the Charpy specimen, B = 0.394 in., W = 0.394 in., and a = 0.079 in. Equation 5-2 then reduces to:

$$\sigma_Y = 33.3\,F_{GY} \qquad \text{(Eqn. 5-3)}$$

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

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

$$A = B(W-a) = 0.1241\,sq.\,in. \qquad \text{(Eqn. 5-4)}$$

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM E23-07a [Reference 15] and A370-09 [Reference 18]. The lateral expansion was measured using a dial gage rig similar to that shown in the same specifications.

Tensile tests were performed on a 20,000-pound Instron, split console test machine (Model 1115) per Procedure RMF 8102 [Reference 12]. The tensile testing met ASTM Specifications E8-09 [Reference 19] and E21-09 [Reference 20] except for a minor deviation that does not have any significant effect on the results provided in this report.

Extension measurements were made with a linear variable displacement transducer (LVDT) extensometer. The extensometer gage length was 1.00 inch. Elevated test temperatures were obtained with a three-zone electric resistance split-tube furnace with a 9-inch hot zone. All tests were conducted in air.

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

5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule 284°, which received a fluence of 2.33 x 10^{19} n/cm^2 (E > 1.0 MeV) in 26.17 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-ESS-001 [Reference 4], BMI-1280 [Reference 21], and BAW-2160 [Reference 22]. The previous capsules, along with the original program unirradiated material input data, were updated using CVGRAPH, Version 5.3 from the hand-drawn plots presented in these earlier 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 the previous Calvert Cliffs Unit 1 capsule reports.

The transition temperature increases and changes in upper-shelf energies for the Capsule 284° materials are summarized in Table 5-9 and led to the following results:

- Irradiation of the reactor vessel Intermediate Shell Plate D-7206-3 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (longitudinal orientation), resulted in an irradiated 30 ft-lb transition temperature of 104.8°F and an irradiated 50 ft-lb transition temperature of 147.5°F. This results in a 30 ft-lb transition temperature increase of 98.6°F and a 50 ft-lb transition temperature increase of 111.6°F for the longitudinally oriented specimens.

- Irradiation of the reactor vessel Intermediate Shell Plate D-7206-3 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), resulted in an irradiated 30 ft-lb transition temperature of 149.6°F and an irradiated 50 ft-lb transition temperature of 182.9°F. This results in a 30 ft-lb transition temperature increase of 127.0°F and a 50 ft-lb transition temperature increase of 128.1°F for the transversely oriented specimens.

- Irradiation of the Surveillance Program Weld Metal (Heat # 33A277) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 16.7°F and an irradiated 50 ft-lb transition temperature of 60.7°F. This results in a 30 ft-lb transition temperature increase of 78.0°F and a 50 ft-lb transition temperature increase of 99.2°F.

- Irradiation of the Heat-Affected-Zone (HAZ) Material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 28.8°F and an irradiated 50 ft-lb transition temperature of 82.3°F. This results in a 30 ft-lb transition temperature increase of 137.3°F and a 50 ft-lb transition temperature increase of 147.1°F.

- The average upper-shelf energy of Intermediate Shell Plate D-7206-3 (longitudinal orientation) resulted in an average energy decrease of 34.1 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 103.3 ft-lb for the longitudinally oriented specimens.

- The average upper-shelf energy of Intermediate Shell Plate D-7206-3 (transverse orientation) resulted in an average energy decrease of 19.8 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 87.7 ft-lb for the transversely oriented specimens.

- The average upper-shelf energy of the Surveillance Program Weld Metal Charpy specimens resulted in an average energy decrease of 43.8 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 108.0 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 14.6 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 113.7 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 [Reference 1] for the Calvert Cliffs Unit 1 reactor vessel surveillance materials are presented in Table 5-10.

  Standard Reference Material (SRM) specimens were not included in the Calvert Cliffs Capsule 284°. However, the SRM unirradiated and previously withdrawn capsule results were reanalyzed in this report. The SRM was contained in Capsule 263°, which was irradiated to a neutron fluence of 5.05 x 10^{18} n/cm^2 (E > 1.0 MeV). The results of the SRM reanalysis will be included in Table 5-10 and shown in Figures 5-13 through 5-15.

  - Irradiation of the Standard Reference Material HSST 01 Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 132.0°F and an irradiated 50 ft-lb transition temperature of 167.0°F. This results in a 30 ft-lb transition temperature increase of 99.8°F and a 50 ft-lb transition temperature increase of 112.1°F.

  - The average upper-shelf energy of the Standard Reference Material HSST 01 Charpy specimens resulted in an average energy decrease of 26.1 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 109.4 ft-lb for the SRM.

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.

All beltline materials exhibit a more than adequate upper-shelf energy level for continued safe plant operation and are predicted to maintain an upper-shelf energy greater than 50 ft-lb throughout the end of the current license (32 EFPY) and license extension (48 EFPY) as required by 10 CFR 50, Appendix G [Reference 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 284° irradiated to 2.33 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 Intermediate Shell Plate D-7206-3 (longitudinal orientation) indicated that irradiation to 2.33 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 [Reference 4]. See Figure 5-20 and Table 5-11.

The results of the tensile tests performed on the surveillance weld metal indicated that irradiation to 2.33 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 [Reference 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 2.33 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 [Reference 4]. See Figure 5-22 and Table 5-11.

The fractured tensile specimens for the Intermediate Shell Plate D-7206-3 material are shown in Figure 5-23, the fractured tensile specimens for the surveillance weld metal are shown in Figure 5-24 and the fractured tensile specimens for the HAZ material are shown in Figure 5-25. The engineering stress-strain curves for the tensile tests are shown in Figures 5-26 through 5-28 for Intermediate Shell Plate D-7206-3, Figures 5-29 through 5-31 for the surveillance weld metal, and Figures 5-32 through 5-34 for the HAZ material.

Table 5-1 Charpy V-notch Data for the Calvert Cliffs Unit 1 Intermediate Shell Plate D-7206-3 Irradiated to a Fluence of 2.33 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	%
164	25	-4	10	14	11	0.28	5
16B	75	24	23	31	22	0.56	10
167	90	32	37	50	31	0.79	15
15D	100	38	33	45	30	0.76	15
16A	125	52	36	49	35	0.89	20
165	150	66	42	57	40	1.02	40
16D	160	71	50	68	42	1.07	50
16C	175	79	55	75	48	1.22	60
15J	225	107	101	137	83	2.11	98
15E	300	149	106	144	83	2.11	100
16E	325	163	103	140	83	2.11	100
166	350	177	103	140	81	2.06	100

Table 5-2 Charpy V-notch Data for the Calvert Cliffs Unit 1 Intermediate Shell Plate D-7206-3 Irradiated to a Fluence of 2.33 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	%
241	25	-4	9	12	11	0.28	5
24D	125	52	23	31	22	0.56	15
24K	140	60	30	41	29	0.74	30
24E	150	66	29	39	30	0.76	25
252	160	71	31	42	26	0.66	25
251	175	79	39	53	39	0.99	35
253	185	85	47	64	44	1.12	60
254	195	91	63	85	51	1.30	80
242	200	93	64	87	56	1.42	80
23U	300	149	90	122	74	1.88	100
23Y	325	163	92	125	79	2.01	100
24J	350	177	81	110	68	1.73	100

Table 5-3 Charpy V-notch Data for the Calvert Cliffs Unit 1 Surveillance Weld Metal (Heat # 33A277) Irradiated to a Fluence of 2.33 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	%
36M	-50	-46	8	11	11	0.28	10
36D	0	-18	28	38	27	0.69	20
36E	15	-9	41	56	34	0.86	35
371	25	-4	36	49	29	0.74	25
36J	35	2	36	49	32	0.81	30
35U	50	10	16	22	19	0.48	25
36L	50	10	53	72	47	1.20	40
36K	60	16	51	69	45	1.14	50
36Y	75	24	64	87	49	1.25	70
36U	250	121	111	150	85	2.16	100
36T	275	135	106	144	77	1.96	100
36P	300	149	107	145	85	2.16	100

Table 5-4 Charpy V-notch Data for the Calvert Cliffs Unit 1 Heat-Affected-Zone (HAZ) Material Irradiated to a Fluence of 2.33 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	%
463	-75	-59	12	16	13	0.33	15
46B	25	-4	28	38	23	0.59	25
45L	30	-1	46	62	37	0.94	35
45U	40	4	54	73	41	1.04	35
46E	50	10	25	34	22	0.56	30
464	60	16	32	43	34	0.86	35
46C	75	24	30	41	27	0.69	40
462	125	52	73	99	52	1.32	85
46D	225	107	88	119	65	1.65	90
461	250	121	116	157	80	2.04	100
45M	275	135	121	164	85	2.16	100
45T	300	149	104	141	76	1.93	100

Table 5-5 Instrumented Charpy Impact Test Results for the Calvert Cliffs Unit 1 Intermediate Shell Plate D-7206-3 Irradiated to a Fluence of 2.33x 10^{19} n/cm^2 (E > 1.0 MeV) (Longitudinal Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy, W_t (ft-lb)	Normalized Energies (ft-lb/in^2)			General Yield Load, F_{gy} (lb)	Time to F_{gy} (msec)	Max. Load, F_m (lb)	Time to F_m (msec)	Fract. Load, F_{bf}(lb)	Arrest Load, F_a (lb)	Yield Stress (ksi)	Flow Stress (ksi)
			Total W_t/A	At P_M W_m/A	Prop. W_p/A								
164	25	12	97	25	72	3500	0.08	3937	0.09	3593	N/A	117	124
16B	75	24	192	123	69	3200	0.07	4113	0.29	4037	N/A	107	122
167	90	36	293	185	108	2800	0.07	4091	0.43	3946	N/A	93	115
15D	100	33	269	229	40	3200	0.08	4119	0.50	4102	N/A	107	122
16A	125	35	282	223	59	2900	0.06	4033	0.50	3982	N/A	97	115
165	150	40	324	218	106	2600	0.06	3947	0.50	3809	500	87	109
16D	160	47	381	277	104	2900	0.07	4082	0.62	3837	1000	97	116
16C	175	52	417	273	144	2600	0.06	3997	0.62	3719	1500	87	110
15J	225	94	755	266	488	2800	0.06	4024	0.60	N/A	N/A	93	114
15E	300	97	783	269	513	2600	0.06	3970	0.62	N/A	N/A	87	109
16E	325	93	748	260	487	2500	0.07	3890	0.62	N/A	N/A	83	106
166	350	94	756	256	500	2500	0.07	3854	0.64	N/A	N/A	83	106

Table 5-6 Instrumented Charpy Impact Test Results for the Calvert Cliffs Unit 1 Intermediate Shell Plate D-7206-3 Irradiated to a Fluence of 2.33 x 10^{19} n/cm^2 (E > 1.0 MeV) (Transverse Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy, W_t (ft-lb)	Normalized Energies (ft-lb/in^2)			General Yield Load, F_{gy} (lb)	Time to F_{gy} (msec)	Max. Load, F_m (lb)	Time to F_m (msec)	Fract. Load, F_{bf} (lb)	Arrest Load, F_a (lb)	Yield Stress (ksi)	Flow Stress (ksi)
			Total W_t/A	At P_M W_m/A	Prop. W_p/A								
241	25	9	71	26	46	3200	0.08	3864	0.09	3486	N/A	107	118
24D	125	22	176	125	50	3000	0.07	3779	0.31	3528	N/A	100	113
24K	140	27	221	89	132	3000	0.07	3834	0.26	3782	500	100	114
24E	150	28	222	146	77	2900	0.07	3839	0.35	3674	700	97	112
252	160	30	243	179	64	2800	0.07	3815	0.43	3812	900	93	110
251	175	38	303	200	103	2800	0.07	3811	0.48	3636	1000	93	110
253	185	44	354	215	139	2800	0.06	3868	0.50	3854	1392	93	111
254	195	58	470	207	262	3000	0.06	3974	0.48	3801	2512	100	116
242	200	59	479	263	216	2800	0.07	3885	0.60	3720	2592	93	111
23U	300	82	657	255	402	2700	0.06	3824	0.60	N/A	N/A	90	109
23Y	325	85	685	210	475	2600	0.06	3818	0.50	N/A	N/A	87	107
24J	350	72	584	252	331	2300	0.07	3639	0.63	N/A	N/A	77	99

Table 5-7 Instrumented Charpy Impact Test Results for the Calvert Cliffs Unit 1 Surveillance Weld Metal (Heat # 33A277) Irradiated to a Fluence of 2.33 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy, W_t (ft-lb)	Normalized Energies (ft-lb/in^2)			General Yield Load, F_{gy} (lb)	Time to F_{gy} (msec)	Max. Load, F_m (lb)	Time to F_m (msec)	Fract. Load, F_{bf} (lb)	Arrest Load, F_a (lb)	Yield Stress (ksi)	Flow Stress (ksi)
			Total W_t/A	At P_M W_m/A	Prop. W_p/A								
36M	-50	8	61	29	32	3300	0.08	4094	0.10	3977	N/A	110	123
36D	0	27	217	25	193	3400	0.08	4036	0.09	3833	400	113	124
36E	15	40	323	235	89	3400	0.07	4083	0.50	3917	700	113	125
371	25	34	273	227	46	3000	0.07	3922	0.50	3915	900	100	115
36J	35	34	274	26	249	3200	0.07	3909	0.09	3854	1000	107	118
35U	50	16	128	26	102	3300	0.08	3774	0.09	3467	700	110	118
36L	50	50	399	286	113	3200	0.07	4030	0.62	3813	1500	107	120
36K	60	48	384	279	105	3100	0.07	3891	0.62	3788	1600	103	116
36Y	75	59	475	272	203	3100	0.07	3905	0.62	3630	1600	103	117
36U	250	100	803	245	558	2600	0.06	3704	0.60	N/A	N/A	87	105
36T	275	94	761	241	520	2500	0.06	3661	0.60	N/A	N/A	83	103
36P	300	99	794	243	551	2500	0.06	3683	0.60	N/A	N/A	83	103

Table 5-8 Instrumented Charpy Impact Test Results for the Calvert Cliffs Unit 1 Heat-Affected-Zone (HAZ) Material Irradiated to a Fluence of 2.33 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy, W_t (ft-lb)	Normalized Energies (ft-lb/in^2)			General Yield Load, F_{gy} (lb)	Time to F_{gy} (msec)	Max. Load, F_m (lb)	Time to F_m (msec)	Fract. Load, F_{bf} (lb)	Arrest Load, F_a (lb)	Yield Stress (ksi)	Flow Stress (ksi)
			Total W_t/A	At P_M W_m/A	Prop. W_p/A								
463	-75	13	103	28	76	3400	0.07	4318	0.09	3947	N/A	113	-
46B	25	25	204	26	178	2800	0.07	4032	0.09	3685	1500	93	114
45L	30	42	339	291	48	3400	0.08	4215	0.61	4190	1700	113	127
45U	40	51	408	290	117	3400	0.07	4188	0.62	3869	2000	113	126
46E	50	23	189	121	68	3095	0.07	3894	0.29	3867	1500	103	116
464	60	31	252	155	97	3000	0.07	3986	0.35	3951	1100	100	116
46C	75	27	221	122	98	3100	0.07	3965	0.29	3828	2100	103	118
462	125	68	546	283	263	3000	0.07	4118	0.62	3500	2400	100	119
46D	225	80	646	270	376	2700	0.07	4017	0.63	N/A	N/A	90	112
461	250	105	845	258	588	2800	0.07	3941	0.60	N/A	N/A	93	112
45M	275	110	883	257	625	2700	0.06	3939	0.60	N/A	N/A	90	111
45T	300	97	781	44	737	2600	0.06	3950	0.60	N/A	N/A	87	-

Table 5-9 Effect of Irradiation to 2.33 x 10^{19} n/cm^2 (E > 1.0 MeV) on the Charpy V-Notch Toughness Properties of the Calvert Cliffs Unit 1 Reactor Vessel Surveillance Capsule 284° 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
Intermediate Shell Plate D-7206-3 (LT)	6.2	104.8	98.6	18.2	122.5	104.3	35.9	147.5	111.6	137.4	103.3	-34.1
Intermediate Shell Plate D-7206-3 (TL)	22.6	149.6	127.0	29.4	161.7	132.3	54.8	182.9	128.1	107.5	87.7	-19.8
Surveillance Program Weld Metal (Heat # 33A277)	-61.3	16.7	78.0	-47.0	39.7	86.7	-38.5	60.7	99.2	151.8	108.0	-43.8
HAZ Material	-108.5	28.8	137.3	-79.8	66.0	145.8	-64.8	82.3	147.1	128.3	113.7	-14.6

Note:
(a) Average value is determined by CVGraph (see Appendix C).

Table 5-10 Comparison of the Calvert Cliffs Unit 1 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper-Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions

Material	Capsule[a]	Capsule Fluence (x 10^{19} n/cm^2, E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		USE Decrease	
			Predicted[b] (°F)	Measured[c] (°F)	Predicted[b] (%)	Measured[c] (%)
Intermediate Shell Plate D-7206-3 (Longitudinal)	263°	0.505	67.7	65.8	20.5	16
	97°	1.94	98.7	111.1	28	26
	284°	2.33	102.7	98.6	29	25
Intermediate Shell Plate D-7206-3 (Transverse)	97°	1.94	98.7	109.5	28	22
	284°	2.33	102.7	127.0	29	18
Surveillance Program Weld Metal (Heat # 33A277)	263°	0.505	74.3	50.4	29	22
	97°	1.94	108.4	104.5	40	31
	284°	2.33	112.8	78.0	42	29
Heat-Affected-Zone Material	263°	0.505	---	100.2	---	27
	97°	1.94	---	83.9	---	37
	284°	2.33	---	137.3	---	11
Standard Reference Material	263°	0.505	110.2	99.8	---	19

Notes:

(a) Capsule 284° (highlighted) is the latest capsule to be withdrawn and tested from the Calvert Cliffs Unit 1 reactor vessel.
(b) Based on Regulatory Guide 1.99, Revision 2, methodology using the mean weight percent values of copper and nickel of the surveillance material.
(c) Calculated by CVGraph Version 5.3 using measured Charpy data (See Appendix C).

Table 5-11 Tensile Properties of the Calvert Cliffs Unit 1 Capsule 284° Reactor Vessel Surveillance Materials Irradiated to 2.33×10^{19} n/cm^2 (E > 1.0 MeV)

Material	Sample Number	Test Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Stress (ksi)	Fracture Strength (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
Intermediate Shell Plate D-7206-3 (Longitudinal)	1K4	125	85	106	3.1	66	207	12.1	23.3	68.1
	1JB	225	82	103	3.4	70	178	9.7	20.5	59.8
	1KY	550	74	98	3.5	70	176	10.5	22.7	60.0
Surveillance Program Weld Metal (Heat # 33A277)	3KT	75	91	104	3.1	65	228	11.6	27.0	71.6
	3L3	150	81	94	3.0	61	155	11.8	26.1	60.6
	3L1	550	75	94	3.2	64	209	11.2	25.7	69.1
Heat-Affected-Zone Material	4KE	75	87	103	3.8	79	198	7.8	18.9	59.9
	4KJ	175	84	98	2.9	61	205	7.8	23.7	70.4
	4KK	550	77	97	3.6	73	231	8.2	16.5	67.7

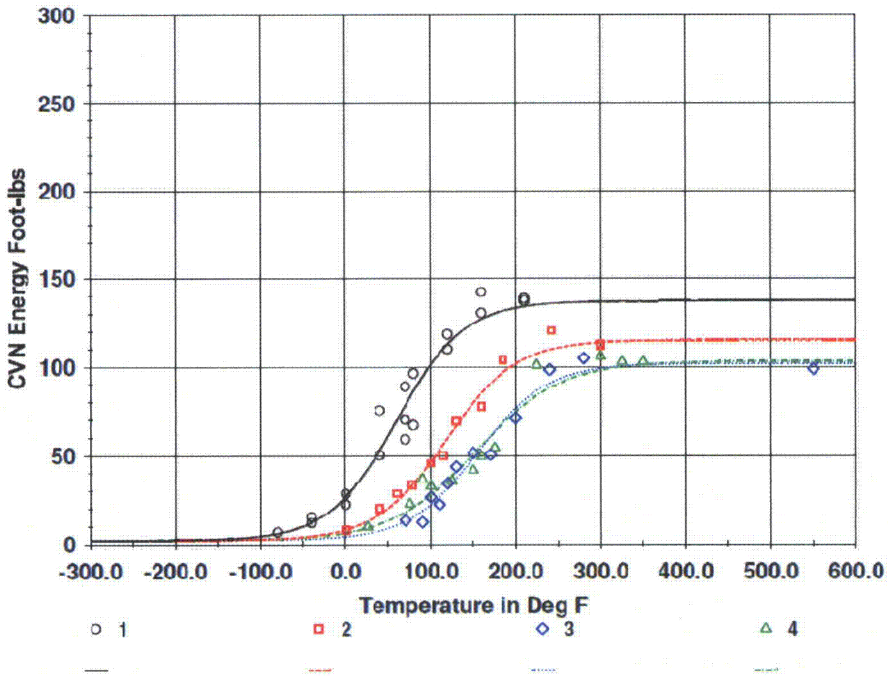
Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Calvert Cliffs Unit 1 Reactor Vessel Intermediate Shell Plate D-7206-3 (Longitudinal Orientation)

IS PLATE D-7206-3 (LONGITUDINAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 11:19 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	LT	C-4441-1
2	Calvert Cliffs 1	263	SA533B1	LT	C-4441-1
3	Calvert Cliffs 1	97	SA533B1	LT	C-4441-1
4	Calvert Cliffs 1	284	SA533B1	LT	C-4441-1



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	137.4	.0	6.2	.0	35.9	.0
2		2.2	115.2	-22.2	72.0	65.8	105.1	69.2
3		2.2	101.8	-35.6	117.3	111.1	152.4	116.5
4		2.2	103.3	-34.1	104.8	98.6	147.5	111.6

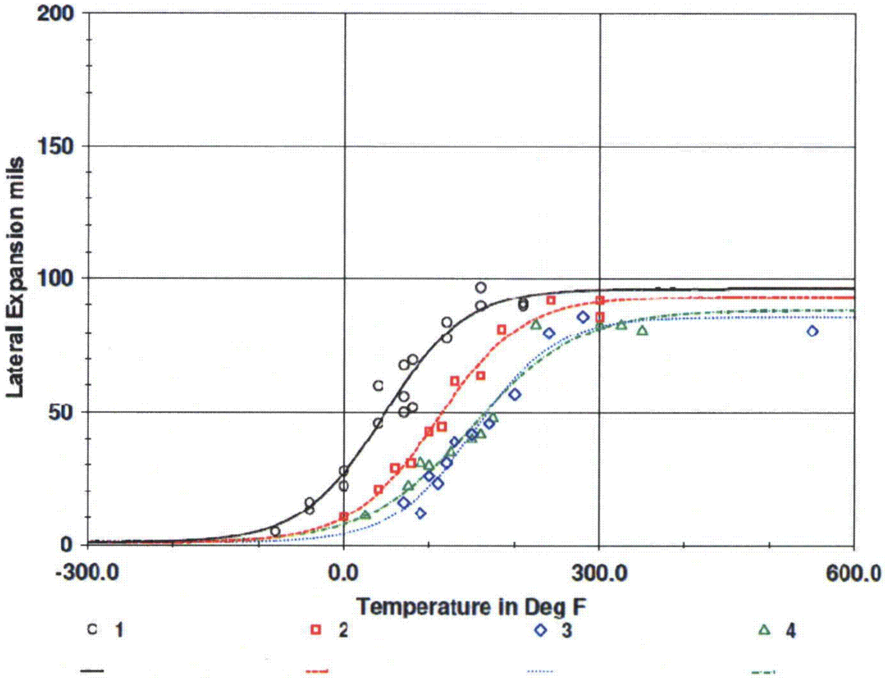
Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Calvert Cliffs Unit 1 Reactor Vessel Intermediate Shell Plate D-7206-3 (Longitudinal Orientation)

IS PLATE D-7206-3 (LONGITUDINAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 11:23 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	LT	C-4441-1
2	Calvert Cliffs 1	263	SA533B1	LT	C-4441-1
3	Calvert Cliffs 1	97	SA533B1	LT	C-4441-1
4	Calvert Cliffs 1	284	SA533B1	LT	C-4441-1



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	96.5	.0	18.2	.0
2		1.0	93.4	-3.1	82.3	64.1
3		1.0	86.1	-10.4	134.3	116.1
4		1.0	88.7	-7.8	122.5	104.3

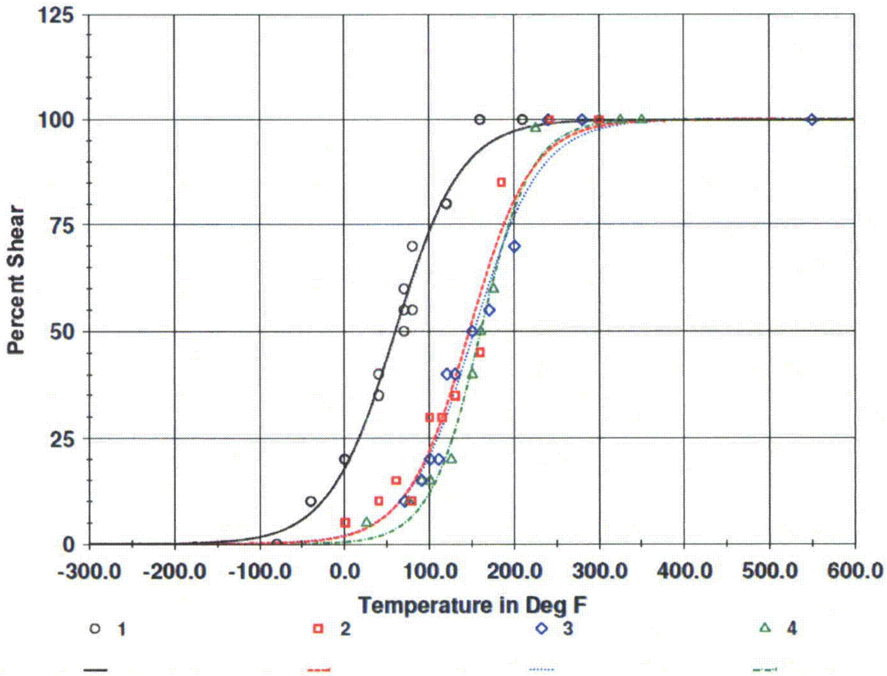
Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Calvert Cliffs Unit 1 Reactor Vessel Intermediate Shell Plate D-7206-3 (Longitudinal Orientation)

IS PLATE D-7206-3 (LONGITUDINAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 11:25 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	LT	C-4441-1
2	Calvert Cliffs 1	263	SA533B1	LT	C-4441-1
3	Calvert Cliffs 1	97	SA533B1	LT	C-4441-1
4	Calvert Cliffs 1	284	SA533B1	LT	C-4441-1



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	59.7	.0
2		.0	100.0	.0	146.5	86.8
3		.0	100.0	.0	152.4	92.7
4		.0	100.0	.0	159.8	100.1

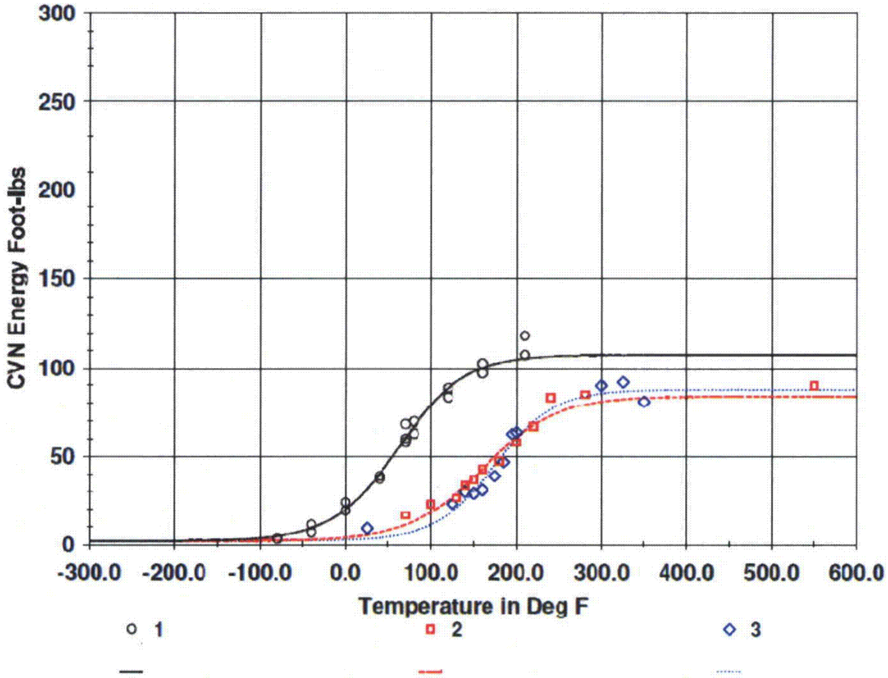
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Calvert Cliffs Unit 1 Reactor Vessel Intermediate Shell Plate D-7206-3 (Transverse Orientation)

IS PLATE D-7206-3 (TRANSVERSE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:08 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	TL	C-4441-1
2	Calvert Cliffs 1	97	SA533B1	TL	C-4441-1
3	Calvert Cliffs 1	284	SA533B1	TL	C-4441-1



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2. 2	107. 5	. 0	22. 6	. 0	54. 8	. 0
2		2. 2	84. 0	- 23. 5	132. 1	109. 5	174. 9	120. 1
3		2. 2	87. 7	- 19. 8	149. 6	127. 0	182. 9	128. 1

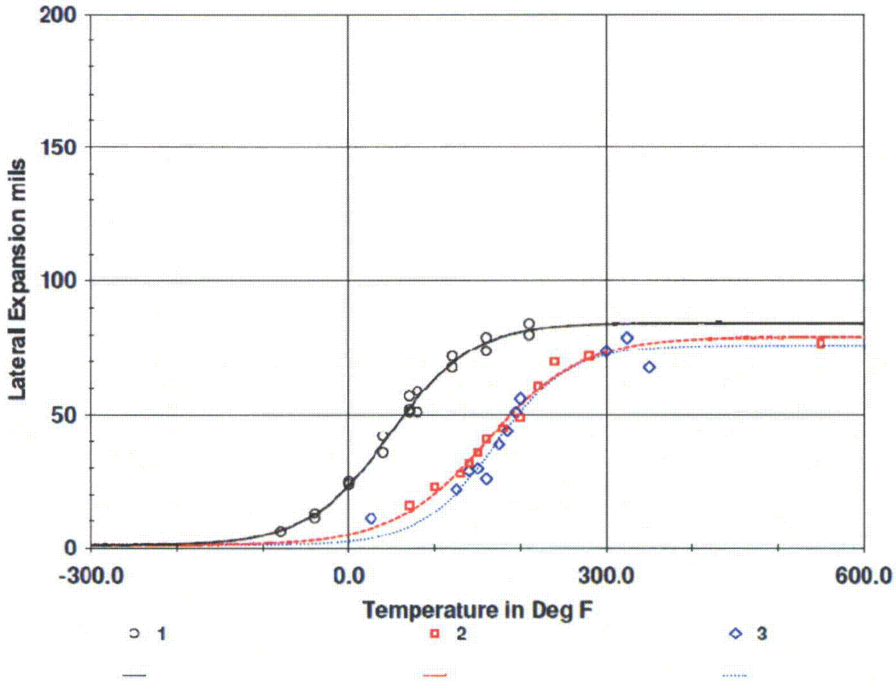
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Calvert Cliffs Unit 1 Reactor Vessel Intermediate Shell Plate D-7206-3 (Transverse Orientation)

IS PLATE D-7206-3 (TRANSVERSE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:12 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	TL	C-4441-1
2	Calvert Cliffs 1	97	SA533B1	TL	C-4441-1
3	Calvert Cliffs 1	284	SA533B1	TL	C-4441-1



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	84.3	.0	29.4	.0
2		1.0	79.3	-5.1	146.0	116.6
3		1.0	76.1	-8.2	161.7	132.3

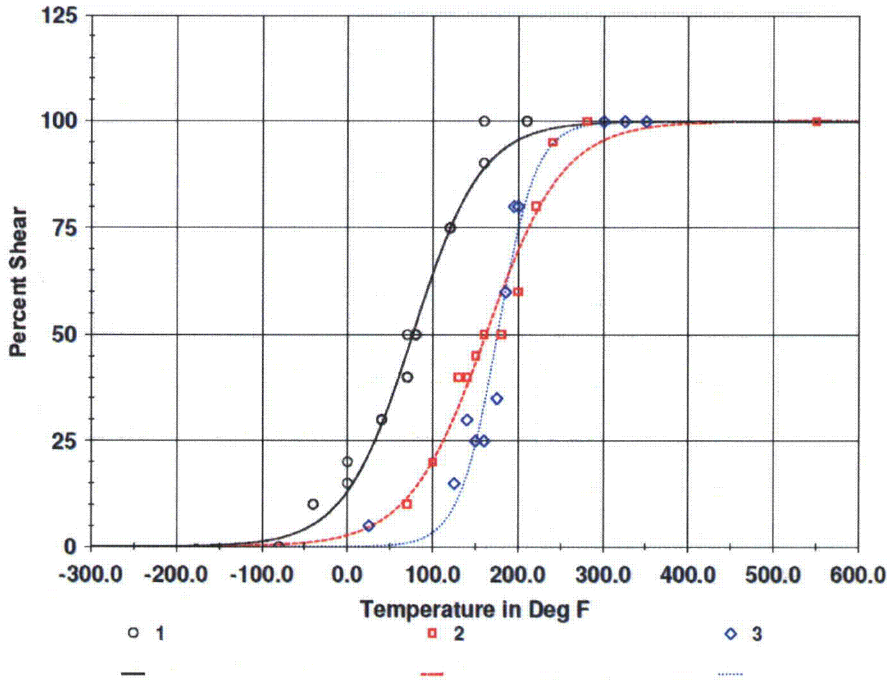
Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Calvert Cliffs Unit 1 Reactor Vessel Intermediate Shell Plate D-7206-3 (Transverse Orientation)

IS PLATE D-7206-3 (TRANSVERSE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:13 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	TL	C-4441-1
2	Calvert Cliffs 1	97	SA533B1	TL	C-4441-1
3	Calvert Cliffs 1	284	SA533B1	TL	C-4441-1



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	76.2	.0
2		.0	100.0	.0	162.0	85.8
3		.0	100.0	.0	175.7	99.5

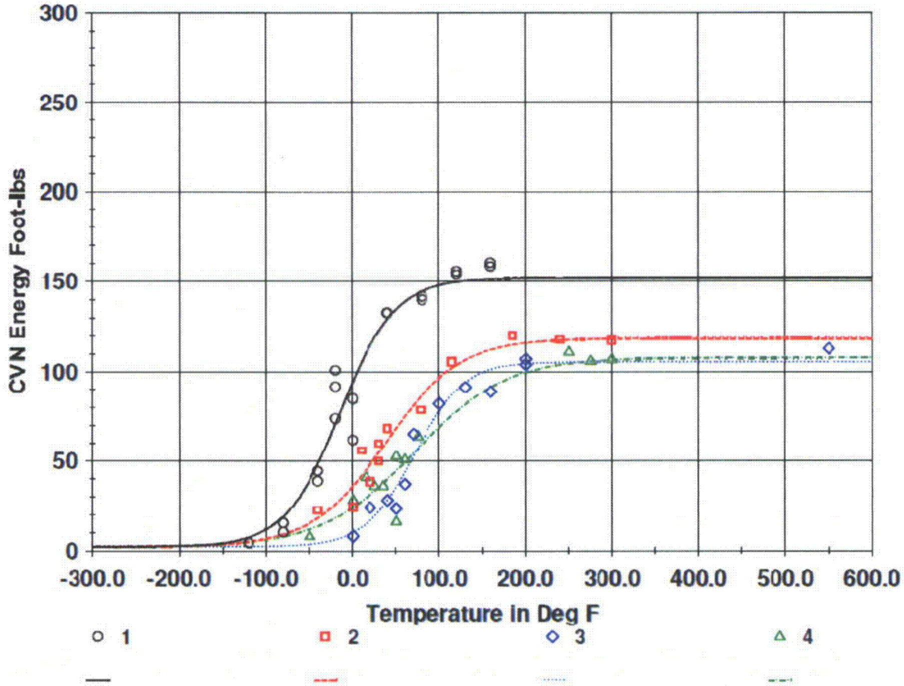
Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for the Calvert Cliffs Unit 1 Reactor Vessel Surveillance Program Weld Metal

SURVEILLANCE WELD METAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:20 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SAW	NA	33A277
2	Calvert Cliffs 1	263	SAW	NA	33A277
3	Calvert Cliffs 1	97	SAW	NA	33A277
4	Calvert Cliffs 1	284	SAW	NA	33A277



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	151.8	.0	-61.3	.0	-38.5	.0
2		2.2	118.5	-33.3	-10.9	50.4	23.0	61.5
3		2.2	105.5	-46.3	43.2	104.5	67.1	105.6
4		2.2	108.0	-43.8	16.7	78.0	60.7	99.2

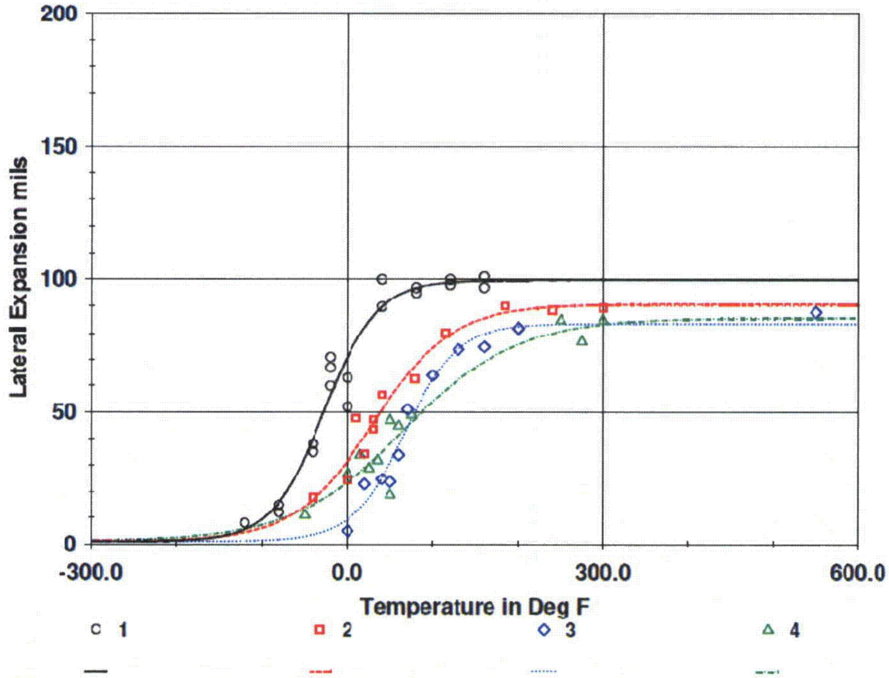
Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for the Calvert Cliffs Unit 1 Reactor Vessel Surveillance Program Weld Metal

SURVEILLANCE WELD METAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:21 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SAW	NA	33A277
2	Calvert Cliffs 1	263	SAW	NA	33A277
3	Calvert Cliffs 1	97	SAW	NA	33A277
4	Calvert Cliffs 1	284	SAW	NA	33A277



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	99.6	.0	-47.0	.0
2		1.0	90.7	-8.9	7.2	54.2
3		1.0	83.7	-16.0	56.4	103.4
4		1.0	85.9	-13.7	39.7	86.7

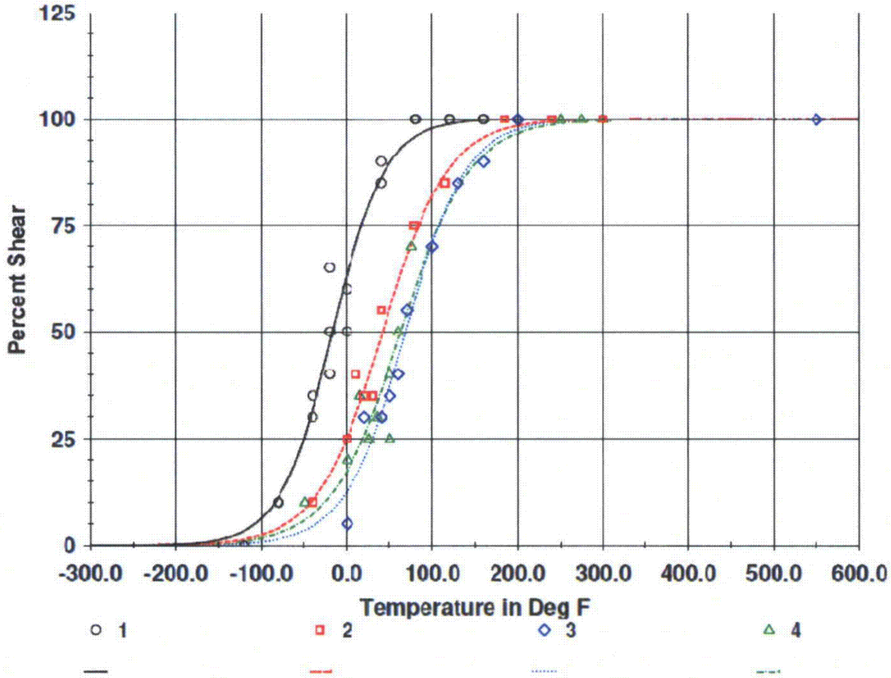
Figure 5-9 Charpy V-Notch Percent Shear vs. Temperature for the Calvert Cliffs Unit 1 Reactor Vessel Surveillance Program Weld Metal

SURVEILLANCE WELD METAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:23 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SAW	NA	33A277
2	Calvert Cliffs 1	263	SAW	NA	33A277
3	Calvert Cliffs 1	97	SAW	NA	33A277
4	Calvert Cliffs 1	284	SAW	NA	33A277



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	-16.6	.0
2		.0	100.0	.0	41.8	58.4
3		.0	100.0	.0	68.9	85.5
4		.0	100.0	.0	62.9	79.5

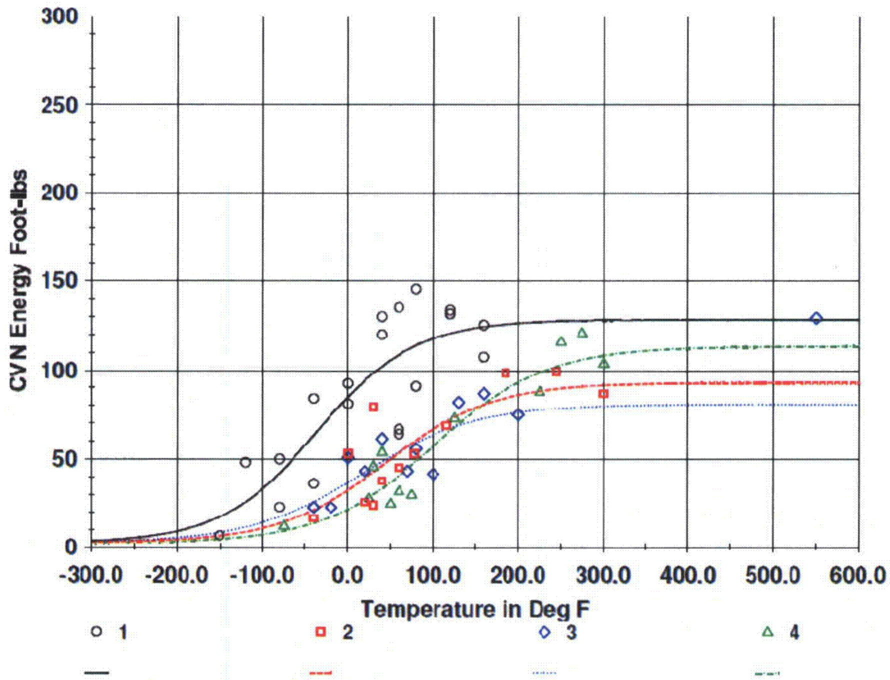
Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for the Calvert Cliffs Unit 1 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:24 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	NA	C-4441-1
2	Calvert Cliffs 1	263	SA533B1	NA	C-4441-1
3	Calvert Cliffs 1	97	SA533B1	NA	C-4441-1
4	Calvert Cliffs 1	284	SA533B1	NA	C-4441-1



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	128.3	.0	-108.5	.0	-64.8	.0
2		2.2	93.1	-35.2	-8.3	100.2	49.8	114.6
3		2.2	81.0	-47.3	-24.6	83.9	44.9	109.7
4		2.2	113.7	-14.6	28.8	137.3	82.3	147.1

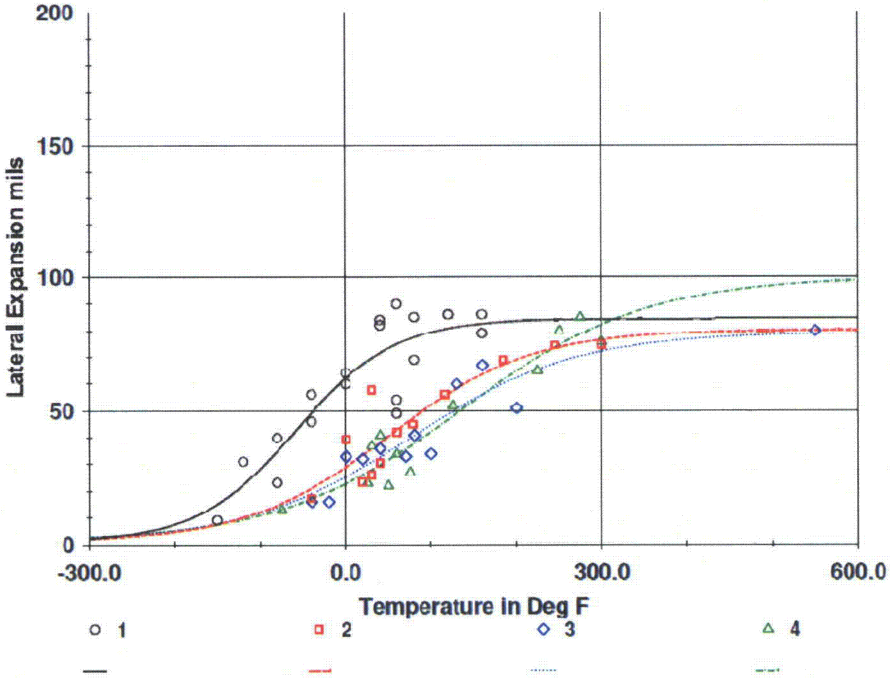
Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for the Calvert Cliffs Unit 1 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:27 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	NA	C-4441-1
2	Calvert Cliffs 1	263	SA533B1	NA	C-4441-1
3	Calvert Cliffs 1	97	SA533B1	NA	C-4441-1
4	Calvert Cliffs 1	284	SA533B1	NA	C-4441-1



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	84.4	.0	-79.8	.0
2		1.0	80.4	-4.1	26.7	106.5
3		1.0	79.3	-5.1	51.6	131.4
4		1.0	100.3	15.9	66.0	145.8

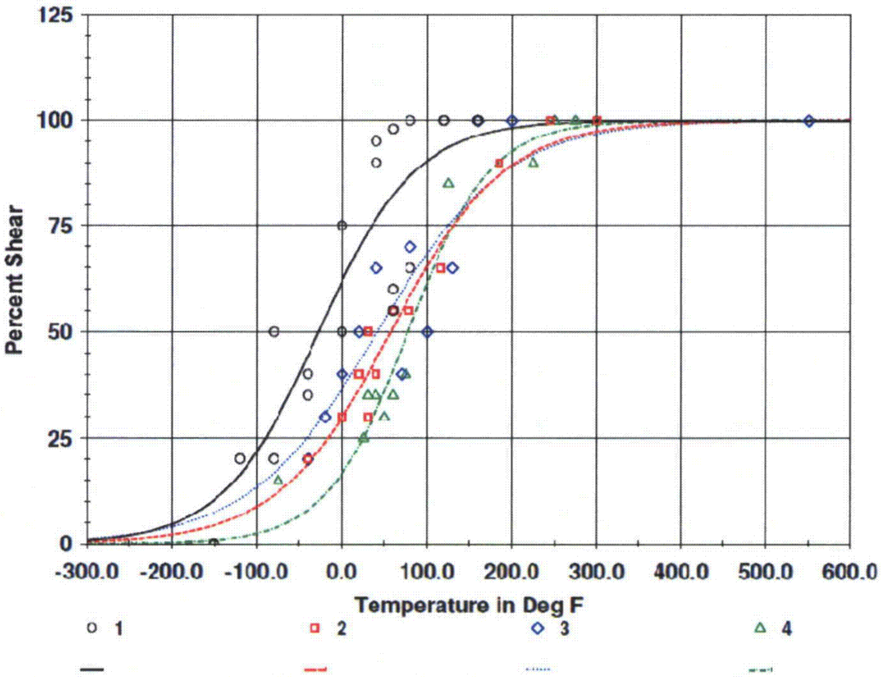
Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for the Calvert Cliffs Unit 1 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:29 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	NA	C-4441-1
2	Calvert Cliffs 1	263	SA533B1	NA	C-4441-1
3	Calvert Cliffs 1	97	SA533B1	NA	C-4441-1
4	Calvert Cliffs 1	284	SA533B1	NA	C-4441-1



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	-27.3	.0
2		.0	100.0	.0	57.3	84.6
3		.0	100.0	.0	41.8	69.1
4		.0	100.0	.0	77.6	104.9

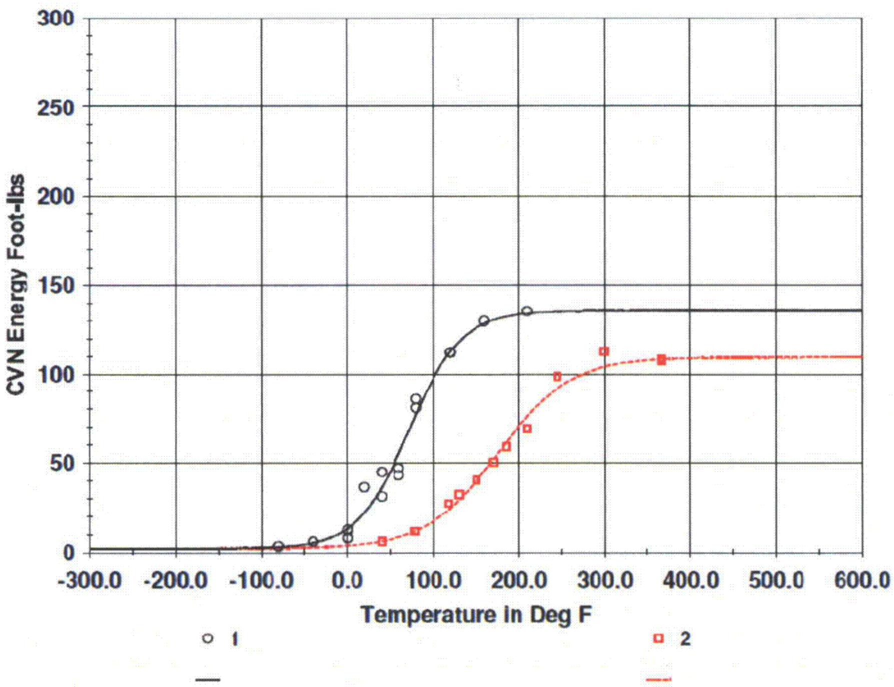
Figure 5-13 Charpy V-Notch Impact Energy vs. Temperature for the Calvert Cliffs Unit 1 Reactor Vessel Standard Reference Material

STANDARD REFERENCE MATERIAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:35 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	LT	HSST-01MY
2	Calvert Cliffs 1	263	SA533B1	LT	HSST-01MY



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	135.5	.0	32.2	.0	54.9	.0
2		2.2	109.4	-26.1	132.0	99.8	167.0	112.1

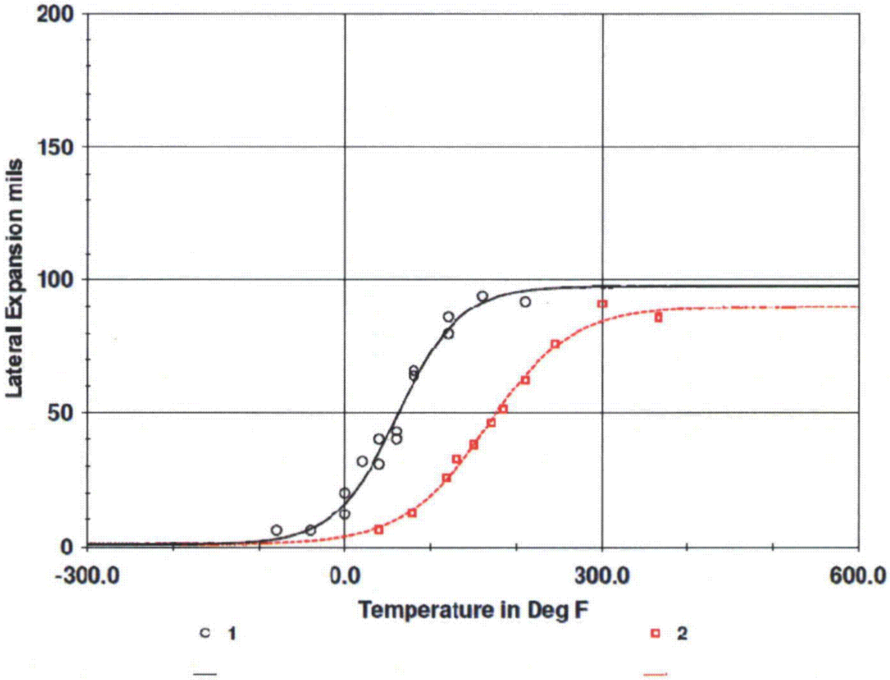
Figure 5-14 Charpy V-Notch Lateral Expansion vs. Temperature for the Calvert Cliffs Unit 1 Reactor Vessel Standard Reference Material

STANDARD REFERENCE MATERIAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:36 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	LT	HSST-01MY
2	Calvert Cliffs 1	263	SA533B1	LT	HSST-01MY



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	97.5	.0	39.2	.0
2		1.0	89.9	-7.6	143.1	103.9

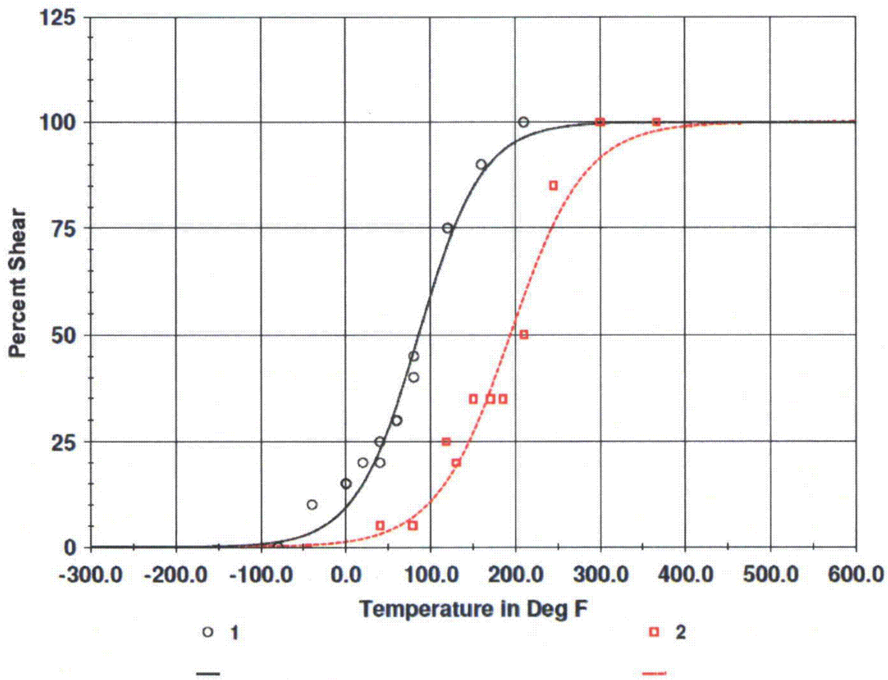
Figure 5-15 Charpy V-Notch Percent Shear vs. Temperature for the Calvert Cliffs Unit 1 Reactor Vessel Standard Reference Material

STANDARD REFERENCE MATERIAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 12:37 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 1	UNIRR	SA533B1	LT	HSST-01MY
2	Calvert Cliffs 1	263	SA533B1	LT	HSST-01MY



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	85.7	.0
2		.0	100.0	.0	193.7	108.0

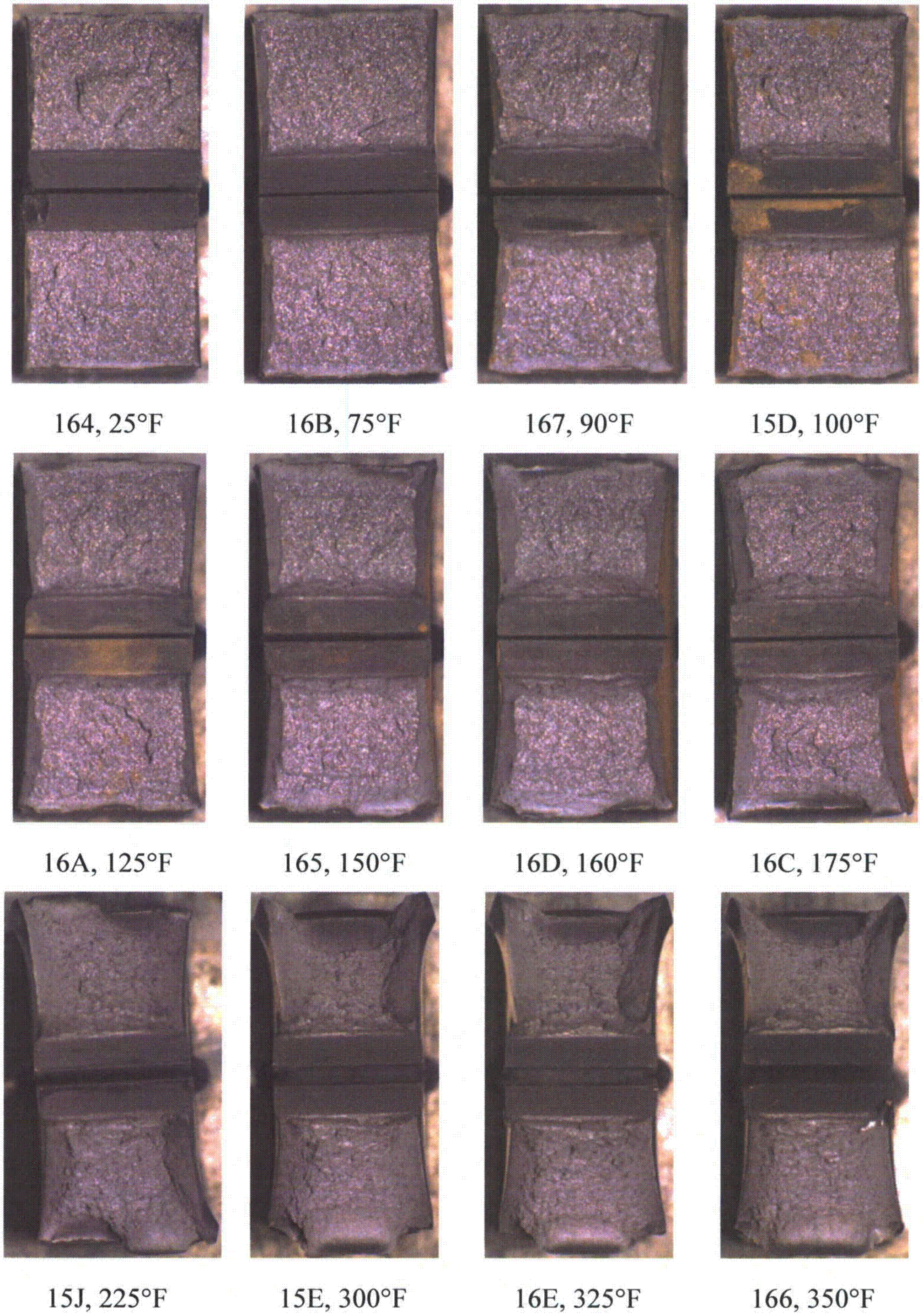


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Calvert Cliffs Unit 1 Reactor Vessel Intermediate Shell Plate D-7206-3 (Longitudinal Orientation)

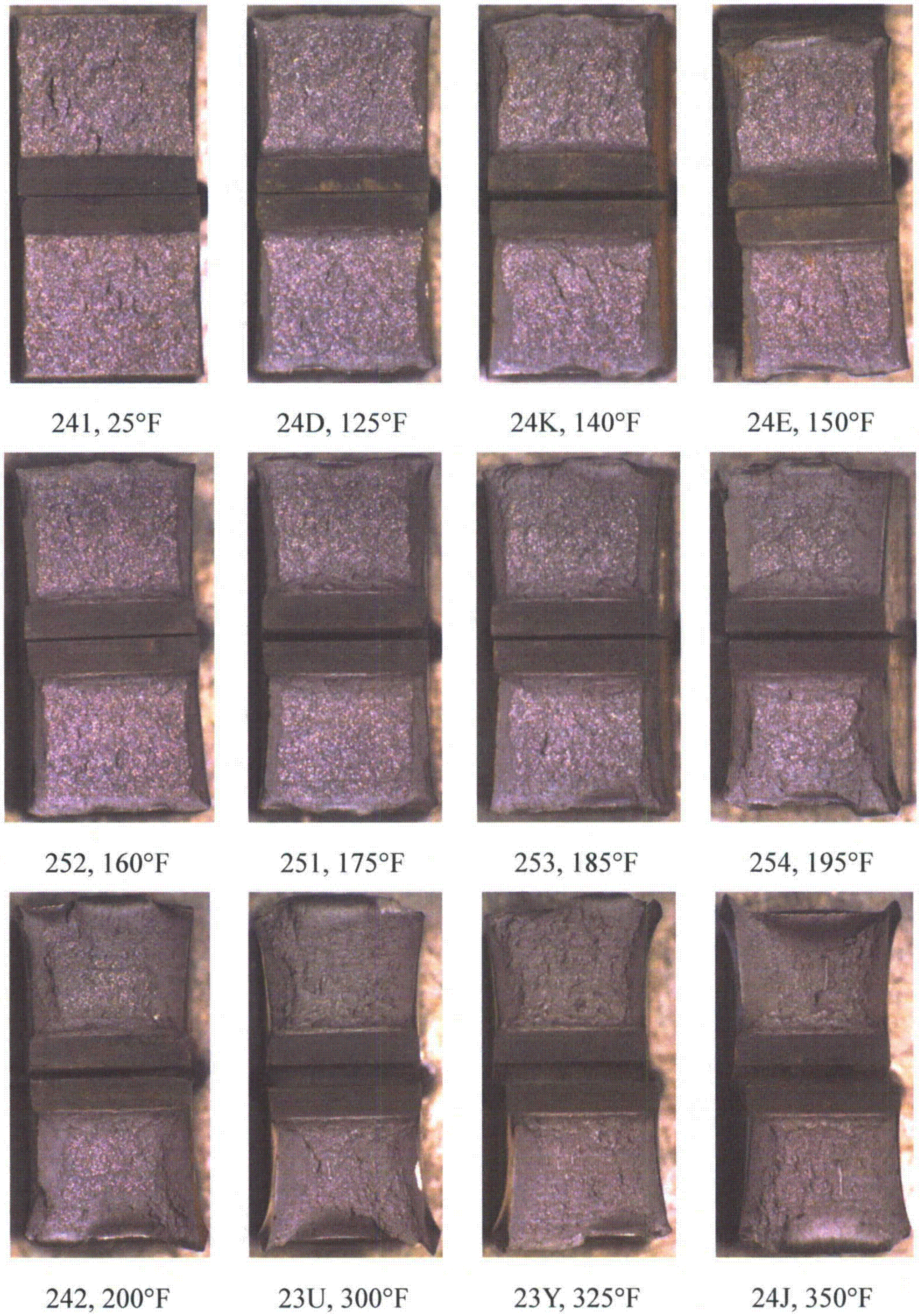
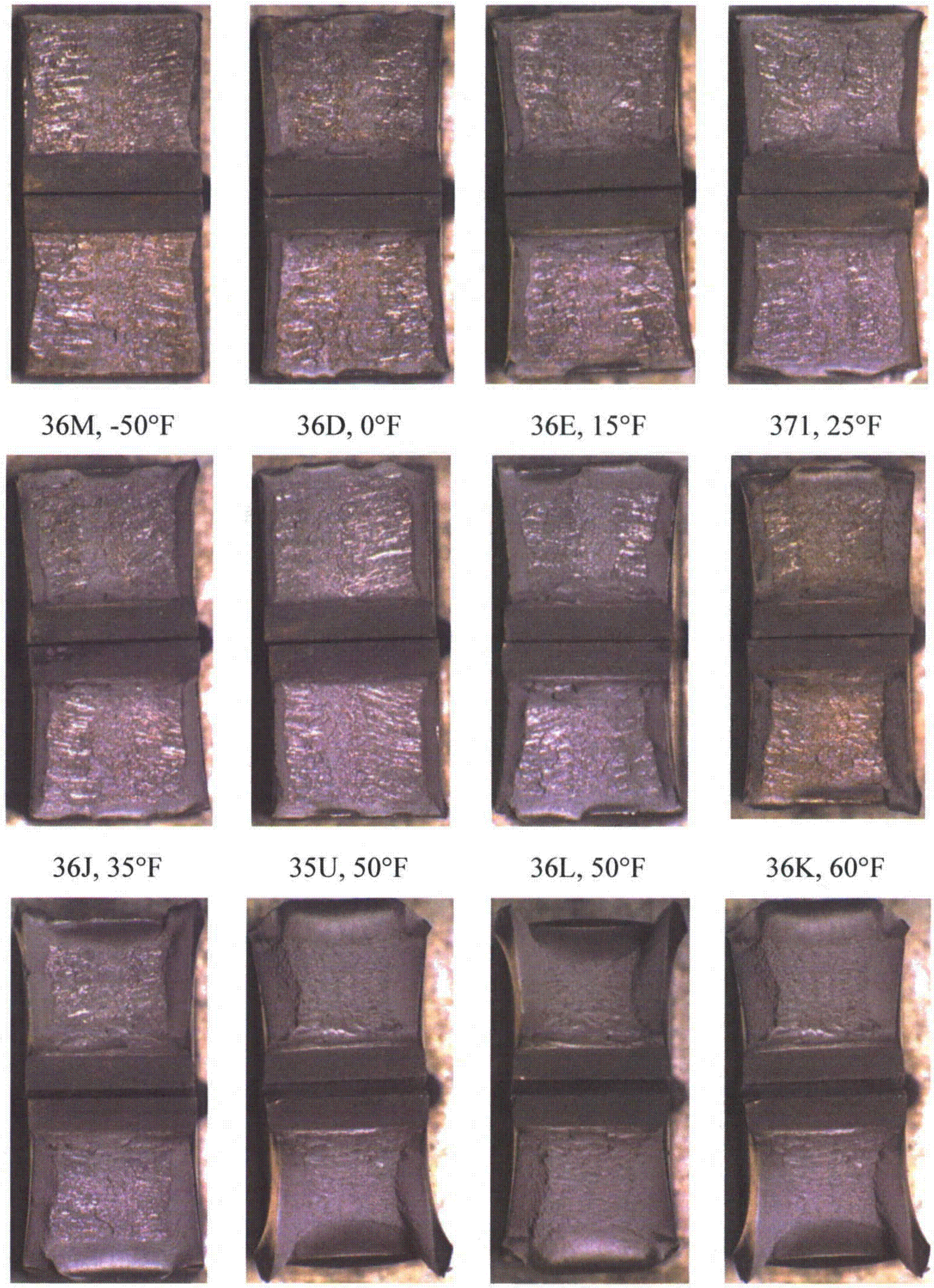


Figure 5-17 Charpy Impact Specimen Fracture Surfaces for Calvert Cliffs Unit 1 Reactor Vessel Intermediate Shell Plate D-7206-3 (Transverse Orientation)



36M, -50°F | 36D, 0°F | 36E, 15°F | 371, 25°F

36J, 35°F | 35U, 50°F | 36L, 50°F | 36K, 60°F

36Y, 75°F | 36U, 250°F | 36T, 275°F | 36P, 300°F

Figure 5-18 Charpy Impact Specimen Fracture Surfaces for the Calvert Cliffs Unit 1 Reactor Vessel Surveillance Program Weld Material

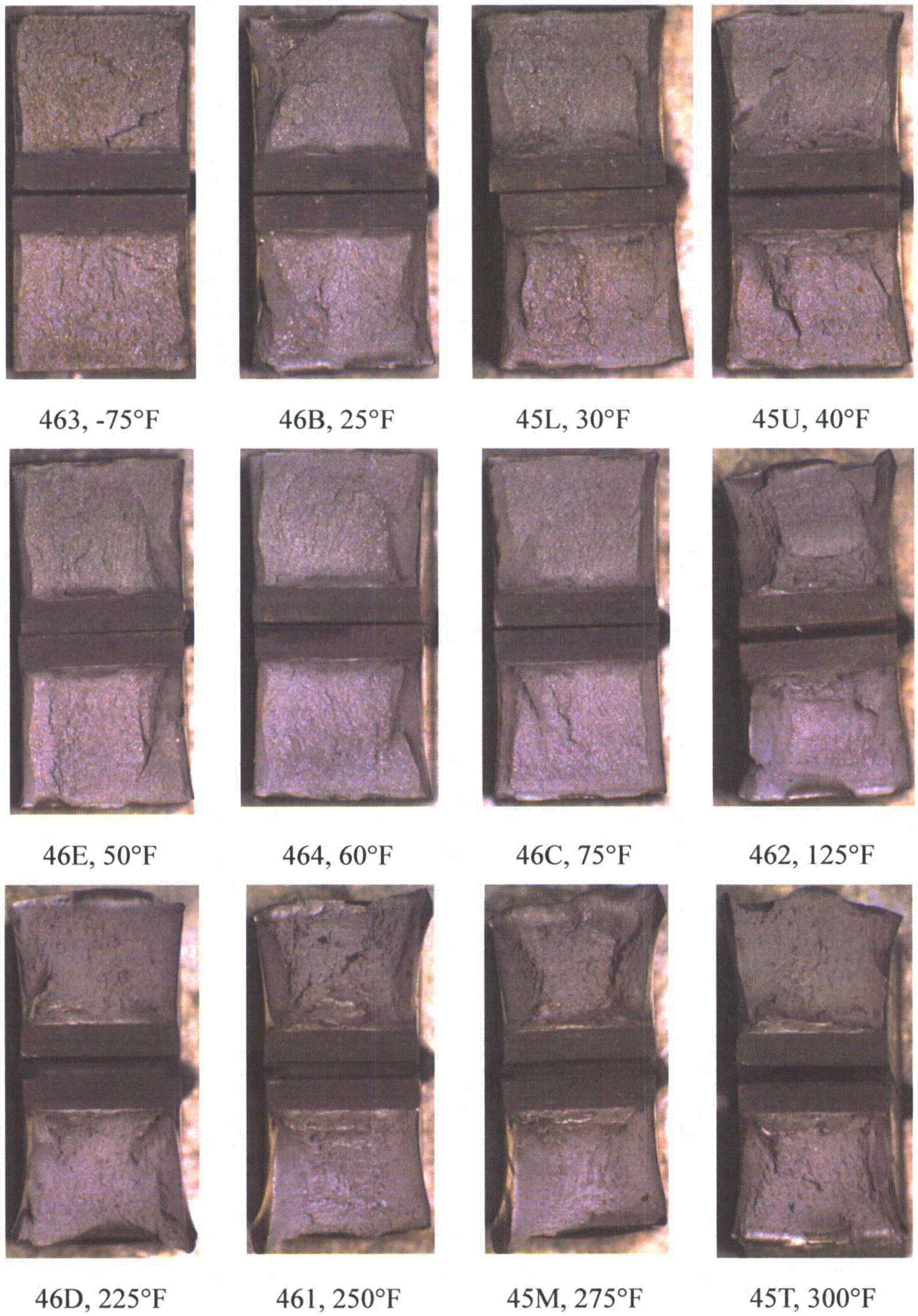
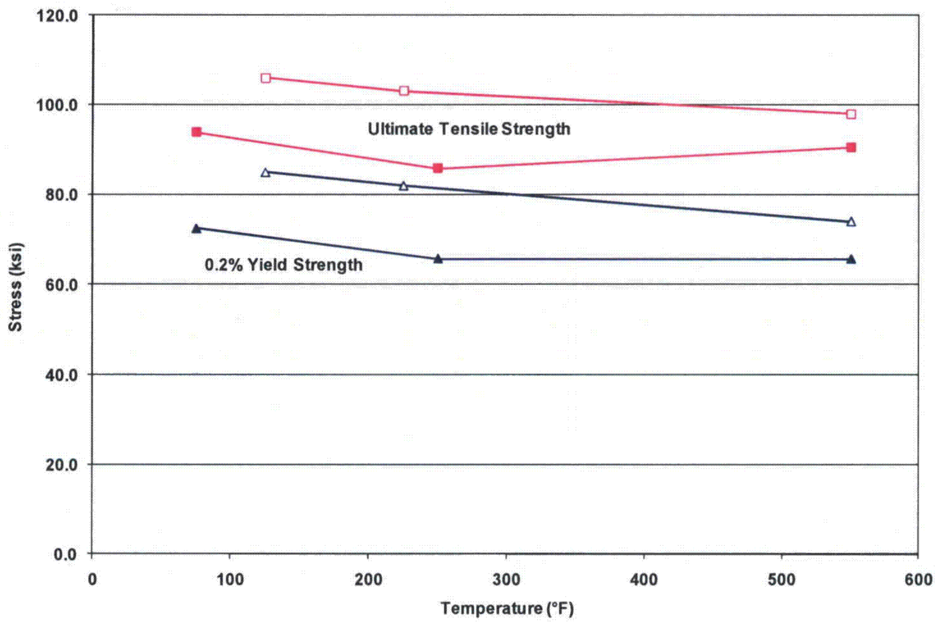


Figure 5-19 Charpy Impact Specimen Fracture Surfaces for the Calvert Cliffs Unit 1 Reactor Vessel Heat-Affected-Zone Material



Legend: ▲ and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 2.33 x 10^{19} n/cm^2 (E > 1.0 MeV)

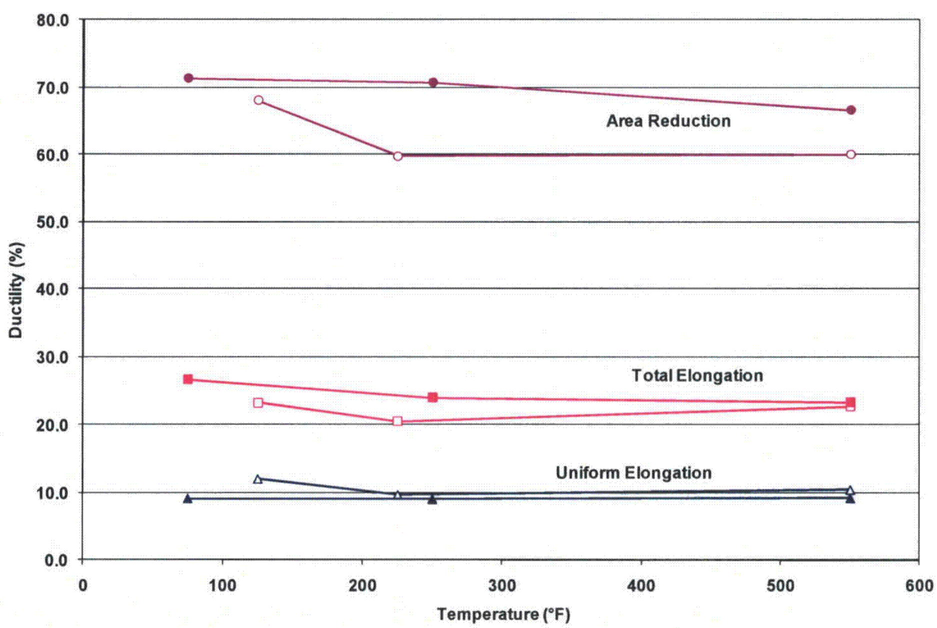
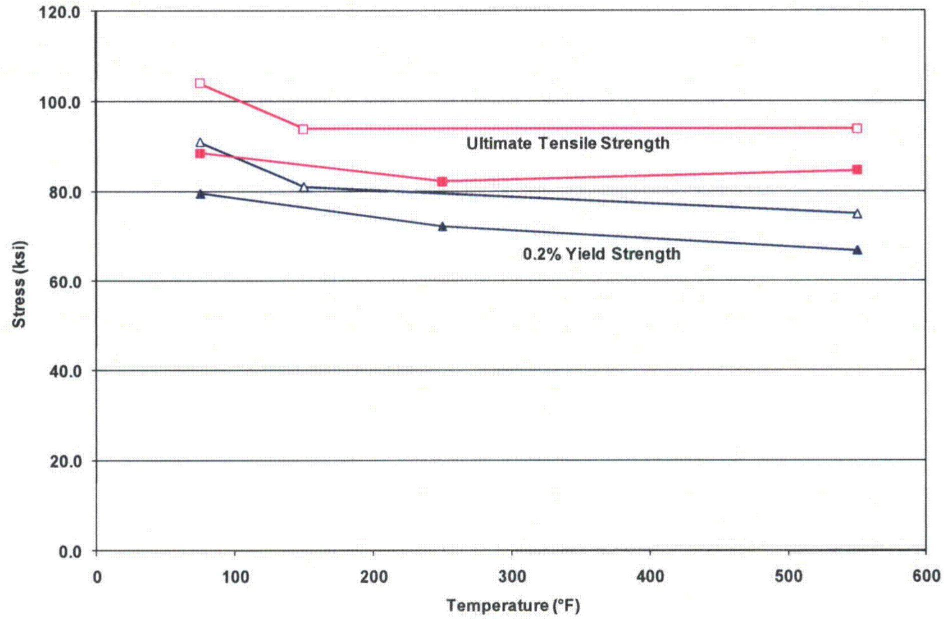


Figure 5-20 Tensile Properties for Calvert Cliffs Unit 1 Reactor Vessel Intermediate Shell Plate D-7206-3 (Longitudinal Orientation)



Legend: ▲and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 2.33 x 10^{19} n/cm^2 (E > 1.0 MeV)

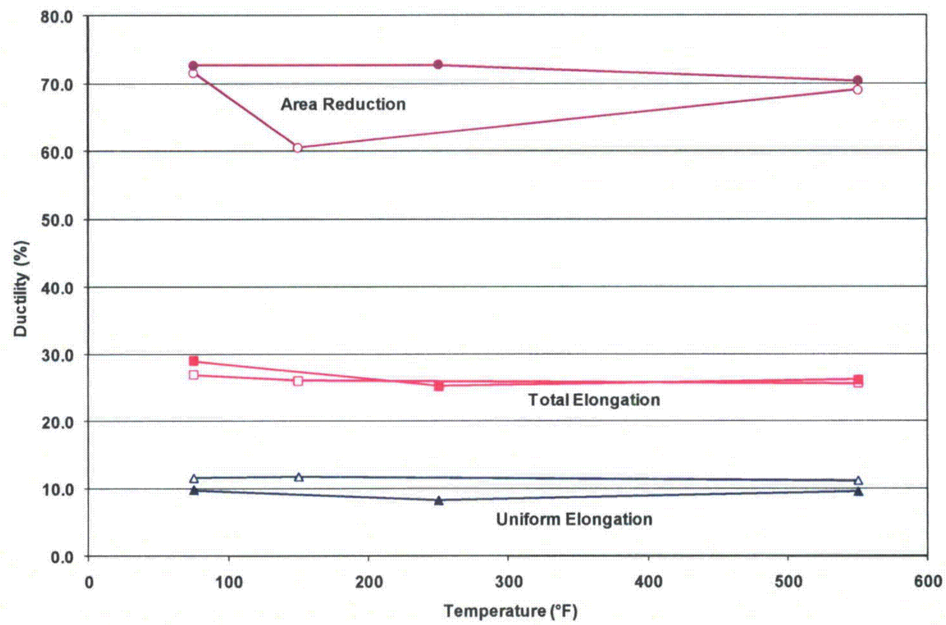
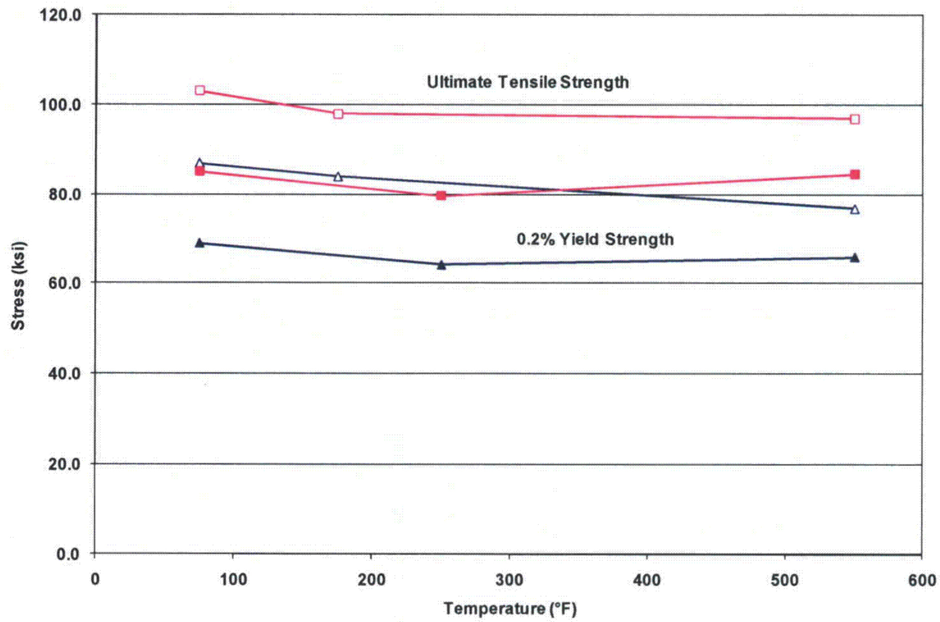


Figure 5-21 Tensile Properties for Calvert Cliffs Unit 1 Reactor Vessel Surveillance Program Weld



Legend: ▲ and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 2.33 x 10^{19} n/cm^2 (E > 1.0 MeV)

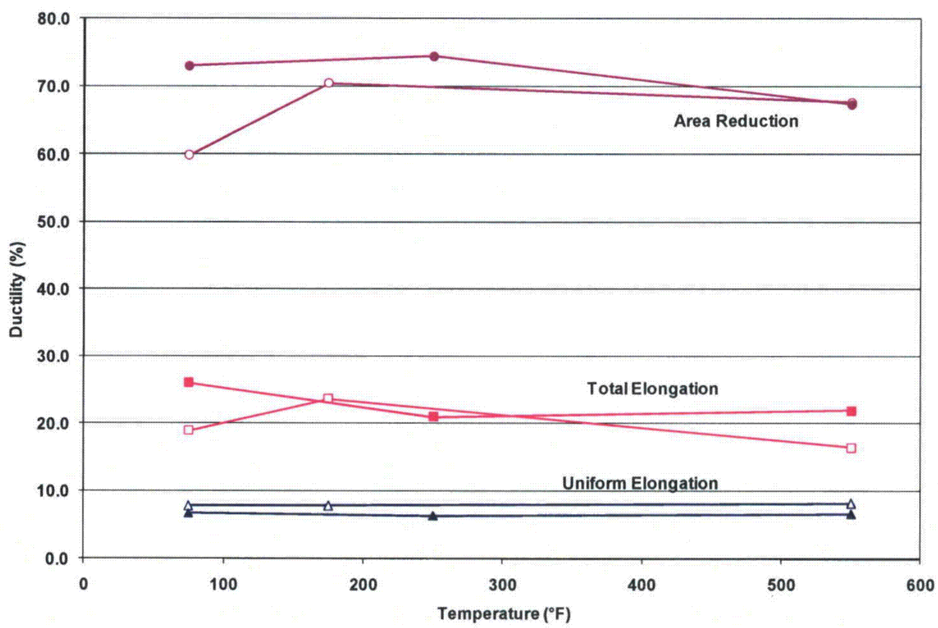
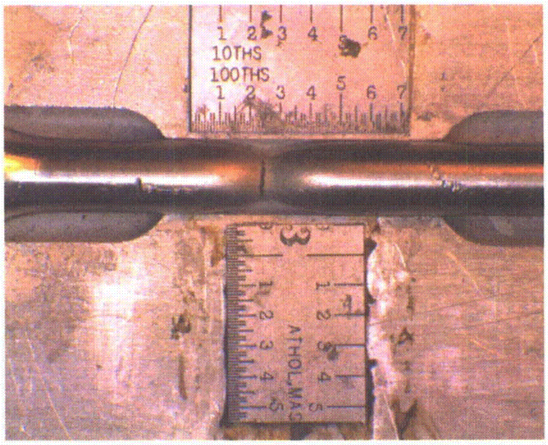
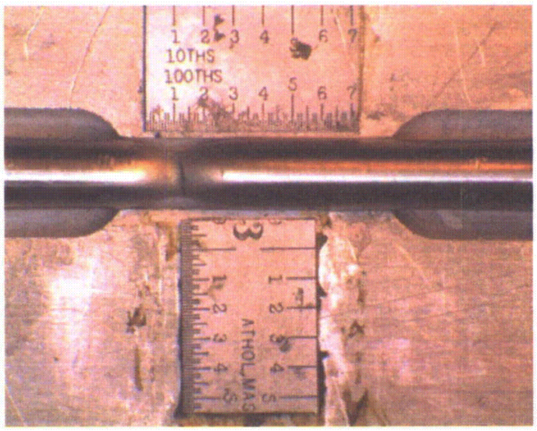


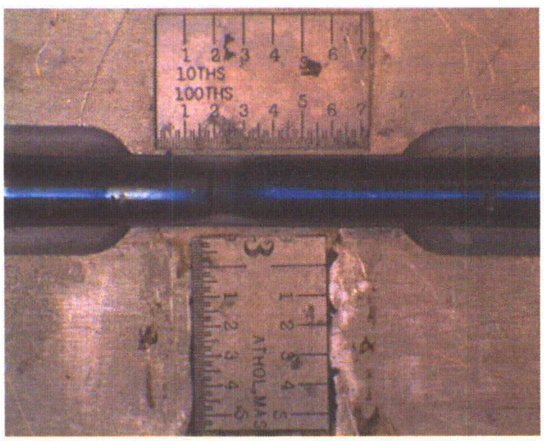
Figure 5-22 Tensile Properties for the Calvert Cliffs Unit 1 Reactor Vessel Heat-Affected-Zone Material



Specimen 1K4- Tested at 125°F

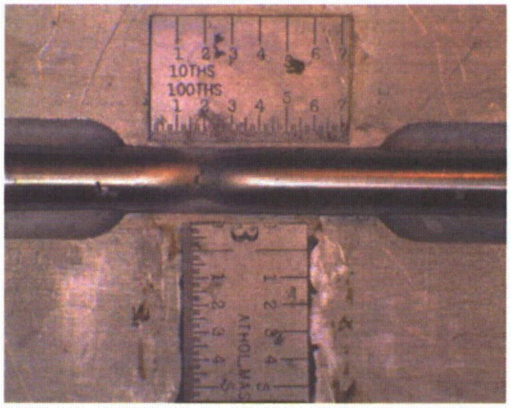


Specimen 1JB - Tested at 225°F

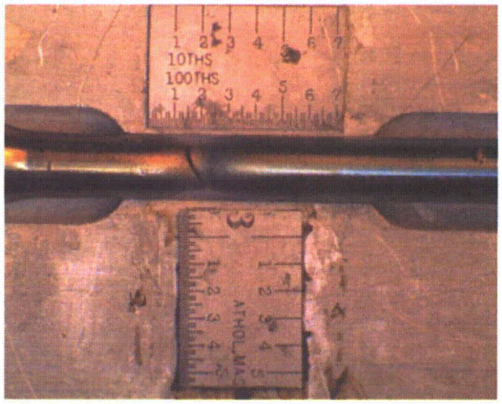


Specimen 1KY - Tested at 550°F

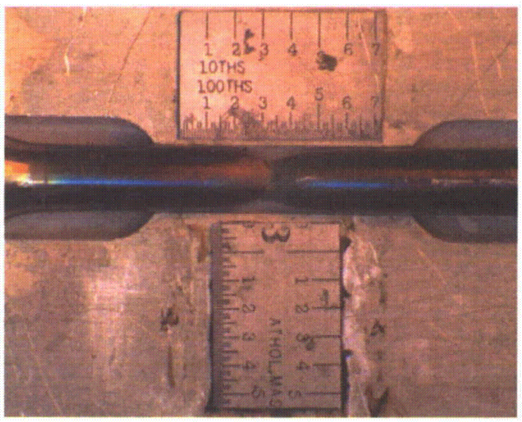
Figure 5-23 Fractured Tensile Specimens from Calvert Cliffs Unit 1 Reactor Vessel Intermediate Shell Plate D-7206-3 (Longitudinal Orientation)



Specimen 3KT - Tested at 75°F

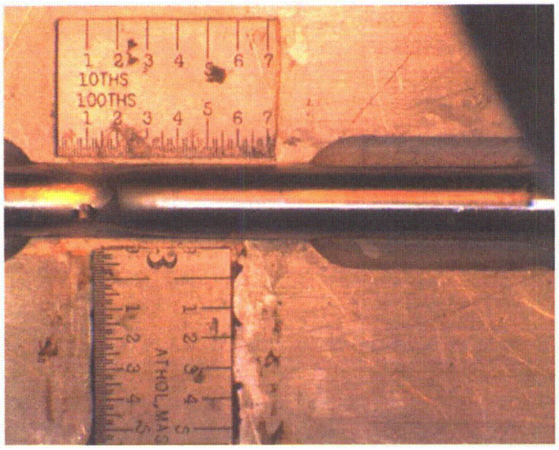


Specimen 3L3 - Tested at 150°F

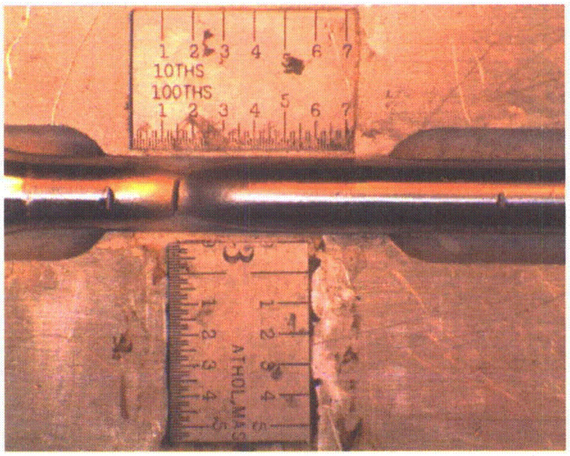


Specimen 3L1 - Tested at 550°F

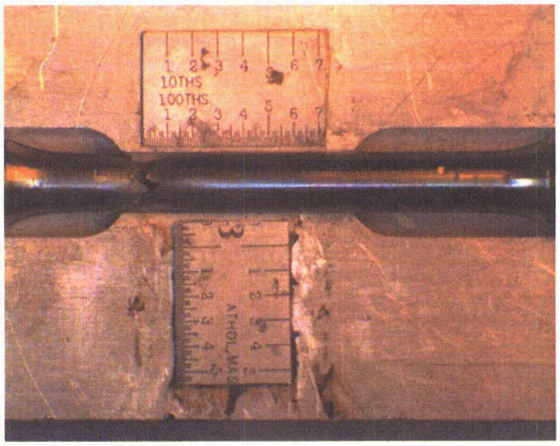
Figure 5-24 Fractured Tensile Specimens from the Calvert Cliffs Unit 1 Reactor Vessel Surveillance Program Weld Metal



Specimen 4KE - Tested at 75°F



Specimen 4KJ - Tested at 175°F



Specimen 4KK - Tested at 550°F

Figure 5-25 Fractured Tensile Specimens from the Calvert Cliffs Unit 1 Reactor Vessel Heat-Affected-Zone Material

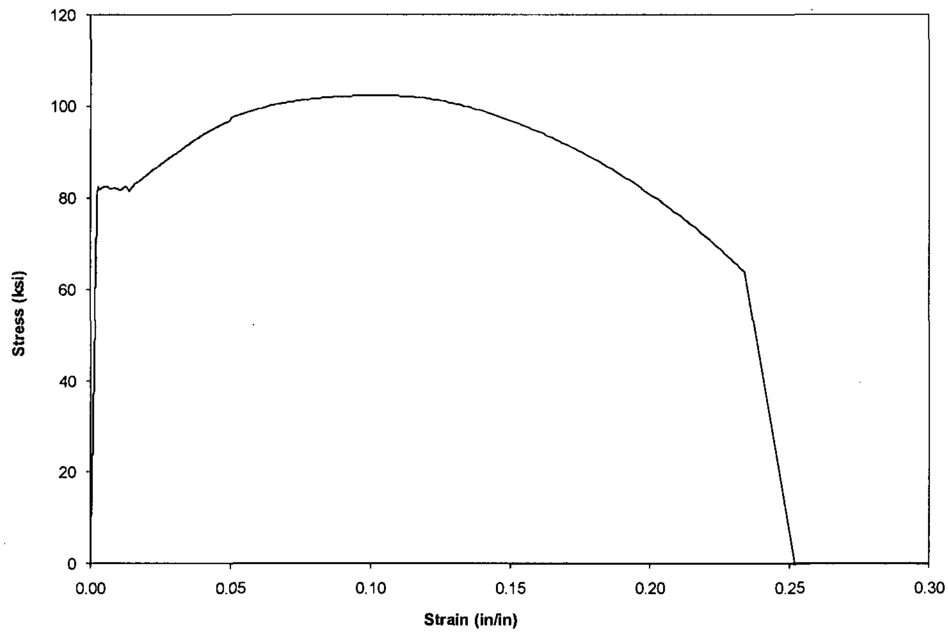


Figure 5-26 Engineering Stress-Strain Curve for Calvert Cliffs Unit 1 Intermediate Shell Plate D-7206-3 Tensile Specimen 1K4 Tested at 75° (Longitudinal Orientation)

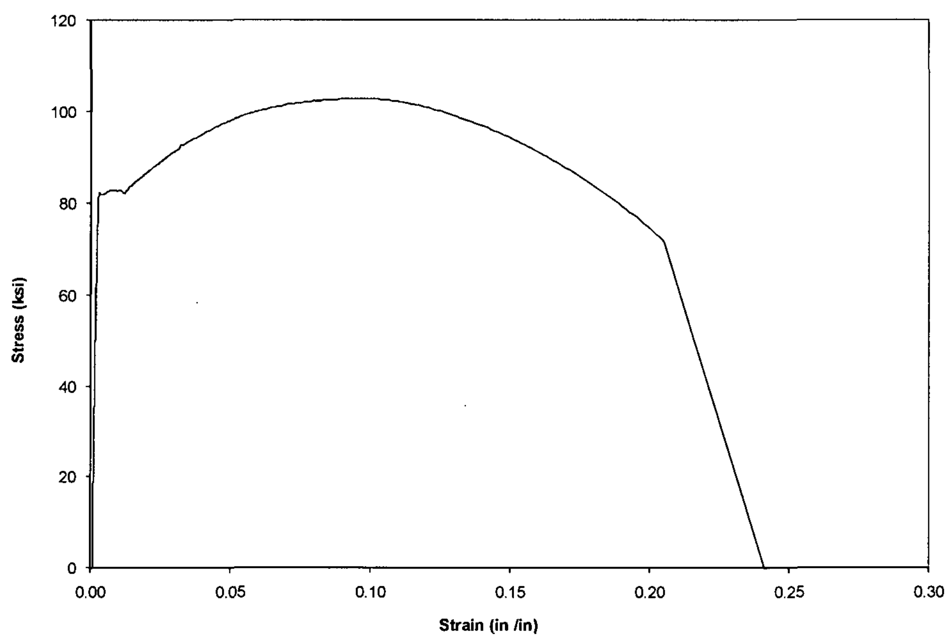


Figure 5-27 Engineering Stress-Strain Curve for Calvert Cliffs Unit 1 Intermediate Shell Plate D-7206-3 Tensile Specimen 1JB Tested at 225° (Longitudinal Orientation)

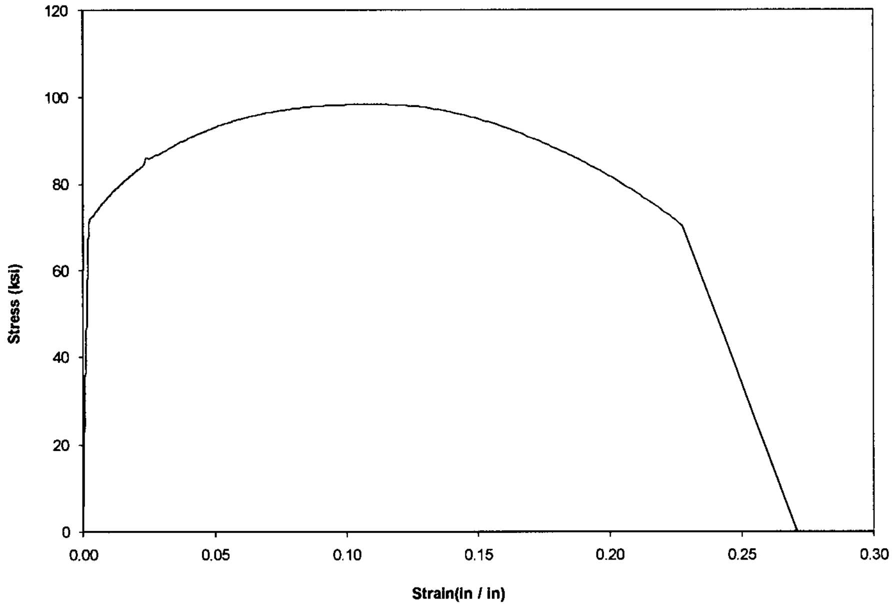


Figure 5-28 Engineering Stress-Strain Curve for Calvert Cliffs Unit 1 Intermediate Shell Plate D-7206-3 Tensile Specimen 1KY Tested at 550° (Longitudinal Orientation)

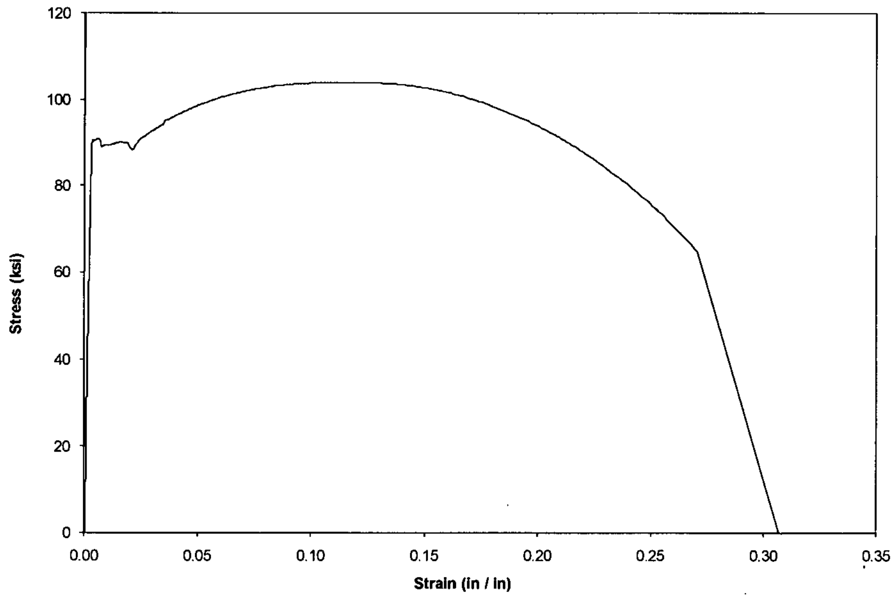


Figure 5-29 Engineering Stress-Strain Curve for Calvert Cliffs Unit 1 Surveillance Program Weld Metal Tensile Specimen 3KT Tested at 75°

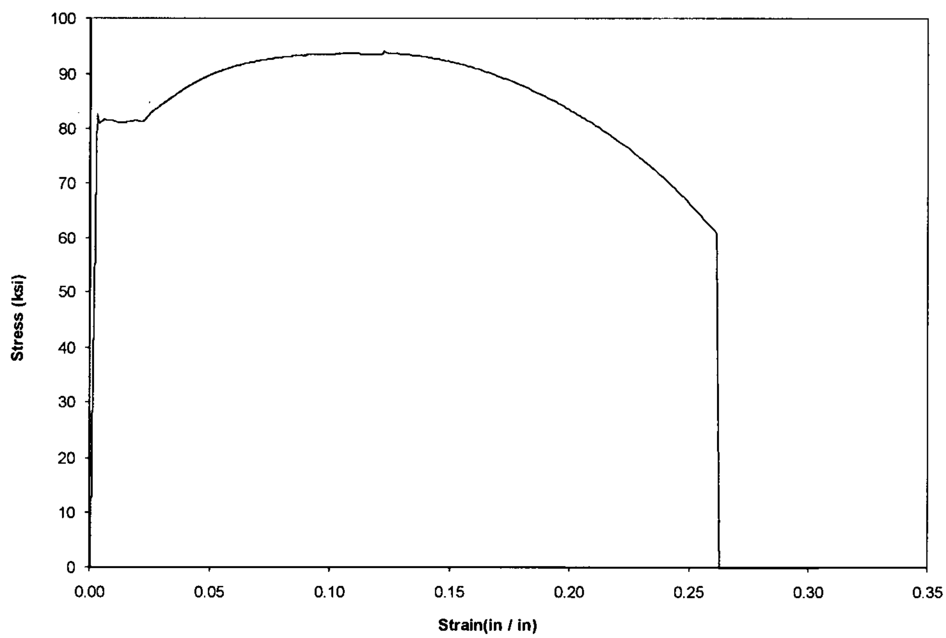


Figure 5-30 Engineering Stress-Strain Curve for Calvert Cliffs Unit 1 Surveillance Program Weld Metal Tensile Specimen 3L3 Tested at 150°

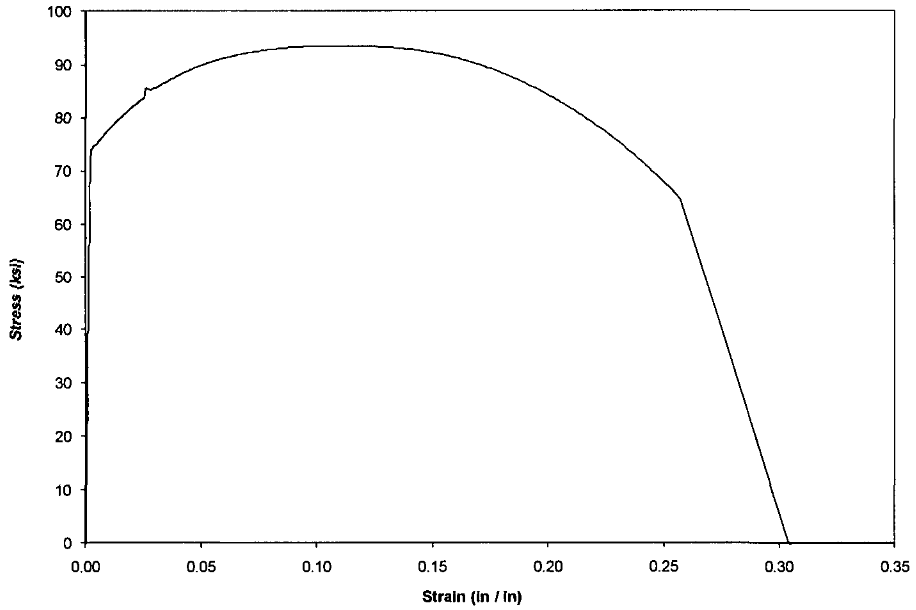


Figure 5-31 Engineering Stress-Strain Curve for Calvert Cliffs Unit 1 Surveillance Program Weld Metal Tensile Specimen 3L1 Tested at 550°

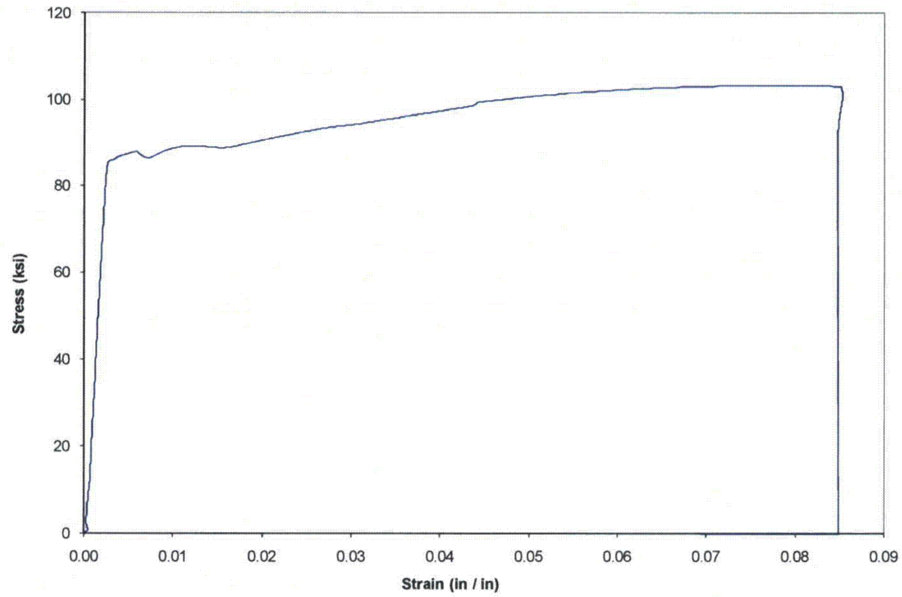


Figure 5-32 Engineering Stress-Strain Curve for Calvert Cliffs Unit 1 Heat-Affected-Zone Material Tensile Specimen 4KE Tested at 75°

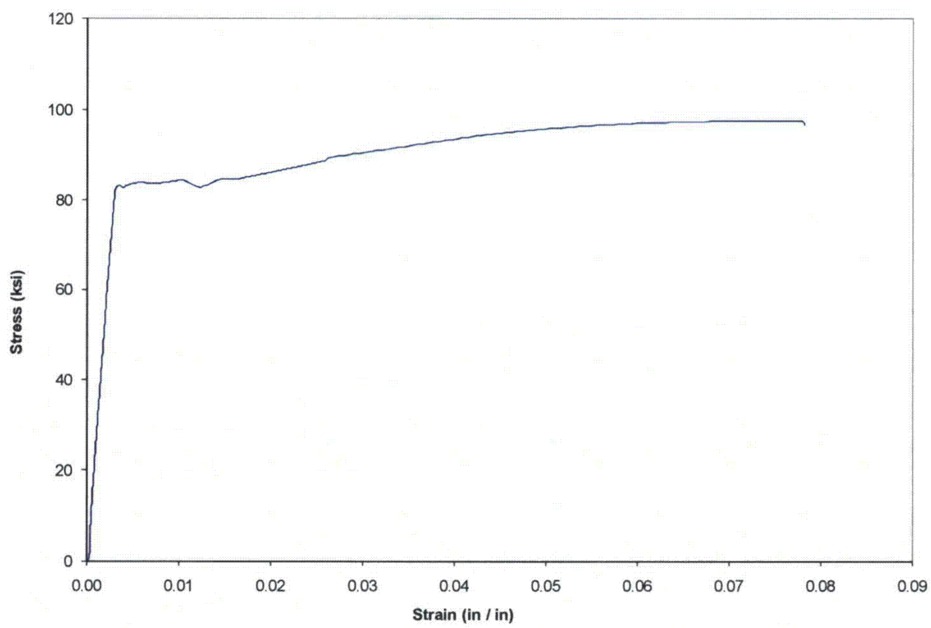


Figure 5-33 Engineering Stress-Strain Curve for Calvert Cliffs Unit 1 Heat-Affected-Zone Material Tensile Specimen 4KJ Tested at 175°

NOTE: This curve is incomplete due to slippage of the extensometer.

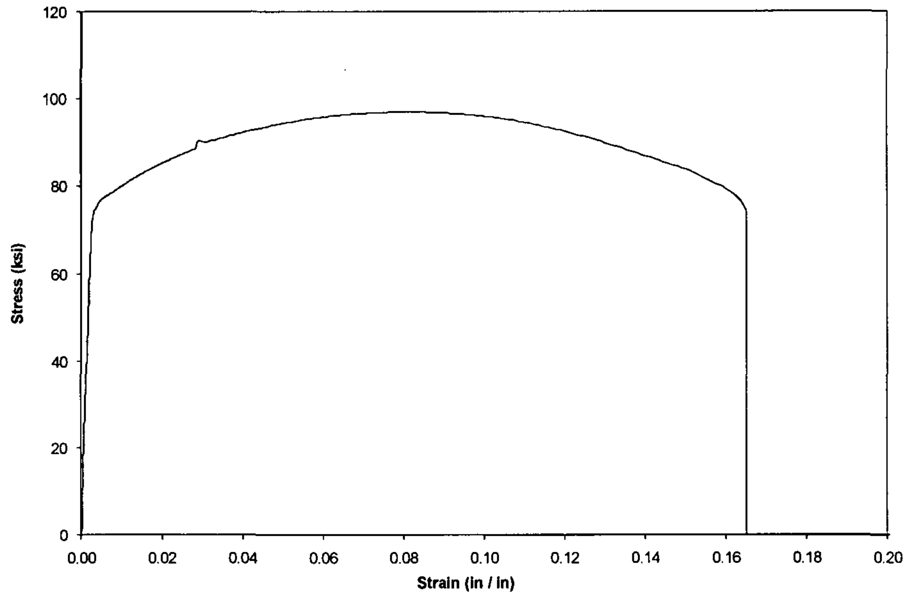


Figure 5-34 Engineering Stress-Strain Curve for Calvert Cliffs Unit 1 Heat-Affected-Zone Material Tensile Specimen 4KK Tested at 550°

6 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION

This section describes a discrete ordinates S_n transport analysis performed for the Calvert Cliffs Unit 1 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 284°, withdrawn at the end of the nineteenth plant operating cycle, is provided. In addition, to provide an up-to-date database applicable to the Calvert Cliffs Unit 1 reactor, the sensor sets from the previously withdrawn capsules (263° and 97°) are presented in Appendix A of this report. Comparisons of the results from these dosimetry evaluations with the analytical predictions served to validate the plant-specific neutron transport calculations. These validated calculations subsequently formed the basis for providing projections of the neutron exposure of the reactor pressure vessel for operating periods extending to 60 Effective Full Power Years (EFPY) at 2737 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. In recent years, however, it has been suggested that an exposure model that accounts for differences in neutron energy spectra between surveillance capsule locations and positions within the vessel wall could lead to an improvement in the uncertainties associated with damage trend curves and improved accuracy in the evaluation of damage gradients through the reactor vessel wall.

Because of this potential shift away from a threshold fluence toward an energy-dependent damage function for data correlation, ASTM Standard Practice E853-01, "Analysis and Interpretation of Light-Water Reactor Surveillance Results," [Reference 23] recommends reporting displacements per iron atom (dpa) along with fluence (E > 1.0 MeV) to provide a database for future reference. The energy-dependent dpa function to be used for this evaluation is specified in ASTM Standard Practice E693-01, "Standard Practice for Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements per Atom" [Reference 24]. 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" [Reference 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 made use of the latest available calculational tools. Furthermore, the neutron transport and dosimetry evaluation methodologies follow the guidance of Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence" [Reference 25]. 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 [Reference 26].

6.2 DISCRETE ORDINATES ANALYSIS

The arrangement of the surveillance capsules in the Calvert Cliffs Unit 1 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 6-2: 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 1.5-inch by 0.75-inch and are approximately 97 inches in height. The containers are positioned axially such that the test specimens are centered on the core midplane, thus spanning the approximate central 5 feet of the 11.4-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 flux and the neutron spectrum in the vicinity of the capsules. However, the capsules are far apart enough 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 Calvert Cliffs Unit 1 reactor vessel and surveillance capsules, a series of fuel-cycle-specific forward transport calculations were carried out using the following three-dimensional flux synthesis technique:

$$\varphi(r,\theta,z) = \varphi(r,\theta) * \frac{\varphi(r,z)}{\varphi(r)} \qquad \text{(Eqn. 6-1)}$$

where $\phi(r,\theta,z)$ is the synthesized three-dimensional neutron flux distribution, $\phi(r,\theta)$ is the transport solution in r,θ geometry, $\phi(r,z)$ is the two-dimensional solution for a cylindrical reactor model using the actual axial core power distribution, and $\phi(r)$ is the one-dimensional solution for a cylindrical reactor model using the same source per unit height as that used in the r,θ two-dimensional calculation. This synthesis procedure was carried out for each operating cycle at Calvert Cliffs Unit 1.

For the Calvert Cliffs Unit 1 transport calculations, the r,θ models depicted in Figure 6-1 and Figure 6-2 were utilized since, with the exception of the capsules, the reactor is octant symmetric. These r,θ 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. For the reactor pressure vessel, however, the average of the as-built inner radius and the minimum pressure vessel thickness were 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 reactor models consisted of 114 radial by 62 azimuthal intervals. Mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration flux convergence criterion utilized in the r,θ calculations was set at a value of 0.001.

The r,z model used for the Calvert Cliffs Unit 1 calculations is shown in Figure 6-3 and extends radially from the centerline of the reactor core out to a location interior to the primary biological shield and over an axial span from an elevation below the lower core plate to above the upper core plate. As in the case of the r,θ models, nominal design dimensions and full-power coolant densities were employed in the calculations. In this case, the homogenous core region was treated as an equivalent cylinder with a volume equal to that of the active core zone. The stainless steel former plates located between the core baffle and core barrel regions were also explicitly included in the model. The r,z geometric mesh description of these reactor models consisted of 103 radial by 137 axial intervals. As in the case of the r,θ calculations, mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration flux convergence criterion utilized in the r,z calculations was also set at a value of 0.001.

The one-dimensional radial model used in the synthesis procedure consisted of the same 103 radial mesh intervals included in the r,z model. Thus, radial synthesis factors could be determined on a meshwise basis throughout the entire geometry.

The core power distributions used in the plant-specific transport analysis were provided by Constellation Energy for each of the first nineteen fuel cycles at Calvert Cliffs Unit 1. Specifically, the data utilized 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 flux, which when multiplied by the appropriate fuel cycle length, generated the incremental fast neutron exposure for each fuel cycle. In constructing these core source distributions, the energy distribution of the source was based on an appropriate fission split for uranium and plutonium isotopes based on the initial enrichment and burnup history of individual fuel assemblies. From these assembly-dependent fission splits, composite values of energy release per fission, neutron yield per fission, and fission spectrum were determined.

All of the transport calculations supporting this analysis were carried out using the DORT discrete ordinates code Version 3.2 [Reference 27] and the BUGLE-96 cross-section library [Reference 28]. The BUGLE-96 library provides a 67-group coupled neutron, gamma-ray cross-section data set produced specifically for light-water reactor (LWR) applications. In these analyses, anisotropic scattering was treated with a P_5 Legendre expansion and angular discretization was modeled with an S_{16} order of angular quadrature. Energy- and space-dependent core power distributions, as well as system operating temperatures, were treated on a fuel-cycle-specific basis.

Selected results from the neutron transport analyses are provided in Tables 6-1 through 6-4. In Table 6-1, the calculated exposure rates and integrated exposures, expressed in terms of both neutron fluence ($E > 1.0$ MeV) and dpa, are given at the radial and azimuthal center of the octant symmetric surveillance capsule positions, i.e., for the 7° capsule and 14° single 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 projected into the future. Similar information is provided in Table 6-2 for the reactor vessel inner radius at four azimuthal locations. The vessel data given in Table 6-2 were taken at the clad/base metal interface, and thus, represent maximum calculated exposure levels on the vessel.

From the data provided in Table 6-2 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 26.17 EFPY at 2737 MWt of plant operation) was 2.32×10^{19} n/cm^2.

Both calculated fluence (E > 1.0 MeV) and dpa data are provided in Tables 6-1 and 6-2. These data tabulations include both plant- and fuel-cycle-specific calculated neutron exposures at the end of the nineteenth fuel cycle as well as future projections to 32, 36, 40, 44, 48, 54 and 60 EFPY at 2737 MWt. The calculations account for uprates from 2560 MWt to 2700 MWt that occurred during Cycle 2, and from 2700 MWt to 2737 MWt that occurred during the current Cycle 20. The projections were based on the assumption that the core power distributions and associated plant operating characteristics from Cycle 19 were representative of future plant operation. The future projections are also based on the current reactor power level of 2737 MWt.

The calculated fast neutron exposures for the three surveillance capsules withdrawn from the Calvert Cliffs Unit 1 reactor are provided in Table 6-3. These assigned neutron exposure levels are based on the plant- and fuel-cycle-specific neutron transport calculations performed for the Calvert Cliffs Unit 1 reactor.

From the data provided in Table 6-3, Capsule 284° received a fluence (E > 1.0 MeV) of 2.33×10^{19} n/cm^2 after exposure through the end of the nineteenth fuel cycle (i.e., after 26.17 EFPY at 2737 MWt of plant operation).

Updated lead factors for the Calvert Cliffs Unit 1 surveillance capsules are provided in Table 6-4. The capsule lead factor is defined as the ratio of the calculated axial average 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 6-4, the lead factors for capsules that have been withdrawn from the reactor (263°, 97°, and 284°) were based on the calculated fluence values for the irradiation period corresponding to the time of withdrawal for the individual capsules. For the capsule remaining in the reactor (83°,104° and 277°), the lead factor corresponds to the calculated fluence values at the end of Cycle 19, the last completed fuel cycle for Calvert Cliffs Unit 1.

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 284°, that was withdrawn from Calvert Cliffs Unit 1 at the end of the nineteenth fuel cycle, is summarized below.

Reaction	Reaction Rates (rps/atom)		M/C Ratio
	Measured	**Calculated**	
$^{63}Cu(n,\alpha)^{60}Co$	5.31E-17	4.63E-17	1.15
$^{54}Fe(n,p)^{54}Mn$	3.89E-15	3.96E-15	0.98
$^{58}Ni(n,p)^{58}Co$	4.56E-15	5.14E-15	0.89
		Average:	1.01
		% Standard Deviation:	13.1

The measured-to-calculated (M/C) reaction rate ratios for the Capsule 284° threshold reactions range from 0.89 to 1.15, and the average M/C ratio is 1.01 ± 13.1% (1σ). This direct comparison falls well within the ± 20% criterion specified in Regulatory Guide 1.190. These comparisons validate the current analytical results described in Section 6.2; therefore, the calculations are deemed applicable for Calvert Cliffs Unit 1.

6.4 CALCULATIONAL UNCERTAINTIES

The uncertainty associated with the calculated neutron exposure of the Calvert Cliffs Unit 1 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 Calvert Cliffs Unit 1 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 Calvert Cliffs Unit 1 analysis was established from results of these three phases of the methods qualification.

The fourth phase of the uncertainty assessment (comparisons with Calvert Cliffs Unit 1 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 Calvert Cliffs Unit 1 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 26.

	Capsule and Vessel IR
PCA Comparisons	3%
H. B. Robinson Comparisons	3%
Analytical Sensitivity Studies	11%
Additional Uncertainty for Factors not Explicitly Evaluated	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 Calvert Cliffs Unit 1.

Table 6-1 Calculated Neutron Exposure Rates and Integrated Exposures at the Surveillance Capsule Center[(a)]

Cycle	Cycle Length [EFPS[(b)]]	Cumulative Irradiation Time [EFPS[(b)]]	Cumulative Irradiation Time [EFPY[(b)]]	Neutron Flux (E > 1.0 MeV) [n/cm^2-s]	
				7° Capsule	14° Capsule
1	4.49E+07	4.49E+07	1.42	5.23E+10	3.77E+10
2	2.18E+07	6.66E+07	2.11	6.02E+10	4.39E+10
3	2.39E+07	9.05E+07	2.87	5.84E+10	4.23E+10
4	3.14E+07	1.22E+08	3.86	5.71E+10	4.16E+10
5	3.52E+07	1.57E+08	4.98	5.96E+10	4.29E+10
6	3.45E+07	1.92E+08	6.07	6.16E+10	4.46E+10
7	3.50E+07	2.27E+08	7.18	6.14E+10	4.43E+10
8	3.36E+07	2.60E+08	8.25	5.62E+10	4.07E+10
9	2.93E+07	2.90E+08	9.18	6.31E+10	4.50E+10
10	5.46E+07	3.44E+08	10.91	4.42E+10	3.05E+10
11	4.33E+07	3.87E+08	12.28	2.84E+10	2.34E+10
12	5.39E+07	4.41E+08	13.99	1.48E+10	1.55E+10
13	5.01E+07	4.91E+08	15.57	2.47E+10	1.90E+10
14	5.22E+07	5.44E+08	17.23	2.26E+10	1.85E+10
15	5.56E+07	5.99E+08	18.99	2.40E+10	1.91E+10
16	5.49E+07	6.54E+08	20.73	2.44E+10	1.97E+10
17	5.52E+07	7.09E+08	22.48	2.53E+10	2.08E+10
18	5.72E+07	7.66E+08	24.29	2.55E+10	1.85E+10
19	5.94E+07	8.26E+08	26.17	2.93E+10	2.16E+10
Future	1.84E+08	1.01E+09	32.00	2.93E+10	2.16E+10
Future	1.26E+08	1.14E+09	36.00	2.93E+10	2.16E+10
Future	1.26E+08	1.26E+09	40.00	2.93E+10	2.16E+10
Future	1.26E+08	1.39E+09	44.00	2.93E+10	2.16E+10
Future	1.26E+08	1.51E+09	48.00	2.93E+10	2.16E+10
Future	1.89E+08	1.70E+09	54.00	2.93E+10	2.16E+10
Future	1.89E+08	1.89E+09	60.00	2.93E+10	2.16E+10

Note:

(a) Neutron exposure values reported for the surveillance capsules are axial averages over the capsules' axial span.

(b) At 2737 MWt.

Table 6-1 (Continued) Calculated Neutron Exposure Rates and Integrated Exposures at the Surveillance Capsule Center[(a)]

Cycle	Cycle Length [EFPS[(b)]]	Cumulative Irradiation Time [EFPS[(b)]]	Cumulative Irradiation Time [EFPY[(b)]]	Cumulative Irradiation Time [EFPY[(c)]]	Neutron Fluence (E > 1.0 MeV) [n/cm^2]	
					7° Capsule	14° Capsule
1	4.49E+07	4.49E+07	1.42	1.44	2.35E+18	1.69E+18
2	2.18E+07	6.66E+07	2.11	2.14	3.66E+18	2.65E+18
3	2.39E+07	9.05E+07	2.87	2.91	5.05E+18	3.66E+18
4	3.14E+07	1.22E+08	3.86	3.92	6.84E+18	4.96E+18
5	3.52E+07	1.57E+08	4.98	5.05	8.94E+18	6.47E+18
6	3.45E+07	1.92E+08	6.07	6.15	1.11E+19	8.01E+18
7	3.50E+07	2.27E+08	7.18	7.28	1.32E+19	9.56E+18
8	3.36E+07	2.60E+08	8.25	8.36	1.51E+19	1.09E+19
9	2.93E+07	2.90E+08	9.18	9.30	1.70E+19	1.23E+19
10	5.46E+07	3.44E+08	10.91	11.06	1.94E+19	1.39E+19
11	4.33E+07	3.87E+08	12.28	12.45	2.06E+19	1.49E+19
12	5.39E+07	4.41E+08	13.99	14.18	2.14E+19	1.58E+19
13	5.01E+07	4.91E+08	15.57	15.79	2.26E+19	1.67E+19
14	5.22E+07	5.44E+08	17.23	17.47	2.38E+19	1.77E+19
15	5.56E+07	5.99E+08	18.99	19.25	2.52E+19	1.87E+19
16	5.49E+07	6.54E+08	20.73	21.01	2.65E+19	1.98E+19
17	5.52E+07	7.09E+08	22.48	22.79	2.79E+19	2.10E+19
18	5.72E+07	7.66E+08	24.29	24.62	2.93E+19	2.20E+19
19	5.94E+07	8.26E+08	26.17	26.53	3.11E+19	2.33E+19
Future	1.84E+08	1.01E+09	32.00	--	3.65E+19	2.73E+19
Future	1.26E+08	1.14E+09	36.00	--	4.02E+19	3.00E+19
Future	1.26E+08	1.26E+09	40.00	--	4.39E+19	3.28E+19
Future	1.26E+08	1.39E+09	44.00	--	4.75E+19	3.55E+19
Future	1.26E+08	1.51E+09	48.00	--	5.12E+19	3.82E+19
Future	1.89E+08	1.70E+09	54.00	--	5.68E+19	4.23E+19
Future	1.89E+08	1.89E+09	60.00	--	6.23E+19	4.64E+19

Note:

(a) Neutron exposure values reported for the surveillance capsules are axial averages over the capsules' axial span.

(b) At 2737 MWt.

(c) At 2700 MWt

Table 6-1 (Continued) Calculated Neutron Exposure Rates and Integrated Exposures at the Surveillance Capsule Center[(a)]

Cycle	Cycle Length [EFPS[(b)]]	Cumulative Irradiation Time [EFPS[(b)]]	Cumulative Irradiation Time [EFPY[(b)]]	Iron Atom Displacement Rate [dpa/s]	
				7° Capsule	14° Capsule
1	4.49E+07	4.49E+07	1.42	7.56E-11	5.47E-11
2	2.18E+07	6.66E+07	2.11	8.70E-11	6.38E-11
3	2.39E+07	9.05E+07	2.87	8.43E-11	6.15E-11
4	3.14E+07	1.22E+08	3.86	8.26E-11	6.04E-11
5	3.52E+07	1.57E+08	4.98	8.61E-11	6.23E-11
6	3.45E+07	1.92E+08	6.07	8.90E-11	6.48E-11
7	3.50E+07	2.27E+08	7.18	8.88E-11	6.44E-11
8	3.36E+07	2.60E+08	8.25	8.13E-11	5.91E-11
9	2.93E+07	2.90E+08	9.18	9.12E-11	6.53E-11
10	5.46E+07	3.44E+08	10.91	6.40E-11	4.44E-11
11	4.33E+07	3.87E+08	12.28	4.13E-11	3.42E-11
12	5.39E+07	4.41E+08	13.99	2.16E-11	2.26E-11
13	5.01E+07	4.91E+08	15.57	3.59E-11	2.76E-11
14	5.22E+07	5.44E+08	17.23	3.28E-11	2.69E-11
15	5.56E+07	5.99E+08	18.99	3.49E-11	2.78E-11
16	5.49E+07	6.54E+08	20.73	3.55E-11	2.87E-11
17	5.52E+07	7.09E+08	22.48	3.67E-11	3.03E-11
18	5.72E+07	7.66E+08	24.29	3.70E-11	2.71E-11
19	5.94E+07	8.26E+08	26.17	4.25E-11	3.16E-11
Future	1.84E+08	1.01E+09	32.00	4.25E-11	3.16E-11
Future	1.26E+08	1.14E+09	36.00	4.25E-11	3.16E-11
Future	1.26E+08	1.26E+09	40.00	4.25E-11	3.16E-11
Future	1.26E+08	1.39E+09	44.00	4.25E-11	3.16E-11
Future	1.26E+08	1.51E+09	48.00	4.25E-11	3.16E-11
Future	1.89E+08	1.70E+09	54.00	4.25E-11	3.16E-11
Future	1.89E+08	1.89E+09	60.00	4.25E-11	3.16E-11

Note:

(a) Neutron exposure values reported for the surveillance capsules are axial averages over the capsules' axial span.

(b) At 2737 MWt.

Table 6-1 (Continued) Calculated Neutron Exposure Rates and Integrated Exposures at the Surveillance Capsule Center[(a)]

Cycle	Cycle Length [EFPS[(b)]]	Cumulative Irradiation Time [EFPS[(b)]]	Cumulative Irradiation Time [EFPY[(b)]]	Cumulative Irradiation Time [EFPY[(c)]]	Iron Atom Displacements [dpa]	
					7° Capsule	14° Capsule
1	4.49E+07	4.49E+07	1.42	1.44	3.39E-03	2.46E-03
2	2.18E+07	6.66E+07	2.11	2.14	5.29E-03	3.84E-03
3	2.39E+07	9.05E+07	2.87	2.91	7.30E-03	5.31E-03
4	3.14E+07	1.22E+08	3.86	3.92	9.89E-03	7.21E-03
5	3.52E+07	1.57E+08	4.98	5.05	1.29E-02	9.40E-03
6	3.45E+07	1.92E+08	6.07	6.15	1.60E-02	1.16E-02
7	3.50E+07	2.27E+08	7.18	7.28	1.91E-02	1.39E-02
8	3.36E+07	2.60E+08	8.25	8.36	2.18E-02	1.59E-02
9	2.93E+07	2.90E+08	9.18	9.30	2.45E-02	1.78E-02
10	5.46E+07	3.44E+08	10.91	11.06	2.80E-02	2.02E-02
11	4.33E+07	3.87E+08	12.28	12.45	2.98E-02	2.17E-02
12	5.39E+07	4.41E+08	13.99	14.18	3.10E-02	2.29E-02
13	5.01E+07	4.91E+08	15.57	15.79	3.28E-02	2.43E-02
14	5.22E+07	5.44E+08	17.23	17.47	3.45E-02	2.57E-02
15	5.56E+07	5.99E+08	18.99	19.25	3.64E-02	2.73E-02
16	5.49E+07	6.54E+08	20.73	21.01	3.83E-02	2.88E-02
17	5.52E+07	7.09E+08	22.48	22.79	4.04E-02	3.05E-02
18	5.72E+07	7.66E+08	24.29	24.62	4.25E-02	3.21E-02
19	5.94E+07	8.26E+08	26.17	26.53	4.50E-02	3.39E-02
Future	1.84E+08	1.01E+09	32.00	--	5.28E-02	3.97E-02
Future	1.26E+08	1.14E+09	36.00	--	5.82E-02	4.37E-02
Future	1.26E+08	1.26E+09	40.00	--	6.35E-02	4.77E-02
Future	1.26E+08	1.39E+09	44.00	--	6.89E-02	5.17E-02
Future	1.26E+08	1.51E+09	48.00	--	7.43E-02	5.57E-02
Future	1.89E+08	1.70E+09	54.00	--	8.23E-02	6.17E-02
Future	1.89E+08	1.89E+09	60.00	--	9.03E-02	6.76E-02

Note:

(a) Neutron exposure values reported for the surveillance capsules are axial averages over the capsules' axial span.

(b) At 2737 MWt.

(c) At 2700 MWt

Table 6-2 Calculated Azimuthal Variation of Maximum Exposure Rates and Integrated Exposures at the Reactor Vessel Clad/Base Metal Interface

Cycle	Cycle Length [EFPS[(a)]]	Cumulative Irradiation Time [EFPS[(a)]]	Cumulative Irradiation Time [EFPY[(a)]]	Neutron Flux (E > 1.0 MeV) [n/cm^2-s]			
				0°	15°	30°	45°
1	4.49E+07	4.49E+07	1.42	3.89E+10	2.50E+10	2.13E+10	1.72E+10
2	2.18E+07	6.66E+07	2.11	4.43E+10	2.91E+10	2.59E+10	2.01E+10
3	2.39E+07	9.05E+07	2.87	4.28E+10	2.79E+10	2.25E+10	1.75E+10
4	3.14E+07	1.22E+08	3.86	4.23E+10	2.77E+10	2.47E+10	1.95E+10
5	3.52E+07	1.57E+08	4.98	4.41E+10	2.84E+10	2.55E+10	1.98E+10
6	3.45E+07	1.92E+08	6.07	4.57E+10	2.96E+10	2.62E+10	2.02E+10
7	3.50E+07	2.27E+08	7.18	4.55E+10	2.94E+10	2.61E+10	2.10E+10
8	3.36E+07	2.60E+08	8.25	4.15E+10	2.69E+10	2.43E+10	1.93E+10
9	2.93E+07	2.90E+08	9.18	4.71E+10	2.98E+10	2.72E+10	2.09E+10
10	5.46E+07	3.44E+08	10.91	3.49E+10	2.04E+10	1.67E+10	1.28E+10
11	4.33E+07	3.87E+08	12.28	2.11E+10	1.63E+10	1.68E+10	1.25E+10
12	5.39E+07	4.41E+08	13.99	1.03E+10	1.13E+10	1.26E+10	1.03E+10
13	5.01E+07	4.91E+08	15.57	1.86E+10	1.30E+10	1.14E+10	1.04E+10
14	5.22E+07	5.44E+08	17.23	1.63E+10	1.27E+10	1.16E+10	1.07E+10
15	5.56E+07	5.99E+08	18.99	1.83E+10	1.34E+10	1.30E+10	1.01E+10
16	5.49E+07	6.54E+08	20.73	1.86E+10	1.40E+10	1.32E+10	1.02E+10
17	5.52E+07	7.09E+08	22.48	1.93E+10	1.48E+10	1.46E+10	1.11E+10
18	5.72E+07	7.66E+08	24.29	1.97E+10	1.26E+10	1.11E+10	9.75E+09
19	5.94E+07	8.26E+08	26.17	2.23E+10	1.46E+10	1.29E+10	1.07E+10
Future	1.84E+08	1.01E+09	32.00	2.23E+10	1.46E+10	1.29E+10	1.07E+10
Future	1.26E+08	1.14E+09	36.00	2.23E+10	1.46E+10	1.29E+10	1.07E+10
Future	1.26E+08	1.26E+09	40.00	2.23E+10	1.46E+10	1.29E+10	1.07E+10
Future	1.26E+08	1.39E+09	44.00	2.23E+10	1.46E+10	1.29E+10	1.07E+10
Future	1.26E+08	1.51E+09	48.00	2.23E+10	1.46E+10	1.29E+10	1.07E+10
Future	1.89E+08	1.70E+09	54.00	2.23E+10	1.46E+10	1.29E+10	1.07E+10
Future	1.89E+08	1.89E+09	60.00	2.23E+10	1.46E+10	1.29E+10	1.07E+10

Note:

(a) At 2737 MWt.

Table 6-2 (Continued) Calculated Azimuthal Variation of Maximum Exposure Rates and Integrated Exposures at the Reactor Vessel Clad/Base Metal Interface

Cycle	Cycle Length [EFPS[a]]	Cumulative Irradiation Time [EFPS[a]]	Cumulative Irradiation Time [EFPY[a]]	Cumulative Irradiation Time [EFPY[b]]	Neutron Fluence (E > 1.0 MeV) [n/cm^2]			
					0°	15°	30°	45°
1	4.49E+07	4.49E+07	1.42	1.44	1.75E+18	1.12E+18	9.58E+17	7.72E+17
2	2.18E+07	6.66E+07	2.11	2.14	2.70E+18	1.75E+18	1.52E+18	1.20E+18
3	2.39E+07	9.05E+07	2.87	2.91	3.72E+18	2.42E+18	2.05E+18	1.62E+18
4	3.14E+07	1.22E+08	3.86	3.92	5.04E+18	3.28E+18	2.83E+18	2.23E+18
5	3.52E+07	1.57E+08	4.98	5.05	6.60E+18	4.28E+18	3.72E+18	2.93E+18
6	3.45E+07	1.92E+08	6.07	6.15	8.17E+18	5.30E+18	4.63E+18	3.63E+18
7	3.50E+07	2.27E+08	7.18	7.28	9.76E+18	6.33E+18	5.54E+18	4.36E+18
8	3.36E+07	2.60E+08	8.25	8.36	1.12E+19	7.23E+18	6.36E+18	5.01E+18
9	2.93E+07	2.90E+08	9.18	9.30	1.25E+19	8.11E+18	7.15E+18	5.62E+18
10	5.46E+07	3.44E+08	10.91	11.06	1.44E+19	9.22E+18	8.07E+18	6.32E+18
11	4.33E+07	3.87E+08	12.28	12.45	1.54E+19	9.93E+18	8.79E+18	6.86E+18
12	5.39E+07	4.41E+08	13.99	14.18	1.59E+19	1.05E+19	9.47E+18	7.41E+18
13	5.01E+07	4.91E+08	15.57	15.79	1.68E+19	1.12E+19	1.00E+19	7.93E+18
14	5.22E+07	5.44E+08	17.23	17.47	1.77E+19	1.19E+19	1.07E+19	8.49E+18
15	5.56E+07	5.99E+08	18.99	19.25	1.87E+19	1.26E+19	1.14E+19	9.06E+18
16	5.49E+07	6.54E+08	20.73	21.01	1.97E+19	1.34E+19	1.21E+19	9.62E+18
17	5.52E+07	7.09E+08	22.48	22.79	2.08E+19	1.42E+19	1.29E+19	1.02E+19
18	5.72E+07	7.66E+08	24.29	24.62	2.19E+19	1.49E+19	1.35E+19	1.08E+19
19	5.94E+07	8.26E+08	26.17	26.53	2.32E+19	1.58E+19	1.43E+19	1.14E+19
Future	1.84E+08	1.01E+09	32.00	--	2.73E+19	1.85E+19	1.67E+19	1.34E+19
Future	1.26E+08	1.14E+09	36.00	--	3.02E+19	2.03E+19	1.83E+19	1.47E+19
Future	1.26E+08	1.26E+09	40.00	--	3.30E+19	2.22E+19	1.99E+19	1.61E+19
Future	1.26E+08	1.39E+09	44.00	--	3.58E+19	2.40E+19	2.15E+19	1.74E+19
Future	1.26E+08	1.51E+09	48.00	--	3.86E+19	2.59E+19	2.31E+19	1.88E+19
Future	1.89E+08	1.70E+09	54.00	--	4.28E+19	2.86E+19	2.56E+19	2.08E+19
Future	1.89E+08	1.89E+09	60.00	--	4.70E+19	3.14E+19	2.80E+19	2.28E+19

Note:

(a) At 2737 MWt.

(b) At 2700 MWt.

Table 6-2 (Continued) Calculated Azimuthal Variation of Maximum Exposure Rates and Integrated Exposures at the Reactor Vessel Clad/Base Metal Interface

Cycle	Cycle Length [EFPS[(a)]]	Cumulative Irradiation Time [EFPS[(a)]]	Cumulative Irradiation Time [EFPY[(a)]]	Iron Atom Displacement Rate [dpa/s]			
				0°	15°	30°	45°
1	4.49E+07	4.49E+07	1.42	5.91E-11	3.83E-11	3.25E-11	2.64E-11
2	2.18E+07	6.66E+07	2.11	6.72E-11	4.45E-11	3.95E-11	3.08E-11
3	2.39E+07	9.05E+07	2.87	6.50E-11	4.27E-11	3.43E-11	2.69E-11
4	3.14E+07	1.22E+08	3.86	6.42E-11	4.23E-11	3.77E-11	3.00E-11
5	3.52E+07	1.57E+08	4.98	6.70E-11	4.34E-11	3.88E-11	3.05E-11
6	3.45E+07	1.92E+08	6.07	6.93E-11	4.53E-11	3.99E-11	3.10E-11
7	3.50E+07	2.27E+08	7.18	6.90E-11	4.49E-11	3.97E-11	3.22E-11
8	3.36E+07	2.60E+08	8.25	6.30E-11	4.11E-11	3.70E-11	2.96E-11
9	2.93E+07	2.90E+08	9.18	7.14E-11	4.56E-11	4.13E-11	3.21E-11
10	5.46E+07	3.44E+08	10.91	5.28E-11	3.13E-11	2.55E-11	1.97E-11
11	4.33E+07	3.87E+08	12.28	3.22E-11	2.50E-11	2.55E-11	1.92E-11
12	5.39E+07	4.41E+08	13.99	1.58E-11	1.74E-11	1.93E-11	1.58E-11
13	5.01E+07	4.91E+08	15.57	2.84E-11	1.99E-11	1.74E-11	1.59E-11
14	5.22E+07	5.44E+08	17.23	2.49E-11	1.95E-11	1.78E-11	1.65E-11
15	5.56E+07	5.99E+08	18.99	2.79E-11	2.05E-11	1.99E-11	1.56E-11
16	5.49E+07	6.54E+08	20.73	2.84E-11	2.14E-11	2.01E-11	1.57E-11
17	5.52E+07	7.09E+08	22.48	2.94E-11	2.28E-11	2.22E-11	1.71E-11
18	5.72E+07	7.66E+08	24.29	3.00E-11	1.94E-11	1.69E-11	1.50E-11
19	5.94E+07	8.26E+08	26.17	3.39E-11	2.25E-11	1.97E-11	1.64E-11
Future	1.84E+08	1.01E+09	32.00	3.39E-11	2.25E-11	1.97E-11	1.64E-11
Future	1.26E+08	1.14E+09	36.00	3.39E-11	2.25E-11	1.97E-11	1.64E-11
Future	1.26E+08	1.26E+09	40.00	3.39E-11	2.25E-11	1.97E-11	1.64E-11
Future	1.26E+08	1.39E+09	44.00	3.39E-11	2.25E-11	1.97E-11	1.64E-11
Future	1.26E+08	1.51E+09	48.00	3.39E-11	2.25E-11	1.97E-11	1.64E-11
Future	1.89E+08	1.70E+09	54.00	3.39E-11	2.25E-11	1.97E-11	1.64E-11
Future	1.89E+08	1.89E+09	60.00	3.39E-11	2.25E-11	1.97E-11	1.64E-11

Note:
(a) At 2737 MWt.

Table 6-2 (Continued) Calculated Azimuthal Variation of Maximum Exposure Rates and Integrated Exposures at the Reactor Vessel Clad/Base Metal Interface

Cycle	Cycle Length [EFPS(a)]	Cumulative Irradiation Time [EFPS(a)]	Cumulative Irradiation Time [EFPY(a)]	Cumulative Irradiation Time [EFPY(b)]	Iron Atom Displacements [dpa]			
					0°	15°	30°	45°
1	4.49E+07	4.49E+07	1.42	1.44	2.65E-03	1.72E-03	1.46E-03	1.19E-03
2	2.18E+07	6.66E+07	2.11	2.14	4.10E-03	2.68E-03	2.31E-03	1.85E-03
3	2.39E+07	9.05E+07	2.87	2.91	5.65E-03	3.70E-03	3.13E-03	2.49E-03
4	3.14E+07	1.22E+08	3.86	3.92	7.66E-03	5.02E-03	4.31E-03	3.43E-03
5	3.52E+07	1.57E+08	4.98	5.05	1.00E-02	6.54E-03	5.67E-03	4.50E-03
6	3.45E+07	1.92E+08	6.07	6.15	1.24E-02	8.11E-03	7.05E-03	5.57E-03
7	3.50E+07	2.27E+08	7.18	7.28	1.48E-02	9.68E-03	8.43E-03	6.70E-03
8	3.36E+07	2.60E+08	8.25	8.36	1.69E-02	1.11E-02	9.68E-03	7.69E-03
9	2.93E+07	2.90E+08	9.18	9.30	1.90E-02	1.24E-02	1.09E-02	8.63E-03
10	5.46E+07	3.44E+08	10.91	11.06	2.19E-02	1.41E-02	1.23E-02	9.71E-03
11	4.33E+07	3.87E+08	12.28	12.45	2.33E-02	1.52E-02	1.34E-02	1.05E-02
12	5.39E+07	4.41E+08	13.99	14.18	2.42E-02	1.61E-02	1.44E-02	1.14E-02
13	5.01E+07	4.91E+08	15.57	15.79	2.56E-02	1.71E-02	1.53E-02	1.22E-02
14	5.22E+07	5.44E+08	17.23	17.47	2.69E-02	1.82E-02	1.62E-02	1.31E-02
15	5.56E+07	5.99E+08	18.99	19.25	2.84E-02	1.93E-02	1.73E-02	1.39E-02
16	5.49E+07	6.54E+08	20.73	21.01	3.00E-02	2.05E-02	1.84E-02	1.48E-02
17	5.52E+07	7.09E+08	22.48	22.79	3.16E-02	2.17E-02	1.97E-02	1.57E-02
18	5.72E+07	7.66E+08	24.29	24.62	3.33E-02	2.28E-02	2.06E-02	1.66E-02
19	5.94E+07	8.26E+08	26.17	26.53	3.53E-02	2.42E-02	2.18E-02	1.75E-02
Future	1.84E+08	1.01E+09	32.00	--	4.16E-02	2.83E-02	2.54E-02	2.06E-02
Future	1.26E+08	1.14E+09	36.00	--	4.58E-02	3.11E-02	2.79E-02	2.26E-02
Future	1.26E+08	1.26E+09	40.00	--	5.01E-02	3.40E-02	3.04E-02	2.47E-02
Future	1.26E+08	1.39E+09	44.00	--	5.44E-02	3.68E-02	3.28E-02	2.68E-02
Future	1.26E+08	1.51E+09	48.00	--	5.87E-02	3.96E-02	3.53E-02	2.89E-02
Future	1.89E+08	1.70E+09	54.00	--	6.51E-02	4.39E-02	3.91E-02	3.20E-02
Future	1.89E+08	1.89E+09	60.00	--	7.15E-02	4.81E-02	4.28E-02	3.51E-02

Note:

(a) At 2737 MWt.

(b) At 2700 MWt.

Table 6-3 Calculated Fast Neutron Exposure of Surveillance Capsules Withdrawn from Calvert Cliffs Unit 1

Capsule	Irradiation Time [EFPY[(a)]]	Irradiation Time [EFPY[(b)]]	Fluence (E > 1.0 MeV) [n/cm^2]	Iron Displacements [dpa]
263°	2.87	2.91	5.05E+18	7.30E-3
97°	10.91	11.06	1.94E+19	2.80E-2
284°	26.17	26.53	2.33E+19	3.39E-2

Note:

(a) At 2737 MWt.
(b) At 2700 MWt.

Table 6-4 Calculated Surveillance Capsule Lead Factors

Capsule Location	Status	Lead Factor
263°	Withdrawn EOC 3	1.36
97°	Withdrawn EOC 10	1.34
284°	Withdrawn EOC 19	1.00
83°	In Reactor[(a)]	1.34
104°	In Reactor[(a)]	1.00
277°	In Reactor[(a)]	1.34

Note:

(a) Lead factors are based on the cumulative integrated exposures from Cycles 1 through 19.

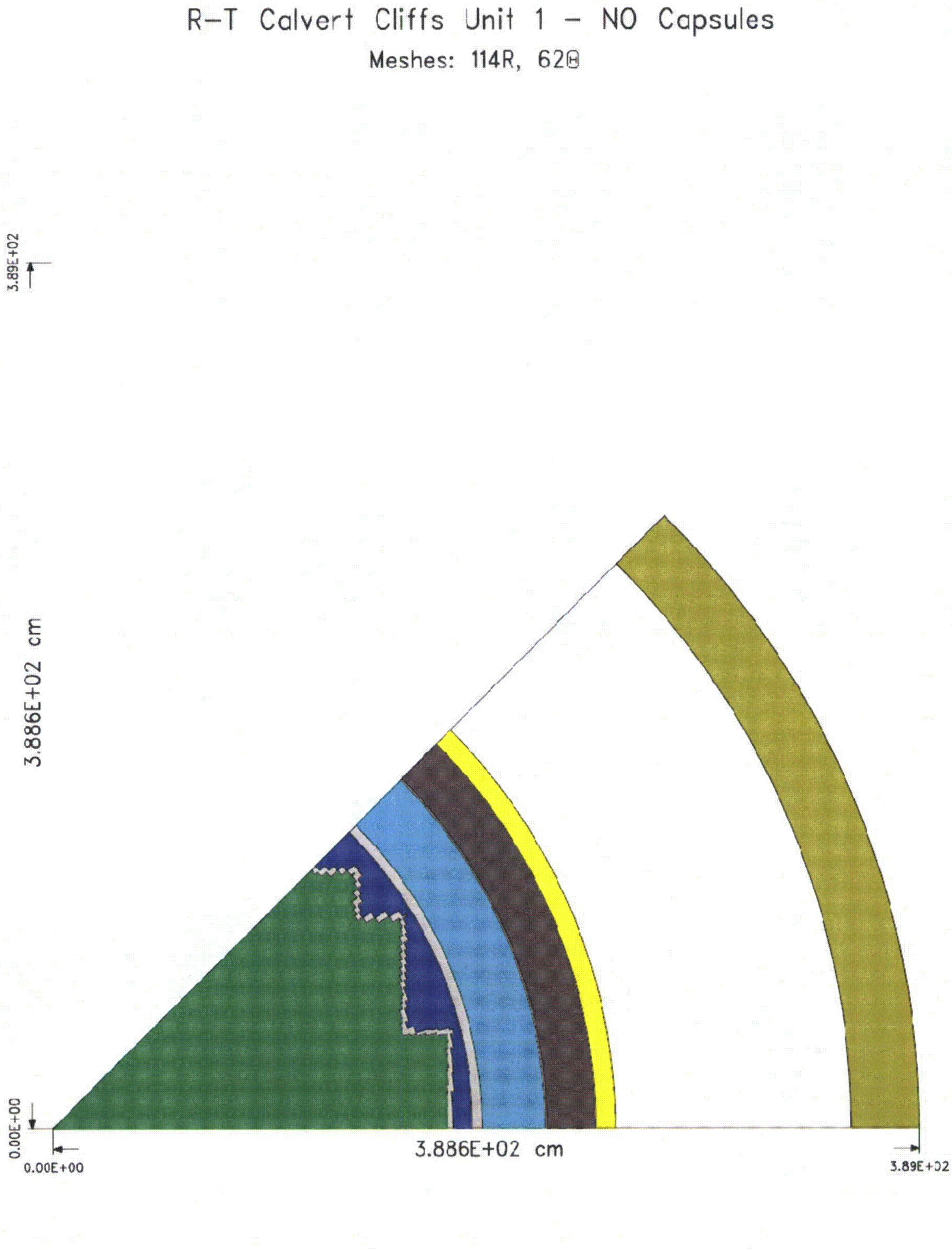


Figure 6-1 Calvert Cliffs Unit 1 r,θ Reactor Geometry without Surveillance Capsules

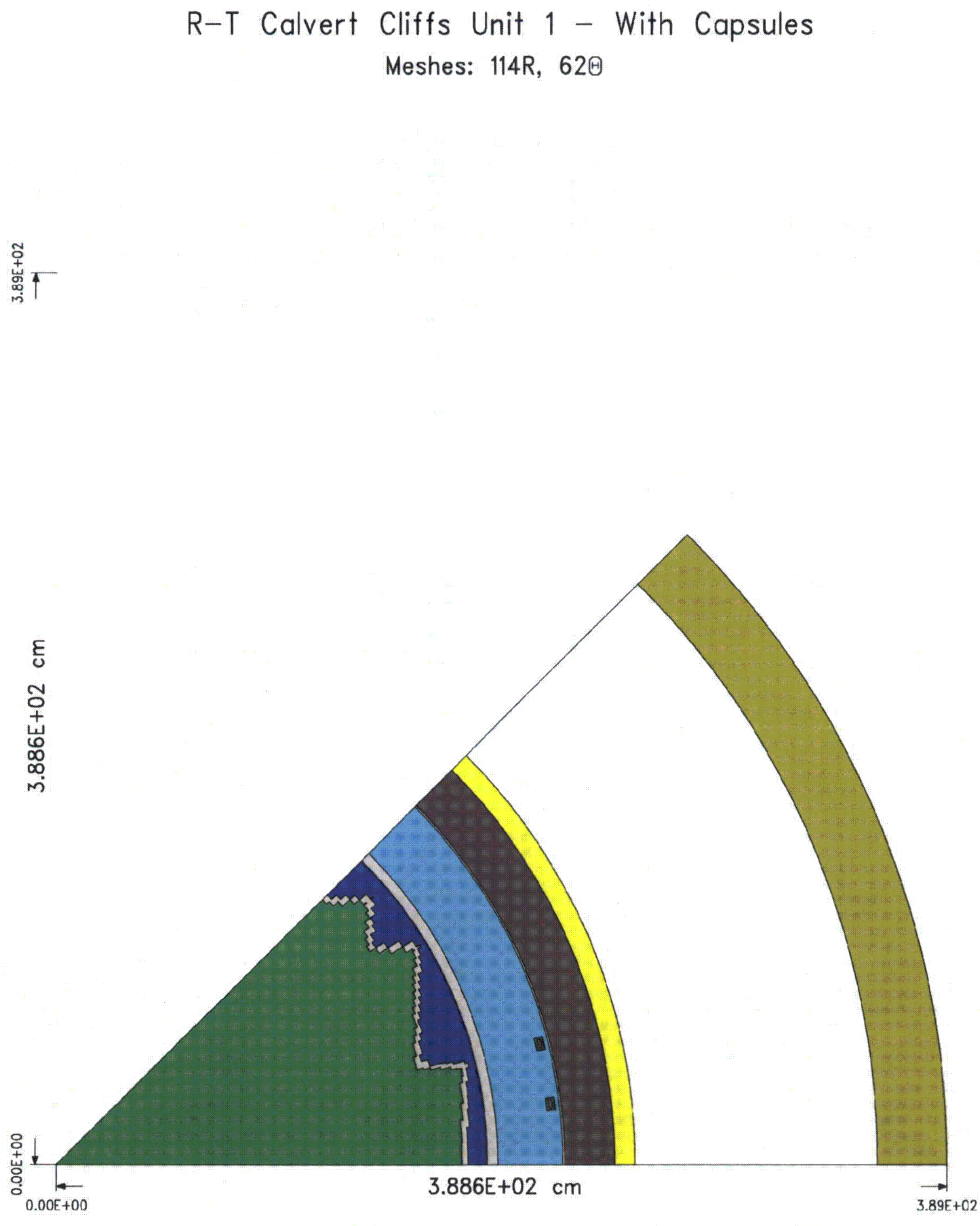


Figure 6-2 Calvert Cliffs Unit 1 r,θ Reactor Geometry with 7° and 14° Surveillance Capsules

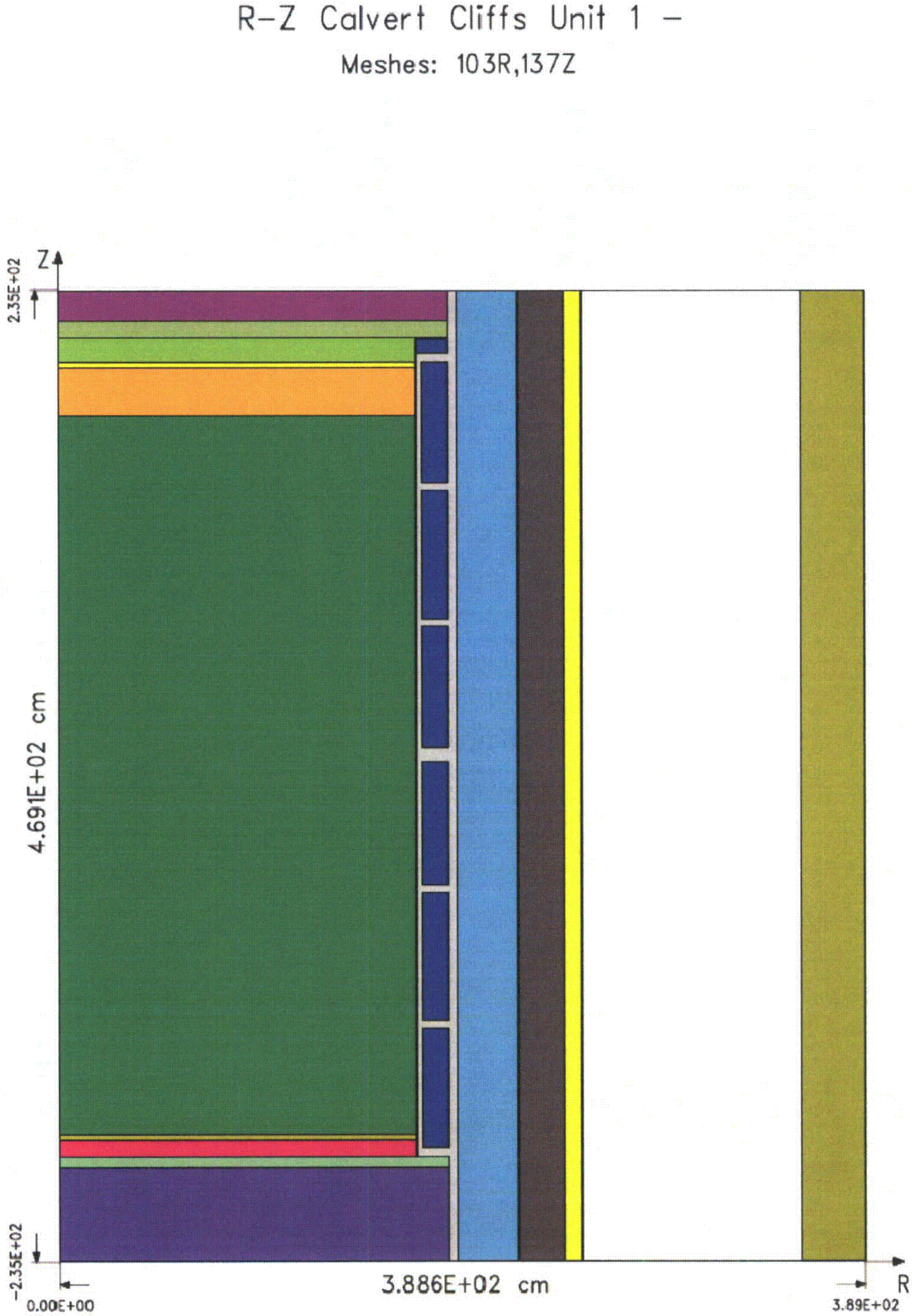


Figure 6-3 Calvert Cliffs Unit 1 r,z Reactor Geometry

7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following surveillance capsule removal schedule (Table 7-1) meets the requirements of ASTM E185-82 [Reference 10] and is recommended for future capsules to be removed from the Calvert Cliffs Unit 1 reactor vessel. Table 7-2 documents the withdrawal schedule for the supplemental surveillance capsules (S1 and S2) which are also contained in the Calvert Cliffs Unit 1 reactor vessel. The two supplemental surveillance capsules are not part of the Calvert Cliffs Unit 1 10 CFR 50, Appendix H [Reference 2] program; therefore, the withdrawal year, EFPY, end-of-cycle and capsule fluence projections shown in Table 7-2 are subject to change.

Table 7-1 Surveillance Capsule Withdrawal Schedule

Capsule Location	Lead Factor[(a)]	Withdrawal EFPY[(b)]	Fluence (n/cm^2)[(c)]
263°	1.36	2.87	5.05×10^{18}
97°	1.34	10.91	1.94×10^{19}
284°	1.00	26.17	2.33×10^{19}
83°	1.34	See Note (d)	---
277°	1.34	See Note (e)	---
104°	1.00	Standby[(f)]	---

Notes:

(a) Updated in Capsule 284° dosimetry analysis; see Table 6-4.

(b) EFPY from plant startup.

(c) Updated in Capsule 284° dosimetry analysis; see Table 6-3.

(d) Capsule 83° should be withdrawn at approximately 34.1 EFPY of plant operation, which is when the fluence on the capsule would equal the projected 48 EFPY peak vessel fluence.

(e) Capsule 277° should be withdrawn after 34.1 EFPY but before 75.1 EFPY, which is when the fluence on the capsule would equal twice the projected 48 EFPY peak vessel fluence. Since the late withdrawal date is past the current end-of-life-extension for Calvert Cliffs Unit 1, Capsule 277° should be withdrawn before 48 EFPY. However, this capsule could be withdrawn and tested at a time when the metallurgical data will be most beneficial to Calvert Cliffs Unit 1 in support of a potential second license extension (40-year extension to 80-year end-of-life).

(f) Capsule 104° is currently unable to be removed from the Calvert Cliffs Unit 1 reactor vessel. Thus, no recommendations for its withdrawal are given.

Table 7-2 Supplemental Surveillance Capsule Withdrawal Schedule

Capsule ID	Capsule Location	Withdrawal EFPY	Withdrawal Year[(a)]	End-of-Cycle (EOC)	Projected Capsule Fluence (n/cm^2)
S1	263°	33.4	2018	23	2.10×10^{19}
S2	263°	51.4	2038	33	3.80×10^{19}

Note:

(a) The withdrawal years were selected to coincide with the next two reactor vessel inservice inspections at Calvert Cliffs Unit 1. The withdrawal EFPY, EOC and projected capsule fluence values were calculated assuming that Capsules S1 and S2 would be withdrawn in 2018 and 2038, respectively. Since the two supplemental capsules are not part of the 10 CFR 50 Appendix H program at Calvert Cliffs Unit 1, the withdrawal years shown are subject to change for either capsule.

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APPENDIX A
VALIDATION OF THE RADIATION TRANSPORT MODELS BASED ON NEUTRON DOSIMETRY MEASUREMENTS

A.1 NEUTRON DOSIMETRY

Comparisons of measured dosimetry results to both the calculated and least-squares adjusted values for all surveillance capsules withdrawn from service to date at Calvert Cliffs Unit 1 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" [Reference 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 Calvert Cliffs Unit 1 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[(a)]]
263°	End of Cycle 3	2.87
97°	End of Cycle 10	10.91
284°	End of Cycle 19	26.17
Note: (a) At 2737 MWt.		

The passive neutron sensors included in the evaluations of Surveillance Capsules 263°, 97°, and 284° are summarized as follows:

Sensor Material	Reaction Of Interest	Capsule 263°	Capsule 97°	Capsule 284°
Copper (Cd)	^{63}Cu(n,α)^{60}Co	X	X	X
Iron	^{54}Fe(n,p)^{54}Mn	X	X	X
Nickel (Cd)	^{58}Ni(n,p)^{58}Co	X	X	X
Titanium	^{46}Ti(n,p)^{46}Sc	X	X	X
Uranium-238*	^{238}U(n,f)^{137}Cs	X	X	X
Cobalt-Aluminum*	^{59}Co(n,γ)^{60}Co	X	X	X

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

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

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

Results from the radiometric counting of the neutron sensors from Capsules 263° and 97°are documented in References A-2 and A-3, respectively. The radiometric counting of the sensors from Capsule 284° was carried out by Pace Analytical Services, Inc. In all cases, the radiometric counting followed established ASTM procedures. Following sample preparation and weighing, the specific activity of each sensor was determined by means of a high-resolution gamma spectrometer. For the copper, iron, nickel, and cobalt-aluminum sensors, these analyses were performed by direct counting of each of the individual samples. In the case of the uranium fission sensors, the analyses were carried out by direct counting preceded by dissolution and chemical separation of cerium or cesium from the sensor material.

The irradiation history of the reactor over the irradiation periods experienced by Capsules 263°, 97°, and 284° was based on the monthly power generation of Calvert Cliffs Unit 1 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 263°, 97°, and 284° is given in Table A-2.

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

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

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

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

In the equation describing the reaction rate calculation, the ratio $[P_j]/[P_{ref}]$ accounts for month-by-month variation of reactor core power level within any given fuel cycle as well as over multiple fuel cycles. The ratio C_j, which was calculated for each fuel cycle using the transport methodology discussed in Section 6.2, accounts for the change in sensor reaction rates caused by variations in flux level induced by changes in core spatial power distributions from fuel cycle to fuel cycle. For a single-cycle irradiation, C_j

is normally taken to be 1.0. However, for multiple-cycle irradiations, particularly those employing low-leakage fuel management, the additional C_j term should be employed. The impact of changing flux levels for constant power operation can be quite significant for sensor sets that have been irradiated for many cycles in a reactor that has transitioned from non-low-leakage to low-leakage fuel management or for sensor sets contained in surveillance capsules that have been moved from one capsule location to another. The fuel-cycle-specific neutron flux values along with the computed values for C_j are listed in Table A-3. These flux values represent the capsule- and cycle-dependent results at the radial and azimuthal center of the respective capsules at the closest axial elevation where the accumulated fluence is equivalent to the axial average fluence over the capsules axial span. The core midplane elevation, which is usually used for the C_j determination, was not used because the back-to-back 1.5-inch baffle horizontal formers at core midplane elevation depress the flux at this axial location. Therefore, the midplane core elevation would provide an underestimated normalization for the calculated capsules' spectrum which is used in the least-squares analysis. Notice that the flux values in Table A-3 are point evaluations at specific axial elevations and thus differ from flux values in Table 6-1 which are axial span averages.

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 applied to the Calvert Cliffs Unit 1 fission sensor reaction rates are summarized as follows:

Correction	Capsule 263°	Capsule 97°	Capsule 284°
^{235}U Impurity/Pu Build-in	0.8645	0.8107	0.7979
^{238}U(γ,f)	0.8442	0.8450	0.8347
Net ^{238}U Correction	0.7298	0.6850	0.6660

These factors 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 263°, 97°, and 284° are given in Table A-4. In Table A-4, the measured specific activities, decay-corrected saturated specific activities, and computed reaction rates for each sensor 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.

It is noticed that the bottom compartment Cobalt monitors' measurements of Capsules 97°, and 284° are consistently low compared to those in the middle and top compartments. Reference A-3, Capsule 97° analysis, states that "The primary cause of this result is believed to be a 0.95-centimeter-thick bracket of Inconel that surrounds the bottom set of dosimeters. The bracket is part of the fixture that attaches the surveillance capsule assembly to the reactor vessel." Reference A-3 also states that for Capsule 97° "The equivalent U-235 fission contamination in the U-238 dosimeters show a similar pattern [to Cobalt]." This report, however, has not attempted to determine the absolute level of ^{235}U fission contamination due to large uncertainties in ^{235}U impurities and thermal flux at the monitor locations.

A.1.2 Least-Squares Evaluation of Sensor Sets

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

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

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

For the least-squares evaluation of the Calvert Cliffs Unit 1 surveillance capsule dosimetry, the FERRET code [Reference A-4] was employed to combine the results of the plant-specific neutron transport calculations and sensor set reaction rate measurements to determine best-estimate values of exposure parameters ($\phi(E > 1.0 \text{ MeV})$ and dpa) along with associated uncertainties for the 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 Calvert Cliffs Unit 1 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 [Reference A-5]. The SNLRML library is an evaluated dosimetry reaction cross-section compilation recommended for use in LWR evaluations by ASTM Standard E1018, "Application of ASTM Evaluated Cross-Section Data File, Matrix E706 (IIB)" [Reference A-6].

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" [Reference A-7].

The following provides a summary of the uncertainties associated with the least-squares evaluation of the Calvert Cliffs Unit 1 surveillance capsule sensor sets.

Reaction Rate Uncertainties

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

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

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	5%
$^{54}Fe(n,p)^{54}Mn$	5%
$^{58}Ni(n,p)^{58}Co$	5%
$^{46}Ti(n,p)^{46}Sc$	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 the most recent cross-section evaluations, and they have been tested with respect to their accuracy and consistency for least-squares evaluations. Further, the library has been empirically tested for use in fission spectra determination as well as in the fluence and energy characterization of 14 MeV neutron sources.

For sensors included in the Calvert Cliffs Unit 1 surveillance program, the following uncertainties in the fission spectrum averaged cross sections are provided in the SNLRML documentation package.

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	4.08-4.16%
$^{54}Fe(n,p)^{54}Mn$	3.05-3.11%
$^{58}Ni(n,p)^{58}Co$	4.49-4.56%
$^{46}Ti(n,p)^{46}Sc$	4.50-4.87%
$^{238}U(n,f)^{137}Cs$	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 input to the least-squares adjustment procedure were obtained directly from the results of plant-specific transport calculations for each surveillance capsule irradiation period and location. The spectrum for each capsule was input in an absolute sense (rather than as simply a relative spectral shape). Therefore, within the constraints of the assigned uncertainties, the calculated data were treated equally with the measurements.

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

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

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

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

where

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

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

The set of parameters defining the input covariance matrix for the Calvert Cliffs Unit 1 calculated spectra was as follows:

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

A.1.3 Comparisons of Measurements and Calculations

Results of the least-squares evaluations of the dosimetry from the Calvert Cliffs Unit 1 surveillance capsules withdrawn to date are provided in Tables A-5 and A-6. In Table A-5, measured, calculated, and best-estimate values for sensor reaction rates are given for each capsule. Also provided in this tabulation are ratios of the measured reaction rates to both the calculated and least-squares adjusted reaction rates. These ratios of M/C and BE/M illustrate the consistency of the fit of the calculated neutron energy spectra to the measured reaction rates both before and after adjustment. In Table A-6, comparison of the calculated and best-estimate values of neutron flux (E > 1.0 MeV) and iron atom displacement rate are tabulated along with the BE/C ratios observed for each of the capsules.

The data comparisons provided in Tables A-5 and A-6 show that the adjustments to the calculated spectra are relatively small and well within the assigned uncertainties for the calculated spectra, measured sensor reaction rates, and dosimetry reaction cross sections. Further, these results indicate that the use of the least-squares evaluation results in a reduction in the uncertainties associated with the exposure of the surveillance capsules. From Section 6.4 of this report, it may be noted that the uncertainty associated with the unadjusted calculation of neutron fluence (E > 1.0 MeV) and iron atom displacements at the surveillance capsule locations is specified as 13% at the 1σ level. From Table A-6, it is noted that the corresponding uncertainties associated with the least-squares adjusted exposure parameters have been reduced to 6-7% for neutron flux (E > 1.0 MeV) and 6% for iron atom displacement rate. Again, the uncertainties from the least-squares evaluation are at the 1σ level.

Further comparisons of the measurement results (from Tables A-5 and A-6) with calculations are given in Tables A-7 and A-8. These comparisons are given on two levels. In Table A-7, calculations of individual threshold sensor reaction rates are compared directly with the corresponding measurements. These threshold reaction rate comparisons provide a good evaluation of the accuracy of the fast neutron portion of the calculated energy spectra. In Table A-8, calculations of fast neutron exposure rates in terms of $\phi(E > 1.0$ MeV) and dpa/s are compared with the best-estimate results obtained from the least-squares evaluation of the capsule dosimetry results. These two levels of comparison yield consistent and similar results with all measurement-to-calculation comparisons falling well within the 20% limits specified as the acceptance criteria in Regulatory Guide 1.190.

In the case of the direct comparison of measured and calculated sensor reaction rates, the M/C comparisons for fast neutron reactions range from 0.89 to 1.30 for the 24 samples included in the data set. The overall average M/C ratio for the entire set of Calvert Cliffs Unit 1 data is 1.07 with an associated standard deviation of 12.0%.

In the comparisons of best-estimate and calculated fast neutron exposure parameters, the corresponding BE/C comparisons for the capsule data sets range from 0.92 to 1.08 for neutron flux (E > 1.0 MeV) and from 0.94 to 1.09 for iron atom displacement rate. The overall average BE/C ratios for neutron flux (E > 1.0 MeV) and iron atom displacement rate are 1.00 with a standard deviation of 8.0% and 1.01 with a standard deviation of 7.4%, 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 Calvert Cliffs Unit 1 reactor pressure vessel.

Note that for Capsule 263°, the Titanium and cadmium-covered Uranium monitors have not been included in the least-squares analysis. The Titanium monitor has been discarded because of the oxidized state of the sampled when counted [Reference A-2] and because the counting is 6.6σ high with respect to similar plants' measurements. The cadmium-covered Uranium monitor was discarded because of the poor condition of the specimens as indicated in Reference A-2.

Note that for Capsule 97°, the Titanium, Uranium and Copper monitors have not been included in the least-squares analysis. The Titanium and Copper monitors are not included because their countings are 4.5σ and 11.2σ high with respect to similar plants' measurements. The cadmium-covered Uranium monitor was discarded because these monitors tent to melt with the cover.

Note that for Capsule 284°, the Titanium and Uranium monitors are not included in the least-squares analysis. The Titanium monitor has been discarded because the counting is -3.7σ low with respect to similar plants' measurements. The cadmium-covered Uranium monitor was discarded because these monitors tend to melt with the cover.

In all capsules, the bare fission monitor is not included because the U-235 impurity content and the thermal flux on the capsule are not know with enough accuracy to correct the measurement readings.

Table A-1 Nuclear Parameters Used in the Evaluation of Neutron Sensors

Monitor Material	Reaction of Interest	Target Atom Fraction	90% Response Range[(a)] (MeV)	Product Half-life	Fission Yield (%)
Copper	^{63}Cu (n,α)	0.6917	5.0 – 12.0	5.272 y	
Iron	^{54}Fe (n,p)	0.0585	2.4 – 8.8	312.1 d	
Nickel	^{58}Ni (n,p)	0.6808	2.1 – 8.8	70.82 d	
Titanium	^{46}Ti(n,p)	0.0825	4.1 – 10.4	83.79 d	
Uranium-238 (Cd)	^{238}U (n,f)^{137}Cs	1.0000	1.5 – 8.1	30.07 y	6.02
Uranium-238 (Cd)	^{238}U (n,f)^{144}Ce	1.0000	1.5 – 8.1	284.89 d	4.55
Cobalt-Aluminum	^{59}Co (n,γ)	0.0017	non-threshold	5.272 y	

Note:

(a) The 90% response range is defined such that, in the neutron spectrum characteristic of the Calvert Cliffs Unit 1 surveillance capsules, approximately 90% of the sensor response is due to neutrons in the energy range specified with approximately 5% of the total response due to neutrons with energies below the lower limit and 5% of the total response due to neutrons with energies above the upper limit.

Table A-2 Monthly Thermal Generation during the First Nineteen Fuel Cycles of the Calvert Cliffs Unit 1 Reactor (Reactor Power of 2560 MWt from 12/27/1974 to 9/8/1977; 2700 MWt from 9/9/1977 to 4/30/2010; and, 2737 MWt from 5/1/2010 to present)

Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)
Dec-74	0	Feb-77	0	Apr-79	1294700	Jun-81	1582420
Jan-75	339490	Mar-77	0	May-79	0	Jul-81	867800
Feb-75	553390	Apr-77	1312200	Jun-79	0	Aug-81	1848100
Mar-75	865790	May-77	1494550	Jul-79	747270	Sep-81	1839020
Apr-75	798980	Jun-77	1683500	Aug-79	1763730	Oct-81	1456380
May-75	1153050	Jul-77	1854120	Sep-79	1846800	Nov-81	1714610
Jun-75	1331640	Aug-77	1862160	Oct-79	1807920	Dec-81	1992730
Jul-75	1625120	Sep-77	1887620	Nov-79	1226660	Jan-82	1918400
Aug-75	823610	Oct-77	1719530	Dec-79	1151040	Feb-82	1803510
Sep-75	1360800	Nov-77	1862350	Jan-80	946140	Mar-82	1984690
Oct-75	1856130	Dec-77	1747660	Feb-80	777990	Apr-82	1607690
Nov-75	1664060	Jan-78	1130950	Mar-80	1795870	May-82	0
Dec-75	1819970	Feb-78	0	Apr-80	1650460	Jun-82	0
Jan-76	1773770	Mar-78	0	May-80	1647220	Jul-82	1448340
Feb-76	1638660	Apr-78	1133350	Jun-80	1837080	Aug-82	1512630
Mar-76	1852110	May-78	1255500	Jul-80	1928450	Sep-82	1279150
Apr-76	1010880	Jun-78	1745710	Aug-80	1928450	Oct-82	1988710
May-76	1874210	Jul-78	1757700	Sep-80	1870130	Nov-82	1875960
Jun-76	1782650	Aug-78	1807920	Oct-80	930070	Dec-82	1860150
Jul-76	1850100	Sep-78	1765150	Nov-80	0	Jan-83	1878230
Aug-76	1866180	Oct-78	1826000	Dec-80	0	Feb-83	1607560
Sep-76	1675730	Nov-78	301320	Jan-81	1086760	Mar-83	1956570
Oct-76	1817960	Dec-78	974270	Feb-81	1785370	Apr-83	1562980
Nov-76	1539650	Jan-79	676970	Mar-81	1936480	May-83	1964610
Dec-76	1233400	Feb-79	1707350	Apr-81	1524100	Jun-83	1769040
Jan-77	0	Mar-79	1916400	May-81	1797880	Jul-83	1978670

Table A-2 (Continued) Monthly Thermal Generation during the First Nineteen Fuel Cycles of the Calvert Cliffs Unit 1 Reactor

Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)
Aug-83	1830020	Oct-85	1536730	Dec-87	2008800	Feb-90	0
Sep-83	1734050	Nov-85	1907060	Jan-88	1908360	Mar-90	0
Oct-83	0	Dec-85	1968620	Feb-88	1766450	Apr-90	268270
Nov-83	0	Jan-86	1846090	Mar-88	1948540	May-90	0
Dec-83	1070690	Feb-86	1783560	Apr-88	447120	Jun-90	0
Jan-84	1902330	Mar-86	1526690	May-88	0	Jul-90	0
Feb-84	1800270	Apr-86	1899290	Jun-88	0	Aug-90	0
Mar-84	1609050	May-86	1950540	Jul-88	1440310	Sep-90	0
Apr-84	1938170	Jun-86	1852630	Aug-88	1836040	Oct-90	1484500
May-84	355560	Jul-86	1823990	Sep-88	1914840	Nov-90	1920670
Jun-84	1910950	Aug-86	1934470	Oct-88	1703460	Dec-90	666920
Jul-84	1994740	Sep-86	1926500	Nov-88	1180010	Jan-91	1813950
Aug-84	1775780	Oct-86	1398120	Dec-88	1990720	Feb-91	680400
Sep-84	1934280	Nov-86	0	Jan-89	1500570	Mar-91	1984690
Oct-84	1938490	Dec-86	0	Feb-89	1745450	Apr-91	1823470
Nov-84	1524100	Jan-87	1044580	Mar-89	152670	May-91	1092790
Dec-84	1008420	Feb-87	1723680	Apr-89	515160	Jun-91	0
Jan-85	1783810	Mar-87	1807920	May-89	301320	Jul-91	847710
Feb-85	1756340	Apr-87	0	Jun-89	0	Aug-91	1986700
Mar-85	1992730	May-87	220970	Jul-89	0	Sep-91	1920670
Apr-85	293540	Jun-87	1924560	Aug-89	0	Oct-91	1801890
May-85	0	Jul-87	682990	Sep-89	0	Nov-91	1928450
Jun-85	0	Aug-87	1707480	Oct-89	0	Dec-91	1988710
Jul-85	0	Sep-87	1885680	Nov-89	0	Jan-92	1994740
Aug-85	447960	Oct-87	2008800	Dec-89	0	Feb-92	1860410
Sep-85	1778760	Nov-87	1224720	Jan-90	0	Mar-92	1185710

Table A-2 (Continued) Monthly Thermal Generation during the First Nineteen Fuel Cycles of the Calvert Cliffs Unit 1 Reactor

Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)
Apr-92	0	Jun-94	1363260	Aug-96	1735600	Oct-98	2006490
May-92	0	Jul-94	1423990	Sep-96	1942350	Nov-98	1941880
Jun-92	0	Aug-94	2007000	Oct-96	1993580	Dec-98	1988500
Jul-92	0	Sep-94	1942330	Nov-96	1941990	Jan-99	2006690
Aug-92	355050	Oct-94	1994740	Dec-96	1941900	Feb-99	1812390
Sep-92	1876060	Nov-94	1941690	Jan-97	1999400	Mar-99	2005000
Oct-92	1897920	Dec-94	2007260	Feb-97	1682190	Apr-99	1944420
Nov-92	1767660	Jan-95	2007420	Mar-97	2006610	May-99	1477310
Dec-92	2006550	Feb-95	1812900	Apr-97	1941910	Jun-99	1941890
Jan-93	2008810	Mar-95	2007240	May-97	1868050	Jul-99	1520710
Feb-93	1811680	Apr-95	1936400	Jun-97	1810170	Aug-99	1796060
Mar-93	2006630	May-95	1996970	Jul-97	1989650	Sep-99	1779540
Apr-93	1926390	Jun-95	1585130	Aug-97	1999430	Oct-99	1835020
May-93	2006740	Jul-95	2007240	Sep-97	1358830	Nov-99	1941260
Jun-93	1485720	Aug-95	1912320	Oct-97	1926790	Dec-99	2003450
Jul-93	1998390	Sep-95	1906720	Nov-97	1941960	Jan-00	1874910
Aug-93	2001110	Oct-95	1994710	Dec-97	2006300	Feb-00	1811830
Sep-93	1931540	Nov-95	1296120	Jan-98	2002850	Mar-00	703810
Oct-93	2002460	Dec-95	1930850	Feb-98	1812460	Apr-00	131910
Nov-93	1921980	Jan-96	2007100	Mar-98	2006190	May-00	2004460
Dec-93	1987230	Feb-96	1812790	Apr-98	194170	Jun-00	1934570
Jan-94	1515840	Mar-96	1836790	May-98	0	Jul-00	2005960
Feb-94	391760	Apr-96	0	Jun-98	1373300	Aug-00	2005560
Mar-94	0	May-96	0	Jul-98	2006550	Sep-00	1825960
Apr-94	0	Jun-96	0	Aug-98	2006480	Oct-00	2006400
May-94	254110	Jul-96	0	Sep-98	1934450	Nov-00	1941390

Table A-2 (Continued) Monthly Thermal Generation during the First Nineteen Fuel Cycles of the Calvert Cliffs Unit 1 Reactor

Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)
Dec-00	2004340	Feb-03	1810390	Apr-05	1932960	Jun-07	1943240
Jan-01	2006190	Mar-03	2006160	May-05	2005250	Jul-07	2007170
Feb-01	1812520	Apr-03	1941540	Jun-05	1933580	Aug-07	2000430
Mar-01	2003350	May-03	2005150	Jul-05	2005290	Sep-07	1937670
Apr-01	1941450	Jun-03	1941020	Aug-05	2005270	Oct-07	1959970
May-01	1892160	Jul-03	2005720	Sep-05	1942660	Nov-07	1943100
Jun-01	1941890	Aug-03	2004790	Oct-05	2008030	Dec-07	2007810
Jul-01	2003260	Sep-03	1937450	Nov-05	1943180	Jan-08	2005550
Aug-01	2005570	Oct-03	2005400	Dec-05	2006950	Feb-08	1407840
Sep-01	1936430	Nov-03	1925610	Jan-06	2007840	Mar-08	958510
Oct-01	2006590	Dec-03	2005940	Feb-06	1247040	Apr-08	1938520
Nov-01	1941610	Jan-04	1993480	Mar-06	0	May-08	2007640
Dec-01	2004560	Feb-04	1812190	Apr-06	1191680	Jun-08	1942020
Jan-02	2001200	Mar-04	1896620	May-06	2008080	Jul-08	1984820
Feb-02	882600	Apr-04	631050	Jun-06	1942350	Aug-08	1986510
Mar-02	0	May-04	1340310	Jul-06	2001500	Sep-08	1941430
Apr-02	0	Jun-04	1941550	Aug-06	2005550	Oct-08	1998920
May-02	0	Jul-04	2006770	Sep-06	1943120	Nov-08	1942510
Jun-02	714170	Aug-04	2006670	Oct-06	2007980	Dec-08	2006020
Jul-02	1672020	Sep-04	1938780	Nov-06	1943170	Jan-09	2007190
Aug-02	2006220	Oct-04	2006220	Dec-06	1513600	Feb-09	1812970
Sep-02	1941150	Nov-04	1943230	Jan-07	1960360	Mar-09	2005720
Oct-02	2005610	Dec-04	2007300	Feb-07	1773730	Apr-09	1942600
Nov-02	1433010	Jan-05	2008040	Mar-07	2004290	May-09	2007390
Dec-02	2006070	Feb-05	1813130	Apr-07	1942780	Jun-09	1939870
Jan-03	2005790	Mar-05	1905640	May-07	2007010	Jul-09	1705370

Table A-2 (Continued) Monthly Thermal Generation during the First Nineteen Fuel Cycles of the Calvert Cliffs Unit 1 Reactor

Month-Year	Thermal Generation (MWt-hr)
Aug-09	2007320
Sep-09	1941550
Oct-09	2001300
Nov-09	1942660
Dec-09	2007410
Jan-10	2007190
Feb-10	1124630
Mar-10	498670

Table A-3 Surveillance Capsule Flux for C_j Factors Calculation

Fuel Cycle	Cycle Length [EFPS(a)]	φ(E > 1.0 MeV) [n/cm²-s] Capsule 263° $z^{(b)}$ = -7.90 cm	Capsule 97° $z^{(b)}$ = -11.0 cm	Capsule 284° $z^{(b)}$ = -11.0 cm
1	4.49E+07	5.26E+10	5.32E+10	3.83E+10
2	2.18E+07	5.96E+10	6.02E+10	4.40E+10
3	2.39E+07	5.85E+10	5.91E+10	4.29E+10
4	3.14E+07		5.76E+10	4.20E+10
5	3.52E+07		6.03E+10	4.34E+10
6	3.45E+07		6.20E+10	4.49E+10
7	3.50E+07		6.18E+10	4.46E+10
8	3.36E+07		5.68E+10	4.11E+10
9	2.93E+07		6.35E+10	4.53E+10
10	5.46E+07		4.47E+10	3.08E+10
11	4.33E+07			2.36E+10
12	5.39E+07			1.53E+10
13	5.01E+07			1.90E+10
14	5.22E+07			1.84E+10
15	5.56E+07			1.91E+10
16	5.49E+07			1.97E+10
17	5.52E+07			2.08E+10
18	5.72E+07			1.86E+10
19	5.94E+07			2.18E+10
Average	---	5.58E+10	5.68E+10	2.84E+10

Note:
(a) At 2737 MWt.
(b) Elevation from core midplane.

Table A-3 (Continued) Surveillance Capsule C_j Factors

Fuel Cycle	Cycle Length [EFPS[a]]	C_j		
		Capsule 263°	Capsule 97°	Capsule 284°
1	4.49E+07	0.942	0.936	1.348
2	2.18E+07	1.067	1.060	1.547
3	2.39E+07	1.047	1.040	1.508
4	3.14E+07		1.014	1.476
5	3.52E+07		1.061	1.527
6	3.45E+07		1.091	1.581
7	3.50E+07		1.088	1.570
8	3.36E+07		0.999	1.445
9	2.93E+07		1.118	1.594
10	5.46E+07		0.787	1.084
11	4.33E+07			0.830
12	5.39E+07			0.540
13	5.01E+07			0.670
14	5.22E+07			0.648
15	5.56E+07			0.673
16	5.49E+07			0.694
17	5.52E+07			0.733
18	5.72E+07			0.654
19	5.94E+07			0.768
Average	---	1.000	1.000	1.000

Note:
(a) At 2737 MWt.

Table A-4a Measured(a) Sensor Activities and Reaction Rates for Surveillance Capsule 263°

Reaction	Location	Measured Activity(b) (dps/g)	Saturated Activity (dps/g)	Reaction Rate(c) (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top	1.96E+05	6.72E+05	1.03E-16
	Middle	1.96E+05	6.72E+05	1.03E-16
	Bottom	2.13E+05	7.30E+05	1.11E-16
	Average			**1.06E-16**
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	3.66E+06	5.34E+06	8.47E-15
	Middle	3.45E+06	5.03E+06	7.99E-15
	Bottom	3.57E+06	5.21E+06	8.26E-15
	Average			**8.24E-15**
$^{58}Ni\ (n,p)\ ^{58}Co$	Top	6.02E+07	7.60E+07	1.09E-14
	Middle	5.46E+07	6.90E+07	9.87E-15
	Bottom	6.09E+07	7.69E+07	1.10E-14
	Average			**1.06E-14**
$^{46}Ti(n,p)^{46}Sc$	Top	1.47E+06	1.90E+06	1.83E-15
	Middle	1.29E+06	1.66E+06	1.60E-15
	Bottom	1.36E+06	1.75E+06	1.69E-15
	Average			**1.71E-15**
$^{238}U\ (n,f)\ ^{144}Ce$ (Cd)	Top	3.61E+05	5.20E+05	4.52E-15
	Middle	3.52E+05	5.07E+05	4.41E-15
	Bottom	3.96E+05	5.70E+05	4.96E-15
	Average			**4.63E-15**
Corrected Average Including ^{235}U, ^{239}Pu, and γ fission corrections(d)				**3.38E-15**

Notes:

(a) Cobalt monitors were also measured but are not reported in this document. Bare ^{238}U monitors' measurements were not reported in Reference A-2.

(b) Measured specific activities are indexed to a counting date of April 20, 1979.

(c) Reaction rates referenced to Rated Reactor Power of 2737 MWt.

(d) See Section A.1.1.

Table A-4b Measured Sensor Activities and Reaction Rates for Surveillance Capsule 97°

Reaction	Location	Measured Activity[a] (dps/g)	Saturated Activity (dps/g)	Reaction Rate[b] (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top	No Sample		
	Middle	6.44E+05	1.26E+06	1.92E-16
	Bottom	No Sample		
	Average			**1.92E-16**
^{54}Fe (n,p) ^{54}Mn	Top	2.80E+06	5.58E+06	8.85E-15
	Middle	2.43E+06	4.85E+06	7.69E-15
	Bottom	2.54E+06	5.07E+06	8.04E-15
	Average			**8.20E-15**
^{58}Ni (n,p) ^{58}Co	Top	4.97E+07	6.91E+07	9.89E-15
	Middle	4.29E+07	5.96E+07	8.54E-15
	Bottom	4.75E+07	6.61E+07	9.46E-15
	Average			**9.30E-15**
^{46}Ti(n,p)^{46}Sc	Top	1.19E+06	1.70E+06	1.64E-15
	Middle	1.18E+06	1.68E+06	1.62E-15
	Bottom	1.19E+06	1.69E+06	1.63E-15
	Average			**1.63E-15**
^{238}U (n,f) ^{137}Cs	Top	2.01E+06	9.84E+06	6.46E-14
	Middle	2.01E+06	9.85E+06	6.47E-14
	Bottom	1.46E+06	7.16E+06	4.70E-14
	Average			**5.88E-14**
^{238}U (n,f) ^{137}Cs (Cd)	Top	9.61E+05	4.70E+06	3.09E-14
	Middle	9.07E+05	4.43E+06	2.91E-14
	Bottom	8.49E+05	4.15E+06	2.73E-14
	Average			**2.91E-14**
Corrected Average Including ^{235}U, ^{239}Pu, and γ fission corrections[c]				**1.99E-14**
^{59}Co (n,γ) ^{60}Co	Top	3.50E+07	6.83E+07	3.93E-12
	Middle	3.49E+07	6.81E+07	3.92E-12
	Bottom	2.35E+07	4.59E+07	2.64E-12
	Average			**3.50E-12**
^{59}Co (n,γ) ^{60}Co (Cd)	Top	4.78E+06	9.33E+06	5.37E-13
	Middle	4.47E+06	8.73E+06	5.02E-13
	Bottom	4.33E+06	8.46E+06	4.87E-13
	Average			**5.09E-13**

Notes:

(a) Measured specific activities are indexed to a counting date of March 19, 1992.

(b) Reaction rates referenced to Rated Reactor Power of 2737 MWt.

(c) See Section A.1.1

Table A-4c Measured Sensor Activities and Reaction Rates for Surveillance Capsule 284°

Reaction	Location	Measured Activity[a] (dps/g)	Saturated Activity (dps/g)	Reaction Rate[b] (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top	2.06E+05	3.52E+05	5.38E-17
	Middle	2.01E+05	3.44E+05	5.25E-17
	Bottom	2.03E+05	3.47E+05	5.30E-17
	Average			**5.31E-17**
^{54}Fe (n,p) ^{54}Mn	Top	1.04E+06	2.55E+06	4.04E-15
	Middle	1.01E+06	2.47E+06	3.92E-15
	Bottom	9.55E+05	2.34E+06	3.71E-15
	Average			**3.89E-15**
^{58}Ni (n,p) ^{58}Co	Top	2.15E+06	3.45E+07	4.94E-15
	Middle	1.91E+06	3.07E+07	4.39E-15
	Bottom	1.89E+06	3.03E+07	4.34E-15
	Average			**4.56E-15**
^{46}Ti(n,p)^{46}Sc	Top	6.41E+04	7.01E+05	6.75E-16
	Middle	5.76E+04	6.30E+05	6.07E-16
	Bottom	6.00E+04	6.56E+05	6.32E-16
	Average			**6.38E-16**
^{238}U (n,f) ^{137}Cs	Top	1.56E+06	4.01E+06	2.63E-14
	Middle	1.85E+06	4.76E+06	3.12E-14
	Bottom	1.51E+06	3.88E+06	2.55E-14
	Average			**2.77E-14**
^{238}U (n,f) ^{137}Cs (Cd)	Top	2.04E+05	5.25E+05	3.45E-15
	Middle	2.14E+05	5.50E+05	3.61E-15
	Bottom	2.00E+05	5.14E+05	3.38E-15
	Average			**3.48E-15**
Corrected Average Including ^{235}U, ^{239}Pu, and γ fission corrections[c]				**2.32E-15**
^{59}Co (n,γ) ^{60}Co	Top	1.48E+07	2.53E+07	1.46E-12
	Middle	1.76E+07	3.01E+07	1.73E-12
	Bottom	1.24E+07	2.12E+07	1.22E-12
	Average			**1.47E-12**
^{59}Co (n,γ) ^{60}Co (Cd)	Top	2.27E+06	3.88E+06	2.24E-13
	Middle	2.43E+06	4.16E+06	2.39E-13
	Bottom	2.13E+06	3.64E+06	2.10E-13
	Average			**2.24E-13**

Notes:

(a) Measured specific activities are indexed to a counting date of October 30, 2010.

(b) Reaction rates referenced to Rated Reactor Power of 2737 MWt.

(c) See Section A.1.1

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

Capsule 263°					
	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	BE/M
$^{63}Cu(n,\alpha)^{60}Co$	1.06E-16	8.09E-17	1.00E-16	1.30	0.95
$^{54}Fe(n,p)^{54}Mn$	8.24E-15	7.40E-15	8.40E-15	1.11	1.02
$^{58}Ni(n,p)^{58}Co$	1.06E-14	9.64E-15	1.09E-14	1.10	1.03
Capsule 97°					
	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	BE/M
$^{54}Fe(n,p)^{54}Mn$	8.20E-15	7.53E-15	7.79E-15	1.09	0.95
$^{58}Ni(n,p)^{58}Co$	9.30E-15	9.82E-15	9.81E-15	0.95	1.05
$^{59}Co(n,\gamma)^{60}Co$	3.50E-12	2.67E-12	3.48E-12	1.31	1.00
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	5.09E-13	5.22E-13	5.10E-13	0.97	1.00
Capsule 284°					
	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	BE/M
$^{63}Cu(n,\alpha)^{60}Co$	5.31E-17	4.63E-17	5.00E-17	1.15	0.94
$^{54}Fe(n,p)^{54}Mn$	3.89E-15	3.96E-15	3.87E-15	0.98	0.99
$^{58}Ni(n,p)^{58}Co$	4.56E-15	5.14E-15	4.88E-15	0.89	1.07
$^{59}Co(n,\gamma)^{60}Co$	1.47E-12	1.28E-12	1.47E-12	1.15	1.00
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	2.24E-13	2.53E-13	2.25E-13	0.89	1.01

Note:
See Section A.1.2 for details describing the Best-Estimate (BE) reaction rates.

Table A-6 Comparison of Calculated and Best Estimate Exposure Rates at the Surveillance Capsule Center

Capsule ID	φ(E > 1.0 MeV) [n/cm²-s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
263°	5.57E+10	6.05E+10	6%	1.08
97°	5.67E+10	5.76E+10	7%	1.01
284°	2.84E+10	2.63E+10	6%	0.92

Note:
Calculated results are based on the synthesized transport calculations following the completion of each respective capsule's irradiation period and are the average neutron exposure rate over the irradiation period for each capsule at a reference thermal power level of 2737 MWt. See Section A.1.2 for details describing the Best-Estimate (BE) exposure rates.

Capsule ID	Iron Atom Displacement Rate [dpa/s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
263°	7.96E-11	8.70E-11	6%	1.09
97°	8.10E-11	8.25E-11	6%	1.01
284°	4.08E-11	3.84E-11	6%	0.94

Note:
Calculated results are based on the synthesized transport calculations following the completion of each respective capsule's irradiation period and are the average neutron exposure rate over the irradiation period for each capsule at a reference thermal power level of 2737 MWt. See Section A.1.2 for details describing the Best'Estimate (BE) exposure rates.

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

Reaction	M/C Ratio		
	Capsule 263°	Capsule 97°	Capsule 284°
$^{63}Cu(n,\alpha)^{60}Co$	1.30	Rejected	1.15
$^{54}Fe(n,p)^{54}Mn$	1.11	1.09	0.98
$^{58}Ni(n,p)^{58}Co$	1.10	0.95	0.89
Average	1.17	1.02	1.01
% Standard Deviation	9.6	9.7	13.1

Note:
The overall average M/C ratio for the set of 24 sensor measurements is 1.07 with an associated standard deviation of 12.0%.

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

Capsule Location	BE/C Ratio	
	ϕ(E > 1.0 MeV)	dpa/s
263°	1.08	1.09
97°	1.01	1.01
284°	0.92	0.94
Average	1.00	1.01
% Standard Deviation	8.0	7.4

A.2 REFERENCES

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

A-2 BMI-1280, *Calvert Cliffs Unit No.1 Nuclear Plant Reactor Pressure Vessel Surveillance Program: Capsule 263°*, J. S. Perrin et al., December 1980.

A-3 BAW-2160, *Analysis of the Calvert Cliffs Unit No.1 Reactor Vessel Surveillance Capsule Withdrawn from the 97° Location*, A. L. Lowe et al., June 1993.

A-4 A. Schmittroth, *FERRET Data Analysis Core*, HEDL-TME 79-40, Hanford Engineering Development Laboratory, Richland, WA, September 1979.

A-5 RSICC Data Library Collection DLC-178, *SNLRML Recommended Dosimetry Cross-Section Compendium*, July 1994.

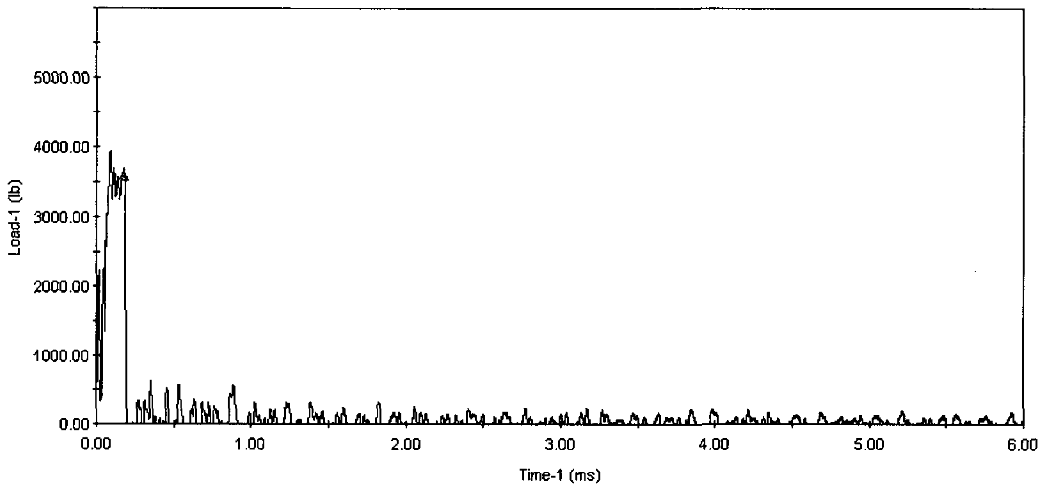
A-6 ASTM Standard E1018-09, *Application of ASTM Evaluated Cross-Section Data File, Matrix E706 (IIB)*, 2010.

A-7 ASTM Standard E944-08, *Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance*, 2010.

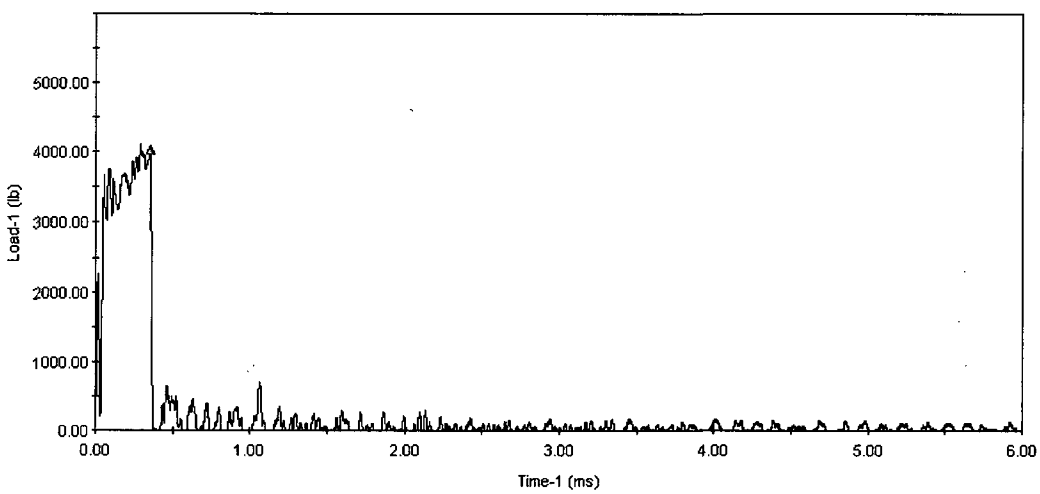
APPENDIX B
LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

- "1XX" denotes Intermediate Shell Course Plate D-7206-3, Longitudinal Orientation
- "2XX" denotes Intermediate Shell Course Plate D-7206-3, Transverse Orientation
- "3XX" denotes Weld Material
- "4XX" denotes Heat-Affected-Zone material

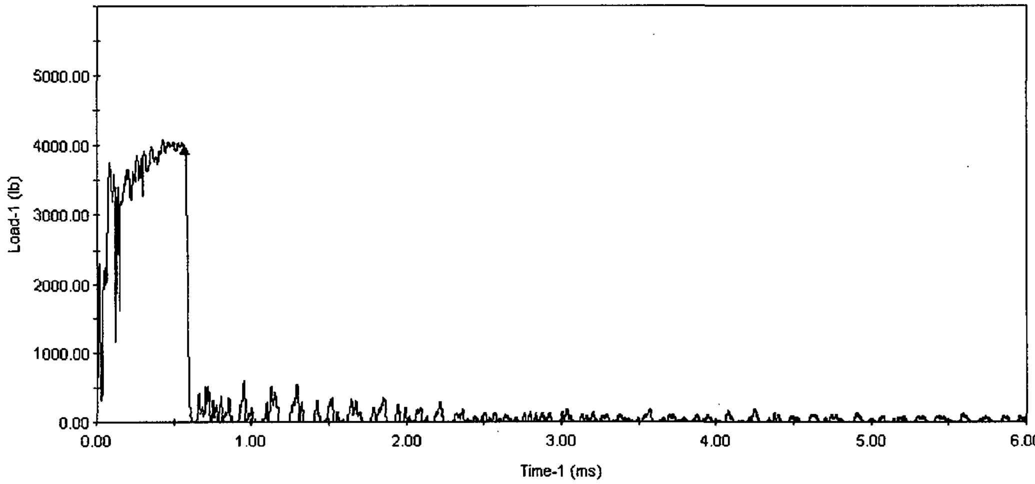
Note that the instrumented Charpy data is for information only. The instrumented tup (striker) was not calibrated per ASTM E2298-09.



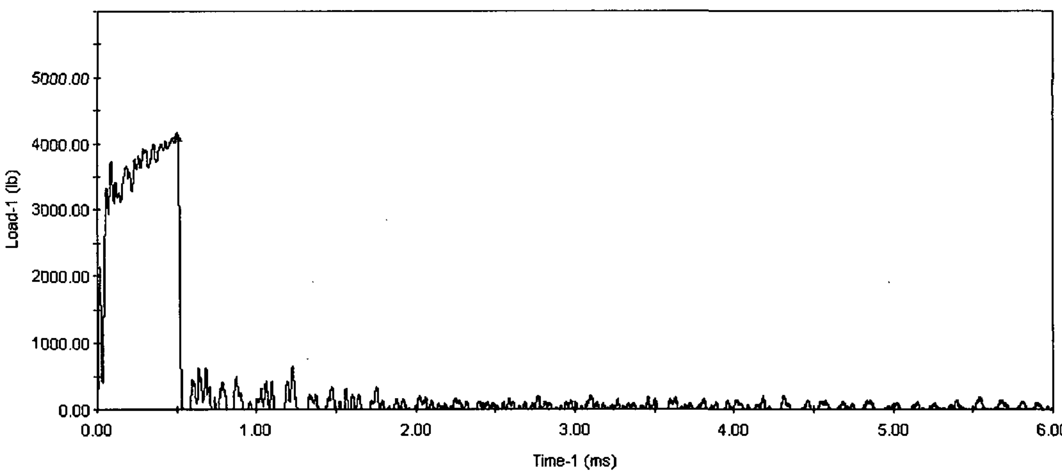
164, 25°F



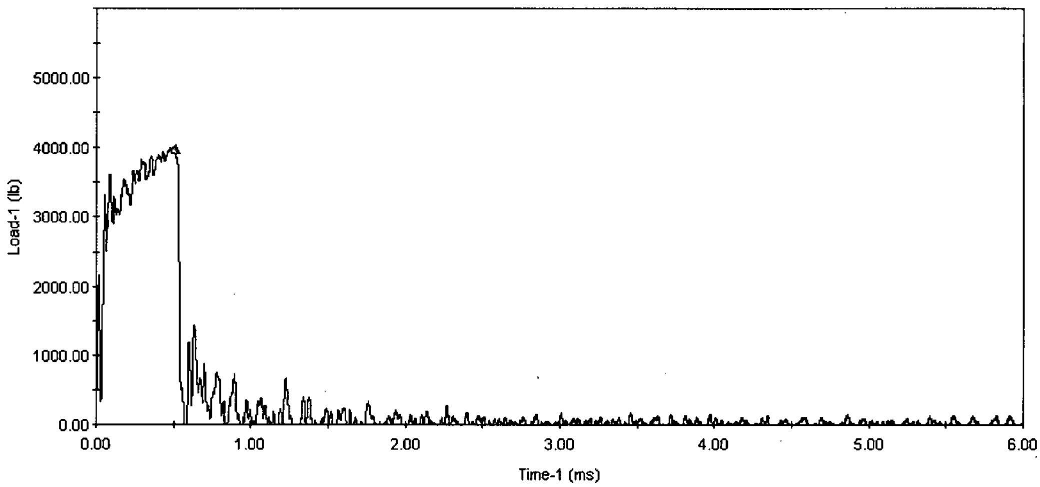
16B, 75°F



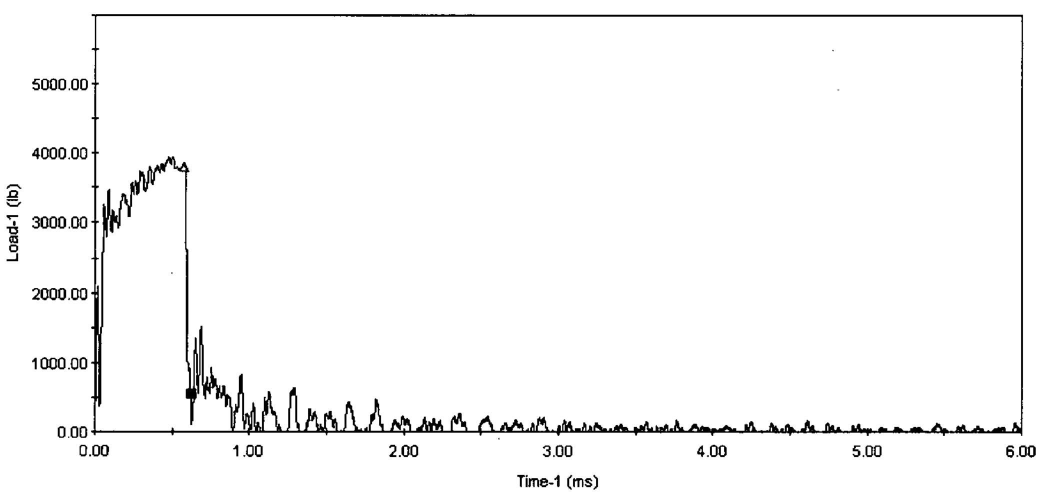
167, 90°F



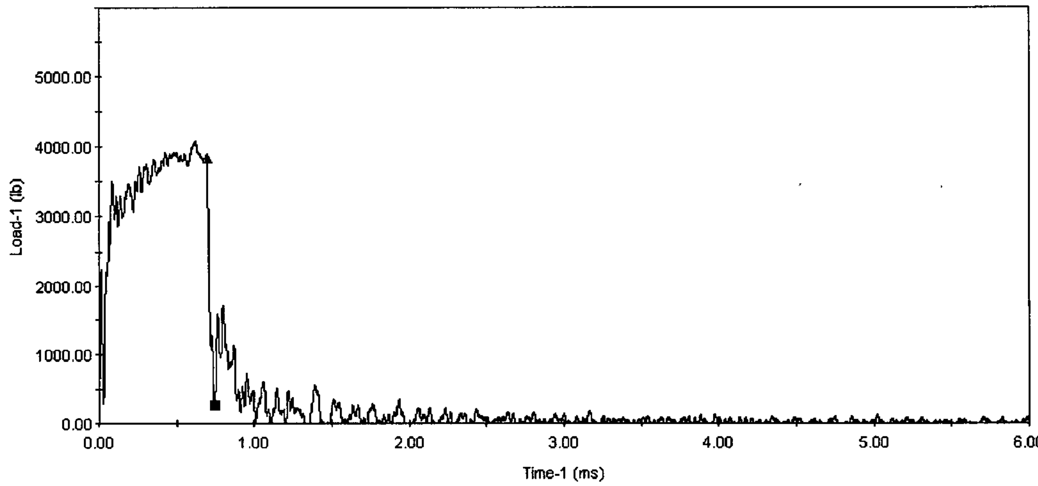
15D, 100°F



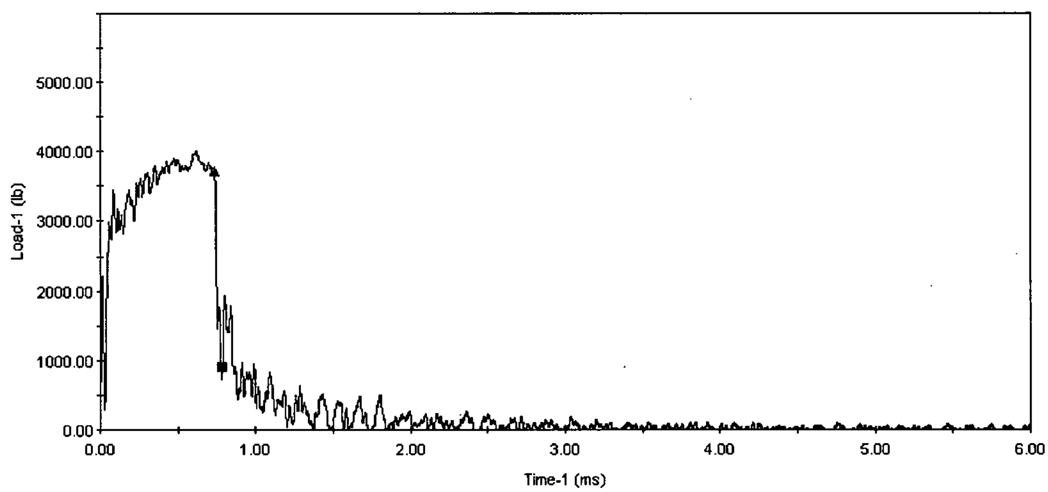
16A, 125°F



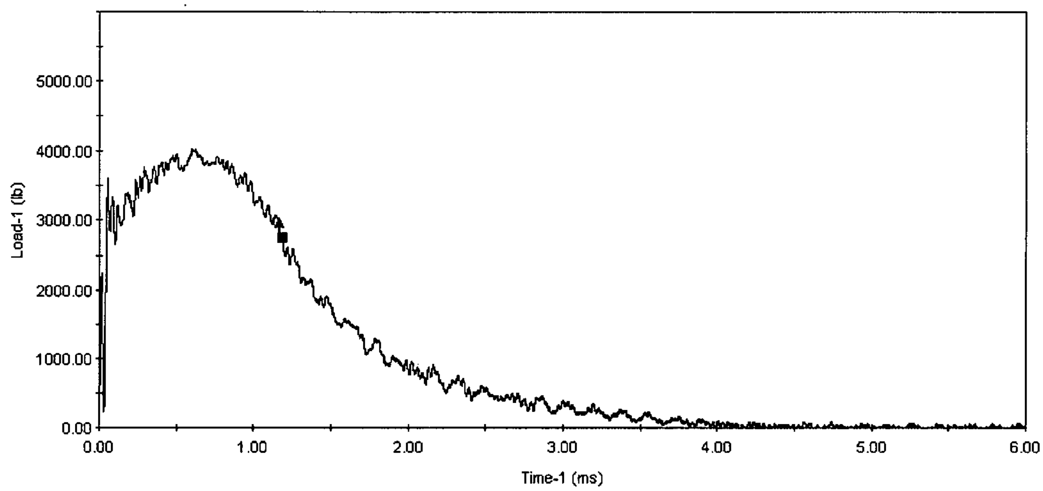
165, 150°F



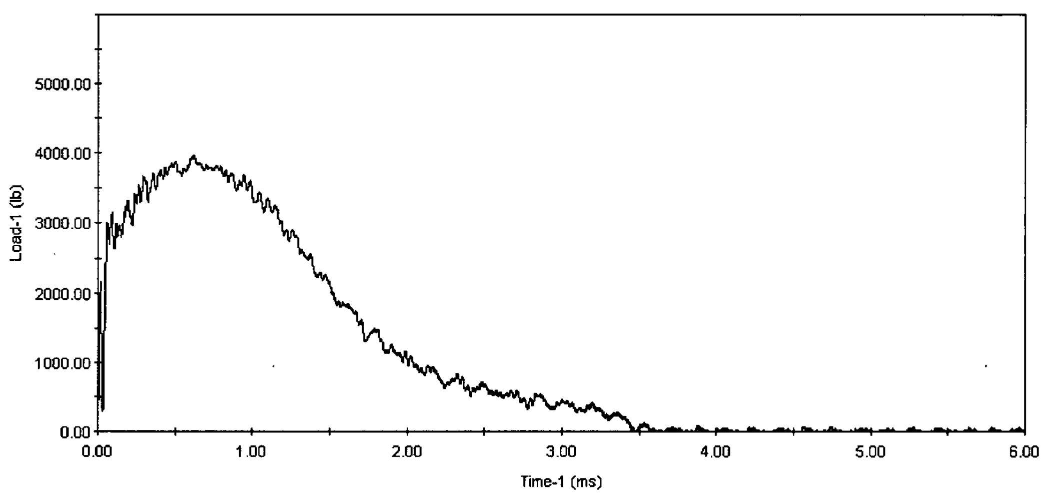
16D, 160°F



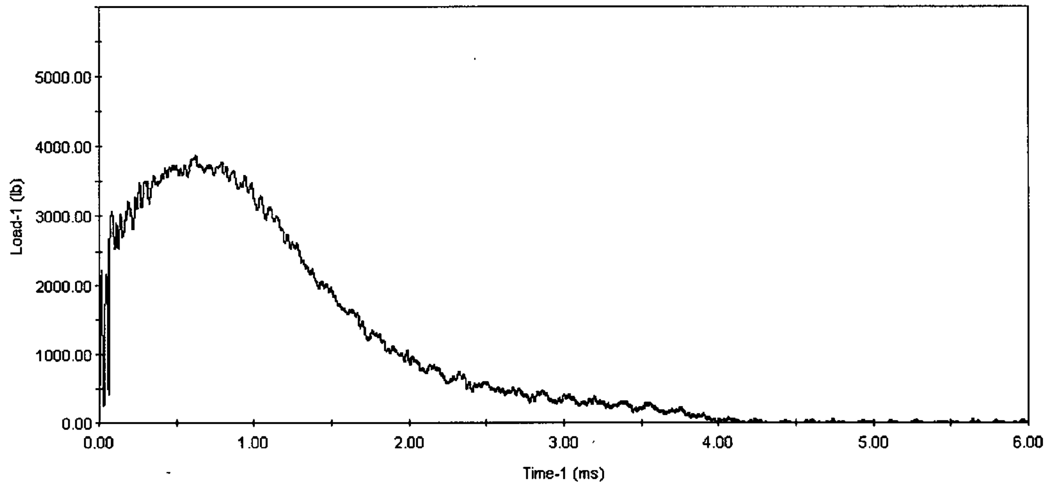
16C, 175°F



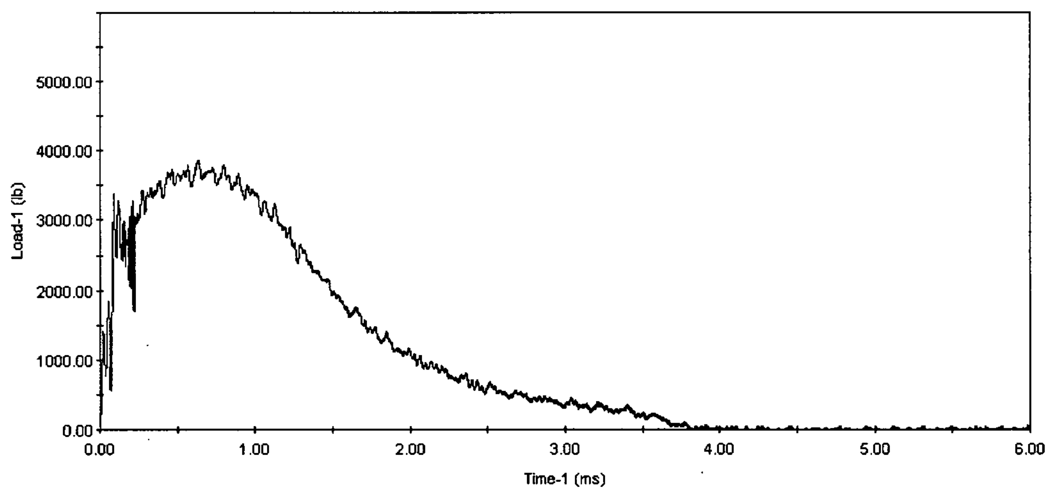
15J, 225°F



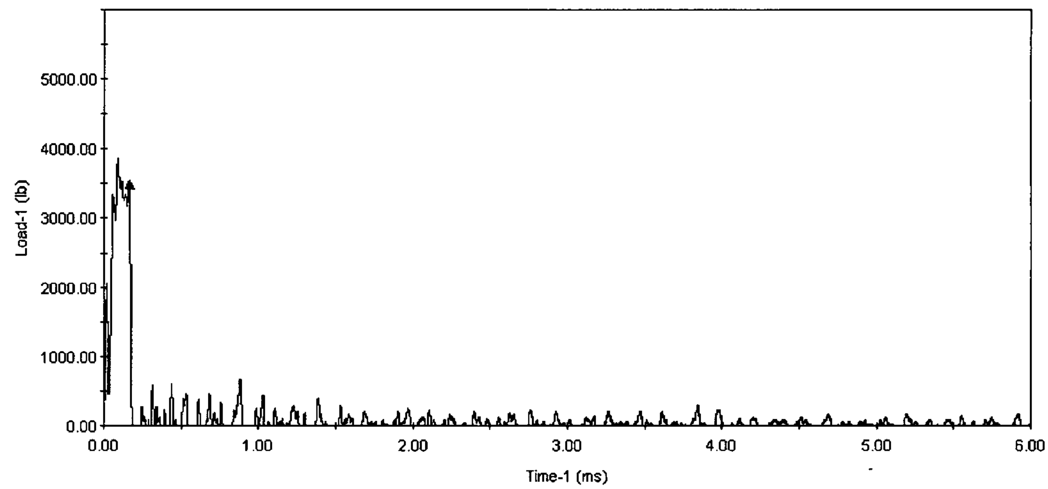
15E, 300°F



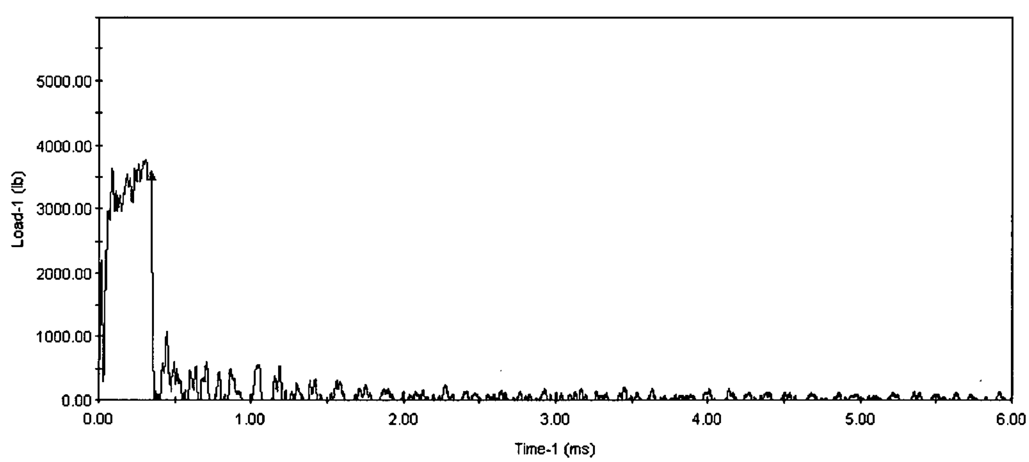
16E, 325°F



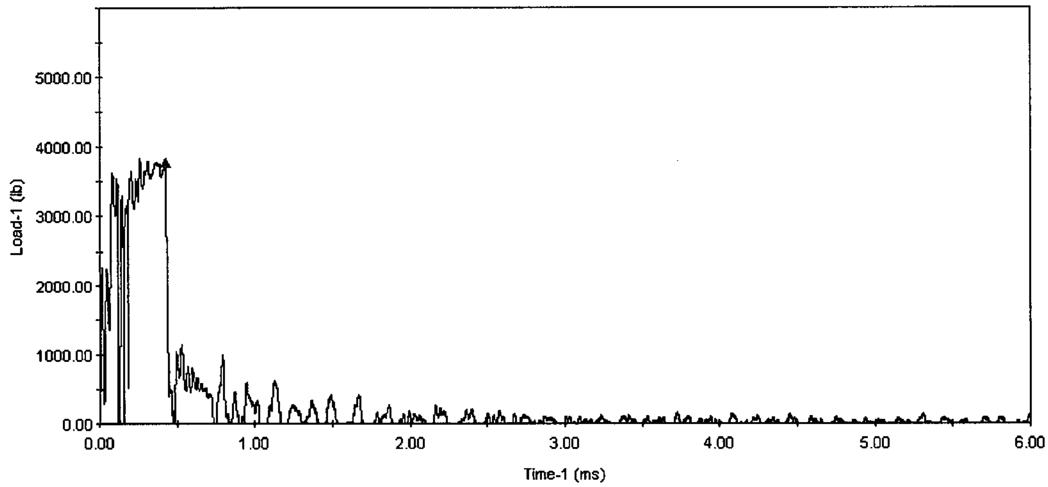
166, 350°F



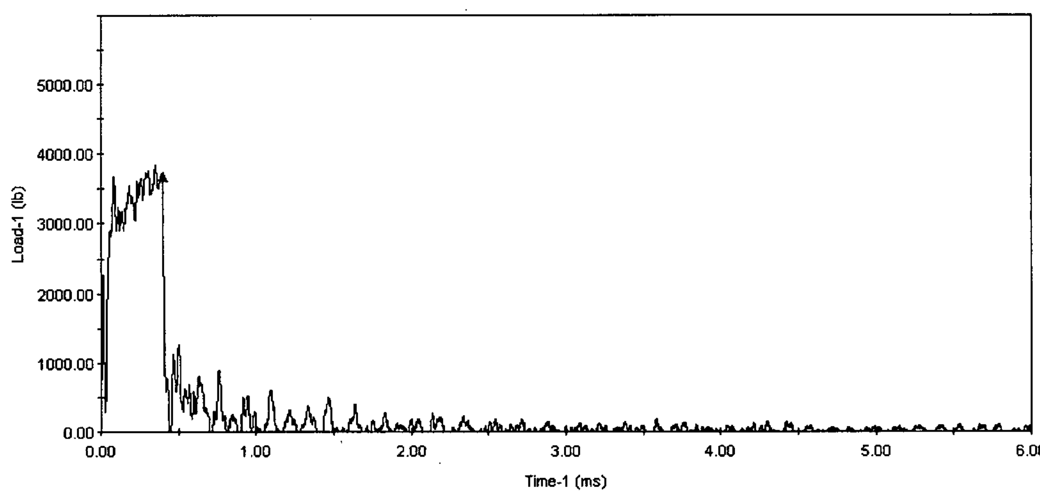
241, 25°F



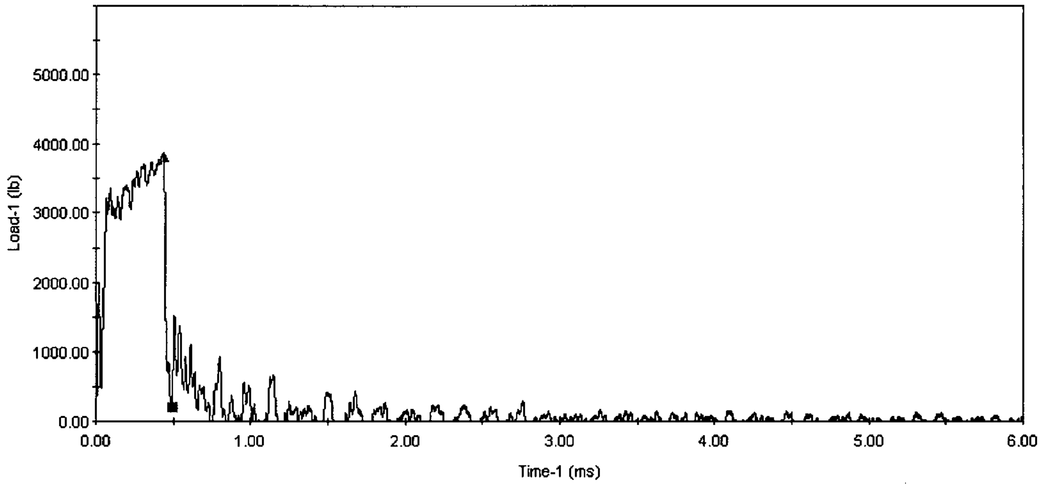
24D, 125°F



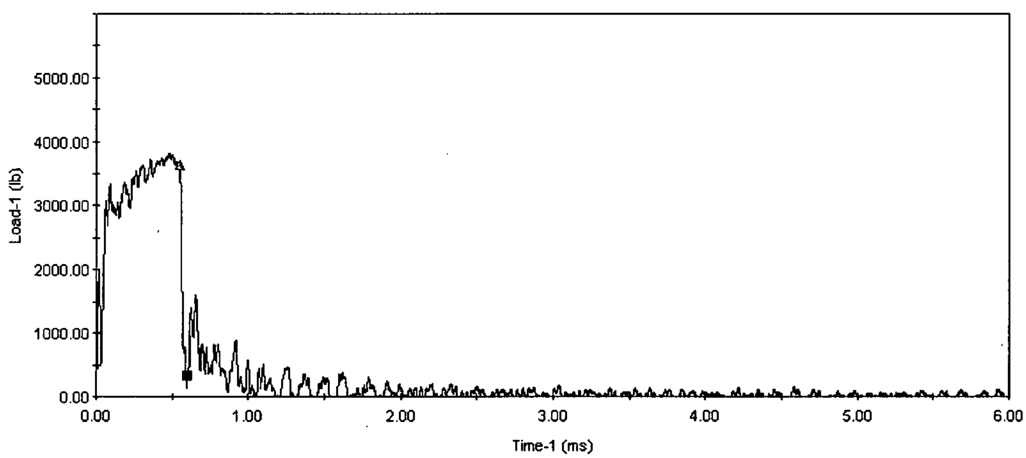
24K, 140°F



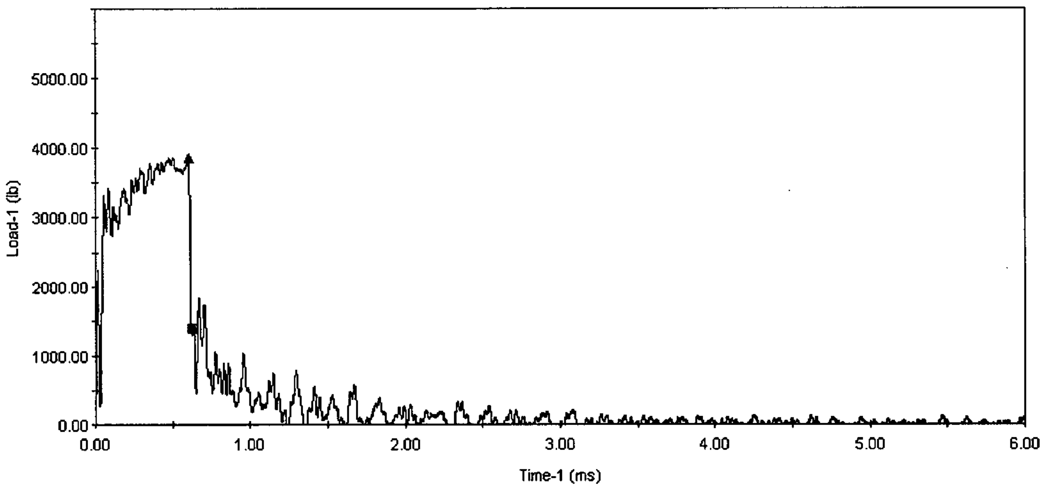
24E, 150°F



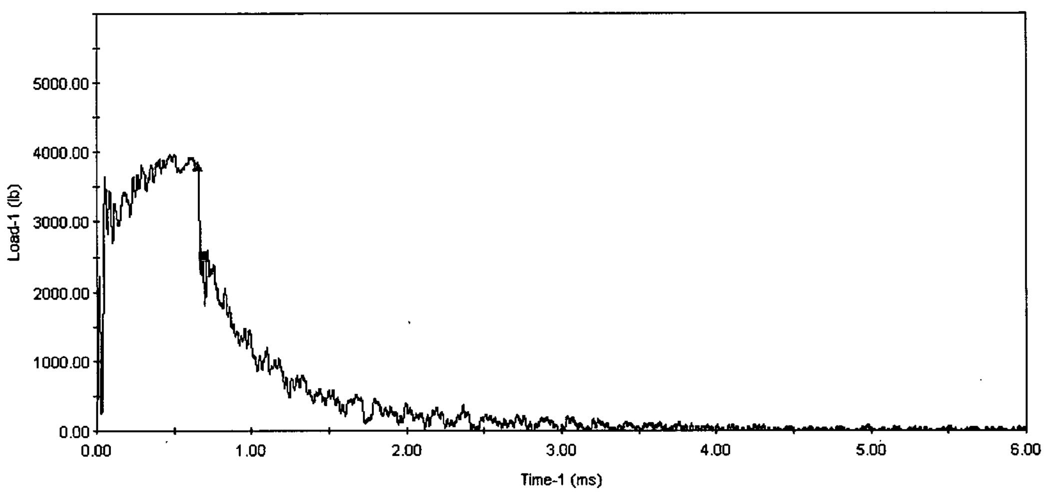
252, 160°F



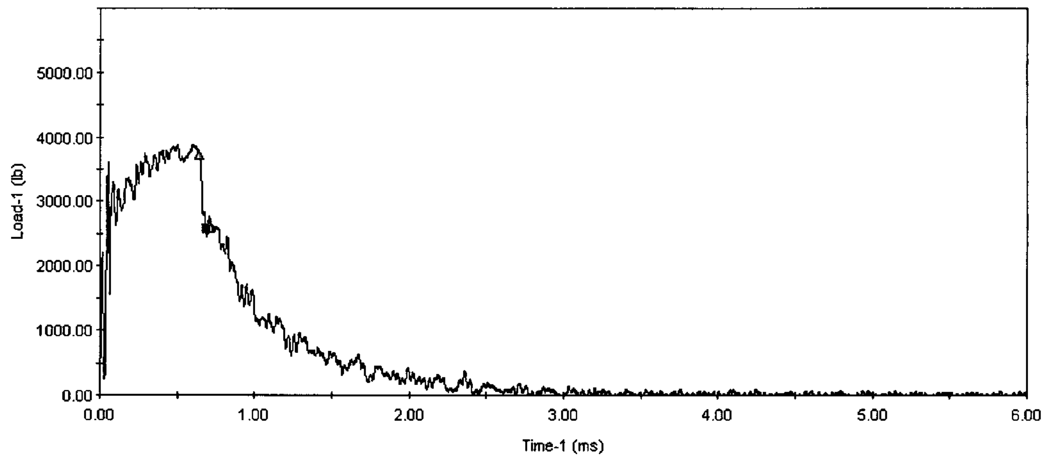
251, 175°F



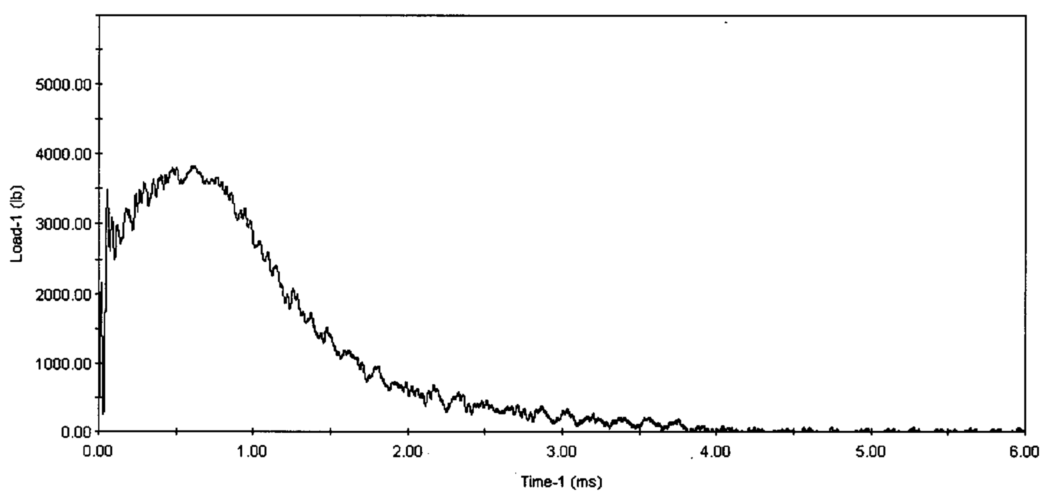
253, 185°F



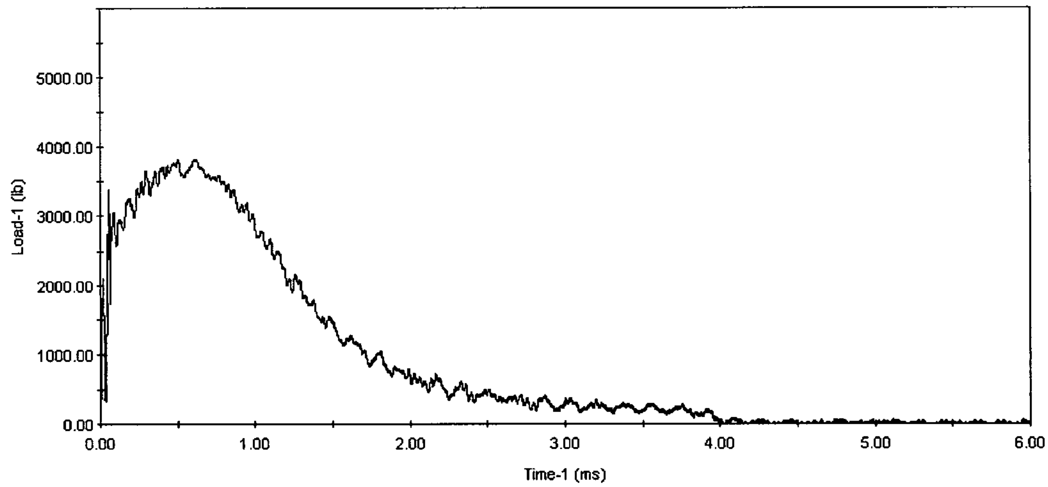
254, 195°F



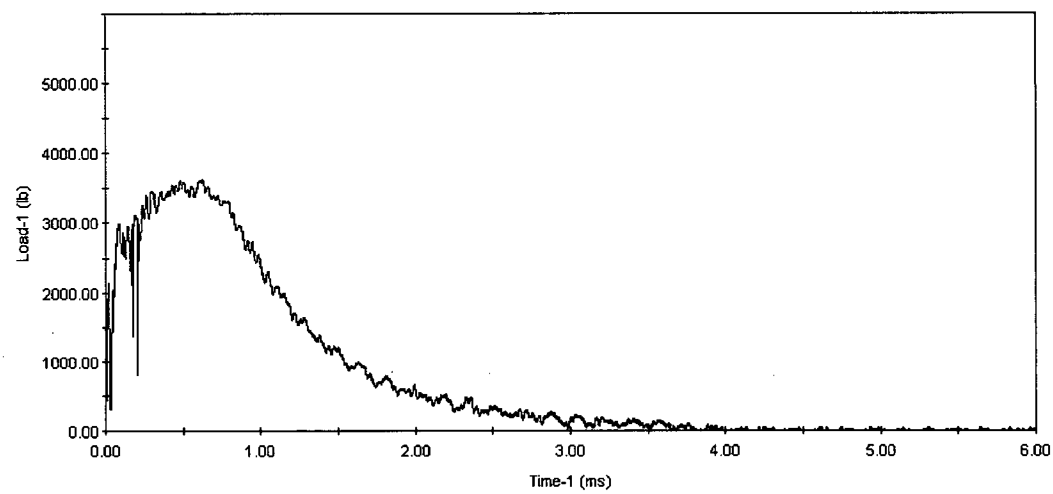
242, 200°F



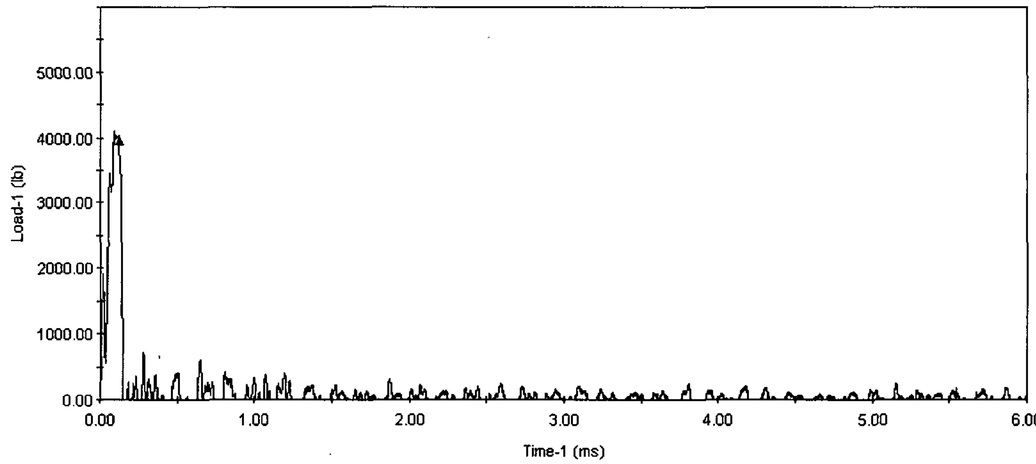
23U, 300°F



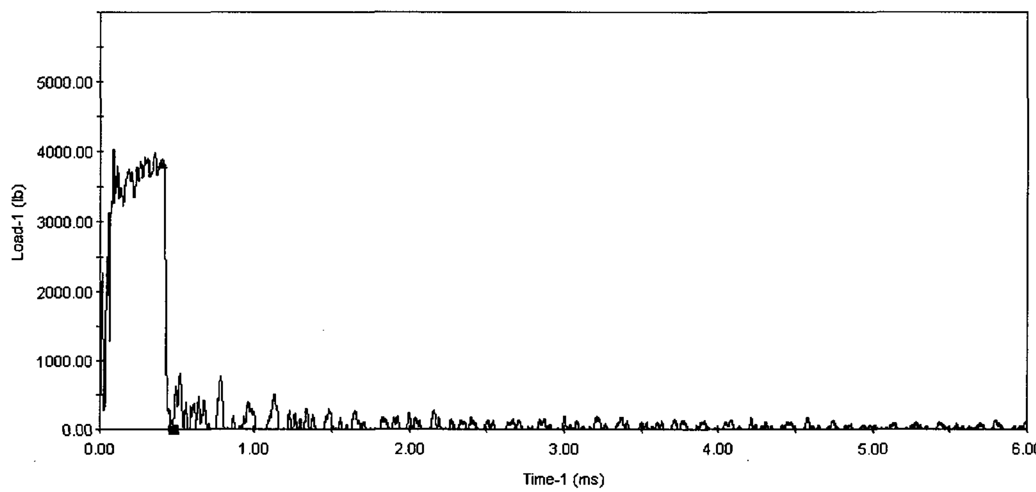
23Y, 325°F



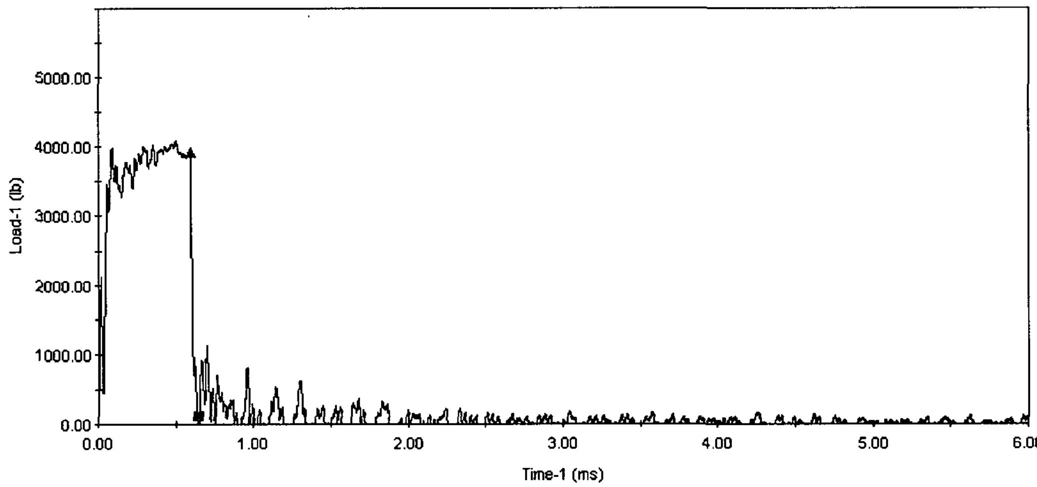
24J, 350°F



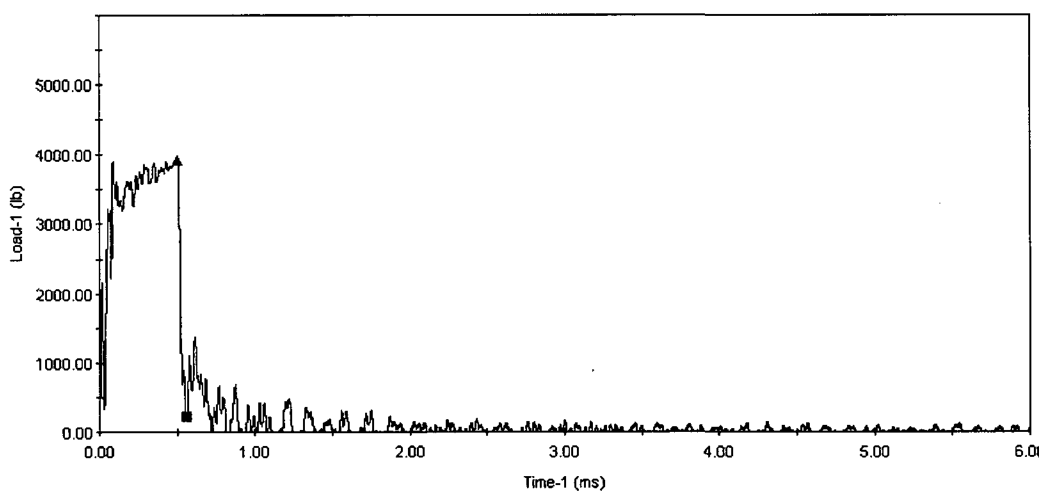
36M, -50°F



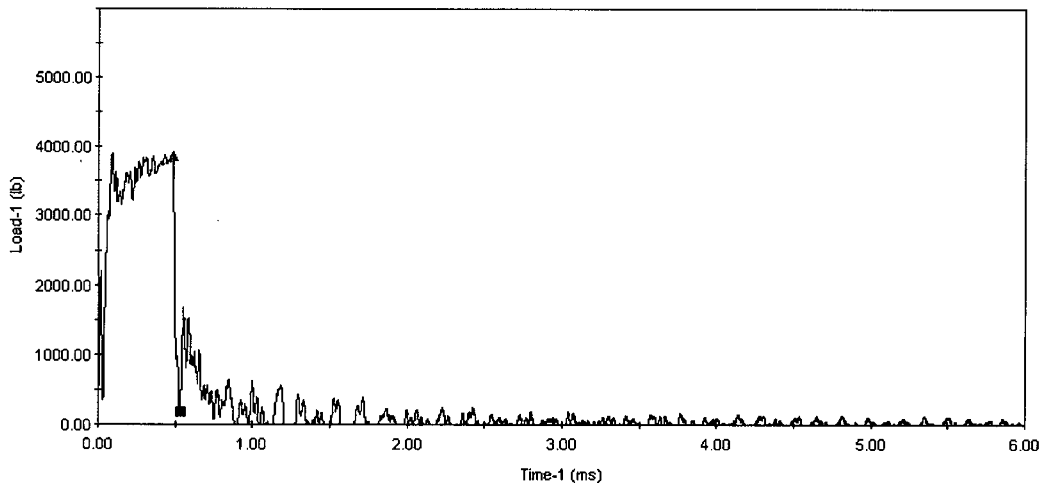
36D, 0°F



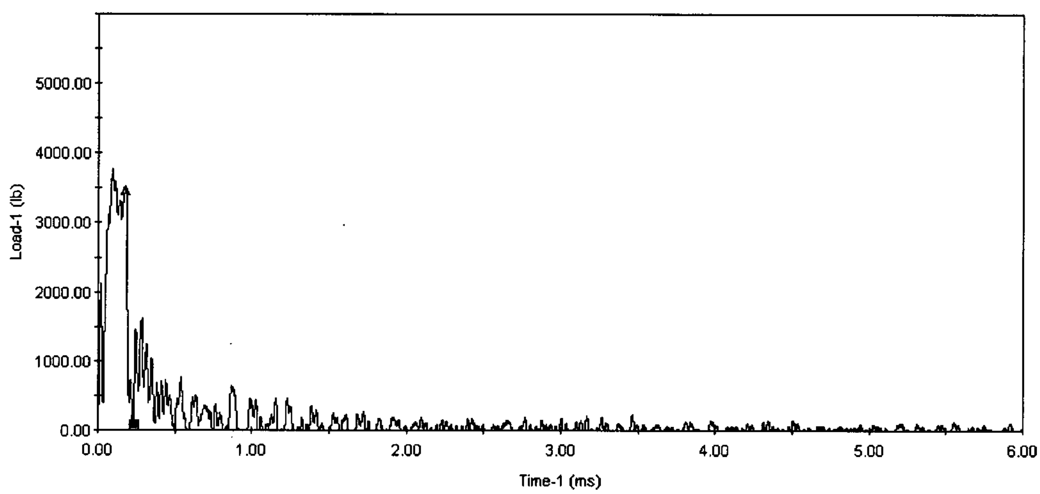
36E, 15°F



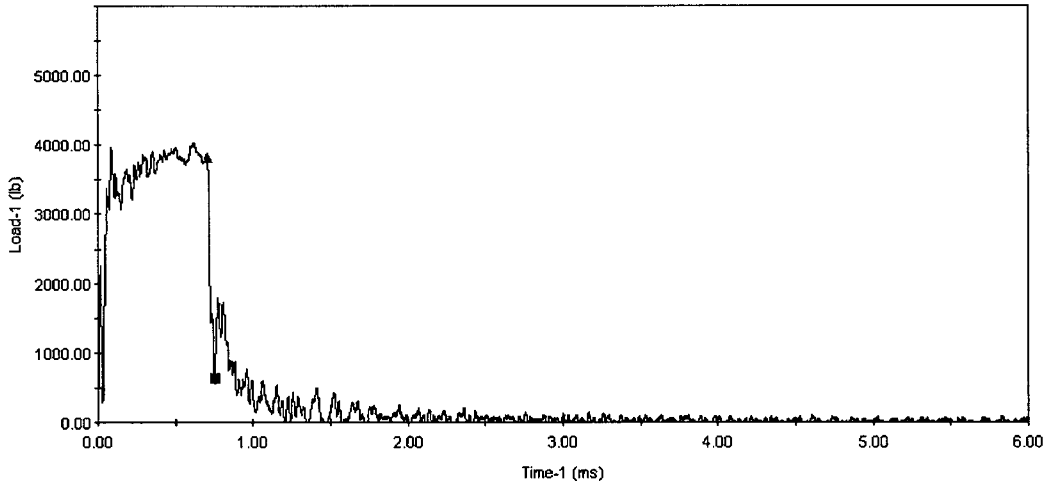
371, 25°F



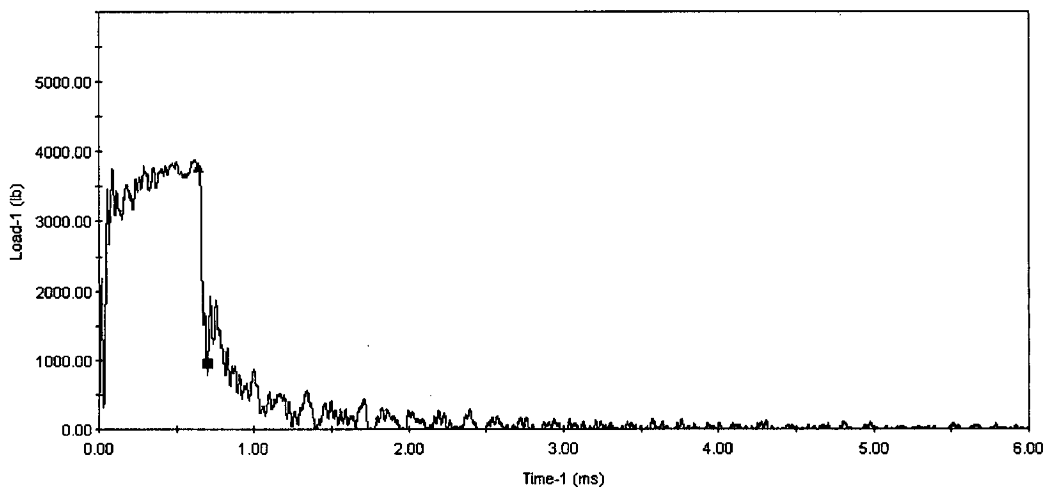
36J, 35°F



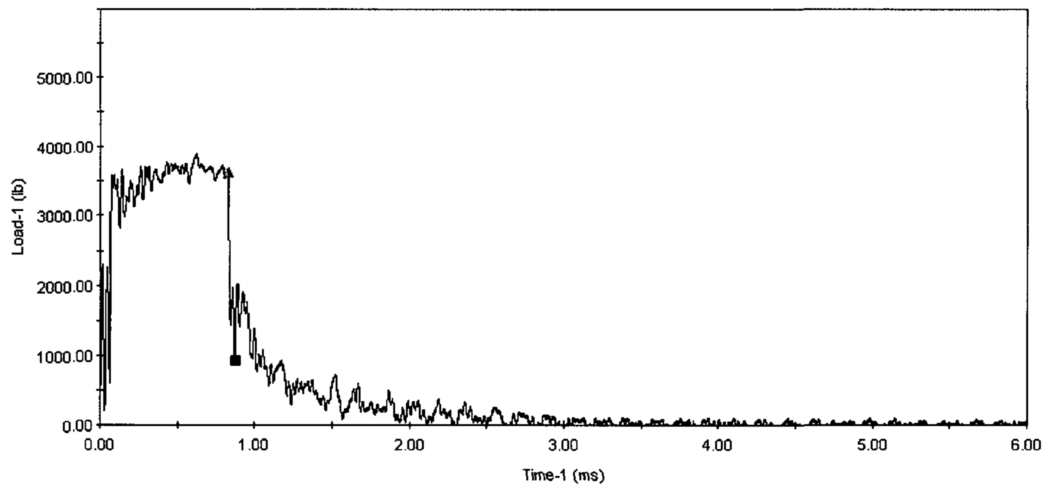
35U, 50°F



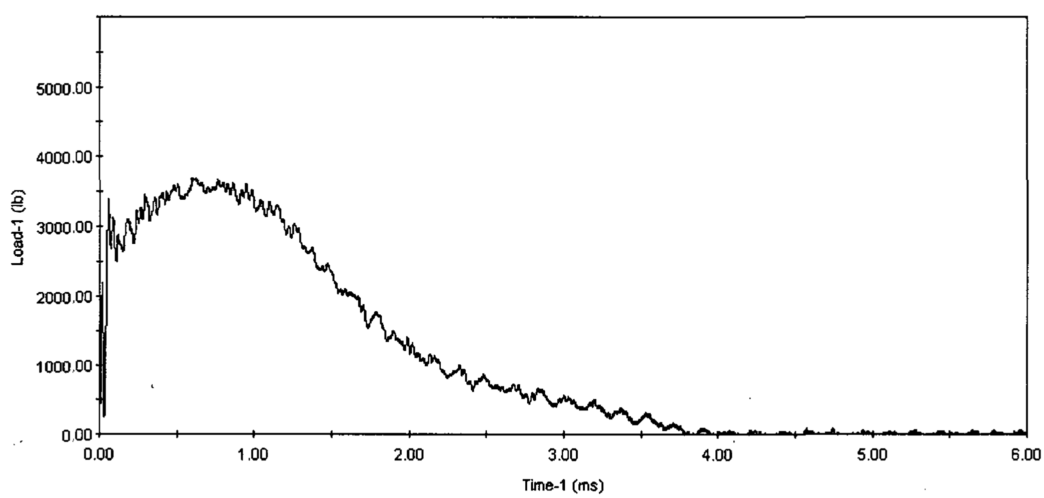
36L, 50°F



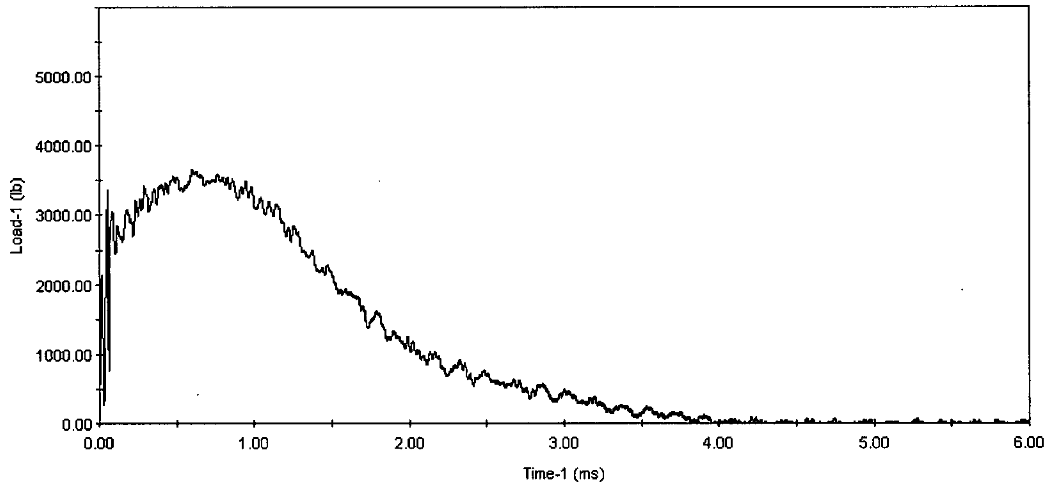
36K, 60°F



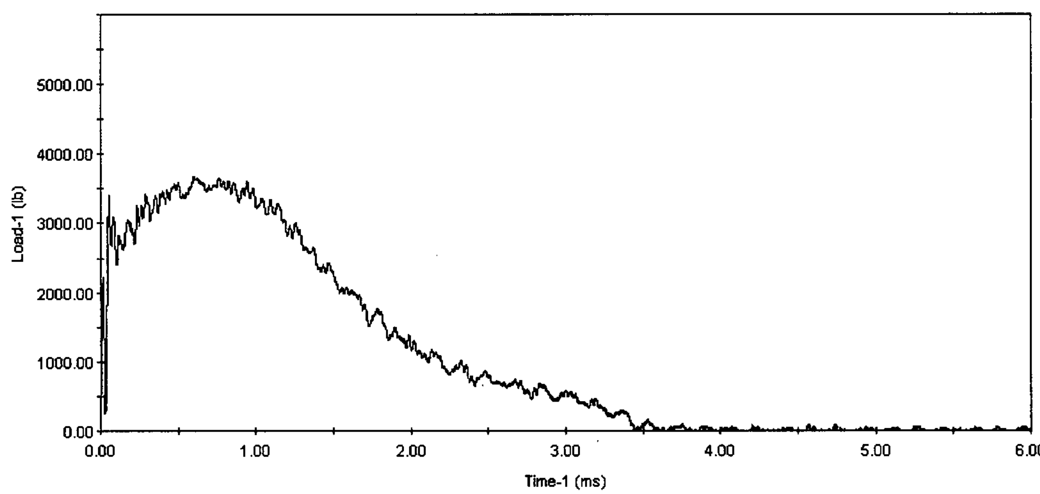
36Y, 75°F



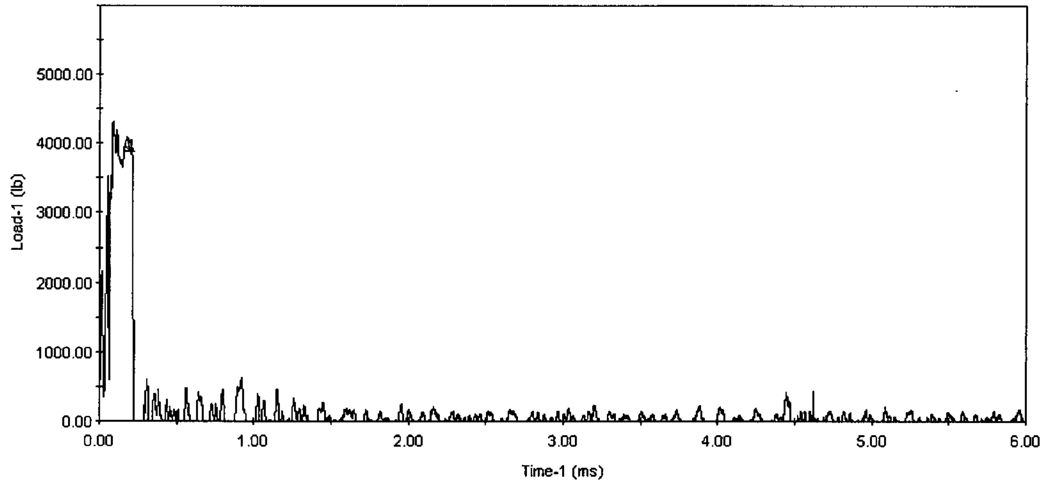
36U, 250°F



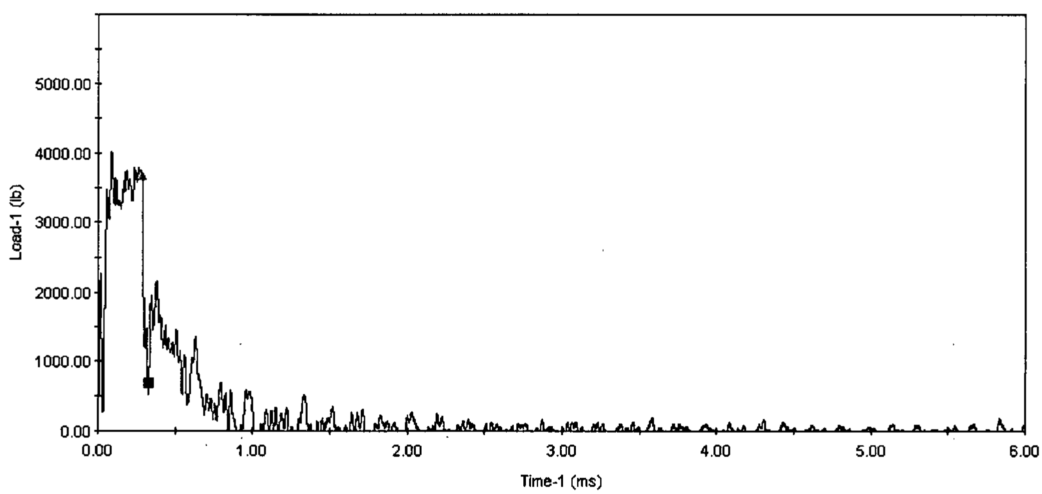
36T, 275°F



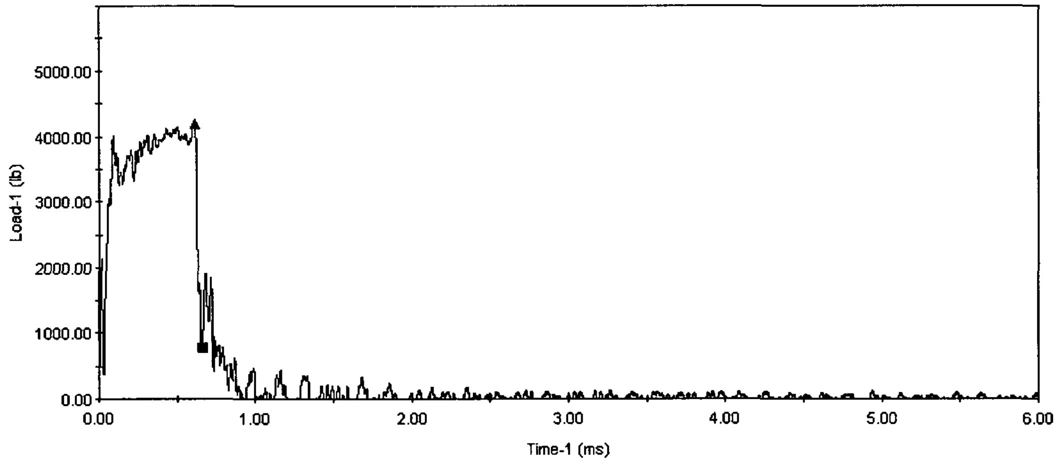
36P, 300°F



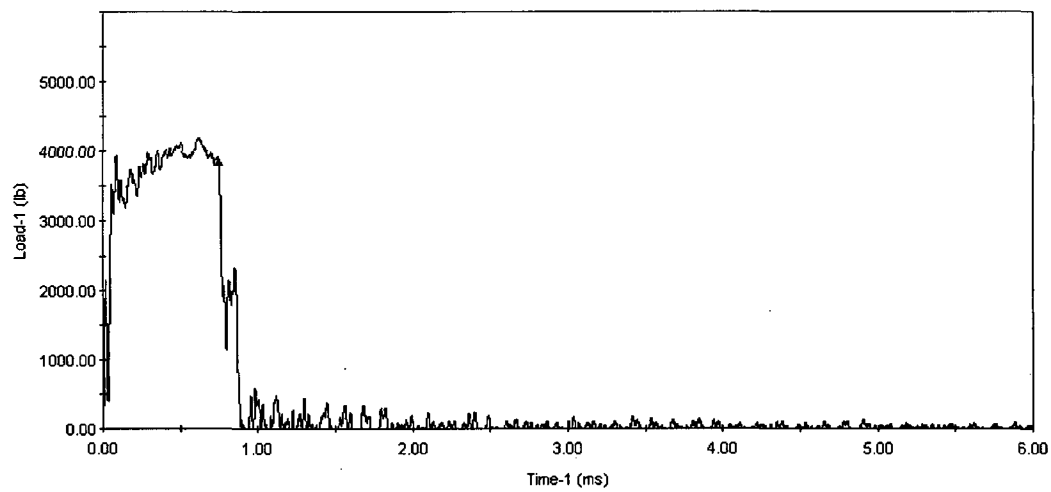
463, -75°F



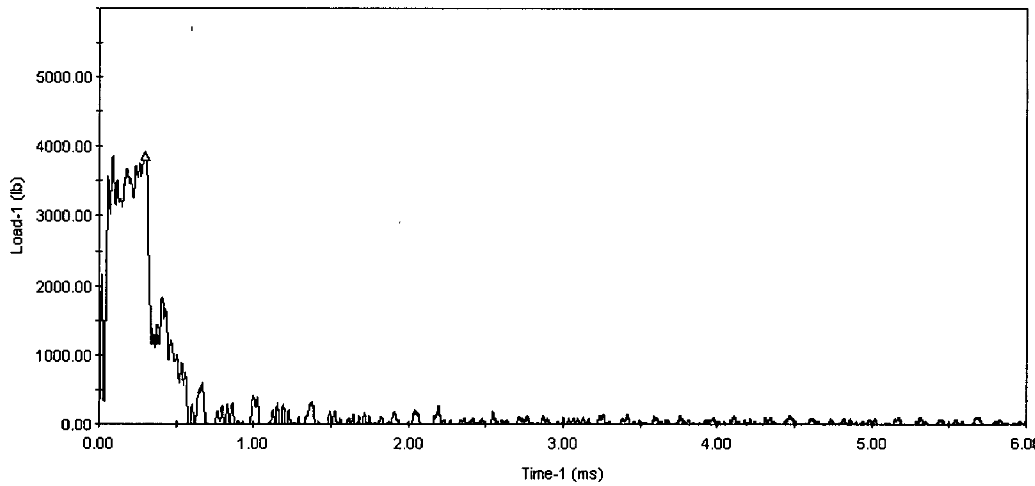
46B, 25°F



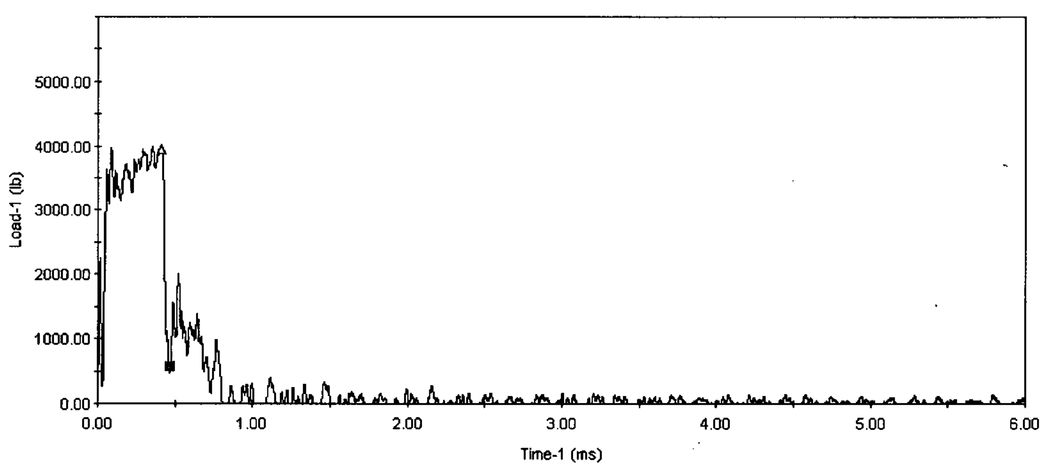
45L, 30°F



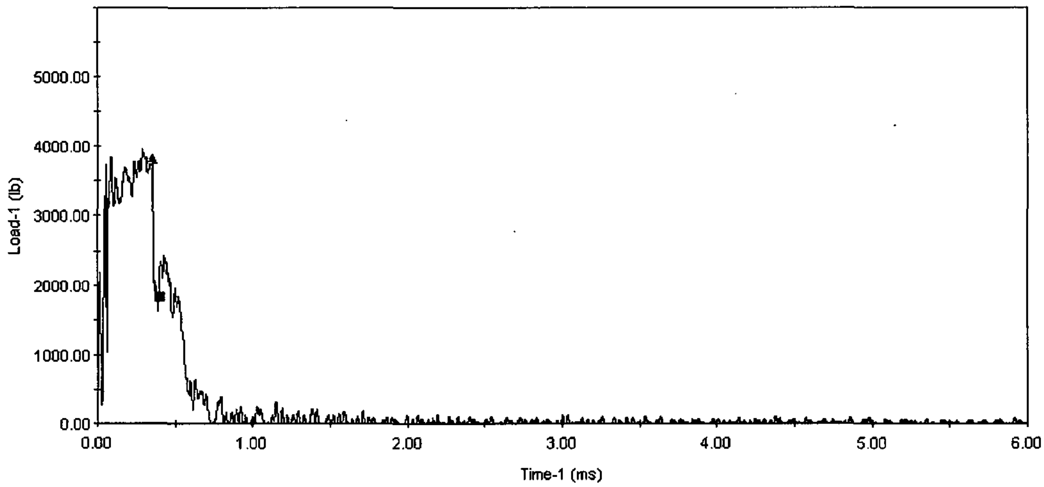
45U, 40°F



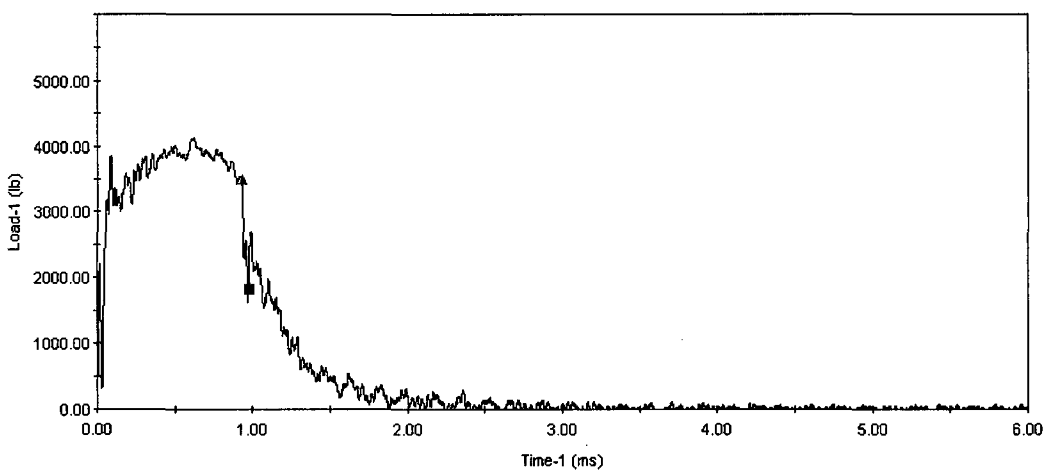
46E, 50°F



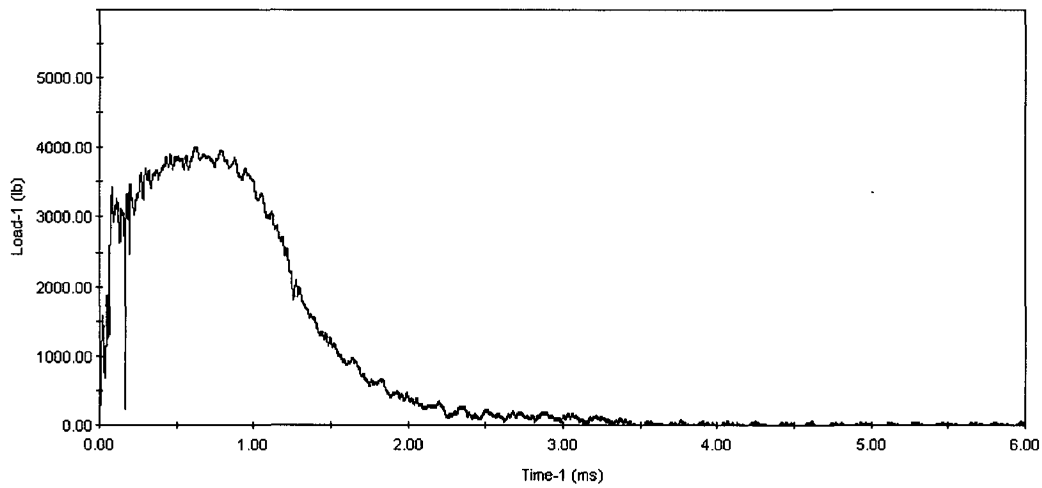
464, 60°F



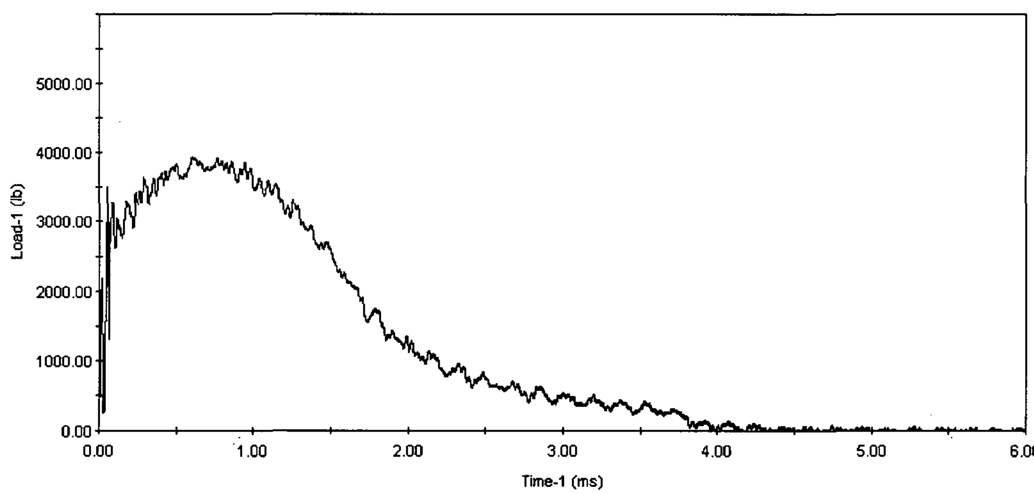
46C, 75°F



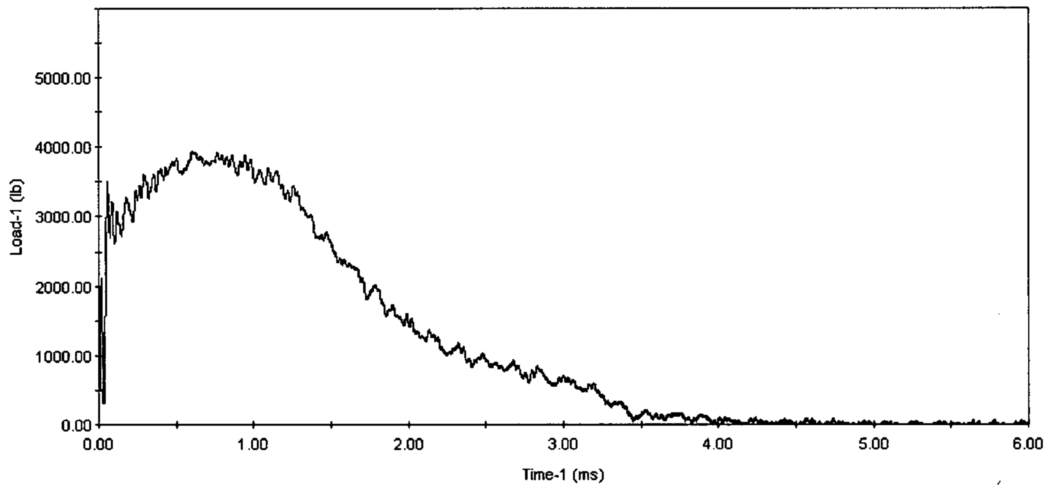
462, 125°F



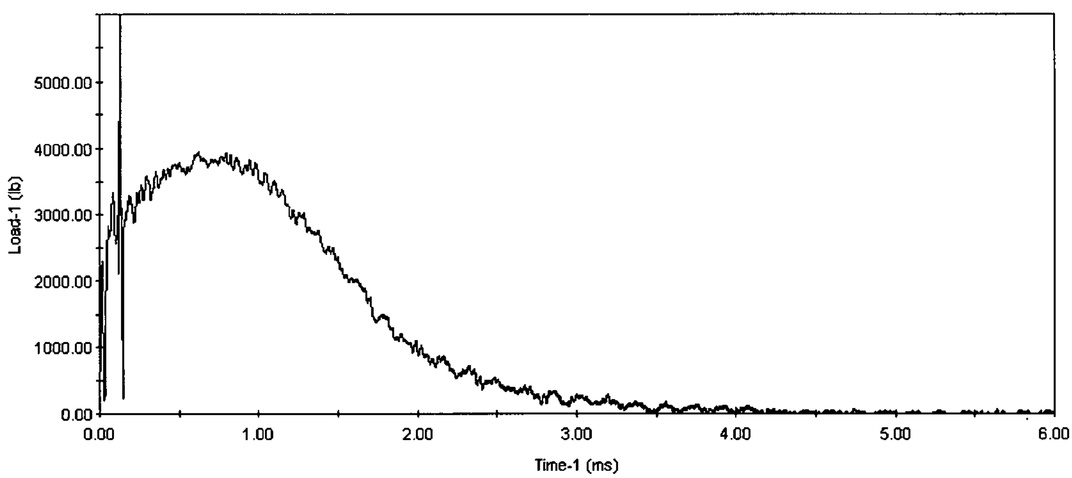
46D, 225°F



461, 250°F



45M, 275°F



45T, 300°F

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

Contained in Table C-1 are the upper-shelf energy (USE) values used as input for the generation of the Charpy V-notch plots using CVGRAPH, Version 5.3. The definition for USE is given in ASTM E185-82 [Reference 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."

If there are specimens tested in sets of three at each temperature, Westinghouse typically reports the set having the highest average energy as the USE (usually unirradiated material). If the specimens were not tested in sets of three at each temperature, Westinghouse reports the average of all Charpy data (≥ 95% shear) as the USE, excluding any values that are deemed outliers using engineering judgment. Hence, the Capsule 284° 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 263° and 97° were also determined by applying this methodology to the Charpy Impact data reported in References C-2 through 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 all cases

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

Material	Capsule			
	Unirradiated	263°	97°	284°
Intermediate Shell Plate D-7206-3 Longitudinal Orientation	137.4	115.2	101.8	103.3
Intermediate Shell Plate D-7206-3 Transverse Orientation	107.5	---	84.0	87.7
Surveillance Program Weld Metal (Heat # 33A277)	151.8	118.5	105.5	108.0
HAZ Material	128.3	93.1	81.0	113.7
SRM	135.5	109.4	---	---

CVGRAPH Version 5.3 plots of all surveillance data are provided in this appendix, on the pages following the reference list. Note that the hand drawn plots of the unirradiated material, as well as Capsules 263° and 97°, in References C-2 through C-4, were updated to CVGRAPH Version 5.3 in this analysis for consistency with the Capsule 284° results.

C.1 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-ESS-001, *Testing and Evaluation of Calvert Cliffs, Units 1 and 2 Reactor Vessel Materials Irradiation Surveillance Program Baseline Samples for the Baltimore Gas & Electric Co.*, January 1975.

C-3 BMI-1280, *Final Report on Calvert Cliffs Unit No. 1 Nuclear Plant Reactor Pressure Vessel Surveillance Program: Capsule 263*, December 1980.

C-4 BAW-2160, *Analysis of Capsule 97° Baltimore Gas & Electric Company Calvert Cliffs Nuclear Power Plant Unit No. 1*, June 1993.

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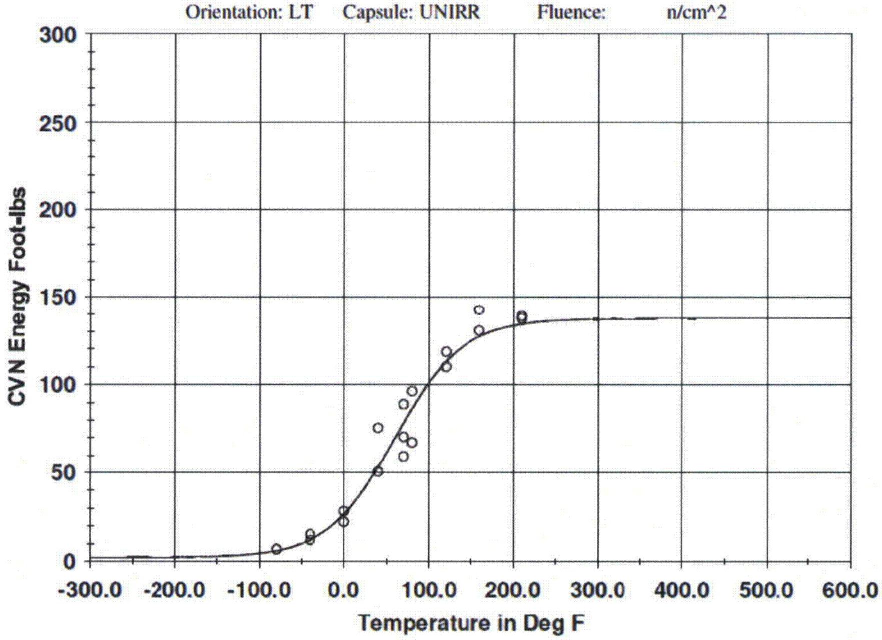
C.2 CVGRAPH VERSION 5.3 INDIVIDUAL PLOTS

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 08:25 AM
Page 1
Coefficients of Curve 1
A = 69.8 B = 67.6 C = 79.45 T0 = 59.85 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=137.4(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=6.2 Deg F Temp@50 ft-lbs=35.9 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-80.00	6.80	6.09	.71
-40.00	12.00	12.33	-.33
-40.00	15.40	12.33	3.07
.00	22.40	26.73	-4.33
.00	28.40	26.73	1.67
40.00	50.50	53.26	-2.76
40.00	75.60	53.26	22.34
70.00	59.50	78.39	-18.89
70.00	70.50	78.39	-7.89

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	89.00	78.39	10.61
80.00	67.30	86.59	-19.29
80.00	96.30	86.59	9.71
120.00	110.00	113.02	-3.02
120.00	118.50	113.02	5.48
160.00	130.75	127.34	3.41
160.00	142.50	127.34	15.16
210.00	137.50	134.38	3.12
210.00	139.00	134.38	4.62

Correlation Coefficient = .976

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 08:31 AM

Page 1

Coefficients of Curve 1

A = 48.75 B = 47.75 C = 94.52 T0 = 46.2 D = 0.00E+00

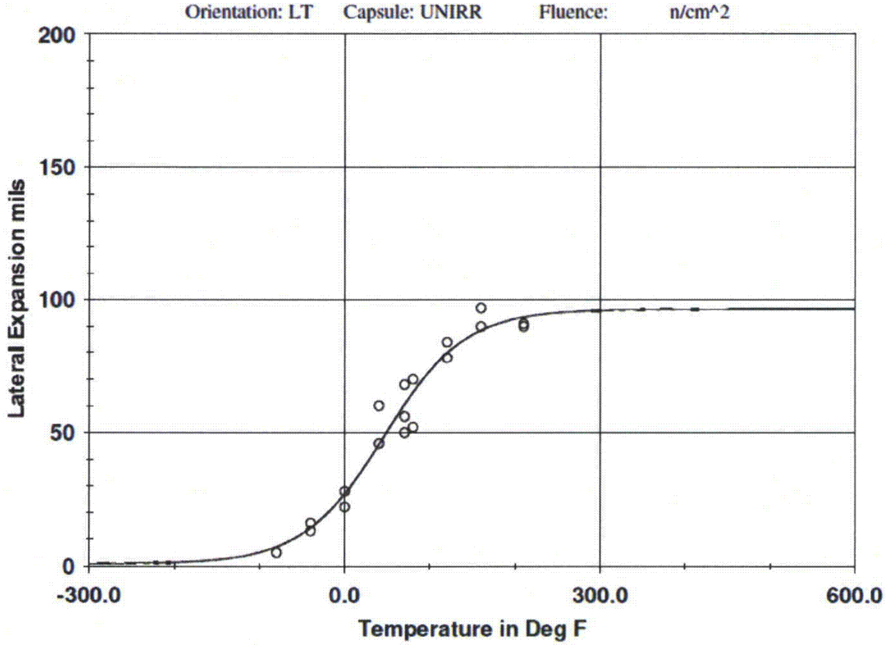
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=96.5 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=18.2 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-80.00	5.00	7.18	-2.18
-40.00	13.00	14.27	-1.27
-40.00	16.00	14.27	1.73
.00	22.00	27.11	-5.11
.00	28.00	27.11	.89
40.00	46.00	45.63	.37
40.00	60.00	45.63	14.37
70.00	50.00	60.53	-10.53
70.00	56.00	60.53	-4.53

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

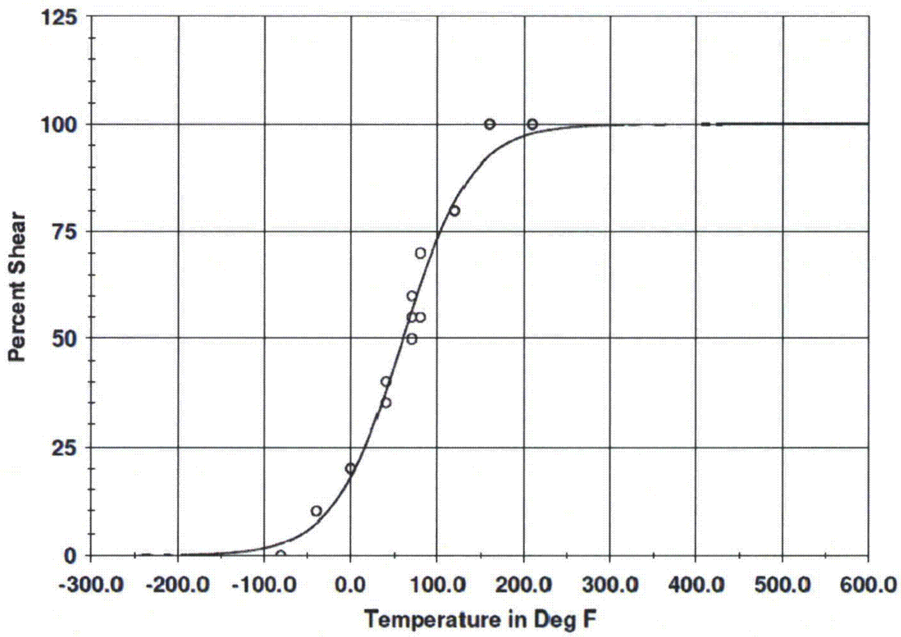
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	68.00	60.53	7.47
80.00	52.00	65.14	-13.14
80.00	70.00	65.14	4.86
120.00	78.00	79.95	-1.95
120.00	84.00	79.95	4.05
160.00	90.00	88.62	1.38
160.00	97.00	88.62	8.38
210.00	90.00	93.62	-3.62
210.00	91.00	93.62	-2.62

Correlation Coefficient = .975

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 08:34 AM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 78.67 T0 = 59.69 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 59.7
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-80.00	.00	2.79	-2.79
-40.00	10.00	7.35	2.65
-40.00	10.00	7.35	2.65
.00	20.00	17.98	2.02
.00	20.00	17.98	2.02
40.00	35.00	37.74	-2.74
40.00	40.00	37.74	2.26
70.00	50.00	56.51	-6.51
70.00	55.00	56.51	-1.51

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

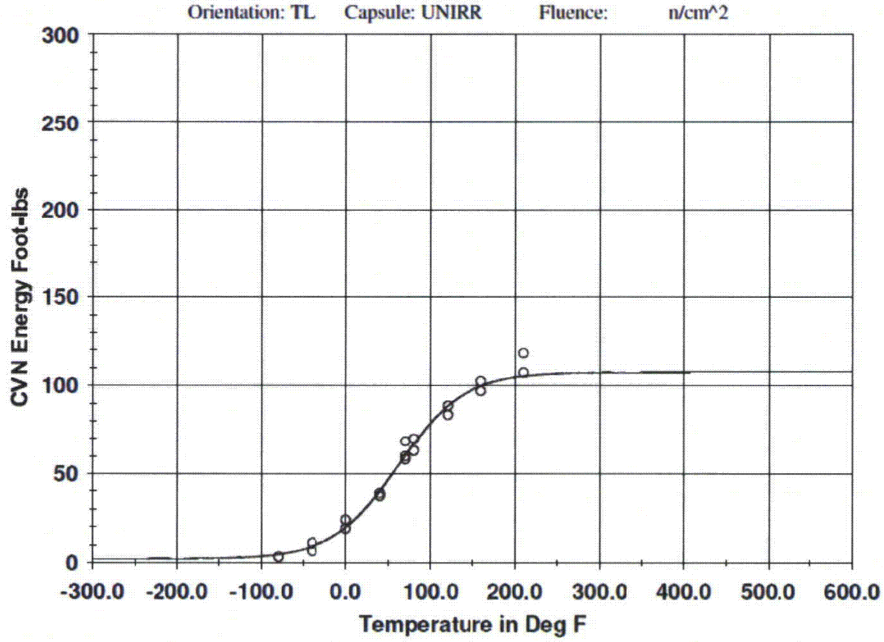
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	60.00	56.51	3.49
80.00	55.00	62.63	-7.63
80.00	70.00	62.63	7.37
120.00	80.00	82.25	-2.25
120.00	80.00	82.25	-2.25
160.00	100.00	92.76	7.24
160.00	100.00	92.76	7.24
210.00	100.00	97.86	2.14
210.00	100.00	97.86	2.14

Correlation Coefficient = .992

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 09:13 AM
Page 1
Coefficients of Curve 1
A = 54.85 B = 52.65 C = 76.64 T0 = 61.8 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=107.5(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=22.6 Deg F Temp@50 ft-lbs=54.8 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-80.00	3.30	4.74	-1.44
-40.00	6.75	9.11	-2.36
-40.00	11.00	9.11	1.89
.00	19.00	19.70	-.70
.00	24.00	19.70	4.30
40.00	37.30	40.26	-2.96
40.00	39.00	40.26	-1.26
70.00	58.30	60.46	-2.16
70.00	60.00	60.46	-.46

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	68.50	60.46	8.04
80.00	63.00	67.12	-4.12
80.00	70.00	67.12	2.88
120.00	83.50	88.58	-5.08
120.00	88.40	88.58	-.18
160.00	97.00	99.96	-2.96
160.00	102.50	99.96	2.54
210.00	107.20	105.34	1.86
210.00	118.30	105.34	12.96

Correlation Coefficient = .993

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 09:15 AM

Page 1

Coefficients of Curve 1

A = 42.67 B = 41.67 C = 95.65 T0 = 47.18 D = 0.00E+00

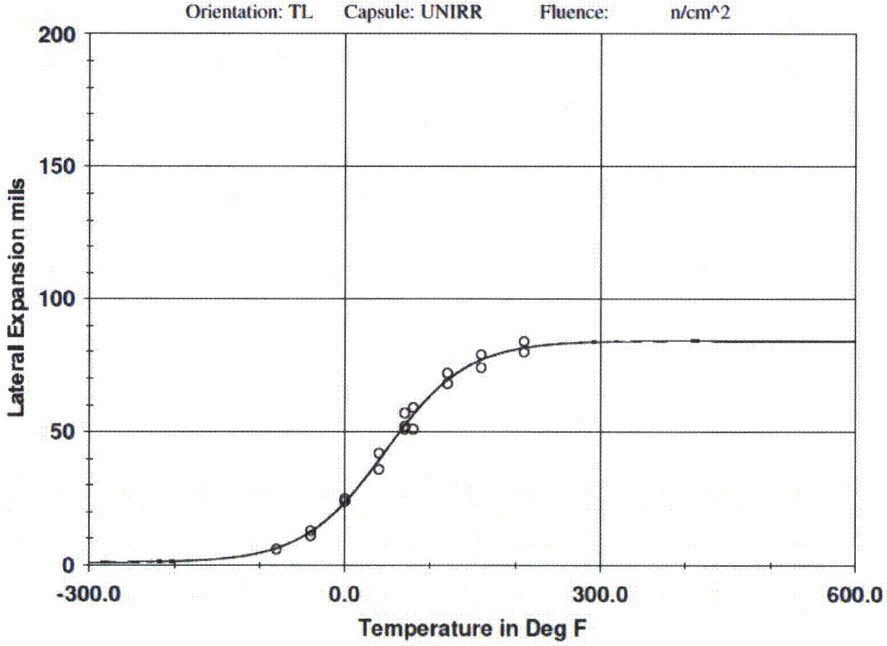
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=84.3 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=29.4 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-80.00	6.00	6.45	-.45
-40.00	11.00	12.59	-1.59
-40.00	13.00	12.59	.41
.00	25.00	23.63	1.37
.00	24.00	23.63	.37
40.00	42.00	39.55	2.45
40.00	36.00	39.55	-3.55
70.00	51.00	52.43	-1.43
70.00	52.00	52.43	-.43

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

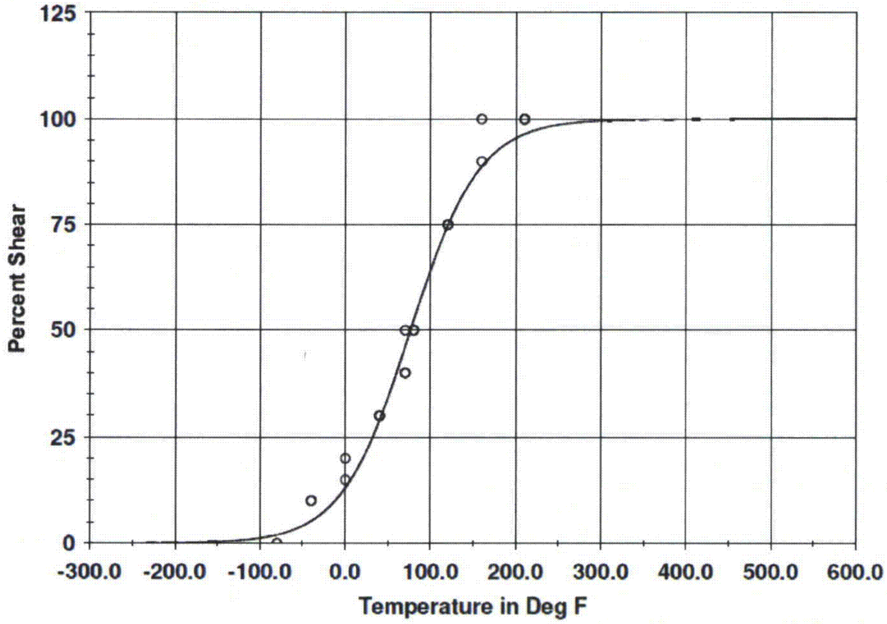
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	57.00	52.43	4.57
80.00	51.00	56.43	-5.43
80.00	59.00	56.43	2.57
120.00	68.00	69.41	-1.41
120.00	72.00	69.41	2.59
160.00	79.00	77.14	1.86
160.00	74.00	77.14	-3.14
210.00	80.00	81.66	-1.66
210.00	84.00	81.66	2.34

Correlation Coefficient = .995

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 09:17 AM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 80.39 T0 = 76.12 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 76.2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-80.00	.00	2.02	-2.02
-40.00	10.00	5.27	4.73
-40.00	10.00	5.27	4.73
.00	20.00	13.08	6.92
.00	15.00	13.08	1.92
40.00	30.00	28.93	1.07
40.00	30.00	28.93	1.07
70.00	40.00	46.20	-6.20
70.00	40.00	46.20	-6.20

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	50.00	46.20	3.80
80.00	50.00	52.41	-2.41
80.00	50.00	52.41	-2.41
120.00	75.00	74.87	.13
120.00	75.00	74.87	.13
160.00	100.00	88.96	11.04
160.00	90.00	88.96	1.04
210.00	100.00	96.55	3.45
210.00	100.00	96.55	3.45

Correlation Coefficient = .992

UNIRRADIATED (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/10/2010 02:55 PM

Page 1

Coefficients of Curve 1

A = 77. B = 74.8 C = 63.03 T0 = -14.78 D = 0.00E+00

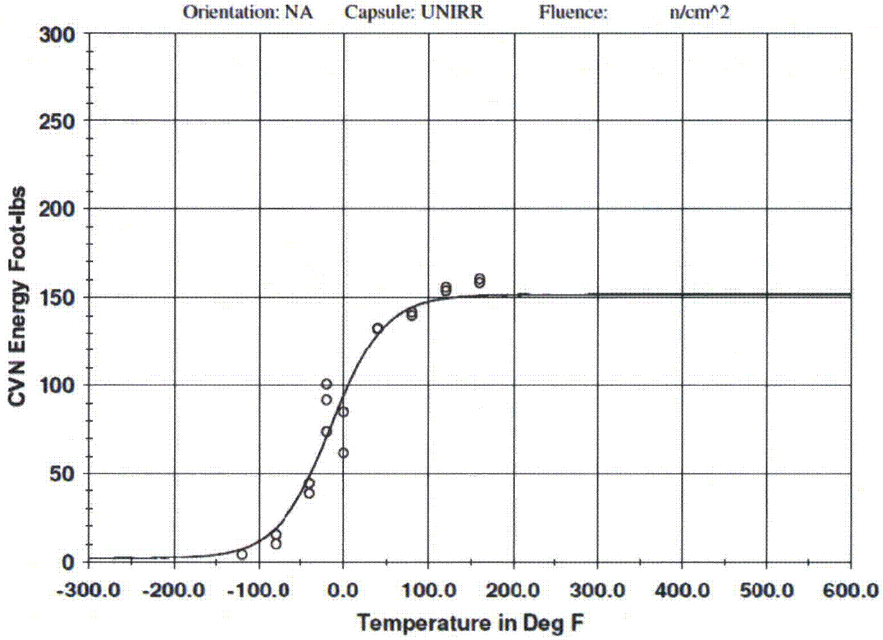
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=151.8(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-61.3 Deg F Temp@50 ft-lbs=-38.5 Deg F

Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-120.00	4.20	7.32	-3.12
-80.00	10.00	18.97	-8.97
-80.00	15.30	18.97	-3.67
40.00	38.60	48.57	9.97
-40.00	44.50	48.57	-4.07
-20.00	74.00	70.81	3.19
-20.00	91.80	70.81	20.99
-20.00	100.70	70.81	29.89
.00	62.00	94.22	-32.22

UNIRRADIATED (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	85.00	94.22	-9.22
40.00	132.80	129.43	3.37
40.00	133.00	129.43	3.57
80.00	140.00	144.76	-4.76
80.00	142.00	144.76	-2.76
120.00	153.90	149.75	4.15
120.00	156.00	149.75	6.25
160.00	158.40	151.22	7.18
160.00	160.60	151.22	9.38

Correlation Coefficient = .972

UNIRRADIATED (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/10/2010 02:56 PM

Page 1

Coefficients of Curve 1

A = 50.32 B = 49.32 C = 60.89 T0 = -27.5 D = 0.00E+00

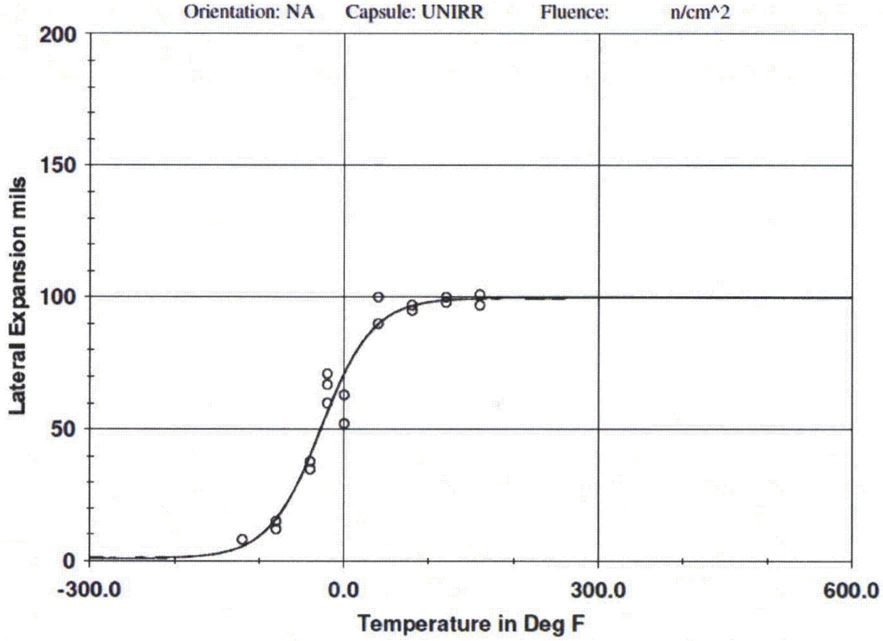
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=99.6 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=-47.0 Deg F

Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-120.00	8.00	5.51	2.49
-80.00	12.00	15.92	-3.92
-80.00	15.00	15.92	-.92
-40.00	35.00	40.33	-5.33
-40.00	38.00	40.33	-2.33
-20.00	60.00	56.36	3.64
-20.00	67.00	56.36	10.64
-20.00	71.00	56.36	14.64
.00	52.00	71.19	-19.19

UNIRRADIATED (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	63.00	71.19	-8.19
40.00	90.00	89.94	.06
40.00	100.00	89.94	10.06
80.00	95.00	96.83	-1.83
80.00	97.00	96.83	.17
120.00	98.00	98.86	-.86
120.00	100.00	98.86	1.14
160.00	101.00	99.43	1.57
160.00	97.00	99.43	-2.43

Correlation Coefficient = .974

UNIRRADIATED (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/10/2010 02:58 PM

Page 1

Coefficients of Curve 1

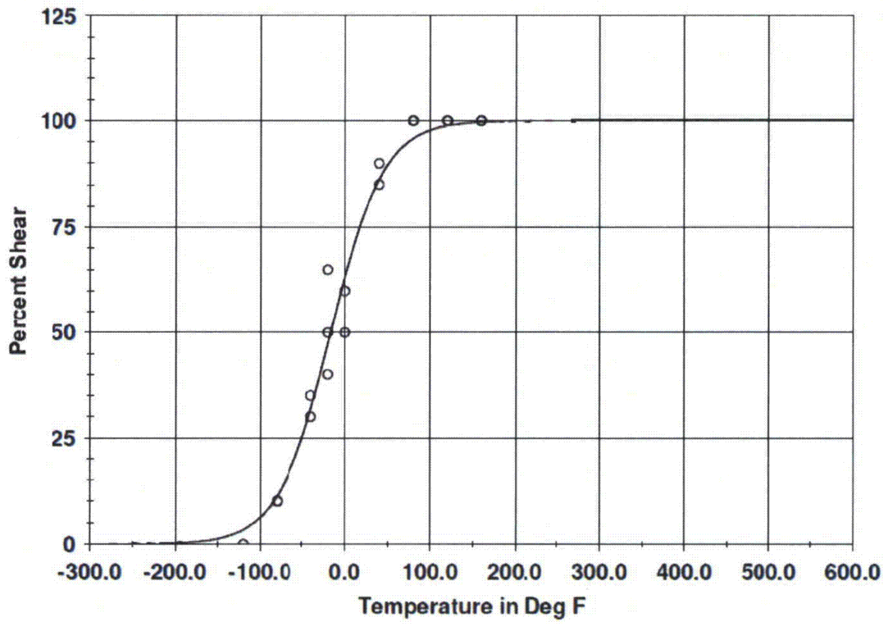
A = 50. B = 50. C = 61.59 T0 = -16.65 D = 0.00E+00

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

Temperature at 50% Shear = -16.6

Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-120.00	.00	3.37	-3.37
-80.00	10.00	11.33	-1.33
80.00	10.00	11.33	1.33
-40.00	30.00	31.90	-1.90
-40.00	35.00	31.90	3.10
-20.00	40.00	47.28	-7.28
-20.00	50.00	47.28	2.72
-20.00	65.00	47.28	17.72
.00	60.00	63.19	-3.19

UNIRRADIATED (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

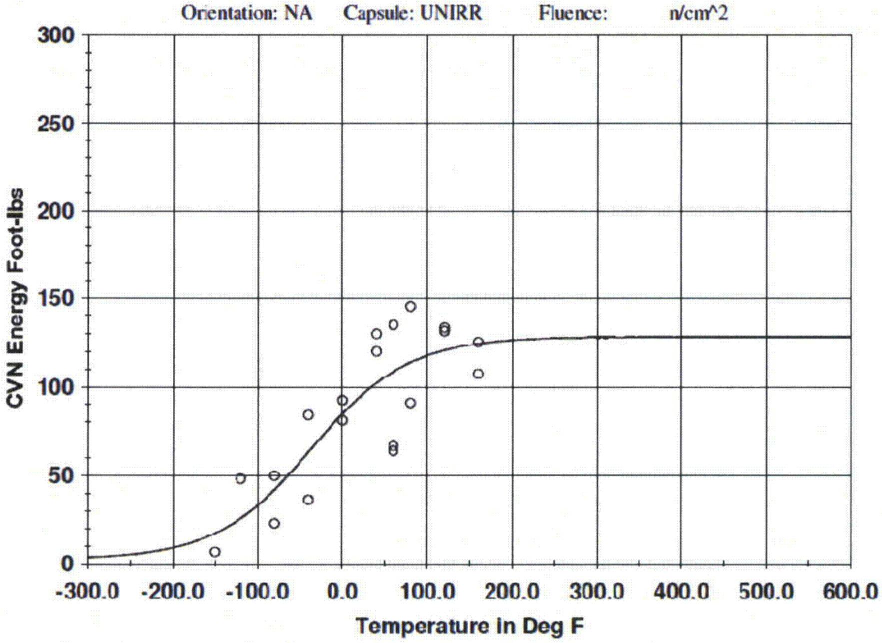
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	50.00	63.19	-13.19
40.00	85.00	86.29	-1.29
40.00	90.00	86.29	3.71
80.00	100.00	95.84	4.16
80.00	100.00	95.84	4.16
120.00	100.00	98.83	1.17
120.00	100.00	98.83	1.17
160.00	100.00	99.68	.32
160.00	100.00	99.68	.32

Correlation Coefficient = .986

UNIRRADIATED (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 10/27/2010 09:12 AM
Page 1
Coefficients of Curve 1
A = 65.25 B = 63.05 C = 113.6 T0 = -36.83 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=128.3(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-108.5 Deg F Temp@50 ft-lbs=-64.8 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-150.00	6.50	17.33	-10.83
-120.00	48.20	25.88	22.32
-80.00	23.00	42.38	-19.38
-80.00	50.00	42.38	7.62
-40.00	36.50	63.49	-26.99
-40.00	84.00	63.49	20.51
.00	81.00	85.01	-4.01
.00	92.50	85.01	7.49
40.00	120.00	102.40	17.60

UNIRRADIATED (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
40.00	130.00	102.40	27.60
60.00	64.00	108.90	-44.90
60.00	66.70	108.90	-42.20
60.00	135.00	108.90	26.10
80.00	91.00	114.01	-23.01
80.00	145.50	114.01	31.49
120.00	131.50	120.80	10.70
120.00	133.50	120.80	12.70
160.00	107.50	124.48	-16.98
160.00	125.30	124.48	.82

Correlation Coefficient = .829

UNIRRADIATED (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/03/2010 10:29 AM

Page 1

Coefficients of Curve 1

A = 42.71 B = 41.71 C = 115.11 T0 = -58.32 D = 0.00E+00

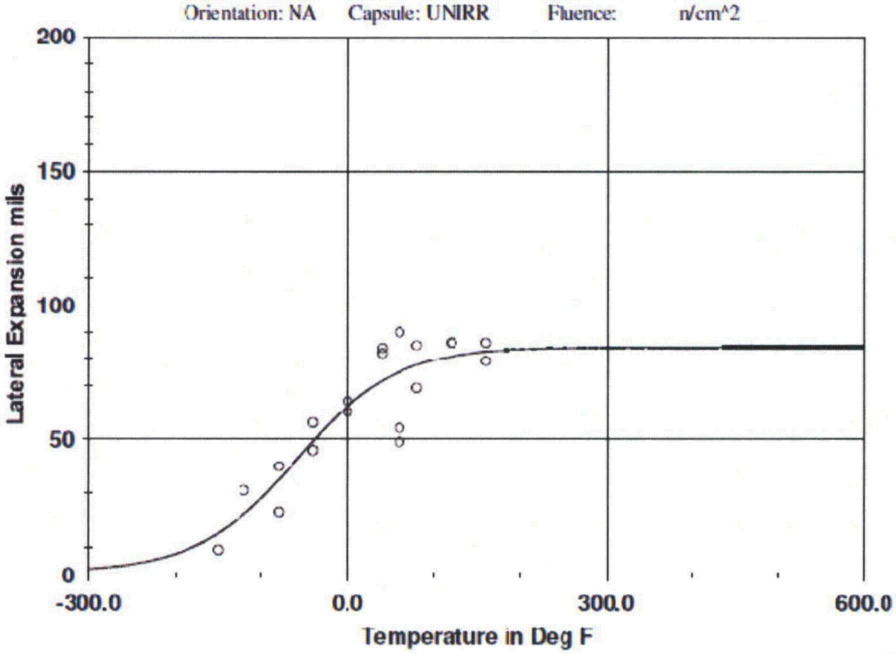
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=84.4 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=-79.8 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-150.00	9.00	15.09	-6.09
-120.00	31.00	22.28	8.72
-80.00	23.00	34.94	-11.94
-80.00	40.00	34.94	5.06
-40.00	46.00	49.29	-3.29
-40.00	56.00	49.29	6.71
.00	64.00	62.20	1.80
.00	60.00	62.20	-2.20
40.00	82.00	71.62	10.38

UNIRRADIATED (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

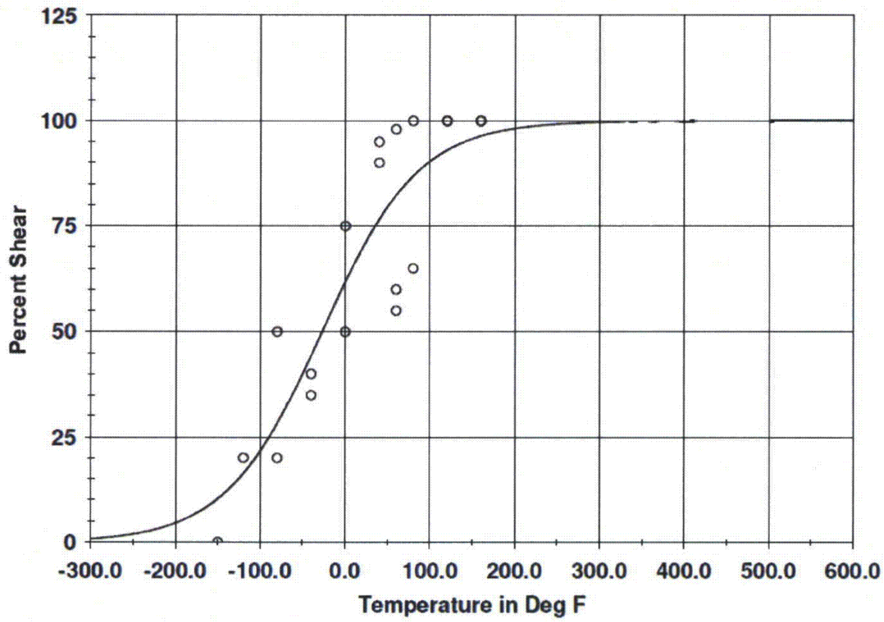
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
40.00	84.00	71.62	12.38
60.00	49.00	74.95	-25.95
60.00	54.00	74.95	-20.95
60.00	90.00	74.95	15.05
80.00	69.00	77.50	-8.50
80.00	85.00	77.50	7.50
120.00	86.00	80.81	5.19
120.00	86.00	80.81	5.19
160.00	79.00	82.58	-3.58
160.00	86.00	82.58	3.42

Correlation Coefficient = .892

UNIRRADIATED (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/03/2010 10:31 AM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 113.44 T0 = -27.36 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -27.3
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150.00	.00	10.32	-10.32
-120.00	20.00	16.34	3.66
-80.00	20.00	28.33	-8.33
-80.00	50.00	28.33	21.67
-40.00	35.00	44.45	-9.45
-40.00	40.00	44.45	-4.45
.00	75.00	61.83	13.17
.00	50.00	61.83	-11.83
40.00	95.00	76.63	18.37

UNIRRADIATED (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

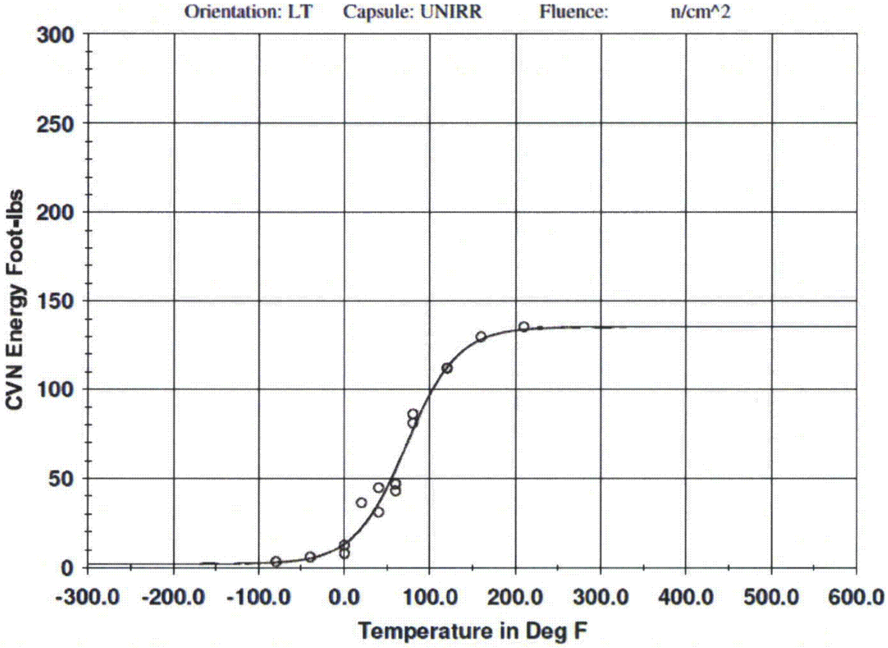
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
40.00	90.00	76.63	13.37
60.00	55.00	82.35	-27.35
60.00	60.00	82.35	-22.35
60.00	98.00	82.35	15.65
80.00	65.00	86.91	-21.91
80.00	100.00	86.91	13.09
120.00	100.00	93.07	6.93
120.00	100.00	93.07	6.93
160.00	100.00	96.45	3.55
160.00	100.00	96.45	3.55

Correlation Coefficient = .894

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 09:55 AM
Page 1
Coefficients of Curve 1
A = 68.85 B = 66.65 C = 60.29 T0 = 72.37 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=135.5(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=32.2 Deg F Temp@50 ft-lbs=54.9 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-80.00	3.40	3.05	.35
-40.00	5.90	5.33	.57
.00	8.00	13.28	-5.28
.00	12.50	13.28	-.78
20.00	36.30	22.15	14.15
40.00	31.00	36.15	-5.15
40.00	44.80	36.15	8.65
60.00	43.00	55.37	-12.37
60.00	47.00	55.37	-8.37

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
80.00	80.90	77.25	3.65
80.00	86.00	77.25	8.75
120.00	112.00	112.74	-.74
120.00	112.20	112.74	-.54
160.00	130.00	128.59	1.41
210.00	135.50	134.13	1.37

Correlation Coefficient = .989

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 09:57 AM

Page 1

Coefficients of Curve 1

A = 49.27 B = 48.27 C = 72.48 T0 = 61.22 D = 0.00E+00

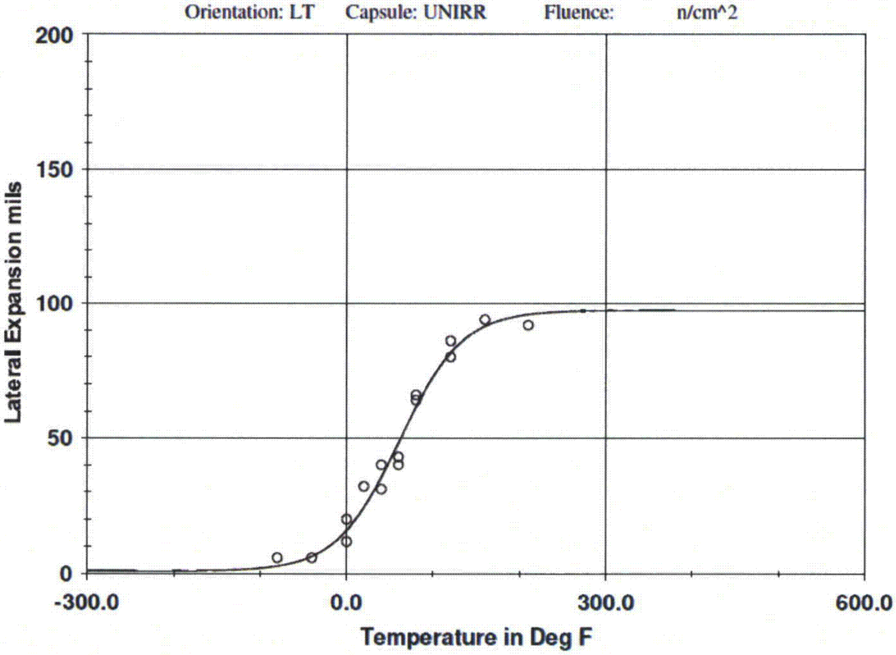
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=97.5 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=39.2 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-80.00	6.00	2.92	3.08
-40.00	6.00	6.57	-.57
.00	12.00	16.05	-4.05
.00	20.00	16.05	3.95
20.00	32.00	24.44	7.56
40.00	31.00	35.53	-4.53
40.00	40.00	35.53	4.47
60.00	40.00	48.46	-8.46
60.00	43.00	48.46	-5.46

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
80.00	64.00	61.51	2.49
80.00	66.00	61.51	4.49
120.00	80.00	81.62	-1.62
120.00	86.00	81.62	4.38
160.00	94.00	91.61	2.39
210.00	92.00	95.98	-3.98

Correlation Coefficient = .988

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 09:59 AM

Page 1

Coefficients of Curve 1

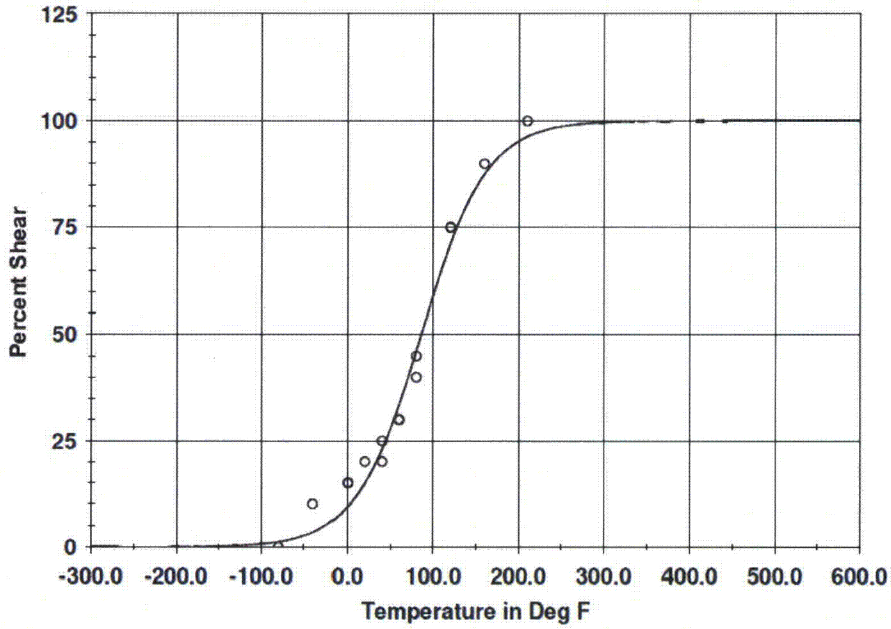
A = 50. B = 50. C = 75.71 T0 = 85.66 D = 0.00E+00

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

Temperature at 50% Shear = 85.7

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-80.00	.00	1.24	-1.24
-40.00	10.00	3.49	6.51
.00	15.00	9.43	5.57
.00	15.00	9.43	5.57
20.00	20.00	15.00	5.00
40.00	20.00	23.04	-3.04
40.00	25.00	23.04	1.96
60.00	30.00	33.67	-3.67
60.00	30.00	33.67	-3.67

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

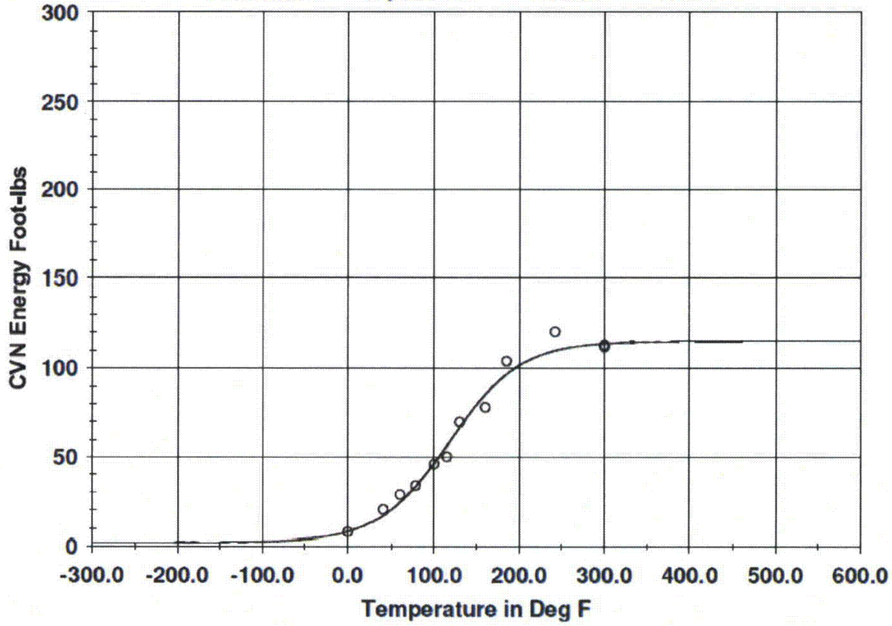
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
80.00	45.00	46.27	-1.27
80.00	40.00	46.27	-6.27
120.00	75.00	71.24	3.76
120.00	75.00	71.24	3.76
160.00	90.00	87.69	2.31
210.00	100.00	96.39	3.61

Correlation Coefficient = .991

CAPSULE 263° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 10:27 AM
Page 1
Coefficients of Curve 1
A = 58.7 B = 56.5 C = 81.97 T0 = 117.81 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=115.2(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=72.0 Deg F Temp@50 ft-lbs=105.1 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	8.00	8.24	-.24
40.00	20.30	16.92	3.38
60.00	28.70	24.36	4.34
78.00	33.70	33.23	.47
100.00	46.00	46.61	-.61
115.00	50.20	56.76	-6.56
130.00	69.80	67.04	2.76
160.00	78.00	85.45	-7.45
185.00	104.00	96.83	7.17

CAPSULE 263° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 263 Fluence: n/cm^2

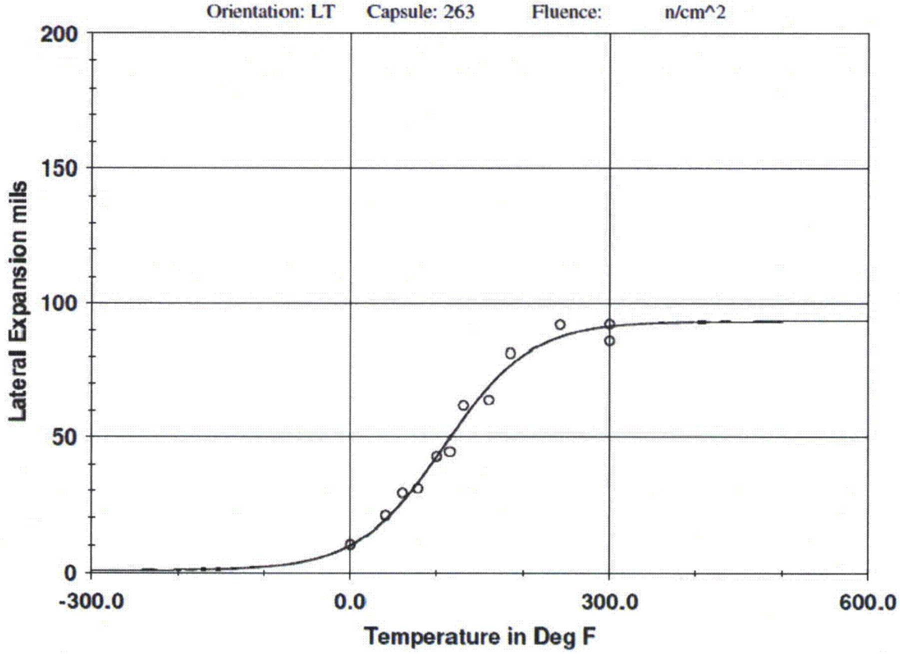
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
242.00	120.50	109.99	10.51
300.00	113.00	113.89	-.89
300.00	112.00	113.89	-1.89

Correlation Coefficient = .992

CAPSULE 263° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 10:30 AM
Page 1
Coefficients of Curve 1
A = 47.22 B = 46.22 C = 99.01 T0 = 109.05 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=93.4 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=82.3 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	10.40	10.20	.20
40.00	20.80	19.36	1.44
60.00	29.20	26.03	3.17
78.00	30.80	33.19	-2.39
100.00	43.00	43.01	-.01
115.00	44.80	50.00	-5.20
130.00	61.80	56.86	4.94
160.00	63.80	69.11	-5.31
185.00	81.40	77.05	4.35

CAPSULE 263° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
242.00	92.20	87.55	4.65
300.00	92.40	91.53	.87
300.00	86.00	91.53	-5.53

Correlation Coefficient = .991

CAPSULE 263° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 10:32 AM

Page 1

Coefficients of Curve 1

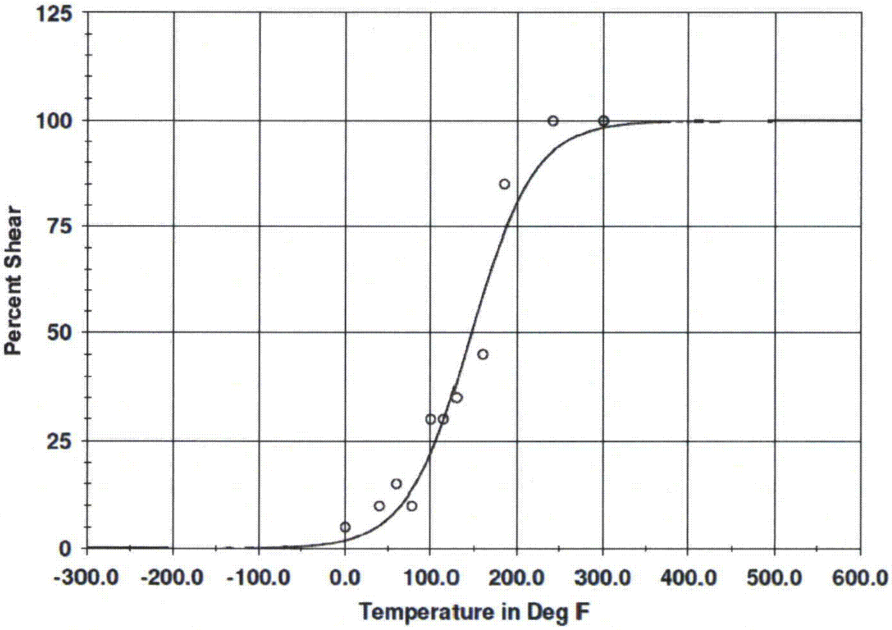
A = 50. B = 50. C = 74.53 T0 = 146.48 D = 0.00E+00

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

Temperature at 50% Shear = 146.5

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: LT Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	5.00	1.93	3.07
40.00	10.00	5.43	4.57
60.00	15.00	8.94	6.06
78.00	10.00	13.73	-3.73
100.00	30.00	22.32	7.68
115.00	30.00	30.05	-.05
130.00	35.00	39.12	-4.12
160.00	45.00	58.97	-13.97
185.00	85.00	73.76	11.24

CAPSULE 263° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 263 Fluence: n/cm^2

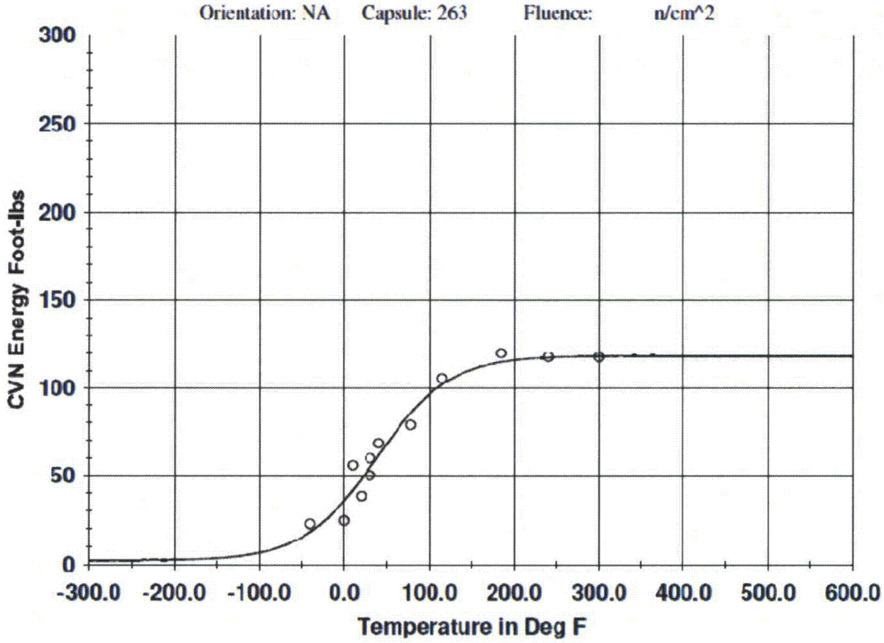
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
242.00	100.00	92.85	7.15
300.00	100.00	98.40	1.60
300.00	100.00	98.40	1.60

Correlation Coefficient = .984

CAPSULE 263° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 10/27/2010 11:20 AM
Page 1
Coefficients of Curve 1
A = 60.35 B = 58.15 C = 84.81 T0 = 38.18 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=118.5(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-10.9 Deg F Temp@50 ft-lbs=23.0 Deg F
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-40.00	22.50	18.09	4.41
.00	24.40	35.81	-11.41
10.00	56.00	41.71	14.29
20.00	38.20	48.07	-9.87
30.00	60.00	54.76	5.24
30.00	50.00	54.76	-4.76
40.00	68.50	61.60	6.90
78.00	78.80	85.81	-7.01
115.00	105.50	102.17	3.33

CAPSULE 263° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 263 Fluence: n/cm^2

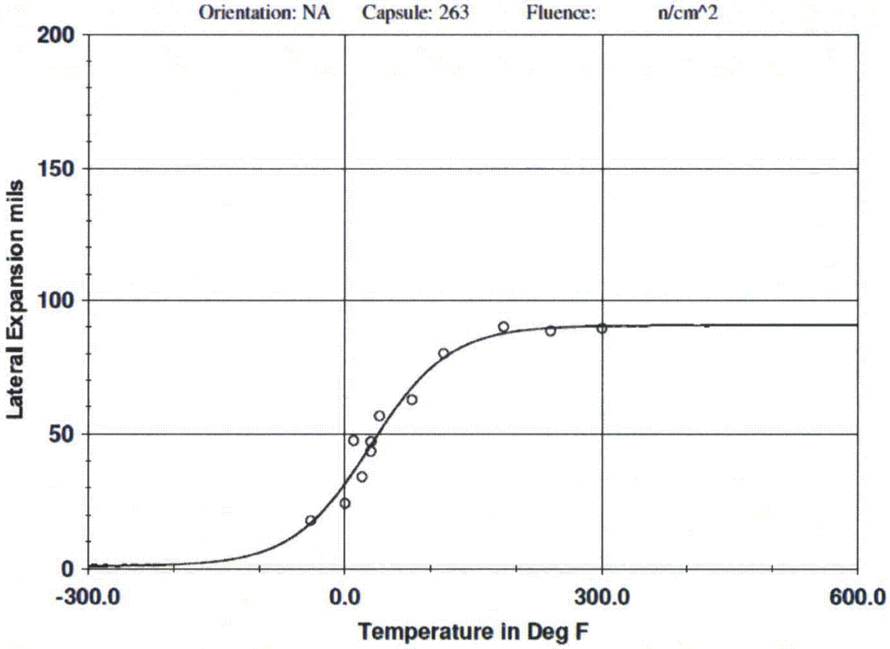
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
185.00	120.00	114.96	5.04
240.00	117.80	117.51	.29
300.00	117.70	118.26	-.56

Correlation Coefficient = .978

CAPSULE 263° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 10/27/2010 11:30 AM
Page 1
Coefficients of Curve 1
A = 45.86 B = 44.86 C = 91.93 T0 = 29.87 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=90.7 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=7.2 Deg F
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-40.00	18.00	17.10	.90
.00	24.40	31.77	-7.37
10.00	47.60	36.31	11.29
20.00	34.20	41.06	-6.86
30.00	47.20	45.92	1.28
30.00	43.60	45.92	-2.32
40.00	56.60	50.78	5.82
78.00	62.70	67.41	-4.71
115.00	80.20	78.55	1.65

CAPSULE 263° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
185.00	90.20	87.74	2.46
240.00	88.60	89.79	-1.19
300.00	89.60	90.46	.86

Correlation Coefficient = .979

CAPSULE 263° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 10/27/2010 11:31 AM

Page 1

Coefficients of Curve 1

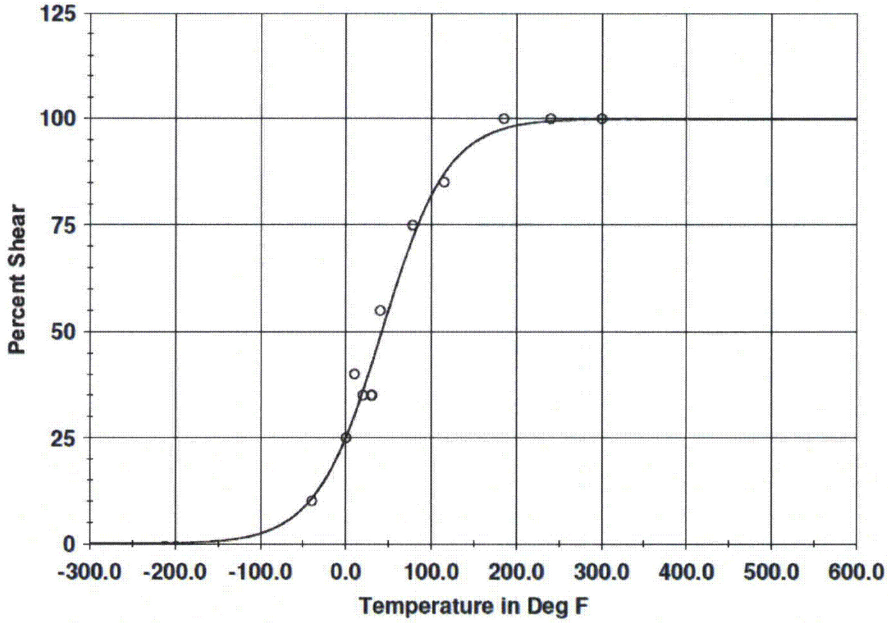
A = 50. B = 50. C = 76.67 T0 = 41.74 D = 0.00E+00

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

Temperature at 50% Shear = 41.8

Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277

Orientation: NA Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40.00	10.00	10.60	-.60
.00	25.00	25.18	-.18
10.00	40.00	30.41	9.59
20.00	35.00	36.19	-1.19
30.00	35.00	42.40	-7.40
30.00	35.00	42.40	-7.40
40.00	55.00	48.86	6.14
78.00	75.00	72.03	2.97
115.00	85.00	87.11	-2.11

CAPSULE 263° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
185.00	100.00	97.67	2.33
240.00	100.00	99.44	.56
300.00	100.00	99.88	.12

Correlation Coefficient = .989

CAPSULE 263° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 11:03 AM

Page 1

Coefficients of Curve 1

A = 47.65 B = 45.45 C = 126. T0 = 43.26 D = 0.00E+00

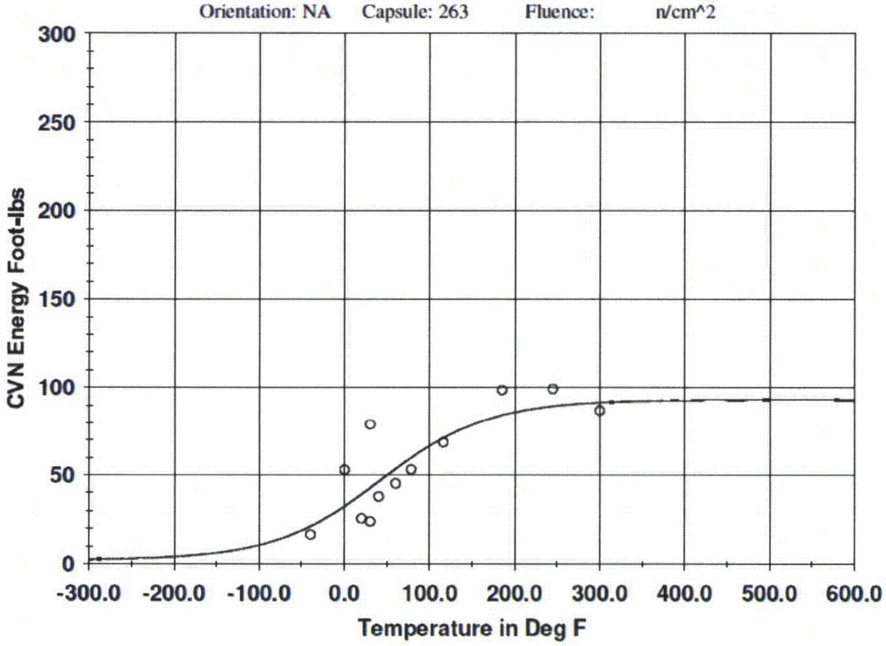
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=93.1(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-8.3 Deg F Temp@50 ft-lbs=49.8 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: NA Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-40.00	16.50	21.34	-4.84
.00	53.00	32.63	20.37
20.00	25.80	39.35	-13.55
30.00	79.00	42.88	36.12
30.00	24.00	42.88	-18.88
40.00	38.00	46.47	-8.47
60.00	45.20	53.65	-8.45
78.00	53.20	59.87	-6.67
116.00	68.70	71.31	-2.61

CAPSULE 263° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
185.00	98.50	84.43	14.07
245.00	99.20	89.55	9.65
300.00	87.00	91.58	-4.58

Correlation Coefficient = .837

CAPSULE 263° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 11:05 AM

Page 1

Coefficients of Curve 1

A = 40.68 B = 39.68 C = 166.31 T0 = 50.62 D = 0.00E+00

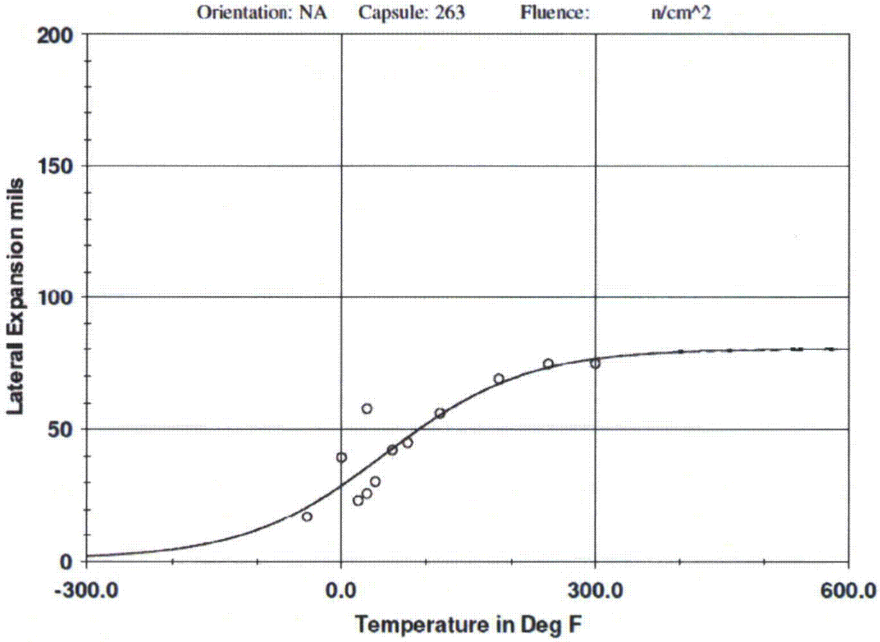
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=80.4 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=26.7 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: NA Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-40.00	17.20	20.97	-3.77
.00	39.40	28.96	10.44
20.00	23.40	33.45	-10.05
30.00	57.80	35.78	22.02
30.00	26.00	35.78	-9.78
40.00	30.40	38.15	-7.75
60.00	42.20	42.91	-.71
78.00	45.00	47.15	-2.15
116.00	56.00	55.52	.48

CAPSULE 263° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
185.00	69.00	67.20	1.80
245.00	74.60	73.36	1.24
300.00	74.80	76.58	-1.78

Correlation Coefficient = .896

CAPSULE 263° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 11:12 AM

Page 1

Coefficients of Curve 1

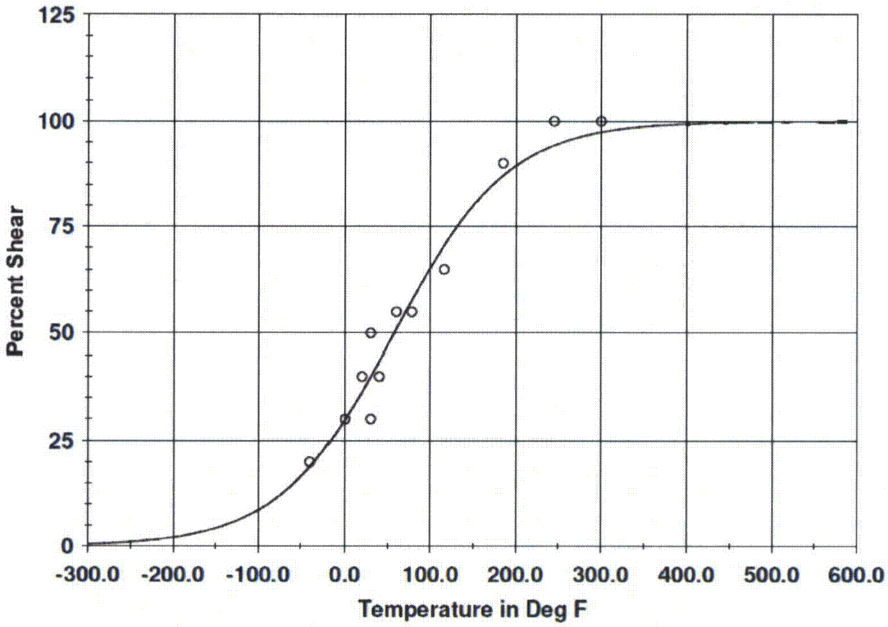
A = 50. B = 50. C = 133.69 T0 = 57.2 D = 0.00E+00

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

Temperature at 50% Shear = 57.3

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: NA Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40.00	20.00	18.94	1.06
.00	30.00	29.82	.18
20.00	40.00	36.43	3.57
30.00	50.00	39.96	10.04
30.00	30.00	39.96	-9.96
40.00	40.00	43.60	-3.60
60.00	55.00	51.05	3.95
78.00	55.00	57.72	-2.72
116.00	65.00	70.67	-5.67

CAPSULE 263° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
185.00	90.00	87.12	2.88
245.00	100.00	94.32	5.68
300.00	100.00	97.42	2.58

Correlation Coefficient = .981

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 11:15 AM

Page 1

Coefficients of Curve 1

A = 55.8 B = 53.6 C = 84.13 T0 = 176.09 D = 0.00E+00

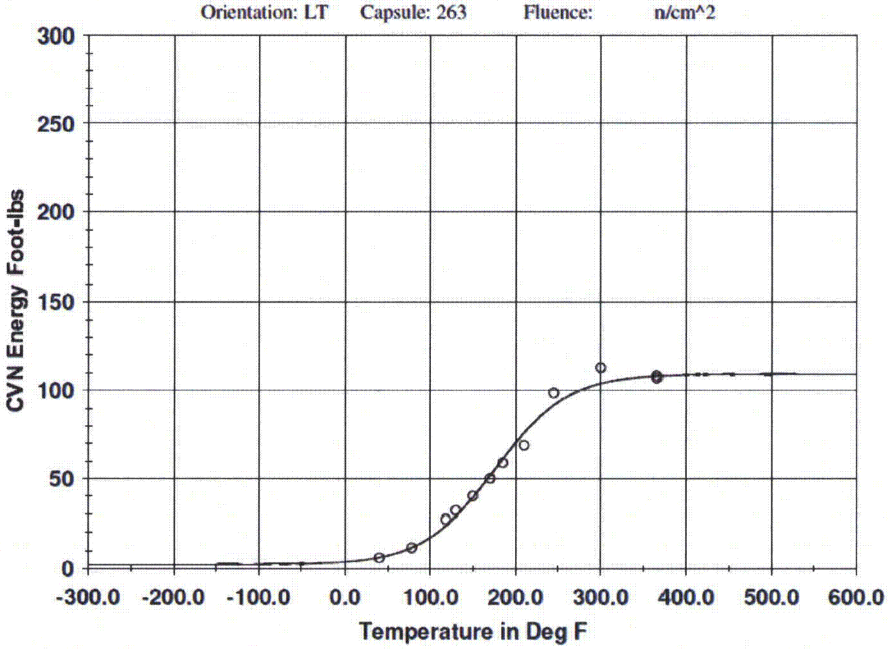
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=109.4(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=132.0 Deg F Temp@50 ft-lbs=167.0 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY

Orientation: LT Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
40.00	6.00	6.26	-.26
78.00	11.70	11.69	.01
118.00	27.10	23.73	3.37
130.00	32.00	29.06	2.94
150.00	40.20	39.69	.51
170.00	50.20	51.93	-1.73
185.00	59.20	61.46	-2.26
210.00	69.10	76.31	-7.21
245.00	98.70	91.96	6.74

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
300.00	112.90	104.05	8.85
366.00	108.40	108.24	.16
366.00	107.00	108.24	-1.24

Correlation Coefficient = .994

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 11:17 AM

Page 1

Coefficients of Curve 1

A = 45.47 B = 44.47 C = 97.44 T0 = 166.43 D = 0.00E+00

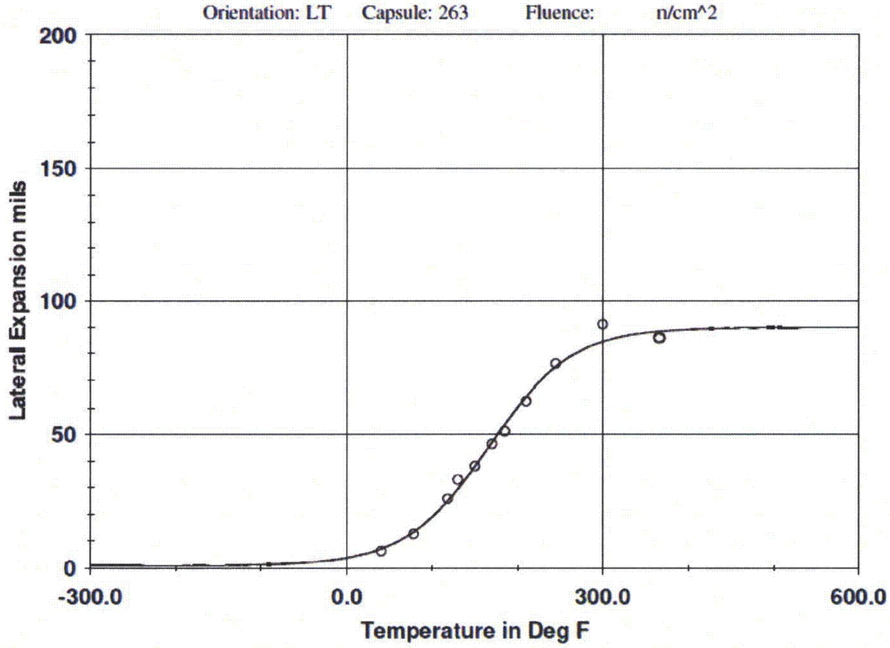
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=89.9 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=143.1 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY

Orientation: LT Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
40.00	6.20	7.18	-.98
78.00	12.60	13.45	-.85
118.00	25.80	25.02	.78
130.00	33.00	29.58	3.42
150.00	38.00	38.04	-.04
170.00	46.40	47.10	-.70
185.00	51.20	53.84	-2.64
210.00	62.40	64.12	-1.72
245.00	76.20	75.15	1.05

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
300.00	91.20	84.55	6.65
366.00	86.00	88.48	-2.48
366.00	85.80	88.48	-2.68

Correlation Coefficient = .996

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 11:18 AM

Page 1

Coefficients of Curve 1

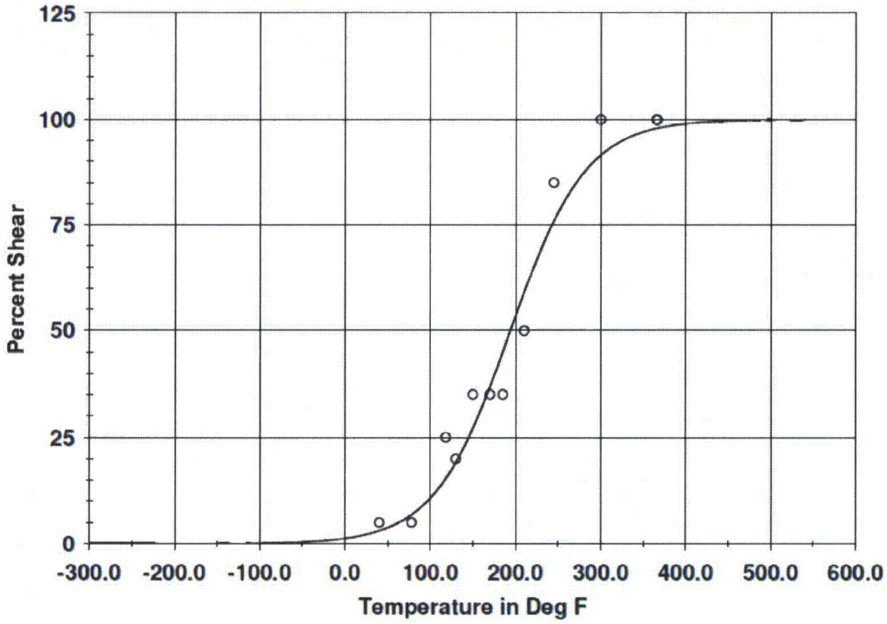
A = 50. B = 50. C = 88.93 T0 = 193.64 D = 0.00E+00

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

Temperature at 50% Shear = 193.7

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY

Orientation: LT Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
40.00	5.00	3.06	1.94
78.00	5.00	6.91	-1.91
118.00	25.00	15.43	9.57
130.00	20.00	19.29	.71
150.00	35.00	27.26	7.74
170.00	35.00	37.01	-2.01
185.00	35.00	45.16	-10.16
210.00	50.00	59.09	-9.09
245.00	85.00	76.04	8.96

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 263 Fluence: n/cm^2

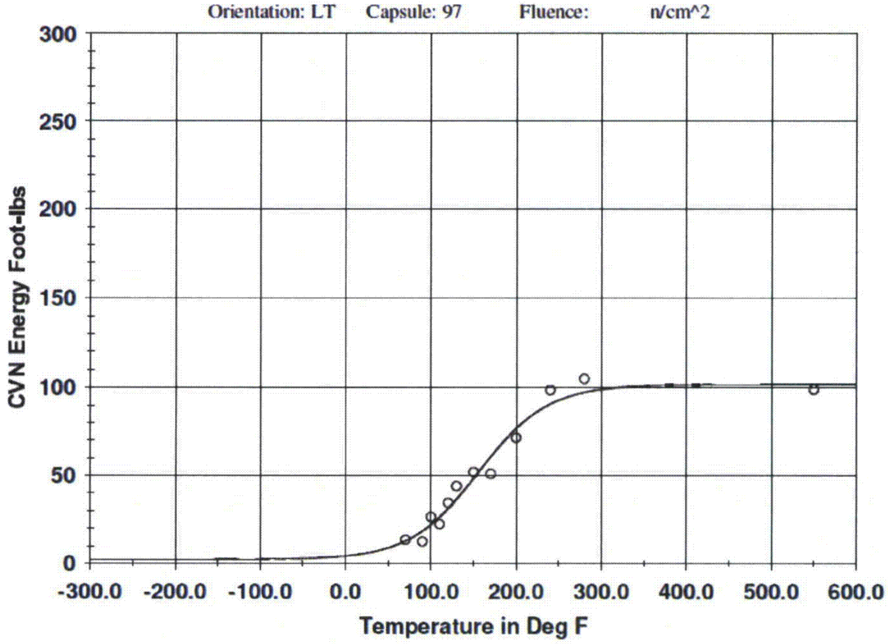
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
300.00	100.00	91.62	8.38
366.00	100.00	97.97	2.03
366.00	100.00	97.97	2.03

Correlation Coefficient = .984

CAPSULE 97° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 12:56 PM
Page 1
Coefficients of Curve 1
A = 52. B = 49.8 C = 80.8 T0 = 155.61 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=101.8(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=117.3 Deg F Temp@50 ft-lbs=152.4 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	13.50	12.88	.62
90.00	12.50	18.60	-6.10
100.00	26.50	22.28	4.22
110.00	22.50	26.54	-4.04
120.00	34.50	31.37	3.13
130.00	44.00	36.72	7.28
150.00	52.00	48.55	3.45
170.00	51.00	60.78	-9.78
200.00	71.50	76.90	-5.40

CAPSULE 97° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 97 Fluence: n/cm^2

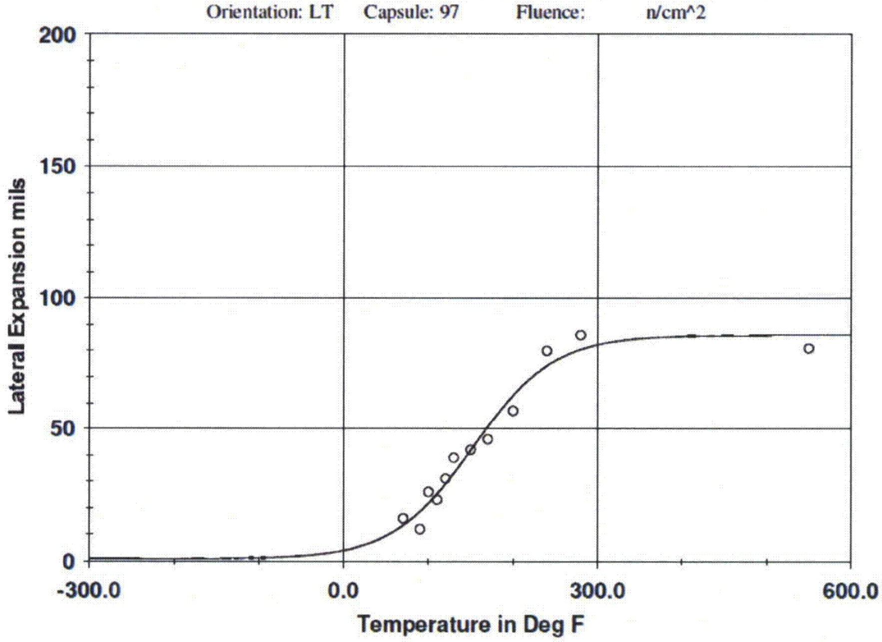
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
240.00	98.50	90.83	7.67
280.00	105.00	97.42	7.58
550.00	99.00	101.79	-2.79

Correlation Coefficient = .984

CAPSULE 97° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 01:10 PM
Page 1
Coefficients of Curve 1
A = 43.54 B = 42.54 C = 94.63 T0 = 153.48 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=86.1 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=134.3 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	16.00	13.44	2.56
90.00	12.00	18.63	-6.63
100.00	26.00	21.76	4.24
110.00	23.00	25.26	-2.26
120.00	31.00	29.08	1.92
130.00	39.00	33.19	5.81
150.00	42.00	41.97	.03
170.00	46.00	50.89	-4.89
200.00	57.00	62.91	-5.91

CAPSULE 97° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
240.00	80.00	74.30	5.70
280.00	86.00	80.58	5.42
550.00	81.00	86.05	-5.05

Correlation Coefficient = .982

CAPSULE 97° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 01:14 PM

Page 1

Coefficients of Curve 1

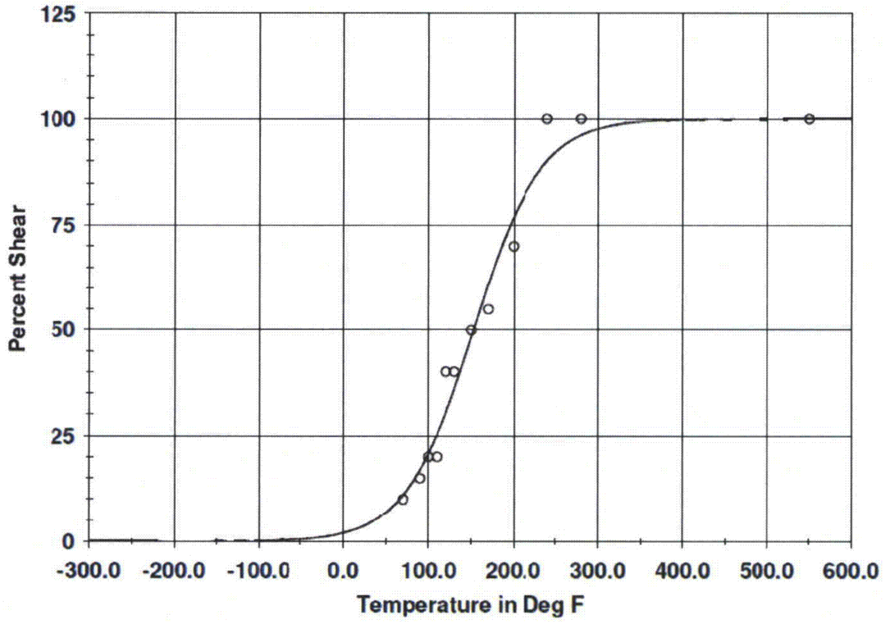
A = 50. B = 50. C = 78.75 T0 = 152.34 D = 0.00E+00

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

Temperature at 50% Shear = 152.4

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: LT Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	10.00	11.00	-1.00
90.00	15.00	17.03	-2.03
100.00	20.00	20.93	-.93
110.00	20.00	25.44	-5.44
120.00	40.00	30.55	9.45
130.00	40.00	36.18	3.82
150.00	50.00	48.51	1.49
170.00	55.00	61.03	-6.03
200.00	70.00	77.04	-7.04

CAPSULE 97° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 97 Fluence: n/cm^2

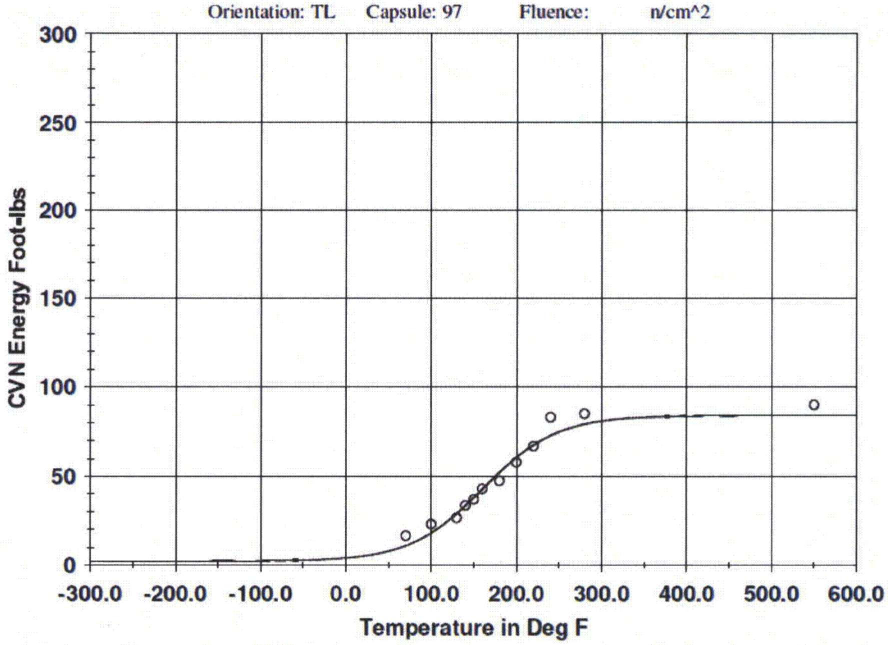
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
240.00	100.00	90.26	9.74
280.00	100.00	96.24	3.76
550.00	100.00	100.00	.00

Correlation Coefficient = .987

CAPSULE 97° (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 01:17 PM
Page 1
Coefficients of Curve 1
A = 43.1 B = 40.9 C = 85.11 T0 = 160.32 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=84.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=132.1 Deg F Temp@50 ft-lbs=174.9 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	16.50	10.95	5.55
100.00	23.00	18.16	4.84
130.00	26.50	29.12	-2.62
140.00	33.50	33.52	-.02
150.00	37.00	38.16	-1.16
160.00	43.00	42.95	.05
180.00	47.50	52.39	-4.89
200.00	58.00	60.90	-2.90
220.00	67.00	67.85	-.85

CAPSULE 97° (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
240.00	83.00	73.10	9.90
280.00	85.00	79.37	5.63
550.00	90.00	83.99	6.01

Correlation Coefficient = .985

CAPSULE 97° (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 01:19 PM

Page 1

Coefficients of Curve 1

A = 40.13 B = 39.13 C = 109.61 T0 = 160.37 D = 0.00E+00

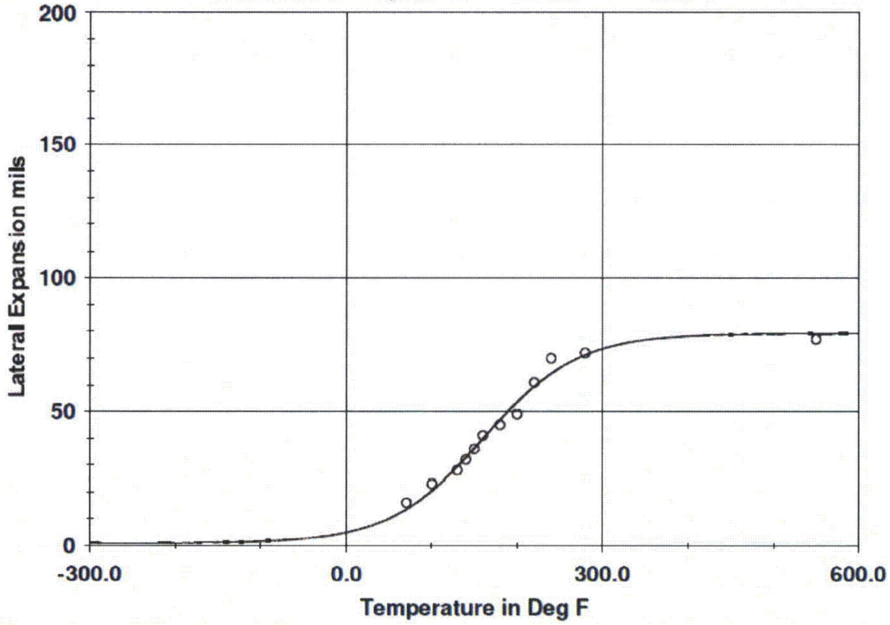
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=79.3 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=146.0 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: TL Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	16.00	13.62	2.38
100.00	23.00	20.52	2.48
130.00	28.00	29.56	-1.56
140.00	32.00	32.94	-.94
150.00	36.00	36.44	-.44
160.00	41.00	40.00	1.00
180.00	45.00	47.06	-2.06
200.00	49.00	53.69	-4.69
220.00	61.00	59.54	1.46

CAPSULE 97° (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
240.00	70.00	64.43	5.57
280.00	72.00	71.33	.67
550.00	77.00	79.20	-2.20

Correlation Coefficient = .991

CAPSULE 97° (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 01:21 PM

Page 1

Coefficients of Curve 1

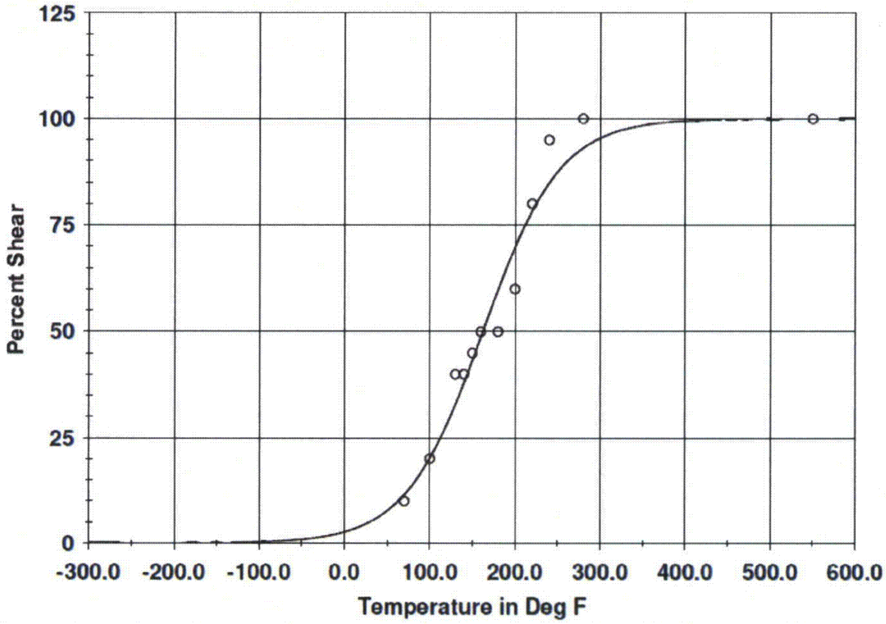
A = 50. B = 50. C = 90.39 T0 = 161.94 D = 0.00E+00

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

Temperature at 50% Shear = 162.0

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: TL Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	10.00	11.57	-1.57
100.00	20.00	20.26	-.26
130.00	40.00	33.04	6.96
140.00	40.00	38.10	1.90
150.00	45.00	43.44	1.56
160.00	50.00	48.93	1.07
180.00	50.00	59.86	-9.86
200.00	60.00	69.89	-9.89
220.00	80.00	78.32	1.68

CAPSULE 97° (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: 97 Fluence: n/cm^2

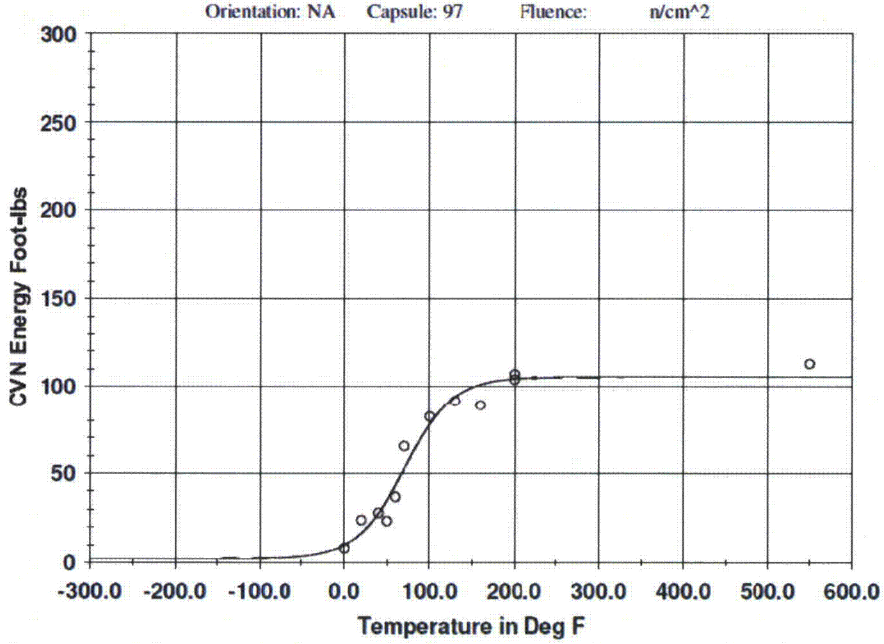
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
240.00	95.00	84.91	10.09
280.00	100.00	93.16	6.84
550.00	100.00	99.98	.02

Correlation Coefficient = .980

CAPSULE 97° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/10/2010 03:07 PM
Page 1
Coefficients of Curve 1
A = 53.85 B = 51.65 C = 56.35 T0 = 71.28 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=105.5(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=43.2 Deg F Temp@50 ft-lbs=67.1 Deg F
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	8.00	9.82	-1.82
20.00	24.00	16.60	7.40
40.00	28.00	27.80	.20
50.00	23.50	35.22	-11.72
60.00	37.00	43.64	-6.64
70.00	65.50	52.67	12.83
100.00	82.50	78.11	4.39
130.00	91.50	94.07	-2.57
160.00	89.00	101.25	-12.25

CAPSULE 97° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 97 Fluence: n/cm^2

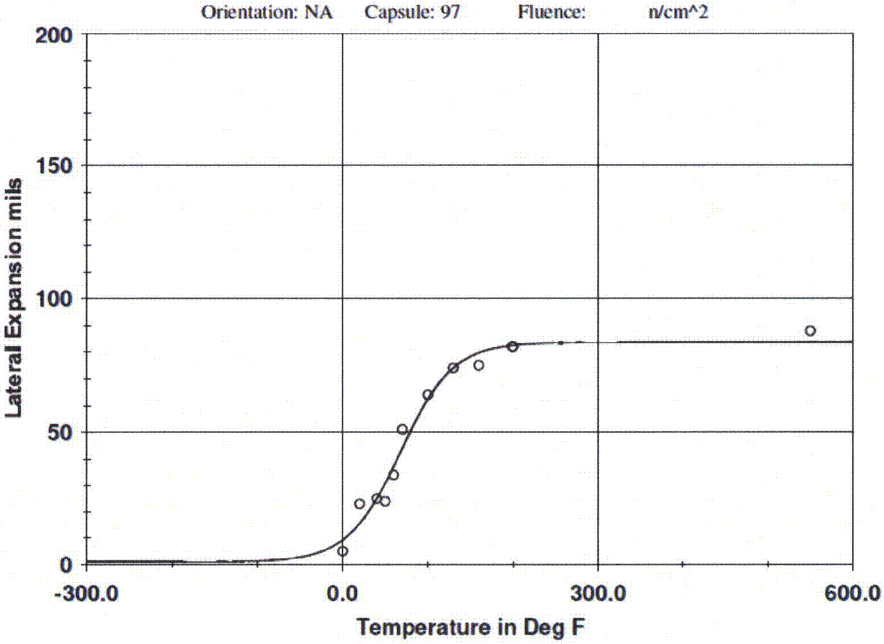
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
200.00	104.00	104.44	-.44
200.00	107.00	104.44	2.56
550.00	113.00	105.50	7.50

Correlation Coefficient = .980

CAPSULE 97° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/10/2010 03:08 PM
Page 1
Coefficients of Curve 1
A = 42.33 B = 41.33 C = 61.31 T0 = 67.33 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=83.7 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=56.4 Deg F
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	5.00	9.27	-4.27
20.00	23.00	15.54	7.46
40.00	25.00	25.04	-.04
50.00	24.00	30.95	-6.95
60.00	34.00	37.41	-3.41
70.00	51.00	44.13	6.87
100.00	64.00	62.48	1.52
130.00	74.00	74.18	-.18
160.00	75.00	79.82	-4.82

CAPSULE 97° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
200.00	82.00	82.58	-.58
200.00	82.00	82.58	-.58
550.00	88.00	83.66	4.34

Correlation Coefficient = .988

CAPSULE 97° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/10/2010 03:09 PM

Page 1

Coefficients of Curve 1

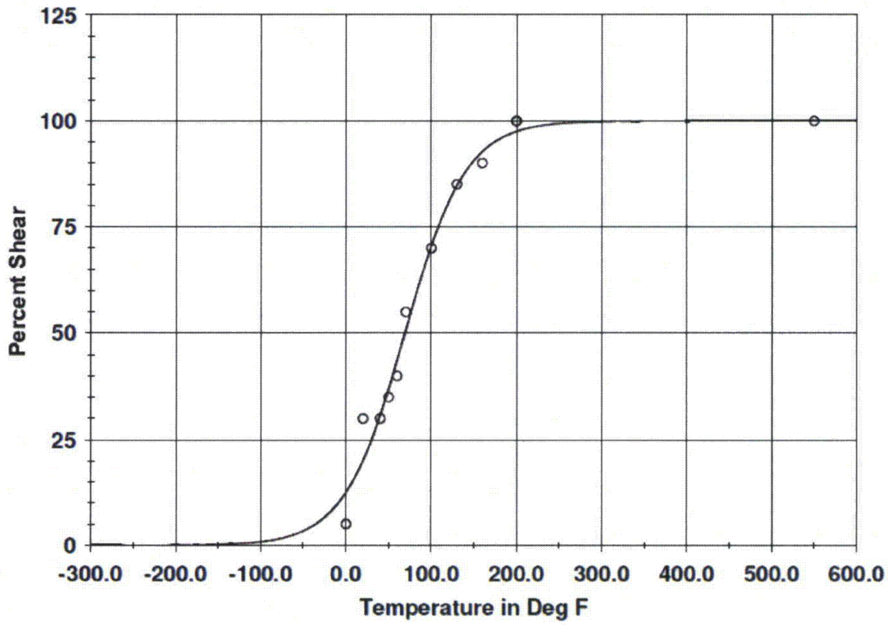
A = 50. B = 50. C = 71.15 T0 = 68.81 D = 0.00E+00

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

Temperature at 50% Shear = 68.9

Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277

Orientation: NA Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	5.00	12.63	-7.63
20.00	30.00	20.23	9.77
40.00	30.00	30.79	-.79
50.00	35.00	37.08	-2.08
60.00	40.00	43.84	-3.84
70.00	55.00	50.84	4.16
100.00	70.00	70.61	-.61
130.00	85.00	84.81	.19
160.00	90.00	92.85	-2.85

CAPSULE 97° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 97 Fluence: n/cm^2

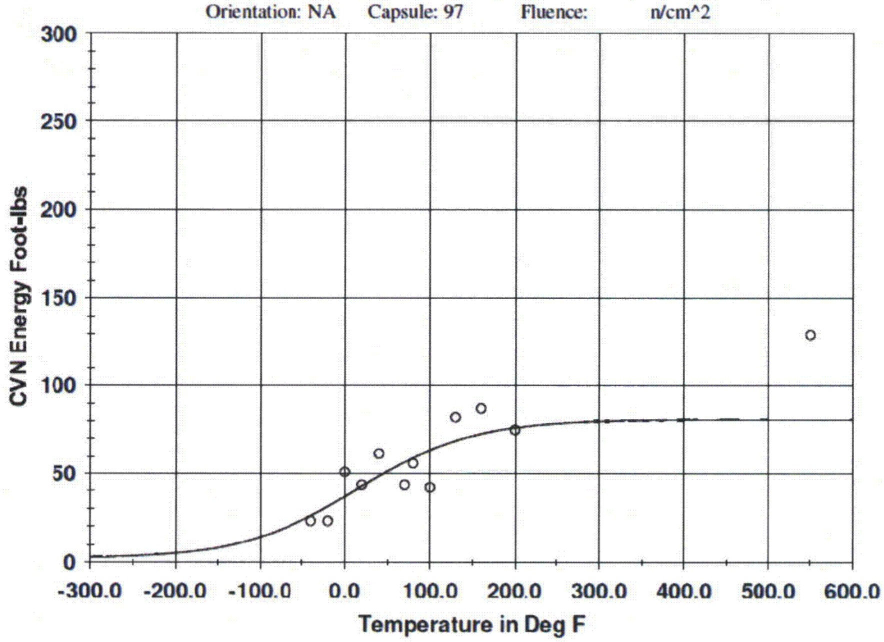
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200.00	100.00	97.56	2.44
200.00	100.00	97.56	2.44
550.00	100.00	100.00	.00

Correlation Coefficient = .991

CAPSULE 97° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 01:31 PM
Page 1
Coefficients of Curve 1
A = 41.6 B = 39.4 C = 133.71 T0 = 15.92 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=81.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-24.6 Deg F Temp@50 ft-lbs=44.9 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-40.00	23.00	26.02	-3.02
-20.00	23.00	31.26	-8.26
.00	51.00	36.93	14.07
20.00	43.50	42.80	.70
40.00	61.50	48.62	12.88
70.00	43.50	56.72	-13.22
80.00	56.00	59.16	-3.16
100.00	42.00	63.56	-21.56
130.00	82.00	68.89	13.11

CAPSULE 97° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
160.00	87.00	72.82	14.18
200.00	75.00	76.28	-1.28
550.00	129.50	80.97	48.53

Correlation Coefficient = .832

CAPSULE 97° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 01:33 PM

Page 1

Coefficients of Curve 1

A = 40.17 B = 39.17 C = 192.9 T0 = 77.15 D = 0.00E+00

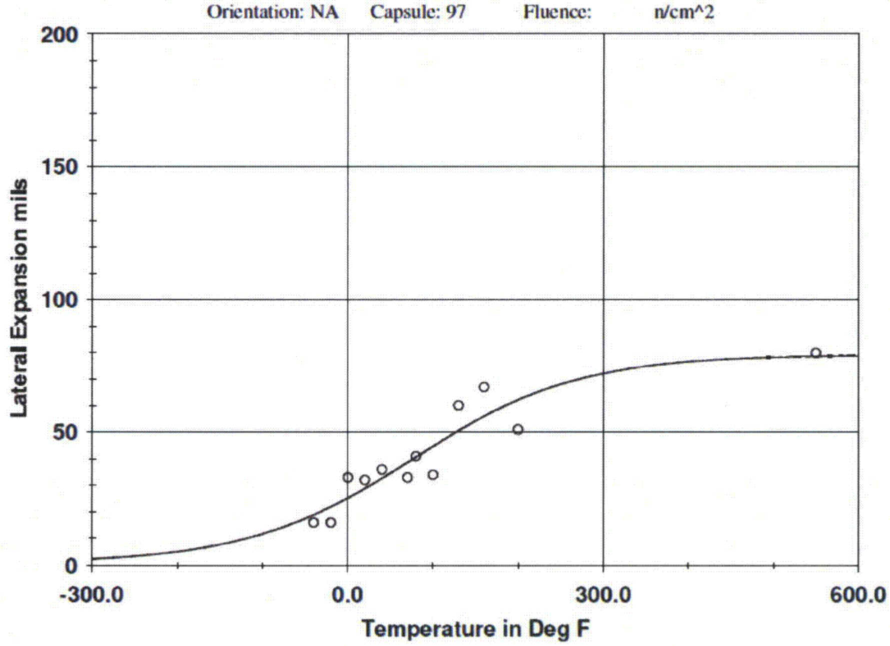
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=79.3 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=51.6 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: NA Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-40.00	16.00	18.93	-2.93
-20.00	16.00	21.96	-5.96
.00	33.00	25.29	7.71
20.00	32.00	28.89	3.11
40.00	36.00	32.72	3.28
70.00	33.00	38.72	-5.72
80.00	41.00	40.75	.25
100.00	34.00	44.79	-10.79
130.00	60.00	50.64	9.36

CAPSULE 97° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
160.00	67.00	56.03	10.97
200.00	51.00	62.21	-11.21
550.00	80.00	78.76	1.24

Correlation Coefficient = .925

CAPSULE 97° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 08/04/2010 01:36 PM

Page 1

Coefficients of Curve 1

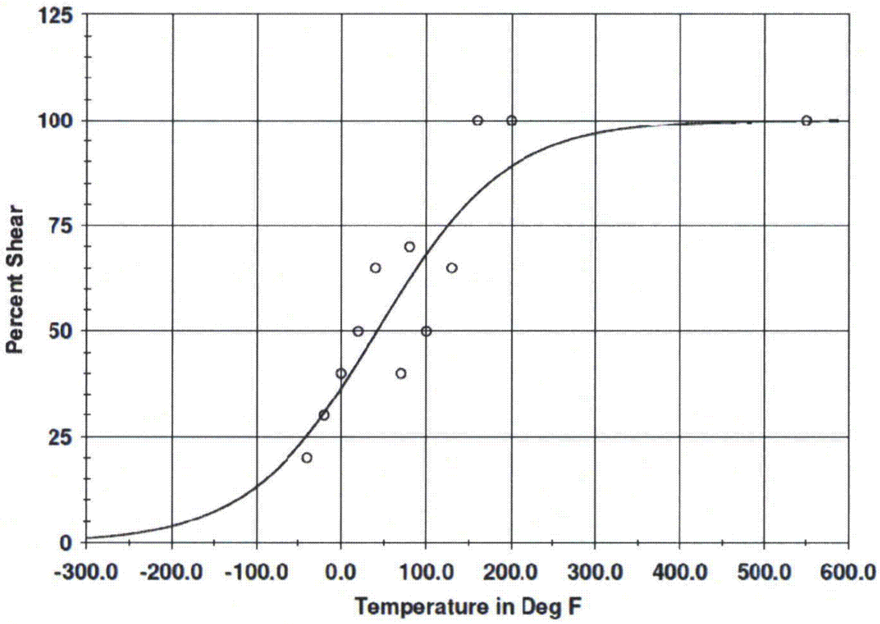
A = 50. B = 50. C = 151.14 T0 = 41.78 D = 0.00E+00

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

Temperature at 50% Shear = 41.8

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: NA Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40.00	20.00	25.31	-5.31
-20.00	30.00	30.63	-.63
.00	40.00	36.52	3.48
20.00	50.00	42.84	7.16
40.00	65.00	49.41	15.59
70.00	40.00	59.23	-19.23
80.00	70.00	62.38	7.62
100.00	50.00	68.36	-18.36
130.00	65.00	76.27	-11.27

CAPSULE 97° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
160.00	100.00	82.70	17.30
200.00	100.00	89.03	10.97
550.00	100.00	99.88	.12

Correlation Coefficient = .898

CAPSULE 284° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 07:51 AM

Page 1

Coefficients of Curve 1

A = 52.75 B = 50.55 C = 99.35 T0 = 152.89 D = 0.00E+00

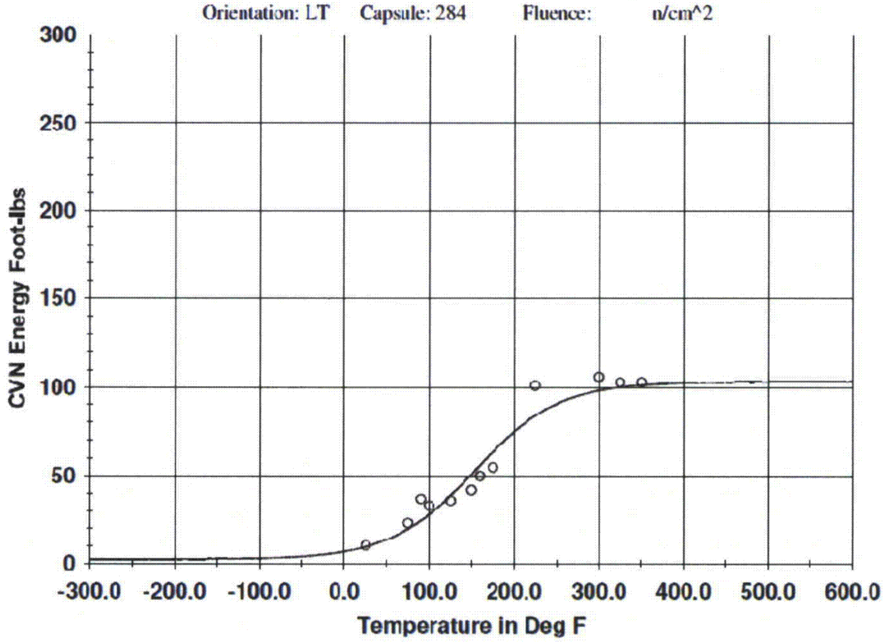
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=103.3(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=104.8 Deg F Temp@50 ft-lbs=147.5 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: LT Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
25.00	10.00	9.36	.64
75.00	23.00	19.64	3.36
90.00	37.00	24.43	12.57
100.00	33.00	28.12	4.88
125.00	36.00	38.92	-2.92
150.00	42.00	51.28	9.28
160.00	50.00	56.36	-6.36
175.00	55.00	63.82	-8.82
225.00	101.00	84.11	16.89

CAPSULE 284° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 284 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
300.00	106.00	98.33	7.67
325.00	103.00	100.23	2.77
350.00	103.00	101.42	1.58

Correlation Coefficient = .974

CAPSULE 284° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 07:55 AM

Page 1

Coefficients of Curve 1

A = 44.85 B = 43.85 C = 121.84 T0 = 150.31 D = 0.00E+00

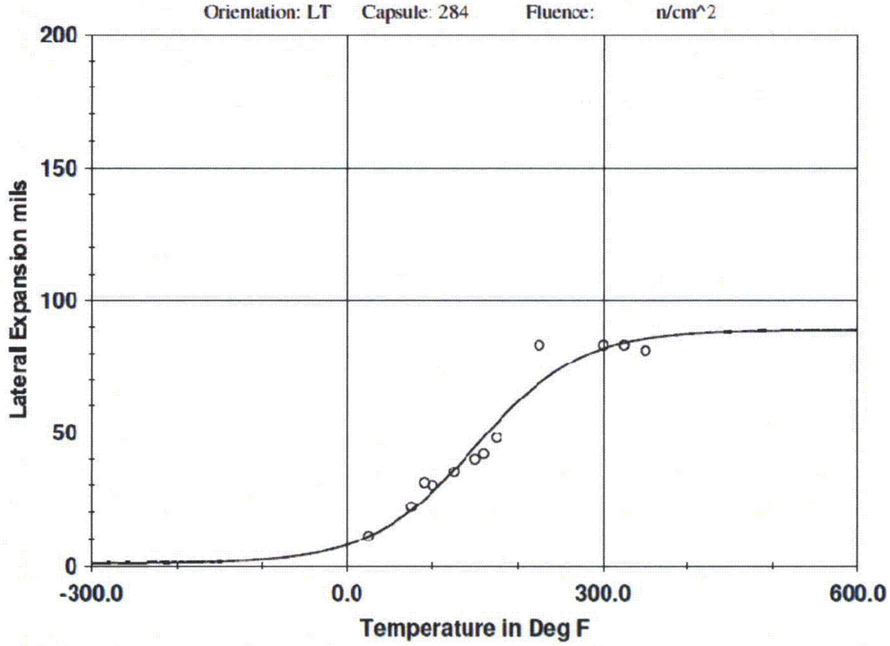
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=88.7 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=122.5 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: LT Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
25.00	11.00	10.94	.06
75.00	22.00	20.74	1.26
90.00	31.00	24.76	6.24
100.00	30.00	27.71	2.29
125.00	35.00	35.87	-.87
150.00	40.00	44.74	-4.74
160.00	42.00	48.33	-6.33
175.00	48.00	53.62	-5.62
225.00	83.00	68.80	14.20

CAPSULE 284° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 284 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
300.00	83.00	81.78	1.22
325.00	83.00	83.98	-.98
350.00	81.00	85.51	-4.51

Correlation Coefficient = .976

CAPSULE 284° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 07:58 AM

Page 1

Coefficients of Curve 1

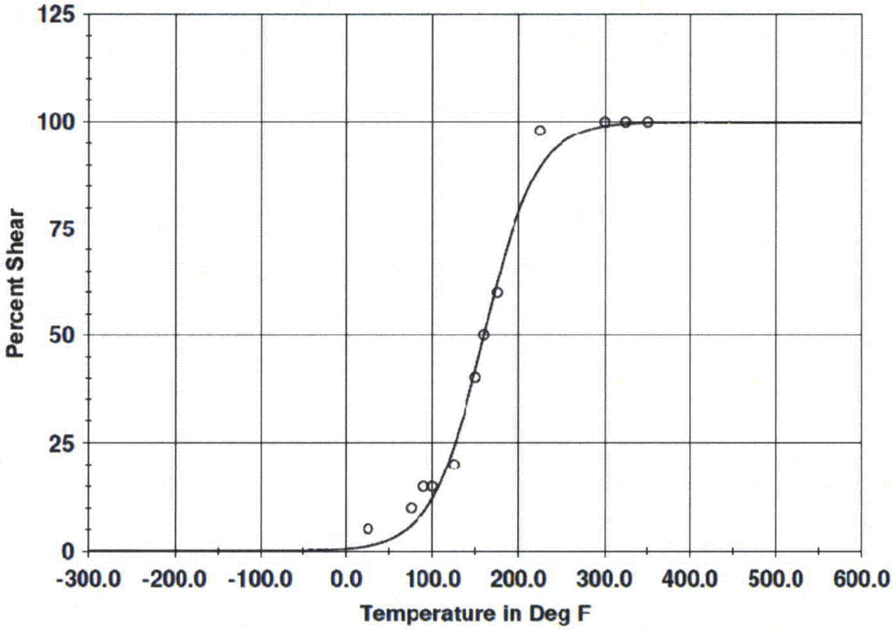
A = 50. B = 50. C = 60.81 T0 = 159.75 D = 0.00E+00

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

Temperature at 50% Shear = 159.8

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C 4441 1

Orientation: LT Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25.00	5.00	1.18	3.82
75.00	10.00	5.80	4.20
90.00	15.00	9.16	5.84
100.00	15.00	12.29	2.71
125.00	20.00	24.18	-4.18
150.00	40.00	42.05	-2.05
160.00	50.00	50.21	-.21
175.00	60.00	62.29	-2.29
225.00	98.00	89.53	8.47

CAPSULE 284° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: LT Capsule: 284 Fluence: n/cm^2

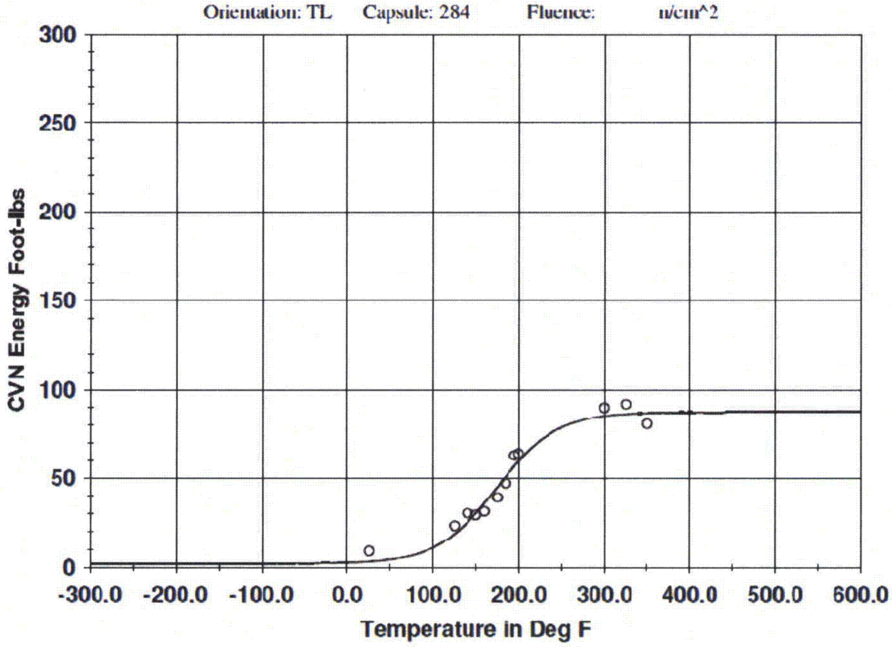
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
300.00	100.00	99.02	.98
325.00	100.00	99.57	.43
350.00	100.00	99.81	.19

Correlation Coefficient = .996

CAPSULE 284° (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 08:11 AM
Page 1
Coefficients of Curve 1
A = 44.95 B = 42.75 C = 68.72 T0 = 174.66 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=87.7(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=149.6 Deg F Temp@50 ft-lbs=182.9 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
25.00	9.00	3.28	5.72
125.00	23.00	18.51	4.49
140.00	30.00	25.05	4.95
150.00	29.00	30.24	-1.24
160.00	31.00	35.97	-4.97
175.00	39.00	45.16	-6.16
185.00	47.00	51.33	-4.33
195.00	63.00	57.25	5.75
200.00	64.00	60.04	3.96

CAPSULE 284° (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: 284 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
300.00	90.00	85.53	4.47
325.00	92.00	86.64	5.36
350.00	81.00	87.18	-6.18

Correlation Coefficient = .983

CAPSULE 284° (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 08:13 AM

Page 1

Coefficients of Curve 1

A = 38.57 B = 37.57 C = 86.47 T0 = 169.92 D = 0.00E+00

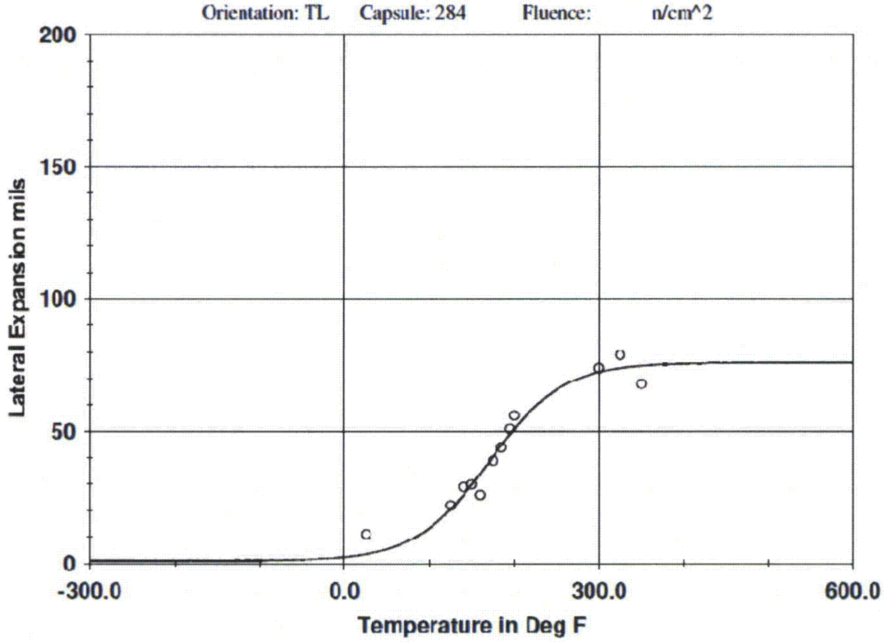
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=76.1 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=161.7 Deg F

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: TL Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
25.00	11.00	3.54	7.46
125.00	22.00	20.63	1.37
140.00	29.00	26.06	2.94
150.00	30.00	30.06	-.06
160.00	26.00	34.27	-8.27
175.00	39.00	40.77	1.77
185.00	44.00	45.05	-1.05
195.00	51.00	49.16	1.84
200.00	56.00	51.13	4.87

CAPSULE 284° (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: 284 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
300.00	74.00	72.60	1.40
325.00	79.00	74.11	4.89
350.00	68.00	74.98	-6.98

Correlation Coefficient = .979

CAPSULE 284° (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 08:15 AM

Page 1

Coefficients of Curve 1

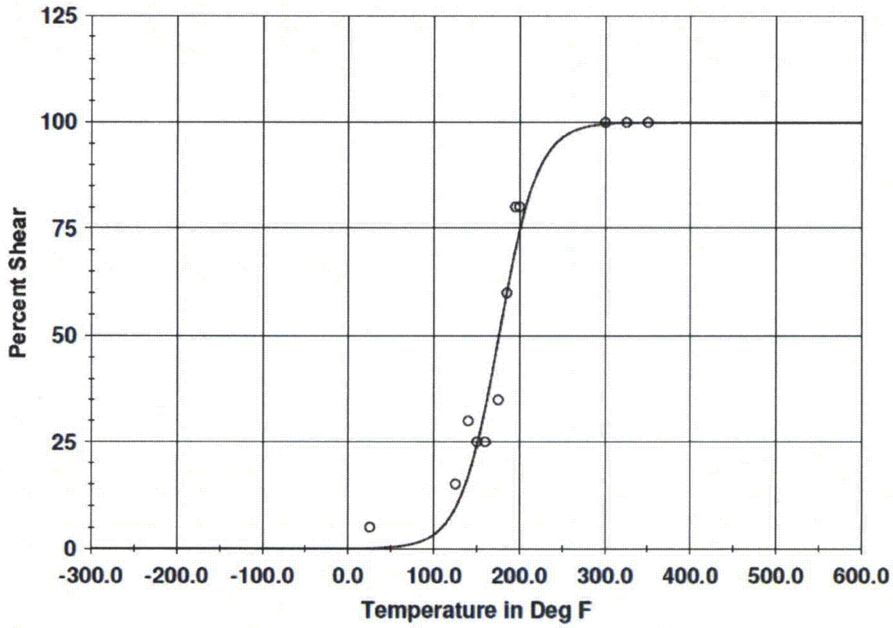
A = 50. B = 50. C = 44.93 T0 = 175.63 D = 0.00E+00

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

Temperature at 50% Shear = 175.7

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: TL Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25.00	5.00	.12	4.88
125.00	15.00	9.50	5.50
140.00	30.00	16.99	13.01
150.00	25.00	24.21	.79
160.00	25.00	33.27	-8.27
175.00	35.00	49.30	-14.30
185.00	60.00	60.28	-.28
195.00	80.00	70.31	9.69
200.00	80.00	74.74	5.26

CAPSULE 284° (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: TL Capsule: 284 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
300.00	100.00	99.61	.39
325.00	100.00	99.87	.13
350.00	100.00	99.96	.04

Correlation Coefficient = .979

CAPSULE 284° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 08:19 AM

Page 1

Coefficients of Curve 1

A = 55.1 B = 52.9 C = 104.99 T0 = 70.79 D = 0.00E+00

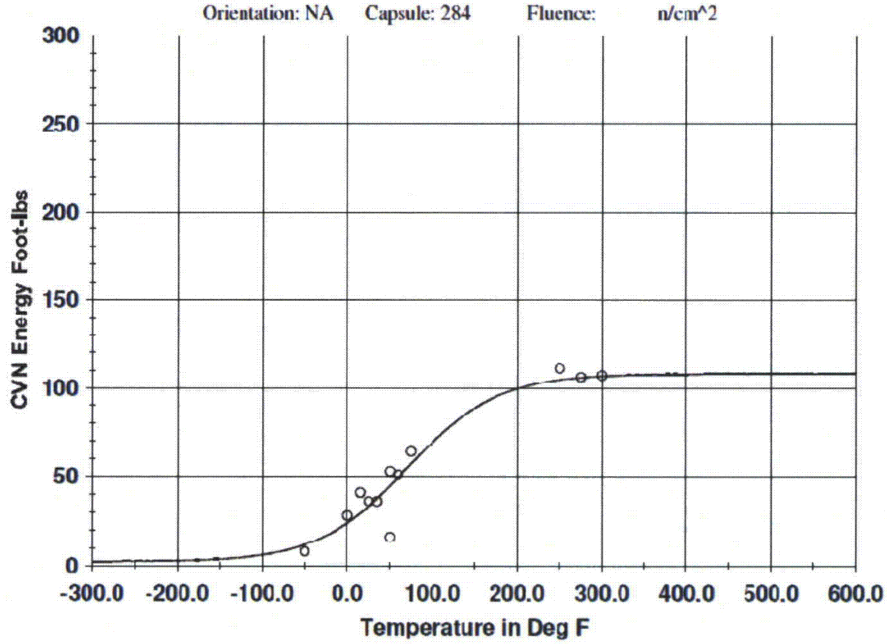
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=108.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=16.7 Deg F Temp@50 ft-lbs=60.7 Deg F

Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277

Orientation: NA Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	8.00	11.83	-3.83
.00	28.00	24.01	3.99
15.00	41.00	29.37	11.63
25.00	36.00	33.39	2.61
35.00	36.00	37.73	-1.73
50.00	16.00	44.76	28.76
50.00	53.00	44.76	8.24
60.00	51.00	49.68	1.32
75.00	64.00	57.22	6.78

CAPSULE 284° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 284 Fluence: n/cm^2

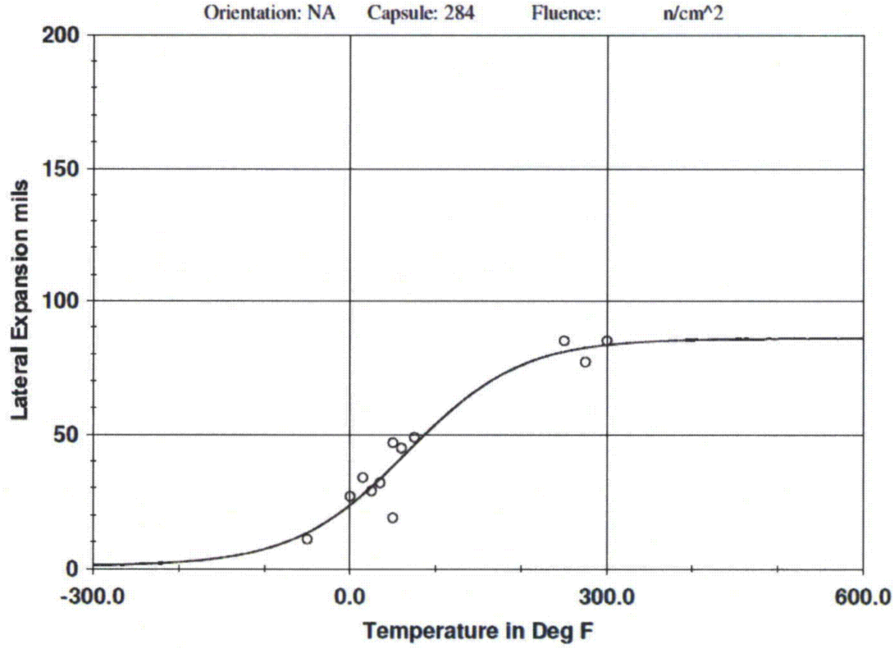
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
250.00	111.00	104.63	6.37
275.00	106.00	105.88	.12
300.00	107.00	106.67	.33

Correlation Coefficient = .958

CAPSULE 284° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 08:21 AM
Page 1
Coefficients of Curve 1
A = 43.45 B = 42.45 C = 132.17 T0 = 66.32 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=85.9 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=39.7 Deg F
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	11.00	13.46	-2.46
.00	27.00	23.77	3.23
15.00	34.00	27.75	6.25
25.00	29.00	30.59	-1.59
35.00	32.00	33.57	-1.57
50.00	19.00	38.23	-19.23
50.00	47.00	38.23	8.77
60.00	45.00	41.42	3.58
75.00	49.00	46.23	2.77

CAPSULE 284° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 284 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
250.00	85.00	80.93	4.07
275.00	77.00	82.43	-5.43
300.00	85.00	83.49	1.51

Correlation Coefficient = .958

CAPSULE 284° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 08:22 AM

Page 1

Coefficients of Curve 1

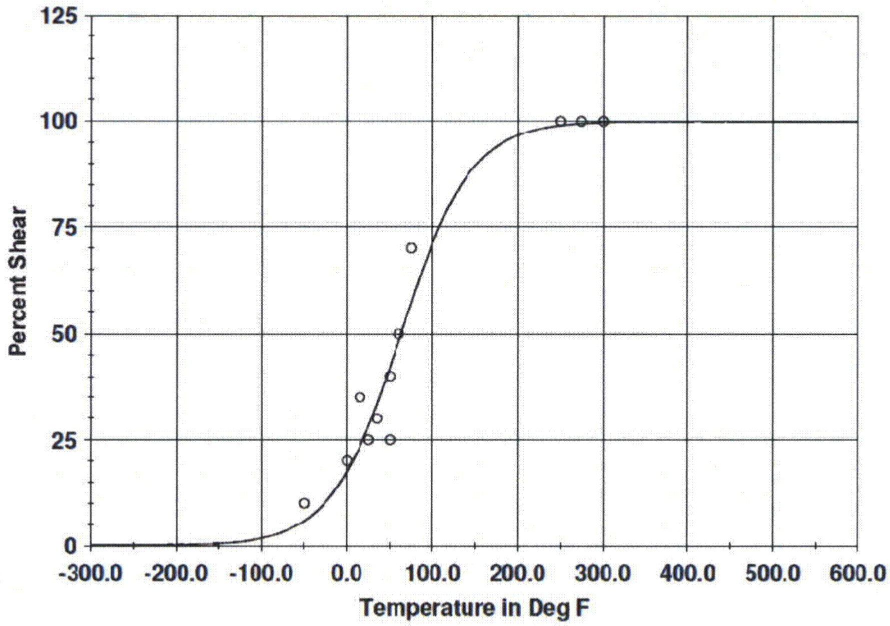
A = 50. B = 50. C = 81.33 T0 = 62.84 D = 0.00E+00

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

Temperature at 50% Shear = 62.9

Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277

Orientation: NA Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	10.00	5.87	4.13
.00	20.00	17.58	2.42
15.00	35.00	23.57	11.43
25.00	25.00	28.28	-3.28
35.00	30.00	33.52	-3.52
50.00	25.00	42.17	-17.17
50.00	40.00	42.17	-2.17
60.00	50.00	48.25	1.75
75.00	70.00	57.42	12.58

CAPSULE 284° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 1 Material: SAW Heat: 33A277
Orientation: NA Capsule: 284 Fluence: n/cm^2

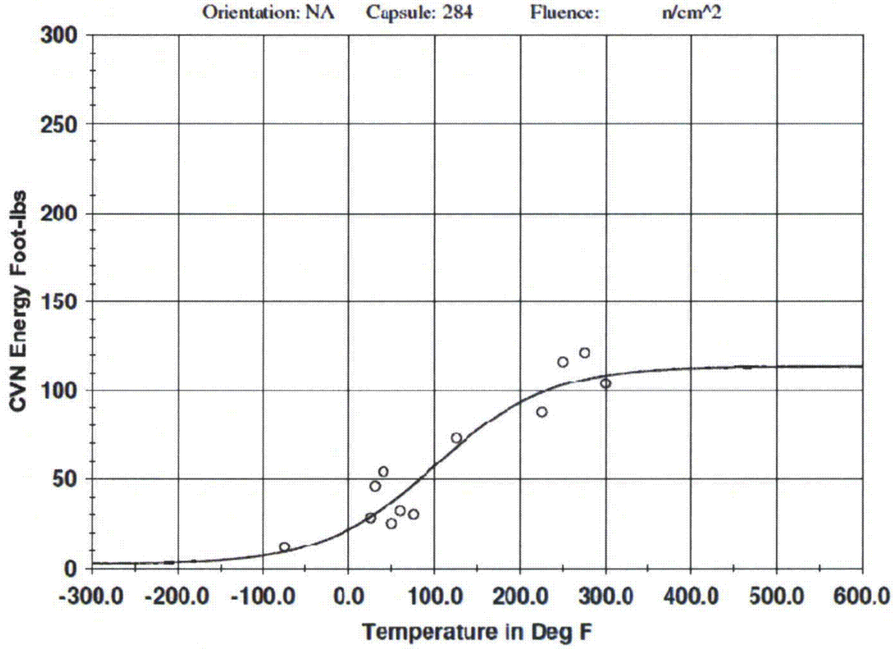
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
250.00	100.00	99.01	.99
275.00	100.00	99.46	.54
300.00	100.00	99.71	.29

Correlation Coefficient = .974

CAPSULE 284° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 08:25 AM
Page 1
Coefficients of Curve 1
A = 57.95 B = 55.75 C = 131.23 T0 = 101.06 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=113.7(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=28.8 Deg F Temp@50 ft-lbs=82.3 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-75.00	12.00	9.33	2.67
25.00	28.00	28.83	-.83
30.00	46.00	30.40	15.60
40.00	54.00	33.73	20.27
50.00	25.00	37.29	12.29
60.00	32.00	41.05	-9.05
75.00	30.00	47.02	-17.02
125.00	73.00	68.01	4.99
225.00	88.00	99.05	-11.05

CAPSULE 284° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 284 Fluence: n/cm^2

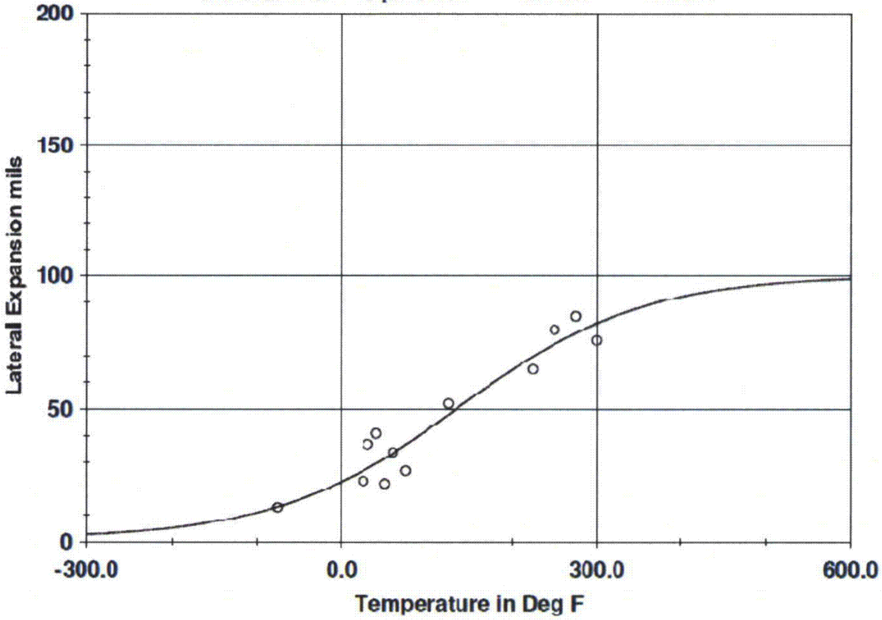
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
250.00	116.00	103.26	12.74
275.00	121.00	106.35	14.65
300.00	104.00	108.57	-4.57

Correlation Coefficient = .946

CAPSULE 284° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 08:27 AM
Page 1
Coefficients of Curve 1
A = 50.65 B = 49.65 C = 215.65 T0 = 136.34 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=100.3 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=66.0 Deg F
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-75.00	13.00	13.26	-.26
25.00	23.00	27.08	-4.08
30.00	37.00	27.98	9.02
40.00	41.00	29.84	11.16
50.00	22.00	31.77	-9.77
60.00	34.00	33.77	.23
75.00	27.00	36.90	-9.90
125.00	52.00	48.04	3.96
225.00	65.00	69.99	-4.99

CAPSULE 284° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 284 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
250.00	80.00	74.64	5.36
275.00	85.00	78.80	6.20
300.00	76.00	82.45	-6.45

Correlation Coefficient = .957

CAPSULE 284° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/17/2011 08:29 AM

Page 1

Coefficients of Curve 1

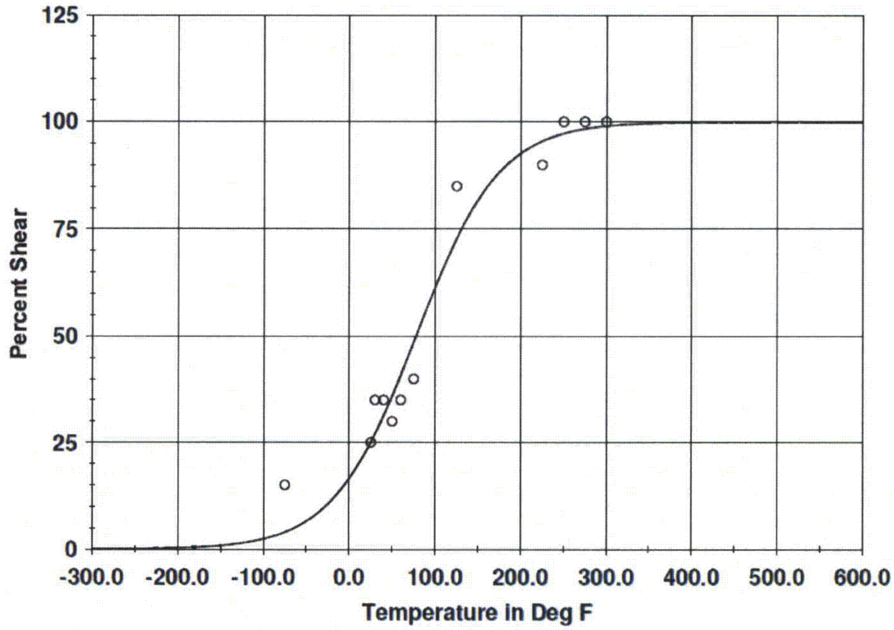
A = 50. B = 50. C = 96. T0 = 77.52 D = 0.00E+00

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

Temperature at 50% Shear = 77.6

Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1

Orientation: NA Capsule: 284 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75.00	15.00	4.00	11.00
25.00	25.00	25.08	-.08
30.00	35.00	27.09	7.91
40.00	35.00	31.39	3.61
50.00	30.00	36.04	-6.04
60.00	35.00	40.97	-5.97
75.00	40.00	48.69	-8.69
125.00	85.00	72.89	12.11
225.00	90.00	95.57	-5.57

CAPSULE 284° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 1 Material: SA533B1 Heat: C-4441-1
Orientation: NA Capsule: 284 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
250.00	100.00	97.32	2.68
275.00	100.00	98.39	1.61
300.00	100.00	99.04	.96

Correlation Coefficient = .980

APPENDIX D
CALVERT CLIFFS UNIT 1 SURVEILLANCE PROGRAM CREDIBILITY EVALUATION

D.1 INTRODUCTION

Regulatory Guide 1.99, Revision 2 [Reference 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. Position C.2 of Regulatory Guide 1.99, Revision 2, describes the method for calculating the adjusted reference temperature and Charpy upper-shelf energy of reactor vessel beltline materials using surveillance capsule data. The methods of Position C.2 can only be applied when two or more credible surveillance data sets become available from the reactor in question.

To date there have been three surveillance capsules removed from the Calvert Cliffs Unit 1 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 Calvert Cliffs Unit 1 reactor vessel surveillance data and determine whether 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" [Reference 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 Calvert Cliffs Unit 1 reactor vessel consists of the following beltline region materials:

- Intermediate Shell Plates D-7206-1, 2 and 3 (Heat # C-4351-2, C-4441-2, and C-4441-1)
- Lower Shell Plates D-7207-1, 2 and 3 (Heat # C-4420-1, B-8489-2, and B-8489-1)
- Intermediate to Lower Shell Circumferential Weld Seam 9-203 (Heat # 33A277)
- Intermediate Shell Longitudinal Weld Seams 2-203-A, B, C (Heat # 12008/20291)
- Lower Shell Longitudinal Weld Seams 3-203-A, B, C (Heat # 21935)

Per the CRVSP, Revision 5 [Reference D-3] for Calvert Cliffs, ASTM E185-70 [Reference D-4] recommended the surveillance program material be representative of the reactor vessel beltline materials. ASTM E185-70 suggested using the plate with the highest T_{NDT}, as determined by the drop-weight test, as the source for base metal and HAZ materials. Two of the Unit 1 plates (D-7207-1 and D-7206-3) had a T_{NDT} of 0°F. Therefore, the surveillance plate was chosen based on a second selection criterion: the plate with the highest temperature at the 30 ft-lb CVN energy level. Based on this criterion, Intermediate Shell Plate D-7206-3 was selected.

The surveillance weld metal was selected as the same weld wire heat/flux type combination used in Intermediate to Lower Shell Circumferential Weld 9-203. The weld wire heat/flux type combination used for surveillance welds was 33A277/1092 for Calvert Cliffs Unit 1. The selection of these weld materials was the general practice for Combustion Engineering surveillance programs because it was considered representative material. Additionally, the surveillance weld metal in the Calvert Cliffs Unit 1 surveillance program (Heat # 33A277) had the highest Cu Wt. % of all the reactor vessel beltline welds. Thus, it was chosen as the surveillance weld metal.

<u>Hence, Criterion 1 is met for the Calvert Cliffs Unit 1 surveillance program.</u>

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

Based on engineering judgment, the scatter in the data presented in these plots is small enough to permit the determination of the 30 ft-lb temperature and the upper-shelf energy of the Calvert Cliffs Unit 1 surveillance materials unambiguously. Hence, the Calvert Cliffs Unit 1 surveillance program meets this criterion.

<u>Hence, Criterion 2 is met for the Calvert Cliffs Unit 1 surveillance program.</u>

Criterion 3: *When there are two or more sets of surveillance data from one reactor, the scatter of ΔRT_{NDT} values about a best-fit line drawn as described in Regulatory Position 2.1 normally should be less than 28°F for welds and 17°F for base metal. Even if the fluence range is large (two or more orders of magnitude), the scatter should not exceed twice those values. Even if the data fail this criterion for use in shift calculations, they may be credible for determining decrease in upper-shelf energy if the upper shelf can be clearly determined, following the definition given in ASTM E185-82 [Reference D-5].*

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 the weld 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 the industry at a meeting held by the NRC on February 12 and 13, 1998 [Reference D-6]. 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 Calvert Cliffs Unit 1 surveillance plate material. The Calvert Cliffs Unit 1 surveillance weld will be evaluated for credibility using the guidance from the appropriate case as explained in Reference D-6. Each surveillance material and its respective evaluation method are described below:

1. IS Plate D-7206-3 (Case 1) – This plate material will be evaluated using the NRC Case 1 guidelines as described above.
2. Heat # 33A277 (Case 4) – This weld heat pertains to IS to LS Circumferential Weld 9-203 in the Calvert Cliffs Unit 1 reactor vessel. This weld heat is contained in the Calvert Cliffs Unit 1 surveillance program as well as the Farley Unit 1 surveillance program. NRC Case 4 per Reference D-6 is entitled "Surveillance Data from Plant and Other Sources" and most closely represents the situation for Calvert Cliffs Unit 1 weld Heat # 33A277.

Case 1: IS Plate D-7206-3 and

Case 4: Weld Heat # 33A277 (Calvert Cliffs Unit 1 data only)

Following the NRC Case 1 and Case 4 guidelines, the Calvert Cliffs Unit 1 surveillance plate and weld metal (Heat # 33A277) will be evaluated using Calvert Cliffs Unit 1 data only. This evaluation is contained in Table D-1.

Table D-1 Calculation of Interim Chemistry Factors for the Credibility Evaluation Using Calvert Cliffs Unit 1 Surveillance Capsule Data Only

Material	Capsule	Capsule f [(a)] ($x\ 10^{19}$ n/cm^2, E > 1.0 MeV)	FF[(b)]	ΔRT_{NDT}[(c)] (°F)	FF*ΔRT_{NDT} (°F)	FF^2
Intermediate Shell Plate D-7206-3 (Longitudinal)	263°	0.505	0.809	65.8	53.25	0.655
	97°	1.94	1.181	111.1	131.22	1.395
	284°	2.33	1.228	98.6	121.13	1.509
Intermediate Shell Plate D-7206-3 (Transverse)	97°	1.94	1.181	109.5	129.33	1.395
	284°	2.33	1.228	127.0	156.02	1.509
				SUM:	590.96	6.463
	$CF_{D-7206-3} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (590.96) \div (6.463) =$ **91.4°F**					
Calvert Cliffs Unit 1 Weld Metal (Heat # 33A277)	263°	0.505	0.809	50.4	40.79	0.655
	97°	1.94	1.181	104.5	123.43	1.395
	284°	2.33	1.228	78.0	95.82	1.509
				SUM :	260.04	3.559
	$CF_{Heat\ \#\ 33A277} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (260.04) \div (3.559) =$ **73.1°F**					

Notes:

(a) f = capsule fluence taken from Table 7-1 of this report.

(b) FF = fluence factor = $f^{(0.28 - 0.10 * \log f)}$.

(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values taken from Section 5 of this report. The measured ΔRT_{NDT} values for the surveillance weld metal do not include the adjustment ratio procedure of Reg. Guide 1.99, Revision 2, Position 2.1 since this calculation is based on the actual surveillance weld metal measured shift values. In addition, only Calvert Cliffs Unit 1 data is being considered; therefore, no temperature adjustment is required.

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 Best-Fit Evaluation for Calvert Cliffs Unit 1 Surveillance Materials Only

Material	Capsule	CF (Slope$_{best-fit}$) (°F)	Capsule Fluence (x10^{19} n/cm^2)	FF	Measured $\Delta RT_{NDT}$$^{(a)}$ (°F)	Predicted $\Delta RT_{NDT}$$^{(b)}$ (°F)	Residual $\Delta RT_{NDT}$$^{(c)}$ (°F)	<17°F (Base Metal) <28°F (Weld)
Intermediate Shell Plate D-7206-3 (Longitudinal)	263°	91.4	0.505	0.809	65.8	74.0	8.2	Yes
	97°	91.4	1.94	1.181	111.1	108.0	3.1	Yes
	284°	91.4	2.33	1.228	98.6	112.3	13.7	Yes
Intermediate Shell Plate D-7206-3 (Transverse)	97°	91.4	1.94	1.181	109.5	108.0	1.5	Yes
	284°	91.4	2.33	1.228	127.0	112.3	14.7	Yes
Calvert Cliffs Unit 1 Weld Metal (Heat # 33A277)	263°	73.1	0.505	0.809	50.4	59.1	8.7	Yes
	97°	73.1	1.94	1.181	104.5	86.3	18.2	Yes
	284°	73.1	2.33	1.228	78.0	89.8	11.8	Yes

Notes:

(a) Measured ΔRT_{NDT} values are taken from Table D-1.

(b) Predicted $\Delta RT_{NDT} = CF_{best-fit} * FF$.

(c) Residual ΔRT_{NDT} = Absolute Value [Predicted ΔRT_{NDT} – Measured ΔRT_{NDT}].

The scatter of ΔRT_{NDT} values about the best-fit line, drawn as described in Regulatory Guide 1.99, Revision 2, Position 2.1, should be less than 17°F for base metal. Table D-2 indicates that all five surveillance data points fall within the +/- 1σ of 17°F scatter band for surveillance base metals; therefore, the IS Plate D-7206-3 data is deemed "credible" per the third criterion.

The scatter of ΔRT_{NDT} values about the best-fit line, drawn as described in Regulatory Guide 1.99, Revision 2, Position 2.1, should be less than 28°F for weld metal. Table D-2 indicates that all three surveillance data points fall within the +/- 1σ of 28°F scatter band for surveillance weld materials; therefore, the weld material (Heat # 33A277) is deemed "credible" per the third criterion when only the Calvert Cliffs Unit 1 data is considered.

Hence, Criterion 3 is met for the Calvert Cliffs Unit 1 surveillance plate material. Criterion 3 is also met for the surveillance weld metal when only Calvert Cliffs Unit 1 data is considered. In accordance with Case 4 of the NRC Credibility Guidelines, the surveillance weld metal will now also be evaluated including the Farley Unit 1 surveillance data to determine if it remains credible when considering all available data.

Case 4: Weld Heat # 33A277 (All data)

In accordance with the NRC Case 4 guidelines, the data from Calvert Cliffs Unit 1 and Farley Unit 1 will now be analyzed together. Data is adjusted to the mean chemical composition and operating temperature of the surveillance capsules. This is performed in Table D-3 below:

Table D-3 Mean Chemical Composition and Operating Temperature for Calvert Cliffs Unit 1 and Farley Unit 1

Material	Capsule	Cu Wt. %	Ni Wt. %	Inlet Temperature during Period of Irradiation (°F)
Weld Metal Heat # 33A277 (Calvert Cliffs Unit 1 data)	263°	0.18	0.16	548.00
	97°	0.18	0.16	548.00
	284°	0.18	0.16	548.00
Weld Metal Heat # 33A277 (Farley Unit 1 data)	Y	0.14	0.19	544.00
	U	0.14	0.19	540.25
	X	0.14	0.19	540.86
	W	0.14	0.19	541.75
	V	0.14	0.19	541.72
	Z	0.14	0.19	541.43
MEAN		0.15	0.18	543.78

Therefore, the Calvert Cliffs Unit 1 and Farley Unit 1 surveillance capsule data will be adjusted to the mean chemical composition and operating temperature calculated in Table D-3.

Calvert Cliffs Unit 1 data

CF_{Mean} = 82.2°F (calculated per Table 1 of Regulatory Guide 1.99, Revision 2 using Cu Wt. % = 0.15 and Ni Wt. % = 0.18 per Table D-3)

$CF_{Surv.\ Weld\ (Calvert\ Cliffs\ Unit\ 1)}$ = 91.8°F (calculated per Table 1 of Regulatory Guide 1.99, Revision 2 using Cu Wt. % = 0.18 and Ni Wt. % = 0.16 per Reference D-3)

Ratio = 82.2 ÷ 91.8 = 0.90 (applied to Calvert Cliffs Unit 1 surveillance data for weld Heat # 33A277 in the credibility evaluation)

Farley Unit 1 data

CF_{Mean} = 82.2°F

$CF_{Surv.\ Weld\ (Farley\ Unit\ 1)}$ = 78.1°F (calculated per Table 1 of Regulatory Guide 1.99, Revision 2 using Cu Wt. % = 0.14 and Ni Wt. % = 0.19 per Reference D-8)

Ratio = 82.2 ÷ 78.1 = 1.05 (applied to Farley Unit 1 surveillance data for weld Heat # 33A277 in the credibility evaluation)

The capsule-specific temperature adjustments are as shown in Table D-4 below:

Table D-4 Operating Temperature Adjustments for the Calvert Cliffs Unit 1 and Farley Unit 1 Surveillance Capsule Data

Material	Capsule	Inlet Temperature during Period of Irradiation (°F)	Mean Operating Temperature (°F)	Temperature Adjustment (°F)
Weld Metal Heat # 33A277 (Calvert Cliffs Unit 1 data)	263°	548.00	543.78	+4.22
	97°	548.00	543.78	+4.22
	284°	548.00	543.78	+4.22
Weld Metal Heat # 33A277 (Farley Unit 1 data)	Y	544.00	543.78	+0.22
	U	540.25	543.78	-3.53
	X	540.86	543.78	-2.92
	W	541.75	543.78	-2.03
	V	541.72	543.78	-2.06
	Z	541.43	543.78	-2.35

Using the chemical composition and operating temperature adjustments described and calculated above, an interim chemistry factor is calculated for weld Heat # 33A277 using the Calvert Cliffs Unit 1 and Farley Unit 1 data. This calculation is shown in Table D-5 below.

Table D-5 Calculation of Weld Heat # 33A277 Interim Chemistry Factor for the Credibility Evaluation Using Farley Unit 1 and Calvert Cliffs Unit 1 Surveillance Capsule Data

Material	Capsule	Capsule f[a] ($x10^{19}$ n/cm^2, E > 1.0 MeV)	FF[b]	ΔRT_{NDT}[c] (°F)	FF*ΔRT_{NDT} (°F)	FF^2
Weld Metal Heat # 33A277 (Calvert Cliffs Unit 1 data)	263°	0.505	0.809	49.2 (50.4)	39.78	0.655
	97°	1.94	1.181	97.8 (104.5)	115.57	1.395
	284°	2.33	1.228	74.0 (78.0)	90.90	1.509
Weld Metal Heat # 33A277 (Farley Unit 1 data)	Y	0.612	0.862	70.5 (66.9)	60.78	0.744
	U	1.73	1.151	75.1 (75.1)	86.48	1.324
	X	3.06	1.295	88.7 (87.4)	114.91	1.678
	W	4.75	1.392	101.1 (98.3)	140.72	1.938
	V	7.14	1.466	121.2 (117.5)	177.71	2.149
	Z	8.47	1.492	116.7 (113.5)	174.10	2.225
				SUM :	1000.96	13.62
	$CF_{Heat\ \#\ 33A277} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (1000.96) \div (13.62) =$ **73.5°F**					

Notes:

(a) f = capsule fluence taken from Table 7-1 and Reference D-8 for Calvert Cliffs Unit 1 and Farley Unit 1, respectively.

(b) FF = fluence factor = $f^{(0.28 - 0.10*\log f)}$.

(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values. Pre-adjusted values are taken from Section 5 of this report and Reference D-3 for Calvert Cliffs Unit 1 and Farley Unit 1, respectively. ΔRT_{NDT} values for the surveillance weld data are adjusted first by the difference in operating temperature then by using the ratio procedure to account for differences in the surveillance weld chemistry and the mean chemical composition (pre-adjusted values are listed in parentheses). The temperature adjustments are shown in Table D-4 of this report. The ratios applied are 0.90 and 1.05 for Calvert Cliffs Unit 1 and Farley Unit 1, respectively.

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-6.

Table D-6 Best-Fit Evaluation for Surveillance Weld Metal Heat # 33A277 Using Calvert Cliffs Unit 1 and Farley Unit 1 Data

Material	Capsule	CF ($Slope_{best-fit}$) (°F)	Capsule f ($x10^{19}$ n/cm², E > 1.0 MeV)	FF	Measured ΔRT_{NDT}[a] (°F)	Predicted ΔRT_{NDT}[b] (°F)	Residual ΔRT_{NDT}[c] (°F)	<28°F (Weld)
Weld Metal Heat # 33A277 (Calvert Cliffs Unit 1 data)	263°	73.5	0.505	0.809	49.2	59.5	10.3	Yes
	97°	73.5	1.94	1.181	97.8	86.8	11.0	Yes
	284°	73.5	2.33	1.228	74.0	90.3	16.3	Yes
Weld Metal Heat # 33A277 (Farley Unit 1 data)	Y	73.5	0.612	0.862	70.5	63.4	7.1	Yes
	U	73.5	1.73	1.151	75.1	84.6	9.4	Yes
	X	73.5	3.06	1.295	88.7	95.2	6.5	Yes
	W	73.5	4.75	1.392	101.1	102.3	1.2	Yes
	V	73.5	7.14	1.466	121.2	107.8	13.5	Yes
	Z	73.5	8.47	1.492	116.7	109.6	7.1	Yes

Notes:

(a) ΔRT_{NDT} values are the adjusted values taken from Table D-5.

(b) Predicted $\Delta RT_{NDT} = CF_{best-fit} * FF$.

(c) Residual ΔRT_{NDT} = Absolute Value [Predicted ΔRT_{NDT} – Measured ΔRT_{NDT}].

The scatter of ΔRT_{NDT} values about the best-fit line, drawn as described in Regulatory Guide 1.99, Revision 2, Position 2.1, should be less than 28°F for weld metal. Table D-6 indicates that 100% (nine out of nine) of the surveillance data points fall within the +/- 1σ of 28°F scatter band for surveillance weld materials. Therefore, the surveillance weld material (Heat # 33A277) is deemed "credible" per the third criterion when all available data is considered.

In conclusion, the combined surveillance data from Calvert Cliffs Unit 1 and Farley Unit 1 for weld Heat # 33A277 may be applied to the Calvert Cliffs Unit 1 reactor vessel weld. The chemistry factor calculation as applicable to the Calvert Cliffs Unit 1 reactor vessel weld is contained in Appendix F of this report.

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 Calvert Cliffs Unit 1 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 Calvert Cliffs Unit 1 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 [Reference D-7] 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 value for Capsule 263° as documented herein, nor does it consider the updated ΔRT_{NDT} as determined by CVGraph. Thus, Table D-7 contains an updated calculation of Residual vs. Fast fluence, considering the recalculated capsule fluence and ΔRT_{NDT} value for Capsule 263°.

Table D-7 Calculation of Residual vs. Fast Fluence for Calvert Cliffs Unit 1

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°	0.505	0.809	99.8	110.15	-10.3

Notes:

(a) Measured ΔT_{30} values for the SRM were taken from Section 5 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 = Measured Shift – RG 1.99 Shift.

Table D-7 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 Calvert Cliffs Unit 1 surveillance program.

D.3 CONCLUSION

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B, the Calvert Cliffs Unit 1 surveillance data is deemed credible for both the surveillance plate and weld specimens.

D.4 REFERENCES

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

D-2 10 CFR 50, Appendix G, *Fracture Toughness Requirements*, Federal Register, Volume 60, No. 243, December 19, 1995.

D-3 *Comprehensive Reactor Vessel Surveillance Program*, Revision 5, W. A. Pavinich, July 2009.

D-4 ASTM E185-70, *Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels*, American Society of Testing and Materials, Philadelphia, PA, 1970.

D-5 ASTM E185-82, Annual Book of ASTM Standards, Section 12, Volume 12.02, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels*.

D-6 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-7 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.

D-8 WCAP-16964-NP, Revision 0, *Analysis of Capsule Z from the Southern Nuclear Operating Company Joseph M. Farley Unit 1 Reactor Vessel Radiation Surveillance Program*, J. M. Conermann and M. A. Hunter, October 2008.

APPENDIX E
CALVERT CLIFFS UNIT 1 UPPER-SHELF ENERGY EVALUATION

Per Regulatory Guide 1.99, Revision 2 [Reference 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-life) and 48 EFPY (end-of-life-extension) 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 and 48 EFPY.

The Calvert Cliffs Unit 1 reactor vessel beltline region minimum thickness is 8.625 inches. Calculation of the 1/4T vessel surface fluence values at 32 and 48 EFPY for the beltline materials is shown as follows:

Maximum Vessel Fluence @ 32 EFPY = 2.73×10^{19} n/cm^2 (E > 1.0 MeV)

1/4T Fluence @ 32 EFPY = $(2.73 \times 10^{19} \text{ n/cm}^2) * e^{(-0.24 * (8.625/4))}$

= 1.627×10^{19} n/cm^2 (E > 1.0 MeV)

Maximum Vessel Fluence @ 48 EFPY = 3.86×10^{19} n/cm^2 (E > 1.0 MeV)

1/4T Fluence @ 48 EFPY = $(3.86 \times 10^{19} \text{ n/cm}^2) * e^{(-0.24 * (8.625/4))}$

= 2.301×10^{19} n/cm^2 (E > 1.0 MeV)

The following pages present the Calvert Cliffs Unit 1 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 (end-of-life). Table E-2 provides the predicted upper-shelf energy values for 48 EFPY (end-of-life-extension).

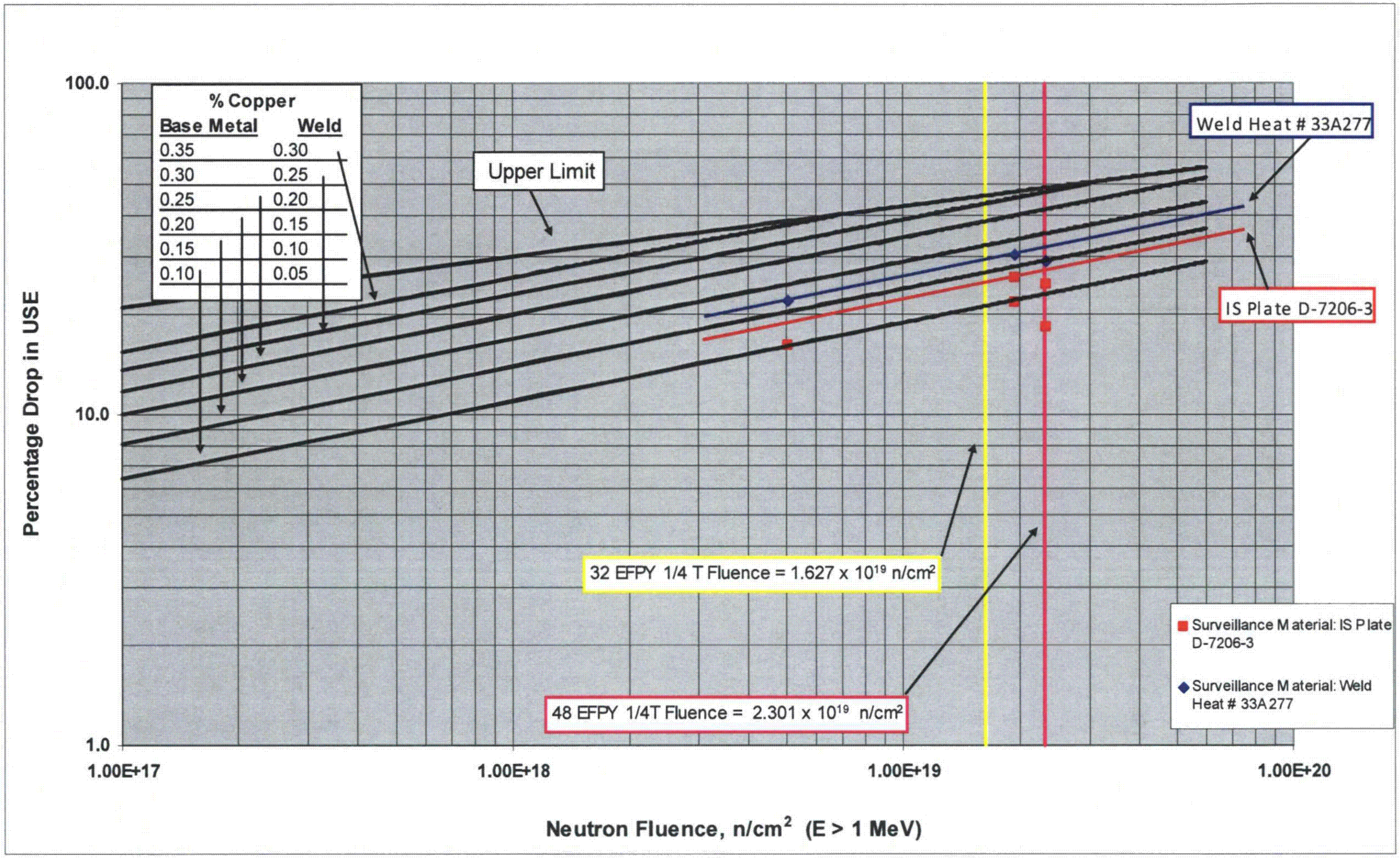


Figure E-1 **Regulatory Guide 1.99, Revision 2 Predicted Decrease in Upper-Shelf Energy as a Function of Copper and Fluence**

Table E-1 Predicted Positions 1.2 and 2.2 Upper-Shelf Energy Values at 32 EFPY

Material	Weight % of Cu	1/4T EOL Fluence[a] ($x10^{19}$ n/cm^2, E > 1.0 MeV)	Unirradiated USE (ft-lb)	Projected USE Decrease (%)	Projected EOL USE (ft-lb)
Position 1.2[b]					
Intermediate Shell Plate D-7206-1	0.11	1.627	90	27	65.7
Intermediate Shell Plate D-7206-2	0.12	1.627	81	27	59.1
Intermediate Shell Plate D-7206-3	0.12	1.627	112	27	81.8
Lower Shell Plate D-7207-1	0.13	1.627	77	27	56.2
Lower Shell Plate D-7207-2	0.12	1.627	90	27	65.7
Lower Shell Plate D-7207-3	0.11	1.627	81	27	59.1
Intermediate Shell Long. Welds 2-203-A, B, C	0.22	1.627	110	44	61.6
Intermediate to Lower Shell Circ. Weld 9-203	0.24	1.627	160	44	89.6
Lower Shell Long. Welds 3-203-A, B, C	0.18	1.627	109	38.5	67.0
Position 2.2[c]					
Intermediate Shell Plate D-7206-3[d]	0.12	1.627	112	25	84.0
Intermediate to Lower Shell Circ. Weld 9-203[d]	0.24	1.627	160	29.5	112.8

Notes:

(a) The fluence values listed pertain to the maximum vessel fluence value at 32 EFPY, though the longitudinal welds vary in location.

(b) Percent USE decrease values were calculated using Figure 2 of Regulatory Guide 1.99, and the fluence and Cu wt. % values for each material. The Cu wt. % values were conservatively rounded up to the next highest line for each plate and weld material, respectively. The percent USE drop of the plates was calculated on the 0.15 Cu wt. % base metal line. The percent USE drop of the Intermediate Shell Longitudinal Welds and the Intermediate to Lower Shell Circ. Weld was calculated on the 0.25 Cu wt. % weld line. The percent USE drop of the Lower Shell Longitudinal Welds was calculated on the 0.20 Cu wt. % weld line.

(c) 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.

(d) The most limiting surveillance data point for Intermediate Shell Plate D-7206-3 is a measured decrease of 26% at a fluence of 1.94 x 10^{19} n/cm^2 pertaining to Capsule 97° (see Table 5-10). The most limiting surveillance data point for the Intermediate to Lower Shell Circumferential Weld 9-203 is a measured decrease of 31% at a fluence of 1.94 x 10^{19} n/cm^2 pertaining to Capsule 97° (see Table 5-10).

Table E-2 Predicted Positions 1.2 and 2.2 Upper-Shelf Energy Values at 48 EFPY

Material	Weight % of Cu	1/4T EOLE Fluence(a) ($x10^{19}$ n/cm², E > 1.0 MeV)	Unirradiated USE (ft-lb)	Projected USE Decrease (%)	Projected EOLE USE (ft-lb)
Position 1.2(b)					
Intermediate Shell Plate D-7206-1	0.11	2.301	90	29.5	63.5
Intermediate Shell Plate D-7206-2	0.12	2.301	81	29.5	57.1
Intermediate Shell Plate D-7206-3	0.12	2.301	112	29.5	79.0
Lower Shell Plate D-7207-1	0.13	2.301	77	29.5	54.3
Lower Shell Plate D-7207-2	0.12	2.301	90	29.5	63.5
Lower Shell Plate D-7207-3	0.11	2.301	81	29.5	57.1
Intermediate Shell Long. Welds 2-203-A, B, C	0.22	2.301	110	48	57.2
Intermediate to Lower Shell Circ. Weld 9-203	0.24	2.301	160	48	83.2
Lower Shell Longitudinal Welds 3-203-A, B, C	0.18	2.301	109	42	63.2
Position 2.2(c)					
Intermediate Shell Plate D-7206-3(d)	0.12	2.301	112	27	81.8
Intermediate to Lower Shell Circ. Weld 9-203(d)	0.24	2.301	160	32.5	108.0

Notes:

(a) The fluence values listed pertain to the maximum vessel fluence value at 48 EFPY, though the longitudinal welds vary in location.

(b) Percent USE decrease values were calculated using Figure 2 of Regulatory Guide 1.99, and the fluence and Cu wt. % values for each material. The Cu wt. % values were conservatively rounded up to the next highest line for each plate and weld material, respectively. The percent USE drop of the plates was calculated on the 0.15 Cu wt. % base metal line. The percent USE drop of the Intermediate Shell Longitudinal Welds and the Intermediate to Lower Shell Circ. Weld was calculated on the 0.25 Cu wt. % weld line. The percent USE drop of the Lower Shell Longitudinal Welds was calculated on the 0.20 Cu wt. % weld line.

(c) 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.

(d) The most limiting surveillance data point for Intermediate Shell Plate D-7206-3 is a measured decrease of 26% at a fluence of 1.94 x 10^{19} n/cm² pertaining to Capsule 97° (See Table 5-10). The most limiting surveillance data point for the Intermediate to Lower Shell Circumferential Weld 9-203 is a measured decrease of 31% at a fluence of 1.94 x 10^{19} n/cm² pertaining to Capsule 97° (See Table 5-10).

USE Conclusion

All of the beltline materials in the Calvert Cliffs Unit 1 reactor vessel are projected to remain above the USE screening criterion value of 50 ft-lb (per 10 CFR 50, Appendix G) at 32 and 48 EFPY.

E.1 REFERENCES

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

APPENDIX F
CALVERT CLIFFS UNIT 1 PRESSURIZED THERMAL SHOCK EVALUATION

A limiting condition on reactor vessel integrity known as Pressurized Thermal Shock (PTS) may occur during a severe system transient such as a loss-of-coolant accident (LOCA) or steam line break. Such transients may challenge the integrity of the reactor vessel under the following conditions: severe overcooling of the inside surface of the vessel wall followed by high repressurization; significant degradation of vessel material toughness caused by radiation embrittlement; and the presence of a critical-size defect anywhere within the vessel wall.

In 1985, the U.S. NRC issued a formal ruling (10 CFR 50.61) on PTS [Reference F-1] that established screening criteria on reactor vessel embrittlement, as measured by the maximum reference nil-ductility transition temperature in the limiting beltline component at the end-of-life, termed RT_{PTS}. RT_{PTS} screening values were set by the U.S. NRC for beltline axial welds, forgings or plates, and for beltline circumferential weld seams for plant operation to the end of plant license. All domestic PWR vessels have been required to evaluate vessel embrittlement in accordance with the criteria through the end-of-life. The U.S. NRC revised 10 CFR 50.61 in 1991 and 1995 to change the procedure for calculating radiation embrittlement. These revisions make the procedure for calculating the reference temperature for pressurized thermal shock (RT_{PTS}) values consistent with the methods given in Regulatory Guide 1.99, Revision 2 [Reference F-2].

These accepted methods were used with the surface fluence of Section 6, the material properties (Initial RT_{NDT}, Position 1.1 Chemistry Factor values) from the CRVSP, Revision 5 [Reference F-3], and the results of this report with regards to the Position 2.1 chemistry factor values (See Table F-2) and credibility evaluation to calculate the following RT_{PTS} values for the Calvert Cliffs Unit 1 surveillance Capsule 284° materials at 32 EFPY (EOL) and 48 EFPY (EOLE). The EOL and EOLE RT_{PTS} calculations are summarized in Table F-3.

F.1 CALCULATION OF POSITION 2.1 CHEMISTRY FACTORS

Ratio Procedure

The Calvert Cliffs Unit 1 (CC-1) Position 1.1 surveillance program weld chemistry factor (91.8°F) is not identical to the vessel weld chemistry factor for the Intermediate to Lower Shell Circumferential Weld 9-203 (117.8°F) per Reference F-3. Thus, the ratio procedure of Regulatory Guide 1.99, Revision 2, Position 2.1 [Reference F-2] is applied to the surveillance data from the Calvert Cliffs Unit 1 surveillance weld (see calculation below).

$CF_{\text{CC-1 Surv Weld}}$ = 91.8°F [See Appendix D]

$CF_{\text{CC-1 Beltline Weld}}$ = 117.8°F [Reference F-3]

$$\text{Ratio} = \frac{117.8}{91.8}$$

Ratio = 1.28

The Farley Unit 1 (Far-1) Position 1.1 surveillance program weld chemistry factor (78.1°F) is also not identical to the vessel weld chemistry factor for the Intermediate to Lower Shell Circumferential Weld 9-203 (117.8°F). Thus, the ratio procedure of Regulatory Guide 1.99, Revision 2, Position 2.1 is applied to the surveillance data from the Far-1 surveillance weld (see calculation below).

$CF_{\text{Far-1 Surv. Weld}}$ = 78.1°F (See Appendix D)

$CF_{\text{CC-1 Beltline Weld}}$ = 117.8°F [Reference F-3]

$$\text{Ratio} = \frac{117.8}{78.1}$$

Ratio = 1.51

Therefore, in Table F-2, the measured ΔRT_{NDT} values for weld Heat # 33A277 from the CC-1 surveillance program will be multiplied by the ratio of 1.28 and the measured ΔRT_{NDT} from the Far-1 surveillance program will be multiplied by the ratio of 1.51.

Temperature Adjustments

Calvert Cliffs Unit 1 utilizes surveillance data from a sister plant (Farley Unit 1). Therefore, temperature adjustments are required. From NRC Industry Meetings on November 12, 1997 and February 12 and 13, 1998, procedural guidelines were presented to adjust the ΔRT_{NDT} for temperature differences when using surveillance data from one reactor vessel applied to another reactor vessel. The following is taken from the handout [Reference F-4] given by the NRC at these industry meetings:

Studies have shown that for temperatures near 550°F, a 1°F decrease in irradiation temperature will result in approximately a 1°F increase in ΔRT_{NDT}.

Thus, for plants that use surveillance data from other reactor vessels that operate at different temperatures or when the capsule is at a different temperature than the plant, this difference must be considered.

The temperature adjustment is as follows:

$$\text{Temp. Adjusted } \Delta RT_{NDT} = \Delta RT_{NDT,\ Measured} + (T_{capsule} - T_{plant})$$

The Far-1 capsule irradiation temperatures ($T_{capsule}$) and measured ΔRT_{NDT} values are taken from Reference F-3 (see also Appendix D). The CC-1 capsules were irradiated to 548°F (T_{Plant}). Table F-1 gives a summary of the temperature adjustments of the Far-1 surveillance data that will be used in Table F-2 to calculate the Position 2.1 chemistry factor value for weld Heat # 33A277. A sample calculation of adjusted ΔRT_{NDT} (for chemistry and temperature) for Far-1 Capsule Y will be shown here.

<u>Temperature Adjustment Procedure</u>

$T_{capsule}$	= 544°F
T_{Plant}	= 548°F
$\Delta RT_{NDT,\ Measured}$	= 66.9°F
Temp. Adjusted ΔRT_{NDT}	= 66.9°F + (544°F - 548°F)
	= 62.9°F

<u>Ratio Procedure</u>

Temp. Adjusted ΔRT_{NDT}	= 62.9°F
Ratio	= 1.51
Chemistry-Adjusted ΔRT_{NDT}	= 1.51 * 62.9°F
	= 95.0°F

The remaining Far-1 measured ΔRT_{NDT} values were adjusted in the same fashion and are shown in Table F-2 (unadjusted ΔRT_{NDT} values are included in parentheses). No temperature adjustments were required for the CC-1 data because the capsules were irradiated at the same temperature as the plant.

Table F-1 Calculation of the Temperature Adjustments for the Farley Unit 1 Surveillance Capsule Data Applicable to Calvert Cliffs Unit 1

Material	Capsule	Inlet Temperature during Period of Irradiation ($T_{Capsule}$) (°F)	Calvert Cliffs Unit 1 Inlet Temperature (T_{Plant}) (°F)	Temperature Adjustment (°F)
Weld Metal Heat # 33A277 (Farley Unit 1 data)	Y	544.00	548	-4.00
	U	540.25		-7.75
	X	540.86		-7.14
	W	541.75		-6.25
	V	541.72		-6.28
	Z	541.43		-6.57

Table F-2 Calculation of Chemistry Factors for Calvert Cliffs Unit 1 using Surveillance Capsule Data

Material	Capsule	Capsule Fluence (a) (x 10^{19} n/cm^2, E > 1.0 MeV)	FF(b)	ΔRT_{NDT}(c) (°F)	FF*ΔRT_{NDT} (°F)	FF^2
Intermediate Shell Plate D-7206-3 (Longitudinal)	263°	0.505	0.809	65.8	53.25	0.655
	97°	1.94	1.181	111.1	131.22	1.395
	284°	2.33	1.228	98.6	121.13	1.509
Intermediate Shell Plate D-7206-3 (Transverse)	97°	1.94	1.181	109.5	129.33	1.395
	284°	2.33	1.228	127.0	156.02	1.509
				SUM:	590.96	6.463
	$CF_{D\text{-}7206\text{-}3} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (590.96) \div (6.463) =$ **91.4°F**					
CC-1 Surveillance Program Weld (Heat # 33A277)	263°	0.505	0.809	64.5 (50.4)	52.21	0.655
	97°	1.94	1.181	133.8 (104.5)	157.99	1.395
	284°	2.33	1.228	99.8 (78.0)	122.65	1.509
Far-1 Surveillance Program Weld (Heat # 33A277)	Y	0.612	0.862	95.0 (66.9)	81.92	0.744
	U	1.73	1.151	101.7 (75.1)	117.03	1.324
	X	3.06	1.295	121.2 (87.4)	156.99	1.678
	W	4.75	1.392	139.0 (98.3)	193.50	1.938
	V	7.14	1.466	167.9 (117.5)	246.22	2.149
	Z	8.47	1.492	161.5 (113.5)	240.87	2.225
				SUM:	1369.38	13.618
	$CF_{Surv.\ Weld} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (1369.38) \div (13.618) =$ **100.6°F**					

Notes:

(a) The Calvert Cliffs Unit 1 calculated capsule fluence values are taken from Table 7-1 of this report. The Farley Unit 1 calculated capsule fluence values are taken from Reference F-3.

(b) FF = fluence factor = $f^{(0.28 - 0.10 * \log(f))}$.

(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values taken from Section 5 of this report for Calvert Cliffs Unit 1 and Reference F-3 for Farley Unit 1. The Farley Unit 1 ΔRT_{NDT} values for the surveillance weld data are adjusted first by the difference in operating temperature. Then, both the Calvert Cliffs Unit 1 and Farley Unit 1 values are further adjusted using the ratio procedure to account for differences in the surveillance weld chemistry and the beltline weld chemistry (pre-adjusted values are listed in parentheses). The temperature adjustments and ratios applied are as follows:

<u>Calvert Cliffs Unit 1</u> – Ratio = 1.28

<u>Farley Unit 1</u> – Ratio = 1.51, Temperature adjustments per Table F-1 (on a capsule-by-capsule basis)

F.2 RT_{PTS} CALCULATIONS

Table F-3 RT_{PTS} Calculations for the Calvert Cliffs Unit 1 Surveillance Capsule 284° Materials at 32 and 48 EFPY

Reactor Vessel Material	R.G. 1.99, Rev. 2 Position	CF[(a)] (°F)	Fluence[(b)] (n/cm², E > 1.0 MeV)	FF	IRT_{NDT} [(c)] (°F)	ΔRT_{NDT} (°F)	σ_U[(c)] (°F)	σ_Δ (°F)	Margin (°F)	RT_{PTS} (°F)
32 EFPY										
Intermediate Shell Plate D-7206-2[(d)]	1.1	83.6	2.730×10^{19}	1.2679	-30	106.0	0	17	34.0	110
	2.1	91.4	2.730×10^{19}	1.2679	-30	115.9	0	8.5[(e)]	17.0	103
Intermediate Shell Plate D-7206-3	1.1	83.6	2.730×10^{19}	1.2679	10	106.0	0	17	34.0	150
	2.1	91.4	2.730×10^{19}	1.2679	10	115.9	0	8.5[(e)]	17.0	143
Intermediate Shell to Lower Shell Circ. Weld 9-203	1.1	117.8	2.730×10^{19}	1.2679	-80	149.4	0	28	56.0	125
	2.1	100.6	2.730×10^{19}	1.2679	-80	127.5	0	14[(e)]	28.0	75
48 EFPY										
Intermediate Shell Plate D-7206-2[(d)]	1.1	83.6	3.860×10^{19}	1.3485	-30	112.7	0	17	34.0	117
	2.1	91.4	3.860×10^{19}	1.3485	-30	123.3	0	8.5[(e)]	17.0	110
Intermediate Shell Plate D-7206-3	1.1	83.6	3.860×10^{19}	1.3485	10	112.7	0	17	34.0	157
	2.1	91.4	3.860×10^{19}	1.3485	10	123.3	0	8.5[(e)]	17.0	150
Intermediate Shell to Lower Shell Circ. Weld 9-203	1.1	117.8	3.860×10^{19}	1.3485	-80	158.8	0	28	56.0	135
	2.1	100.6	3.860×10^{19}	1.3485	-80	135.6	0	14[(e)]	28.0	84

Notes:

(a) Position 1.1 Chemistry Factor values taken from Reference F-3 and Position 2.1 Chemistry Factor values taken from Table F-2.
(b) Maximum end-of-life and end-of-life-extension fluence values taken from Table 6-2 of this report.
(c) Initial RT_{NDT} values are measured and are taken from Reference F-3.
(d) Intermediate Shell Plate D-7206-2 is the same heat of material as the surveillance capsule plate material Intermediate Shell Plate D-7206-3 [Reference F-3].
(e) A reduced σ_Δ term is used since the surveillance data is deemed credible per Appendix D.

PTS Conclusion

All of the surveillance Capsule 284° materials for Calvert Cliffs Unit 1 are projected to remain below the PTS screening criterion value of 270°F for plates and 300°F for circumferential welds (per 10 CFR 50.61) at 32 and 48 EFPY.

F.3 REFERENCES

F-1 10 CFR 50.61, *Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events*, Federal Register, Volume 60, No. 243, December 19, 1995.

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

F-3 *Comprehensive Reactor Vessel Surveillance Program,* Revision 5, W. A. Pavinich, July 2009.

F-4 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.

APPENDIX G
CALVERT CLIFFS UNIT 1 PRESSURE-TEMPERATURE LIMIT CURVE APPLICABILITY CHECK

G.1 CALCULATION OF ART VALUES FOR CAPSULE MATERIALS

The adjusted reference temperature (ART) values are calculated for Calvert Cliffs Unit 1 at 48 EFPY for each reactor vessel surveillance capsule material (Intermediate Shell Plate D-7206-3 and Intermediate to Lower Shell Circ. Weld 9-203) at the 1/4T and 3/4T locations. These values, along with these materials' initial properties, are used to perform an applicability check on the current heatup and cooldown pressure-temperature (P-T) limit curves. The ART values are calculated per Regulatory Guide 1.99, Revision 2, Positions 1.1 and 2.1 [Reference G-1]. The initial properties for the Capsule 284° materials are documented in the CRVSP, Revision 5 [Reference G-2].

The Calvert Cliffs Unit 1 (CC-1) Intermediate Shell Plate D-7206-3 surveillance data has been deemed <u>credible</u> per Appendix D of this report. Therefore, when using the Intermediate Shell Plate D-7206-3 surveillance data, a reduced σ_Δ value can be used. The CC-1 Intermediate Shell to Lower Shell Circ. Weld 9-203 surveillance data has been deemed <u>credible</u> per Appendix D of this report. Therefore, when using the Intermediate to Lower Shell Circ. Weld 9-203 surveillance data, a reduced σ_Δ value can be used.

The Calvert Cliffs Unit 1 reactor vessel beltline region minimum thickness is 8.625 inches. Calculation of the 1/4T and 3/4T vessel fluence values at 48 EFPY for the beltline materials is shown as follows:

Maximum Vessel Fluence @ 48 EFPY = 3.86×10^{19} n/cm^2 (E > 1.0 MeV)

1/4T Fluence @ 48 EFPY = $(3.86 \times 10^{19}$ n/cm$^2) * e^{(-0.24 * (8.625 / 4))}$

= 2.301×10^{19} n/cm^2 (E > 1.0 MeV)

Maximum Vessel Fluence @ 48 EFPY = 3.86×10^{19} n/cm^2 (E > 1.0 MeV)

3/4T Fluence @ 48 EFPY = $(3.86 \times 10^{19}$ n/cm$^2) * e^{(-0.24 * (3*8.625 / 4))}$

= 0.817×10^{19} n/cm^2 (E > 1.0 MeV)

Tables G-1 and G-2 contain the calculations for 1/4T and 3/4T ART values for the CC-1 reactor vessel surveillance Capsule 284° materials.

Table G-1 Calculation of the Calvert Cliffs Unit 1 Reactor Vessel Surveillance Capsule Material ART Values at the 1/4T Location for 48 EFPY

Reactor Vessel Material	R.G. 1.99, Rev. 2 Position	CF[a] (°F)	1/4T Fluence (n/cm^2, E > 1.0 MeV)	FF	IRT_{NDT} [b] (°F)	ΔRT_{NDT} (°F)	σ_I [b] (°F)	σ_Δ (°F)	Margin (°F)	ART (°F)
Intermediate Shell Plate D-7206-2[c]	1.1	83.6	2.301×10^{19}	1.2252	-30	102.4	0	17	34.0	106
	2.1	91.4	2.301×10^{19}	1.2252	-30	112.0	0	8.5[d]	17.0	99
Intermediate Shell Plate D-7206-3	1.1	83.6	2.301×10^{19}	1.2252	10	102.4	0	17	34.0	146
	2.1	91.4	2.301×10^{19}	1.2252	10	112.0	0	8.5[d]	17.0	139
Intermediate Shell to Lower Shell Circ. Weld 9-203	1.1	117.8	2.301×10^{19}	1.2252	-80	144.3	0	28	56.0	120
	2.1	100.6	2.301×10^{19}	1.2252	-80	123.2	0	14[d]	28.0	71

Notes:

(a) Position 1.1 Chemistry Factor values taken from Reference G-2 and Position 2.1 Chemistry Factor values taken from Appendix F.
(b) Initial RT_{NDT} values are measured and are taken from Reference G-2.
(c) Intermediate Shell Plate D-7206-2 is the same heat of material as the surveillance capsule plate material Intermediate Shell Plate D-7206-3 [Reference G-2].
(d) A reduced σ_Δ term is used since the surveillance data is deemed credible per Appendix D.

Table G-2 Calculation of the Calvert Cliffs Unit 1 Reactor Vessel Surveillance Capsule Material ART Values at the 3/4T Location for 48 EFPY

Reactor Vessel Material	R.G. 1.99, Rev. 2 Position	CF[a] (°F)	3/4T Fluence (n/cm^2, E > 1.0 MeV)	FF	IRT_{NDT} [b] (°F)	ΔRT_{NDT} (°F)	σ_I[b] (°F)	σ_Δ (°F)	Margin (°F)	ART (°F)
Intermediate Shell Plate D-7206-2[c]	1.1	83.6	0.817×10^{19}	0.9434	-30	78.9	0	17	34.0	83
	2.1	91.4	0.817×10^{19}	0.9434	-30	86.3	0	8.5[d]	17.0	73
Intermediate Shell Plate D-7206-3	1.1	83.6	0.817×10^{19}	0.9434	10	78.9	0	17	34.0	123
	2.1	91.4	0.817×10^{19}	0.9434	10	86.3	0	8.5[d]	17.0	113
Intermediate Shell to Lower Shell Circ. Weld 9-203	1.1	117.8	0.817×10^{19}	0.9434	-80	111.1	0	28	56.0	87
	2.1	100.6	0.817×10^{19}	0.9434	-80	94.9	0	14[d]	28.0	43

Notes:

(a) Position 1.1 Chemistry Factor values taken from Reference G-2 and Position 2.1 Chemistry Factor values taken from Appendix F.
(b) Initial RT_{NDT} values are measured and are taken from Reference G-2.
(c) Intermediate Shell Plate D-7206-2 is the same heat of material as the surveillance capsule plate material Intermediate Shell Plate D-7206-3 [Reference G-2].
(d) A reduced σ_Δ term is used since the surveillance data is deemed credible per Appendix D.

G.2 P-T LIMIT CURVE APPLICABILITY

The current P-T limit curves for CC-1 are based on Lower Shell Longitudinal Welds 3-203-A, B, C [Reference G-3]. It must be ensured that the current surveillance capsule results from Capsule 284° do not invalidate the current P-T limit curves for Calvert Cliffs Unit 1. Table G-3 compares Capsule 284° materials' initial properties to the Lower Shell Longitudinal Welds 3-203-A, B, C material properties. Reference G-2 confirms that all CC-1 reactor vessel beltline materials use the same fluence value. It can be determined from the properties in Table G-3 that welds 3-203-A, B, C have more limiting material properties than the Capsule 284° materials at any fluence, as long as the fluence on each material is the same.

Table G-3 Comparison of CC-1 Surveillance Capsule 284° Materials Initial Properties to Lower Shell Long. Welds 3-203-A, B, C for P-T Limit Curve Development

Material Property	Reactor Vessel Material		
	Intermediate Shell Plate D-7206-3[a]	Intermediate Shell to Lower Shell Circ. Weld 9-203[a]	Lower Shell Long. Weld 3-203-A, B, C[b]
Initial RT_{NDT} (°F)	10	-80	-56
Margin (°F)	17	28	66
Chemistry Factor (°F)	91.4	100.6	174

Notes:

(a) Values are summarized in Tables G-1 and G-2 of this report.
(b) Values taken from WCAP-17014-NP, Revision 0 [Reference G-3].

Furthermore, the fluence value used in the current P-T limit curve analysis of record [Reference G-4] is 4.49 x 10^{19} n/cm^2 (E > 1.0 MeV). Using the updated fluence values contained in Table 6-2, the EFPY applicability term can be calculated. Using linear interpolation, the peak vessel fluence value is not projected to reach 4.49 x 10^{19} n/cm^2 (E > 1.0 MeV) until about 57 EFPY. Since the revised EFPY term for Calvert Cliffs Unit 1 is past end-of-life-extension (48 EFPY), the current P-T limit curves are projected to remain valid throughout the period of extended operation.

P-T Limit Curve Applicability Conclusion

It is concluded that Lower Shell Longitudinal Welds 3-203-A, B, C will continue to be more limiting for use in the development of the P-T limit curves. The surveillance Capsule 284° analysis does not invalidate the current P-T limit curves. Additionally, based on the fluence value used in the analysis of record for Calvert Cliffs Unit 1 and interpolation of the peak fluence values from Table 6-2, the P-T limit curves for CC-1 are predicted to remain applicable through end-of-life-extension (48 EFPY).

G.3 REFERENCES

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

G-2 *Comprehensive Reactor Vessel Surveillance Program*, Revision 5, W. A. Pavinich, July 2009.

G-3 WCAP-17014-NP, Revision 0, *Analysis of Capsule W from the McGuire Unit No. 1 Reactor Vessel Radiation Surveillance Program for the Calvert Cliffs Unit 1 Vessel Weld Metal*, C. C. Heinecke and M. A. Hunter, December 2008.

G-4 Constellation Energy Group, LLC, Letter to US NRC, *Calvert Cliffs Nuclear Power Plant Unit Nos. 1 & 2; Docket Nos. 50-317 & 50-318, License Amendment Request: Revision to Technical Specification P-T Curves*, Peter E. Katz, May 28, 2003.