ATTACHMENT (1)

WCAP-17501-NP, REVISION 0, ANALYSIS OF CAPSULE 104° FROM THE CALVERT CLIFFS UNIT NO. 2 REACTOR VESSEL RADIATION SURVEILLANCE PROGRAM

WCAP-17501-NP
Revision 0

February 2012

Analysis of Capsule 104° from the Calvert Cliffs Unit No. 2 Reactor Vessel Radiation Surveillance Program

Westinghouse

WCAP-17501-NP
Revision 0

Analysis of Capsule 104° from the Calvert Cliffs Unit No. 2 Reactor Vessel Radiation Surveillance Program

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EXECUTIVE SUMMARY

The purpose of this report is to document the testing results of surveillance Capsule 104° from Calvert Cliffs Unit 2. Capsule 104° was removed at 27.13 Effective Full Power Years, 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. All the calculations and dosimetry evaluations described in this report were based on nuclear cross-section data derived from ENDF/B-VI, and made use of the latest available calculational tools. In this document, EFPYs are expressed in terms of 2737 MWt, the reference power of the analysis, except in the case of tables with exposure cumulative parameters for which EFPY at 2700 MWt for the first seventeen cycles are also included for the purpose of direct comparison with previous documents. Capsule 104° received a fluence of 2.44 x 10^{19} n/cm^2 (E > 1.0 MeV) after irradiation to 27.13 EFPY. The peak clad/base metal interface vessel fluence after 27.13 EFPY of plant operation was 2.53 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 2 Capsule 104° are less than the Regulatory Guide 1.99, Revision 2 [Reference 1] predictions. 2) The Calvert Cliffs Unit 2 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 (52 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 (52 EFPY) as required by 10 CFR 50.61 [Reference 3]. The PTS evaluation is presented in Appendix F. 5) The Capsule 104° evaluations, material properties and fluence, did not affect the applicability of the current Calvert Cliffs Unit 2 pressure-temperature (P-T) limit curves. The current Calvert Cliffs Unit 2 P-T limit curves are now applicable through 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 104°, the third capsule removed and tested from the Calvert Cliffs Unit 2 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 104°. 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 2 capsule reports.

- Capsule 104° received an average fast neutron fluence (E > 1.0 MeV) of 2.44 x 10^{19} n/cm^2 after 27.13 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel Lower Shell Plate D-8907-2 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (longitudinal orientation), resulted in an irradiated 30 ft-lb transition temperature of 146.9°F and an irradiated 50 ft-lb transition temperature of 179.7°F. This results in a 30 ft-lb transition temperature increase of 135.6°F and a 50 ft-lb transition temperature increase of 143.6°F for the longitudinally oriented specimens.

- Irradiation of the Surveillance Program Weld Metal (Heat # 10137) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 16.0°F and an irradiated 50 ft-lb transition temperature of 27.4°F. This results in a 30 ft-lb transition temperature increase of 69.7°F and a 50 ft-lb transition temperature increase of 58.2°F.

- Irradiation of the Heat-Affected-Zone (HAZ) Material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 40.4°F and an irradiated 50 ft-lb transition temperature of 112.9°F. This results in a 30 ft-lb transition temperature increase of 105.4°F and a 50 ft-lb transition temperature increase of 123.6°F.

- Irradiation of the Standard Reference Material (SRM) HSST 01 Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 190.5°F and an irradiated 50 ft-lb transition temperature of 217.9°F. This results in a 30 ft-lb transition temperature increase of 165.5°F and a 50 ft-lb transition temperature increase of 163.7°F.

- The average upper-shelf energy of Lower Shell Plate D-8907-2 (longitudinal orientation) resulted in an average energy decrease of 33.9 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 107.7 ft-lb for the longitudinally oriented specimens.

- The average upper-shelf energy of the Surveillance Program Weld Metal Charpy specimens resulted in an average energy decrease of 28.6 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 110.3 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 33.7 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 94.0 ft-lb for the HAZ Material.

- The average upper-shelf energy of the SRM HSST 01 Charpy specimens resulted in an average energy decrease of 49.2 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 92.3 ft-lb for the SRM.

- 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 2 reactor vessel surveillance materials are presented in Table 5-10.

  Lower Shell Plate D-8907-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), were not included in the Calvert Cliffs Capsule 104°. However, the transversely orientated unirradiated and previously withdrawn capsule results for the Lower Shell Plate D-8907-2 Charpy specimens were reanalyzed in this report. The transverse orientation Lower Shell Plate D-8907-2 was contained in Capsule 97°, which was irradiated to a neutron fluence of 1.95 x 10^{19} n/cm^2 (E > 1.0 MeV). The results of the transverse orientation Lower Shell Plate D-8907-2 reanalysis will be included in Table 5-10 and shown in Figures 5-4 through 5-6.

  - Irradiation of the Lower Shell Plate D-8907-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), resulted in an irradiated 30 ft-lb transition temperature of 137.5°F and an irradiated 50 ft-lb transition temperature of 179.0°F. This results in a 30 ft-lb transition temperature increase of 102.6°F and a 50 ft-lb transition temperature increase of 112.7°F.

  - The average upper-shelf energy of the Lower Shell Plate D-8907-2 (transverse orientation) Charpy specimens resulted in an average energy decrease of 27.7 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 86.7 ft-lb for the transversely oriented specimens.

- Based on the credibility evaluation presented in Appendix D, the Calvert Cliffs Unit 2 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 (52 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 (52 EFPY).

- Based on the Pressure-Temperature (P-T) limit curve applicability check in Appendix G, the Capsule 104° evaluations, material properties and fluence did not affect the applicability of the current Calvert Cliffs Unit 2 P-T limit curves. The current Calvert Cliffs Unit 2 P-T limit curves are now applicable through 48 EFPY.

- The calculated 52 EFPY (end-of-life-extension) neutron fluence values (E > 1.0 MeV) at the core mid-plane for the Calvert Cliffs Unit 2 reactor vessel using the Regulatory Guide 1.99, Revision 2, attenuation formula (i.e., Equation # 3 in the guide) are as follows:

  Calculated (52 EFPY): Vessel inner radius* = 4.28 x 10^{19} n/cm^2

  (Calculated using the fluence data contained in Table 6-2)

  Vessel 1/4 thickness = 2.551 x 10^{19} n/cm^2

  Vessel 3/4 thickness = 0.906 x 10^{19} n/cm^2

  * Clad/base metal interface

- Because the end of life (EOL) fluence projection of this report is significantly lower than that in CA06959, Revision 0 [Reference 29], a brief explanation for the difference is outlined here. Reference 29 projected EOL peak clad base metal interface (CBMI) fluence is 6.16 × 10^{19} n/cm^2 for an estimated a thermal power generation of 51.55 EFPY at 2700 MWt through 8/13/2036. In this analysis, the EOL thermal power generation through August 13, 2036 is estimated to be 52 EFPY at 2737 MWt and the corresponding EOL peak CBMI fluence is 4.28 × 10^{19} n/cm^2. The reason for the significant decrease in estimated peak CBMI fluence is that Reference 29 uses cycle 9 flux data to perform the extrapolations while the current analysis considers the low leakage core loading pattern that Calvert Cliffs Unit 2 has implemented since Cycle 10. More specifically, the current analysis uses actual core designed data from cycles 1 through 18 to perform cycle-specific transport calculations and future fluence projections are estimated with cycle 18 flux data.

- The current report uses slightly overestimated EFPY (and thus, overestimated time integrated exposure parameters). Notice that the cycle-wise exposure rates (flux and dpa/s) are still correct. The integrated exposure parameters are evaluated to be at most 6% overestimated (for Cycle 2) and 3% or less for Cycle 18 and future projections. It is recommended that in future fluence analyses the EFPY (and time integrated exposure) be corrected according to the following table:

Cycle	WCAP-17501		Design Basis (Correct)	
	EFPY	Cycle EFPS	EFPY	Cycle EFPS
1	1.39	43726821	1.35	42485757
2	2.28	28304427	2.16	25718102
3	3.22	29688012	3.10	29608142
4	4.63	44516242	4.47	43254621
5	5.79	36570373	5.58	34876668
6	6.93	36036347	6.69	35097928
7	8.14	38027913	7.83	35999575
8	9.65	47657946	9.32	47065957
9	11.16	47778629	10.81	47165729
10	12.74	49689016	12.39	49575113
11	14.48	54905721	14.12	54692572
12	16.20	54341141	15.84	54265144
13	18.00	56854841	17.63	56679027
14	19.71	54010369	19.35	54000053
15	21.51	56713759	21.14	56582528
16	23.41	59877642	23.04	59921647
17	25.27	58649289	24.89	58414854
18	27.13	58743605	26.74	58556027

2 INTRODUCTION

This report presents the results of the examination of Capsule 104°, 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 2 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Calvert Cliffs Unit 2 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-48 [Reference 5], "Summary Report on Manufacture of Test Specimens and Assembly of Capsules for Irradiation Surveillance of Calvert Cliffs – Unit 2 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], "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels." 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 2.

Capsule 104° was removed from the reactor after 27.13 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 104° removed from the Calvert Cliffs Unit 2 reactor vessel and discusses the analysis of the data.

3 BACKGROUND

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

A method for ensuring the integrity of reactor pressure vessels has been presented in "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code [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 2 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 2 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:

- Lower Shell Plate D-8907-2 (longitudinal orientation)
- Lower Shell Plate D-8907-2 (transverse orientation)
- Weld metal fabricated by a submerged arc process with Mil B-4 weld filler wire, Heat Number 10137 Linde Type 0091 flux, Lot Number 3999, 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 Lower Shell Plates D-8907-1 and D-8907-2
- Heavy-Section Steel Technology (HSST) 01 Standard Reference Material (SRM)

Test material obtained from the lower 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 Lower Shell Plate D-8907-1 and adjacent Lower Shell Plate D-8907-3, and Lower Shell Plate D-8907-1 and adjacent Lower Shell Plate D-8907-2, respectively.

Charpy V-notch impact specimens from Lower Shell Plate D-8907-2 were machined in the longitudinal orientation (longitudinal axis of the specimen parallel to the major rolling direction) and also in the transverse orientation (longitudinal axis of the specimen perpendicular to the major rolling direction). The core-region weld Charpy impact specimens were machined from the weldment such that the long dimension of each Charpy specimen was perpendicular (normal) to the weld direction. The notch of the weld metal Charpy specimens was machined such that the direction of crack propagation in the specimen was in the welding direction.

Tensile specimens from Lower Shell Plate D-8907-2 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 2 surveillance program, including Capsule 104°, 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 2 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:

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

The chemical composition and 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 104° 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 II, the manufacture of Calvert Cliffs Unit 2 test specimens report, CENPD-48 [Reference 5], Tables III, XIX and XX, and the CRVSP, Revision 5 [Reference 7], Table 3-8.

Capsule 104° was removed after 27.13 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 2 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 2 Surveillance Test Materials – Intermediate Shell Plates (Unirradiated)

Element	Intermediate Shell Plate D-8906-1	Intermediate Shell Plate D-8906-2	Intermediate Shell Plate D-8906-3
	Combustion Engineering Analysis[(a)]		
Si	0.21	0.23	0.27
S	0.015	0.018	0.017
P	0.006	0.007	0.005
Mn	1.36	1.39	1.38
C	0.24	0.24	0.22
Cr	0.08	0.09	0.08
Ni	**0.56**	**0.56**	**0.55**
Mo	0.63	0.64	0.63
V	0.004	0.004	0.004
Cb	< 0.01	< 0.01	< 0.01
B	0.0003	0.0004	0.0003
Co	0.011	0.011	0.011
N	0.007	0.008	0.007
Cu	**0.15**	**0.11**	**0.14**
Al	0.023	0.021	0.023
W	< 0.01	< 0.01	< 0.01
Ti	< 0.01	< 0.01	< 0.01
As	0.012	0.012	0.010
Sn	0.019	0.006	0.016
Zr	0.001	0.001	0.001

Note:
(a) Data obtained from CENPD-48 [Reference 5].

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

Element	Lower Shell Plate D-8907-1	Lower Shell Plate D-8907-2[b]	Lower Shell Plate D-8907-3
	Combustion Engineering Analysis[a]		
Si	0.17	0.21	0.18
S	0.011	0.010	0.012
P	0.005	0.005	0.006
Mn	1.26	1.22	1.26
C	0.22	0.23	0.24
Cr	0.09	0.11	0.07
Ni	**0.60**	**0.66**	**0.74**
Mo	0.61	0.63	0.63
V	0.004	0.004	0.004
Cb	< 0.01	< 0.01	< 0.01
B	0.0003	0.0001	0.0004
Co	0.010	0.011	0.011
N	0.007	0.006	0.010
Cu	**0.15**	**0.14**	**0.11**
Al	0.021	0.022	0.019
W	< 0.01	< 0.01	< 0.01
Ti	< 0.01	< 0.01	< 0.01
As	0.014	0.012	0.017
Sn	0.007	0.006	0.006
Zr	0.002	0.001	0.001

Notes:

(a) Data obtained from CENPD-48 [Reference 5].
(b) Surveillance program plate material.

Table 4-3 Chemical Composition (wt %) of the Calvert Cliffs Unit 2 Surveillance Test Materials – Weld and HAZ (Unirradiated)

Element	Intermediate to Lower Shell Girth Weld 9-203 (Heat # 10137/Linde 0091) [D-8907-1/D-8907-3][b]	HAZ Material [D-8907-1/D-8907-2][c]
	Combustion Engineering Analysis[a]	
Si	0.17	0.17
S	0.013	0.010
P	0.016	0.014
Mn	1.11	1.13
C	0.13	0.14
Cr	0.05	0.04
Ni	**0.06**[d]	**0.07**
Mo	0.53	0.54
V	0.010	0.004
Cb	< 0.01	< 0.01
B	0.0003	0.0002
Co	0.009	0.010
N	0.008	0.008
Cu	**0.21**[d]	**0.22**
Al	< 0.001	< 0.001
W	< 0.01	< 0.01
Ti	< 0.01	< 0.01
As	0.013	0.018
Sn	0.004	0.005
Zr	0.001	0.002

Notes:

(a) Data obtained from CENPD-48 [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 2 Surveillance Test Materials

Material(a)	Temperature(a) (°F)	Time(a) (hours)	Cooling(a)
Intermediate Shell Plates D-8906-1, D-8906-2 and D-8906-3	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-8907-1, D-8907-2 and D-8907-3	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 # 10137/Linde 0091)	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 2 Capsule 104°

Compartment Position[a]	Compartment Number (Specimen Type and Material)[a]	Specimen Numbers[a]
1	5314 (Tensile HAZ Specimens)	4JE, 4JM, 4K4
2	5324 (Charpy Impact HAZ Specimens)	43D, 43B, 45D, 44B, 44T, 42M, 462, 45C, 453, 43C, 44A, 434
3	5336 (Charpy Impact SRM Plate Specimens)	67B, 67D, 67M, 67E, 66K, 66E, 66B, 66P, 67C, 66J, 67J, 66L
4	5341 (Tensile Longitudinal Plate Specimens)	1KP, 1K2, 1KE
5	5351 (Charpy Impact Longitudinal Plate Specimens)	12M, 123, 162, 15U, 122, 13B, 142, 11Y, 11K, 15M, 12C, 15P
6	5363 (Charpy Impact Weld Specimens)	35L, 343, 313, 32P, 316, 31K, 31J, 32T, 34D, 31E, 341, 31M
7	5373 (Tensile Weld Specimens)	3JP, 3K4, 3L4

Note:
(a) Data obtained from CENPD-48 [Reference 5].

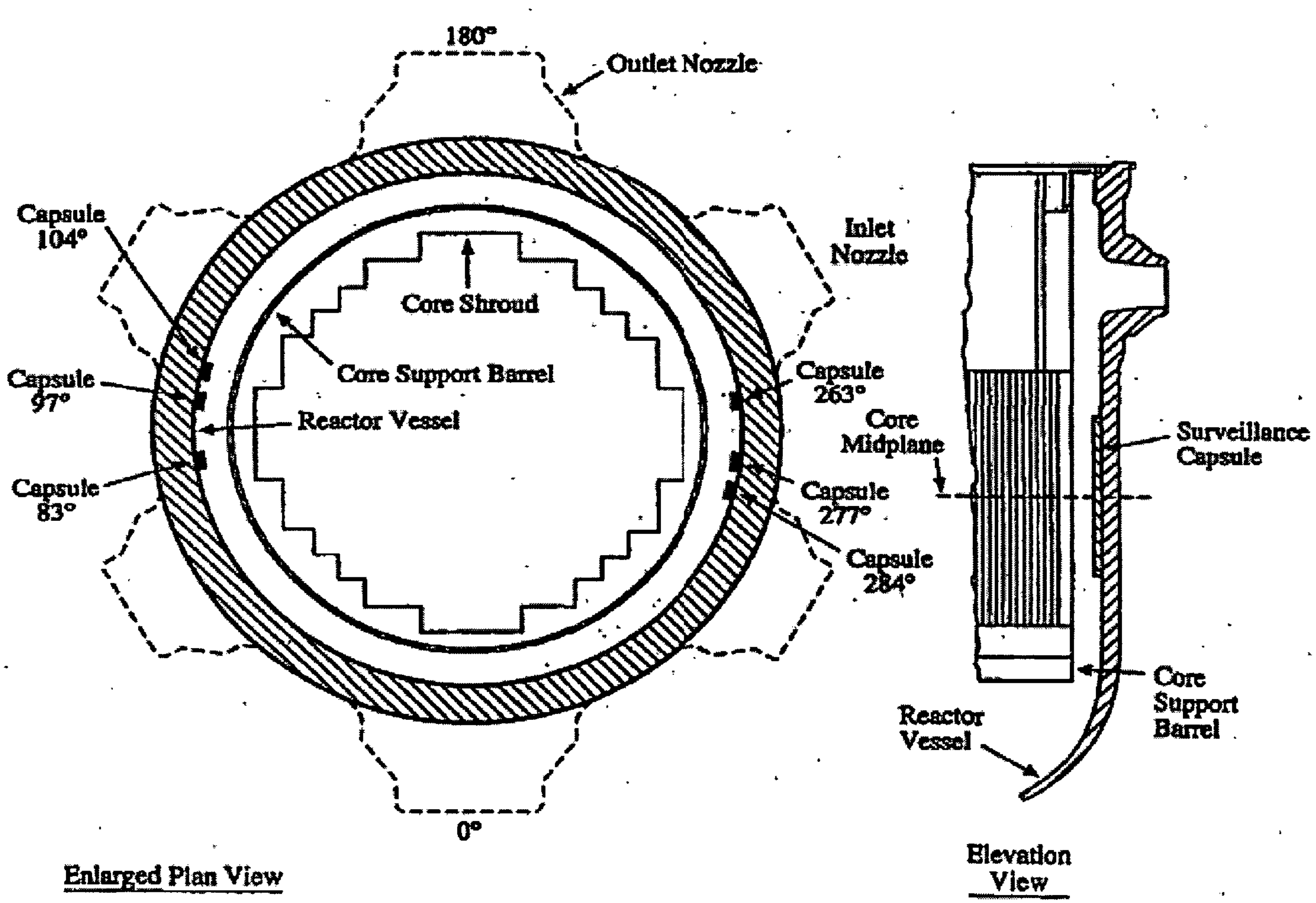


Figure 4-1 Arrangement of Surveillance Capsules in the Calvert Cliffs Unit 2 Reactor Vessel

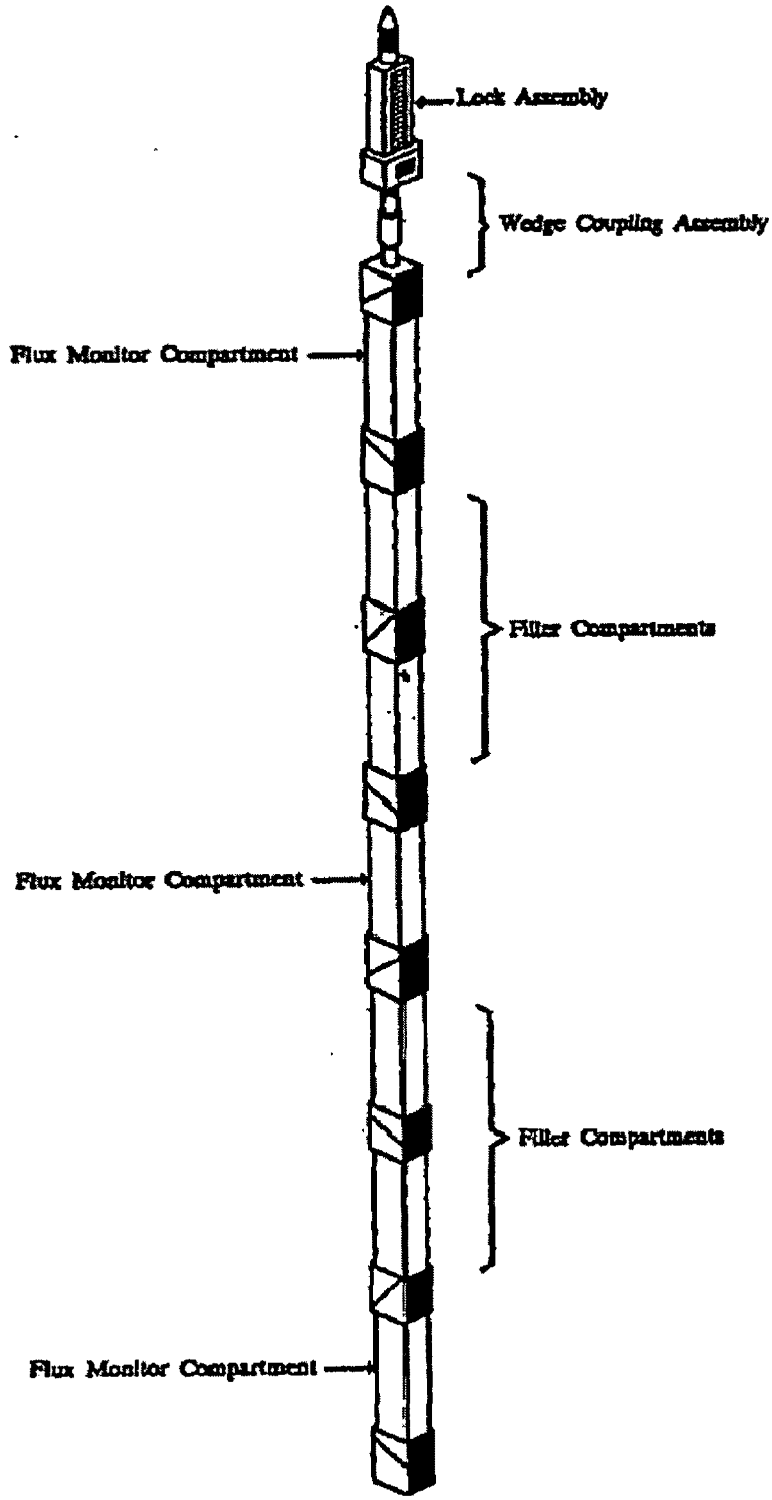


Figure 4-2 Original Surveillance Program Capsule in the Calvert Cliffs Unit 2 Reactor Vessel

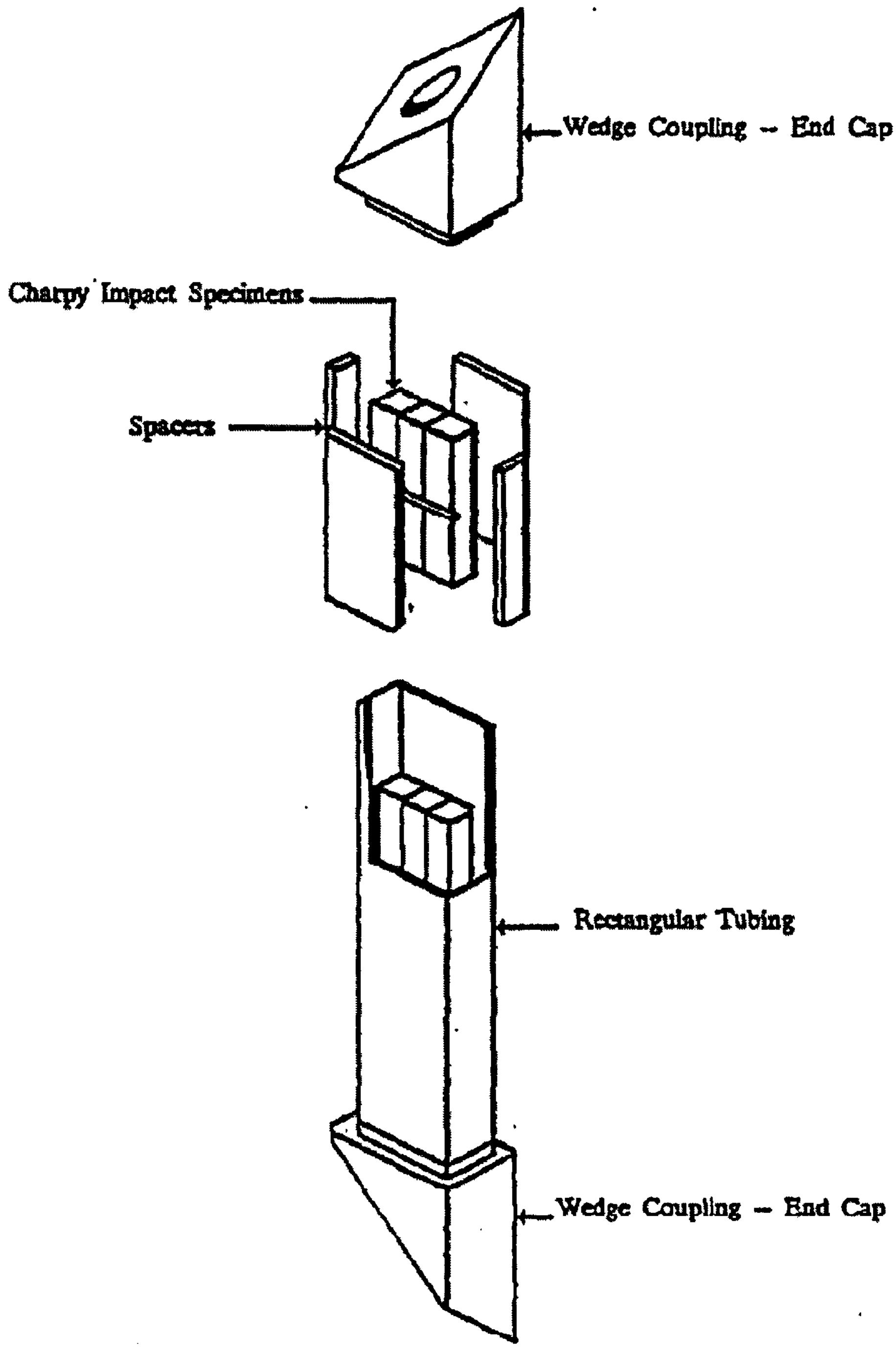


Figure 4-3 Surveillance Capsule Charpy Impact Specimen Compartment Assembly in the Calvert Cliffs Unit 2 Reactor Vessel

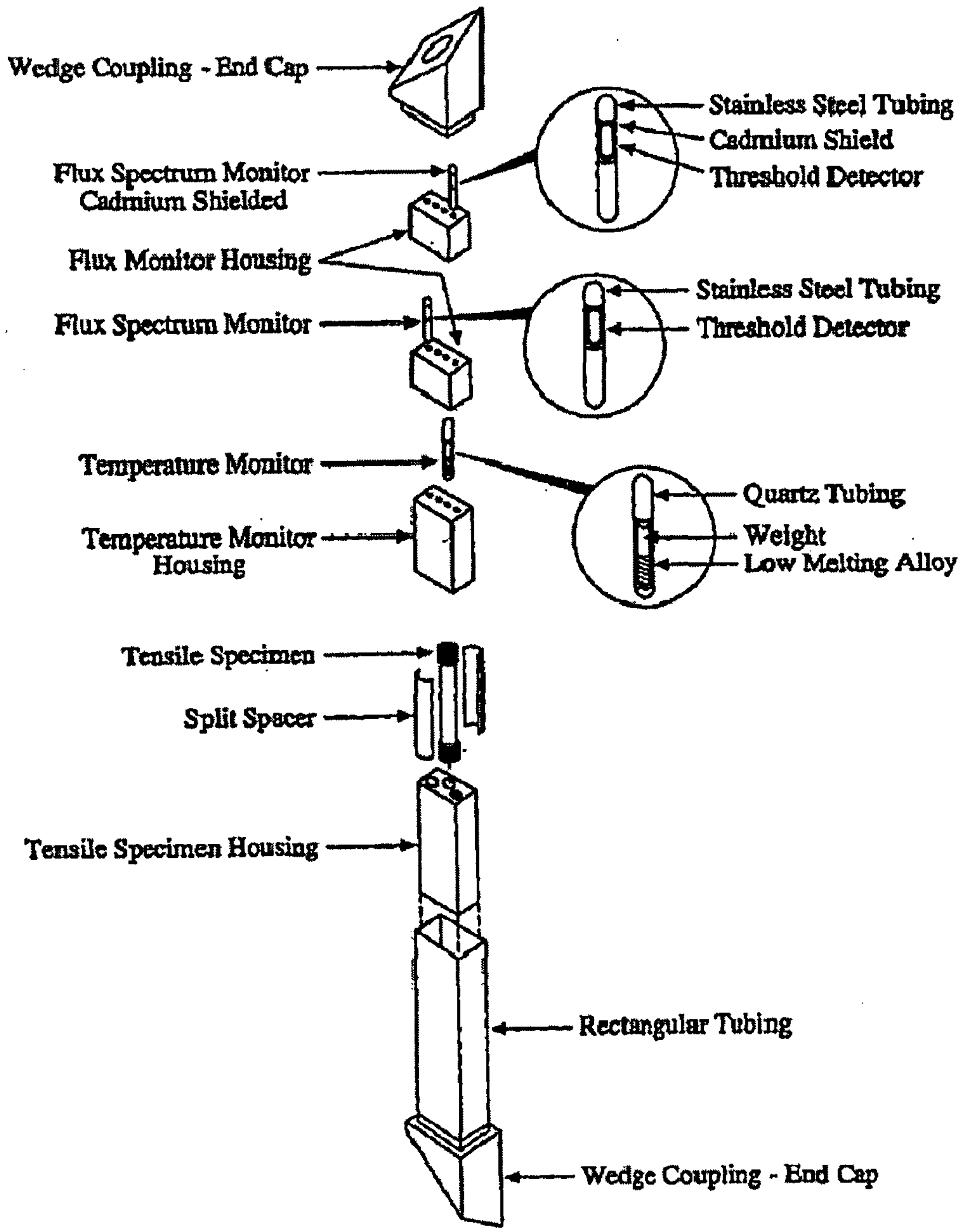


Figure 4-4 Surveillance Capsule Tensile and Flux-Monitor Compartment Assembly in the Calvert Cliffs Unit 2 Reactor Vessel

5 TESTING OF SPECIMENS FROM CAPSULE 104°

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 ASTM Specification E185-82 [Reference 10] and Westinghouse Procedure RMF 8402, Revision 3 [Reference 11].

The capsule was opened upon receipt at the hot cell laboratory per Procedure RTU 5004 [Reference 12]. The specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in CENPD-48 [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 13] and Procedure RMF 8103, Revision 2 [Reference 14] 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. The Instron Impulse system has not been calibrated to ASTM Standard E2298-09 [Reference 15], so the instrumented energy, load, time and stress data are considered for information only in Tables 5-5 through 5-8. 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 16]:

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

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 $\varphi = 45°$ and $\rho = 0.010$ 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 13] and A370-09 [Reference 17]. The lateral expansion was measured using a dial gage rig similar to that shown in the same specifications.

Tensile tests were performed on a 250 KN Instron screw driven tensile machine (Model 5985) per Procedure RTU 5016 [Reference 18]. 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 104°, which received a fluence of 2.44×10^{19} n/cm^2 (E > 1.0 MeV) in 27.13 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 5-3 and 5-7 through 5-15. The unirradiated and previously withdrawn capsule results were taken from TR-ESS-001 [Reference 4], SwRI-06-7524 [Reference 21], and BAW-2199 [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 2 capsule reports.

The transition temperature increases and changes in upper-shelf energies for the Capsule 104° materials are summarized in Table 5-9 and led to the following results:

- Irradiation of the reactor vessel Lower Shell Plate D-8907-2 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (longitudinal orientation), resulted in an irradiated 30 ft-lb transition temperature of 146.9°F and an irradiated 50 ft-lb transition temperature of 179.7°F. This results in a 30 ft-lb transition temperature increase of 135.6°F and a 50 ft-lb transition temperature increase of 143.6°F for the longitudinally oriented specimens.

- Irradiation of the Surveillance Program Weld Metal (Heat # 10137) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 16.0°F and an irradiated 50 ft-lb transition temperature of 27.4°F. This results in a 30 ft-lb transition temperature increase of 69.7°F and a 50 ft-lb transition temperature increase of 58.2°F.

- Irradiation of the Heat-Affected-Zone (HAZ) Material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 40.4°F and an irradiated 50 ft-lb transition temperature of 112.9°F. This results in a 30 ft-lb transition temperature increase of 105.4°F and a 50 ft-lb transition temperature increase of 123.6°F.

- Irradiation of the reactor vessel Standard Reference Material (SRM) HSST 01 Charpy specimens, resulted in an irradiated 30 ft-lb transition temperature of 190.5°F and an irradiated 50 ft-lb transition temperature of 217.9°F. This results in a 30 ft-lb transition temperature increase of 165.5°F and a 50 ft-lb transition temperature increase of 163.7°F.

- The average upper-shelf energy of Lower Shell Plate D-8907-2 (longitudinal orientation) resulted in an average energy decrease of 33.9 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 107.7 ft-lb for the longitudinally oriented specimens.

- The average upper-shelf energy of the Surveillance Program Weld Metal Charpy specimens resulted in an average energy decrease of 28.6 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 110.3 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 33.7 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 94.0 ft-lb for the HAZ Material.

- The average upper-shelf energy of the SRM HSST 01 Charpy specimens resulted in an average energy decrease of 49.2 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 92.3 ft-lb.

- 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 2 reactor vessel surveillance materials are presented in Table 5-10.

  Lower Shell Plate D-8907-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), were not included in the Calvert Cliffs Capsule 104°. However, the transversely orientated unirradiated and previously withdrawn capsule results for the Lower Shell Plate D-8907-2 Charpy specimens were reanalyzed in this report. The transverse orientation Lower Shell Plate D-8907-2 was contained in Capsule 97°, which was irradiated to a neutron fluence of 1.95×10^{19} n/cm^2 (E > 1.0 MeV). The results of the transverse orientation Lower Shell Plate D-8907-2 reanalysis will be included in Table 5-10 and shown in Figures 5-4 through 5-6.

  - Irradiation of the Lower Shell Plate D-8907-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), resulted in an irradiated 30 ft-lb transition temperature of 137.5°F and an irradiated 50 ft-lb transition temperature of 179.0°F. This results in a 30 ft-lb transition temperature increase of 102.6°F and a 50 ft-lb transition temperature increase of 112.7°F.

  - The average upper-shelf energy of the Lower Shell Plate D-8907-2 (transverse orientation) Charpy specimens resulted in an average energy decrease of 27.7 ft-lb after irradiation. This results in an irradiated average upper-shelf energy of 86.7 ft-lb for the transversely oriented specimens.

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 (52 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 104° irradiated to 2.44 x 10^{19} n/cm^2 (E > 1.0 MeV) are presented in Table 5-11 and are compared with unirradiated results as shown in Figures 5-20 through 5-22.

The results of the tensile tests performed on the Lower Shell Plate D-8907-2 (longitudinal orientation) indicated that irradiation to 2.44 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 2.44 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 2.44 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 Lower Shell Plate D-8907-2 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 Lower Shell Plate D-8907-2, 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 2 Lower Shell Plate D-8907-2 Irradiated to a Fluence of 2.44 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	%
15P	0	-18	4	5	8	0.20	0
11Y	75	24	22	30	25	0.64	10
13B	125	52	26	35	27	0.69	20
11K	150	66	28	38	28	0.71	30
12M	155	68	31	42	35	0.89	40
122	165	74	37	50	35	0.89	30
123	175	79	45	61	44	1.12	50
15U	190	88	51	69	47	1.20	55
15M	210	99	82	111	69	1.76	75
142	325	163	92	125	74	1.88	100
12C	340	171	108	146	82	2.09	100
162	350	177	123	167	81	2.06	100

Table 5-2 Charpy V-Notch Data for the Calvert Cliffs Unit 2 Surveillance Weld Metal (Heat # 10137) Irradiated to a Fluence of 2.44 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	%
341	0	-18	9	12	15	0.38	15
316	15	-9	11	15	13	0.33	20
313	20	-7	86	117	62	1.58	60
34D	25	-4	42	57	43	1.09	50
32P	30	-1	25	34	27	0.69	50
31K	50	10	105	142	83	2.11	70
32T	60	16	63	85	55	1.40	75
31E	75	24	165	224	96	2.44	90
35L	150	66	91	123	81	2.06	100
343	225	107	97	132	81	2.06	100
31J	250	121	136	184	92	2.34	100
31M	275	135	117	159	93	2.37	100

Table 5-3 Charpy V-Notch Data for the Calvert Cliffs Unit 2 Heat-Affected-Zone (HAZ) Material Irradiated to a Fluence of 2.44 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	%
44T	-75	-59	15	20	11	0.28	10
43D	-25	-32	12	16	14	0.36	20
45D	-15	-26	10	14	8	0.20	25
44A	0	-18	35	47	32	0.81	30
453	20	-7	20	27	21	0.53	30
43B	40	4	17	23	20	0.51	25
45C	50	10	17	23	17	0.43	30
43C	75	24	73	99	59	1.50	70
42M	250	121	61	83	60	1.53	90
462	275	135	70	95	63	1.60	100
434	300	149	85	115	73	1.86	100
44B	325	163	127	172	78	1.98	100

Table 5-4 Charpy V-Notch Data for the Calvert Cliffs Unit 2 Standard Reference Material (SRM) HSST 01 Irradiated to a Fluence of 2.44 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	%
67M	75	24	4.5	6	11	0.28	10
66B	150	66	21	28	24	0.61	20
67D	175	79	28	38	26	0.66	30
67J	190	88	22	30	28	0.71	40
66J	200	93	26	35	27	0.69	40
66L	210	99	47	64	41	1.04	50
67B	220	104	52	71	45	1.14	50
67E	225	107	56	76	48	1.22	60
66E	235	113	67	91	55	1.40	75
66P	325	163	95	129	75	1.91	100
66K	350	177	89	121	70	1.78	100
67C	375	191	93	126	80	2.04	100

Table 5-5 Instrumented Charpy Impact Test Results for the Calvert Cliffs Unit 2 Lower Shell Plate D-8907-2 Irradiated to a Fluence of 2.44 x 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 F_M W_m/A	Prop. W_p/A								
15P	0	3.9	31	26	6	2310	0.05	3890	0.09	3890	NA	77	103
11Y	75	19.4	156	160	-3	3130	0.05	3820	0.38	3820	NA	104	116
13B	125	24.3	196	145	51	2570	0.05	3800	0.35	3500	490	86	106
11K	150	26.0	210	135	74	2540	0.05	3615	0.35	3260	1200	85	102
12M	155	29.2	235	173	62	2640	0.05	3630	0.43	3530	800	88	104
122	165	34.8	280	204	77	2520	0.05	3700	0.50	3500	1210	84	104
123	175	42.3	341	259	82	2760	0.05	3780	0.63	3680	1270	92	109
15U	190	47.0	379	251	127	2670	0.05	3810	0.60	3680	1280	89	108
15M	210	73.3	591	246	345	2540	0.05	3740	0.60	3440	1940	85	105
142	325	83.4	672	240	432	2690	0.05	3650	0.60	NA	NA	90	106
12C	340	98.4	793	243	550	2770	0.05	3690	0.60	NA	NA	92	108
162	350	111.1	895	245	650	2300	0.05	3770	0.61	NA	NA	77	101

Table 5-6 Instrumented Charpy Impact Test Results for the Calvert Cliffs Unit 2 Surveillance Weld Metal (Heat # 10137) Irradiated to a Fluence of 2.44 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_{br} (lb)	Arrest Load, F_a (lb)	Yield Stress (ksi)	Flow Stress (ksi)
			Total W_t/A	At F_M W_m/A	Prop. W_p/A								
341	0	9.7	78	35	43	3270	0.08	4240	0.12	4240	NA	109	125
316	15	11.7	94	27	68	2500	0.05	3960	0.09	3330	500	83	108
313	20	78.5	633	226	406	2600	0.05	3390	0.60	2910	1660	87	100
34D	25	38.2	308	226	82	3100	0.05	3920	0.50	3650	1120	103	117
32P	30	23.0	185	122	63	2810	0.05	3820	0.29	3770	1100	94	110
31K	50	94.4	761	304	457	2740	0.05	3540	0.77	2570	1700	91	105
32T	60	56.8	458	275	183	3150	0.06	3790	0.62	3470	2060	105	116
31E	75	151.4	1220	322	898	2050	0.05	3700	0.79	NA	NA	68	96
35L	150	82.3	663	249	414	2730	0.05	3640	0.60	NA	NA	91	106
343	225	87.6	706	245	461	2600	0.05	3630	0.60	NA	NA	87	104
31J	250	123.6	996	341	655	2630	0.05	3250	0.95	NA	NA	88	98
31M	275	105.7	852	247	604	2200	0.05	3650	0.63	NA	NA	73	97

Table 5-7 Instrumented Charpy Impact Test Results for the Calvert Cliffs Unit 2 Heat-Affected-Zone (HAZ) Material Irradiated to a Fluence of 2.44 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) Total W_t/A	At F_M W_m/A	Prop. W_p/A	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)
44T	-75	13.2	106	26	81	2530	0.05	4350	0.09	3840	NA	84	115
43D	-25	11.8	95	24	71	2560	0.05	4070	0.09	3130	450	85	110
45D	-15	9.8	79	35	44	1890	0.05	4180	0.11	3280	500	63	101
44A	0	31.9	257	35	222	2970	0.07	4130	0.11	3890	840	99	118
453	20	19.7	159	110	48	2550	0.05	3830	0.26	3660	490	85	106
43B	40	17.2	139	96	43	1900	0.05	3430	0.26	3370	NA	63	89
45C	50	16.0	129	93	36	2620	0.05	3660	0.24	3470	410	87	105
43C	75	64.9	523	259	264	2740	0.05	3900	0.60	3570	2570	91	111
42M	250	54.1	436	184	252	2180	0.05	3410	0.48	NA	NA	73	93
462	275	62.7	505	119	386	2300	0.05	3600	0.31	NA	NA	77	98
434	300	78.4	632	229	403	2060	0.05	3500	0.61	NA	NA	69	93
44B	325	116.8	941	255	686	1740	0.05	3830	0.63	NA	NA	58	93

Table 5-8 Instrumented Charpy Impact Test Results for the Calvert Cliffs Unit 2 Standard Reference Material (SRM) HSST 01 Irradiated to a Fluence of 2.44 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 F_M W_m/A	Prop. W_p/A								
67M	75	4.0	32	12	20	3100	0.05	3450	0.06	3450	NA	103	109
66B	150	20.3	164	115	48	2760	0.05	3560	0.29	3560	250	92	105
67D	175	26.6	214	180	34	2770	0.05	3820	0.43	3740	570	92	110
67J	190	19.0	153	118	35	2300	0.05	3570	0.26	3440	490	77	98
66J	200	23.5	189	140	49	2480	0.05	3700	0.36	3560	950	83	103
66L	210	43.0	346	210	136	2300	0.05	3890	0.50	3700	1930	77	103
67B	220	47.8	385	216	169	3200	0.05	3890	0.50	3660	2170	107	118
67E	225	48.7	392	257	135	2360	0.05	3780	0.48	3720	2000	79	102
66E	235	60.7	489	259	230	2900	0.05	3900	0.60	3530	2580	97	113
66P	325	85.9	692	246	446	3140	0.05	3730	0.60	NA	NA	105	114
66K	350	79.8	643	247	396	2200	0.05	3680	0.61	NA	NA	73	98
67C	375	84.5	681	251	430	2780	0.05	3750	0.60	NA	NA	93	109

Table 5-9 Effect of Irradiation to 2.44 x 10^{19} n/cm^2 (E > 1.0 MeV) on the Charpy V-Notch Toughness Properties of the Calvert Cliffs Unit 2 Reactor Vessel Surveillance Capsule 104° Materials

Material	Average 30 ft-lb Transition Temperature[a] (°F)			Average 35 mil Lateral Expansion Temperature[a] (°F)			Average 50 ft-lb Transition Temperature[a] (°F)			Average Energy Absorption at Full Shear[a] (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Lower Shell Plate D-8907-2 (LT)	11.3	146.9	135.6	21.4	148.1	126.7	36.1	179.7	143.6	141.6	107.7	-33.9
Surveillance Program Weld Metal (Heat # 10137)	-53.7	16.0	69.7	-41.0	20.7	61.7	-30.8	27.4	58.2	138.9	110.3	-28.6
HAZ Material	-65.0	40.4	105.4	-43.3	59.6	102.9	-10.7	112.9	123.6	127.7	94.0	-33.7
SRM	25.0	190.5	165.5	42.0	197.1	155.1	54.2	217.9	163.7	141.5	92.3	-49.2

Note:

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

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

Material	Capsule[a]	Capsule Fluence ($x 10^{19}$ n/cm², E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		USE Decrease	
			Predicted[b] (°F)	Measured[c] (°F)	Predicted[b] (%)	Measured[c] (%)
Lower Shell Plate D-8907-2 (Longitudinal)	263°	0.825	96.0	86.4	23	19
	97°	1.95	120.0	111.6	28	24
	104°	2.44	125.9	135.6	30	24
Lower Shell Plate D-8907-2 (Transverse)	97°	1.95	120.0	102.6	28	24
Surveillance Program Weld Metal (Heat # 10137)	263°	0.825	91.6	72.7	38	24
	97°	1.95	114.5	82.9	46	30
	104°	2.44	120.0	69.7	48	21
Heat-Affected-Zone Material	263°	0.825	---	130.6	---	18
	97°	1.95	---	121.2	---	36
	104°	2.44	---	105.4	---	26
Standard Reference Material	263°	0.825	---	125.6	---	36
	104°	2.44	---	165.5	---	35

Notes:

(a) Capsule 104° (highlighted) is the latest capsule to be withdrawn and tested from the Calvert Cliffs Unit 2 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 2 Capsule 104° Reactor Vessel Surveillance Materials Irradiated to 2.44×10^{19} n/cm^2 (E > 1.0 MeV)

Material	Sample Number	Test Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Stress (ksi)	Fracture Strength (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
Lower Shell Plate D-8907-2 (Longitudinal)	1KP	175	79.2	99.2	3.3	68	208	10.3	22	67
	1K2	250	75.2	96.8	3.2	65	207	11.0	23	69
	1KE	550	73.5	94.3	3.3	66	177	10.9	23	63
Surveillance Program Weld Metal (Heat # 10137)	3JP	75	87.4	99.5	3.6	73	172	7.4	22[(a)]	57
	3K4	150	81.8	94.4	3.0	60	209	10.8	25	71
	3L4	550	78.5	93.2	3.1	64	172	9.8	24	63
Heat-Affected-Zone Material	4JE	75	82.7	96.9	3.0	62	197	9.2	22	69
	4JM	150	81.1	94.3	3.0	61	204	7.8	26[(a)]	70
	4K4	550	73.8	91.5	3.4	70	104	8.4	20[(a)]	33

Note:

(a) The extensometer slipped during testing after the ultimate strength was reached, therefore the elongation at fracture could not be taken from extensometer output. The distance between extensometer indentation marks was measured after placing the fracture surfaces together in order to calculate the elongation at fracture.

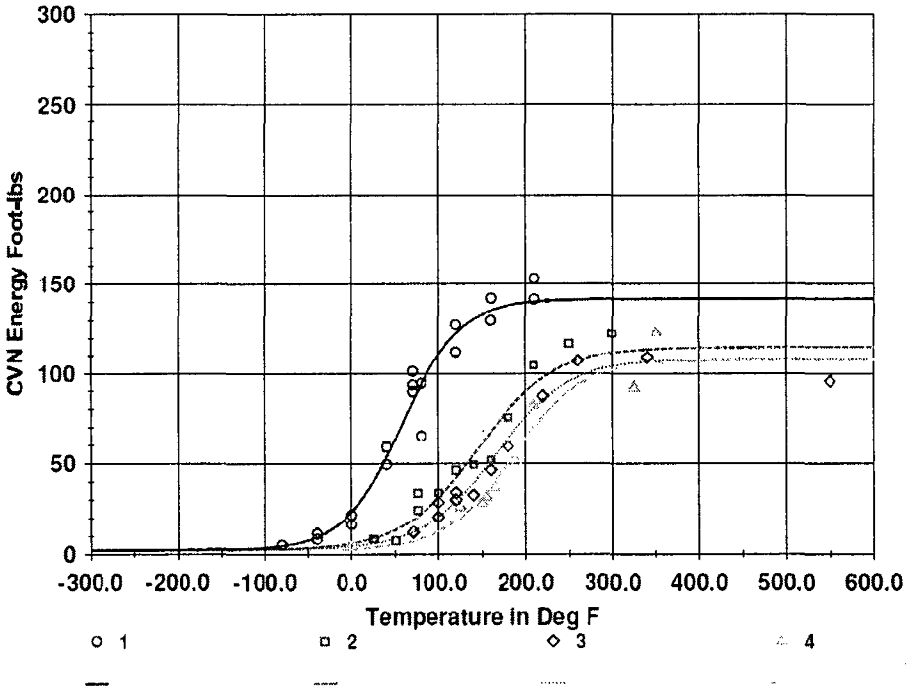
Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Calvert Cliffs Unit 2 Reactor Vessel Lower Shell Plate D-8907-2 (Longitudinal Orientation)

LS PLATE D-8907-2 (LONGITUDINAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/03/2011 07:11 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	LT	C-5286-1
2	Calvert Cliffs 2	263	SA533B1	LT	C-5286-1
3	Calvert Cliffs 2	97	SA533B1	LT	C-5286-1
4	Calvert Cliffs 2	104	SA533B1	LT	C-5286-1



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	141.6	.0	11.3	.0	36.1	.0
2		2.2	114.7	-26.9	97.7	86.4	132.7	96.6
3		2.2	108.0	-33.6	122.9	111.6	158.1	122.0
4		2.2	107.7	-33.9	146.9	135.6	179.7	143.6

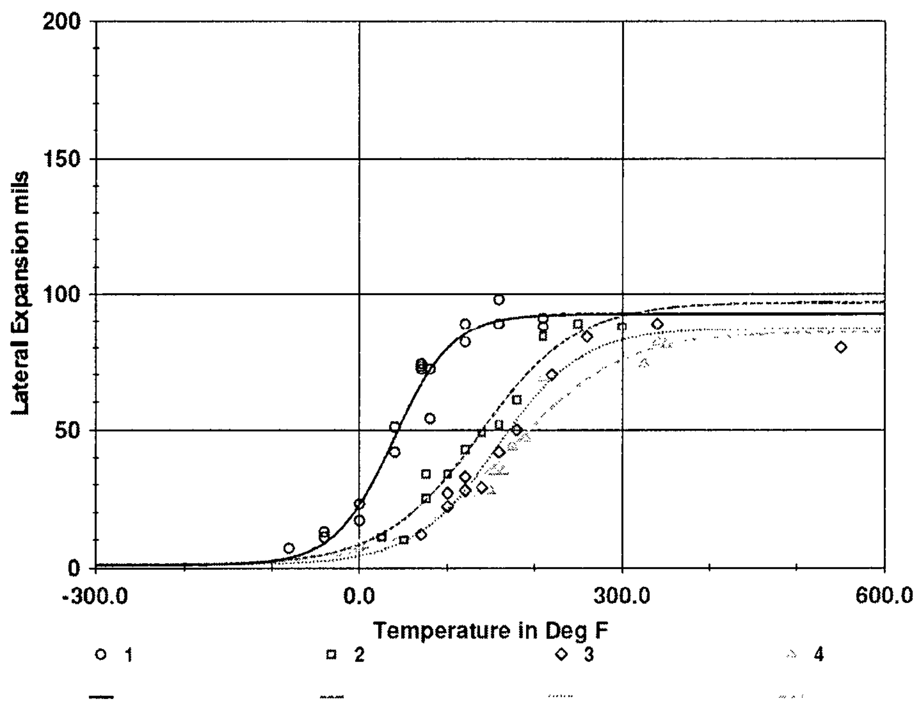
Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Calvert Cliffs Unit 2 Reactor Vessel Lower Shell Plate D-8907-2 (Longitudinal Orientation)

LS PLATE D-8907-2 (LONGITUDINAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 07:15 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	LT	C-5286-1
2	Calvert Cliffs 2	263	SA533B1	LT	C-5286-1
3	Calvert Cliffs 2	97	SA533B1	LT	C-5286-1
4	Calvert Cliffs 2	104	SA533B1	LT	C-5286-1



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	92.6	.0	21.4	.0
2		1.0	97.0	4.3	104.7	83.3
3		1.0	87.2	-5.4	137.6	116.2
4		1.0	86.1	-6.5	148.1	126.7

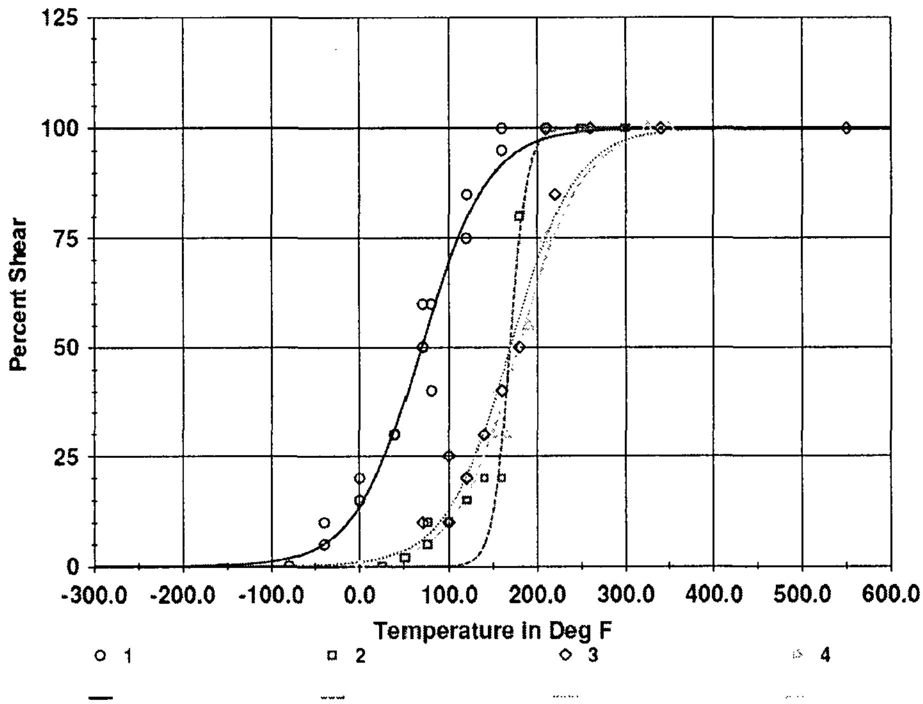
Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Calvert Cliffs Unit 2 Reactor Vessel Lower Shell Plate D-8907-2 (Longitudinal Orientation)

LS PLATE D-8907-2 (LONGITUDINAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 07:50 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	LT	C-5286-1
2	Calvert Cliffs 2	263	SA533B1	LT	C-5286-1
3	Calvert Cliffs 2	97	SA533B1	LT	C-5286-1
4	Calvert Cliffs 2	104	SA533B1	LT	C-5286-1



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	69.1	.0
2		.0	100.0	.0	169.1	100.0
3		.0	100.0	.0	170.0	100.9
4		.0	100.0	.0	178.8	109.7

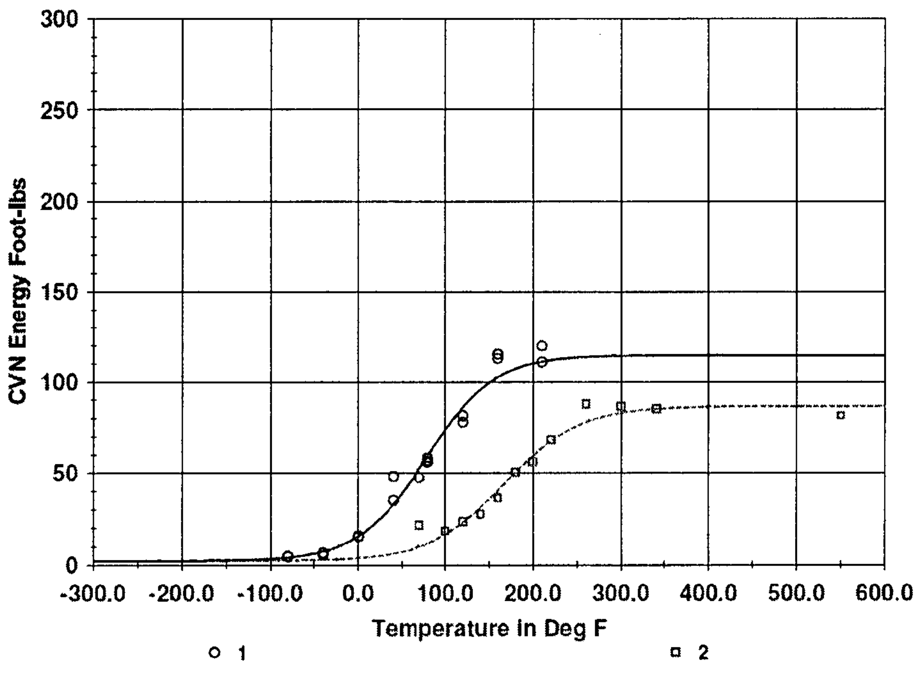
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Calvert Cliffs Unit 2 Reactor Vessel Lower Shell Plate D-8907-2 (Transverse Orientation)

LS PLATE D-8907-2 (TRANSVERSE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 07:52 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	TL	C-5286-1
2	Calvert Cliffs 2	97	SA533B1	TL	C-5286-1



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	114.4	.0	34.9	.0	66.3	.0
2		2.2	86.7	-27.7	137.5	102.6	179.0	112.7

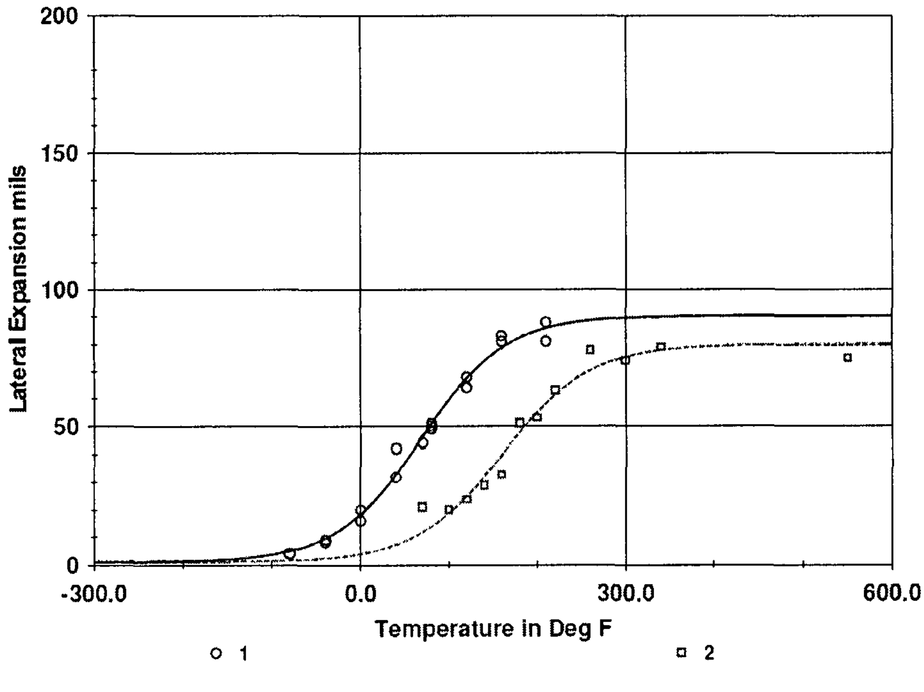
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Calvert Cliffs Unit 2 Reactor Vessel Lower Shell Plate D-8907-2 (Transverse Orientation)

LS PLATE D-8907-2 (TRANSVERSE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:09 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	TL	C-5286-1
2	Calvert Cliffs 2	97	SA533B1	TL	C-5286-1



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	90.4	.0	44.7	.0
2		1.0	79.9	-10.6	147.6	102.9

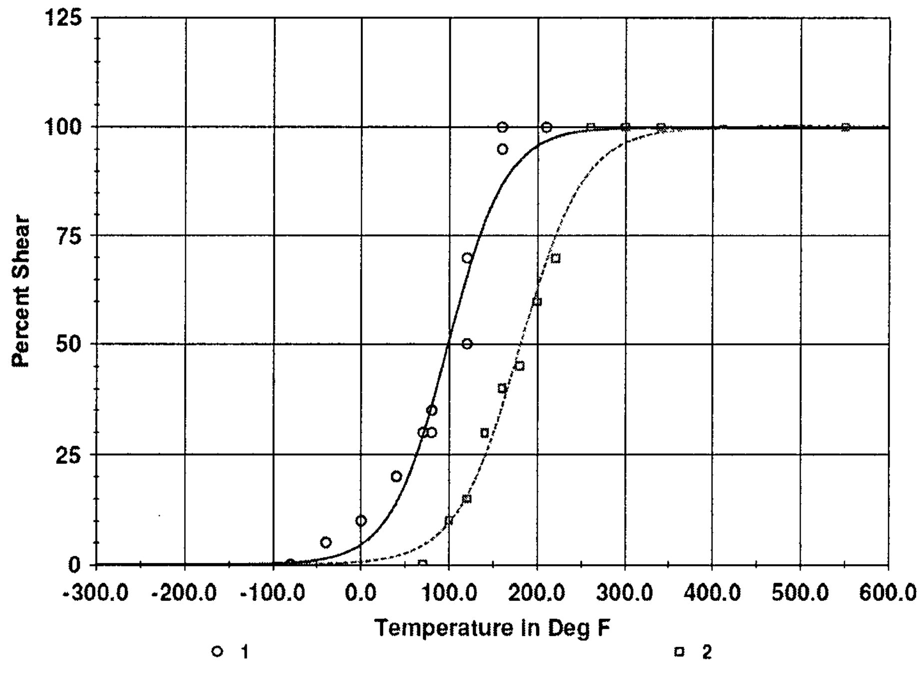
Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Calvert Cliffs Unit 2 Reactor Vessel Lower Shell Plate D-8907-2 (Transverse Orientation)

LS PLATE D-8907-2 (TRANSVERSE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:10 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	TL	C-5286-1
2	Calvert Cliffs 2	97	SA533B1	TL	C-5286-1



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	98.5	.0
2		.0	100.0	.0	180.8	82.3

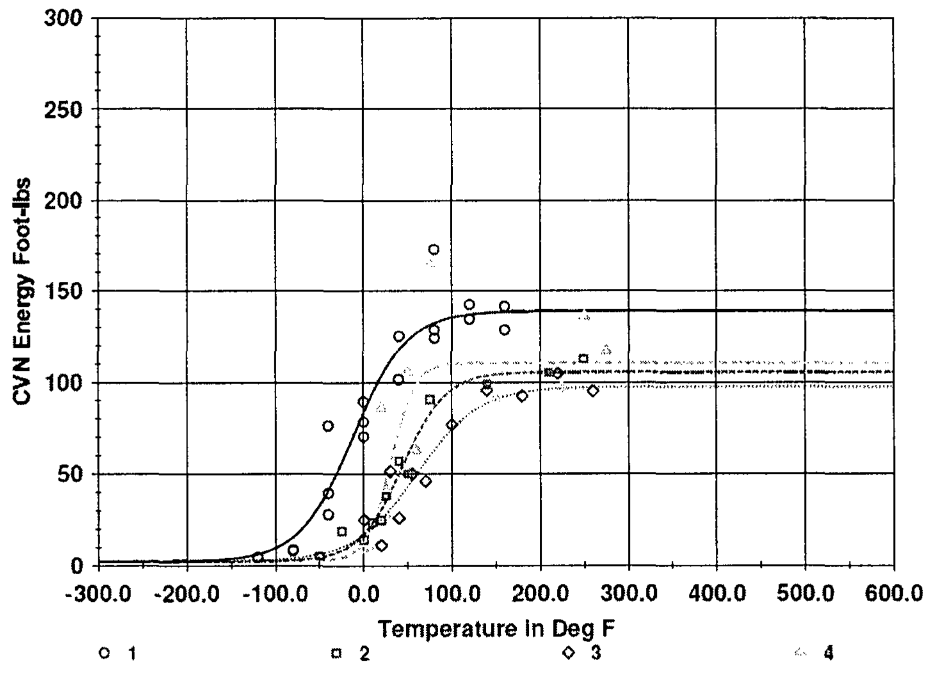
Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for the Calvert Cliffs Unit 2 Reactor Vessel Surveillance Program Weld Metal

SURVEILLANCE WELD METAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:13 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SAW	NA	10137
2	Calvert Cliffs 2	263	SAW	NA	10137
3	Calvert Cliffs 2	97	SAW	NA	10137
4	Calvert Cliffs 2	104	SAW	NA	10137



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	138.9	.0	-53.7	.0	-30.8	.0
2		2.2	105.3	-33.6	19.0	72.7	39.9	70.7
3		2.2	97.3	-41.6	29.2	82.9	60.6	91.4
4		2.2	110.3	-28.6	16.0	69.7	27.4	58.2

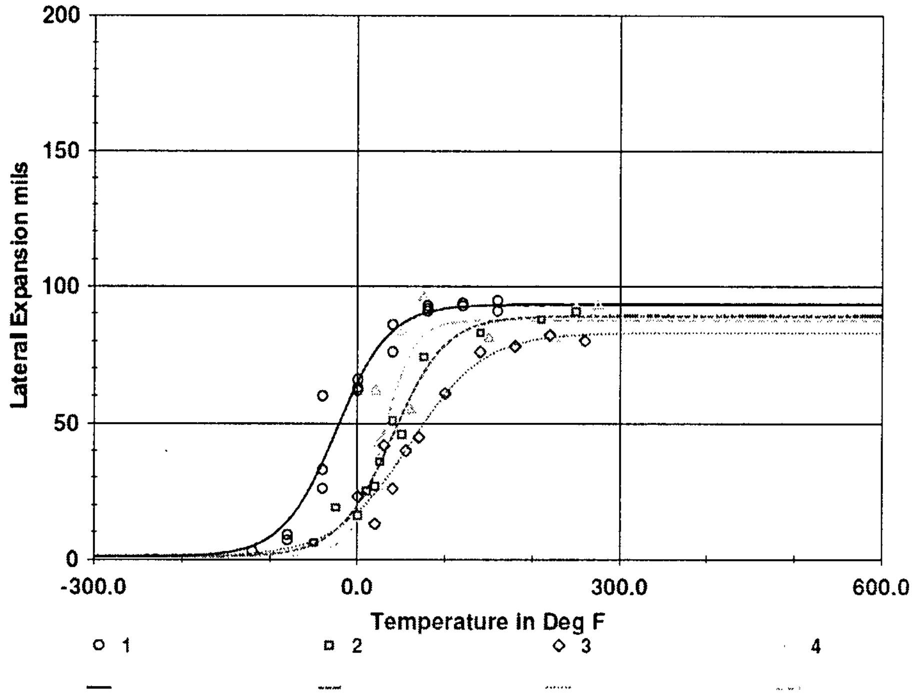
Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for the Calvert Cliffs Unit 2 Reactor Vessel Surveillance Program Weld Metal

SURVEILLANCE WELD METAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:16 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SAW	NA	10137
2	Calvert Cliffs 2	263	SAW	NA	10137
3	Calvert Cliffs 2	97	SAW	NA	10137
4	Calvert Cliffs 2	104	SAW	NA	10137



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	93.5	.0	-41.0	.0
2		1.0	89.2	-4.2	25.2	66.2
3		1.0	83.0	-10.5	44.7	85.7
4		1.0	87.8	-5.7	20.7	61.7

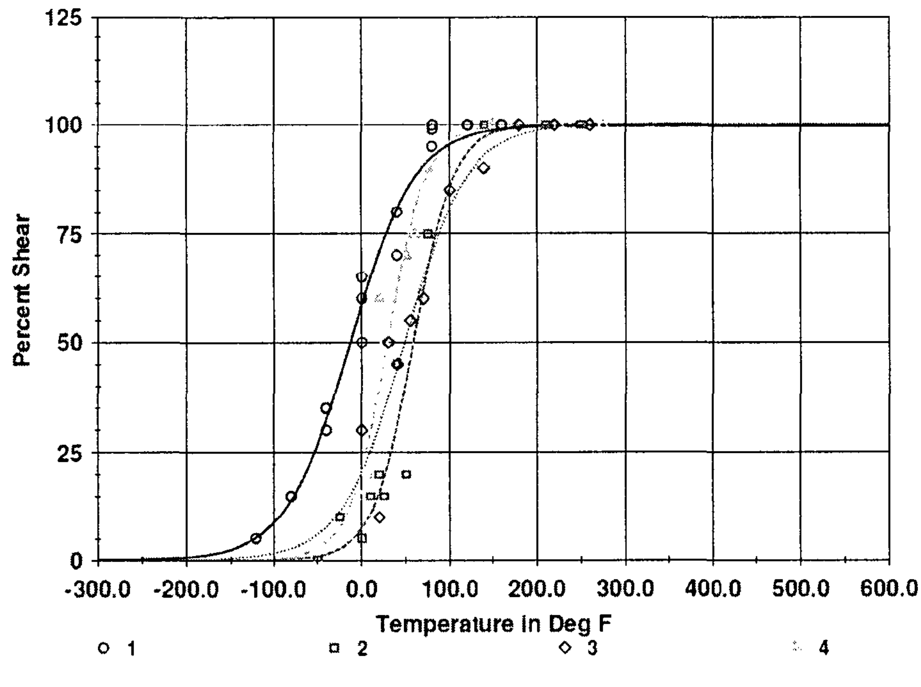
Figure 5-9 Charpy V-Notch Percent Shear vs. Temperature for the Calvert Cliffs Unit 2 Reactor Vessel Surveillance Program Weld Metal

SURVEILLANCE WELD METAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:18 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SAW	NA	10137
2	Calvert Cliffs 2	263	SAW	NA	10137
3	Calvert Cliffs 2	97	SAW	NA	10137
4	Calvert Cliffs 2	104	SAW	NA	10137



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	-12.9	.0
2		.0	100.0	.0	58.5	71.4
3		.0	100.0	.0	48.8	61.7
4		.0	100.0	.0	29.0	41.9

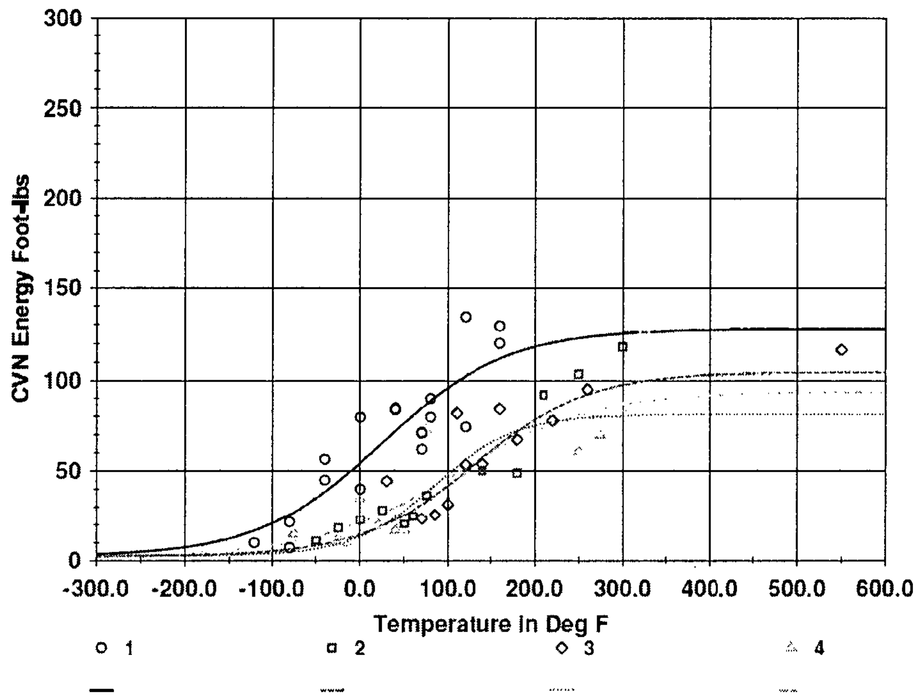
Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for the Calvert Cliffs Unit 2 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:21 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	NA	C-5286-1
2	Calvert Cliffs 2	263	SA533B1	NA	C-5286-1
3	Calvert Cliffs 2	97	SA533B1	NA	C-5286-1
4	Calvert Cliffs 2	104	SA533B1	NA	C-5286-1



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	127.7	.0	-65.0	.0	-10.7	.0
2		2.2	104.5	-23.2	65.6	130.6	121.2	131.9
3		2.2	81.4	-46.3	56.2	121.2	104.3	115.0
4		2.2	94.0	-33.7	40.4	105.4	112.9	123.6

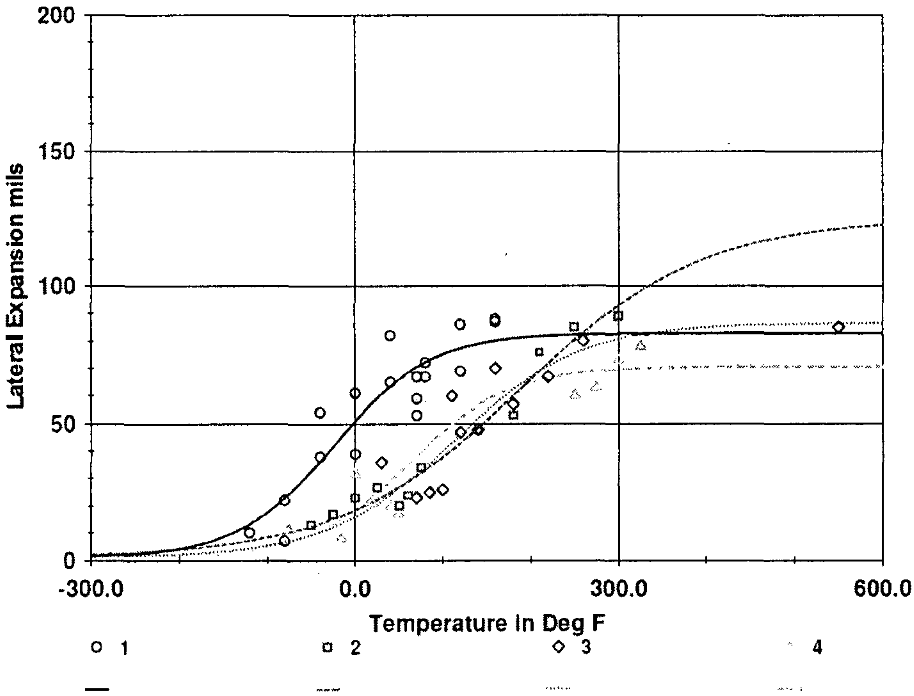
Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for the Calvert Cliffs Unit 2 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:23 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	NA	C-5286-1
2	Calvert Cliffs 2	263	SA533B1	NA	C-5286-1
3	Calvert Cliffs 2	97	SA533B1	NA	C-5286-1
4	Calvert Cliffs 2	104	SA533B1	NA	C-5286-1



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	82.8	.0	-43.3	.0
2		1.0	125.1	42.3	87.8	131.1
3		1.0	86.5	3.8	83.0	126.3
4		1.0	70.5	-12.3	59.6	102.9

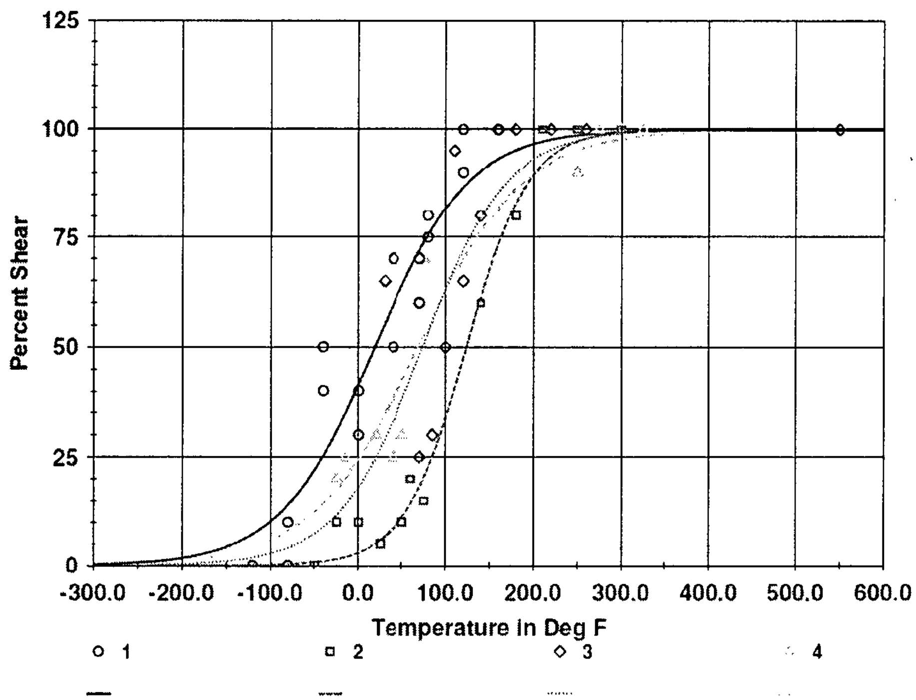
Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for the Calvert Cliffs Unit 2 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:24 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	NA	C-5286-1
2	Calvert Cliffs 2	263	SA533B1	NA	C-5286-1
3	Calvert Cliffs 2	97	SA533B1	NA	C-5286-1
4	Calvert Cliffs 2	104	SA533B1	NA	C-5286-1



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	18.6	.0
2		.0	100.0	.0	123.8	105.2
3		.0	100.0	.0	74.0	55.4
4		.0	100.0	.0	68.5	49.9

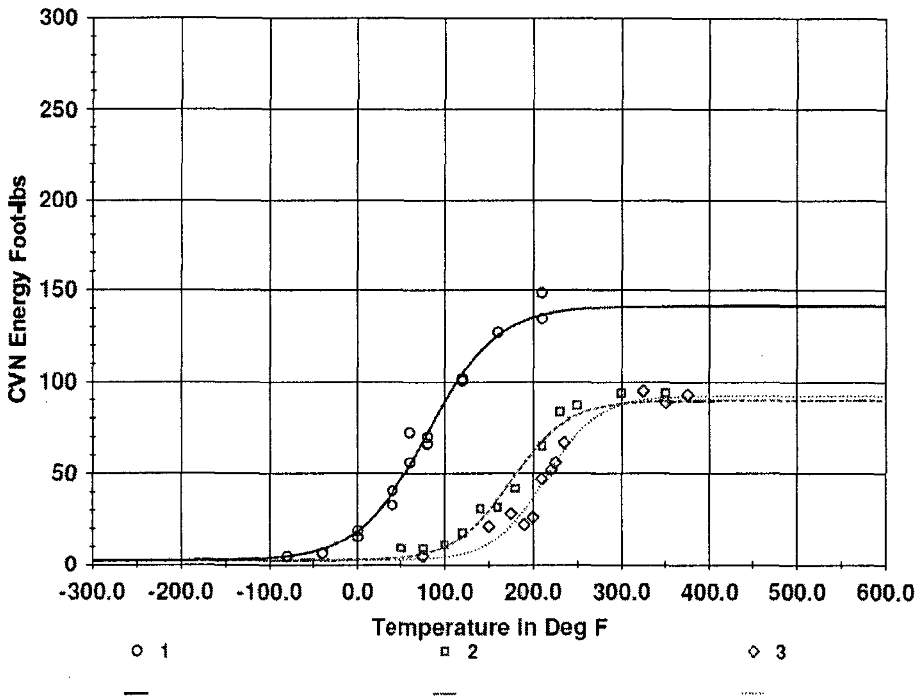
Figure 5-13 Charpy V-Notch Impact Energy vs. Temperature for the Calvert Cliffs Unit 2 Reactor Vessel Standard Reference Material

STANDARD REFERENCE MATERIAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:27 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	LT	HSST-01MY
2	Calvert Cliffs 2	263	SA533B1	LT	HSST-01MY
3	Calvert Cliffs 2	104	SA533B1	LT	HSST-01MY



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2. 2	141. 5	. 0	25. 0	. 0	54. 2	. 0
2		2. 2	89. 9	-51. 6	150. 6	125. 6	181. 0	126. 8
3		2. 2	92. 3	-49. 2	190. 5	165. 5	217. 9	163. 7

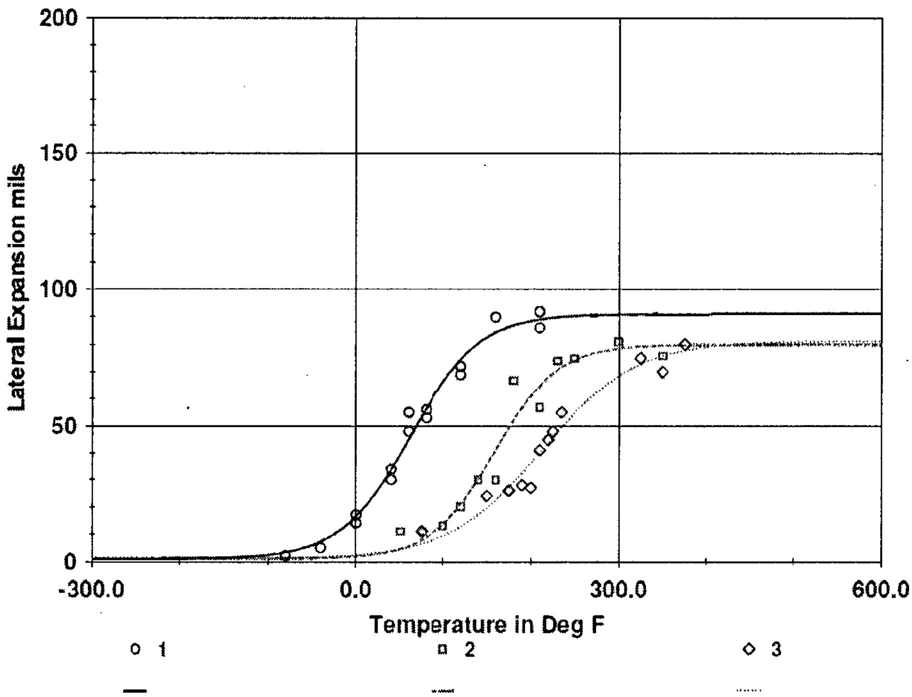
Figure 5-14 Charpy V-Notch Lateral Expansion vs. Temperature for the Calvert Cliffs Unit 2 Reactor Standard Reference Material

STANDARD REFERENCE MATERIAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:29 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	LT	HSST-01MY
2	Calvert Cliffs 2	263	SA533B1	LT	HSST-01MY
3	Calvert Cliffs 2	104	SA533B1	LT	HSST-01MY



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	91.1	.0	42.0	.0
2		1.0	79.9	-11.2	148.8	106.8
3		1.0	81.3	-9.9	197.1	155.1

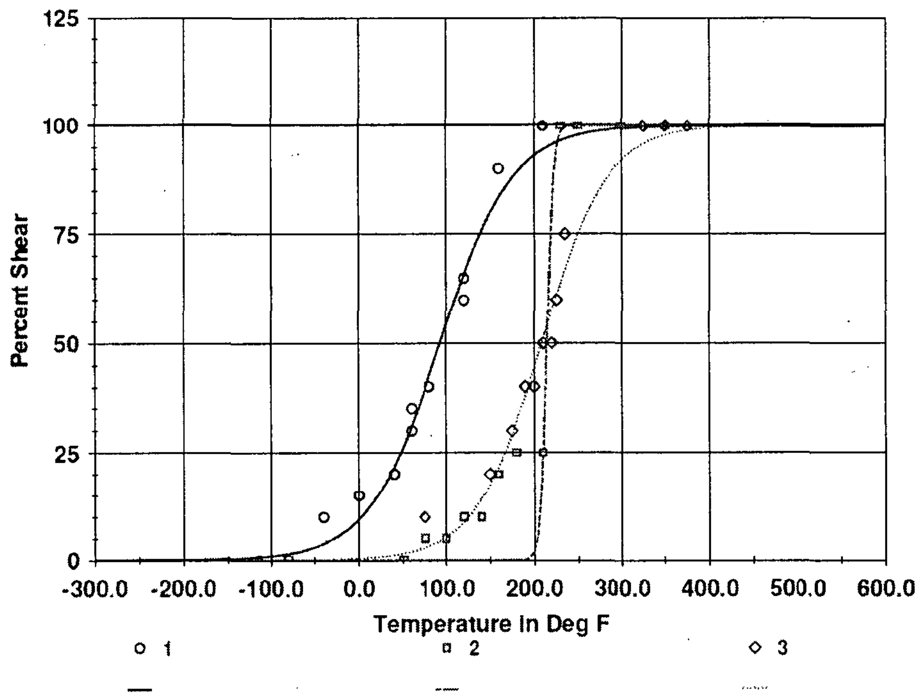
Figure 5-15 Charpy V-Notch Percent Shear vs. Temperature for the Calvert Cliffs Unit 2 Reactor Vessel Standard Reference Material

STANDARD REFERENCE MATERIAL

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/08/2011 08:30 AM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Calvert Cliffs 2	UNIRR	SA533B1	LT	HSST-01MY
2	Calvert Cliffs 2	263	SA533B1	LT	HSST-01MY
3	Calvert Cliffs 2	104	SA533B1	LT	HSST-01MY



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	92.9	.0
2		.0	100.0	.0	214.4	121.5
3		.0	100.0	.0	208.6	115.7

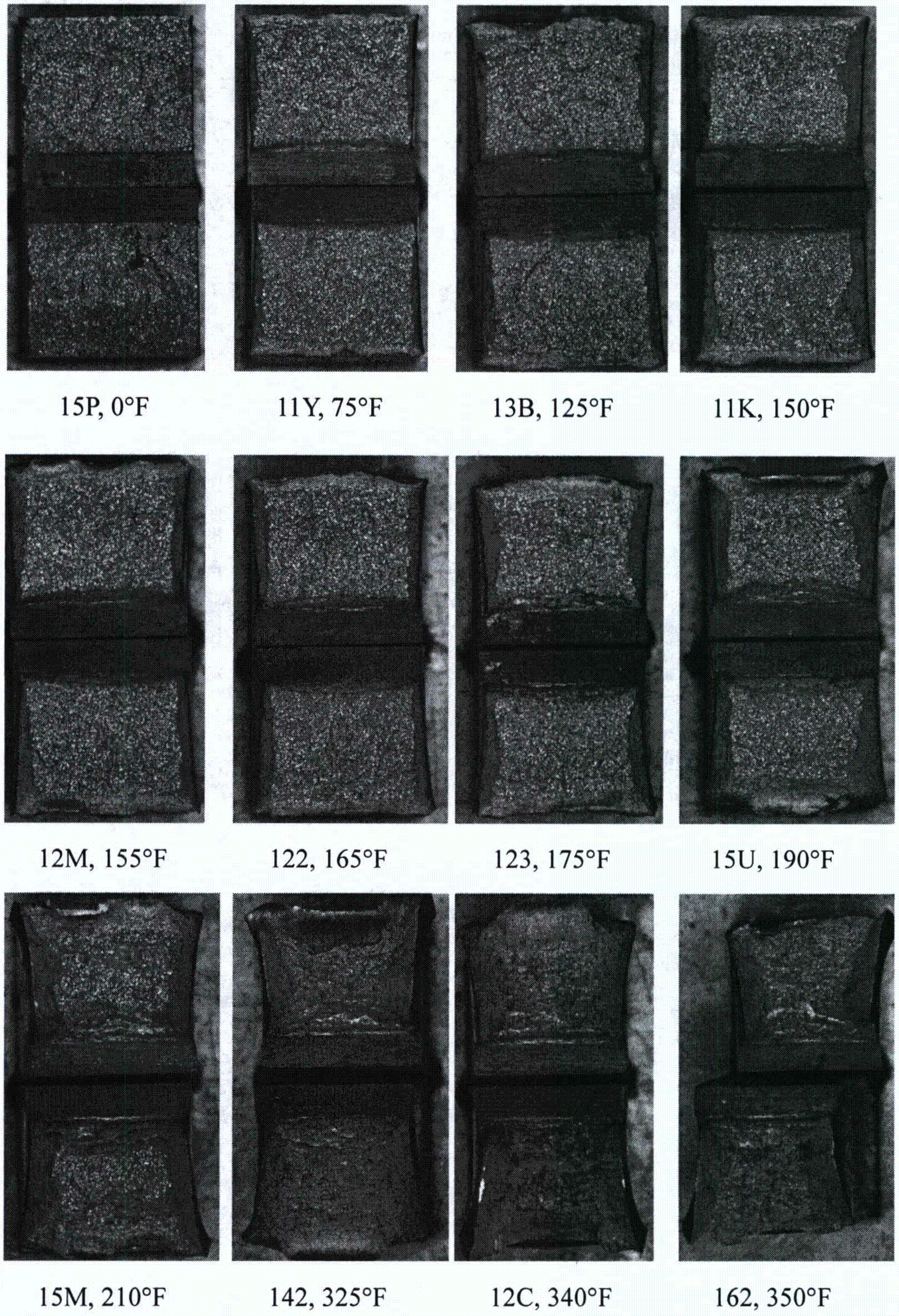


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Calvert Cliffs Unit 2 Reactor Vessel Lower Shell Plate D-8907-2 (Longitudinal Orientation)

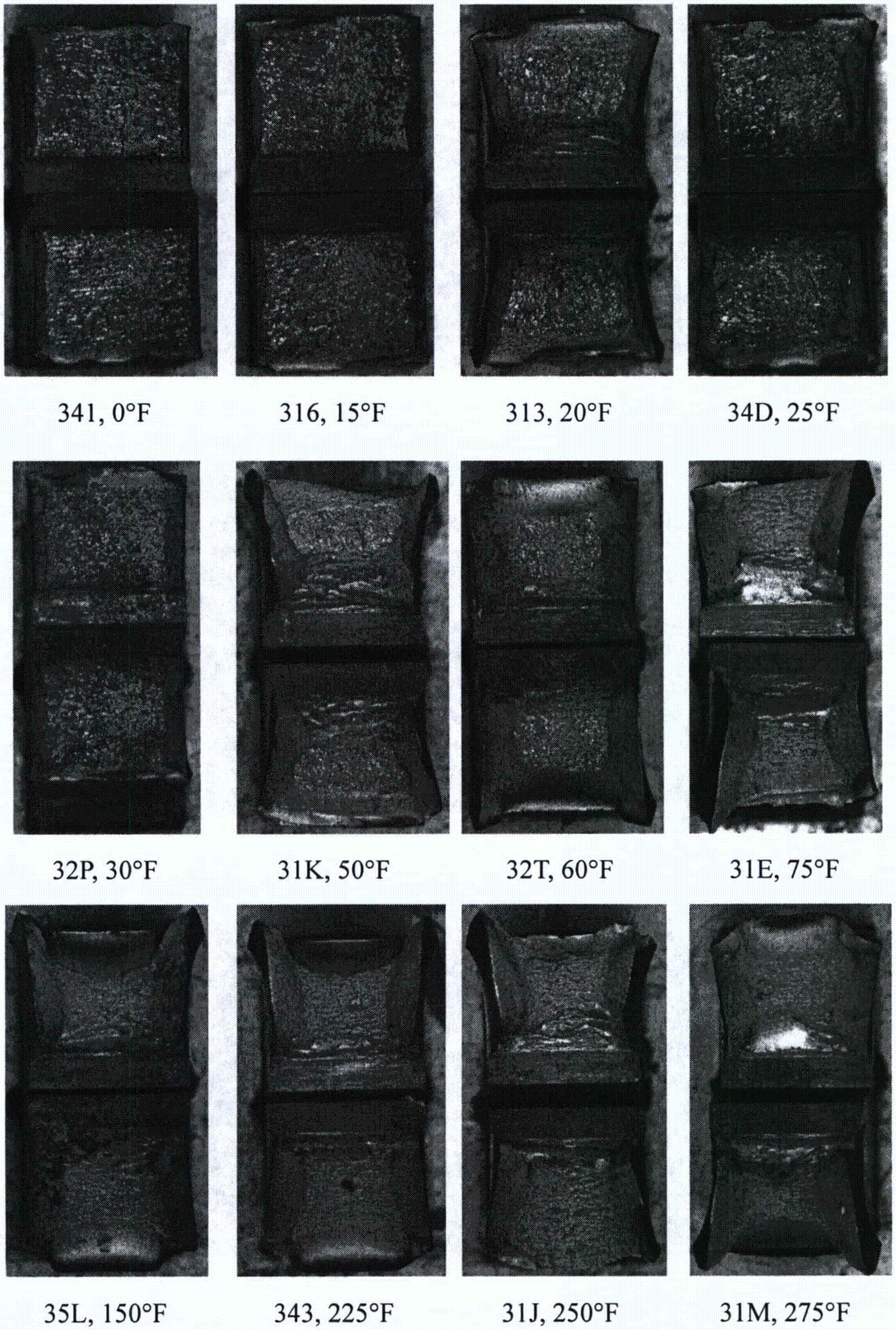


Figure 5-17 Charpy Impact Specimen Fracture Surfaces for Calvert Cliffs Unit 2 Reactor Vessel Surveillance Program Weld Material

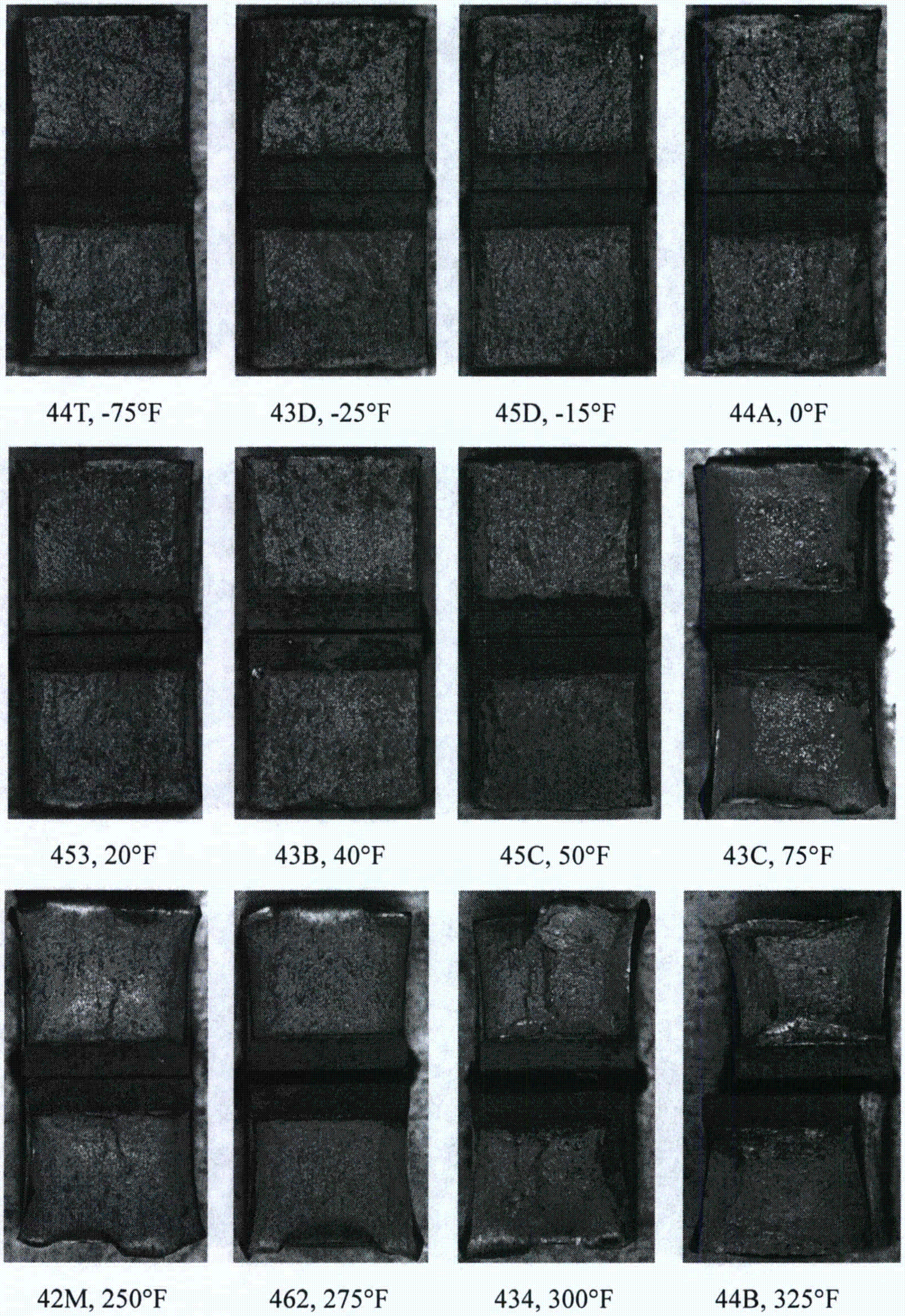


Figure 5-18 Charpy Impact Specimen Fracture Surfaces for the Calvert Cliffs Unit 2 Reactor Vessel Heat-Affected-Zone Material

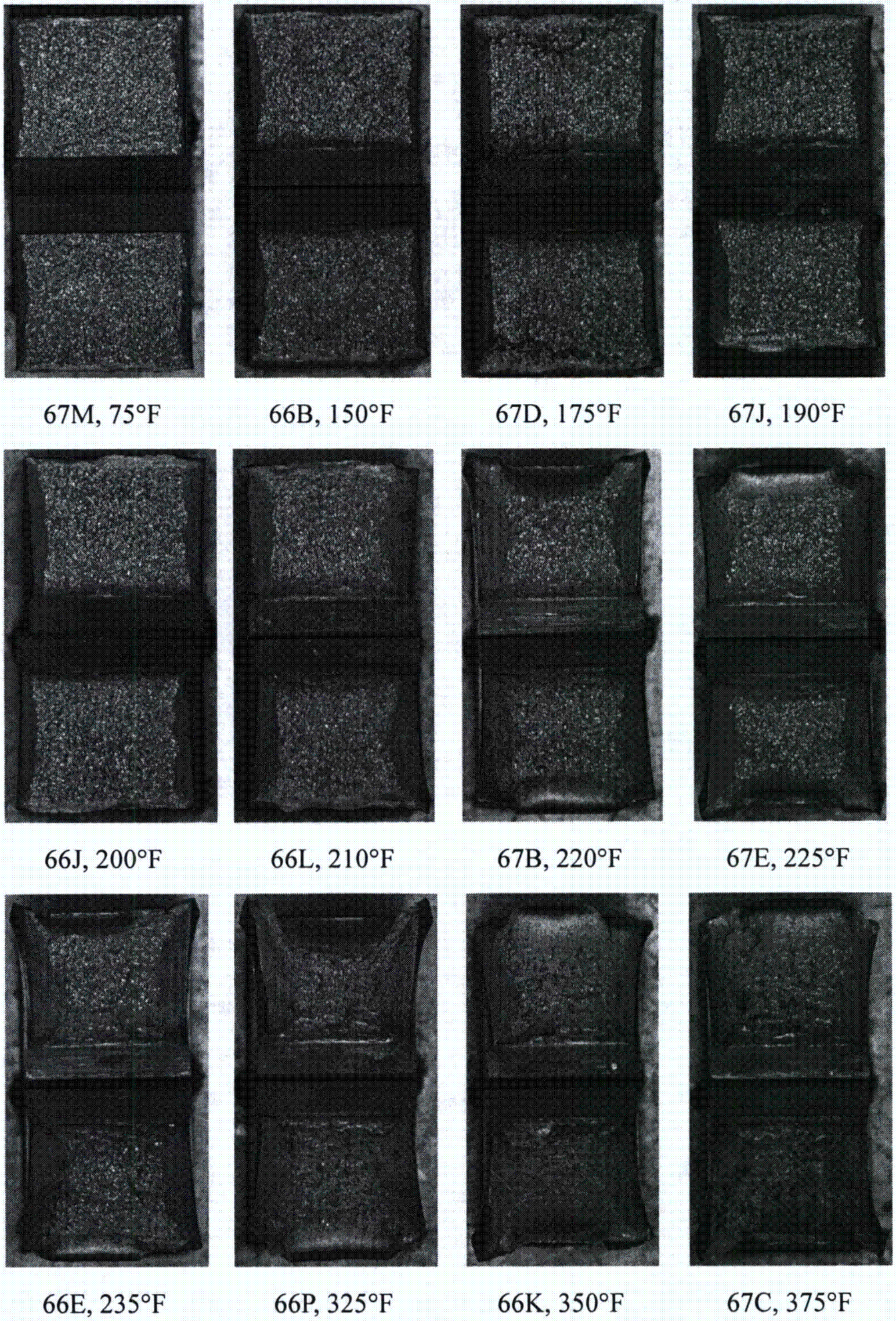
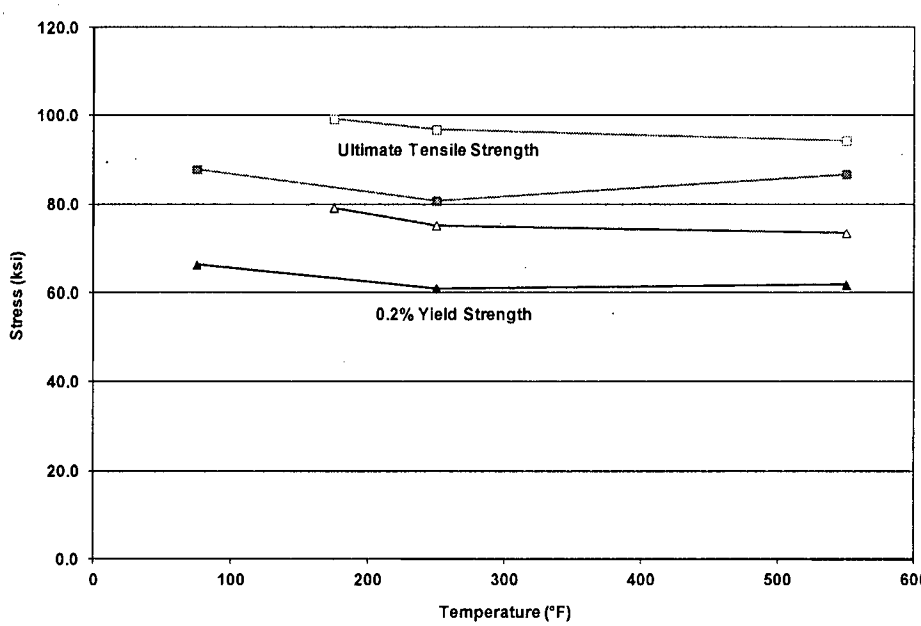


Figure 5-19 Charpy Impact Specimen Fracture Surfaces for the Calvert Cliffs Unit 2 Reactor Vessel Standard Reference Material



Legend: ▲ and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 2.44 x 10^{19} n/cm^2 (E > 1.0 MeV)

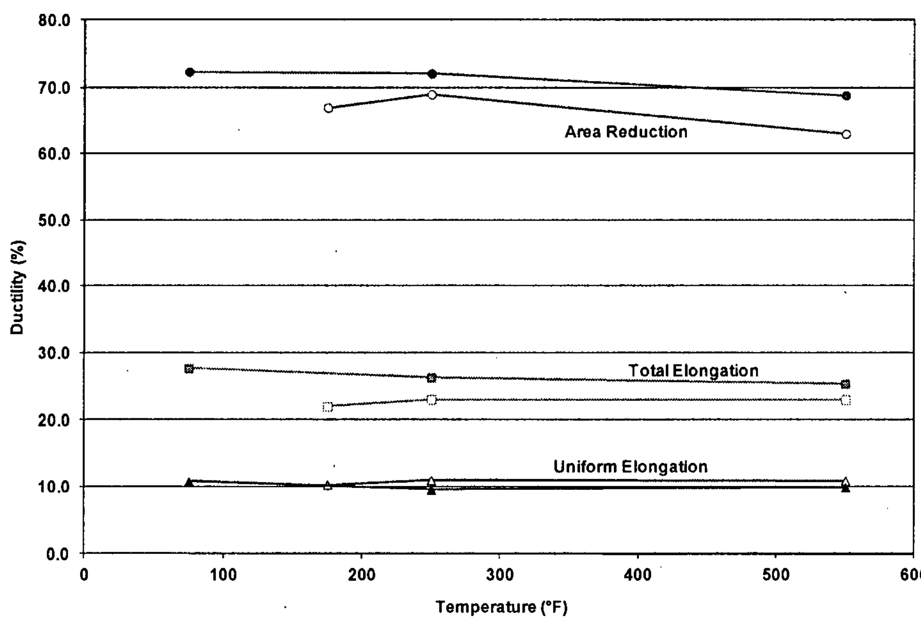
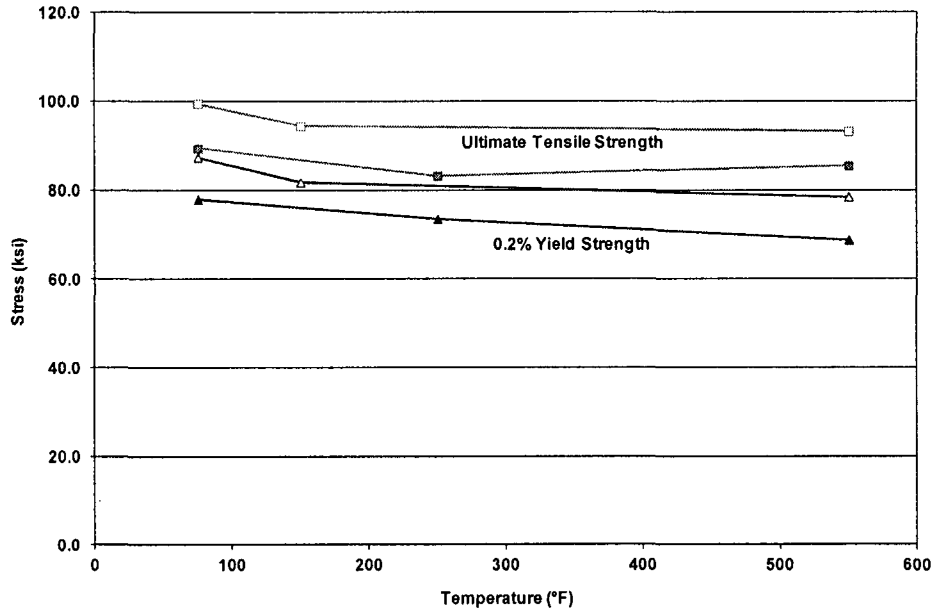


Figure 5-20 Tensile Properties for Calvert Cliffs Unit 2 Reactor Vessel Lower Shell Plate D-8907-2 (Longitudinal Orientation)



Legend: ▲ and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 2.44 x 10^{19} n/cm^2 (E > 1.0 MeV)

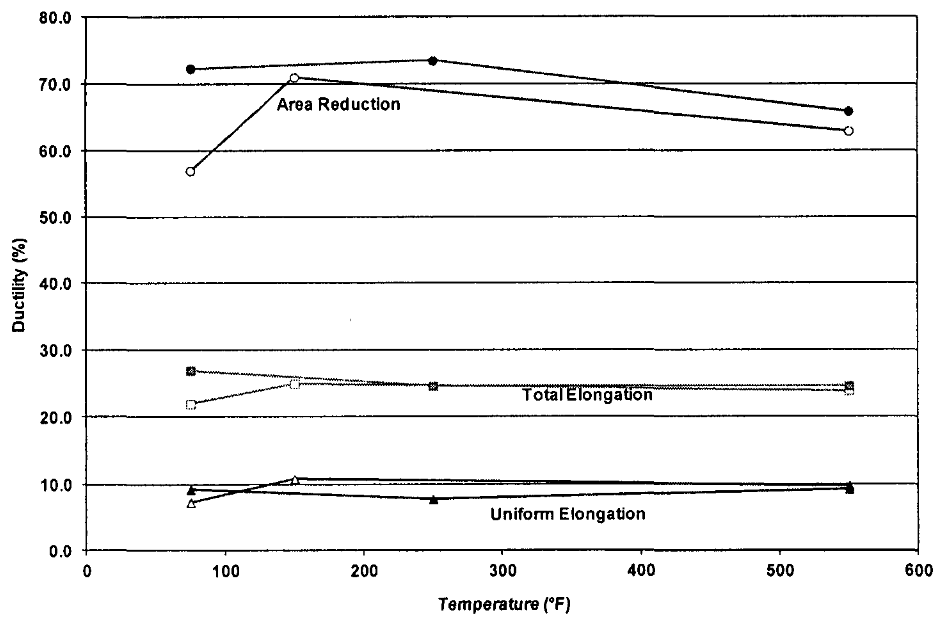
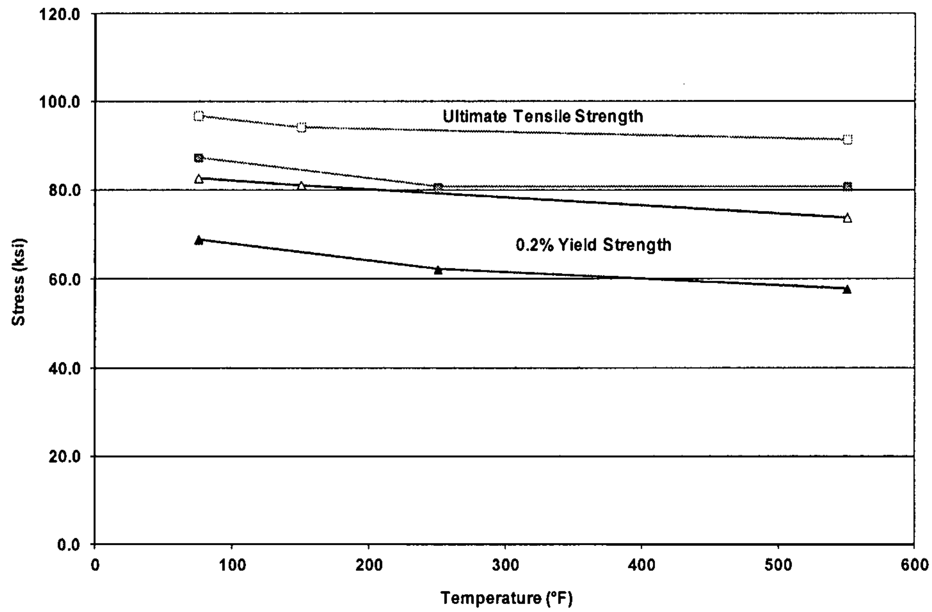


Figure 5-21 Tensile Properties for Calvert Cliffs Unit 2 Reactor Vessel Surveillance Program Weld Material



Legend: ▲ and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 2.44 x 10^{19} n/cm^2 (E > 1.0 MeV)

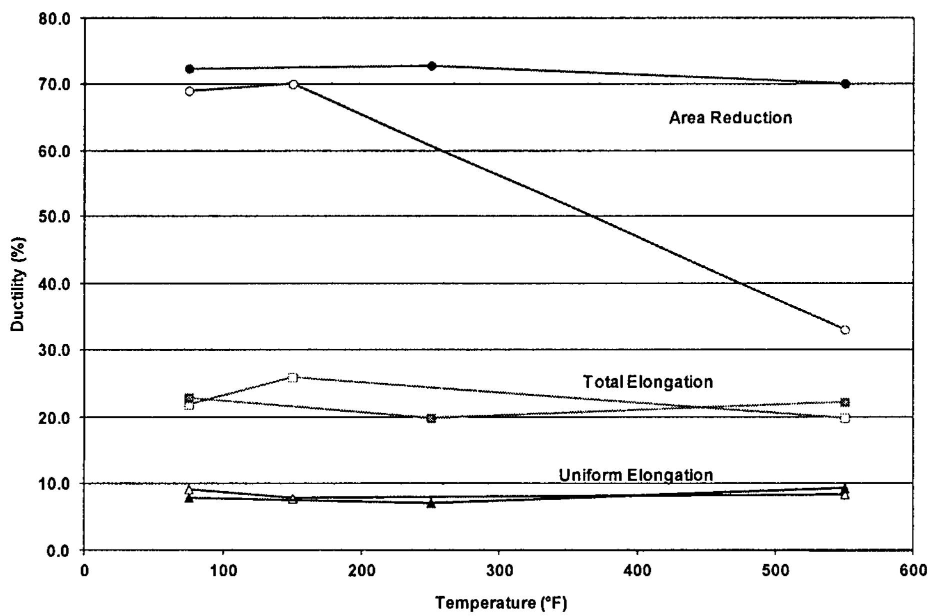
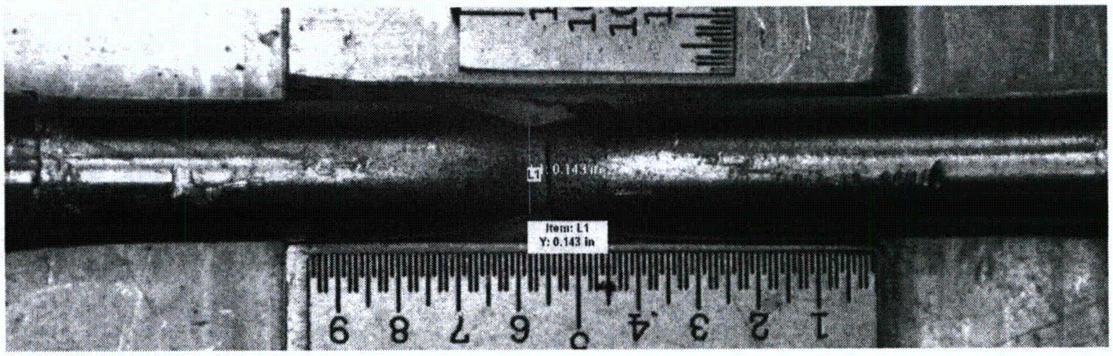
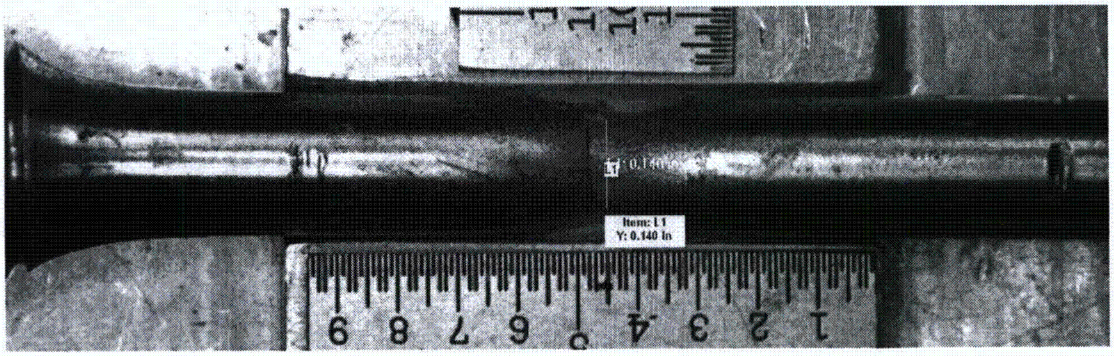


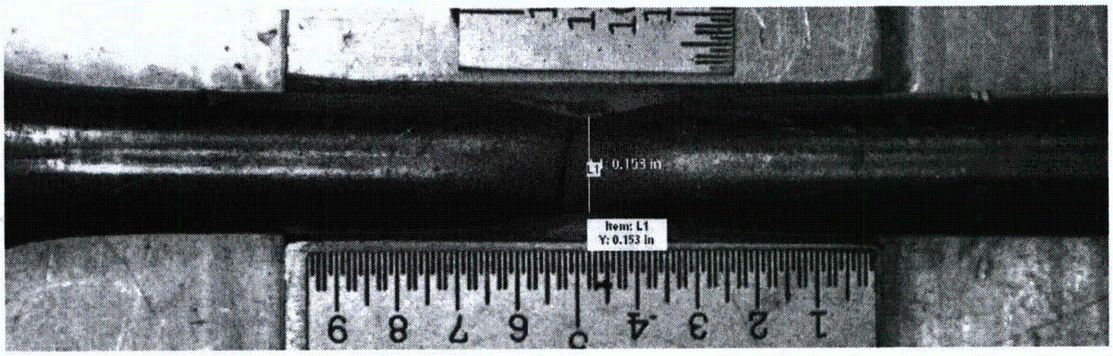
Figure 5-22 Tensile Properties for the Calvert Cliffs Unit 2 Reactor Vessel Heat-Affected-Zone Material



Specimen 1KP - Tested at 175°F

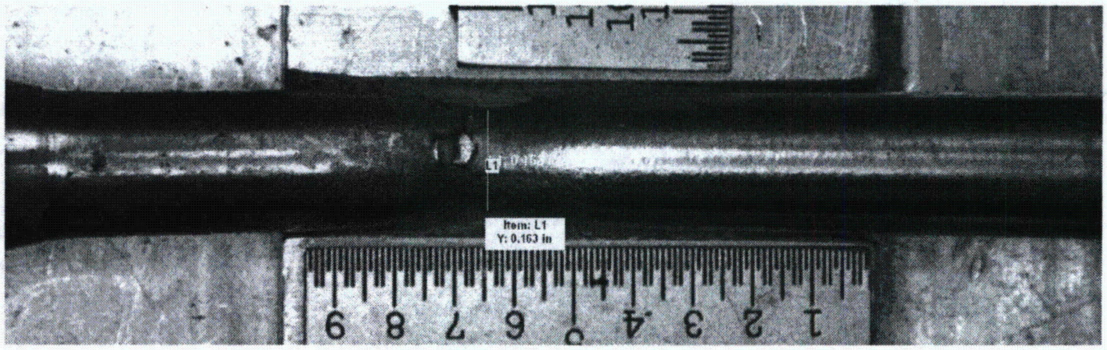


Specimen 1K2 - Tested at 250°F

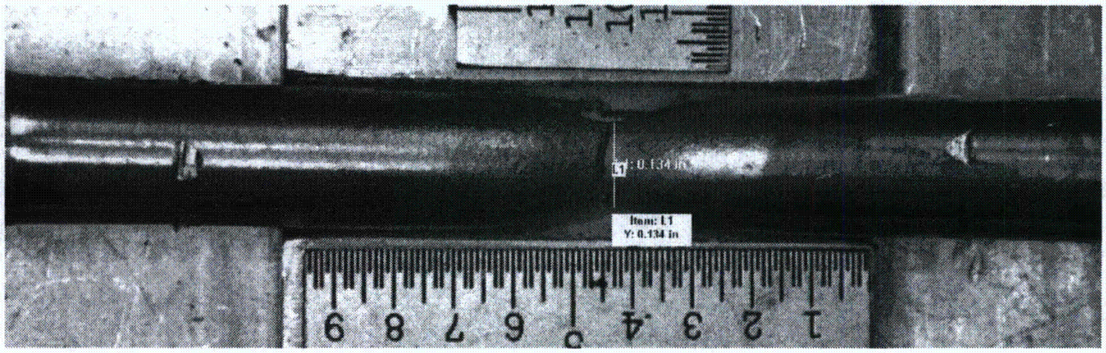


Specimen 1KE - Tested at 550°F

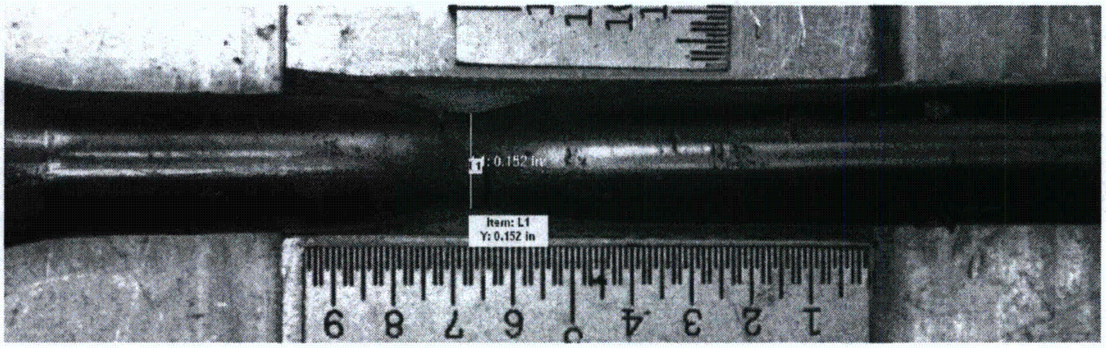
Figure 5-23 Fractured Tensile Specimens from Calvert Cliffs Unit 2 Reactor Vessel Lower Shell Plate D-8907-2 (Longitudinal Orientation)



Specimen 3JP - Tested at 75°F

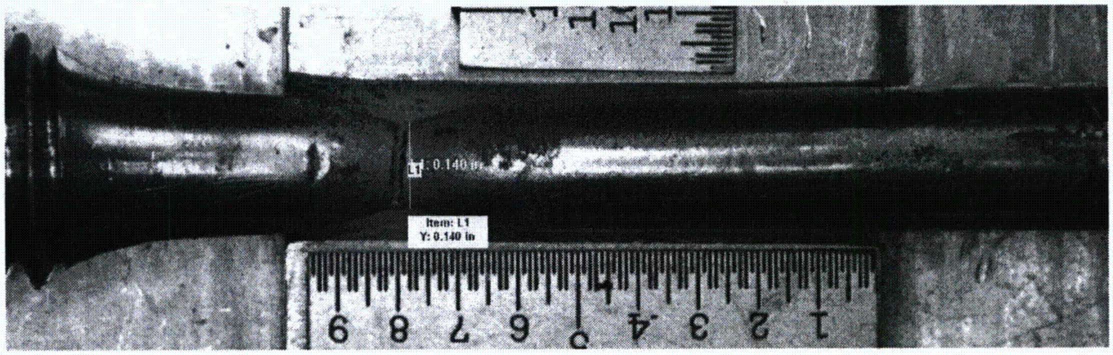


Specimen 3K4 - Tested at 150°F

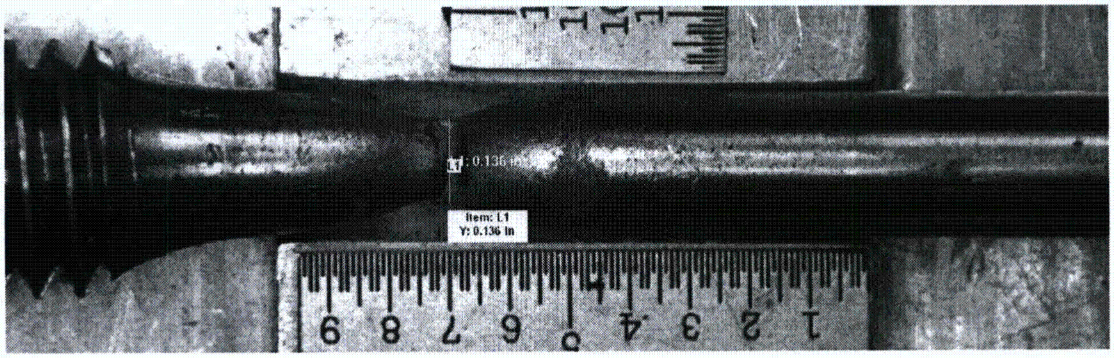


Specimen 3L4 - Tested at 550°F

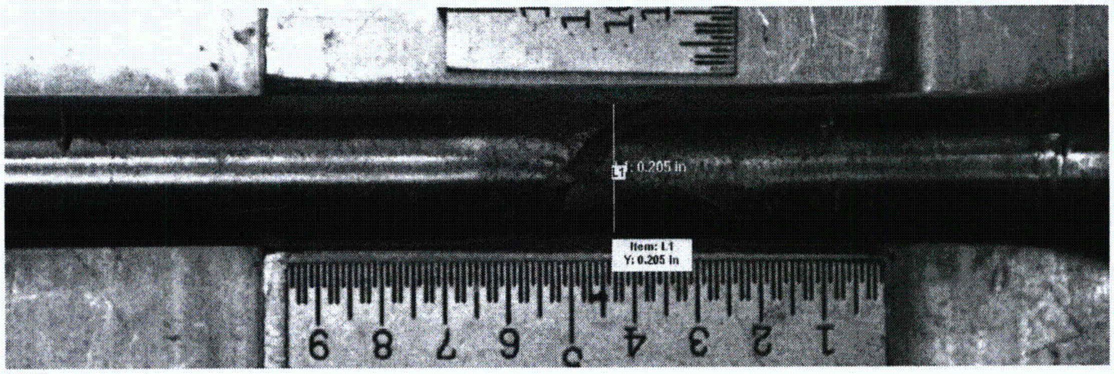
Figure 5-24 Fractured Tensile Specimens from the Calvert Cliffs Unit 2 Reactor Vessel Surveillance Program Weld Metal



Specimen 4JE - Tested at 75°F



Specimen 4JM - Tested at 150°F



Specimen 4K4 - Tested at 550°F

Figure 5-25 Fractured Tensile Specimens from the Calvert Cliffs Unit 2 Reactor Vessel Heat-Affected-Zone Material

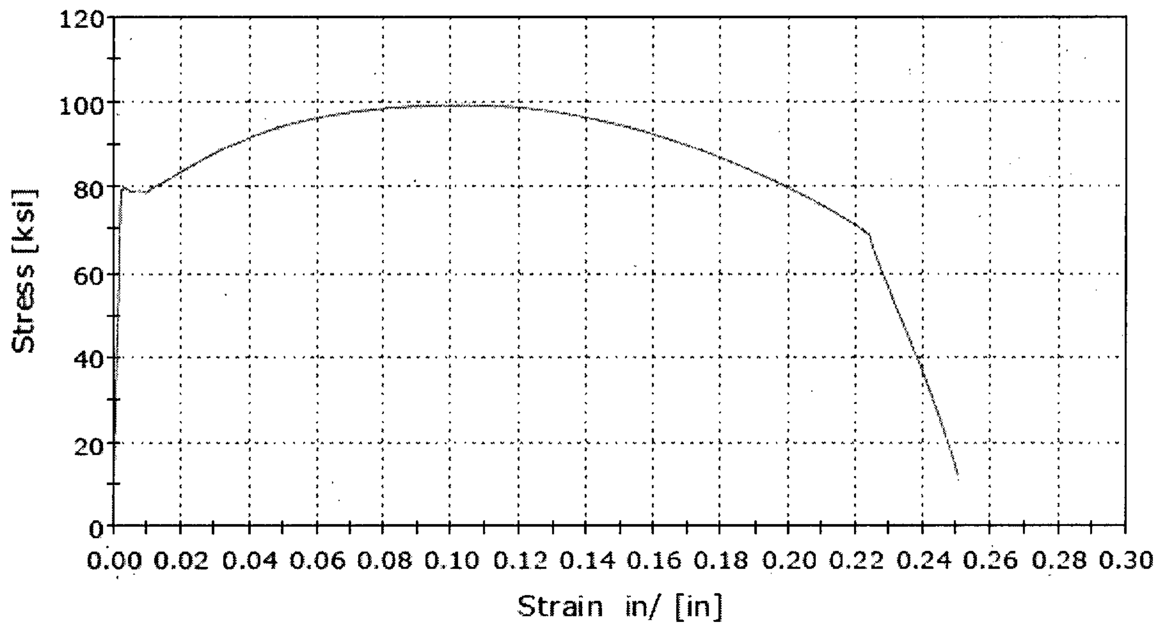


Figure 5-26 Engineering Stress-Strain Curve for Calvert Cliffs Unit 2 Lower Shell Plate D-8907-2 Tensile Specimen 1KP Tested at 175° (Longitudinal Orientation)

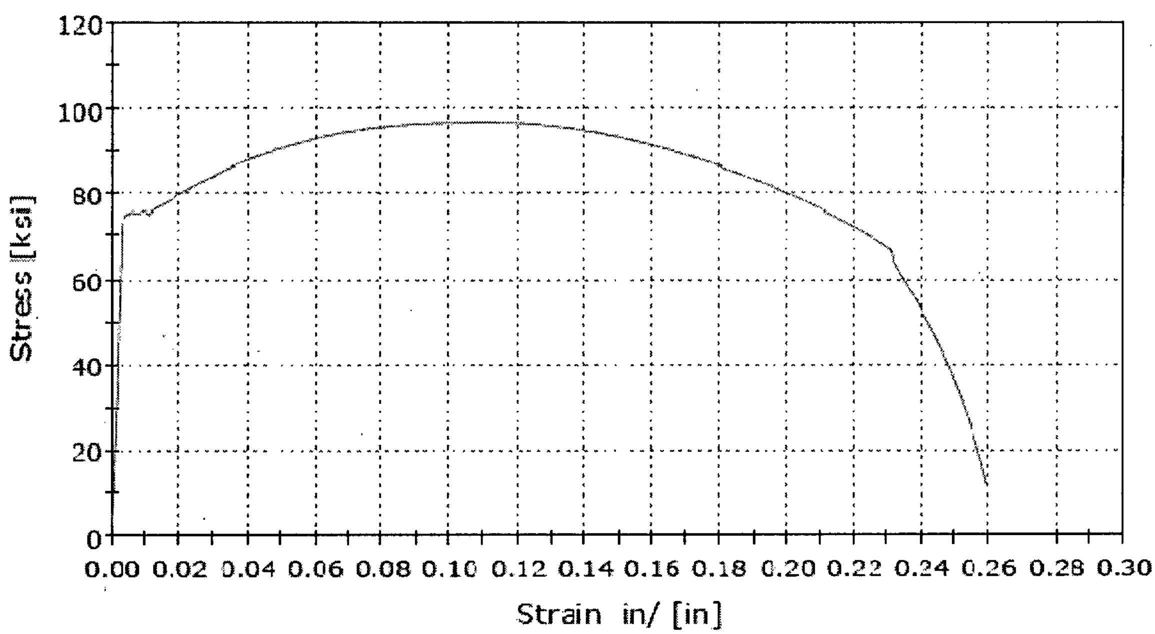


Figure 5-27 Engineering Stress-Strain Curve for Calvert Cliffs Unit 2 Lower Shell Plate D-8907-2 Tensile Specimen 1K2 Tested at 250° (Longitudinal Orientation)

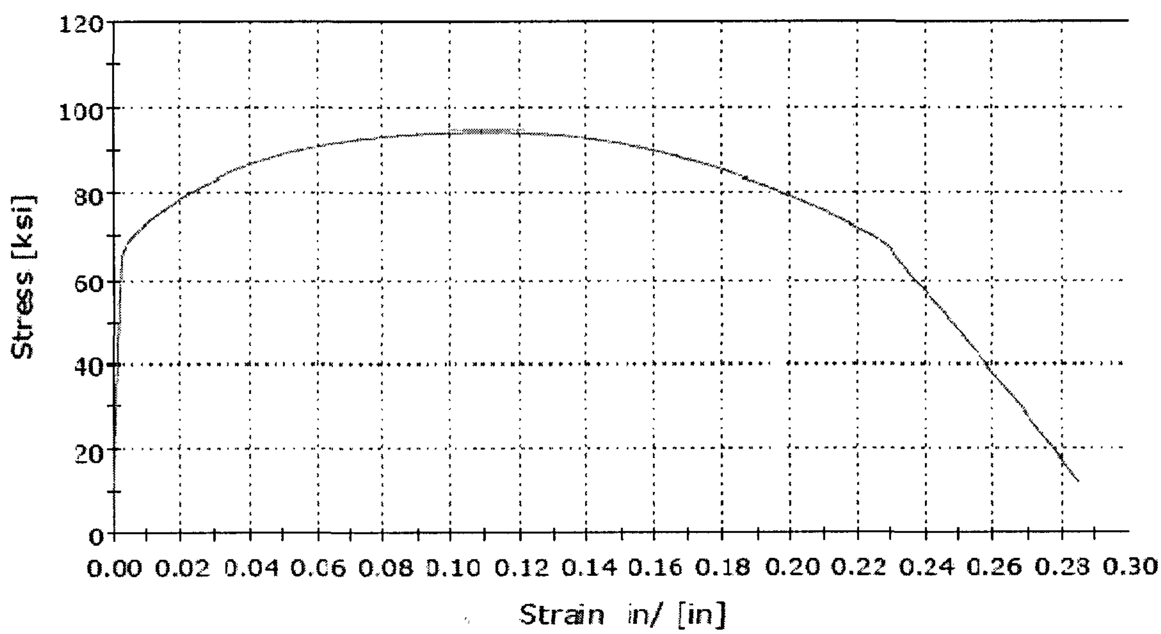


Figure 5-28 Engineering Stress-Strain Curve for Calvert Cliffs Unit 2 Lower Shell Plate D-8907-2 Tensile Specimen 1KE Tested at 550° (Longitudinal Orientation)

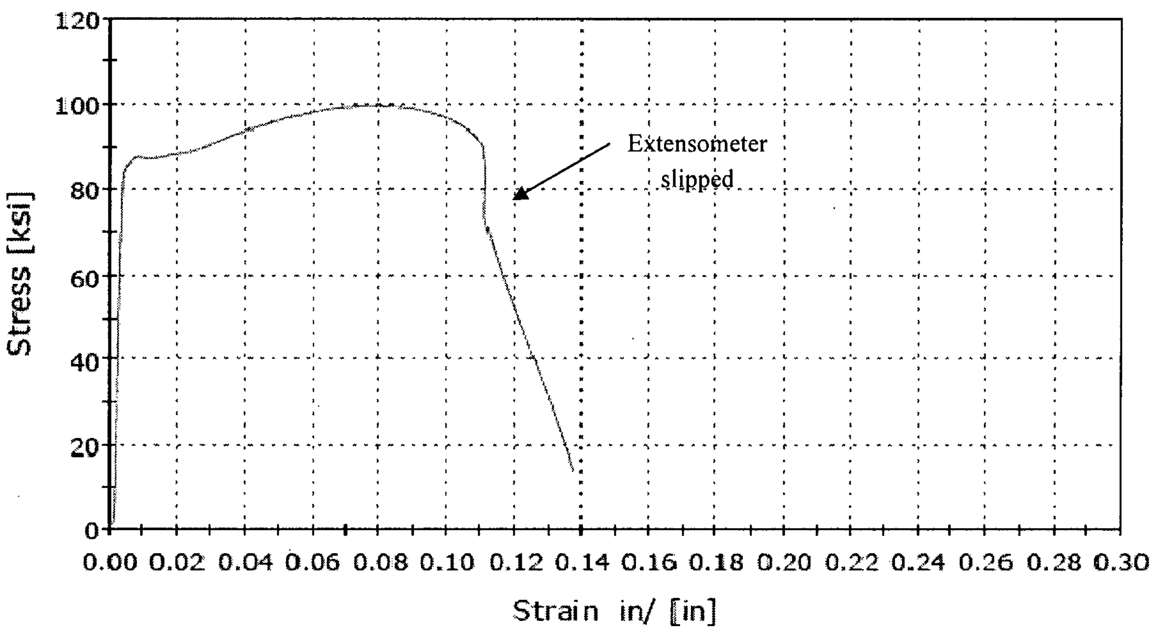


Figure 5-29 Engineering Stress-Strain Curve for Calvert Cliffs Unit 2 Surveillance Program Weld Metal Tensile Specimen 3JP Tested at 75°

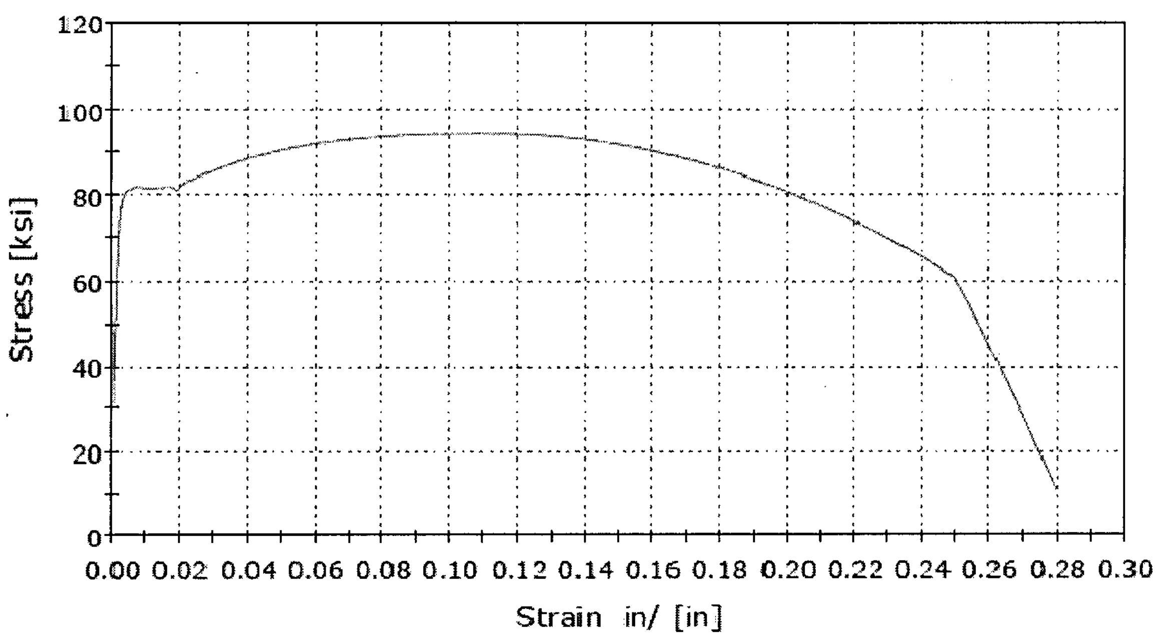


Figure 5-30 Engineering Stress-Strain Curve for Calvert Cliffs Unit 2 Surveillance Program Weld Metal Tensile Specimen 3K4 Tested at 150°

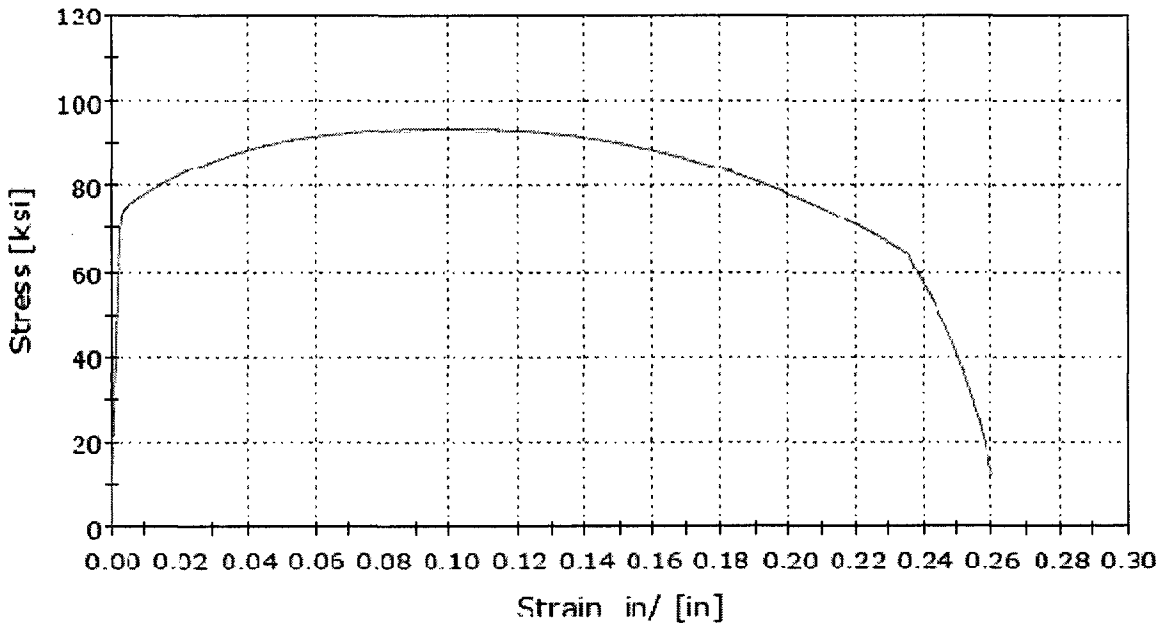


Figure 5-31 Engineering Stress-Strain Curve for Calvert Cliffs Unit 2 Surveillance Program Weld Metal Tensile Specimen 3L4 Tested at 550°

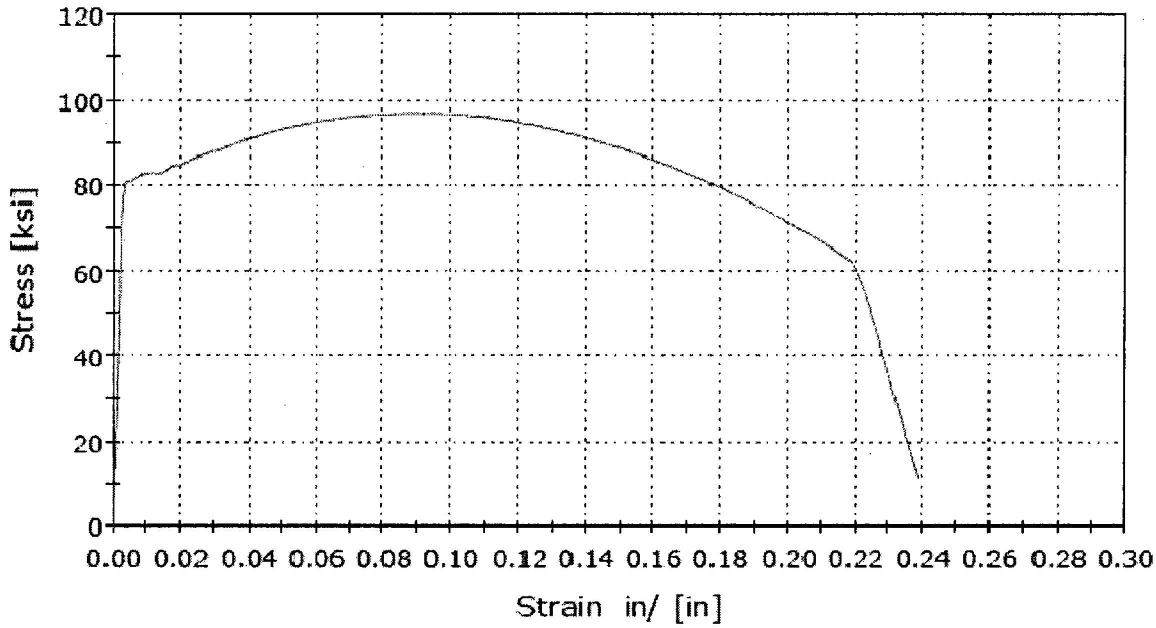


Figure 5-32 Engineering Stress-Strain Curve for Calvert Cliffs Unit 2 Heat-Affected-Zone Material Tensile Specimen 4JE Tested at 75°

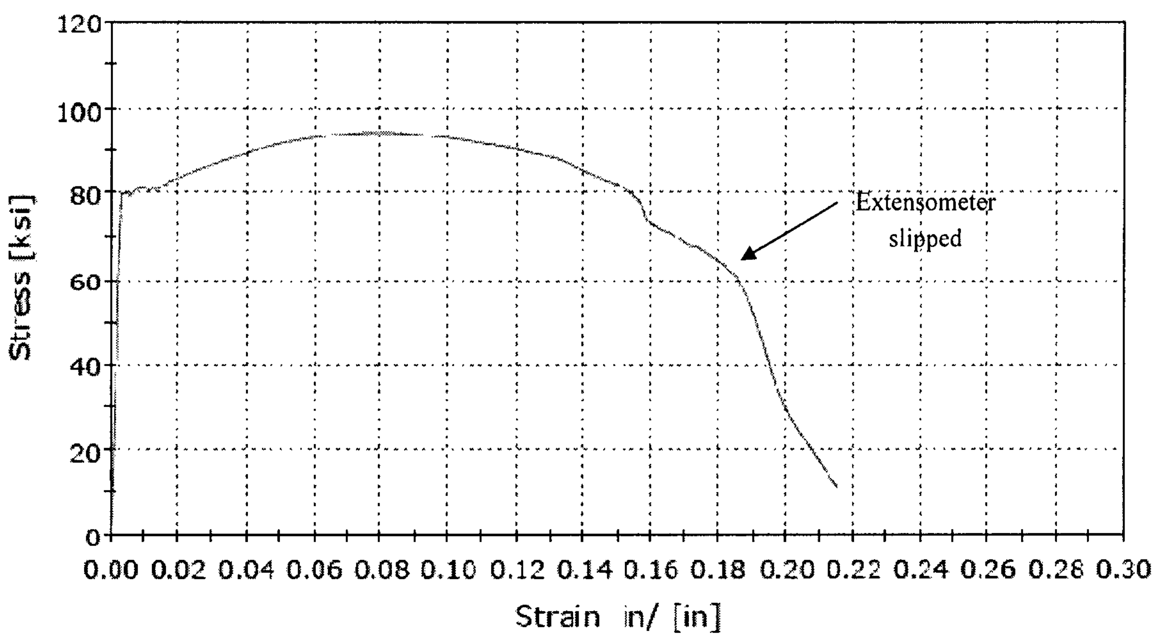


Figure 5-33 Engineering Stress-Strain Curve for Calvert Cliffs Unit 2 Heat-Affected-Zone Material Tensile Specimen 4JM Tested at 150°

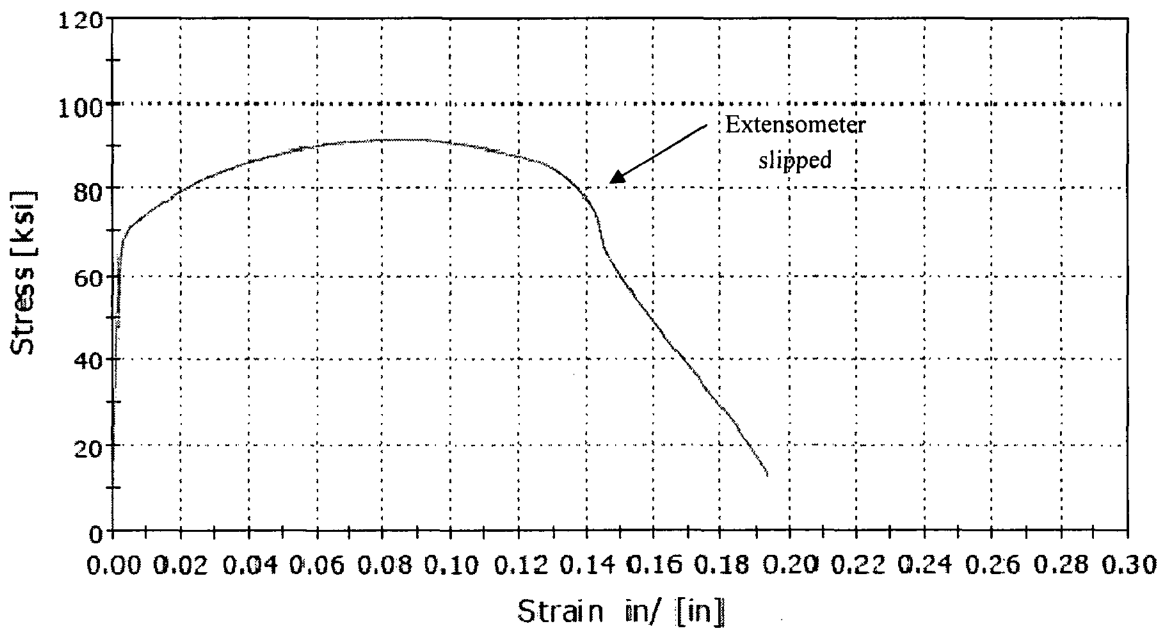


Figure 5-34 Engineering Stress-Strain Curve for Calvert Cliffs Unit 2 Heat-Affected-Zone Material Tensile Specimen 4K4 Tested at 550°

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 2 reactor to determine the neutron radiation environment within the reactor pressure vessel and surveillance capsules. In this analysis, fast neutron exposure parameters in terms of fast neutron fluence (E > 1.0 MeV) and iron atom displacements (dpa) were established on a plant- and fuel-cycle-specific basis. An evaluation of the most recent dosimetry sensor set from Capsule 104°, withdrawn at the end of the eighteenth plant operating cycle, is provided. In addition, to provide an up-to-date database applicable to the Calvert Cliffs Unit 2 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 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. However, in recent years, it has been suggested that an exposure model that accounts for differences in neutron energy spectra between surveillance capsule locations and positions within the vessel wall could lead to an improvement in the uncertainties associated with damage trend curves and improved accuracy in the evaluation of damage gradients through the reactor vessel wall.

Because of this potential shift away from a threshold fluence toward an energy-dependent damage function for data correlation, ASTM Standard Practice E853-01, "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 E693-94, "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 using 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 2 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 enough apart that they do not interfere with one another. In order to determine the neutron environment at the test specimen location, the capsules themselves must be included in the analytical model.

In performing the fast neutron exposure evaluations for the Calvert Cliffs Unit 2 reactor vessel and surveillance capsules, a series of fuel-cycle-specific forward transport calculations were carried out using the following three-dimensional flux synthesis technique:

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

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 2.

For the Calvert Cliffs Unit 2 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 ensure 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 2 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 ensure 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 18 fuel cycles at Calvert Cliffs Unit 2. 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° 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, in terms of both calculated fluence (E > 1.0 MeV) and dpa data are 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 eighteenth fuel cycle (i.e., after 27.13 EFPY at 2737 MWt of plant operation) was 2.53×10^{19} n/cm^2.

These data tabulations include both plant- and fuel-cycle-specific calculated neutron exposures at the end of the eighteenth 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 1, and from 2700 MWt to 2737 MWt that occurred during Cycle 18. The projections were based on the assumption that the core power distributions and associated plant operating characteristics from Cycle 18 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 2 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 2 reactor. From the data provided in Table 6-3, Capsule 104° received a fluence (E > 1.0 MeV) of 2.44×10^{19} n/cm^2 after exposure through the end of the eighteenth fuel cycle (i.e., after 27.13 EFPY at 2737 MWt of plant operation).

Updated lead factors for the Calvert Cliffs Unit 2 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 104°) 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°, 284° and 277°), the lead factor corresponds to the calculated fluence values at the end of Cycle 18, the last completed fuel cycle for Calvert Cliffs Unit 2.

6.3 NEUTRON DOSIMETRY

The validity of the calculated neutron exposures previously reported in Section 6.2 is demonstrated by a direct comparison against the measured sensor reaction rates and via a least-squares evaluation performed for each of the capsule dosimetry sets. However, since the neutron dosimetry measurement data merely 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 104°, which was withdrawn from Calvert Cliffs Unit 2 at the end of the eighteenth fuel cycle, is summarized below.

Reaction	Reaction Rates (rps/atom)		M/C Ratio
	Measured	Calculated	
$^{63}Cu(n,\alpha)^{60}Co$	4.22E-17	4.67E-17	0.90
$^{54}Fe(n,p)^{54}Mn$	3.77E-15	3.98E-15	0.95
$^{58}Ni(n,p)^{58}Co$	5.21E-15	5.17E-15	1.01
$^{238}U(Cd)(n,f)$ FP	9.08E-15	1.31E-14	0.69
		Average:	0.89
		% Standard Deviation:	16

The measured-to-calculated (M/C) reaction rate ratios for the Capsule 104° threshold reactions range from 0.69 to 1.01, and the average M/C ratio is 0.89 ± 16% (1σ). This direct comparison falls 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 2.

6.4 CALCULATIONAL UNCERTAINTIES

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

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

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

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

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

The first phase of the methods qualification (PCA comparisons) addressed the adequacy of basic transport calculation and dosimetry evaluation techniques and associated cross sections. This phase, however, did not test the accuracy of commercial core neutron source calculations nor did it address uncertainties in operational or geometric variables that impact power reactor calculations. The second phase of the qualification (H. B. Robinson comparisons) addressed uncertainties in these additional areas that are primarily methods-related and would tend to apply generically to all fast neutron exposure evaluations. The third phase of the qualification (analytical sensitivity study) identified the potential uncertainties introduced into the overall evaluation due to calculational methods approximations, as well as to a lack of knowledge relative to various plant-specific input parameters. The overall calculational uncertainty applicable to the Calvert Cliffs Unit 2 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 2 measurements) was used solely to demonstrate the validity of the transport calculations and to confirm the uncertainty estimates associated with the analytical results. The comparison was used only as a check and was not used in any way to modify the calculated surveillance capsule and pressure vessel neutron exposures previously described in Section 6.2. As such, the validation of the Calvert Cliffs Unit 2 analytical model based on the measured plant dosimetry is completely described in Appendix A.

The following summarizes the uncertainties developed from the first three phases of the methodology qualification. Additional information pertinent to these evaluations is provided in Reference 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 2.

Table 6-1 Calculated Neutron Exposure Rates and Integrated Exposures at the Surveillance Capsule Center

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] (a)	
				7° Capsule	14° Capsule
1	4.37E+07	4.37E+07	1.39	5.35E+10	3.86E+10
2	2.83E+07	7.20E+07	2.28	5.53E+10	3.99E+10
3	2.97E+07	1.02E+08	3.22	6.00E+10	4.43E+10
4	4.45E+07	1.46E+08	4.63	5.77E+10	4.14E+10
5	3.66E+07	1.83E+08	5.79	5.95E+10	4.40E+10
6	3.60E+07	2.19E+08	6.93	6.40E+10	4.63E+10
7	3.80E+07	2.57E+08	8.14	6.16E+10	4.42E+10
8	4.77E+07	3.05E+08	9.65	4.73E+10	3.21E+10
9	4.78E+07	3.52E+08	11.16	4.55E+10	3.03E+10
10	4.97E+07	4.02E+08	12.74	2.82E+10	2.29E+10
11	5.49E+07	4.57E+08	14.48	2.58E+10	1.93E+10
12	5.43E+07	5.11E+08	16.20	2.57E+10	2.14E+10
13	5.69E+07	5.68E+08	18.00	2.42E+10	2.05E+10
14	5.40E+07	6.22E+08	19.71	2.67E+10	2.17E+10
15	5.67E+07	6.79E+08	21.51	2.76E+10	2.19E+10
16	5.99E+07	7.39E+08	23.41	2.53E+10	1.94E+10
17	5.86E+07	7.97E+08	25.27	2.80E+10	2.03E+10
18	5.87E+07	8.56E+08	27.13	2.87E+10	2.12E+10
Future	1.54E+08	1.01E+09	32.00	2.87E+10	2.12E+10
Future	1.26E+08	1.14E+09	36.00	2.87E+10	2.12E+10
Future	1.26E+08	1.26E+09	40.00	2.87E+10	2.12E+10
Future	1.26E+08	1.39E+09	44.00	2.87E+10	2.12E+10
Future	1.26E+08	1.51E+09	48.00	2.87E+10	2.12E+10
Future	1.26E+08	1.64E+09	52.00	2.87E+10	2.12E+10
Future	6.31E+07	1.70E+09	54.00	2.87E+10	2.12E+10
Future	1.89E+08	1.89E+09	60.00	2.87E+10	2.12E+10

Notes:

(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

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] (a)	
					7° Capsule	14° Capsule
1	4.37E+07	4.37E+07	1.39	1.40	2.34E+18	1.69E+18
2	2.83E+07	7.20E+07	2.28	2.31	3.90E+18	2.82E+18
3	2.97E+07	1.02E+08	3.22	3.27	5.69E+18	4.13E+18
4	4.45E+07	1.46E+08	4.63	4.70	8.25E+18	5.98E+18
5	3.66E+07	1.83E+08	5.79	5.87	1.04E+19	7.58E+18
6	3.60E+07	2.19E+08	6.93	7.03	1.27E+19	9.25E+18
7	3.80E+07	2.57E+08	8.14	8.25	1.51E+19	1.09E+19
8	4.77E+07	3.05E+08	9.65	9.78	1.73E+19	1.25E+19
9	4.78E+07	3.52E+08	11.16	11.32	1.95E+19	1.39E+19
10	4.97E+07	4.02E+08	12.74	12.91	2.09E+19	1.51E+19
11	5.49E+07	4.57E+08	14.48	14.68	2.23E+19	1.61E+19
12	5.43E+07	5.11E+08	16.20	16.42	2.37E+19	1.73E+19
13	5.69E+07	5.68E+08	18.00	18.25	2.51E+19	1.84E+19
14	5.40E+07	6.22E+08	19.71	19.98	2.65E+19	1.96E+19
15	5.67E+07	6.79E+08	21.51	21.81	2.81E+19	2.08E+19
16	5.99E+07	7.39E+08	23.41	23.73	2.96E+19	2.20E+19
17	5.86E+07	7.97E+08	25.27	25.61	3.13E+19	2.32E+19
18	5.87E+07	8.56E+08	27.13	--	3.30E+19	2.44E+19
Future	1.54E+08	1.01E+09	32.00	--	3.82E+19	2.83E+19
Future	1.26E+08	1.14E+09	36.00	--	4.19E+19	3.10E+19
Future	1.26E+08	1.26E+09	40.00	--	4.55E+19	3.37E+19
Future	1.26E+08	1.39E+09	44.00	--	4.91E+19	3.64E+19
Future	1.26E+08	1.51E+09	48.00	--	5.27E+19	3.91E+19
Future	1.26E+08	1.64E+09	52.00	--	5.64E+19	4.17E+19
Future	6.31E+07	1.70E+09	54.00	--	5.82E+19	4.31E+19
Future	1.89E+08	1.89E+09	60.00	--	6.36E+19	4.71E+19

Notes:

(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

Cycle	Cycle Length [EFPS[b]]	Cumulative Irradiation Time [EFPS[b]]	Cumulative Irradiation Time [EFPY[b]]	Iron Atom Displacement Rate [dpa/s] [a]	
				7° Capsule	14° Capsule
1	4.37E+07	4.37E+07	1.39	7.74E-11	5.62E-11
2	2.83E+07	7.20E+07	2.28	8.02E-11	5.81E-11
3	2.97E+07	1.02E+08	3.22	8.69E-11	6.44E-11
4	4.45E+07	1.46E+08	4.63	8.35E-11	6.03E-11
5	3.66E+07	1.83E+08	5.79	8.62E-11	6.39E-11
6	3.60E+07	2.19E+08	6.93	9.27E-11	6.74E-11
7	3.80E+07	2.57E+08	8.14	8.93E-11	6.44E-11
8	4.77E+07	3.05E+08	9.65	6.86E-11	4.69E-11
9	4.78E+07	3.52E+08	11.16	6.59E-11	4.43E-11
10	4.97E+07	4.02E+08	12.74	4.10E-11	3.35E-11
11	5.49E+07	4.57E+08	14.48	3.75E-11	2.82E-11
12	5.43E+07	5.11E+08	16.20	3.75E-11	3.13E-11
13	5.69E+07	5.68E+08	18.00	3.53E-11	3.00E-11
14	5.40E+07	6.22E+08	19.71	3.88E-11	3.17E-11
15	5.67E+07	6.79E+08	21.51	4.02E-11	3.20E-11
16	5.99E+07	7.39E+08	23.41	3.69E-11	2.84E-11
17	5.86E+07	7.97E+08	25.27	4.07E-11	2.97E-11
18	5.87E+07	8.56E+08	27.13	4.18E-11	3.10E-11
Future	1.54E+08	1.01E+09	32.00	4.18E-11	3.10E-11
Future	1.26E+08	1.14E+09	36.00	4.18E-11	3.10E-11
Future	1.26E+08	1.26E+09	40.00	4.18E-11	3.10E-11
Future	1.26E+08	1.39E+09	44.00	4.18E-11	3.10E-11
Future	1.26E+08	1.51E+09	48.00	4.18E-11	3.10E-11
Future	1.26E+08	1.64E+09	52.00	4.18E-11	3.10E-11
Future	6.31E+07	1.70E+09	54.00	4.18E-11	3.10E-11
Future	1.89E+08	1.89E+09	60.00	4.18E-11	3.10E-11

Notes:

(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

Cycle	Cycle Length [EFPS[b]]	Cumulative Irradiation Time [EFPS[b]]	Cumulative Irradiation Time [EFPY[b]]	Cumulative Irradiation Time [EFPY[c]]	Iron Atom Displacements [dpa] [a]	
					7° Capsule	14° Capsule
1	4.37E+07	4.37E+07	1.39	1.40	3.39E-03	2.46E-03
2	2.83E+07	7.20E+07	2.28	2.31	5.66E-03	4.10E-03
3	2.97E+07	1.02E+08	3.22	3.27	8.24E-03	6.01E-03
4	4.45E+07	1.46E+08	4.63	4.70	1.20E-02	8.70E-03
5	3.66E+07	1.83E+08	5.79	5.87	1.51E-02	1.10E-02
6	3.60E+07	2.19E+08	6.93	7.03	1.84E-02	1.35E-02
7	3.80E+07	2.57E+08	8.14	8.25	2.18E-02	1.59E-02
8	4.77E+07	3.05E+08	9.65	9.78	2.51E-02	1.82E-02
9	4.78E+07	3.52E+08	11.16	11.32	2.83E-02	2.03E-02
10	4.97E+07	4.02E+08	12.74	12.91	3.03E-02	2.19E-02
11	5.49E+07	4.57E+08	14.48	14.68	3.24E-02	2.35E-02
12	5.43E+07	5.11E+08	16.20	16.42	3.44E-02	2.52E-02
13	5.69E+07	5.68E+08	18.00	18.25	3.64E-02	2.69E-02
14	5.40E+07	6.22E+08	19.71	19.98	3.85E-02	2.86E-02
15	5.67E+07	6.79E+08	21.51	21.81	4.08E-02	3.04E-02
16	5.99E+07	7.39E+08	23.41	23.73	4.30E-02	3.21E-02
17	5.86E+07	7.97E+08	25.27	25.61	4.54E-02	3.38E-02
18	5.87E+07	8.56E+08	27.13	--	4.78E-02	3.57E-02
Future	1.54E+08	1.01E+09	32.00	--	5.55E-02	4.14E-02
Future	1.26E+08	1.14E+09	36.00	--	6.08E-02	4.53E-02
Future	1.26E+08	1.26E+09	40.00	--	6.61E-02	4.92E-02
Future	1.26E+08	1.39E+09	44.00	--	7.13E-02	5.31E-02
Future	1.26E+08	1.51E+09	48.00	--	7.66E-02	5.70E-02
Future	1.26E+08	1.64E+09	52.00	--	8.19E-02	6.09E-02
Future	6.31E+07	1.70E+09	54.00	--	8.45E-02	6.29E-02
Future	1.89E+08	1.89E+09	60.00	--	9.24E-02	6.88E-02

Notes:

(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	4.37E+07	4.37E+07	1.39	4.20E+10	2.70E+10	2.30E+10	1.85E+10
2	2.83E+07	7.20E+07	2.28	4.28E+10	2.74E+10	2.54E+10	2.06E+10
3	2.97E+07	1.02E+08	3.22	4.48E+10	2.99E+10	2.69E+10	2.10E+10
4	4.45E+07	1.46E+08	4.63	4.37E+10	2.79E+10	2.50E+10	1.97E+10
5	3.66E+07	1.83E+08	5.79	4.42E+10	2.96E+10	2.66E+10	2.11E+10
6	3.60E+07	2.19E+08	6.93	4.84E+10	3.12E+10	2.79E+10	2.17E+10
7	3.80E+07	2.57E+08	8.14	4.68E+10	2.99E+10	2.78E+10	2.12E+10
8	4.77E+07	3.05E+08	9.65	3.84E+10	2.19E+10	1.78E+10	1.34E+10
9	4.78E+07	3.52E+08	11.16	3.74E+10	2.08E+10	1.61E+10	1.17E+10
10	4.97E+07	4.02E+08	12.74	2.12E+10	1.60E+10	1.47E+10	1.09E+10
11	5.49E+07	4.57E+08	14.48	2.01E+10	1.34E+10	1.20E+10	1.09E+10
12	5.43E+07	5.11E+08	16.20	1.94E+10	1.52E+10	1.43E+10	1.17E+10
13	5.69E+07	5.68E+08	18.00	1.81E+10	1.45E+10	1.42E+10	1.15E+10
14	5.40E+07	6.22E+08	19.71	2.01E+10	1.52E+10	1.35E+10	1.05E+10
15	5.67E+07	6.79E+08	21.51	2.13E+10	1.54E+10	1.45E+10	1.13E+10
16	5.99E+07	7.39E+08	23.41	2.00E+10	1.39E+10	1.32E+10	1.15E+10
17	5.86E+07	7.97E+08	25.27	2.20E+10	1.39E+10	1.26E+10	1.11E+10
18	5.87E+07	8.56E+08	27.13	2.24E+10	1.46E+10	1.28E+10	1.04E+10
Future	1.54E+08	1.01E+09	32.00	2.24E+10	1.46E+10	1.28E+10	1.04E+10
Future	1.26E+08	1.14E+09	36.00	2.24E+10	1.46E+10	1.28E+10	1.04E+10
Future	1.26E+08	1.26E+09	40.00	2.24E+10	1.46E+10	1.28E+10	1.04E+10
Future	1.26E+08	1.39E+09	44.00	2.24E+10	1.46E+10	1.28E+10	1.04E+10
Future	1.26E+08	1.51E+09	48.00	2.24E+10	1.46E+10	1.28E+10	1.04E+10
Future	1.26E+08	1.64E+09	52.00	2.24E+10	1.46E+10	1.28E+10	1.04E+10
Future	6.31E+07	1.70E+09	54.00	2.24E+10	1.46E+10	1.28E+10	1.04E+10
Future	1.89E+08	1.89E+09	60.00	2.24E+10	1.46E+10	1.28E+10	1.04E+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/cm²]			
					0°	15°	30°	45°
1	4.37E+07	4.37E+07	1.39	1.40	1.83E+18	1.18E+18	1.01E+18	8.10E+17
2	2.83E+07	7.20E+07	2.28	2.31	3.05E+18	1.96E+18	1.73E+18	1.39E+18
3	2.97E+07	1.02E+08	3.22	3.27	4.38E+18	2.84E+18	2.52E+18	2.02E+18
4	4.45E+07	1.46E+08	4.63	4.70	6.32E+18	4.08E+18	3.64E+18	2.89E+18
5	3.66E+07	1.83E+08	5.79	5.87	7.93E+18	5.16E+18	4.60E+18	3.66E+18
6	3.60E+07	2.19E+08	6.93	7.03	9.64E+18	6.27E+18	5.59E+18	4.43E+18
7	3.80E+07	2.57E+08	8.14	8.25	1.14E+19	7.38E+18	6.63E+18	5.22E+18
8	4.77E+07	3.05E+08	9.65	9.78	1.32E+19	8.43E+18	7.48E+18	5.86E+18
9	4.78E+07	3.52E+08	11.16	11.32	1.50E+19	9.39E+18	8.22E+18	6.41E+18
10	4.97E+07	4.02E+08	12.74	12.91	1.60E+19	1.02E+19	8.95E+18	6.95E+18
11	5.49E+07	4.57E+08	14.48	14.68	1.71E+19	1.09E+19	9.61E+18	7.54E+18
12	5.43E+07	5.11E+08	16.20	16.42	1.82E+19	1.17E+19	1.04E+19	8.18E+18
13	5.69E+07	5.68E+08	18.00	18.25	1.92E+19	1.26E+19	1.12E+19	8.83E+18
14	5.40E+07	6.22E+08	19.71	19.98	2.03E+19	1.34E+19	1.19E+19	9.40E+18
15	5.67E+07	6.79E+08	21.51	21.81	2.15E+19	1.43E+19	1.27E+19	1.00E+19
16	5.99E+07	7.39E+08	23.41	23.73	2.27E+19	1.51E+19	1.35E+19	1.07E+19
17	5.86E+07	7.97E+08	25.27	25.61	2.40E+19	1.59E+19	1.43E+19	1.14E+19
18	5.87E+07	8.56E+08	27.13	--	2.53E+19	1.68E+19	1.50E+19	1.20E+19
Future	1.54E+08	1.01E+09	32.00	--	2.87E+19	1.90E+19	1.70E+19	1.36E+19
Future	1.26E+08	1.14E+09	36.00	--	3.15E+19	2.08E+19	1.86E+19	1.49E+19
Future	1.26E+08	1.26E+09	40.00	--	3.43E+19	2.26E+19	2.02E+19	1.62E+19
Future	1.26E+08	1.39E+09	44.00	--	3.71E+19	2.45E+19	2.18E+19	1.75E+19
Future	1.26E+08	1.51E+09	48.00	--	4.00E+19	2.63E+19	2.34E+19	1.88E+19
Future	1.26E+08	1.64E+09	52.00	--	4.28E+19	2.81E+19	2.50E+19	2.01E+19
Future	6.31E+07	1.70E+09	54.00	--	4.42E+19	2.90E+19	2.58E+19	2.08E+19
Future	1.89E+08	1.89E+09	60.00	--	4.84E+19	3.18E+19	2.82E+19	2.27E+19

Notes:

(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	4.37E+07	4.37E+07	1.39	6.37E-11	4.13E-11	3.50E-11	2.84E-11
2	2.83E+07	7.20E+07	2.28	6.50E-11	4.20E-11	3.87E-11	3.16E-11
3	2.97E+07	1.02E+08	3.22	6.80E-11	4.57E-11	4.09E-11	3.23E-11
4	4.45E+07	1.46E+08	4.63	6.63E-11	4.27E-11	3.81E-11	3.02E-11
5	3.66E+07	1.83E+08	5.79	6.71E-11	4.52E-11	4.05E-11	3.23E-11
6	3.60E+07	2.19E+08	6.93	7.34E-11	4.78E-11	4.24E-11	3.33E-11
7	3.80E+07	2.57E+08	8.14	7.11E-11	4.57E-11	4.23E-11	3.27E-11
8	4.77E+07	3.05E+08	9.65	5.81E-11	3.35E-11	2.72E-11	2.07E-11
9	4.78E+07	3.52E+08	11.16	5.67E-11	3.19E-11	2.46E-11	1.81E-11
10	4.97E+07	4.02E+08	12.74	3.23E-11	2.46E-11	2.25E-11	1.68E-11
11	5.49E+07	4.57E+08	14.48	3.06E-11	2.05E-11	1.84E-11	1.68E-11
12	5.43E+07	5.11E+08	16.20	2.96E-11	2.33E-11	2.19E-11	1.80E-11
13	5.69E+07	5.68E+08	18.00	2.75E-11	2.22E-11	2.17E-11	1.76E-11
14	5.40E+07	6.22E+08	19.71	3.06E-11	2.33E-11	2.06E-11	1.62E-11
15	5.67E+07	6.79E+08	21.51	3.24E-11	2.37E-11	2.21E-11	1.74E-11
16	5.99E+07	7.39E+08	23.41	3.05E-11	2.13E-11	2.02E-11	1.77E-11
17	5.86E+07	7.97E+08	25.27	3.35E-11	2.14E-11	1.92E-11	1.70E-11
18	5.87E+07	8.56E+08	27.13	3.41E-11	2.24E-11	1.95E-11	1.60E-11
Future	1.54E+08	1.01E+09	32.00	3.41E-11	2.24E-11	1.95E-11	1.60E-11
Future	1.26E+08	1.14E+09	36.00	3.41E-11	2.24E-11	1.95E-11	1.60E-11
Future	1.26E+08	1.26E+09	40.00	3.41E-11	2.24E-11	1.95E-11	1.60E-11
Future	1.26E+08	1.39E+09	44.00	3.41E-11	2.24E-11	1.95E-11	1.60E-11
Future	1.26E+08	1.51E+09	48.00	3.41E-11	2.24E-11	1.95E-11	1.60E-11
Future	1.26E+08	1.64E+09	52.00	3.41E-11	2.24E-11	1.95E-11	1.60E-11
Future	6.31E+07	1.70E+09	54.00	3.41E-11	2.24E-11	1.95E-11	1.60E-11
Future	1.89E+08	1.89E+09	60.00	3.41E-11	2.24E-11	1.95E-11	1.60E-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	4.37E+07	4.37E+07	1.39	1.40	2.78E-03	1.80E-03	1.53E-03	1.24E-03
2	2.83E+07	7.20E+07	2.28	2.31	4.62E-03	2.99E-03	2.63E-03	2.14E-03
3	2.97E+07	1.02E+08	3.22	3.27	6.64E-03	4.35E-03	3.84E-03	3.10E-03
4	4.45E+07	1.46E+08	4.63	4.70	9.59E-03	6.25E-03	5.54E-03	4.44E-03
5	3.66E+07	1.83E+08	5.79	5.87	1.20E-02	7.90E-03	7.01E-03	5.62E-03
6	3.60E+07	2.19E+08	6.93	7.03	1.46E-02	9.59E-03	8.51E-03	6.80E-03
7	3.80E+07	2.57E+08	8.14	8.25	1.73E-02	1.13E-02	1.01E-02	8.02E-03
8	4.77E+07	3.05E+08	9.65	9.78	2.01E-02	1.29E-02	1.14E-02	9.01E-03
9	4.78E+07	3.52E+08	11.16	11.32	2.27E-02	1.44E-02	1.25E-02	9.84E-03
10	4.97E+07	4.02E+08	12.74	12.91	2.43E-02	1.56E-02	1.36E-02	1.07E-02
11	5.49E+07	4.57E+08	14.48	14.68	2.60E-02	1.67E-02	1.46E-02	1.16E-02
12	5.43E+07	5.11E+08	16.20	16.42	2.76E-02	1.80E-02	1.58E-02	1.26E-02
13	5.69E+07	5.68E+08	18.00	18.25	2.91E-02	1.92E-02	1.71E-02	1.36E-02
14	5.40E+07	6.22E+08	19.71	19.98	3.08E-02	2.05E-02	1.82E-02	1.45E-02
15	5.67E+07	6.79E+08	21.51	21.81	3.26E-02	2.18E-02	1.94E-02	1.54E-02
16	5.99E+07	7.39E+08	23.41	23.73	3.44E-02	2.31E-02	2.06E-02	1.65E-02
17	5.86E+07	7.97E+08	25.27	25.61	3.64E-02	2.44E-02	2.18E-02	1.75E-02
18	5.87E+07	8.56E+08	27.13	--	3.84E-02	2.57E-02	2.29E-02	1.84E-02
Future	1.54E+08	1.01E+09	32.00	--	4.36E-02	2.91E-02	2.59E-02	2.09E-02
Future	1.26E+08	1.14E+09	36.00	--	4.79E-02	3.19E-02	2.83E-02	2.29E-02
Future	1.26E+08	1.26E+09	40.00	--	5.22E-02	3.47E-02	3.08E-02	2.49E-02
Future	1.26E+08	1.39E+09	44.00	--	5.64E-02	3.75E-02	3.32E-02	2.69E-02
Future	1.26E+08	1.51E+09	48.00	--	6.07E-02	4.03E-02	3.57E-02	2.89E-02
Future	1.26E+08	1.64E+09	52.00	--	6.50E-02	4.32E-02	3.81E-02	3.10E-02
Future	6.31E+07	1.70E+09	54.00	--	6.71E-02	4.45E-02	3.94E-02	3.20E-02
Future	1.89E+08	1.89E+09	60.00	--	7.36E-02	4.88E-02	4.30E-02	3.50E-02

Notes:

(a) At 2737 MWt

(b) At 2700 MWt

Table 6-3 Calculated Fast Neutron Exposure of Surveillance Capsules Withdrawn from Calvert Cliffs Unit 2

Capsule	Irradiation Time [EFPY(a)]	Irradiation Time [EFPY(b)]	Fluence (E > 1.0 MeV) [n/cm^2]	Iron Displacements [dpa]
263°	4.63	4.70	8.25E+18	1.20E-02
97°	11.16	11.32	1.95E+19	2.83E-02
104°	27.13	--	2.44E+19	3.57E-02

Notes:

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

Table 6-4 Calculated Surveillance Capsule Lead Factors

Capsule Location	Status	Lead Factor
263°	Withdrawn EOC 4	1.31
97°	Withdrawn EOC 9	1.30
104°	Withdrawn EOC 18	0.97
83°	In Reactor[(a)]	1.30
284°	In Reactor[(a)]	0.97
277°	In Reactor[(a)]	1.30

Note:
(a) Lead factors are based on the cumulative exposures from Cycles 1 through 18.

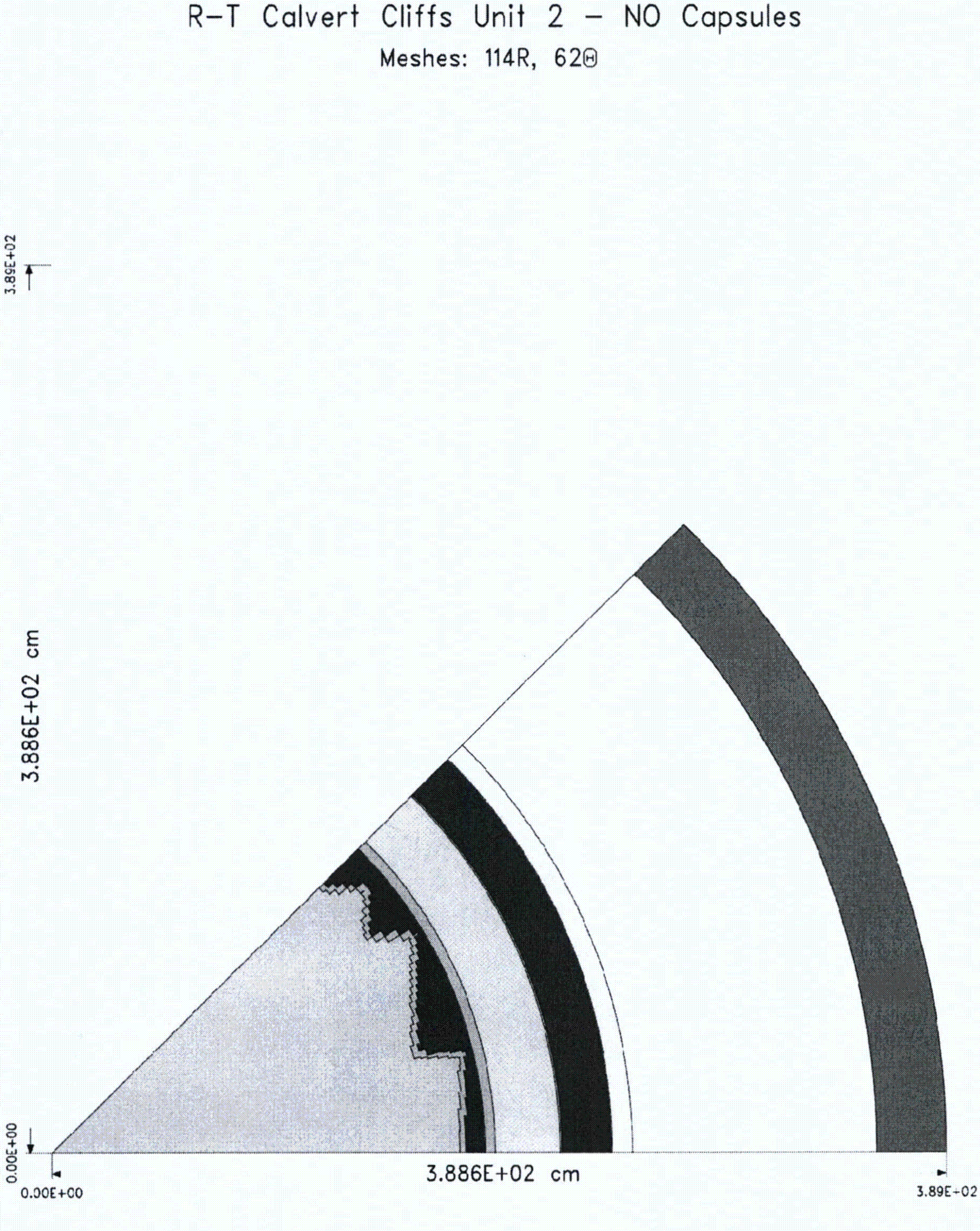


Figure 6-1 Calvert Cliffs Unit 2 r,θ Reactor Geometry without Surveillance Capsules

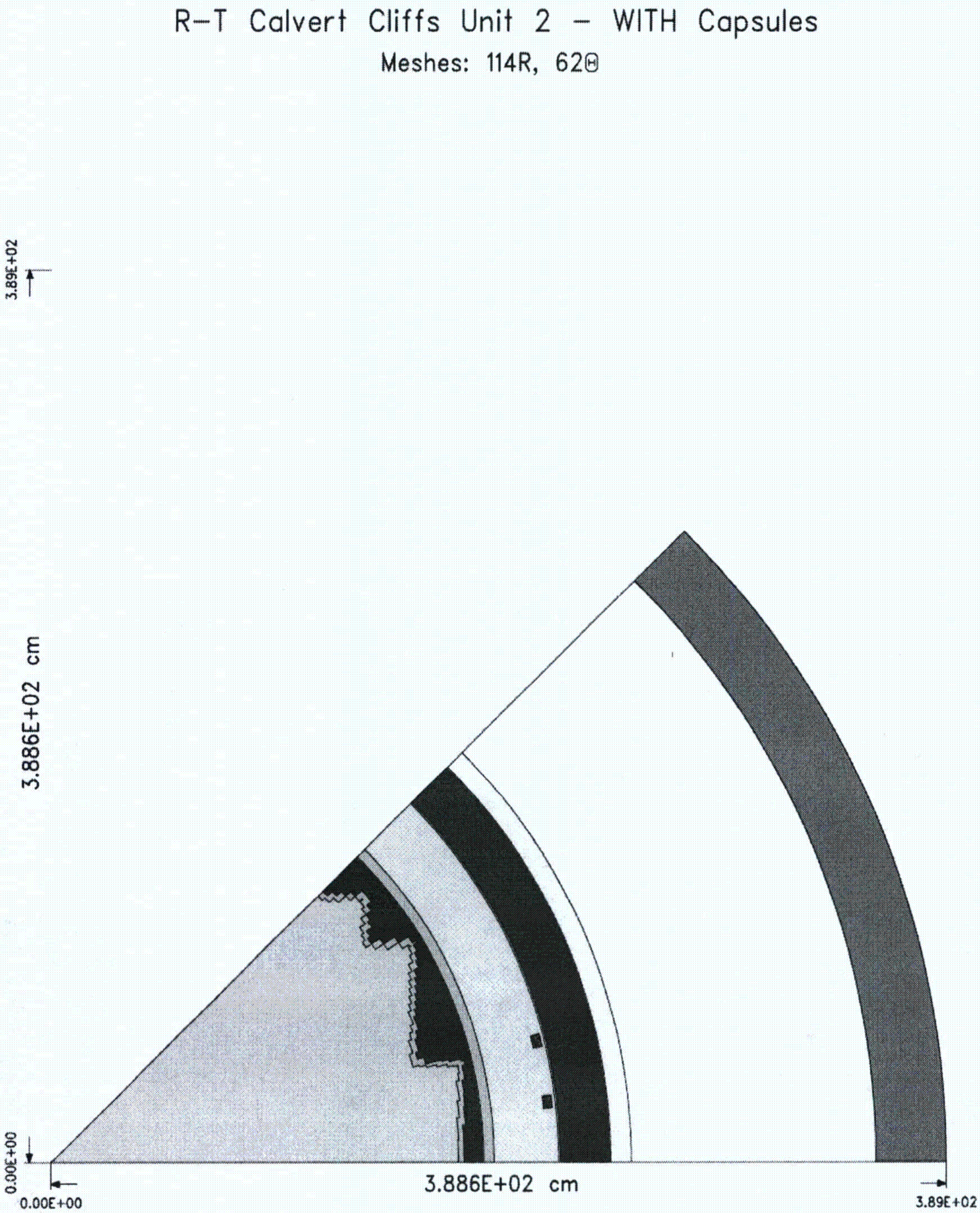


Figure 6-2 Calvert Cliffs Unit 2 r,θ Reactor Geometry with 7° and 14° Surveillance Capsules

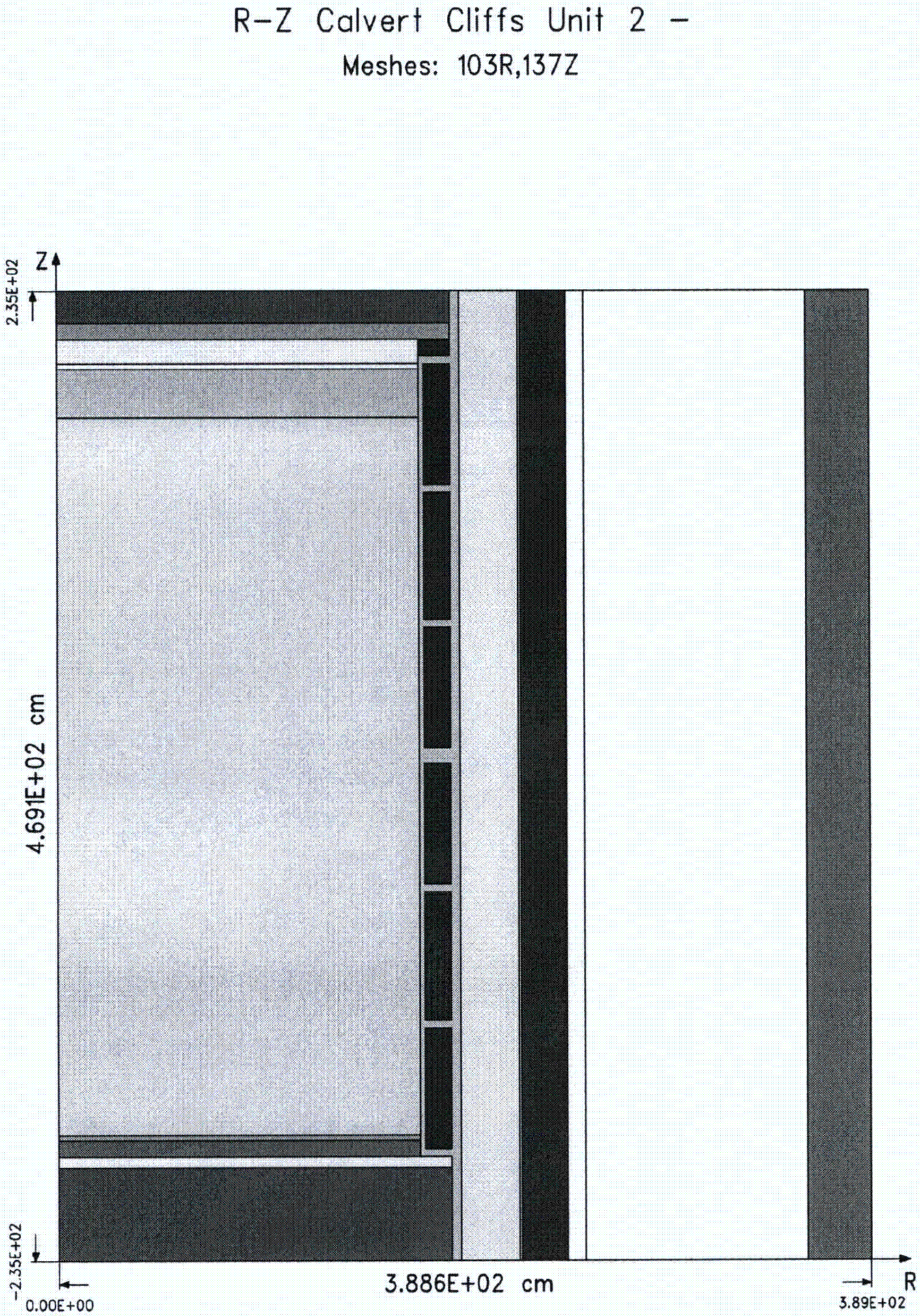


Figure 6-3 Calvert Cliffs Unit 2 r,z Reactor Geometry

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 2 reactor vessel.

Table 7-1 Surveillance Capsule Withdrawal Schedule

Capsule Location	Lead Factor[(a)]	Withdrawal EFPY[(b)]	Fluence (n/cm^2)[(c)]
263°	1.31	4.63	8.25E+18
97°	1.30	11.16	1.95E+19
104°	0.97	27.13	2.44E+19
83°	1.30	See Note (d)	---
277°	1.30	See Note (e)	---
284°	0.97	Standby[(f)]	---

Notes:

(a) Updated in Capsule 104° dosimetry analysis; see Table 6-4.

(b) EFPY from plant startup.

(c) Updated in Capsule 104° dosimetry analysis; see Table 6-3.

(d) Capsule 83° should be withdrawn at the next refueling outage after approximately 37 EFPY of plant operation, which is when the fluence on the capsule would equal the projected 60-year (52 EFPY) peak vessel fluence.

(e) Capsule 277° should be withdrawn at a fluence not less than once or greater than twice the peak end of extended life vessel fluence at the vessel inner wall (4.28×10^{19} < fluence in n/cm^2 < 8.56×10^{19}). Note that this capsule also satisfies the requirement in the safety evaluation report for Calvert Cliffs License Renewal, that one capsule containing dosimetry is to be removed during the final five years of the extended license. Withdrawal of this capsule at the next refueling outage after approximately 51 EFPY of plant operation would be within the specified fluence range and would equal the projected 80-year (70 EFPY) peak vessel fluence.

(f) Capsule 284° currently has a lead factor less than one. If additional metallurgical data is needed for Calvert Cliffs Unit 2, relocation of this capsule to a higher lead factor location should be considered. However, this can be revisited at a later time; therefore, no recommendations for its withdrawal are given.

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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 2 are described herein. The sensor sets from these capsules have been analyzed in accordance with the current dosimetry evaluation methodology described in Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence" [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 2 Reactor Vessel Materials Surveillance Program are presented. The capsule designation, location within the reactor, and time of withdrawal of each of these dosimetry sets were as follows:

Capsule Azimuthal Location	Withdrawal Time	Irradiation Time [EFPY[a]]
263°	End of Cycle 4	4.63
97°	End of Cycle 9	11.16
104°	End of Cycle 18	27.13

Note:
(a) At 2737 MWt.

The passive neutron sensors included in the evaluations of Surveillance Capsules 263°, 97°, and 104° are summarized as follows:

Sensor Material	Reaction Of Interest	Capsule 263°	Capsule 97°	Capsule 104°
Copper (Cd)	$^{63}Cu(n,\alpha)^{60}Co$	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*	$^{238}U(n,f)FP$	X	X	X
Cobalt-Aluminum*	$^{59}Co(n,\gamma)^{60}Co$	X	X	X
Note: * The cobalt-aluminum and uranium monitors for this plant include both bare 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 104° was carried out by PACE Analytical Services, Inc. In all cases, the radiometric counting followed established ASTM procedures.

In the case of PACE analysis of Capsule 104°, following sample preparation and weighing, the specific activity of each sensor was determined by means of a high-resolution gamma spectrometer. For the 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 cesium, zirconium and ruthenium from the sensor material. PACE reports that the cadmium covered uranium dosimetry samples were a powder mixture of uranium oxide and cadmium oxide. The mixture was weighed, counted, dissolved and the solution was then analyzed by Inductively Coupled Plasma (ICP) to determine the cadmium weight. The cadmium weight was then subtracted from the gross weight to obtain a uranium oxide weight. The titanium wire samples in this project had individually broken into multiple pieces. For each titanium sample, between 2 and 14 individual pieces were retrieved and used to compose the sample for counting. For the cadmium covered copper wire dosimetry, PACE was unable to retrieve the copper wire, which had totally amalgamated into the cadmium. For each cadmium covered copper wire, a representative sample portion was weighed, counted, dissolved and the solution was analyzed by ICP to obtain the measurement weight of copper wire.

The irradiation history of the reactor over the irradiation periods experienced by Capsules 263°, 97°, and 104° was based on the monthly power generation of Calvert Cliffs Unit 2 from initial reactor criticality through the end of the dosimetry evaluation period. For the sensor sets utilized in the surveillance capsules, the half-lives of the product isotopes are long enough that a monthly histogram describing reactor operation has proven to be an adequate representation for use in radioactive decay corrections for the reactions of interest in the exposure evaluations. The irradiation history applicable to Capsules 263°, 97°, and 104° is given in Table A-2.

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

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

where:

R	=	Reaction rate averaged over the irradiation period and referenced to operation at a core power level of P_{ref} (rps/nucleus).
A	=	Measured specific activity (dps/g).
N_0	=	Number of target element atoms per gram of sensor.
F	=	Atom fraction of the target isotope in the target element.
Y	=	Number of product atoms produced per reaction.
P_j	=	Average core power level during irradiation period j (MW).
P_{ref}	=	Maximum or reference power level of the reactor (MW).
C_j	=	Calculated ratio of $\phi(E > 1.0\ \text{MeV})$ 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 at the time of withdrawal. 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. The point flux evaluation is accurate for the computation of Cj.

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

Correction	Capsule 263°	Capsule 97°	Capsule 104°
^{235}U Impurity/Pu Build-in	0.8530	0.8107	0.7945
$^{238}U(\gamma,f)$	0.8461	0.8461	0.8357
Net ^{238}U Correction	0.7217	0.6859	0.6640

The factors for Capsules 263° and 104° were applied in a multiplicative fashion to the decay-corrected cadmium-covered uranium fission sensor reaction rates. The factors for Capsule 97° were **not** applied. By comparing calculated activities (which by previous experience should agree to within 15%), it has been deduced that Reference A-3 reports cadmium cover uranium measurements with corrections factors applied. In that sense, the current analysis uses the correction factors from Reference A-3, which explicitly states the use of a photo-fission correction factor. In this regard, Reference A-3 indicates that Nuclear Environmental Services Incorporated (NESI) was asked to perform alpha spectrometry measurements, which revealed that the CC2-97°, 1 5G Sh ^{238}U dosimeter contains 5277 ppm ±35% ^{235}U impurity. Reference A-3 does not explicitly mention, however, the specific correction factor that may have been applied to account for the impurity and/or the plutonium build in.

Results of the sensor reaction rate determinations for Capsules 263°, 97°, and 104° 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 in the cases of Capsule 263° and 104°.

The bottom compartment bare Uranium and Cobalt monitors' measurements of Capsules 263°, 97°, and 104° are consistently low compared to those in the middle and top compartments. The behavior is attributed to 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.

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 sections, σ_{ig}, each with an uncertainty δ. The primary objective of the least-squares evaluation is to produce unbiased estimates of the neutron exposure parameters at the location of the measurement.

For the least-squares evaluation of the Calvert Cliffs Unit 2 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 2 application, the calculated neutron spectrum was obtained from the results of plant-specific neutron transport calculations described in Section 6.2 of this report. The sensor reaction rates were derived from the measured specific activities using the procedures described in Section A.1.1. The dosimetry reaction cross sections and uncertainties were obtained from the SNLRML dosimetry cross-section library [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 2 surveillance capsule sensor sets.

Reaction Rate Uncertainties

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

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

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

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

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	4.08-4.16%
$^{54}Fe(n,p)^{54}Mn$	3.05-3.11%
$^{58}Ni(n,p)^{58}Co$	4.49-4.56%
$^{46}Ti(n,p)^{46}Sc$	4.51-4.87%
$^{238}U(n,f)^{137}Cs$	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 inputs to the least-squares adjustment procedure were obtained directly from the results of plant-specific transport calculations for each surveillance capsule irradiation period and location. The spectrum for each capsule was input in an absolute sense (rather than as simply a relative spectral shape). Therefore, within the constraints of the assigned uncertainties, the calculated data were treated equally with the measurements.

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

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

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

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

where

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

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

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

Flux Normalization Uncertainty (R_n)	15%
Flux Group Uncertainties (R_g, $R_{g'}$)	
(E > 0.0055 MeV)	15%
(0.68 eV < E < 0.0055 MeV)	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 2 surveillance capsules withdrawn to date are provided in Tables A-5 and A-6. In Table A-5, measured, calculated, and best-estimate values for sensor reaction rates are given for each capsule. Also provided in this tabulation are ratios of the measured reaction rates to both the calculated and least-squares adjusted reaction rates. These ratios of M/C and M/BE illustrate the consistency of the fit of the calculated neutron energy spectra to the measured reaction rates both before and after adjustment. In Table A-6, comparison of the calculated and best-estimate values of neutron flux (E > 1.0 MeV) and iron atom displacement rate are tabulated along with the BE/C ratios observed for each of the capsules.

The data comparisons provided in Tables A-5 and A-6 show that the adjustments to the calculated spectra are relatively small and well within the assigned uncertainties for the calculated spectra, measured sensor reaction rates, and dosimetry reaction cross sections. Further, these results indicate that the use of the least-squares evaluation results in a reduction in the uncertainties associated with the exposure of the surveillance capsules. From Section 6.4 of this report, it may be noted that the uncertainty associated with the unadjusted calculation of neutron fluence (E > 1.0 MeV) and iron atom displacements at the surveillance capsule locations is specified as 13% at the 1σ level. From Table A-8, it is noted that the corresponding uncertainties associated with the least-squares adjusted exposure parameters have been reduced to 4.0% for neutron flux (E > 1.0 MeV) and 3.1% 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, for the individual threshold foils considered in the least-squares analysis, the average M/C comparisons for fast neutron reactions range from 0.69 to 1.19 for the 31 samples included in the data set. The overall average M/C ratio for the entire set of Calvert Cliffs Unit 2 data is 0.94 with an associated standard deviation of 9.9%.

In the comparisons of best-estimate and calculated fast neutron exposure parameters, the corresponding BE/C comparisons for the capsule data sets range from 0.88 to 0.95 for neutron flux (E > 1.0 MeV) and from 0.90 to 0.95 for iron atom displacement rate. The overall average BE/C ratios for neutron flux (E > 1.0 MeV) and iron atom displacement rate are 0.91 with a standard deviation of 4.0% and 0.92 with a standard deviation of 3.1%, 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 2 reactor pressure vessel.

Note that for Capsule 263°, two of the three cadmium-covered Uranium monitors have not been included in the least-squares analysis. Two cadmium-covered Uranium monitors were discarded because of the poor condition of the specimens as indicated in Reference A-2 (monitors were contaminated with cadmium and the cadmium cover disintegrated at some unknown time during irradiation). For remaining cadmium-covered Uranium monitor, for which the cadmium cover also disintegrated at some unknown time during irradiation, Combustion Engineeering, Inc. made an atomic absorption determination that was included in the analysis.

Note that for Capsule 97°, the Copper, Titanium and cadmium-covered Cobalt monitors have not been included in the least-squares analysis. The Copper, Titanium and Cobalt monitors are not included because their countings are 4.1σ, 5σ and 5.1σ high with respect to similar plants' measurements, respectively. No bare Cobalt monitors results were reported in Reference A-3.

Note that for Capsule 104°, the Titanium and bare Uranium monitors are not included in the least-squares analysis. The Titanium monitor has been discarded because the counting is 6σ high with respect to similar plants' measurements. The cadmium-covered Uranium monitor was not discarded because these monitors were -2.3σ with respect to similar plants' measurements. However, the original uranium metal foil oxidized and forms a powder mixed with cadmium oxide powder. In the analysis, uranium dioxide, UO_2, has been assumed for the oxidation state of the oxide.

In all capsules, the bare Uranium monitors are not included because the U-235 impurity content and the thermal flux on the capsule are not known 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	$^{63}Cu\ (n,\alpha)$	0.6917	5.0 – 11.9	5.272 y	
Iron	$^{54}Fe\ (n,p)$	0.0585	2.4 – 8.7	312.1 d	
Nickel	$^{58}Ni\ (n,p)$	0.6808	2.1 – 8.7	70.82 d	
Titanium	$^{46}Ti(n,p)$	0.0825	4.1 – 10.4	83.79 d	
Uranium-238(b)	$^{238}U\ (n,f)^{137}Cs$	1.0000	1.5 – 7.9	30.07 y	6.02
Uranium-238(b)	$^{238}U\ (n,f)^{103}Ru$	1.0000	1.5 – 7.9	39.26 d	6.26
Uranium-238(b)	$^{238}U\ (n,f)^{95}Zr$	1.0000	1.5 – 7.9	64.02 d	5.15
Cobalt-Aluminum(c)	$^{59}Co\ (n,\gamma)$	1.0000	non-threshold	5.272 y	

Notes:

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

(b) For Capsule 104°, the Uranium measurements were reported per unit mass of Uranium oxide. Thus, the analysis assumes UO_2, or an equivalent target atom fraction of 0.881572.

(c) For Capsule 263° and 97°, the Cobalt measurement are reported per gram of Cobalt. For Capsule 104°, the measurements are reported per gram of Cobalt-Aluminum and a Cobalt content of 0.17 a/o is assumed.

Table A-2 Monthly Thermal Generation during the First Eighteen Fuel Cycles of the Calvert Cliffs Unit 2 Reactor (Reactor Power of 2560 MWt from 12/07/1976 to 10/18/1977; 2700 MWt from 10/19/1977 to 2/22/2009; and, 2737 MWt from 3/17/2009 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)
Nov-76	18432	Dec-78	1883736	Jan-81	589032	Feb-83	1608146
Dec-76	491459	Jan-79	1314144	Feb-81	0	Mar-83	1890043
Jan-77	1355305	Feb-79	1711886	Mar-81	1551092	Apr-83	1933074
Feb-77	1501901	Mar-79	1891642	Apr-81	1421105	May-83	1930482
Mar-77	1800499	Apr-79	1933762	May-81	1994396	Jun-83	1933215
Apr-77	1763451	May-79	1866305	Jun-81	1854536	Jul-83	1989315
May-77	816108	Jun-79	1758672	Jul-81	1739847	Aug-83	1545196
Jun-77	1604751	Jul-79	1735992	Aug-81	1743011	Sep-83	1586667
Jul-77	1824276	Aug-79	1700352	Sep-81	1335765	Oct-83	1296083
Aug-77	1450906	Sep-79	1417824	Oct-81	1961940	Nov-83	1568846
Sep-77	1785016	Oct-79	1879902	Nov-81	1803944	Dec-83	1822497
Oct-77	1283701	Nov-79	0	Dec-81	1972804	Jan-84	1996767
Nov-77	1913998	Dec-79	1422360	Jan-52	1959795	Feb-84	1782217
Dec-77	1910347	Jan-80	1359504	Feb-82	905239	Mar-84	1998385
Jan-78	1876867	Feb-80	1779408	Mar-82	1974241	Apr-84	1626228
Feb-78	1703138	Mar-80	1929096	Apr-82	1881782	May-84	0
Mar-78	1856585	Apr-80	1863000	May-82	1976927	Jun-84	0
Apr-78	1262304	May-80	1922616	Jun-82	1852073	Jul-84	1211910
May-78	1260295	Jun-80	1876608	Jul-82	1927212	Aug-84	1659447
Jun-78	1365725	Jul-80	1723032	Aug-82	1367000	Sep-84	1469994
Jul-78	1079827	Aug-80	1820880	Sep-82	1717000	Oct-84	1866319
Aug-78	1804226	Sep-80	1529928	Oct-82	905000	Nov-84	1874178
Sep-78	1515413	Oct-80	1711368	Nov-82	0	Dec-84	1998678
Oct-78	863784	Nov-80	1694520	Dec-82	0	Jan-85	1950430
Nov-78	1561226	Dec-80	1349784	Jan-83	1296481	Feb-85	1801273

Table A-2 (Continued) Monthly Thermal Generation during the First Eighteen Fuel Cycles of the Calvert Cliffs Unit 2 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)
Mar-85	1989882	Apr-87	0	May-89	0	Jun-91	1086403
Apr-85	1577934	May-87	0	Jun-89	0	Jul-91	2000576
May-85	1257574	Jun-87	0	Jul-89	0	Aug-91	2006340
Jun-85	1934720	Jul-87	1435223	Aug-89	0	Sep-91	1920654
Jul-85	1485446	Aug-87	1997667	Sep-89	0	Oct-91	1162312
Aug-85	1634150	Sep-87	1895948	Oct-89	0	Nov-91	415426
Sep-85	1929517	Oct-87	1813391	Nov-89	0	Dec-91	2005781
Oct-85	1756180	Nov-87	1804125	Dec-89	0	Jan-92	1843271
Nov-85	0	Dec-87	1848160	Jan-90	0	Feb-92	1872867
Dec-85	1550132	Jan-88	1952162	Feb-90	0	Mar-92	1187755
Jan-86	1984432	Feb-88	1654239	Mar-90	0	Apr-92	1707340
Feb-86	1678177	Mar-88	0	Apr-90	0	May-92	1995905
Mar-86	1907013	Apr-88	1643667	May-90	0	Jun-92	1498563
Apr-86	1937020	May-88	1863681	Jun-90	0	Jul-92	1557529
May-86	1690501	Jun-88	1938335	Jul-90	0	Aug-92	1757061
Jun-86	1782055	Jul-88	2001391	Aug-90	0	Sep-92	1832651
Jul-86	1582756	Aug-88	1945508	Sep-90	0	Oct-92	1784321
Aug-86	1926214	Sep-88	1921417	Oct-90	0	Nov-92	1937690
Sep-86	1553646	Oct-88	1941005	Nov-90	0	Dec-92	1995474
Oct-86	1991848	Nov-88	1931845	Dec-90	0	Jan-93	1999836
Nov-86	1932914	Dec-88	2002776	Jan-91	0	Feb-93	1610920
Dec-86	2002060	Jan-89	1806093	Feb-91	0	Mar-93	0
Jan-87	1979543	Feb-89	1802081	Mar-91	0	Apr-93	0
Feb-87	1795300	Mar-89	1034562	Apr-91	0	May-93	0
Mar-87	1618167	Apr-89	0	May-91	1146357	Jun-93	802275

Table A-2 (Continued) Monthly Thermal Generation during the First Eighteen Fuel Cycles of the Calvert Cliffs Unit 2 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)
Jul-93	1899709	Aug-95	1991189	Sep-97	1919600	Oct-99	2006511
Aug-93	1997329	Sep-95	1871749	Oct-97	1989880	Nov-99	1939312
Sep-93	1942142	Oct-95	1995146	Nov-97	1937688	Dec-99	2003142
Oct-93	1944012	Nov-95	1942200	Dec-97	2006499	Jan-00	2006535
Nov-93	1931211	Dec-95	2006715	Jan-98	2006272	Feb-00	1374862
Dec-93	2002102	Jan-96	2003930	Feb-98	1812439	Mar-00	2006283
Jan-94	1513287	Feb-96	1730265	Mar-98	2003831	Apr-00	1938535
Feb-94	1799244	Mar-96	1683467	Apr-98	1941748	May-00	2006644
Mar-94	2005485	Apr-96	1929940	May-98	2006778	Jun-00	1936548
Apr-94	1941686	May-96	2002384	Jun-98	1931416	Jul-00	2000175
May-94	1508185	Jun-96	1933449	Jul-98	1476731	Aug-00	2001498
Jun-94	1941922	Jul-96	2000334	Aug-98	1504278	Sep-00	1933488
Jul-94	1823026	Aug-96	1982088	Sep-98	1925485	Oct-00	2006051
Aug-94	1435535	Sep-96	1922791	Oct-98	2007018	Nov-00	1941425
Sep-94	1410192	Oct-96	1987401	Nov-98	1940513	Dec-00	2003330
Oct-94	1748712	Nov-96	1739522	Dec-98	2006797	Jan-01	2006171
Nov-94	1585574	Dec-96	1985257	Jan-99	2006668	Feb-01	1811473
Dec-94	2004274	Jan-97	1980479	Feb-99	1810695	Mar-01	995350
Jan-95	1650542	Feb-97	1762417	Mar-99	743157	Apr-01	0
Feb-95	1786954	Mar-97	780849	Apr-99	0	May-01	1049668
Mar-95	1104057	Apr-97	0	May-99	1427240	Jun-01	1863146
Apr-95	0	May-97	459069	Jun-99	1941987	Jul-01	2006856
May-95	648873	Jun-97	1918099	Jul-99	2006611	Aug-01	1942074
Jun-95	1936904	Jul-97	1985028	Aug-99	1998445	Sep-01	1937954
Jul-95	1926252	Aug-97	1974675	Sep-99	1933855	Oct-01	1833455

Table A-2 (Continued) Monthly Thermal Generation during the First Eighteen Fuel Cycles of the Calvert Cliffs Unit 2 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)
Nov-01	1934884	Dec-03	1999078	Jan-06	1960274	Feb-08	1878107
Dec-01	2003230	Jan-04	1841771	Feb-06	1813540	Mar-08	2003908
Jan-02	2003631	Feb-04	1877495	Mar-06	2007945	Apr-08	1942948
Feb-02	1808078	Mar-04	2002627	Apr-06	1943236	May-08	2000270
Mar-02	2005211	Apr-04	1942145	May-06	2006377	Jun-08	1942170
Apr-02	1933062	May-04	2003942	Jun-06	1943243	Jul-08	1996364
May-02	2002801	Jun-04	1935074	Jul-06	2007395	Aug-08	1988356
Jun-02	1941315	Jul-04	2007078	Aug-06	2007889	Sep-08	1929826
Jul-02	2002929	Aug-04	2003650	Sep-06	1942947	Oct-08	2001860
Aug-02	2001072	Sep-04	1930069	Oct-06	1981674	Nov-08	1941097
Sep-02	1935979	Oct-04	2005176	Nov-06	1606071	Dec-08	2003359
Oct-02	2006415	Nov-04	1938881	Dec-06	1966267	Jan-09	2006642
Nov-02	1940365	Dec-04	2008135	Jan-07	2007880	Feb-09	1412135
Dec-02	2004611	Jan-05	2008083	Feb-07	1559723	Mar-09	879474
Jan-03	2004240	Feb-05	1388707	Mar-07	0	Apr-09	1942544
Feb-03	901908	Mar-05	978244	Apr-07	1683654	May-09	2006957
Mar-03	0	Apr-05	1943343	May-07	2007759	Jun-09	1937407
Apr-03	491785	May-05	2008062	Jun-07	1939994	Jul-09	2003084
May-03	1912832	Jun-05	1939850	Jul-07	2006588	Aug-09	2007882
Jun-03	1941153	Jul-05	2001291	Aug-07	1999215	Sep-09	1958165
Jul-03	2003747	Aug-05	2000495	Sep-07	1943055	Oct-09	2024085
Aug-03	2000819	Sep-05	1941968	Oct-07	2007775	Nov-09	1960413
Sep-03	1934305	Oct-05	2007848	Nov-07	1943136	Dec-09	2025522
Oct-03	2002912	Nov-05	1943291	Dec-07	2004041	Jan-10	2025517
Nov-03	1938746	Dec-05	2004789	Jan-08	2007492	Feb-10	1176589

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

Month-Year	Thermal Generation (MWt-hr)
Mar-10	2023060
Apr-10	1959776
May-10	2013775
Jun-10	1922715
Jul-10	1983103
Aug-10	2004861
Sep-10	1956753
Oct-10	2010481
Nov-10	1952412
Dec-10	2017691
Jan-11	2025729
Feb-11	843462

Table A-3 Surveillance Capsule Flux for C_j Factors Calculation

Fuel Cycle	Cycle Length [EFPS[(a)]]	$\varphi(E > 1.0\ MeV)$ [n/cm^2-s] Capsule 263° $z^{(b)}$ = - 14.737 cm	Capsule 97° $z^{(b)}$ = - 15.671cm	Capsule 104° $z^{(b)}$ = - 16.202 cm
1	4.37E+07	5.38E+10	5.39E+10	3.90E+10
2	2.83E+07	5.48E+10	5.50E+10	3.97E+10
3	2.97E+07	6.03E+10	6.05E+10	4.47E+10
4	4.45E+07	5.80E+10	5.81E+10	4.18E+10
5	3.66E+07		5.92E+10	4.38E+10
6	3.60E+07		6.43E+10	4.65E+10
7	3.80E+07		6.13E+10	4.40E+10
8	4.77E+07		4.75E+10	3.23E+10
9	4.78E+07		4.57E+10	3.05E+10
10	4.97E+07			2.29E+10
11	5.49E+07			1.94E+10
12	5.43E+07			2.13E+10
13	5.69E+07			2.03E+10
14	5.40E+07			2.16E+10
15	5.67E+07			2.17E+10
16	5.99E+07			1.95E+10
17	5.86E+07			2.05E+10
18	5.87E+07			2.14E+10
Average	---	5.66E+10	5.55E+10	2.86E+10

Notes:

(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 104°
1	4.37E+07	0.950	0.972	1.362
2	2.83E+07	0.969	0.990	1.388
3	2.97E+07	1.066	1.090	1.561
4	4.45E+07	1.024	1.047	1.461
5	3.66E+07		1.067	1.530
6	3.60E+07		1.158	1.626
7	3.80E+07		1.105	1.538
8	4.77E+07		0.855	1.128
9	4.78E+07		0.823	1.066
10	4.97E+07			0.799
11	5.49E+07			0.678
12	5.43E+07			0.744
13	5.69E+07			0.710
14	5.40E+07			0.755
15	5.67E+07			0.759
16	5.99E+07			0.680
17	5.86E+07			0.715
18	5.87E+07			0.747
Average	---	1.000	1.000	1.000

Note:
(a) At 2737 MWt.

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

Reaction	Location	Measured Activity[a] (dps/g)	Saturated Activity (dps/g)	Reaction Rate[b] (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top	2.69E+05	6.24E+05	9.51E-17
	Middle	2.68E+05	6.21E+05	9.48E-17
	Bottom	2.87E+05	6.65E+05	1.01E-16
	Average			**9.71E-17**
^{54}Fe (n,p) ^{54}Mn	Top	4.00E+06	4.74E+06	7.51E-15
	Middle	3.76E+06	4.45E+06	7.07E-15
	Bottom	3.85E+06	4.56E+06	7.24E-15
	Average			**7.27E-15**
^{58}Ni (n,p) ^{58}Co	Top	5.35E+07	6.08E+07	8.71E-15
	Middle	5.10E+07	5.79E+07	8.29E-15
	Bottom	5.69E+07	6.47E+07	9.26E-15
	Average			**8.75E-15**
^{46}Ti(n,p)^{46}Sc	Top	1.03E+06	1.17E+06	1.12E-15
	Middle	1.07E+06	1.22E+06	1.17E-15
	Bottom	9.16E+05	1.04E+06	1.00E-15
	Average			**1.10E-15**
^{238}U (n,f) ^{137}Cs	Top	6.59E+05	6.58E+06	4.91E-14
	Middle	6.94E+05	6.93E+06	5.17E-14
	Bottom	5.71E+05	5.70E+06	4.25E-14
	Average			**4.78E-14**
^{238}U (n,f) ^{137}Cs (Cd)	Top	1.76E+05	1.75E+06	1.31E-14
	Middle	3.78E+05	3.77E+06	2.82E-14
	Bottom	1.16E+05	1.15E+06	8.62E-15
	Middle[c]			2.82E-14
Corrected Middle Including ^{235}U, ^{239}Pu, and γ fission corrections[c]				**2.03E-14**
^{59}Co (n,γ) ^{60}Co	Top	1.48E+10	3.42E+10	3.35E-12
	Middle	1.53E+10	3.55E+10	3.48E-12
	Bottom	1.08E+10	2.51E+10	2.46E-12
	Average			**3.09E-12**
^{59}Co (n,γ) ^{60}Co (Cd)	Top	1.83E+09	4.24E+09	4.15E-13
	Middle	1.60E+09	3.70E+09	3.62E-13
	Bottom	1.77E+09	4.09E+09	4.01E-13
	Average			**3.92E-13**

Notes:

(a) Measured specific activities are indexed to a counting date of 10/16/1982.

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

(c) Middle monitor weight was determined by atomic absorption. See also 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	4.87E+05	9.14E+05	1.40E-16
	Middle	4.03E+05	7.57E+05	1.15E-16
	Bottom	4.05E+05	7.60E+05	1.16E-16
	Average			**1.24E-16**
^{54}Fe (n,p) ^{54}Mn	Top	2.98E+06	5.08E+06	8.08E-15
	Middle	2.70E+06	4.60E+06	7.33E-15
	Bottom	2.65E+06	4.51E+06	7.17E-15
	Average			**7.53E-15**
^{58}Ni (n,p) ^{58}Co	Top	4.31E+07	5.33E+07	7.64E-15
	Middle	4.81E+07	5.95E+07	8.52E-15
	Bottom	4.98E+07	6.16E+07	8.82E-15
	Average			**8.33E-15**
^{46}Ti(n,p)^{46}Sc	Top	1.36E+06	1.71E+06	1.65E-15
	Middle	1.14E+06	1.44E+06	1.39E-15
	Bottom	1.23E+06	1.55E+06	1.49E-15
	Average			**1.51E-15**
^{238}U (n,f) ^{137}Cs	Top	1.83E+06	8.72E+06	5.73E-14
	Middle	1.62E+06	7.72E+06	5.07E-14
	Bottom	1.27E+06	6.02E+06	3.95E-14
	Average			**4.92E-14**
^{238}U (n,f)^{137}Cs (Cd) [c]	Top	7.87E+05	3.74E+06	2.46E-14
	Middle	7.72E+05	3.67E+06	2.41E-14
	Bottom	7.98E+05	3.80E+06	2.49E-14
	Average			2.45E-14
Corrected Average Including ^{235}U, ^{239}Pu, and γ fission corrections				**2.45E-14**
^{59}Co (n,γ) ^{60}Co	Top	NA	NA	NA
	Middle	NA	NA	NA
	Bottom	NA	NA	NA
	Average			NA
^{59}Co (n,γ) ^{60}Co (Cd)	Top	1.75E+10	3.28E+10	3.21E-12
	Middle	1.61E+10	3.02E+10	2.95E-12
	Bottom	1.15E+10	2.16E+10	2.11E-12
	Average			**2.76E-12**

Notes:

(a) Measured specific activities are indexed to a counting date of 02/20/1993.

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

(c) See Section A.1.1. It has been assumed that the measurements were reported in Reference 22 with corrections.

Table A-4c Measured Sensor Activities and Reaction Rates for Surveillance Capsule 104°

Reaction	Location	Measured Activity[(a)] (dps/g)	Saturated Activity (dps/g)	Reaction Rate[(b)] (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top	1.86E+05	2.95E+05	4.50E-17
	Middle	1.69E+05	2.68E+05	4.09E-17
	Bottom	1.69E+05	2.68E+05	4.09E-17
	Average			**4.22E-17**
^{54}Fe (n,p) ^{54}Mn	Top	1.21E+06	2.59E+06	4.12E-15
	Middle	1.06E+06	2.27E+06	3.61E-15
	Bottom	1.05E+06	2.25E+06	3.58E-15
	Average			**3.77E-15**
^{58}Ni (n,p) ^{58}Co	Top	4.61E+06	4.01E+07	5.75E-15
	Middle	3.85E+06	3.35E+07	4.80E-15
	Bottom	4.07E+06	3.54E+07	5.07E-15
	Average			**5.21E-15**
^{46}Ti(n,p)^{46}Sc	Top	1.37E+05	8.96E+05	8.63E-16
	Middle	1.15E+05	7.52E+05	7.25E-16
	Bottom	1.16E+05	7.59E+05	7.31E-16
	Average			**7.73E-16**
^{238}U (n,f) ^{137}Cs	Top	1.81E+06	4.43E+06	3.30E-14
	Middle	1.55E+06	3.80E+06	2.83E-14
	Bottom	1.09E+06	2.67E+06	1.99E-14
	Average			**2.71E-14**
^{238}U (n,f) ^{103}Ru	Top	1.83E+05	7.08E+06	5.07E-14
	Middle	1.56E+05	6.03E+06	4.32E-14
	Bottom	1.13E+05	4.37E+06	3.13E-14
	Average			**4.17E-14**
^{238}U (n,f) ^{95}Zr	Top	5.70E+05	6.04E+06	5.26E-14
	Middle	4.66E+05	4.94E+06	4.30E-14
	Bottom	3.17E+05	3.36E+06	2.93E-14
	Average			**4.16E-14**
^{238}U (n,f) ^{137}Cs (Cd)	Top	6.92E+05	1.69E+06	1.26E-14
	Middle	6.05E+05	1.48E+06	1.10E-14
	Bottom	5.34E+05	1.31E+06	9.74E-15
	Average			1.11E-14
Corrected Average Including ^{235}U, ^{239}Pu, and γ fission corrections[(c)]				**7.39E-15**

Table A-4c(Continued) Measured Sensor Activities and Reaction Rates for Surveillance Capsule 104°

^{238}U (n,f) ^{103}Ru (Cd)	Top	5.19E+04	2.01E+06	1.44E-14
	Middle	5.31E+04	2.05E+06	1.47E-14
	Bottom	5.13E+04	1.98E+06	1.42E-14
	Average			1.44E-14
Corrected Average Including ^{235}U, ^{239}Pu, and γ fission corrections[(c)]				**9.58E-15**
^{238}U (n,f) ^{95}Zr (Cd)	Top	1.87E+05	1.98E+06	1.73E-14
	Middle	1.59E+05	1.69E+06	1.47E-14
	Bottom	1.57E+05	1.66E+06	1.45E-14
	Average			1.55E-14
Corrected Average Including ^{235}U, ^{239}Pu, and γ fission corrections[(c)]				**1.03E-14**
^{59}Co (n,γ) ^{60}Co	Top	1.40E+07	2.22E+07	1.28E-12
	Middle	1.33E+07	2.11E+07	1.21E-12
	Bottom	9.75E+06	1.55E+07	8.89E-13
	Average			**1.13E-12**
^{59}Co (n,γ) ^{60}Co (Cd)	Top	2.06E+06	3.26E+06	1.88E-13
	Middle	2.02E+06	3.20E+06	1.84E-13
	Bottom	1.84E+06	2.92E+06	1.68E-13
	Average			**1.80E-13**

Notes:

(a) Measured specific activities are indexed to a counting date of 08/22/2011. Uranium measurements are reported per gram of Uranium Oxide while Cobalt measurements are reported per gram of Cobalt-Aluminum.

(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	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	9.71E-17	8.15E-17	9.03E-17	1.19	1.08
$^{54}Fe(n,p)^{54}Mn$	7.27E-15	7.47E-15	7.23E-15	0.97	1.01
$^{58}Ni(n,p)^{58}Co$	8.75E-15	9.74E-15	9.18E-15	0.90	0.95
$^{59}Co\ (n,\gamma)^{60}Co$	3.09E-12	3.01E-12	3.09E-12	1.03	1.00
$^{59}Co(Cd)(n,\gamma)^{60}Co$	3.92E-13	5.26E-13	3.97E-13	0.75	0.99
$^{238}U(Cd)(n,f)\ ^{137}Cs$	2.03E-14	2.54E-14	2.31E-14	0.80	0.88
Capsule 97°					
	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{54}Fe(n,p)^{54}Mn$	7.53E-15	7.34E-15	7.12E-15	1.02	1.05
$^{58}Ni(n,p)^{58}Co$	8.33E-15	9.58E-15	8.92E-15	0.87	0.93
$^{238}U(Cd)(n,f)\ ^{137}Cs$	2.45E-14	2.50E-14	2.39E-14	0.98	1.03
Capsule 104°					
	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	4.22E-17	4.67E-17	4.31E-17	0.90	0.98
$^{54}Fe(n,p)^{54}Mn$	3.77E-15	3.98E-15	3.71E-15	0.95	1.02
$^{58}Ni(n,p)^{58}Co$	5.21E-15	5.17E-15	4.90E-15	1.01	1.06
$^{59}Co(n,\gamma)^{60}Co$	1.13E-12	1.46E-12	1.13E-12	0.77	1.00
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	1.80E-13	2.57E-13	1.82E-13	0.70	0.99
$^{238}U(Cd)(n,f)$ FP	9.08E-15	1.31E-14	1.19E-14	0.69	0.76

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	$\varphi(E > 1.0\ MeV)$ [n/cm²-s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
263°	5.65E+10	5.00E+10	6	0.88
97°	5.54E+10	5.31E+10	6	0.95
104°	2.86E+10	2.58E+10	6	0.90

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 BE exposure rates.

Capsule ID	Iron Atom Displacement Rate [dpa/s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
263°	8.09E-11	7.27E-11	5	0.90
97°	7.94E-11	7.61E-11	6	0.95
104°	4.12E-11	3.72E-11	5	0.90

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 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 104°
$^{63}Cu(n,\alpha)^{60}Co$	1.19	Rejected	0.90
$^{54}Fe(n,p)^{54}Mn$	0.97	1.02	0.95
$^{58}Ni(n,p)^{58}Co$	0.90	0.87	1.01
$^{238}U(Cd)(n,f)$ FP	0.80	0.98	0.69
Average	0.97	0.96	0.89
% Standard Deviation	17	8.1	16

Note:
The overall average M/C ratio for the set of 31 sensor measurements is 0.94 with an associated standard deviation of 9.9%.

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°	0.88	0.90
97°	0.95	0.95
104°	0.90	0.90
Average	0.91	0.92
% Standard Deviation	4.0	3.1

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 SWRI-06-7524, *Reactor Vessel Material Surveillance Program for Calvert Cliffs Unit 2 Analysis of 263° Capsule*, E. B. Norris, September 1985.

A-3 BAW-2199, *Analysis of the Calvert Cliffs Unit No. 2 Reactor Vessel Surveillance Capsule Withdrawn from the 97° Location of the Beltline Region*, A. L. Lowe et al., February 1994.

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.

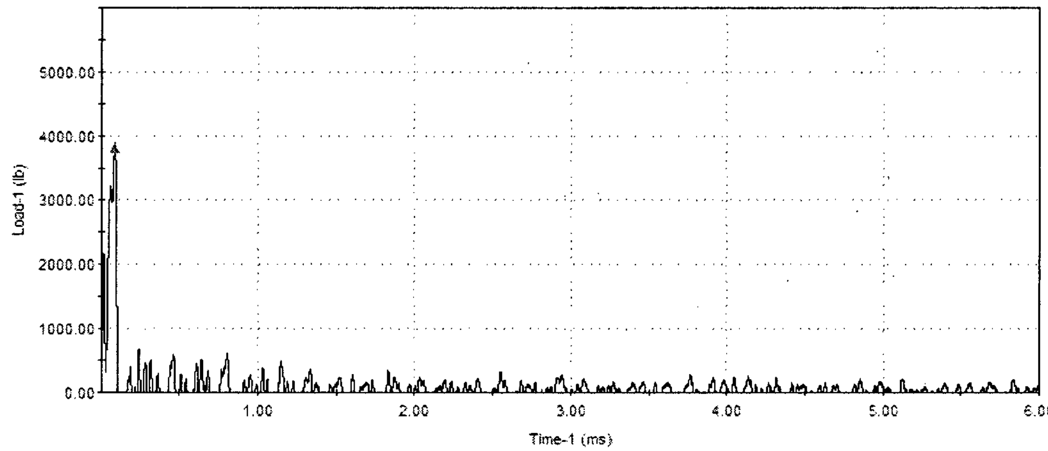
A-6 ASTM Standard E1018-09, *Application of ASTM Evaluated Cross-Section Data File, Matrix E706 (IIB)*, 2010.

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

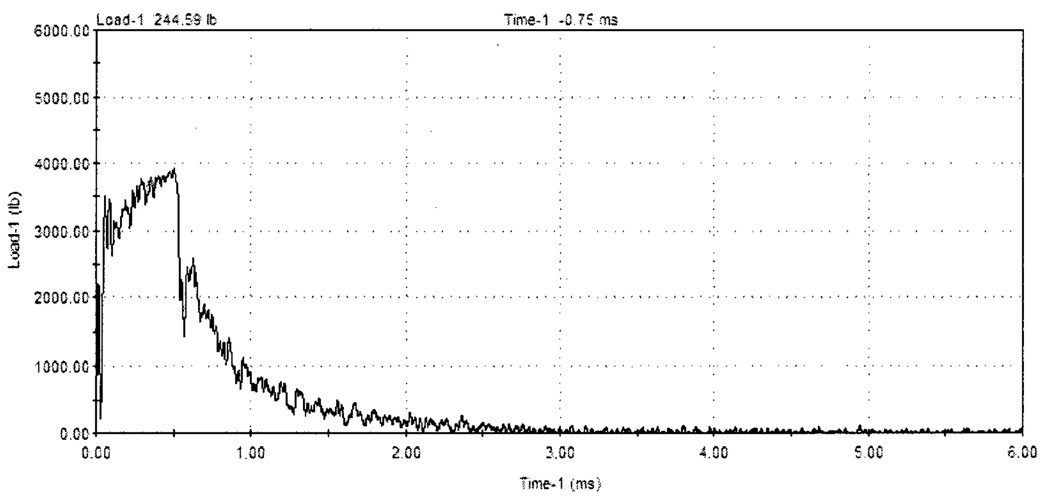
APPENDIX B
LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

- "1XX" denotes Lower Shell Course Plate D-8907-2, Longitudinal Orientation
- "3XX" denotes Weld Material
- "4XX" denotes Heat-Affected-Zone Material
- "6XX" denotes Standard Reference Material (SRM)

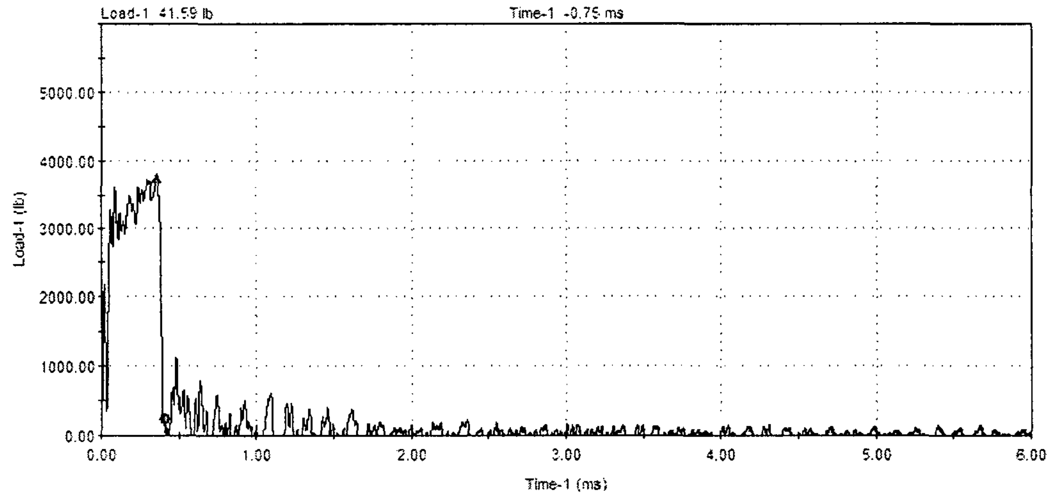
Note that the instrumented Charpy data is for information only. The instrumented tup (striker) was not calibrated per ASTM E2298-09.



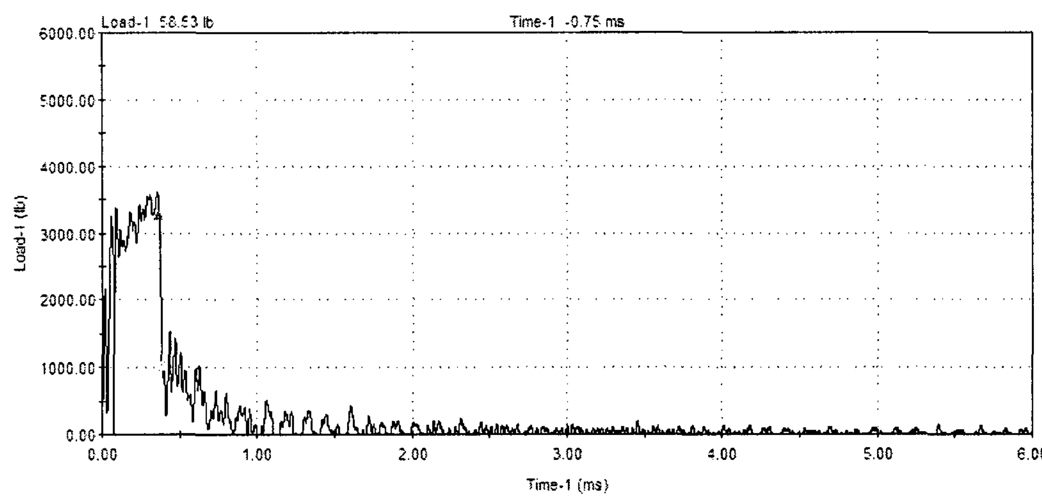
15P, 0°F



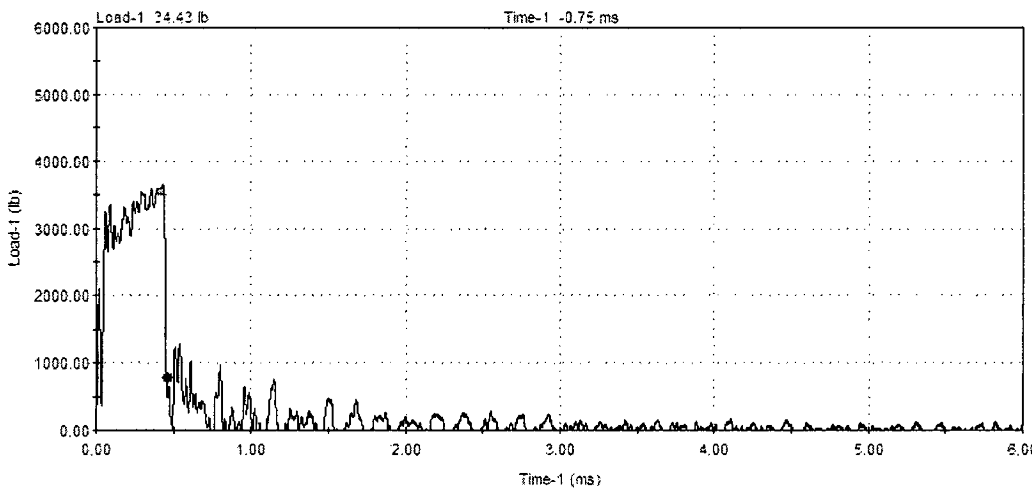
11Y, 75°F



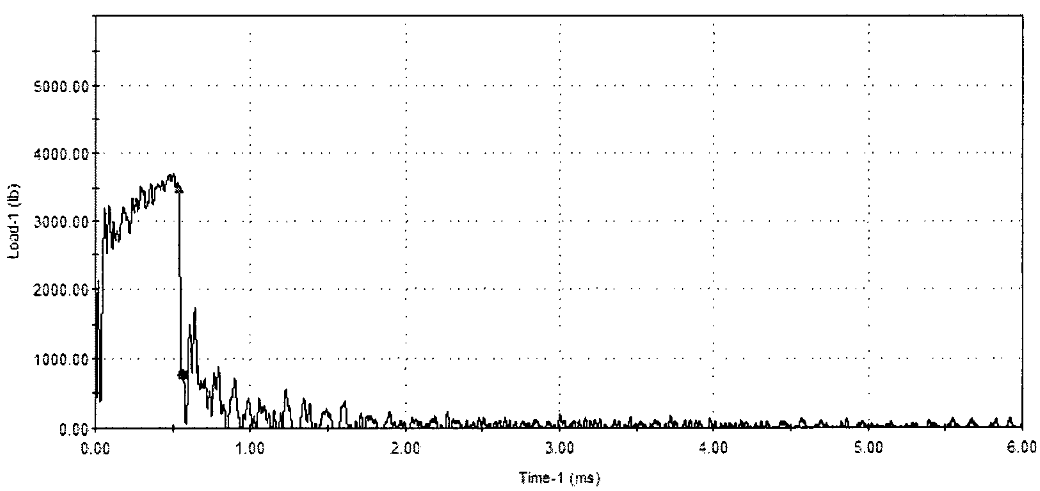
13B, 125°F



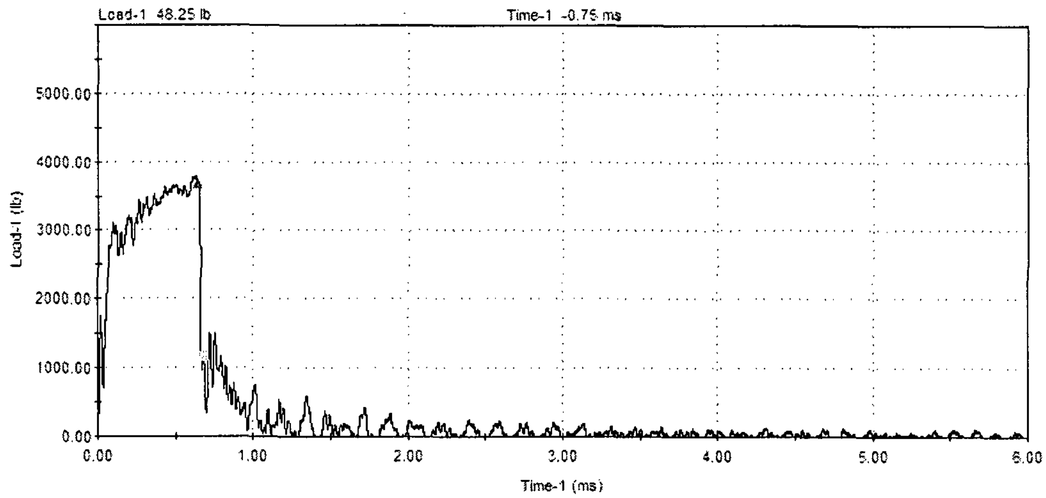
11K, 150°F



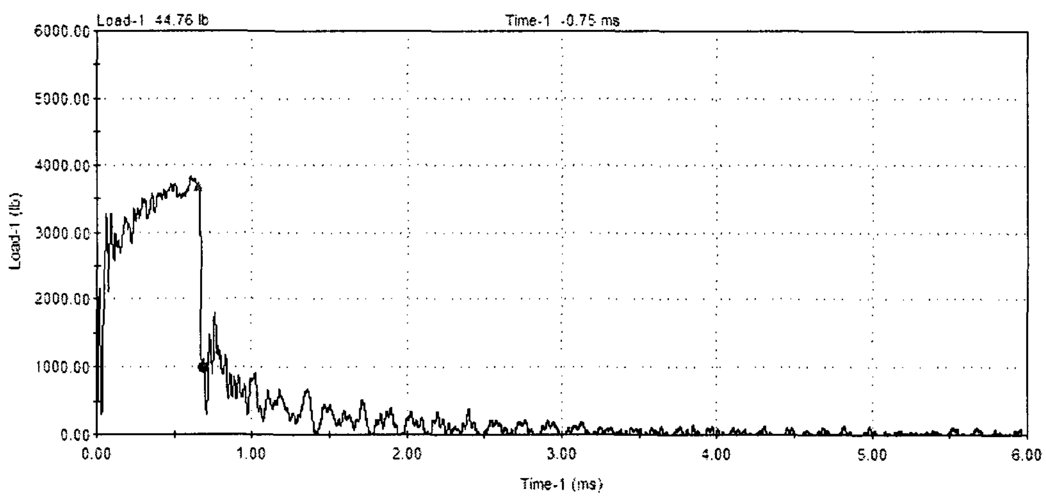
12M, 155°F



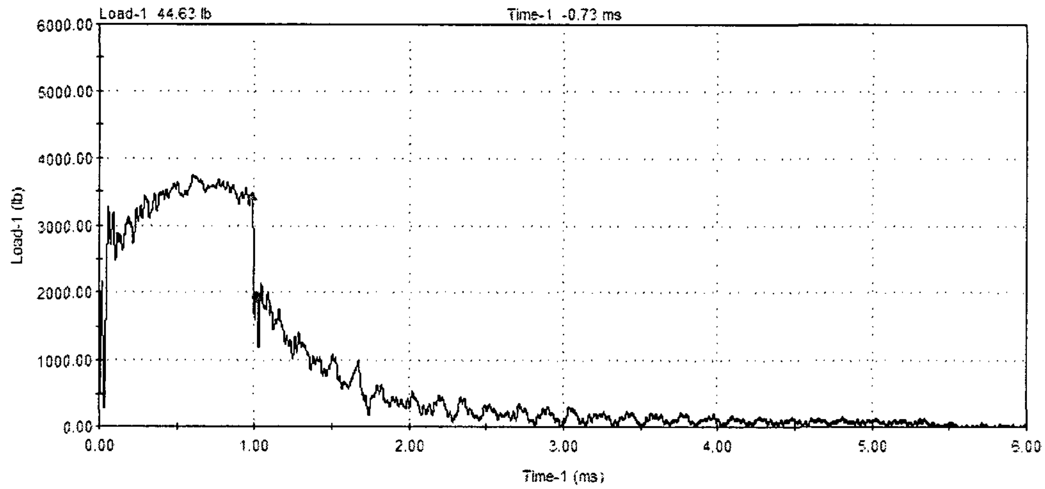
122, 165°F



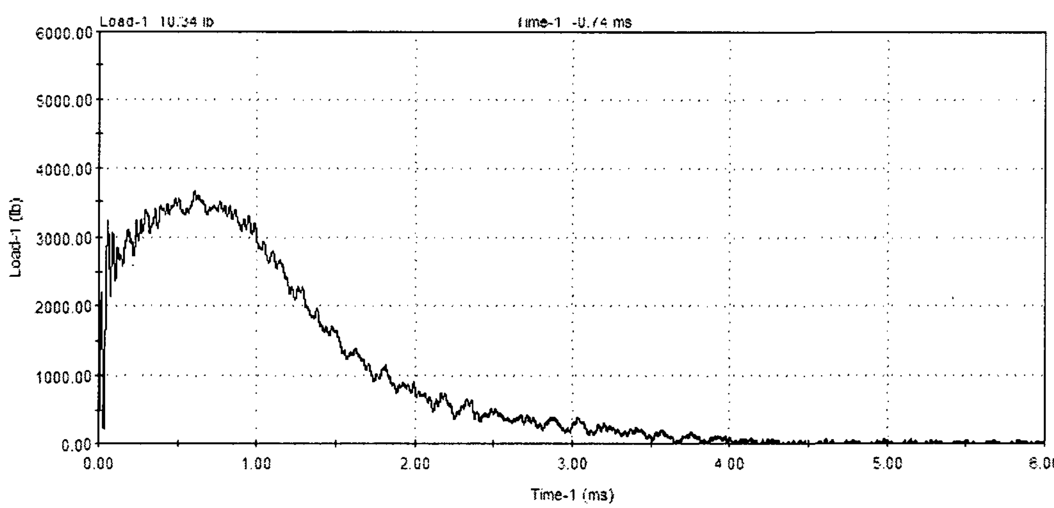
123, 175°F



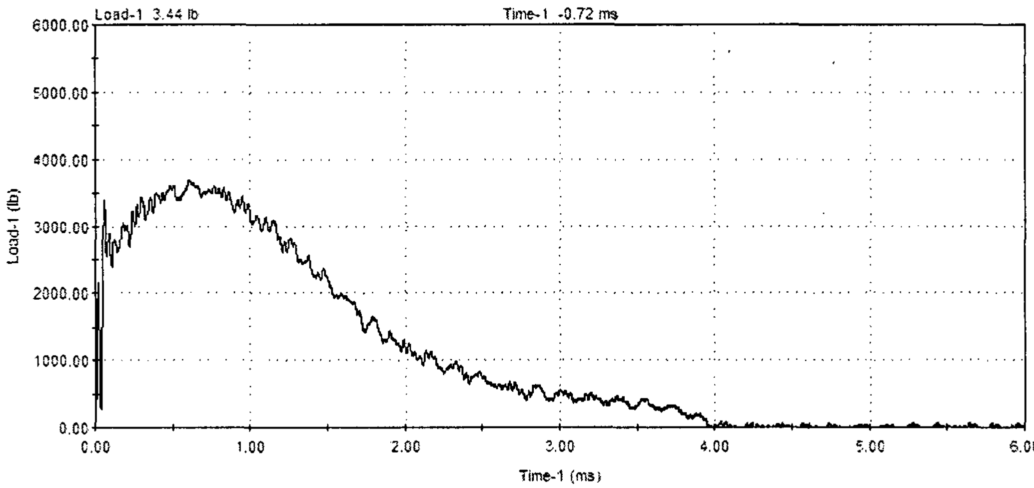
15U, 190°F



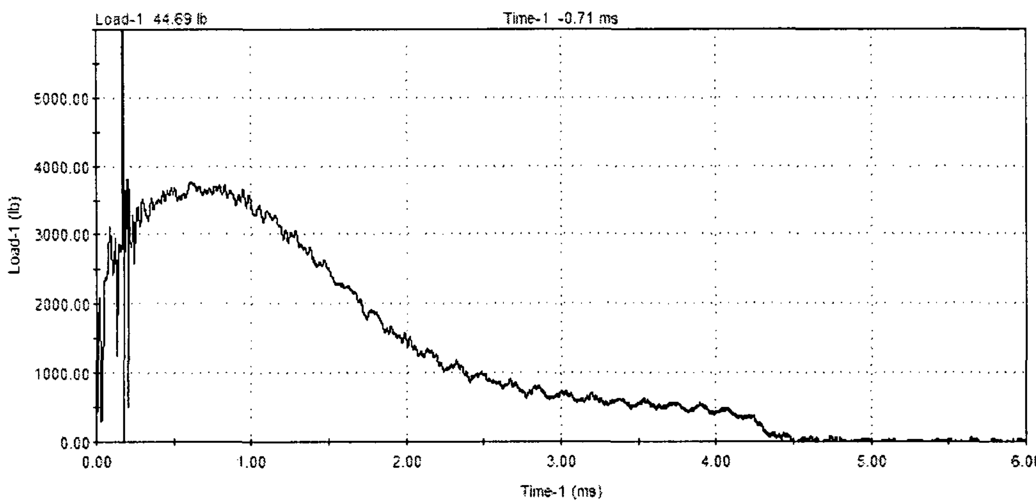
15M, 210°F



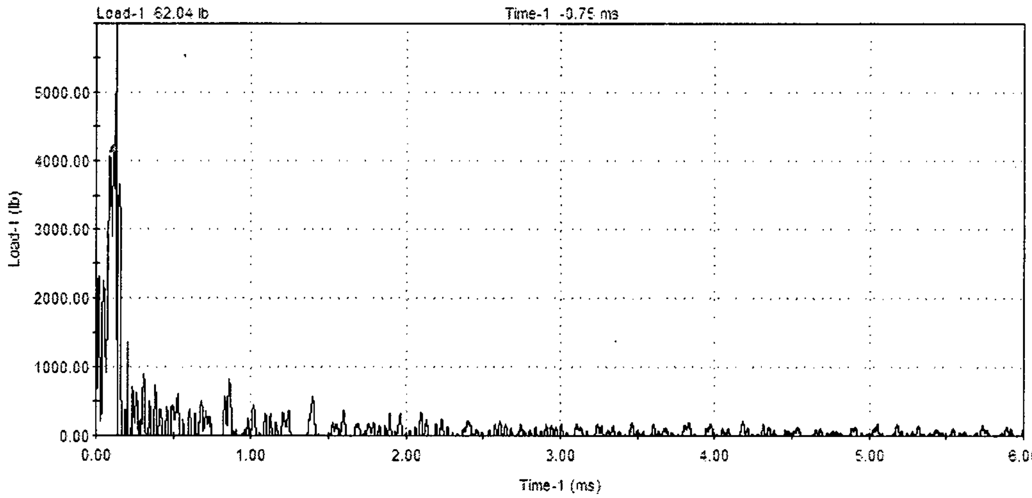
142, 325°F



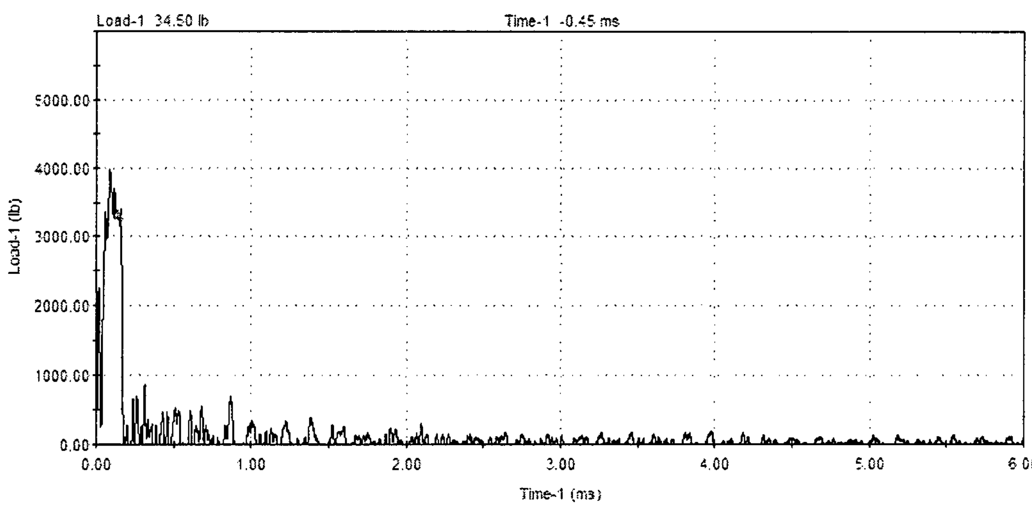
12C, 340°F



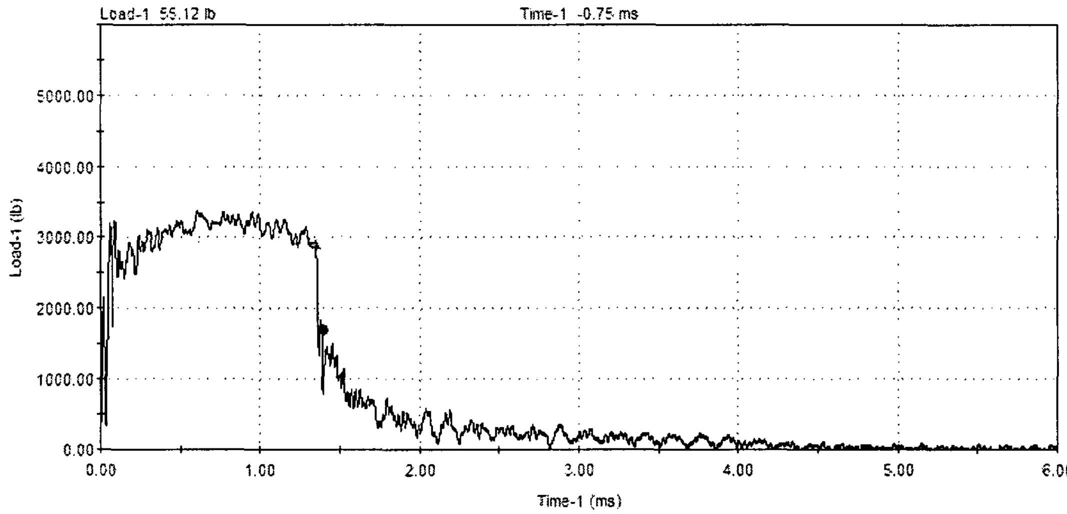
162, 350°F



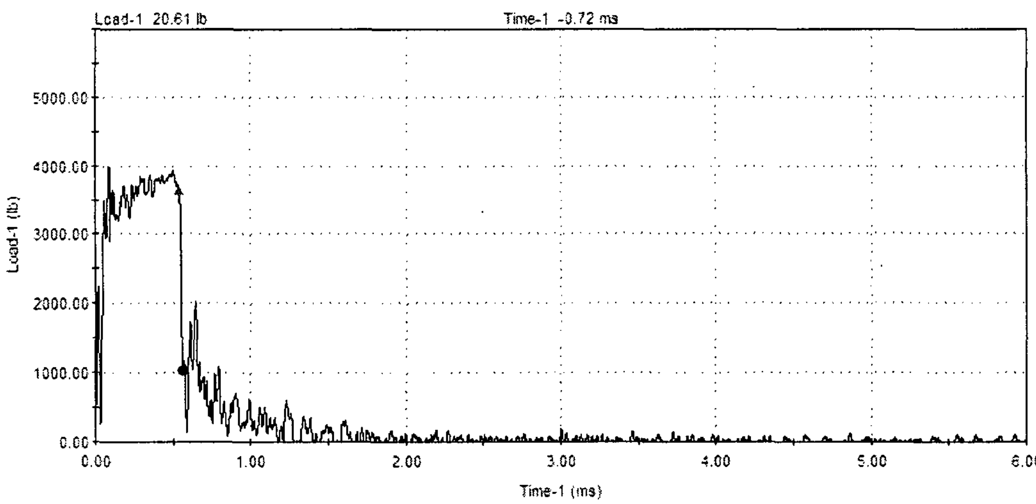
341, 0°F



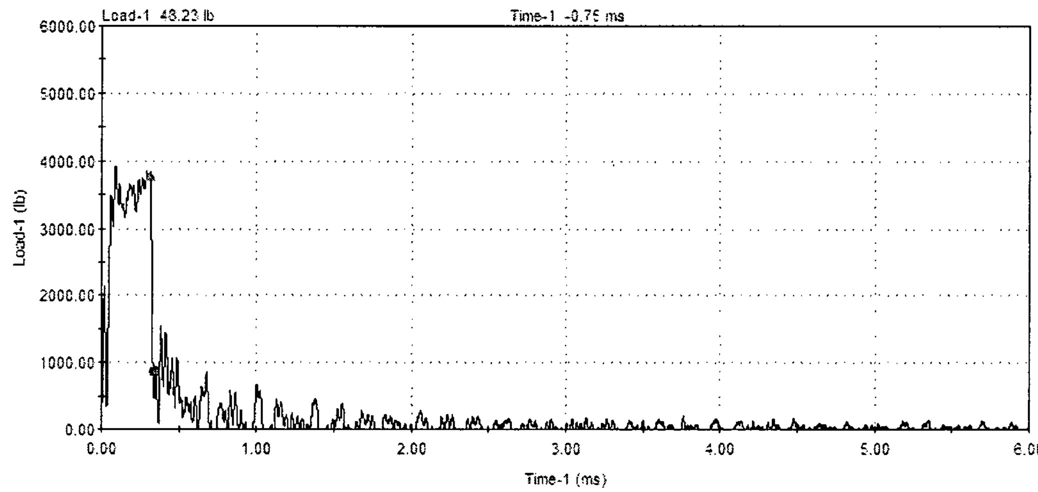
316, 15°F



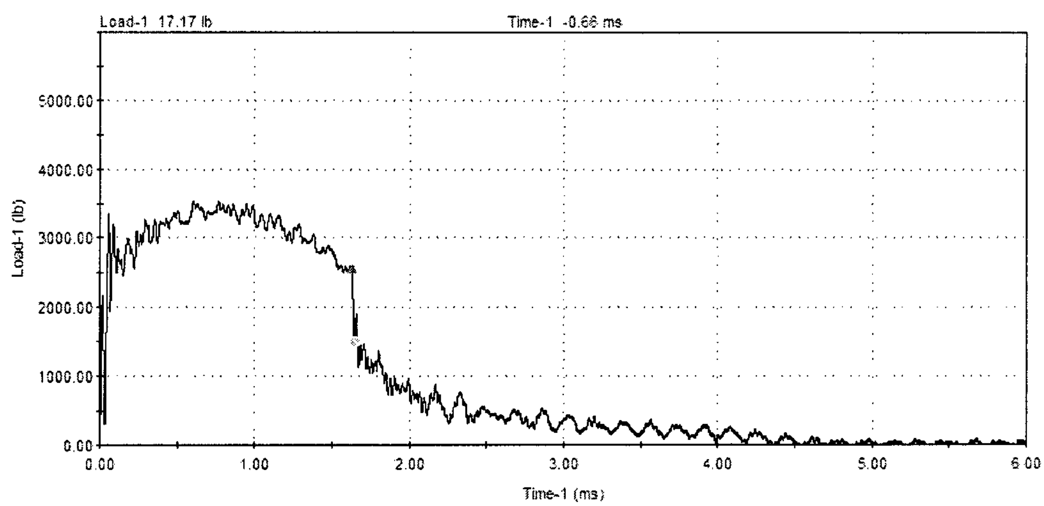
313, 20°F



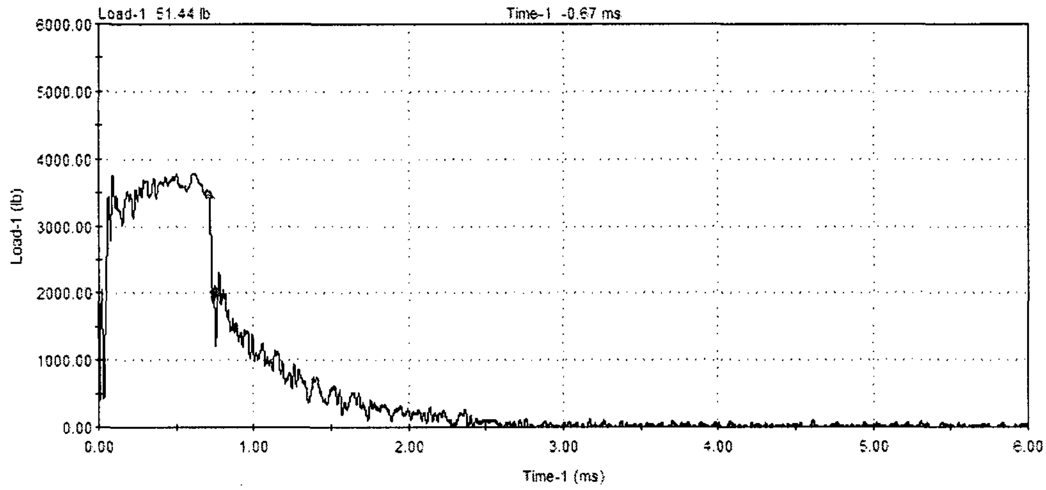
34D, 25°F



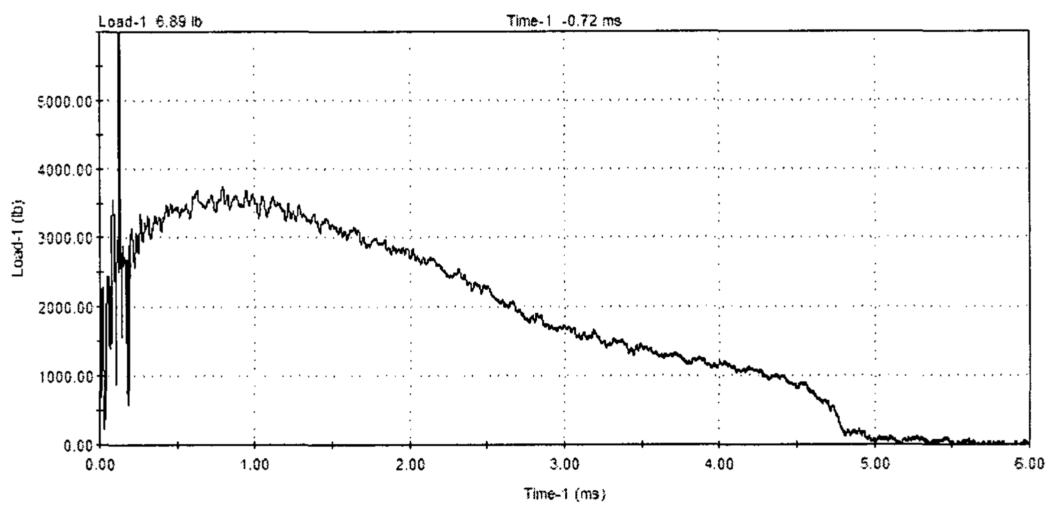
32P, 30°F



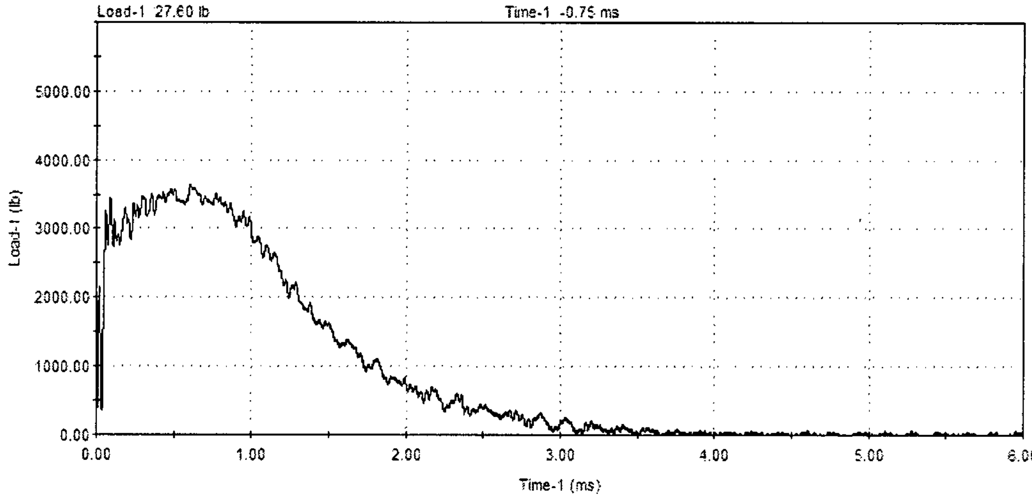
31K, 50°F



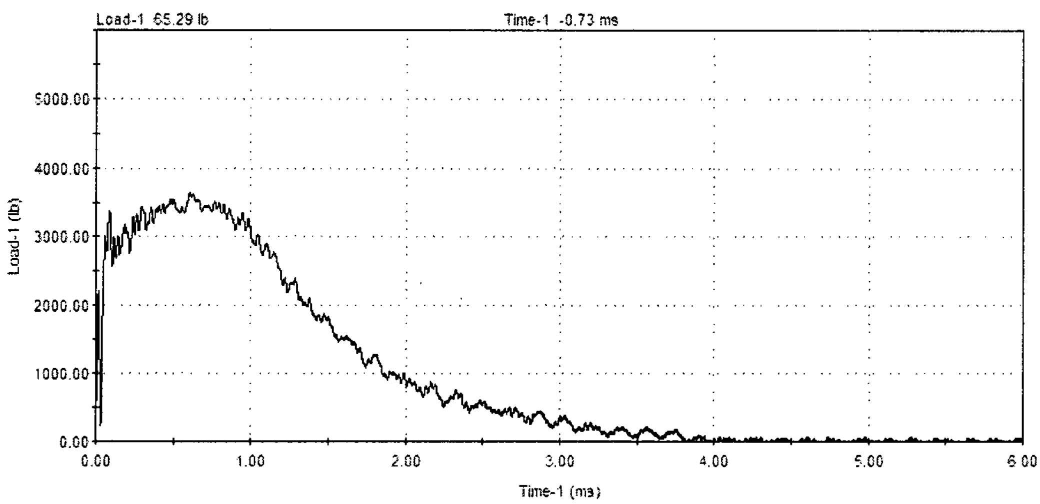
32T, 60°F



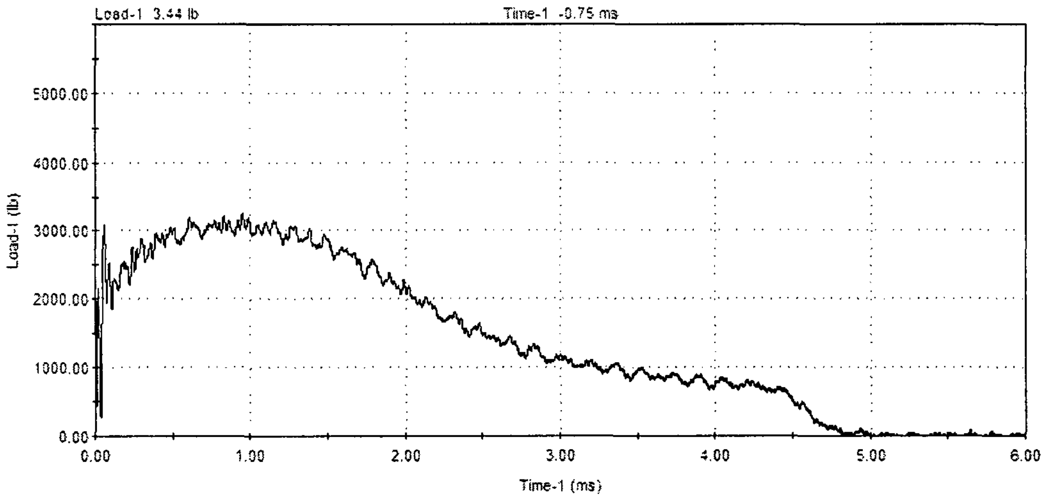
31E, 75°F



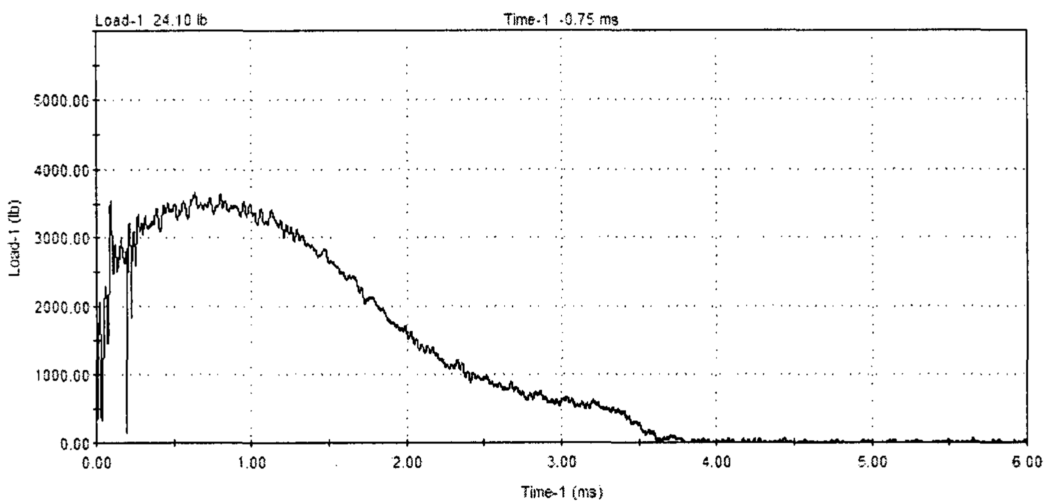
35L, 150°F



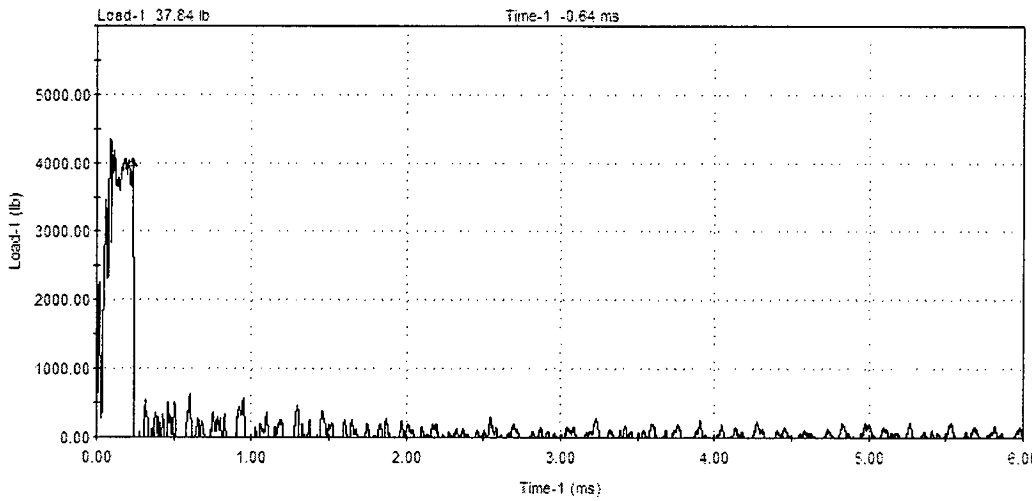
343, 225°F



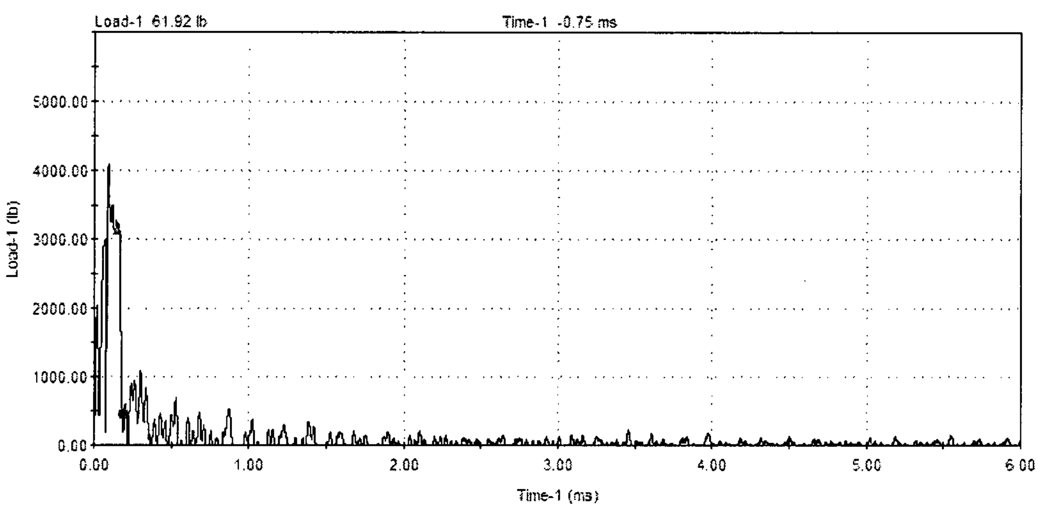
31J, 250°F



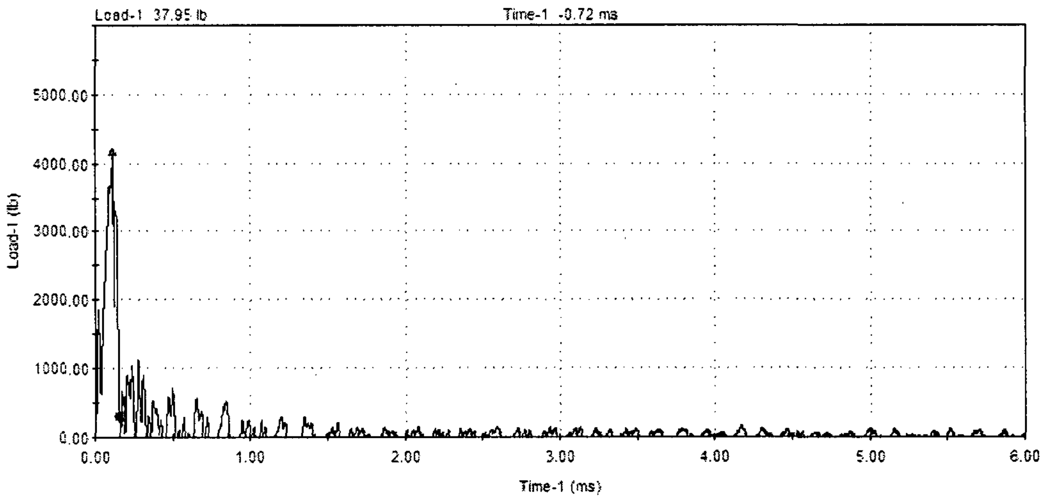
31M, 275°F



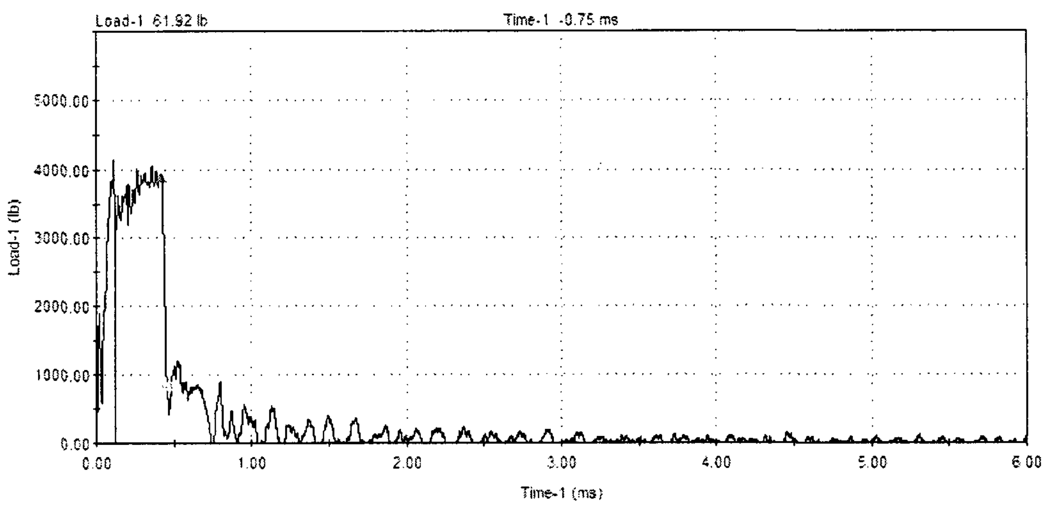
44T, -75°F



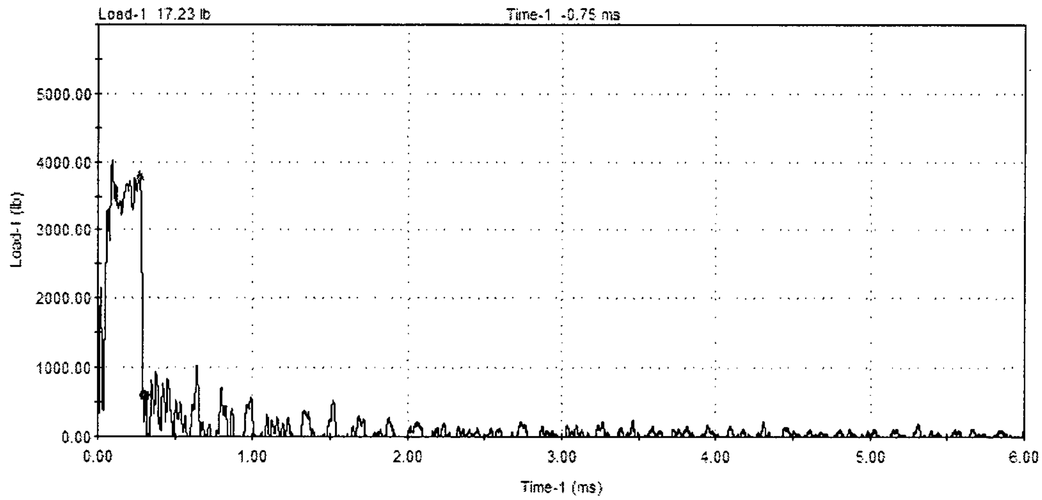
43D, -25°F



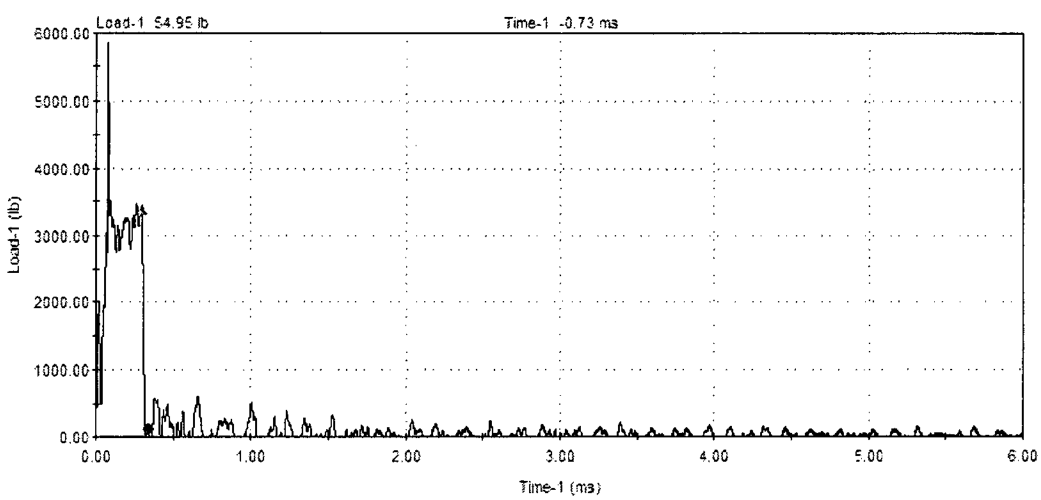
45D, -15°F



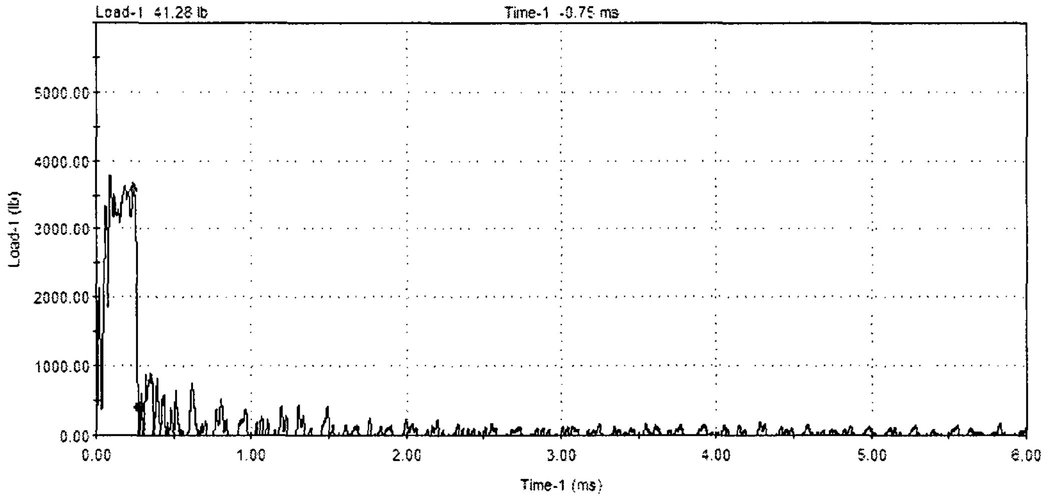
44A, 0°F



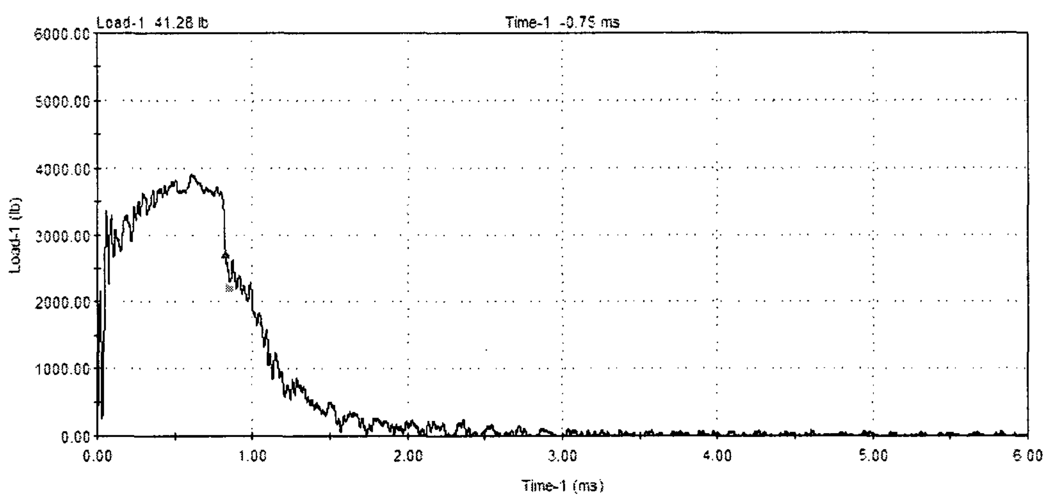
453, 20°F



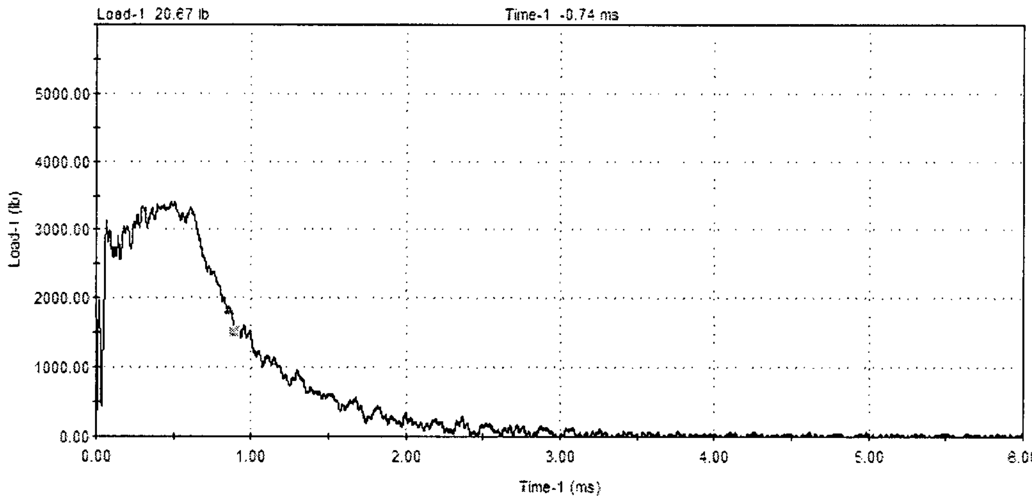
43B, 40°F



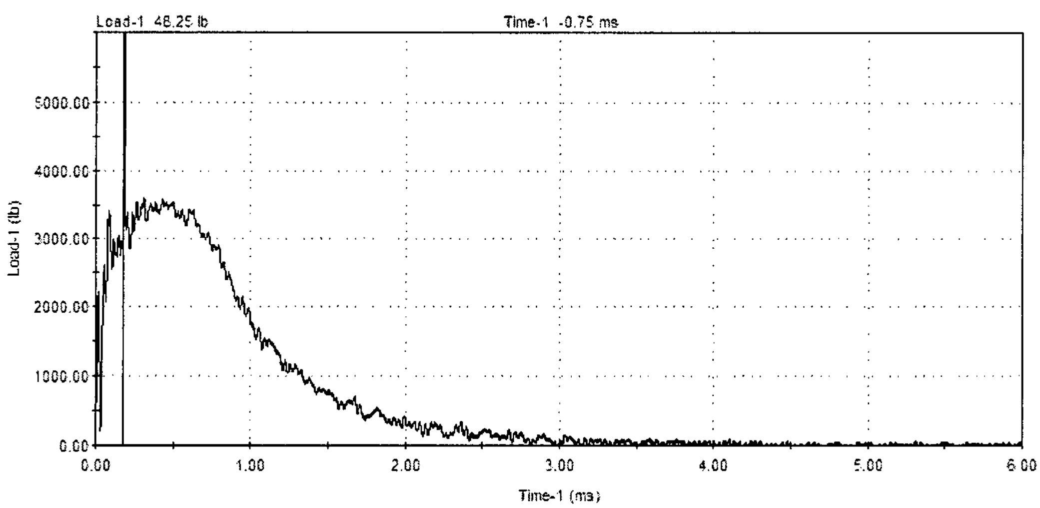
45C, 50°F



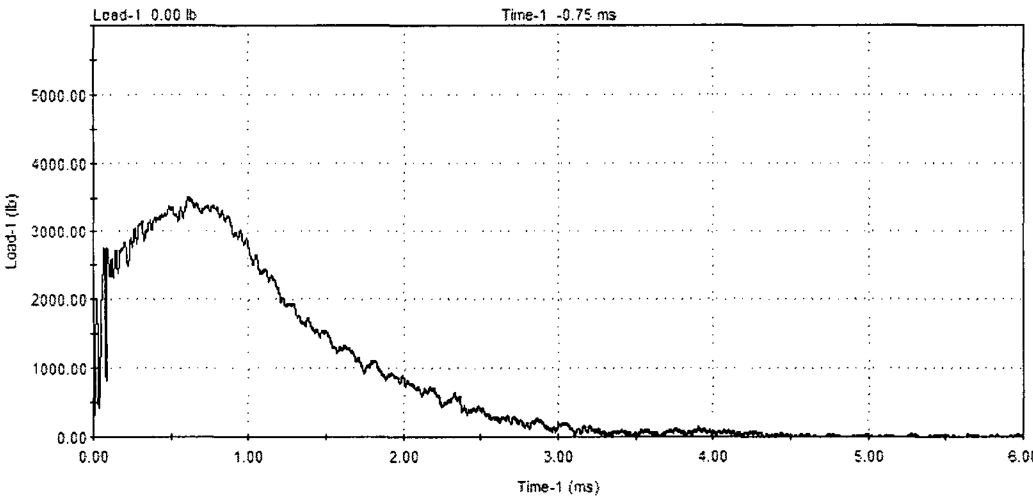
43C, 75°F



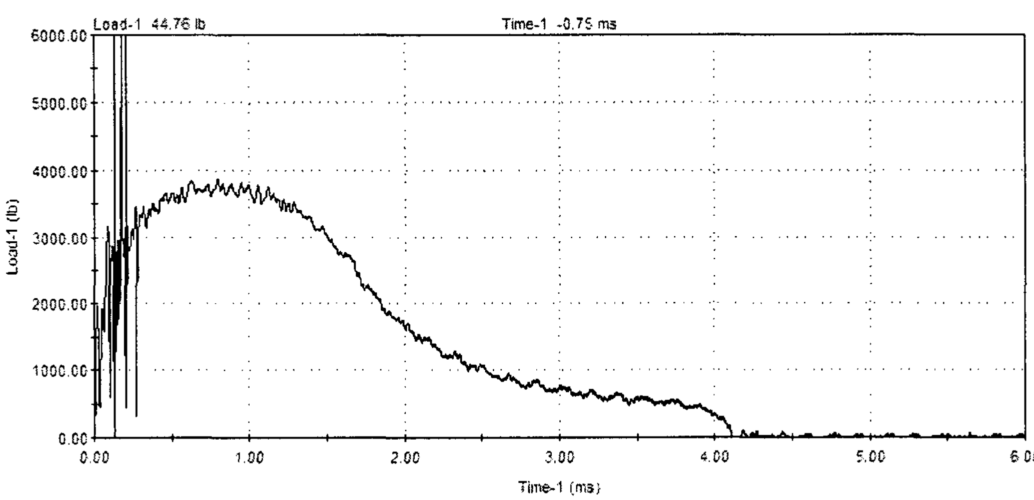
42M, 250°F



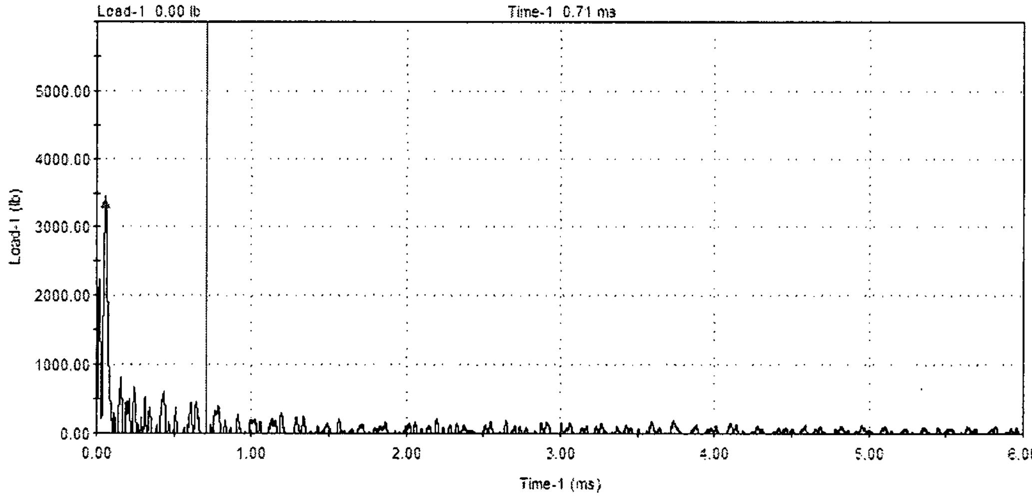
462, 275°F



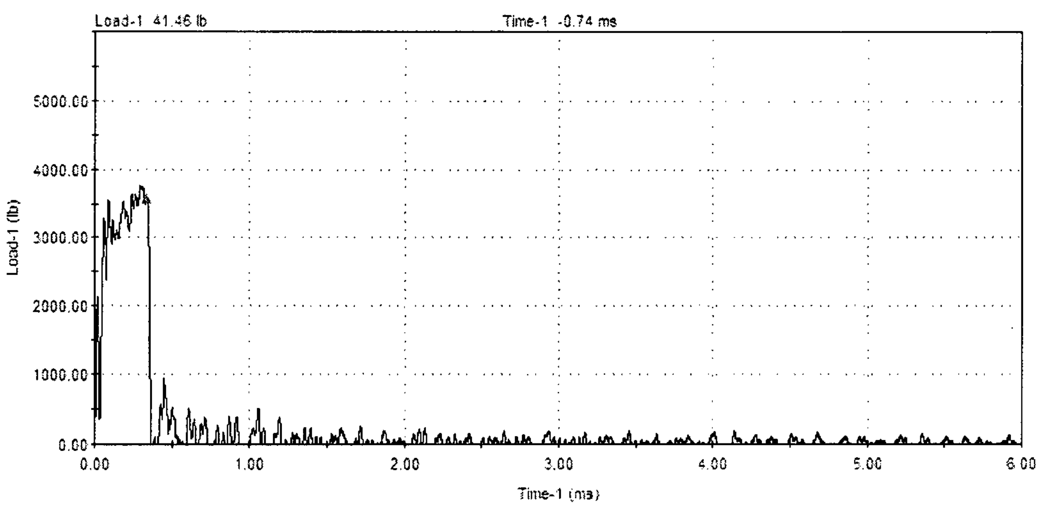
434, 300°F



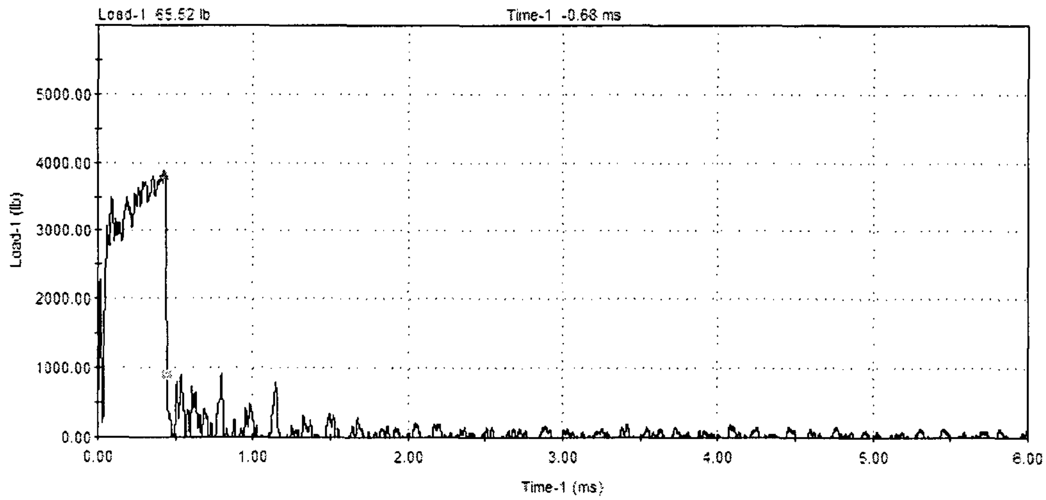
44B, 325°F



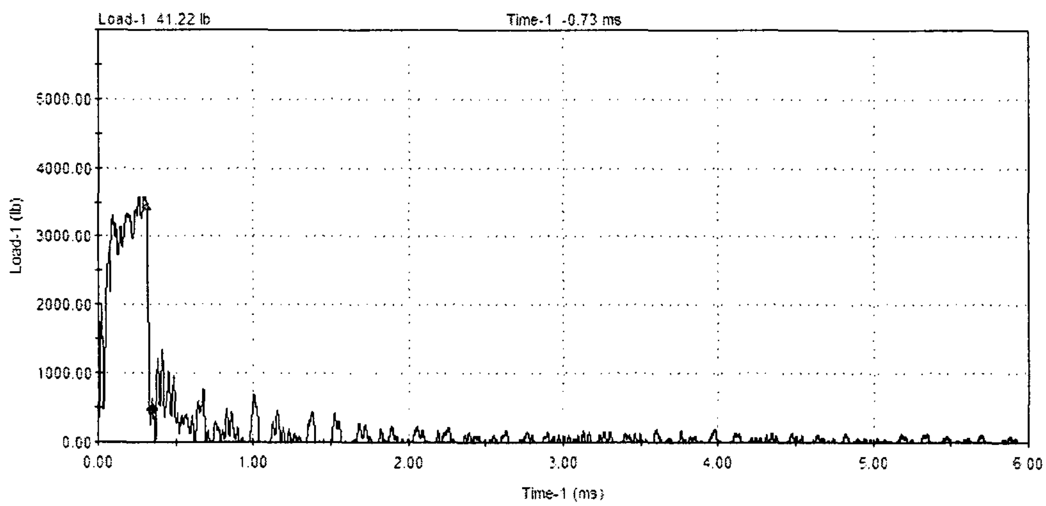
67M, 75°F



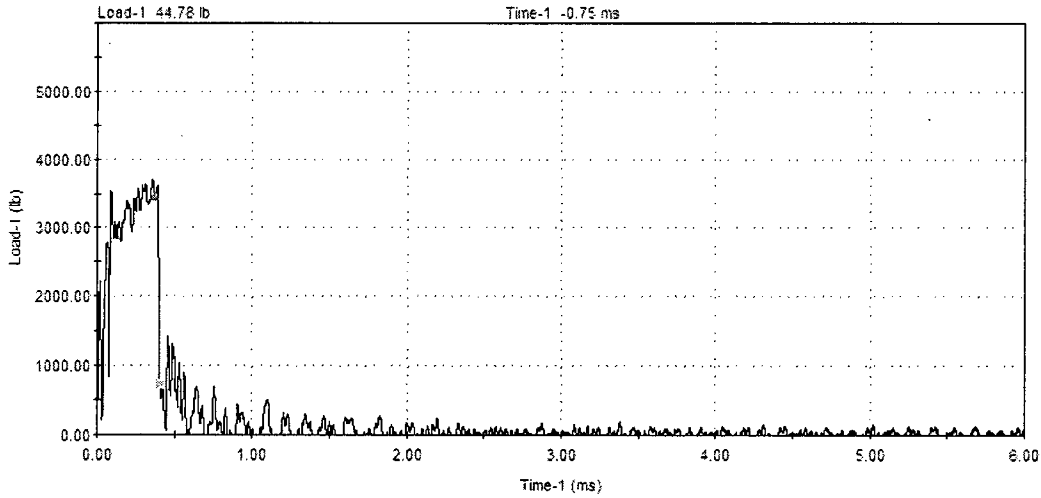
66B, 150°F



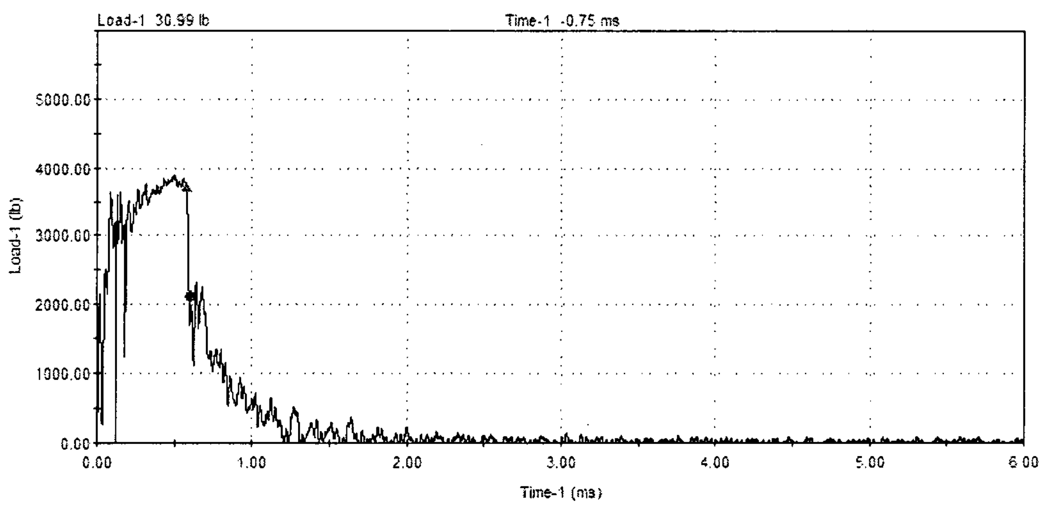
67D, 175°F



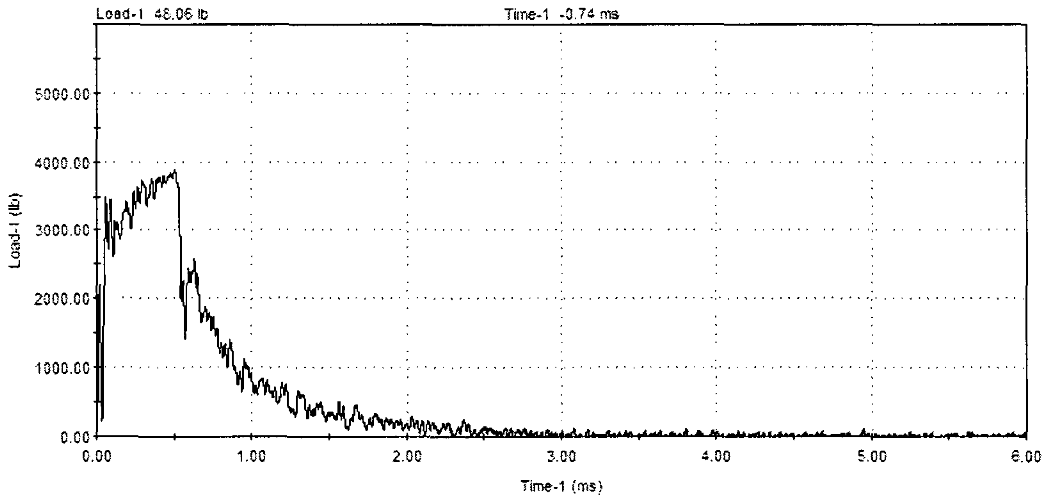
67J, 190°F



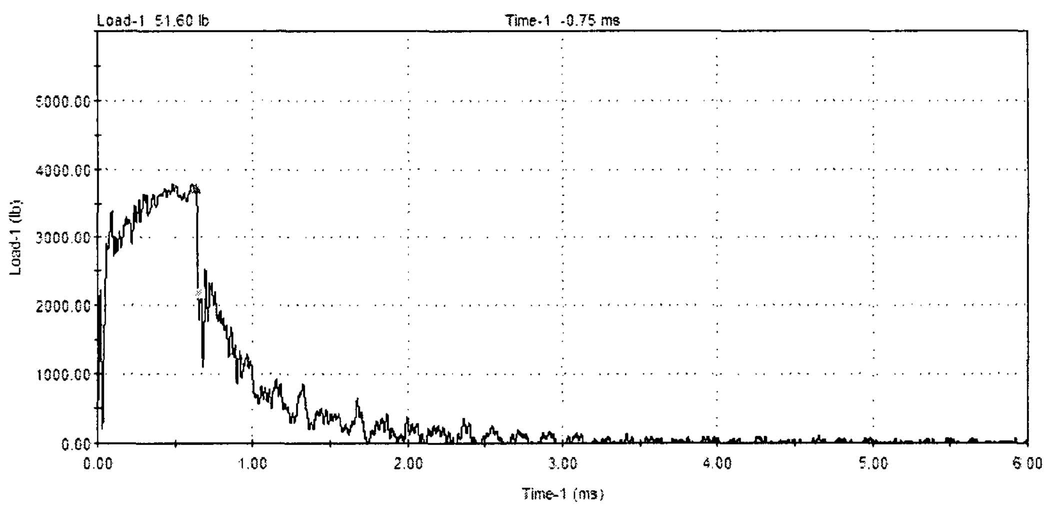
66J, 200°F



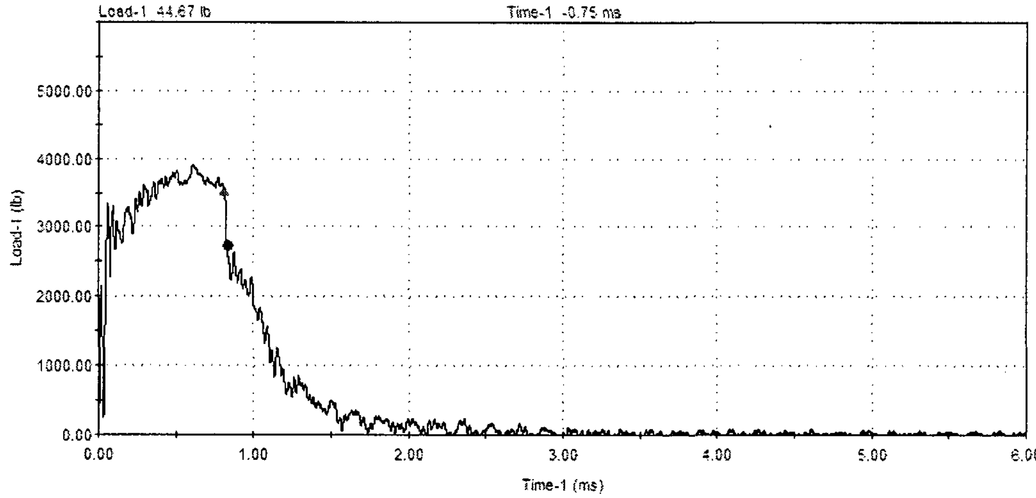
66L, 210°F



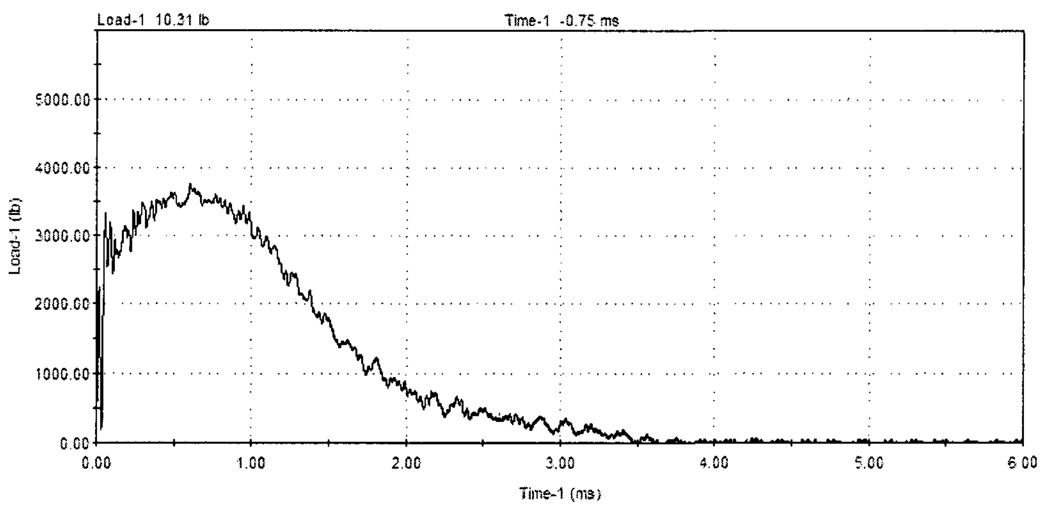
67B, 220°F



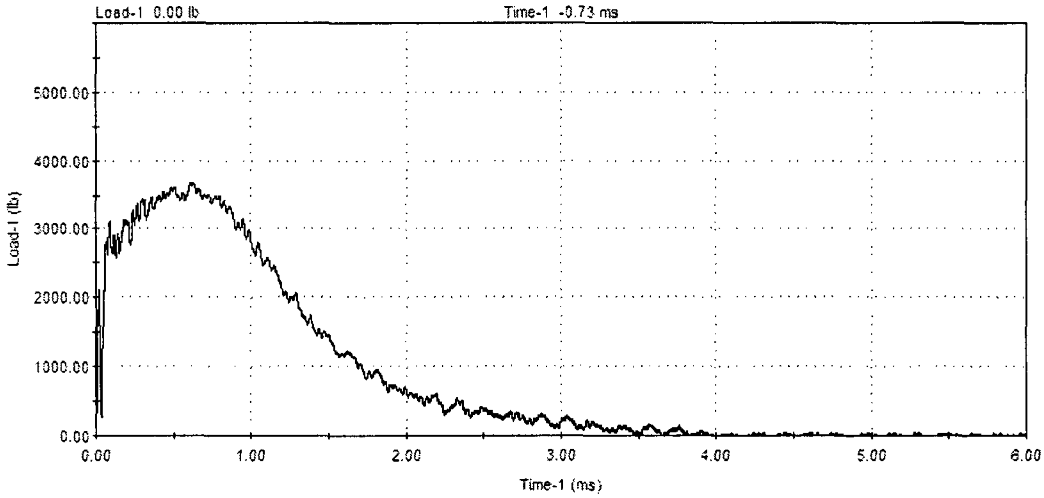
67E, 225°F



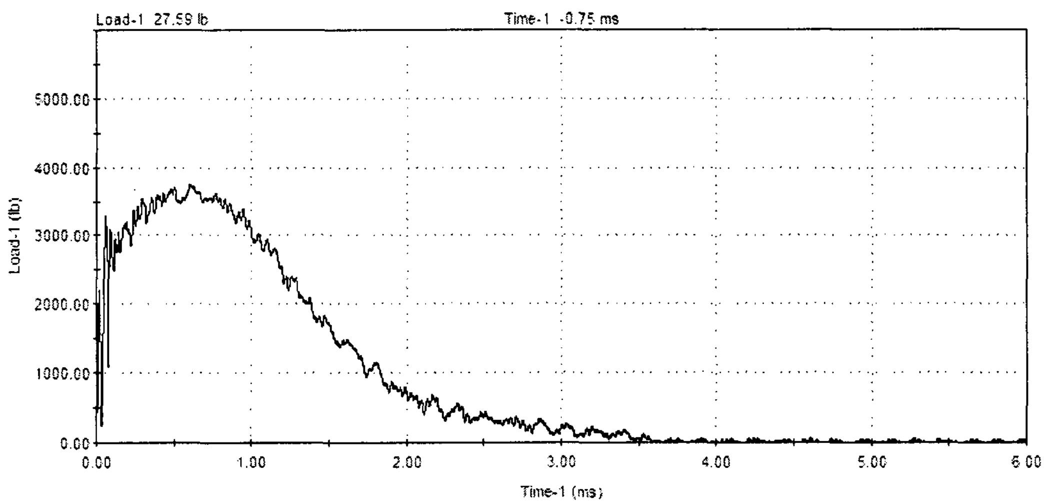
66E, 235°F



66P, 325°F



66K, 350°F



67C, 375°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 104° 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 TR-ESS-001 [Reference C-2], SwRI-06-7524 [Reference C-3] and BAW-2199 [Reference 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°	104°
Lower Shell Plate D-8907-2 Longitudinal Orientation	141.6	114.7	108.0	107.7
Lower Shell Plate D-8907-2 Transverse Orientation	114.4	---	86.7	---
Surveillance Program Weld Metal (Heat # 10137)	138.9	105.3	97.3	110.3
HAZ Material	127.7	104.5	81.4	94.0
SRM	141.5	89.9	---	92.3

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 104° 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 SwRI-06-7524, *Reactor Vessel Material Surveillance Program for Calvert Cliffs Unit 2 Analysis of 263° Capsule*, September 1985.

C-4 BAW-2199, *Analysis of Capsule 97° Baltimore Gas & Electric Company Calvert Cliffs Nuclear Power Plant Unit No. 2*, February 1994.

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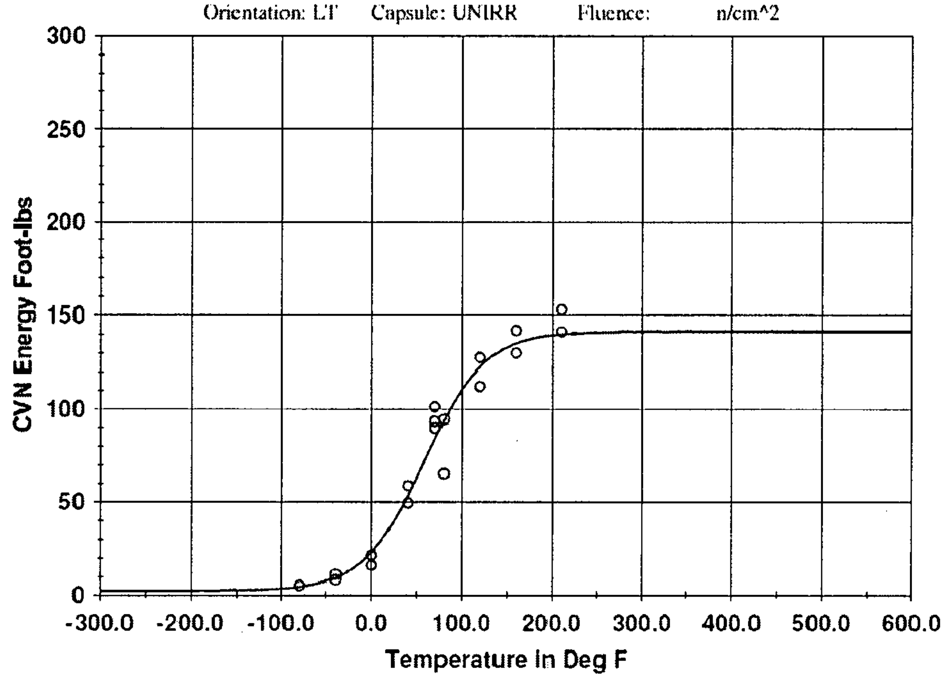
C.2 CVGRAPH VERSION 5.3 INDIVIDUAL PLOTS

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 12:35 PM
Page 1
Coefficients of Curve 1
A = 71.9 B = 69.7 C = 67.15 T0 = 57.93 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=141.6(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=11.3 Deg F Temp@50 ft-lbs=36.1 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-80.00	5.00	4.45	.55
-40.00	8.20	9.36	-1.16
-40.00	11.00	9.36	1.64
.00	16.00	23.27	-7.27
.00	21.50	23.27	-1.77
40.00	49.50	53.72	-4.22
40.00	59.00	53.72	5.28
70.00	90.00	84.30	5.70
70.00	93.50	84.30	9.20

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

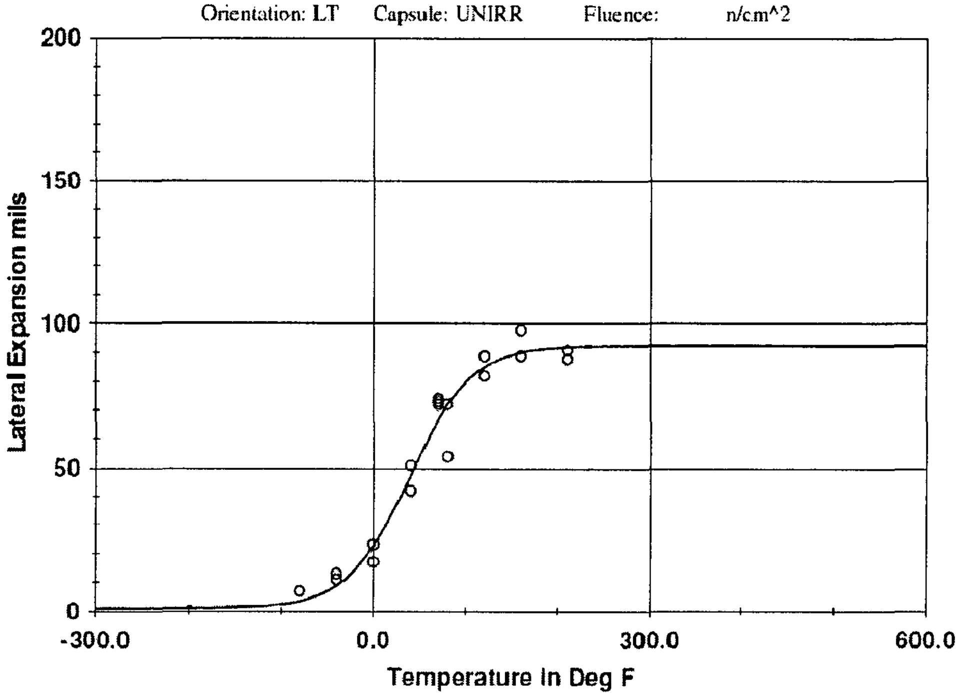
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	101.00	84.30	16.70
80.00	65.50	94.02	-28.52
80.00	94.50	94.02	.48
120.00	112.00	122.64	-10.64
120.00	127.50	122.64	4.86
160.00	130.00	135.24	-5.24
160.00	142.00	135.24	6.76
210.00	141.50	140.11	1.39
210.00	153.00	140.11	12.89

Correlation Coefficient = .981

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 12:41 PM
Page 1
Coefficients of Curve 1
A = 46.82 B = 45.82 C = 66.88 T0 = 38.97 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=92.6 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=21.4 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-80.00	7.00	3.54	3.46
-40.00	11.00	8.89	2.11
-40.00	13.00	8.89	4.11
.00	17.00	22.78	-5.78
.00	23.00	22.78	.22
40.00	42.00	47.52	-5.52
40.00	51.00	47.52	3.48
70.00	72.00	66.67	5.33
70.00	73.00	66.67	6.33

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	74.00	66.67	7.33
80.00	54.00	71.86	-17.86
80.00	72.00	71.86	.14
120.00	82.00	85.17	-3.17
120.00	89.00	85.17	3.83
160.00	89.00	90.24	-1.24
160.00	98.00	90.24	7.76
210.00	88.00	92.08	-4.08
210.00	91.00	92.08	-1.08

Correlation Coefficient = .981

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 12:47 PM

Page 1

Coefficients of Curve 1

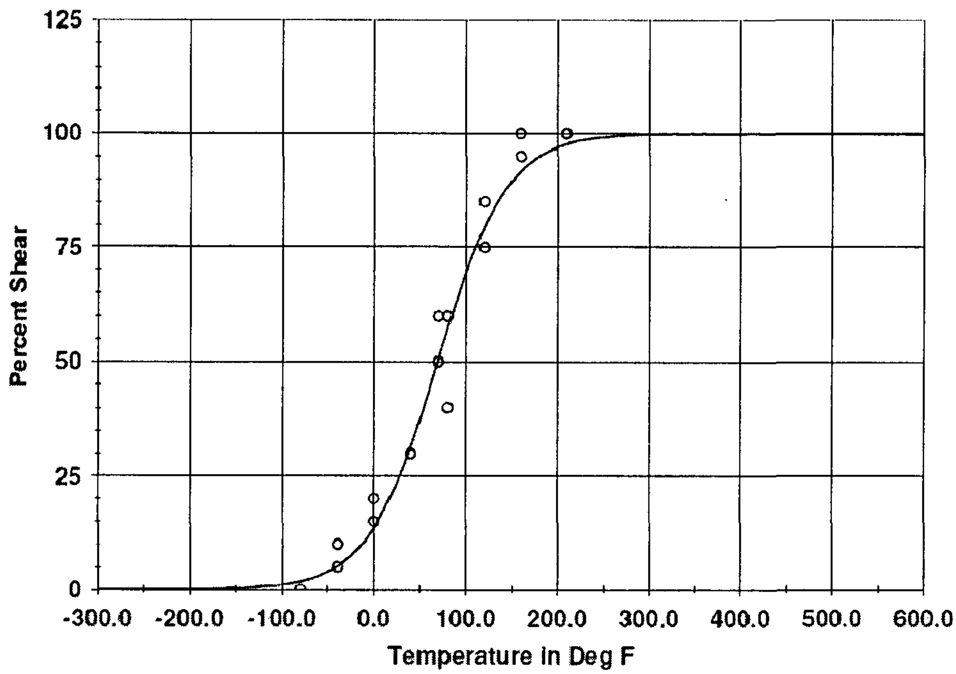
A = 50. B = 50. C = 75.07 T0 = 69.05 D = 0.00E+00

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

Temperature at 50% Shear = 69.1

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-80.00	.00	1.85	-1.85
-40.00	5.00	5.19	-.19
-40.00	10.00	5.19	4.81
.00	15.00	13.71	1.29
.00	20.00	13.71	6.29
40.00	30.00	31.56	-1.56
40.00	30.00	31.56	-1.56
70.00	50.00	50.63	-.63
70.00	50.00	50.63	-.63

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	60.00	50.63	9.37
80.00	40.00	57.24	-17.24
80.00	60.00	57.24	2.76
120.00	75.00	79.53	-4.53
120.00	85.00	79.53	5.47
160.00	95.00	91.86	3.14
160.00	100.00	91.86	8.14
210.00	100.00	97.71	2.29
210.00	100.00	97.71	2.29

Correlation Coefficient = .986

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 12:52 PM

Page 1

Coefficients of Curve 1

A = 58.3 B = 56.1 C = 77.45 T0 = 77.83 D = 0.00E+00

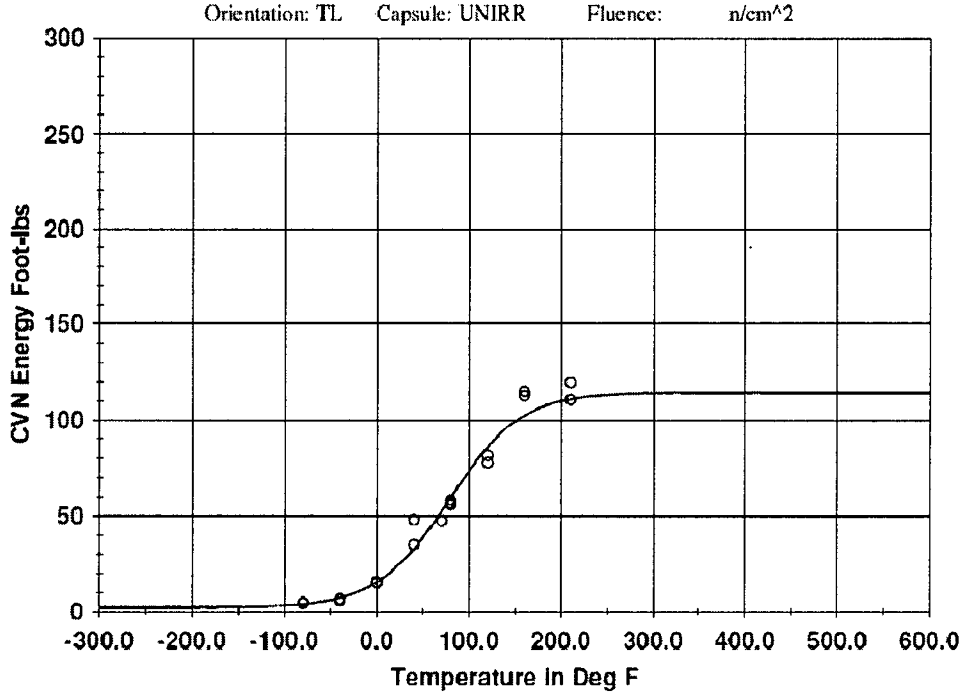
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=114.4(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=34.9 Deg F Temp@50 ft-lbs=66.3 Deg F

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-80.00	4.50	4.07	.43
-80.00	4.80	4.07	.73
-40.00	5.50	7.31	-1.81
-40.00	6.60	7.31	-.71
.00	15.00	15.46	-.46
.00	15.50	15.46	.04
40.00	35.00	32.89	2.11
40.00	48.00	32.89	15.11
70.00	47.50	52.65	-5.15

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

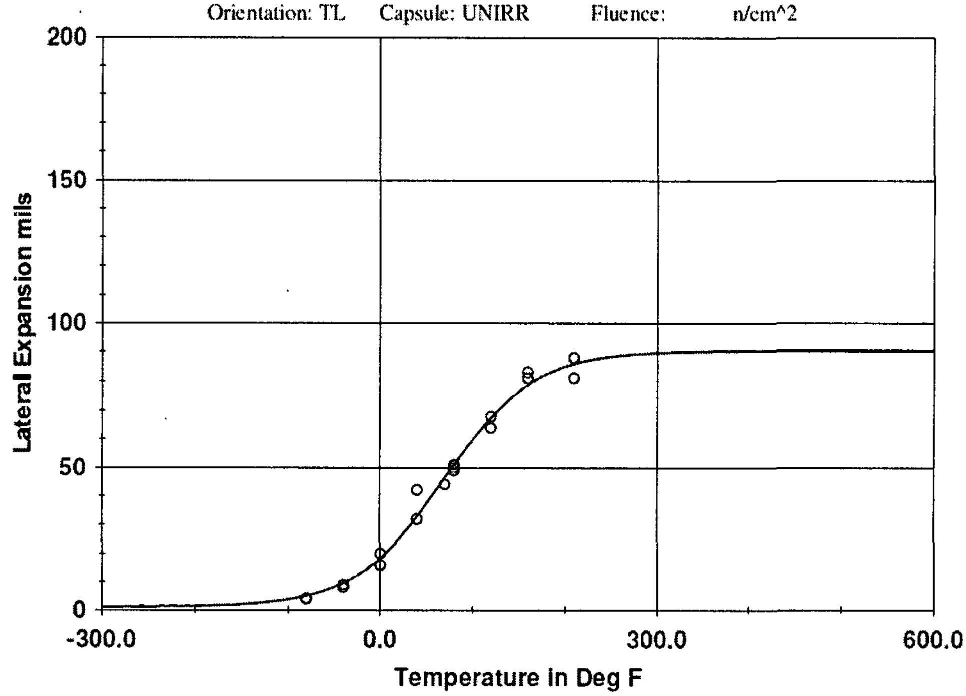
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
80.00	56.00	59.87	-3.87
80.00	57.00	59.87	-2.87
80.00	58.50	59.87	-1.37
120.00	78.00	86.15	-8.15
120.00	81.50	86.15	-4.65
160.00	112.50	102.40	10.10
160.00	115.00	102.40	12.60
210.00	110.50	110.82	-.32
210.00	119.50	110.82	8.68

Correlation Coefficient = .988

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 12:55 PM
Page 1
Coefficients of Curve 1
A = 45.71 B = 44.71 C = 96.75 T0 = 68.33 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=90.4 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=44.7 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-80.00	4.00	4.98	-.98
-80.00	4.00	4.98	-.98
-40.00	9.00	9.61	-.61
-40.00	8.00	9.61	-1.61
.00	16.00	18.51	-2.51
.00	20.00	18.51	1.49
40.00	32.00	32.98	-.98
40.00	42.00	32.98	9.02
70.00	44.00	46.49	-2.49

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
80.00	51.00	51.08	-.08
80.00	50.00	51.08	-1.08
80.00	49.00	51.08	-2.08
120.00	64.00	67.56	-3.56
120.00	68.00	67.56	.44
160.00	81.00	78.74	2.26
160.00	83.00	78.74	4.26
210.00	81.00	85.89	-4.89
210.00	88.00	85.89	2.11

Correlation Coefficient = .994

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 12:57 PM

Page 1

Coefficients of Curve 1

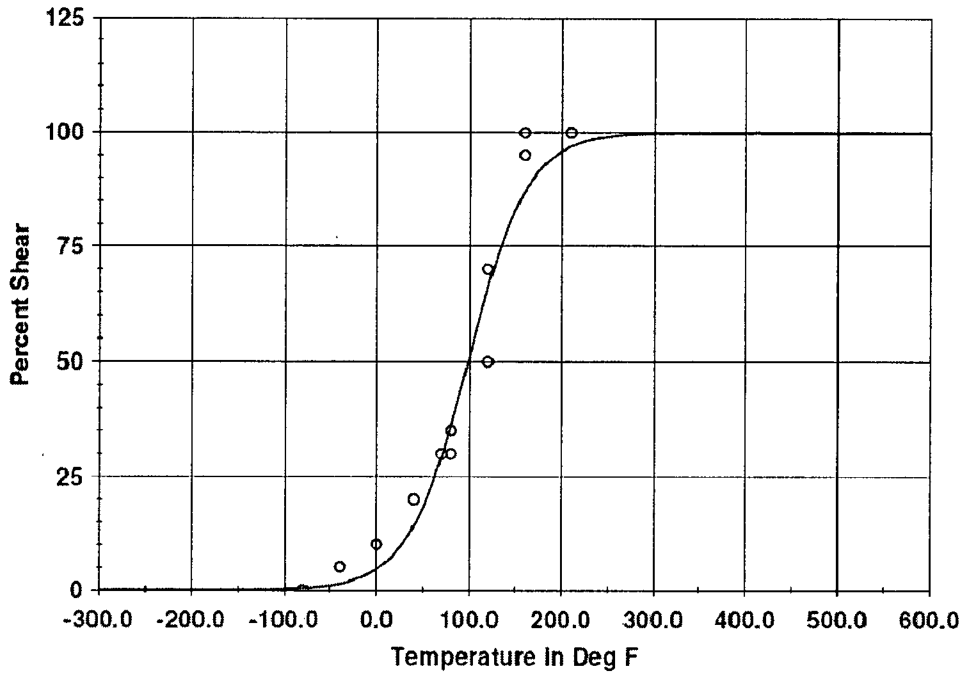
A = 50. B = 50. C = 64.9 T0 = 98.42 D = 0.00E+00

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

Temperature at 50% Shear = 98.5

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-80.00	.00	.41	-.41
-80.00	.00	.41	-.41
-40.00	5.00	1.39	3.61
-40.00	5.00	1.39	3.61
.00	10.00	4.60	5.40
.00	10.00	4.60	5.40
40.00	20.00	14.18	5.82
40.00	20.00	14.18	5.82
70.00	30.00	29.41	.59

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
80.00	35.00	36.18	-1.18
80.00	30.00	36.18	-6.18
80.00	35.00	36.18	-1.18
120.00	50.00	66.04	-16.04
120.00	70.00	66.04	3.96
160.00	95.00	86.96	8.04
160.00	100.00	86.96	13.04
210.00	100.00	96.89	3.11
210.00	100.00	96.89	3.11

Correlation Coefficient = .986

UNIRRADIATED (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:00 PM

Page 1

Coefficients of Curve 1

A = 70.55 B = 68.35 C = 61.38 T0 = -11.84 D = 0.00E+00

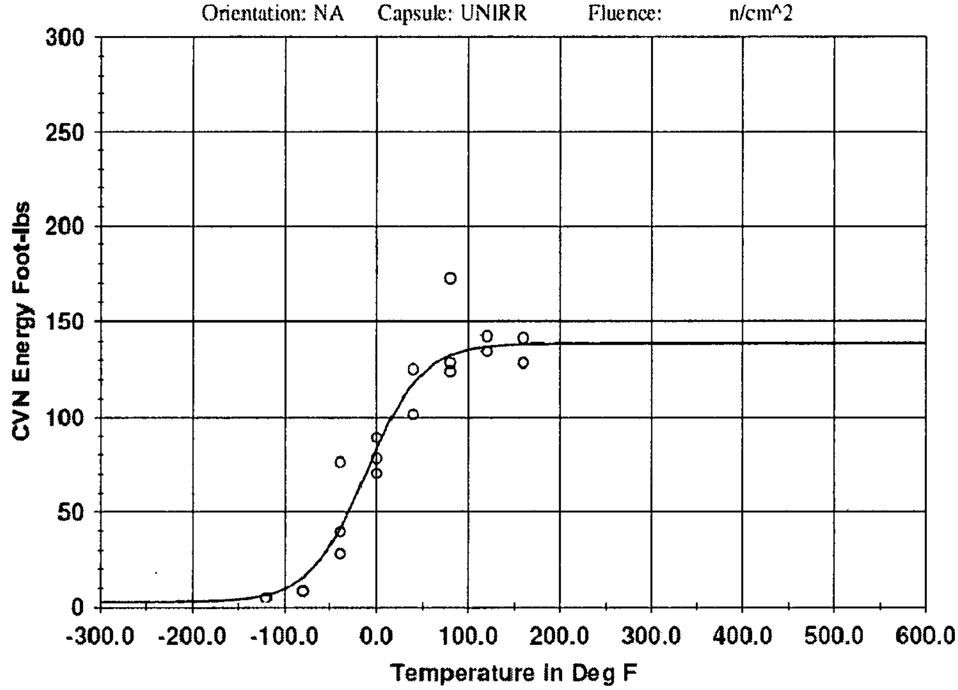
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=138.9(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-53.7 Deg F Temp@50 ft-lbs=-30.8 Deg F

Plant: Calvert Cliffs 2 Material: SAW Heat: 10137

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-120.00	4.30	6.11	-1.81
-80.00	8.00	15.58	-7.58
-80.00	8.50	15.58	-7.08
-40.00	28.00	41.22	-13.22
-40.00	39.50	41.22	-1.72
-40.00	76.50	41.22	35.28
.00	70.50	83.57	-13.07
.00	78.50	83.57	-5.07
.00	89.50	83.57	5.93

UNIRRADIATED (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

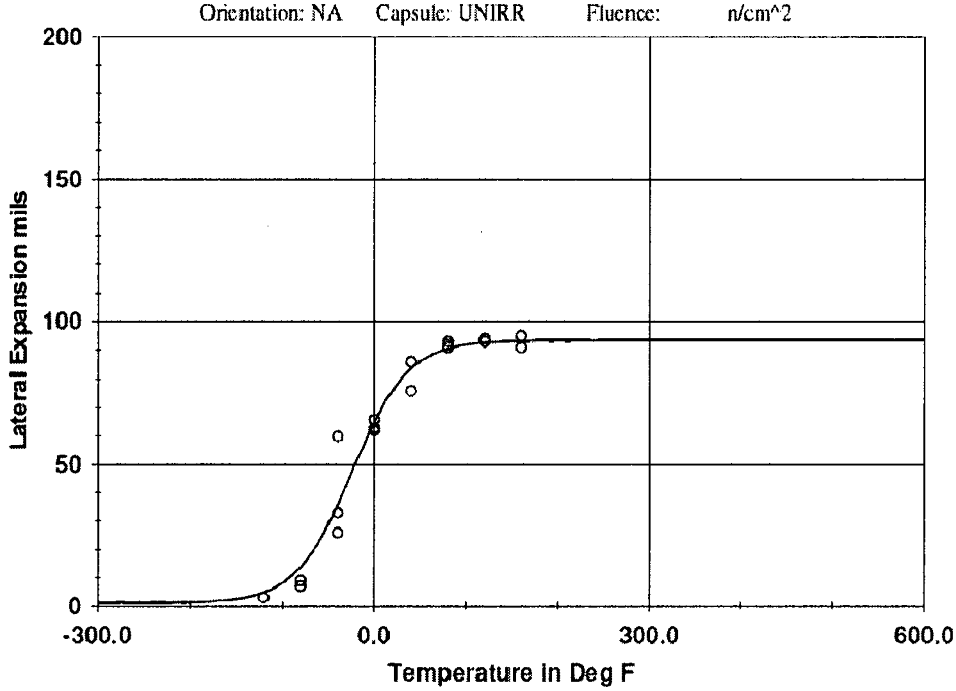
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
40.00	101.50	117.59	-16.09
40.00	125.00	117.59	7.41
80.00	124.00	132.37	-8.37
80.00	128.50	132.37	-3.87
80.00	172.50	132.37	40.13
120.00	134.50	137.06	-2.56
120.00	142.50	137.06	5.44
160.00	128.50	138.40	-9.90
160.00	141.50	138.40	3.10

Correlation Coefficient = .958

UNIRRADIATED (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:03 PM
Page 1
Coefficients of Curve 1
A = 47.23 B = 46.23 C = 60.51 T0 = -24.68 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=93.5 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=-41.0 Deg F
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-120.00	3.00	4.80	-1.80
-80.00	7.00	13.80	-6.80
-80.00	9.00	13.80	-4.80
-40.00	26.00	35.77	-9.77
-40.00	33.00	35.77	-2.77
-40.00	60.00	35.77	24.23
.00	63.00	65.10	-2.10
.00	62.00	65.10	-3.10
.00	66.00	65.10	.90

UNIRRADIATED (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

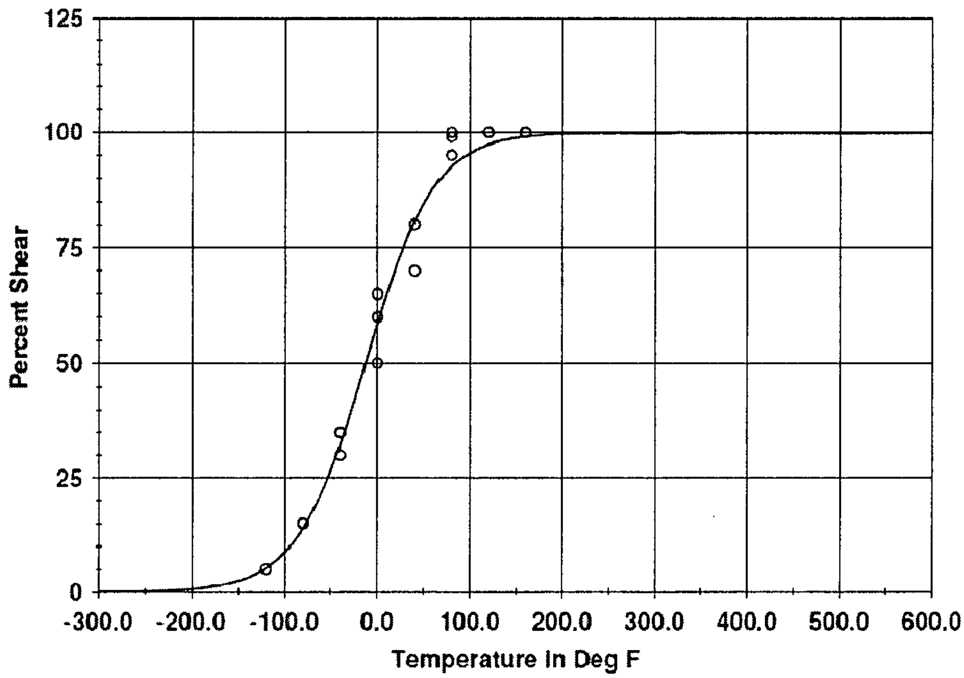
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
40.00	76.00	83.70	-7.70
40.00	86.00	83.70	2.30
80.00	92.00	90.63	1.37
80.00	93.00	90.63	2.37
80.00	91.00	90.63	.37
120.00	93.00	92.68	.32
120.00	94.00	92.68	1.32
160.00	91.00	93.25	-2.25
160.00	95.00	93.25	1.75

Correlation Coefficient = .977

UNIRRADIATED (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:10 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 73.94 T0 = -13. D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -12.9
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-120.00	5.00	5.24	-.24
-80.00	15.00	14.04	.96
-80.00	15.00	14.04	.96
-40.00	30.00	32.51	-2.51
-40.00	35.00	32.51	2.49
-40.00	35.00	32.51	2.49
.00	60.00	58.70	1.30
.00	50.00	58.70	-8.70
.00	65.00	58.70	6.30

UNIRRADIATED (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

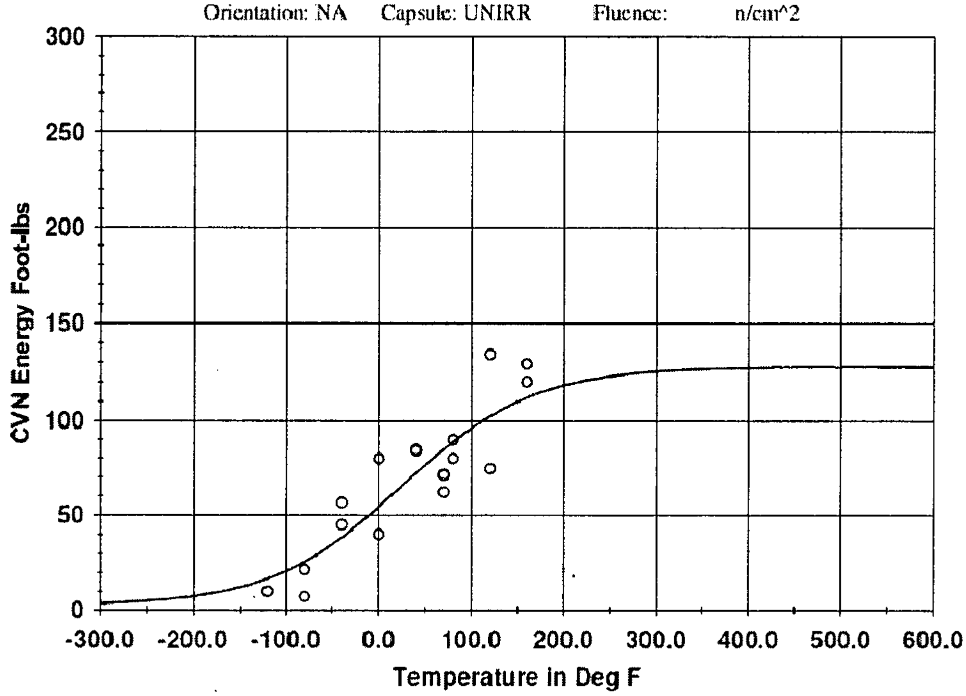
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
40.00	70.00	80.74	-10.74
40.00	80.00	80.74	-.74
80.00	99.00	92.52	6.48
80.00	95.00	92.52	2.48
80.00	100.00	92.52	7.48
120.00	100.00	97.33	2.67
120.00	100.00	97.33	2.67
160.00	100.00	99.08	.92
160.00	100.00	99.08	.92

Correlation Coefficient = .991

UNIRRADIATED (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:14 PM
Page 1
Coefficients of Curve 1
A = 64.95 B = 62.75 C = 140.93 T0 = 23.48 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=127.7(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-65.0 Deg F Temp@50 ft-lbs=-10.7 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-120.00	9.80	16.69	-6.89
-80.00	7.00	25.69	-18.69
-80.00	21.50	25.69	-4.19
-40.00	45.00	38.45	6.55
-40.00	56.50	38.45	18.05
.00	40.00	54.59	-14.59
.00	80.00	54.59	25.41
40.00	84.00	72.27	11.73
40.00	85.00	72.27	12.73

UNIRRADIATED (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

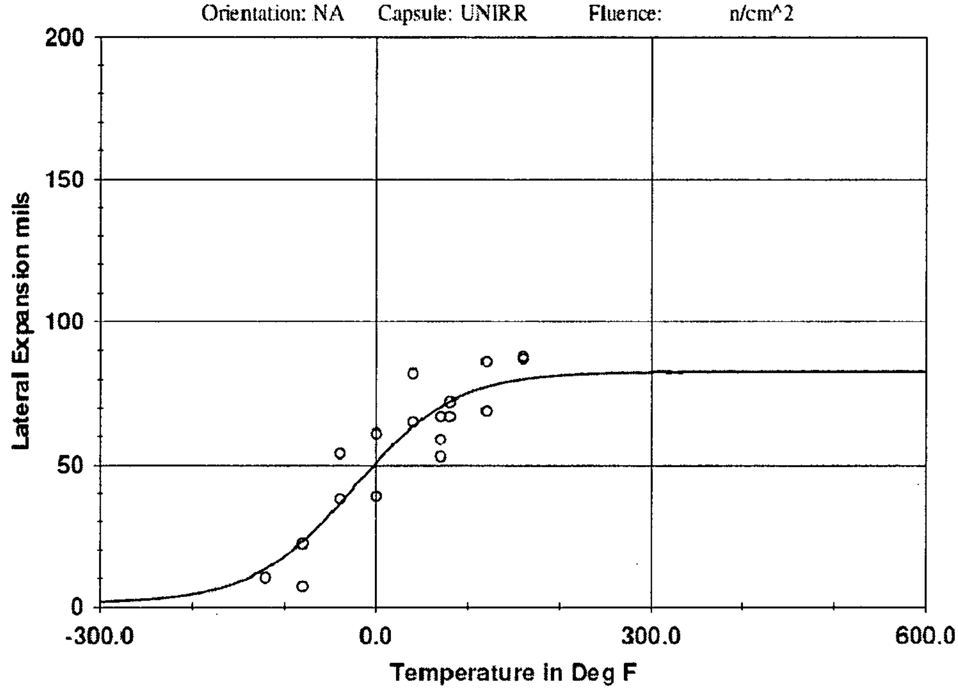
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	62.00	84.94	-22.94
70.00	71.00	84.94	-13.94
70.00	71.50	84.94	-13.44
80.00	80.00	88.85	-8.85
80.00	90.00	88.85	1.15
120.00	74.50	102.27	-27.77
120.00	134.00	102.27	31.73
160.00	120.00	111.90	8.10
160.00	129.00	111.90	17.10

Correlation Coefficient = .883

UNIRRADIATED (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:16 PM
Page 1
Coefficients of Curve 1
A = 41.89 B = 40.89 C = 109.56 T0 = -24.66 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=82.8 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=-43.3 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-120.00	10.00	13.21	-3.21
-80.00	7.00	22.83	-15.83
-80.00	22.00	22.83	-.83
-40.00	38.00	36.20	1.80
-40.00	54.00	36.20	17.80
.00	39.00	50.94	-11.94
.00	61.00	50.94	10.06
40.00	82.00	63.56	18.44
40.00	65.00	63.56	1.44

UNIRRADIATED (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

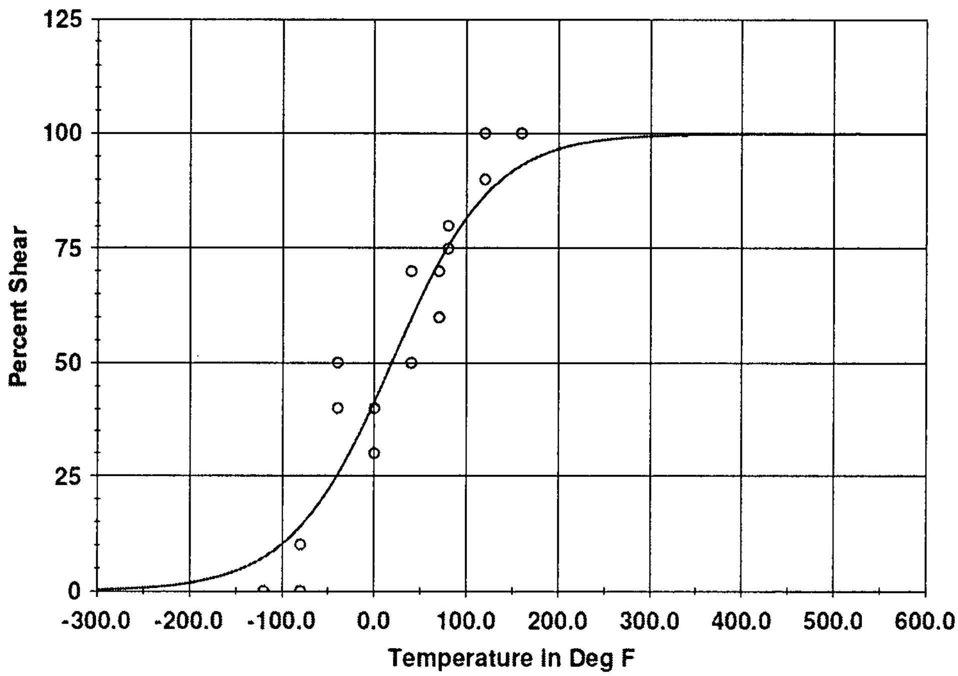
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	53.00	70.45	-17.45
70.00	59.00	70.45	-11.45
70.00	67.00	70.45	-3.45
80.00	72.00	72.24	-.24
80.00	67.00	72.24	-5.24
120.00	69.00	77.34	-8.34
120.00	86.00	77.34	8.66
160.00	88.00	80.07	7.93
160.00	87.00	80.07	6.93

Correlation Coefficient = .907

UNIRRADIATED (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:18 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 108.57 T0 = 18.59 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 18.6
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-120.00	.00	7.22	-7.22
-80.00	.00	13.99	-13.99
-80.00	10.00	13.99	-3.99
-40.00	40.00	25.37	14.63
-40.00	50.00	25.37	24.63
.00	40.00	41.52	-1.52
.00	30.00	41.52	-11.52
40.00	70.00	59.73	10.27
40.00	50.00	59.73	-9.73

UNIRRADIATED (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

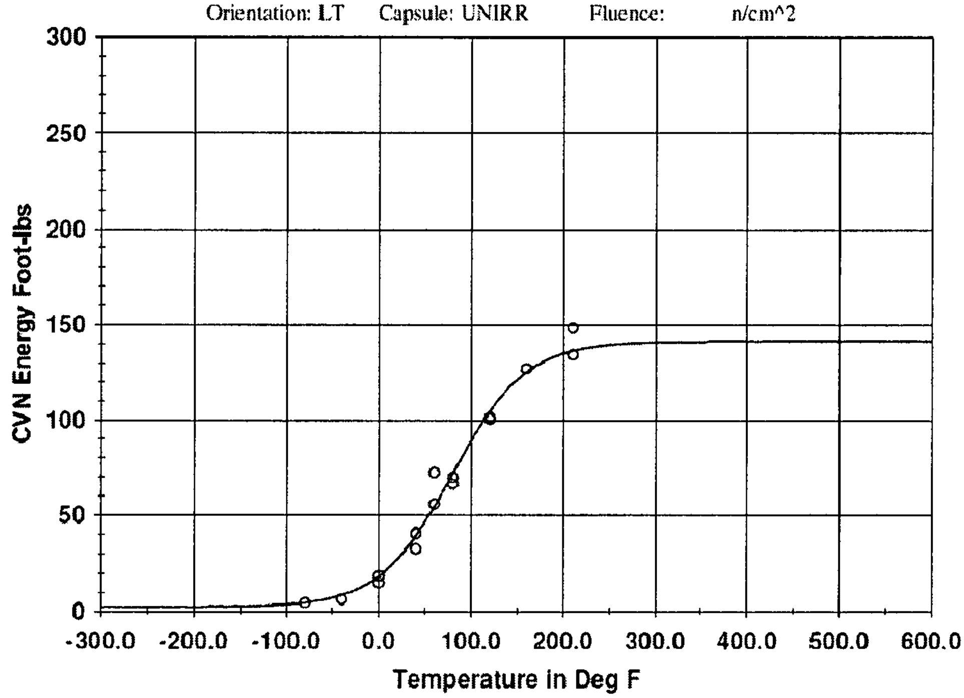
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	60.00	72.05	-12.05
70.00	60.00	72.05	-12.05
70.00	70.00	72.05	-2.05
80.00	75.00	75.61	-.61
80.00	80.00	75.61	4.39
120.00	90.00	86.62	3.38
120.00	100.00	86.62	13.38
160.00	100.00	93.12	6.88
160.00	100.00	93.12	6.88

Correlation Coefficient = .943

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:20 PM
Page 1
Coefficients of Curve 1
A = 71.85 B = 69.65 C = 78.89 T0 = 79.73 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=141.5(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=25.0 Deg F Temp@50 ft-lbs=54.2 Deg F
Plant: Calvert Cliffs 2 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	4.50	4.59	-.09
-40.00	6.20	8.59	-2.39
.00	15.00	18.49	-3.49
.00	18.50	18.49	.01
40.00	32.50	39.46	-6.96
40.00	40.50	39.46	1.04
60.00	56.00	54.78	1.22
60.00	72.50	54.78	17.72
80.00	66.50	72.09	-5.59

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

Page 2
Plant: Calvert Cliffs 2 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	70.00	72.09	-2.09
120.00	100.50	104.60	-4.10
120.00	101.50	104.60	-3.10
160.00	127.00	125.40	1.60
210.00	134.50	136.56	-2.06
210.00	148.50	136.56	11.94

Correlation Coefficient = .991

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:36 PM

Page 1

Coefficients of Curve 1

A = 46.06 B = 45.06 C = 78.28 T0 = 61.55 D = 0.00E+00

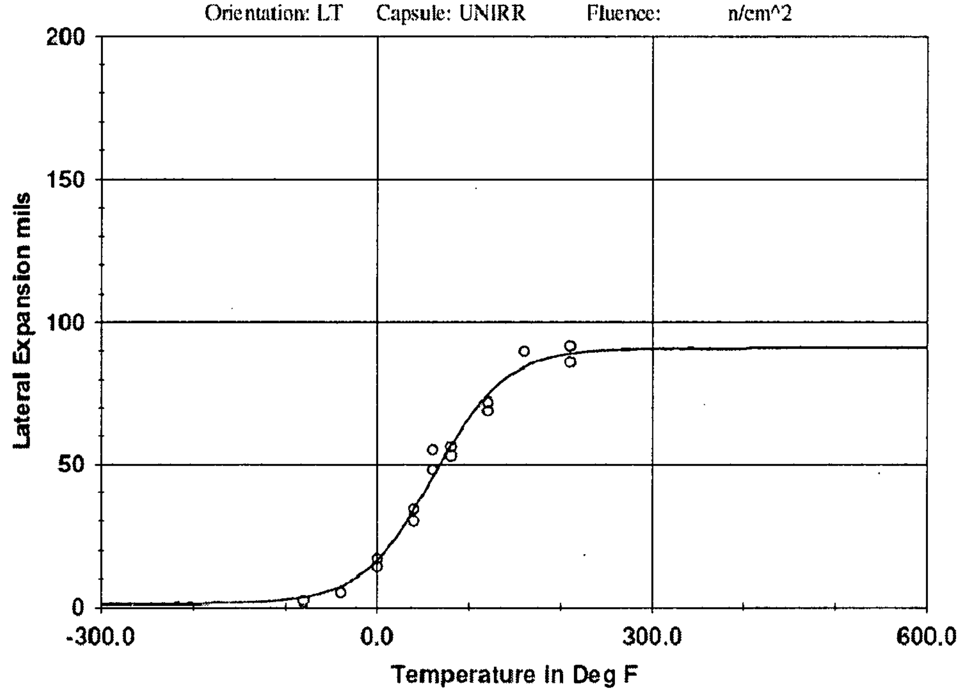
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=91.1 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=42.0 Deg F

Plant: Calvert Cliffs 2 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	2.00	3.36	-1.36
-40.00	5.00	7.26	-2.26
.00	14.00	16.49	-2.49
.00	17.00	16.49	.51
40.00	30.00	33.96	-3.96
40.00	34.00	33.96	.04
60.00	48.00	45.17	2.83
60.00	55.00	45.17	9.83
80.00	53.00	56.49	-3.49

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

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

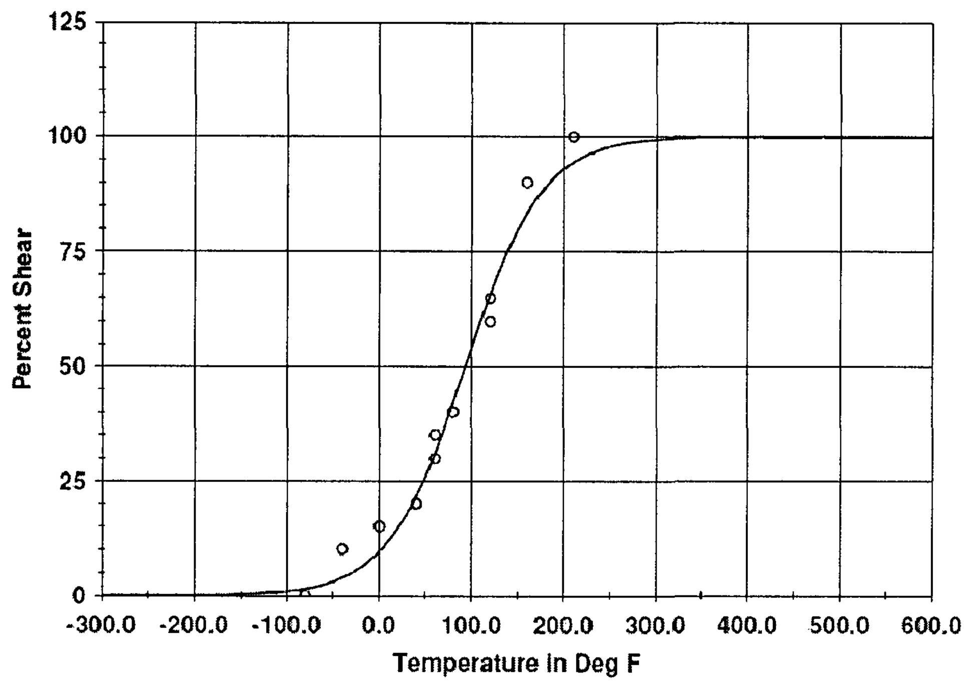
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
80.00	56.00	56.49	-.49
120.00	69.00	74.60	-5.60
120.00	72.00	74.60	-2.60
160.00	90.00	84.39	5.61
210.00	86.00	89.14	-3.14
210.00	92.00	89.14	2.86

Correlation Coefficient = .991

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:41 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 82.68 T0 = 92.87 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 92.9
Plant: Calvert Cliffs 2 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	1.50	-1.50
-40.00	10.00	3.86	6.14
.00	15.00	9.56	5.44
.00	15.00	9.56	5.44
40.00	20.00	21.77	-1.77
40.00	20.00	21.77	-1.77
60.00	30.00	31.10	-1.10
60.00	35.00	31.10	3.90
80.00	40.00	42.28	-2.28

UNIRRADIATED (STANDARD REFERENCE MATERIAL)

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

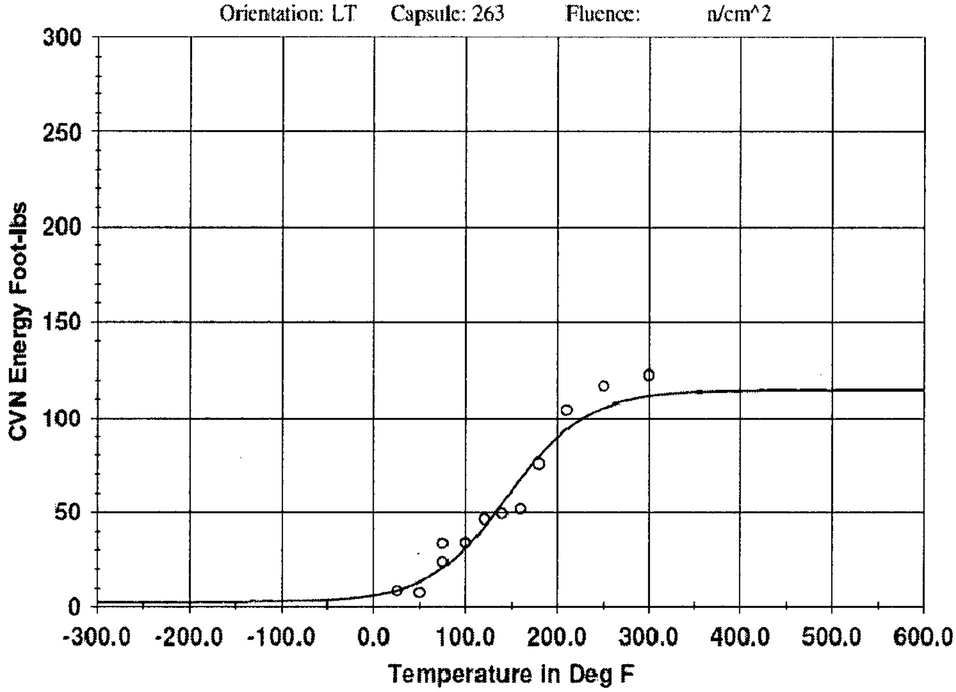
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
80.00	40.00	42.28	-2.28
120.00	60.00	65.84	-5.84
120.00	65.00	65.84	-.84
160.00	90.00	83.53	6.47
210.00	100.00	94.44	5.56
210.00	100.00	94.44	5.56

Correlation Coefficient = .992

CAPSULE 263° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 10:26 AM
Page 1
Coefficients of Curve 1
A = 58.45 B = 56.25 C = 86.37 T0 = 145.74 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=114.7(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=97.7 Deg F Temp@50 ft-lbs=132.7 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
25.00	8.50	8.67	-.17
50.00	7.50	13.25	-5.75
75.00	24.00	20.51	3.49
75.00	33.50	20.51	12.99
100.00	34.00	31.17	2.83
120.00	46.50	42.17	4.33
140.00	49.50	54.72	-5.22
160.00	52.00	67.66	-15.66
180.00	75.50	79.66	-4.16

CAPSULE 263° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
210.00	104.50	93.98	10.52
250.00	117.00	105.47	11.53
300.00	122.50	111.63	10.87

Correlation Coefficient = .977

CAPSULE 263° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 10:31 AM

Page 1

Coefficients of Curve 1

A = 48.99 B = 47.99 C = 111.9 T0 = 138.22 D = 0.00E+00

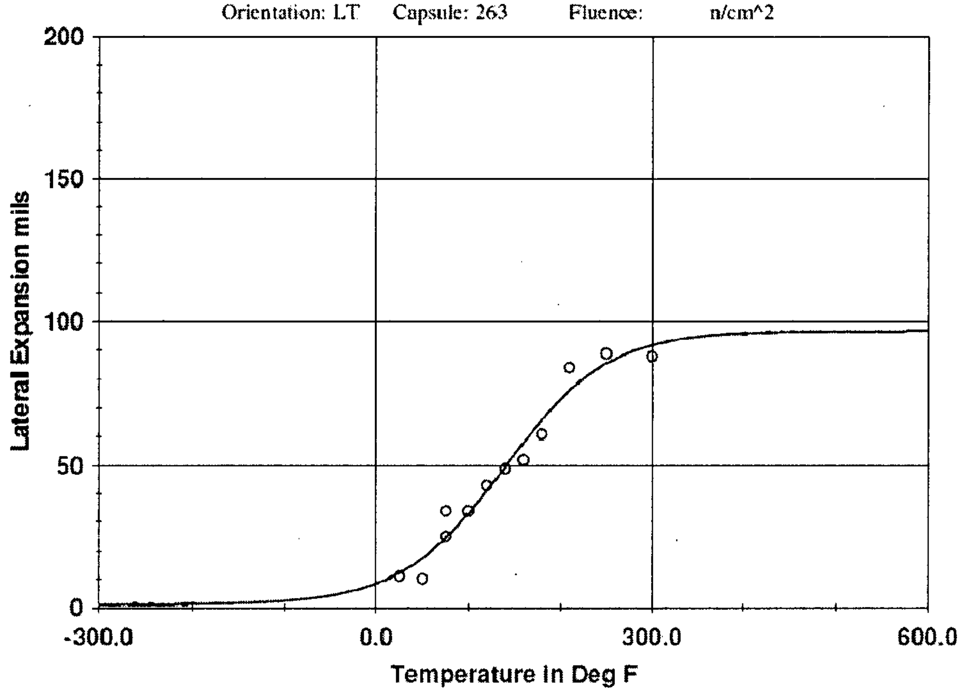
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=97.0 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=104.7 Deg F

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
25.00	11.00	12.21	-1.21
50.00	10.00	17.44	-7.44
75.00	25.00	24.44	.56
75.00	34.00	24.44	9.56
100.00	34.00	33.21	.79
120.00	43.00	41.24	1.76
140.00	49.00	49.75	-.75
160.00	52.00	58.21	-6.21
180.00	61.00	66.12	-5.12

CAPSULE 263° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
210.00	84.00	76.14	7.86
250.00	89.00	85.51	3.49
300.00	88.00	91.93	-3.93

Correlation Coefficient = .982

CAPSULE 263° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 10:43 AM

Page 1

Coefficients of Curve 1

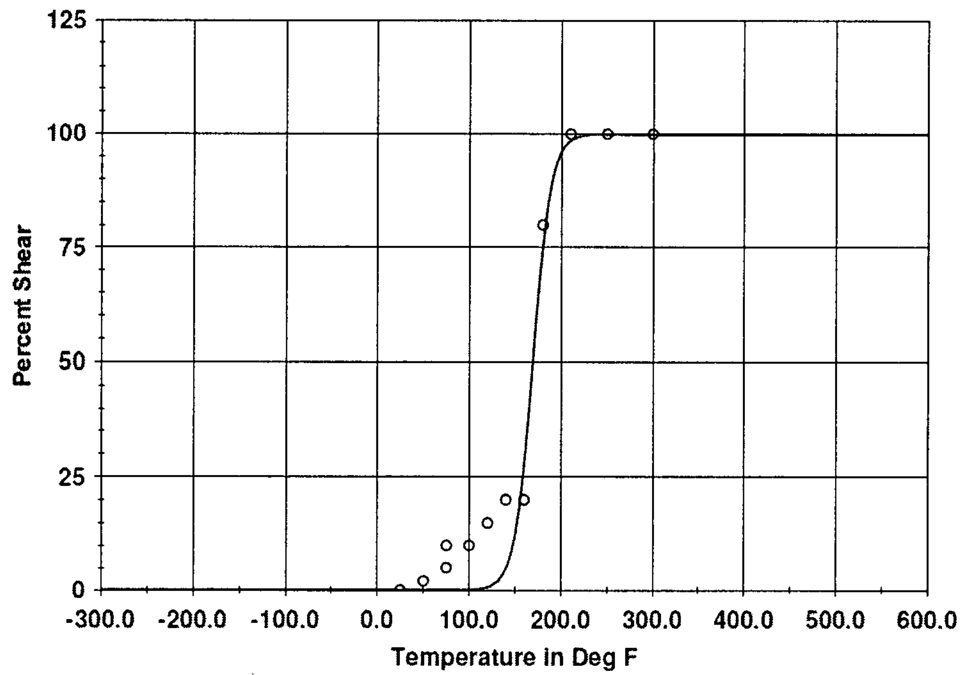
A = 50. B = 50. C = 19.51 T0 = 169.08 D = 0.00E+00

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

Temperature at 50% Shear = 169.1

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25.00	.00	.00	.00
50.00	2.00	.00	2.00
75.00	10.00	.01	9.99
75.00	5.00	.01	4.99
100.00	10.00	.08	9.92
120.00	15.00	.65	14.35
140.00	20.00	4.83	15.17
160.00	20.00	28.28	-8.28
180.00	80.00	75.38	4.62

CAPSULE 263° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 263 Fluence: n/cm^2

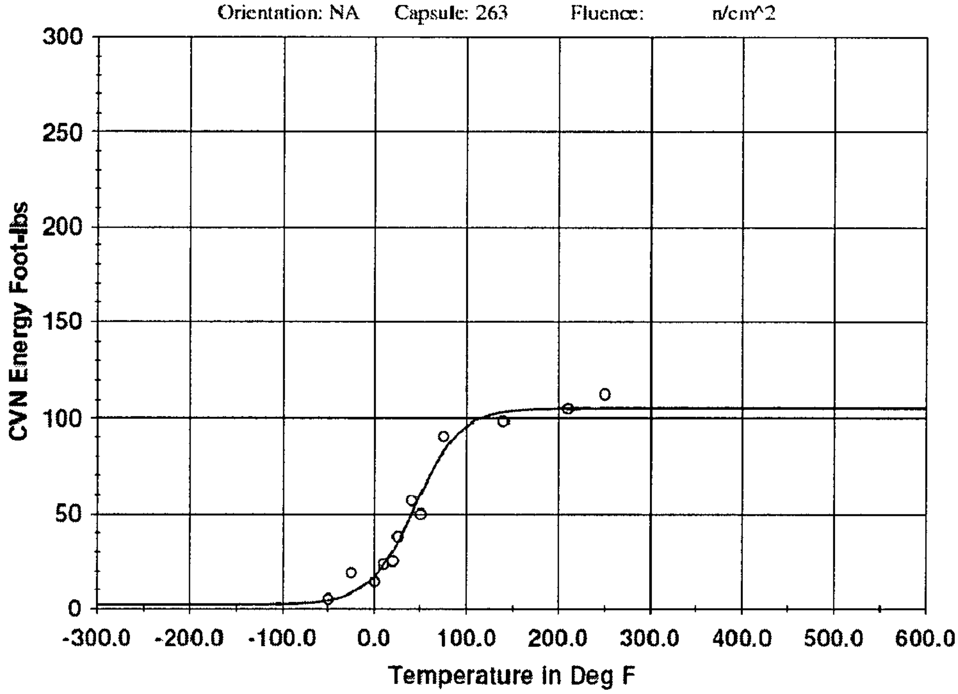
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
210.00	100.00	98.51	1.49
250.00	100.00	99.97	.03
300.00	100.00	100.00	.00

Correlation Coefficient = .990

CAPSULE 263° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 10:46 AM
Page 1
Coefficients of Curve 1
A = 53.75 B = 51.55 C = 49.16 T0 = 43.48 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=105.3(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=19.0 Deg F Temp@50 ft-lbs=39.9 Deg F
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	5.00	4.45	.55
-25.00	19.00	8.19	10.81
.00	14.00	17.22	-3.22
10.00	23.50	23.22	.28
20.00	25.00	30.84	-5.84
25.00	38.00	35.24	2.76
40.00	57.00	50.11	6.89
50.00	50.00	60.55	-10.55
75.00	90.50	82.91	7.59

CAPSULE 263° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 263 Fluence: n/cm^2

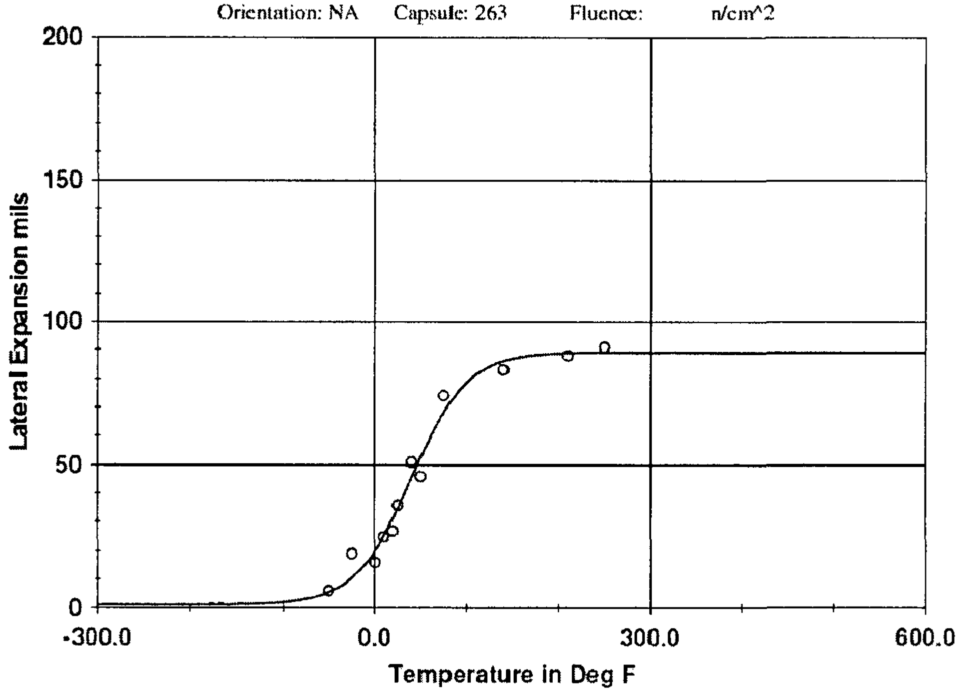
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
140.00	98.50	103.31	-4.81
210.00	105.00	105.18	-.18
250.00	112.50	105.28	7.22

Correlation Coefficient = .986

CAPSULE 263° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 10:49 AM
Page 1
Coefficients of Curve 1
A = 45.12 B = 44.12 C = 61.06 T0 = 39.43 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=89.2 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=25.2 Deg F
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	6.00	5.48	.52
-25.00	19.00	10.54	8.46
.00	16.00	20.02	-4.02
10.00	25.00	25.36	-.36
20.00	27.00	31.54	-4.54
25.00	36.00	34.88	1.12
40.00	51.00	45.53	5.47
50.00	46.00	52.69	-6.69
75.00	74.00	68.27	5.73

CAPSULE 263° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
140.00	83.00	86.09	-3.09
210.00	88.00	88.91	-.91
250.00	91.00	89.15	1.85

Correlation Coefficient = .989

CAPSULE 263° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 10:51 AM

Page 1

Coefficients of Curve 1

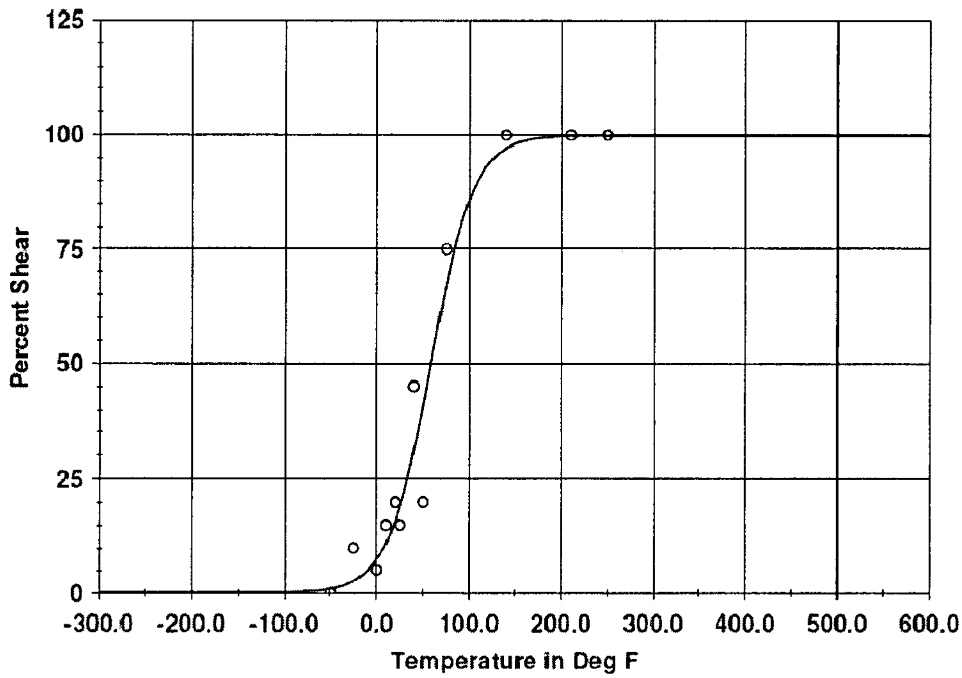
A = 50. B = 50. C = 46.36 T0 = 58.42 D = 0.00E+00

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

Temperature at 50% Shear = 58.5

Plant: Calvert Cliffs 2 Material: SAW Heat: 10137

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	.00	.92	-.92
-25.00	10.00	2.66	7.34
.00	5.00	7.45	-2.45
10.00	15.00	11.02	3.98
20.00	20.00	16.01	3.99
25.00	15.00	19.13	-4.13
40.00	45.00	31.12	13.88
50.00	20.00	41.02	-21.02
75.00	75.00	67.16	7.84

CAPSULE 263° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
140.00	100.00	97.12	2.88
210.00	100.00	99.86	.14
250.00	100.00	99.97	.03

Correlation Coefficient = .977

CAPSULE 263° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 10:54 AM

Page 1

Coefficients of Curve 1

A = 53.35 B = 51.15 C = 130.22 T0 = 129.71 D = 0.00E+00

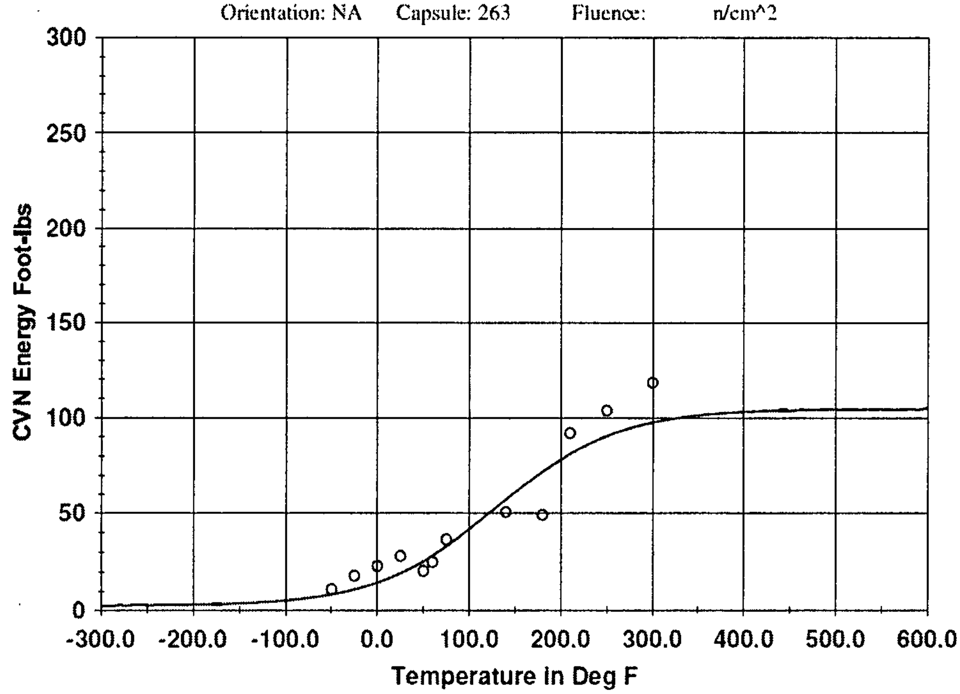
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=104.5(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=65.6 Deg F Temp@50 ft-lbs=121.2 Deg F

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	11.00	8.29	2.71
-25.00	18.00	10.90	7.10
.00	23.00	14.48	8.52
25.00	28.00	19.27	8.73
50.00	20.50	25.44	-4.94
60.00	25.00	28.32	-3.32
75.00	36.50	33.04	3.46
140.00	50.50	57.38	-6.88
180.00	49.00	72.18	-23.18

CAPSULE 263° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 263 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
210.00	92.00	81.42	10.58
250.00	103.50	90.57	12.93
300.00	118.00	97.53	20.47

Correlation Coefficient = .951

CAPSULE 263° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 10:58 AM

Page 1

Coefficients of Curve 1

A = 63.05 B = 62.05 C = 209.64 T0 = 189.93 D = 0.00E+00

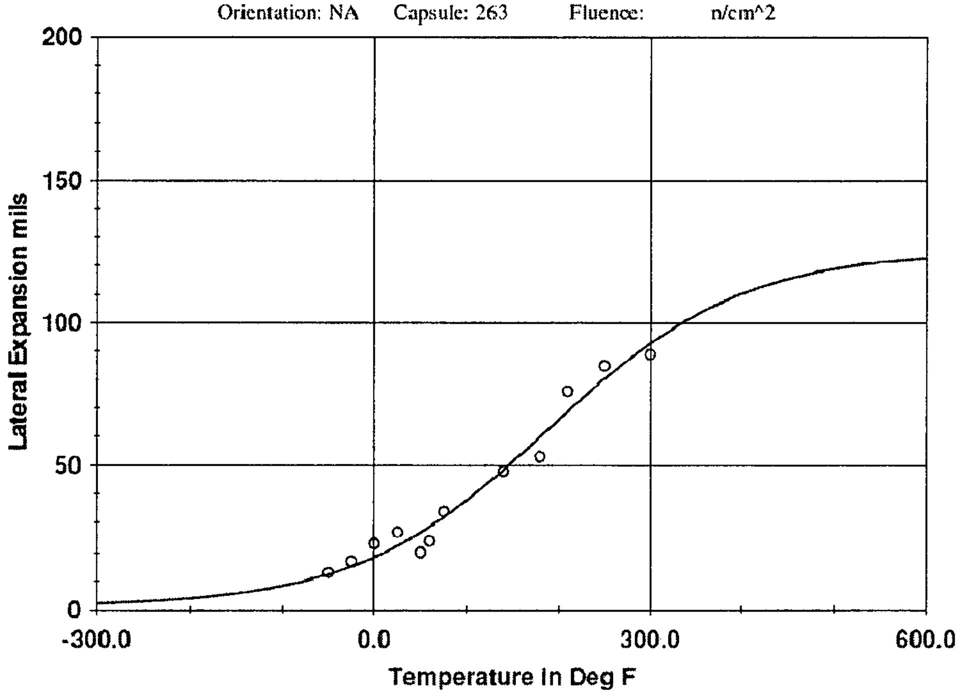
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=125.1 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=87.8 Deg F

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	13.00	12.42	.58
-25.00	17.00	15.15	1.85
.00	23.00	18.42	4.58
25.00	27.00	22.31	4.69
50.00	20.00	26.85	-6.85
60.00	24.00	28.86	-4.86
75.00	34.00	32.07	1.93
140.00	48.00	48.54	-.54
180.00	53.00	60.11	-7.11

CAPSULE 263° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 263 Fluence: n/cm^2

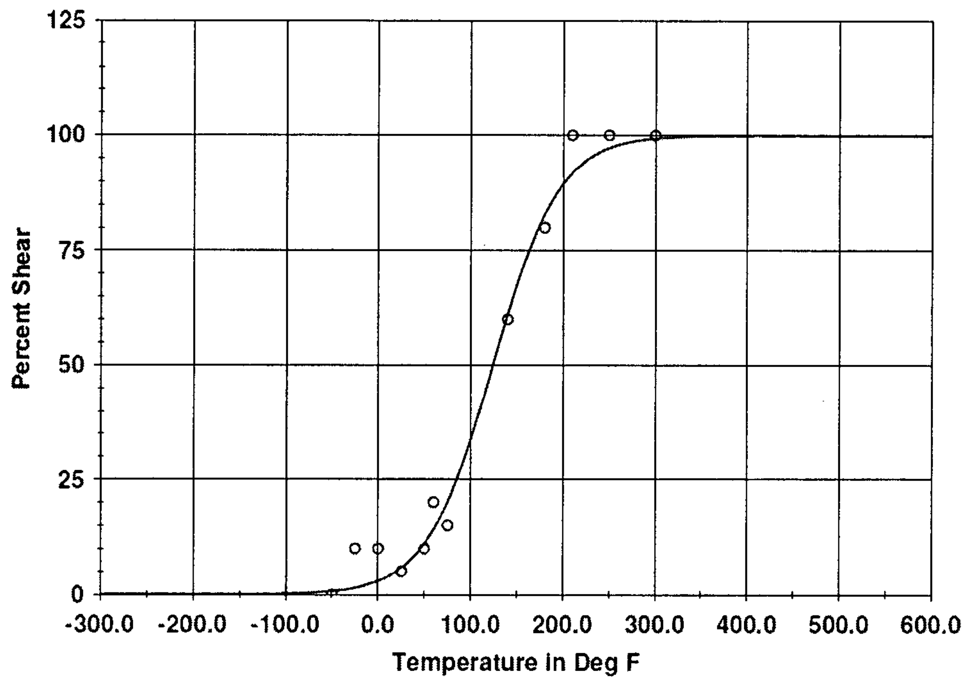
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
210.00	76.00	68.97	7.03
250.00	85.00	80.35	4.65
300.00	89.00	92.92	-3.92

Correlation Coefficient = .984

CAPSULE 263° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 11:00 AM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 71.01 T0 = 123.77 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 123.8
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	.00	.74	-.74
-25.00	10.00	1.49	8.51
.00	10.00	2.97	7.03
25.00	5.00	5.83	-.83
50.00	10.00	11.13	-1.13
60.00	20.00	14.23	5.77
75.00	15.00	20.20	-5.20
140.00	60.00	61.23	-1.23
180.00	80.00	82.97	-2.97

CAPSULE 263° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 263 Fluence: n/cm^2

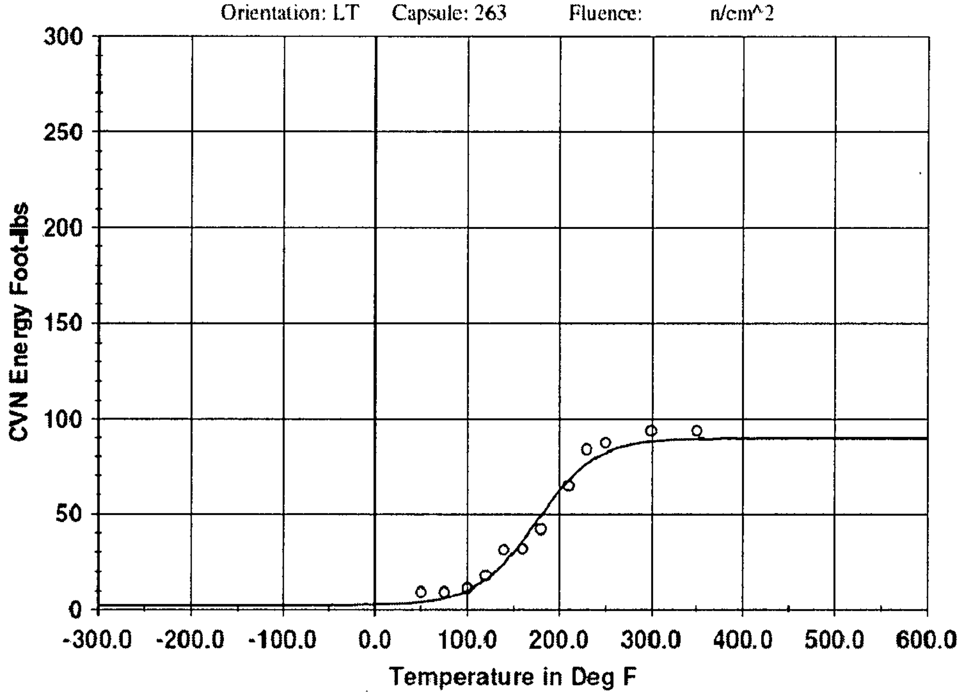
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
210.00	100.00	91.90	8.10
250.00	100.00	97.22	2.78
300.00	100.00	99.31	.69

Correlation Coefficient = .994

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 11:16 AM
Page 1
Coefficients of Curve 1
A = 46.05 B = 43.85 C = 64.05 T0 = 175.15 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=89.9(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=150.6 Deg F Temp@50 ft-lbs=181.0 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 263 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
50.00	9.00	3.93	5.07
75.00	9.00	5.88	3.12
100.00	11.00	9.86	1.14
120.00	17.50	15.49	2.01
140.00	31.00	24.14	6.86
160.00	31.50	35.86	-4.36
180.00	42.00	49.36	-7.36
210.00	65.00	67.80	-2.80
230.00	84.00	76.50	7.50

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

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

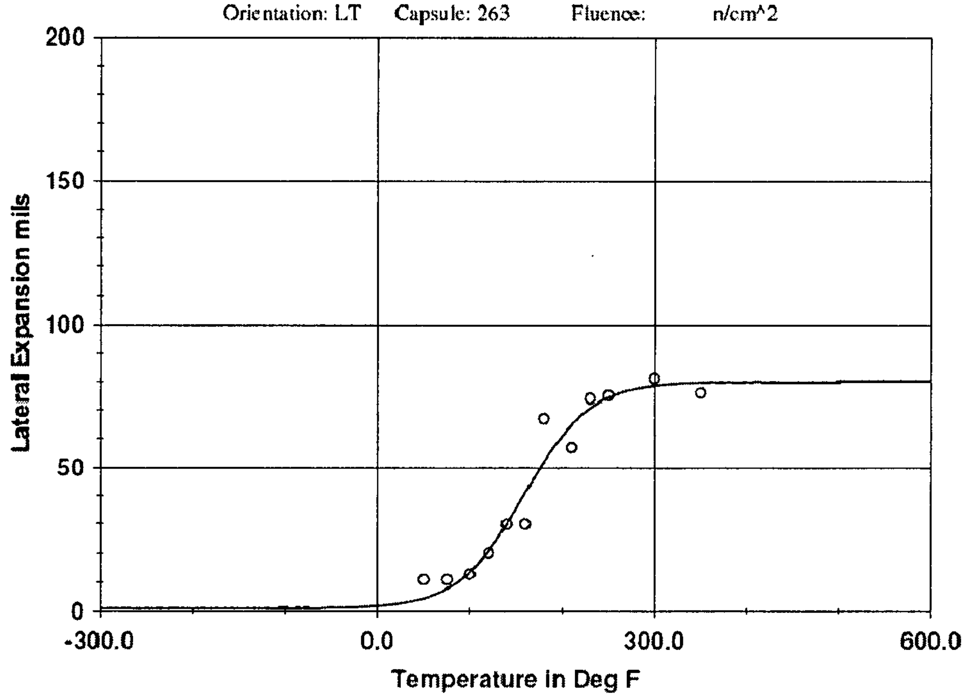
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
250.00	87.50	82.17	5.33
300.00	94.00	88.16	5.84
350.00	94.00	89.53	4.47

Correlation Coefficient = .991

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 11:18 AM
Page 1
Coefficients of Curve 1
A = 40.47 B = 39.47 C = 70.86 T0 = 158.62 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=79.9 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=148.8 Deg F
Plant: Calvert Cliffs 2 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
50.00	11.00	4.52	6.48
75.00	11.00	7.81	3.19
100.00	13.00	13.67	-.67
120.00	20.00	20.86	-.86
140.00	30.00	30.33	-.33
160.00	30.00	41.24	-11.24
180.00	67.00	52.03	14.97
210.00	57.00	64.95	-7.95
230.00	74.00	70.66	3.34

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

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

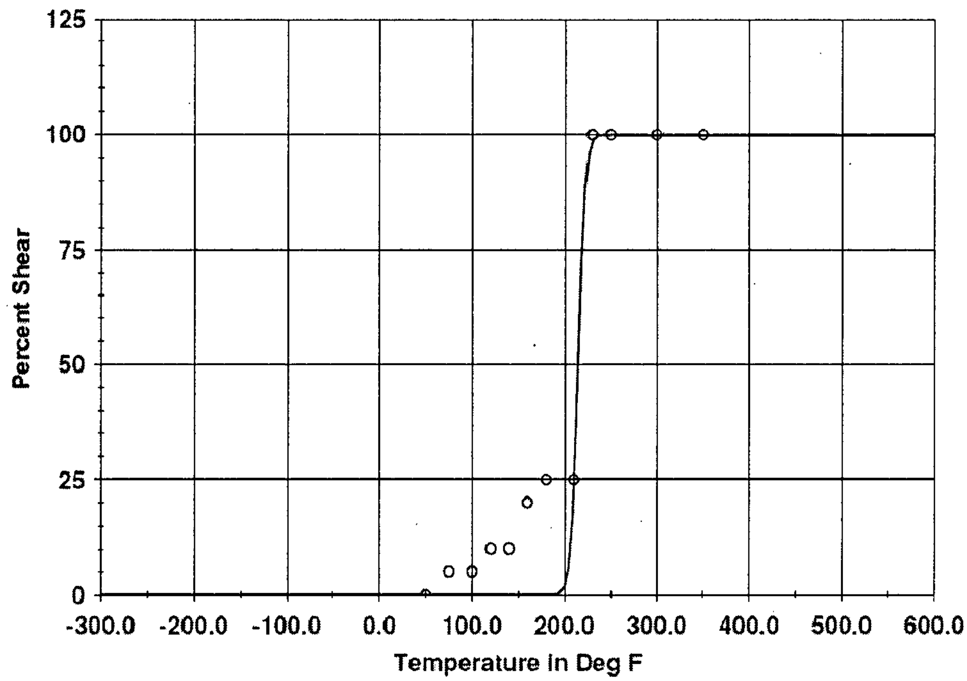
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
250.00	75.00	74.38	.62
300.00	81.00	78.52	2.48
350.00	76.00	79.60	-3.60

Correlation Coefficient = .973

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 06/28/2011 11:19 AM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 7.43 T0 = 214.35 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 214.4
Plant: Calvert Cliffs 2 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
50.00	.00	.00	.00
75.00	5.00	.00	5.00
100.00	5.00	.00	5.00
120.00	10.00	.00	10.00
140.00	10.00	.00	10.00
160.00	20.00	.00	20.00
180.00	25.00	.01	24.99
210.00	25.00	23.65	1.35
230.00	100.00	98.54	1.46

CAPSULE 263° (STANDARD REFERENCE MATERIAL)

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

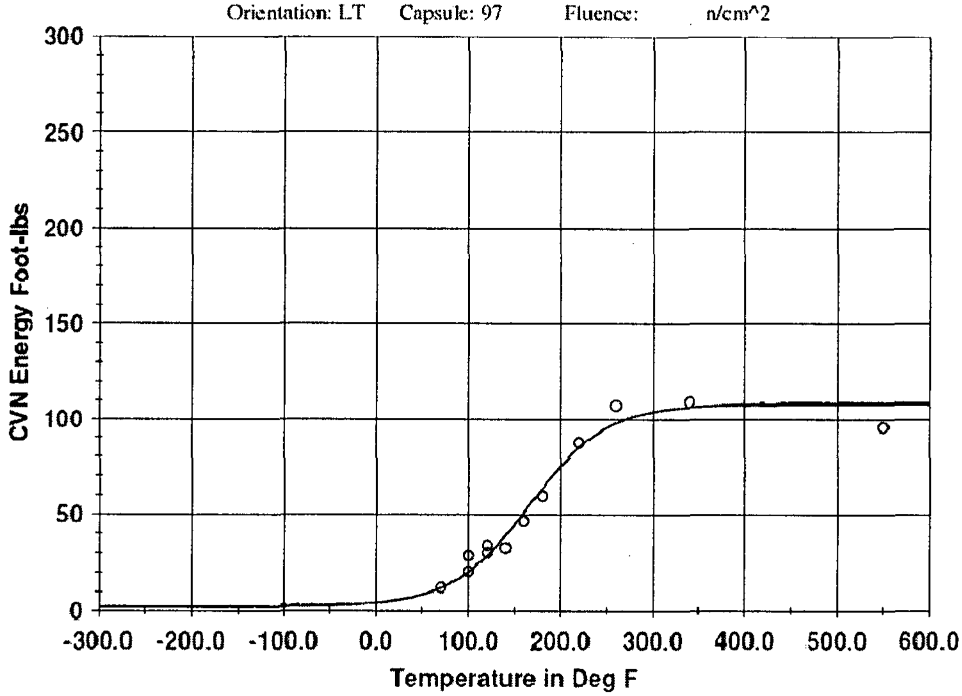
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
250.00	100.00	99.99	.01
300.00	100.00	100.00	.00
350.00	100.00	100.00	.00

Correlation Coefficient = .988

CAPSULE 97° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:52 PM
Page 1
Coefficients of Curve 1
A = 55.1 B = 52.9 C = 83.97 T0 = 166.16 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=122.9 Deg F Temp@50 ft-lbs=158.1 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	12.00	11.93	.07
100.00	28.50	20.33	8.17
100.00	20.50	20.33	.17
120.00	30.00	28.63	1.37
120.00	34.00	28.63	5.37
140.00	32.50	39.13	-6.63
160.00	46.50	51.23	-4.73
180.00	59.50	63.74	-4.24
220.00	87.50	85.03	2.47

CAPSULE 97° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
260.00	107.00	97.78	9.22
340.00	109.00	106.34	2.66
550.00	95.50	107.99	-12.49

Correlation Coefficient = .984

CAPSULE 97° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:54 PM

Page 1

Coefficients of Curve 1

A = 44.12 B = 43.12 C = 97.13 T0 = 158.43 D = 0.00E+00

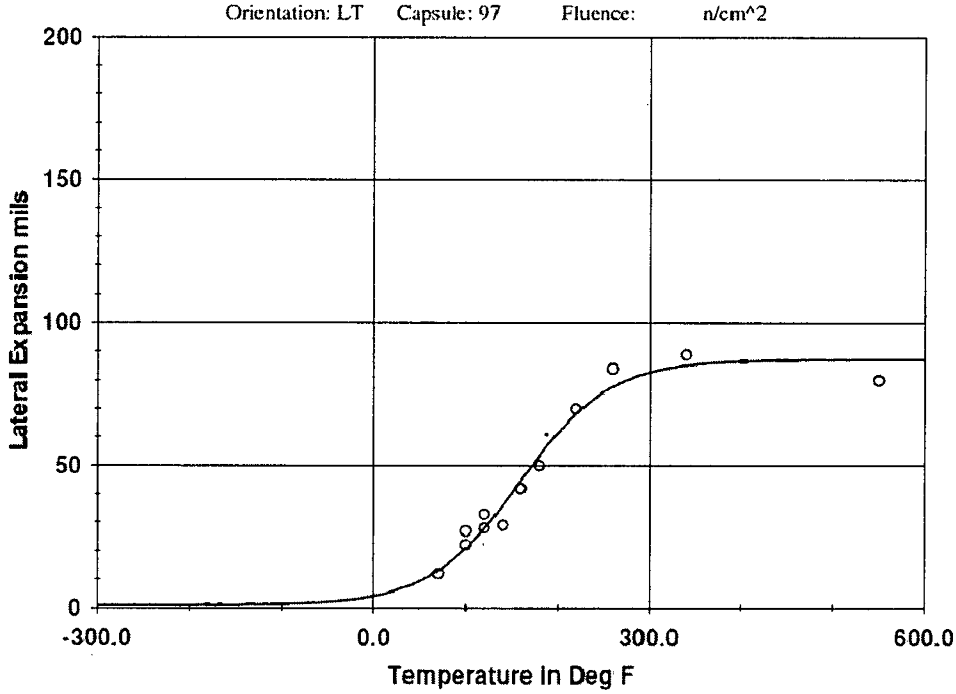
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=87.2 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=137.6 Deg F

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	12.00	13.02	-1.02
100.00	27.00	20.92	6.08
100.00	22.00	20.92	1.08
120.00	28.00	27.90	.10
120.00	33.00	27.90	5.10
140.00	29.00	36.04	-7.04
160.00	42.00	44.82	-2.82
180.00	50.00	53.55	-3.55
220.00	70.00	68.30	1.70

CAPSULE 97° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 97 Fluence: n/cm^2

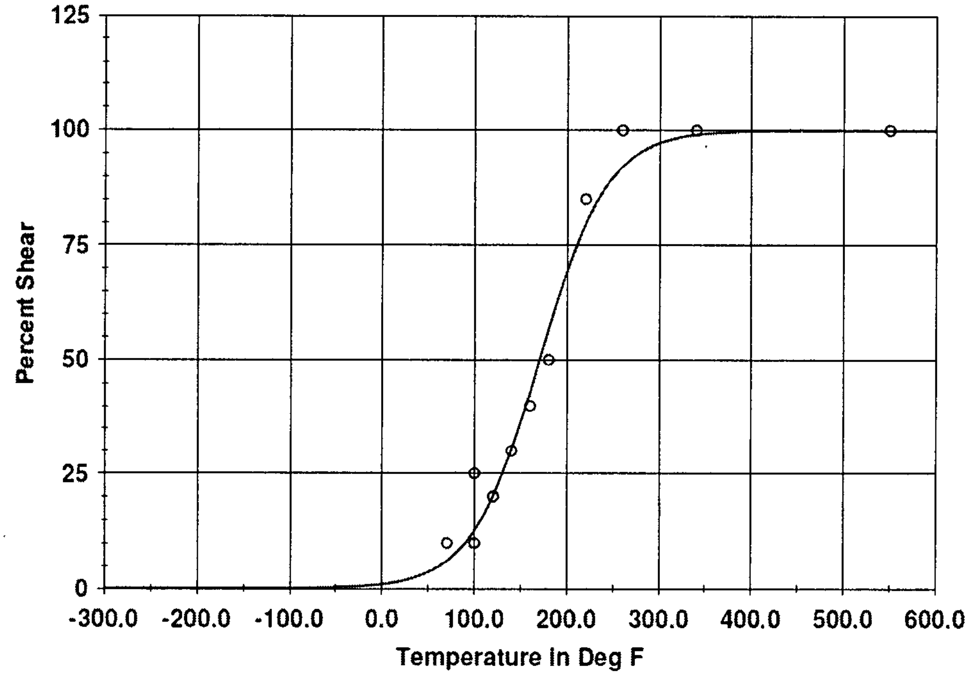
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
260.00	84.00	77.77	6.23
340.00	89.00	85.24	3.76
550.00	80.00	87.22	-7.22

Correlation Coefficient = .985

CAPSULE 97° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 01:58 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 73.1 T0 = 169.96 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 170.0
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	10.00	6.10	3.90
100.00	25.00	12.85	12.15
100.00	10.00	12.85	-2.85
120.00	20.00	20.31	-.31
120.00	20.00	20.31	-.31
140.00	30.00	30.58	-.58
160.00	40.00	43.23	-3.23
180.00	50.00	56.82	-6.82
220.00	85.00	79.72	5.28

CAPSULE 97° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 97 Fluence: n/cm^2

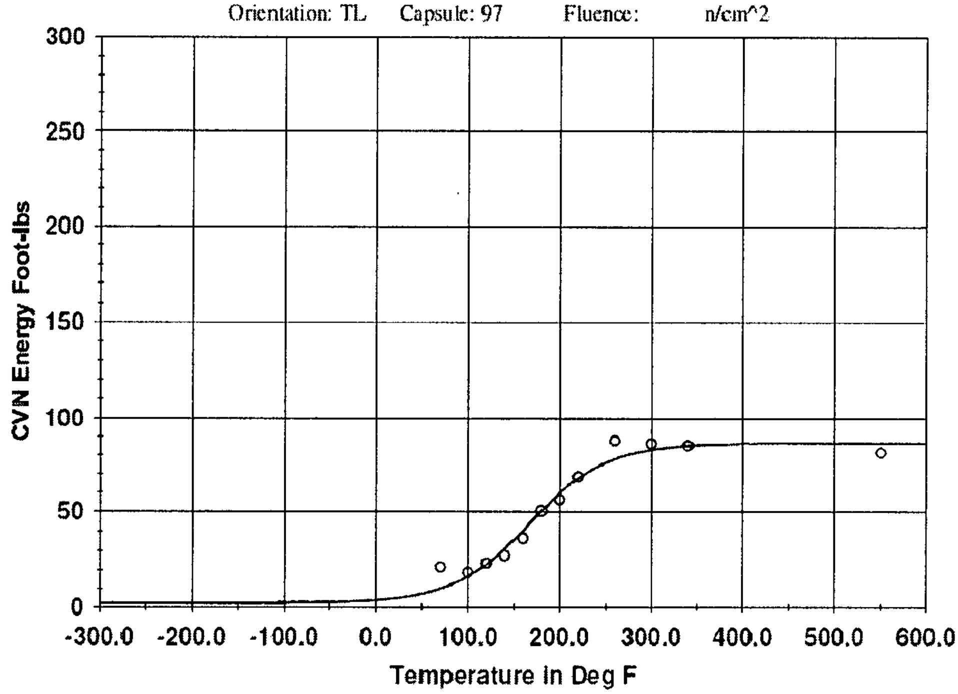
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
260.00	100.00	92.15	7.85
340.00	100.00	99.05	.95
550.00	100.00	100.00	.00

Correlation Coefficient = .990

CAPSULE 97° (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 02:04 PM
Page 1
Coefficients of Curve 1
A = 44.45 B = 42.25 C = 84.92 T0 = 167.71 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=86.7(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=137.5 Deg F Temp@50 ft-lbs=179.0 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: TL Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	21.50	9.89	11.61
100.00	18.50	16.46	2.04
120.00	23.50	22.93	.57
140.00	27.50	31.13	-3.63
160.00	36.50	40.63	-4.13
180.00	50.50	50.52	-.02
200.00	56.50	59.78	-3.28
220.00	68.50	67.61	.89
260.00	88.00	78.07	9.93

CAPSULE 97° (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: TL Capsule: 97 Fluence: n/cm^2

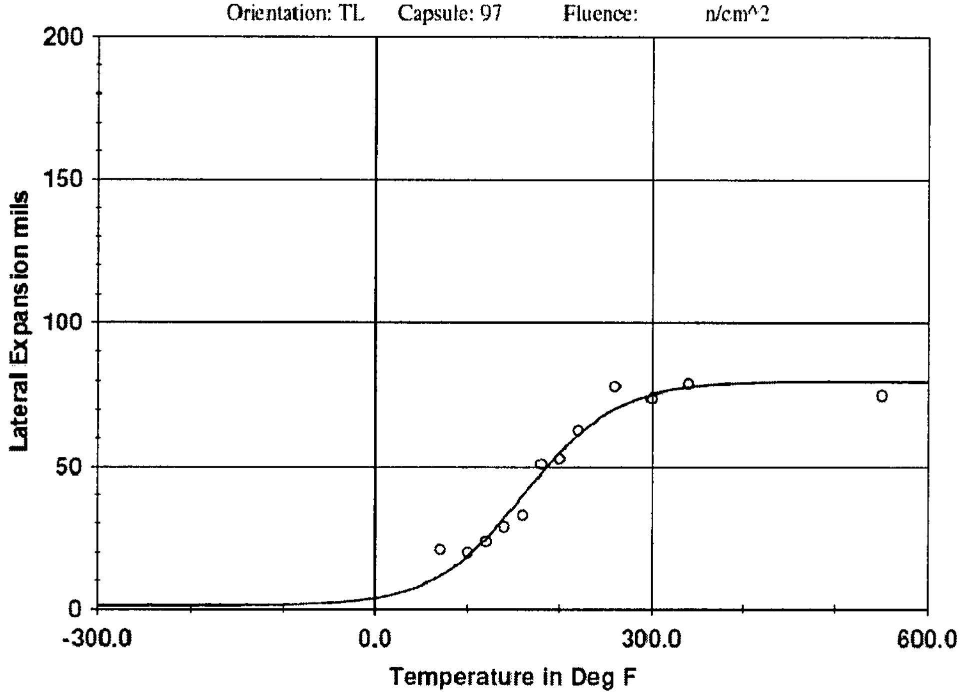
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
300.00	86.50	83.11	3.39
340.00	85.50	85.26	.24
550.00	81.50	86.69	-5.19

Correlation Coefficient = .982

CAPSULE 97° (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 02:06 PM
Page 1
Coefficients of Curve 1
A = 40.44 B = 39.44 C = 99.06 T0 = 161.27 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=79.9 Lower Shelf L.E.=1.0(Fixed)
Temp. @L.E. 35 mils=147.6 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: TL Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	21.00	11.78	9.22
100.00	20.00	18.74	1.26
120.00	24.00	24.90	-.90
140.00	29.00	32.10	-3.10
160.00	33.00	39.93	-6.93
180.00	51.00	47.81	3.19
200.00	53.00	55.12	-2.12
220.00	63.00	61.42	1.58
260.00	78.00	70.42	7.58

CAPSULE 97° (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: TL Capsule: 97 Fluence: n/cm^2

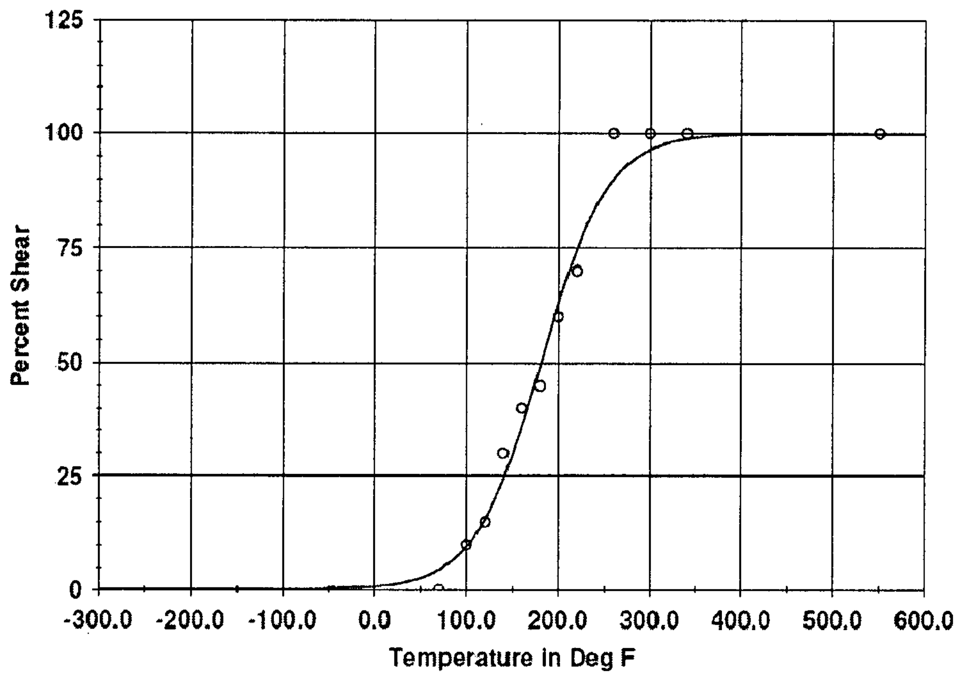
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
300.00	74.00	75.36	-1.36
340.00	79.00	77.80	1.20
550.00	75.00	79.85	-4.85

Correlation Coefficient = .981

CAPSULE 97° (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 02:08 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 72.01 T0 = 180.73 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 180.8
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: TL Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	.00	4.41	-4.41
100.00	10.00	9.60	.40
120.00	15.00	15.62	-.62
140.00	30.00	24.39	5.61
160.00	40.00	35.99	4.01
180.00	45.00	49.49	-4.49
200.00	60.00	63.07	-3.07
220.00	70.00	74.85	-4.85
260.00	100.00	90.04	9.96

CAPSULE 97° (TRANSVERSE ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: TL Capsule: 97 Fluence: n/cm^2

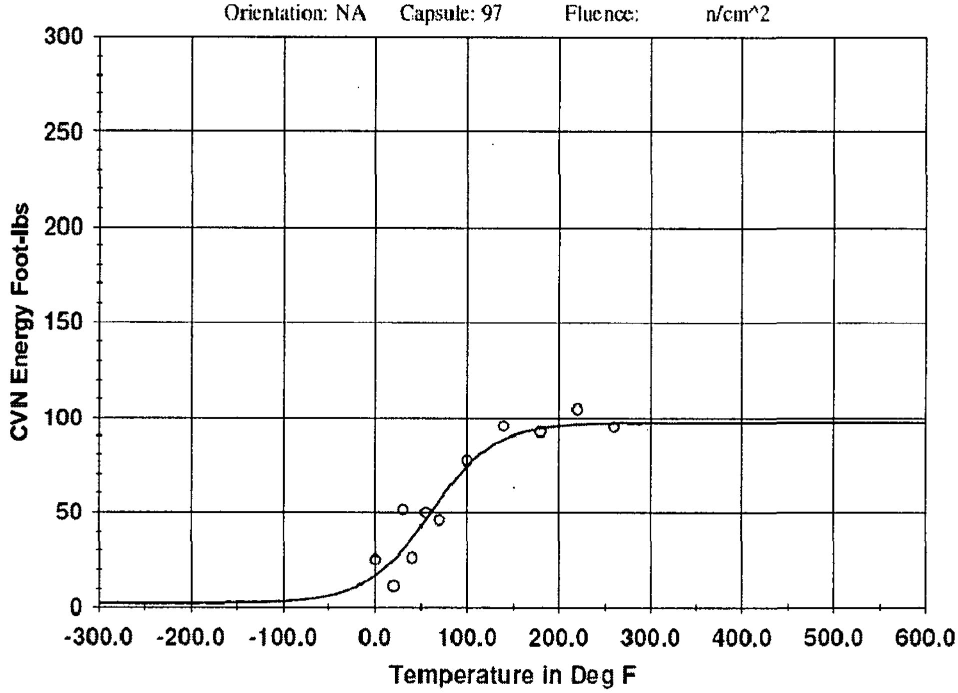
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
300.00	100.00	96.49	3.51
340.00	100.00	98.81	1.19
550.00	100.00	100.00	.00

Correlation Coefficient = .993

CAPSULE 97° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 02:19 PM
Page 1
Coefficients of Curve 1
A = 49.75 B = 47.55 C = 70.19 T0 = 60.18 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=97.3(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=29.2 Deg F Temp@50 ft-lbs=60.6 Deg F
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	25.00	16.71	8.29
20.00	11.00	25.16	-14.16
30.00	51.50	30.48	21.02
40.00	26.00	36.44	-10.44
55.00	50.00	46.25	3.75
70.00	46.00	56.36	-10.36
100.00	77.00	74.16	2.84
140.00	95.50	88.43	7.07
180.00	92.50	94.27	-1.77

CAPSULE 97° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
220.00	104.50	96.31	8.19
260.00	95.00	96.98	-1.98

Correlation Coefficient = .950

CAPSULE 97° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 02:25 PM

Page 1

Coefficients of Curve 1

A = 41.98 B = 40.98 C = 83.94 T0 = 59.11 D = 0.00E+00

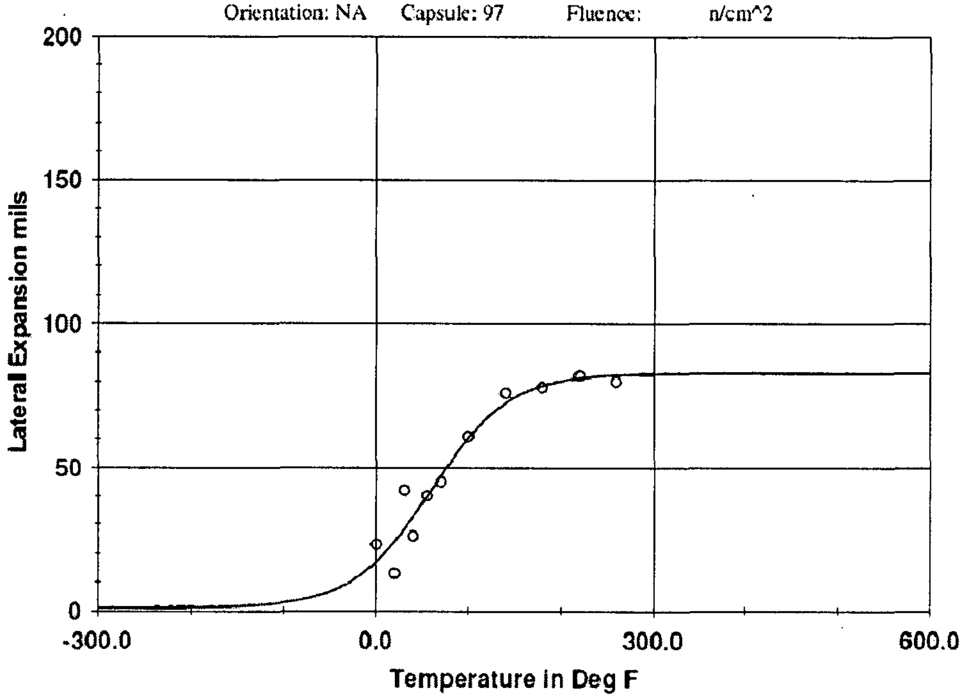
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=83.0 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=44.7 Deg F

Plant: Calvert Cliffs 2 Material: SAW Heat: 10137

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	23.00	17.10	5.90
20.00	13.00	24.15	-11.15
30.00	42.00	28.31	13.69
40.00	26.00	32.80	-6.80
55.00	40.00	39.97	.03
70.00	45.00	47.26	-2.26
100.00	61.00	60.49	.51
140.00	76.00	72.54	3.46
180.00	78.00	78.60	-.60

CAPSULE 97° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
220.00	82.00	81.22	.78
260.00	80.00	82.27	-2.27

Correlation Coefficient = .967

CAPSULE 97° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 02:28 PM

Page 1

Coefficients of Curve 1

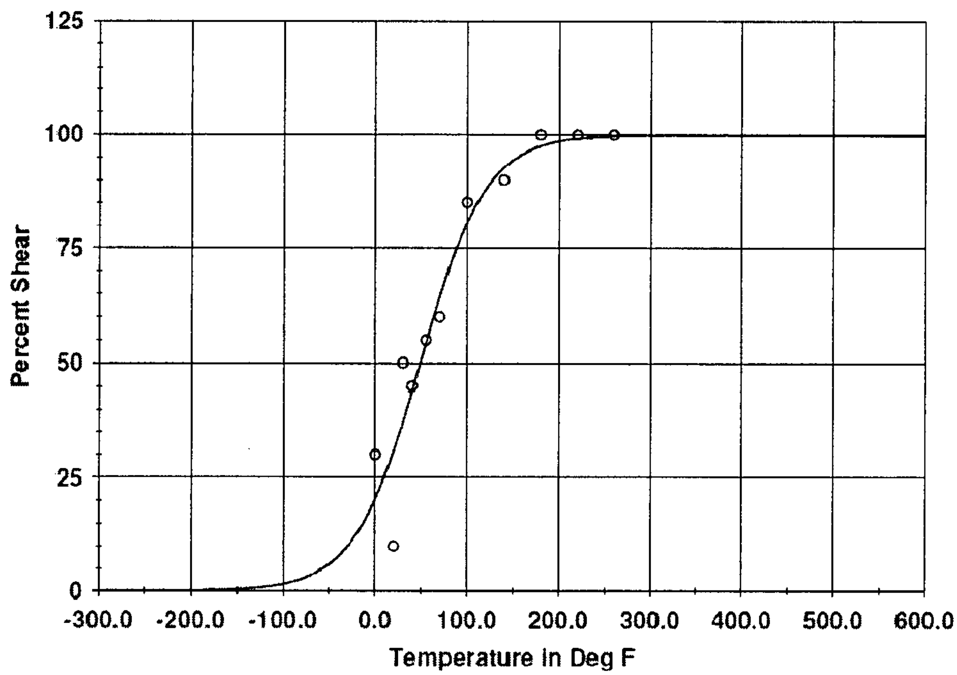
A = 50. B = 50. C = 71.57 T0 = 48.7 D = 0.00E+00

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

Temperature at 50% Shear = 48.8

Plant: Calvert Cliffs 2 Material: SAW Heat: 10137

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	30.00	20.41	9.59
20.00	10.00	30.96	-20.96
30.00	50.00	37.22	12.78
40.00	45.00	43.95	1.05
55.00	55.00	54.39	.61
70.00	60.00	64.45	-4.45
100.00	85.00	80.74	4.26
140.00	90.00	92.77	-2.77
180.00	100.00	97.51	2.49

CAPSULE 97° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 97 Fluence: n/cm^2

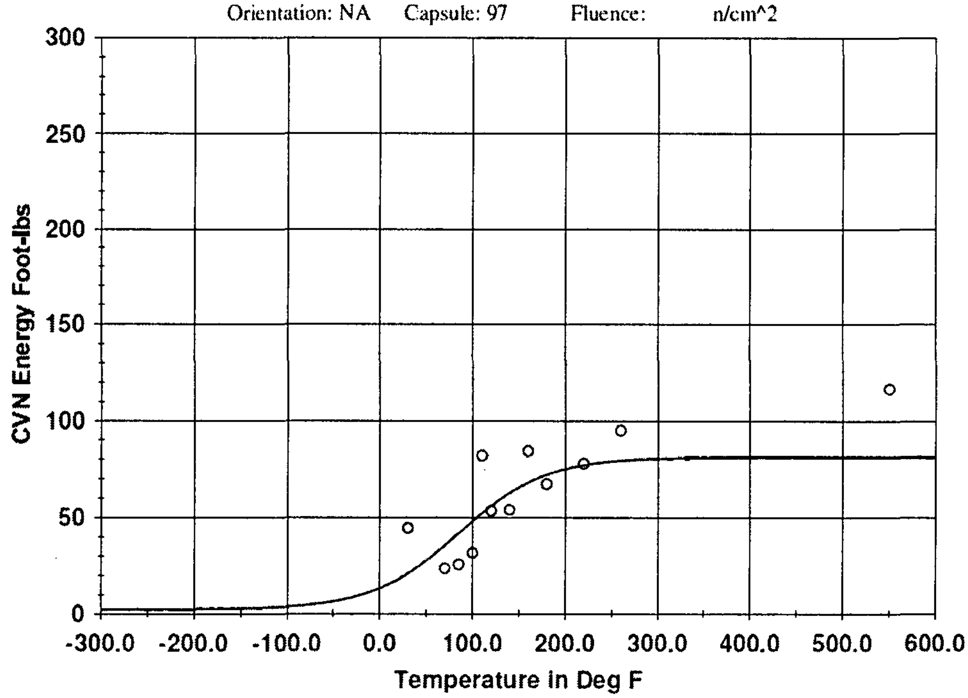
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
220.00	100.00	99.17	.83
260.00	100.00	99.73	.27

Correlation Coefficient = .961

CAPSULE 97° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 02:31 PM
Page 1
Coefficients of Curve 1
A = 41.8 B = 39.6 C = 93.04 T0 = 84.74 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=81.4(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=56.2 Deg F Temp@50 ft-lbs=104.3 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
30.00	44.50	20.86	23.64
70.00	23.50	35.58	-12.08
85.00	25.50	41.91	-16.41
100.00	31.50	48.24	-16.74
110.00	82.00	52.29	29.71
120.00	53.50	56.13	-2.63
140.00	54.00	62.90	-8.90
160.00	84.50	68.29	16.21
180.00	67.50	72.35	-4.85

CAPSULE 97° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 97 Fluence: n/cm^2

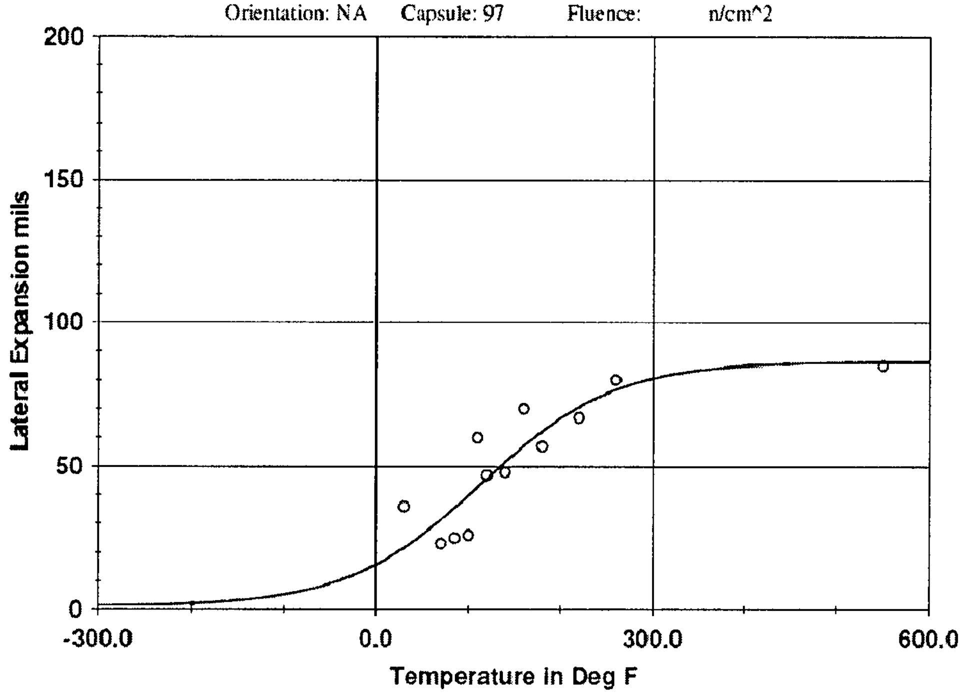
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
220.00	78.00	77.30	.70
260.00	95.00	79.61	15.39
550.00	116.50	81.40	35.10

Correlation Coefficient = .793

CAPSULE 97° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 02:35 PM
Page 1
Coefficients of Curve 1
A = 43.77 B = 42.77 C = 144.66 T0 = 113.04 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=86.5 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=83.0 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 97 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
30.00	36.00	21.60	14.40
70.00	23.00	31.41	-8.41
85.00	25.00	35.58	-10.58
100.00	26.00	39.93	-13.93
110.00	60.00	42.87	17.13
120.00	47.00	45.83	1.17
140.00	48.00	51.65	-3.65
160.00	70.00	57.19	12.81
180.00	57.00	62.27	-5.27

CAPSULE 97° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
220.00	67.00	70.67	-3.67
260.00	80.00	76.63	3.37
550.00	85.00	86.34	-1.34

Correlation Coefficient = .884

CAPSULE 97° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/23/2011 02:38 PM

Page 1

Coefficients of Curve 1

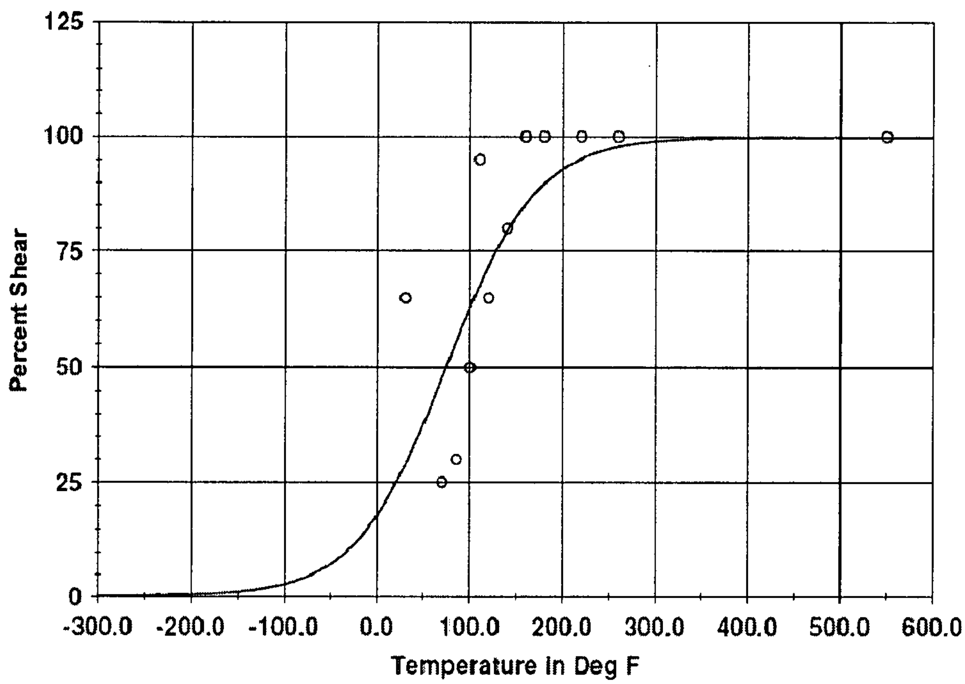
A = 50. B = 50. C = 97.51 T0 = 73.97 D = 0.00E+00

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

Temperature at 50% Shear = 74.0

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
30.00	65.00	28.87	36.13
70.00	25.00	47.96	-22.96
85.00	30.00	55.63	-25.63
100.00	50.00	63.04	-13.04
110.00	95.00	67.68	27.32
120.00	65.00	71.99	-6.99
140.00	80.00	79.48	.52
160.00	100.00	85.38	14.62
180.00	100.00	89.79	10.21

CAPSULE 97° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 97 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
220.00	100.00	95.23	4.77
260.00	100.00	97.84	2.16
550.00	100.00	99.99	.01

Correlation Coefficient = .761

CAPSULE 104° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/02/2011 03:01 PM

Page 1

Coefficients of Curve 1

A = 54.95 B = 52.75 C = 78.24 T0 = 187.01 D = 0.00E+00

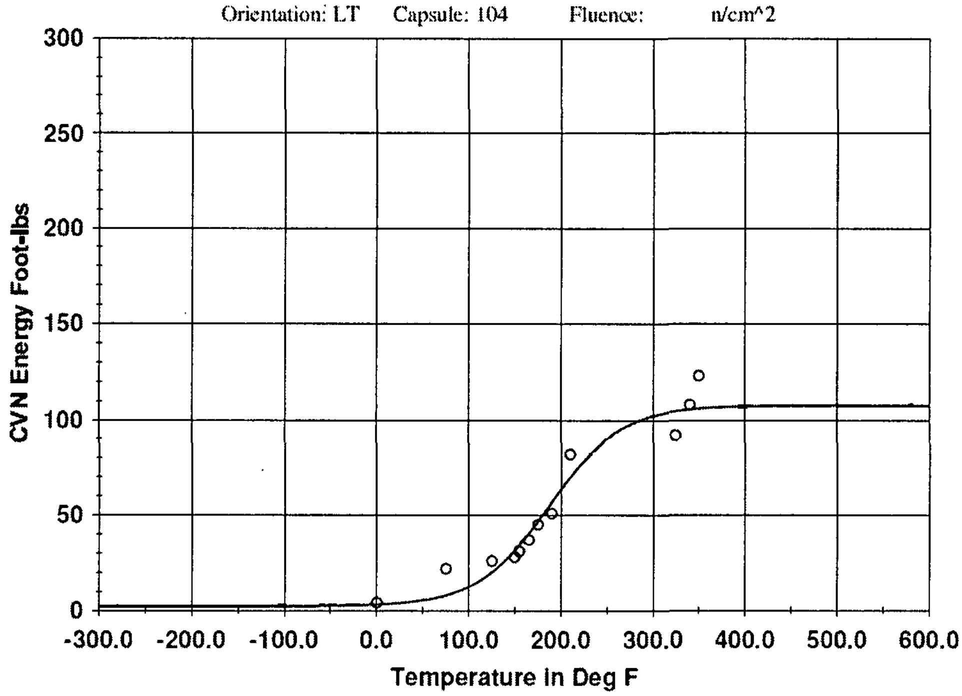
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=107.7(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=146.9 Deg F Temp@50 ft-lbs=179.7 Deg F

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

Orientation: LT Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	4.00	3.08	.92
75.00	22.00	7.90	14.10
125.00	26.00	20.14	5.86
150.00	28.00	31.71	-3.71
155.00	31.00	34.50	-3.50
165.00	37.00	40.49	-3.49
175.00	45.00	46.92	-1.92
190.00	51.00	56.96	-5.96
210.00	82.00	70.02	11.98

CAPSULE 104° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 104 Fluence: n/cm^2

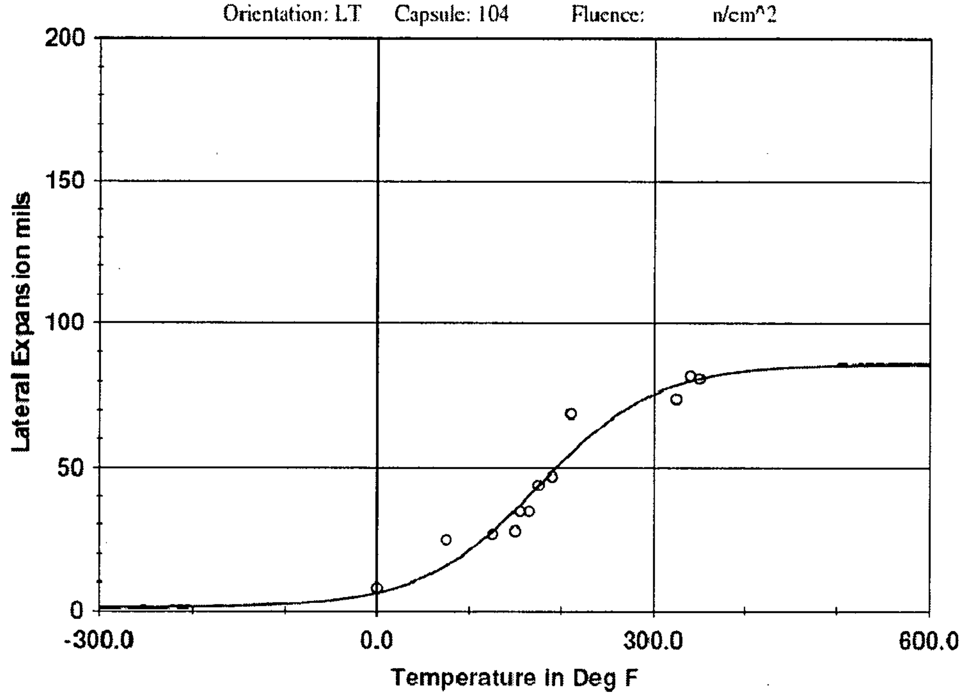
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
325.00	92.00	104.69	-12.69
340.00	108.00	105.63	2.37
350.00	123.00	106.09	16.91

Correlation Coefficient = .972

CAPSULE 104° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/02/2011 02:51 PM
Page 1
Coefficients of Curve 1
A = 43.57 B = 42.57 C = 128.03 T0 = 174.23 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=148.1 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	8.00	6.25	1.75
75.00	25.00	15.91	9.09
125.00	27.00	27.96	-.96
150.00	28.00	35.61	-7.61
155.00	35.00	37.22	-2.22
165.00	35.00	40.51	-5.51
175.00	44.00	43.83	.17
190.00	47.00	48.79	-1.79
210.00	69.00	55.17	13.83

CAPSULE 104° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 104 Fluence: n/cm^2

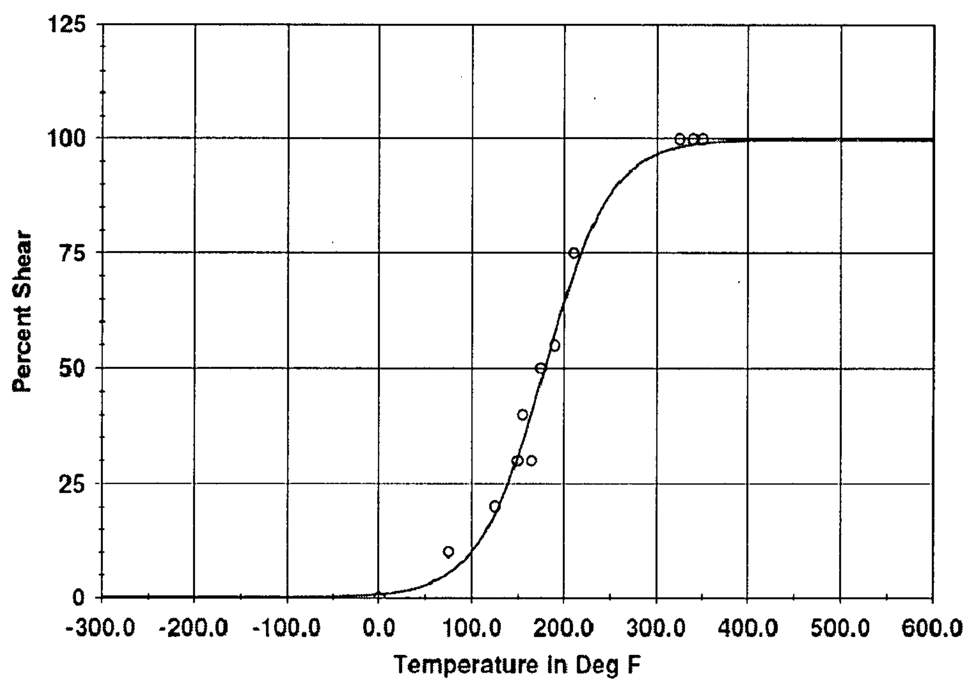
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
325.00	74.00	78.77	-4.77
340.00	82.00	80.20	1.80
350.00	81.00	81.01	-.01

Correlation Coefficient = .970

CAPSULE 104° (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/02/2011 02:57 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 72. T0 = 178.73 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 178.8
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	.00	.69	-.69
75.00	10.00	5.31	4.69
125.00	20.00	18.35	1.65
150.00	30.00	31.04	-1.04
155.00	40.00	34.09	5.91
165.00	30.00	40.58	-10.58
175.00	50.00	47.41	2.59
190.00	55.00	57.76	-2.76
210.00	75.00	70.44	4.56

CAPSULE 104° (LONGITUDINAL ORIENTATION)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: LT Capsule: 104 Fluence: n/cm^2

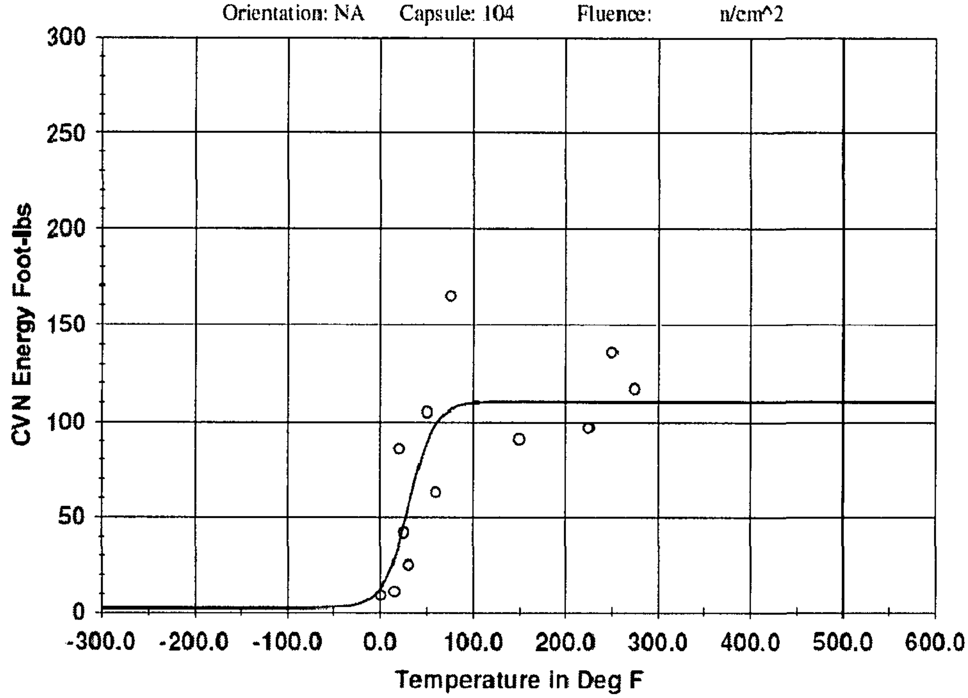
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
325.00	100.00	98.31	1.69
340.00	100.00	98.88	1.12
350.00	100.00	99.15	.85

Correlation Coefficient = .993

CAPSULE 104° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/04/2011 08:26 AM
Page 1
Coefficients of Curve 1
A = 56.25 B = 54.05 C = 27.49 T0 = 30.54 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=110.3(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=16.0 Deg F Temp@50 ft-lbs=27.4 Deg F
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	9.00	12.77	-3.77
15.00	11.00	28.59	-17.59
20.00	86.00	36.49	49.51
25.00	42.00	45.51	-3.51
30.00	25.00	55.20	-30.20
50.00	105.00	89.19	15.81
60.00	63.00	98.96	-35.96
75.00	165.00	106.21	58.79
150.00	91.00	110.28	-19.28

CAPSULE 104° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 104 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
225.00	97.00	110.30	-13.30
250.00	136.00	110.30	25.70
275.00	117.00	110.30	6.70

Correlation Coefficient = .801

CAPSULE 104° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/04/2011 08:28 AM

Page 1

Coefficients of Curve 1

A = 44.39 B = 43.39 C = 35.33 T0 = 28.44 D = 0.00E+00

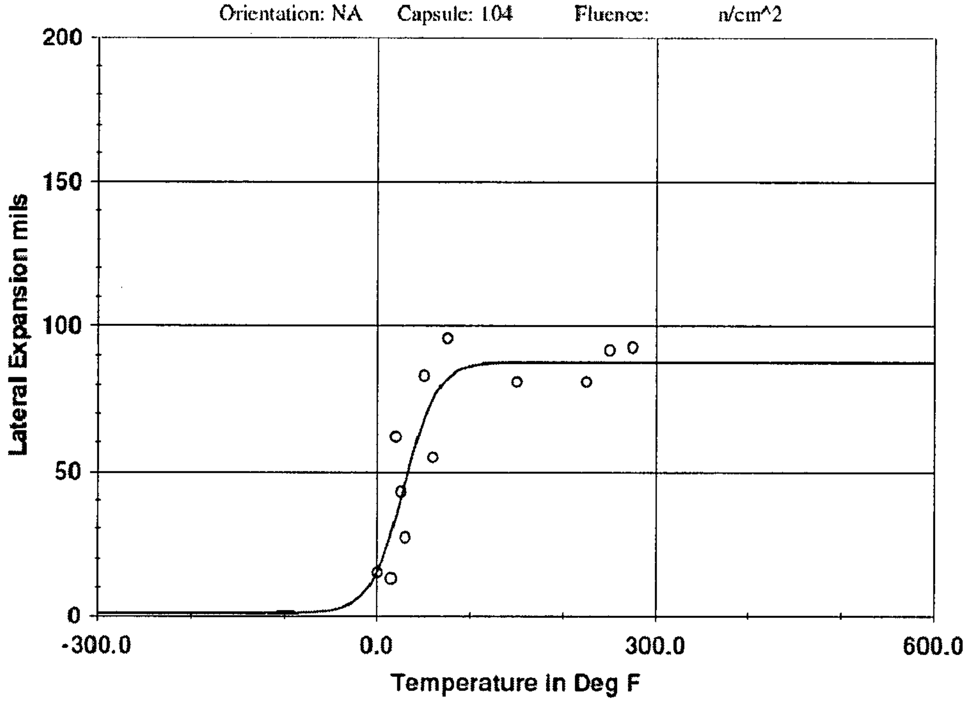
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=87.8 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=20.7 Deg F

Plant: Calvert Cliffs 2 Material: SAW Heat: 10137

Orientation: NA Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	15.00	15.46	-.46
15.00	13.00	28.63	-15.63
20.00	62.00	34.21	27.79
25.00	43.00	40.18	2.82
30.00	27.00	46.30	-19.30
50.00	83.00	68.00	15.00
60.00	55.00	75.33	-20.33
75.00	96.00	81.98	14.02
150.00	81.00	87.69	-6.69

CAPSULE 104° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 104 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
225.00	81.00	87.78	-6.78
250.00	92.00	87.78	4.22
275.00	93.00	87.78	5.22

Correlation Coefficient = .879

CAPSULE 104° (SURVEILLANCE WELD METAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/04/2011 08:30 AM

Page 1

Coefficients of Curve 1

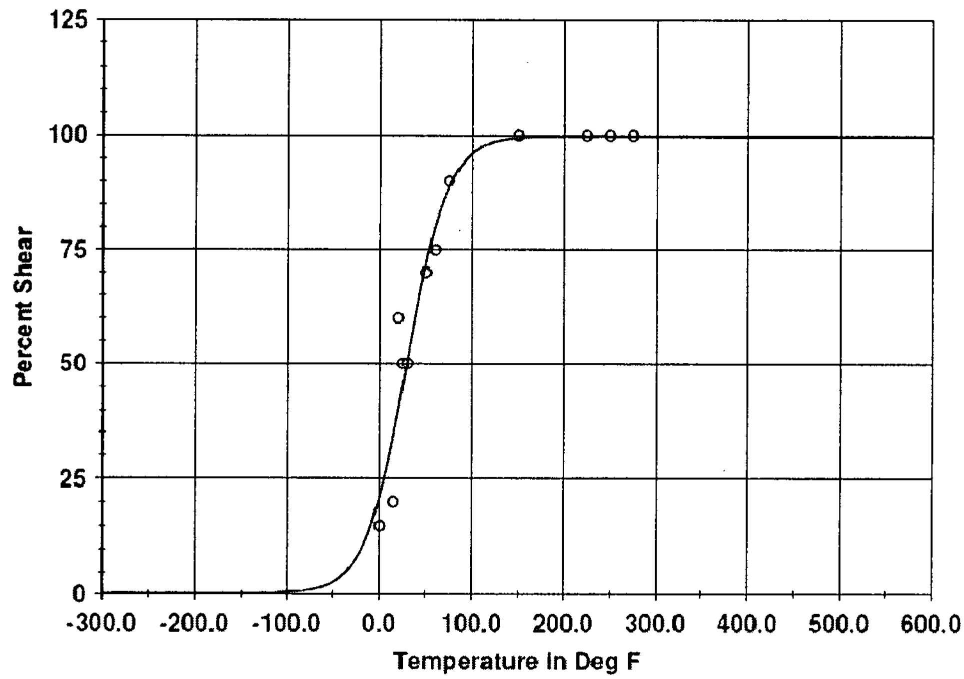
A = 50. B = 50. C = 44.28 T0 = 28.91 D = 0.00E+00

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

Temperature at 50% Shear = 29.0

Plant: Calvert Cliffs 2 Material: SAW Heat: 10137

Orientation: NA Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	15.00	21.31	-6.31
15.00	20.00	34.78	-14.78
20.00	60.00	40.07	19.93
25.00	50.00	45.59	4.41
30.00	50.00	51.23	-1.23
50.00	70.00	72.16	-2.16
60.00	75.00	80.28	-5.28
75.00	90.00	88.91	1.09
150.00	100.00	99.58	.42

CAPSULE 104° (SURVEILLANCE WELD METAL)

Page 2
Plant: Calvert Cliffs 2 Material: SAW Heat: 10137
Orientation: NA Capsule: 104 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
225.00	100.00	99.99	.01
250.00	100.00	100.00	.00
275.00	100.00	100.00	.00

Correlation Coefficient = .966

CAPSULE 104° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/02/2011 03:55 PM

Page 1

Coefficients of Curve 1

A = 48.1 B = 45.9 C = 158.19 T0 = 106.3 D = 0.00E+00

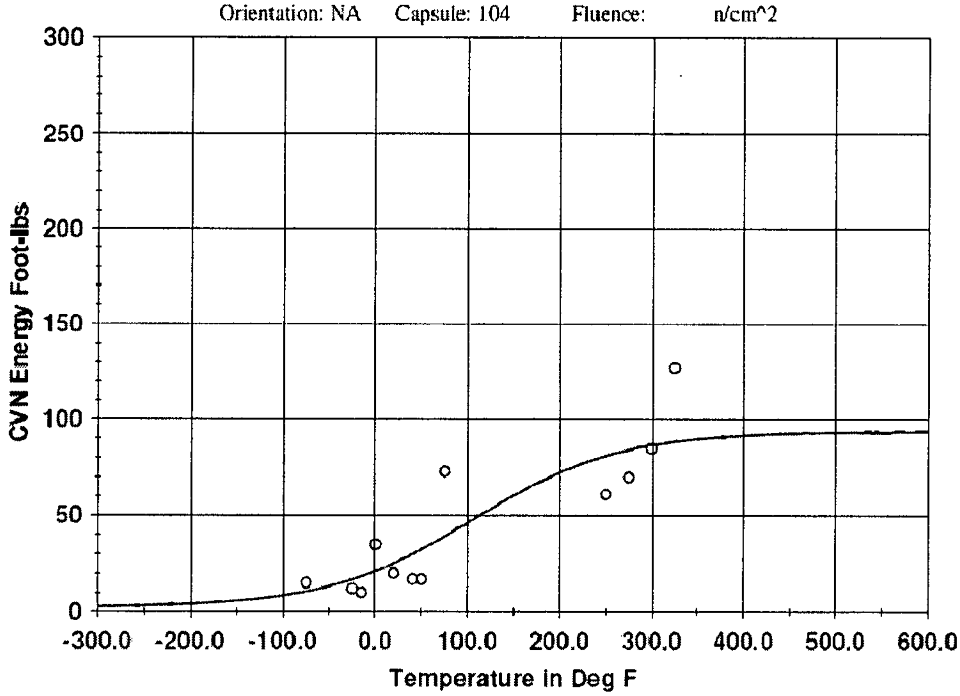
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=94.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=40.4 Deg F Temp@50 ft-lbs=112.9 Deg F

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1

Orientation: NA Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-75.00	15.00	10.62	4.38
-25.00	12.00	16.87	-4.87
-15.00	10.00	18.49	-8.49
.00	35.00	21.19	13.81
20.00	20.00	25.28	-5.28
40.00	17.00	29.92	-12.92
50.00	17.00	32.42	-15.42
75.00	73.00	39.14	33.86
250.00	61.00	81.17	-20.17

CAPSULE 104° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 104 Fluence: n/cm^2

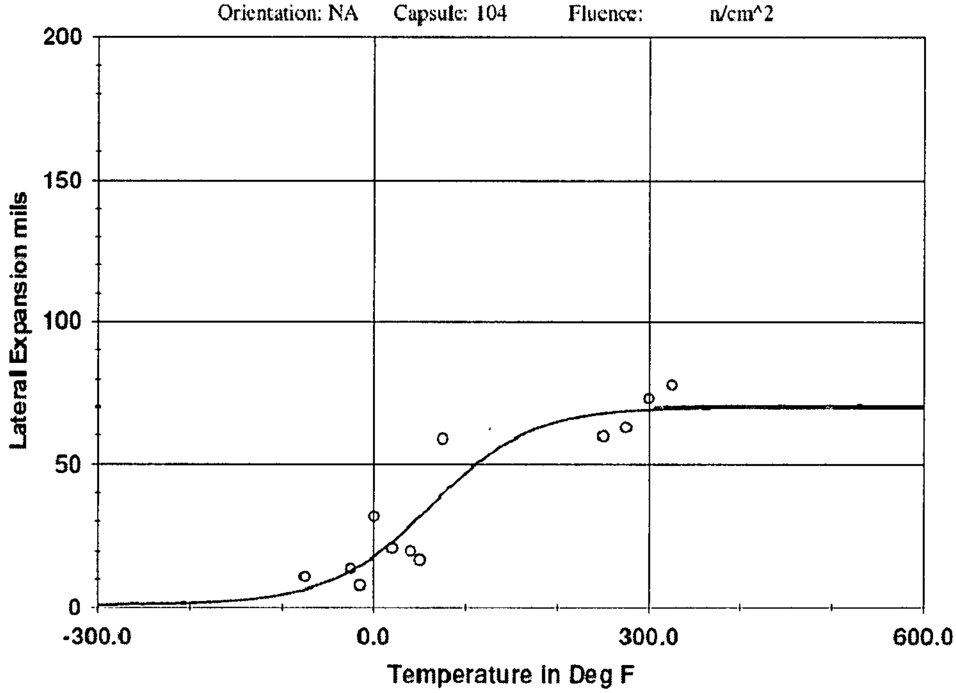
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
275.00	70.00	84.27	-14.27
300.00	85.00	86.70	-1.70
325.00	127.00	88.56	38.44

Correlation Coefficient = .863

CAPSULE 104° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/02/2011 04:01 PM
Page 1
Coefficients of Curve 1
A = 35.73 B = 34.73 C = 111.76 T0 = 61.96 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=70.5 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=59.6 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-75.00	11.00	6.51	4.49
-25.00	14.00	13.10	.90
-15.00	8.00	14.99	-6.99
.00	32.00	18.23	13.77
20.00	21.00	23.27	-2.27
40.00	20.00	28.99	-8.99
50.00	17.00	32.03	-15.03
75.00	59.00	39.77	19.23
250.00	60.00	68.15	-8.15

CAPSULE 104° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 104 Fluence: n/cm^2

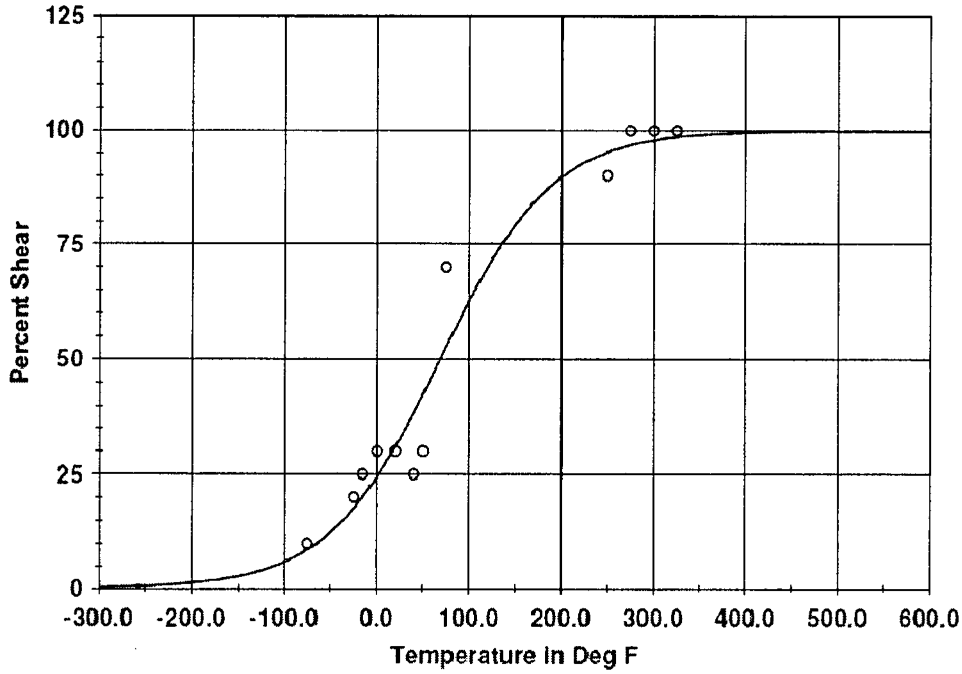
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
275.00	63.00	68.97	-5.97
300.00	73.00	69.50	3.50
325.00	78.00	69.85	8.15

Correlation Coefficient = .924

CAPSULE 104° (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/02/2011 04:03 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 121.65 T0 = 68.46 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 68.5
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75.00	10.00	8.64	1.36
-25.00	20.00	17.70	2.30
-15.00	25.00	20.23	4.77
.00	30.00	24.50	5.50
20.00	30.00	31.07	-1.07
40.00	25.00	38.51	-13.51
50.00	30.00	42.47	-12.47
75.00	70.00	52.69	17.31
250.00	90.00	95.19	-5.19

CAPSULE 104° (HEAT AFFECTED ZONE)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: C-5286-1
Orientation: NA Capsule: 104 Fluence: n/cm^2

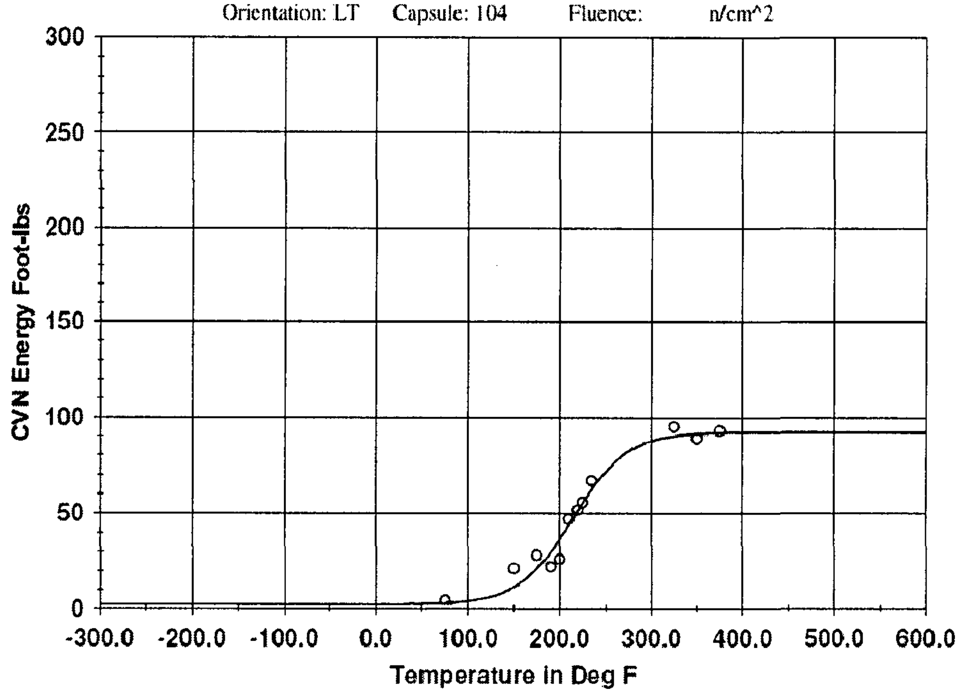
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
275.00	100.00	96.76	3.24
300.00	100.00	97.83	2.17
325.00	100.00	98.55	1.45

Correlation Coefficient = .974

CAPSULE 104° (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/04/2011 08:00 AM
Page 1
Coefficients of Curve 1
A = 47.25 B = 45.05 C = 58.89 T0 = 214.25 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=92.3(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=190.5 Deg F Temp@50 ft-lbs=217.9 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
75.00	4.50	2.99	1.51
150.00	21.00	11.33	9.67
175.00	28.00	21.00	7.00
190.00	22.00	29.68	-7.68
200.00	26.00	36.55	-10.55
210.00	47.00	44.00	3.00
220.00	52.00	51.63	.37
225.00	56.00	55.38	.62
235.00	67.00	62.50	4.50

CAPSULE 104° (STANDARD REFERENCE MATERIAL)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 104 Fluence: n/cm^2

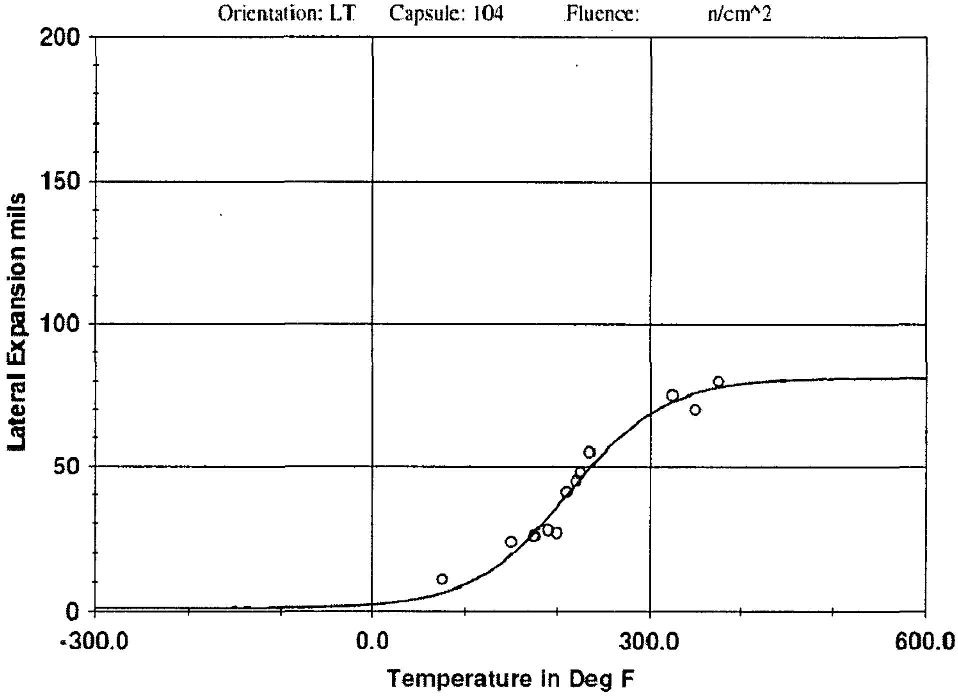
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
325.00	95.00	90.25	4.75
350.00	89.00	91.41	-2.41
375.00	93.00	91.92	1.08

Correlation Coefficient = .983

CAPSULE 104° (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/04/2011 08:03 AM
Page 1
Coefficients of Curve 1
A = 41.13 B = 40.13 C = 104.92 T0 = 213.16 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=81.3 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=197.1 Deg F
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
75.00	11.00	6.38	4.62
150.00	24.00	19.52	4.48
175.00	26.00	27.14	-1.14
190.00	28.00	32.41	-4.41
200.00	27.00	36.12	-9.12
210.00	41.00	39.92	1.08
220.00	45.00	43.74	1.26
225.00	48.00	45.63	2.37
235.00	55.00	49.36	5.64

CAPSULE 104° (STANDARD REFERENCE MATERIAL)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 104 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
325.00	75.00	72.74	2.26
350.00	70.00	75.74	-5.74
375.00	80.00	77.74	2.26

Correlation Coefficient = .979

CAPSULE 104° (STANDARD REFERENCE MATERIAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 11/04/2011 08:05 AM

Page 1

Coefficients of Curve 1

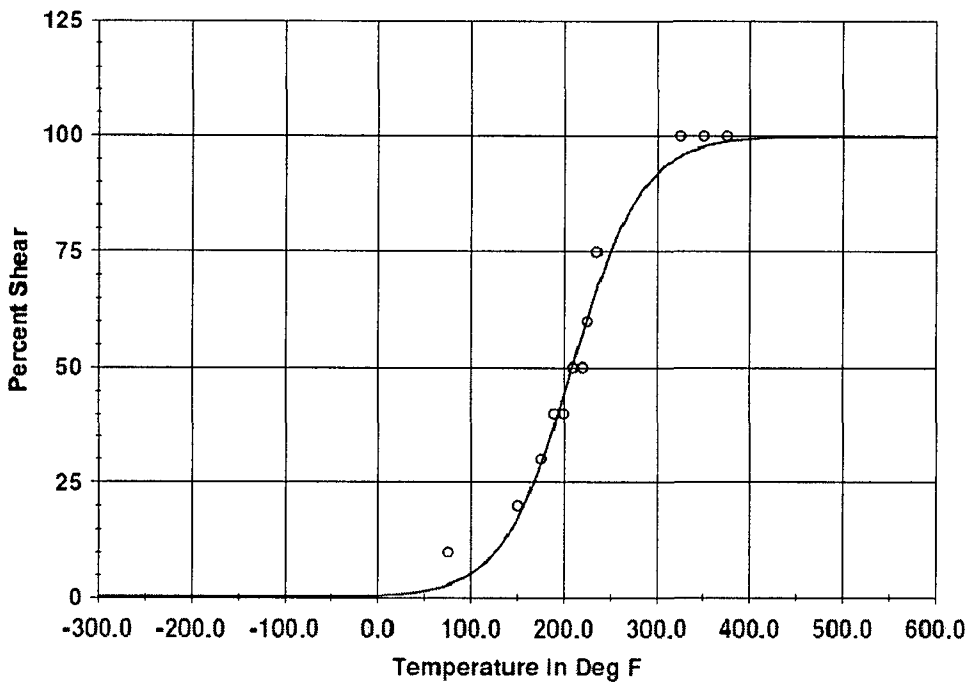
A = 50. B = 50. C = 75.33 T0 = 208.6 D = 0.00E+00

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

Temperature at 50% Shear = 208.6

Plant: Calvert Cliffs 2 Material: SA533B1 Heat: HSST-01MY

Orientation: LT Capsule: 104 Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75.00	10.00	2.80	7.20
150.00	20.00	17.43	2.57
175.00	30.00	29.07	.93
190.00	40.00	37.90	2.10
200.00	40.00	44.32	-4.32
210.00	50.00	50.93	-.93
220.00	50.00	57.51	-7.51
225.00	60.00	60.72	-.72
235.00	75.00	66.84	8.16

CAPSULE 104° (STANDARD REFERENCE MATERIAL)

Page 2
Plant: Calvert Cliffs 2 Material: SA533B1 Heat: HSST-01MY
Orientation: LT Capsule: 104 Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
325.00	100.00	95.65	4.35
350.00	100.00	97.71	2.29
375.00	100.00	98.81	1.19

Correlation Coefficient = .990

APPENDIX D
CALVERT CLIFFS UNIT 2 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 2 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 2 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 2 reactor vessel consists of the following beltline region materials:

- Intermediate Shell Plates D-8906-1, 2 and 3 (Heat # A-4463-1, B-9427-2 and A-4463-2)
- Lower Shell Plates D-8907-1, 2 and 3 (Heat # C-5804-1, C-5286-1, C-5803-3)
- Intermediate to Lower Shell Circumferential Weld Seam 9-203 (Heat # 10137)
- Intermediate Shell Longitudinal Weld Seams 2-203-A, B, C (Heat # A8746)
- Lower Shell Longitudinal Weld Seams 3-203-A, B, C (Heat # 33A277)

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 2 plates (D-8906-2 and D-8907-2) had a T_{NDT} of 10°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, Lower Shell Plate D-8907-2 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 10137/0091 for Calvert Cliffs Unit 2. 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 2 surveillance program (Heat # 10137) had the second highest Cu Wt. % of all the reactor vessel beltline welds. Thus, it was chosen as the surveillance weld metal.

Hence, Criterion 1 is met for the Calvert Cliffs Unit 2 surveillance program.

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

Based on engineering judgment, the scatter in the data presented in these plots is small enough to permit the determination of the 30 ft-lb temperature and the upper-shelf energy of the Calvert Cliffs Unit 2 surveillance materials unambiguously. Hence, the Calvert Cliffs Unit 2 surveillance program meets this criterion.

Hence, Criterion 2 is met for the Calvert Cliffs Unit 2 surveillance program.

Criterion 3: *When there are two or more sets of surveillance data from one reactor, the scatter of ΔRT_{NDT} values about a best-fit line drawn as described in Regulatory Position 2.1 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 2 surveillance material.

Following the NRC Case 1, the Calvert Cliffs Unit 2 surveillance plate and weld metal (Heat # 10137) will be evaluated using Calvert Cliffs Unit 2 data. This evaluation is contained in Table D-1.

Table D-1 Calculation of Interim Chemistry Factors for the Credibility Evaluation Using Calvert Cliffs Unit 2 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
Lower Shell Plate D-8907-2 (Longitudinal)	263°	0.825	0.946	86.4	81.74	0.895
	97°	1.95	1.182	111.6	131.97	1.398
	104°	2.44	1.240	135.6	168.16	1.538
Lower Shell Plate D-8907-2 (Transverse)	97°	1.95	1.182	102.6	121.32	1.398
				SUM:	503.19	5.229
	$CF_{D\text{-}8907\text{-}2} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (503.19) \div (5.229) =$ **96.2°F**					
Calvert Cliffs Unit 2 Weld Metal (Heat # 10137)	263°	0.825	0.946	72.7	68.78	0.895
	97°	1.95	1.182	82.9	98.03	1.398
	104°	2.44	1.240	69.7	86.44	1.538
				SUM:	253.24	3.831
	$CF_{Heat\,\#\,10137} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (253.24) \div (3.831) =$ **66.1°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 2 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 2 Surveillance Materials

Material	Capsule	CF (Slope$_{best-fit}$) (°F)	Capsule Fluence ($x10^{19}$ n/cm^2)	FF	Measured ΔRT_{NDT}[(a)] (°F)	Predicted ΔRT_{NDT}[(b)] (°F)	Residual ΔRT_{NDT}[(c)] (°F)	<17°F (Base Metal) <28°F (Weld)
Lower Shell Plate D-8907-2 (Longitudinal)	263°	96.2	0.825	0.946	86.4	91.0	4.6	Yes
	97°	96.2	1.95	1.182	111.6	113.8	2.2	Yes
	104°	96.2	2.44	1.240	135.6	119.3	16.3	Yes
Lower Shell Plate D-8907-2 (Transverse)	97°	96.2	1.95	1.182	102.6	113.8	11.2	Yes
Calvert Cliffs Unit 2 Weld Metal (Heat # 10137)	263°	66.1	0.825	0.946	72.7	62.5	10.2	Yes
	97°	66.1	1.95	1.182	82.9	78.2	4.7	Yes
	104°	66.1	2.44	1.240	69.7	82.0	12.3	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 four surveillance data points fall within the +/- 1σ of 17°F scatter band for surveillance base metals; therefore, the Lower Shell Plate D-8907-2 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 # 10137) is deemed "credible" per the third criterion.

Hence, Criterion 3 is met for the Calvert Cliffs Unit 2 surveillance plate and weld metal.

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 2 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 2 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 and ΔRT_{NDT} values for Capsule 263°, nor does it consider the surveillance data from Capsule 104°. Thus, Table D-3 contains an updated calculation of Residual vs. Fast fluence, considering the recalculated capsule fluence and ΔRT_{NDT} values for Capsule 263° and the surveillance data from Capsule 104°.

Table D-3 Calculation of Residual vs. Fast Fluence for Calvert Cliffs Unit 2

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°	0.825	0.946	125.6	128.76	-3.2
104°	2.44	1.240	165.5	168.78	-3.3

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-3 shows a 2σ uncertainty of less than 50°F, which is the allowable scatter in NUREG/CR-6413, ORNL/TM-13133.

Hence, Criterion 5 is met for the Calvert Cliffs Unit 2 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 2 surveillance data for both the surveillance plate and weld specimens are deemed credible.

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, *Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels*, American Society for 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.

APPENDIX E
CALVERT CLIFFS UNIT 2 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 52 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 52 EFPY.

The Calvert Cliffs Unit 2 reactor vessel beltline region minimum thickness is 8.625 inches. Calculation of the 1/4T vessel surface fluence values at 32 and 52 EFPY for the beltline materials is shown as follows:

Maximum Vessel Fluence @ 32 EFPY = 2.87×10^{19} n/cm^2 (E > 1.0 MeV)

1/4T Fluence @ 32 EFPY = $(2.87 \times 10^{19}\ \text{n/cm}^2) * e^{(-0.24 * (8.625/4))}$

= 1.711×10^{19} n/cm^2 (E > 1.0 MeV)

Maximum Vessel Fluence @ 52 EFPY = 4.28×10^{19} n/cm^2 (E > 1.0 MeV)

1/4T Fluence @ 52 EFPY = $(4.28 \times 10^{19}\ \text{n/cm}^2) * e^{(-0.24 * (8.625/4))}$

= 2.551×10^{19} n/cm^2 (E > 1.0 MeV)

The following pages present the Calvert Cliffs Unit 2 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 (EOL)). Table E-2 provides the predicted upper-shelf energy values for 52 EFPY (end-of-life-extension (EOLE)).

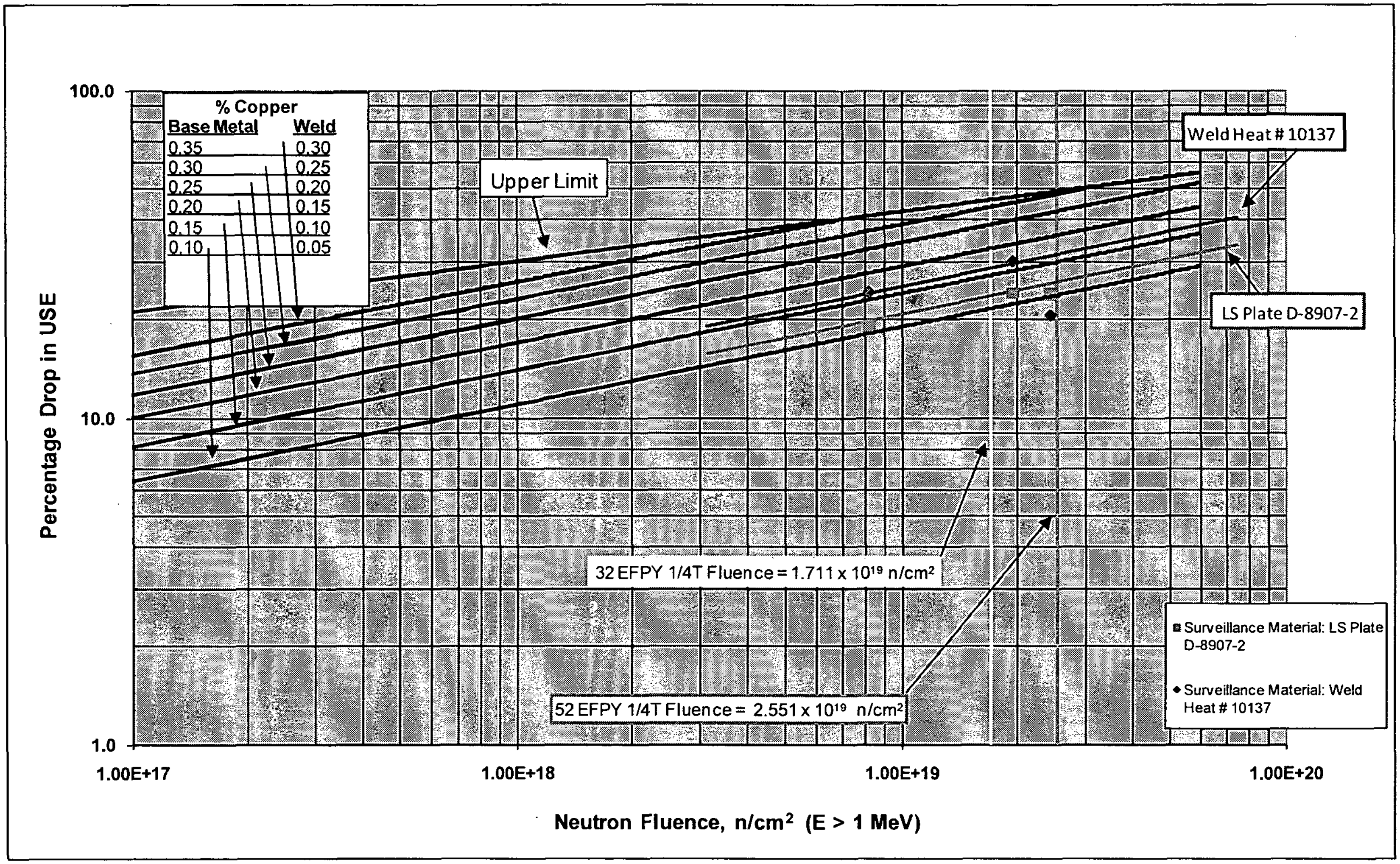


Figure E-1 **Regulatory Guide 1.99, Revision 2 Predicted Decrease in Upper-Shelf Energy as a Function of Copper and Fluence**

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-8906-1	0.15	1.711	77	27	56.2
Intermediate Shell Plate D-8906-2	0.11	1.711	74	27	54.0
Intermediate Shell Plate D-8906-3	0.14	1.711	75	27	54.8
Lower Shell Plate D-8907-1	0.15	1.711	83	27	60.6
Lower Shell Plate D-8907-2	0.14	1.711	115	27	84.0
Lower Shell Plate D-8907-3	0.11	1.711	85	27	62.1
Intermediate Shell Long. Welds 2-203-A, B, C	0.16	1.711	84	34.5[c]	55.0
Intermediate to Lower Shell Circ. Weld 9-203	0.21	1.711	140	44	78.4
Lower Shell Long. Welds 3-203-A, B, C	0.24	1.711	160	44	89.6
Position 2.2[d]					
Lower Shell Plate D-8907-2[e]	0.14	1.711	115	23	88.6
Intermediate to Lower Shell Circ. Weld 9-203[e]	0.21	1.711	140	29	99.4

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, unless otherwise noted. The percent USE drop of the plates was calculated based on the 0.15 Cu wt. % base metal line. The percent USE drop of the Intermediate to Lower Shell Circ. Weld and the Lower Shell Long. Welds was calculated based on the 0.25 Cu wt. % weld line.

(c) The Intermediate Shell Long. Welds' projected USE value at EOL is close to the 10 CFR 50, Appendix G screening criteria. Therefore, the percent USE decrease value that corresponded to the specific Cu wt. % (0.16) for this material was determined using interpolation between the existing weld lines on Figure 2 of Regulatory Guide 1.99, Revision 2.

(d) 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.

(e) The most limiting surveillance data point for Lower Shell Plate D-8907-2 is a measured decrease of 24% at a fluence of 1.95 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 30% at a fluence of 1.95 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 52 EFPY

Material	Weight % of Cu	1/4T EOLE Fluence[(a)] ($x10^{19}$ n/cm^2, E > 1.0 MeV)	Unirradiated USE (ft-lb)	Projected USE Decrease (%)	Projected EOLE USE (ft-lb)
Position 1.2[(b)]					
Intermediate Shell Plate D-8906-1	0.15	2.551	77	30	53.9
Intermediate Shell Plate D-8906-2	0.11	2.551	74	30	51.8
Intermediate Shell Plate D-8906-3	0.14	2.551	75	30	52.5
Lower Shell Plate D-8907-1	0.15	2.551	83	30	58.1
Lower Shell Plate D-8907-2	0.14	2.551	115	30	80.5
Lower Shell Plate D-8907-3	0.11	2.551	85	30	59.5
Intermediate Shell Long. Welds 2-203-A, B, C	0.16	2.551	84	37.5[(c)]	52.5
Intermediate to Lower Shell Circ. Weld 9-203	0.21	2.551	140	48	72.8
Lower Shell Longitudinal Welds 3-203-A, B, C	0.24	2.551	160	48	83.2
Position 2.2[(d)]					
Lower Shell Plate D-8907-2[(e)]	0.14	2.551	115	25.5	85.7
Intermediate to Lower Shell Circ. Weld 9-203[(e)]	0.21	2.551	140	32	95.2

Notes:

(a) The fluence values listed pertain to the maximum vessel fluence value at 52 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, unless otherwise noted. The percent USE drop of the plates was calculated based on the 0.15 Cu wt. % base metal line. The percent USE drop of the Intermediate to Lower Shell Circ. Weld and the Lower Shell Long. Welds was calculated based on the 0.25 Cu wt. % weld line.

(c) The Intermediate Shell Long. Welds' projected USE value at EOLE is close to the 10 CFR 50, Appendix G screening criteria. Therefore, the percent USE decrease value that corresponded to the specific Cu wt. % (0.16) for this material was determined using interpolation between the existing weld lines on Figure 2 of Regulatory Guide 1.99, Revision 2.

(d) 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.

(e) The most limiting surveillance data point for Lower Shell Plate D-8907-2 is a measured decrease of 24% at a fluence of 1.95 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 30% at a fluence of 1.95 x 10^{19} n/cm^2 pertaining to Capsule 97° (see Table 5-10).

USE Conclusion

All of the beltline materials in the Calvert Cliffs Unit 2 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 52 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 2 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 2 surveillance Capsule 104° materials at 32 EFPY (EOL) and 52 EFPY (EOLE).

Also, Calvert Cliffs Unit 2 has sister plant surveillance data from Calvert Cliffs Unit 1 and Farley Unit 1 for weld Heat # 33A277. Data from WCAP-17365-NP, Revision 0 [Reference F-4] was used to determine the Position 2.1 chemistry factor value for this material applicable to Calvert Cliffs Unit 2 (See Table F-3). Weld Heat # 33A277 has been deemed credible per WCAP-17365-NP, Revision 0.

The EOL and EOLE RT_{PTS} calculations are summarized in Table F-4.

F.1 CALCULATION OF POSITION 2.1 CHEMISTRY FACTORS

Ratio Procedure

The Calvert Cliffs Unit 2 (CC-2) Position 1.1 surveillance program weld chemistry factor (96.8°F) is identical to the vessel weld chemistry factor for the Intermediate to Lower Shell Circumferential Weld 9-203 (96.8°F) per Reference F-3. Thus, in Table F-2, the ratio procedure of Regulatory Guide 1.99, Revision 2, Position 2.1 [Reference F-2] is not used for the CC-2 surveillance weld metal (Heat # 10137) because the ratio is equal to one.

Credible sister plant data for Weld Heat # 33A277 is available from the Calvert Cliffs Unit 1 (CC-1) and Farley Unit 1 (Far-1) surveillance programs.

The CC-1 Position 1.1 surveillance program weld chemistry factor (91.8°F) is not identical to the Calvert Cliffs Unit 2 vessel weld chemistry factor for the Lower Shell Longitudinal Welds 3-203-A, B, C (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 [Reference F-4]

$CF_{\text{CC-2 Beltline Weld}}$ = 117.8°F [Reference F-4]

$$\text{Ratio} = \frac{117.8}{91.8}$$

Ratio = 1.28

The 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 Lower Shell Longitudinal Welds 3-203-A, B, C (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 [Reference F-4]

$CF_{\text{CC-2 Beltline Weld}}$ = 117.8°F [Reference F-4]

$$\text{Ratio} = \frac{117.8}{78.1}$$

Ratio = 1.51

Therefore, in Table F-3, 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} values from the Far-1 surveillance program will be multiplied by the ratio of 1.51.

Temperature Adjustments

Calvert Cliffs Unit 2 utilizes surveillance data from two sister plants (Calvert Cliffs Unit 1 and 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-5] 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 CC-1 and Far-1 capsule irradiation temperatures ($T_{capsule}$) and measured ΔRT_{NDT} values are taken from Reference F-4. The irradiation temperature of the CC-2 reactor vessel is 548°F (T_{Plant}). Table F-1 gives a summary of the temperature adjustments of the CC-1 and Far-1 surveillance data that will be used in Table F-3 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 is shown below:

Temperature Adjustment Procedure

$T_{capsule}$	= 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

Ratio Procedure

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 and CC-1 measured ΔRT_{NDT} values were adjusted in the same fashion and are shown in Table F-3 (unadjusted ΔRT_{NDT} values are included in parentheses). No temperature adjustments were required for the CC-1 data because the CC-1 capsules were irradiated at the same temperature as CC-2.

Table F-1 Calculation of the Temperature Adjustments for the Calvert Cliffs Unit 1 and Farley Unit 1 Surveillance Capsule Data Applicable to Calvert Cliffs Unit 2

Material	Capsule	Inlet Temperature during Period of Irradiation ($T_{Capsule}$) (°F)	Calvert Cliffs Unit 2 Inlet Temperature (T_{Plant}) (°F)	Temperature Adjustment (°F)
Weld Metal Heat # 33A277 (Calvert Cliffs Unit 1 data)	263°	548.00	548	0.00
	97°	548.00		0.00
	284°	548.00		0.00
Weld Metal Heat # 33A277 (Farley Unit 1 data)	Y	544.00		-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 2 using CC-2 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
Lower Shell Plate D-8907-2 (Longitudinal)	263°	0.825	0.946	86.4	81.74	0.895
	97°	1.95	1.182	111.6	131.97	1.398
	104°	2.44	1.240	135.6	168.16	1.538
Lower Shell Plate D-8907-2 (Transverse)	97°	1.95	1.182	102.6	121.32	1.398
				SUM:	503.19	5.229
	$CF_{D\text{-}8907\text{-}2} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (503.19) \div (5.229) =$ **96.2°F**					
CC-2 Surveillance Program Weld (Heat # 10137)	263°	0.825	0.946	72.7	68.78	0.895
	97°	1.95	1.182	82.9	98.03	1.398
	104°	2.44	1.240	69.7	86.44	1.538
				SUM:	253.24	3.831
	$CF_{Heat\ \#\ 10137} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (253.24) \div (3.831) =$ **66.1°F**					

Notes:

(a) The Calvert Cliffs Unit 2 calculated capsule fluence values are 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 for Calvert Cliffs Unit 2. No temperature or ratio adjustments were applied to the Calvert Cliffs Unit 2 surveillance data because the capsules were irradiated at the same temperature as the plant and the ratio was equal to one, respectively.

Table F-3 Calculation of Chemistry Factors for Calvert Cliffs Unit 2 using CC-1 and Far-1 Sister Plant 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
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
	$CF_{Heat\ \#\ 33A277} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (1369.38) \div (13.618) =$ **100.6°F**					

Notes:

(a) The Calvert Cliffs Unit 1 and Farley Unit 1 calculated capsule fluence values are taken from Reference F-4.

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

(c) The Calvert Cliffs Unit 1 and Farley Unit 1 ΔRT_{NDT} values are the measured 30 ft-lb shift values and were taken from Reference F-4. 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:

Calvert Cliffs Unit 1 – Ratio = 1.28, Temperature adjustments per Table F-1 (adjustments are equal to zero)

Farley Unit 1 – Ratio = 1.51, Temperature adjustments per Table F-1 (on a capsule-by-capsule basis)

F.2 RT_{PTS} CALCULATIONS

Table F-4 RT_{PTS} Calculations for the Calvert Cliffs Unit 2 Surveillance Capsule Materials at 32 and 52 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										
Lower Shell Plate D-8907-2	1.1	101.5	2.870×10^{19}	1.2801	20	129.9	0	17	34.0	184
	2.1	96.2	2.870×10^{19}	1.2801	20	123.1	0	8.5[d]	17.0	160
Intermediate Shell to Lower Shell Circ. Weld 9-203	1.1	96.8	2.870×10^{19}	1.2801	-60	123.9	0	28	56.0	120
	2.1	66.1	2.870×10^{19}	1.2801	-60	84.6	0	14[d]	28.0	53
Lower Shell Longitudinal Weld 3-203-A, B, C	1.1	117.8	2.870×10^{19}	1.2801	-80	150.8	0	28	56.0	127
	2.1	100.6	2.870×10^{19}	1.2801	-80	128.8	0	14[d]	28.0	77
52 EFPY										
Lower Shell Plate D-8907-2	1.1	101.5	4.280×10^{19}	1.3707	20	139.1	0	17	34.0	193
	2.1	96.2	4.280×10^{19}	1.3707	20	131.9	0	8.5[d]	17.0	169
Intermediate Shell to Lower Shell Circ. Weld 9-203	1.1	96.8	4.280×10^{19}	1.3707	-60	132.7	0	28	56.0	129
	2.1	66.1	4.280×10^{19}	1.3707	-60	90.6	0	14[d]	28.0	59
Lower Shell Longitudinal Welds 3-203-A, B, C	1.1	117.8	4.280×10^{19}	1.3707	-80	161.5	0	28	56.0	137
	2.1	100.6	4.280×10^{19}	1.3707	-80	137.9	0	14[d]	28.0	86

Notes:

(a) Position 1.1 Chemistry Factor values were calculated per Reference F-1 and Position 2.1 Chemistry Factor values taken from Tables F-2 and F-3.
(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) A reduced σ_Δ term is used since the surveillance data is deemed credible per Appendix D and Reference F-4.

PTS Conclusion

All of the surveillance Capsule 104° materials for Calvert Cliffs Unit 2 are projected to remain below the PTS screening criterion value of 270°F for plates and longitudinal welds and 300°F for circumferential welds (per 10 CFR 50.61) at 32 and 52 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, dated December 19, 1995, effective January 18, 1996.

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 WCAP-17365-NP, Revision 0, *Analysis of Capsule 284° from the Calvert Cliffs Unit No. 1 Reactor Vessel Radiation Surveillance Program*, E. J. Long and J. I. Duo, March 2011.

F-5 K. Wichman, M. Mitchell, and A. Hiser, USNRC, Generic Letter 92-01 and RPV Integrity Assessment Workshop Handouts, *NRC/Industry Workshop on RPV Integrity Issues*, February 12, 1998.

APPENDIX G
CALVERT CLIFFS UNIT 2 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 2 at 52 EFPY for each reactor vessel surveillance capsule material (Lower Shell Plate D-8907-2, Intermediate to Lower Shell Circ. Weld 9-203 and Lower Shell Axial Welds 3-203-A, B, C) 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 104° materials are documented in the CRVSP, Revision 5 [Reference G-2].

The Calvert Cliffs Unit 2 (CC-2) Lower Shell Plate D-8907-2 surveillance data has been deemed credible per Appendix D of this report. Therefore, when using the Lower Shell Plate D-8907-2 surveillance data, a reduced σ_Δ value can be used. The CC-2 Intermediate Shell to Lower Shell Circ. Weld 9-203 surveillance data has been deemed credible 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. Finally, the CC-1 and Far-1 surveillance weld data (Heat # 33A277), which is applicable to the CC-2 Lower Shell Axial Welds 3-203-A, B, C, has been deemed credible per WCAP-17365-NP, Revision 0 [Reference G-3]. Therefore, when using the Lower Shell Longitudinal Welds 3-203-A, B, C surveillance data, a reduced σ_Δ value can be used.

The Calvert Cliffs Unit 2 reactor vessel beltline region minimum thickness is 8.625 inches. Calculation of the 1/4T and 3/4T vessel fluence values at 52 EFPY for the beltline materials is shown as follows:

Maximum Vessel Fluence @ 52 EFPY = 4.28×10^{19} n/cm^2 (E > 1.0 MeV)

1/4T Fluence @ 52 EFPY = $(4.28 \times 10^{19} \text{ n/cm}^2) * e^{(-0.24 * (8.625/4))}$

= 2.551×10^{19} n/cm^2 (E > 1.0 MeV)

Maximum Vessel Fluence @ 52 EFPY = 4.28×10^{19} n/cm^2 (E > 1.0 MeV)

3/4T Fluence @ 52 EFPY = $(4.28 \times 10^{19} \text{ n/cm}^2) * e^{(-0.24 * (3*8.625/4))}$

= 0.906×10^{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-2 reactor vessel surveillance Capsule 104° materials, as well as for the CC-1 and Far-1 surveillance materials that apply to the CC-2 reactor vessel.

Table G-1 Calculation of the Calvert Cliffs Unit 2 Reactor Vessel Surveillance Capsule Material ART Values at the 1/4T Location for 52 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)
Lower Shell Plate D-8907-2	1.1	101.5	2.551×10^{19}	1.2512	20	127.0	0	17	34.0	181
	2.1	96.2	2.551×10^{19}	1.2512	20	120.4	0	8.5[(c)]	17.0	157
Intermediate Shell to Lower Shell Circ. Weld 9-203	1.1	96.8	2.551×10^{19}	1.2512	-60	121.1	0	28	56.0	117
	2.1	66.1	2.551×10^{19}	1.2512	-60	82.7	0	14[(c)]	28.0	51
Lower Shell Longitudinal Weld 3-203-A, B, C	1.1	117.8	2.551×10^{19}	1.2512	-80	147.4	0	28	56.0	123
	2.1	100.6	2.551×10^{19}	1.2512	-80	125.9	0	14[(c)]	28.0	74

Notes:

(a) Position 1.1 Chemistry Factor values were calculated per Reference G-1 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) A reduced σ_Δ term is used since the surveillance data is deemed credible per Appendix D and Reference G-3.

Table G-2 Calculation of the Calvert Cliffs Unit 2 Reactor Vessel Surveillance Capsule Material ART Values at the 3/4T Location for 52 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)
Lower Shell Plate D-8907-2	1.1	101.5	0.906×10^{19}	0.9724	20	98.7	0	17	34.0	153
	2.1	96.2	0.906×10^{19}	0.9724	20	93.5	0	8.5[(c)]	17.0	131
Intermediate Shell to Lower Shell Circ. Weld 9-203	1.1	96.8	0.906×10^{19}	0.9724	-60	94.1	0	28	56.0	90
	2.1	66.1	0.906×10^{19}	0.9724	-60	64.3	0	14[(c)]	28.0	32
Lower Shell Longitudinal Weld 3-203-A, B, C	1.1	117.8	0.906×10^{19}	0.9724	-80	114.5	0	28	56.0	91
	2.1	100.6	0.906×10^{19}	0.9724	-80	97.8	0	14[(c)]	28.0	46

Notes:

(a) Position 1.1 Chemistry Factor values were calculated per Reference G-1 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) A reduced σ_Δ term is used since the surveillance data is deemed credible per Appendix D and Reference G-3.

G.2 P-T LIMIT CURVE APPLICABILITY

The current P-T limit curves for CC-2 are based on Intermediate Shell Plate D-8906-1 [Reference G-2]. It must be ensured that the current surveillance capsule results from Capsule 104°, and the updated surveillance capsule results for weld Heat # 33A277, do not invalidate the current P-T limit curves for Calvert Cliffs Unit 2. Table G-3 compares Capsule 104° materials' initial properties to the Intermediate Shell Plate D-8906-1 material properties. Reference G-2 confirms that all CC-2 reactor vessel beltline materials use the same fluence value. It can be determined from the properties in Table G-3 that plate D-8906-1 has more limiting material properties than the Capsule 104° materials and weld Heat # 33A277 at any fluence, as long as the fluence on each material is the same.

Table G-3 Comparison of CC-2 Surveillance Capsule Materials Initial Properties to Intermediate Shell Plate D-8906-1 for P-T Limit Curve Development

Material Property	Reactor Vessel Material			
	Lower Shell Plate D-8907-2(a)	Intermediate Shell to Lower Shell Circ. Weld 9-203(a)	Lower Shell Longitudinal Weld 3-203-A, B, C(a)	Intermediate Shell Plate D-8906-1(b)
Initial RT_{NDT} (°F)	20	-60	-80	10
Margin (°F)	17.0	28.0	28.0	34
Chemistry Factor (°F)	96.2	66.1	100.6	108

Notes:

(a) Values are summarized in Tables G-1 and G-2 of this report.
(b) Values taken from CRVSP, Revision 5 [Reference G-2].

Furthermore, the fluence value used in the current P-T limit curve analysis of record [Reference G-4] is 4.00 x 10^{19} n/cm^2 (E > 1.0 MeV). The applicability term (EFPY) corresponding to 4.00 x 10^{19} n/cm^2 (E > 1.0 MeV), was taken directly from Table 6-2 and is equal to 48 EFPY. Therefore, the current P-T limit curves are valid to 48 EFPY.

P-T Limit Curve Applicability Conclusion

It is concluded that Intermediate Shell Plate D-8906-1 will continue to be more limiting for use in the development of the P-T limit curves. The surveillance Capsule 104° analysis does not invalidate the current P-T limit curves. Additionally, based on the comparison of the fluence value used in the analysis of record for Calvert Cliffs Unit 2 and the peak fluence values from Table 6-2, the P-T limit curves for CC-2 are predicted to remain applicable to 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-17365-NP, Revision 0, *Analysis of Capsule 284° from the Calvert Cliffs Unit No. 1 Reactor Vessel Radiation Surveillance Program*, E. J. Long and J. I. Duo, March 2011.

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.