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Analysis of Capsule V from the Exelon Generation Braidwood Unit 2 Reactor Vessel Radiation Surveillance Program

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Benjamin E. Mays*
Materials Center of Excellence

Peter C. Cronstrand*
Chemistry and Component Engineering – Sweden

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Reviewers: Elliot J. Long*
Materials Center of Excellence

Arzu Alpan*
Nuclear Operations and Radiation Analysis

Approved: David B. Love*, Manager
Materials Center of Excellence

Laurent P. Houssay*, Manager
Nuclear Operations and Radiation Analysis

*Electronically approved records are authenticated in the electronic document management system.

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

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EXECUTIVE SUMMARY

The purpose of this report is to document the testing results of surveillance Capsule V from Braidwood Unit 2. Capsule V was removed at 18.41 effective full-power years (EFPY) and stored in the spent fuel pool. Post-irradiation mechanical tests of the Charpy V-notch and tensile specimens were performed during Cycle 19 to satisfy license renewal commitments. A fluence evaluation utilizing the neutron transport and dosimetry cross-section libraries was derived from the Evaluated Nuclear Data File (ENDF) database (specifically, ENDF/B-VI). Capsule V received a fluence of 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV) after irradiation to 18.41 EFPY. The peak clad/base metal interface vessel fluence after 57 EFPY (end-of-license extension) of plant operation is projected to be 2.95 x 10^{19} n/cm^2 (E > 1.0 MeV).

This evaluation led to the following conclusions: 1) The measured percent decreases in upper-shelf energy for the surveillance forging and weld materials contained in Braidwood Unit 2 Capsule V are less than the Regulatory Guide 1.99, Revision 2 [Ref. 1] predictions. 2) With consideration of surveillance data, all beltline and extended beltline materials exhibit adequate upper-shelf energy levels for continued safe plant operation and are predicted to maintain an upper-shelf energy greater than 50 ft-lb through end-of-license extension (57 EFPY) as required by 10 CFR 50, Appendix G [Ref. 2]. The upper-shelf energy evaluation is presented in Appendix D.

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

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance Capsule V, the fourth capsule removed and tested from the Braidwood 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 6.02, Charpy V-notch plots for Capsule V and previous capsules, along with the program input data.

- Capsule V received an average fast neutron fluence (E > 1.0 MeV) of 3.73 x 10^{19} n/cm^2 after 18.41 effective full-power years (EFPY) of plant operation.

- Irradiation of the reactor vessel Lower Shell Forging [50D102/50C97]-1-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (tangential orientation), resulted in an irradiated 30 ft-lb transition temperature of 7.5°F and an irradiated 50 ft-lb transition temperature of 35.2°F. This results in a 30 ft-lb transition temperature increase of 28.4°F and a 50 ft-lb transition temperature increase of 32.8°F for the tangentially oriented specimens.

- Irradiation of the reactor vessel Lower Shell Forging [50D102/50C97]-1-1 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (axial orientation), resulted in an irradiated 30 ft-lb transition temperature of 39.9°F and an irradiated 50 ft-lb transition temperature of 71.0°F. This results in a 30 ft-lb transition temperature increase of 63.3°F and a 50 ft-lb transition temperature increase of 62.9°F for the axially oriented specimens.

- Irradiation of the Surveillance Program Weld Material (Heat # 442011) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 26.4°F and an irradiated 50 ft-lb transition temperature of 87.6°F. This results in a 30 ft-lb transition temperature increase of 45.6°F and a 50 ft-lb transition temperature increase of 45.4°F.

- Irradiation of the Heat-Affected Zone (HAZ) Material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -113.2°F and an irradiated 50 ft-lb transition temperature of -68.4°F. This results in a 30 ft-lb transition temperature increase of 27.5°F and a 50 ft-lb transition temperature increase of 33.4°F.

- The average upper-shelf energy of Lower Shell Forging [50D102/50C97]-1-1 (tangential orientation) resulted in an average energy decrease of 2 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 166 ft-lb for the tangentially oriented specimens.

- The average upper-shelf energy of Lower Shell Forging [50D102/50C97]-1-1 (axial orientation) resulted in an average energy decrease of 9 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 144 ft-lb for the axially oriented specimens.

- The average upper-shelf energy of the Surveillance Program Weld Material (Heat # 442011) Charpy specimens resulted in an average energy decrease of 5 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 64 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 1 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 154 ft-lb for the HAZ Material.

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

- Based on the upper-shelf energy evaluation in Appendix D, all beltline and extended beltline materials contained in the Braidwood Unit 2 reactor vessel exhibit adequate upper-shelf energy levels for continued safe plant operation and are predicted to maintain an upper-shelf energy greater than 50 ft-lb through end-of-license extension (57 EFPY) as required by 10 CFR 50, Appendix G [Ref. 2].

- The maximum calculated 57 EFPY (end-of-license extension) neutron fluence (E > 1.0 MeV) for the Braidwood Unit 2 reactor vessel beltline using the Regulatory Guide 1.99, Revision 2 [Ref. 1] attenuation formula (i.e., Equation # 3 in the Guide) is as follows:

  Calculated (57 EFPY): Vessel peak clad/base metal interface fluence* = 2.95 x 10^{19} n/cm^2
  Vessel peak quarter-thickness (1/4T) fluence = 1.77 x 10^{19} n/cm^2

  *This fluence value is documented in Table 6-6

2 INTRODUCTION

This report presents the results of the examination of Capsule V, the fourth capsule removed and tested in the continuing surveillance program, which monitors the effects of neutron irradiation on the Exelon Generation (Exelon) Braidwood Unit 2 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Braidwood Unit 2 reactor pressure vessel materials was designed and recommended by Westinghouse Electric Company LLC. A detailed description of the surveillance program and the pre-irradiation mechanical properties of the reactor vessel materials are presented in WCAP-11188 [Ref. 3], "Commonwealth Edison Company Braidwood Station Unit No. 2 Reactor Vessel Radiation Surveillance Program." The surveillance program was originally planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-82 [Ref. 4], "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels." Capsule V was removed from the reactor after 18.41 EFPY of exposure and stored in the spent fuel pool. During Cycle 19, it was shipped to the Westinghouse Materials Center of Excellence Hot Cell Facility, where the post-irradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

This report summarizes the testing and post-irradiation data obtained from surveillance Capsule V removed from the Braidwood 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 SA508 Class 3 (base material of the Braidwood Unit 2 reactor pressure vessel beltline) are well documented in the literature. Generally, low-alloy ferritic materials show an increase in hardness and tensile properties and a decrease in ductility and toughness during high-energy irradiation.

A method for ensuring the integrity of reactor pressure vessels has been presented in "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code [Ref. 5]. 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 E208-06 [Ref. 6]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (axial) to the major working direction of the forging. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ic} curve) which appears in Appendix G to Section XI of the ASME Code [Ref. 5]. 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 Braidwood 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 Braidwood Unit 2 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant startup. The six capsules were positioned in the reactor vessel, as shown in Figure 4-1, between the core barrel and the vessel wall, at various azimuthal locations. The vertical center of the capsules is opposite the vertical center of the core. The capsules contain specimens made from the following:

- Lower Shell Forging [50D102/50C97]-1-1 (tangential orientation)
- Lower Shell Forging [50D102/50C97]-1-1 (axial orientation)
- Weld metal fabricated with weld wire Heat Number 442011, Linde Type 80 flux, which is equivalent to the heat number and Flux Type used in the actual fabrication of the intermediate shell to lower shell circumferential weld seam
- Weld heat-affected zone (HAZ) material of Lower Shell Forging [50D102/50C97]-1-1

Test material obtained from the lower shell forging (after thermal heat treatment and forming of the forging) was taken at least one forging thickness from the quenched edges of the forging. All test specimens were machined from the ¼ thickness location of the forging after performing a simulated post-weld stress-relieving treatment on the test material. Weld test specimens were removed from the weld metal of a stress-relieved weldment joining Lower Shell Forging [50D102/50C97]-1-1 and adjacent Intermediate Shell Forging [49D963/49C904]-1-1. All heat-affected zone specimens were obtained from the weld heat-affected zone of Lower Shell Forging [50D102/50C97]-1-1.

Charpy V-notch impact specimens from Lower Shell Forging [50D102/50C97]-1-1 were machined in the tangential orientation (longitudinal axis of the specimen parallel to the major working direction) and also in the axial orientation (longitudinal axis of the specimen perpendicular to the major working direction). The core-region weld Charpy impact specimens were machined from the weldment such that the long dimension of each Charpy specimen was perpendicular (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 Forging [50D102/50C97]-1-1 were machined both in the tangential and axial orientation. Tensile specimens from the weld metal were oriented perpendicular to the welding direction.

Compact tension test specimens (1/2T) from forging [50D102/50C97]-1-1 were machined in both the tangential and axial orientations. Compact tension test specimens from the weld metal were machined perpendicular to the weld direction with the notch oriented in the direction of the weld. All specimens were fatigue precracked according to ASTM E399-12 [Ref. 7].

All six capsules contain dosimeter wires of pure iron, copper, nickel, and aluminum-0.15 weight percent cobalt (cadmium-shielded and unshielded). In addition, cadmium-shielded dosimeters of Neptunium (^{237}Np) and Uranium (^{238}U) were placed in the capsules to measure the integrated flux at specific neutron energy levels.

The capsules contain thermal monitors made from two low-melting-point eutectic alloys, which were sealed in Pyrex®[1] tubes. These thermal monitors were located in three different positions in the capsule. These thermal monitors are used to define the maximum temperature attained by the test specimens during irradiation. The composition of the two eutectic alloys and their melting points are as follows:

2.5% Ag, 97.5% Pb	Melting Point: 579°F (304°C)
1.5% Ag, 1.0% Sn, 97.5% Pb	Melting Point: 590°F (310°C)

The chemical composition and the heat treatment of the various mechanical specimens in Capsule V are presented in Tables 4-1 and 4-2, respectively. The data in Tables 4-1 and 4-2 was obtained from the original surveillance program report, WCAP-11188 [Ref. 3], Appendix A.

Capsule V was removed after 18.41 EFPY of plant operation. This capsule contained Charpy V-notch specimens, tensile specimens, compact tension specimens, dosimeters, and thermal monitors.

The arrangement of the various mechanical specimens, dosimeters and thermal monitors contained in Capsule V is shown in Figure 4-2.

[1]Pyrex® is a registered trademark of Corning Incorporated.

Table 4-1 Chemical Composition (wt. %) of the Braidwood Unit 2 Reactor Vessel Surveillance Materials (Unirradiated)[(a)]

Element	Lower Shell Forging [50D102/50C97]-1-1		Surveillance Weld Metal	
	Note (b)	Note (c)	Notes (d,e)	Notes (c,e)
C	0.22	0.24	0.066	0.069
Mn	1.30	1.38	1.44	1.45
P	0.006	0.013	0.015	0.011
S	0.004	0.009	0.012	0.013
Si	0.28	0.30	0.48	0.53
Ni	**0.75**	**0.77**	**0.67**	**0.64**
Mo	0.49	0.56	0.44	0.46
Cr	0.08	0.095	0.10	0.082
Cu	**0.06**	**0.057**	**0.04**	**0.040**
Al	0.025	0.024	0.004	0.007
Co	0.011	0.008	0.011	0.004
Pb	0.0003 max	<0.001	0.0006	<0.001
W	0.005 max	<0.01	0.010	<0.01
Ti	0.005 max	0.004	0.007	0.003
Zr	0.005 max	<0.002	0.003	<0.002
V	0.01 max	<0.002	0.005	<0.002
Sn	0.007	0.004	0.005	0.004
As	0.008	0.007	0.004	0.004
Cb	0.005 max	<0.002	0.004	<0.002
N_2	0.0084	0.009	0.013	0.012
B	Not Reported	<0.001	0.0007	<0.001

Notes:

(a) Data obtained from WCAP-11188, Tables A-2 and A-3 [Ref. 3]

(b) Chemical analyses by The Japan Steel Works, LTD.

(c) Westinghouse analyses from the surveillance program test plate and weldment.

(d) Chemical analysis of "Filler Wire Qualification Test" by Babcock & Wilcox.

(e) The surveillance weld was fabricated with the same wire and flux type as that used in the intermediate to lower shell circumferential weld seam WF-562. The reactor vessel weld was fabricated using weld wire heat number 442011, with a Linde 80 flux, Lot Number 8061. The surveillance weld was fabricated using weld wire heat number 442011, with a Linde 80 flux, Lot Number 0344.

Table 4-2 Heat Treatment History of the Braidwood Unit 2 Reactor Vessel Surveillance Materials[(a)]

Material	Temperature (°F)	Time (hours)	Cooling
Lower Shell Forging [50D102/50C97]-1-1	Austenitizing: 1600 ± 25	6.5[(b)]	Water Quenched
	Tempered: 1225 ± 25	12.25[(b)]	Air Cooled
	Stress Relief: 1150 ± 50	11.75[(c)]	Furnace Cooled
Intermediate to Lower Shell Circumferential Weld Seam	Stress Relief: 1150 ± 50	11.75[(c)]	Furnace Cooled
Surveillance Program Test Material			
Surveillance Program Test Forging [50D102/50C97]-1-1	Post-Weld Stress Relief[(c,d)]: 1150 ± 50	14.25	Furnace Cooled
Surveillance Program Test Weldment (Heat # 442011)	Post-Weld Stress Relief[(c,d)]: 1150 ± 50	12.50	Furnace Cooled

Notes:

(a) Data obtained from WCAP-15369, Table 4-1 [Ref. 15].
(b) Data obtained from The Japan Steel Works, LTD. Material Test Reports.
(c) Data from Babcock & Wilcox Certifications.
(d) The stress relief heat treatments received by the surveillance test forging and weldment have been simulated.

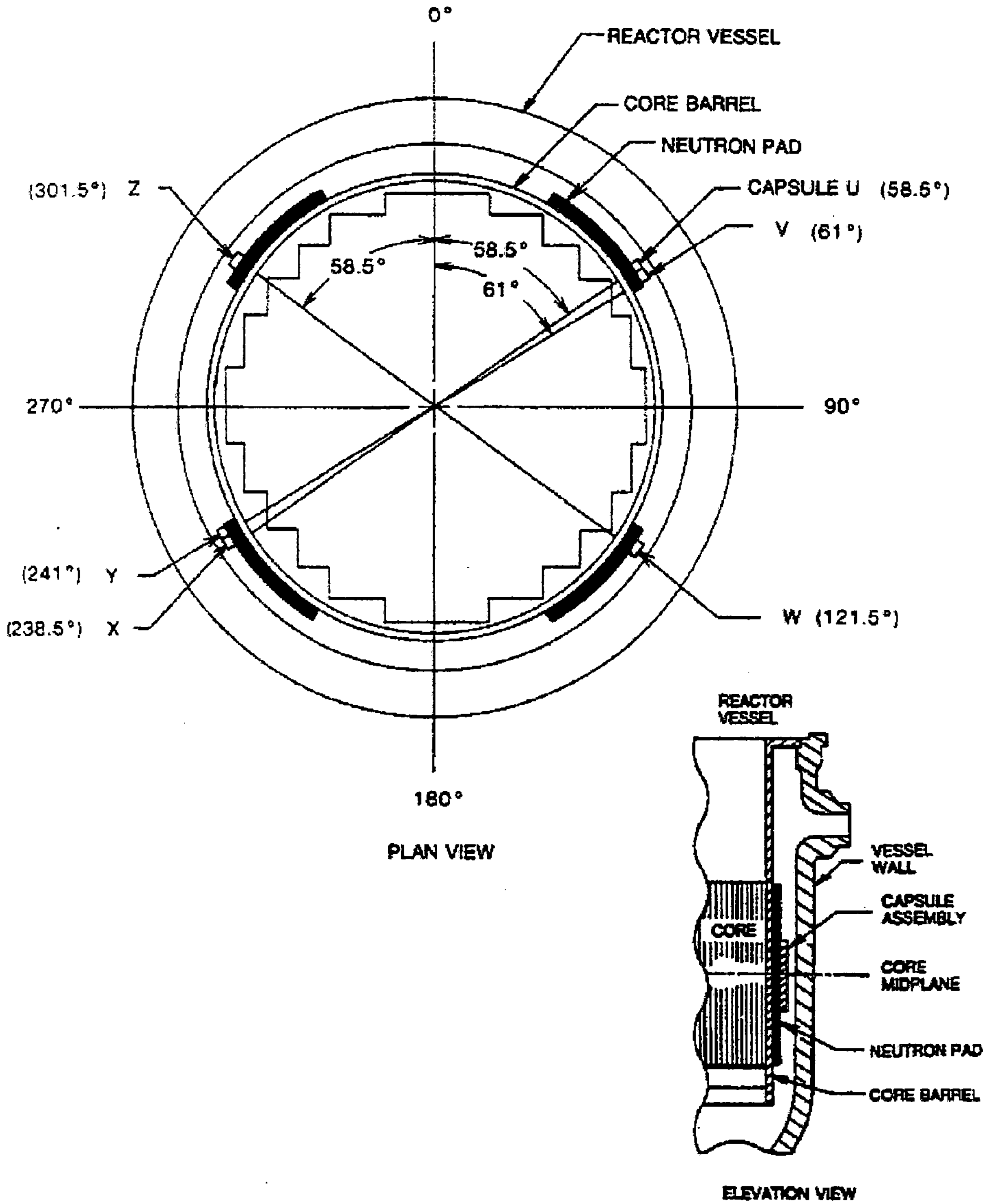

Figure 4-1 Arrangement of Surveillance Capsules in the Braidwood Unit 2 Reactor Vessel

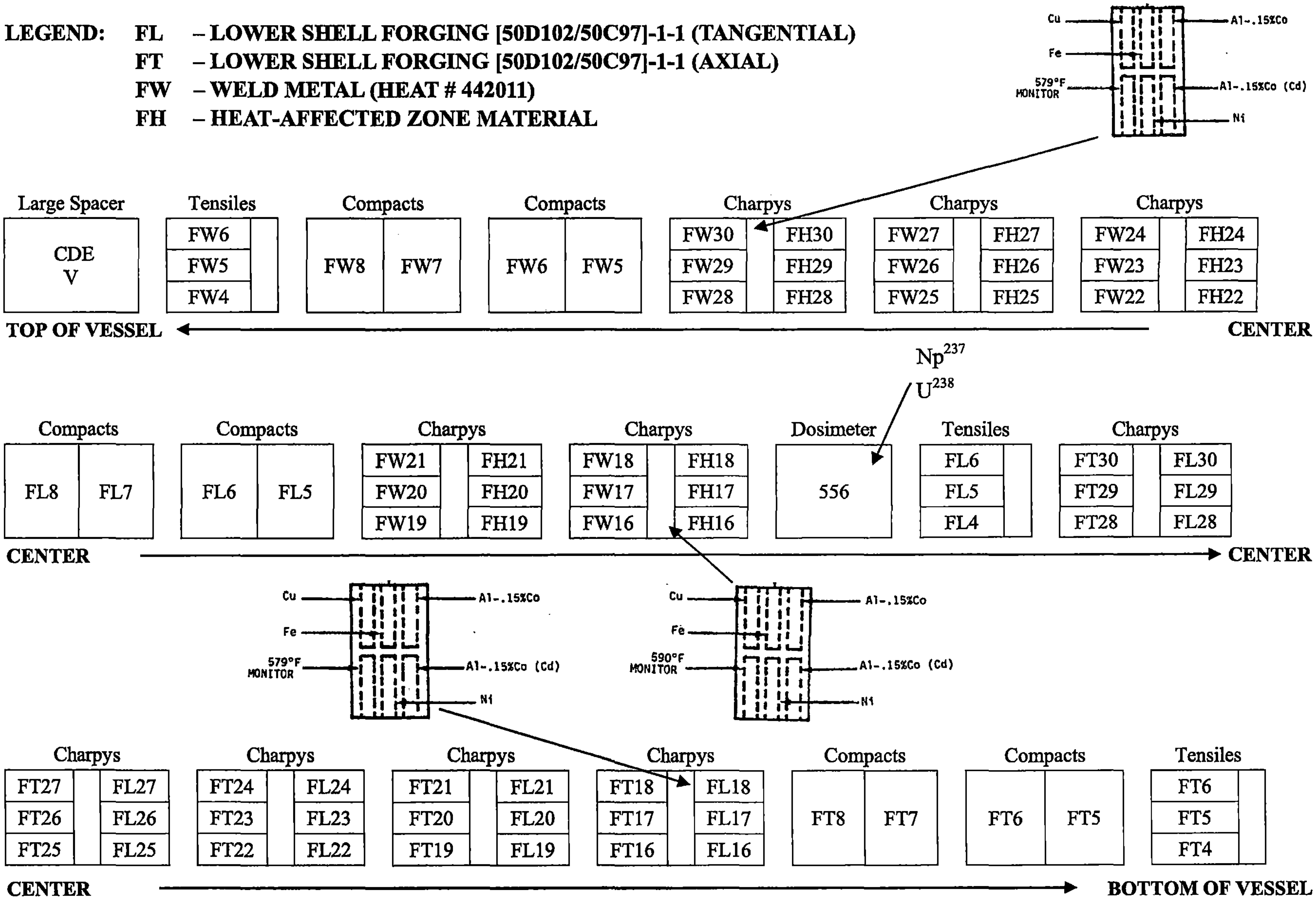

Figure 4-2 Capsule V Diagram Showing the Location of Specimens, Thermal Monitors, and Dosimeters

5 TESTING OF SPECIMENS FROM CAPSULE V

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed at the Westinghouse Materials Center of Excellence Hot Cell Facility. Testing was performed in accordance with 10 CFR 50, Appendix H [Ref. 2] and ASTM Specification E185-82 [Ref. 4].

Capsule V was opened upon receipt at the hot cell laboratory. The specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in WCAP-11188 [Ref. 3]. All of the items were in their proper locations.

Examination of the thermal monitors indicated that none of the three temperature monitors had melted. Based on this examination, the maximum temperature to which the specimens were exposed was less than 579°F (304°C), assuming a uniform temperature throughout the capsule.

The Charpy impact tests were performed per ASTM Specification E185-82 [Ref. 4] and E23-07a [Ref. 8] on a Tinius-Olsen Model 74, 358J machine. The Charpy machine striker was instrumented with an Instron®[1] Impulse system. Instrumented testing and calibration were performed to ASTM E2298-15 [Ref. 9].

The instrumented striker load signal data acquisition rate was 819 kHz with data acquired for 10 ms. From the load-time curve, the load of general yielding (F_{gy}), the maximum load (F_m) and the time to maximum load were determined. Under some test conditions, a sharp drop in load indicative of fast fracture was observed. The load at which fast fracture was initiated is identified as the brittle fracture initiation/load at initiation of unstable crack propagation (F_{bf}). The termination load after the fast load drop is identified as the arrest load/load at end of unstable crack propagation (F_a). F_{gy}, F_m, F_{bf}, and F_a were determined per the guidance in ASTM Standard E2298-15 [Ref. 9].

The pre-maximum load energy (W_m) was determined by integrating the load-time record to the maximum load point via the instrumented Charpy software. The pre-maximum load energy 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 impact energy (W_t) and the pre-maximum load energy (W_m). W_t is compared to the absorbed energy measured from the dial energy (KV).

Percent shear was determined from post-fracture photographs using the ratio-of-areas method in compliance with ASTM E23-07a [Ref. 8] and A370-15 [Ref. 10]. The lateral expansion was measured using a dial gage rig similar to that shown in the same ASTM Standards.

Tensile tests were performed on a 250 kN Instron screw driven tensile machine (Model 5985) per ASTM E185-82 [Ref. 4]. Testing met ASTM Specifications E8/E8M-15a [Ref. 11] for room temperature or E21-09 [Ref. 12] for elevated temperatures.

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[1]Instron is a registered trademark of Instron Corporation.

The tensile specimens were, nominally, 4.230 inches long with a 1.000 inch gage length and 0.250 inch in diameter, per WCAP-11188 [Ref. 3]. Strain measurements were made using an extensometer, which was attached to the 1.000 inch gage section of the tensile specimen. The strain rate obtained met the requirements of ASTM E8/E8M-15a [Ref. 11] and ASTM E21-09 [Ref. 12].

Elevated test temperatures were obtained with a three-zone electric resistance split-tube Instron SF-16 furnace with an 11-inch hot zone. For the elevated tests, temperature was measured by two Type N thermocouples in contact with the gage section of the specimen per ASTM E21-09 [Ref. 12]. Tensile specimens were soaked at temperature (± 5°F) for a minimum of 20 minutes before testing. All tests were conducted in air.

The yield load, ultimate load, fracture load, uniform elongation and elongation at fracture were determined directly from the load-extension curve. The yield strength (0.2% offset method), ultimate tensile strength and fracture strength were calculated using the original cross-sectional area. Yield point elongation (YPE) was calculated as the difference in strain between the upper yield strength and the onset of uniform strain hardening using the methodology described in ASTM E8/E8M-15a [Ref. 11]. The final diameter and final gage length were determined from post-fracture photographs. This final diameter measurement was used to calculate the fracture stress (fracture true stress) and the percent reduction in area. The final and original gage lengths were used to calculate total elongation after fracture.

5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule V, which received a fluence of 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV) in 18.41 EFPY of operation, are presented in Table 5-1 through 5-8 and are compared with the unirradiated and previously withdrawn capsule results as shown in Figures 5-1 through 5-12. The unirradiated and previously withdrawn capsule results were taken from WCAP-11188 [Ref. 3], WCAP-12845 [Ref. 13], WCAP-14228 [Ref. 14], and WCAP-15369 [Ref. 15]. The previous capsules, along with the original program unirradiated material input data, were updated using CVGRAPH, Version 6.02.

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

- Irradiation of the reactor vessel Lower Shell Forging [50D102/50C97]-1-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (tangential orientation), resulted in an irradiated 30 ft-lb transition temperature of 7.5°F and an irradiated 50 ft-lb transition temperature of 35.2°F. This results in a 30 ft-lb transition temperature increase of 28.4°F and a 50 ft-lb transition temperature increase of 32.8°F for the tangentially oriented specimens.

- Irradiation of the reactor vessel Lower Shell Forging [50D102/50C97]-1-1 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (axial orientation), resulted in an irradiated 30 ft-lb transition temperature of 39.9°F and an irradiated 50 ft-lb transition temperature of 71.0°F. This results in a 30 ft-lb transition temperature increase of 63.3°F and a 50 ft-lb transition temperature increase of 62.9°F for the axially oriented specimens.

- Irradiation of the Surveillance Program Weld Material (Heat # 442011) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 26.4°F and an irradiated 50 ft-lb transition temperature of 87.6°F. This results in a 30 ft-lb transition temperature increase of 45.6°F and a 50 ft-lb transition temperature increase of 45.4°F.

- Irradiation of the HAZ Material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -113.2°F and an irradiated 50 ft-lb transition temperature of -68.4°F. This decrease results in a 30 ft-lb transition temperature increase of 27.5°F and a 50 ft-lb transition temperature increase of 33.4°F.

- The average upper-shelf energy of Lower Shell Forging [50D102/50C97]-1-1 (tangential orientation) resulted in an average energy decrease of 2 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 166 ft-lb for the tangentially oriented specimens.

- The average upper-shelf energy of Lower Shell Forging [50D102/50C97]-1-1 (axial orientation) resulted in an average energy decrease of 9 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 144 ft-lb for the axially oriented specimens.

- The average upper-shelf energy of the Surveillance Program Weld Material (Heat # 442011) Charpy specimens resulted in an average energy decrease of 5 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 64 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 1 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 154 ft-lb for the HAZ Material.

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

The fracture appearance of each irradiated Charpy specimen from the various materials is shown in Figures 5-13 through 5-16. The fractures show an increasingly ductile or tougher appearance with increasing test temperature. Load-time records for the individual instrumented Charpy specimens are contained in Appendix B.

With consideration of the surveillance data, all beltline and extended beltline materials exhibit adequate upper-shelf energy levels for continued safe plant operation and are predicted to maintain an upper-shelf energy greater than 50 ft-lb through end-of-license extension (57 EFPY) as required by 10 CFR 50, Appendix G [Ref. 2]. This evaluation is contained in Appendix D.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in Capsule V irradiated to 3.73 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 5-17 through 5-19.

The results of the tensile tests performed on the Lower Shell Forging [50D102/50C97]-1-1 (tangential orientation) indicated that irradiation to 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV) caused increases in the 0.2 percent offset yield strength and the ultimate tensile strength when compared to unirradiated data [Ref. 3]. See Figure 5-17 and Table 5-11.

The results of the tensile tests performed on the Lower Shell Forging [50D102/50C97]-1-1 (axial orientation) indicated that irradiation to 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV) caused increases in the 0.2 percent offset yield strength and the ultimate tensile strength when compared to unirradiated data [Ref. 3]. See Figure 5-18 and Table 5-11.

The results of the tensile tests performed on the Surveillance Program Weld Material (Heat # 442011) indicated that irradiation to 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV) caused increases in the 0.2 percent offset yield strength and the ultimate tensile strength when compared to unirradiated data [Ref. 3]. See Figure 5-19 and Table 5-11.

The fractured tensile specimens for the Lower Shell Forging [50D102/50C97]-1-1 (tangential orientation) material are shown in Figure 5-20, the fractured tensile specimens for the Lower Shell Forging [50D102/50C97]-1-1 (axial orientation) are shown in Figure 5-21, and the fracture tensile specimens for the Surveillance Program Weld Material (Heat # 442011) are shown in Figure 5-22. The engineering stress-strain curves for the tensile tests are shown in Figures 5-23 through 5-28.

5.4 1/2T COMPACT TENSION SPECIMEN TESTS

Per the surveillance capsule testing contract, the 1/2T Compact Tension Specimens were not tested and are being stored at the Westinghouse Materials Center of Excellence Hot Cell Facility.

Table 5-1 Charpy V-notch Data for the Braidwood Unit 2 Lower Shell Forging Irradiated to a Fluence of 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV) (Tangential Orientation)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	°F	°C	ft-lbs	Joules	mils	mm	%
FL23	-10	-23	12.5	17	9	0.2	5
FL26	0	-18	32	43	25.5	0.6	10
FL24	10	-12	8	11	7	0.2	15
FL22	15	-9	18.5	25	16	0.4	15
FL20	15	-9	54	73	39	1.0	20
FL16	20	-7	19.5	26	18	0.5	15
FL25	25	-4	55	75	39	1.0	30
FL29	30	-1	51	69	39	1.0	20
FL27	50	10	77	104	53	1.3	40
FL30	72	22	94	127	65	1.7	45
FL17	125	52	122	165	81	2.1	75
FL28	175	79	140	190	88	2.2	90
FL19	200	93	162	220	84	2.1	100
FL18	210	99	165	224	83	2.1	100
FL21	220	104	170	230	89	2.3	100

Table 5-2 Charpy V-notch Data for the Braidwood Unit 2 Lower Shell Forging Irradiated to a Fluence of 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV) (Axial Orientation)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	°F	°C	ft-lbs	Joules	mils	mm	%
FT24	-10	-23	18	24	12	0.3	5
FT22	10	-12	12	16	10	0.3	10
FT18	15	-9	30	41	23	0.6	15
FT21	25	-4	32	43	24	0.6	15
FT23	30	-1	9	12	8	0.2	15
FT20	35	2	42	57	32	0.8	25
FT29	45	7	14.5	20	14	0.4	15
FT27	50	10	57	77	39	1.0	30
FT28	60	16	36	49	29	0.7	25
FT26	72	22	42	57	33	0.8	30
FT16	125	52	96	130	68	1.7	60
FT19	175	79	107	145	77	2.0	80
FT30	200	93	144	195	87	2.2	100
FT17	210	99	139	188	92	2.3	100
FT25	220	104	150	203	81	2.1	100

Table 5-3 Charpy V-notch Data for the Braidwood Unit 2 Surveillance Program Weld Material (Heat # 442011) Irradiated to a Fluence of 3.73 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	%
FW24	-50	-46	4	5	3	0.1	10
FW21	-30	-34	11	15	9.5	0.2	15
FW28	-10	-23	24	33	21	0.5	25
FW18	0	-18	27	37	25	0.6	30
FW19	10	-12	25	34	24	0.6	35
FW25	25	-4	31	42	26	0.7	35
FW29	30	-1	25	34	22	0.6	40
FW17	40	4	31	42	29	0.7	50
FW16	50	10	36	49	33	0.8	55
FW27	60	16	44	60	40	1.0	55
FW26	72	22	50	68	43	1.1	65
FW20	125	52	55	75	48	1.2	85
FW23	175	79	59	80	54	1.4	95
FW30	200	93	70	95	59	1.5	100
FW22	220	104	62	84	54	1.4	100

Table 5-4 Charpy V-notch Data for the Braidwood Unit 2 Heat-Affected Zone (HAZ) Material Irradiated to a Fluence of 3.73 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	%
FH29	-200	-129	4.5	6	2.5	0.1	5
FH23	-150	-101	41	56	20	0.5	10
FH22	-125	-87	16.5	22	10	0.3	5
FH30	-100	-73	31	42	19	0.5	15
FH27	-80	-62	34	46	21	0.5	15
FH18	-60	-51	48	65	29	0.7	20
FH20	-50	-46	93	126	51	1.3	40
FH25	-10	-23	62	84	34	0.9	45
FH21	30	-1	107	145	64	1.6	60
FH19	72	22	122	165	68	1.7	70
FH16	125	52	180	244	80	2.0	100
FH24	150	66	144	195	81	2.1	100
FH26	175	79	122	165	70	1.8	90
FH28	200	93	115	156	73	1.9	100
FH17	210	99	178	241	78	2.0	100

Table 5-5 Instrumented Charpy Impact Test Results for the Braidwood Unit 2 Lower Shell Forging [50D102/50C97]-1-1 Irradiated to a Fluence of 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV) (Tangential Orientation)

Sample Number	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, (KV-W_t)/KV (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
FL23	-10	12.5	11.49	8.08	9.08	3900	0.21	3100	3500	0
FL26	0	32	29.64	7.38	27.87	4300	0.48	3200	4200	0
FL24	10	8	5.62[a]	29.75[a]	3.27[a]	3700[a]	0.09[a]	3100[a]	3400[a]	0[a]
FL22	15	18.5	15.49[a]	16.27[a]	2.60[a]	3900[a]	0.09[a]	3000[a]	3700[a]	0[a]
FL20	15	54	50.90	5.74	34.76	4300	0.60	3100	4200	0
FL16	20	19.5	15.44[a]	20.82[a]	3.58[a]	4300[a]	0.12[a]	3000[a]	3800[a]	0[a]
FL25	25	55	49.58	9.85	35.74	4400	0.60	3200	4300	700
FL29	30	51	47.55	6.76	33.48	4100	0.60	3000	4000	0
FL27	50	77	65.75	14.61	33.51	4200	0.60	2900	4000	1200
FL30	72	94	83.15	11.54	34.63	4300	0.60	3100	3600	1800
FL17	125	122	111.39	8.70	32.25	4100	0.60	2800	2300	900
FL28	175	140	128.82	7.99	31.76	4000	0.60	2700	2300	1500
FL19	200	162	148.94	8.06	41.79	4100	0.80	2400	0	0
FL18	210	165	151.50	8.18	54.48	4000	0.99	2600	0	0
FL21	220	170	155.22	8.69	50.74	3900	0.95	2500	0	0

Note:

(a) The difference between instrumented Charpy and dial values was greater than 15% for specimens FL16 and FL22 and greater than 25% for specimen FL24. The values were neither adjusted nor discarded as required by Reference 9 since this data is not required and is presented for informational purposes only.

Table 5-6 Instrumented Charpy Impact Test Results for the Braidwood Unit 2 Lower Shell Forging [50D102/50C97]-1-1 Irradiated to a Fluence of 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV) (Axial Orientation)

Sample Number	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, $(KV-W_t)/KV$ (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
FT24	-10	18	16.97	5.72	3.78	4300	0.12	3200	3800	0
FT22	10	12	10.63	11.42	3.37	3800	0.09	3100	3500	0
FT18	15	30	27.05	9.83	26.22	4000	0.47	3100	4000	0
FT21	25	32	29.83	6.78	28.11	4100	0.51	3100	3900	0
FT23	30	9	6.47[a]	28.11[a]	3.30[a]	3700[a]	0.09[a]	3100[a]	3300[a]	0[a]
FT20	35	42	34.65[a]	17.50[a]	28.23[a]	4100[a]	0.50[a]	3000[a]	4100[a]	0[a]
FT29	45	14.5	9.16[a]	36.83[a]	3.33[a]	3600[a]	0.09[a]	3100[a]	3600[a]	0[a]
FT27	50	57	50.07	12.16	45.22	4400	0.80	3000	4000	0
FT28	60	36	28.66[a]	20.39[a]	27.67[a]	4000[a]	0.50[a]	3000[a]	4000[a]	0[a]
FT26	72	42	33.64[a]	19.90[a]	27.74[a]	4100[a]	0.50[a]	3000[a]	3900[a]	0[a]
FT16	125	96	84.36	12.13	32.98	4100	0.60	2800	3400	1900
FT19	175	107	99.06	7.42	32.16	4000	0.60	2600	2900	1800
FT30	200	144	131.86	8.43	31.30	3900	0.60	2500	0	0
FT17	210	139	127.09	8.57	31.43	3900	0.61	2600	0	0
FT25	220	150	136.04	9.31	51.90	3900	0.95	2600	0	0

Note:

(a) The difference between instrumented Charpy and dial values was greater than 15% for specimens FT20, FT26 and FT28 and greater than 25% for specimens FT23 and FT29. The values were neither adjusted nor discarded as required by Reference 9 since this data is not required and is presented for informational purposes only.

Table 5-7 Instrumented Charpy Impact Test Results for the Braidwood Unit 2 Surveillance Program Weld Material (Heat # 442011) Irradiated to a Fluence of 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample Number	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, $(KV-W_t)/KV$ (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
FW24	-50	4	3.78	5.50	2.97	3700	0.09	3200	3700	0
FW21	-30	11	9.51	13.55	4.12	3900	0.12	3300	3500	0
FW28	-10	24	22.26	7.25	14.65	3800	0.29	3100	3700	0
FW18	0	27	23.77	11.96	22.71	3800	0.44	3000	3800	0
FW19	10	25	20.63[(a)]	17.48[(a)]	17.97[(a)]	3700[(a)]	0.36[(a)]	3000[(a)]	3600[(a)]	300[(a)]
FW25	25	31	26.05[(a)]	15.97[(a)]	18.05[(a)]	3700[(a)]	0.36[(a)]	3000[(a)]	3700[(a)]	700[(a)]
FW29	30	25	20.62[(a)]	17.52[(a)]	17.80[(a)]	3700[(a)]	0.36[(a)]	3000[(a)]	3500[(a)]	600[(a)]
FW17	40	31	26.71	13.84	17.85	3600	0.36	3100	3600	1100
FW16	50	36	32.02	11.06	17.59	3600	0.36	2800	3600	1500
FW27	60	44	40.35	8.30	24.67	3700	0.48	2900	3500	1400
FW26	72	50	45.46	9.08	14.32	3800	0.29	2900	3200	2100
FW20	125	55	49.78	9.49	24.25	3600	0.48	2700	3200	2300
FW23	175	59	55.10	6.61	23.37	3500	0.48	2600	1900	1500
FW30	200	70	63.70	9.00	30.46	3600	0.60	2500	0	0
FW22	220	62	56.90	8.23	13.19	3500	0.29	2600	0	0

Note:

(a) The difference between instrumented Charpy and dial values was greater than 15% for specimens FW19, FW25 and FW29. The values were not adjusted as required by Reference 9 since this data is not required and is presented for informational purposes only.

Table 5-8 Instrumented Charpy Impact Test Results for the Braidwood Unit 2 Heat-Affected Zone (HAZ) Material Irradiated to a Fluence of 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample Number	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, (KV-W_t)/KV (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
FH29	-200	4.5	5.14	-14.22%	3.80	4900	0.09	3500	4900	0
FH23	-150	41	38.10	7.07%	32.39	4600	0.50	3900	4400	0
FH22	-125	16.5	16.63	-0.79%	3.88	4600	0.09	4000	4300	0
FH30	-100	31	29.25	5.65%	26.03	4400	0.43	3400	4300	0
FH27	-80	34	31.16	8.35%	30.37	4400	0.51	3400	4300	0
FH18	-60	48	44.57	7.15%	36.42	4400	0.60	3300	4200	0
FH20	-50	93	85.83	7.71%	36.26	4400	0.61	3300	3900	0
FH25	-10	62	55.85	9.92%	45.96	4300	0.76	3200	4200	1500
FH21	30	107	95.13	11.09%	57.61	4200	0.99	3100	3200	1400
FH19	72	122	111.66	8.48%	4.27	4300	0.11	2800	3100	1100
FH16	125	180	165.49	8.06%	44.31	4300	0.80	2700	0	0
FH24	150	144	132.29	8.13%	55.12	4100	0.98	2600	0	0
FH26	175	122	111.19	8.86%	55.01	4100	0.99	2700	2600	1100
FH28	200	115	102.69	10.70%	52.40	4000	0.95	2700	0	0
FH17	210	178	164.70	7.47%	52.34	4000	0.95	2600	0	0

Table 5-9 Effect of Irradiation to 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV) on the Charpy V-Notch Toughness Properties of the Braidwood Unit 2 Reactor Vessel Surveillance Capsule V 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 ≥ 95% Shear[(b)] (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Lower Shell Forging [50D102/50C97]-1-1 (Tangential)	-20.9	7.5	28.4	0.4	29.4	29.0	2.5	35.2	32.8	168	166	-2
Lower Shell Forging [50D102/50C97]-1-1 (Axial)	-23.4	39.9	63.3	3.4	66.0	62.6	8.1	71.0	62.9	153	144	-9
Surveillance Weld Material (Heat # 442011)	-19.2	26.4	45.6	7.5	52.2	44.7	42.2	87.6	45.4	69	64	-5
Heat-Affected Zone (HAZ) Material	-140.7	-113.2	27.5	-80.0	-49.9	30.1	-101.8	-68.4	33.4	155	154	-1

Notes:

(a) Average value is determined by CVGRAPH, Version 6.02 (see Appendix C).

(b) Upper-shelf Energy (USE) values are a calculated average from unirradiated and Capsule V Charpy test results for specimens that achieved greater than or equal to 95% shear.

Table 5-10 Comparison of the Braidwood 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	Capsule Fluence (x 10^{19} n/cm^2, E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		Upper-Shelf Energy Decrease	
			Predicted[(a)] (°F)	Measured[(b)] (°F)	Predicted[(a)] (%)	Measured[(b)] (%)
Lower Shell Forging [50D102/50C97]-1-1 (Tangential)	U	0.387	27.3	0.0[(c)]	15	0[(d)]
	X	1.15	38.4	0.0[(c)]	20	1
	W	2.07	44.3	4.6	23	1
	V	3.73	49.6	28.4	26	1
Lower Shell Forging [50D102/50C97]-1-1 (Axial)	U	0.387	27.3	0.0[(c)]	15	10
	X	1.15	38.4	33.8	20	5
	W	2.07	44.3	33.1	23	4
	V	3.73	49.6	63.3	26	6
Surveillance Weld Material (Heat # 442011)	U	0.387	30.2	0.0[(c)]	15	10
	X	1.15	42.6	26.1	20	1
	W	2.07	49.1	23.7	23	1
	V	3.73	55.0	45.6	26	7
Heat-Affected Zone Material	U	0.387	---	0.0[(c)]	---	0[(d)]
	X	1.15	---	0.0[(c)]	---	19
	W	2.07	---	3.7	---	0[(d)]
	V	3.73	---	27.5	---	1

Notes:

(a) Based on Regulatory Guide 1.99, Revision 2 [Ref. 1], methodology using the capsule fluence and mean weight percent values of copper and nickel of the surveillance material.

(b) Calculated by CVGRAPH, Version 6.02 using measured Charpy data (See Appendix C).

(c) A negative ΔRT_{NDT} value was calculated. Physically, this should not occur; therefore, a conservative value of zero is shown in this table.

(d) An increase in USE values was calculated. Physically, this should not occur; therefore, conservative values of 0% are shown in this table.

Table 5-11 Tensile Properties of the Braidwood Unit 2 Capsule V Reactor Vessel Surveillance Materials Irradiated to 3.73×10^{19} n/cm^2 (E > 1.0 MeV)

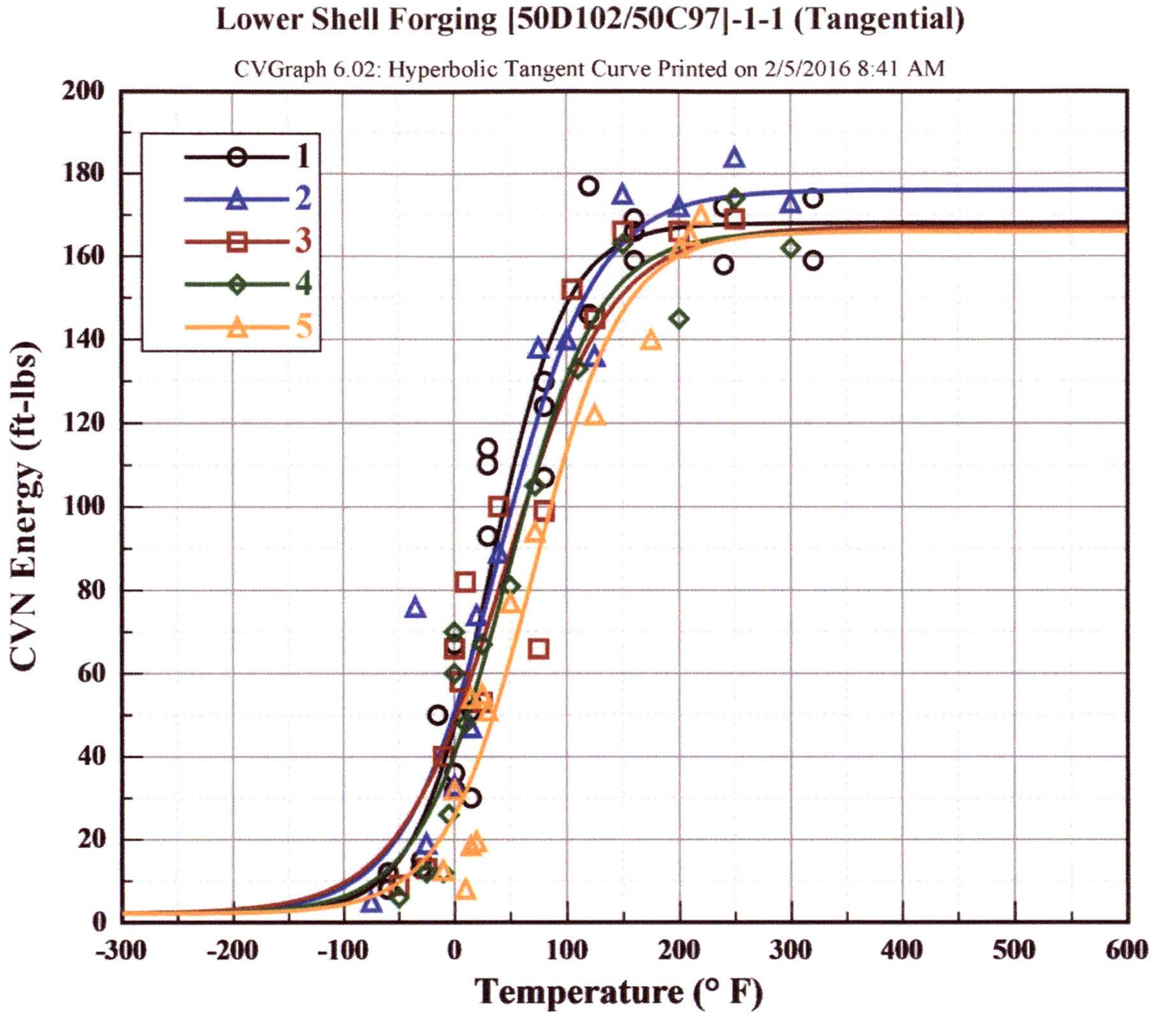
Material	Sample Number	Test Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Strength (ksi)	Fracture True Stress (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
Lower Shell Forging [50D102/50C97]-1-1 (Tangential)	FL4	76	78.4	99.1	2.94	59.9	191	10.6	25.5	68.6
	FL5	150	75.5	95.4	2.77	57.4	194	9.2	22.9	70.4
	FL6	550	70.5	94.8	3.06	63.2	160	8.5	21.6	60.4
Lower Shell Forging [50D102/50C97]-1-1 (Axial)	FT4	76	77.8	98.0	3.19	65.0	185	10.3	24.1	65.0
	FT5	150	74.9	94.7	2.94	60.0	188	10.1	23.5	68.2
	FT6	550	69.5	93.0	3.12	64.6	161	9.2	20.2	59.9
Surveillance Weld Material (Heat # 442011)	FW4	78	81.5	96.3	3.31	68.5	178	8.5	20.5	61.4
	FW5	150	77.3	90.1	3.18	64.3	166	8.1	19.5	61.4
	FW6	550	74.4	88.8	3.31	67.5	161	5.3	16.6	58.0

Lower Shell Forging [50D102/50C97]-1-1 (Tangential)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 2/5/2016 8:41 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	SA508CL3	Tangential	[50D102/50C97]-1-1
2	Braidwood 2	U	SA508CL3	Tangential	[50D102/50C97]-1-1
3	Braidwood 2	X	SA508CL3	Tangential	[50D102/50C97]-1-1
4	Braidwood 2	W	SA508CL3	Tangential	[50D102/50C97]-1-1
5	Braidwood 2	V	SA508CL3	Tangential	[50D102/50C97]-1-1

Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Tangential Orientation)



Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	---	2.2	168	0	-20.9	0	2.5	0
2	---	2.2	176	8	-30.5	-9.6	-0.8	-3.3
3	---	2.2	167	-1	-30.5	-9.6	2.6	0.1
4	---	2.2	166	-2	-16.3	4.6	12	9.5
5	---	2.2	166	-2	7.5	28.4	35.3	32.8

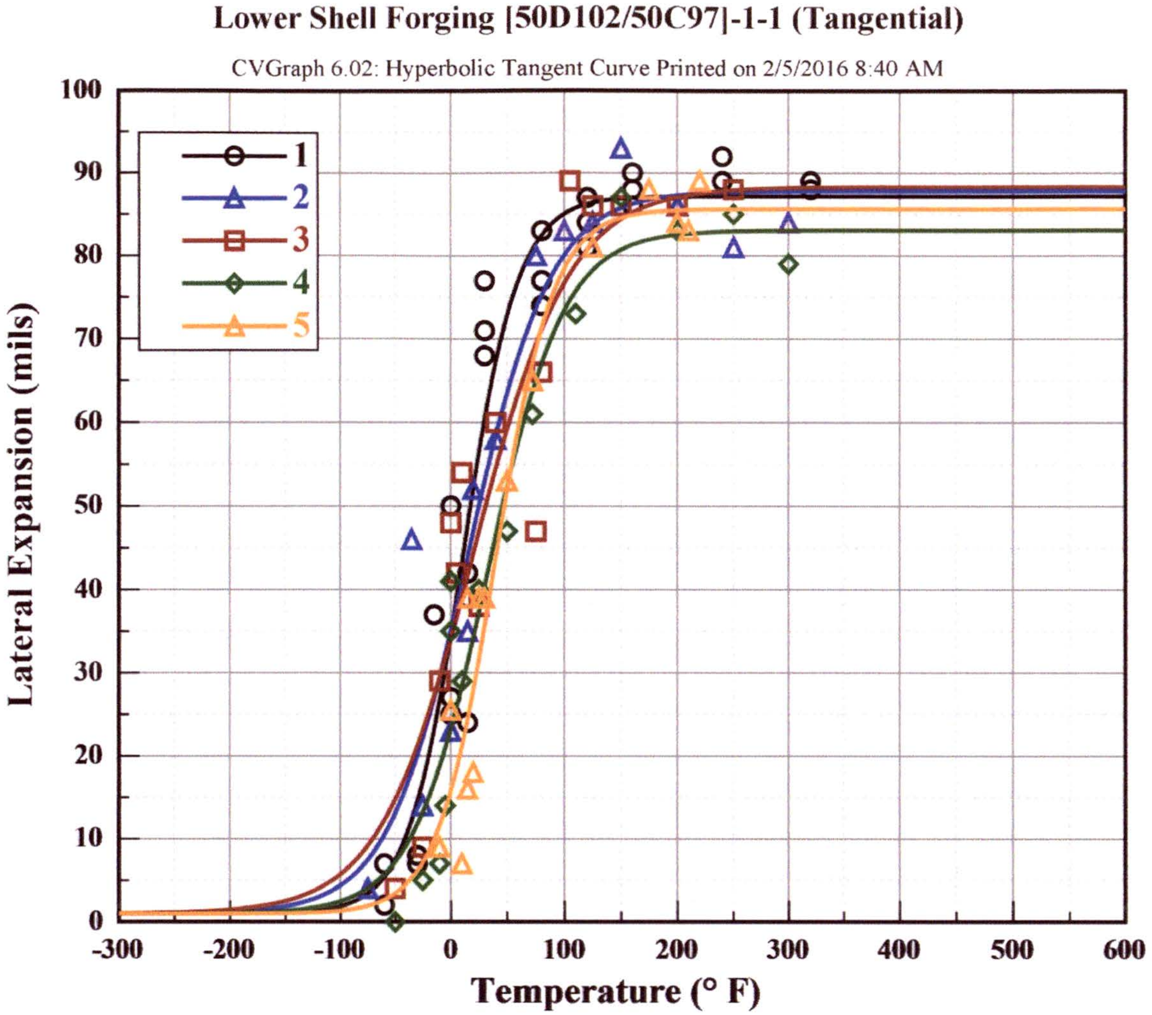
Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Tangential Orientation) – Continued

Lower Shell Forging [50D102/50C97]-1-1 (Tangential)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 2/5/2016 8:40 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	SA508CL3	Tangential	[50D102/50C97]-1-1
2	Braidwood 2	U	SA508CL3	Tangential	[50D102/50C97]-1-1
3	Braidwood 2	X	SA508CL3	Tangential	[50D102/50C97]-1-1
4	Braidwood 2	W	SA508CL3	Tangential	[50D102/50C97]-1-1
5	Braidwood 2	V	SA508CL3	Tangential	[50D102/50C97]-1-1

Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Tangential Orientation)



Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	- - -	1	87.18	0	0.4	0
2	- - -	1	87.82	0.64	0	-0.4
3	- - -	1	88.28	1.10	1.7	1.3
4	- - -	1	83.06	-4.12	21.4	21
5	- - -	1	85.62	-1.56	29.4	29

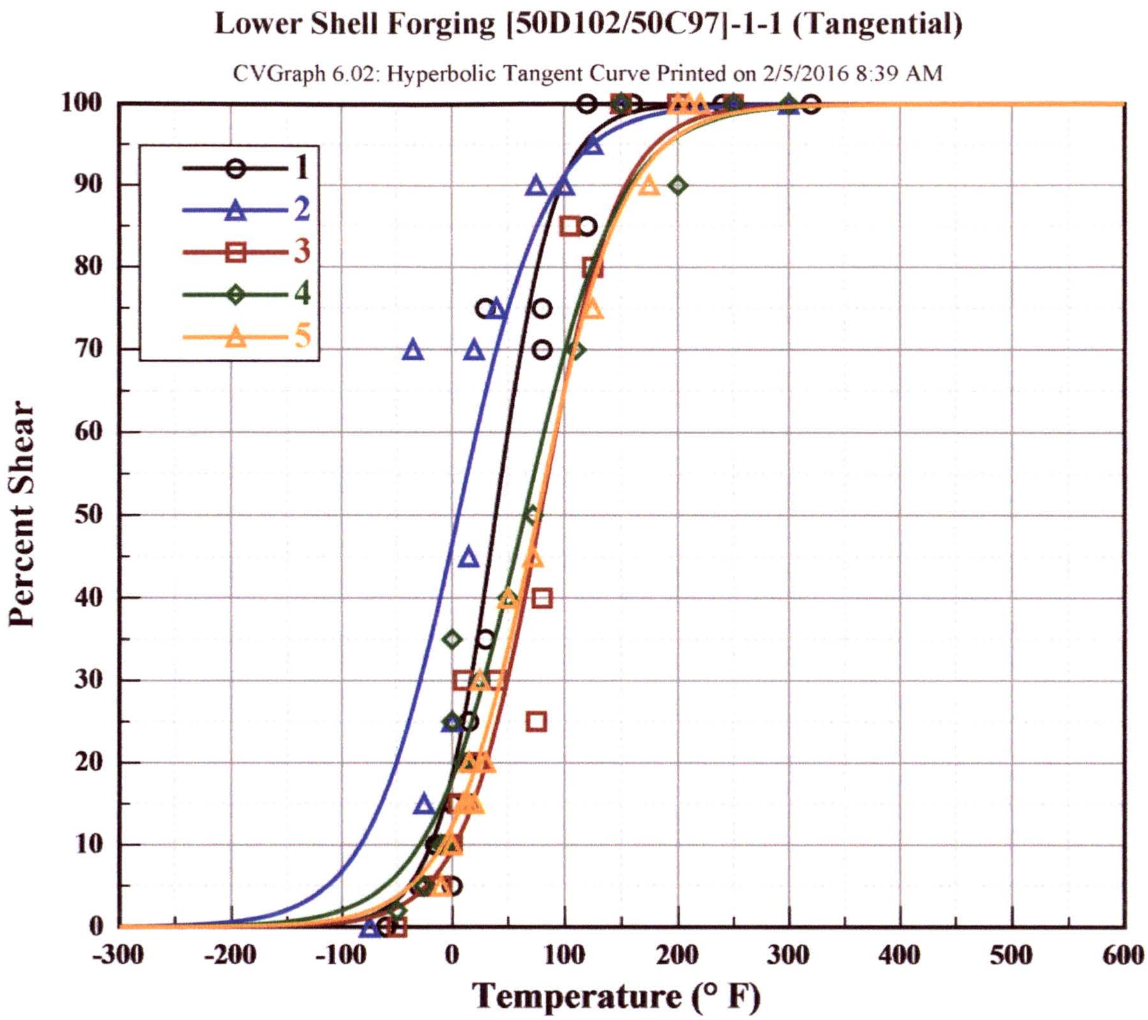
Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Tangential Orientation) – Continued

Lower Shell Forging [50D102/50C97]-1-1 (Tangential)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 2/5/2016 8:39 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	SA508CL3	Tangential	[50D102/50C97]-1-1
2	Braidwood 2	U	SA508CL3	Tangential	[50D102/50C97]-1-1
3	Braidwood 2	X	SA508CL3	Tangential	[50D102/50C97]-1-1
4	Braidwood 2	W	SA508CL3	Tangential	[50D102/50C97]-1-1
5	Braidwood 2	V	SA508CL3	Tangential	[50D102/50C97]-1-1

Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Tangential Orientation)



Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	- - -	0	100	0	39.1	0
2	- - -	0	100	0	5.8	-33.3
3	- - -	0	100	0	78.5	39.4
4	- - -	0	100	0	64.6	25.5
5	- - -	0	100	0	76	36.9

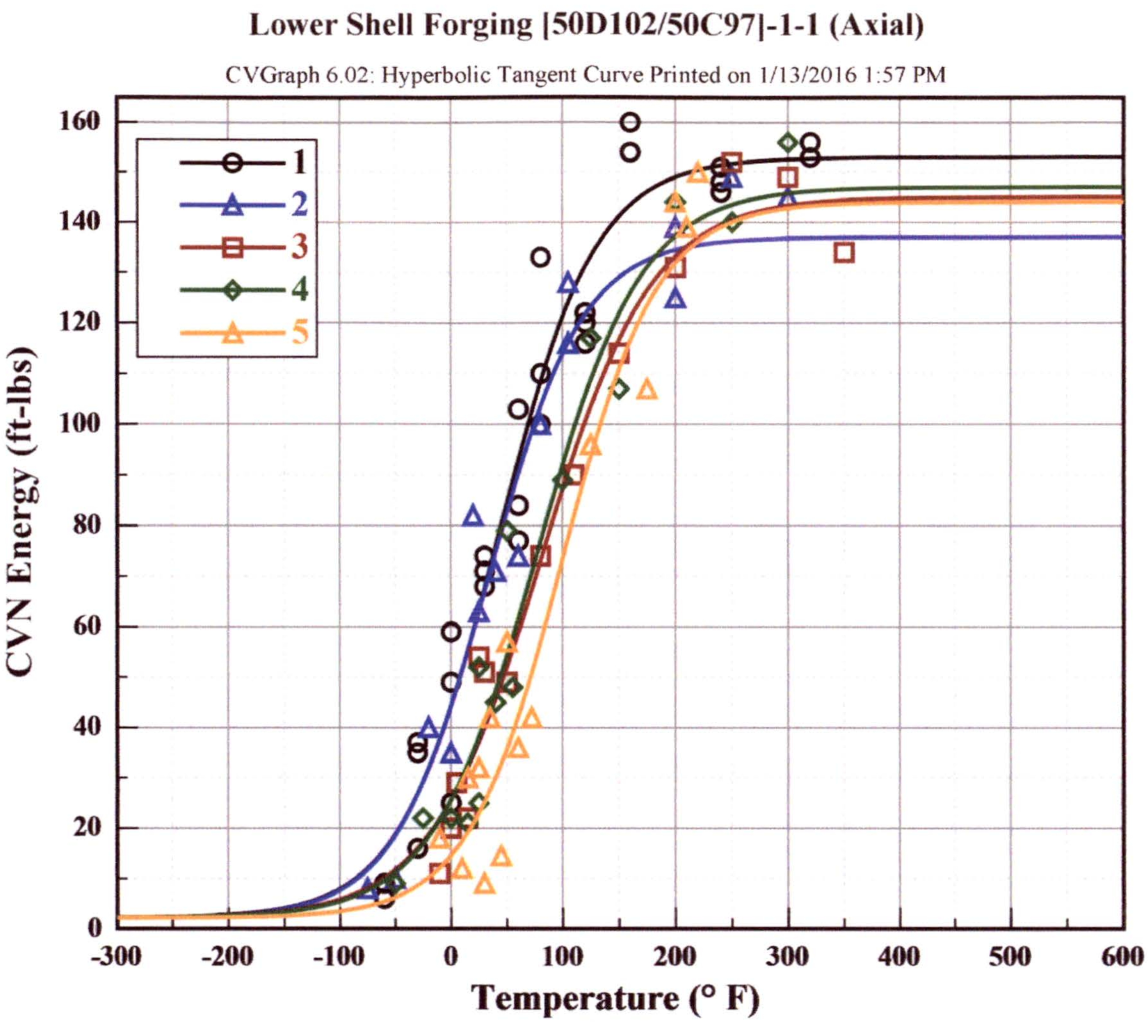
Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Tangential Orientation) – Continued

Lower Shell Forging [50D102/50C97]-1-1 (Axial)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:57 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	SA508CL3	Axial	[50D102/50C97]-1-1
2	Braidwood 2	U	SA508CL3	Axial	[50D102/50C97]-1-1
3	Braidwood 2	X	SA508CL3	Axial	[50D102/50C97]-1-1
4	Braidwood 2	W	SA508CL3	Axial	[50D102/50C97]-1-1
5	Braidwood 2	V	SA508CL3	Axial	[50D102/50C97]-1-1

Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Axial Orientation)



Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	---	2.2	153	0	-23.4	0	8.1	0
2	---	2.2	137	-16	-23.5	-0.10	8.1	0
3	---	2.2	145	-8	10.4	33.8	46.7	38.6
4	---	2.2	147	-6	9.7	33.1	43.8	35.7
5	---	2.2	144	-9	39.9	63.3	71	62.9

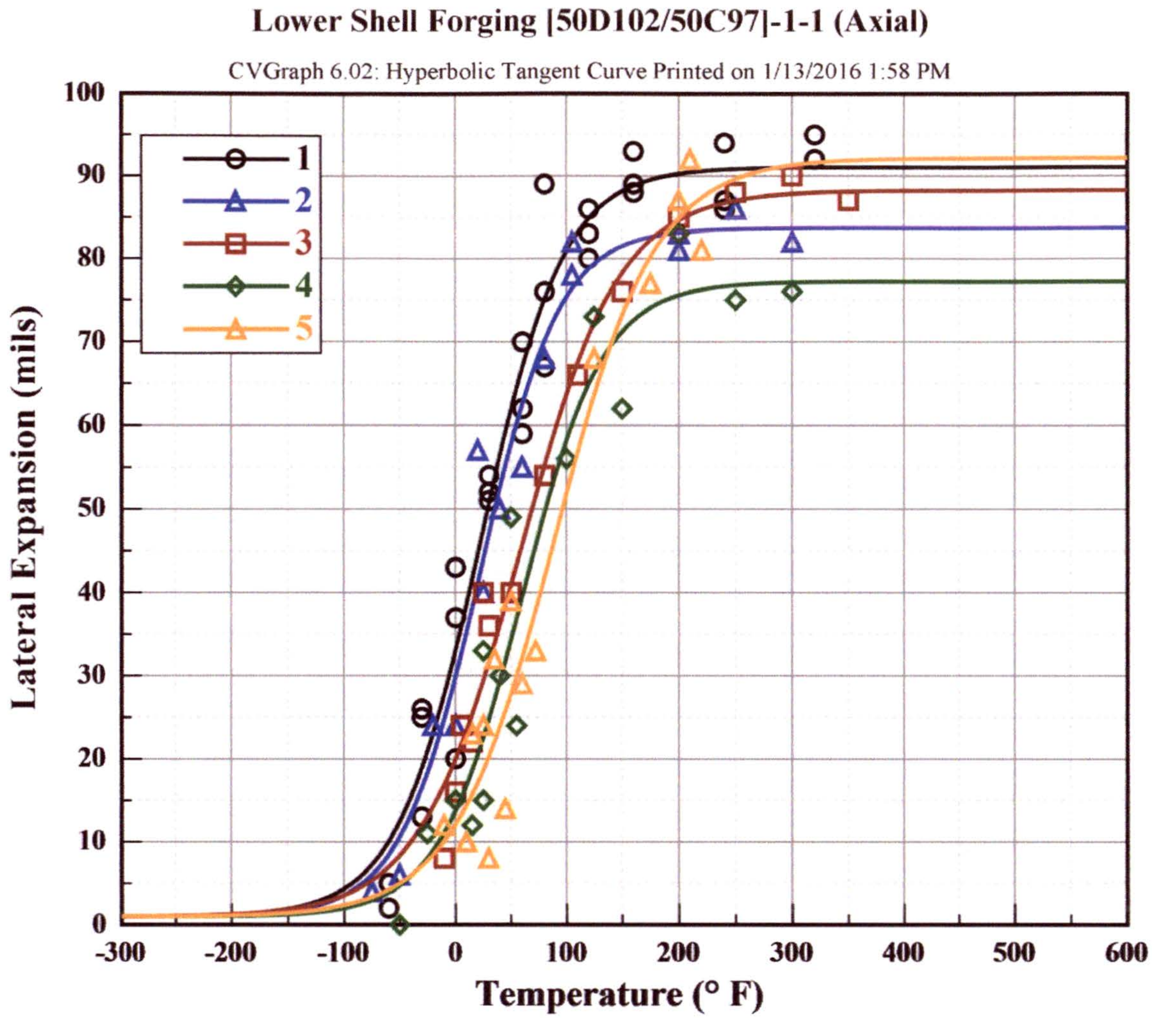
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Axial Orientation) – Continued

Lower Shell Forging [50D102/50C97]-1-1 (Axial)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:58 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	SA508CL3	Axial	[50D102/50C97]-1-1
2	Braidwood 2	U	SA508CL3	Axial	[50D102/50C97]-1-1
3	Braidwood 2	X	SA508CL3	Axial	[50D102/50C97]-1-1
4	Braidwood 2	W	SA508CL3	Axial	[50D102/50C97]-1-1
5	Braidwood 2	V	SA508CL3	Axial	[50D102/50C97]-1-1

Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Axial Orientation)



Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	- - -	1	91.04	0	3.4	0
2	- - -	1	83.7	-7.34	9.5	6.1
3	- - -	1	88.21	-2.83	37.4	34
4	- - -	1	77.22	-13.82	51.3	47.9
5	- - -	1	92.16	1.12	66	62.6

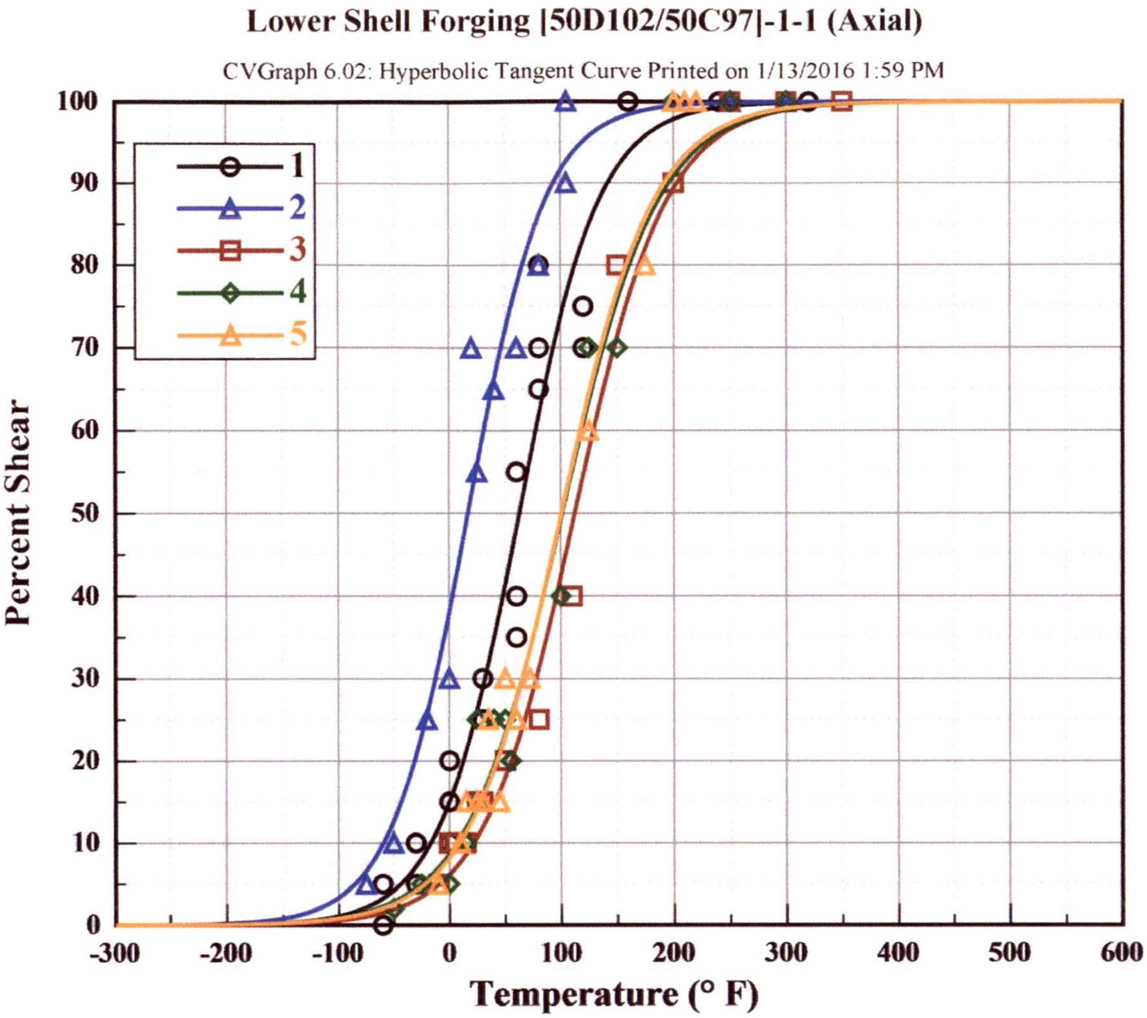
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Axial Orientation) – Continued

Lower Shell Forging [50D102/50C97]-1-1 (Axial)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:59 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	SA508CL3	Axial	[50D102/50C97]-1-1
2	Braidwood 2	U	SA508CL3	Axial	[50D102/50C97]-1-1
3	Braidwood 2	X	SA508CL3	Axial	[50D102/50C97]-1-1
4	Braidwood 2	W	SA508CL3	Axial	[50D102/50C97]-1-1
5	Braidwood 2	V	SA508CL3	Axial	[50D102/50C97]-1-1

Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Axial Orientation)



Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	- - -	0	100	0	62.5	0
2	- - -	0	100	0	17.1	-45.4
3	- - -	0	100	0	112.4	49.9
4	- - -	0	100	0	101.3	38.8
5	- - -	0	100	0	100.4	37.9

Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Axial Orientation) – Continued

Surveillance Program Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 2:03 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	WELD	N/A	442011
2	Braidwood 2	U	WELD	N/A	442011
3	Braidwood 2	X	WELD	N/A	442011
4	Braidwood 2	W	WELD	N/A	442011
5	Braidwood 2	V	WELD	N/A	442011

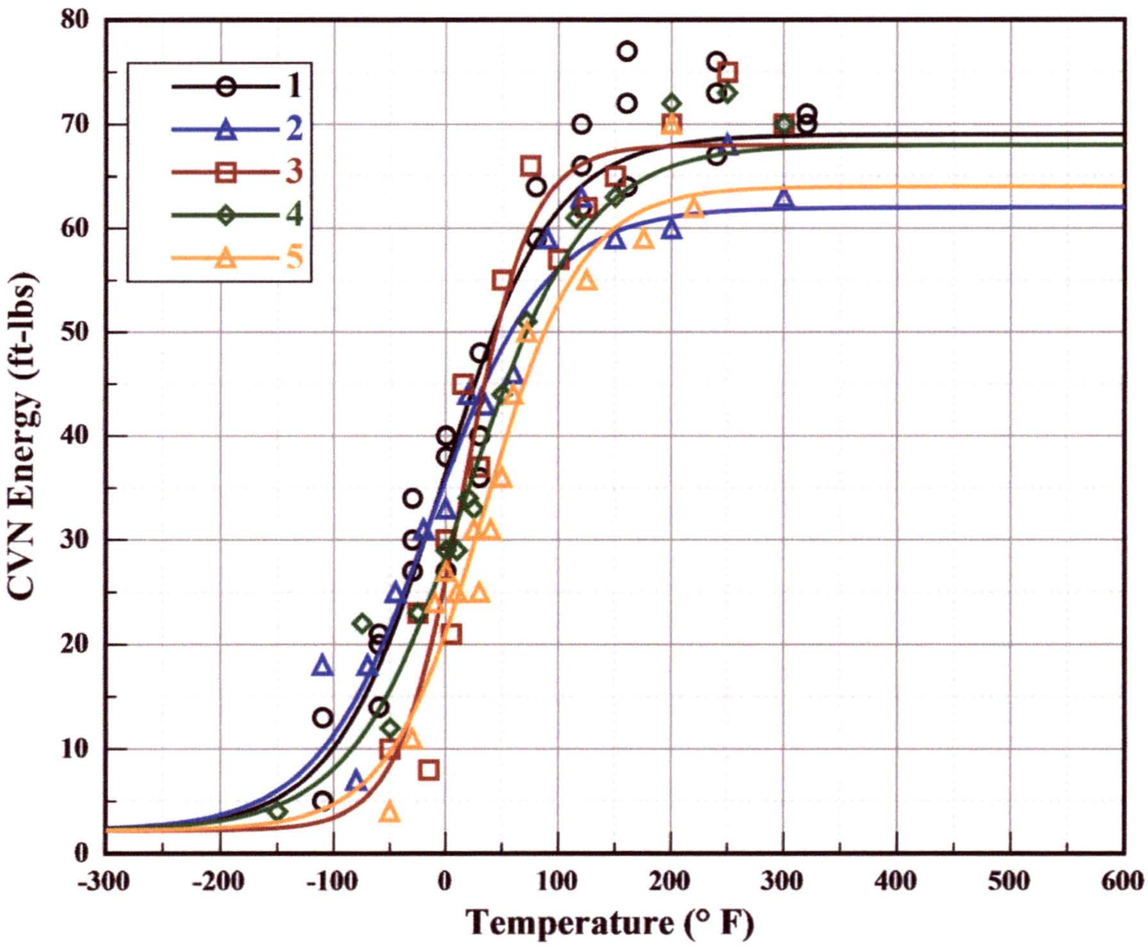


Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for Braidwood Unit 2 Reactor Vessel Surveillance Program Weld Material (Heat # 442011)

Surveillance Program Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 2:03 PM

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	---	2.2	69	0	-19.2	0	42.2	0
2	---	2.2	62	-7	-20	-0.80	57.7	15.5
3	---	2.2	68	-1	6.9	26.1	44.7	2.5
4	---	2.2	68	-1	4.5	23.7	71.8	29.6
5	---	2.2	64	-5	26.4	45.6	87.6	45.4

Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for Braidwood Unit 2 Reactor Vessel Surveillance Program Weld Material (Heat # 442011) – Continued

Surveillance Program Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 2:04 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	WELD	N/A	442011
2	Braidwood 2	U	WELD	N/A	442011
3	Braidwood 2	X	WELD	N/A	442011
4	Braidwood 2	W	WELD	N/A	442011
5	Braidwood 2	V	WELD	N/A	442011

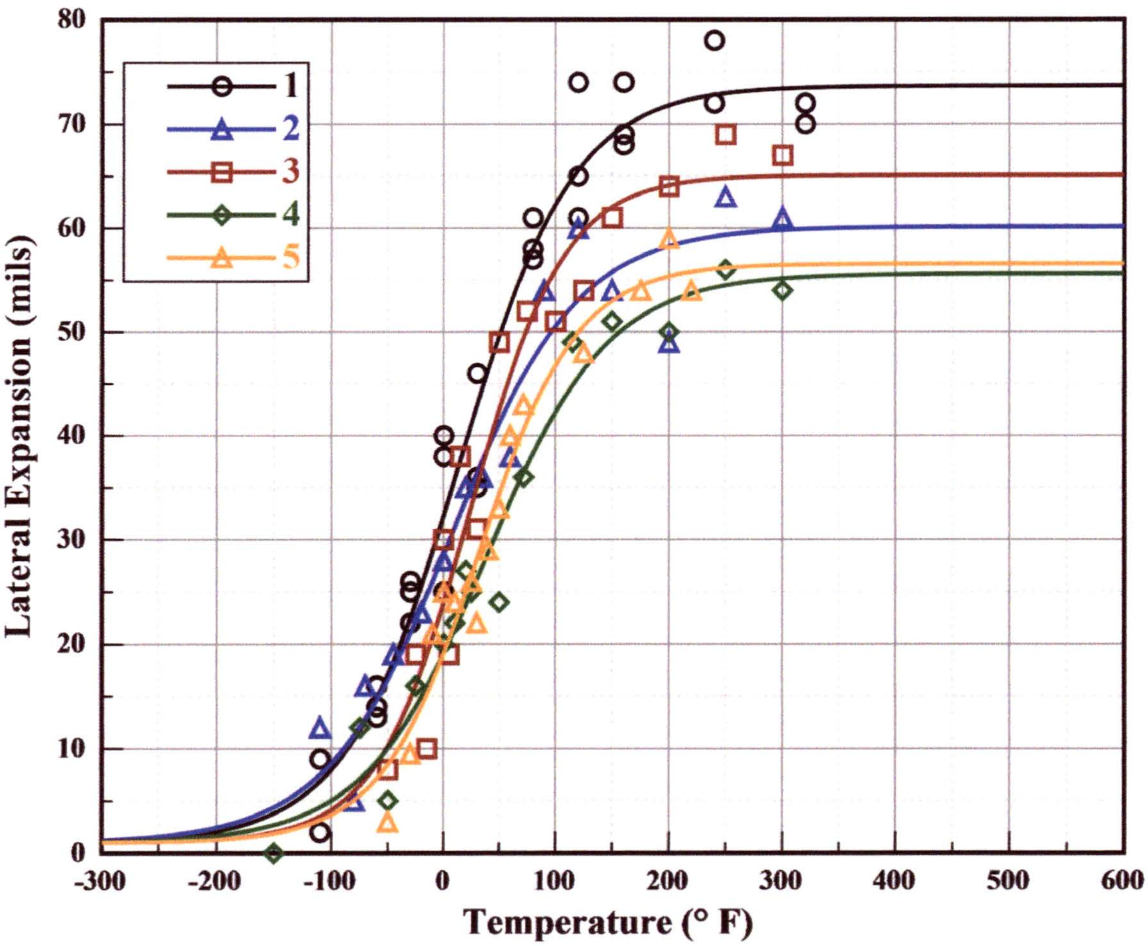


Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for Braidwood Unit 2 Reactor Vessel Surveillance Program Weld Material (Heat # 442011)

Surveillance Program Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 2:04 PM

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	- - -	1	73.67	0	7.5	0
2	- - -	1	60.15	-13.52	24.7	17.2
3	- - -	1	65.09	-8.58	29.6	22.1
4	- - -	1	55.61	-18.06	65.7	58.2
5	- - -	1	56.57	-17.1	52.2	44.7

Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for Braidwood Unit 2 Reactor Vessel Surveillance Program Weld Material (Heat # 442011) – Continued

Surveillance Program Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 2:04 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	WELD	N/A	442011
2	Braidwood 2	U	WELD	N/A	442011
3	Braidwood 2	X	WELD	N/A	442011
4	Braidwood 2	W	WELD	N/A	442011
5	Braidwood 2	V	WELD	N/A	442011

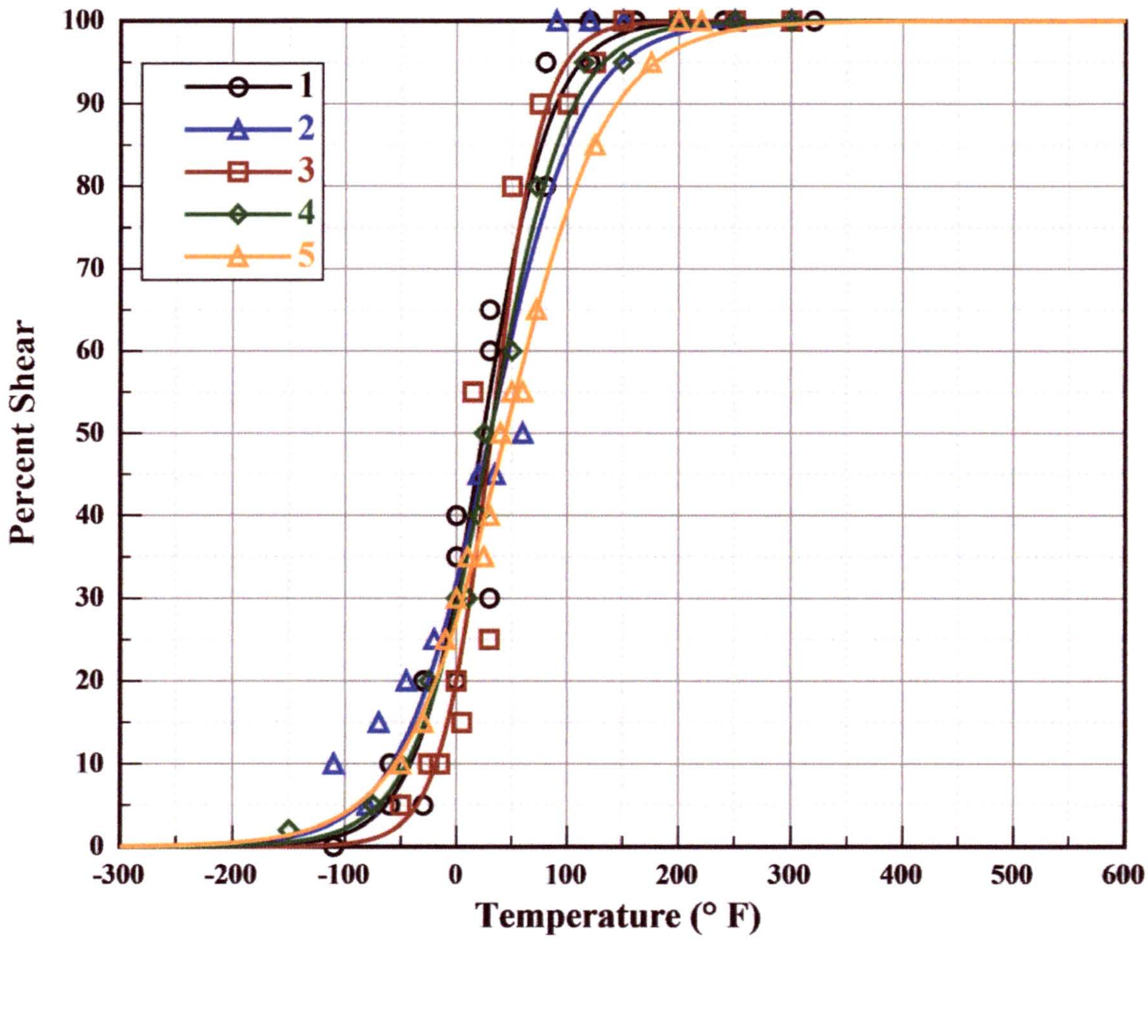


Figure 5-9 Charpy V-Notch Percent Shear vs. Temperature for Braidwood Unit 2 Reactor Vessel Surveillance Program Weld Material (Heat # 442011)

Surveillance Program Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 2:04 PM

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	- - -	0	100	0	24.1	0
2	- - -	0	100	0	30.6	6.5
3	- - -	0	100	0	31.7	7.6
4	- - -	0	100	0	30.9	6.8
5	- - -	0	100	0	44.5	20.4

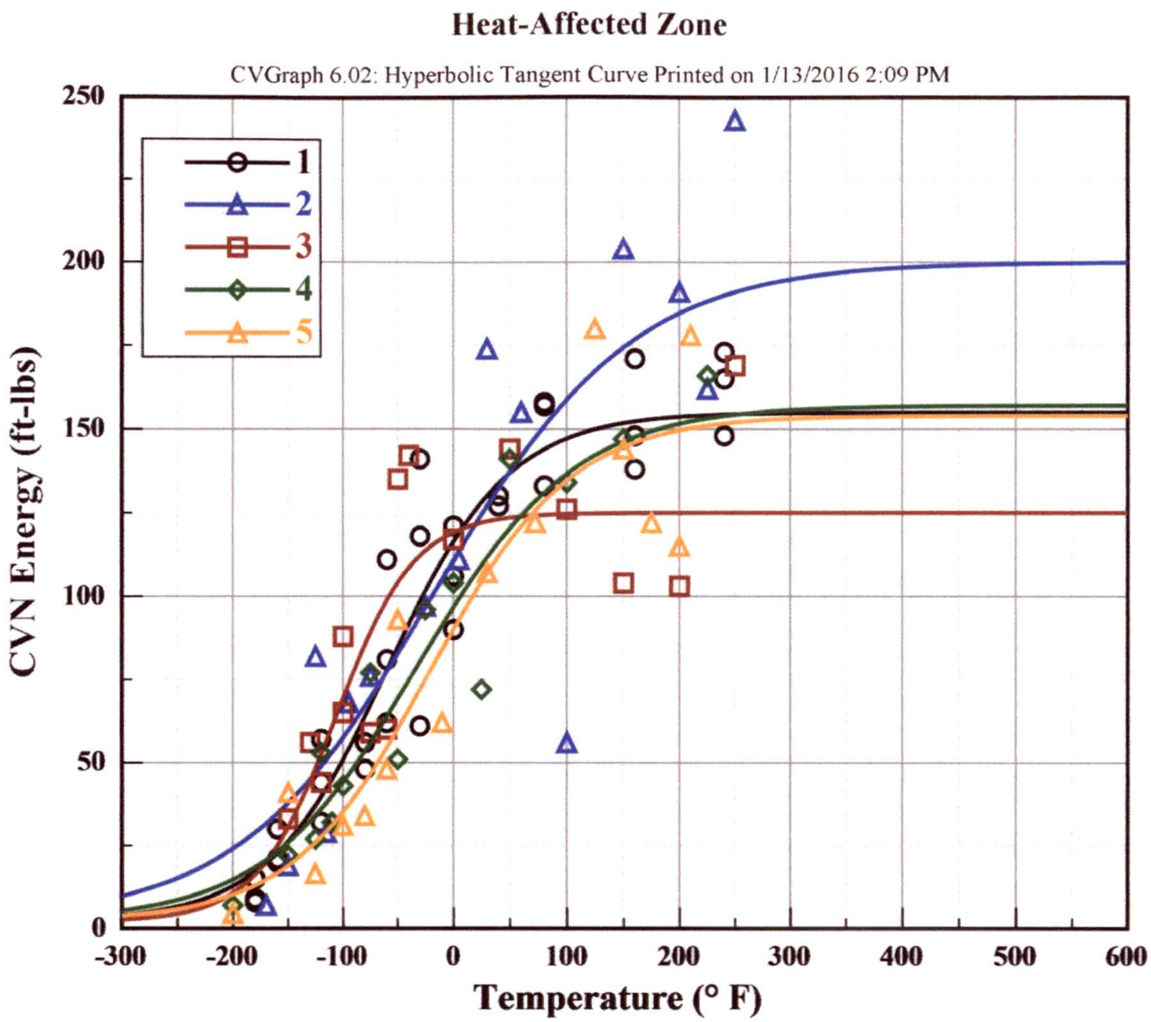
Figure 5-9 Charpy V-Notch Percent Shear vs. Temperature for Braidwood Unit 2 Reactor Vessel Surveillance Program Weld Material (Heat # 442011) – Continued

Heat-Affected Zone

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 2:09 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	SA508CL3	N/A	[50D102/50C97]-1-1
2	Braidwood 2	U	SA508CL3	N/A	[50D102/50C97]-1-1
3	Braidwood 2	X	SA508CL3	N/A	[50D102/50C97]-1-1
4	Braidwood 2	W	SA508CL3	N/A	[50D102/50C97]-1-1
5	Braidwood 2	V	SA508CL3	N/A	[50D102/50C97]-1-1

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



Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	---	2.2	155	0	-140.7	0	-101.8	0
2	---	2.2	200	45	-175.9	-35.2	-117.4	-15.6
3	---	2.2	125	-30	-151	-10.3	-123.1	-21.3
4	---	2.2	157	2	-137	3.70	-87.3	14.5
5	---	2.2	154	-1	-113.2	27.5	-68.4	33.4

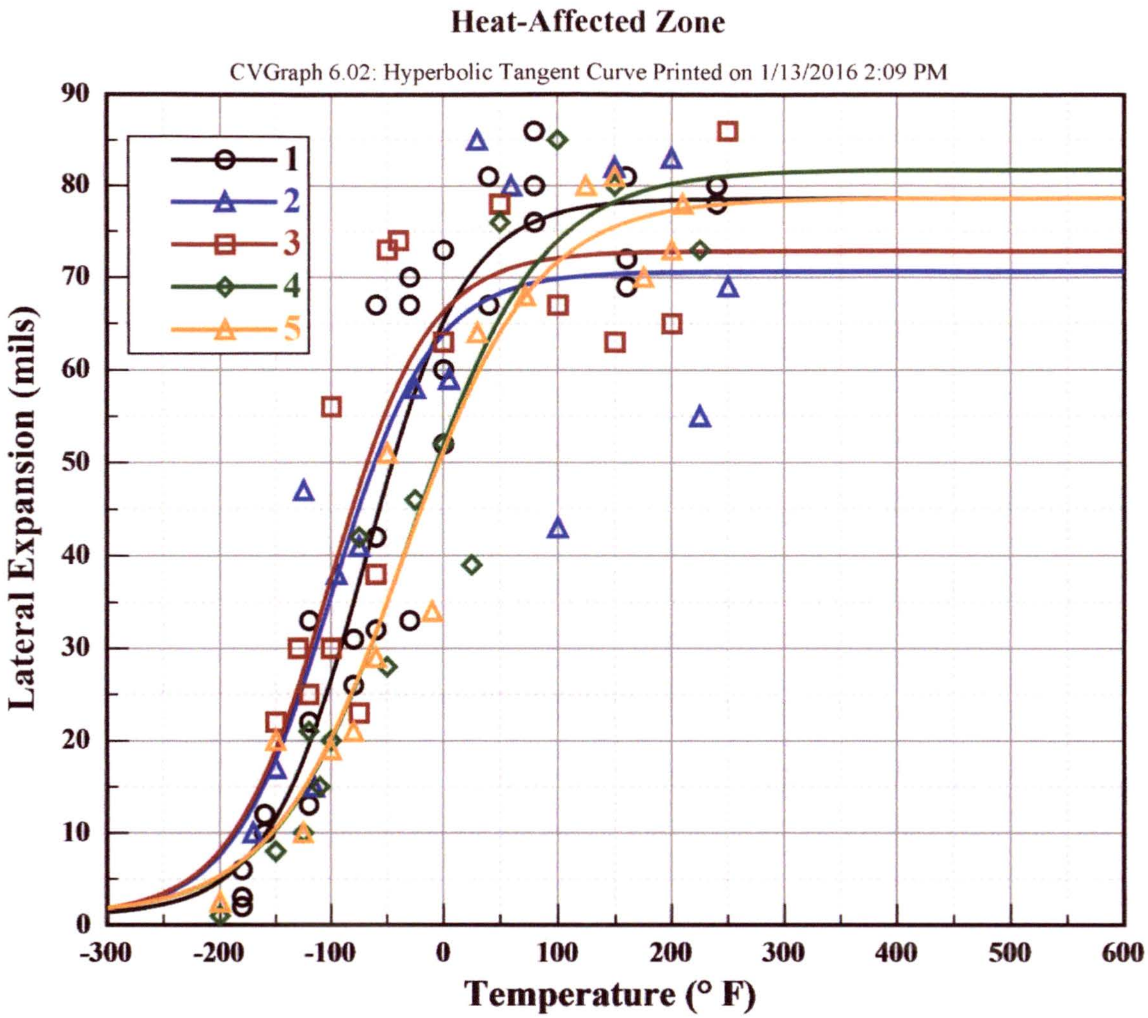
Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Braidwood Unit 2 Reactor Vessel Heat-Affected Zone Material – Continued

Heat-Affected Zone

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 2:09 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	SA508CL3	N/A	[50D102/50C97]-1-1
2	Braidwood 2	U	SA508CL3	N/A	[50D102/50C97]-1-1
3	Braidwood 2	X	SA508CL3	N/A	[50D102/50C97]-1-1
4	Braidwood 2	W	SA508CL3	N/A	[50D102/50C97]-1-1
5	Braidwood 2	V	SA508CL3	N/A	[50D102/50C97]-1-1

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



Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	---	1	78.6	0	-80	0
2	---	1	70.64	-7.96	-101.6	-21.6
3	---	1	72.87	-5.73	-106.4	-26.4
4	---	1	81.71	3.11	-49.8	30.2
5	---	1	78.6	0	-49.9	30.1

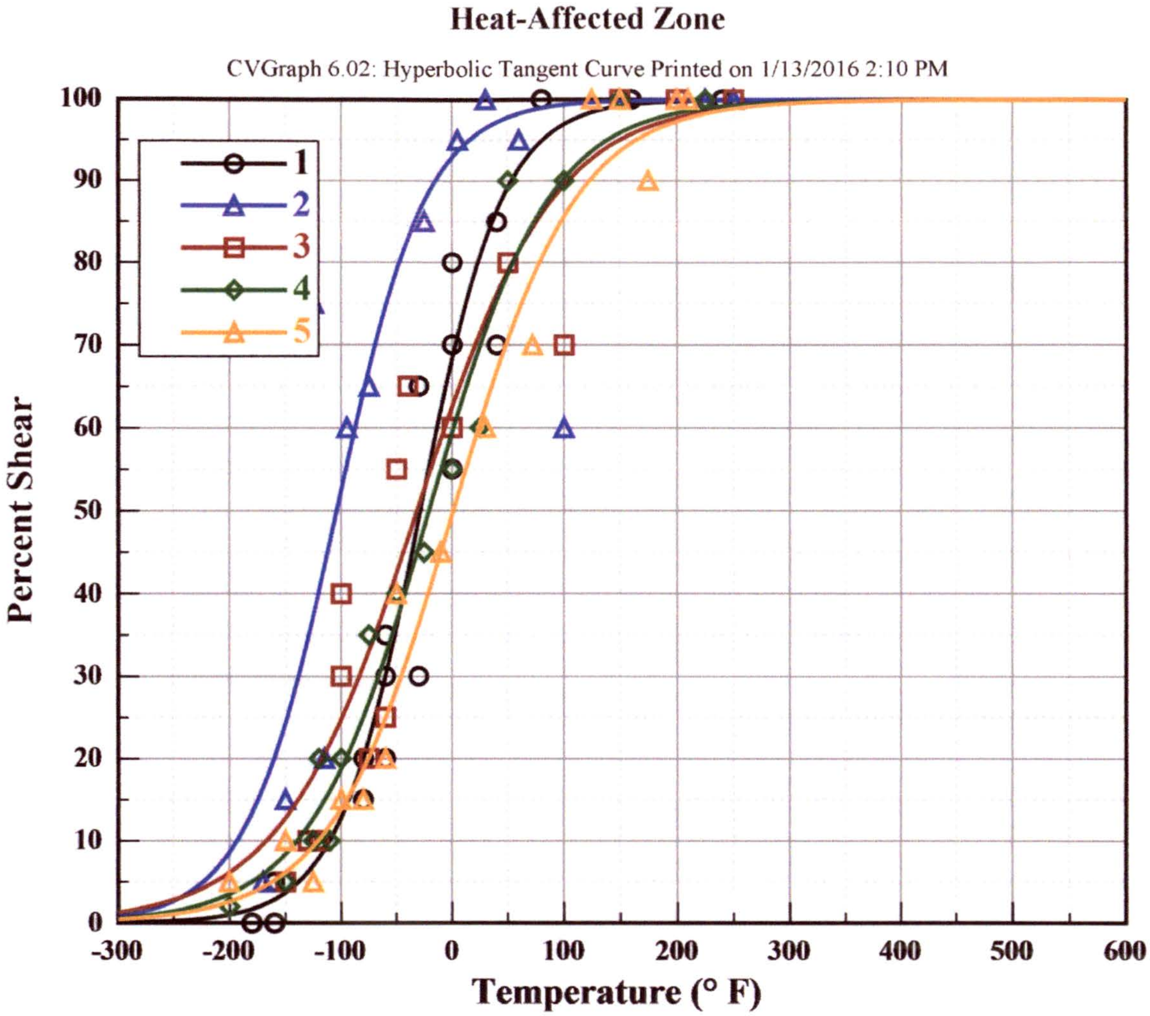
Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Braidwood Unit 2 Reactor Vessel Heat-Affected Zone Material – Continued

Heat-Affected Zone

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 2:10 PM

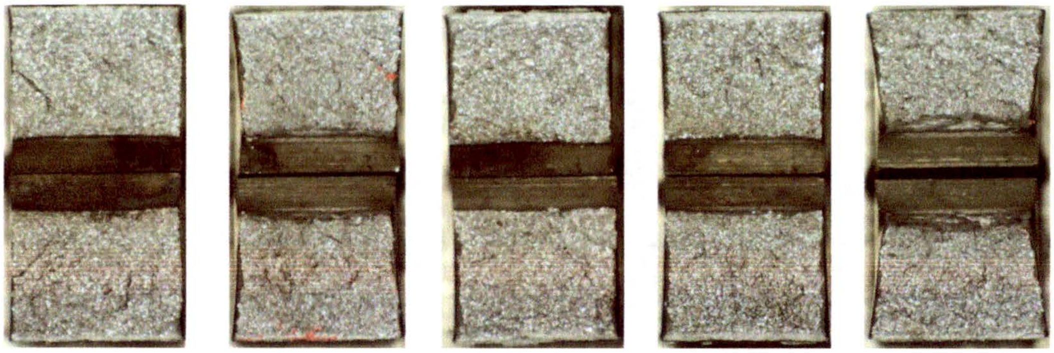
Curve	Plant	Capsule	Material	Ori.	Heat #
1	Braidwood 2	UNIRR	SA508CL3	N/A	[50D102/50C97]-1-1
2	Braidwood 2	U	SA508CL3	N/A	[50D102/50C97]-1-1
3	Braidwood 2	X	SA508CL3	N/A	[50D102/50C97]-1-1
4	Braidwood 2	W	SA508CL3	N/A	[50D102/50C97]-1-1
5	Braidwood 2	V	SA508CL3	N/A	[50D102/50C97]-1-1

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

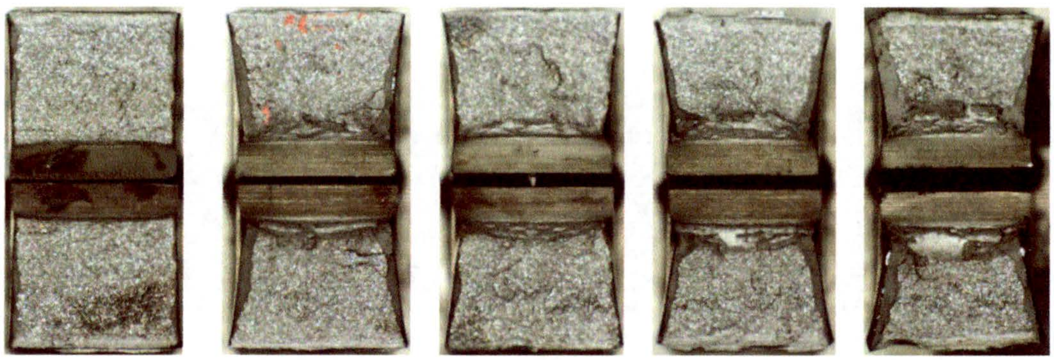


Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	- - -	0	100	0	-28.7	0
2	- - -	0	100	0	-104	-75.3
3	- - -	0	100	0	-31.6	-2.9
4	- - -	0	100	0	-20.6	8.1
5	- - -	0	100	0	1.2	29.9

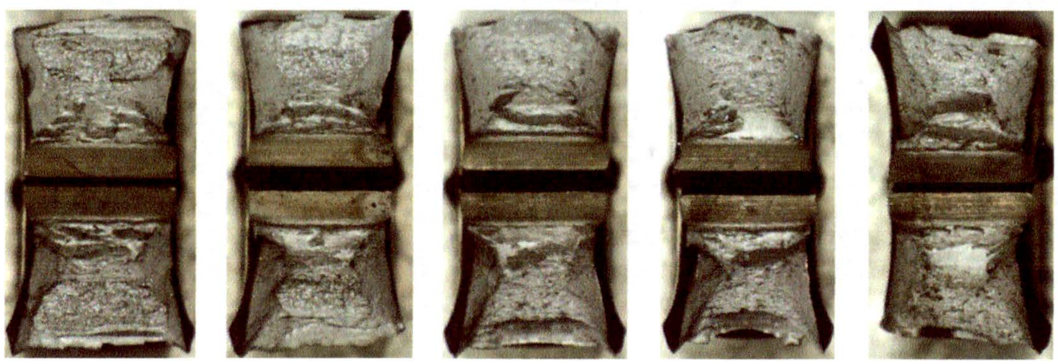
Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for Braidwood Unit 2 Reactor Vessel Heat-Affected Zone Material – Continued



FL23, -10°F FL26, 0°F FL24, 10°F FL22, 15°F FL20, 15°F



FL16, 20°F FL25, 25°F FL29, 30°F FL27, 50°F FL30, 72°F



FL17, 125°F FL28, 175°F FL19, 200°F FL18, 210°F FL21, 220°F

Figure 5-13 Charpy Impact Specimen Fracture Surfaces for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Tangential Orientation)

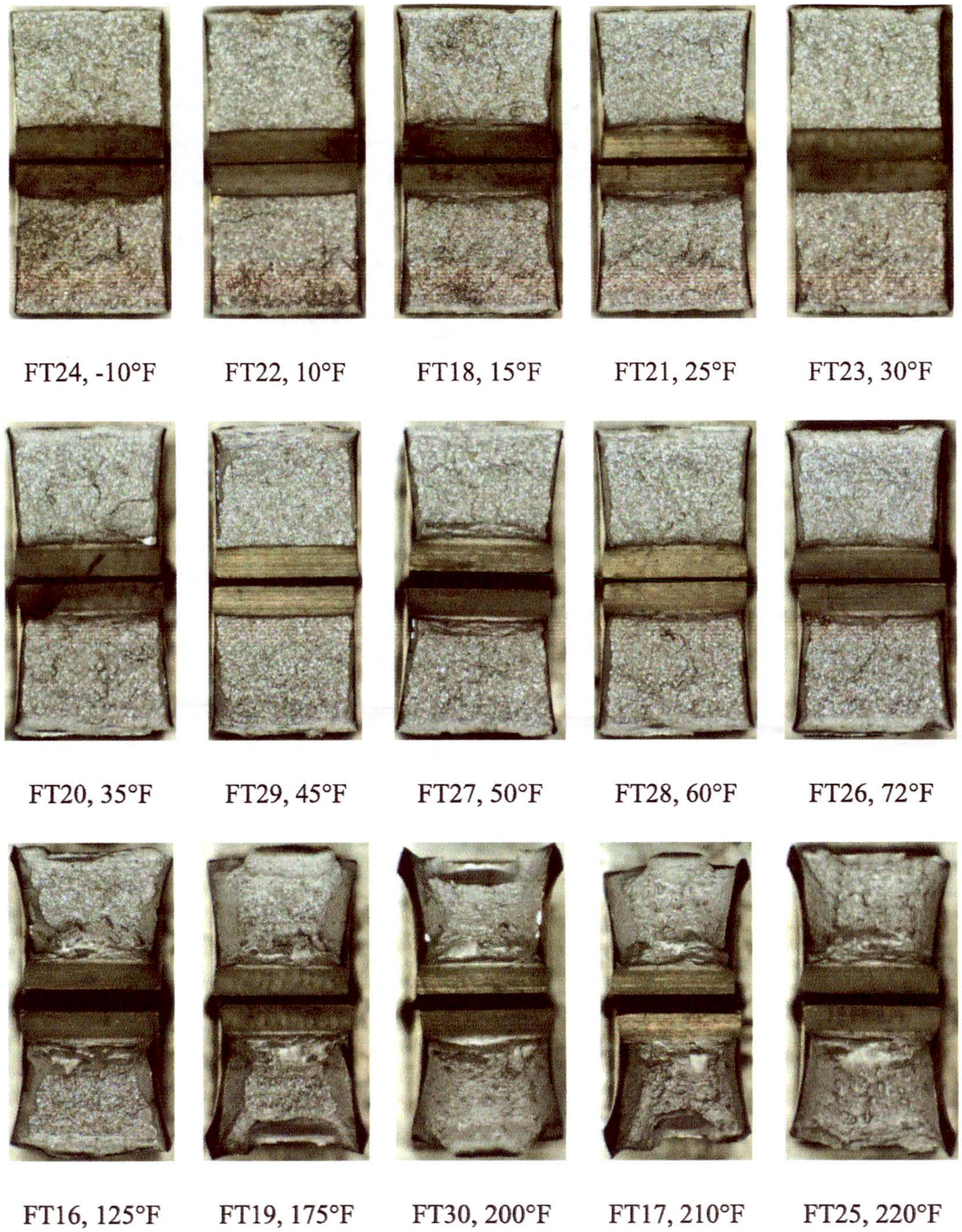


Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Axial Orientation)

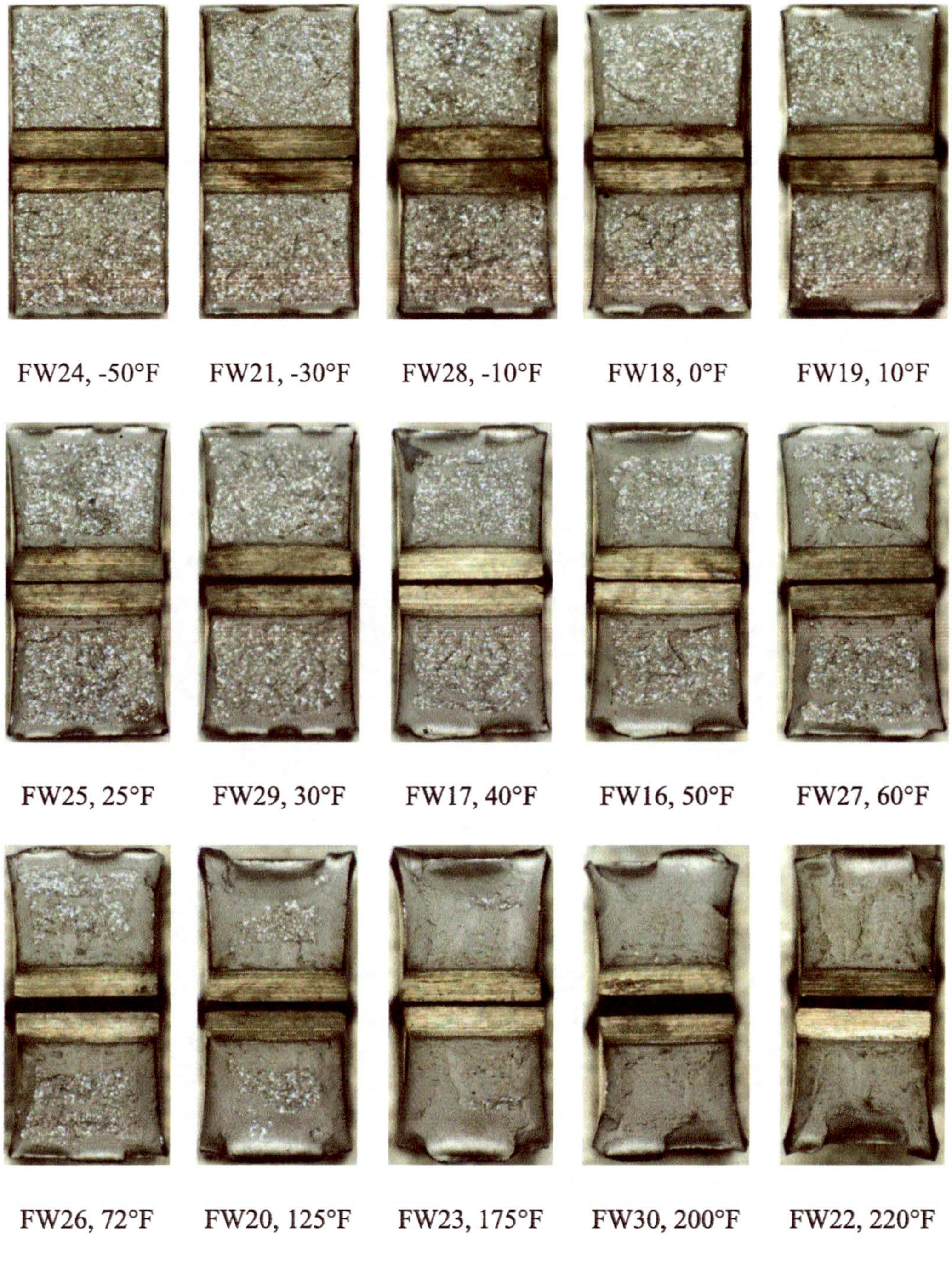
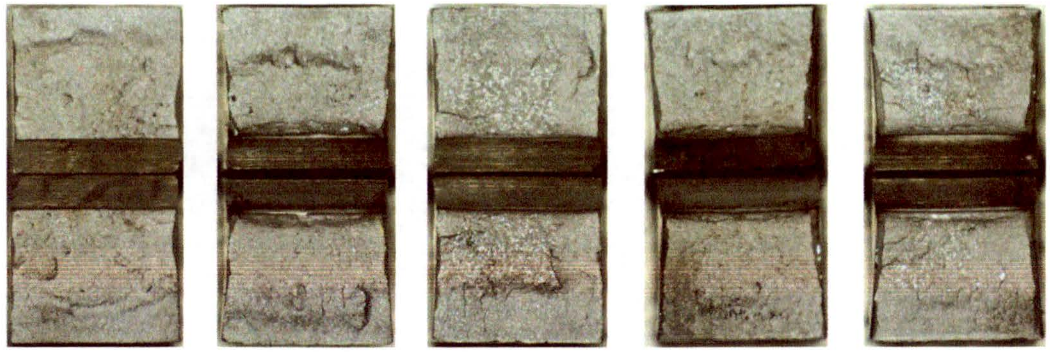
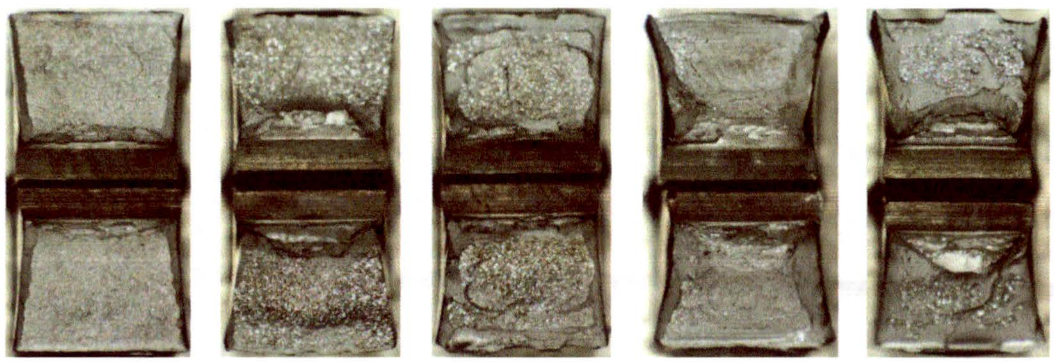


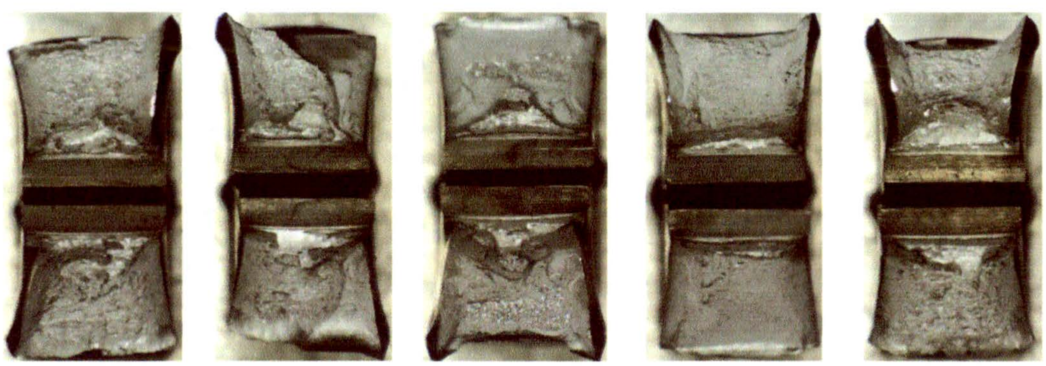
Figure 5-15 Charpy Impact Specimen Fracture Surfaces for the Braidwood Unit 2 Reactor Vessel Surveillance Program Weld Material (Heat # 442011)



FH29, -200°F FH23, -150°F FH22, -125°F FH30, -100°F FH27, -80°F

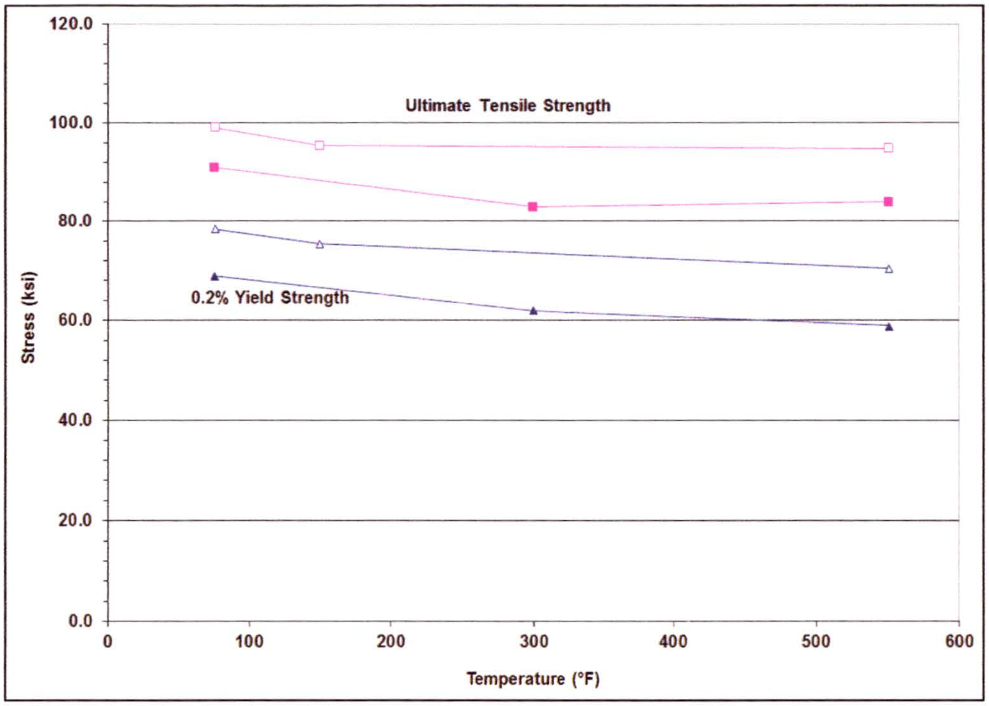


FH18, -60°F FH20, -50°F FH25, -10°F FH21, 30°F FH19, 72°F



FH16, 125°F FH24, 150°F FH26, 175°F FH28, 200°F FH17, 210°F

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



Legend: ▲, ●, and ■ are unirradiated
Δ, ○, and □ are irradiated to 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV)

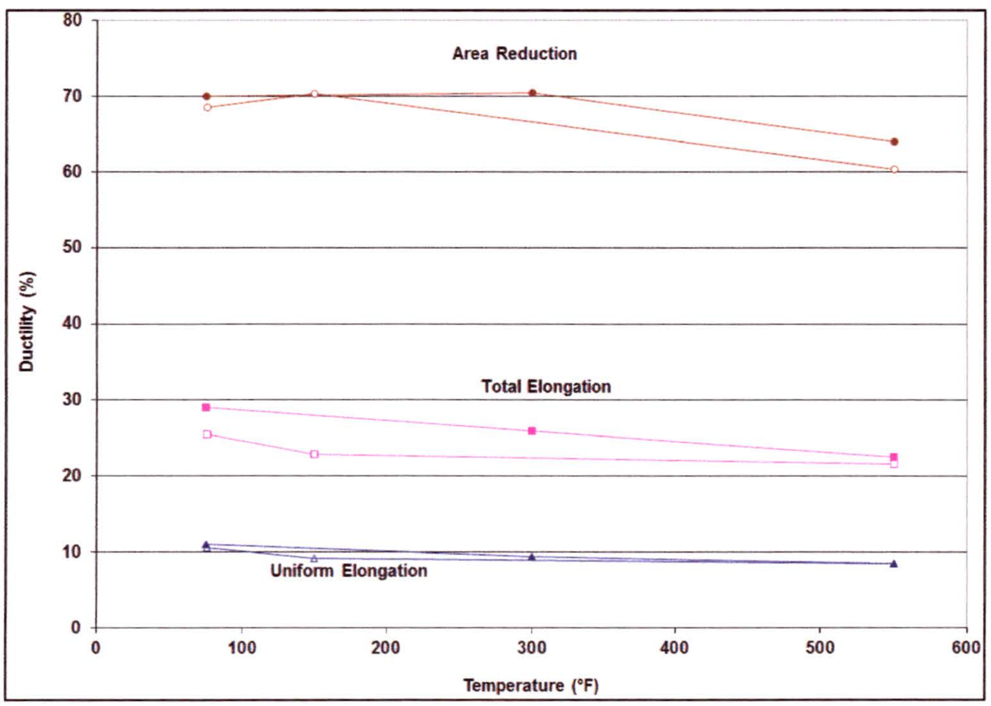
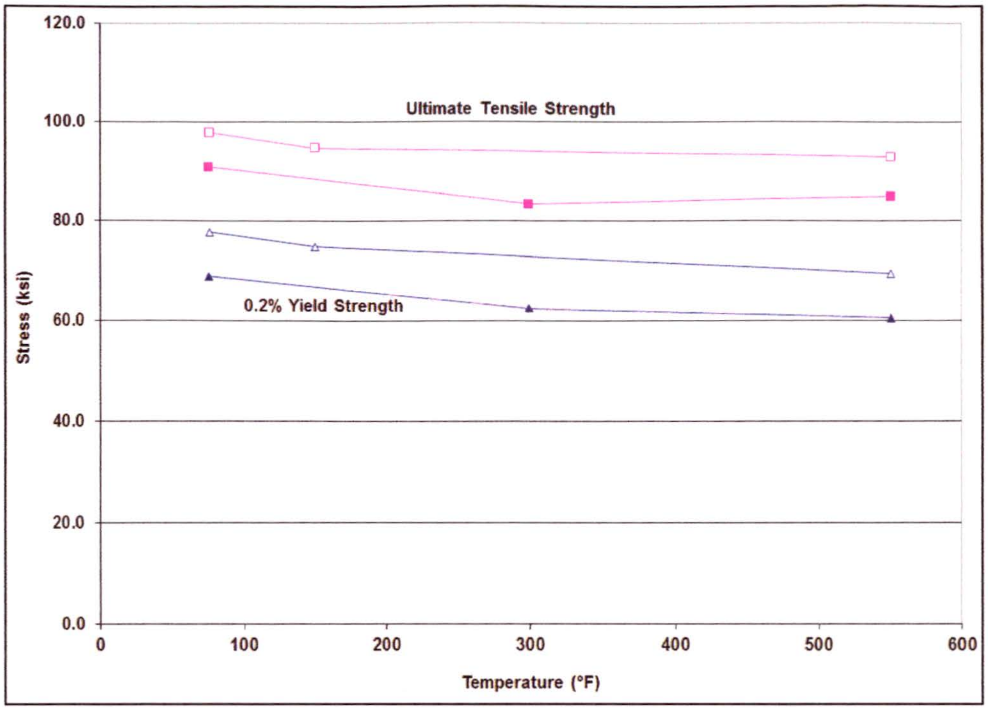


Figure 5-17 Tensile Properties for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Tangential Orientation)



Legend: ▲, ●, and ■ are unirradiated
Δ, ○, and □ are irradiated to 3.73×10^{19} n/cm^2 (E > 1.0 MeV)

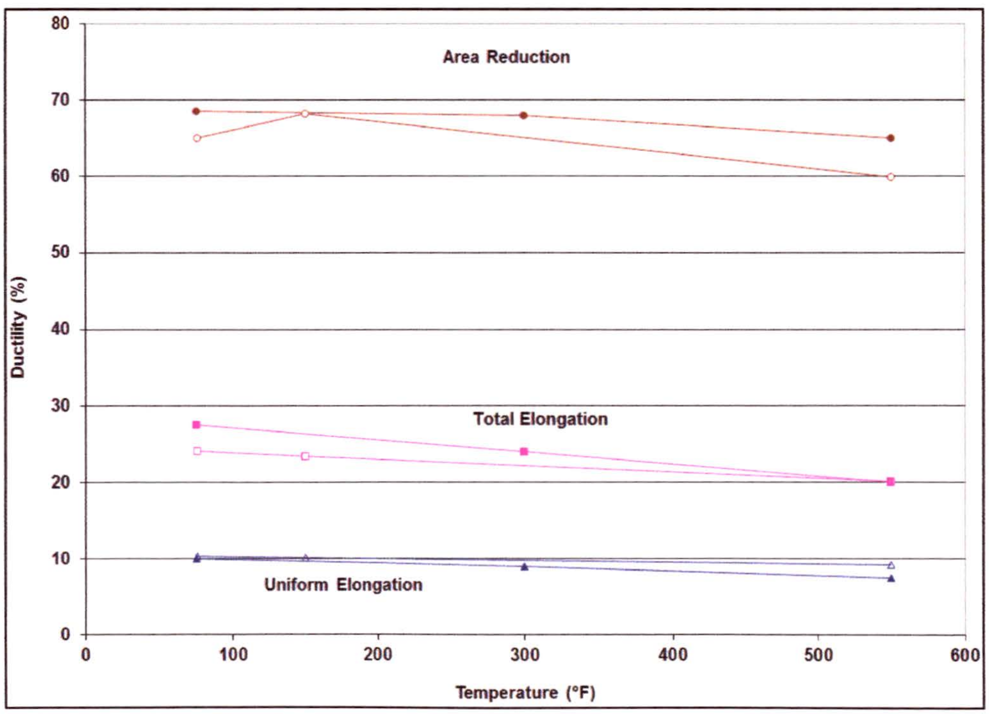
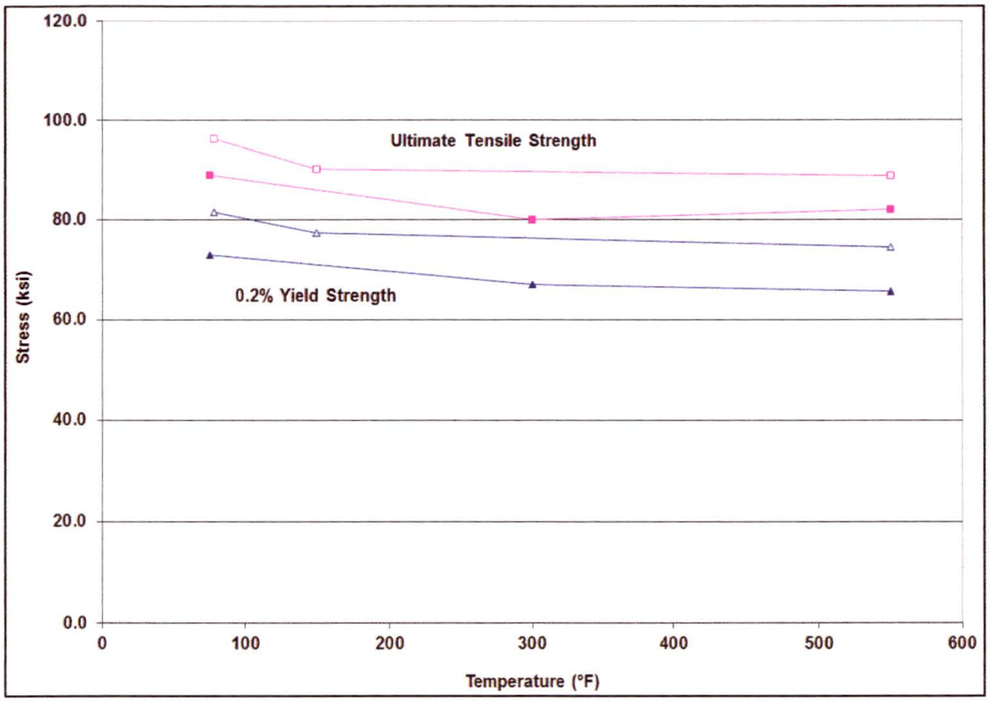


Figure 5-18 Tensile Properties for Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Axial Orientation)



Legend: ▲,●, and ■ are unirradiated
Δ, ○, and □ are irradiated to 3.73 x 10^{19} n/cm^2 (E > 1.0 MeV)

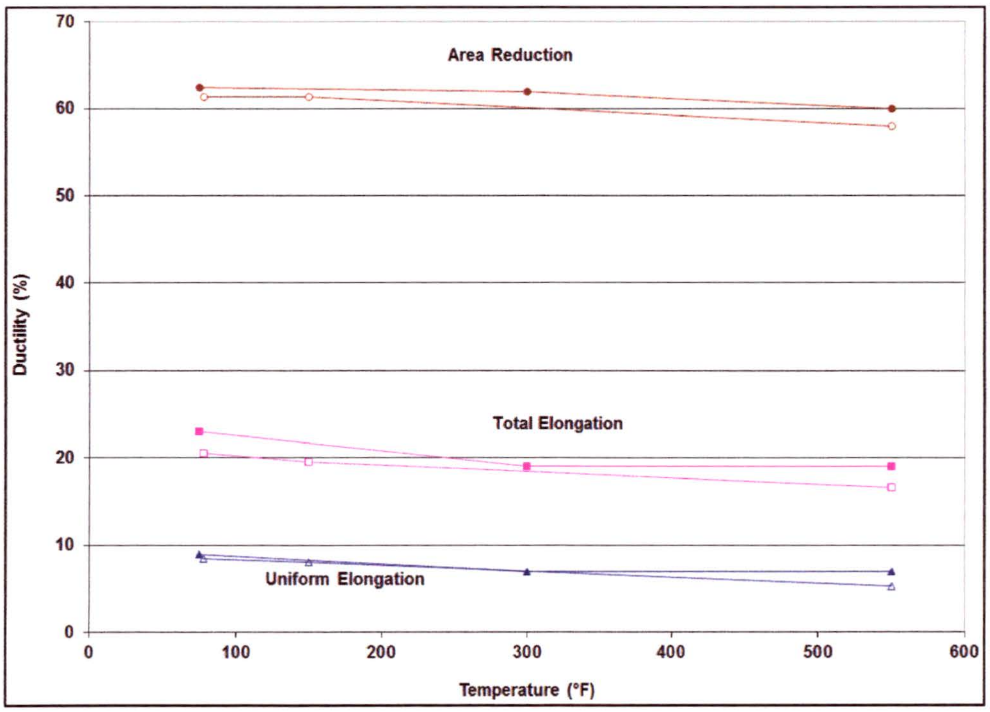
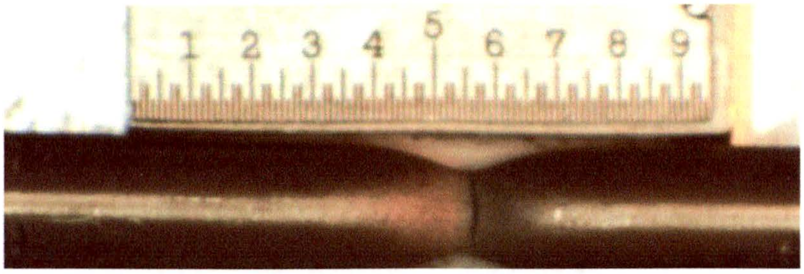
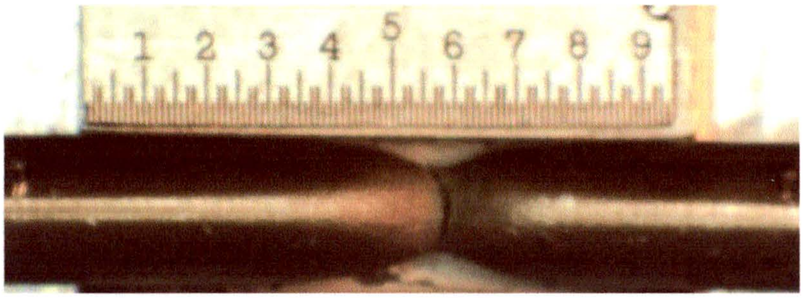


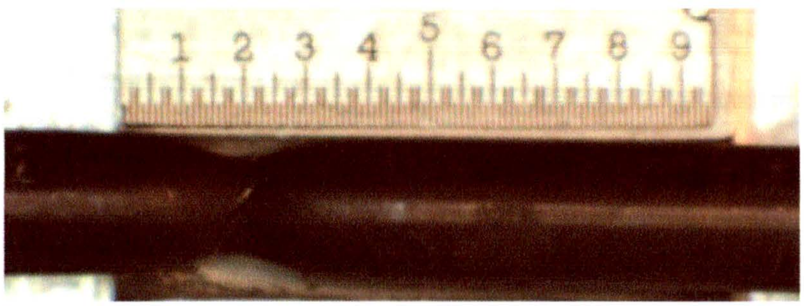
Figure 5-19 Tensile Properties for the Braidwood Unit 2 Reactor Vessel Surveillance Program Weld Material (Heat # 442011)



FL4 – Tested at 76°F

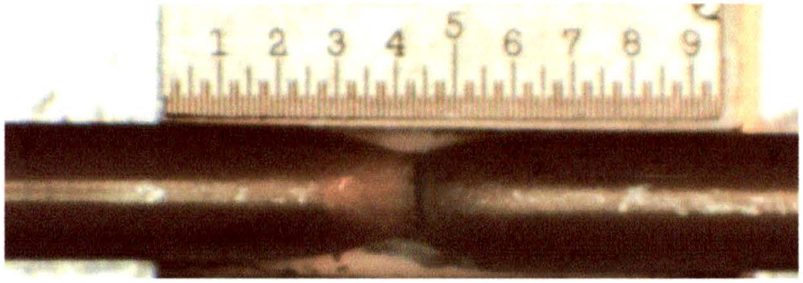


FL5 – Tested at 150°F

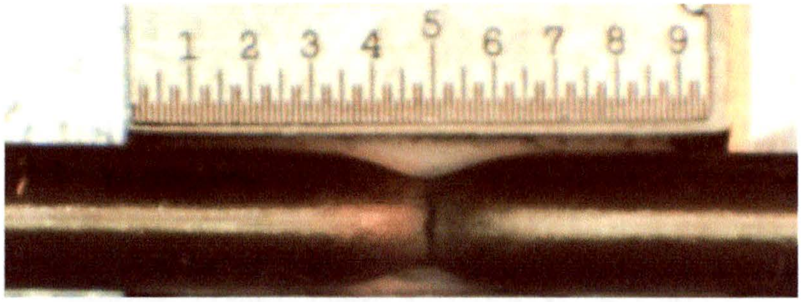


FL6 – Tested at 550°F

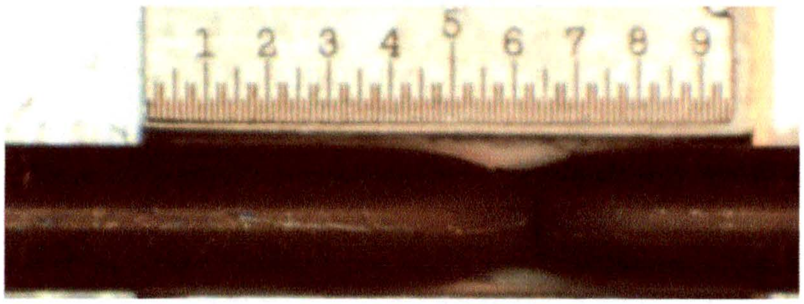
Figure 5-20 Fractured Tensile Specimens from Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Tangential Orientation)



FT4 – Tested at 76°F

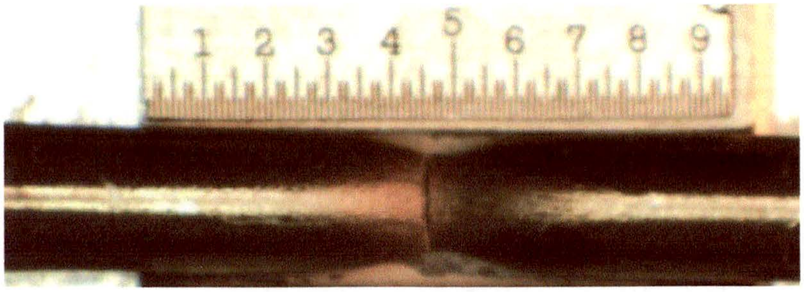


FT5 – Tested at 150°F

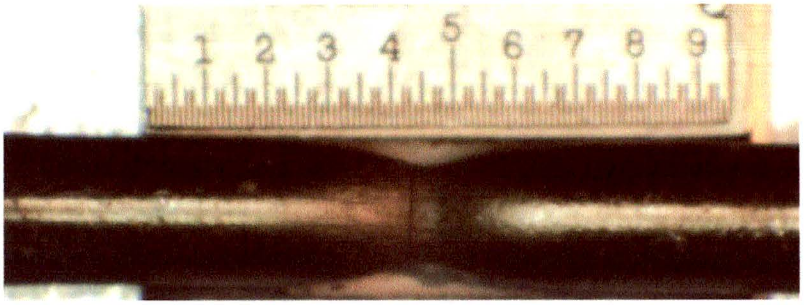


FT6 – Tested at 550°F

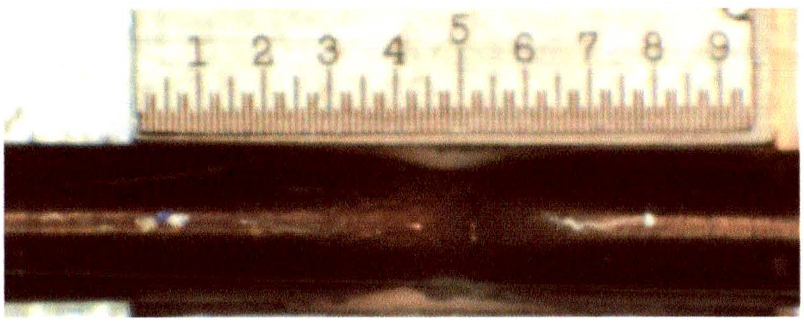
Figure 5-21 Fractured Tensile Specimens from Braidwood Unit 2 Reactor Vessel Lower Shell Forging [50D102/50C97]-1-1 (Axial Orientation)



FW4 – Tested at 78°F

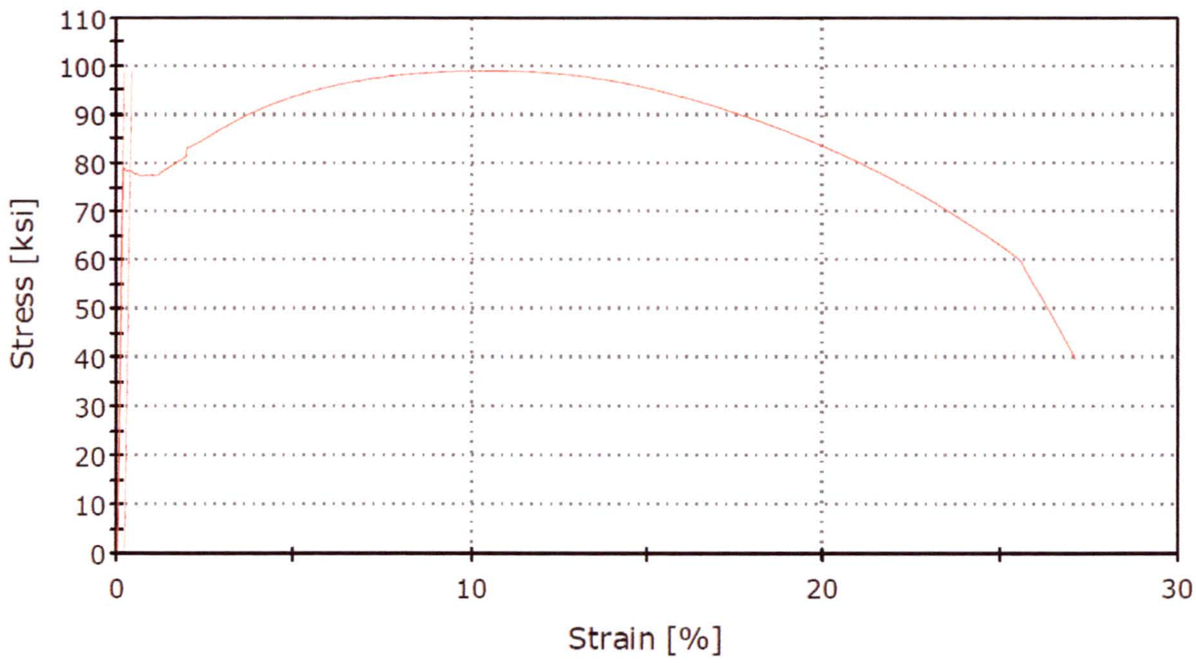


FW5 – Tested at 150°F

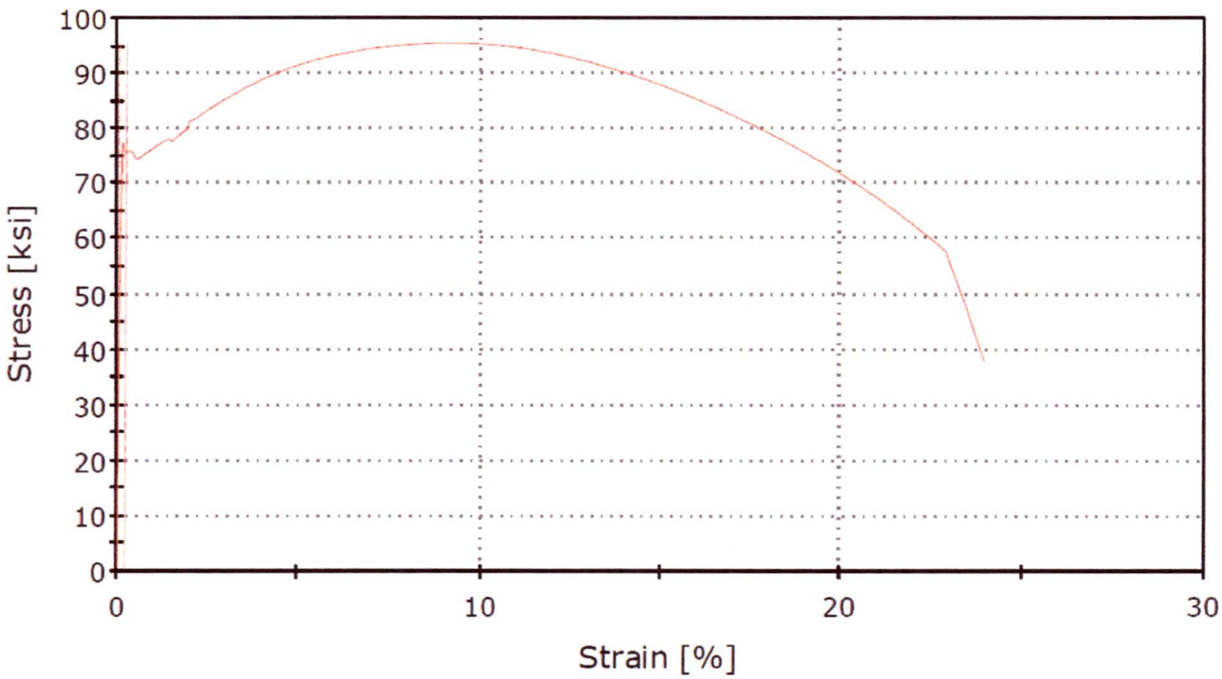


FW6 – Tested at 550°F

Figure 5-22 Fractured Tensile Specimens from the Braidwood Unit 2 Reactor Vessel Surveillance Program Weld Material (Heat # 442011)

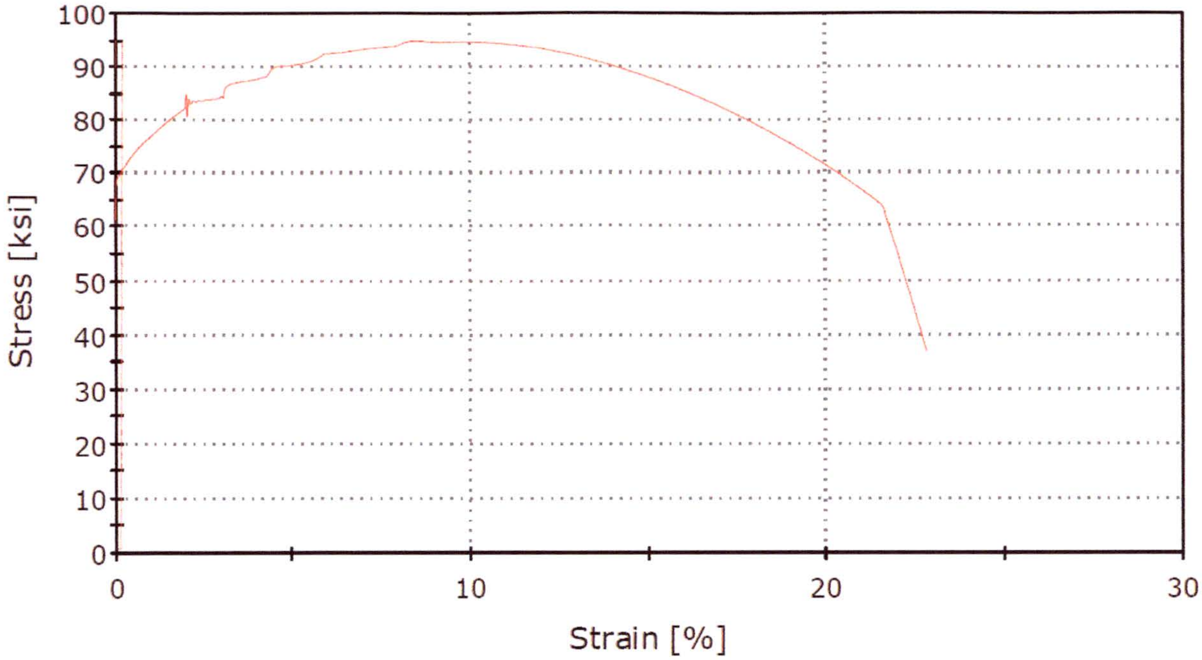


Tensile Specimen FL4 Tested at 76°F



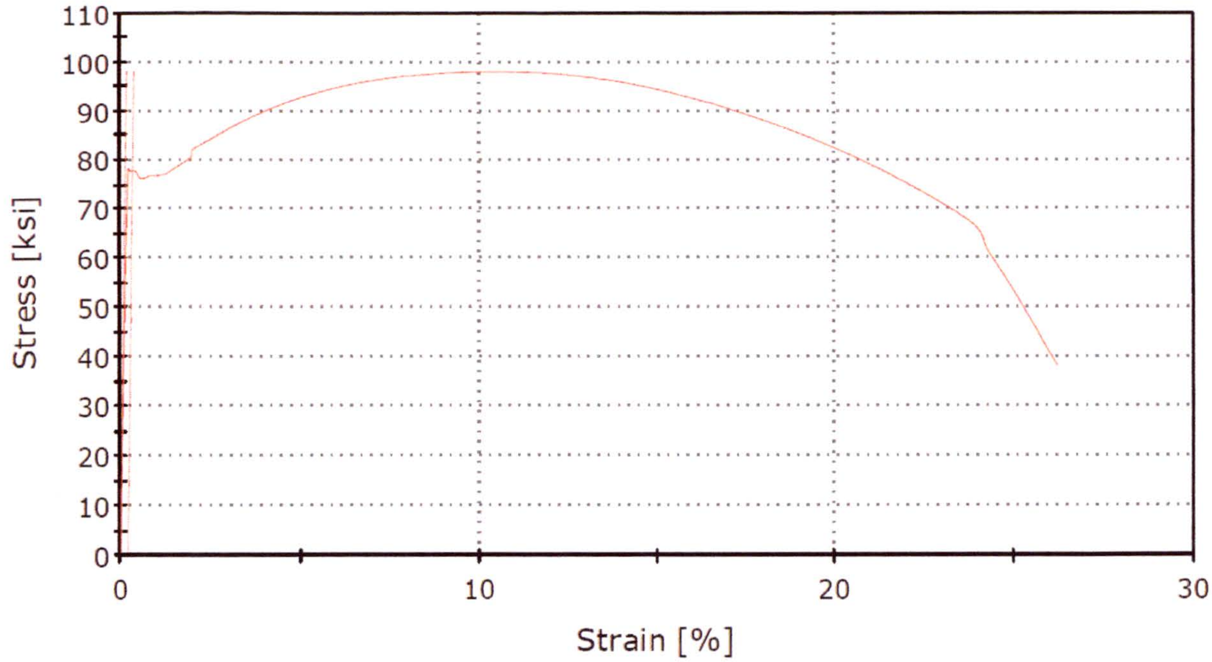
Tensile Specimen FL5 Tested at 150°F

Figure 5-23 Engineering Stress-Strain Curves for Braidwood Unit 2 Lower Shell Forging [50D102/50C97]-1-1 Tensile Specimens FL4 and FL5 (Tangential Orientation)

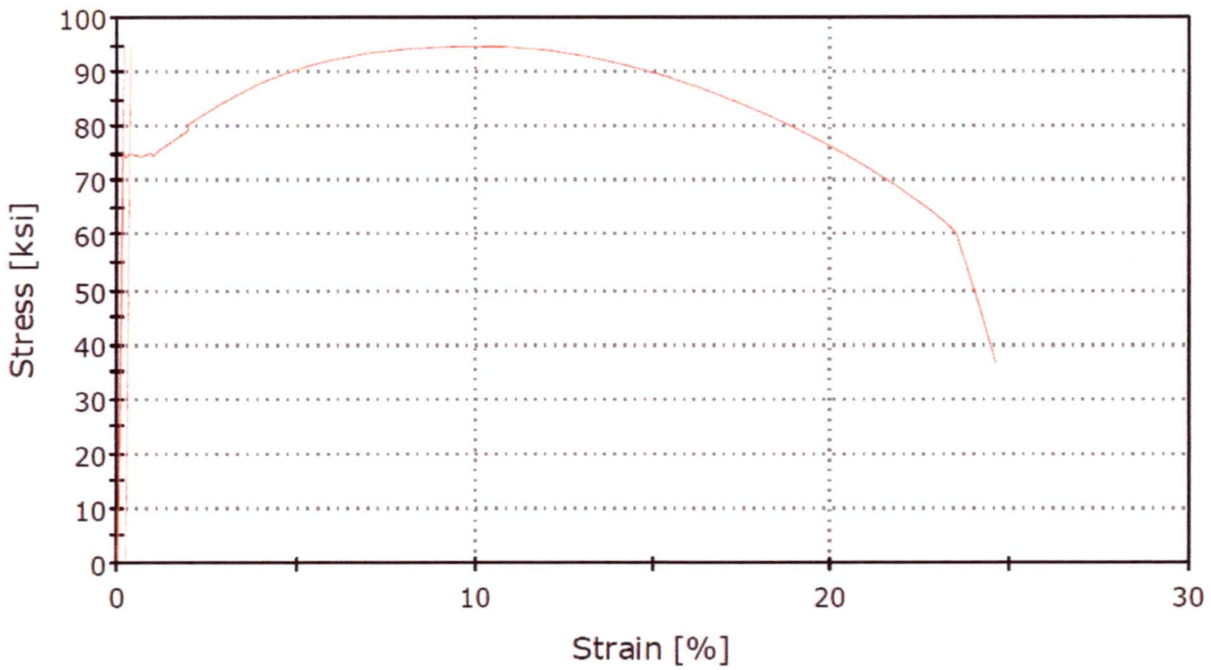


Tensile Specimen FL6 Tested at 550°F

Figure 5-24 Engineering Stress-Strain Curve for Braidwood Unit 2 Lower Shell Forging [50D102/50C97]-1-1 Tensile Specimen FL6 (Tangential Orientation)

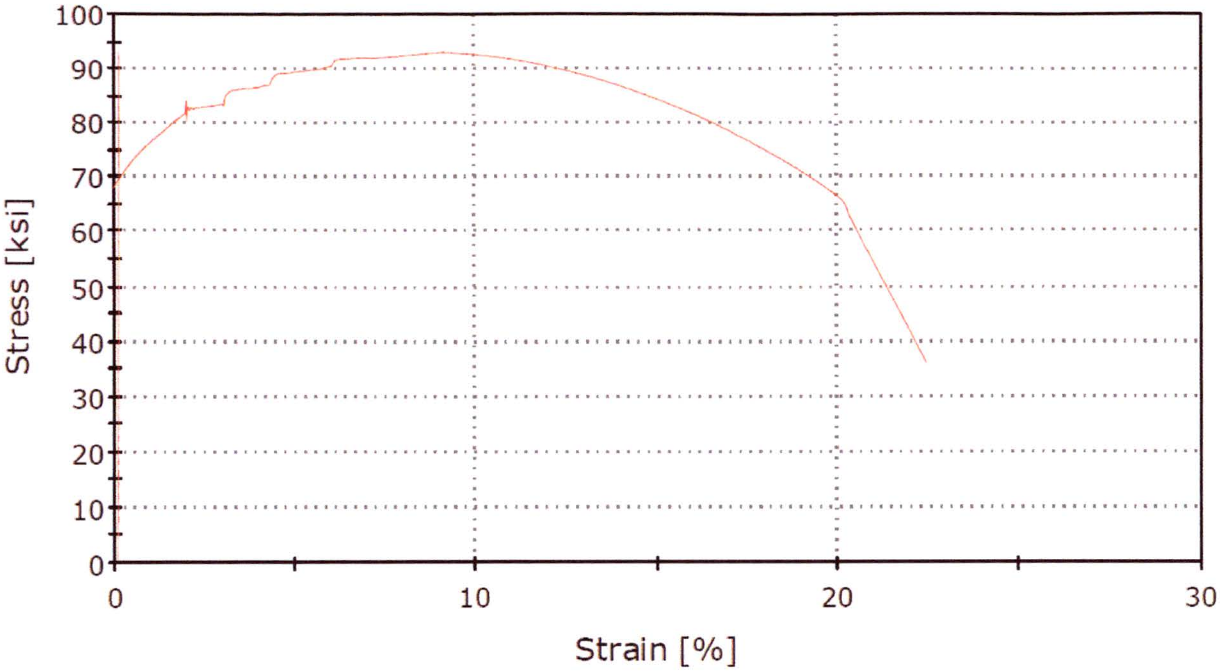


Tensile Specimen FT4 Tested at 76°F



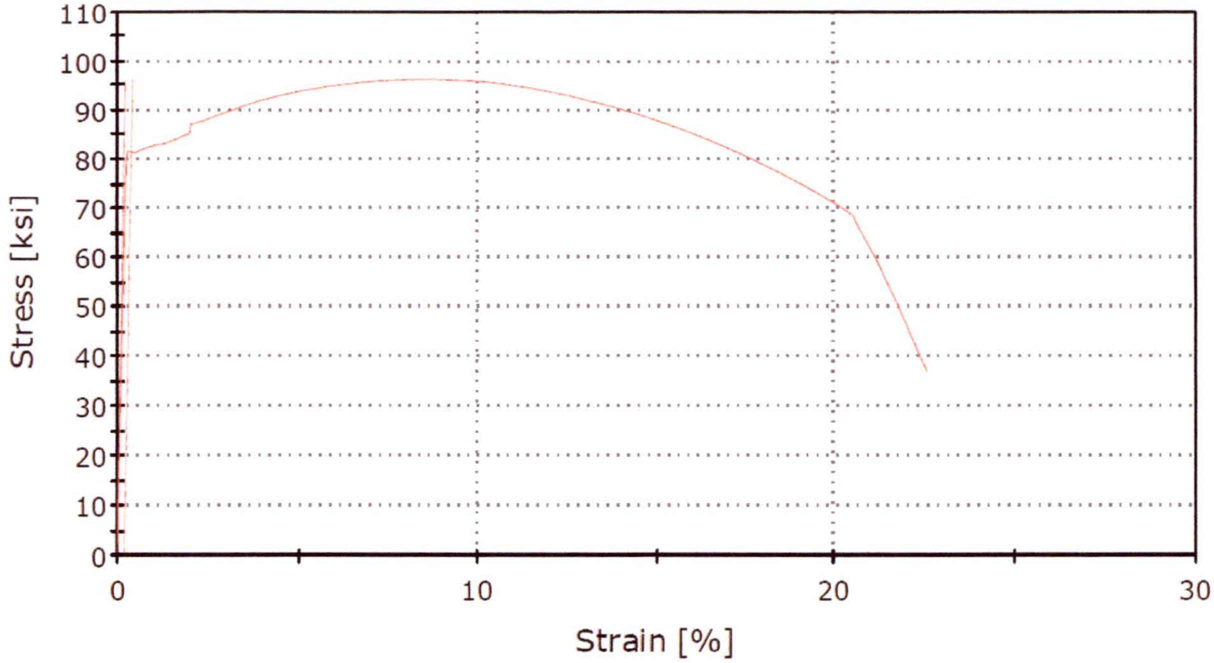
Tensile Specimen FT5 Tested at 150°F

Figure 5-25 Engineering Stress-Strain Curves for Braidwood Unit 2 Lower Shell Forging [50D102/50C97]-1-1 Tensile Specimens FT4 and FT5 (Axial Orientation)

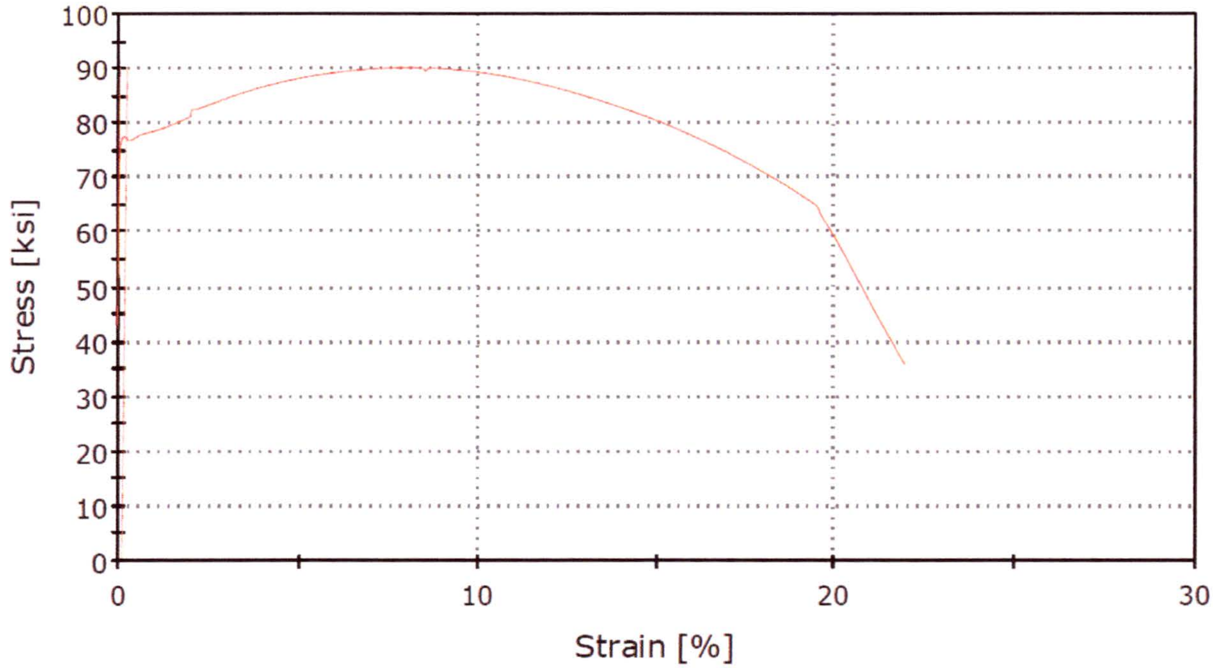


Tensile Specimen FT6 Tested at 550°F

Figure 5-26 Engineering Stress-Strain Curve for Braidwood Unit 2 Lower Shell Forging [50D102/50C97]-1-1 Tensile Specimen FT6 (Axial Orientation)

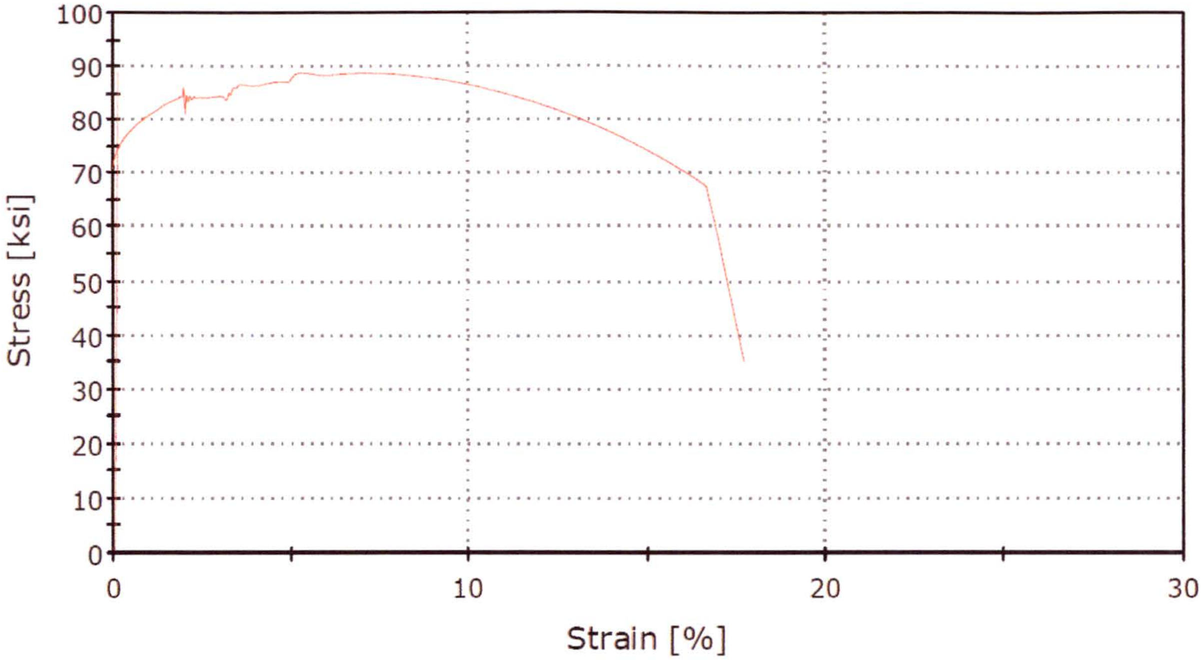


Tensile Specimen FW4 Tested at 78°F



Tensile Specimen FW5 Tested at 150°F

Figure 5-27 Engineering Stress-Strain Curves for Braidwood Unit 2 Surveillance Weld Material Tensile Specimens FW4 and FW5



Tensile Specimen FW6 Tested at 550°F

Figure 5-28 Engineering Stress-Strain Curve for Braidwood Unit 2 Surveillance Weld Material Tensile Specimen FW6

6 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION

This section describes a discrete ordinates (S_n) transport analysis performed for the Braidwood 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 V, withdrawn at the end of the 14^{th} plant operating cycle, is provided. In addition, the sensor sets from the previously withdrawn and analyzed capsules (U, W, and X) were re-analyzed and are presented. Comparisons of the results from these dosimetry evaluations with the analytical predictions served to validate the plant-specific neutron transport calculations. These validated calculations subsequently form the basis for projections of the neutron exposure of the reactor pressure vessel for operating periods extending to 60 effective full-power years (EFPY).

The use of fast neutron fluence (E > 1.0 MeV) to correlate measured material property changes to the neutron exposure of the material has traditionally been accepted for the development of damage trend curves as well as for the implementation of trend curve data to assess the condition of the vessel. However, in recent years, it has been suggested that an exposure model that accounts for differences in neutron energy spectra between surveillance capsule locations and positions within the vessel wall could lead to an improvement in the uncertainties associated with damage trend curves and improved accuracy in the evaluation of damage gradients through the reactor vessel wall.

Because of this potential shift away from a threshold fluence toward an energy-dependent damage function for data correlation, ASTM Standard Practice E853-13, "Standard Practice for Analysis and Interpretation of Light-Water Reactor Surveillance Results," [Ref. 16] 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" [Ref. 17]. The application of the dpa parameter to the assessment of embrittlement gradients through the thickness of the reactor vessel wall has already been promulgated in Revision 2 to Regulatory Guide 1.99, "Radiation Embrittlement of Reactor Vessel Materials" [Ref. 1].

All of the calculations and dosimetry evaluations described in this section and in Appendix A were based on nuclear cross-section data derived from ENDF/B-VI and used the latest available calculational tools. Furthermore, the neutron transport and dosimetry evaluation methodologies follow the guidance of Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence" [Ref. 18]. 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" [Ref. 19].

6.2 DISCRETE ORDINATES ANALYSIS

The arrangement of the surveillance capsules in the Braidwood Unit 2 reactor vessel is shown in Figure 4-1. Six irradiation capsules attached to the neutron pad are included in the reactor design that constitutes the reactor vessel surveillance program. The capsules are located at azimuthal angles of 58.5°, 61.0°, 121.5°, 238.5°, 241.0°, and 301.5°, as shown in Figure 4-1. These full-core positions correspond to the octant symmetric locations shown in Figures 6-2 and 6-3: 29.0° from the core cardinal axes (for the 61.0° and 241.0° capsules) and 31.5° from the core cardinal axes (for the 58.5°, 121.5°, 238.5°, and 301.5° capsules). The stainless steel specimen containers are 1.63-inch by 1.25-inch and are approximately 60 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 12-foot-high reactor core.

From a neutronic standpoint, the surveillance capsules and associated support structures are significant. The presence of these materials has a significant effect on both the spatial distribution of neutron fluence rate and the neutron spectrum in the vicinity of the capsules. However, the capsules are far enough apart that they do not interfere with one another. In order to determine the neutron environment at the test specimen location, the capsules themselves must be included in the analytical model.

In performing the fast neutron exposure evaluations for the Braidwood 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 $\varphi(r,\theta,z)$ is the synthesized three-dimensional neutron flux distribution, $\varphi(r,\theta)$ is the transport solution in r,θ geometry, $\varphi(r,z)$ is the two-dimensional solution for a cylindrical reactor model using the actual axial core power distribution, and $\varphi(r)$ 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 Braidwood Unit 2.

For the Braidwood Unit 2 transport calculations, the r,θ models depicted in Figure 6-1 through 6-3 were utilized because, with the exception of the neutron pads, the reactor is octant symmetric. These r,θ models include the core, the reactor internals, the neutron pads – including explicit representations of octants not containing surveillance capsules and octants with surveillance capsules at 29° and 31.5°, 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. Likewise, water temperatures, and hence, coolant densities in the reactor core and downcomer regions of the reactor were taken to be representative of full power operating conditions. The coolant densities were treated on a fuel-cycle-specific basis. The reactor core itself was treated as a homogeneous mixture of fuel, cladding, water, and miscellaneous core structures such as fuel assembly grids, guide tubes, et cetera. The geometric mesh description of the r,θ reactor model in Figure 6-1 consisted of 257 radial by 131 azimuthal intervals. The geometric mesh description of the r,θ reactor models in Figure 6-2 and Figure 6-3 consisted of 255 radial by 143 azimuthal intervals. Mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration flux convergence criterion utilized in the r,θ calculations was set at a value of 0.001.

The r,z model used for the Braidwood Unit 2 calculations is shown in Figure 6-4 and extends radially from the centerline of the reactor core out to the primary biological shield and over an axial span from an elevation below the lower core support to several feet 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 153 radial by 216 axial intervals. As in the case of the r,θ calculations, mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration flux convergence criterion utilized in the r,z calculations was also set at a value of 0.001.

The one-dimensional radial model used in the synthesis procedure consisted of the same 153 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 for each of the first 19 fuel cycles at Braidwood Unit 2 included cycle-dependent fuel assembly initial enrichments, burnups, and axial power distributions (note that Cycles 1 through 18 have been completed; Cycle 19 is based on the expected core design for this cycle and an assumed cycle length of 1.5 EFPY). This information was used to develop spatial- and energy-dependent core source distributions averaged over each individual fuel cycle. Therefore, the results from the neutron transport calculations provided data in terms of fuel-cycle-averaged neutron fluence rate, which when multiplied by the appropriate fuel cycle length, generated the incremental fast neutron exposure for each fuel cycle. In constructing these core source distributions, the energy distribution of the source was based on an appropriate fission split for uranium and plutonium isotopes based on the initial ^{235}U 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 [Ref. 22] and the BUGLE-96 cross-section library [Ref. 21]. The BUGLE-96 library provides a coupled 47-neutron, 20-gamma-group cross-section data set produced specifically for light-water reactor (LWR) applications. In these analyses, anisotropic scattering was treated with a P_5 Legendre expansion, and angular discretization was modeled with an S_{16} order of angular quadrature. Energy- and space-dependent core power distributions, as well as system operating temperatures, were treated on a fuel-cycle-specific basis.

Selected results from the neutron transport analyses are provided in Tables 6-1 through 6-12. In Tables 6-1 and 6-2, the calculated exposure rates and integral exposures expressed in terms of fast neutron fluence rate (E > 1.0 MeV) and fast neutron fluence (E > 1.0 MeV), respectively, are given at the radial and azimuthal center of the surveillance capsule positions, i.e., for the 29.0° and 31.5° dual capsule holder locations and 31.5° single capsule holder location. In Tables 6-3 and 6-4, the calculated exposure rates and integral exposures expressed in terms of iron atom displacement rate (dpa/s) and iron atom displacements (dpa), respectively, are given at the radial and azimuthal center of the surveillance capsule positions, i.e., for the 29.0° and 31.5° dual capsule holder locations and 31.5° single capsule holder location. All surveillance capsules have been removed from Braidwood Unit 2, therefore results are not presented beyond Cycle 14 (as there are no capsules receiving fluence). These results, representative of the average axial exposure of the material specimens, establish the calculated exposure of the surveillance capsules.

Similar information in terms of calculated fast neutron fluence rate (E > 1.0 MeV), fast neutron fluence (E > 1.0 MeV), dpa/s, and dpa, are provided in Tables 6-5 through 6-8, for the reactor vessel inner radius at four azimuthal locations, as well as the maximum exposure observed within the octant. The vessel data given in Tables 6-5 through 6-8 were taken at the clad/base metal interface and represent maximum calculated exposure levels on the vessel. From the data provided in Table 6-6, it is noted that the peak clad/base metal interface vessel fluence (E > 1.0 MeV) at the end of Cycle 18 (i.e., after 24.07 EFPY of plant operation) was 1.25E+19 n/cm^2.

Table 6-6 and Table 6-8 include both plant- and fuel-cycle-specific calculated neutron exposures at the end of Cycle 18, at the end of projected Cycle 19, and at further projections to 60 EFPY. The calculations account for the uprate from 3411 MWt to 3586.6 MWt that occurred during Cycle 9, and incorporate an uprate from 3586.6 MWt to 3645 MWt that occurred during Cycle 17. The uprated reactor power level is however represented by 3658 MW to account for calorimetric uncertainties. The projections are based on the assumption that the average core power distributions and associated plant operating characteristics from the designs of Cycles 18 and 19 are representative of future plant operation. The future projections are based on the uprated reactor power level of 3645 MWt, but represented by 3658 MW to account for calorimetric uncertainty.

The calculated fast neutron exposures for all six surveillance capsules withdrawn from the Braidwood Unit 2 reactor are provided in Table 6-9. These neutron exposure levels are based on the plant- and fuel-cycle-specific neutron transport calculations performed for the Braidwood Unit 2 reactor. From the data provided in Table 6-9, Capsule V received a fast neutron fluence (E > 1.0 MeV) of 3.73E+19 n/cm^2 after exposure through the end of the 14th fuel cycle (i.e., after 18.41 EFPY).

Updated lead factors for the Braidwood Unit 2 surveillance capsules are provided in Table 6-10. The capsule lead factor is defined as the ratio of the calculated fluence (E > 1.0 MeV) at the geometric radial and azimuthal center of the surveillance capsule to the corresponding maximum calculated fluence at the pressure vessel clad/base metal interface. In Table 6-10, the lead factors for capsules that have been withdrawn from the reactor (Capsules U, W, X, V, Z, and Y) were based on the calculated fluence values for the irradiation period corresponding to the time of withdrawal for the individual capsules.

Table 6-11 presents the maximum fast neutron fluences (E > 1.0 MeV) and Table 6-12 presents the maximum dpa for pressure vessel materials.

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 V, which was withdrawn from Braidwood Unit 2 at the end of the 14th fuel cycle, is summarized below.

Reaction	**Reaction Rate (rps/atom)**		**M/C**
	Measured (M)	**Calculated (C)**	
Cu-63(n,α)Co-60	4.02E-17	3.57E-17	1.13
Fe-54(n,p)Mn-54	3.82E-15	3.86E-15	0.99
U-238(Cd)(n,f)Cs-137	2.20E-14	2.06E-14	1.07
Np-237(Cd)(n,f)Cs-137	1.99E-13	1.99E-13	1.00
Average			1.05
% Standard Deviation			6.3

The measured-to-calculated (M/C) reaction rate ratios for the Capsule V threshold reactions range from 0.99 to 1.13, and the average M/C ratio is 1.05 ± 6.3% (1σ). This direct comparison falls within the ± 20% criterion specified in Regulatory Guide 1.190 [Ref. 18]. This comparison validates the current analytical results described in Section 6.2; therefore, the calculations are deemed applicable for Braidwood Unit 2.

6.4 CALCULATIONAL UNCERTAINTIES

The uncertainty associated with the calculated neutron exposure of the Braidwood 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 Braidwood 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 Braidwood Unit 2 analysis was established from results of these three phases of the methods qualification.

The fourth phase of the uncertainty assessment (comparisons with Braidwood 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 Braidwood 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 20.

Description	**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 Braidwood Unit 2.

Table 6-1 Calculated Fast Neutron Fluence Rate (E > 1.0 MeV) at the Surveillance Capsule Center at Core Midplane for Cycles 1-14

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	Neutron Fluence Rate (n/cm^2-s)		
			Dual Capsule Holder		Single Capsule Holder
			29.0°	31.5°	31.5°
1	1.18	1.18	9.61E+10	1.04E+11	1.03E+11
2	1.12	2.30	6.98E+10	7.86E+10	7.76E+10
3	1.12	3.42	7.27E+10	7.91E+10	7.80E+10
4A[(a)]	0.82	4.24	7.16E+10	7.79E+10	7.68E+10
4B[(a)]	0.34	4.58	7.23E+10	7.87E+10	7.76E+10
5	1.27	5.85	6.34E+10	6.84E+10	6.74E+10
6	1.34	7.19	6.31E+10	6.87E+10	6.78E+10
7	1.37	8.56	6.65E+10	6.92E+10	6.81E+10
8	1.40	9.96	5.88E+10	6.16E+10	6.07E+10
9	1.36	11.33	5.41E+10	5.88E+10	5.80E+10
10	1.45	12.78	5.08E+10	5.53E+10	5.46E+10
11	1.38	14.15	5.45E+10	5.94E+10	5.86E+10
12	1.44	15.60	6.19E+10	6.57E+10	6.47E+10
13	1.45	17.04	6.11E+10	6.45E+10	6.36E+10
14	1.37	18.41	6.26E+10	6.69E+10	6.60E+10

Note:

(a) Cycle 4 was divided into sub-cycles 4A and 4B because surveillance Capsule X was removed during a mid-cycle outage in Cycle 4.

Table 6-2 Calculated Fast Neutron Fluence (E > 1.0 MeV) at the Surveillance Capsule Center at Core Midplane for Cycles 1-14

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	Neutron Fluence (n/cm^2)		
			Dual Capsule Holder		Single Capsule Holder
			29.0°	31.5°	31.5°
1	1.18	1.18	3.57E+18	3.87E+18	3.81E+18
2	1.12	2.30	6.04E+18	6.65E+18	6.57E+18
3	1.12	3.42	8.60E+18	9.44E+18	9.31E+18
4A	0.82	4.24	1.05E+19	1.15E+19	1.13E+19
4B	0.34	4.58	1.12E+19	1.23E+19	1.21E+19
5	1.27	5.85	1.38E+19	1.50E+19	1.48E+19
6	1.34	7.19	1.64E+19	1.79E+19	1.77E+19
7	1.37	8.56	1.93E+19	2.09E+19	2.07E+19
8	1.40	9.96	2.19E+19	2.37E+19	2.33E+19
9	1.36	11.33	2.43E+19	2.62E+19	2.58E+19
10	1.45	12.78	2.66E+19	2.87E+19	2.83E+19
11	1.38	14.15	2.89E+19	3.13E+19	3.09E+19
12	1.44	15.60	3.18E+19	3.43E+19	3.38E+19
13	1.45	17.04	3.46E+19	3.72E+19	3.67E+19
14	1.37	18.41	3.73E+19	4.01E+19	3.96E+19

Table 6-3 Calculated Iron Atom Displacement Rate at the Surveillance Capsule Center and at Core Midplane for Cycles 1-14

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	Iron Atom Displacement Rate (dpa/s)		
			Dual Capsule Holder		Single Capsule Holder
			29.0°	31.5°	31.5°
1	1.18	1.18	1.89E-10	2.05E-10	2.02E-10
2	1.12	2.30	1.37E-10	1.54E-10	1.52E-10
3	1.12	3.42	1.42E-10	1.55E-10	1.53E-10
4A	0.82	4.24	1.40E-10	1.53E-10	1.50E-10
4B	0.34	4.58	1.42E-10	1.54E-10	1.52E-10
5	1.27	5.85	1.24E-10	1.34E-10	1.32E-10
6	1.34	7.19	1.23E-10	1.34E-10	1.32E-10
7	1.37	8.56	1.30E-10	1.35E-10	1.33E-10
8	1.40	9.96	1.15E-10	1.20E-10	1.18E-10
9	1.36	11.33	1.06E-10	1.15E-10	1.13E-10
10	1.45	12.78	9.90E-11	1.08E-10	1.06E-10
11	1.38	14.15	1.06E-10	1.16E-10	1.14E-10
12	1.44	15.60	1.21E-10	1.28E-10	1.26E-10
13	1.45	17.04	1.19E-10	1.26E-10	1.24E-10
14	1.37	18.41	1.22E-10	1.30E-10	1.28E-10

Table 6-4 Calculated Iron Atom Displacements at the Surveillance Capsule Center at Core Midplane for Cycles 1-14

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	Iron Atom Displacements (dpa)		
			Dual Capsule Holder		Single Capsule Holder
			29.0°	31.5°	31.5°
1	1.18	1.18	7.03E-03	7.62E-03	7.50E-03
2	1.12	2.30	1.19E-02	1.31E-02	1.29E-02
3	1.12	3.42	1.69E-02	1.85E-02	1.83E-02
4A	0.82	4.24	2.06E-02	2.25E-02	2.22E-02
4B	0.34	4.58	2.21E-02	2.41E-02	2.38E-02
5	1.27	5.85	2.70E-02	2.95E-02	2.91E-02
6	1.34	7.19	3.22E-02	3.52E-02	3.47E-02
7	1.37	8.56	3.79E-02	4.10E-02	4.04E-02
8	1.40	9.96	4.30E-02	4.63E-02	4.56E-02
9	1.36	11.33	4.75E-02	5.13E-02	5.05E-02
10	1.45	12.78	5.20E-02	5.62E-02	5.53E-02
11	1.38	14.15	5.66E-02	6.12E-02	6.03E-02
12	1.44	15.60	6.21E-02	6.71E-02	6.60E-02
13	1.45	17.04	6.76E-02	7.28E-02	7.17E-02
14	1.37	18.41	7.29E-02	7.84E-02	7.72E-02

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

Cycle	Cycle Length (EFPY)	Total Time (EFPY)	Neutron Fluence Rate (n/cm²-s)				
			0°	15°	30°	45°	Maximum
1	1.18	1.18	1.27E+10	2.04E+10	2.28E+10	2.55E+10	2.55E+10
2	1.12	2.3	1.01E+10	1.48E+10	1.79E+10	2.11E+10	2.11E+10
3	1.12	3.42	1.02E+10	1.54E+10	1.75E+10	1.94E+10	1.94E+10
4A	0.82	4.24	1.04E+10	1.55E+10	1.72E+10	1.90E+10	1.90E+10
4B	0.34	4.58	1.04E+10	1.56E+10	1.74E+10	1.93E+10	1.93E+10
5	1.27	5.85	9.69E+09	1.43E+10	1.58E+10	1.68E+10	1.68E+10
6	1.34	7.19	9.38E+09	1.42E+10	1.59E+10	1.72E+10	1.72E+10
7	1.37	8.56	8.00E+09	1.41E+10	1.63E+10	1.47E+10	1.75E+10
8	1.40	9.96	9.16E+09	1.38E+10	1.47E+10	1.30E+10	1.58E+10
9	1.36	11.33	9.08E+09	1.21E+10	1.32E+10	1.35E+10	1.36E+10
10	1.45	12.78	8.25E+09	1.12E+10	1.27E+10	1.28E+10	1.30E+10
11	1.38	14.15	9.34E+09	1.25E+10	1.37E+10	1.41E+10	1.41E+10
12	1.44	15.60	9.04E+09	1.38E+10	1.53E+10	1.46E+10	1.62E+10
13	1.45	17.04	8.80E+09	1.35E+10	1.49E+10	1.35E+10	1.57E+10
14	1.37	18.41	9.80E+09	1.42E+10	1.58E+10	1.51E+10	1.64E+10
15	1.43	19.85	9.50E+09	1.47E+10	1.61E+10	1.51E+10	1.73E+10
16	1.41	21.26	9.92E+09	1.51E+10	1.63E+10	1.50E+10	1.76E+10
17	1.45	22.71	9.38E+09	1.48E+10	1.61E+10	1.48E+10	1.74E+10
18	1.36	24.07	1.04E+10	1.44E+10	1.50E+10	1.53E+10	1.59E+10
19[(a)]	1.50	25.57	9.32E+09	1.42E+10	1.60E+10	1.51E+10	1.69E+10

Note:

(a) Values beyond end of cycle (EOC) 18 are projected. Braidwood Unit 2 is currently operating in Cycle 19. Cycle 19 core design was used with an assumed cycle length of 1.5 EFPY.

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

Cycle ID	Cycle Length (EFPY)	Total Time (EFPY)	Neutron Fluence (n/cm^2)				
			0°	15°	30°	45°	Maximum
1	1.18	1.18	4.71E+17	7.56E+17	8.48E+17	9.47E+17	9.47E+17
2	1.12	2.3	8.17E+17	1.26E+18	1.46E+18	1.67E+18	1.67E+18
3	1.12	3.42	1.18E+18	1.80E+18	2.07E+18	2.35E+18	2.35E+18
4A	0.82	4.24	1.45E+18	2.21E+18	2.52E+18	2.84E+18	2.84E+18
4B	0.34	4.58	1.56E+18	2.37E+18	2.70E+18	3.05E+18	3.05E+18
5	1.27	5.85	1.94E+18	2.94E+18	3.33E+18	3.72E+18	3.72E+18
6	1.34	7.19	2.34E+18	3.54E+18	4.00E+18	4.45E+18	4.45E+18
7	1.37	8.56	2.69E+18	4.15E+18	4.71E+18	5.09E+18	5.09E+18
8	1.40	9.96	3.09E+18	4.76E+18	5.36E+18	5.66E+18	5.66E+18
9	1.36	11.33	3.48E+18	5.28E+18	5.92E+18	6.23E+18	6.23E+18
10	1.45	12.78	3.85E+18	5.79E+18	6.50E+18	6.82E+18	6.82E+18
11	1.38	14.15	4.26E+18	6.33E+18	7.10E+18	7.43E+18	7.43E+18
12	1.44	15.60	4.65E+18	6.93E+18	7.76E+18	8.06E+18	8.09E+18
13	1.45	17.04	5.05E+18	7.54E+18	8.44E+18	8.68E+18	8.81E+18
14	1.37	18.41	5.47E+18	8.16E+18	9.12E+18	9.33E+18	9.52E+18
15	1.43	19.85	5.90E+18	8.82E+18	9.85E+18	1.00E+19	1.03E+19
16	1.41	21.26	6.35E+18	9.50E+18	1.06E+19	1.07E+19	1.11E+19
17	1.45	22.71	6.78E+18	1.02E+19	1.13E+19	1.14E+19	1.19E+19
18	1.36	24.07	7.19E+18	1.07E+19	1.19E+19	1.20E+19	1.25E+19
19[(a)]	1.50	25.57	7.63E+18	1.14E+19	1.27E+19	1.27E+19	1.33E+19
		32.00	9.63E+18	1.43E+19	1.58E+19	1.58E+19	1.66E+19
		36.00	1.09E+19	1.61E+19	1.78E+19	1.77E+19	1.87E+19
		40.00	1.21E+19	1.79E+19	1.97E+19	1.96E+19	2.08E+19
		44.00	1.34E+19	1.97E+19	2.17E+19	2.15E+19	2.28E+19
		48.00	1.46E+19	2.15E+19	2.36E+19	2.35E+19	2.49E+19
		52.00	1.59E+19	2.33E+19	2.56E+19	2.54E+19	2.70E+19
		54.00	1.65E+19	2.42E+19	2.66E+19	2.63E+19	2.80E+19
		57.00	1.74E+19	2.56E+19	2.81E+19	2.78E+19	2.95E+19
		60.00	1.84E+19	2.69E+19	2.95E+19	2.92E+19	3.11E+19

Note:

(a) Values beyond EOC 18 are projected. Braidwood Unit 2 is currently operating in Cycle 19. Cycle 19 core design was used with an assumed cycle length of 1.5 EFPY.

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

Cycle ID	Cycle Length (EFPY)	Total Time (EFPY)	Iron Atom Displacement Rate (dpa/s)				
			0°	15°	30°	45°	Maximum
1	1.18	1.18	1.97E-11	3.13E-11	3.53E-11	4.04E-11	4.04E-11
2	1.12	2.3	1.57E-11	2.28E-11	2.76E-11	3.33E-11	3.33E-11
3	1.12	3.42	1.59E-11	2.37E-11	2.70E-11	3.07E-11	3.07E-11
4A	0.82	4.24	1.61E-11	2.39E-11	2.66E-11	3.01E-11	3.01E-11
4B	0.34	4.58	1.62E-11	2.41E-11	2.69E-11	3.05E-11	3.05E-11
5	1.27	5.85	1.51E-11	2.20E-11	2.44E-11	2.66E-11	2.66E-11
6	1.34	7.19	1.46E-11	2.19E-11	2.46E-11	2.71E-11	2.71E-11
7	1.37	8.56	1.25E-11	2.17E-11	2.52E-11	2.34E-11	2.68E-11
8	1.40	9.96	1.43E-11	2.12E-11	2.27E-11	2.06E-11	2.43E-11
9	1.36	11.33	1.41E-11	1.87E-11	2.05E-11	2.14E-11	2.14E-11
10	1.45	12.78	1.28E-11	1.73E-11	1.97E-11	2.02E-11	2.02E-11
11	1.38	14.15	1.45E-11	1.93E-11	2.12E-11	2.24E-11	2.24E-11
12	1.44	15.60	1.41E-11	2.13E-11	2.36E-11	2.31E-11	2.48E-11
13	1.45	17.04	1.37E-11	2.08E-11	2.30E-11	2.14E-11	2.42E-11
14	1.37	18.41	1.52E-11	2.18E-11	2.44E-11	2.39E-11	2.52E-11
15	1.43	19.85	1.48E-11	2.27E-11	2.48E-11	2.40E-11	2.65E-11
16	1.41	21.26	1.54E-11	2.32E-11	2.52E-11	2.38E-11	2.70E-11
17	1.45	22.71	1.46E-11	2.27E-11	2.49E-11	2.35E-11	2.67E-11
18	1.36	24.07	1.62E-11	2.21E-11	2.31E-11	2.42E-11	2.43E-11
19[(a)]	1.50	25.57	1.45E-11	2.19E-11	2.48E-11	2.39E-11	2.59E-11

Note:

(a) Values beyond EOC 18 are projected. Braidwood Unit 2 is currently operating in cycle 19. Cycle 19 core design was used with an assumed cycle length of 1.5 EFPY.

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

Cycle ID	Cycle Length (EFPY)	Total Time (EFPY)	Iron Atom Displacements (dpa)				
			0°	15°	30°	45°	Maximum
1	1.18	1.18	7.33E-04	1.16E-03	1.31E-03	1.50E-03	1.50E-03
2	1.12	2.3	1.27E-03	1.94E-03	2.25E-03	2.64E-03	2.64E-03
3	1.12	3.42	1.83E-03	2.78E-03	3.20E-03	3.72E-03	3.72E-03
4A	0.82	4.24	2.25E-03	3.40E-03	3.89E-03	4.50E-03	4.50E-03
4B	0.34	4.58	2.42E-03	3.65E-03	4.18E-03	4.82E-03	4.82E-03
5	1.27	5.85	3.02E-03	4.53E-03	5.15E-03	5.88E-03	5.88E-03
6	1.34	7.19	3.64E-03	5.45E-03	6.19E-03	7.03E-03	7.03E-03
7	1.37	8.56	4.18E-03	6.39E-03	7.28E-03	8.04E-03	8.04E-03
8	1.40	9.96	4.81E-03	7.33E-03	8.28E-03	8.96E-03	8.96E-03
9	1.36	11.33	5.41E-03	8.12E-03	9.15E-03	9.86E-03	9.86E-03
10	1.45	12.78	5.99E-03	8.91E-03	1.00E-02	1.08E-02	1.08E-02
11	1.38	14.15	6.62E-03	9.75E-03	1.10E-02	1.18E-02	1.18E-02
12	1.44	15.60	7.23E-03	1.07E-02	1.20E-02	1.28E-02	1.28E-02
13	1.45	17.04	7.86E-03	1.16E-02	1.30E-02	1.37E-02	1.37E-02
14	1.37	18.41	8.51E-03	1.26E-02	1.41E-02	1.48E-02	1.48E-02
15	1.43	19.85	9.18E-03	1.36E-02	1.52E-02	1.58E-02	1.58E-02
16	1.41	21.26	9.87E-03	1.46E-02	1.63E-02	1.69E-02	1.70E-02
17	1.45	22.71	1.05E-02	1.57E-02	1.75E-02	1.80E-02	1.82E-02
18	1.36	24.07	1.12E-02	1.65E-02	1.84E-02	1.89E-02	1.92E-02
19[(a)]	1.50	25.57	1.19E-02	1.76E-02	1.96E-02	2.01E-02	2.04E-02
		32.00	1.50E-02	2.20E-02	2.44E-02	2.50E-02	2.55E-02
		36.00	1.69E-02	2.48E-02	2.74E-02	2.80E-02	2.87E-02
		40.00	1.89E-02	2.76E-02	3.05E-02	3.10E-02	3.18E-02
		44.00	2.08E-02	3.04E-02	3.35E-02	3.41E-02	3.50E-02
		48.00	2.27E-02	3.32E-02	3.65E-02	3.71E-02	3.82E-02
		52.00	2.47E-02	3.59E-02	3.95E-02	4.01E-02	4.13E-02
		54.00	2.56E-02	3.73E-02	4.11E-02	4.17E-02	4.29E-02
		57.00	2.71E-02	3.94E-02	4.33E-02	4.39E-02	4.53E-02
		60.00	2.86E-02	4.15E-02	4.56E-02	4.62E-02	4.77E-02

Note:

(a) Values beyond EOC 18 are projected. Braidwood Unit 2 is currently operating in cycle 19. Cycle 19 core design was used with an assumed cycle length of 1.5 EFPY.

Table 6-9 Calculated Fast Neutron Exposure of Surveillance Capsules Withdrawn from Braidwood Unit 2

Capsule	Irradiation Cycle(s)	Cumulative Irradiation Time (EFPY)	Neutron Fluence (E > 1.0 MeV) (n/cm^2)	Iron Atom Displacements (dpa)
U	1	1.18	3.87E+18	7.62E-03
X	1-4A	4.24	1.15E+19	2.25E-02
W	1-7	8.56	2.07E+19	4.04E-02
V	1-14	18.41	3.73E+19	7.29E-02
Y[(a)]	1-10	12.78	2.66E+19	5.20E-02
Z[(a)]	1-10	12.78	2.83E+19	5.53E-02

Note:

(a) Capsules Y and Z were removed and placed in the spent fuel pool. No testing or analysis has been performed on these capsules.

Table 6-10 Calculated Surveillance Capsule Lead Factors

Capsule Location	Status	Lead Factor[(b)]
58.5° (Capsule U)	Withdrawn EOC 1	4.08
238.5° (Capsule X)	Withdrawn during a mid-cycle outage in Cycle 4	4.03
121.5° (Capsule W)	Withdrawn EOC 7	4.06
61° (Capsule V)	Withdrawn EOC 14	3.92
241° (Capsule Y) [(a)]	Withdrawn EOC 10	3.90
301.5° (Capsule Z)[(a)]	Withdrawn EOC 10	4.15

Notes:

(a) Capsules Y and Z were removed and placed in the spent fuel pool. No testing or analysis has been performed on these capsules.

(b) The capsule lead factors are slightly different from those determined in Reference 23 (for example, 3.90 vs 3.89 for Capsule Y). These differences could be attributed to the change from RadTrack Version 1.1.1 to 2.0 or some input data may now carry more significant figures. RadTrack is a graphical user interface (GUI) that encompasses Westinghouse's currently-approved fluence calculation and dosimetry analysis methodology.

Table 6-11 Calculated Maximum Fast Neutron Fluence (E > 1.0 MeV) at the Pressure Vessel Welds and Shells

Material	Fast Neutron Fluence (n/cm^2)			
	24.07 EFPY	25.57 EFPY	30 EFPY	36 EFPY
Outlet Nozzle Forging to Vessel Shell Welds (WR-20)	3.26E+16	3.50E+16	4.48E+16	5.10E+16
Inlet Nozzle Forging to Vessel Shell Welds (WR-19)	4.33E+16	4.64E+16	5.95E+16	6.76E+16
Nozzle Shell	4.11E+18	4.38E+18	5.53E+18	6.25E+18
Nozzle Shell to Intermediate Shell Circumferential Weld (WR-34)	4.11E+18	4.38E+18	5.53E+18	6.25E+18
Intermediate Shell	1.24E+19	1.32E+19	1.65E+19	1.85E+19
Intermediate Shell to Lower Shell Circumferential Weld (WR-18)	1.21E+19	1.29E+19	1.59E+19	1.79E+19
Lower Shell	1.25E+19	1.33E+19	1.65E+19	1.85E+19
Lower Shell to Lower Vessel Head Circumferential Weld (WR-29)	5.62E+15	5.99E+15	7.44E+15	8.34E+15

Material	Fast Neutron Fluence (n/cm^2)			
	48 EFPY	54 EFPY	57 EFPY	60 EFPY
Outlet Nozzle Forging to Vessel Shell Welds (WR-20)	6.95E+16	7.87E+16	8.33E+16	8.79E+16
Inlet Nozzle Forging to Vessel Shell Welds (WR-19)	9.20E+16	1.04E+17	1.10E+17	1.16E+17
Nozzle Shell	8.40E+18	9.48E+18	1.00E+19	1.06E+19
Nozzle Shell to Intermediate Shell Circumferential Weld (WR-34)	8.40E+18	9.48E+18	1.00E+19	1.06E+19
Intermediate Shell	2.46E+19	2.77E+19	2.92E+19	3.08E+19
Intermediate Shell to Lower Shell Circumferential Weld (WR-18)	2.37E+19	2.65E+19	2.80E+19	2.94E+19
Lower Shell	2.45E+19	2.75E+19	2.89E+19	3.04E+19
Lower Shell to Lower Vessel Head Circumferential Weld (WR-29)	1.10E+16	1.24E+16	1.31E+16	1.37E+16

Table 6-12 Calculated Maximum Iron Atom Displacements at the Pressure Vessel Welds and Shells

Material	Iron Atom Displacements (dpa)			
	24.07 EFPY	25.57 EFPY	30 EFPY	36 EFPY
Outlet Nozzle Forging to Vessel Shell Welds (WR-20)	8.64E-05	9.18E-05	1.16E-04	1.31E-04
Inlet Nozzle Forging to Vessel Shell Welds (WR-19)	9.59E-05	1.02E-04	1.29E-04	1.45E-04
Nozzle Shell	6.30E-03	6.71E-03	8.48E-03	9.58E-03
Nozzle Shell to Intermediate Shell Circumferential Weld (WR-34)	6.30E-03	6.71E-03	8.48E-03	9.58E-03
Intermediate Shell	1.90E-02	2.02E-02	2.53E-02	2.84E-02
Intermediate Shell to Lower Shell Circumferential Weld (WR-18)	1.86E-02	1.98E-02	2.45E-02	2.75E-02
Lower Shell	1.92E-02	2.04E-02	2.53E-02	2.84E-02
Lower Shell to Lower Vessel Head Circumferential Weld (WR-29)	3.55E-05	3.77E-05	4.67E-05	5.23E-05

Material	Iron Atom Displacements (dpa)			
	48 EFPY	54 EFPY	57 EFPY	60 EFPY
Outlet Nozzle Forging to Vessel Shell Welds (WR-20)	1.75E-04	1.98E-04	2.09E-04	2.20E-04
Inlet Nozzle Forging to Vessel Shell Welds (WR-19)	1.95E-04	2.20E-04	2.32E-04	2.44E-04
Nozzle Shell	1.29E-02	1.45E-02	1.54E-02	1.62E-02
Nozzle Shell to Intermediate Shell Circumferential Weld (WR-34)	1.29E-02	1.45E-02	1.54E-02	1.62E-02
Intermediate Shell	3.78E-02	4.25E-02	4.49E-02	4.72E-02
Intermediate Shell to Lower Shell Circumferential Weld (WR-18)	3.64E-02	4.09E-02	4.31E-02	4.53E-02
Lower Shell	3.75E-02	4.21E-02	4.44E-02	4.67E-02
Lower Shell to Lower Vessel Head Circumferential Weld (WR-29)	6.92E-05	7.76E-05	8.19E-05	8.61E-05

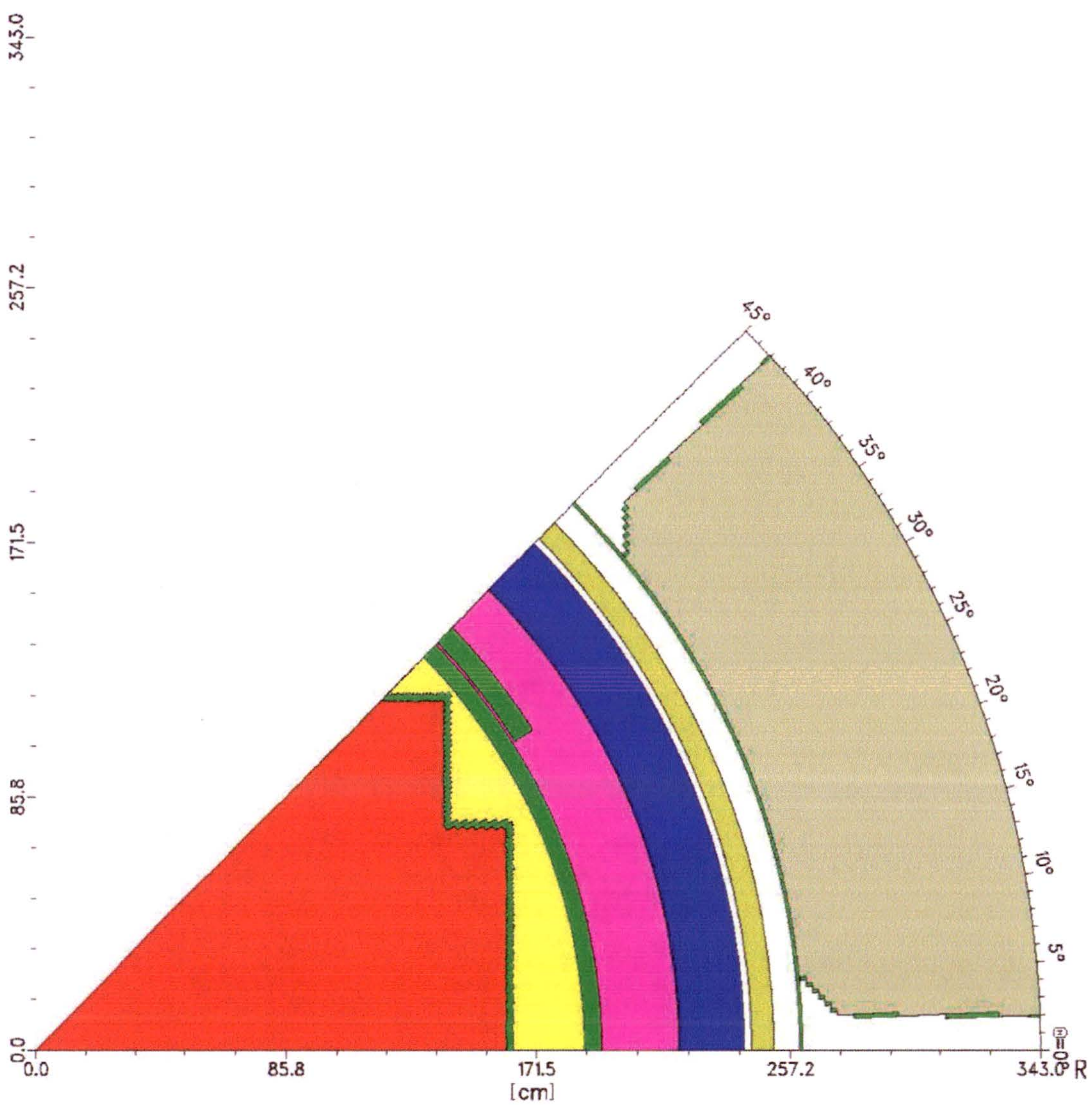


Figure 6-1 Braidwood Unit 2 r,θ Reactor Geometry Plan View at the Core Midplane without Surveillance Capsules and 12.5° Neutron Pad Configuration

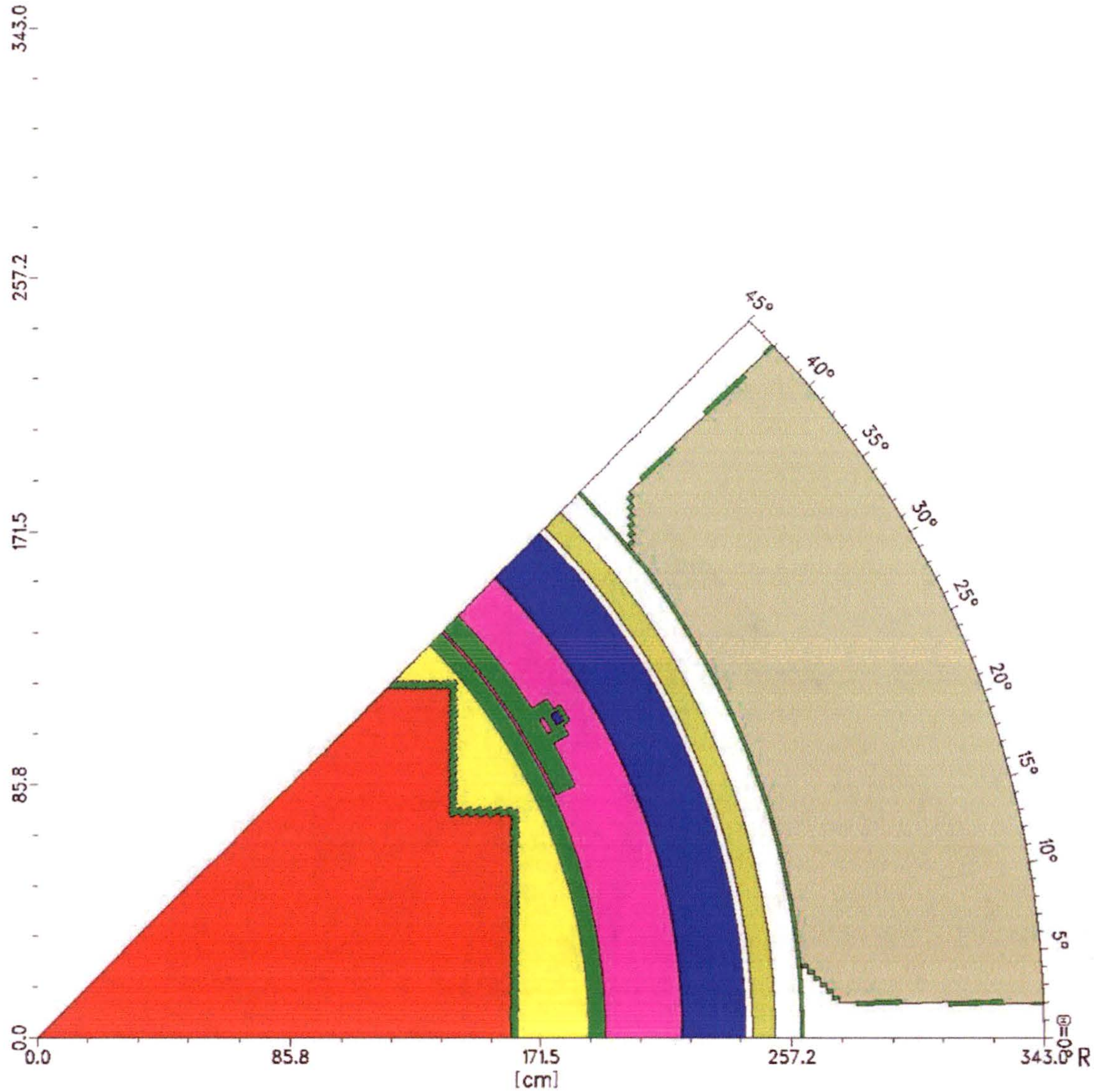


Figure 6-2 Braidwood Unit 2 r,θ Reactor Geometry Plan View at the Core Midplane with a Single Capsule Holder and 20.0° Neutron Pad Configuration

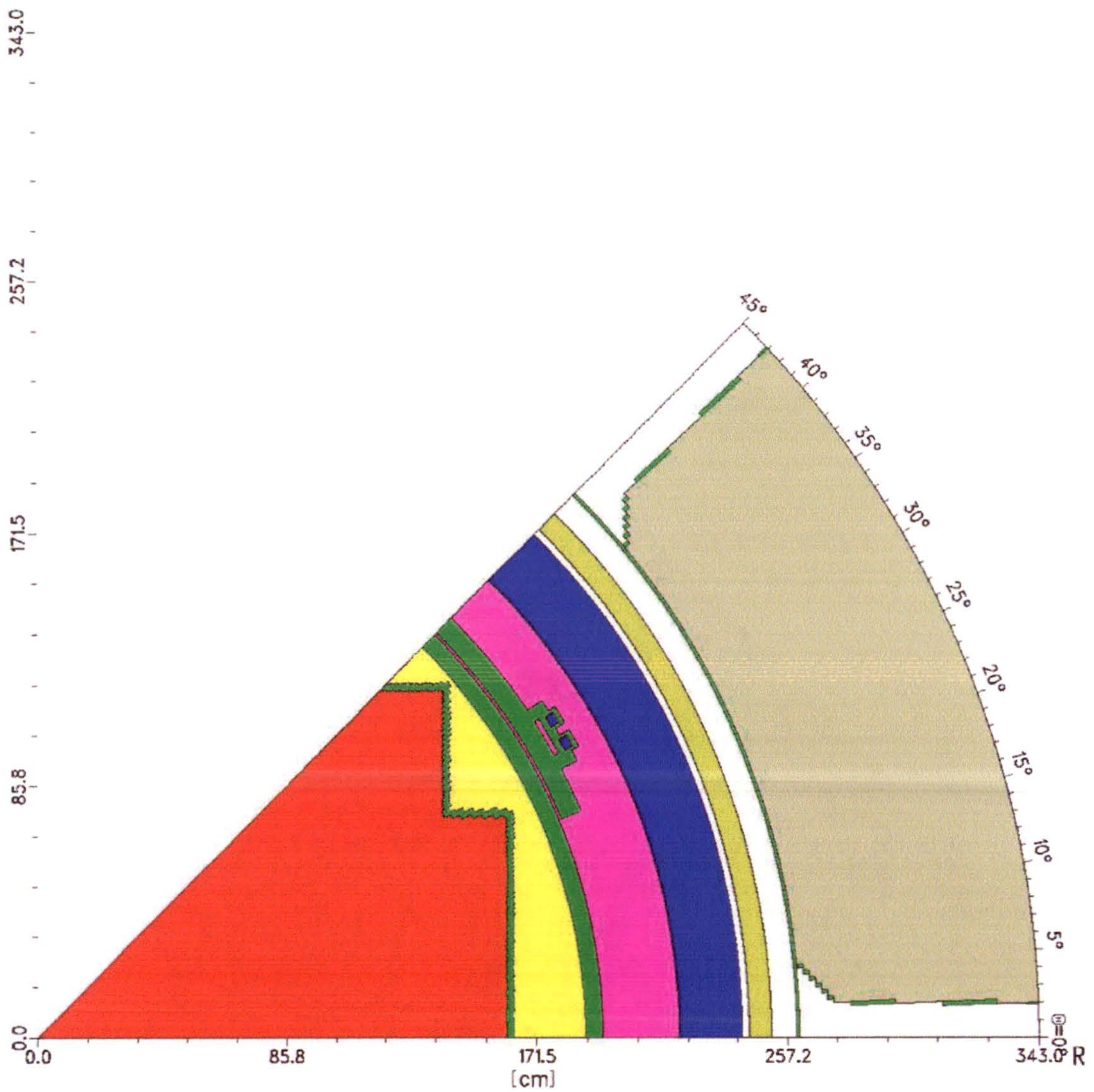


Figure 6-3 Braidwood Unit 2 r,θ Reactor Geometry Plan View at the Core Midplane with a Dual Capsule Holder and 22.5° Neutron Pad Configuration

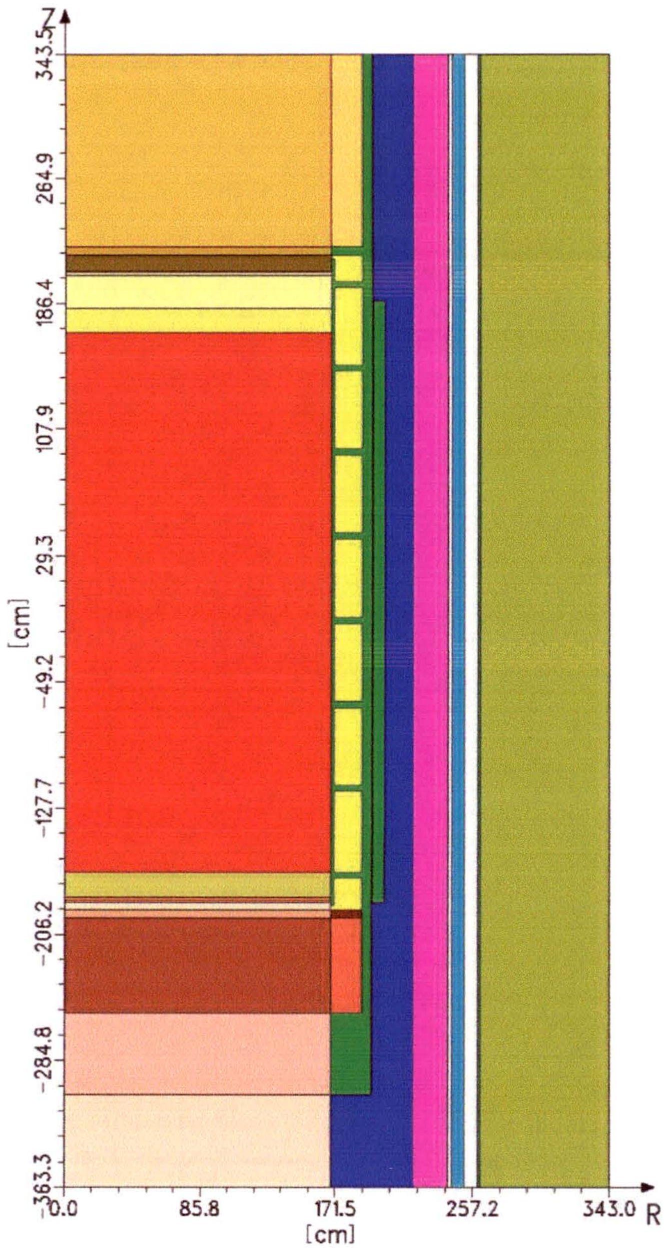


Figure 6-4 Braidwood Unit 2 r,z Reactor Geometry Elevation View

7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following surveillance capsule removal schedule (Table 7-1) meets the requirements of ASTM E185-82 [Ref. 4].

Table 7-1 Surveillance Capsule Withdrawal Schedule

Capsule ID and Location	Status	Capsule Lead Factor[(a)]	Withdrawal EFPY[(b, c)]	Capsule Fluence (n/cm^2, E > 1.0 MeV)[(c)]
U (58.5°)	Withdrawn (EOC 1)	4.08	1.18	3.87E+18
X (238.5°)	Withdrawn (EOC 4A)	4.03	4.24	1.15E+19
W (121.5°)	Withdrawn (EOC 7)	4.06	8.56	2.07E+19
Z[(d)] (301.5°)	Withdrawn (EOC 10)	4.15	12.78	2.83E+19
Y[(e)] (241.0°)	Withdrawn (EOC 10)	3.90	12.78	2.66E+19
V[(f)] (61.0°)	Withdrawn (EOC 14)	3.92	18.41	3.73E+19

Notes:

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

(b) EFPY from plant startup.

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

(d) Capsule Z was removed and placed in the spent fuel pool. Capsule Z could be reinserted into the Braidwood Unit 2 reactor vessel to provide meaningful metallurgical data for 80 years of plant operation. If Capsule Z were reinserted into either vacant 31.5° dual-capsule location, it would receive the projected 80-year (76 EFPY) fluence of 3.96×10^{19} n/cm^2 in 5.4 EFPY. Capsule Z would exceed two times the projected 80-year (76 EFPY) fluence of 7.93×10^{19} n/cm^2 in 24.2 EFPY. However, since the Braidwood Unit 2 surveillance capsule positions have relatively high fast flux, reinsertion of this capsule can be revisited at a later date if an additional 20-year license extension is sought.

(e) Capsule Y should remain in the spent fuel pool. Potential reinsertion and/or testing of this capsule can be revisited at a later date if additional metallurgical data are needed for Braidwood Unit 2.

(f) The neutron fluence exposure of Capsule V is greater than once, but less than twice the peak vessel fluence (2.95×10^{19} n/cm^2) at 57 EFPY; therefore, Capsule V satisfies the requirements for a license renewal capsule for 60 years of plant operation.

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

A.1.1 Sensor Reaction Rate Determinations

In this section, the results of the evaluations of the four surveillance capsules analyzed to date as part of the Braidwood 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)
Surveillance Capsule U	58.5°	End of Cycle 1	1.18
Surveillance Capsule X	238.5°	During a mid-cycle outage in Cycle 4	4.24
Surveillance Capsule W	121.5°	End of Cycle 7	8.56
Surveillance Capsule V	61°	End of Cycle 14	18.41

The passive neutron sensors included in the evaluations of surveillance Capsules U, X, W, and V are summarized as follows:

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

Notes:

(a) The nickel monitors were not considered for Capsule V. The reaction product has a relatively short half-life (70.82 days, see Table A-1), and decayed away beyond utility in the intervening period between when Capsule V was pulled (October 2009) and when it was counted (December 2015).

(b) The cobalt-aluminum monitors for this plant include both bare and cadmium-covered sensors.

This section also includes the results of the evaluations of the four midplane EVND capsules and two off-midplane capsules analyzed to date. The EVND was irradiated during Cycle 14, then removed and analyzed. The capsule designation, azimuthal location outside the vessel, and axial location were as follows:

Capsule	Azimuthal Location from Cardinal Axis	Axial Location
EVND Capsule A	0.5°	Core Midplane
EVND Capsule B	14.5°	Core Midplane
EVND Capsule C	29.5°	Core Midplane
EVND Capsule E	44.5°	Core Midplane
EVND Capsule D	44.5°	Top of Active Core
EVND Capsule F	44.5°	Bottom of Active Core

The passive neutron sensors included in the evaluations of EVND Capsules A, B, C, D, E, and F are summarized as follows:

Sensor Material	Reaction Of Interest	Capsule A	Capsule B	Capsule C	Capsule D	Capsule E	Capsule F
Copper	$^{63}Cu(n,\alpha)^{60}Co$	X	X	X	X	X	X
Titanium	$^{46}Ti(n,p)^{46}Sc$	X	X	X	X	X	X
Iron	$^{54}Fe(n,p)^{54}Mn$	X	X	X	X	X	X
Nickel	$^{58}Ni(n,p)^{58}Co$	X	X	X	X	X	X
Niobium	$^{93}Nb(n,n')^{93m}Nb$	X	X	X	X	X	X
Cobalt-Aluminum[(a)]	$^{59}Co(n,\gamma)^{60}Co$	X	X	X	X	X	X

Note:

(a) The cobalt-aluminum monitors for this plant include both bare and cadmium-covered sensors.

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

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

Results from the radiometric counting of the neutron sensors from Capsules U, X, and W are documented in References A-2, A-3, and A-4, respectively. The radiometric counting of the sensors from Capsule V was carried out by Pace Analytical Services, Inc. The radiometric counting followed established ASTM procedures. Results from the radiometric counting of EVND irradiated during Cycle 14 are documented in Reference A-5.

The irradiation history of the reactor over the irradiation periods experienced by Capsules U, X, W and V was based on the monthly thermal power generation of Braidwood Unit 2 from initial reactor criticality through the end of the dosimetry evaluation period. Analysis of the EVND used Cycle 14 monthly thermal generation data. For the sensor sets utilized in the surveillance capsules and EVND, 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 surveillance Capsules U, X, W, and V and EVND irradiated during Cycle 14 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 ϕ (E > 1.0 MeV) during irradiation period j to the time weighted average ϕ (E > 1.0 MeV) over the entire irradiation period.
λ	=	Decay constant of the product isotope (1/sec).
t_j	=	Length of irradiation period j (sec).
$t_{d,j}$	=	Decay time following irradiation period j (sec).

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

In the equation describing the reaction rate calculation, the ratio $[P_j]/[P_{ref}]$ accounts for month-by-month variation of reactor core power level within any given fuel cycle as well as over multiple fuel cycles. The ratio C_j, which was calculated for each fuel cycle using the transport methodology discussed in Section 6.2, accounts for the change in sensor reaction rates caused by variations in fluence rate level induced by changes in core spatial power distributions from fuel cycle to fuel cycle. For a single-cycle irradiation, C_j is normally taken to be 1.0. However, for multiple-cycle irradiations, the additional C_j term should be employed. The impact of changing fluence rate levels for constant power operation can be quite significant for sensor sets that have been irradiated for many cycles in a reactor that has transitioned from non-low-leakage to low-leakage fuel management or for sensor sets contained in surveillance capsules that have been moved from one capsule location to another.

The fuel-cycle-specific neutron fluence rates and the computed values for C_j are listed in Tables A-3 and A-4, respectively, for Capsules U, X, W, and V. These fluence rates represent the capsule- and cycle-dependent results at the radial and azimuthal center of the respective capsules at core midplane.

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

Correction	Capsule U	Capsule W	Capsule X	Capsule V
^{235}U Impurity/Pu Build-in	0.8690	0.8396	0.8071	0.7511
$^{238}U(\gamma,f)$	0.9665	0.9670	0.9696	0.9682
Net ^{238}U Correction	0.8399	0.8119	0.7826	0.7272
$^{237}Np(\gamma,f)$ Correction	0.9903	0.9903	0.9911	0.9906

The correction factors for surveillance Capsules U, X, W, and V were applied in a multiplicative fashion to the decay-corrected cadmium-covered uranium fission sensor reaction rates.

Results of the sensor reaction rate determinations for surveillance Capsules U, X, W, and V are given in Tables A-5 through A-8. In Tables A-5 through A-8, 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.

Results of the sensor reaction rate determinations for midplane EVND Capsules A, B, C, and E are given in Tables A-9 through A-12. Results of the sensor reaction rate determinations for off-midplane EVND Capsules D and F are given in Table A-13 and A-14. In Tables A-9 through A-14, the measured specific activities, decay-corrected saturated specific activities, and computed reaction rates for each sensor are listed.

A.1.2 Least-Squares Evaluation of Sensor Sets

Least-squares adjustment methods provide the capability of combining the measurement data with the corresponding neutron transport calculations resulting in a best-estimate neutron energy spectrum with associated uncertainties. Best-estimates for key exposure parameters such as fluence rate (E > 1.0 MeV) or dpa/s along with their uncertainties are then easily obtained from the adjusted spectrum. In general, the least-squares methods, as applied to 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 Braidwood Unit 2 dosimetry, the FERRET code [Ref. A-6] was employed to combine the results of the plant-specific neutron transport calculations and sensor set reaction rate measurements to determine best-estimate values of exposure parameters [fluence rate (E > 1.0 MeV) and dpa] along with associated uncertainties for the four in-vessel capsules and six ex-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 Braidwood Unit 2 application, the calculated neutron spectrum was obtained from the results of plant-specific neutron transport calculations described in Section 6.2 of this report. The sensor reaction rates were derived from the measured specific activities using the procedures described in Section A.1.1. The dosimetry reaction cross sections and uncertainties were obtained from the SNLRML dosimetry cross-section library [Ref. A-7].

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 E944-13, "Standard Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance" [Ref. A-8].

The following provides a summary of the uncertainties associated with the least-squares evaluation of the Braidwood Unit 2 surveillance capsule and EVND sensor sets.

Reaction Rate Uncertainties

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

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

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	5%
$^{46}Ti(n,p)^{46}Sc$	5%
$^{54}Fe(n,p)^{54}Mn$	5%
$^{58}Ni(n,p)^{58}Co$	5%
$^{93}Nb(n,n')^{93m}Nb$	5%
$^{238}U(n,f)FP$	10%
$^{237}Np(n,f)FP$	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 Braidwood 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%
$^{46}Ti(n,p)^{46}Sc$	4.50-4.87%
$^{54}Fe(n,p)^{54}Mn$	3.05-3.11%
$^{58}Ni(n,p)^{58}Co$	4.49-4.56%
$^{93}Nb(n,n')^{93m}Nb$	6.96-7.23%
$^{238}U(n,f)^{137}Cs$	0.54-0.64%
$^{237}Np(n,f)^{137}Cs$	10.32-10.97%
$^{59}Co(n,\gamma)^{60}Co$	0.79-3.59%

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

Calculated Neutron Spectrum

The neutron spectra inputs to the least-squares adjustment procedure were obtained directly from the results of plant-specific transport calculations for each surveillance capsule and EVND 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 Braidwood Unit 2 calculated spectra was as follows:

Fluence Rate Normalization Uncertainty (R_n)	15%
Fluence Rate Group Uncertainties (R_g, $R_{g'}$)	
(E > 0.0055 MeV)	15%
(0.68 eV < E < 0.0055 MeV)	25%
(E < 0.68 eV)	50%
Short Range Correlation (θ)	
(E > 0.0055 MeV)	0.9
(0.68 eV < E < 0.0055 MeV)	0.5
(E < 0.68 eV)	0.5
Fluence Rate Group Correlation Range (γ)	
(E > 0.0055 MeV)	6
(0.68 eV < E < 0.0055 MeV)	3
(E < 0.68 eV)	2

A.1.3 Comparisons of Measurements and Calculations

Results of the least-squares evaluations of the dosimetry from the Braidwood Unit 2 surveillance capsules withdrawn to date are provided in Tables A-15, A-16, A-17, and A-18 for surveillance Capsules U, X, W, and V, respectively. Results of the least-squares evaluations of the EVND midplane capsules withdrawn to date are provided in Tables A-19, A-20, A-21, and A-22 for EVND Capsules A, B, C, and E, respectively. Results of the least-squares evaluations of the EVND off-midplane capsules withdrawn to date are provided in Tables A-23 and A-24 for EVND Capsules D and F, respectively. In these tables, measured, calculated, and best-estimate values for sensor reaction rates are given for each capsule. Also provided in these tabulations are ratios of the measured reaction rates to both the calculated and least-squares adjusted reaction rates. These ratios of M/C and M/BE illustrate the consistency of the fit of the calculated neutron energy spectra to the measured reaction rates both before and after adjustment. Additionally, comparisons of the calculated and best-estimate values of neutron fluence rate (E > 1.0 MeV) and iron atom displacement rate are tabulated along with the BE/C ratios observed for each of the capsules. Note that for surveillance Capsule V, nickel foils were omitted due to their lack of meaningful information. The reaction product has a relatively short half-life (70.82 days, see Table A-1), and decayed away beyond utility in the intervening period between when Capsule V was pulled (October 2009) and when it was counted (December 2015).

The data comparisons provided in Tables A-15 through A-22 show that the adjustments to the calculated spectra are relatively small and within the assigned uncertainties for the calculated spectra, measured sensor reaction rates, and dosimetry reaction cross sections. Further, these results indicate that the use of the least-squares evaluation results in a reduction in the uncertainties associated with the exposure of the surveillance capsules. From Section 6.4 of this report, the calculational uncertainty is specified as 13% at the 1σ level.

Further comparisons of the measurement results with calculations are given in Tables A-25 through A-27 for in-vessel surveillance capsules, EVND midplane capsules, and EVND off-midplane capsules, respectively. In these tables, 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. Calculations of fast neutron exposure rates in terms of fast neutron fluence rate (E > 1.0 MeV) and dpa/s are compared with the best-estimate results obtained from the least-squares evaluation of the capsule dosimetry results in Tables A-28 and A-29 for in-vessel surveillance capsules and EVND midplane capsules, respectively. These comparisons yield consistent and similar results with all measurement-to-calculation comparisons falling within the 20% limits specified as the acceptance criteria in Regulatory Guide 1.190 [Ref. A-1].

The measurement-to-calculation comparisons based on individual sensor reactions without recourse to the least-squares adjustment procedure are summarized in Table A-30. A similar comparison for exposure rates expressed in terms of fast (E > 1.0 MeV) flux and iron atom displacement rate (dpa/s) is summarized in Table A-31.

These data comparisons show similar and consistent results with the linear average M/C ratio of 0.98 in excellent agreement with the resultant least-squares BE/C ratios of 0.97 and 1.00 for neutron flux (E > 1.0 MeV) and iron atom displacement rate, respectively. The comparisons demonstrate that the calculated results are validated within the context of the assigned 13% (1σ) uncertainty.

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 Braidwood Unit 2 reactor pressure vessel.

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

Surveillance Capsules				
Reaction of Interest	Product Half-life(a) (Days)	Target Atom Fraction(a)	90% Response Range(b) (MeV)	Fission Yield (%)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	1925.5	0.6917	5.0 – 11.9	N/A
$^{54}Fe\ (n,p)\ ^{54}Mn$	312.11	0.05845	2.1 – 8.5	N/A
$^{58}Ni\ (n,p)\ ^{58}Co$	70.82	0.68077	1.5 – 8.3	N/A
$^{238}U\ (n,f)\ ^{137}Cs$	10983.07	1.0000	1.3 – 7.0	6.02
$^{237}Np\ (n,f)\ ^{137}Cs$	10983.07	1.0000	0.34 – 3.8	6.17
$^{59}Co\ (n,\gamma)\ ^{60}Co$	1925.5	0.0015	non-threshold	N/A

Ex-Vessel Neutron Dosimetry				
Reaction of Interest	Product Half-life(a) (Days)	Target Atom Fraction(a)	90% Response Range(c) (MeV)	Fission Yield (%)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	1925.5	0.6917	5.2 – 12.6	N/A
$^{46}Ti\ (n,p)\ ^{46}Sc$	83.79	0.0825	4.1 – 11.2	N/A
$^{54}Fe\ (n,p)\ ^{54}Mn$	312.11	0.05845	2.0 – 9.3	N/A
$^{58}Ni\ (n,p)\ ^{58}Co$	70.82	0.68077	1.3 – 9.1	N/A
$^{93}Nb\ (n,n')\ ^{93m}Nb$	5890.0	1.000	0.3 – 4.6	N/A
$^{59}Co\ (n,\gamma)\ ^{60}Co$	1925.5	0.00438	non-threshold	N/A

Notes:

(a) Half-life data are from ASTM E1005-10 [Ref. A-9]; target atom fraction data are from ASTM E1005-10 [Ref. A-9], with the exception of ^{59}Co, which is from the materials specification for the cobalt foils.

(b) The 90% response range is defined such that, in the neutron spectrum characteristic of the Braidwood 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. All surveillance capsules exhibit a similar response range with minor variations; the listed values are for surveillance Capsule V (with the exception of ^{58}Ni, which was not used for Capsule V – in this case, Capsule W is used).

(c) The 90% response range is defined such that, in the neutron spectrum characteristic of the Braidwood Unit 2 EVND 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. All EVND capsules exhibit a similar response range with minor variations; the listed values are for EVND Capsule E.

Table A-2 Monthly Thermal Generation during the First 14 Fuel Cycles of the Braidwood Unit 2 Reactor

Cycle 1		Cycle 2		Cycle 3		Cycle 4A	
Month	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**
May-88	116073	May-90	85374	Nov-91	122919	May-93	1937581
Jun-88	533248	Jun-90	1472014	Dec-91	2015229	Jun-93	2342521
Jul-88	1169397	Jul-90	2415715	Jan-92	2422273	Jul-93	2415905
Aug-88	1916252	Aug-90	2451032	Feb-92	1949523	Aug-93	2458798
Sep-88	984844	Sep-90	2318122	Mar-92	2275870	Sep-93	2391762
Oct-88	498112	Oct-90	2316935	Apr-92	2356176	Oct-93	1449593
Nov-88	1618294	Nov-90	2262639	May-92	1605206	Nov-93	2408486
Dec-88	1961212	Dec-90	2397002	Jun-92	2144813	Dec-93	2491223
Jan-89	2244107	Jan-91	2498943	Jul-92	2379800	Jan-94	1667825
Feb-89	724667	Feb-91	2085837	Aug-92	2256254	Feb-94	2220994
Mar-89	303269	Mar-91	2465072	Sep-92	2171245	Mar-94	2522680
Apr-89	2278398	Apr-91	2364969	Oct-92	2465600	Apr-94	337197
May-89	1675139	May-91	1620535	Nov-92	2191093		
Jun-89	1714433	Jun-91	2225330	Dec-92	2439339		
Jul-89	1857133	Jul-91	2343558	Jan-93	2399465		
Aug-89	2099116	Aug-91	1686282	Feb-93	1930384		
Sep-89	1908625	Sep-91	616849	Mar-93	249733		
Oct-89	2202479	Oct-91	0	Apr-93	0		
Nov-89	2283637						
Dec-89	2472337						
Jan-90	1961079						
Feb-90	1251329						
Mar-90	537829						
Apr-90	0						

Table A-2 (cont.) Monthly Thermal Generation during the First 14 Fuel Cycles of the Braidwood Unit 2 Reactor

Cycle 4B		Cycle 5		Cycle 6		Cycle 7	
Month	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**
May-94	62421	Nov-94	768974	May-96	1055524	Nov-97	823552
Jun-94	2255220	Dec-94	2497819	Jun-96	2440428	Dec-97	2521367
Jul-94	2507249	Jan-95	2520337	Jul-96	2500074	Jan-98	2108233
Aug-94	2263461	Feb-95	2279240	Aug-96	2531092	Feb-98	1934344
Sep-94	2422475	Mar-95	2525597	Sep-96	2439919	Mar-98	2514507
Oct-94	513830	Apr-95	2257489	Oct-96	2529792	Apr-98	2438838
		May-95	1941115	Nov-96	2441614	May-98	2519109
		Jun-95	2431948	Dec-96	2520596	Jun-98	2452226
		Jul-95	2471174	Jan-97	2527817	Jul-98	2535785
		Aug-95	2465290	Feb-97	2277566	Aug-98	2529717
		Sep-95	2433346	Mar-97	2518645	Sep-98	2448068
		Oct-95	2525801	Apr-97	2425177	Oct-98	2546789
		Nov-95	2437770	May-97	2528888	Nov-98	2453031
		Dec-95	2513286	Jun-97	2440632	Dec-98	2536624
		Jan-96	2519358	Jul-97	2525136	Jan-99	2532937
		Feb-96	2338534	Aug-97	2342665	Feb-99	2229402
		Mar-96	1068728	Sep-97	1996840	Mar-99	2510984
		Apr-96	0	Oct-97	0	Apr-99	1337992

Table A-2 (cont.) Monthly Thermal Generation during the First 14 Fuel Cycles of the Braidwood Unit 2 Reactor

Cycle 8		Cycle 9		Cycle 10		Cycle 11	
Month	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**
May-99	792775	Nov-00	1971851	May-02	1492764	Nov-03	924855
Jun-99	2481789	Dec-00	2523191	Jun-02	2576463	Dec-03	2208313
Jul-99	2566856	Jan-01	2535345	Jul-02	2664202	Jan-04	2648166
Aug-99	2575841	Feb-01	2260181	Aug-02	2423204	Feb-04	2490418
Sep-99	2514570	Mar-01	2529666	Sep-02	2578984	Mar-04	2666704
Oct-99	2620200	Apr-01	2445489	Oct-02	2670503	Apr-04	2575907
Nov-99	2620200	May-01	2433139	Nov-02	2526727	May-04	2662466
Dec-99	1792748	Jun-01	2486507	Dec-02	2380652	Jun-04	2566145
Jan-00	2566309	Jul-01	2571305	Jan-03	2666831	Jul-04	2666522
Feb-00	2416809	Aug-01	2565886	Feb-03	2405353	Aug-04	2666585
Mar-00	2585039	Sep-01	2478229	Mar-03	2661555	Sep-04	2575742
Apr-00	2135902	Oct-01	2271153	Apr-03	2577220	Oct-04	2669419
May-00	2566309	Nov-01	1558485	May-03	2663979	Nov-04	2579875
Jun-00	2474009	Dec-01	2533510	Jun-03	2566897	Dec-04	2525664
Jul-00	2486923	Jan-02	2531767	Jul-03	2659507	Jan-05	2662794
Aug-00	2536590	Feb-02	2285984	Aug-03	2666221	Feb-05	2408374
Sep-00	2477204	Mar-02	2539072	Sep-03	2580656	Mar-05	2365701
Oct-00	1650194	Apr-02	1538311	Oct-03	2617346	Apr-05	1285249
				Nov-03	214518		

Table A-2 (cont.) Monthly Thermal Generation during the First 14 Fuel Cycles of the Braidwood Unit 2 Reactor

Cycle 12		Cycle 13		Cycle 14	
Month	**MWt-h**	**Month**	**MWt-h**	**Month**	**MWt-h**
May-05	2234513	Nov-06	2279455	May-08	1131033
Jun-05	2580389	Dec-06	2665455	Jun-08	2578649
Jul-05	2660557	Jan-07	2665584	Jul-08	2666012
Aug-05	2666131	Feb-07	2407312	Aug-08	2666139
Sep-05	2580543	Mar-07	2656050	Sep-08	2579919
Oct-05	2669803	Apr-07	2578858	Oct-08	2664427
Nov-05	2578547	May-07	2643254	Nov-08	2583710
Dec-05	2667850	Jun-07	2578834	Dec-08	2460020
Jan-06	2665952	Jul-07	2665497	Jan-09	2665967
Feb-06	2406134	Aug-07	2432497	Feb-09	2407999
Mar-06	2666219	Sep-07	2578997	Mar-09	2662427
Apr-06	2573991	Oct-07	2664925	Apr-09	2423673
May-06	2665488	Nov-07	2583048	May-09	2665478
Jun-06	2579266	Dec-07	2665056	Jun-09	2579925
Jul-06	2665790	Jan-08	2665146	Jul-09	2572861
Aug-06	2664719	Feb-08	2414961	Aug-09	2279475
Sep-06	2579118	Mar-08	2661487	Sep-09	2579821
Oct-06	1202474	Apr-08	1658214	Oct-09	924927

Table A-3 Surveillance Capsules U, X, W, and V Fast Neutron Fluence Rates for C_j Calculation, Core Midplane Elevation

Fuel Cycle	Cycle Length (EFPY)	φ(E > 1.0 MeV) [n/cm²-s]			
		Capsule U	Capsule X	Capsule W	Capsule V
1	1.18	1.04E+11	1.04E+11	1.03E+11	9.61E+10
2	1.12		7.86E+10	7.76E+10	6.98E+10
3	1.12		7.91E+10	7.80E+10	7.27E+10
4A	0.82		7.79E+10	7.68E+10	7.16E+10
4B	0.34			7.76E+10	7.23E+10
5	1.27			6.74E+10	6.34E+10
6	1.34			6.78E+10	6.31E+10
7	1.37			6.81E+10	6.65E+10
8	1.40				5.88E+10
9	1.36				5.41E+10
10	1.45				5.08E+10
11	1.38				5.45E+10
12	1.44				6.19E+10
13	1.45				6.11E+10
14	1.37				6.26E+10
Time-Weighted Average	--	1.04E+11	8.57E+10	7.65E+10	6.41E+10

Table A-4 Surveillance Capsules U, X, W, and V C_j Factors, Core Midplane Elevation

Fuel Cycle	Cycle Length (EFPY)	C_j			
		Capsule U	Capsule X	Capsule W	Capsule V
1	1.18	1.00	1.22	1.34	1.50
2	1.12		0.92	1.02	1.09
3	1.12		0.92	1.02	1.13
4A	0.82		0.91	1.00	1.12
4B	0.34			1.02	1.13
5	1.27			0.88	0.99
6	1.34			0.89	0.98
7	1.37			0.89	1.04
8	1.40				0.92
9	1.36				0.84
10	1.45				0.79
11	1.38				0.85
12	1.44				0.97
13	1.45				0.95
14	1.37				0.98

Table A-5 Measured Sensor Activities and Reaction Rates for Surveillance Capsule U

Target Isotope	Measured Activity (dps/g)[(a)]	Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)	Corrected Average Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	5.41E+04	4.30E+05	6.55E-17	6.06E-17	6.06E-17
^{63}Cu (n,α) ^{60}Co	4.78E+04	3.80E+05	5.79E-17		
^{54}Fe (n,p) ^{54}Mn	4.81E+04	3.82E+05	5.83E-17	5.88E-15	5.88E-15
^{54}Fe (n,p) ^{54}Mn	1.31E+06	4.03E+06	6.40E-15		
^{54}Fe (n,p) ^{54}Mn	1.16E+06	3.57E+06	5.66E-15		
^{58}Ni (n,p) ^{58}Co	1.14E+06	3.51E+06	5.57E-15	7.68E-15	7.68E-15
^{58}Ni (n,p) ^{58}Co	4.99E+06	5.78E+07	8.28E-15		
^{58}Ni (n,p) ^{58}Co	4.46E+06	5.17E+07	7.40E-15		
^{59}Co (n,γ) ^{60}Co	4.44E+06	5.14E+07	7.36E-15	5.54E-12	5.54E-12
^{59}Co (n,γ) ^{60}Co	1.08E+07	8.58E+07	5.60E-12		
^{59}Co (n,γ) ^{60}Co	1.07E+07	8.50E+07	5.54E-12		
^{59}Co(Cd) (n,γ) ^{60}Co	1.06E+07	8.42E+07	5.49E-12	2.86E-12	2.86E-12
^{59}Co(Cd) (n,γ) ^{60}Co	5.42E+06	4.30E+07	2.81E-12		
^{59}Co(Cd) (n,γ) ^{60}Co	5.57E+06	4.42E+07	2.89E-12		
^{238}U(Cd) (n,f) ^{137}Cs	5.56E+06	4.42E+07	2.88E-12	3.95E-14	3.32E-14
^{237}Np(Cd) (n,f) ^{137}Cs	1.54E+05	6.01E+06	3.95E-14	3.46E-13	3.43E-13

Note:

(a) Measured activity decay corrected to October 17, 1990.

Table A-6 Measured Sensor Activities and Reaction Rates for Surveillance Capsule X

Target Isotope	Measured Activity (dps/g)(a)	Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)	Corrected Average Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	1.35E+05	3.68E+05	5.61E-17	5.24E-17	5.24E-17
^{63}Cu (n,α) ^{60}Co	1.23E+05	3.35E+05	5.11E-17		
^{63}Cu (n,α) ^{60}Co	1.20E+05	3.27E+05	4.99E-17		
^{54}Fe (n,p) ^{54}Mn	1.71E+06	3.23E+06	5.13E-15	4.76E-15	4.76E-15
^{54}Fe (n,p) ^{54}Mn	1.53E+06	2.89E+06	4.59E-15		
^{54}Fe (n,p) ^{54}Mn	1.52E+06	2.87E+06	4.56E-15		
^{58}Ni (n,p) ^{58}Co	9.39E+06	4.92E+07	7.04E-15	6.58E-15	6.58E-15
^{58}Ni (n,p) ^{58}Co	8.48E+06	4.44E+07	6.36E-15		
^{58}Ni (n,p) ^{58}Co	8.43E+06	4.42E+07	6.32E-15		
^{59}Co (n,γ) ^{60}Co	2.27E+07	6.18E+07	4.03E-12	4.11E-12	4.11E-12
^{59}Co (n,γ) ^{60}Co	2.35E+07	6.40E+07	4.18E-12		
^{59}Co(Cd) (n,γ) ^{60}Co	2.32E+07	6.32E+07	4.12E-12	2.19E-12	2.19E-12
^{59}Co(Cd) (n,γ) ^{60}Co	1.20E+07	3.27E+07	2.13E-12		
^{238}U(Cd) (n,f) ^{137}Cs	1.24E+07	3.38E+07	2.20E-12	3.54E-14	2.87E-14
^{237}Np(Cd) (n,f) ^{137}Cs	1.26E+07	3.43E+07	2.24E-12	2.35E-13	2.33E-13

Note:

(a) Measured activity decay corrected to August 30, 1994.

Table A-7 Measured Sensor Activities and Reaction Rates for Surveillance Capsule W

Target Isotope	Measured Activity (dps/g)[a]	Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)	Corrected Average Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	1.88E+05	3.35E+05	5.12E-17	4.73E-17	4.73E-17
^{63}Cu (n,α) ^{60}Co	1.68E+05	3.00E+05	4.57E-17		
^{63}Cu (n,α) ^{60}Co	1.65E+05	2.94E+05	4.49E-17		
^{54}Fe (n,p) ^{54}Mn	1.76E+06	3.19E+06	5.06E-15	4.68E-15	4.68E-15
^{54}Fe (n,p) ^{54}Mn	1.55E+06	2.81E+06	4.46E-15		
^{54}Fe (n,p) ^{54}Mn	1.57E+06	2.85E+06	4.52E-15		
^{58}Ni (n,p) ^{58}Co	7.41E+06	4.95E+07	7.09E-15	6.63E-15	6.63E-15
^{58}Ni (n,p) ^{58}Co	6.66E+06	4.45E+07	6.37E-15		
^{58}Ni (n,p) ^{58}Co	6.72E+06	4.49E+07	6.43E-15		
^{59}Co (n,γ) ^{60}Co	3.14E+07	5.60E+07	3.66E-12	3.68E-12	3.68E-12
^{59}Co (n,γ) ^{60}Co	3.18E+07	5.67E+07	3.70E-12		
^{59}Co (n,γ) ^{60}Co	3.15E+07	5.62E+07	3.67E-12		
^{59}Co(Cd) (n,γ) ^{60}Co	1.60E+07	2.86E+07	1.86E-12	1.93E-12	1.93E-12
^{59}Co(Cd) (n,γ) ^{60}Co	1.66E+07	2.96E+07	1.93E-12		
^{59}Co(Cd) (n,γ) ^{60}Co	1.70E+07	3.03E+07	1.98E-12		
^{238}U(Cd) (n,f) ^{137}Cs	8.49E+05	4.94E+06	3.25E-14	3.25E-14	2.54E-14
^{237}Np(Cd) (n,f) ^{137}Cs	6.60E+06	3.84E+07	2.45E-13	2.45E-13	2.43E-13

Note:

(a) Measured activity decay corrected to October 15, 1999.

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

Target Isotope	Measured Activity (dps/g)(a)	Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)	Corrected Average Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	1.06E+05	2.87E+05	4.38E-17	4.03E-17	4.03E-17
^{63}Cu (n,α) ^{60}Co	9.36E+04	2.54E+05	3.87E-17		
^{63}Cu (n,α) ^{60}Co	9.24E+04	2.51E+05	3.82E-17		
^{54}Fe (n,p) ^{54}Mn	1.78E+04	2.61E+06	4.14E-15	3.83E-15	3.83E-15
^{54}Fe (n,p) ^{54}Mn	1.56E+04	2.28E+06	3.62E-15		
^{54}Fe (n,p) ^{54}Mn	1.60E+04	2.34E+06	3.72E-15		
^{59}Co (n,γ) ^{60}Co	1.55E+07	4.20E+07	2.74E-12	2.82E-12	2.82E-12
^{59}Co (n,γ) ^{60}Co	1.63E+07	4.42E+07	2.88E-12		
^{59}Co (n,γ) ^{60}Co	1.60E+07	4.34E+07	2.83E-12		
^{59}Co(Cd) (n,γ) ^{60}Co	8.73E+06	2.37E+07	1.54E-12	1.55E-12	1.55E-12
^{59}Co(Cd) (n,γ) ^{60}Co	8.82E+06	2.39E+07	1.56E-12		
^{59}Co(Cd) (n,γ) ^{60}Co	8.78E+06	2.38E+07	1.55E-12		
^{238}U(Cd) (n,f) ^{137}Cs	1.34E+06	4.61E+06	3.02E-14	3.02E-14	2.20E-14
^{237}Np(Cd) (n,f) ^{137}Cs	9.17E+06	3.15E+07	2.01E-13	2.01E-13	1.99E-13

Note:

(a) Measured activity decay corrected to October 19, 2015.

Table A-9 Measured Sensor Activities and Reaction Rates for Midplane EVND Capsule A

Target Isotope	Measured Activity (dps/g)(a)	Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	4.28E+02	2.67E+03	4.07E-19	4.07E-19
^{46}Ti (n,p) ^{46}Sc	2.98E+03	5.46E+03	5.26E-18	5.26E-18
^{54}Fe (n,p) ^{54}Mn	9.85E+03	1.73E+04	2.74E-17	2.74E-17
^{54}Fe (n,p) ^{54}Mn	9.85E+03	1.73E+04	2.74E-17	
^{58}Ni (n,p) ^{58}Co	1.26E+05	2.54E+05	3.64E-17	3.64E-17
^{93}Nb (n,n') ^{93m}Nb	4.74E+04	8.36E+05	1.29E-16	1.29E-16
^{59}Co (n,γ) ^{60}Co	3.14E+05	1.96E+06	4.37E-14	4.37E-14
^{59}Co(Cd) (n,γ) ^{60}Co	1.73E+05	1.08E+06	2.41E-14	2.41E-14

Note:

(a) Measured activity decay corrected to December 17, 2009.

Table A-10 Measured Sensor Activities and Reaction Rates for Midplane EVND Capsule B

Target Isotope	Measured Activity (dps/g)(a)	Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	5.44E+02	3.39E+03	5.17E-19	5.17E-19
$^{46}Ti\ (n,p)\ ^{46}Sc$	3.88E+03	7.11E+03	6.85E-18	6.85E-18
$^{54}Fe\ (n,p)\ ^{54}Mn$	1.39E+04	2.44E+04	3.87E-17	3.83E-17
$^{54}Fe\ (n,p)\ ^{54}Mn$	1.36E+04	2.39E+04	3.79E-17	
$^{58}Ni\ (n,p)\ ^{58}Co$	1.64E+05	3.30E+05	4.73E-17	4.73E-17
$^{93}Nb\ (n,n')\ ^{93m}Nb$	6.16E+04	1.09E+06	1.68E-16	1.68E-16
$^{59}Co\ (n,\gamma)\ ^{60}Co$	5.22E+05	3.25E+06	7.27E-14	7.27E-14
$^{59}Co(Cd)\ (n,\gamma)\ ^{60}Co$	2.67E+05	1.66E+06	3.72E-14	3.72E-14

Note:

(a) Measured activity decay corrected to December 17, 2009.

Table A-11 Measured Sensor Activities and Reaction Rates for Midplane EVND Capsule C

Target Isotope	Measured Activity (dps/g)(a)	Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	5.41E+02	3.37E+03	5.14E-19	5.14E-19
$^{46}Ti\ (n,p)\ ^{46}Sc$	3.83E+03	7.02E+03	6.76E-18	6.76E-18
$^{54}Fe\ (n,p)\ ^{54}Mn$	1.42E+04	2.49E+04	3.95E-17	3.95E-17
$^{54}Fe\ (n,p)\ ^{54}Mn$	1.42E+04	2.49E+04	3.95E-17	
$^{58}Ni\ (n,p)\ ^{58}Co$	1.75E+05	3.53E+05	5.05E-17	5.05E-17
$^{93}Nb\ (n,n')\ ^{93m}Nb$	6.87E+04	1.21E+06	1.87E-16	1.87E-16
$^{59}Co\ (n,\gamma)\ ^{60}Co$	5.92E+05	3.69E+06	8.24E-14	8.24E-14
$^{59}Co(Cd)\ (n,\gamma)\ ^{60}Co$	3.03E+05	1.89E+06	4.22E-14	4.22E-14

Note:

(a) Measured activity decay corrected to December 17, 2009.

Table A-12 Measured Sensor Activities and Reaction Rates for Midplane EVND Capsule E

Target Isotope	Measured Activity (dps/g)[(a)]	Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	3.67E+02	2.29E+03	3.49E-19	3.49E-19
^{46}Ti (n,p) ^{46}Sc	2.62E+03	4.80E+03	4.63E-18	4.63E-18
^{54}Fe (n,p) ^{54}Mn	1.04E+04	1.83E+04	2.90E-17	2.85E-17
^{54}Fe (n,p) ^{54}Mn	1.01E+04	1.77E+04	2.81E-17	
^{58}Ni (n,p) ^{58}Co	1.32E+05	2.66E+05	3.81E-17	3.81E-17
^{93}Nb (n,n′) ^{93m}Nb	6.43E+04	1.13E+06	1.75E-16	1.75E-16
^{59}Co (n,γ) ^{60}Co	3.66E+05	2.28E+06	5.09E-14	5.09E-14
$^{59}Co(Cd)$ (n,γ) ^{60}Co	2.22E+05	1.38E+06	3.09E-14	3.09E-14

Note:

(a) Measured activity decay corrected to December 17, 2009.

Table A-13 Measured Sensor Activities and Reaction Rates for Off-Midplane EVND Capsule D

Target Isotope	Measured Activity (dps/g)[(a)]	Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	1.35E+02	8.41E+02	1.28E-19	1.28E-19
^{46}Ti (n,p) ^{46}Sc	1.17E+03	2.14E+03	2.07E-18	2.07E-18
^{54}Fe (n,p) ^{54}Mn	3.81E+03	6.69E+03	1.06E-17	1.10E-17
^{54}Fe (n,p) ^{54}Mn	4.09E+03	7.18E+03	1.14E-17	
^{58}Ni (n,p) ^{58}Co	5.87E+04	1.18E+05	1.69E-17	1.69E-17
^{93}Nb (n,n′) ^{93m}Nb	2.61E+04	4.60E+05	7.10E-17	7.10E-17
^{59}Co (n,γ) ^{60}Co	1.71E+05	1.07E+06	2.38E-14	2.38E-14
$^{59}Co(Cd)$ (n,γ) ^{60}Co	9.90E+04	6.17E+05	1.38E-14	1.38E-14

Note:

(a) Measured activity decay corrected to December 17, 2009.

Table A-14 Measured Sensor Activities and Reaction Rates for Off-Midplane EVND Capsule F

Target Isotope	Measured Activity (dps/g)[(a)]	Saturated Activity (dps/g)	Reaction Rate (rps/atom)	Average Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	1.30E+02	8.10E+02	1.24E-19	1.24E-19
^{46}Ti (n,p) ^{46}Sc	1.07E+03	1.96E+03	1.89E-18	1.89E-18
^{54}Fe (n,p) ^{54}Mn	4.15E+03	7.28E+03	1.16E-17	1.12E-17
^{54}Fe (n,p) ^{54}Mn	3.89E+03	6.83E+03	1.08E-17	
^{58}Ni (n,p) ^{58}Co	5.70E+04	1.15E+05	1.64E-17	1.64E-17
^{93}Nb (n,n') ^{93m}Nb	2.13E+04	3.76E+05	5.80E-17	5.80E-17
^{59}Co (n,γ) ^{60}Co	2.52E+05	1.57E+06	3.51E-14	3.51E-14
^{59}Co(Cd) (n,γ) ^{60}Co	1.23E+05	7.66E+05	1.71E-14	1.71E-14

Note:

(a) Measured activity decay corrected to December 17, 2009.

Table A-15 Least-Squares Evaluation of Dosimetry in Surveillance Capsule U (31.5° Azimuth, Core Midplane – Dual Capsule Holder) Cycle 1 Irradiation

Reaction	Reaction Rate (rps/atom)			M/C	M/BE	BE/C
	Measured (M)	Calculated (C)	Best-Estimate (BE)			
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	6.06E-17	5.33E-17	5.75E-17	1.14	1.05	1.08
$^{54}Fe\ (n,p)\ ^{54}Mn$	5.87E-15	6.06E-15	5.95E-15	0.97	0.99	0.98
$^{58}Ni\ (n,p)\ ^{58}Co$	7.68E-15	8.52E-15	8.16E-15	0.90	0.94	0.96
$^{59}Co\ (n,\gamma)\ ^{60}Co$	5.54E-12	5.08E-12	5.49E-12	1.09	1.01	1.08
$^{59}Co(Cd)\ (n,\gamma)\ ^{60}Co$	2.86E-12	3.27E-12	2.89E-12	0.87	0.99	0.88
$^{238}U(Cd)\ (n,f)\ ^{137}Cs$	3.31E-14	3.31E-14	3.18E-14	1.00	1.04	0.96
$^{237}Np(Cd)\ (n,f)\ ^{137}Cs$	3.43E-13	3.26E-13	3.28E-13	1.05	1.04	1.00
Average of Fast Energy Threshold Reactions				1.01	1.01	1.00
Standard Deviation				8.9%	4.6%	5.0%

Parameter	Calculated (C)	% Unc.	Best-Estimate (BE)	% Unc.	BE/C
Fluence Rate E > 1.0 MeV (n/cm^2-s)	1.05E+11	13	1.01E+11	6	0.95
Fluence Rate E > 0.1 MeV (n/cm^2-s)	4.69E+11	-	4.62E+11	10	0.98
dpa/s	2.03E-10	13	1.98E-10	8	0.97

Table A-16 Least-Squares Evaluation of Dosimetry in Surveillance Capsule X (31.5° Azimuth, Core Midplane – Single Capsule Holder) Cycles 1 through Mid-Cycle Outage in Cycle 4

Reaction	Reaction Rate (rps/atom)			M/C	M/BE	BE/C
	Measured (M)	Calculated (C)	Best-Estimate (BE)			
^{63}Cu (n,α) ^{60}Co	5.23E-17	4.54E-17	4.95E-17	1.15	1.05	1.09
^{54}Fe (n,p) ^{54}Mn	4.76E-15	5.06E-15	4.93E-15	0.94	0.96	0.98
^{58}Ni (n,p) ^{58}Co	6.58E-15	7.10E-15	6.84E-15	0.93	0.96	0.96
^{59}Co (n,γ) ^{60}Co	4.11E-12	4.12E-12	4.08E-12	1.00	1.01	0.99
^{59}Co(Cd) (n,γ) ^{60}Co	2.19E-12	2.66E-12	2.22E-12	0.82	0.99	0.83
^{238}U(Cd) (n,f) ^{137}Cs	2.87E-14	2.73E-14	2.58E-14	1.05	1.11	0.95
^{237}Np(Cd) (n,f) ^{137}Cs	2.32E-13	2.67E-13	2.40E-13	0.87	0.97	0.90
Average of Fast Energy Threshold Reactions				0.99	1.01	0.98
Standard Deviation				11.3%	6.7%	7.2%

Parameter	Calculated (C)	% Unc.	Best-Estimate (BE)	% Unc.	BE/C
Fluence Rate E > 1.0 MeV (n/cm^2-s)	8.65E+10	13	8.04E+10	6	0.92
Fluence Rate E > 0.1 MeV (n/cm^2-s)	3.83E+11	-	3.56E+11	10	0.92
dpa/s	1.66E-10	13	1.56E-10	8	0.93

Table A-17 Least-Squares Evaluation of Dosimetry in Surveillance Capsule W (31.5° Azimuth, Core Midplane – Single Capsule Holder) Cycles 1-7 Irradiation

Reaction	Reaction Rate (rps/atom) Measured (M)	Calculated (C)	Best-Estimate (BE)	M/C	M/BE	BE/C
^{63}Cu (n,α) ^{60}Co	4.73E-17	4.09E-17	4.59E-17	1.16	1.03	1.12
^{54}Fe (n,p) ^{54}Mn	4.68E-15	4.51E-15	4.77E-15	1.04	0.98	1.06
^{58}Ni (n,p) ^{58}Co	6.63E-15	6.32E-15	6.68E-15	1.05	0.99	1.06
^{59}Co (n,γ) ^{60}Co	3.67E-12	3.33E-12	3.64E-12	1.10	1.01	1.09
^{59}Co(Cd) (n,γ) ^{60}Co	1.92E-12	2.17E-12	1.95E-12	0.89	0.99	0.90
^{238}U(Cd) (n,f) ^{137}Cs	2.54E-14	2.42E-14	2.51E-14	1.05	1.01	1.04
^{237}Np(Cd) (n,f) ^{137}Cs	2.43E-13	2.37E-13	2.42E-13	1.03	1.00	1.02
Average of Fast Energy Threshold Reactions				1.07	1.00	1.06
Standard Deviation				5.0%	1.9%	3.5%

Parameter	Calculated (C)	% Unc.	Best-Estimate (BE)	% Unc.	BE/C
Fluence Rate E > 1.0 MeV (n/cm^2-s)	7.68E+10	13	7.88E+10	6	1.02
Fluence Rate E > 0.1 MeV (n/cm^2-s)	3.39E+11	-	3.46E+11	10	1.01
dpa/s	1.47E-10	13	1.51E-10	7	1.02

Table A-18 Least-Squares Evaluation of Dosimetry in Surveillance Capsule V (29.0° Azimuth, Core Midplane – Dual Capsule Holder) Cycles 1-14 Irradiation

Reaction	Reaction Rate (rps/atom)			M/C	M/BE	BE/C
	Measured (M)	Calculated (C)	Best-Estimate (BE)			
^{63}Cu (n,α) ^{60}Co	4.02E-17	3.57E-17	3.90E-17	1.13	1.03	1.09
^{54}Fe (n,p) ^{54}Mn	3.82E-15	3.86E-15	3.97E-15	0.99	0.96	1.03
^{59}Co (n,γ) ^{60}Co	2.82E-12	2.99E-12	2.80E-12	0.94	1.01	0.94
$^{59}Co(Cd)$ (n,γ) ^{60}Co	1.55E-12	1.94E-12	1.57E-12	0.80	0.99	0.81
$^{238}U(Cd)$ (n,f) ^{137}Cs	2.20E-14	2.06E-14	2.09E-14	1.07	1.05	1.02
$^{237}Np(Cd)$ (n,f) ^{137}Cs	1.99E-13	1.99E-13	1.99E-13	1.00	1.00	1.00
Average of Fast Energy Threshold Reactions				1.05	1.01	1.04
Standard Deviation				6.3%	3.9%	3.7%

Parameter	Calculated (C)	% Unc.	Best-Estimate (BE)	% Unc.	BE/C
Fluence Rate E > 1.0 MeV (n/cm^2-s)	6.47E+10	13	6.54E+10	6	1.01
Fluence Rate E > 0.1 MeV (n/cm^2-s)	2.84E+11	-	2.85E+11	10	1.00
dpa/s	1.24E-10	13	1.25E-10	8	1.00

Table A-19 Least-Squares Evaluation of Dosimetry in EVND Capsule A (0.5° Azimuth, Core Midplane) Cycle 14 Irradiation

Reaction	Reaction Rate (rps/atom) Measured (M)	Calculated (C)	Best-Estimate (BE)	M/C	M/BE	BE/C
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	4.07E-19	4.38E-19	3.98E-19	0.93	1.02	0.91
$^{46}Ti\ (n,p)\ ^{46}Sc$	5.26E-18	5.87E-18	5.24E-18	0.90	1.00	0.89
$^{54}Fe\ (n,p)\ ^{54}Mn$	2.74E-17	3.11E-17	2.77E-17	0.88	0.99	0.89
$^{58}Ni\ (n,p)\ ^{58}Co$	3.63E-17	4.35E-17	3.83E-17	0.84	0.95	0.88
$^{93}Nb\ (n,n')\ ^{93m}Nb$	1.29E-16	1.23E-16	1.25E-16	1.05	1.03	1.01
$^{59}Co\ (n,\gamma)\ ^{60}Co$	4.37E-14	4.00E-14	4.36E-14	1.09	1.00	1.09
$^{59}Co(Cd)\ (n,\gamma)\ ^{60}Co$	2.41E-14	2.28E-14	2.41E-14	1.06	1.00	1.06
Average of Fast Energy Threshold Reactions				0.92	1.00	0.92
Standard Deviation				8.7%	3.1%	5.9%

Parameter	Calculated (C)	% Unc.	Best-Estimate (BE)	% Unc.	BE/C
Fluence Rate E > 1.0 MeV (n/cm^2-s)	5.25E+08	13	5.01E+08	6	0.95
Fluence Rate E > 0.1 MeV (n/cm^2-s)	4.91E+09	-	5.13E+09	10	1.04
dpa/s	1.68E-12	13	1.71E-12	8	1.02

Table A-20 Least-Squares Evaluation of Dosimetry in EVND Capsule B (14.5° Azimuth, Core Midplane) Cycle 14 Irradiation

Reaction	Reaction Rate (rps/atom)			M/C	M/BE	BE/C
	Measured (M)	Calculated (C)	Best-Estimate (BE)			
^{63}Cu (n,α) ^{60}Co	5.17E-19	5.30E-19	5.06E-19	0.98	1.02	0.96
^{46}Ti (n,p) ^{46}Sc	6.85E-18	7.29E-18	6.82E-18	0.94	1.00	0.94
^{54}Fe (n,p) ^{54}Mn	3.83E-17	4.02E-17	3.75E-17	0.95	1.02	0.93
^{58}Ni (n,p) ^{58}Co	4.73E-17	5.65E-17	5.10E-17	0.84	0.93	0.90
^{93}Nb (n,n') ^{93m}Nb	1.68E-16	1.66E-16	1.64E-16	1.01	1.02	0.99
^{59}Co (n,γ) ^{60}Co	7.27E-14	7.39E-14	7.28E-14	0.98	1.00	0.98
^{59}Co(Cd) (n,γ) ^{60}Co	3.72E-14	3.59E-14	3.71E-14	1.03	1.00	1.03
Average of Fast Energy Threshold Reactions				0.94	1.00	0.94
Standard Deviation				6.8%	3.9%	3.6%

Parameter	Calculated (C)	% Unc.	Best-Estimate (BE)	% Unc.	BE/C
Fluence Rate E > 1.0 MeV (n/cm^2-s)	7.01E+08	13	6.64E+08	6	0.94
Fluence Rate E > 0.1 MeV (n/cm^2-s)	6.76E+09	-	6.81E+09	10	1.00
dpa/s	2.31E-12	13	2.30E-12	8	0.99

Table A-21 Least-Squares Evaluation of Dosimetry in EVND Capsule C (29.5° Azimuth, Core Midplane) Cycle 14 Irradiation

Reaction	Reaction Rate (rps/atom)			M/C	M/BE	BE/C
	Measured (M)	Calculated (C)	Best-Estimate (BE)			
^{63}Cu (n,α) ^{60}Co	5.14E-19	5.25E-19	5.03E-19	0.98	1.02	0.96
^{46}Ti (n,p) ^{46}Sc	6.76E-18	7.27E-18	6.82E-18	0.93	0.99	0.94
^{54}Fe (n,p) ^{54}Mn	3.95E-17	4.11E-17	3.87E-17	0.96	1.02	0.94
^{58}Ni (n,p) ^{58}Co	5.05E-17	5.82E-17	5.35E-17	0.87	0.94	0.92
^{93}Nb (n,n') ^{93m}Nb	1.87E-16	1.82E-16	1.83E-16	1.03	1.02	1.00
^{59}Co (n,γ) ^{60}Co	8.24E-14	8.50E-14	8.25E-14	0.97	1.00	0.97
^{59}Co(Cd) (n,γ) ^{60}Co	4.22E-14	4.13E-14	4.21E-14	1.02	1.00	1.02
Average of Fast Energy Threshold Reactions				0.95	1.00	0.95
Standard Deviation				6.2%	3.5%	3.2%

Parameter	Calculated (C)	% Unc.	Best-Estimate (BE)	% Unc.	BE/C
Fluence Rate E > 1.0 MeV (n/cm^2-s)	7.64E+08	13	7.37E+08	6	0.96
Fluence Rate E > 0.1 MeV (n/cm^2-s)	7.73E+09	-	7.86E+09	10	1.01
dpa/s	2.61E-12	13	2.62E-12	8	1.00

Table A-22 Least-Squares Evaluation of Dosimetry in EVND Capsule E (44.5° Azimuth, Core Midplane) Cycle 14 Irradiation

Reaction	Reaction Rate (rps/atom)			M/C	M/BE	BE/C
	Measured (M)	Calculated (C)	Best-Estimate (BE)			
^{63}Cu (n,α) ^{60}Co	3.49E-19	3.73E-19	3.41E-19	0.93	1.02	0.91
^{46}Ti (n,p) ^{46}Sc	4.62E-18	5.22E-18	4.67E-18	0.89	0.99	0.89
^{54}Fe (n,p) ^{54}Mn	2.85E-17	3.11E-17	2.83E-17	0.92	1.01	0.91
^{58}Ni (n,p) ^{58}Co	3.81E-17	4.51E-17	4.04E-17	0.84	0.94	0.89
^{93}Nb (n,n') ^{93m}Nb	1.75E-16	1.63E-16	1.69E-16	1.08	1.03	1.04
^{59}Co (n,γ) ^{60}Co	5.09E-14	5.43E-14	5.11E-14	0.94	1.00	0.94
^{59}Co(Cd) (n,γ) ^{60}Co	3.09E-14	3.13E-14	3.08E-14	0.99	1.00	0.98
Average of Fast Energy Threshold Reactions				0.93	1.00	0.93
Standard Deviation				9.6%	3.6%	6.8%

Parameter	Calculated (C)	% Unc.	Best-Estimate (BE)	% Unc.	BE/C
Fluence Rate E > 1.0 MeV (n/cm^2-s)	6.80E+08	13	6.60E+08	6	0.97
Fluence Rate E > 0.1 MeV (n/cm^2-s)	7.06E+09	-	7.43E+09	10	1.05
dpa/s	2.33E-12	13	2.41E-12	8	1.03

Table A-23 Least-Squares Evaluation of Dosimetry in EVND Capsule D (44.5° Azimuth, Top of Active Core) Cycle 14 Irradiation

Reaction	Reaction Rate (rps/atom)			M/C	M/BE	BE/C
	Measured (M)	Calculated (C)	Best-Estimate (BE)			
^{63}Cu (n,α) ^{60}Co	1.28E-19	1.69E-19	1.33E-19	0.76	0.96	0.79
^{46}Ti (n,p) ^{46}Sc	2.07E-18	2.38E-18	1.96E-18	0.87	1.05	0.82
^{54}Fe (n,p) ^{54}Mn	1.10E-17	1.42E-17	1.15E-17	0.77	0.95	0.81
^{58}Ni (n,p) ^{58}Co	1.69E-17	2.06E-17	1.70E-17	0.82	0.99	0.83
^{93}Nb (n,n') ^{93m}Nb	7.10E-17	7.36E-17	6.93E-17	0.97	1.02	0.94
^{59}Co (n,γ) ^{60}Co	2.38E-14	2.56E-14	2.38E-14	0.93	1.00	0.93
^{59}Co(Cd) (n,γ) ^{60}Co	1.38E-14	1.47E-14	1.38E-14	0.94	1.00	0.94
Average of Fast Energy Threshold Reactions				0.84	0.99	0.84
Standard Deviation				10.2%	4.2%	7.0%

Parameter	Calculated (C)	% Unc.	Best-Estimate (BE)	% Unc.	BE/C
Fluence Rate E > 1.0 MeV (n/cm^2-s)	3.07E+08	13	2.74E+08	6	0.89
Fluence Rate E > 0.1 MeV (n/cm^2-s)	3.19E+09	-	3.09E+09	10	0.96
dpa/s	1.06E-12	13	1.00E-12	8	0.94

Table A-24 Least-Squares Evaluation of Dosimetry in EVND Capsule F (44.5° Azimuth, Bottom of Active Core) Cycle 14 Irradiation

Reaction	Reaction Rate (rps/atom)			M/C	M/BE	BE/C
	Measured (M)	Calculated (C)	Best-Estimate (BE)			
^{63}Cu (n,α) ^{60}Co	1.23E-19	1.67E-19	1.29E-19	0.74	0.96	0.77
^{46}Ti (n,p) ^{46}Sc	1.89E-18	2.34E-18	1.86E-18	0.81	1.02	0.79
^{54}Fe (n,p) ^{54}Mn	1.12E-17	1.40E-17	1.11E-17	0.80	1.00	0.80
^{58}Ni (n,p) ^{58}Co	1.64E-17	2.03E-17	1.63E-17	0.81	1.01	0.80
^{93}Nb (n,n') ^{93m}Nb	5.79E-17	7.35E-17	5.89E-17	0.79	0.98	0.80
^{59}Co (n,γ) ^{60}Co	3.51E-14	2.60E-14	3.47E-14	1.35	1.01	1.33
^{59}Co(Cd) (n,γ) ^{60}Co	1.71E-14	1.49E-14	1.71E-14	1.15	1.00	1.15
Average of Fast Energy Threshold Reactions				0.79	0.99	0.79
Standard Deviation				3.7%	2.4%	1.6%

Parameter	Calculated (C)	% Unc.	Best-Estimate (BE)	% Unc.	BE/C
Fluence Rate E > 1.0 MeV (n/cm^2-s)	3.06E+08	13	2.49E+08	6	0.81
Fluence Rate E > 0.1 MeV (n/cm^2-s)	3.21E+09	-	2.69E+09	10	0.83
dpa/s	1.06E-12	13	8.85E-13	8	0.83

Table A-25 Comparison of Measured/Calculated (M/C) Sensor Reaction Rate Ratios for Fast Neutron Threshold Reactions – In-Vessel Surveillance Capsules

Reaction	M/C					Std. Dev.
	Capsule U	Capsule X	Capsule W	Capsule V	Average	
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	1.14	1.15	1.16	1.13	1.15	1.1%
$^{54}Fe\ (n,p)\ ^{54}Mn$	0.97	0.94	1.04	0.99	0.99	4.3%
$^{58}Ni\ (n,p)\ ^{58}Co$	0.90	0.93	1.05	-	0.96	8.3%
$^{238}U(Cd)\ (n,f)\ ^{137}Cs$	1.00	1.05	1.05	1.07	1.04	2.9%
$^{237}Np(Cd)\ (n,f)\ ^{137}Cs$	1.05	0.87	1.03	1.00	0.99	8.2%
Average of M/C Results					1.03	8.1%

Table A-26 Comparison of Measured/Calculated (M/C) Sensor Reaction Rate Ratios for Fast Neutron Threshold Reactions – Ex-Vessel Midplane Capsules

Reaction	M/C					Std. Dev.
	Capsule A	Capsule B	Capsule C	Capsule E	Average	
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	0.93	0.98	0.98	0.93	0.96	3.0%
$^{46}Ti\ (n,p)\ ^{46}Sc$	0.9	0.94	0.93	0.89	0.92	2.6%
$^{54}Fe\ (n,p)\ ^{54}Mn$	0.88	0.95	0.96	0.92	0.93	3.9%
$^{58}Ni\ (n,p)\ ^{58}Co$	0.84	0.84	0.87	0.84	0.85	1.8%
$^{93}Nb\ (n,n')\ ^{93m}Nb$	1.05	1.01	1.02	1.08	1.04	3.0%
Average of M/C Results					0.94	7.4%

Table A-27 Comparison of Measured/Calculated (M/C) Sensor Reaction Rate Ratios for Fast Neutron Threshold Reactions – Ex-Vessel Off-Midplane Capsules

Reaction	M/C	
	Capsule D	Capsule F
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	0.76	0.74
$^{46}Ti\ (n,p)\ ^{46}Sc$	0.87	0.81
$^{54}Fe\ (n,p)\ ^{54}Mn$	0.77	0.80
$^{58}Ni\ (n,p)\ ^{58}Co$	0.82	0.81
$^{93}Nb\ (n,n')\ ^{93m}Nb$	0.97	0.79

Table A-28 Comparison of Best-Estimate/Calculated (BE/C) Exposure Rate Ratios – In-Vessel Surveillance Capsules

Capsule	Fast Fluence Rate (E > 1.0 MeV)	Iron Atom Displacement Rate
	BE/C	BE/C
U	0.95	0.97
X	0.92	0.93
W	1.02	1.02
V	1.01	1.00
Average	0.98	0.98
Standard deviation	4.9%	4.0%

Table A-29 Comparison of Best-Estimate/Calculated (BE/C) Exposure Rate Ratios – Ex-Vessel Midplane Capsules

Capsule	Fast Fluence Rate (E > 1.0 MeV)	Iron Atom Displacement Rate
	BE/C	BE/C.
A	0.95	1.02
B	0.94	0.99
C	0.96	1.00
E	0.97	1.03
Average	0.96	1.01
Standard deviation	1.4%	1.8%

Table A-30 Summary of Measured/Calculated (M/C) Sensor Reaction Rate Ratios for Fast Neutron Threshold Reactions – In-Vessel Surveillance Capsules and Ex-Vessel Midplane Capsules

Reaction	In-Vessel		Ex-Vessel Midplane		Combined	
	Avg. M/C	Std. Dev.	Avg. M/C	Std. Dev.	Avg. M/C	Std. Dev.
^{63}Cu (n,α) ^{60}Co	1.15	1.1%	0.96	3.0%	1.05	1.5%
^{46}Ti (n,p) ^{46}Sc	-	-	0.92	2.6%	-	-
^{54}Fe (n,p) ^{54}Mn	0.99	4.3%	0.93	3.9%	0.96	2.9%
^{58}Ni (n,p) ^{58}Co	0.96	8.3%	0.85	1.8%	0.90	4.5%
^{93}Nb (n,n') ^{93m}Nb	-	-	1.04	2.9%	-	-
^{238}U(Cd) (n,f) ^{137}Cs	1.04	2.9%	-	-	-	-
^{237}Np(Cd) (n,f) ^{137}Cs	0.99	8.2%	-	-	-	-
Average	1.02	8.1%	0.94	7.4%	0.98	5.5%

Table A-31 Summary of Best-Estimate/Calculated (BE/C) Exposure Rate Ratios – In-Vessel Surveillance Capsules and Ex-Vessel Midplane Capsules

Parameter	In-Vessel		Ex-Vessel Midplane		Combined	
	Avg. BE/C	Std. Dev.	Avg. BE/C	Std. Dev.	Avg. BE/C	Std. Dev.
Fast Fluence Rate (E > 1.0 MeV)	0.98	4.9%	0.96	1.4%	0.97	2.6%
Iron Atom Displacement Rate	0.98	4.0%	1.01	1.8%	1.00	2.2%

A.2 REFERENCES

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

A-2 Westinghouse Report, WCAP-12845, Revision 0, *Analysis of Capsule U from the Commonwealth Edison Company Braidwood Unit 2 Reactor Vessel Radiation Surveillance Program*, October 1989.

A-3 Westinghouse Report, WCAP-14228, Revision 0, *Analysis of Capsule W from Commonwealth Edison Company Braidwood Unit 2 Reactor Vessel Radiation Surveillance Program*, July 1994.

A-4 Westinghouse Report, WCAP-15369, Revision 0, *Analysis of Capsule X from Commonwealth Edison Company Braidwood Unit 2 Reactor Vessel Radiation Surveillance Program*, March 1999.

A-5 Westinghouse Report WCAP-17333-NP, Revision 1, *Ex-Vessel Neutron Dosimetry Program for Braidwood Unit 2 Cycle 15*, October 2012.

A-6 A. Schmittroth, *FERRET Data Analysis Core*, HEDL-TME 79-40, Hanford Engineering Development Laboratory, Richland, WA, September 1979.

A-7 RSICC Data Library Collection DLC-178, *SNLRML Recommended Dosimetry Cross-Section Compendium*, July 1994.

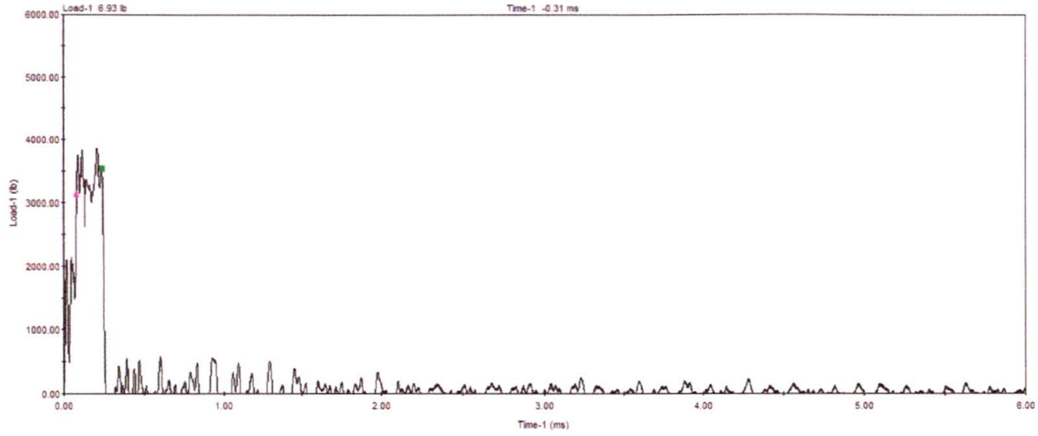
A-8 ASTM Standard E944-13, *Standard Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance*, E 706 (IIA), 2013.

A-9 ASTM Standard E1005-10, *Standard Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance*, E 706 (IIIA), 2010.

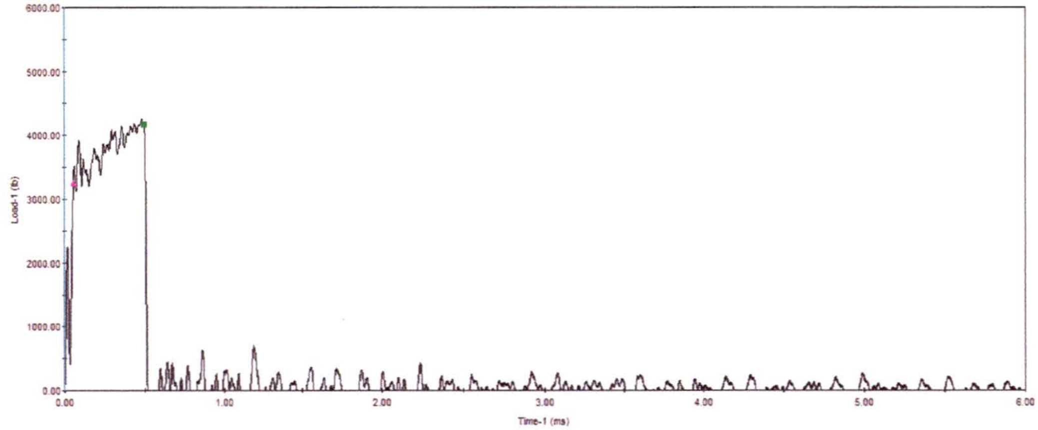
APPENDIX B LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

- "FLXX" denotes Lower Shell Forging [50D102/50C97]-1-1, tangential orientation
- "FTXX" denotes Lower Shell Forging [50D102/50C97]-1-1, axial orientation
- "FWXX" denotes weld material
- "FHXX" denotes heat-affected zone material

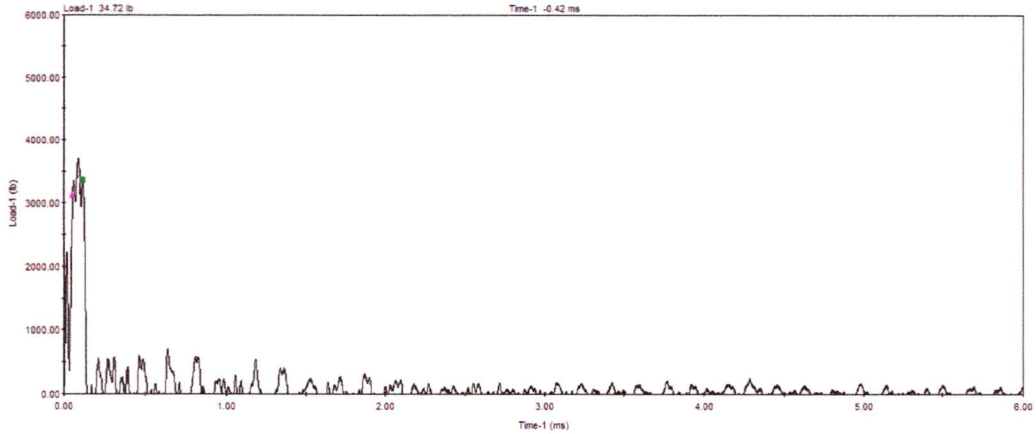
Note that the instrumented Charpy data is not required per ASTM Standards E185-82 or E23-07a.



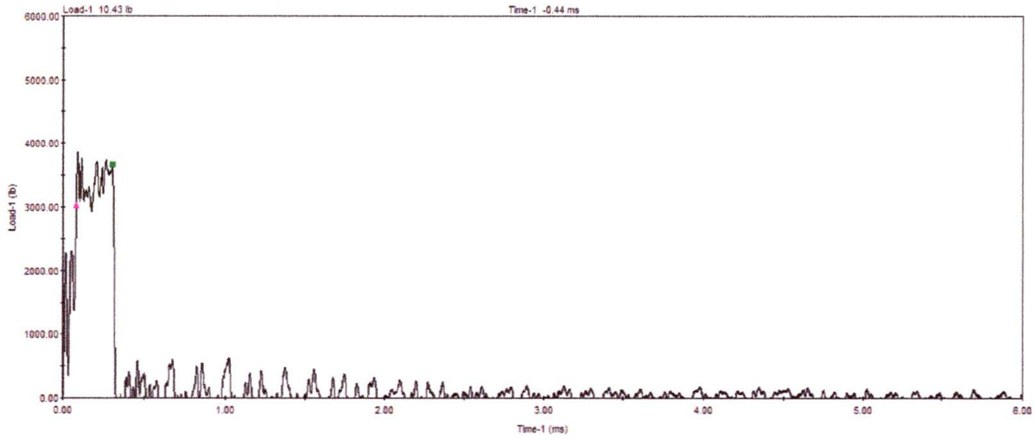
FL23: Tested at -10°F



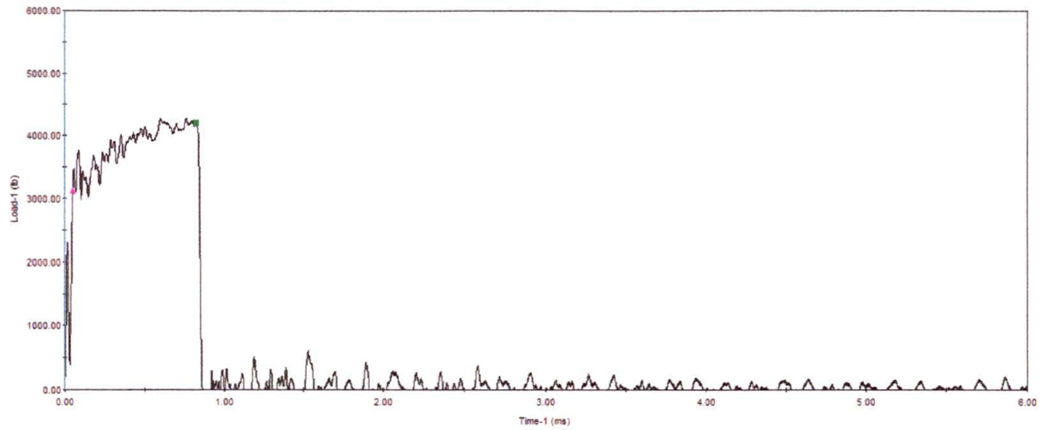
FL26: Tested at 0°F



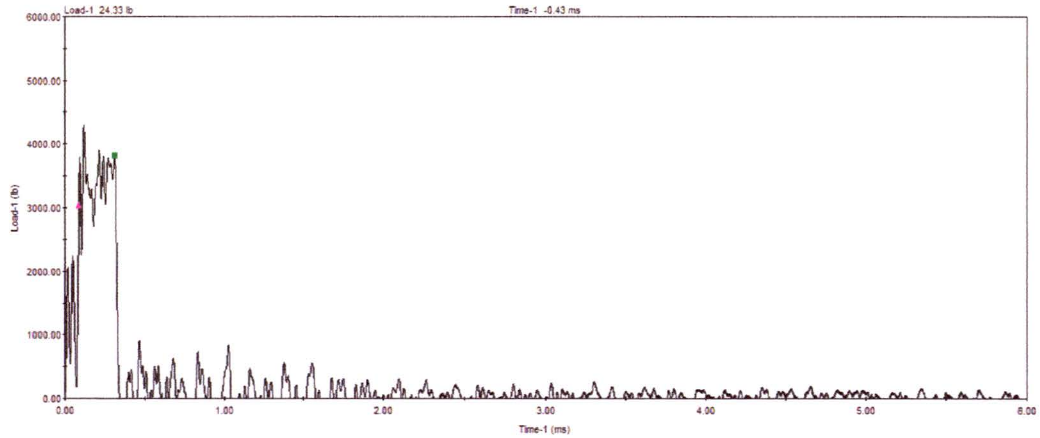
FL24: Tested at 10°F



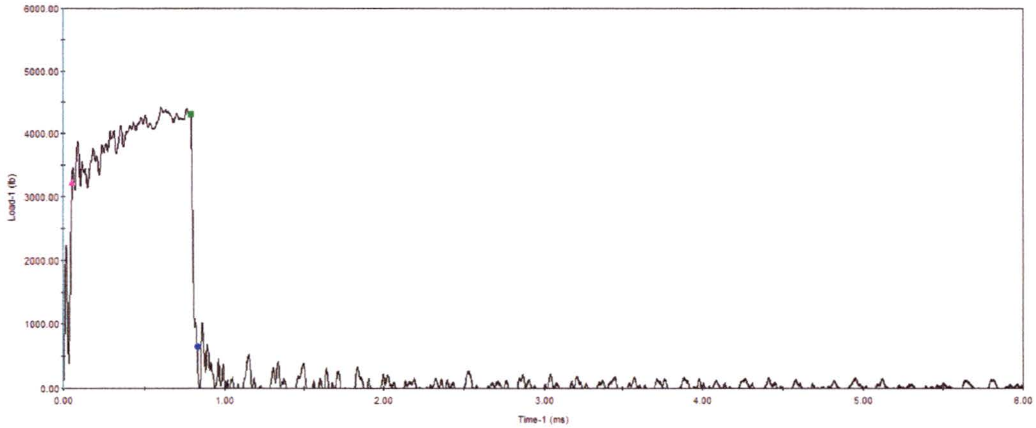
FL22: Tested at 15°F



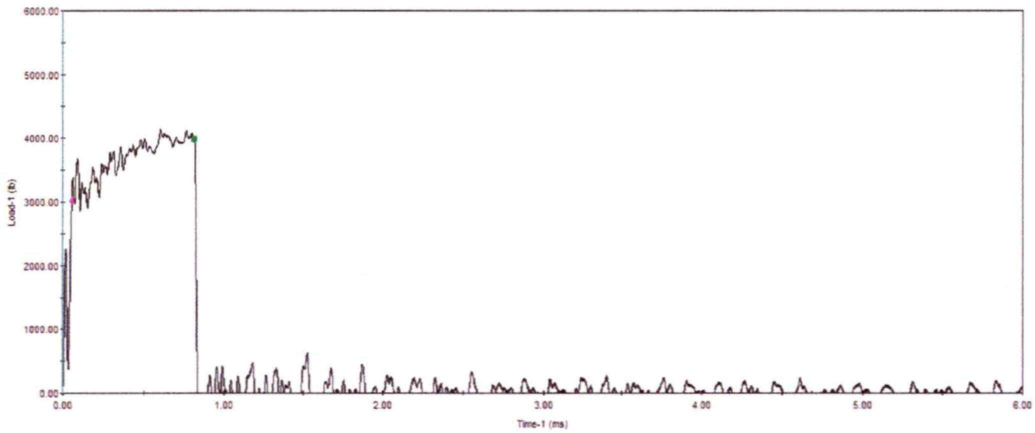
FL20: Tested at 15°F



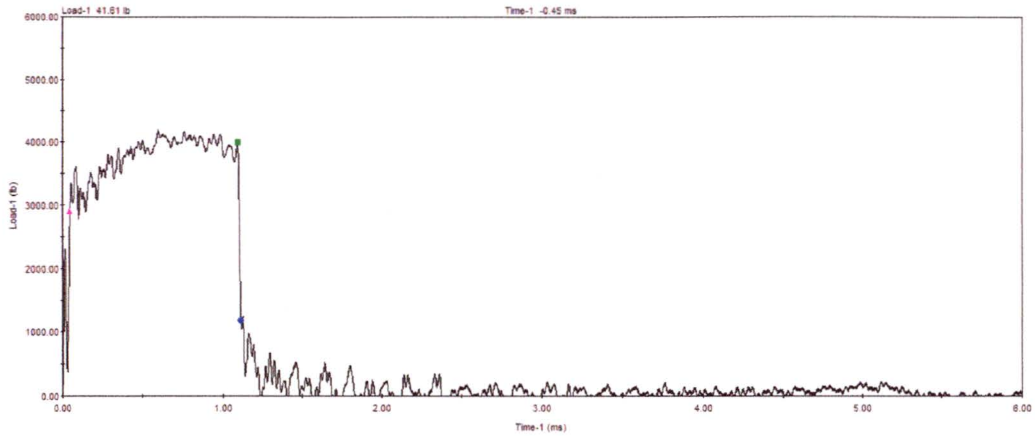
FL16: Tested at 20°F



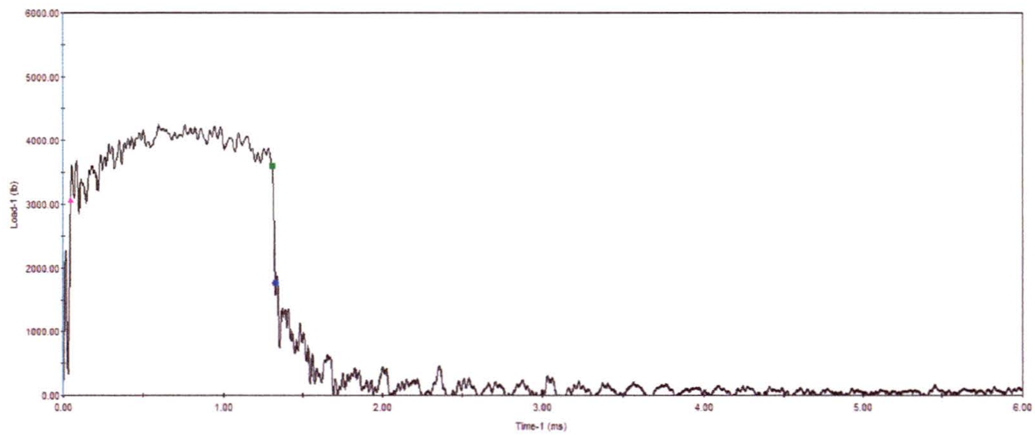
FL25: Tested at 25°F



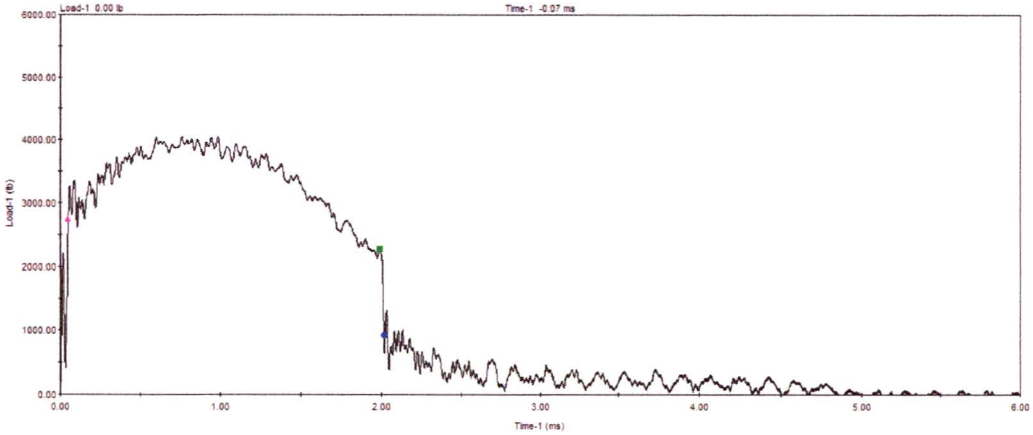
FL29: Tested at 30°F



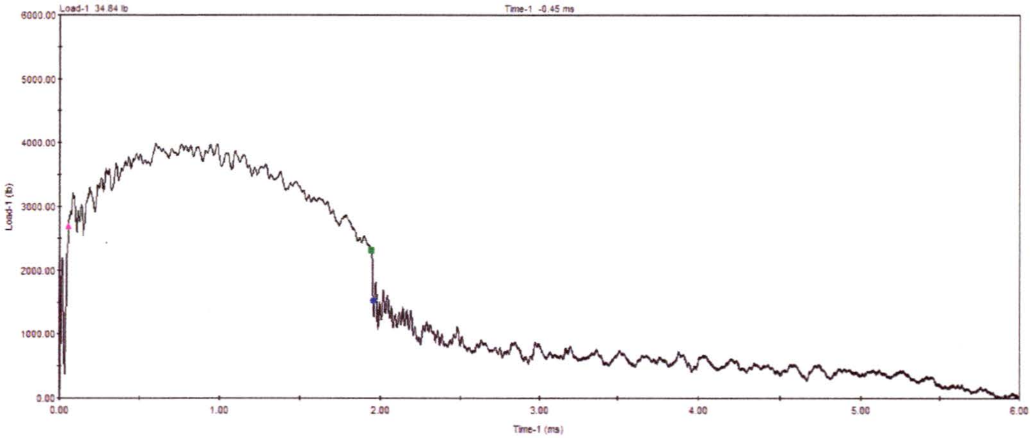
FL27: Tested at 50°F



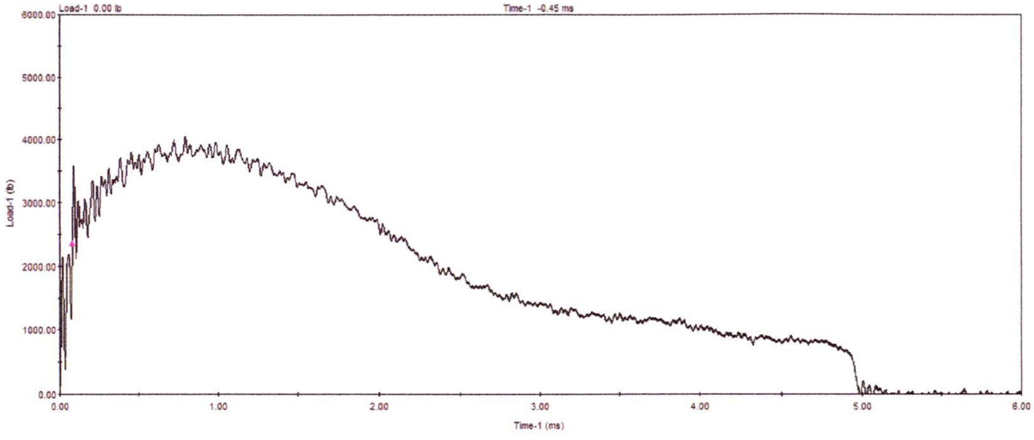
FL30: Tested at 72°F



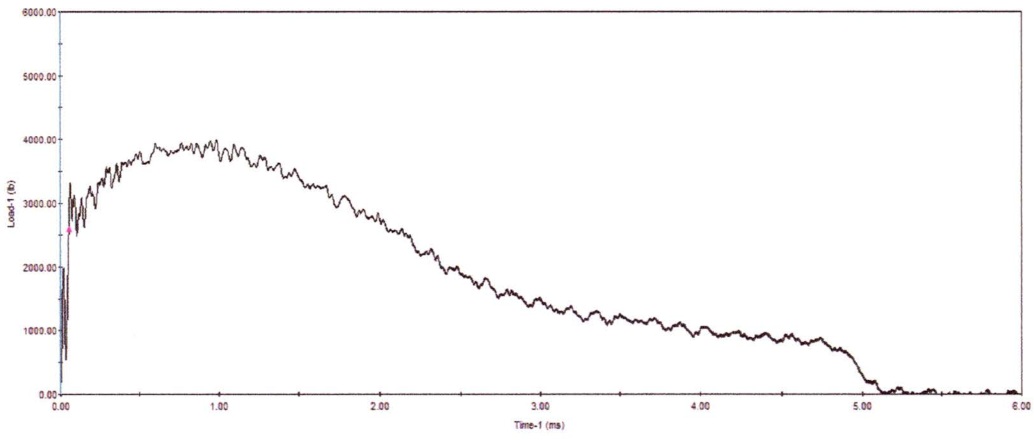
FL17: Tested at 125°F



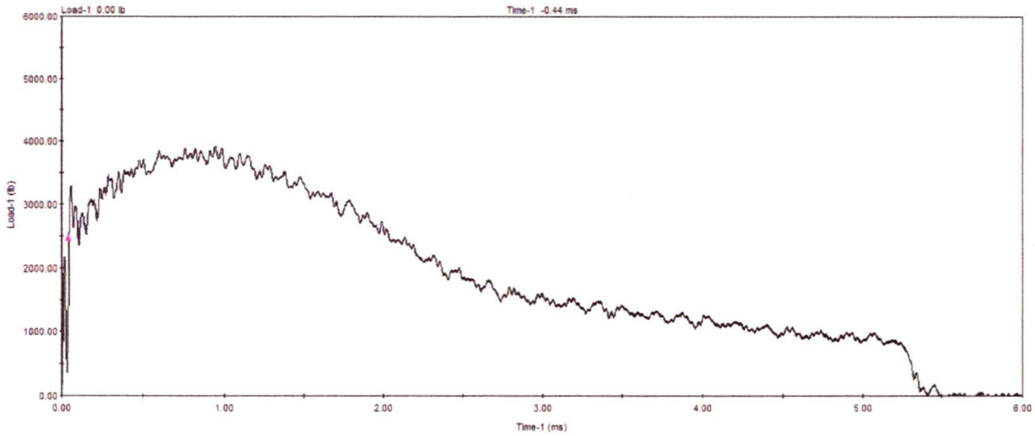
FL28: Tested at 175°F



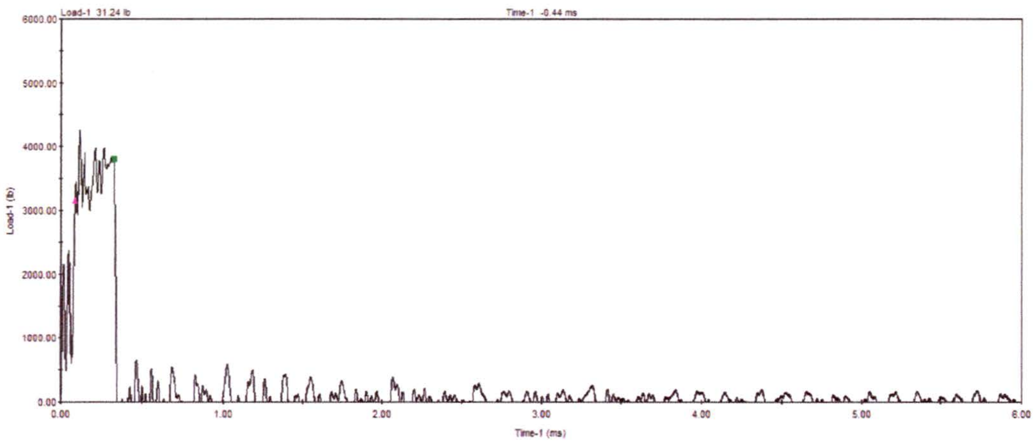
FL19: Tested at 200°F



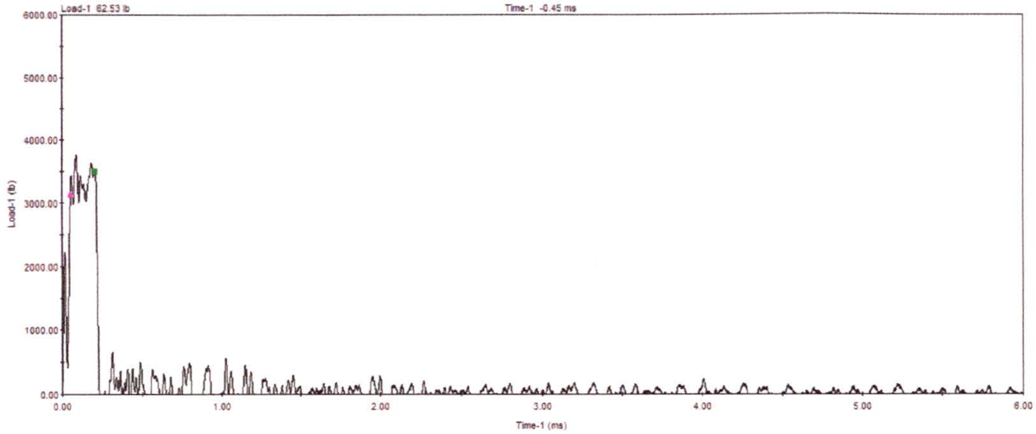
FL18: Tested at 210°F



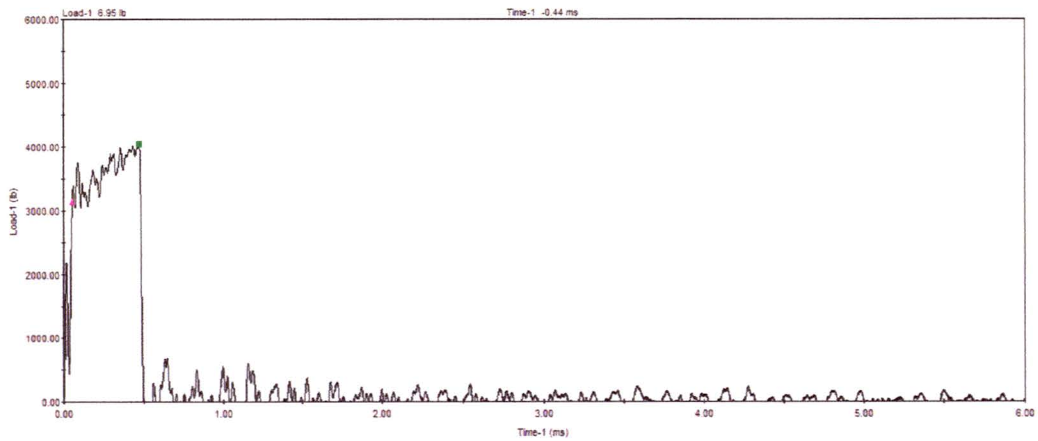
FL21: Tested at 220°F



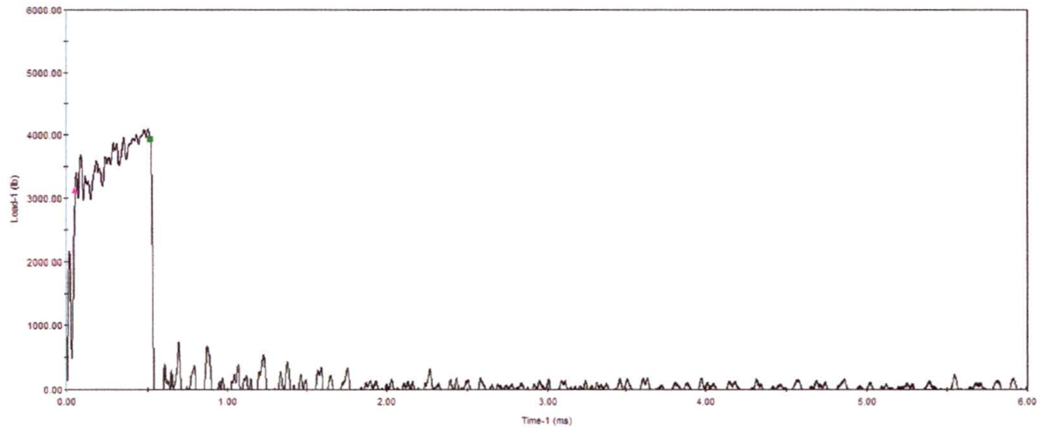
FT24: Tested at -10°F



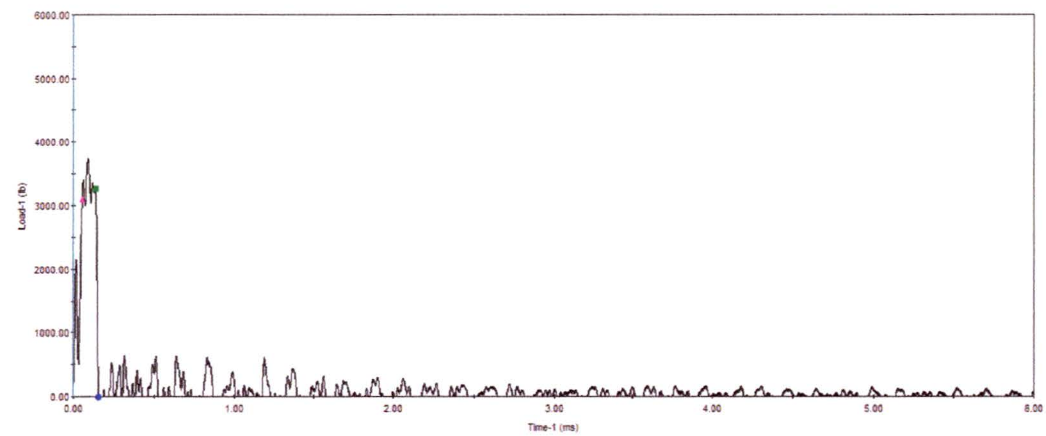
FT22: Tested at 10°F



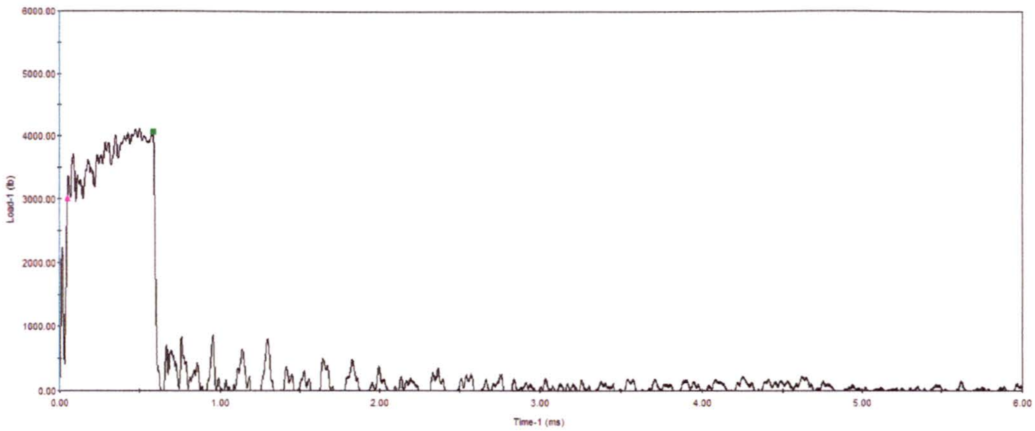
FT18: Tested at 15°F



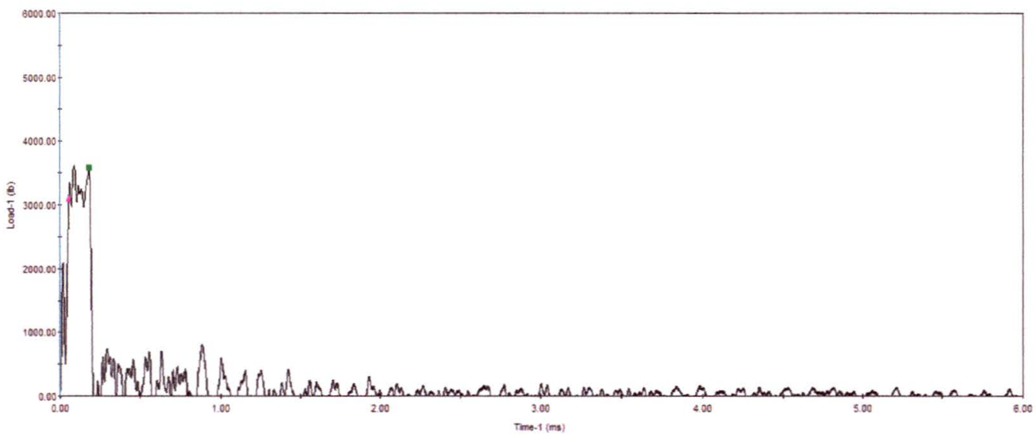
FT21: Tested at 25°F



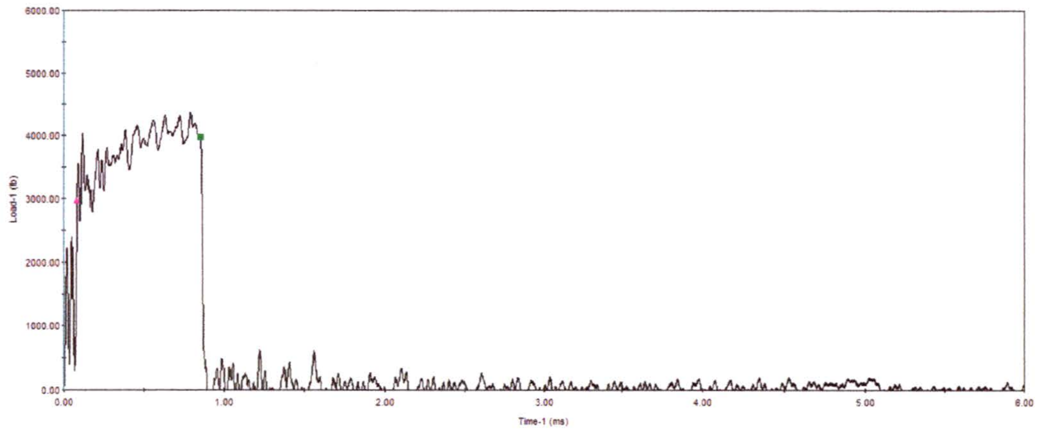
FT23: Tested at 30°F



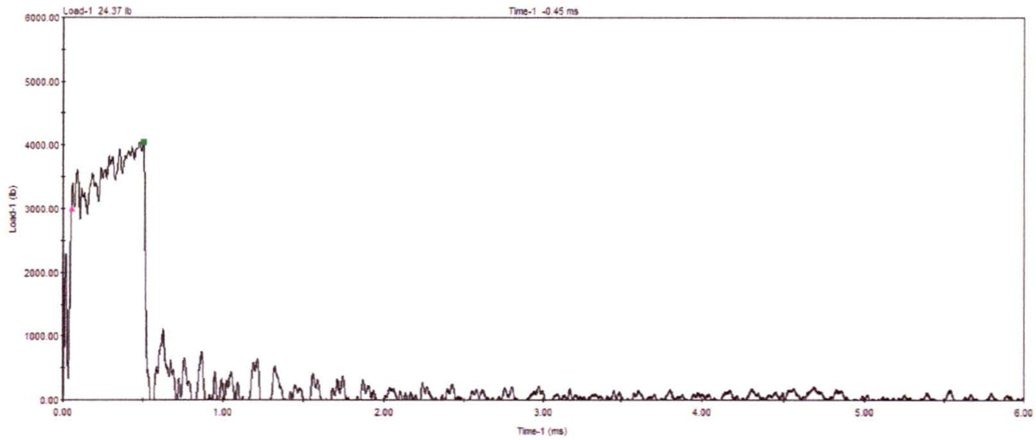
FT20: Tested at 35°F



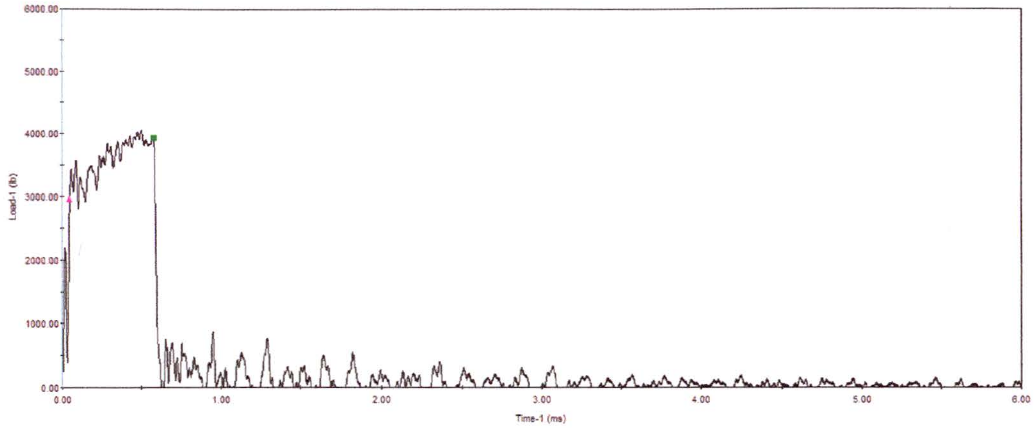
FT29: Tested at 45°F



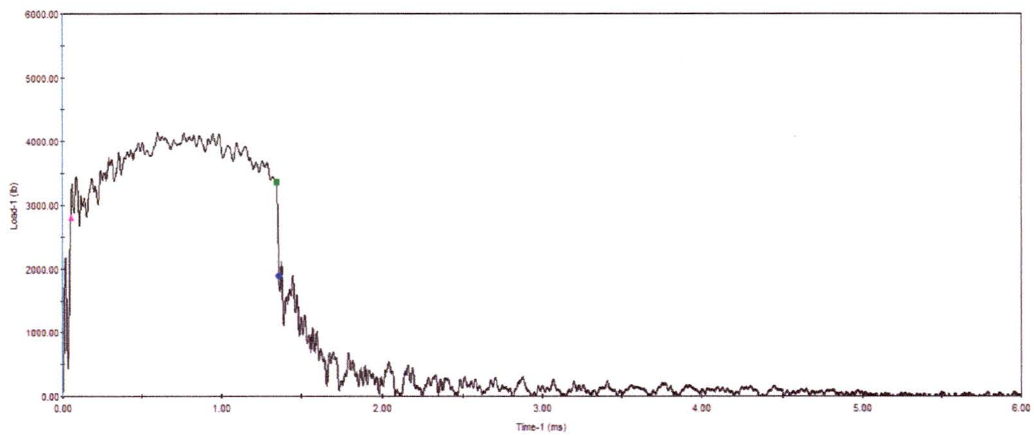
FT27: Tested at 50°F



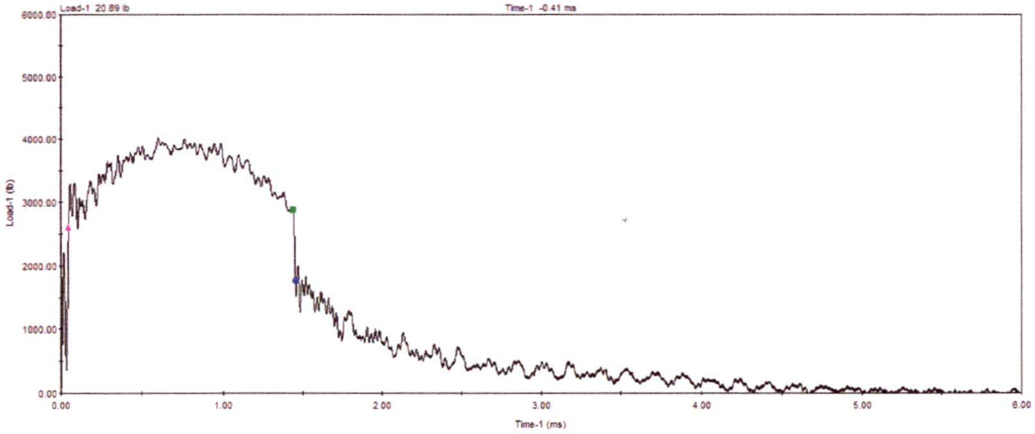
FT28: Tested at 60°F



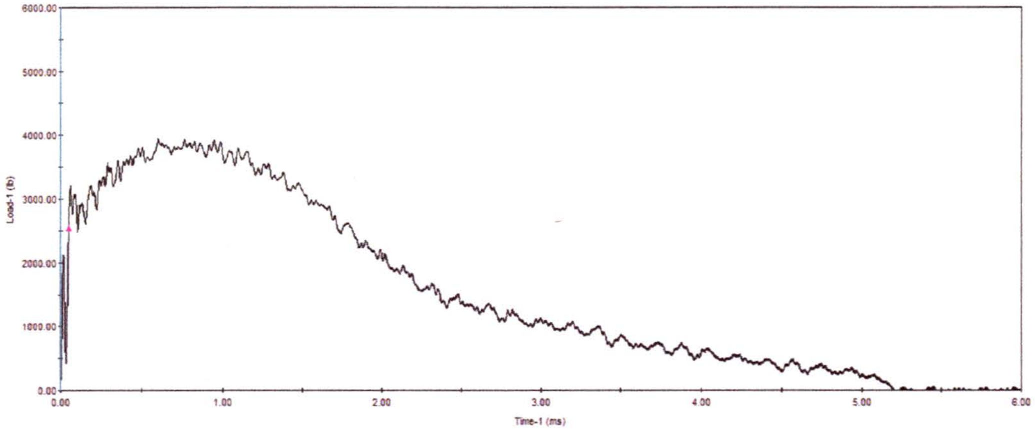
FT26: Tested at 72°F



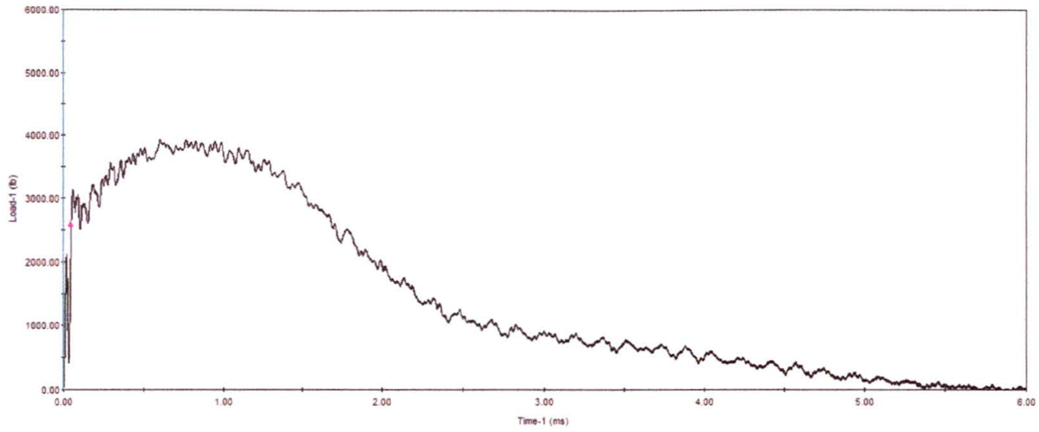
FT16: Tested at 125°F



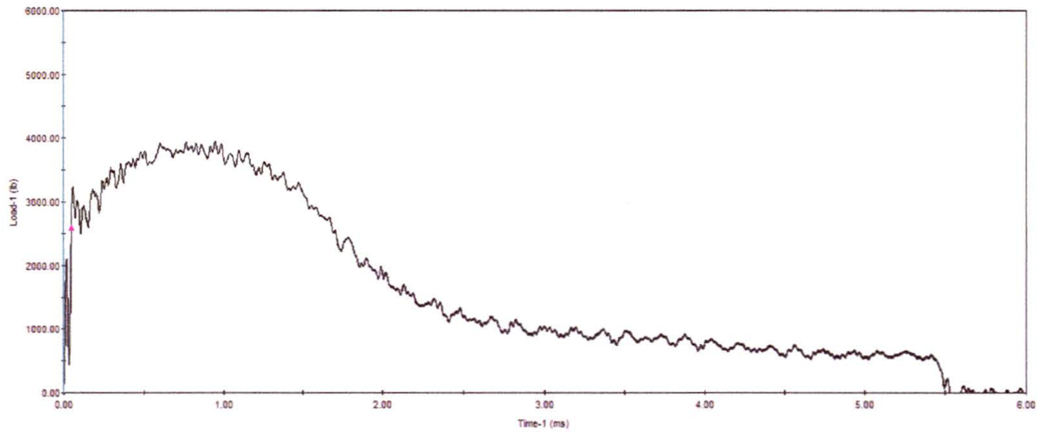
FT19: Tested at 175°F



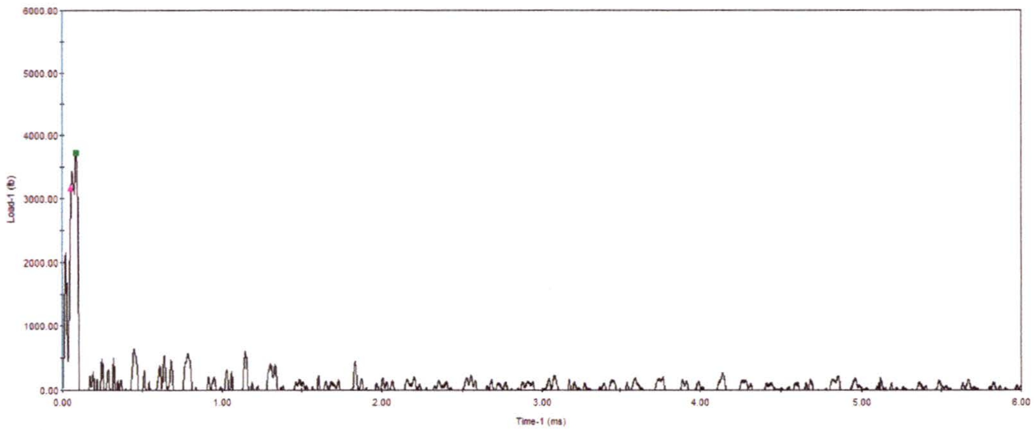
FT30: Tested at 200°F



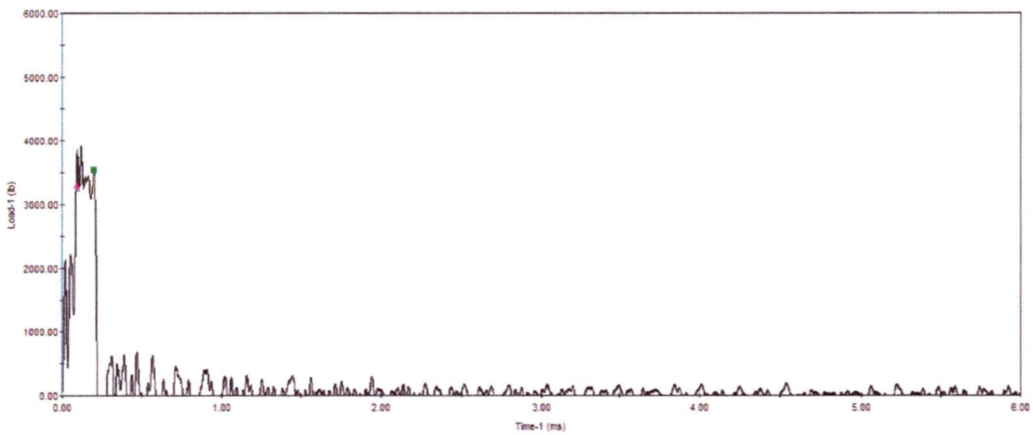
FT17: Tested at 210°F



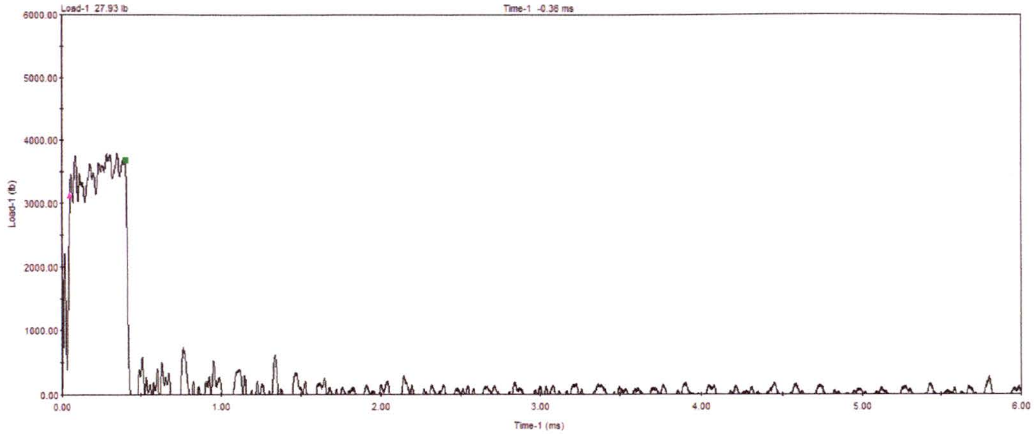
FT25: Tested at 220°F



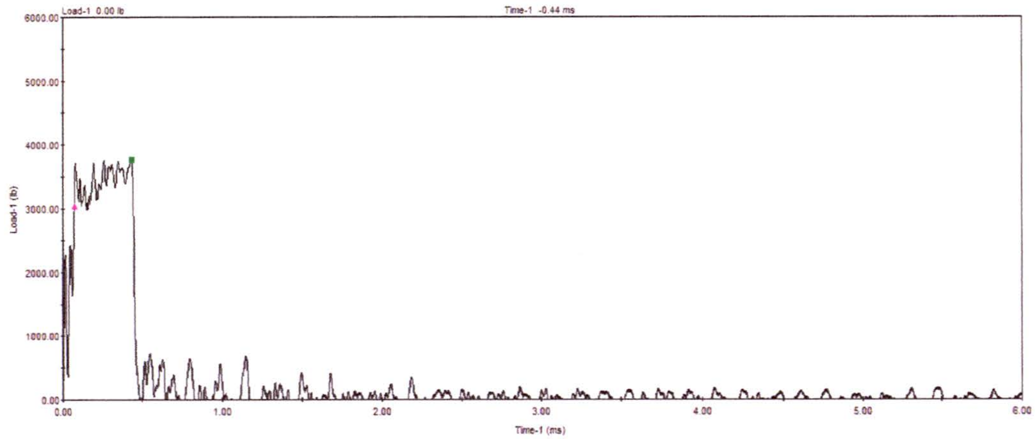
FW24: Tested at -50°F



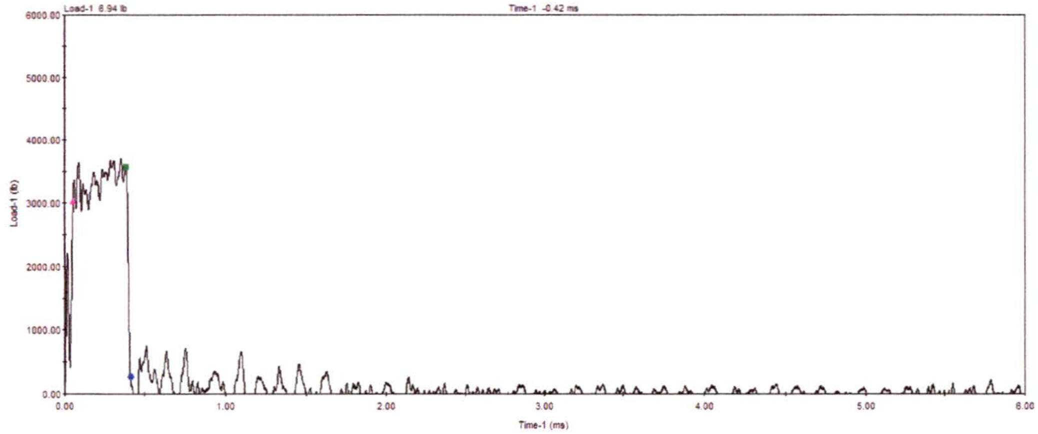
FW21: Tested at -30°F



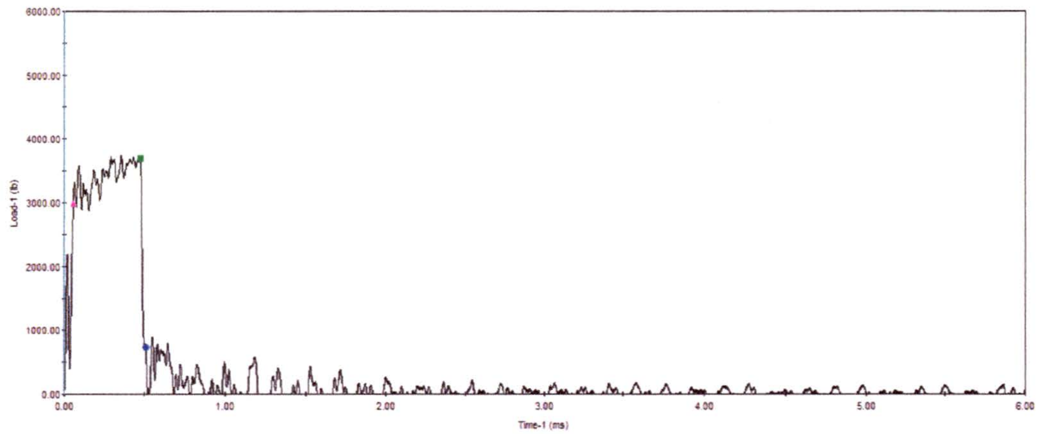
FW28: Tested at -10°F



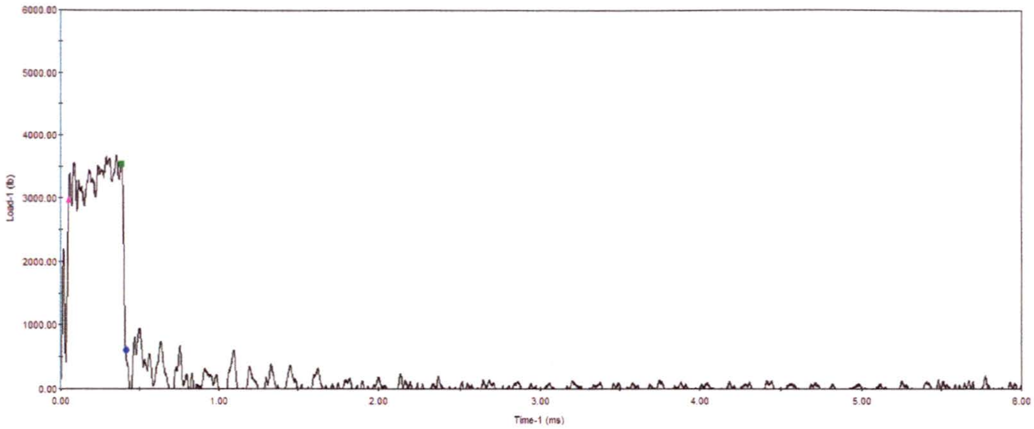
FW18: Tested at 0°F



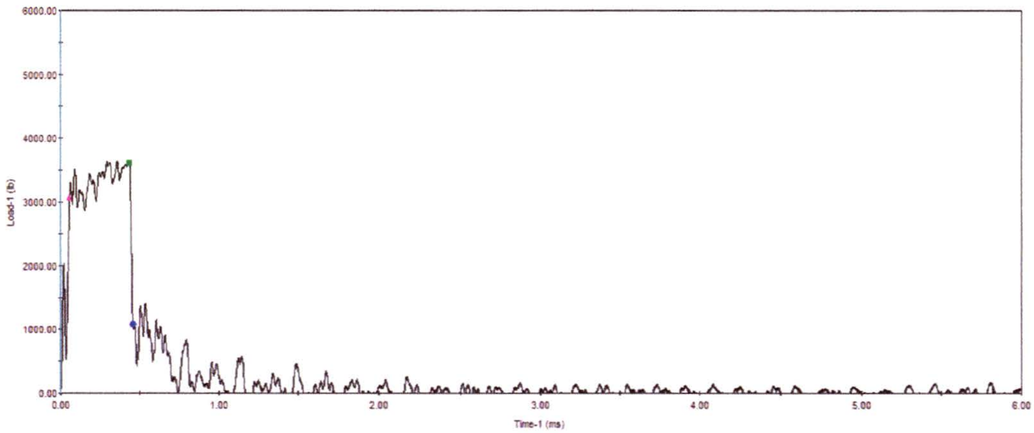
FW19: Tested at 10°F



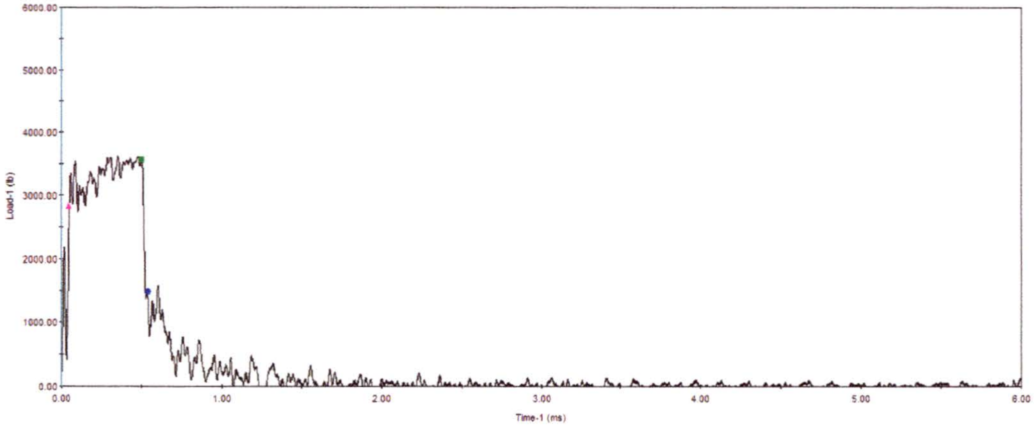
FW25: Tested at 25°F



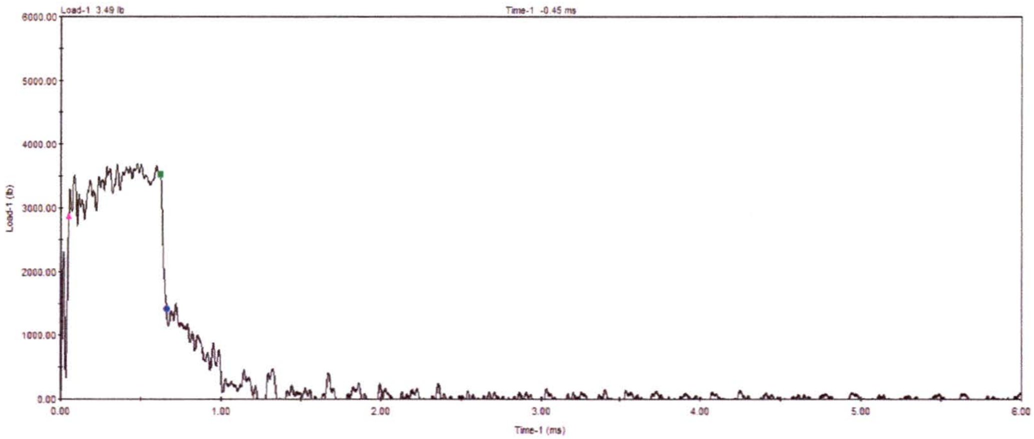
FW29: Tested at 30°F



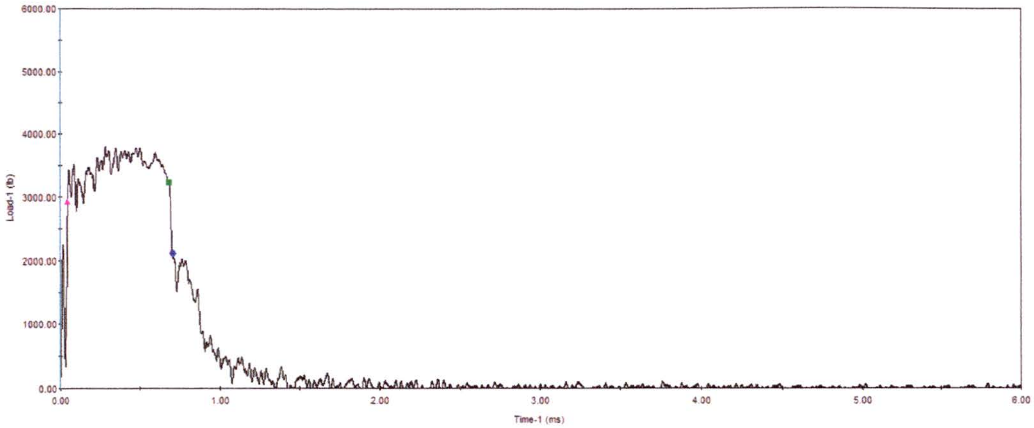
FW17: Tested at 40°F



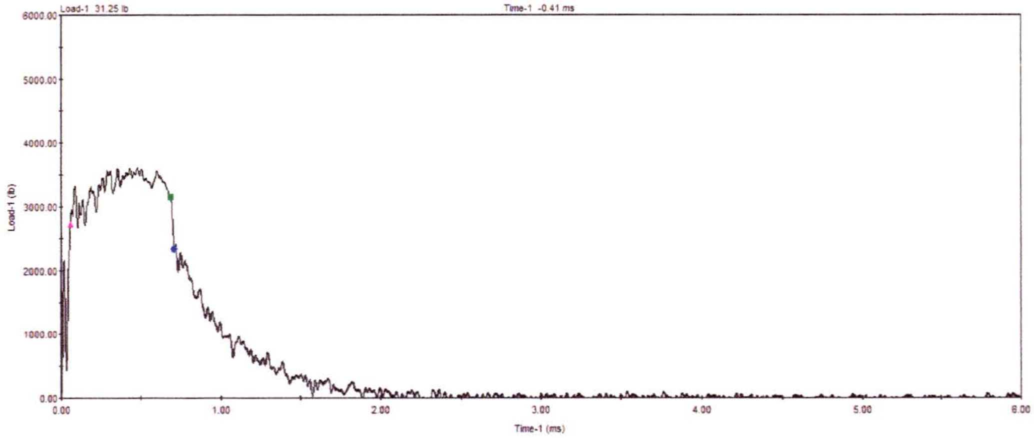
FW16: Tested at 50°F



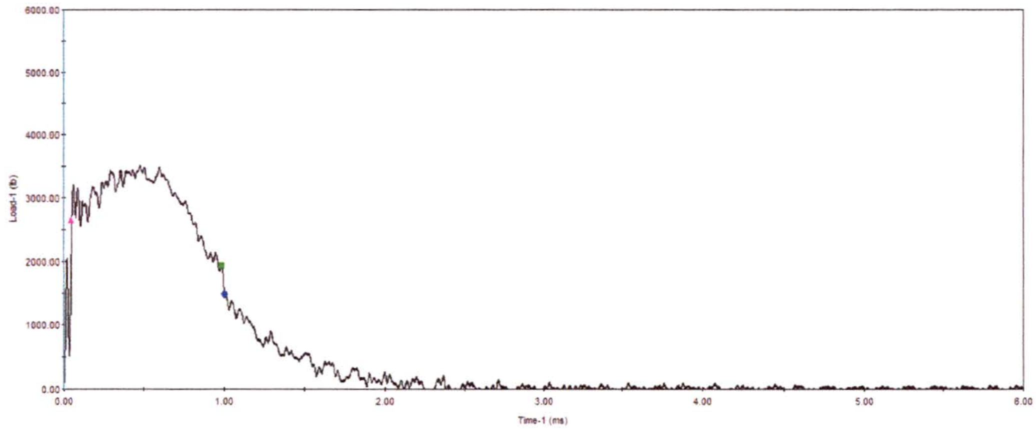
FW27: Tested at 60°F



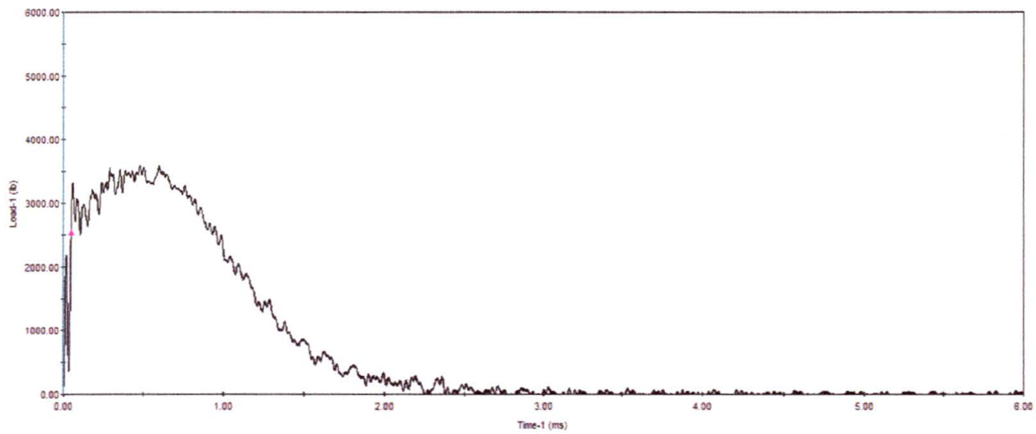
FW26: Tested at 72°F



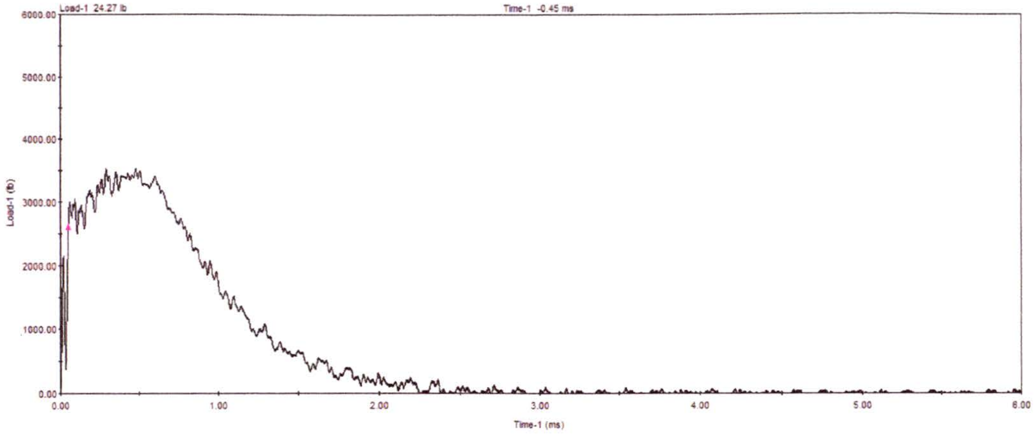
FW20: Tested at 125°F



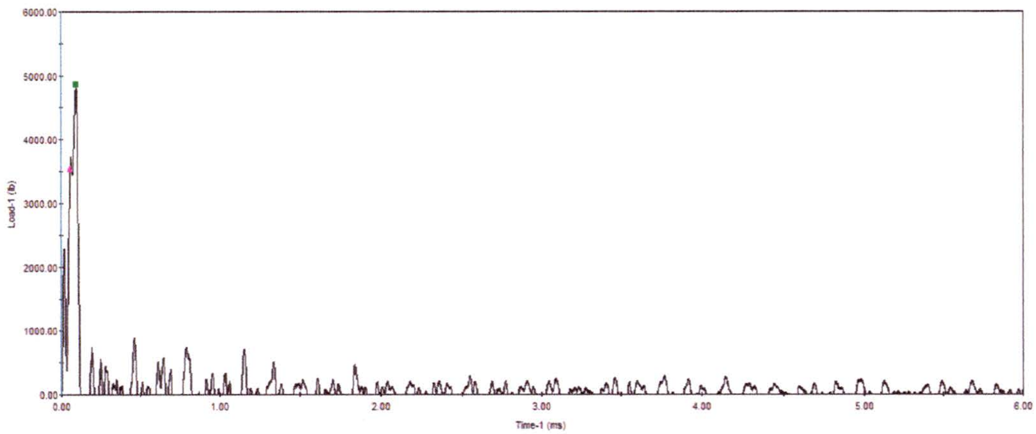
FW23: Tested at 175°F



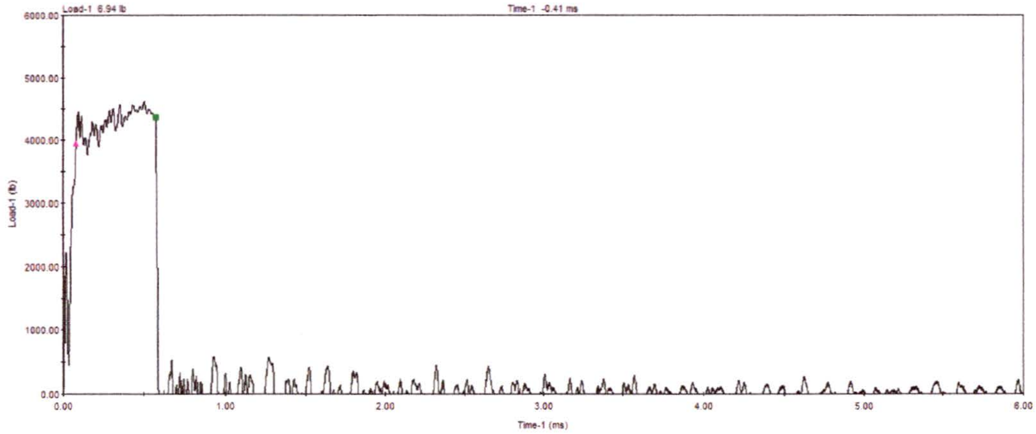
FW30: Tested at 200°F



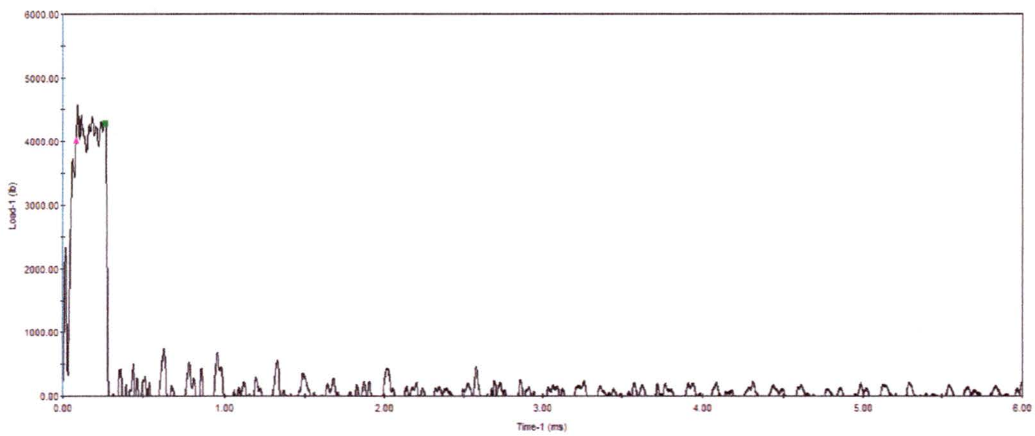
FW22: Tested at 220°F



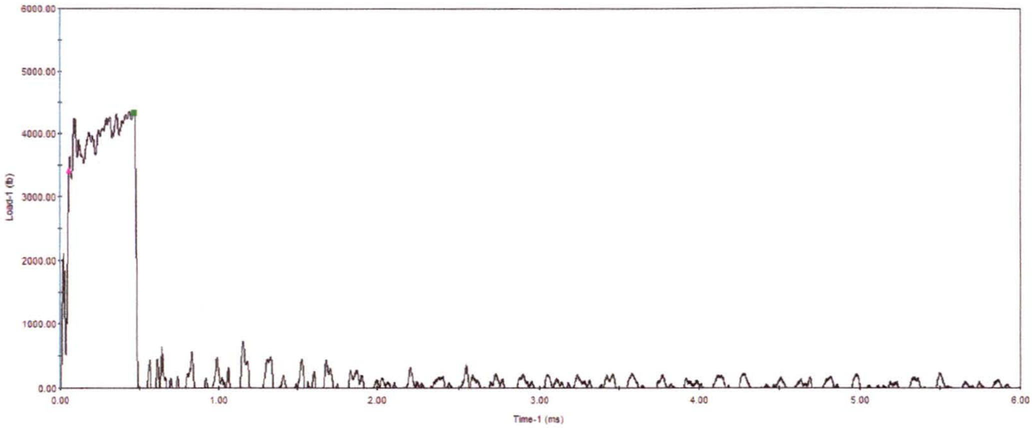
FH29: Tested at -200°F



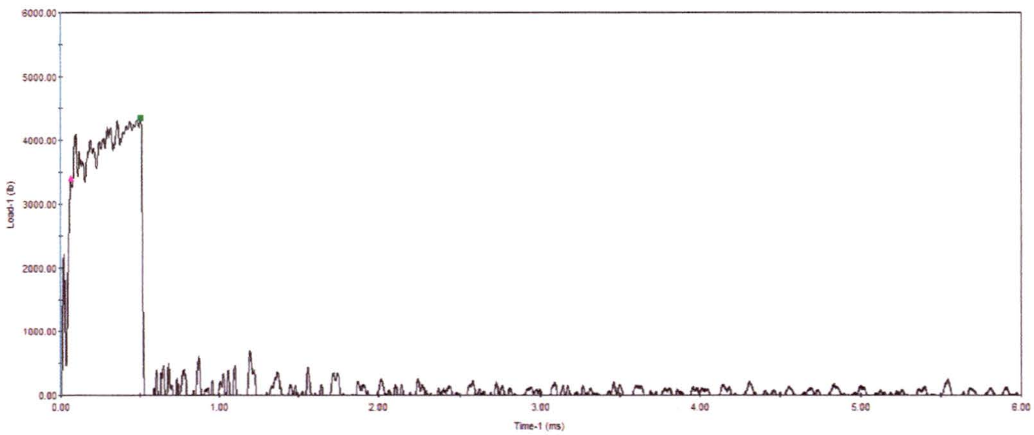
FH23: Tested at -150°F



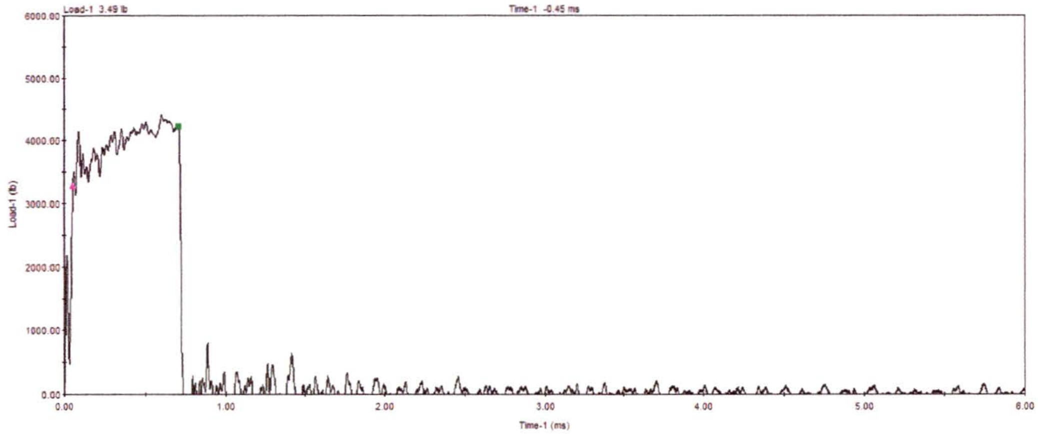
FH22: Tested at -125°F



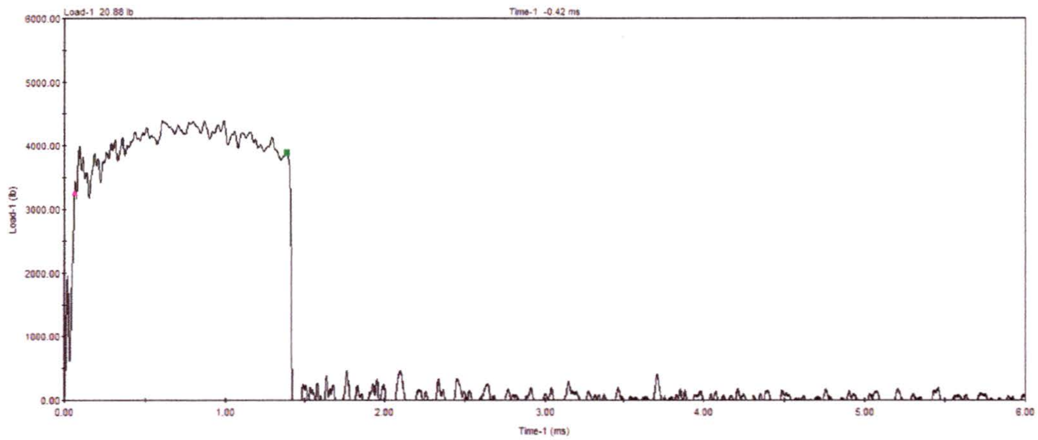
FH30: Tested at -100°F



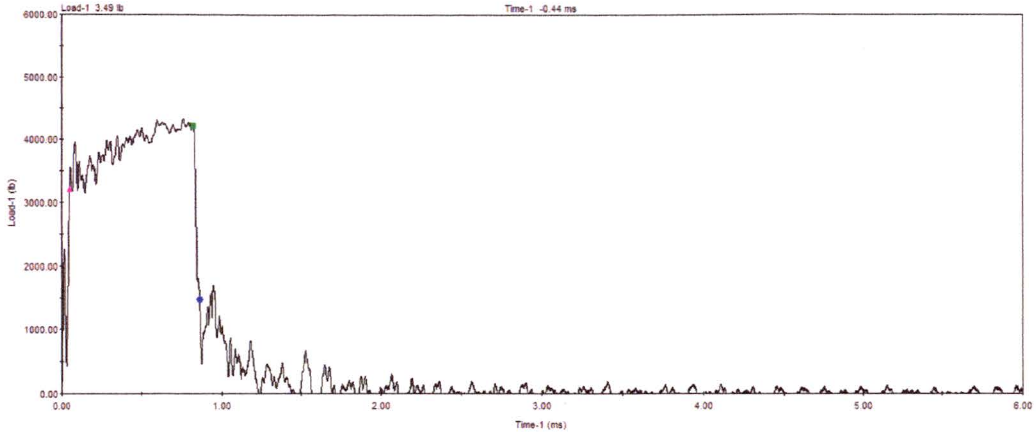
FH27: Tested at -80°F



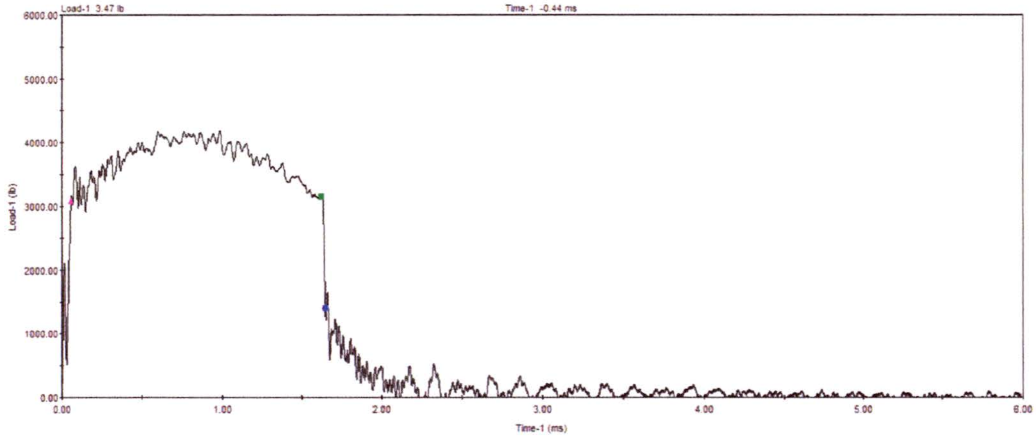
FH18: Tested at -60°F



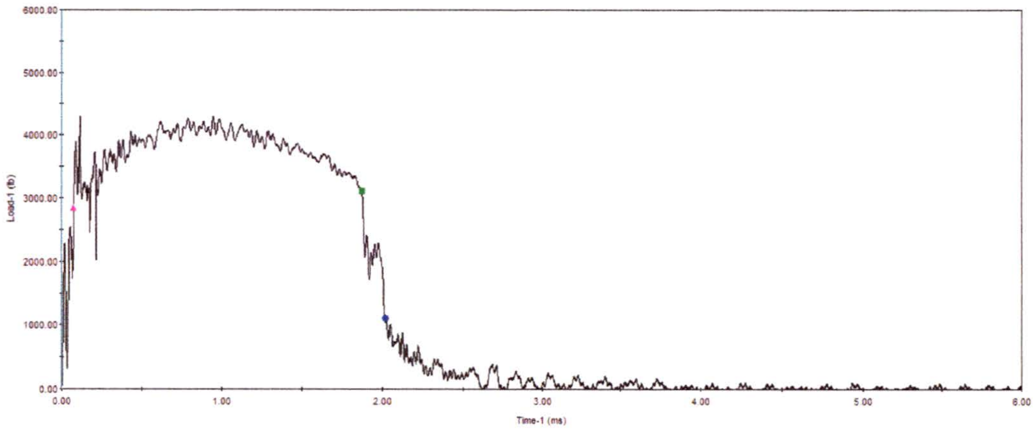
FH20: Tested at -50°F



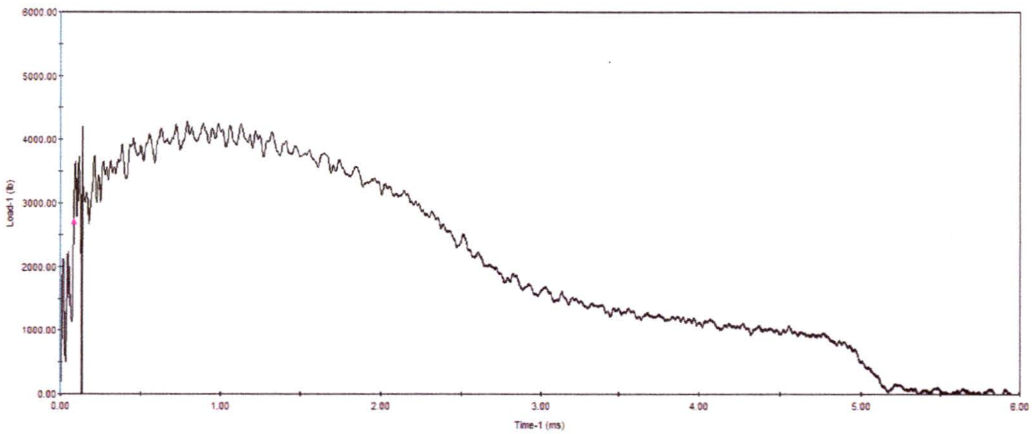
FH25: Tested at -10°F



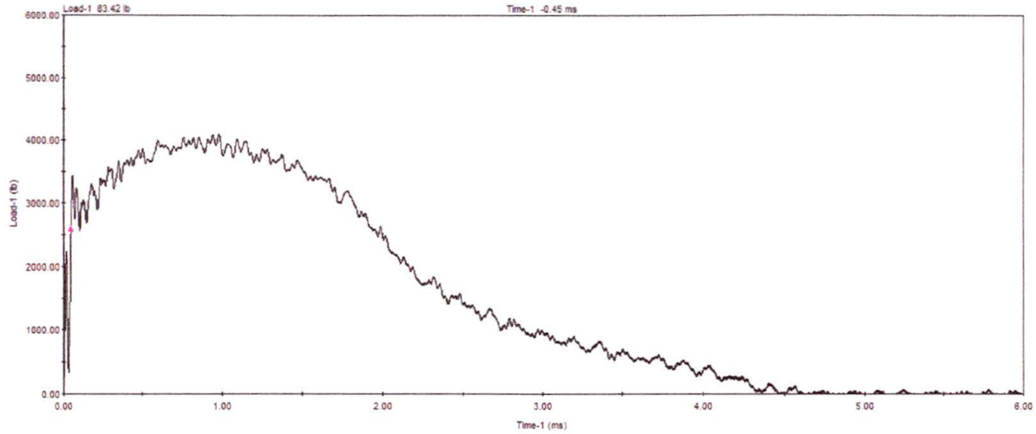
FH21: Tested at 30°F



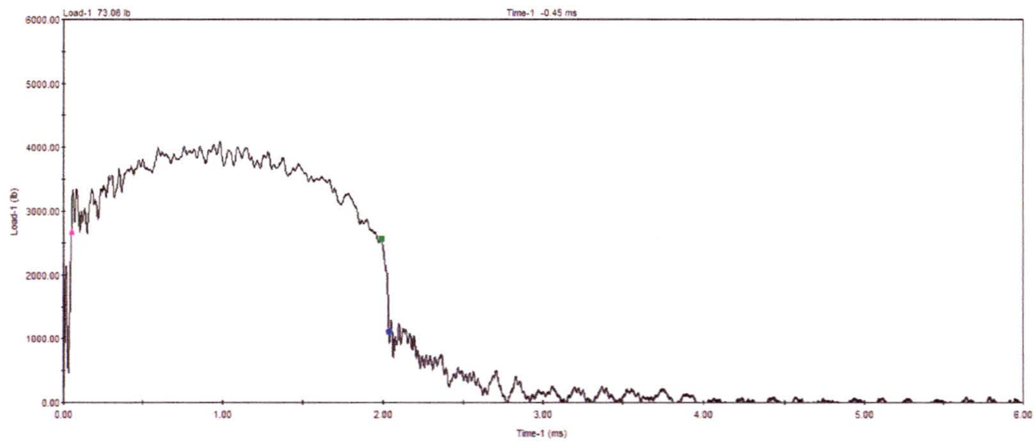
FH19: Tested at 72°F



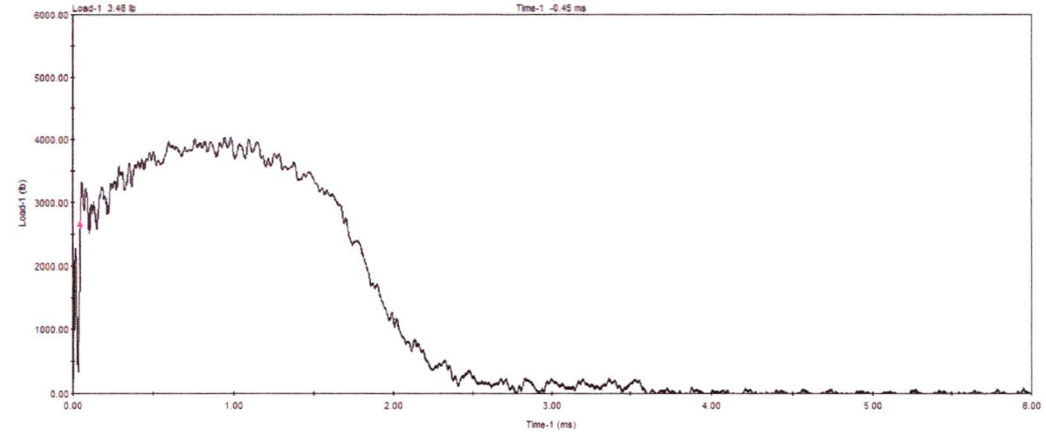
FH16: Tested at 125°F



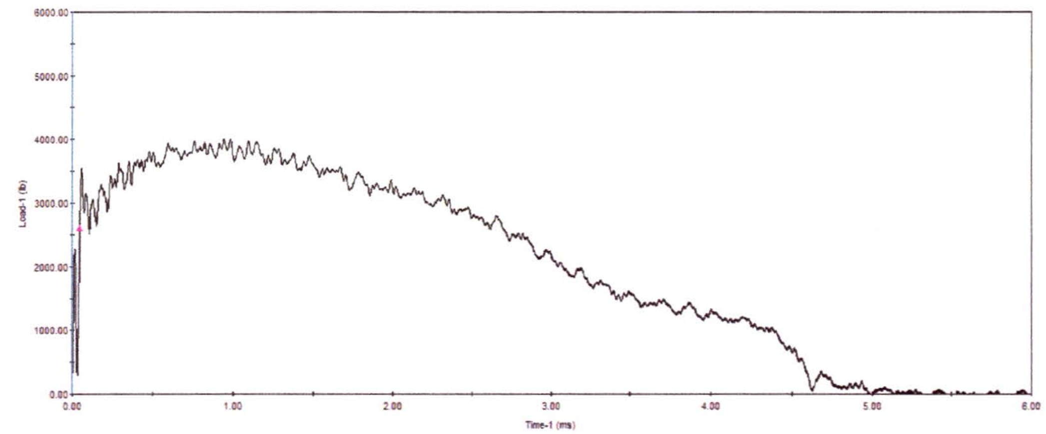
FH24: Tested at 150°F



FH26: Tested at 175°F



FH28: Tested at 200°F



FH17: Tested at 210°F

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

C.1 METHODOLOGY

Contained in Table C-1 are the upper-shelf energy (USE) values that are used as input for the generation of the Charpy V-notch plots using CVGRAPH, Version 6.02. The definition for USE is given in ASTM E185-82 [Ref. C-1], Section 4.18, and reads as follows:

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

Westinghouse reports the average of all Charpy data (≥ 95% shear) as the USE, excluding any values that are deemed outliers using engineering judgment. Hence, the Capsule V 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 U, X, and W, were also determined by applying the methodology described above to the Charpy impact data reported in WCAP-11188 [Ref. C-2], WCAP-12845 [Ref. C-3], WCAP-14228 [Ref. C-4], and WCAP-15369 [Ref. C-5]. 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 mil in order to be consistent with the previous capsule analysis [Ref. C-5].

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

Material	Capsule				
	Unirradiated	U	X	W	V
	(ft-lbs)	(ft-lbs)	(ft-lbs)	(ft-lbs)	(ft-lbs)
Lower Shell Forging [50D102/50C97]-1-1 (Tangential Orientation)	168	176	167	166	166
Lower Shell Forging [50D102/50C97]-1-1 (Axial Orientation)	153	137	145	147	144
Surveillance Weld Metal (Heat # 442011)	69	62	68	68	64
Heat-Affected Zone (HAZ) Material	155	200	125	157	154

CVGRAPH, Version 6.02 plots of all surveillance data are provided in this appendix, on the pages following the reference list.

C.2 REFERENCES

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

C-2 Westinghouse Report WCAP-11188, Revision 0, *Commonwealth Edison Company Braidwood Station Unit No. 2 Reactor Vessel Radiation Surveillance Program*, December 1986.

C-3 Westinghouse Report WCAP-12845, Revision 0, *Analysis of Capsule U from the Commonwealth Edison Company Braidwood Unit 2 Reactor Vessel Radiation Surveillance Program*, March 1991.

C-4 Westinghouse Report WCAP-14228, Revision 0, *Analysis of Capsule X from the Commonwealth Edison Company Braidwood Unit 2 Reactor Vessel Radiation Surveillance Program*, March 1995.

C-5 Westinghouse Report WCAP-15369, Revision 0, *Analysis of Capsule W from Commonwealth Edison Company Braidwood Unit 2 Reactor Vessel Radiation Surveillance Program*, March 2000.

C.3 CVGRAPH VERSION 6.02 INDIVIDUAL PLOTS

BRAIDWOOD UNIT 2 UNIRRADIATED (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:26 PM

A = 85.10 B = 82.90 C = 66.90 T0 = 32.65 D = 0.00

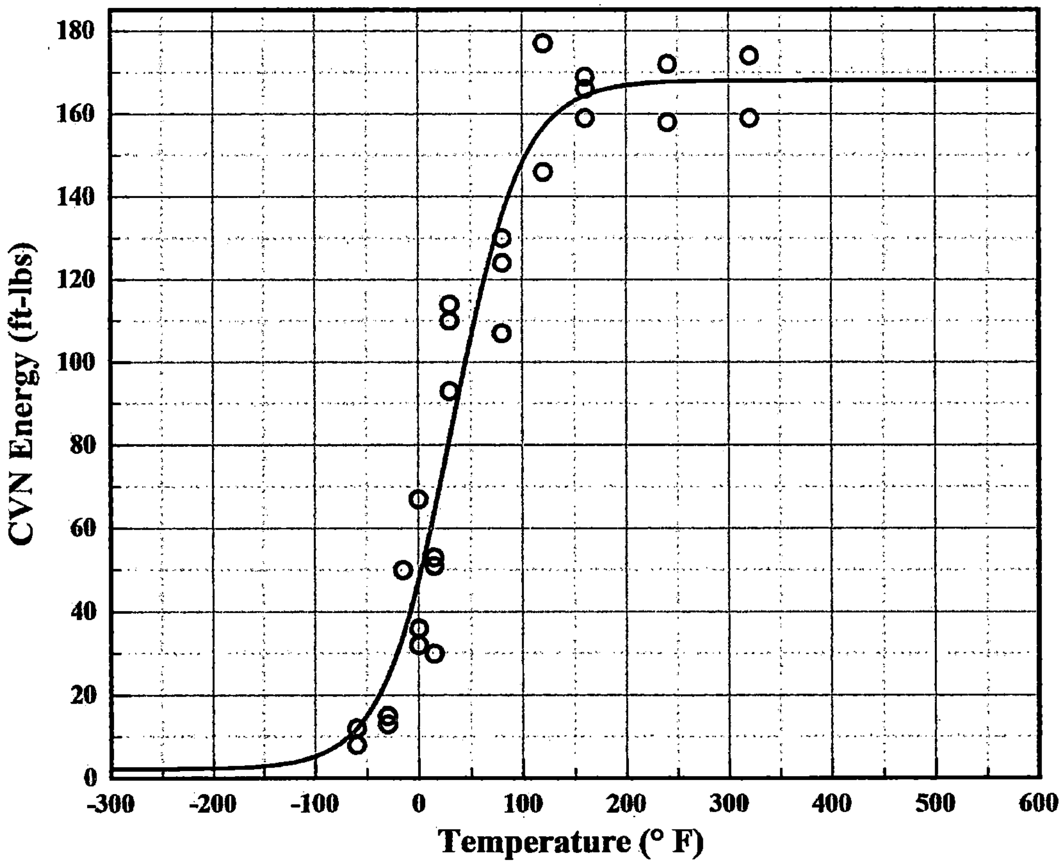
Correlation Coefficient = 0.965

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

Upper Shelf Energy = 168.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-20.90° F Temp@35 ft-lbs=-14.10° F Temp@50 ft-lbs= 2.50° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-60	8.0	12.0	-3.98
-60	12.0	12.0	0.02
-30	13.0	24.3	-11.28
-30	15.0	24.3	-9.28
-15	50.0	34.4	15.64
-15	50.0	34.4	15.64
0	32.0	47.6	-15.57
0	36.0	47.6	-11.57
0	67.0	47.6	19.43
15	30.0	63.7	-33.72
15	53.0	63.7	-10.72
15	51.0	63.7	-12.72
30	93.0	81.8	11.18
30	110.0	81.8	28.18
30	114.0	81.8	32.18
80	107.0	135.6	-28.61
80	124.0	135.6	-11.61
80	130.0	135.6	-5.61
120	146.0	156.7	-10.66
120	177.0	156.7	20.34
120	177.0	156.7	20.34
160	159.0	164.4	-5.40
160	166.0	164.4	1.60
160	169.0	164.4	4.60
240	158.0	167.7	-9.66
240	172.0	167.7	4.34
320	159.0	168.0	-8.97
320	174.0	168.0	6.03

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BRAIDWOOD UNIT 2 UNIRRADIATED (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:28 PM

A = 44.09 B = 43.09 C = 48.50 T0 = 10.74 D = 0.00

Correlation Coefficient = 0.957

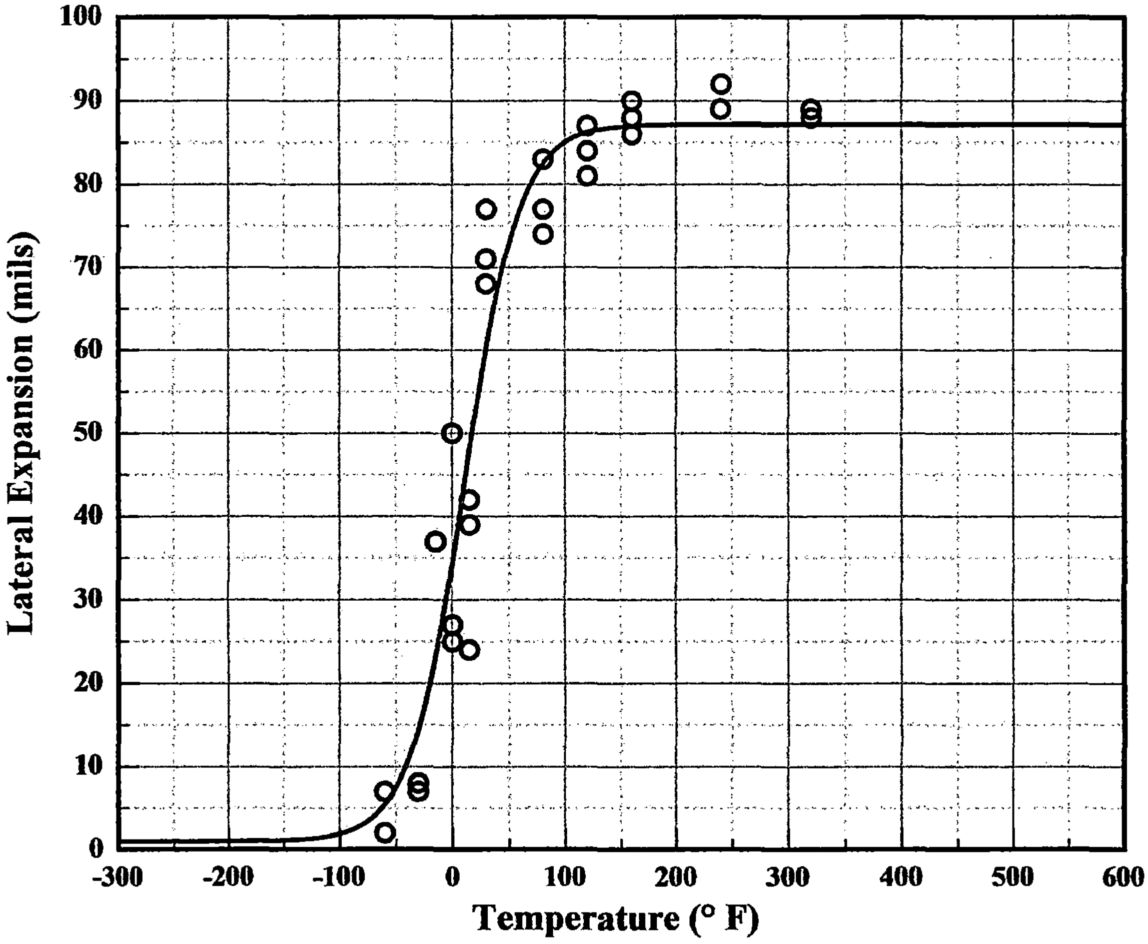
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 87.18 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 0.40° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-60	2.0	5.4	-3.42
-60	7.0	5.4	1.58
-30	7.0	14.5	-7.53
-30	8.0	14.5	-6.53
-15	37.0	23.1	13.85
-15	37.0	23.1	13.85
0	25.0	34.7	-9.70
0	27.0	34.7	-7.70
0	50.0	34.7	15.30
15	24.0	47.9	-23.86
15	42.0	47.9	-5.86
15	39.0	47.9	-8.86
30	68.0	60.4	7.65
30	71.0	60.4	10.65
30	77.0	60.4	16.65
80	74.0	82.5	-8.49
80	77.0	82.5	-5.49
80	83.0	82.5	0.51
120	81.0	86.2	-5.24
120	87.0	86.2	0.76
120	84.0	86.2	-2.24
160	86.0	87.0	-1.00
160	88.0	87.0	1.00
160	90.0	87.0	3.00
240	89.0	87.2	1.83
240	92.0	87.2	4.83
320	89.0	87.2	1.82
320	88.0	87.2	0.82

CVGraph 6.02 10/16/2015 Page 2/2

BRAIDWOOD UNIT 2 UNIRRADIATED (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:29 PM

A = 50.00 B = 50.00 C = 52.96 T0 = 39.04 D = 0.00

Correlation Coefficient = 0.963

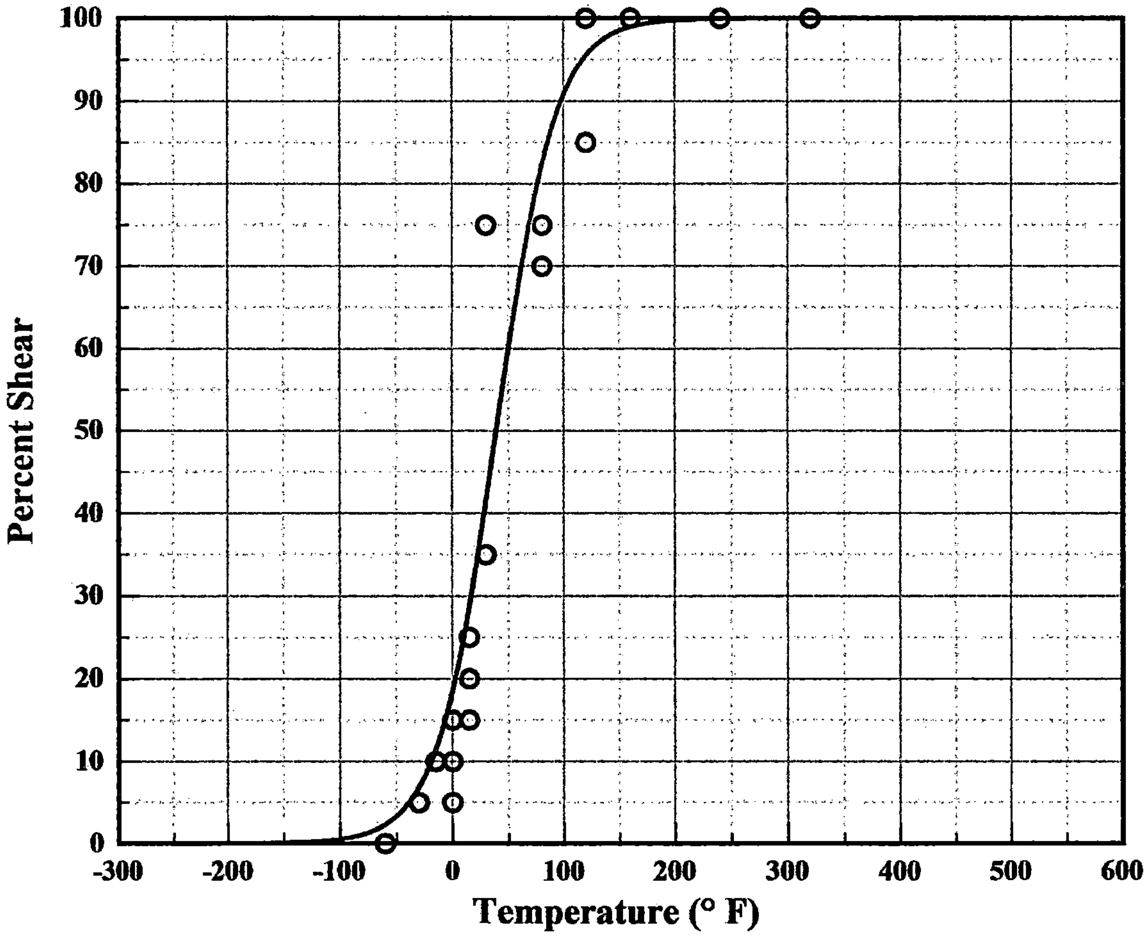
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 39.10

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-60	0.0	2.3	-2.32
-60	0.0	2.3	-2.32
-30	5.0	6.9	-1.87
-30	5.0	6.9	-1.87
-15	10.0	11.5	-1.50
-15	10.0	11.5	-1.50
0	10.0	18.6	-8.63
0	5.0	18.6	-13.63
0	15.0	18.6	-3.63
15	15.0	28.7	-13.74
15	20.0	28.7	-8.74
15	25.0	28.7	-3.74
30	35.0	41.5	-6.54
30	75.0	41.5	33.46
30	75.0	41.5	33.46
80	70.0	82.4	-12.44
80	70.0	82.4	-12.44
80	75.0	82.4	-7.44
120	85.0	95.5	-10.51
120	100.0	95.5	4.49
120	100.0	95.5	4.49
160	100.0	99.0	1.03
160	100.0	99.0	1.03
160	100.0	99.0	1.03
240	100.0	99.9	0.05
240	100.0	99.9	0.05
320	100.0	100.0	0.00
320	100.0	100.0	0.00

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BRAIDWOOD UNIT 2 UNIRRADIATED (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:30 PM

A = 77.60 B = 75.40 C = 87.74 T0 = 41.75 D = 0.00

Correlation Coefficient = 0.978

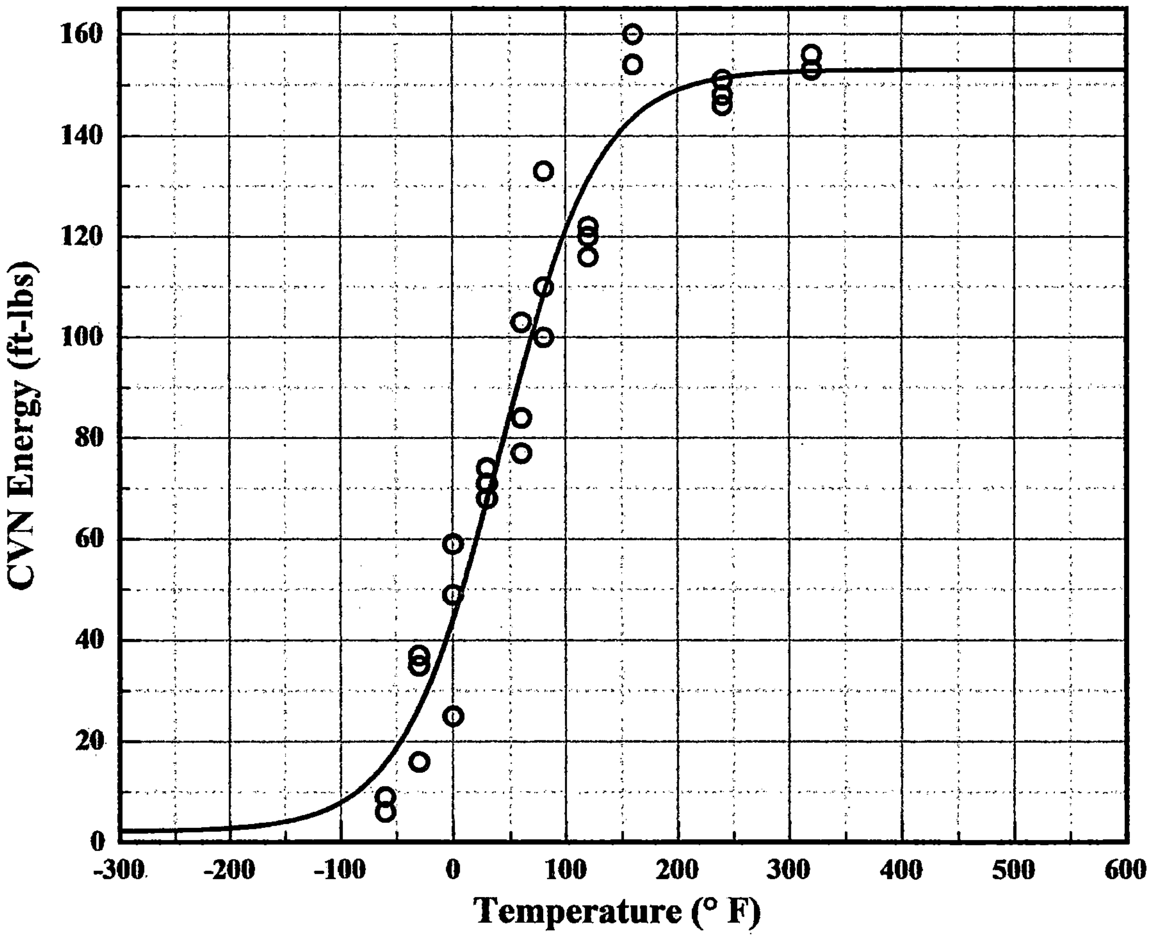
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 153.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-23.40° F Temp@35 ft-lbs=-14.40° F Temp@50 ft-lbs= 8.10° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-60	6.0	15.7	-9.70
-60	9.0	15.7	-6.70
-30	16.0	26.8	-10.79
-30	35.0	26.8	8.21
-30	37.0	26.8	10.21
0	25.0	44.2	-19.21
0	49.0	44.2	4.79
0	59.0	44.2	14.79
30	68.0	67.6	0.44
30	71.0	67.6	3.44
30	74.0	67.6	6.44
60	77.0	93.1	-16.06
60	84.0	93.1	-9.06
60	103.0	93.1	9.94
80	100.0	108.5	-8.54
80	110.0	108.5	1.46
80	133.0	108.5	24.46
120	116.0	131.3	-15.31
120	120.0	131.3	-11.31
120	122.0	131.3	-9.31
160	154.0	143.5	10.54
160	154.0	143.5	10.54
160	160.0	143.5	16.54
240	146.0	151.4	-5.37
240	148.0	151.4	-3.37
240	151.0	151.4	-0.37
320	153.0	152.7	0.26
320	153.0	152.7	0.26
320	156.0	152.7	3.26

CVGraph 6.02 10/16/2015 Page 2/2

BRAIDWOOD UNIT 2 UNIRRADIATED (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:32 PM

A = 46.02 B = 45.02 C = 75.07 T0 = 22.14 D = 0.00

Correlation Coefficient = 0.980

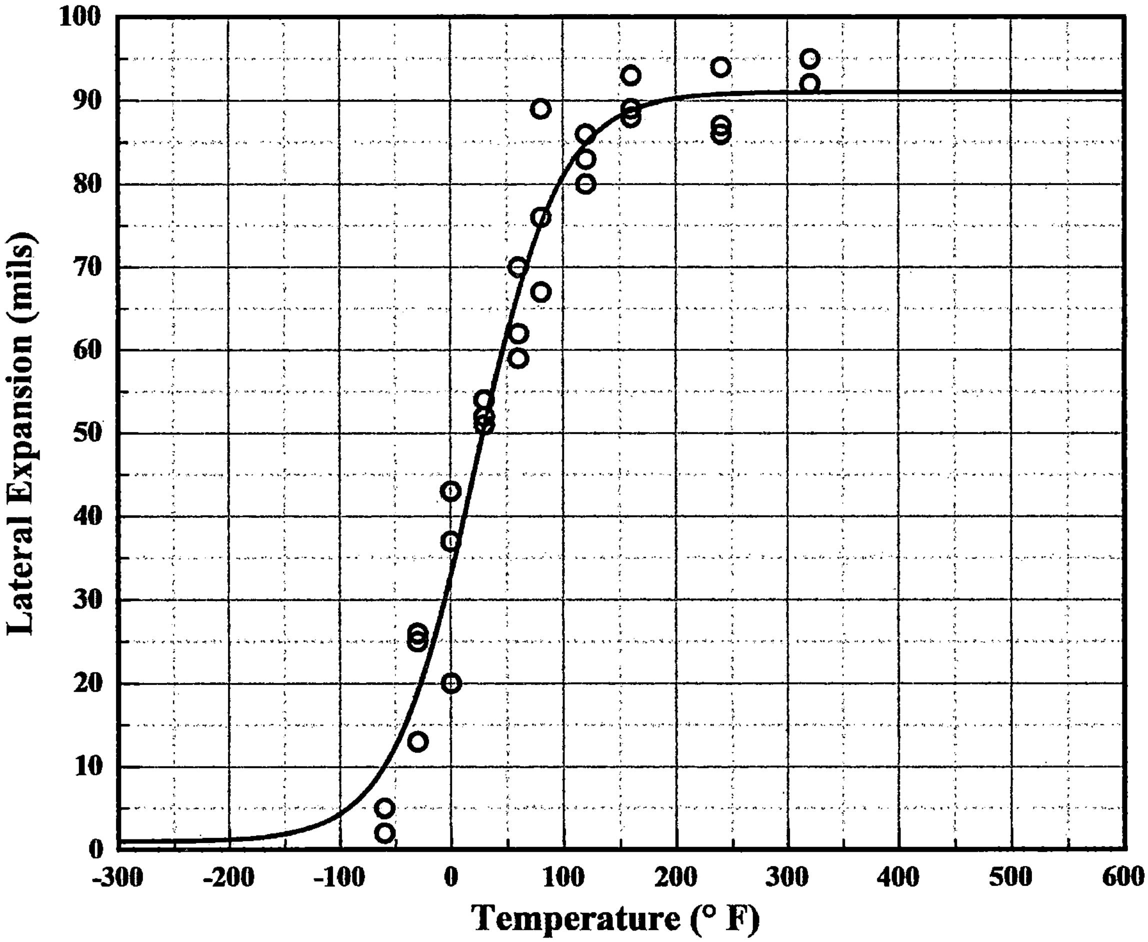
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 91.04 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 3.40° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-60	2.0	10.1	-8.08
-60	5.0	10.1	-5.08
-30	13.0	19.0	-5.97
-30	26.0	19.0	7.03
-30	25.0	19.0	6.03
0	20.0	33.1	-13.12
0	37.0	33.1	3.88
0	43.0	33.1	9.88
30	51.0	50.7	0.28
30	54.0	50.7	3.28
30	52.0	50.7	1.28
60	59.0	67.0	-7.98
60	62.0	67.0	-4.98
60	70.0	67.0	3.02
80	67.0	75.2	-8.17
80	76.0	75.2	0.83
80	89.0	75.2	13.83
120	86.0	84.9	1.14
120	83.0	84.9	-1.86
120	80.0	84.9	-4.86
160	93.0	88.8	4.19
160	88.0	88.8	-0.81
160	89.0	88.8	0.19
240	87.0	90.8	-3.77
240	94.0	90.8	3.23
240	86.0	90.8	-4.77
320	92.0	91.0	0.99
320	92.0	91.0	0.99
320	95.0	91.0	3.99

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BRAIDWOOD UNIT 2 UNIRRADIATED (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:34 PM

A = 50.00 B = 50.00 C = 72.14 T0 = 62.46 D = 0.00

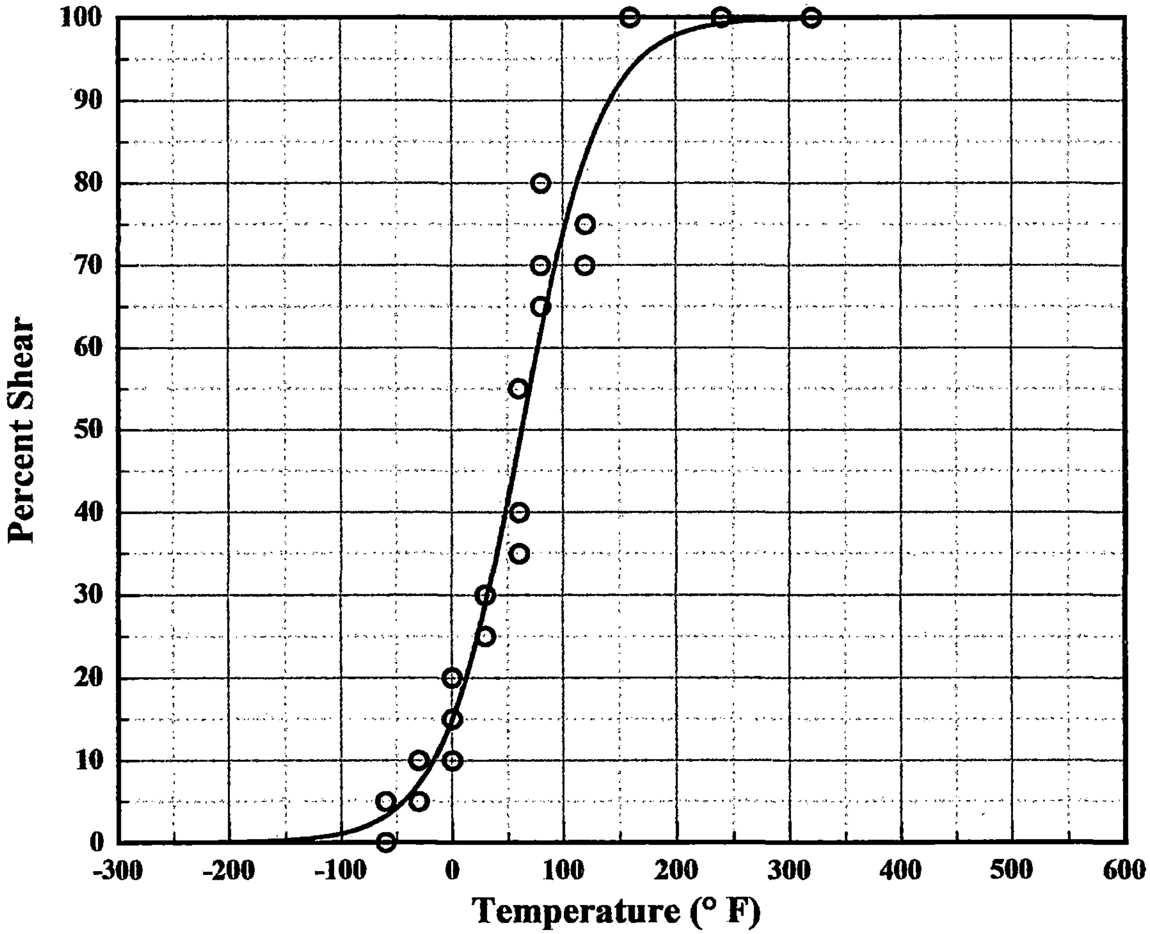
Correlation Coefficient = 0.985

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

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

Temperature at 50% Shear = 62.50

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-60	0.0	3.2	-3.25
-60	5.0	3.2	1.75
-30	10.0	7.2	2.85
-30	5.0	7.2	-2.15
-30	10.0	7.2	2.85
0	10.0	15.0	-5.04
0	15.0	15.0	-0.04
0	20.0	15.0	4.96
30	25.0	28.9	-3.91
30	30.0	28.9	1.09
30	30.0	28.9	1.09
60	35.0	48.3	-13.29
60	40.0	48.3	-8.29
60	55.0	48.3	6.71
80	65.0	61.9	3.08
80	70.0	61.9	8.08
80	80.0	61.9	18.08
120	70.0	83.1	-13.13
120	75.0	83.1	-8.13
120	75.0	83.1	-8.13
160	100.0	93.7	6.27
160	100.0	93.7	6.27
160	100.0	93.7	6.27
240	100.0	99.3	0.72
240	100.0	99.3	0.72
240	100.0	99.3	0.72
320	100.0	99.9	0.08
320	100.0	99.9	0.08
320	100.0	99.9	0.08

CVGraph 6.02 10/16/2015 Page 2/2

BRAIDWOOD UNIT 2 UNIRRADIATED (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:35 PM

A = 35.60 B = 33.40 C = 97.39 T0 = -2.77 D = 0.00

Correlation Coefficient = 0.977

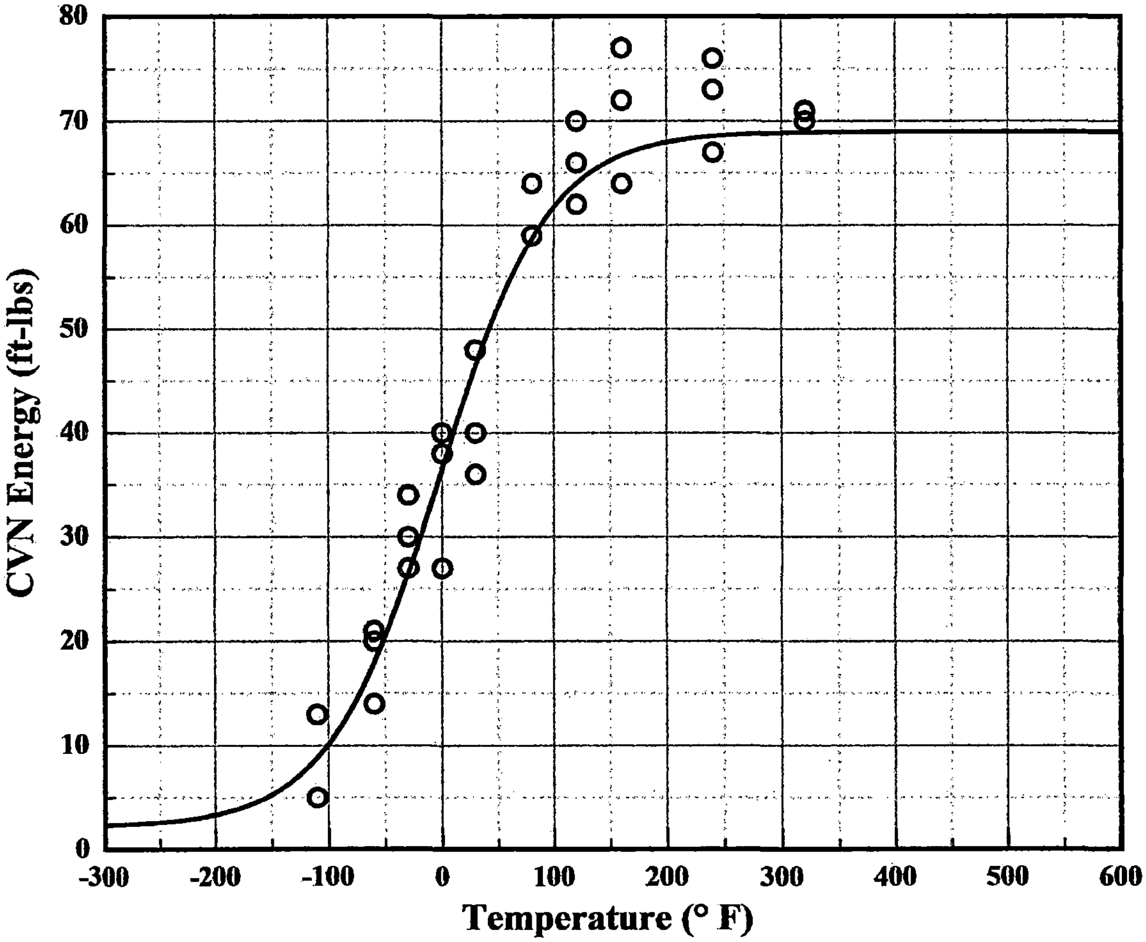
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 69.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-19.20° F Temp@35 ft-lbs= -4.50° F Temp@50 ft-lbs= 42.20° F

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: **N/A** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (WELD)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-110	5.0	8.8	-3.85
-110	13.0	8.8	4.15
-60	14.0	18.0	-3.96
-60	20.0	18.0	2.04
-60	21.0	18.0	3.04
-30	27.0	26.5	0.50
-30	30.0	26.5	3.50
-30	34.0	26.5	7.50
0	27.0	36.5	-9.55
0	38.0	36.5	1.45
0	40.0	36.5	3.45
30	36.0	46.4	-10.43
30	40.0	46.4	-6.43
30	48.0	46.4	1.57
80	59.0	58.7	0.32
80	59.0	58.7	0.32
80	64.0	58.7	5.32
120	62.0	64.0	-2.03
120	66.0	64.0	1.97
120	70.0	64.0	5.97
160	64.0	66.7	-2.72
160	72.0	66.7	5.28
160	77.0	66.7	10.28
240	67.0	68.5	-1.55
240	73.0	68.5	4.45
240	76.0	68.5	7.45
320	70.0	68.9	1.09
320	71.0	68.9	2.09
320	71.0	68.9	2.09

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BRAIDWOOD UNIT 2 UNIRRADIATED (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:35 PM

A = 37.33 B = 36.33 C = 102.06 T0 = 14.03 D = 0.00

Correlation Coefficient = 0.985

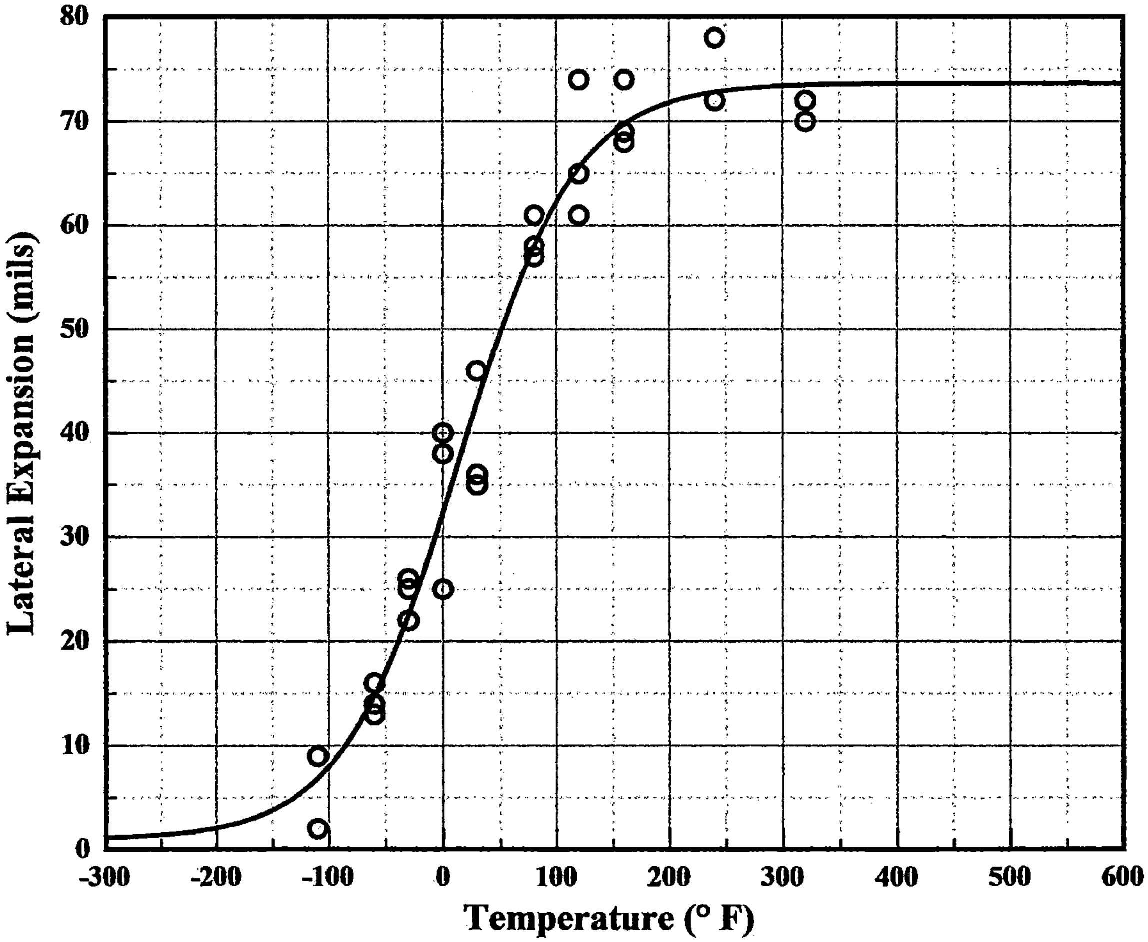
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 73.67 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 7.50° F

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: N/A Capsule: UNIRR

BRAIDWOOD UNIT 2 UNIRRADIATED (WELD)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-110	2.0	6.9	-4.88
-110	9.0	6.9	2.12
-60	13.0	14.8	-1.80
-60	14.0	14.8	-0.80
-60	16.0	14.8	1.20
-30	22.0	22.6	-0.56
-30	25.0	22.6	2.44
-30	26.0	22.6	3.44
0	25.0	32.4	-7.37
0	38.0	32.4	5.63
0	40.0	32.4	7.63
30	35.0	43.0	-7.97
30	36.0	43.0	-6.97
30	46.0	43.0	3.03
80	57.0	58.0	-1.01
80	58.0	58.0	-0.01
80	61.0	58.0	2.99
120	61.0	65.6	-4.57
120	74.0	65.6	8.43
120	65.0	65.6	-0.57
160	68.0	69.7	-1.73
160	69.0	69.7	-0.73
160	74.0	69.7	4.27
240	72.0	72.8	-0.81
240	72.0	72.8	-0.81
240	78.0	72.8	5.19
320	72.0	73.5	-1.49
320	70.0	73.5	-3.49
320	72.0	73.5	-1.49

CVGraph 6.02 10/16/2015 Page 2/2

BRAIDWOOD UNIT 2 UNIRRADIATED (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:36 PM

A = 50.00 B = 50.00 C = 59.85 T0 = 24.04 D = 0.00

Correlation Coefficient = 0.985

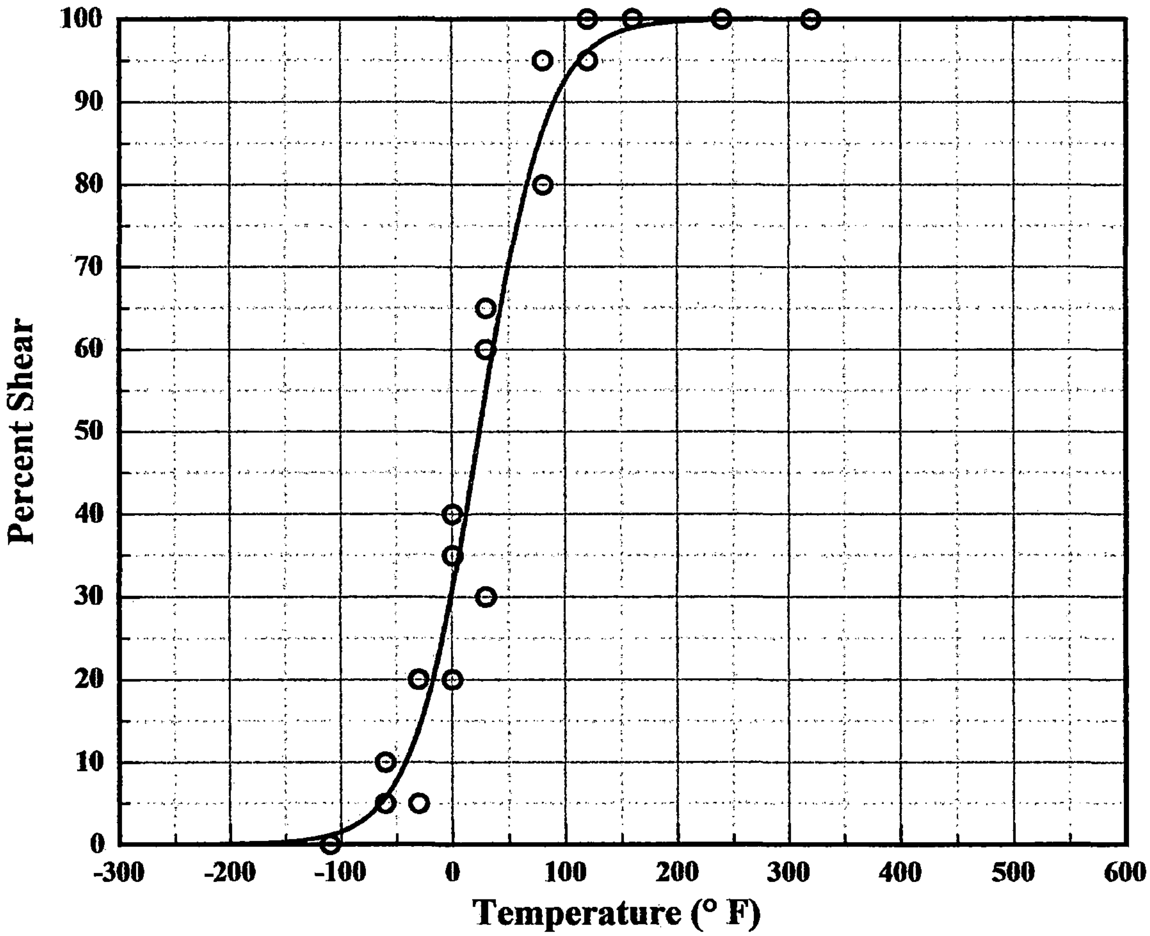
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 24.10

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: **N/A** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (WELD)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-110	0.0	1.1	-1.12
-110	0.0	1.1	-1.12
-60	10.0	5.7	4.31
-60	10.0	5.7	4.31
-60	5.0	5.7	-0.69
-30	5.0	14.1	-9.12
-30	20.0	14.1	5.88
-30	20.0	14.1	5.88
0	20.0	30.9	-10.94
0	35.0	30.9	4.06
0	40.0	30.9	9.06
30	30.0	55.0	-24.97
30	60.0	55.0	5.03
30	65.0	55.0	10.03
80	95.0	86.6	8.35
80	80.0	86.6	-6.65
80	95.0	86.6	8.35
120	95.0	96.1	-1.11
120	100.0	96.1	3.89
120	95.0	96.1	-1.11
160	100.0	98.9	1.05
160	100.0	98.9	1.05
160	100.0	98.9	1.05
240	100.0	99.9	0.07
240	100.0	99.9	0.07
240	100.0	99.9	0.07
320	100.0	100.0	0.01
320	100.0	100.0	0.01
320	100.0	100.0	0.01

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BRAIDWOOD UNIT 2 UNIRRADIATED (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:38 PM

A = 78.60 B = 76.40 C = 108.82 T0 = -58.99 D = 0.00

Correlation Coefficient = 0.953

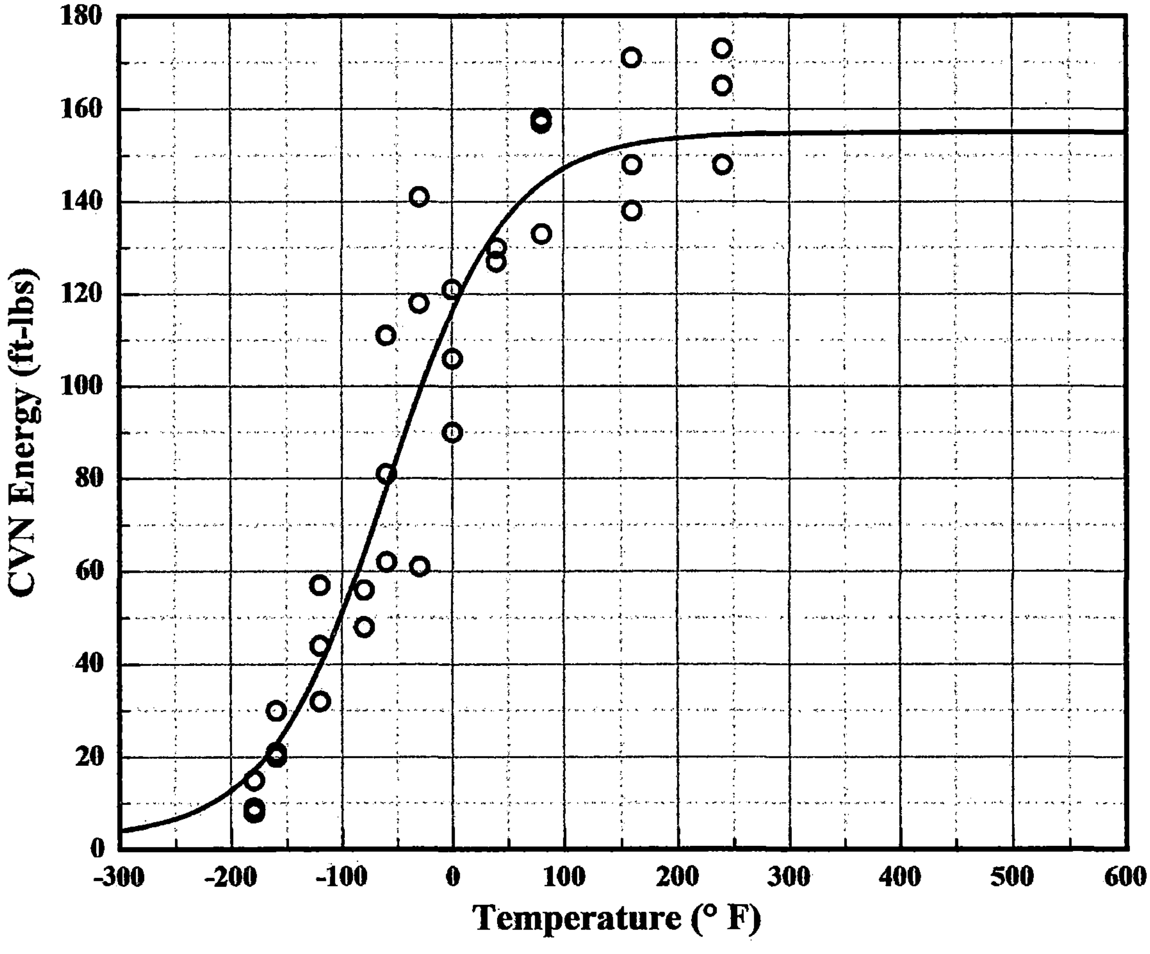
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temp@30 ft-lbs=-140.70° F Temp@35 ft-lbs=-129.50° F Temp@50 ft-lbs=-101.80° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **N/A** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/3

Plant: Braidwood 2 Material: SA508CL3 Heat: [50D102/50C97]-1-1
Orientation: N/A Capsule: UNIRR

BRAIDWOOD UNIT 2 UNIRRADIATED (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-180	8.0	17.1	-9.11
-180	9.0	17.1	-8.11
-180	15.0	17.1	-2.11
-160	20.0	22.8	-2.84
-160	21.0	22.8	-1.84
-160	30.0	22.8	7.16
-120	32.0	39.8	-7.75
-120	44.0	39.8	4.25
-120	57.0	39.8	17.25
-80	48.0	64.0	-16.03
-80	56.0	64.0	-8.03
-60	62.0	77.9	-15.89
-60	81.0	77.9	3.11
-60	111.0	77.9	33.11
-30	61.0	98.5	-37.48
-30	118.0	98.5	19.52
-30	141.0	98.5	42.52
0	90.0	116.4	-26.38
0	106.0	116.4	-10.38
0	121.0	116.4	4.62
40	127.0	133.7	-6.68
40	130.0	133.7	-3.68
80	133.0	144.0	-10.98
80	157.0	144.0	13.02
80	158.0	144.0	14.02
160	138.0	152.3	-14.32
160	148.0	152.3	-4.32
160	171.0	152.3	18.68
240	148.0	154.4	-6.38

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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: N/A Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
240	165.0	154.4	10.62
240	173.0	154.4	18.62

CVGraph 6.02 10/16/2015 Page 3/3

BRAIDWOOD UNIT 2 UNIRRADIATED (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:39 PM

A = 39.80 B = 38.80 C = 88.05 T0 = -69.06 D = 0.00

Correlation Coefficient = 0.949

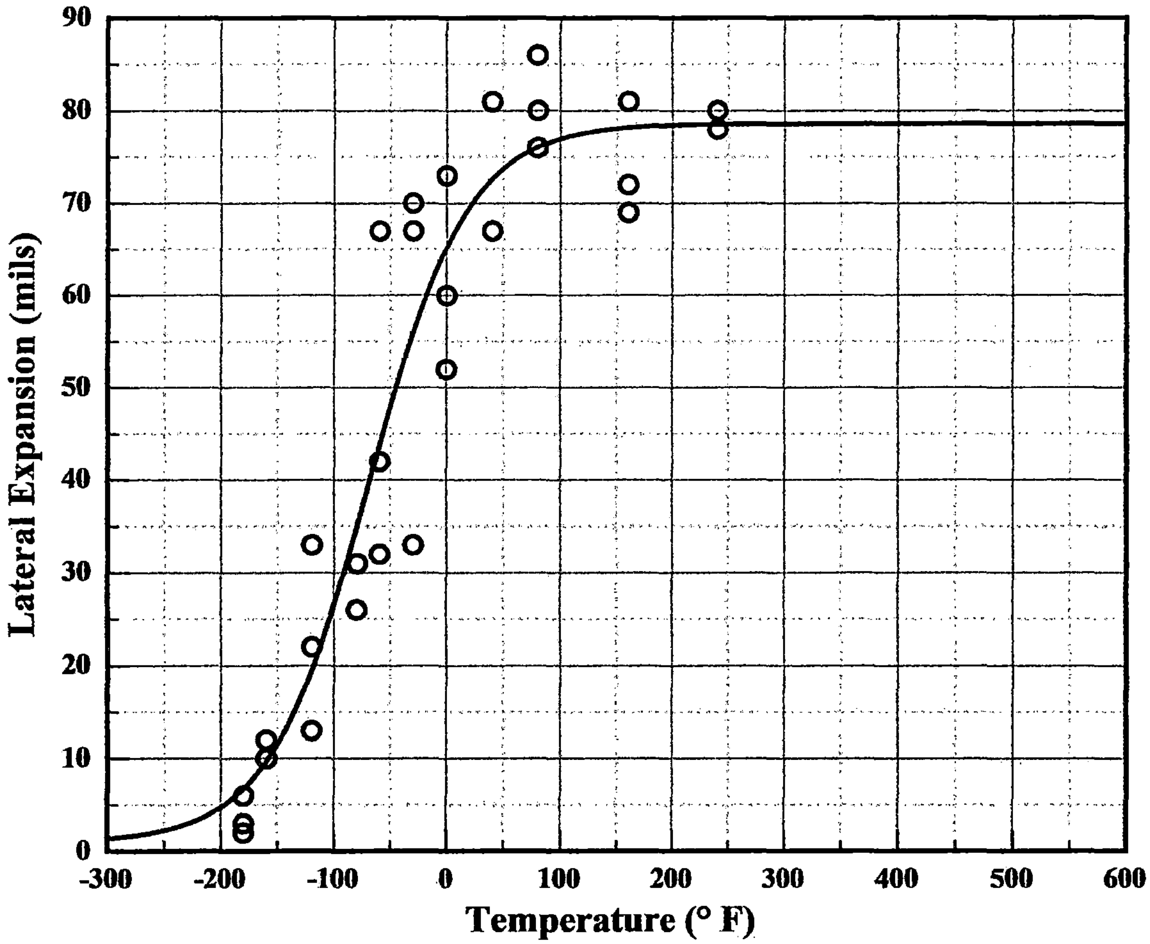
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 78.60 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-80.00° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **N/A** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/3

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-180	2.0	6.8	-4.78
-180	3.0	6.8	-3.78
-180	6.0	6.8	-0.78
-160	10.0	9.7	0.27
-160	10.0	9.7	0.27
-160	12.0	9.7	2.27
-120	13.0	19.6	-6.56
-120	22.0	19.6	2.44
-120	33.0	19.6	13.44
-80	26.0	35.0	-9.01
-80	31.0	35.0	-4.01
-60	32.0	43.8	-11.78
-60	42.0	43.8	-1.78
-60	67.0	43.8	23.22
-30	70.0	56.0	14.03
-30	33.0	56.0	-22.97
-30	67.0	56.0	11.03
0	52.0	65.2	-13.22
0	60.0	65.2	-5.22
0	73.0	65.2	7.78
40	67.0	72.6	-5.59
40	81.0	72.6	8.41
80	76.0	76.1	-0.06
80	80.0	76.1	3.94
80	86.0	76.1	9.94
160	69.0	78.2	-9.18
160	72.0	78.2	-6.18
160	81.0	78.2	2.82
240	80.0	78.5	1.47

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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: N/A Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
240	80.0	78.5	1.47
240	78.0	78.5	-0.53

CVGraph 6.02 10/16/2015 Page 3/3

BRAIDWOOD UNIT 2 UNIRRADIATED (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/16/2015 3:39 PM

A = 50.00 B = 50.00 C = 74.50 T0 = -28.75 D = 0.00

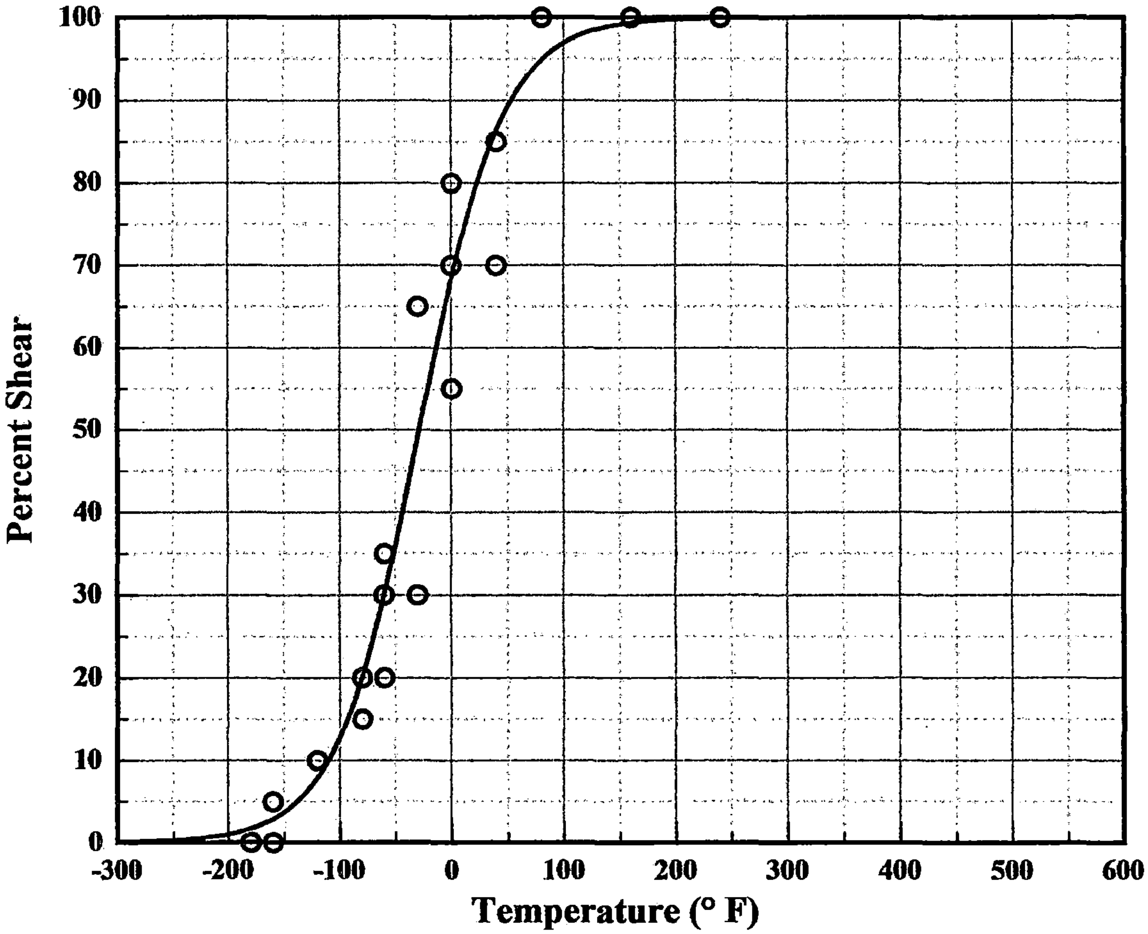
Correlation Coefficient = 0.982

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

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

Temperature at 50% Shear = -28.70

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **UNIRR**



CVGraph 6.02 10/16/2015 Page 1/3

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-180	0.0	1.7	-1.69
-180	0.0	1.7	-1.69
-180	0.0	1.7	-1.69
-160	0.0	2.9	-2.86
-160	0.0	2.9	-2.86
-160	5.0	2.9	2.14
-120	10.0	7.9	2.05
-120	10.0	7.9	2.05
-120	10.0	7.9	2.05
-80	20.0	20.2	-0.17
-80	15.0	20.2	-5.17
-60	20.0	30.2	-10.18
-60	30.0	30.2	-0.18
-60	35.0	30.2	4.82
-30	65.0	49.2	15.84
-30	30.0	49.2	-19.16
-30	65.0	49.2	15.84
0	55.0	68.4	-13.39
0	70.0	68.4	1.61
0	80.0	68.4	11.61
40	70.0	86.4	-16.36
40	85.0	86.4	-1.36
80	100.0	94.9	5.12
80	100.0	94.9	5.12
80	100.0	94.9	5.12
160	100.0	99.4	0.63
160	100.0	99.4	0.63
160	100.0	99.4	0.63
240	100.0	99.9	0.07

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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **UNIRR**

BRAIDWOOD UNIT 2 UNIRRADIATED (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
240	100.0	99.9	0.07
240	100.0	99.9	0.07

CVGraph 6.02 10/16/2015 Page 3/3

BRAIDWOOD UNIT 2 CAPSULE U (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:21 AM

A = 89.10 B = 86.90 C = 86.35 T0 = 41.04 D = 0.00

Correlation Coefficient = 0.960

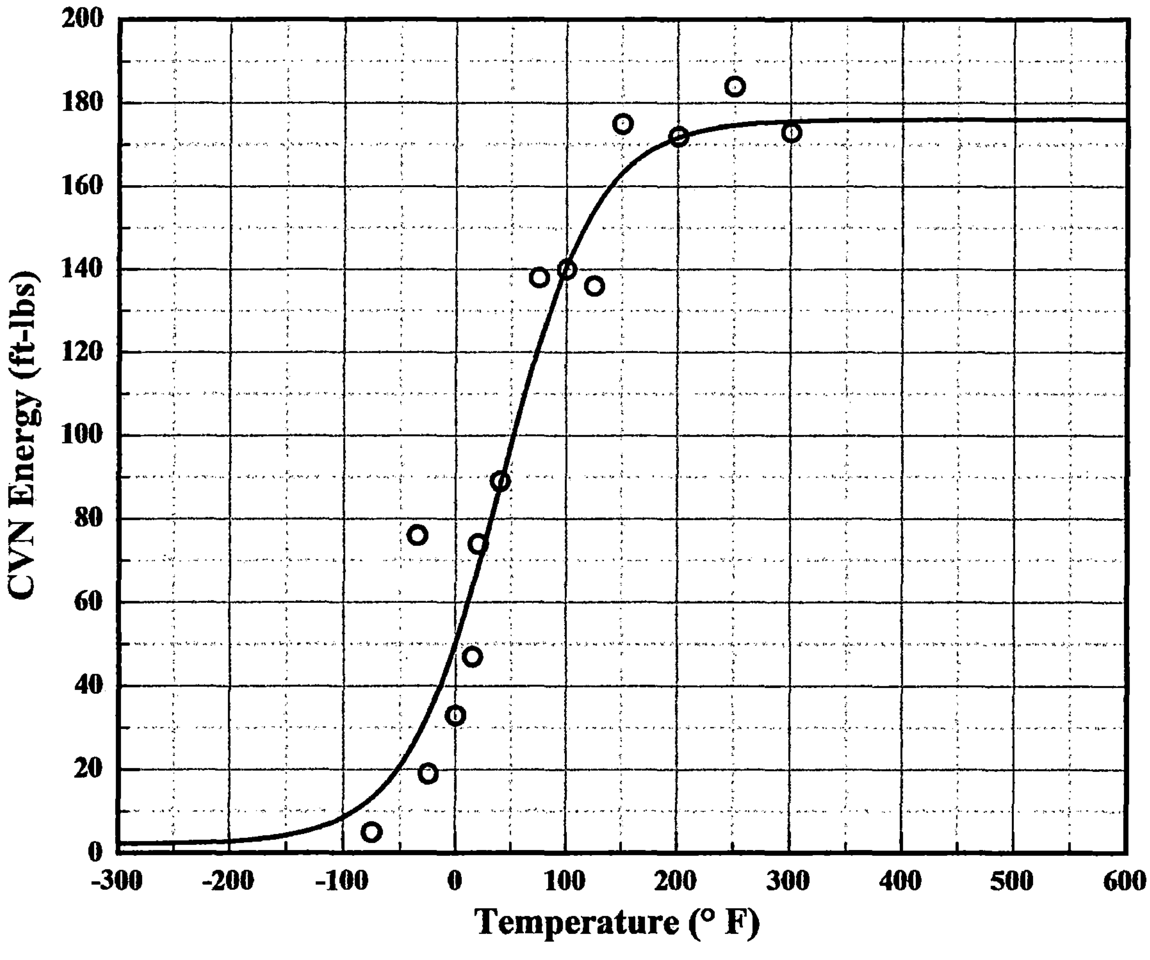
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 176.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-30.50° F Temp@35 ft-lbs=-21.90° F Temp@50 ft-lbs= -0.80° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **U**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: U

BRAIDWOOD UNIT 2 CAPSULE U (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-75	5.0	13.3	-8.27
-35	76.0	27.7	48.31
-25	19.0	33.1	-14.15
0	33.0	50.7	-17.65
15	47.0	63.7	-16.66
20	74.0	68.3	5.66
40	89.0	88.1	0.94
75	138.0	121.6	16.38
100	140.0	140.7	-0.66
125	136.0	154.3	-18.25
150	175.0	163.1	11.90
200	172.0	171.7	0.27
250	184.0	174.6	9.36
300	173.0	175.6	-2.57

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BRAIDWOOD UNIT 2 CAPSULE U (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:22 AM

A = 44.41 B = 43.41 C = 72.28 T0 = 15.85 D = 0.00

Correlation Coefficient = 0.945

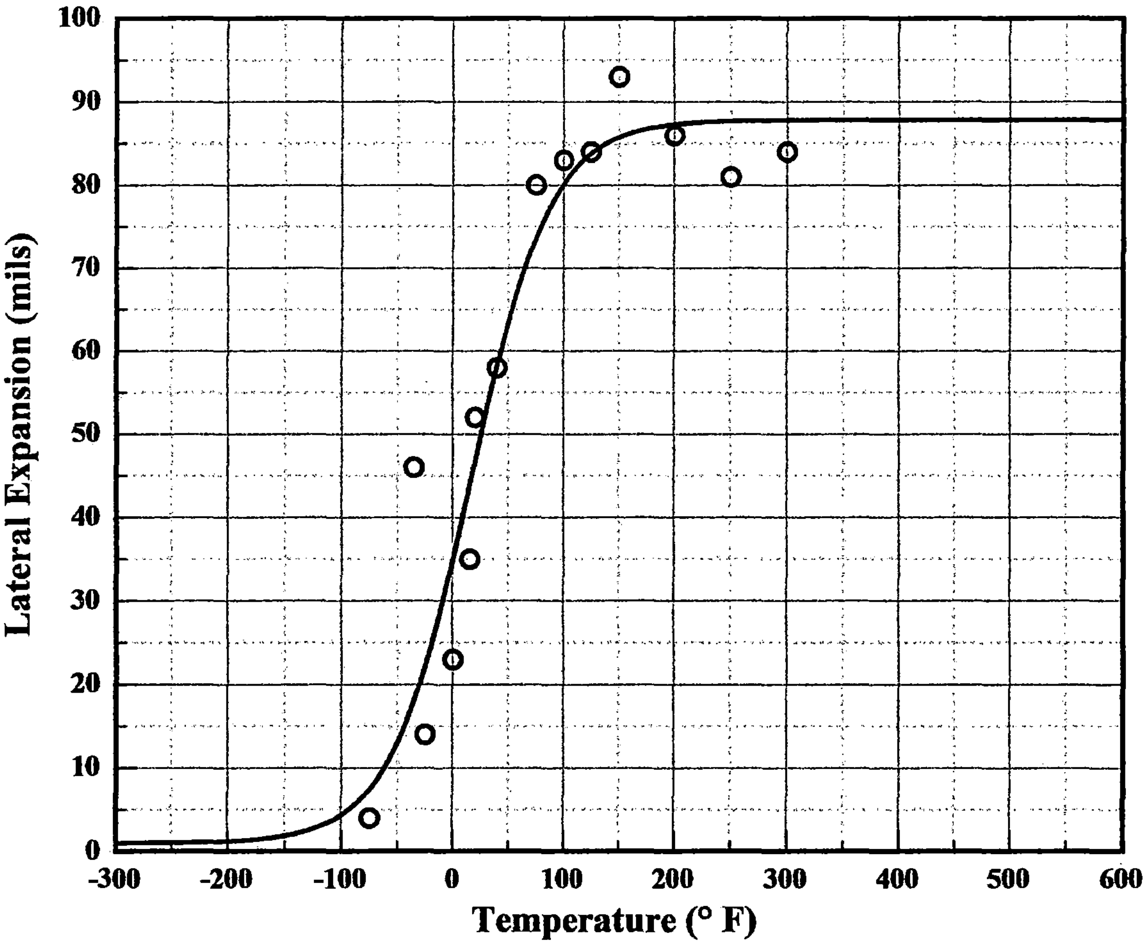
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 87.82 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 0.00° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **U**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **U**

BRAIDWOOD UNIT 2 CAPSULE U (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-75	4.0	7.5	-3.50
-35	46.0	18.1	27.92
-25	14.0	22.2	-8.19
0	23.0	35.0	-12.04
15	35.0	43.9	-8.90
20	52.0	46.9	5.10
40	58.0	58.4	-0.40
75	80.0	73.7	6.32
100	83.0	80.1	2.89
125	84.0	83.8	0.22
150	93.0	85.8	7.25
200	86.0	87.3	-1.29
250	81.0	87.7	-6.69
300	84.0	87.8	-3.79

CVGraph 6.02 10/19/2015 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE U (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:23 AM

A = 50.00 B = 50.00 C = 80.85 T0 = 5.70 D = 0.00

Correlation Coefficient = 0.897

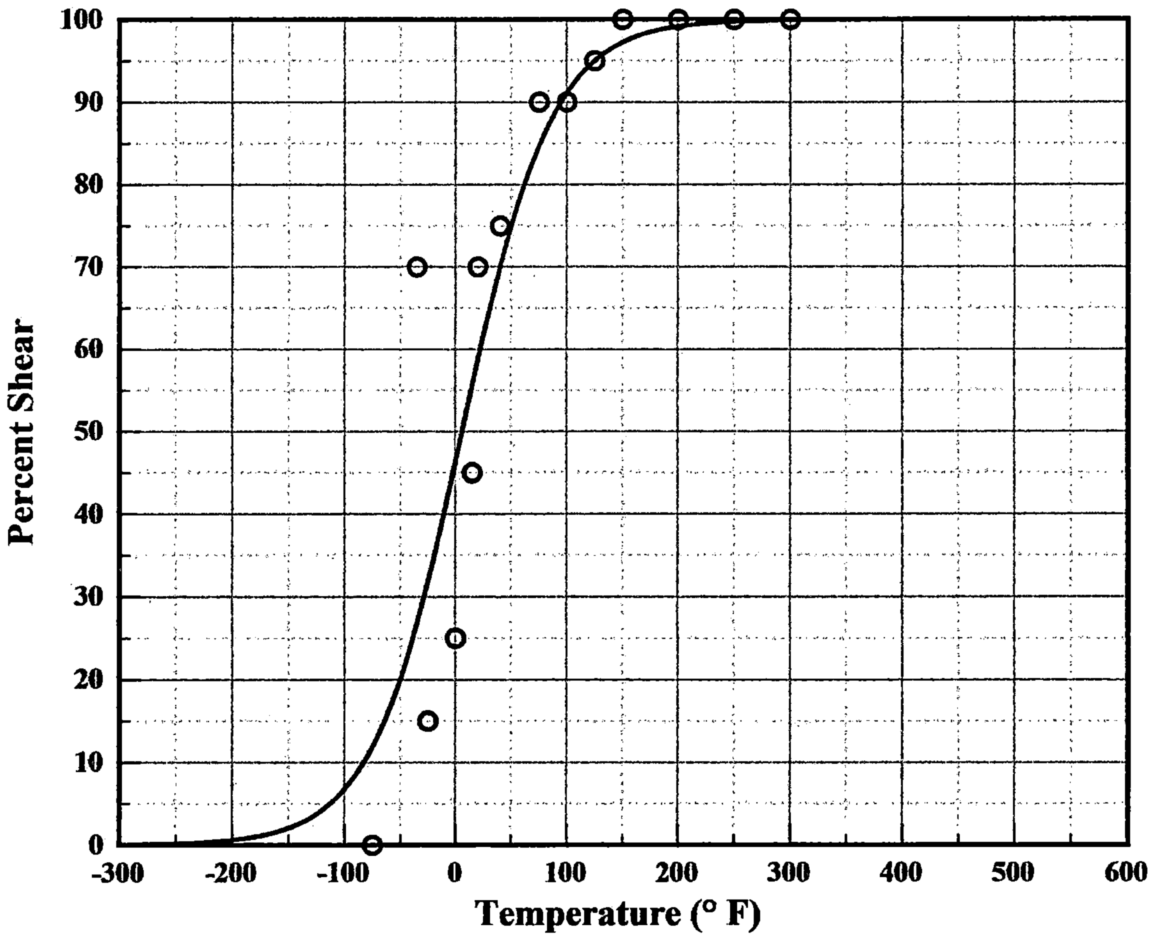
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 5.80

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **U**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **U**

BRAIDWOOD UNIT 2 CAPSULE U (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-75	0.0	12.0	-11.96
-35	70.0	26.8	43.24
-25	15.0	31.9	-16.87
0	25.0	46.5	-21.48
15	45.0	55.7	-10.72
20	70.0	58.7	11.25
40	75.0	70.0	4.98
75	90.0	84.7	5.26
100	90.0	91.2	-1.15
125	95.0	95.0	-0.03
150	100.0	97.3	2.74
200	100.0	99.2	0.81
250	100.0	99.8	0.24
300	100.0	99.9	0.07

CVGraph 6.02 10/19/2015 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE U (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:24 AM

A = 69.60 B = 67.40 C = 84.34 T0 = 33.29 D = 0.00

Correlation Coefficient = 0.977

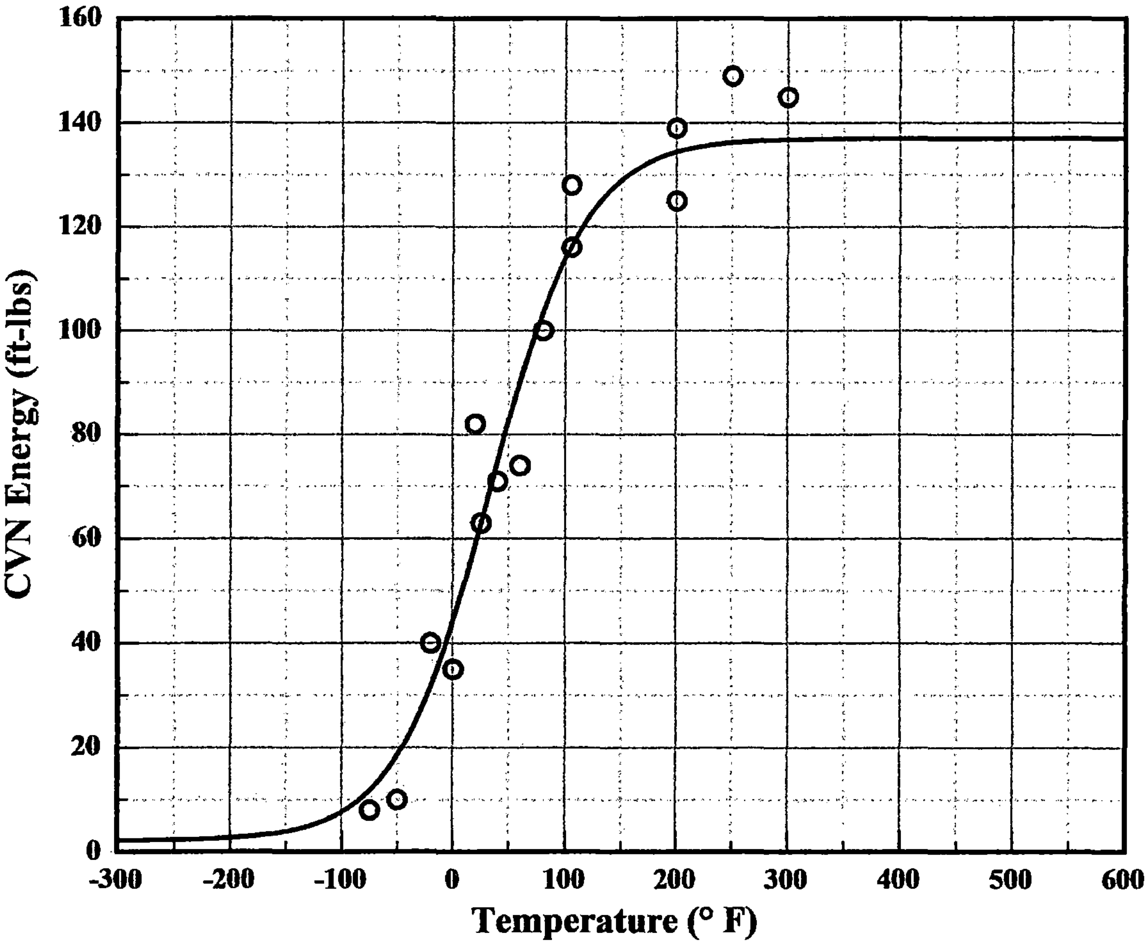
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 137.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-23.50° F Temp@35 ft-lbs=-14.50° F Temp@50 ft-lbs= 8.10° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **U**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **U**

BRAIDWOOD UNIT 2 CAPSULE U (AXIAL)
Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-75	8.0	11.8	-3.80
-50	10.0	18.6	-8.63
-20	40.0	31.9	8.10
0	35.0	44.3	-9.30
20	82.0	59.1	22.93
25	63.0	63.0	0.00
40	71.0	75.0	-3.95
60	74.0	90.3	-16.26
80	100.0	103.5	-3.53
105	116.0	116.2	-0.19
105	128.0	116.2	11.81
200	125.0	134.5	-9.46
200	139.0	134.5	4.54
250	149.0	136.2	12.79
300	145.0	136.8	8.24

CVGraph 6.02 10/19/2015 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE U (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:26 AM

A = 42.35 B = 41.35 C = 71.01 T0 = 22.19 D = 0.00

Correlation Coefficient = 0.981

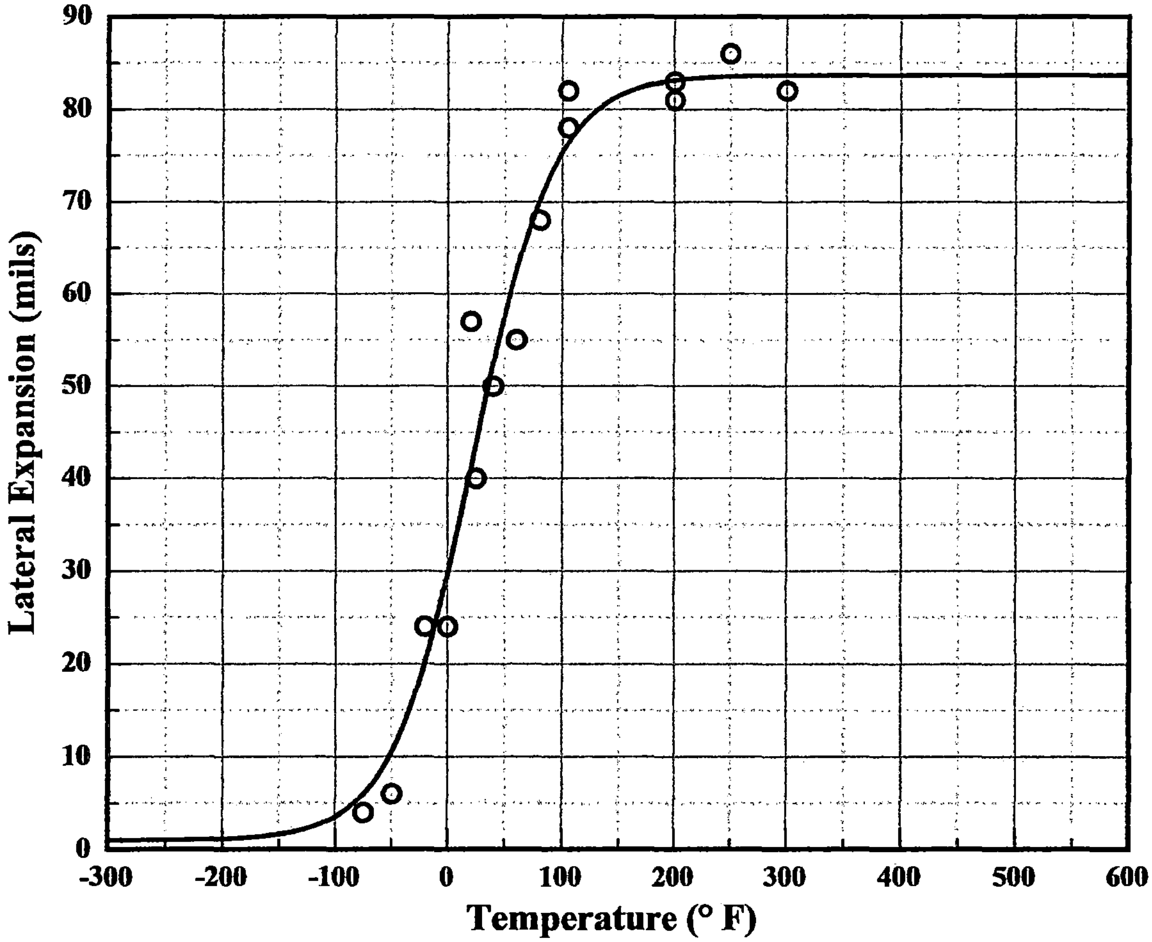
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 83.70 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 9.50° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **U**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **U**

BRAIDWOOD UNIT 2 CAPSULE U (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-75	4.0	6.0	-2.03
-50	6.0	10.6	-4.57
-20	24.0	20.3	3.69
0	24.0	29.8	-5.83
20	57.0	41.1	15.93
25	40.0	44.0	-3.98
40	50.0	52.5	-2.51
60	55.0	62.5	-7.50
80	68.0	70.1	-2.13
105	78.0	76.4	1.62
105	82.0	76.4	5.62
200	81.0	83.1	-2.15
200	83.0	83.1	-0.15
250	86.0	83.6	2.44
300	82.0	83.7	-1.66

CVGraph 6.02 10/19/2015 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE U (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:25 AM

A = 50.00 B = 50.00 C = 69.47 T0 = 17.06 D = 0.00

Correlation Coefficient = 0.983

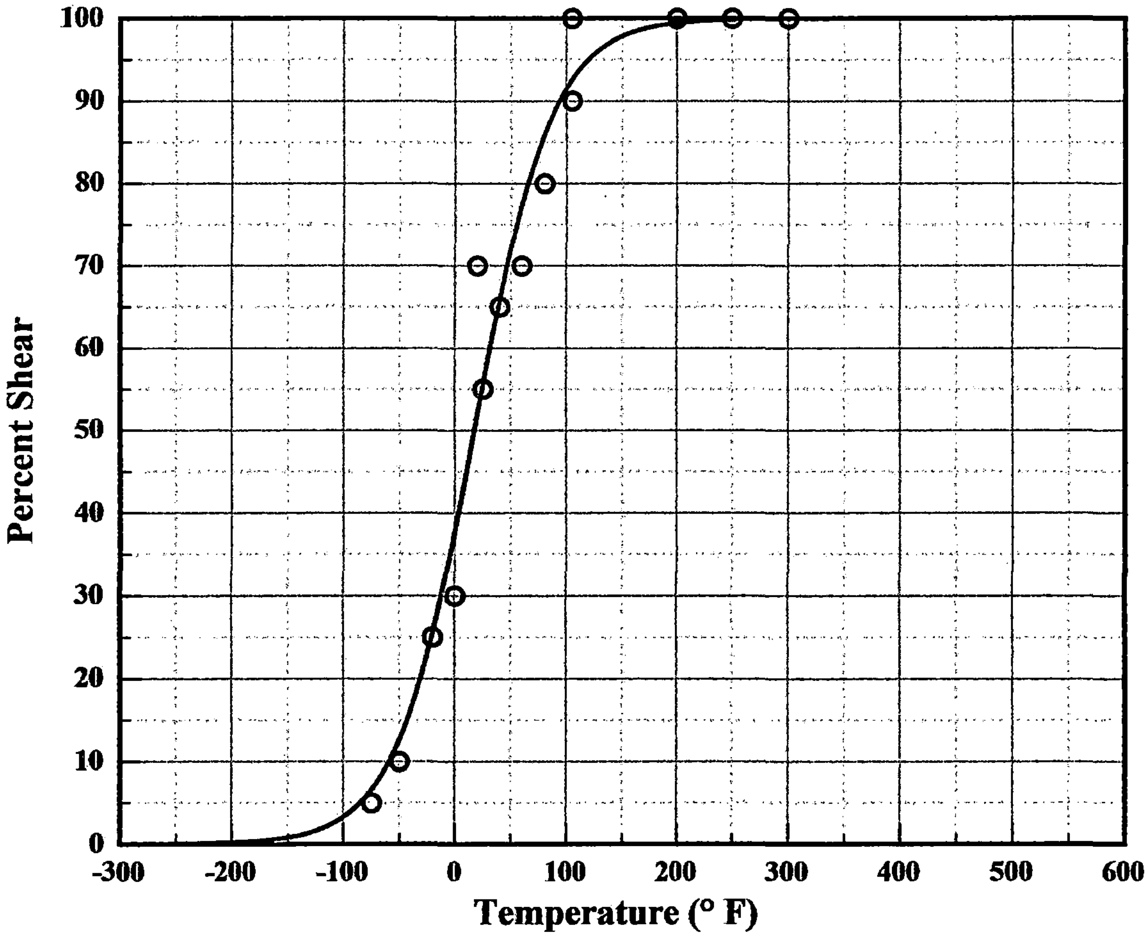
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 17.10

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **U**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **U**

BRAIDWOOD UNIT 2 CAPSULE U (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-75	5.0	6.6	-1.60
-50	10.0	12.7	-2.67
-20	25.0	25.6	-0.60
0	30.0	38.0	-7.96
20	70.0	52.1	17.88
25	55.0	55.7	-0.69
40	65.0	65.9	-0.94
60	70.0	77.5	-7.49
80	80.0	86.0	-5.96
105	90.0	92.6	-2.63
105	100.0	92.6	7.37
200	100.0	99.5	0.51
200	100.0	99.5	0.51
250	100.0	99.9	0.12
300	100.0	100.0	0.03

CVGraph 6.02 10/19/2015 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE U (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:27 AM

A = 32.10 B = 29.90 C = 102.06 T0 = -12.86 D = 0.00

Correlation Coefficient = 0.977

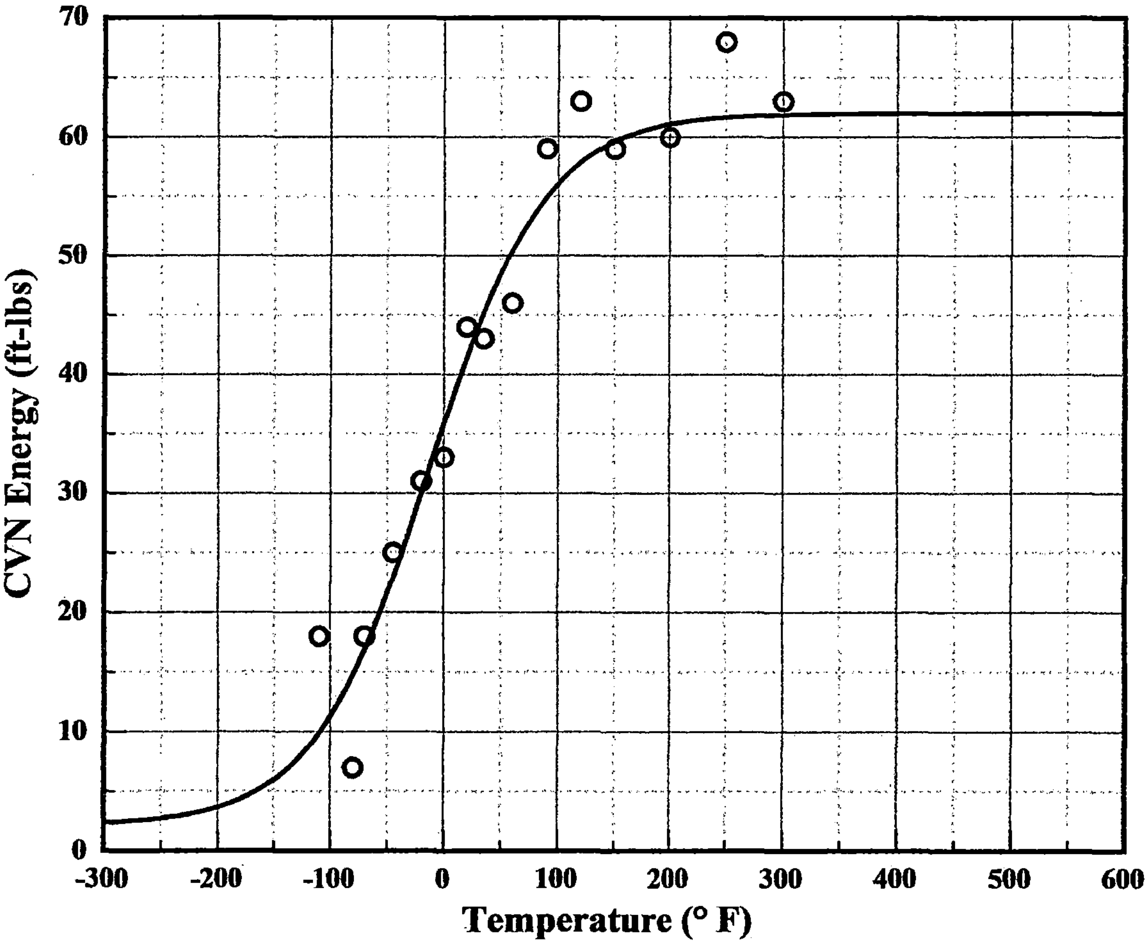
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 62.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-20.00° F Temp@35 ft-lbs= -2.90° F Temp@50 ft-lbs= 57.70° F

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **U**



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Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: **N/A** Capsule: **U**

BRAIDWOOD UNIT 2 CAPSULE U (WELD)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-110	18.0	10.0	8.04
-80	7.0	14.8	-7.85
-70	18.0	16.9	1.09
-45	25.0	23.0	2.02
-20	31.0	30.0	0.99
0	33.0	35.8	-2.85
20	44.0	41.4	2.59
35	43.0	45.2	-2.18
60	46.0	50.4	-4.43
90	59.0	55.0	4.03
120	63.0	57.9	5.12
150	59.0	59.6	-0.64
200	60.0	61.1	-1.09
250	68.0	61.7	6.34
300	63.0	61.9	1.13

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BRAIDWOOD UNIT 2 CAPSULE U (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:27 AM

A = 30.57 B = 29.57 C = 112.55 T0 = 7.63 D = 0.00

Correlation Coefficient = 0.973

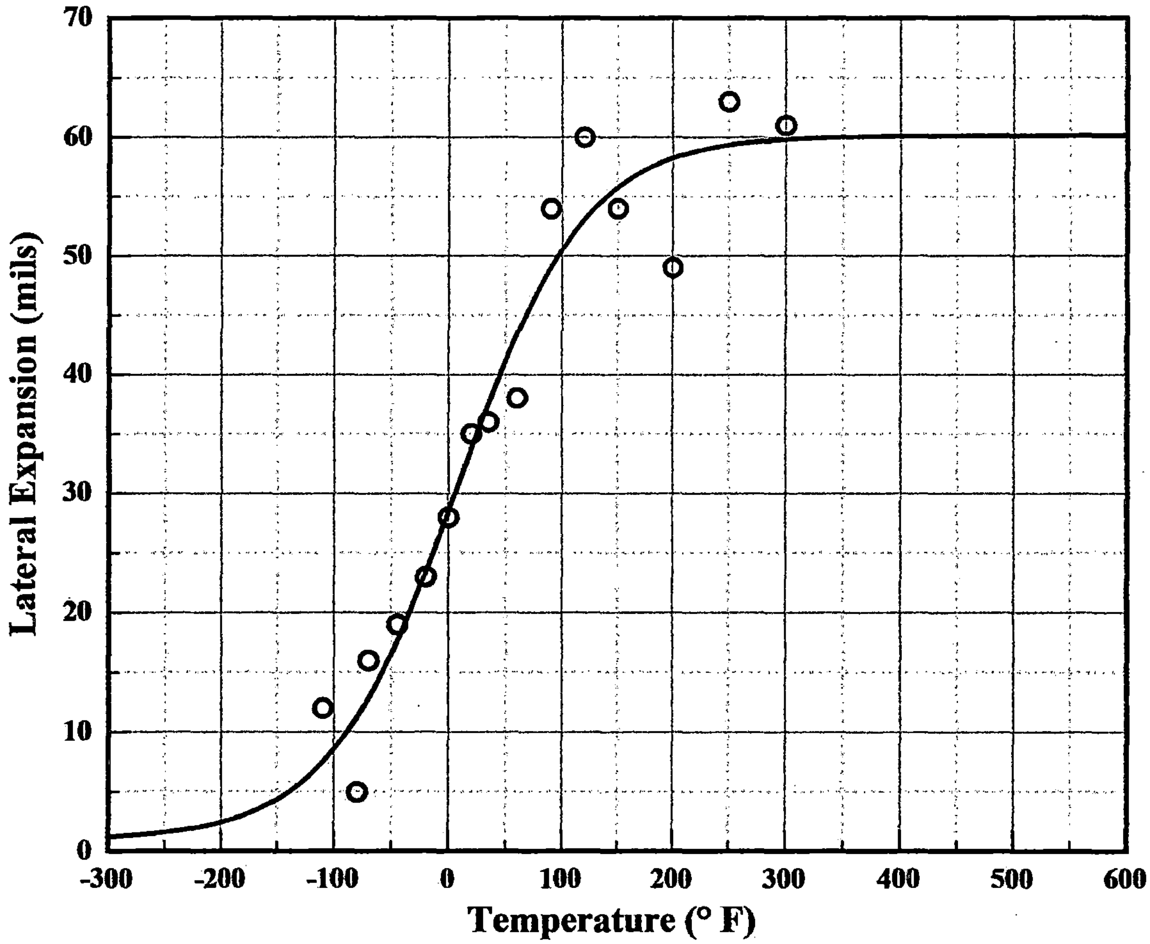
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 60.15 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 24.70° F

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **U**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: N/A Capsule: U

BRAIDWOOD UNIT 2 CAPSULE U (WELD)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-110	12.0	7.5	4.49
-80	5.0	11.3	-6.29
-70	16.0	12.9	3.11
-45	19.0	17.7	1.33
-20	23.0	23.5	-0.45
0	28.0	28.6	-0.57
20	35.0	33.8	1.19
35	36.0	37.6	-1.62
60	38.0	43.4	-5.42
90	54.0	49.0	4.97
120	60.0	53.1	6.93
150	54.0	55.8	-1.78
200	49.0	58.3	-9.27
250	63.0	59.4	3.64
300	61.0	59.8	1.18

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BRAIDWOOD UNIT 2 CAPSULE U (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:28 AM

A = 50.00 B = 50.00 C = 80.22 T0 = 30.51 D = 0.00

Correlation Coefficient = 0.978

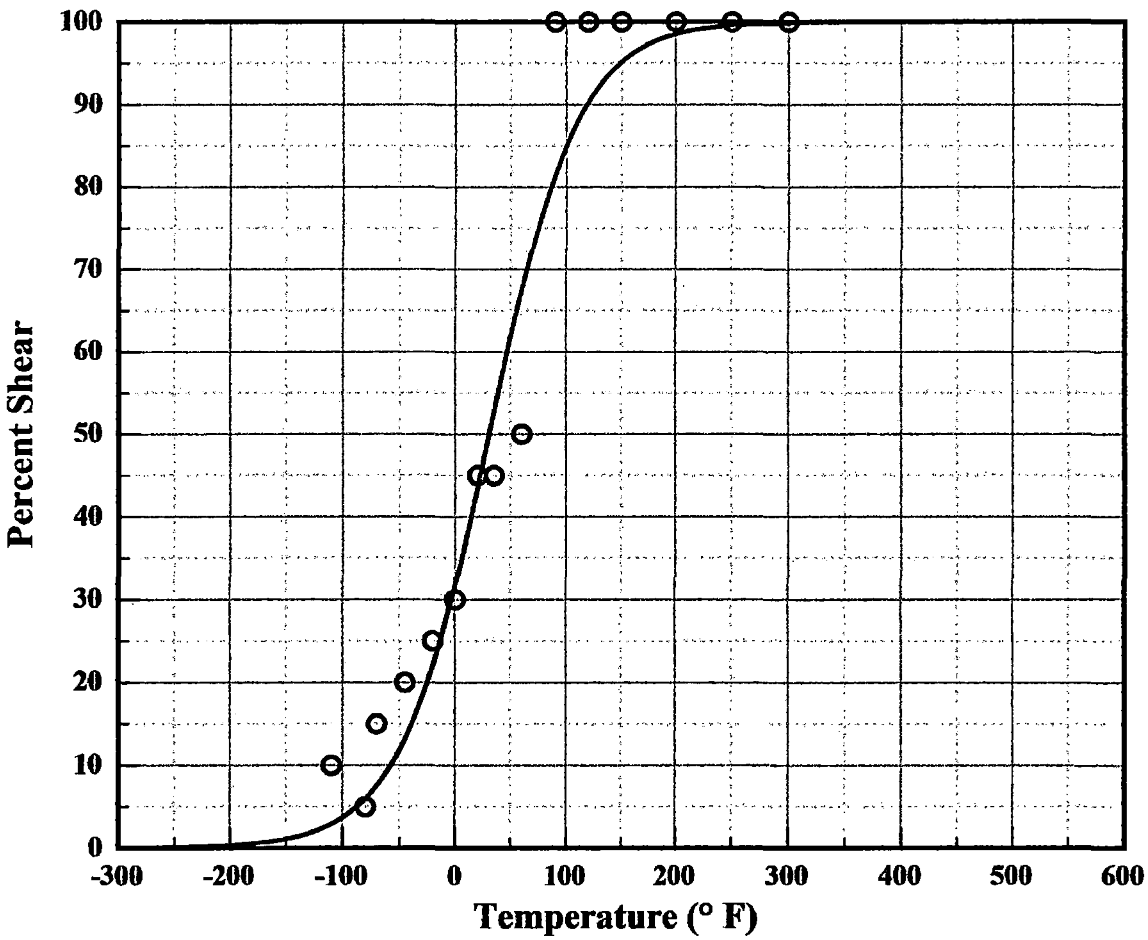
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 30.60

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **U**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: N/A Capsule: **U**

BRAIDWOOD UNIT 2 CAPSULE U (WELD)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-110	10.0	2.9	7.08
-80	5.0	6.0	-0.98
-70	15.0	7.5	7.46
-45	20.0	13.2	6.79
-20	25.0	22.1	2.89
0	30.0	31.8	-1.85
20	45.0	43.5	1.51
35	45.0	52.8	-7.79
60	50.0	67.6	-17.59
90	100.0	81.5	18.50
120	100.0	90.3	9.70
150	100.0	95.2	4.84
200	100.0	98.6	1.44
250	100.0	99.6	0.42
300	100.0	99.9	0.12

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BRAIDWOOD UNIT 2 CAPSULE U (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:29 AM

A = 101.10 B = 98.90 C = 175.45 T0 = -17.10 D = 0.00

Correlation Coefficient = 0.855

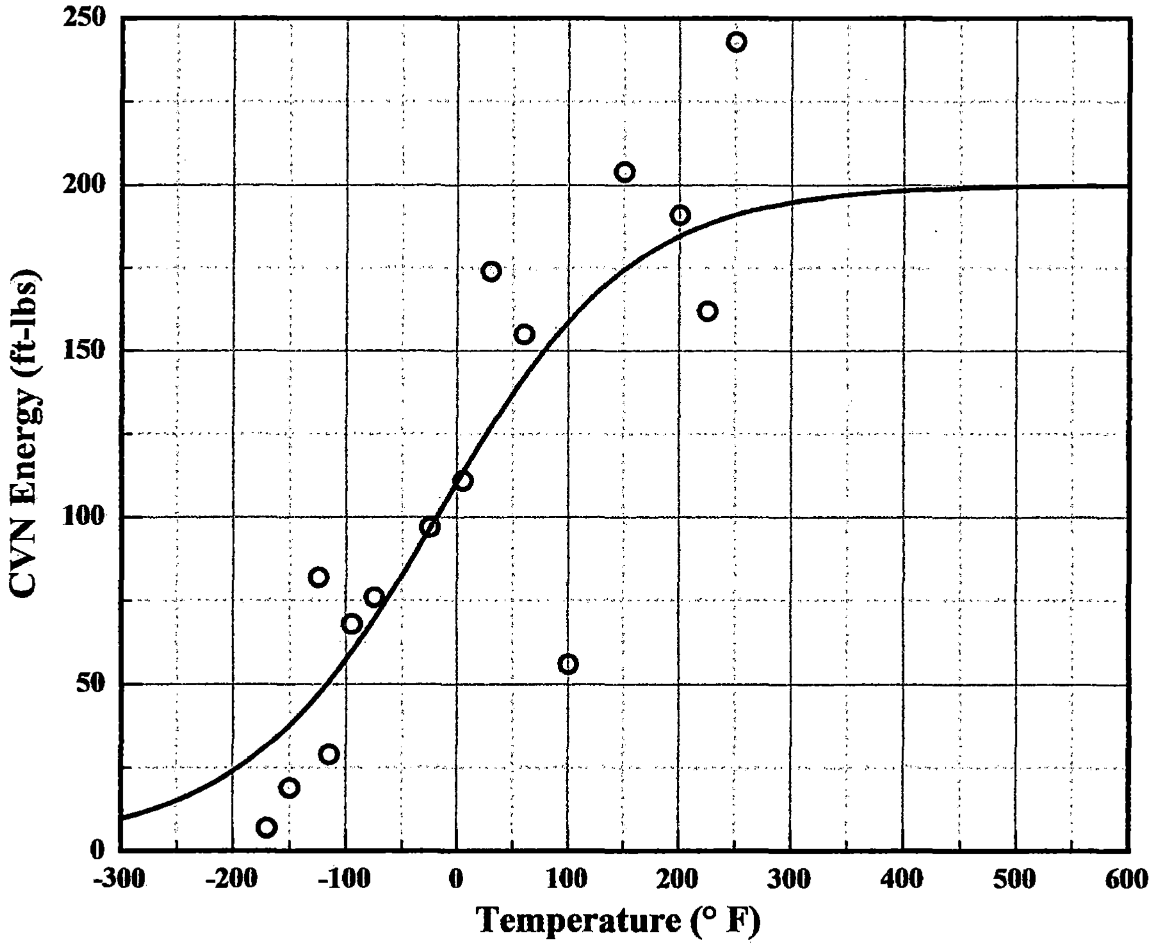
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 200.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-175.90° F Temp@35 ft-lbs=-158.80° F Temp@50 ft-lbs=-117.40° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **N/A** Capsule: **U**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: N/A Capsule: U

BRAIDWOOD UNIT 2 CAPSULE U (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-170	7.0	31.7	-24.66
-150	19.0	37.8	-18.85
-125	82.0	46.9	35.06
-115	29.0	51.0	-22.01
-95	68.0	59.9	8.14
-75	76.0	69.6	6.40
-25	97.0	96.6	0.35
5	111.0	113.5	-2.49
30	174.0	127.0	46.97
60	155.0	142.0	13.04
100	56.0	158.8	-102.79
150	204.0	174.4	29.63
200	191.0	184.6	6.36
225	162.0	188.2	-26.22
250	243.0	191.0	51.99

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BRAIDWOOD UNIT 2 CAPSULE U (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:29 AM

A = 35.82 B = 34.82 C = 89.24 T0 = -99.59 D = 0.00

Correlation Coefficient = 0.853

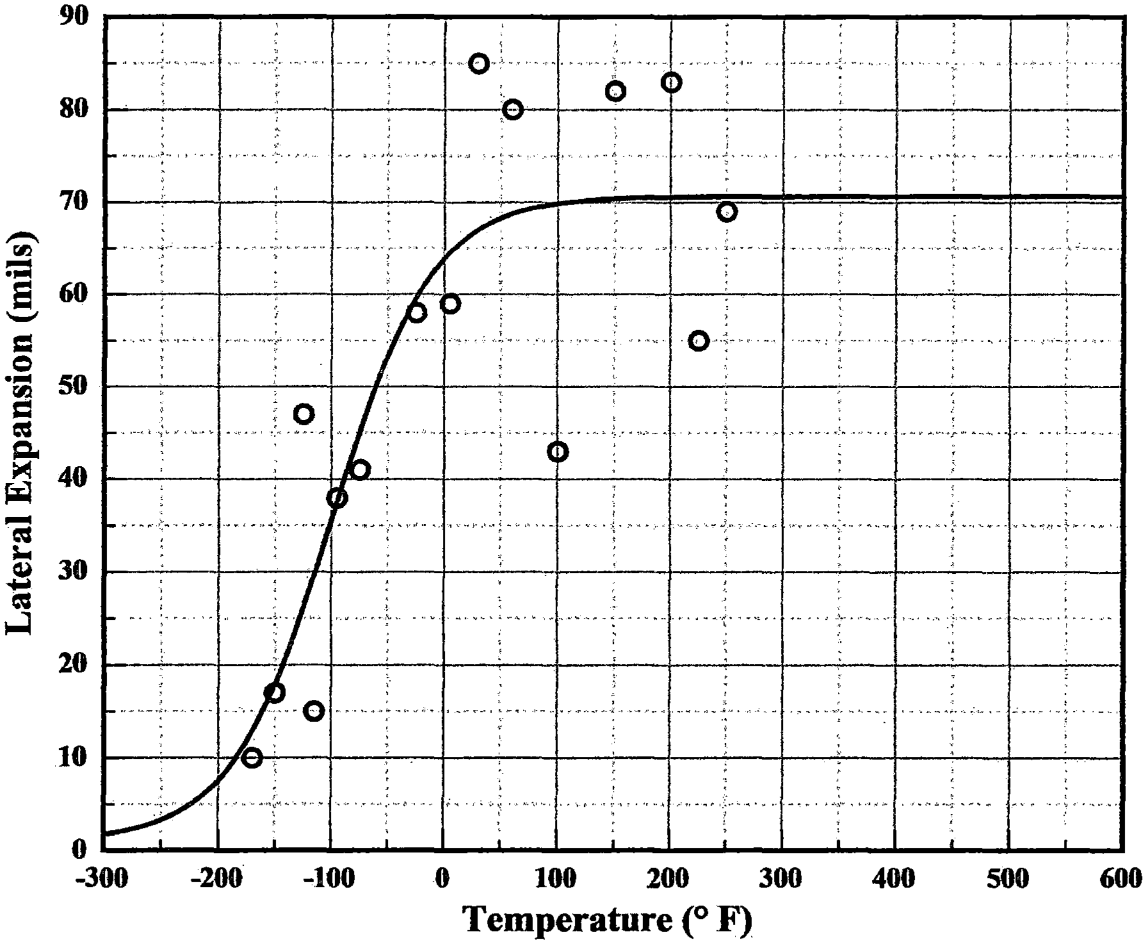
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 70.64 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-101.60° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **N/A** Capsule: **U**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: N/A Capsule: U

BRAIDWOOD UNIT 2 CAPSULE U (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-170	10.0	12.9	-2.91
-150	17.0	18.0	-1.01
-125	47.0	26.2	20.83
-115	15.0	29.9	-14.87
-95	38.0	37.6	0.39
-75	41.0	45.2	-4.18
-25	58.0	59.6	-1.62
5	59.0	64.5	-5.54
30	85.0	67.0	17.98
60	80.0	68.7	11.25
100	43.0	69.9	-26.85
150	82.0	70.4	11.62
200	83.0	70.6	12.44
225	55.0	70.6	-15.59
250	69.0	70.6	-1.61

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BRAIDWOOD UNIT 2 CAPSULE U (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:30 AM

A = 50.00 B = 50.00 C = 81.16 T0 = -104.08 D = 0.00

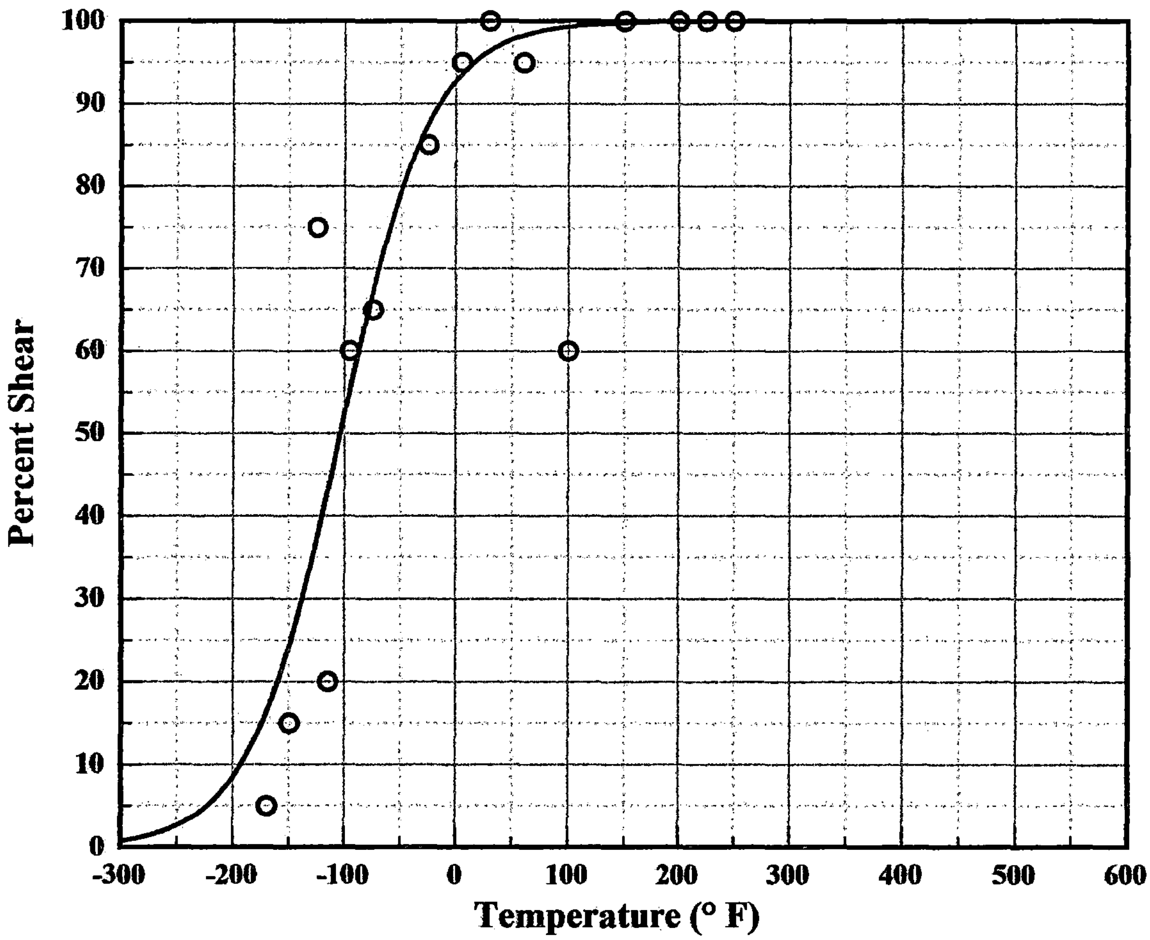
Correlation Coefficient = 0.879

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

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

Temperature at 50% Shear = -104.00

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **U**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: N/A Capsule: U

BRAIDWOOD UNIT 2 CAPSULE U (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-170	5.0	16.5	-11.46
-150	15.0	24.4	-9.39
-125	75.0	37.4	37.61
-115	20.0	43.3	-23.32
-95	60.0	55.6	4.43
-75	65.0	67.2	-2.19
-25	85.0	87.5	-2.53
5	95.0	93.6	1.37
30	100.0	96.5	3.54
60	95.0	98.3	-3.28
100	60.0	99.3	-39.35
150	100.0	99.8	0.19
200	100.0	99.9	0.06
225	100.0	100.0	0.03
250	100.0	100.0	0.02

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BRAIDWOOD UNIT 2 CAPSULE X (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:31 AM

A = 84.60 B = 82.40 C = 94.61 T0 = 44.92 D = 0.00

Correlation Coefficient = 0.941

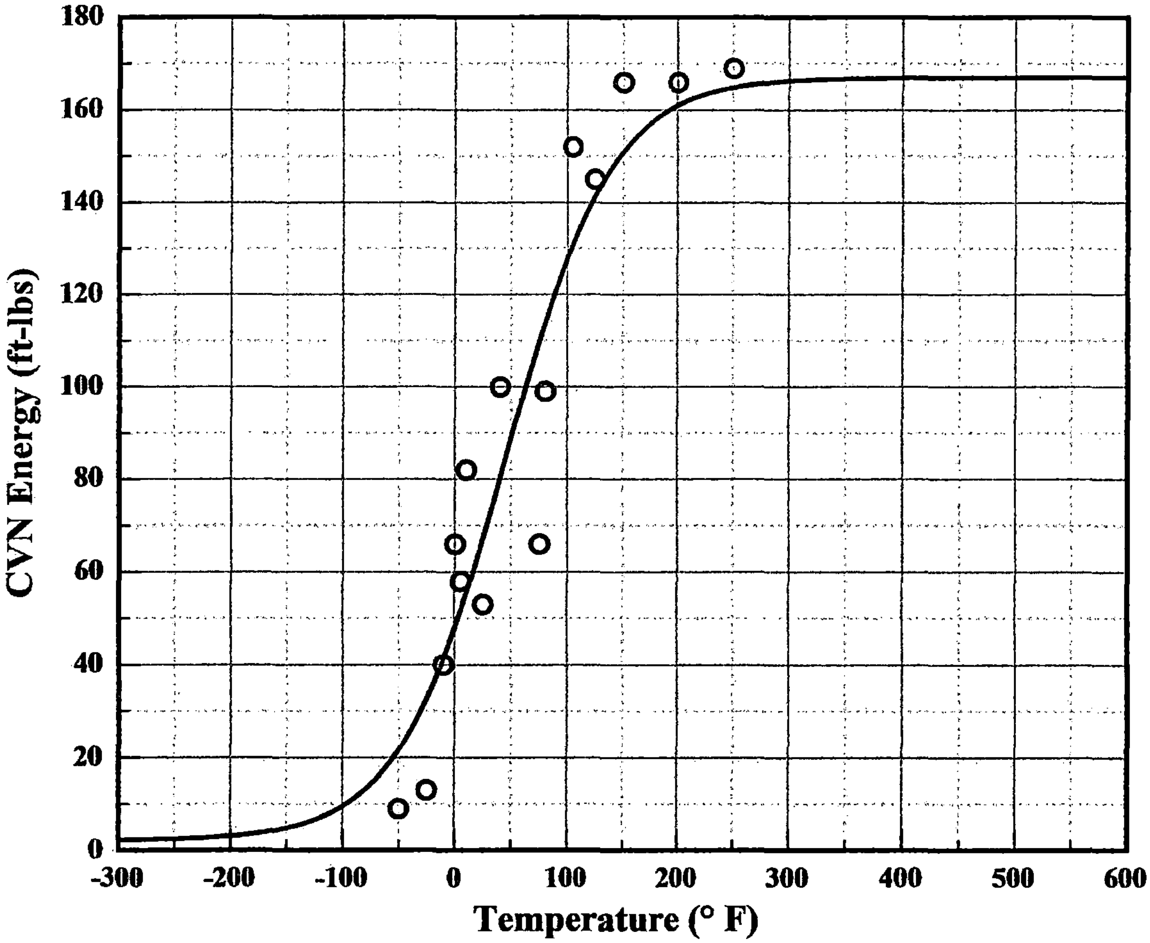
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 167.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-30.50° F Temp@35 ft-lbs=-20.90° F Temp@50 ft-lbs= 2.60° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **X**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **X**

BRAIDWOOD UNIT 2 CAPSULE X (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-50	9.0	21.7	-12.73
-25	13.0	32.8	-19.81
-10	40.0	41.5	-1.50
0	66.0	48.2	17.83
5	58.0	51.8	6.24
10	82.0	55.5	26.50
25	53.0	67.5	-14.50
40	100.0	80.3	19.68
75	66.0	110.0	-43.95
80	99.0	113.8	-14.83
105	152.0	130.9	21.13
125	145.0	141.4	3.61
150	166.0	150.9	15.12
200	166.0	161.0	4.98
250	169.0	164.9	4.13

CVGraph 6.02 10/19/2015 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE X (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 10:35 AM

A = 44.64 B = 43.64 C = 84.41 T0 = 20.61 D = 0.00

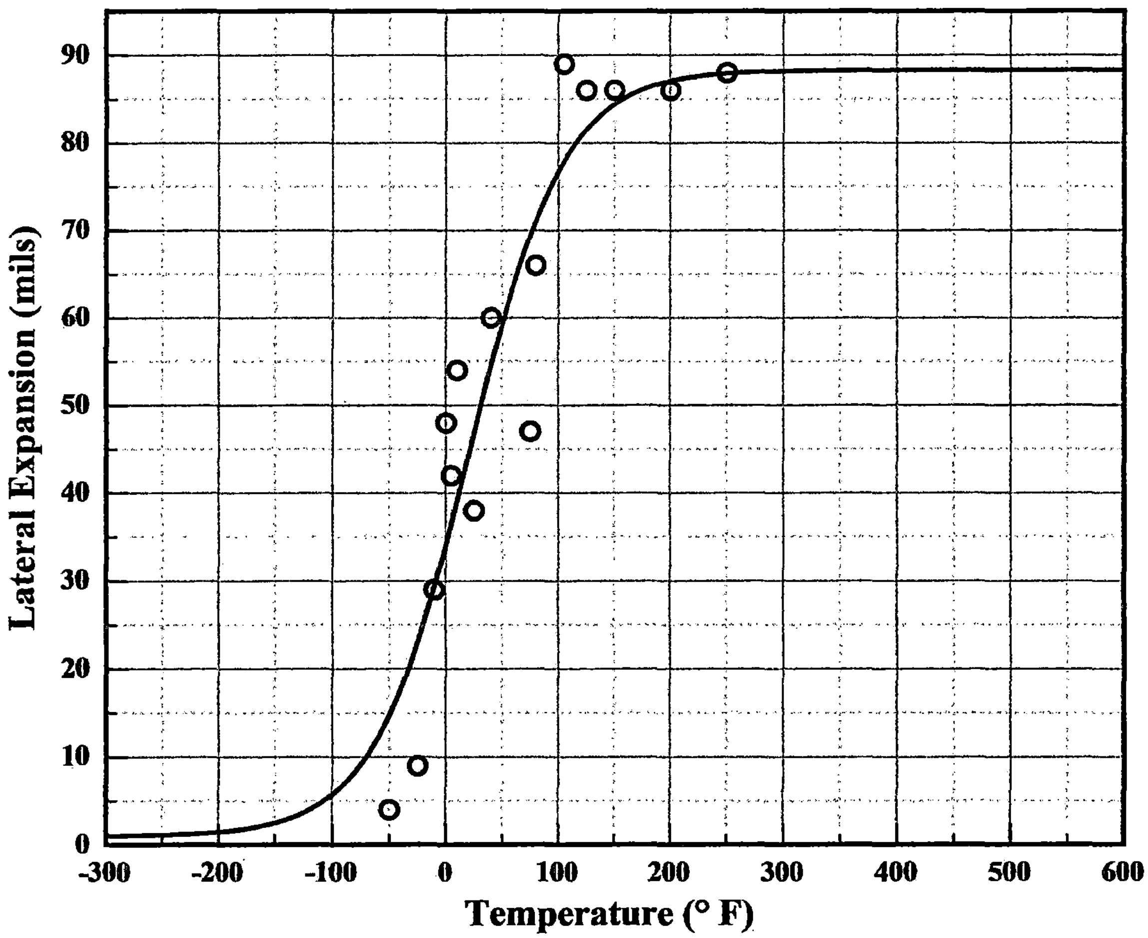
Correlation Coefficient = 0.930

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

Upper Shelf L.E. = 88.28 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 1.70° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **X**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **X**

BRAIDWOOD UNIT 2 CAPSULE X (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-50	4.0	14.8	-10.79
-25	9.0	23.1	-14.12
-10	29.0	29.5	-0.48
0	48.0	34.2	13.81
5	42.0	36.7	5.34
10	54.0	39.2	14.81
25	38.0	46.9	-8.91
40	60.0	54.5	5.50
75	47.0	69.4	-22.43
80	66.0	71.1	-5.12
105	89.0	77.9	11.12
125	86.0	81.5	4.50
150	86.0	84.4	1.60
200	86.0	87.1	-1.06
250	88.0	87.9	0.09

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BRAIDWOOD UNIT 2 CAPSULE X (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:32 AM

A = 50.00 B = 50.00 C = 68.94 T0 = 78.41 D = 0.00

Correlation Coefficient = 0.966

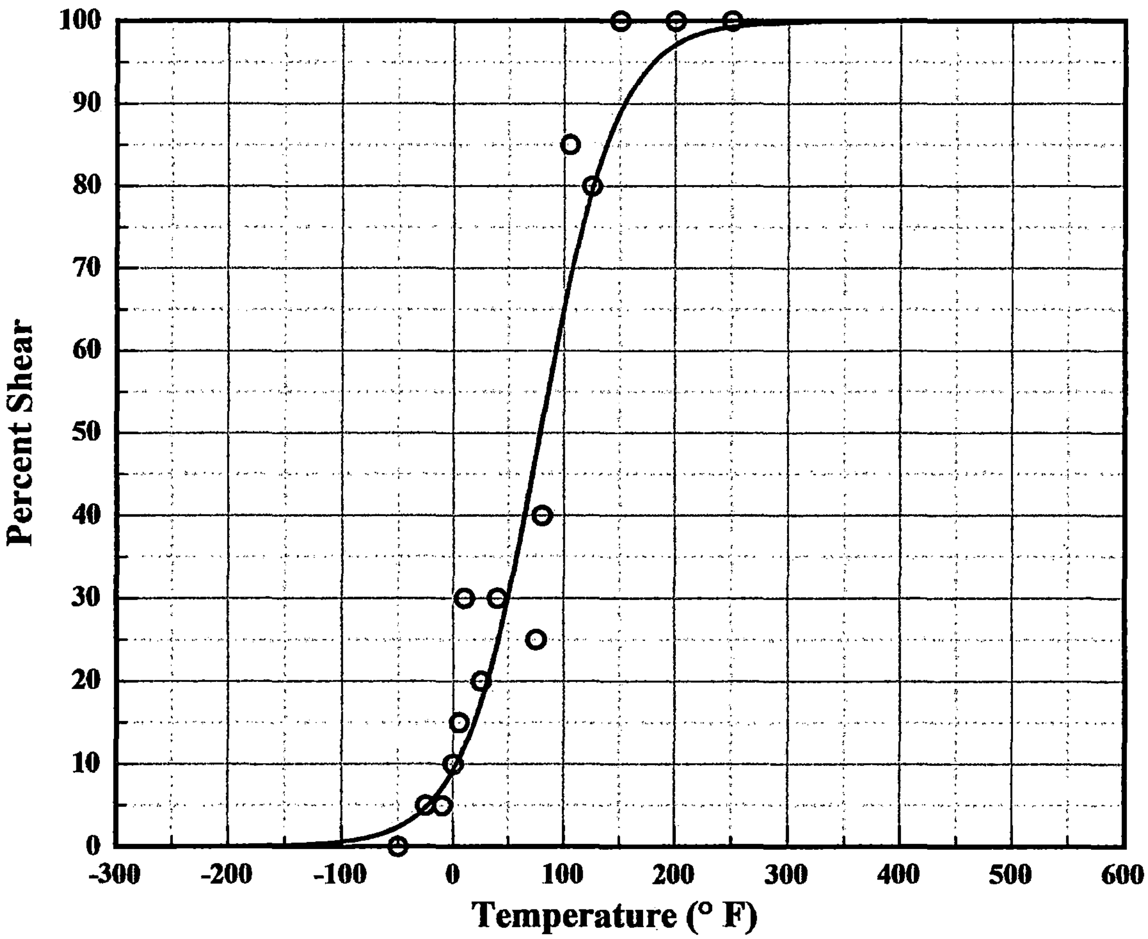
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 78.50

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **X**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **X**

BRAIDWOOD UNIT 2 CAPSULE X (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-50	0.0	2.4	-2.35
-25	5.0	4.7	0.26
-10	5.0	7.1	-2.14
0	10.0	9.3	0.68
5	15.0	10.6	4.37
10	30.0	12.1	17.92
25	20.0	17.5	2.48
40	30.0	24.7	5.29
75	25.0	47.5	-22.53
80	40.0	51.2	-11.15
105	85.0	68.4	16.62
125	80.0	79.4	0.56
150	100.0	88.9	11.14
200	100.0	97.1	2.85
250	100.0	99.3	0.68

CVGraph 6.02 10/19/2015 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE X (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 2/5/2016 8:26 AM

A = 73.60 B = 71.40 C = 99.03 T0 = 80.65 D = 0.00

Correlation Coefficient = 0.985

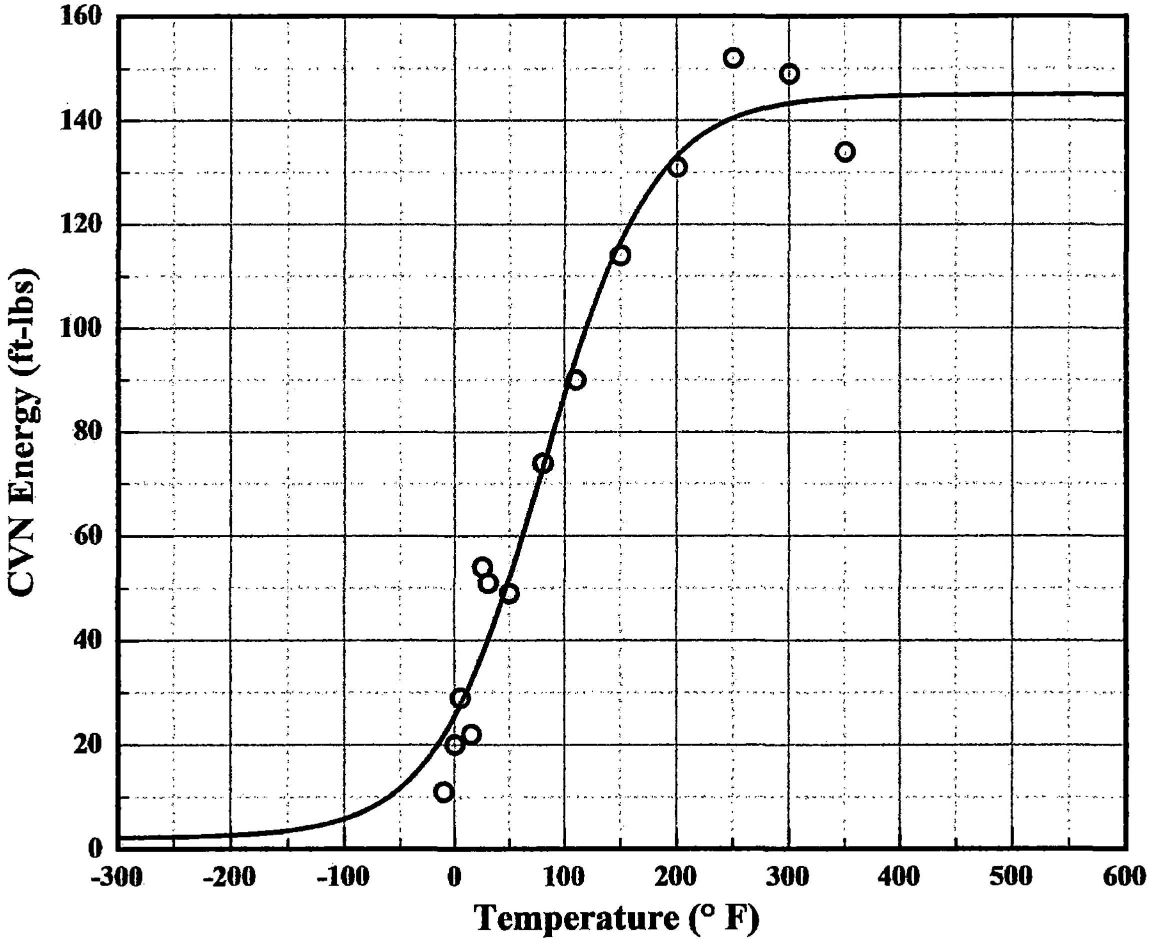
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temp@30 ft-lbs= 10.40° F Temp@35 ft-lbs= 20.80° F Temp@50 ft-lbs= 46.70° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **X**



CVGraph 6.02 02/05/2016 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **X**

BRAIDWOOD UNIT 2 CAPSULE X (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-10	11.0	21.9	-10.93
0	20.0	25.6	-5.62
5	29.0	27.7	1.34
15	22.0	32.2	-10.16
25	54.0	37.2	16.77
30	51.0	40.0	11.04
50	49.0	52.2	-3.18
80	74.0	73.1	0.87
110	90.0	94.2	-4.16
150	114.0	116.8	-2.76
200	131.0	133.2	-2.24
250	152.0	140.5	11.52
300	149.0	143.3	5.68
350	134.0	144.4	-10.38

CVGraph 6.02 02/05/2016 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE X (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:34 AM

A = 44.61 B = 43.61 C = 90.03 T0 = 57.52 D = 0.00

Correlation Coefficient = 0.989

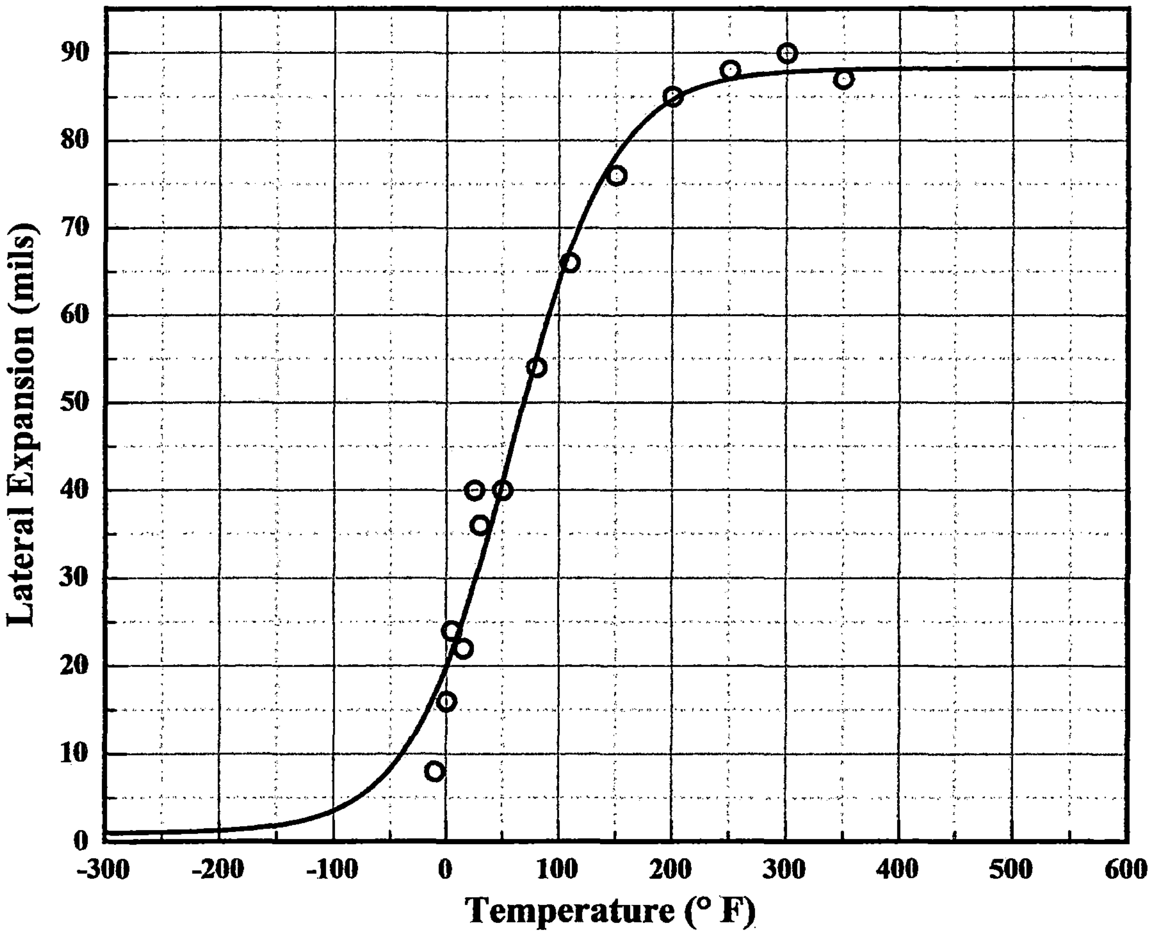
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 88.21 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 37.40° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **X**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **X**

BRAIDWOOD UNIT 2 CAPSULE X (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-10	8.0	16.9	-8.91
0	16.0	20.0	-4.01
5	24.0	21.7	2.29
15	22.0	25.4	-3.42
25	40.0	29.5	10.49
30	36.0	31.7	4.32
50	40.0	41.0	-0.97
80	54.0	55.3	-1.27
110	66.0	67.5	-1.49
150	76.0	78.3	-2.30
200	85.0	84.7	0.32
250	88.0	87.0	0.98
300	90.0	87.8	2.19
350	87.0	88.1	-1.08

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BRAIDWOOD UNIT 2 CAPSULE X (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:35 AM

A = 50.00 B = 50.00 C = 82.38 T0 = 112.34 D = 0.00

Correlation Coefficient = 0.994

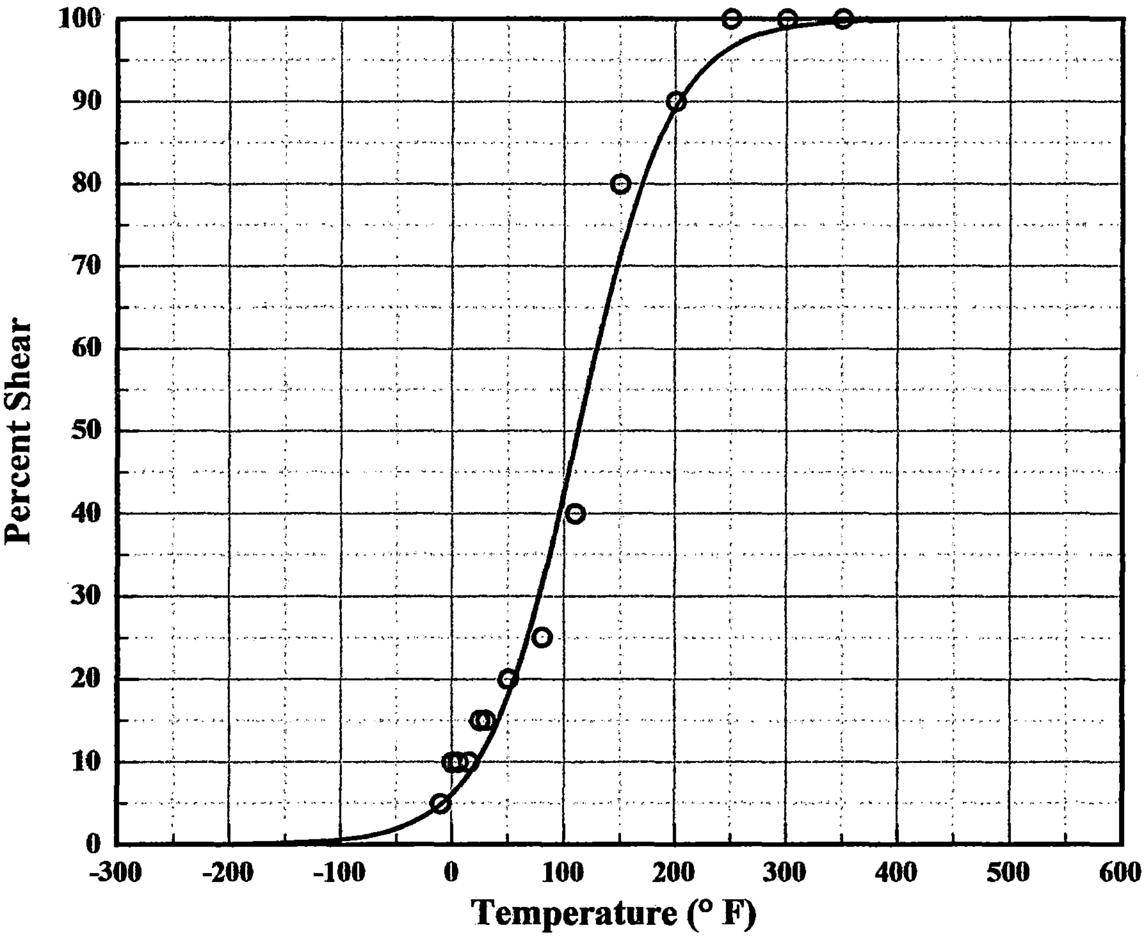
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 112.40

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **X**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **X**

BRAIDWOOD UNIT 2 CAPSULE X (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-10	5.0	4.9	0.12
0	10.0	6.1	3.86
5	10.0	6.9	3.12
15	10.0	8.6	1.40
25	15.0	10.7	4.29
30	15.0	11.9	3.07
50	20.0	18.0	1.96
80	25.0	31.3	-6.32
110	40.0	48.6	-8.58
150	80.0	71.4	8.61
200	90.0	89.4	0.64
250	100.0	96.6	3.42
300	100.0	99.0	1.04
350	100.0	99.7	0.31

CVGraph 6.02 10/19/2015 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE X (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:36 AM

A = 35.10 B = 32.90 C = 58.67 T0 = 16.03 D = 0.00

Correlation Coefficient = 0.960

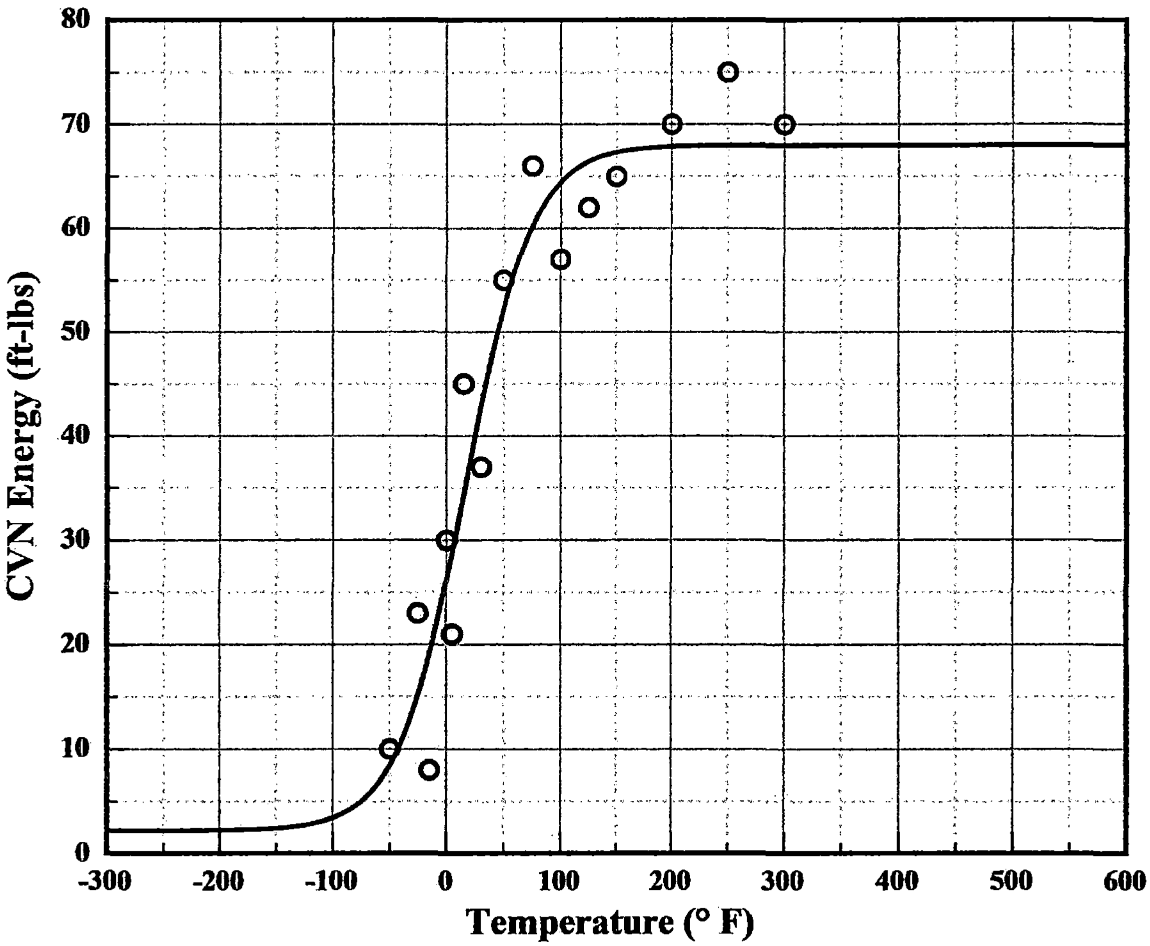
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 68.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= 6.90° F Temp@35 ft-lbs= 15.90° F Temp@50 ft-lbs= 44.70° F

Plant: **Braidwood 2** Material: **WELD** Heat:**442011**

Orientation: **N/A** Capsule: **X**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: N/A Capsule: X

BRAIDWOOD UNIT 2 CAPSULE X (WELD)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-50	10.0	8.5	1.53
-25	23.0	15.2	7.77
-15	8.0	19.2	-11.16
0	30.0	26.3	3.67
5	21.0	29.0	-7.99
15	45.0	34.5	10.48
30	37.0	42.8	-5.79
50	55.0	52.3	2.73
75	66.0	60.2	5.77
100	57.0	64.4	-7.44
125	62.0	66.4	-4.44
150	65.0	67.3	-2.32
200	70.0	67.9	2.12
250	75.0	68.0	7.02
300	70.0	68.0	2.00

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BRAIDWOOD UNIT 2 CAPSULE X (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:36 AM

A = 33.05 B = 32.05 C = 83.91 T0 = 24.46 D = 0.00

Correlation Coefficient = 0.967

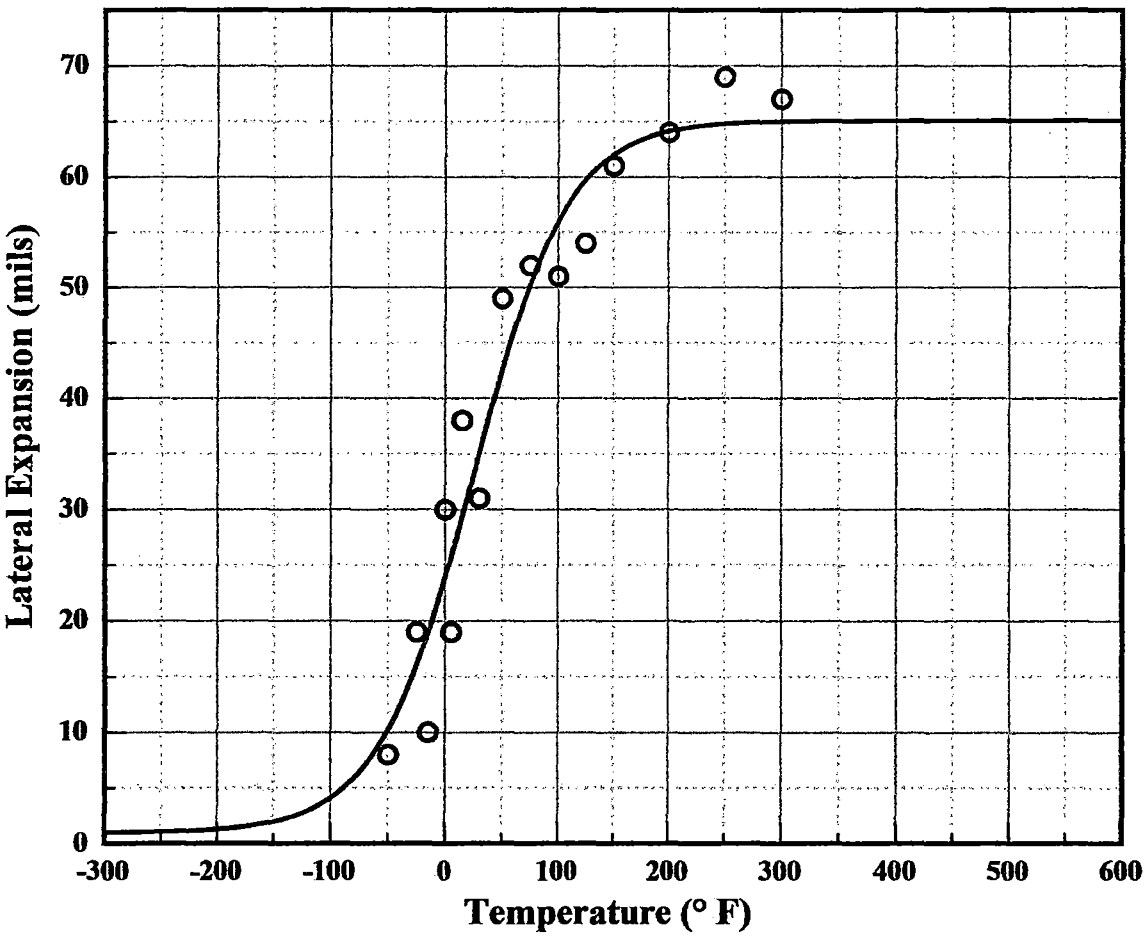
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 65.09 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 29.60° F

Plant: **Braidwood 2** Material: **WELD** Heat:**442011**

Orientation: **N/A** Capsule: **X**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat:**442011**
Orientation: N/A Capsule: **X**

BRAIDWOOD UNIT 2 CAPSULE X (WELD)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-50	8.0	10.3	-2.29
-25	19.0	16.1	2.92
-15	10.0	19.0	-9.00
0	30.0	24.0	6.04
5	19.0	25.7	-6.74
15	38.0	29.4	8.55
30	31.0	35.2	-4.16
50	49.0	42.5	6.49
75	52.0	50.3	1.69
100	51.0	56.0	-5.00
125	54.0	59.7	-5.74
150	61.0	62.0	-1.03
200	64.0	64.1	-0.13
250	69.0	64.8	4.21
300	67.0	65.0	2.00

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BRAIDWOOD UNIT 2 CAPSULE X (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:37 AM

A = 50.00 B = 50.00 C = 45.72 T0 = 31.64 D = 0.00

Correlation Coefficient = 0.971

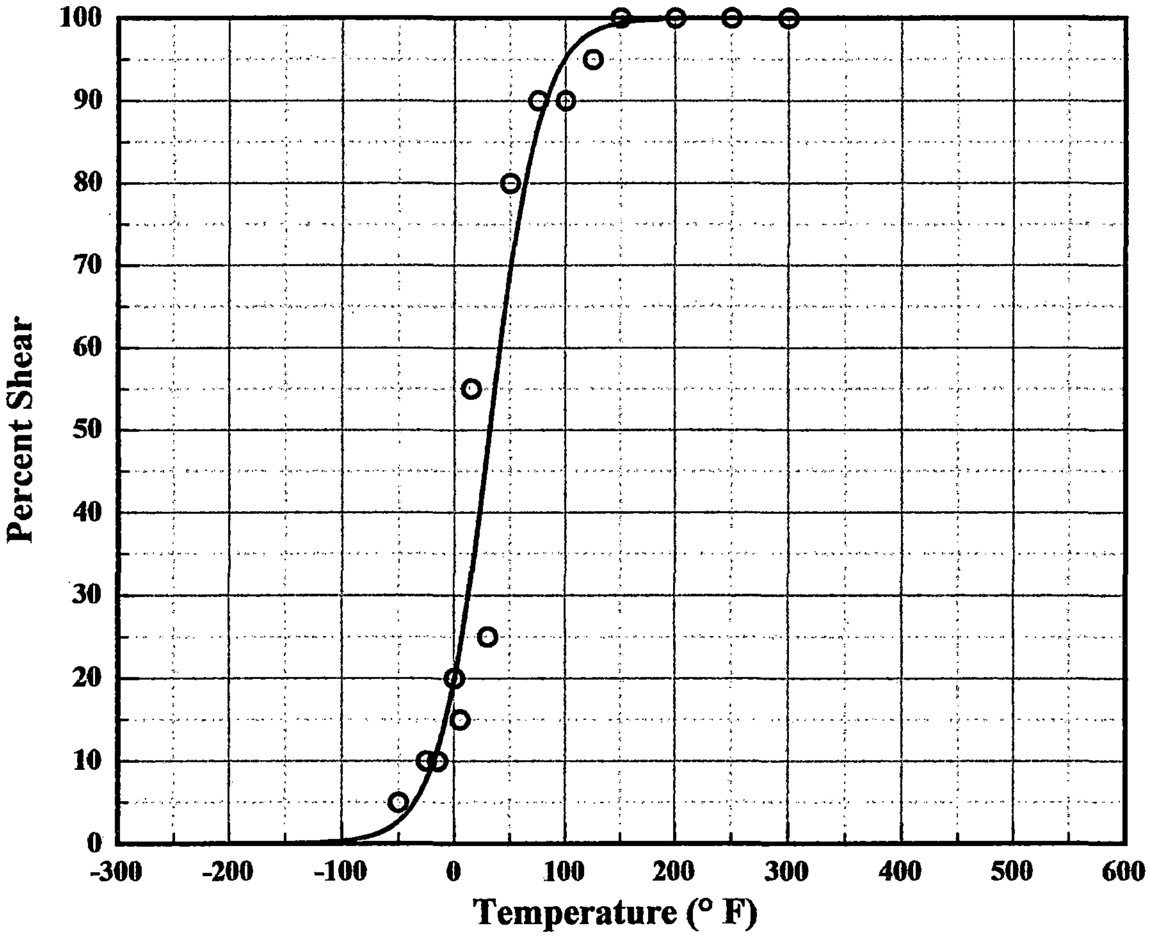
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 31.70

Plant: **Braidwood 2** Material: **WELD** Heat:**442011**

Orientation: **N/A** Capsule: **X**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: **N/A** Capsule: **X**

BRAIDWOOD UNIT 2 CAPSULE X (WELD)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-50	5.0	2.7	2.27
-25	10.0	7.7	2.26
-15	10.0	11.5	-1.50
0	20.0	20.0	-0.03
5	15.0	23.8	-8.77
15	55.0	32.6	22.44
30	25.0	48.2	-23.21
50	80.0	69.1	10.93
75	90.0	87.0	3.05
100	90.0	95.2	-5.21
125	95.0	98.3	-3.34
150	100.0	99.4	0.56
200	100.0	99.9	0.06
250	100.0	100.0	0.01
300	100.0	100.0	0.00

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BRAIDWOOD UNIT 2 CAPSULE X (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:38 AM

A = 63.60 B = 61.40 C = 71.72 T0 = -106.96 D = 0.00

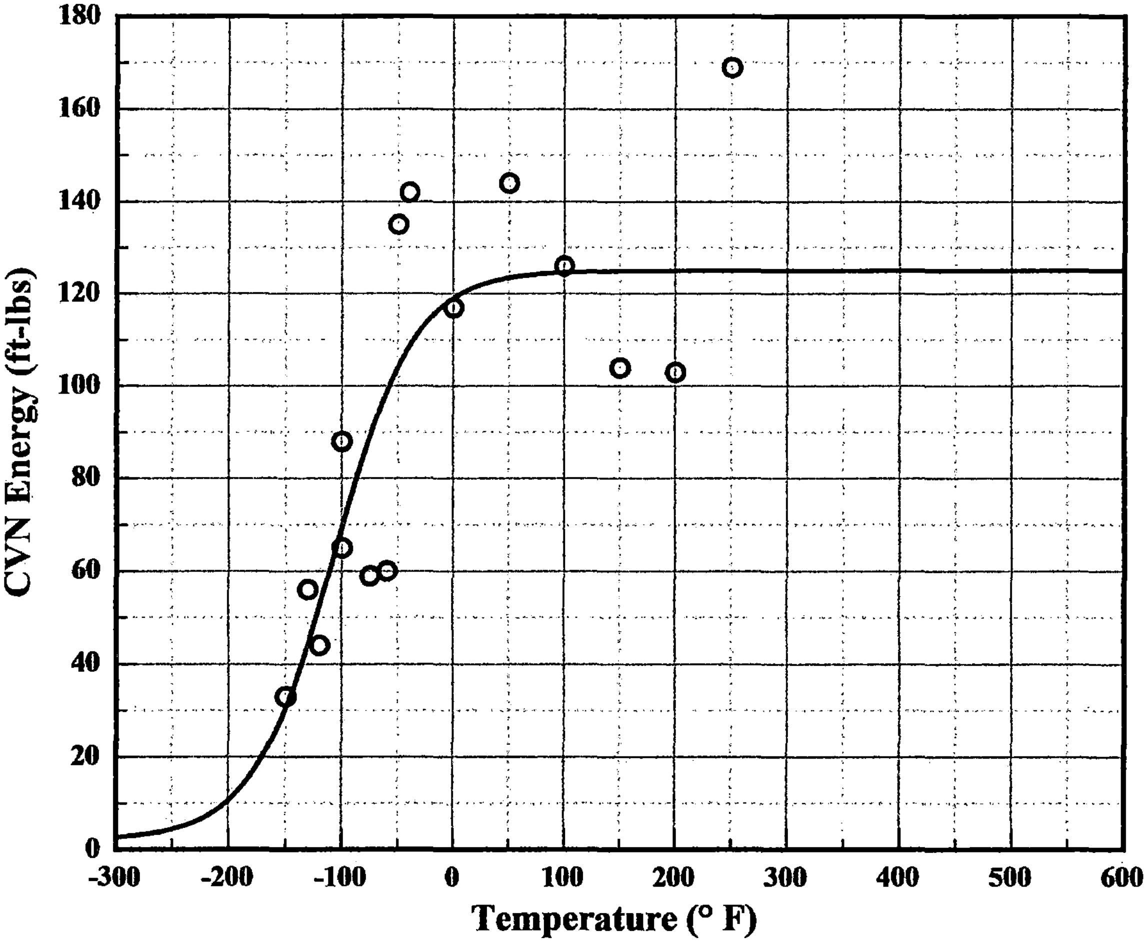
Correlation Coefficient = 0.816

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

Upper Shelf Energy = 125.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-151.00° F Temp@35 ft-lbs=-143.10° F Temp@50 ft-lbs=-123.10° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **X**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: N/A Capsule: X

BRAIDWOOD UNIT 2 CAPSULE X (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-150	33.0	30.6	2.38
-130	56.0	44.5	11.48
-120	44.0	52.6	-8.55
-100	88.0	69.5	18.46
-100	65.0	69.5	-4.54
-75	59.0	89.3	-30.28
-60	60.0	98.9	-38.90
-50	135.0	104.2	30.83
-40	142.0	108.6	33.44
0	117.0	119.1	-2.08
50	144.0	123.5	20.52
100	126.0	124.6	1.38
150	104.0	124.9	-20.91
200	103.0	125.0	-21.98
250	169.0	125.0	44.01

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BRAIDWOOD UNIT 2 CAPSULE X (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:39 AM

A = 36.93 B = 35.93 C = 88.77 T0 = -101.65 D = 0.00

Correlation Coefficient = 0.828

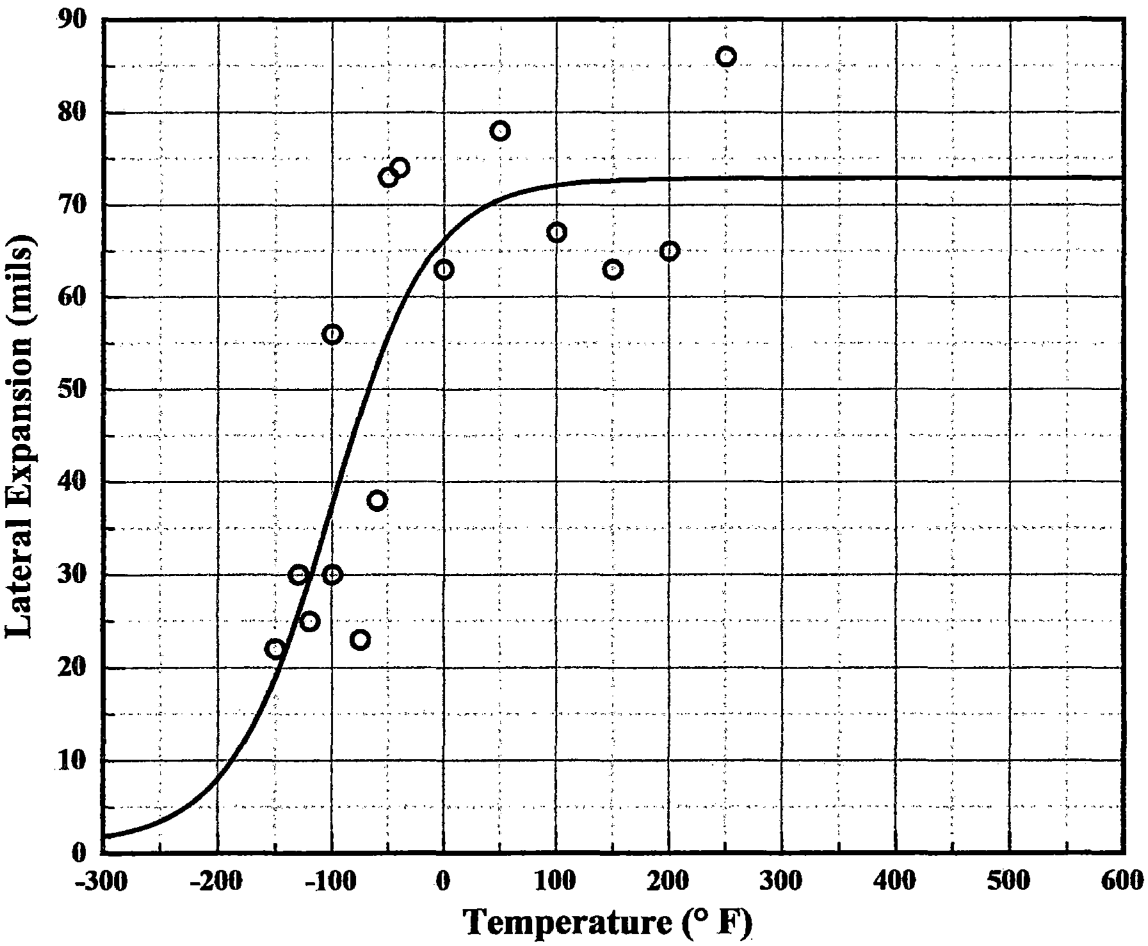
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 72.87   Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-106.40° F

Plant: **Braidwood 2**   Material: **SA508CL3**   Heat: **[50D102/50C97]-1-1**

Orientation: **N/A**   Capsule: **X**



CVGraph 6.02   10/19/2015   Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: N/A Capsule: **X**

BRAIDWOOD UNIT 2 CAPSULE X (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-150	22.0	19.1	2.91
-130	30.0	25.8	4.17
-120	25.0	29.6	-4.61
-100	56.0	37.6	18.40
-100	30.0	37.6	-7.60
-75	23.0	47.4	-24.41
-60	38.0	52.7	-14.66
-50	73.0	55.8	17.24
-40	74.0	58.5	15.47
0	63.0	66.3	-3.26
50	78.0	70.6	7.42
100	67.0	72.1	-5.11
150	63.0	72.6	-9.62
200	65.0	72.8	-7.79
250	86.0	72.8	13.16

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BRAIDWOOD UNIT 2 CAPSULE X (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:39 AM

A = 50.00 B = 50.00 C = 123.30 T0 = -31.66 D = 0.00

Correlation Coefficient = 0.946

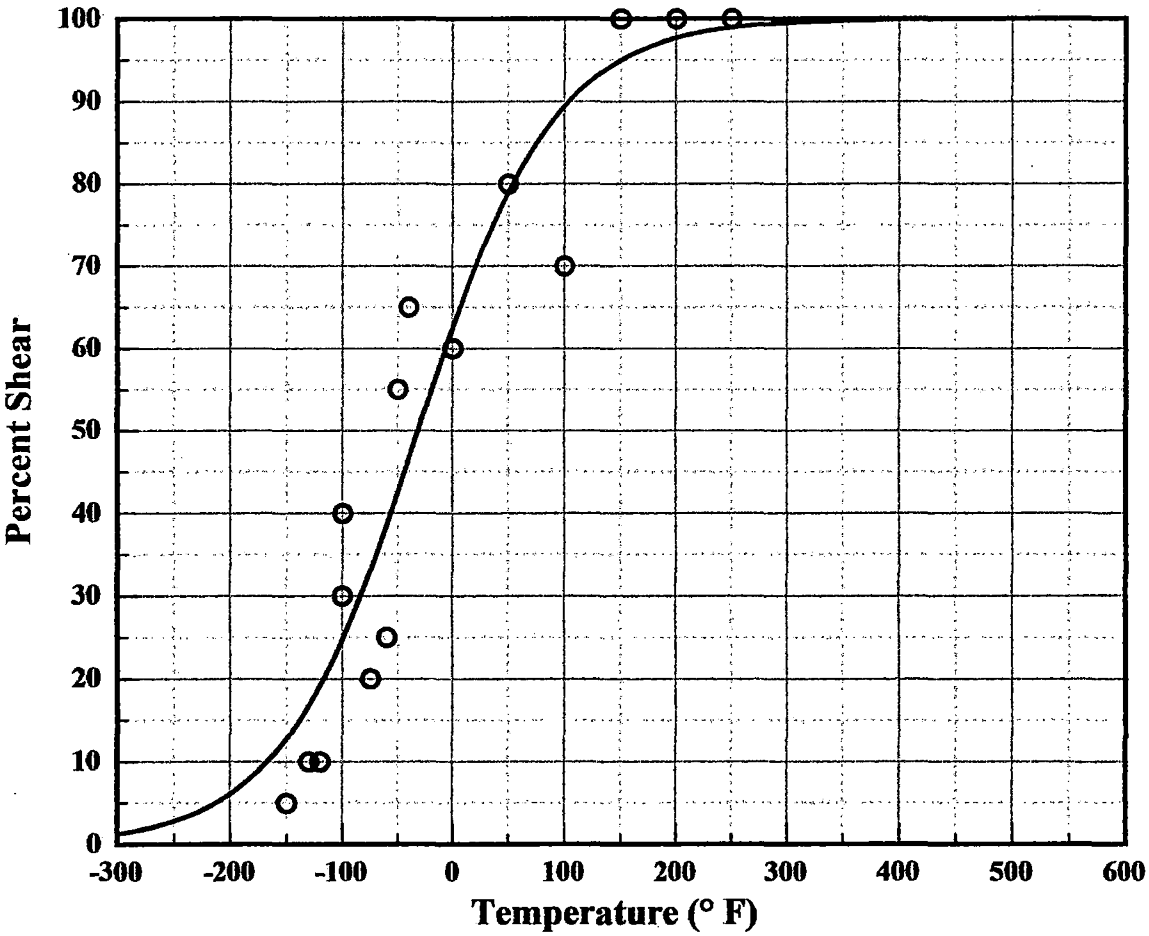
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = -31.60

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **N/A** Capsule: **X**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **X**

BRAIDWOOD UNIT 2 CAPSULE X (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-150	5.0	12.8	-7.79
-130	10.0	16.9	-6.87
-120	10.0	19.3	-9.26
-100	40.0	24.8	15.18
-100	30.0	24.8	5.18
-75	20.0	33.1	-13.12
-60	25.0	38.7	-13.71
-50	55.0	42.6	12.38
-40	65.0	46.6	18.38
0	60.0	62.6	-2.56
50	80.0	79.0	1.01
100	70.0	89.4	-19.43
150	100.0	95.0	4.99
200	100.0	97.7	2.28
250	100.0	99.0	1.03

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BRAIDWOOD UNIT 2 CAPSULE W (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:40 AM

A = 84.10 B = 81.90 C = 80.83 T0 = 47.78 D = 0.00

Correlation Coefficient = 0.973

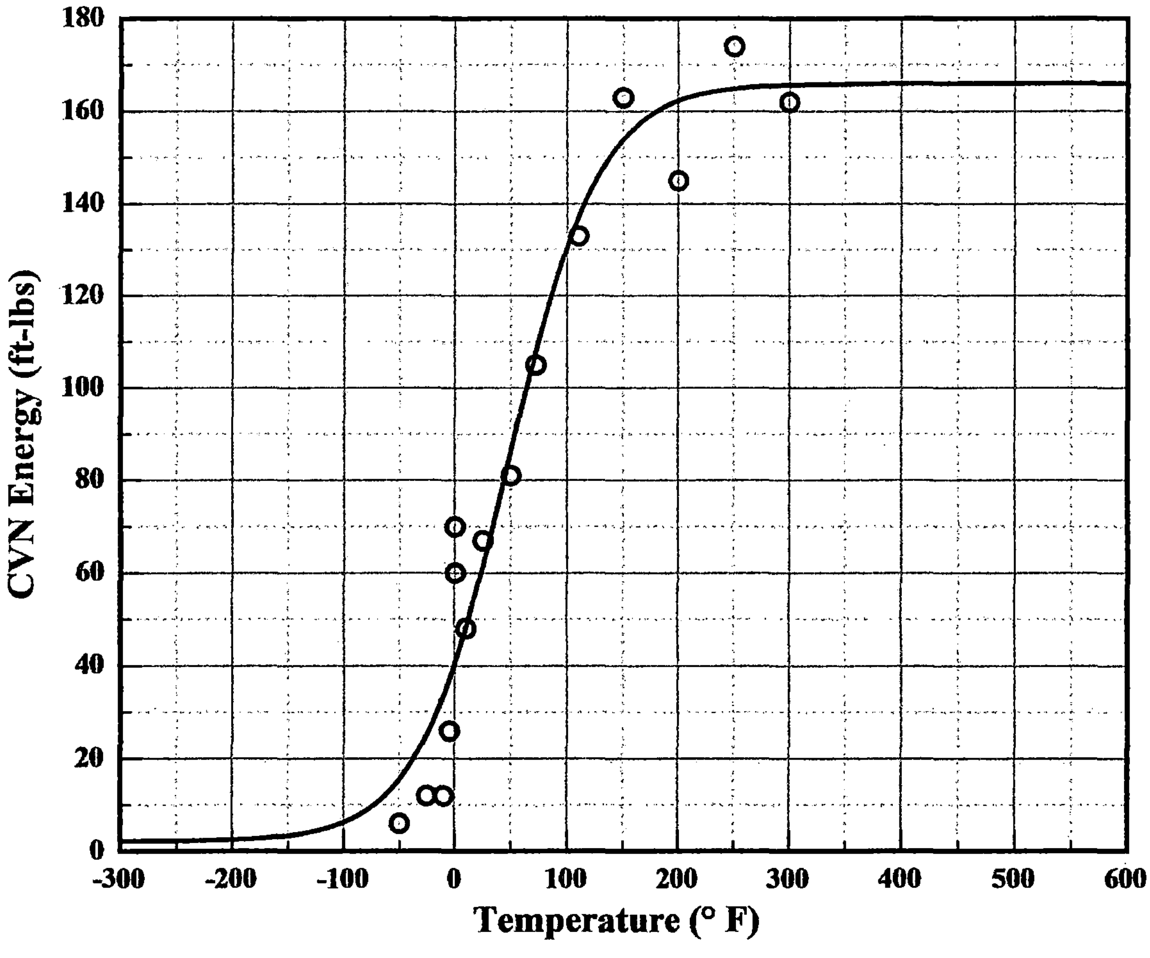
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 166.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-16.30° F Temp@35 ft-lbs= -8.10° F Temp@50 ft-lbs= 12.00° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **W**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **W**

BRAIDWOOD UNIT 2 CAPSULE W (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-50	6.0	15.6	-9.58
-25	12.0	25.4	-13.42
-10	12.0	33.8	-21.84
-5	26.0	37.1	-11.11
0	70.0	40.6	29.37
0	60.0	40.6	19.37
10	48.0	48.4	-0.38
25	67.0	61.6	5.39
50	81.0	86.3	-5.35
72	105.0	107.9	-2.93
110	133.0	137.1	-4.07
150	163.0	153.9	9.09
200	145.0	162.3	-17.30
250	174.0	164.9	9.09
300	162.0	165.7	-3.68

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BRAIDWOOD UNIT 2 CAPSULE W (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:41 AM

A = 42.03 B = 41.03 C = 66.47 T0 = 32.82 D = 0.00

Correlation Coefficient = 0.968

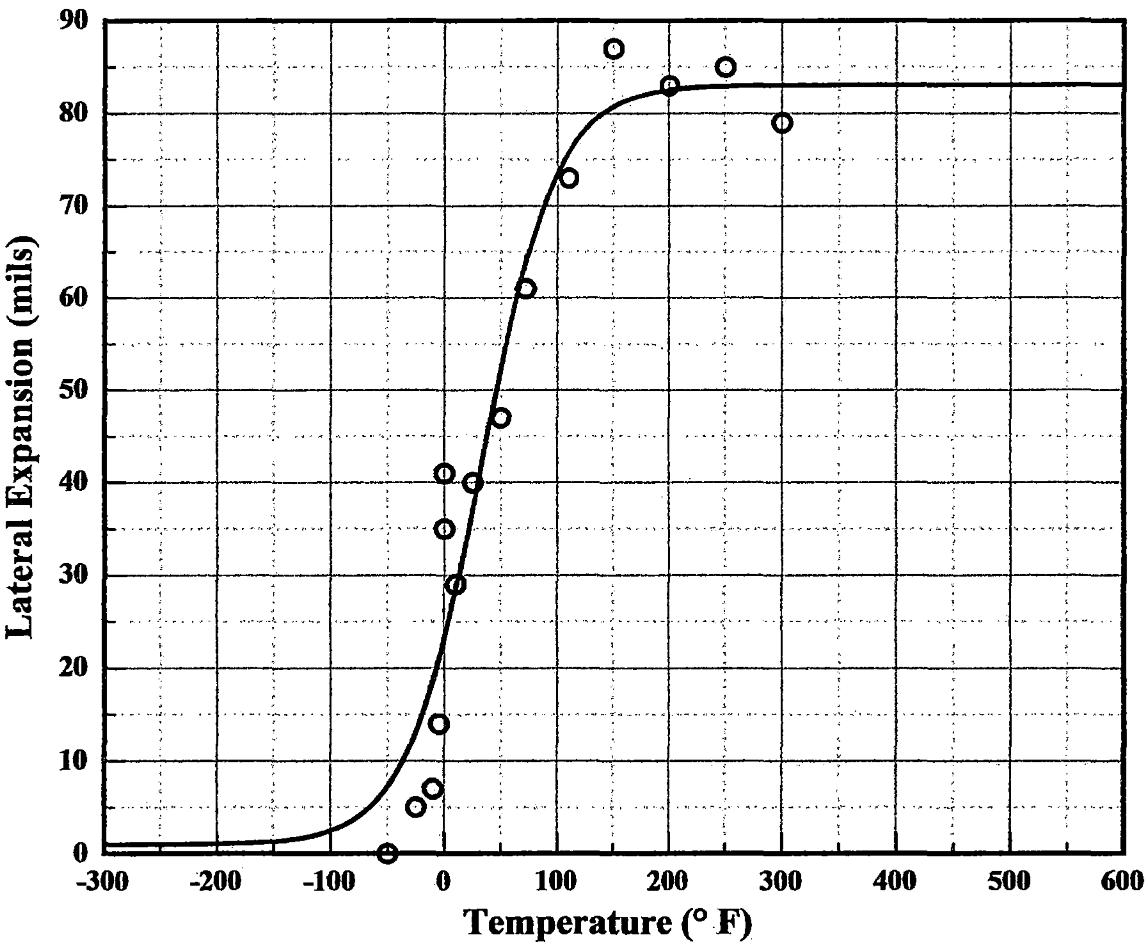
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 83.06 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 21.40° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **W**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: W

BRAIDWOOD UNIT 2 CAPSULE W (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-50	0.0	7.3	-7.27
-25	5.0	13.3	-8.26
-10	7.0	18.7	-11.74
-5	14.0	20.9	-6.92
0	41.0	23.3	17.73
0	35.0	23.3	11.73
10	29.0	28.5	0.53
25	40.0	37.2	2.77
50	47.0	52.4	-5.41
72	61.0	63.8	-2.76
110	73.0	75.7	-2.73
150	87.0	80.7	6.28
200	83.0	82.5	0.47
250	85.0	82.9	2.06
300	79.0	83.0	-4.03

CVGraph 6.02 10/19/2015 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE W (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:41 AM

A = 50.00 B = 50.00 C = 85.28 T0 = 64.56 D = 0.00

Correlation Coefficient = 0.982

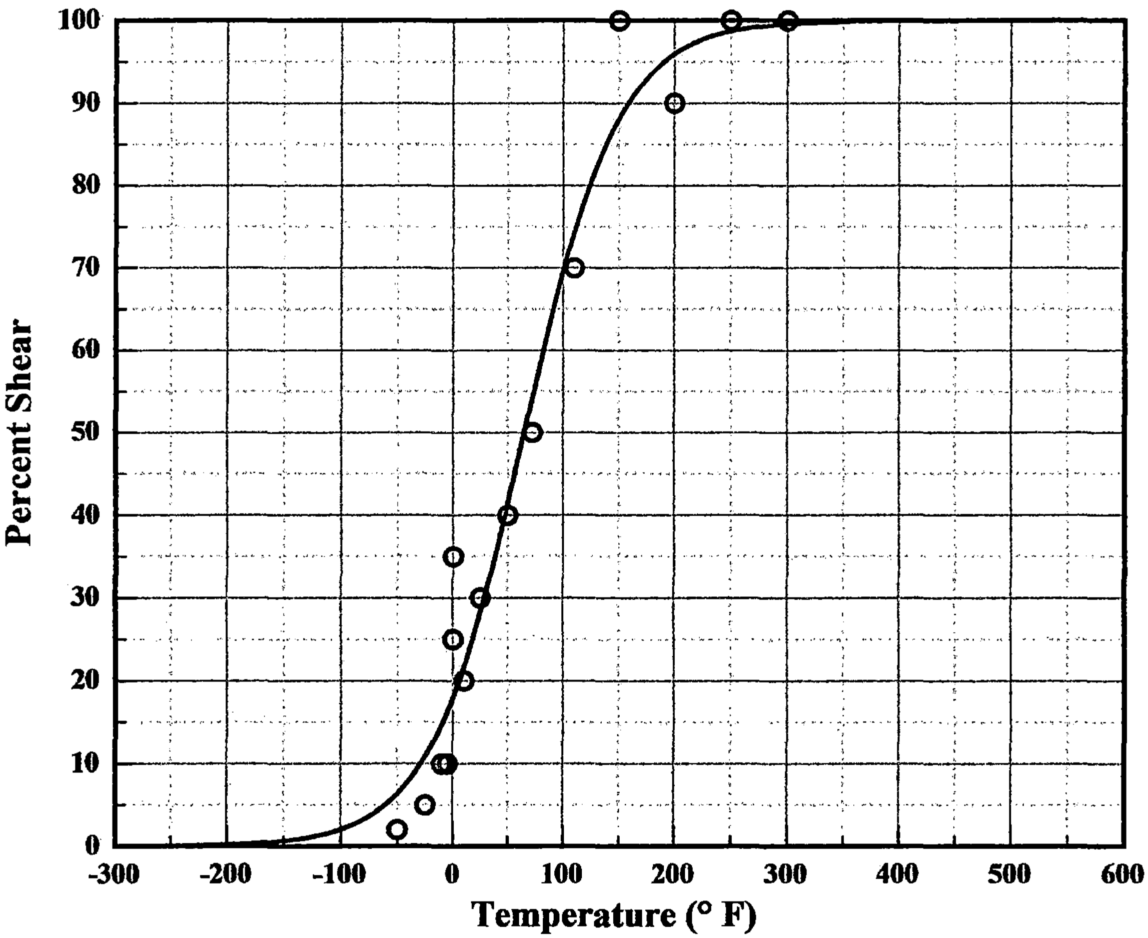
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 64.60

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **W**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **W**

BRAIDWOOD UNIT 2 CAPSULE W (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-50	2.0	6.4	-4.38
-25	5.0	10.9	-5.91
-10	10.0	14.8	-4.82
-5	10.0	16.4	-6.37
0	35.0	18.0	16.96
0	25.0	18.0	6.96
10	20.0	21.8	-1.76
25	30.0	28.3	1.66
50	40.0	41.5	-1.55
72	50.0	54.4	-4.35
110	70.0	74.4	-4.38
150	100.0	88.1	11.88
200	90.0	96.0	-5.99
250	100.0	98.7	1.28
300	100.0	99.6	0.40

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BRAIDWOOD UNIT 2 CAPSULE W (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:46 AM

A = 74.60 B = 72.40 C = 93.68 T0 = 76.93 D = 0.00

Correlation Coefficient = 0.976

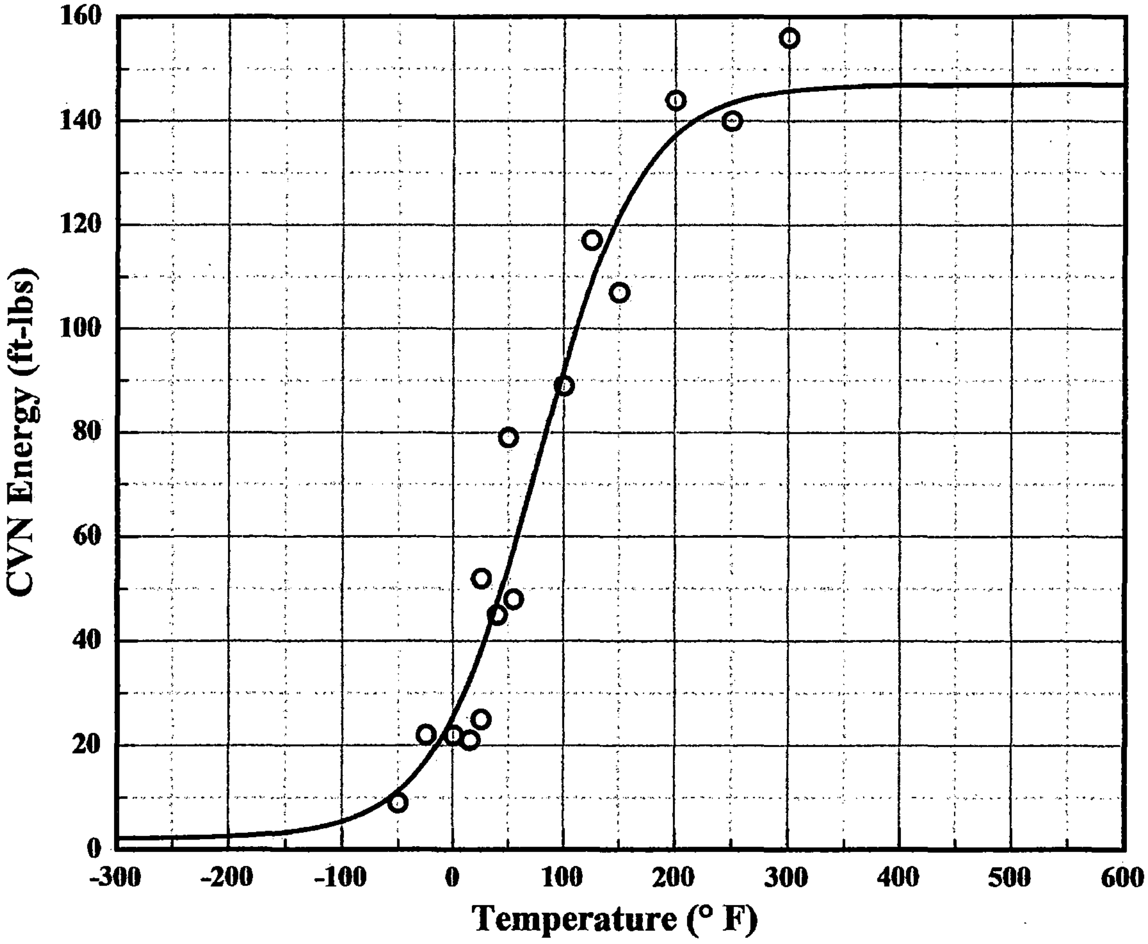
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 147.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= 9.70° F Temp@35 ft-lbs= 19.50° F Temp@50 ft-lbs= 43.80° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **W**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **W**

BRAIDWOOD UNIT 2 CAPSULE W (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-50	9.0	11.2	-2.23
-25	22.0	17.0	5.05
0	22.0	25.7	-3.67
15	21.0	32.7	-11.67
25	52.0	38.1	13.88
25	25.0	38.1	-13.12
40	45.0	47.4	-2.45
50	79.0	54.3	24.66
55	48.0	58.0	-9.95
100	89.0	92.1	-3.07
125	117.0	108.8	8.20
150	107.0	121.9	-14.85
200	144.0	137.2	6.76
250	140.0	143.5	-3.49
300	156.0	145.8	10.23

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BRAIDWOOD UNIT 2 CAPSULE W (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:46 AM

A = 39.11 B = 38.11 C = 73.78 T0 = 59.24 D = 0.00

Correlation Coefficient = 0.963

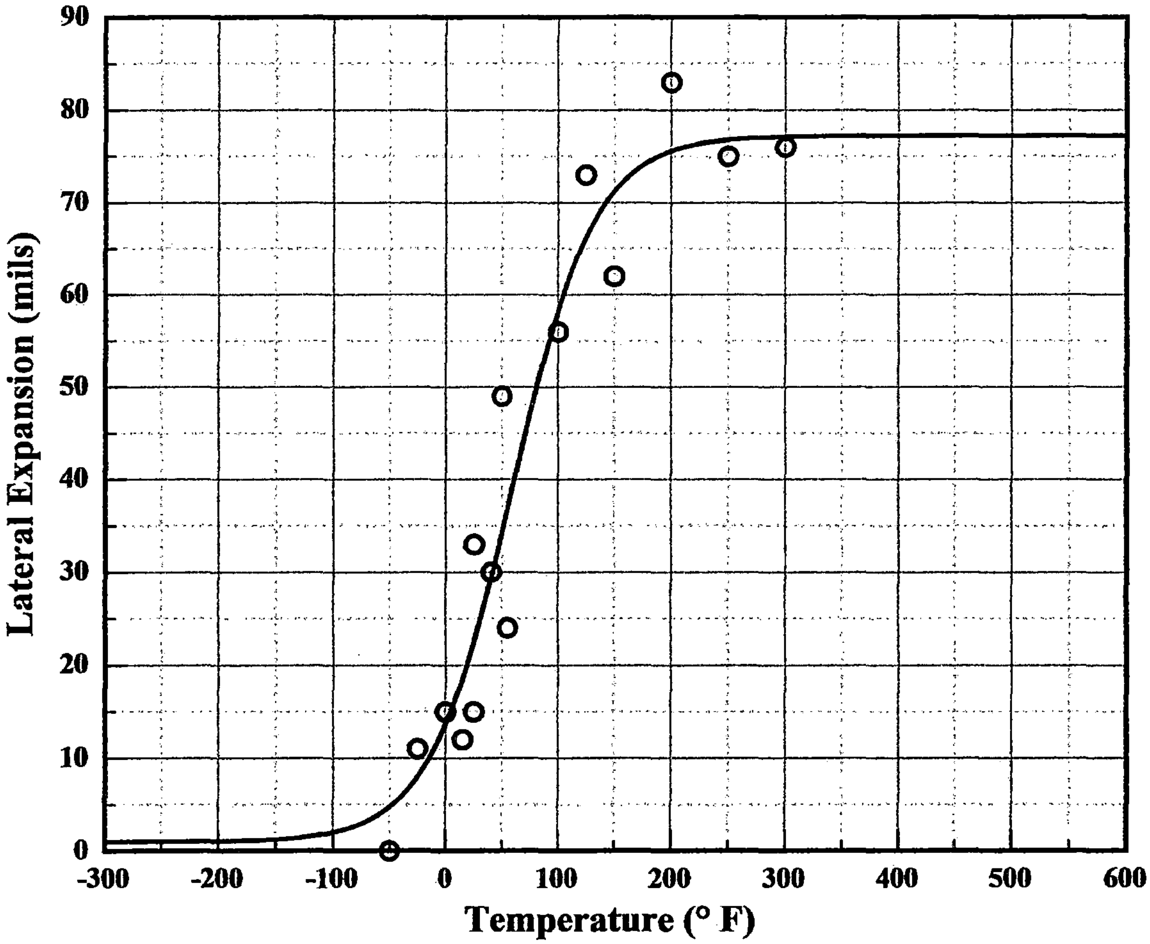
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 77.22 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 51.30° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **W**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **W**

BRAIDWOOD UNIT 2 CAPSULE W (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-50	0.0	4.8	-4.75
-25	11.0	8.0	2.95
0	15.0	13.7	1.26
15	12.0	18.7	-6.65
25	33.0	22.6	10.41
25	15.0	22.6	-7.59
40	30.0	29.4	0.61
50	49.0	34.4	14.64
55	24.0	36.9	-12.92
100	56.0	58.3	-2.26
125	73.0	66.2	6.75
150	62.0	71.2	-9.23
200	83.0	75.6	7.42
250	75.0	76.8	-1.79
300	76.0	77.1	-1.11

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BRAIDWOOD UNIT 2 CAPSULE W (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:47 AM

A = 50.00 B = 50.00 C = 85.85 T0 = 101.20 D = 0.00

Correlation Coefficient = 0.989

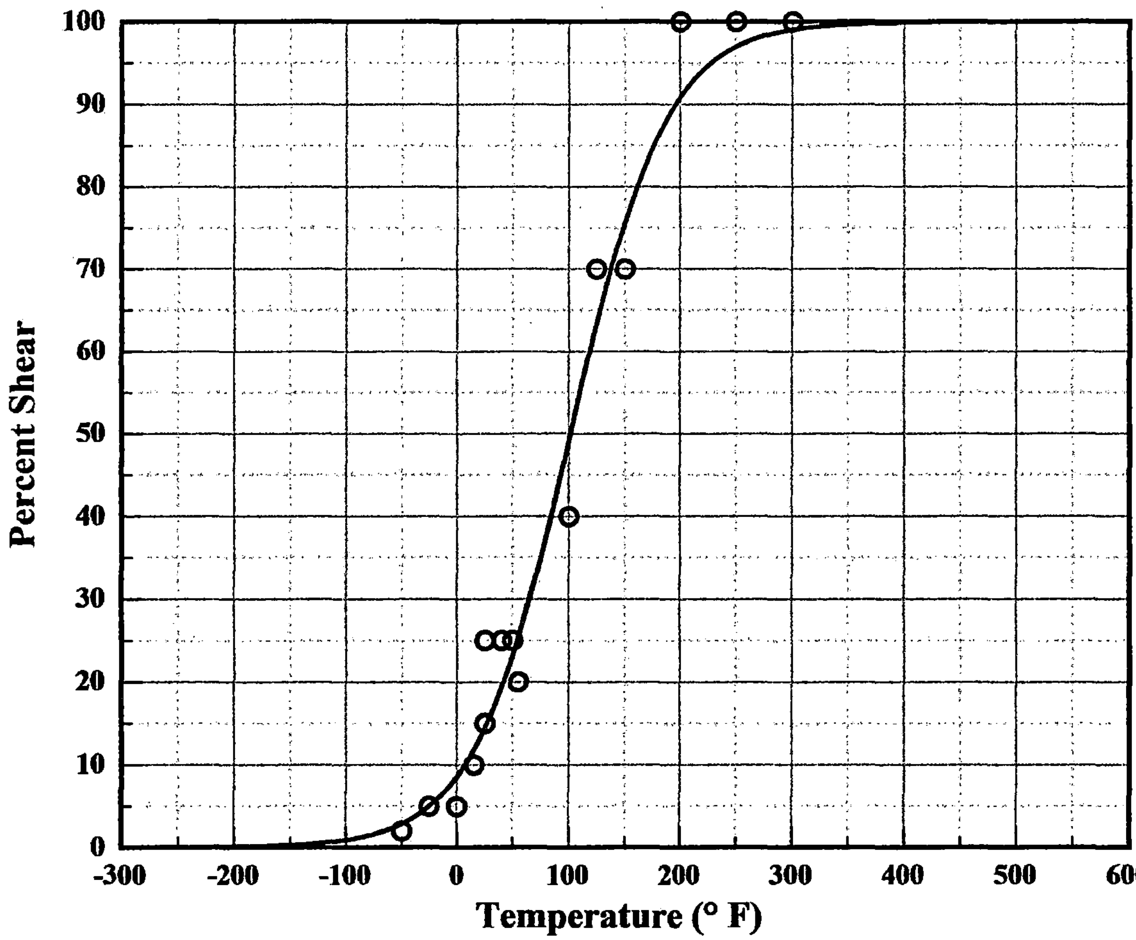
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 101.30

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **W**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **W**

BRAIDWOOD UNIT 2 CAPSULE W (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-50	2.0	2.9	-0.87
-25	5.0	5.0	-0.02
0	5.0	8.6	-3.65
15	10.0	11.8	-1.83
25	25.0	14.5	10.51
25	15.0	14.5	0.51
40	25.0	19.4	5.63
50	25.0	23.3	1.73
55	20.0	25.4	-5.42
100	40.0	49.3	-9.30
125	70.0	63.5	6.49
150	70.0	75.7	-5.71
200	100.0	90.9	9.10
250	100.0	97.0	3.03
300	100.0	99.0	0.96

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BRAIDWOOD UNIT 2 CAPSULE W (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:48 AM

A = 35.10 B = 32.90 C = 104.38 T0 = 20.74 D = 0.00

Correlation Coefficient = 0.986

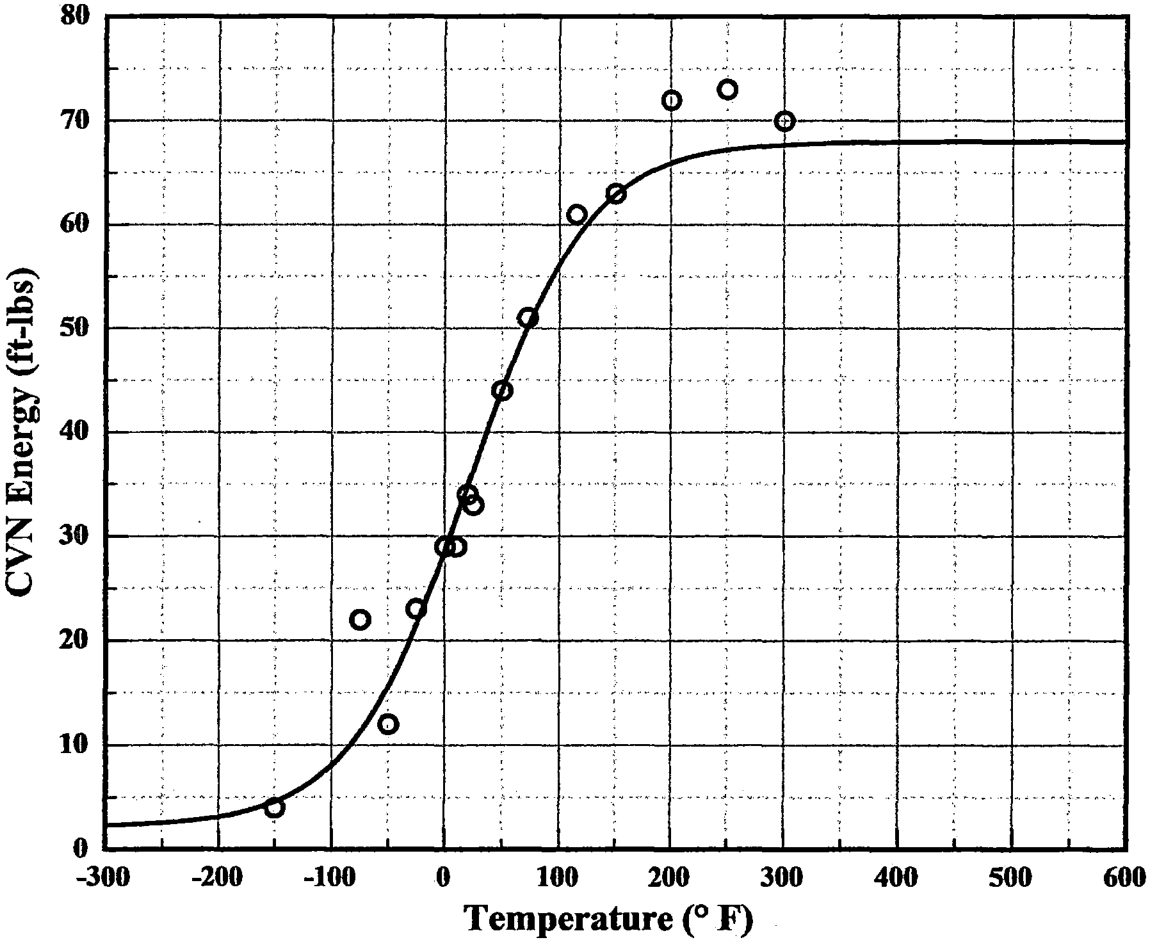
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 68.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= 4.50° F Temp@35 ft-lbs= 20.50° F Temp@50 ft-lbs= 71.80° F

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **W**



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Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: N/A Capsule: W

BRAIDWOOD UNIT 2 CAPSULE W (WELD)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-150	4.0	4.6	-0.61
-75	22.0	11.3	10.74
-50	12.0	15.7	-3.69
-25	23.0	21.5	1.46
0	29.0	28.6	0.35
10	29.0	31.7	-2.73
20	34.0	34.9	-0.87
25	33.0	36.4	-3.44
50	44.0	44.1	-0.09
72	51.0	50.1	0.93
115	61.0	58.7	2.28
150	63.0	62.9	0.10
200	72.0	65.9	6.05
250	73.0	67.2	5.80
300	70.0	67.7	2.31

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BRAIDWOOD UNIT 2 CAPSULE W (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:48 AM

A = 28.31 B = 27.31 C = 109.31 T0 = 38.29 D = 0.00

Correlation Coefficient = 0.983

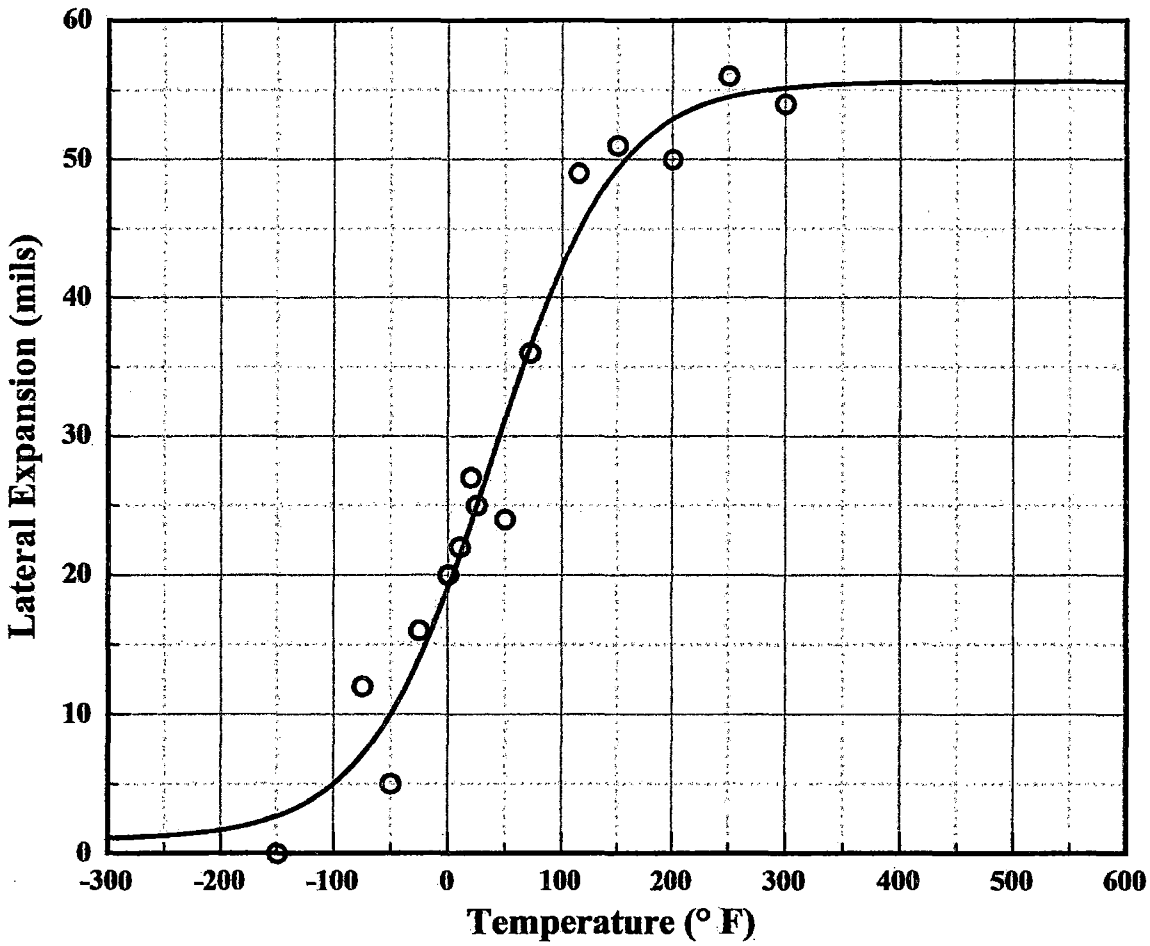
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 55.61 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 65.70° F

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **W**



CVGraph 6.02 10/19/2015 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: N/A Capsule: **W**

BRAIDWOOD UNIT 2 CAPSULE W (WELD)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-150	0.0	2.7	-2.69
-75	12.0	7.1	4.90
-50	5.0	10.1	-5.06
-25	16.0	14.1	1.95
0	20.0	19.1	0.89
10	22.0	21.4	0.61
20	27.0	23.8	3.22
25	25.0	25.0	0.00
50	24.0	31.2	-7.22
72	36.0	36.5	-0.47
115	49.0	44.8	4.16
150	51.0	49.3	1.65
200	50.0	52.9	-2.92
250	56.0	54.5	1.50
300	54.0	55.2	-1.16

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BRAIDWOOD UNIT 2 CAPSULE W (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:49 AM

A = 50.00 B = 50.00 C = 68.86 T0 = 30.80 D = 0.00

Correlation Coefficient = 0.997

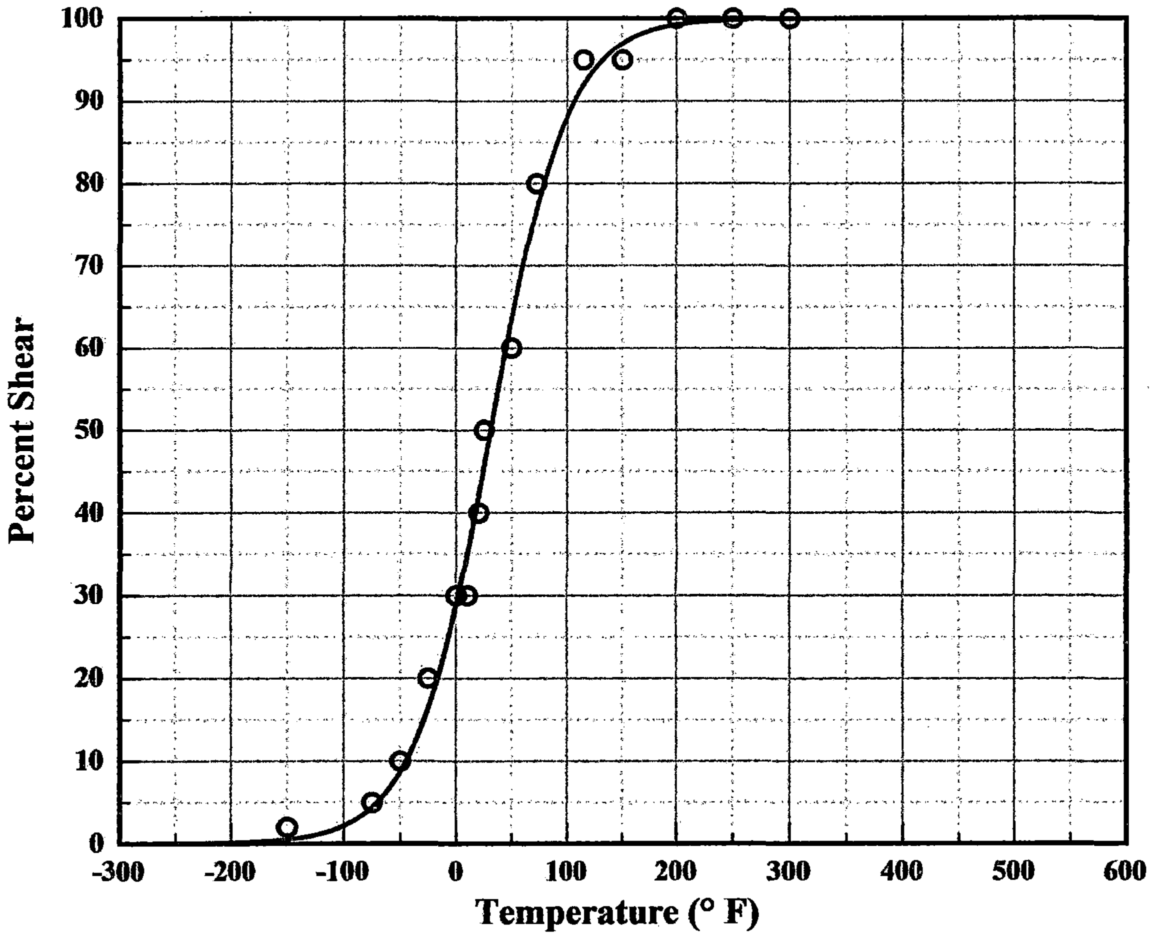
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 30.90

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **W**



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Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: N/A Capsule: W

BRAIDWOOD UNIT 2 CAPSULE W (WELD)
Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-150	2.0	0.5	1.48
-75	5.0	4.4	0.58
-50	10.0	8.7	1.27
-25	20.0	16.5	3.49
0	30.0	29.0	0.98
10	30.0	35.3	-5.34
20	40.0	42.2	-2.22
25	50.0	45.8	4.20
50	60.0	63.6	-3.59
72	80.0	76.8	3.20
115	95.0	92.0	2.97
150	95.0	97.0	-1.96
200	100.0	99.3	0.73
250	100.0	99.8	0.17
300	100.0	100.0	0.04

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BRAIDWOOD UNIT 2 CAPSULE W (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:50 AM

A = 79.60 B = 77.40 C = 139.22 T0 = -31.27 D = 0.00

Correlation Coefficient = 0.951

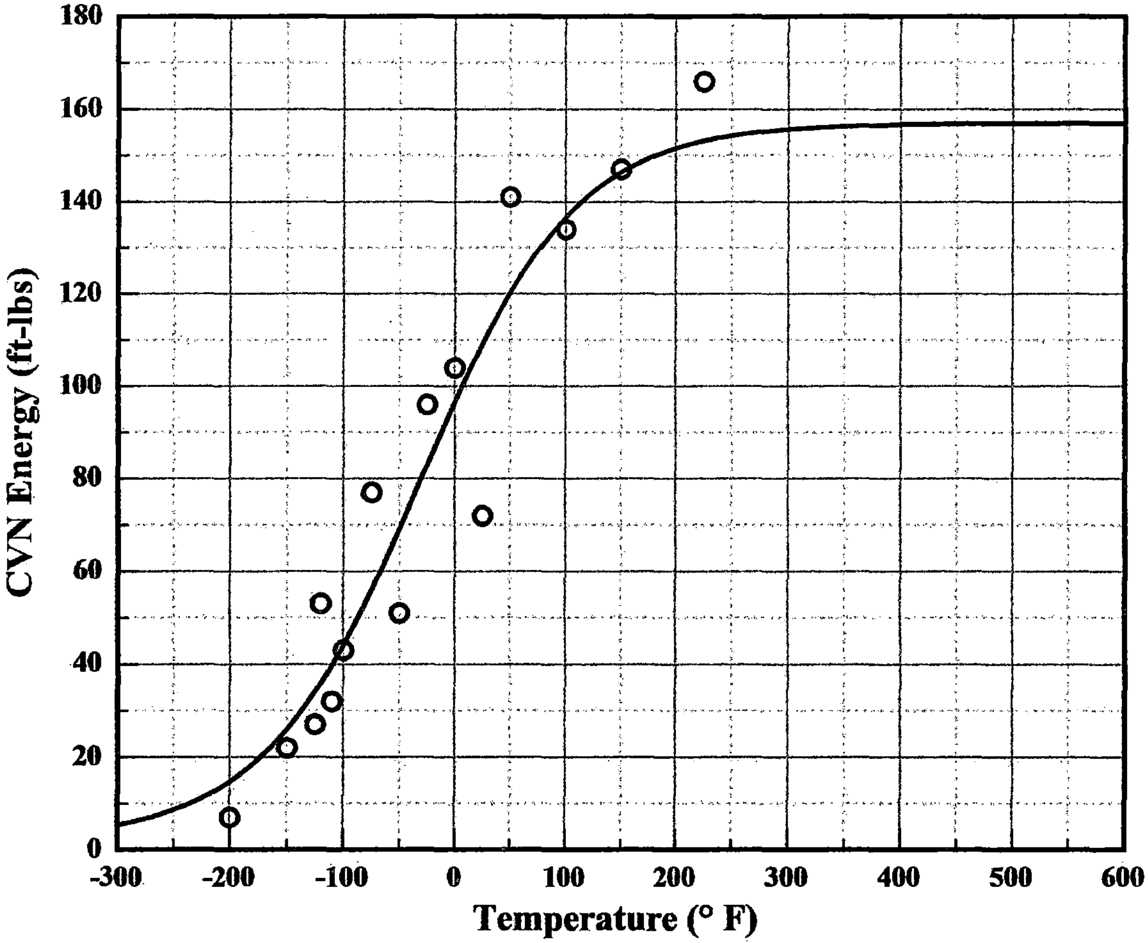
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 157.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs=-137.00° F Temp@35 ft-lbs=-122.70° F Temp@50 ft-lbs=-87.30° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **N/A** Capsule: **W**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **W**

BRAIDWOOD UNIT 2 CAPSULE W (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-200	7.0	14.8	-7.79
-150	22.0	26.0	-4.00
-125	27.0	34.2	-7.16
-120	53.0	36.0	16.98
-110	32.0	40.0	-7.97
-100	43.0	44.2	-1.22
-75	77.0	56.1	20.94
-50	51.0	69.2	-18.25
-25	96.0	83.1	12.92
0	104.0	96.7	7.30
25	72.0	109.3	-37.28
50	141.0	120.3	20.74
100	134.0	136.6	-2.61
150	147.0	146.3	0.66
225	166.0	153.2	12.80

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BRAIDWOOD UNIT 2 CAPSULE W (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:50 AM

A = 41.36 B = 40.36 C = 116.97 T0 = -31.31 D = 0.00

Correlation Coefficient = 0.951

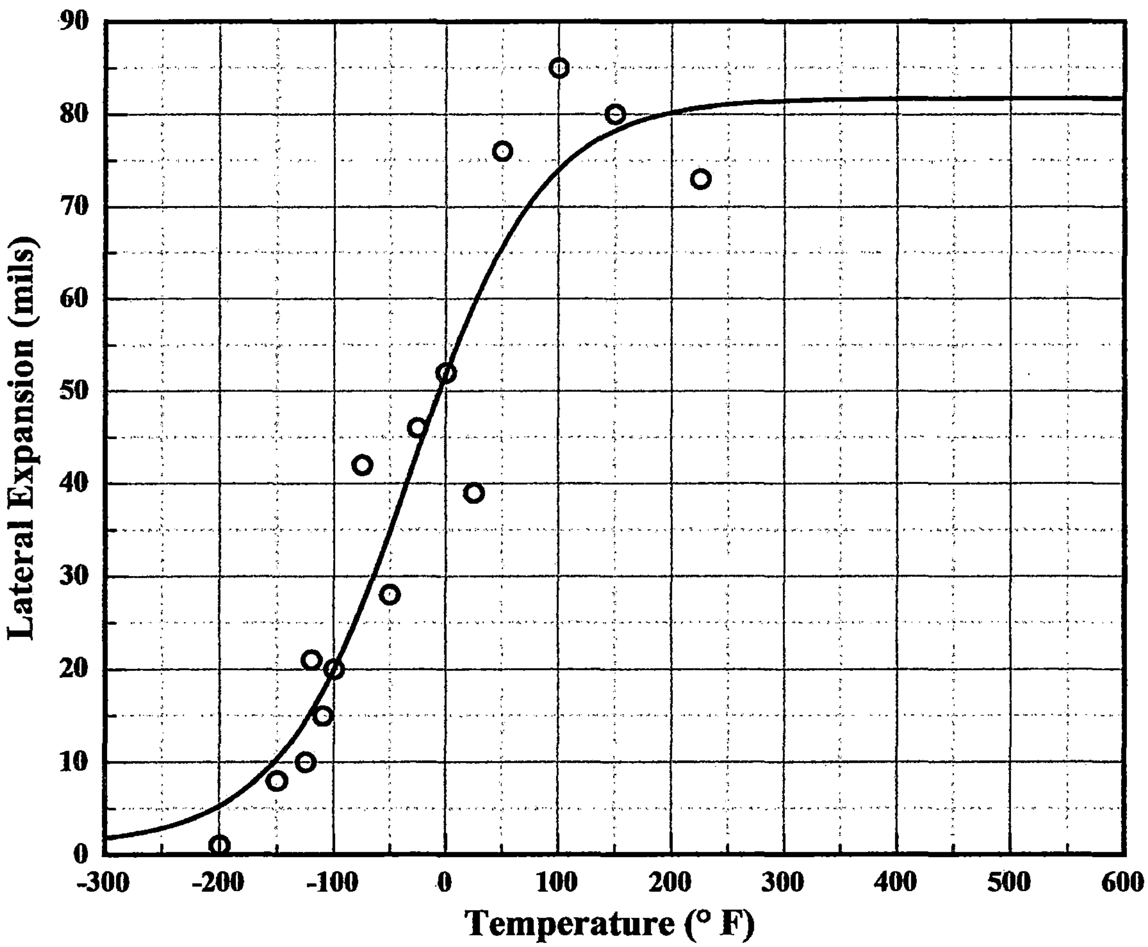
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 81.71   Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-49.80° F

Plant: **Braidwood 2**   Material: **SA508CL3**   Heat: **[50D102/50C97]-1-1**

Orientation: **N/A**   Capsule: **W**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: N/A Capsule: W

BRAIDWOOD UNIT 2 CAPSULE W (HEAT-AFFECTED ZONE)
Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-200	1.0	5.3	-4.27
-150	8.0	10.4	-2.38
-125	10.0	14.5	-4.54
-120	21.0	15.5	5.47
-110	15.0	17.7	-2.68
-100	20.0	20.1	-0.05
-75	42.0	26.9	15.05
-50	28.0	35.0	-6.96
-25	46.0	43.5	2.47
0	52.0	51.9	0.09
25	39.0	59.4	-20.41
50	76.0	65.6	10.38
100	85.0	74.0	11.02
150	80.0	78.2	1.77
225	73.0	80.7	-7.71

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BRAIDWOOD UNIT 2 CAPSULE W (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 10/19/2015 8:50 AM

A = 50.00 B = 50.00 C = 108.37 T0 = -20.64 D = 0.00

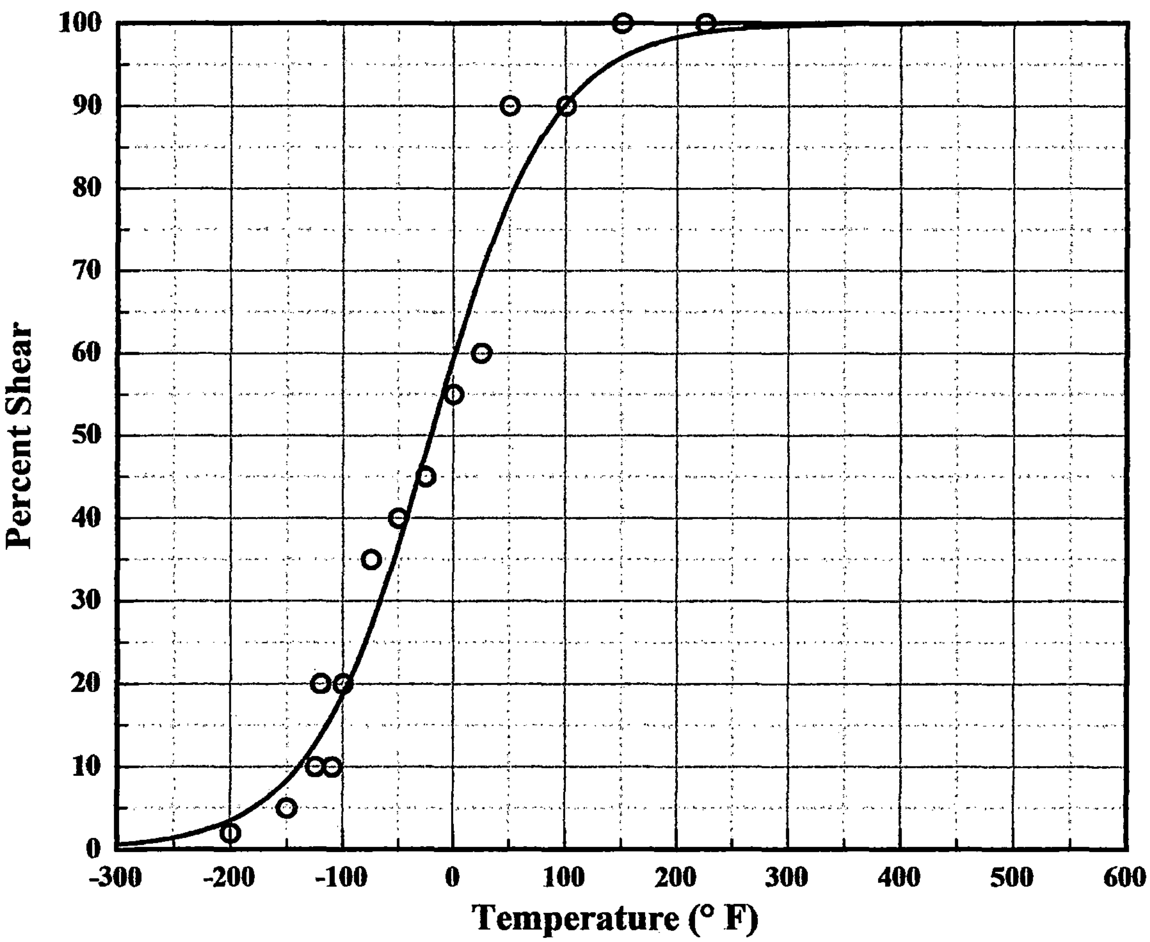
Correlation Coefficient = 0.987

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

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

Temperature at 50% Shear = -20.60

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **W**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: N/A Capsule: W

BRAIDWOOD UNIT 2 CAPSULE W (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-200	2.0	3.5	-1.52
-150	5.0	8.4	-3.41
-125	10.0	12.7	-2.72
-120	20.0	13.8	6.22
-110	10.0	16.1	-6.12
-100	20.0	18.8	1.22
-75	35.0	26.8	8.17
-50	40.0	36.8	3.22
-25	45.0	48.0	-2.99
0	55.0	59.4	-4.41
25	60.0	69.9	-9.90
50	90.0	78.6	11.35
100	90.0	90.3	-0.26
150	100.0	95.9	4.11
225	100.0	98.9	1.06

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BRAIDWOOD UNIT 2 CAPSULE V (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:20 PM

A = 84.10 B = 81.90 C = 79.20 T0 = 70.33 D = 0.00

Correlation Coefficient = 0.974

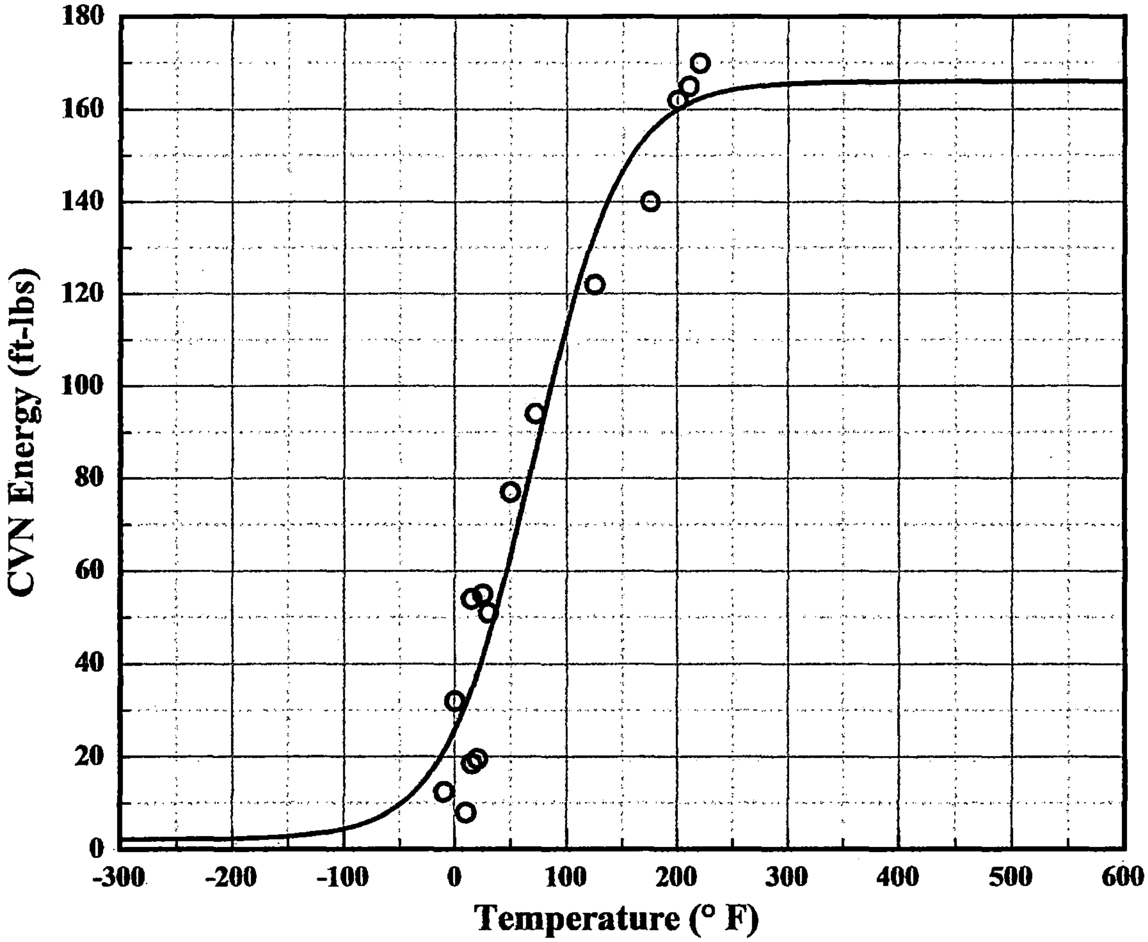
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 166.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= 7.50° F Temp@35 ft-lbs= 15.50° F Temp@50 ft-lbs= 35.30° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **V**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **V**

BRAIDWOOD UNIT 2 CAPSULE V (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-10	12.5	21.2	-8.74
0	32.0	25.9	6.08
10	8.0	31.5	-23.51
15	18.5	34.7	-16.18
15	54.0	34.7	19.32
20	19.5	38.1	-18.59
25	55.0	41.8	13.25
30	51.0	45.7	5.34
50	77.0	63.5	13.47
72	94.0	85.8	8.17
125	122.0	133.1	-11.09
175	140.0	155.1	-15.12
200	162.0	160.0	1.97
210	165.0	161.3	3.68
220	170.0	162.3	7.66

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BRAIDWOOD UNIT 2 CAPSULE V (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:20 PM

A = 43.31 B = 42.31 C = 50.82 T0 = 39.45 D = 0.00

Correlation Coefficient = 0.969

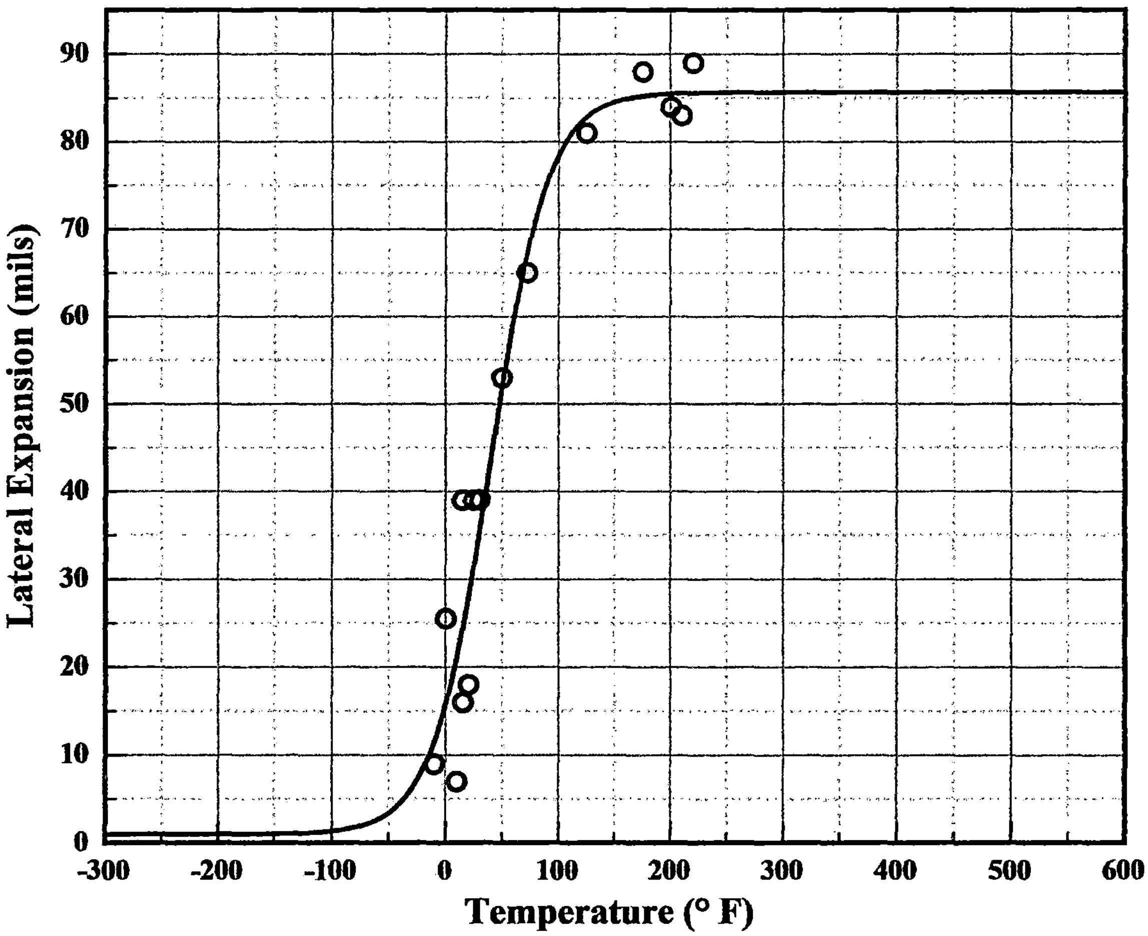
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 85.62 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 29.40° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **V**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **V**

BRAIDWOOD UNIT 2 CAPSULE V (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-10	9.0	11.6	-2.58
0	25.5	15.8	9.71
10	7.0	21.2	-14.21
15	16.0	24.4	-8.40
15	39.0	24.4	14.60
20	18.0	27.9	-9.87
25	39.0	31.6	7.40
30	39.0	35.5	3.46
50	53.0	52.0	1.02
72	65.0	67.2	-2.23
125	81.0	82.8	-1.80
175	88.0	85.2	2.78
200	84.0	85.5	-1.47
210	83.0	85.5	-2.52
220	89.0	85.6	3.44

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BRAIDWOOD UNIT 2 CAPSULE V (TANGENTIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:21 PM

A = 50.00 B = 50.00 C = 77.41 T0 = 75.99 D = 0.00

Correlation Coefficient = 0.994

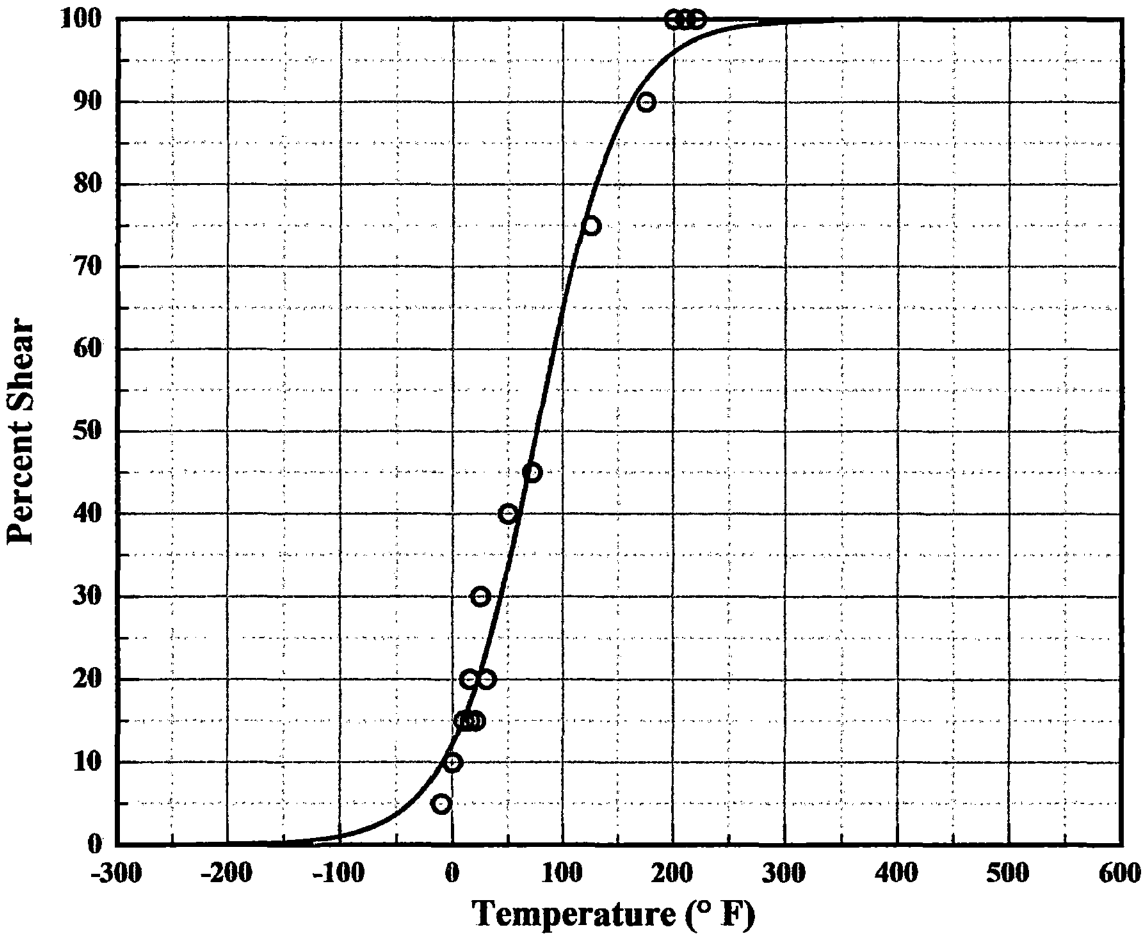
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 76.00

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Tangential** Capsule: **V**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Tangential** Capsule: **V**

BRAIDWOOD UNIT 2 CAPSULE V (TANGENTIAL)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-10	5.0	9.8	-4.78
0	10.0	12.3	-2.31
10	15.0	15.4	-0.38
15	15.0	17.1	-2.14
15	20.0	17.1	2.86
20	15.0	19.1	-4.05
25	30.0	21.1	8.88
30	20.0	23.4	-3.36
50	40.0	33.8	6.18
72	45.0	47.4	-2.43
125	75.0	78.0	-3.01
175	90.0	92.8	-2.81
200	100.0	96.1	3.90
210	100.0	97.0	3.04
220	100.0	97.6	2.36

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BRAIDWOOD UNIT 2 CAPSULE V (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:22 PM

A = 73.10 B = 70.90 C = 84.78 T0 = 99.62 D = 0.00

Correlation Coefficient = 0.969

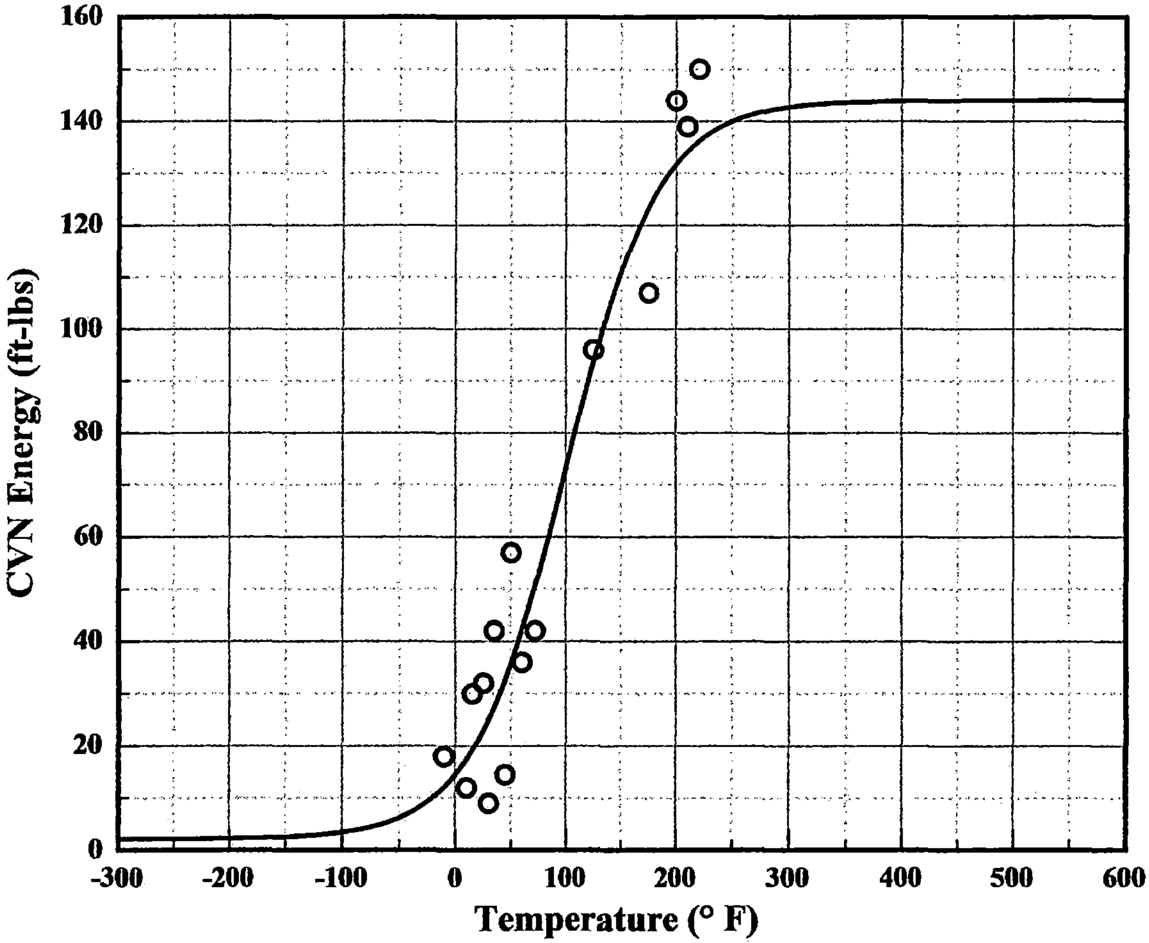
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 144.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= 39.90° F Temp@35 ft-lbs= 48.80° F Temp@50 ft-lbs= 71.00° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **V**



CVGraph 6.02 01/13/2016 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **V**

BRAIDWOOD UNIT 2 CAPSULE V (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-10	18.0	12.1	5.87
10	12.0	17.5	-5.48
15	30.0	19.2	10.84
25	32.0	23.0	8.99
30	9.0	25.2	-16.19
35	42.0	27.6	14.44
45	14.5	32.8	-18.35
50	57.0	35.8	21.23
60	36.0	42.2	-6.19
72	42.0	50.8	-8.79
125	96.0	93.7	2.29
175	107.0	123.5	-16.51
200	144.0	131.9	12.14
210	139.0	134.2	4.77
220	150.0	136.2	13.83

CVGraph 6.02 01/13/2016 Page 2/2

BRAIDWOOD UNIT 2 CAPSULE V (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:23 PM

A = 46.58 B = 45.58 C = 90.43 T0 = 89.48 D = 0.00

Correlation Coefficient = 0.970

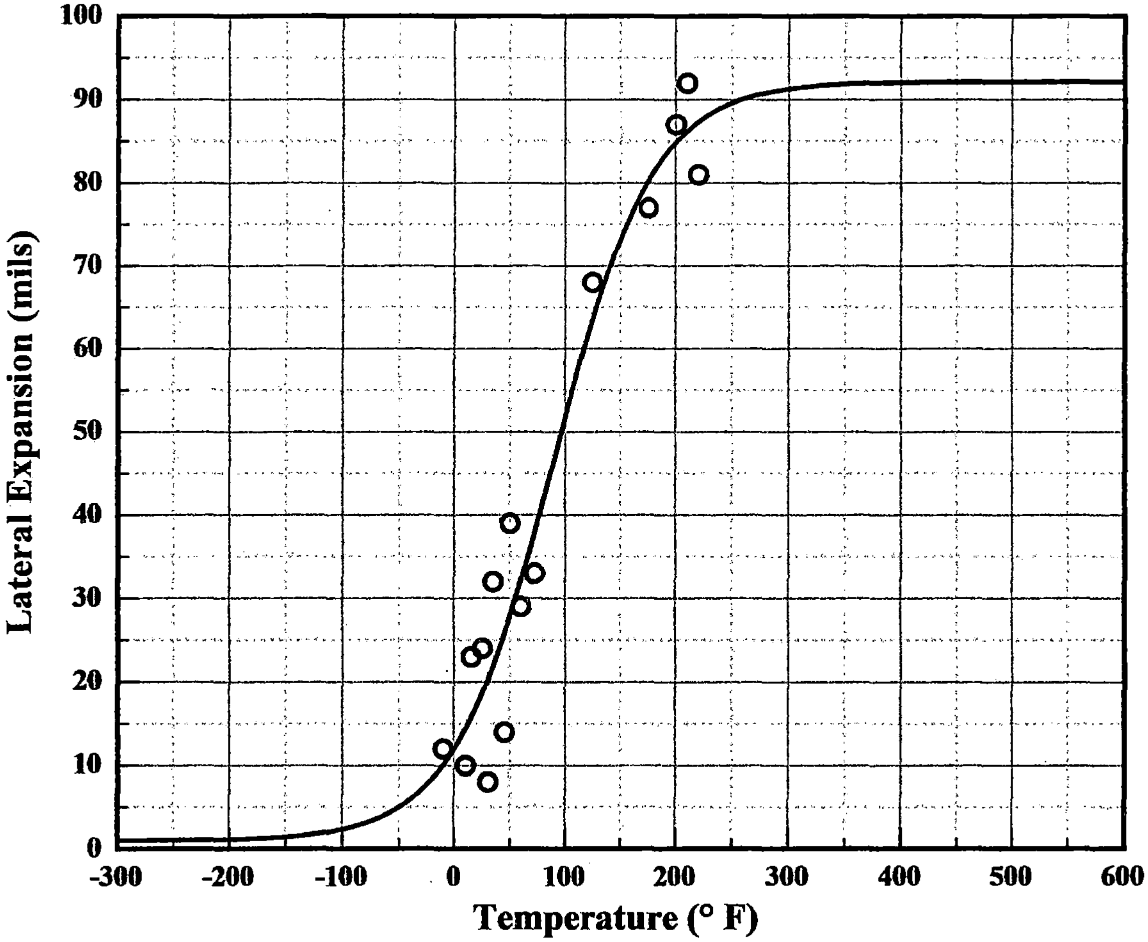
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 92.16 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 66.00° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **V**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **V**

BRAIDWOOD UNIT 2 CAPSULE V (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-10	12.0	10.1	1.91
10	10.0	14.4	-4.41
15	23.0	15.7	7.28
25	24.0	18.7	5.34
30	8.0	20.3	-12.29
35	32.0	22.0	9.98
45	14.0	25.8	-11.81
50	39.0	27.9	11.14
60	29.0	32.2	-3.23
72	33.0	37.9	-4.88
125	68.0	63.6	4.38
175	77.0	80.2	-3.21
200	87.0	84.9	2.12
210	92.0	86.2	5.77
220	81.0	87.3	-6.35

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BRAIDWOOD UNIT 2 CAPSULE V (AXIAL)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:23 PM

A = 50.00 B = 50.00 C = 83.06 T0 = 100.33 D = 0.00

Correlation Coefficient = 0.990

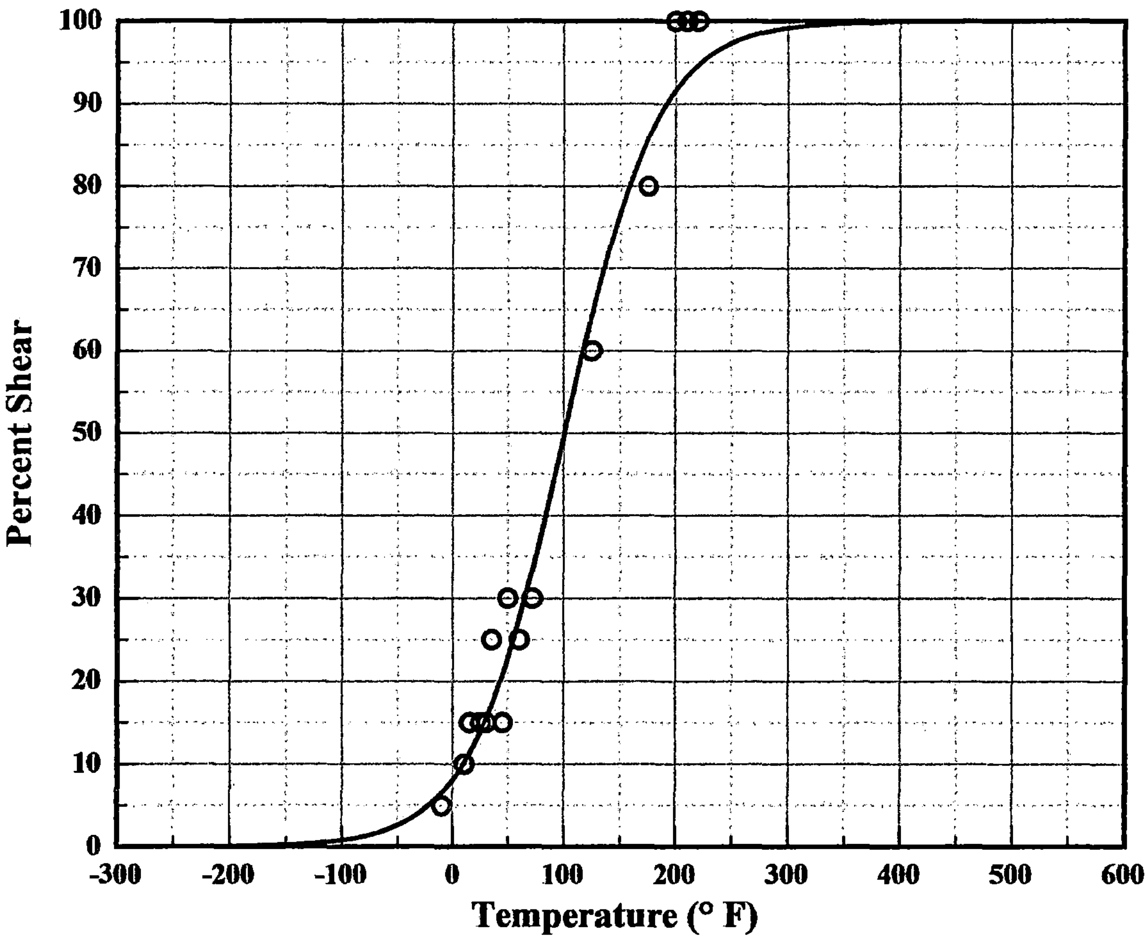
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 100.40

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **Axial** Capsule: **V**



CVGraph 6.02 01/13/2016 Page 1/2

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **Axial** Capsule: **V**

BRAIDWOOD UNIT 2 CAPSULE V (AXIAL)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-10	5.0	6.6	-1.56
10	10.0	10.2	-0.20
15	15.0	11.4	3.64
25	15.0	14.0	0.99
30	15.0	15.5	-0.53
35	25.0	17.2	7.82
45	15.0	20.9	-5.88
50	30.0	22.9	7.07
60	25.0	27.5	-2.46
72	30.0	33.6	-3.57
125	60.0	64.4	-4.43
175	80.0	85.8	-5.79
200	100.0	91.7	8.32
210	100.0	93.3	6.66
220	100.0	94.7	5.31

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BRAIDWOOD UNIT 2 CAPSULE V (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:24 PM

A = 33.10 B = 30.90 C = 85.64 T0 = 34.99 D = 0.00

Correlation Coefficient = 0.975

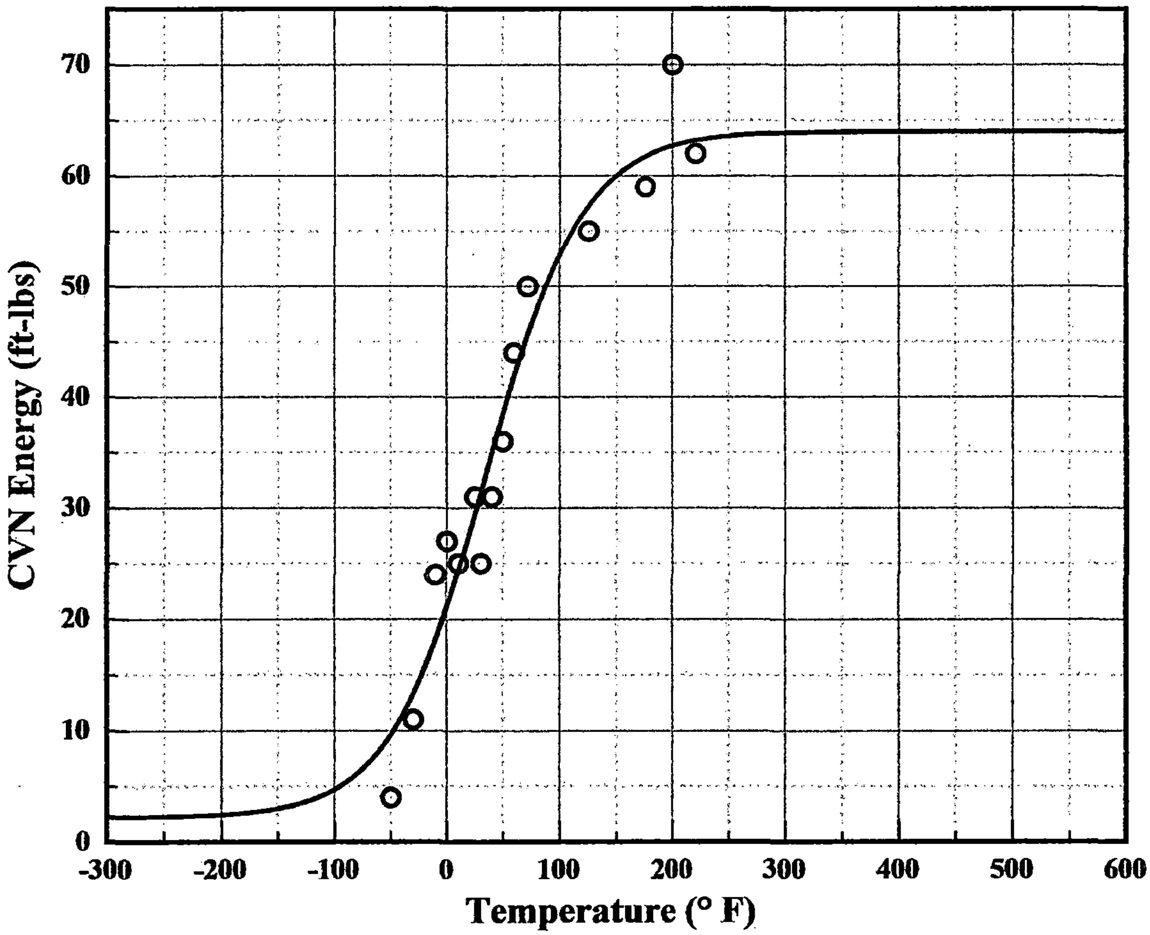
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf Energy = 64.00 (Fixed) Lower Shelf Energy = 2.20 (Fixed)

Temp@30 ft-lbs= 26.40° F Temp@35 ft-lbs= 40.30° F Temp@50 ft-lbs= 87.60° F

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **V**



CVGraph 6.02 01/13/2016 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: **N/A** Capsule: **V**

BRAIDWOOD UNIT 2 CAPSULE V (WELD)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-50	4.0	9.7	-5.67
-30	11.0	13.3	-2.31
-10	24.0	18.2	5.79
0	27.0	21.1	5.87
10	25.0	24.3	0.67
25	31.0	29.5	1.49
30	25.0	31.3	-6.30
40	31.0	34.9	-3.91
50	36.0	38.5	-2.46
60	44.0	41.9	2.12
72	50.0	45.7	4.32
125	55.0	57.3	-2.27
175	59.0	61.7	-2.74
200	70.0	62.7	7.28
220	62.0	63.2	-1.19

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BRAIDWOOD UNIT 2 CAPSULE V (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:25 PM

A = 28.78 B = 27.78 C = 88.25 T0 = 32.07 D = 0.00

Correlation Coefficient = 0.977

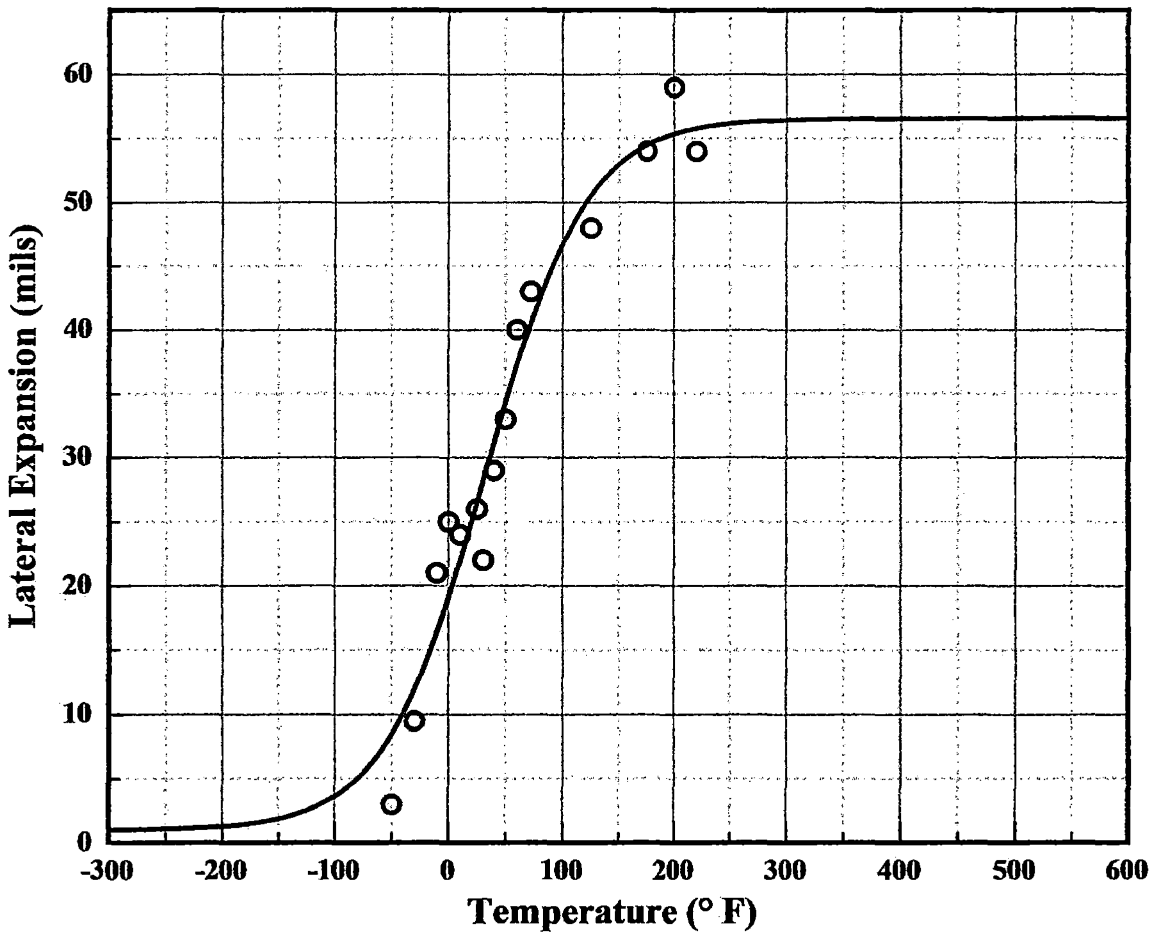
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 56.57 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils= 52.20° F

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **V**



CVGraph 6.02 01/13/2016 Page 1/2

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: N/A Capsule: V

BRAIDWOOD UNIT 2 CAPSULE V (WELD)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-50	3.0	8.5	-5.49
-30	9.5	11.9	-2.43
-10	21.0	16.5	4.54
0	25.0	19.1	5.89
10	24.0	22.0	2.02
25	26.0	26.6	-0.56
30	22.0	28.1	-6.13
40	29.0	31.3	-2.27
50	33.0	34.4	-1.35
60	40.0	37.3	2.70
72	43.0	40.6	2.44
125	48.0	50.5	-2.54
175	54.0	54.5	-0.47
200	59.0	55.4	3.64
220	54.0	55.8	-1.79

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BRAIDWOOD UNIT 2 CAPSULE V (WELD)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:25 PM

A = 50.00 B = 50.00 C = 91.11 T0 = 44.40 D = 0.00

Correlation Coefficient = 0.997

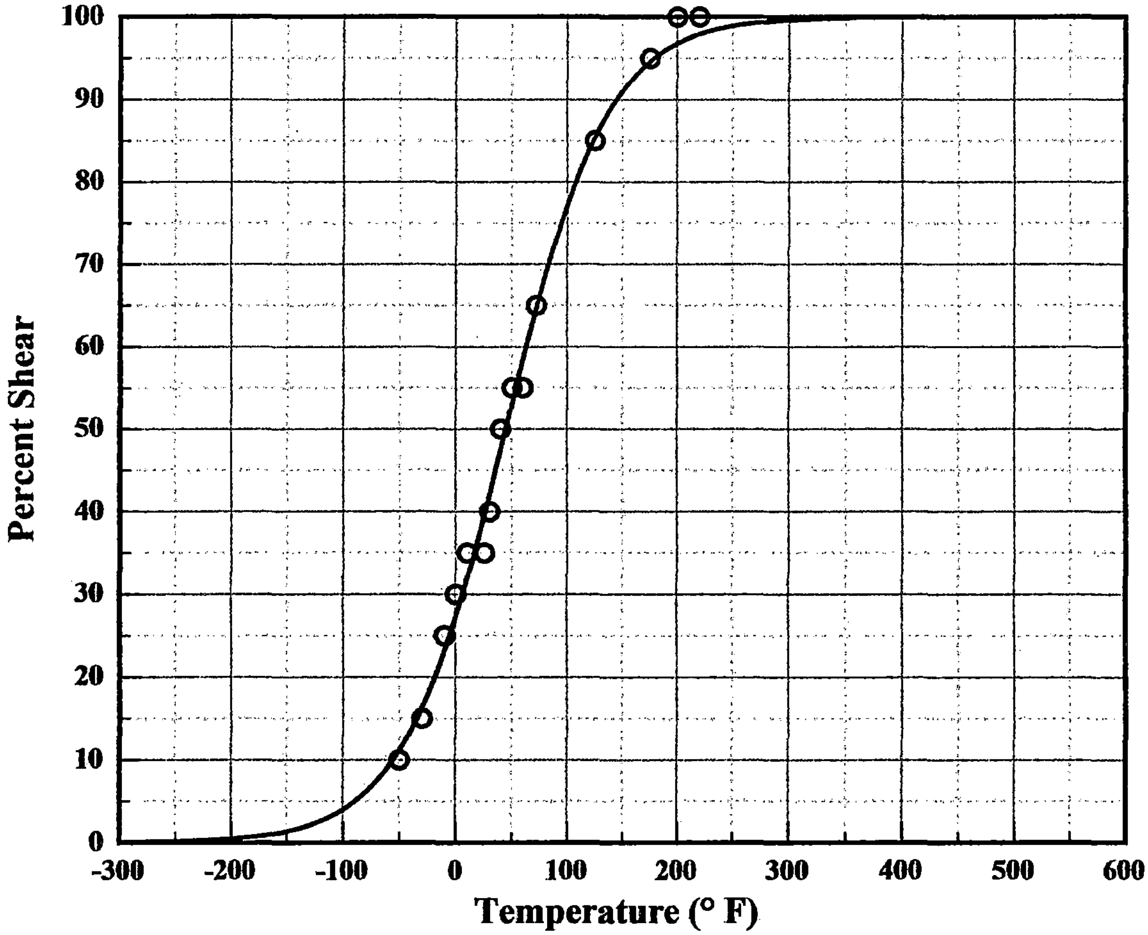
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temperature at 50% Shear = 44.50

Plant: **Braidwood 2** Material: **WELD** Heat: **442011**

Orientation: **N/A** Capsule: **V**



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Plant: **Braidwood 2** Material: **WELD** Heat: **442011**
Orientation: **N/A** Capsule: **V**

BRAIDWOOD UNIT 2 CAPSULE V (WELD)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-50	10.0	11.2	-1.18
-30	15.0	16.3	-1.34
-10	25.0	23.2	1.75
0	30.0	27.4	2.61
10	35.0	32.0	3.03
25	35.0	39.5	-4.51
30	40.0	42.2	-2.16
40	50.0	47.6	2.41
50	55.0	53.1	1.93
60	55.0	58.5	-3.48
72	65.0	64.7	0.30
125	85.0	85.4	-0.44
175	95.0	94.6	0.38
200	100.0	96.8	3.18
220	100.0	97.9	2.07

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BRAIDWOOD UNIT 2 CAPSULE V (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:29 PM

A = 78.10 B = 75.90 C = 124.86 T0 = -19.89 D = 0.00

Correlation Coefficient = 0.926

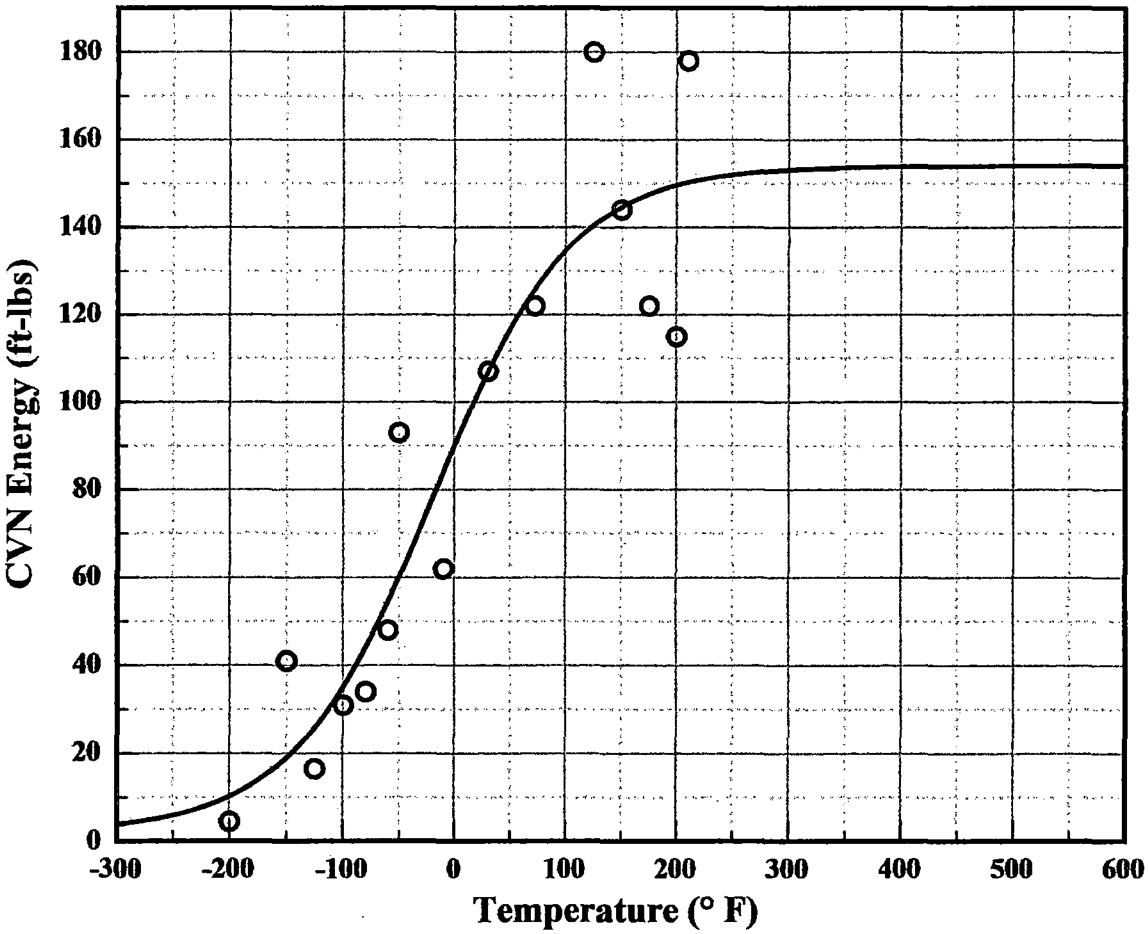
Equation is A + B * [Tanh((T-T0)/(C+DT))]

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

Temp@30 ft-lbs=-113.20° F Temp@35 ft-lbs=-100.30° F Temp@50 ft-lbs=-68.40° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **N/A** Capsule: **V**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **V**

BRAIDWOOD UNIT 2 CAPSULE V (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input CVN	Computed CVN	Differential
-200	4.5	10.2	-5.73
-150	41.0	19.0	22.00
-125	16.5	26.0	-9.47
-100	31.0	35.1	-4.14
-80	34.0	44.1	-10.14
-60	48.0	54.5	-6.52
-50	93.0	60.1	32.86
-10	62.0	84.1	-22.10
30	107.0	106.9	0.09
72	122.0	125.7	-3.66
125	180.0	140.4	39.57
150	144.0	144.6	-0.63
175	122.0	147.6	-25.59
200	115.0	149.6	-34.65
210	178.0	150.3	27.73

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BRAIDWOOD UNIT 2 CAPSULE V (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:29 PM

A = 39.80 B = 38.80 C = 116.58 T0 = -35.42 D = 0.00

Correlation Coefficient = 0.966

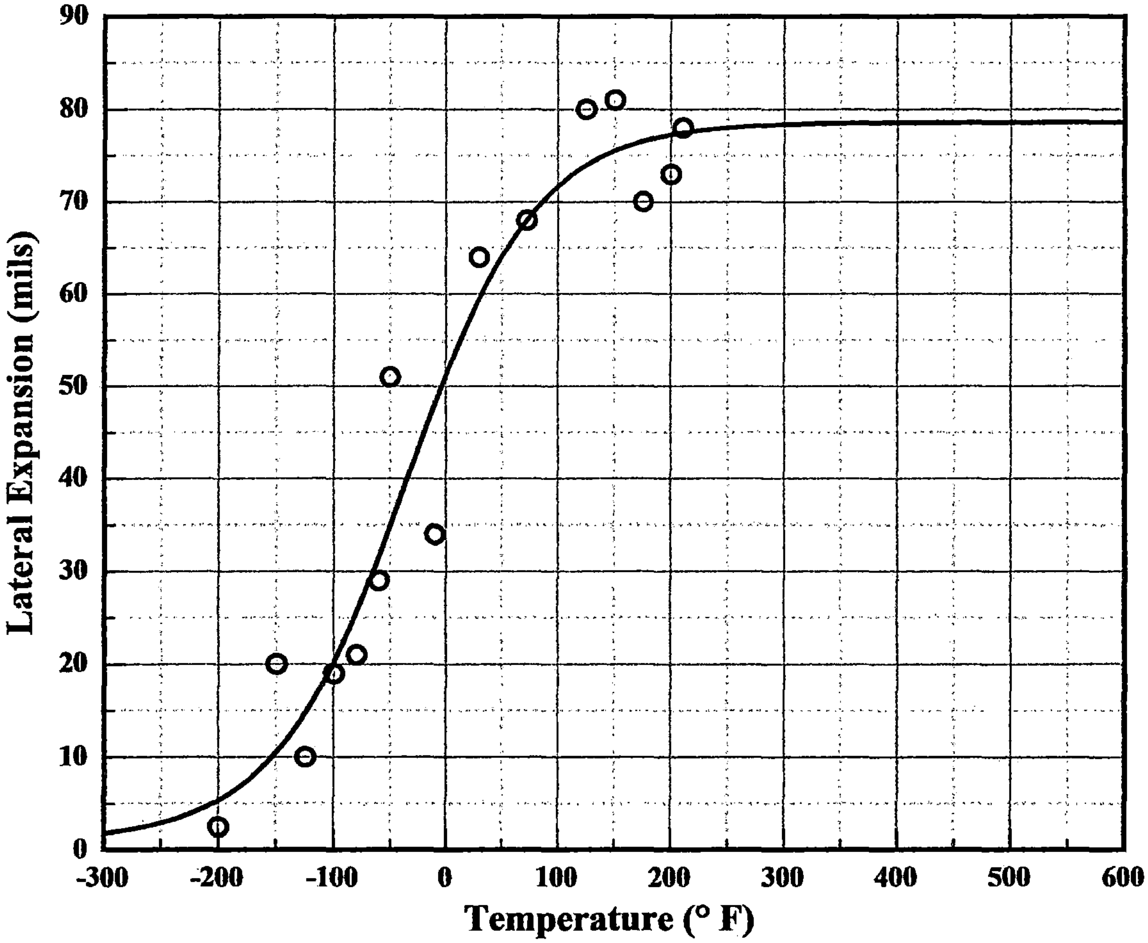
Equation is A + B * [Tanh((T-T0)/(C+DT))]

Upper Shelf L.E. = 78.60 Lower Shelf L.E. = 1.00 (Fixed)

Temp@35 mils=-49.90° F

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**

Orientation: **N/A** Capsule: **V**



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Plant: Braidwood 2 Material: SA508CL3 Heat: [50D102/50C97]-1-1
Orientation: N/A Capsule: V

BRAIDWOOD UNIT 2 CAPSULE V (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input L. E.	Computed L. E.	Differential
-200	2.5	5.4	-2.85
-150	20.0	10.5	9.47
-125	10.0	14.7	-4.74
-100	19.0	20.3	-1.27
-80	21.0	25.6	-4.65
-60	29.0	31.7	-2.74
-50	51.0	35.0	16.03
-10	34.0	48.1	-14.13
30	64.0	59.5	4.45
72	68.0	68.0	0.01
125	80.0	73.9	6.05
150	81.0	75.5	5.49
175	70.0	76.6	-6.56
200	73.0	77.3	-4.26
210	78.0	77.5	0.53

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BRAIDWOOD UNIT 2 CAPSULE V (HEAT-AFFECTED ZONE)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 1/13/2016 1:30 PM

A = 50.00 B = 50.00 C = 111.00 T0 = 1.19 D = 0.00

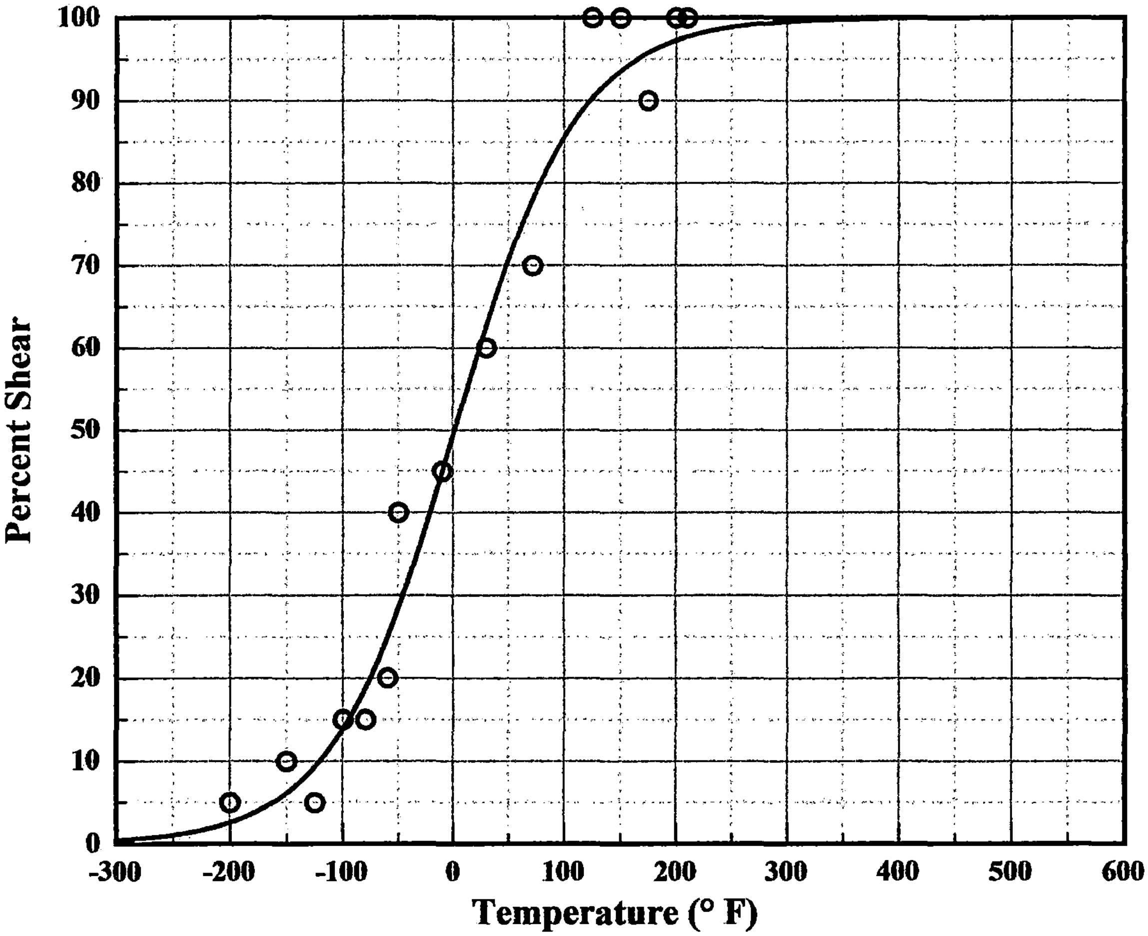
Correlation Coefficient = 0.989

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

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

Temperature at 50% Shear = 1.20

Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: **N/A** Capsule: **V**



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Plant: **Braidwood 2** Material: **SA508CL3** Heat: **[50D102/50C97]-1-1**
Orientation: N/A Capsule: **V**

BRAIDWOOD UNIT 2 CAPSULE V (HEAT-AFFECTED ZONE)

Charpy V-Notch Data

Temperature (° F)	Input %Shear	Computed %Shear	Differential
-200	5.0	2.6	2.40
-150	10.0	6.2	3.84
-125	5.0	9.3	-4.33
-100	15.0	13.9	1.09
-80	15.0	18.8	-3.80
-60	20.0	24.9	-4.93
-50	40.0	28.4	11.55
-10	45.0	45.0	0.02
30	60.0	62.7	-2.69
72	70.0	78.2	-8.17
125	100.0	90.3	9.70
150	100.0	93.6	6.41
175	90.0	95.8	-5.82
200	100.0	97.3	2.71
210	100.0	97.7	2.27

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APPENDIX D BRAIDWOOD UNIT 2 UPPER-SHELF ENERGY EVALUATION

D.1 EVALUATION

Per U.S. Regulatory Guide 1.99, Revision 2 [Ref. D-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 D-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 USE may be obtained by plotting the reduced plant surveillance data on Figure 2 of the Guide (Figure D-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 end-of-license extension (57 effective full-power years [EFPY]) USE of the vessel materials can be predicted using the corresponding quarter-thickness (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 [Ref. D-1].

The Braidwood Unit 2 reactor vessel beltline region thickness is 8.5 inches per Reference D-3. Calculation of the 1/4T vessel fluence values at 57 EFPY for the beltline and extended beltline materials is shown in Table D-1. The following pages present the Braidwood Unit 2 USE evaluation. Figure D-1, as indicated above, is used in making predictions in accordance with Regulatory Guide 1.99, Revision 2 [Ref. D-1]. Table D-2 provides the predicted USE values for 57 EFPY (end-of-license extension).

Table D-1 Braidwood Unit 2 Pressure Vessel 1/4T Fast Neutron Fluence Calculation

Material	57 EFPY Fluence (x 10^{19} n/cm^2, E > 1.0 MeV)	
	Surface	1/4T[(a)]
Beltline Materials		
Nozzle Shell Forging	1.00	0.600
Intermediate Shell Forging	2.92	1.75
Lower Shell Forging	2.89	1.74
Nozzle to Intermediate Shell Forging Circumferential (Circ.) Weld Seam	1.00	0.600
Intermediate to Lower Shell Forging Circ. Weld Seam	2.80	1.68
Extended Beltline Materials		
Inlet Nozzle Forgings	0.0110	Note (b)
Outlet Nozzle Forgings	0.00833	Note (b)
Inlet Nozzle to Nozzle Shell Forging Circ. Weld Seams	0.0110	Note (b)
Outlet Nozzle to Nozzle Shell Forging Circ. Weld Seams	0.00833	Note (b)

Notes:

(a) 1/4T fluence values were calculated from the surface fluence, the reactor vessel beltline thickness (8.5 inches) and equation $f = f_{surf} * e^{-0.24\,(x)}$ from Regulatory Guide 1.99, Revision 2, where x = the depth into the vessel wall (inches).

(b) Consistent with the time-limited aging analysis (TLAA) evaluation as documented in Reference D-3, the maximum fluence values for the extended beltline materials at 57 EFPY were less than the minimum fluence value displayed on Figure 2 of Regulatory Guide 1.99, Revision 2. The minimum fluence value (2 x 10^{17} n/cm^2) displayed on Figure 2 of Regulatory Guide 1.99, Revision 2 was conservatively used to determine the projected USE decrease; see Table D-2.

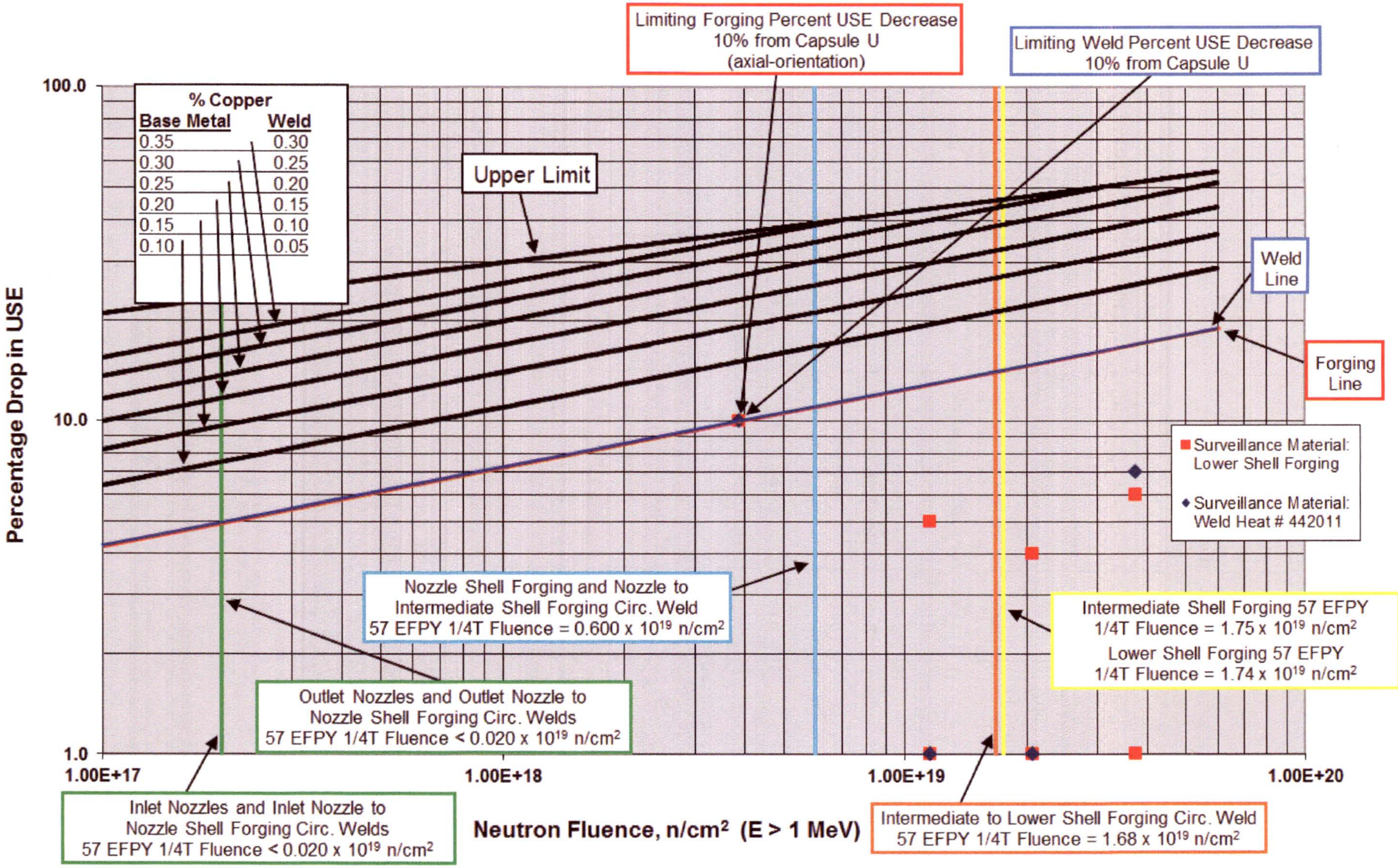

Figure D-1 **Regulatory Guide 1.99, Revision 2 Predicted Decrease in Upper-Shelf Energy as a Function of Copper and Fluence**

Table D-2 Predicted Positions 1.2 and 2.2 Upper-Shelf Energy Values at 57 EFPY

Material	Weight % Cu	1/4T EOLE Fluence (x 10^{19} n/cm^2, E > 1.0 MeV)	Unirradiated USE (ft-lb)	Projected USE Decrease (%)	Projected EOLE USE (ft-lb)
Position 1.2[(a)]					
Beltline Materials					
Nozzle Shell Forging	0.04	0.600	115	17.0	95
Intermediate Shell Forging	0.03	1.75	119	22.0	93
Lower Shell Forging	0.06	1.74	144	22.0	112
Nozzle to Intermediate Shell Forging Circ. Weld Seam WF-645 (Heat # H4498)	0.04	0.600	90	17.0	75
Intermediate to Lower Shell Forging Circ. Weld Seam WF-562 (Heat # 442011)	0.03	1.68	80	22.0	62
Extended Beltline Materials					
Inlet Nozzle 01-001	0.07	Note (c)	136	7.5	126
Inlet Nozzle 01-002	0.07	Note (c)	136	7.5	126
Inlet Nozzle 02-001	0.09	Note (c)	120	7.5	111
Inlet Nozzle 02-002	0.09	Note (c)	116	7.5	107
Outlet Nozzle 01-002	0.09	Note (c)	117	7.5	108
Outlet Nozzle 01-003	0.09	Note (c)	115	7.5	106
Outlet Nozzle 02-001	0.07	Note (c)	129	7.5	119
Outlet Nozzle 02-002	0.09	Note (c)	156	7.5	144
Inlet Nozzle to Nozzle Shell Forging Circ. Weld Seams WF-654 (Heat # 41404)	0.18	Note (c)	73	14.0	63
Outlet Nozzle to Nozzle Shell Forging Circ. Weld Seams WF-654 (Heat # 41404)	0.18	Note (c)	73	14.0	63
Position 2.2[(b)]					
Lower Shell Forging	0.06	1.74	144	14.5	123
Intermediate to Lower Shell Forging Circ. Weld Seam WF-562 (Heat # 442011)	0.03	1.68	80	14.0	69

Notes:

(a) Calculated using the Cu wt. % values and 1/4T fluence value for each material and Regulatory Guide 1.99, Revision 2, Position 1.2. In calculating Position 1.2 percent USE decreases, the base metal and weld Cu weight percentages were conservatively rounded up to the nearest line in Regulatory Guide 1.99, Revision 2, Figure 2.

(b) Calculated using surveillance capsule measured percent decrease in USE from Table 5-10 and Regulatory Guide 1.99, Revision 2, Position 2.2; see Figure D-1.

(c) The minimum fluence value (2 x 10^{17} n/cm^2) displayed on Figure 2 of Regulatory Guide 1.99, Revision 2 was conservatively used to determine the projected USE decrease.

USE Conclusion

As shown in Table D-2, all of the Braidwood Unit 2 reactor vessel beltline and extended beltline materials are projected to remain above the USE screening criterion of 50 ft-lbs (per 10 CFR 50, Appendix G [Ref. D-2]) at 57 EFPY.

D.2 REFERENCES

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

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

D-3 Westinghouse Report WCAP-17607-NP, Revision 0, *Braidwood Station Units 1 and 2 Reactor Vessel Integrity Evaluation to Support License Renewal Time-Limited Aging Analysis*, December 2012.