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Analysis of Capsule W from the Comanche Peak Unit No. 2 Reactor Vessel Radiation Surveillance Program

Westinghouse

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September 2010

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EXECUTIVE SUMMARY

The purpose of this report is to document the testing results of surveillance Capsule W from Comanche Peak Unit 2. Capsule W was removed at 14.51 EFPY and post-irradiation mechanical tests of the Charpy V-notch and tensile specimens were performed. A fluence evaluation utilizing the neutron transport and dosimetry cross-section libraries was derived from the ENDF/B-VI database. Capsule W received a fluence of 3.38 x 10^{19} n/cm^2 (E > 1.0 MeV) after irradiation to 14.51 EFPY. The peak clad/base metal interface vessel fluence after 14.51 EFPY of plant operation was 8.76 x 10^{18} n/cm^2 (E > 1.0 MeV).

This evaluation led to the following conclusions: 1) The measured percent decrease in upper shelf energy for all the surveillance materials contained in Comanche Peak Unit 2 Capsule W are less than the Regulatory Guide 1.99, Revision 2 [Ref. 1] predictions. 2) The Comanche Peak Unit 2 surveillance plate data is judged to be not credible; however, the weld data is judged to be credible. This credibility evaluation can be found in Appendix D. 3) All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are predicted to maintain an upper shelf energy greater than 50 ft-lb throughout the current license (36 EFPY) and a potential license renewal (54 EFPY) as required by 10 CFR 50, Appendix G [Ref. 2]. The upper shelf energy evaluation is presented in Appendix E.

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

Upon completion of the Comanche Peak Unit 2 Capsule W testing, one of the thermocouples used to monitor the temperature of the Charpy impact specimens in the thermal soak bath was found to have slightly drifted outside of the calibration range. With the exception of 1 data point, the largest adjustment that could be applied to any test temperature is ≤0.8°F (Heat Affected Zone (HAZ) Charpy impact specimen CH31, tested at -175°F, potentially fell outside the tolerance range by no more than 2°F).

Even though the Charpy impact specimen test data are input to the curves and evaluations documented in this report, it has been determined based on engineering judgment that this issue does not significantly impact the results contained within this report. The margin term applied to calculations of reference temperature shifts compensates for such small variances in Charpy testing.

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance Capsule W, the third capsule removed and tested from the Comanche Peak Unit 2 reactor pressure vessel, led to the following conclusions:

- Charpy V-notch test data were plotted using a symmetric hyperbolic tangent curve-fitting program. Appendix C presents the CVGRAPH, Version 5.3, Charpy V-notch plots for Capsule W and previous capsules, along with the program input data.

- Capsule W received an average fast neutron fluence (E > 1.0 MeV) of 3.38 $x10^{19}$ n/cm^2 after 14.51 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel Intermediate Shell Plate R3807-2 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (longitudinal orientation), resulted in an irradiated 30 ft-lb transition temperature of 13.8°F and an irradiated 50 ft-lb transition temperature of 61.4°F. This results in a 30 ft-lb transition temperature increase of 23.2°F and a 50 ft-lb transition temperature increase of 33.0°F for the longitudinally oriented specimens.

- Irradiation of the reactor vessel Intermediate Shell Plate R3807-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), resulted in an irradiated 30 ft-lb transition temperature of 62.3°F and an irradiated 50 ft-lb transition temperature of 123.9°F. This results in a 30 ft-lb transition temperature increase of 74.4°F and a 50 ft-lb transition temperature increase of 81.8°F for the transversely oriented specimens.

- Irradiation of the Surveillance Program Weld Metal (Heat # 89833) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 34.4°F and an irradiated 50 ft-lb transition temperature of 50.9°F. This results in a 30 ft-lb transition temperature increase of 84.0°F and a 50 ft-lb transition temperature increase of 51.3°F.

- Irradiation of the Heat-Affected-Zone (HAZ) Material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -80.3°F and an irradiated 50 ft-lb transition temperature of -56.6°F. This results in a 30 ft-lb transition temperature increase of 29.2°F and a 50 ft-lb transition temperature increase of 18.8°F.

- The average upper shelf energy of Intermediate Shell Plate R3807-2 (longitudinal orientation) resulted in an average energy increase of 3.4 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 118.4 ft-lb for the longitudinally oriented specimens.

- The average upper shelf energy of Intermediate Shell Plate R3807-2 (transverse orientation) did not change after irradiation. This results in an irradiated average upper shelf energy of 84.0 ft-lb for the transversely oriented specimens.

- The average upper shelf energy of the Surveillance Program Weld Metal Charpy specimens resulted in an average energy decrease of 10.5 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 83.5 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 5 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 111.0 ft-lb for the HAZ Material.

- A comparison of the measured 30 ft-lb shift in transition temperature values for the Comanche Peak Unit 2 reactor vessel surveillance materials is presented in Table 5-10.

- Based on the credibility evaluation presented in Appendix D, the Comanche Peak Unit 2 surveillance plate data is not credible but the surveillance weld data is credible.

- Based on the upper shelf energy evaluation in Appendix E, all beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are predicted to maintain an upper shelf energy greater than 50 ft-lb throughout the end of the current license (36 EFPY) and a potential license renewal (54 EFPY) as required by 10 CFR 50, Appendix G [Ref. 2].

2 INTRODUCTION

This report presents the results of the examination of Capsule W, the third capsule removed and tested in the continuing surveillance program, which monitors the effects of neutron irradiation on the Luminant Comanche Peak Unit 2 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Comanche Peak Unit 2 reactor pressure vessel materials was designed and recommended by the Westinghouse Electric Corporation. A description of the surveillance program and the pre-irradiation mechanical properties of the reactor vessel materials are presented in WCAP-10684 [Ref. 3], "Texas Utilities Generating Company Comanche Peak Unit No. 2 Reactor Vessel Radiation Surveillance Program." The surveillance program was 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 W was removed from the reactor after 14.51 EFPY of exposure and shipped to the Westinghouse Science and Technology Department Hot Cell Facility, where the post-irradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

This report summarizes the testing of the post-irradiation data obtained from surveillance Capsule W removed from the Comanche Peak Unit 2 reactor vessel and discusses the analysis of the data.

3 BACKGROUND

The ability of the large steel pressure vessel containing the reactor core and its primary coolant to resist fracture constitutes an important factor in ensuring safety in the nuclear industry. The beltline region of the reactor pressure vessel is the most critical region of the vessel because it is subjected to significant fast neutron bombardment. The overall effects of fast neutron irradiation on the mechanical properties of low-alloy, ferritic pressure vessel steels such as SA533 Grade B Class 1 (base material of the Comanche Peak 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 [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 (transverse) to the major working direction of the plate. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ic} curve) which appears in Appendix G to Section XI of the ASME Code [Ref. 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 Comanche Peak 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 Comanche Peak 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 between the neutron pads and the vessel wall as shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core. The capsules contain specimens made from the following:

- Intermediate Shell Plate R3807-2 (longitudinal orientation)
- Intermediate Shell Plate R3807-2 (transverse orientation)
- Weld metal fabricated with 3/16-inch Mil B-4 weld filler wire, Heat Number 89833 Linde Type 124 flux, Lot Number 1061, which is identical to that used in the actual fabrication of the intermediate to lower shell circumferential weld seam
- Weld heat-affected-zone (HAZ) material of Intermediate Shell Plate R3807-2

Test material obtained from the intermediate shell course plate (after thermal heat treatment and forming of the plate) was taken at least one plate thickness from the quenched edges of the plate. All test specimens were machined from the ¼ and ¾ thickness locations of the plate after performing a simulated post-weld stress-relieving treatment on the test material. Test specimens were also removed from weld and heat-affected-zone metal of a stress-relieved weldment joining Intermediate Shell Plate R3807-2 and adjacent Lower Shell Plate R3816-2. All heat-affected-zone specimens were obtained from the weld heat-affected-zone of Intermediate Shell Plate R3807-2.

Charpy V-notch impact specimens from Intermediate Shell Plate R3807-2 were machined in the longitudinal orientation (longitudinal axis of the specimen parallel to the major rolling direction) and also in the transverse orientation (longitudinal axis of the specimen perpendicular to the major rolling direction). The core-region weld Charpy impact specimens were machined from the weldment such that the long dimension of each Charpy specimen was perpendicular (normal) to the weld direction. The notch of the weld metal Charpy specimens was machined such that the direction of crack propagation in the specimen was in the welding direction.

Tensile specimens from Intermediate Shell Plate R3807-2 were machined in both the longitudinal and transverse orientations. Tensile specimens from the weld metal were oriented perpendicular to the welding direction.

Compact Test (CT) specimens from Intermediate Shell Plate R3807-2 were machined in the longitudinal and transverse orientations. CT specimens from the weld metal were machined with the notch oriented in the direction of welding. All specimens were fatigue pre-cracked according to ASTM E399 [Ref. 7].

All six capsules contained 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 contained thermal monitors made from two low-melting-point eutectic alloys, which were sealed in Pyrex tubes. These thermal monitors were used to define the maximum temperature attained by the test specimens during irradiation. The composition of the two eutectic alloys and their melting points are as follows:

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

The chemical composition and heat treatment of the unirradiated surveillance materials are presented in Tables 4-1 through 4-4. The data in Tables 4-1 through 4-4 was obtained from the unirradiated surveillance program report, WCAP-10684 [Ref. 3], Appendix A.

Capsule W was removed after 14.51 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch, tensile, 1/2T-CT fracture mechanics specimens, dosimeters, and thermal monitors.

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

Table 4-1 Chemical Composition (wt%) of the Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plates (Unirradiated)[(a)]

Element	Intermediate Shell Plate R3807-1	Intermediate Shell Plate R3807-2 [(b)]		Intermediate Shell Plate R3807-3
	Combustion Engineering Analysis	Combustion Engineering Analysis	Westinghouse Analysis	Combustion Engineering Analysis
C	0.210	0.220	0.220	0.220
Mn	1.420	1.400	1.360	1.300
P	0.006	0.007	0.014	0.007
S	0.015	0.016	0.014	0.009
Si	0.250	0.240	0.250	0.190
Ni	0.640	0.640	0.620	0.600
Mo	0.600	0.590	0.580	0.580
Cr	0.050	0.040	0.056	0.060
Cu	0.060	0.060	0.065	0.050
Al	0.020	0.025	0.018	0.023
Co	0.012	0.013	0.014	0.009
Pb	<0.001	<0.001	0.002	<0.001
W	<0.01	<0.01	<0.01	<0.01
Ti	<0.01	<0.01	0.004	<0.01
Zr	<0.001	<0.001	<0.002	<0.001
V	0.002	0.003	<0.002	0.002
Sn	0.003	0.004	0.002	0.003
As	0.004	0.005	0.004	0.005
Cb	<0.01	<0.01	<0.002	<0.01
N_2	0.009	0.010	0.008	0.007
B	<0.001	<0.001	<0.001	<0.001

Notes:

(a) Data obtained from WCAP-10684, Rev. 0 [Ref. 3].
(b) Surveillance program test plate.

Table 4-2 Chemical Composition (wt%) of the Comanche Peak Unit 2 Reactor Vessel Lower Shell Plates (Unirradiated)[(a)]

Element	Lower Shell Plate R3816-1	Lower Shell Plate R3816-2	Lower Shell Plate R3816-3
	Combustion Engineering Analysis		
C	0.230	0.230	0.220
Mn	1.480	1.480	1.500
P	0.001	0.002	0.008
S	0.004	0.012	0.008
Si	0.190	0.210	0.190
Ni	0.590	0.650	0.630
Mo	0.490	0.500	0.520
Cr	0.030	0.030	0.040
Cu	0.050	0.030	0.040
Al	0.026	0.026	0.018
Co	0.020	0.012	0.012
Pb	<0.001	<0.001	<0.001
W	<0.01	<0.01	<0.01
Ti	<0.01	<0.01	<0.01
Zr	<0.001	<0.001	<0.001
V	0.003	0.003	0.003
Sn	0.001	0.001	0.002
As	0.009	0.011	0.015
Cb	<0.01	<0.01	<0.01
N_2	0.028	0.014	0.014
B	<0.001	<0.001	<0.001

Note:
(a) Data obtained from WCAP-10684, Rev. 0 [Ref. 3].

Table 4-3 Chemical Composition (wt%) of the Comanche Peak Unit 2 Reactor Vessel Weld Materials (Unirradiated)[(a)]

Element	Intermediate and Lower Shell Longitudinal Weld Seams		Closing Circumferential Weld Seam	Surveillance Weldment (Identical to the Closing Circumferential Weld Seam)
	Wire Flux Test Weld Sample	Sample Production Weld Seam No. 101-142A[(b)]	Wire Flux Test Weld Sample	
	Combustion Engineering Analysis	Combustion Engineering Analysis	Combustion Engineering Analysis	Westinghouse Analysis
C	0.160	0.160	0.088	0.110
Mn	1.320	1.240	1.330	1.370
P	0.005	0.004	0.004	0.011
S	0.011	0.009	0.010	0.014
Si	0.160	0.190	0.510	0.490
Ni	0.050	0.080	0.030	0.072
Mo	0.540	0.590	0.540	0.590
Cr	0.020	0.020	0.030	0.058
Cu	0.700	0.050	0.050	0.030
Al	-	0.004	-	0.006
Co	-	0.011	-	0.008
Pb	-	<0.001	-	0.001
W	-	0.010	-	<0.01
Ti	-	<0.01	-	0.002
Zr	-	0.001	-	<0.002
V	0.004	0.005	0.003	<0.002
Sn	-	0.003	-	0.003
As	-	0.021	-	0.018
Cb	-	<0.01	-	<0.002
N_2	-	0.007	-	0.008
B	-	0.001	-	0.001

Notes:

(a) Data obtained from WCAP-10684, Rev. 0 [Ref. 3].

(b) Actual beltline production weld chemistry (Lower Shell Plate Seam No. 101-142A).

Table 4-4 Heat Treatment History of the Comanche Peak Unit 2 Reactor Vessel Surveillance Materials[a]

Material	Temperature (°F)	Time (hours)	Cooling
Intermediate Shell Plates R3807-1, R3807-2, and R3807-3	Austenitized @ 1600 ± 25 (871°C)	4.00	Water-Quenched
	Tempered @ 1225 ± 25 (663°C)	4.00	Air-Cooled
	Stress Relieved @ 1150 ± 50 (621°C)	19.25[b]	Furnace-Cooled
Lower Shell Plates R3816-1, R3816-2, and R3816-3	Austenitized @ 1600 ± 25 (871°C)	4.00	Water-Quenched
	Tempered @ 1225 ± 25 (663°C)	4.00	Air-Cooled
	Stress Relieved @ 1150 ± 50 (621°C)	14.5[b]	Furnace-Cooled
Intermediate Shell Longitudinal Weld Seams	Stress Relieved @ 1150 ± 50 (621°C)	19.25[b]	Furnace-Cooled
Lower Shell Longitudinal Weld Seams	Stress Relieved @ 1150 ± 50 (621°C)	14.5[b]	Furnace-Cooled
Intermediate to Lower Shell Circ. Weld Seam	Local Stress Relieved @ 1150 ± 50 (621°C)	8.00	Furnace-Cooled
Surveillance Program Test Material			
Surveillance Program Test Plate "D" (Representative of Closing Circ. Weld Seam)	Post Weld Stress Relieved @ 1150 ± 50 (621°C)	8.5[c]	Furnace-Cooled

Notes:

(a) Data obtained from WCAP-10684, Rev. 0 [Ref. 3].
(b) Stress Relief includes the intermediate to lower shell closing circ. seam post weld heat treatment.
(c) The stress relief heat treatment received by the surveillance test weldment has been simulated.

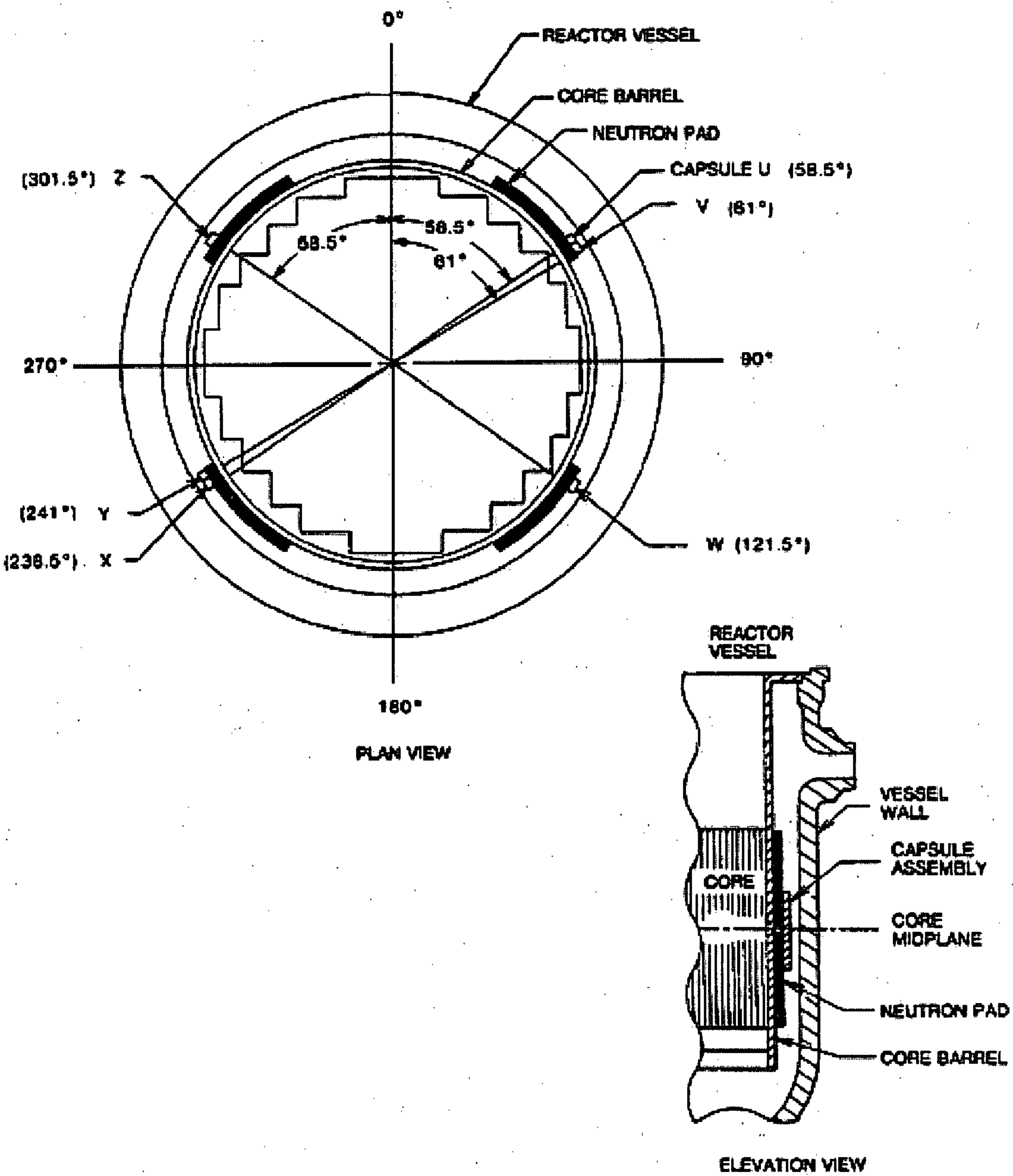


Figure 4-1 **Arrangement of Surveillance Capsules in the Comanche Peak Unit 2 Reactor Vessel**

LEGEND:
CL – INTERMEDIATE SHELL PLATE R3807-2 (LONGITUDINAL)
CT – INTERMEDIATE SHELL PLATE R3807-2 (TRANSVERSE)
CW – WELD METAL (HEAT # 89833)
CH – HEAT AFFECTED ZONE MATERIAL

Large Spacer	Tensiles	Compacts		Compacts		Charpys		Charpys		Charpys	
TXC W	CW9	CW12	CW11	CW10	CW9	CW45	CH45	CW42	CH42	CW39	CH39
	CW8					CW44	CH44	CW41	CH41	CW38	CH38
	CW7					CW43	CH43	CW40	CH40	CW37	CH37

TOP OF VESSEL ← **CENTER**

Compacts		Compacts		Charpys		Charpys		Dosimeter	Tensiles	Charpys	
CL12	CL11	CL10	CL9	CW36	CH36	CW33	CH33	515	CL9	CT45	CL45
				CW35	CH35	CW32	CH32		CL8	CT44	CL44
				CW34	CH34	CW31	CH31		CL7	CT43	CL43

CENTER → **CENTER**

Charpys		Charpys		Charpys		Charpys		Compacts		Compacts		Tensiles
CT42	CL42	CT39	CL39	CT36	CL36	CT33	CL33	CT12	CT11	CT10	CT9	CT9
CT41	CL41	CT38	CL38	CT35	CL35	CT32	CL32					CT8
CT40	CL40	CT37	CL37	CT34	CL34	CT31	CL31					CT7

CENTER → **BOTTOM OF VESSEL**

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

5 TESTING OF SPECIMENS FROM CAPSULE W

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed at the Remote Metallographic Facility at the Westinghouse Research and Technology Department (RTU). Testing was performed in accordance with 10 CFR 50, Appendices G and H [Ref. 2], ASTM Specification E185-82 [Ref. 4], and Westinghouse Procedure RMF 8402, Revision 3 [Ref. 8] as detailed by Westinghouse RMF Procedures 8102, Revision 3 [Ref. 9], and 8103, Revision 2 [Ref. 10].

The capsule was opened upon receipt at the hot cell laboratory per Procedure RMF 8804, Revision 3 [Ref. 11]. The specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in WCAP-10684 [Ref. 3]. All items were in their proper locations.

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

The Charpy impact tests were performed per ASTM Specification E23-07a [Ref. 12] and Procedure RMF 8103 on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy machine is instrumented with an Instron Impulse instrumentation system, feeding information into a computer. With this system, load-time and energy-time signals can be recorded in addition to the standard measurement of Charpy energy (E_D). From the load-time curve, the load of general yielding (P_{GY}), the time to general yielding (T_{GY}), the maximum load (P_M), and the time to maximum load (T_M) can be determined. Under some test conditions, a sharp drop in load indicative of fast fracture was observed. The load at which fast fracture was initiated is identified as the fast fracture load (P_F). If the fast load drop terminates well above zero load, the termination load is identified as the arrest load (P_A).

The energy at maximum load (E_M) was determined by comparing the energy-time record and the load-time record. The energy at maximum load is approximately equivalent to the energy required to initiate a crack in the specimen. Therefore, the propagation energy for the crack (E_P) is the difference between the total energy to fracture (E_D) and the energy at maximum load (E_M).

The yield stress (σ_Y) was calculated from the three-point bend formula having the following expression [Ref. 13]:

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

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

Therefore, (for L = 4W),

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

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

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

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

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

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

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM E23-07a [Ref. 12] and A370-09 [Ref. 14]. The lateral expansion was measured using a dial gage rig similar to that shown in the same specifications.

Tensile tests were performed on a 20,000-pound Instron, split console test machine (Model 1115) per ASTM Specifications E8-09 [Ref. 15] and E21-09 [Ref. 16] and Procedure RMF 8102 [Ref. 9]. Extension measurements were made with a linear variable displacement transducer (LVDT) extensometer. The extensometer gage length was 1.00 inch. Elevated test temperatures were obtained with a three-zone electric resistance split-tube furnace with a 9-inch hot zone. All tests were conducted in air.

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

5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule W, which received a fluence of 3.38 x 10^{19} n/cm^2 (E > 1.0 MeV) in 14.51 EFPY of operation, are presented in Tables 5-1 through 5-8 and are compared with the unirradiated and previously withdrawn capsule results as shown in Figures 5-1 through 5-12. The unirradiated and previously withdrawn capsule results were taken from WCAP-10684 [Ref. 3], WCAP-14315 [Ref. 17], and WCAP-16277-NP [Ref. 18].

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

- Irradiation of the reactor vessel Intermediate Shell Plate R3807-2 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (longitudinal orientation), resulted in an irradiated 30 ft-lb transition temperature of 13.8°F and an irradiated 50 ft-lb transition temperature of 61.4°F. This results in a 30 ft-lb transition temperature increase of 23.2°F and a 50 ft-lb transition temperature increase of 33.0°F for the longitudinally oriented specimens.

- Irradiation of the reactor vessel Intermediate Shell Plate R3807-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), resulted in an irradiated 30 ft-lb transition temperature of 62.3°F and an irradiated 50 ft-lb transition temperature of 123.9°F. This results in a 30 ft-lb transition temperature increase of 74.4°F and a 50 ft-lb transition temperature increase of 81.8°F for the transversely oriented specimens.

- Irradiation of the Surveillance Program Weld Metal (Heat # 89833) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 34.4°F and an irradiated 50 ft-lb transition temperature of 50.9°F. This results in a 30 ft-lb transition temperature increase of 84.0°F and a 50 ft-lb transition temperature increase of 51.3°F.

- Irradiation of the Heat-Affected-Zone (HAZ) Material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -80.3°F and an irradiated 50 ft-lb transition temperature of -56.6°F. This results in a 30 ft-lb transition temperature increase of 29.2°F and a 50 ft-lb transition temperature increase of 18.8°F.

- The average upper shelf energy of the Intermediate Shell Plate R3807-2 (longitudinal orientation) resulted in an average energy increase of 3.4 ft-lb after irradiation to 3.38 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 118.4 ft-lb for the longitudinally oriented specimens.

- The average upper shelf energy of the Intermediate Shell Plate R3807-2 (transverse orientation) did not change after irradiation to 3.38 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 84.0 ft-lb for the transversely oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted in an average energy decrease of 10.5 ft-lb after irradiation to 3.38 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 83.5 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 5 ft-lb after irradiation to 3.38 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 111.0 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 Comanche Peak 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.

All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are predicted to maintain an upper shelf energy greater than 50 ft-lb throughout the end of the current license (36 EFPY) and a potential license renewal (54 EFPY) as required by 10 CFR 50, Appendix G [Ref. 2]. This evaluation can be found in Appendix E.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in Capsule W irradiated to 3.38E+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 Intermediate Shell Plate R3807-2 (longitudinal orientation) indicated that irradiation to 3.38E+19 n/cm^2 (E > 1.0 MeV) caused approximately an 8 ksi increase in the 0.2 percent offset yield strength and approximately a 6 to 7 ksi increase in 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 Intermediate Shell Plate R3807-2 (transverse orientation) indicated that irradiation to 3.38E+19 n/cm^2 (E > 1.0 MeV) caused approximately a 9 to 10 ksi increase in the 0.2 percent offset yield strength and approximately a 6 to 8 ksi increase in 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 weld metal indicated that irradiation to 3.38E+19 n/cm^2 (E > 1.0 MeV) caused approximately a 7 to 8 ksi increase in the 0.2 percent offset yield strength and approximately a 5 to 6 ksi increase in 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 Intermediate Shell Plate R3807-2 material are shown in Figures 5-20 and 5-21, while the fractured tensile specimens for the surveillance weld metal are shown in Figure 5-22. The engineering stress-strain curves for the tensile tests are shown in Figures 5-23 through 5-25.

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 Research and Technology Department.

Table 5-1 Charpy V-notch Data for the Comanche Peak Unit 2 Intermediate Shell Plate R3807-2 Irradiated to a Fluence of 3.38E+19 n/cm² (E > 1.0 MeV) (Longitudinal Orientation)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	°F	°C	ft-lbs	Joules	mils	mm	%
CL36	-50	-46	7	9	5	0.13	5
CL38	-20	-29	19	26	15	0.38	10
CL44	-15	-26	14	19	12	0.30	10
CL33	-10	-23	38	51	29	0.74	20
CL39	0	-18	32	43	27	0.69	15
CL41	25	-4	34	46	27	0.69	15
CL42	40	4	44	60	34	0.86	25
CL45	60	16	43	58	34	0.86	25
CL34	80	27	56	76	45	1.14	40
CL31	125	52	75	102	61	1.55	60
CL35	200	93	110	149	84	2.13	100
CL43	275	135	117	159	83	2.11	100
CL40	300	149	118	160	80	2.03	100
CL32	325	163	123	167	85	2.16	100
CL37	350	177	124	168	77	1.96	100

Table 5-2 Charpy V-notch Data for the Comanche Peak Unit 2 Intermediate Shell Plate R3807-2 Irradiated to a Fluence of 3.38E+19 n/cm^2 (E > 1.0 MeV) (Transverse Orientation)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	°F	°C	ft-lbs	Joules	mils	mm	%
CT43	-90	-68	7	9	5	0.13	2
CT39	30	-1	18	24	17	0.43	15
CT31	50	10	31	42	28	0.71	25
CT34	55	13	23	31	21	0.53	20
CT41	65	18	34	46	31	0.79	25
CT44	75	24	46	62	35	0.89	25
CT38	100	38	42	57	38	0.97	45
CT33	125	52	43	58	44	1.12	40
CT42	130	54	50	68	47	1.19	40
CT45	140	60	46	62	44	1.12	40
CT32	150	66	58	79	48	1.22	75
CT36	200	93	75	102	60	1.52	95
CT35	275	135	85	115	62	1.57	100
CT40	300	149	88	119	66	1.68	100
CT37	325	163	88	119	68	1.73	100

Table 5-3 Charpy V-notch Data for the Comanche Peak Unit 2 Surveillance Weld Metal Irradiated to a Fluence of 3.38E+19 n/cm^2 (E > 1.0 MeV)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	°F	°C	ft-lbs	Joules	mils	mm	%
CW38	-90	-68	5	7	5	0.13	5
CW40	25	-4	21	28	24	0.61	50
CW45	30	-1	17	23	18	0.46	40
CW33	30	-1	25	34	29	0.74	50
CW43	35	2	31	42	30	0.76	55
CW42	40	4	32	43	29	0.74	55
CW35	45	7	44	60	43	1.09	60
CW31	45	7	59	80	52	1.32	65
CW32	50	10	60	81	50	1.27	70
CW41	50	10	35	47	41	1.04	55
CW36	75	24	65	88	55	1.40	80
CW44	175	79	74	100	67	1.70	98
CW37	275	135	86	117	78	1.98	100
CW39	300	149	87	118	76	1.93	100
CW34	325	163	87	118	69	1.75	100

Table 5-4 Charpy V-notch Data for the Comanche Peak Unit 2 Heat-Affected-Zone (HAZ) Material Irradiated to a Fluence of 3.38E+19 n/cm^2 (E > 1.0 MeV)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	°F	°C	ft-lbs	Joules	mils	mm	%
CH31	-175	-115	5	6	3	0.08	2
CH39	-90	-68	18	24	11	0.28	15
CH44	-80	-62	18	24	10	0.25	20
CH33	-75	-59	41	56	25	0.64	30
CH42	-75	-59	60	81	36	0.91	60
CH37	-70	-57	16	22	12	0.30	15
CH43	-65	-54	62	84	38	0.97	60
CH41	-60	-51	74	100	40	1.02	50
CH34	-60	-51	27	37	19	0.48	45
CH36	-60	-51	25	34	18	0.46	25
CH38	-50	-46	57	77	36	0.91	45
CH32	-25	-32	79	107	45	1.14	70
CH45	200	93	93	126	64	1.63	98
CH40	225	107	147	199	80	2.03	100
CH35	275	135	93	126	62	1.57	100

Table 5-5 Instrumented Charpy Impact Test Results for the Comanche Peak Unit 2 Intermediate Shell Plate R3807-2 Irradiated to a Fluence of 3.38E+19 n/cm^2 (E > 1.0 MeV) (Longitudinal Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy, E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			General Yield Load, P_{GY} (lb)	Time to P_{GY} (msec)	Max. Load, P_M (lb)	Time to P_M (msec)	Fract. Load, P_F (lb)	Arrest Load, P_A (lb)	Yield Stress (ksi)	Flow Stress (ksi)
			Total E_D/A	At P_M E_M/A	Prop. Ep/A								
CL36	-50	7	57	26	32	2260	0.01	4016	0.09	3333	0	75	104
CL38	-20	17	140	120	20	1432	0.01	3902	0.29	3868	0	48	89
CL44	-15	12	97	27	70	572	0.00	3843	0.09	3502	0	19	74
CL33	-10	35	280	227	52	2187	0.01	4068	0.50	4019	0	73	104
CL39	0	28	229	211	18	2181	0.01	3996	0.47	3993	0	73	103
CL41	25	29	231	223	9	2169	0.01	4016	0.50	3971	0	72	103
CL42	40	37	298	273	25	2075	0.01	4002	0.62	3872	0	69	101
CL45	60	34	275	261	14	2163	0.01	3926	0.60	3909	0	72	101
CL34	80	48	383	263	120	1976	0.02	3918	0.61	3732	895	66	98
CL31	125	68	551	253	298	2179	0.01	3851	0.60	3364	1855	73	100
CL35	200	100	810	253	557	2033	0.01	3725	0.62	n/a	n/a	68	96
CL43	275	106	858	311	547	2080	0.02	3633	0.77	n/a	n/a	69	95
CL40	300	108	869	314	554	1931	0.05	3771	0.80	n/a	n/a	64	95
CL32	325	113	909	242	667	2046	0.01	3704	0.60	n/a	n/a	68	96
CL37	350	112	902	243	659	3412	0.44	3640	0.63	n/a	n/a	114	117

Table 5-6 Instrumented Charpy Impact Test Results for the Comanche Peak Unit 2 Intermediate Shell Plate R3807-2 Irradiated to a Fluence of 3.38E+19 n/cm^2 (E > 1.0 MeV) (Transverse Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy, E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			General Yield Load, P_{GY} (lb)	Time to P_{GY} (msec)	Max. Load, P_M (lb)	Time to P_M (msec)	Fract. Load, P_F (lb)	Arrest Load, P_A (lb)	Yield Stress (ksi)	Flow Stress (ksi)
			Total E_D/A	At P_M E_M/A	Prop. Ep/A								
CT43	-90	7	57	34	23	928	0.01	4311	0.11	4307	0	31	87
CT39	30	14	113	26	87	923	0.01	3789	0.09	3665	0	31	78
CT31	50	23	187	146	41	1722	0.01	3778	0.36	3757	0	57	92
CT34	55	16	126	114	12	1463	0.01	3732	0.29	3732	0	49	87
CT41	65	26	207	196	11	2165	0.01	3814	0.46	3814	0	72	100
CT44	75	40	320	222	97	2074	0.01	4037	0.50	4023	221	69	102
CT38	100	35	281	199	82	2038	0.01	3750	0.48	3712	146	68	96
CT33	125	36	288	173	115	2033	0.01	3621	0.43	3521	960	68	94
CT42	130	44	353	193	160	2096	0.01	3698	0.47	3416	1530	70	96
CT45	140	41	331	193	138	2138	0.01	3676	0.47	3331	1417	71	97
CT32	150	49	393	193	200	1882	0.01	3637	0.48	3564	1810	63	92
CT36	200	68	548	246	302	2023	0.01	3694	0.60	3290	2748	67	95
CT35	275	78	632	183	448	1925	0.01	3554	0.48	n/a	n/a	64	91
CT40	300	81	653	186	467	1735	0.01	3592	0.48	n/a	n/a	58	89
CT37	325	81	649	231	418	1695	0.01	3486	0.60	n/a	n/a	56	86

Table 5-7 Instrumented Charpy Impact Test Results for the Comanche Peak Unit 2 Surveillance Weld Metal Irradiated to a Fluence of 3.38E+19 n/cm^2 (E > 1.0 MeV)

Sample No.	Test Temp. (°F)	*Charpy* Energy, E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Total E_D/A	At P_M E_M/A	Prop. E_p/A	General Yield Load, P_{GY} (lb)	Time to P_{GY} (msec)	Max. Load, P_M (lb)	Time to P_M (msec)	Fract. Load, P_F (lb)	Arrest Load, P_A (lb)	Yield Stress (ksi)	Flow Stress (ksi)
CW38	-90	5	41	29	13	2161	0.02	4118	0.09	4053	0	72	105
CW40	25	16	127	24	102	2240	0.01	3675	0.09	3149	391	75	98
CW45	30	10	78	26	52	2219	0.02	3728	0.09	3530	0	74	99
CW33	30	22	176	26	150	2135	0.02	3657	0.09	3412	716	71	96
CW43	35	24	196	26	171	2177	0.01	3668	0.09	3609	238	72	97
CW42	40	25	204	26	178	2160	0.01	3721	0.09	3638	423	72	98
CW35	45	37	297	200	97	2099	0.01	3687	0.48	3673	1457	70	96
CW31	45	53	423	258	165	2192	0.02	3806	0.60	3617	1903	73	100
CW32	50	53	429	269	160	2019	0.02	3875	0.62	3591	1006	67	98
CW41	50	31	248	113	136	2141	0.02	3620	0.29	3452	1019	71	96
CW36	75	60	480	200	280	2309	0.02	3750	0.47	3230	2064	77	101
CW44	175	68	549	238	311	2235	0.02	3523	0.60	2570	2197	74	96
CW37	275	80	643	233	410	2220	0.02	3540	0.60	n/a	n/a	74	96
CW39	300	80	644	235	409	2152	0.02	3531	0.61	n/a	n/a	72	95
CW34	325	81	649	233	416	2133	0.02	3488	0.60	n/a	n/a	71	94

Table 5-8 Instrumented Charpy Impact Test Results for the Comanche Peak Unit 2 Heat-Affected-Zone (HAZ) Material Irradiated to a Fluence of 3.38E+19 n/cm² (E > 1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy, E_D (ft-lb)	Normalized Energies (ft-lb/in²)			General Yield Load, P_{GY} (lb)	Time to P_{GY} (msec)	Max. Load, P_M (lb)	Time to P_M (msec)	Fract. Load, P_F (lb)	Arrest Load, P_A (lb)	Yield Stress (ksi)	Flow Stress (ksi)
			Total E_D/A	At P_M E_M/A	Prop. E_P/A								
CH31	-175	5	39	32	7	2284	0.02	4912	0.09	4676	0	76	120
CH39	-90	17	138	30	109	2284	0.01	4392	0.09	4178	0	76	111
CH44	-80	14	112	30	83	2266	0.00	4442	0.09	3893	124	75	112
CH33	-75	34	275	29	246	2152	0.01	4428	0.09	4317	0	72	110
CH42	-75	51	414	29	386	2143	0.01	4409	0.09	4082	1090	71	109
CH37	-70	13	106	28	78	2040	0.01	4277	0.09	3835	0	68	105
CH43	-65	53	427	30	398	2169	0.01	4311	0.09	3404	1293	72	108
CH41	-60	67	536	303	233	2045	0.01	4466	0.62	3882	1095	68	108
CH34	-60	23	182	29	153	2137	0.01	4326	0.09	3398	1268	71	108
CH36	-60	21	168	27	141	2275	0.01	4359	0.09	3986	0	76	110
CH38	-50	51	413	298	115	2287	0.02	4351	0.62	4202	297	76	111
CH32	-25	71	572	299	273	2274	0.01	4368	0.61	4046	1952	76	111
CH45	200	84	678	249	428	2250	0.02	3752	0.60	n/a	n/a	75	100
CH40	225	136	1093	415	678	2170	0.01	3908	0.94	n/a	n/a	72	101
CH35	275	86	697	263	433	2015	0.01	3812	0.62	n/a	n/a	67	97

Table 5-9 Effect of Irradiation to 3.38E+19 n/cm^2 (E > 1.0 MeV) on the Charpy V-Notch Toughness Properties of the Comanche Peak Unit 2 Reactor Vessel Surveillance Capsule W Materials

Material	Average 30 ft-lb Transition Temperature[(a)] (°F)			Average 35 mil Lateral Expansion Temperature[(a)] (°F)			Average 50 ft-lb Transition Temperature[(a)] (°F)			Average Energy Absorption at Full Shear[(a)] (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Intermediate Shell Plate R3807-2 (LT)	-9.4	13.8	23.2	33.4	45.8	12.4	28.4	61.4	33	115	118.4	3.4
Intermediate Shell Plate R3807-2 (TL)	-12.1	62.3	74.4	39.1	89.6	50.5	42.1	123.9	81.8	84	84	0
Surveillance Program Weld Metal (Heat #89833)	-49.6	34.4	84	0.7	39.3	38.6	-0.4	50.9	51.3	94	83.5	-10.5
HAZ Material	-109.5	-80.3	29.2	-48.9	-47.5	1.4	-75.4	-56.6	18.8	116	111	-5

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

Table 5-10 Comparison of the Comanche Peak 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		USE Decrease	
			Predicted (°F) [(a)]	Measured (°F) [(b)]	Predicted (%) [(a)]	Measured (%) [(b)]
Intermediate Shell Plate R3807-2 (Longitudinal)	U	0.317	25.3	1.6	15	---
	X	2.16	44.7	1.6	23	---
	W	3.38	48.8	23.2	26	---
Intermediate Shell Plate R3807-2 (Transverse)	U	0.317	25.3	23.4	15	---
	X	2.16	44.7	52.9	23	---
	W	3.38	48.8	74.4	26	0
Surveillance Program Weld Metal	U	0.317	20.7	3.6	15	10
	X	2.16	36.6	48.2	23	---
	W	3.38	40.0	84.0	26	11
Heat Affected Zone Material	U	0.317	---	0.0[(c)]	---	---
	X	2.16	---	26.2	---	0
	W	3.38	---	29.2	---	4

Notes:

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

(b) Calculated by CVGraph Version 5.3 using measured Charpy data (See Appendix C).

(c) Measured ΔRT_{NDT} value was determined to be negative, but physically a reduction should not occur; therefore, a conservative value of zero is used.

Table 5-11 Tensile Properties of the Comanche Peak Unit 2 Capsule W Reactor Vessel Surveillance Materials Irradiated to 3.38E+19 n/cm^2 (E > 1.0 MeV)

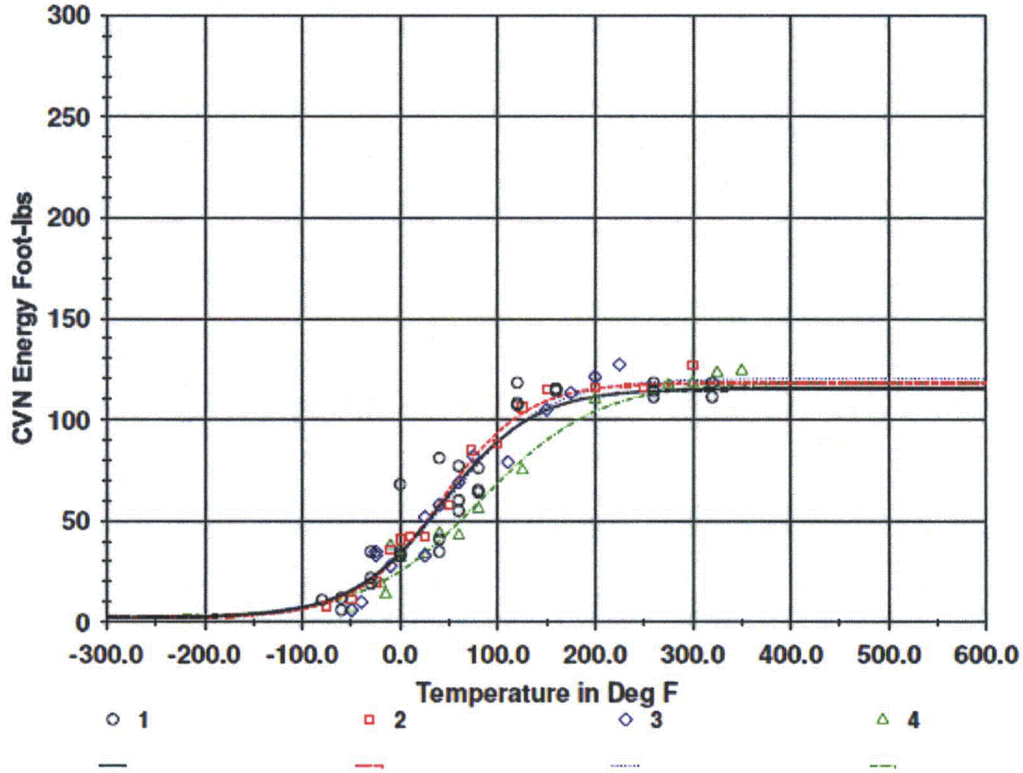
Material	Sample Number	Test Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Stress (ksi)	Fracture Strength (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
Intermediate Shell Plate R3807-2 (Longitudinal)	CL7	100	75.3	95.2	3.13	195.7	63.7	10.4	23.1	67
	CL8	200	72.0	90.7	3.00	168.0	61.1	9.3	21.6	64
	CL9	550	68.1	91.7	3.30	162.7	67.2	1.8	18.0	59
Intermediate Shell Plate R3807-2 (Transverse)	CT7	100	75.9	95.7	3.30	169.6	67.2	10.5	23.9	60
	CT8	200	72.2	91.2	3.10	162.8	63.2	8.9	21.0	61
	CT9	550	69.3	92.2	3.45	157.1	70.3	8.9	18.6	55
Weld Metal (Heat # 89833)	CW7	100	75.6	90.1	2.93	187.6	59.6	9.9	23.6	68
	CW8	200	73.2	87.1	2.85	182.8	58.1	9.2	22.7	68
	CW9	550	69.6	89.1	3.18	177.7	64.7	9.6	20.2	64

IS PLATE R3807-2 (LONGITUDINAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:21 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SA533B1	LT	C5522-2
2	Comanche Peak 2	U	SA533B1	LT	C5522-2
3	Comanche Peak 2	X	SA533B1	LT	C5522-2
4	Comanche Peak 2	W	SA533B1	LT	C5522-2



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	115.0	.0	-9.4	.0	28.4	.0
2		2.2	118.0	3.0	-7.8	1.6	26.9	-1.5
3		2.2	120.0	5.0	-7.8	1.6	31.5	3.1
4		2.2	118.4	3.4	13.8	23.2	61.4	33.0

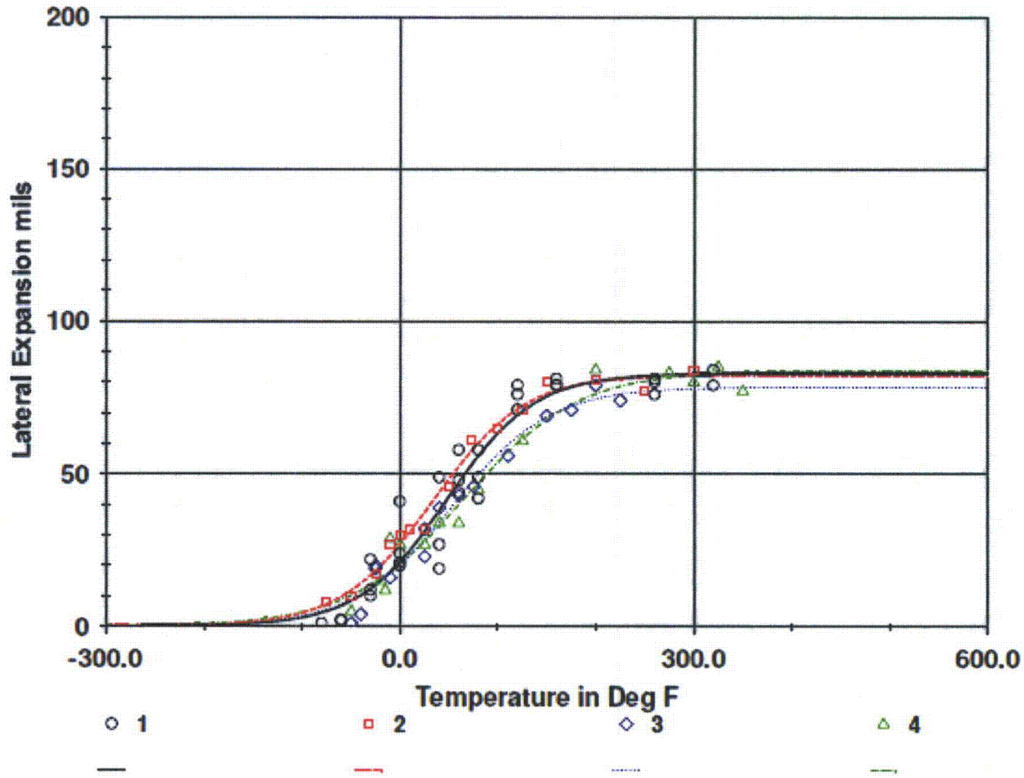
Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Longitudinal Orientation)

IS PLATE R3807-2 (LONGITUDINAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:24 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SA533B1	LT	C5522-2
2	Comanche Peak 2	U	SA533B1	LT	C5522-2
3	Comanche Peak 2	X	SA533B1	LT	C5522-2
4	Comanche Peak 2	W	SA533B1	LT	C5522-2



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	82.8	.0	33.4	.0
2		.0	82.5	-.4	19.4	-14.0
3		.0	78.3	-4.5	42.2	8.8
4		.0	83.8	.9	45.8	12.4

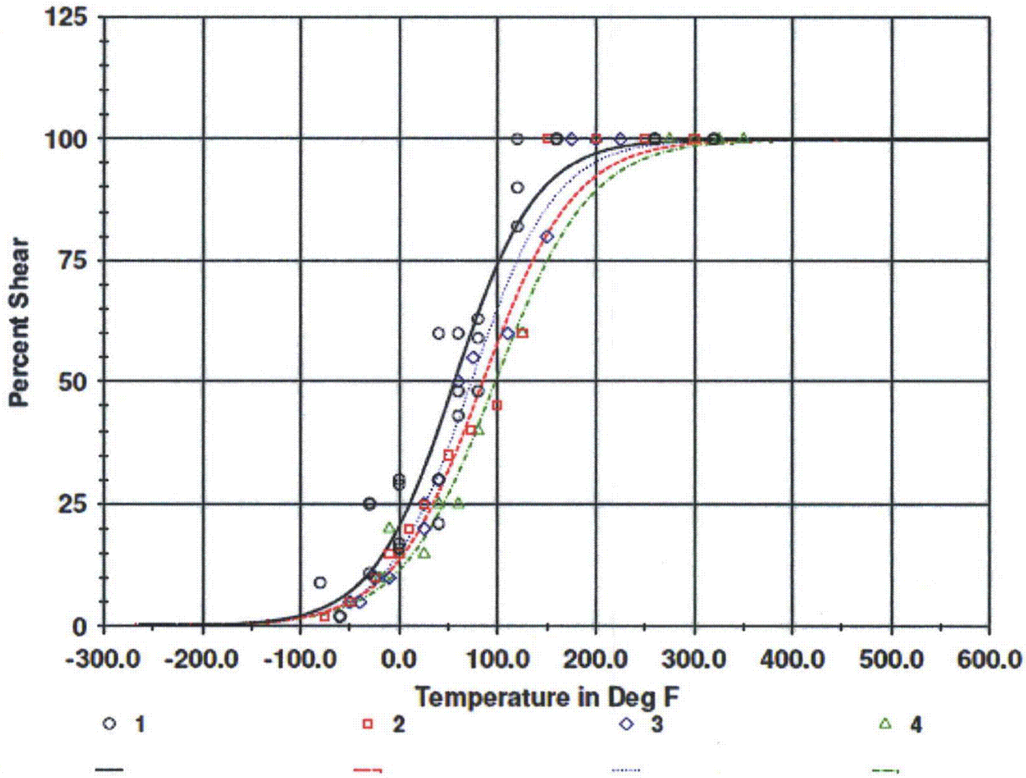
Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Longitudinal Orientation)

IS PLATE R3807-2 (LONGITUDINAL)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:23 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SA533B1	LT	C5522-2
2	Comanche Peak 2	U	SA533B1	LT	C5522-2
3	Comanche Peak 2	X	SA533B1	LT	C5522-2
4	Comanche Peak 2	W	SA533B1	LT	C5522-2



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	56.0	.0
2		.0	100.0	.0	85.0	29.0
3		.0	100.0	.0	73.6	17.6
4		.0	100.0	.0	97.6	41.6

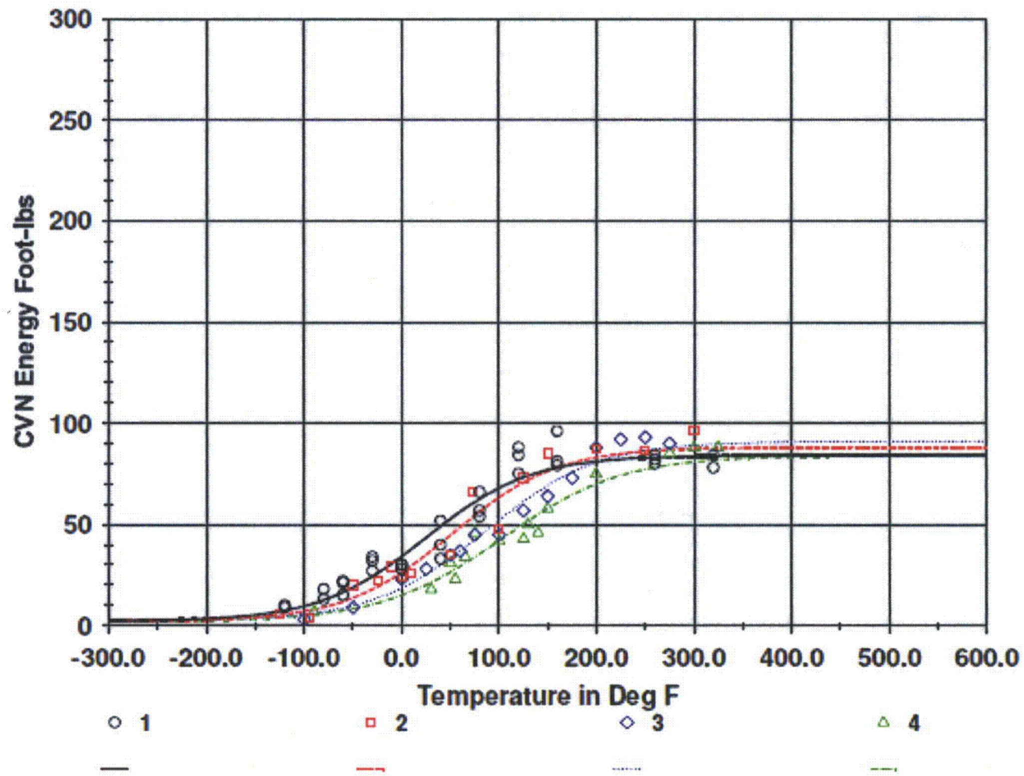
Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Longitudinal Orientation)

IS PLATE R3807-2 (TRANSVERSE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:29 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SA533B1	TL	C5522-2
2	Comanche Peak 2	U	SA533B1	TL	C5522-2
3	Comanche Peak 2	X	SA533B1	TL	C5522-2
4	Comanche Peak 2	W	SA533B1	TL	C5522-2



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	84.0	.0	-12.1	.0	42.1	.0
2		2.2	88.0	4.0	11.3	23.4	63.2	21.1
3		2.2	91.0	7.0	40.8	52.9	94.6	52.5
4		2.2	84.0	.0	62.3	74.4	123.9	81.8

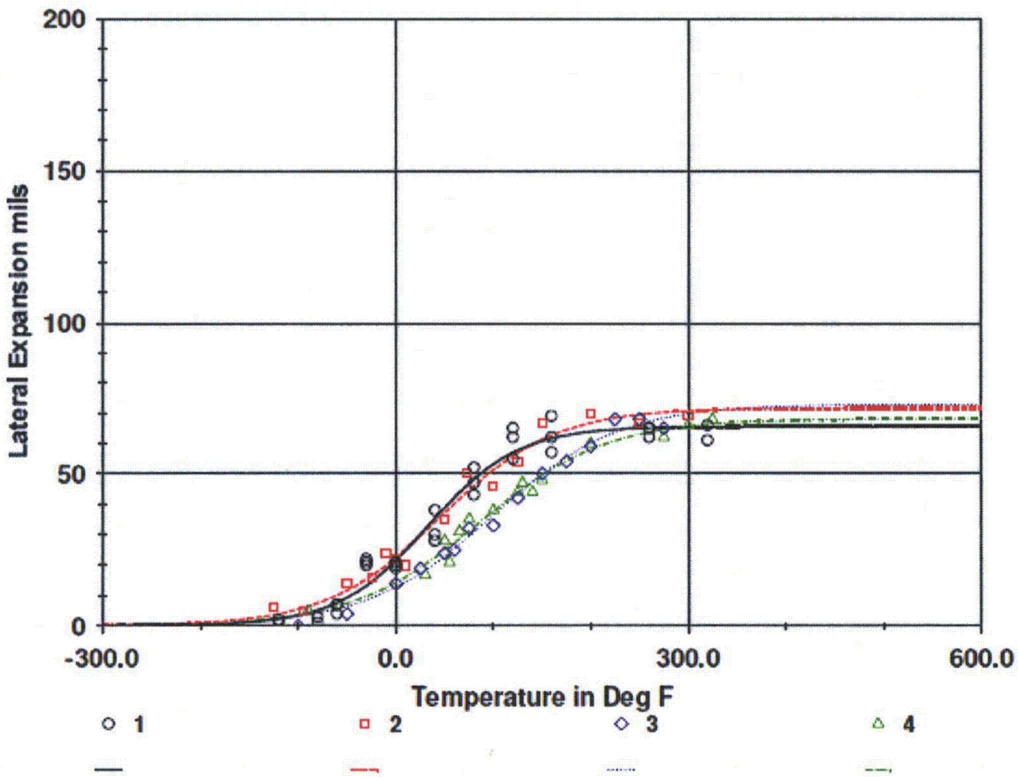
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Transverse Orientation)

IS PLATE R3807-2 (TRANSVERSE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:30 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SA533B1	TL	C5522-2
2	Comanche Peak 2	U	SA533B1	TL	C5522-2
3	Comanche Peak 2	X	SA533B1	TL	C5522-2
4	Comanche Peak 2	W	SA533B1	TL	C5522-2



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	65.6	.0	39.1	.0
2		.0	71.6	6.0	43.1	4.0
3		.0	72.9	7.3	95.6	56.5
4		.0	68.2	2.6	89.6	50.5

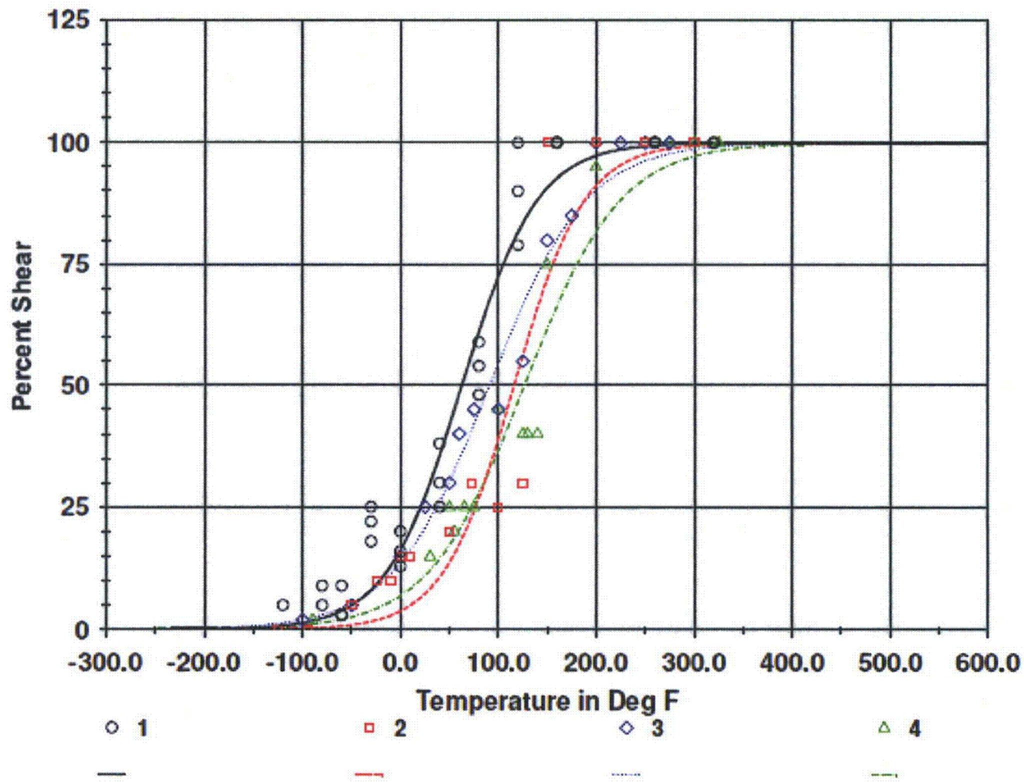
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Transverse Orientation)

IS PLATE R3807-2 (TRANSVERSE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:29 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SA533B1	TL	C5522-2
2	Comanche Peak 2	U	SA533B1	TL	C5522-2
3	Comanche Peak 2	X	SA533B1	TL	C5522-2
4	Comanche Peak 2	W	SA533B1	TL	C5522-2



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	62.7	.0
2		.0	100.0	.0	116.2	53.5
3		.0	100.0	.0	91.3	28.6
4		.0	100.0	.0	126.7	64.0

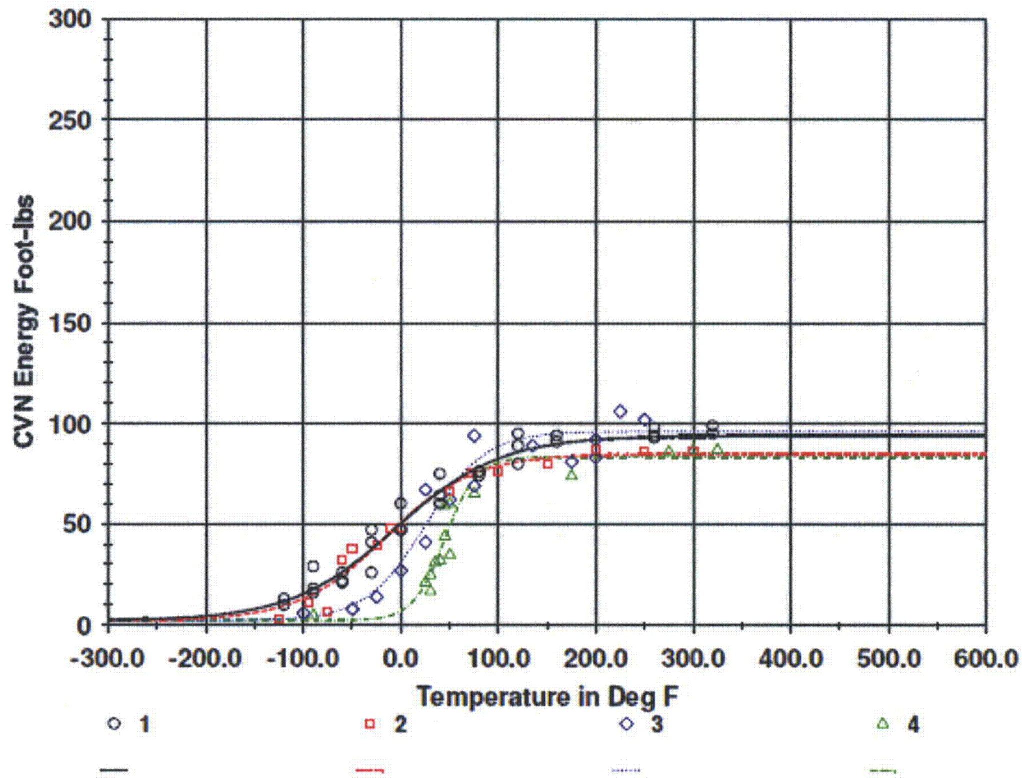
Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Transverse Orientation)

SURVEILLANCE PROGRAM WELD

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:38 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SAW	NA	89833
2	Comanche Peak 2	U	SAW	NA	89833
3	Comanche Peak 2	X	SAW	NA	89833
4	Comanche Peak 2	W	SAW	NA	89833



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	94.0	.0	-49.6	.0	-.4	.0
2		2.2	85.0	-9.0	-46.0	3.6	-1.2	-.8
3		2.2	96.0	2.0	-1.4	48.2	26.3	26.7
4		2.2	83.5	-10.5	34.4	84.0	50.9	51.3

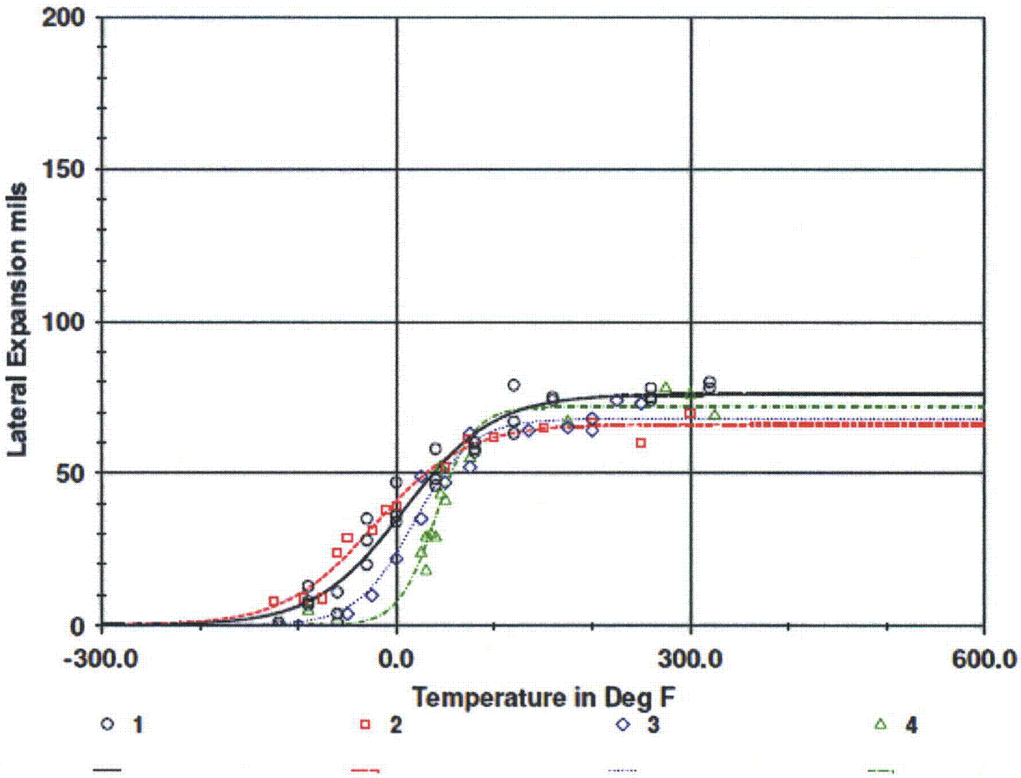
Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for the Comanche Peak Unit 2 Reactor Vessel Surveillance Program Weld Metal

SURVEILLANCE PROGRAM WELD

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:45 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SAW	NA	89833
2	Comanche Peak 2	U	SAW	NA	89833
3	Comanche Peak 2	X	SAW	NA	89833
4	Comanche Peak 2	W	SAW	NA	89833



Results

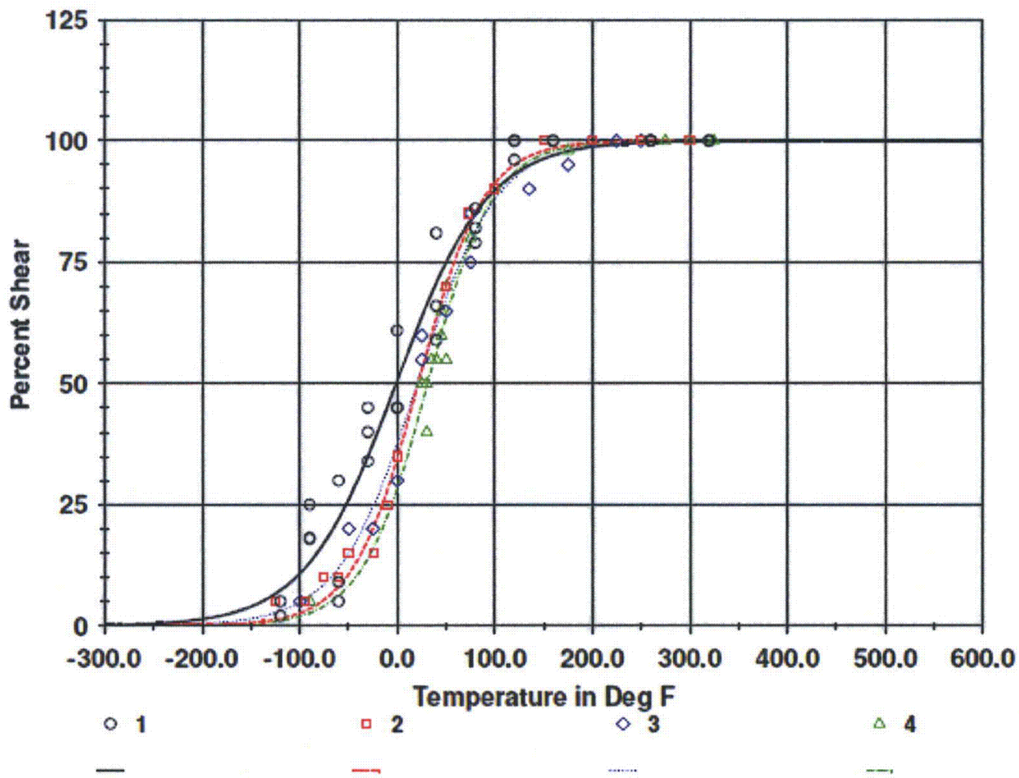
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	76.0	.0	.7	.0
2		.0	66.1	-9.9	-16.7	-17.4
3		.0	67.9	-8.1	20.3	19.6
4		.0	71.9	-4.2	39.3	38.6

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

SURVEILLANCE PROGRAM WELD

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:44 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SAW	NA	89833
2	Comanche Peak 2	U	SAW	NA	89833
3	Comanche Peak 2	X	SAW	NA	89833
4	Comanche Peak 2	W	SAW	NA	89833



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	-1.2	.0
2		.0	100.0	.0	21.6	22.8
3		.0	100.0	.0	20.8	22.0
4		.0	100.0	.0	31.2	32.4

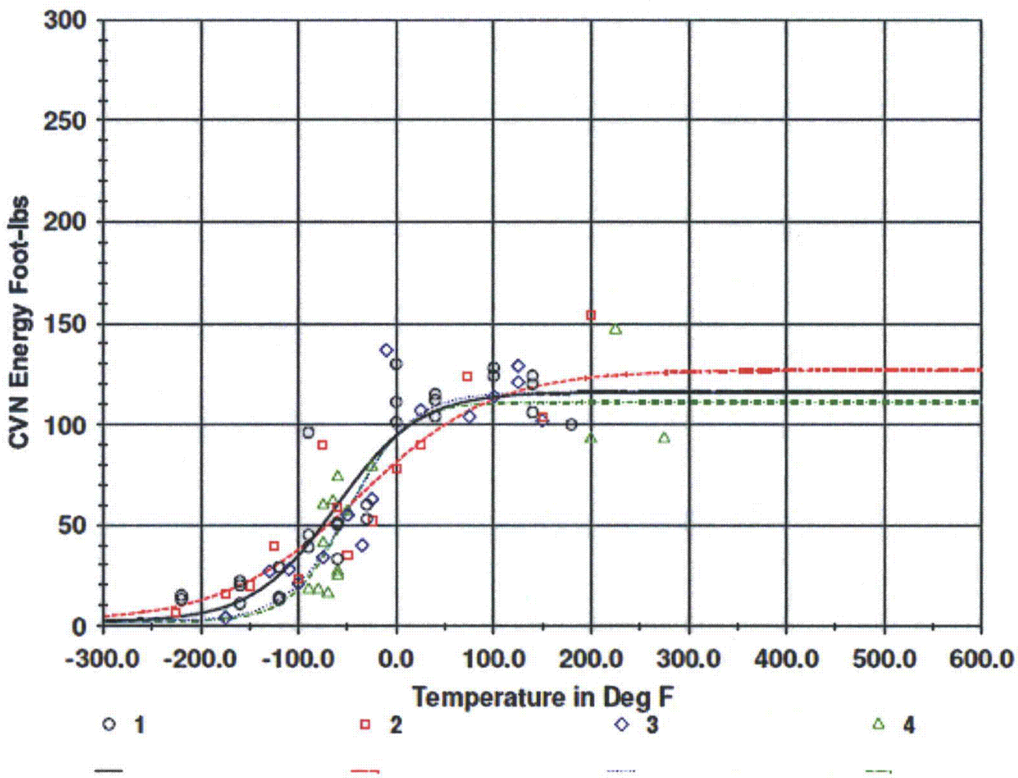
Figure 5-9 Charpy V-Notch Percent Shear vs. Temperature for the Comanche Peak Unit 2 Reactor Vessel Surveillance Program Weld Metal

HEAT AFFECTED ZONE

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:47 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SA533B1	NA	C5522-2
2	Comanche Peak 2	U	SA533B1	NA	C5522-2
3	Comanche Peak 2	X	SA533B1	NA	C5522-2
4	Comanche Peak 2	W	SA533B1	NA	C5522-2



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	116.0	.0	-109.5	.0	-75.4	.0
2		2.2	127.0	11.0	-122.7	-13.2	-70.1	5.3
3		2.2	116.0	.0	-83.3	26.2	-57.4	18.0
4		2.2	111.0	-5.0	-80.3	29.2	-56.6	18.8

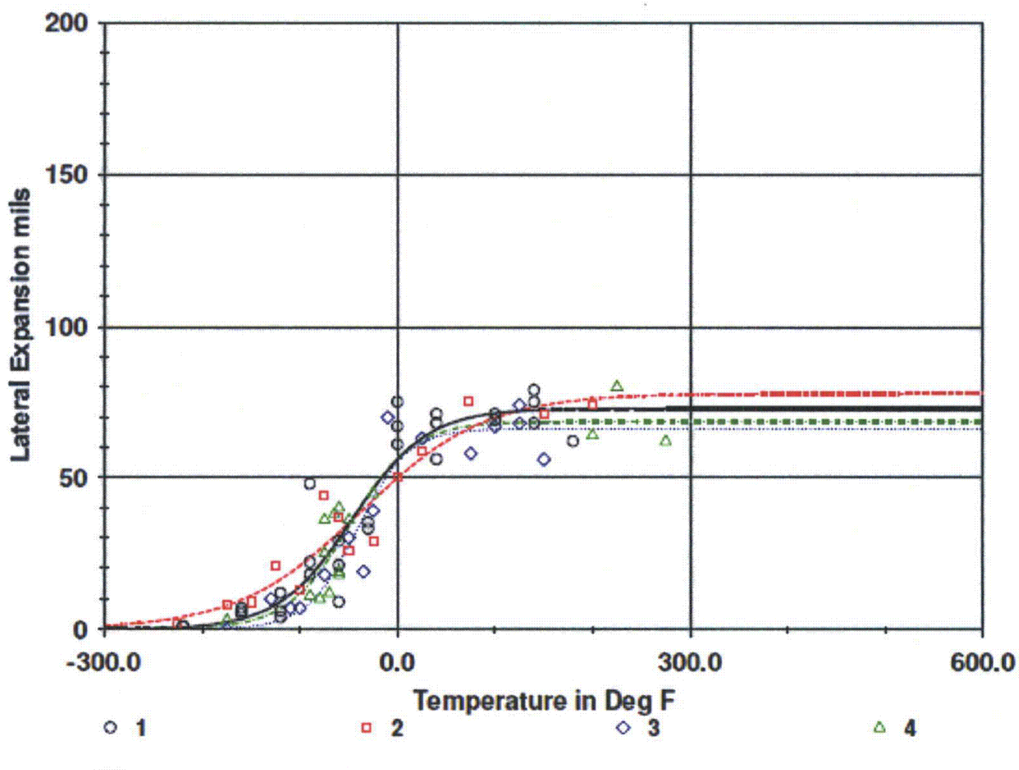
Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for the Comanche Peak Unit 2 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:49 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SA533B1	NA	C5522-2
2	Comanche Peak 2	U	SA533B1	NA	C5522-2
3	Comanche Peak 2	X	SA533B1	NA	C5522-2
4	Comanche Peak 2	W	SA533B1	NA	C5522-2



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	72.8	.0	-48.9	.0
2		.0	77.8	5.0	-49.4	-.5
3		.0	66.1	-6.7	-37.8	11.1
4		.0	68.6	-4.2	-47.5	1.4

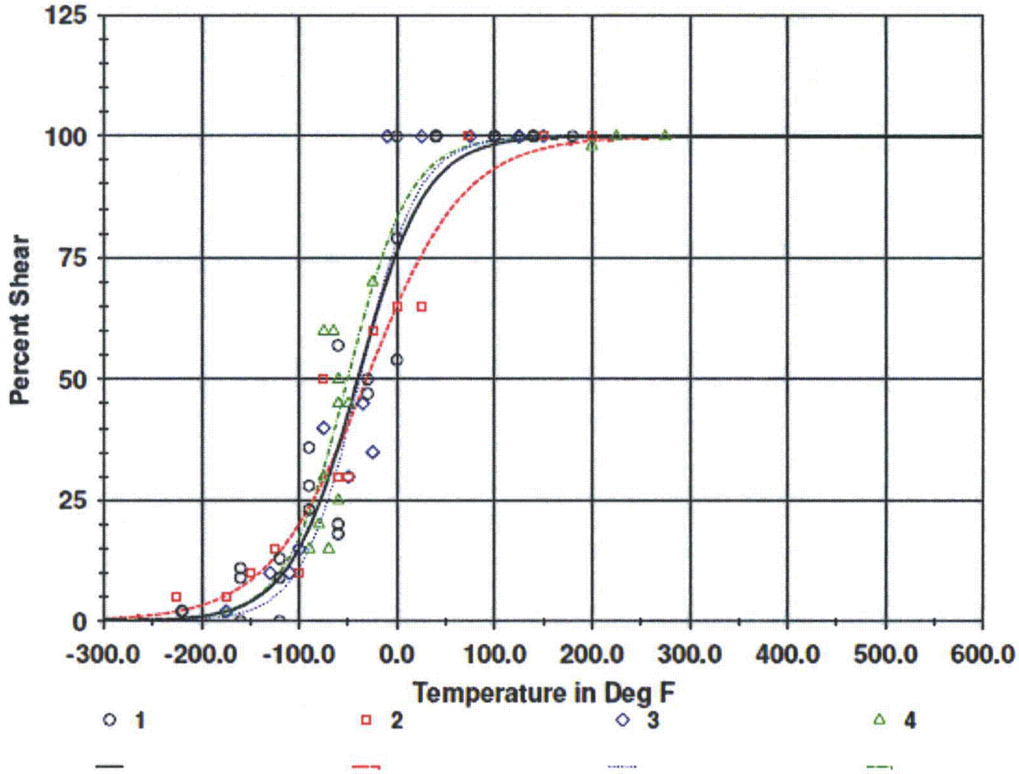
Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for the Comanche Peak Unit 2 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/21/2010 03:48 PM

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Comanche Peak 2	UNIRR	SA533B1	NA	C5522-2
2	Comanche Peak 2	U	SA533B1	NA	C5522-2
3	Comanche Peak 2	X	SA533B1	NA	C5522-2
4	Comanche Peak 2	W	SA533B1	NA	C5522-2



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	-40.3	.0
2		.0	100.0	.0	-31.1	9.2
3		.0	100.0	.0	-38.1	2.2
4		.0	100.0	.0	-50.6	-10.3

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

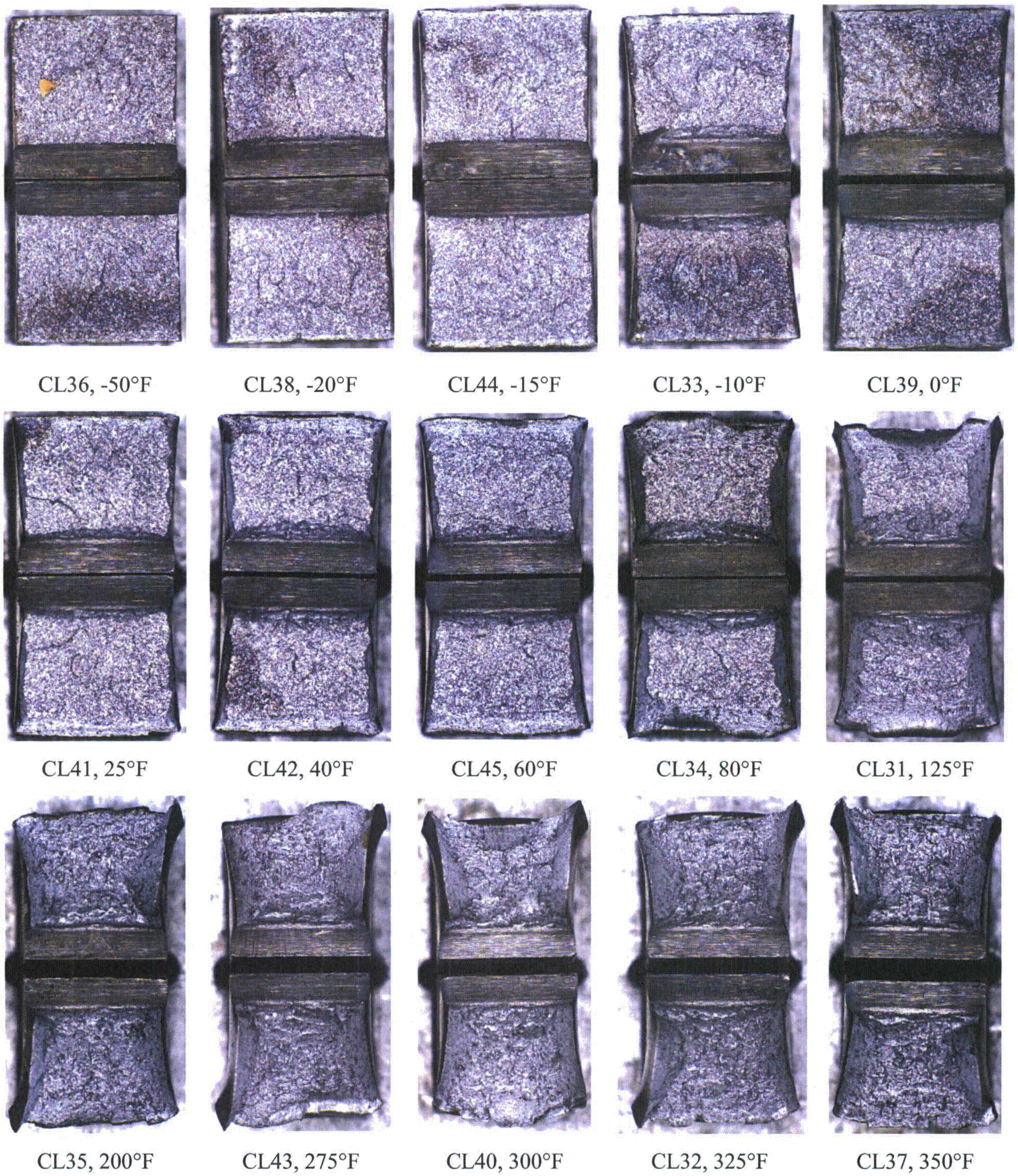


Figure 5-13 Charpy Impact Specimen Fracture Surfaces for Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Longitudinal Orientation)

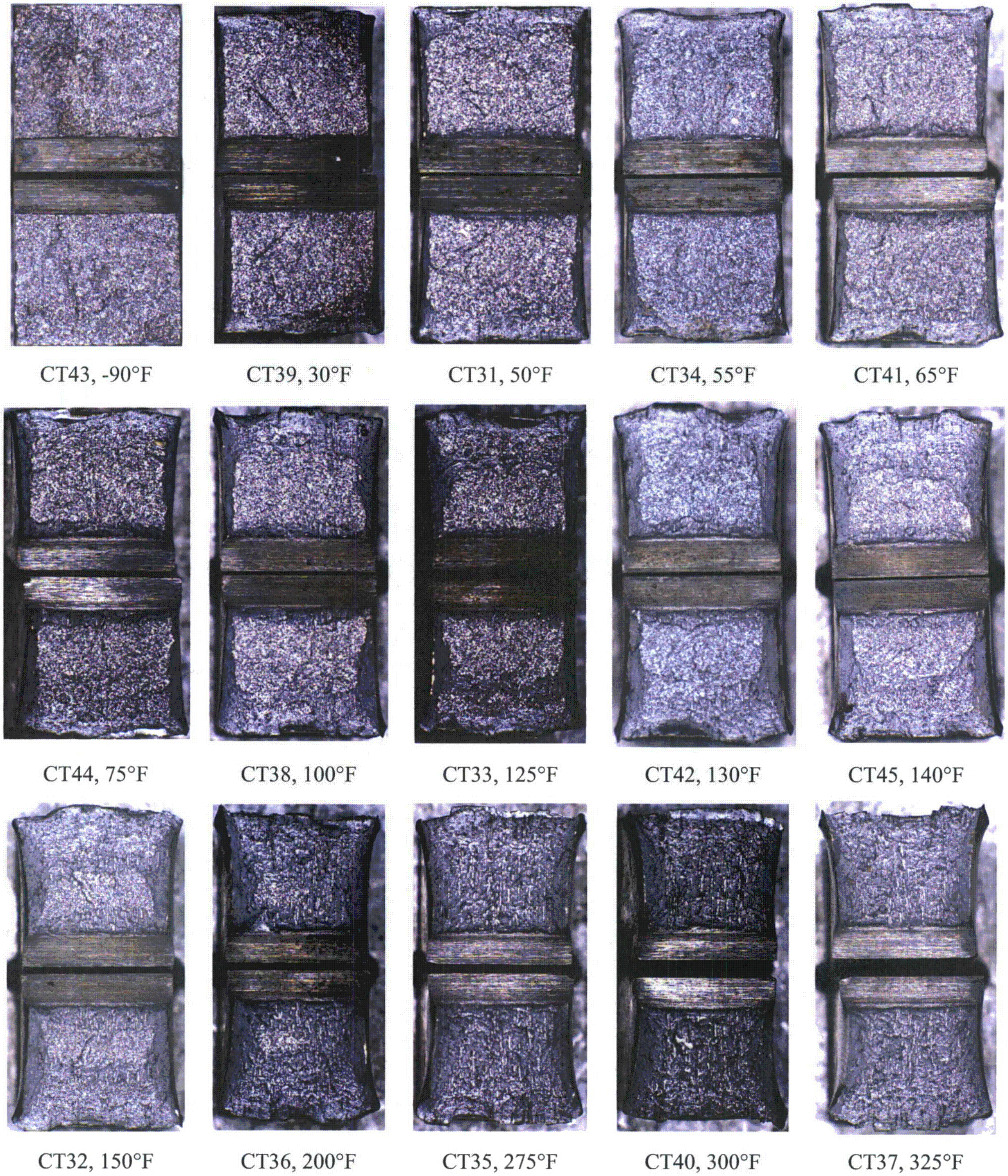


Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Transverse Orientation)

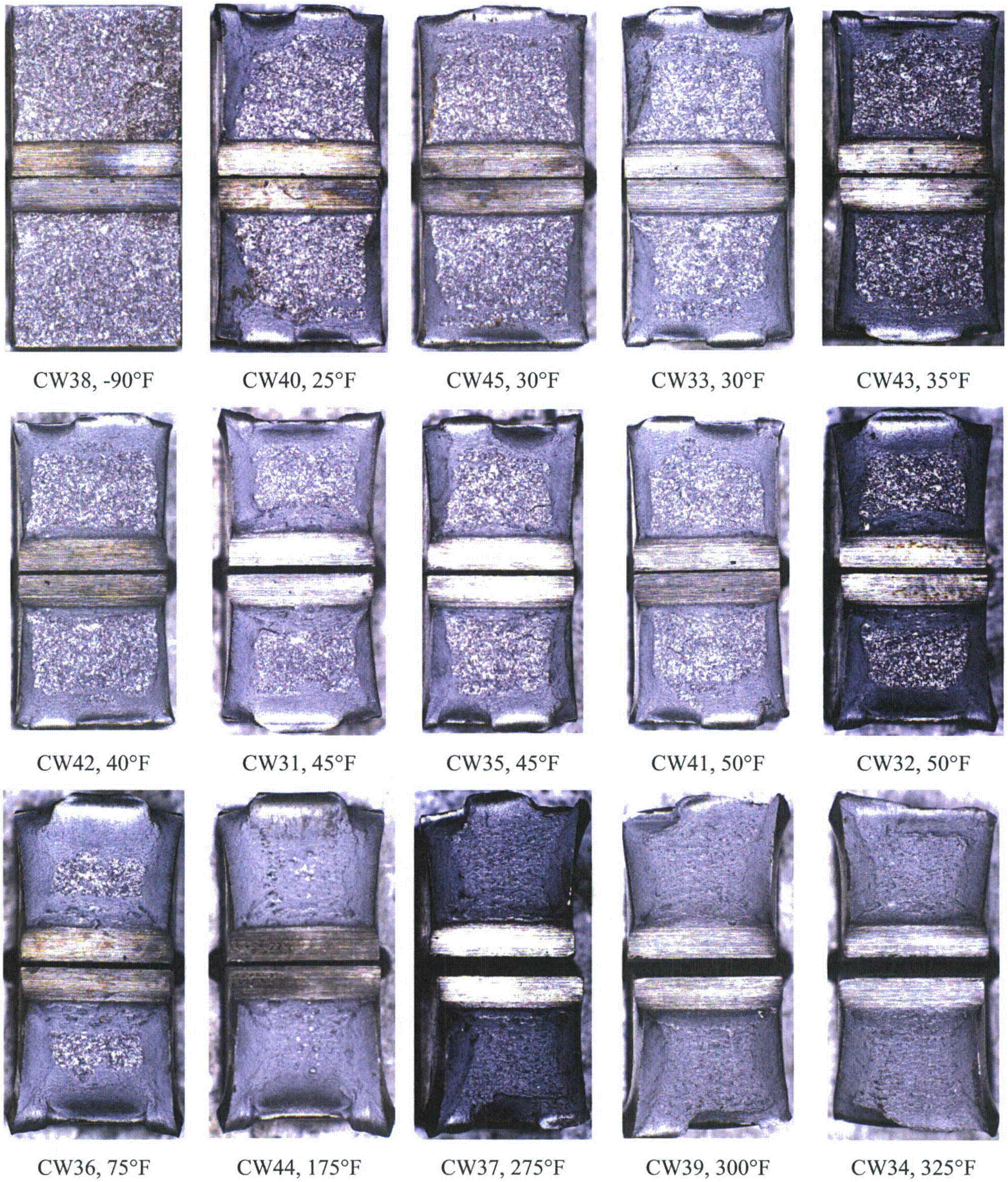


Figure 5-15 Charpy Impact Specimen Fracture Surfaces for the Comanche Peak Unit 2 Reactor Vessel Surveillance Program Weld Metal

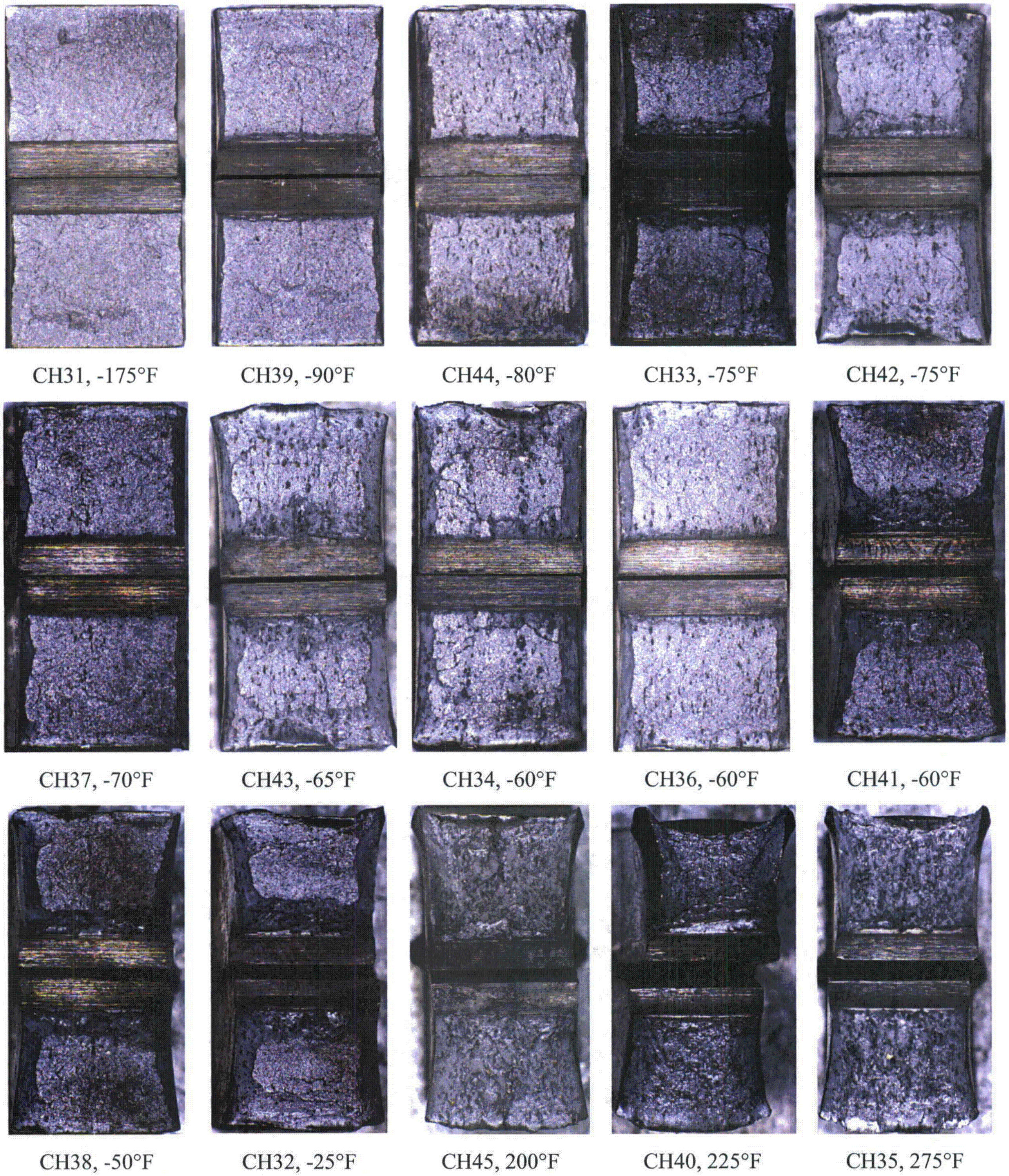
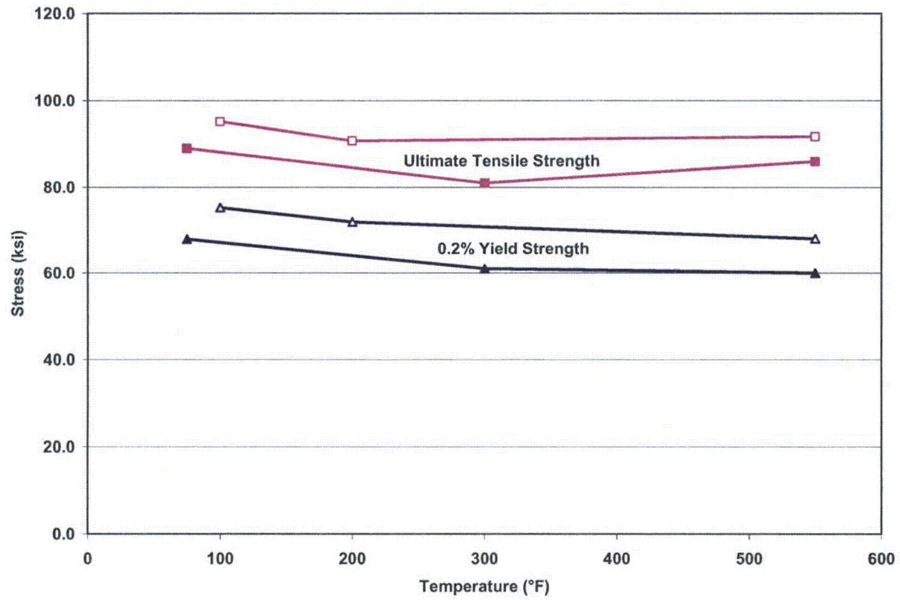


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for the Comanche Peak Unit 2 Reactor Vessel Heat-Affected-Zone Material



Legend: ▲ and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 3.38E+19 n/cm^2 (E > 1.0 MeV)

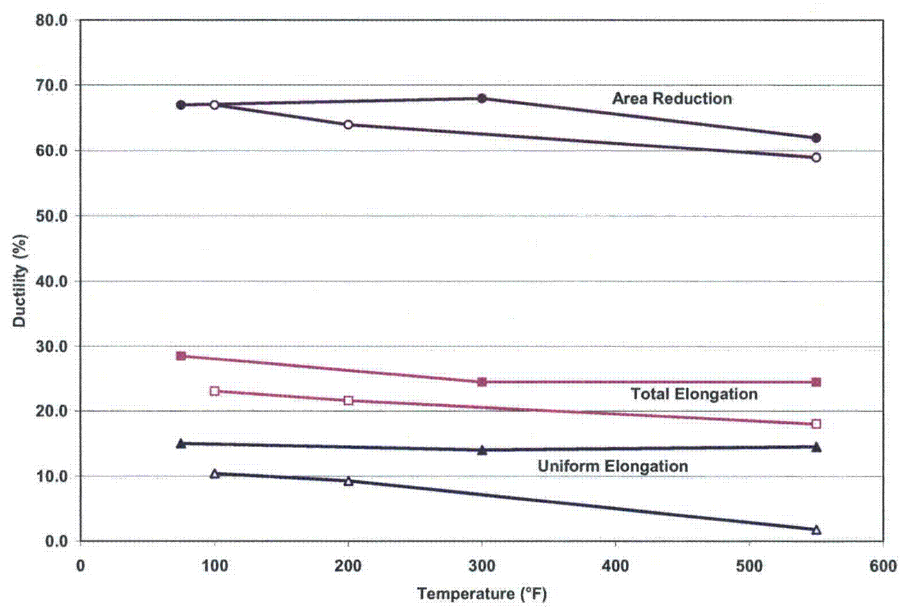
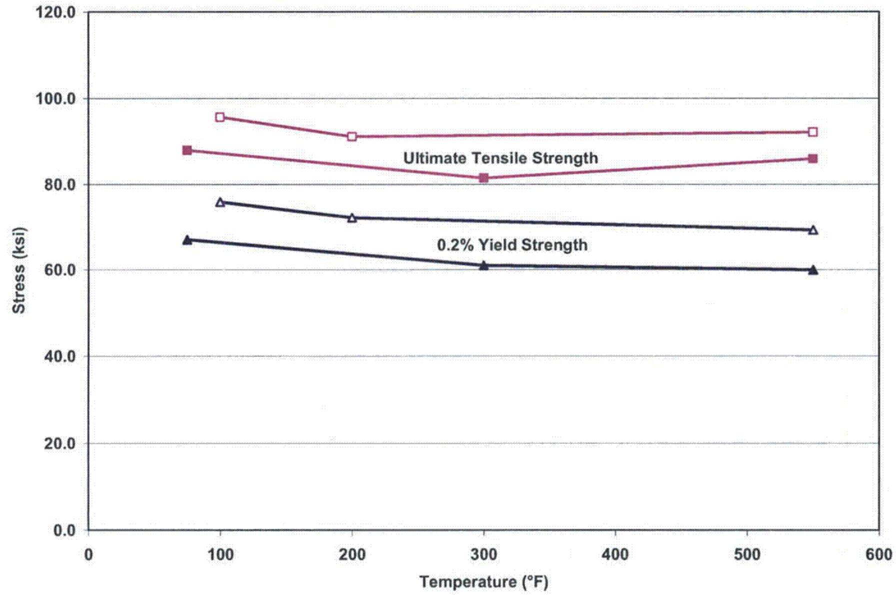


Figure 5-17 Tensile Properties for Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Longitudinal Orientation)



Legend: ▲ and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 3.38E+19 n/cm^2 (E > 1.0 MeV)

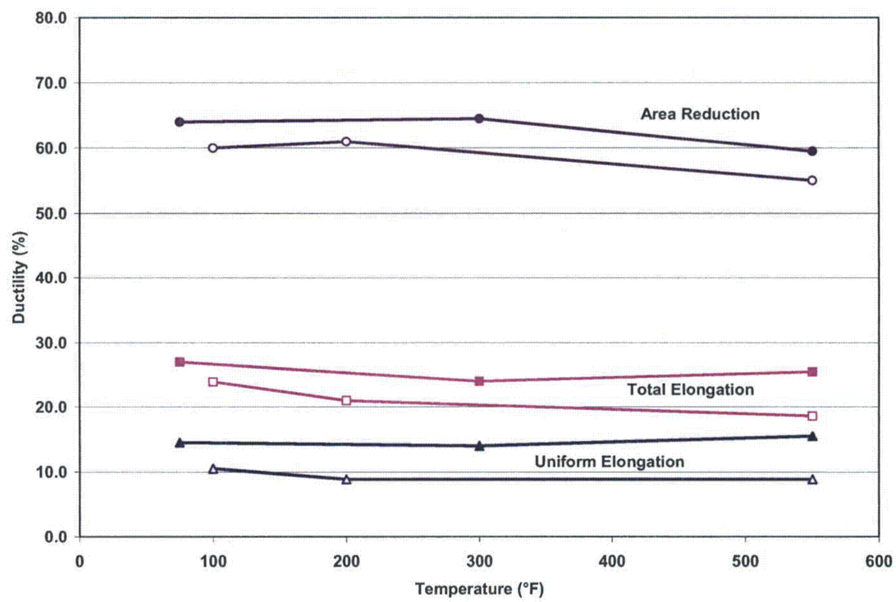
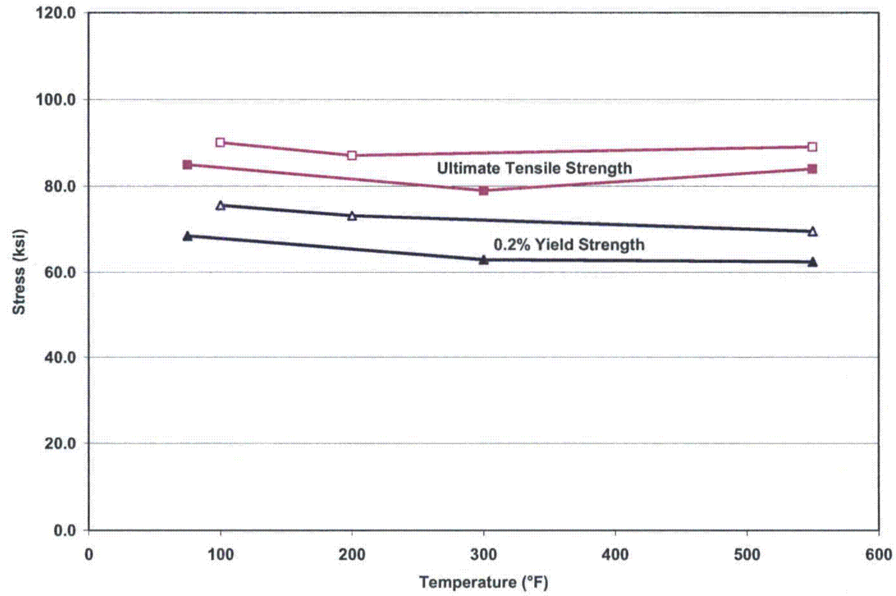


Figure 5-18 Tensile Properties for Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Transverse Orientation)



Legend: ▲and ● and ■ are unirradiated
Δ and ○ and □ are irradiated to 3.38E+19 n/cm^2 (E > 1.0 MeV)

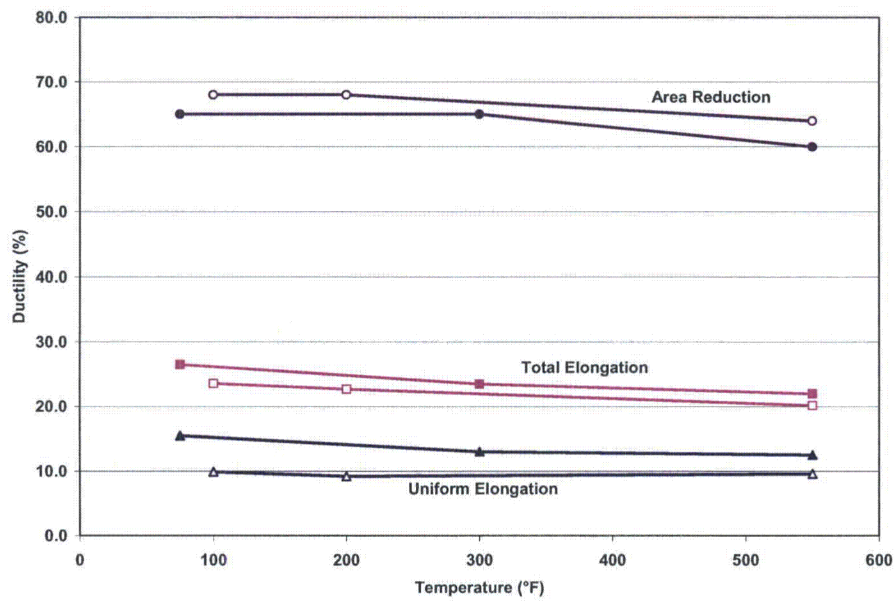
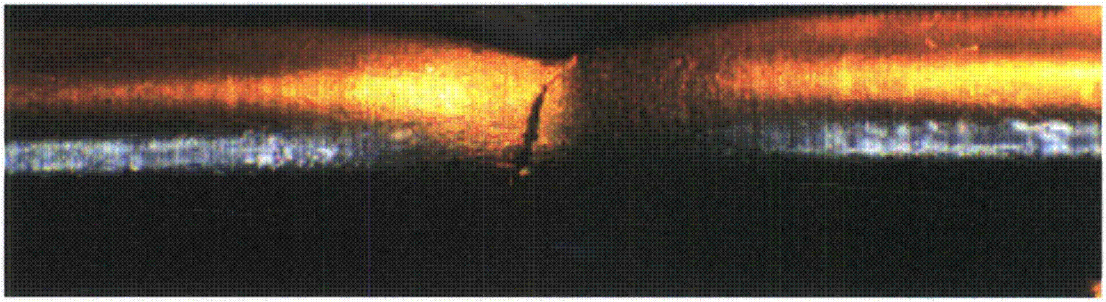
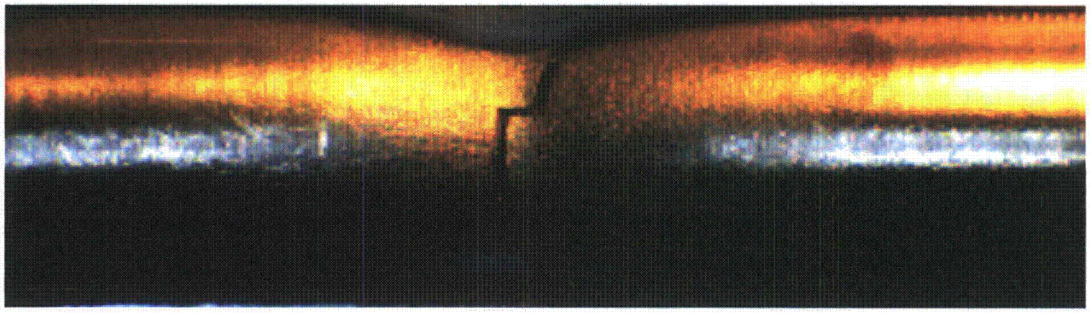


Figure 5-19 Tensile Properties for the Comanche Peak Unit 2 Reactor Vessel Surveillance Program Weld Metal



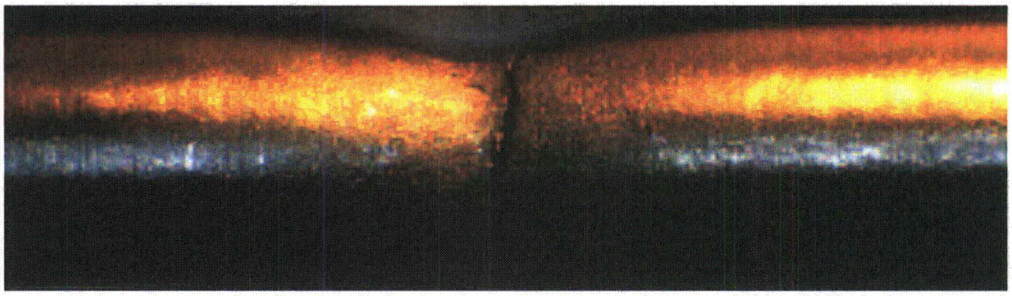
Specimen CL7- Tested at 100°F



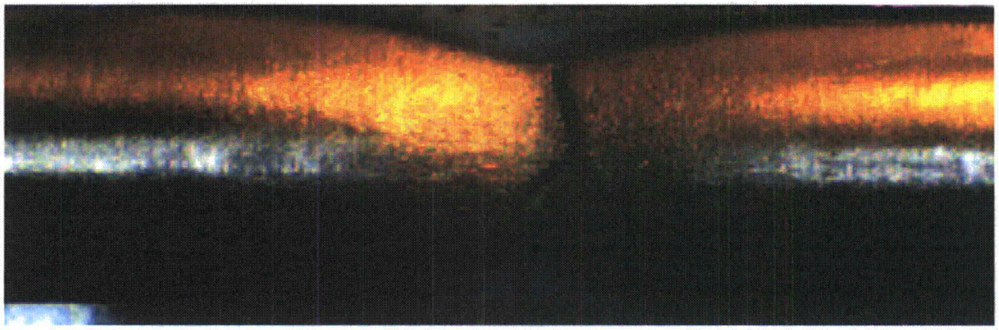
Specimen CL8- Tested at 200°F

Specimen CL9- Tested at 550°F

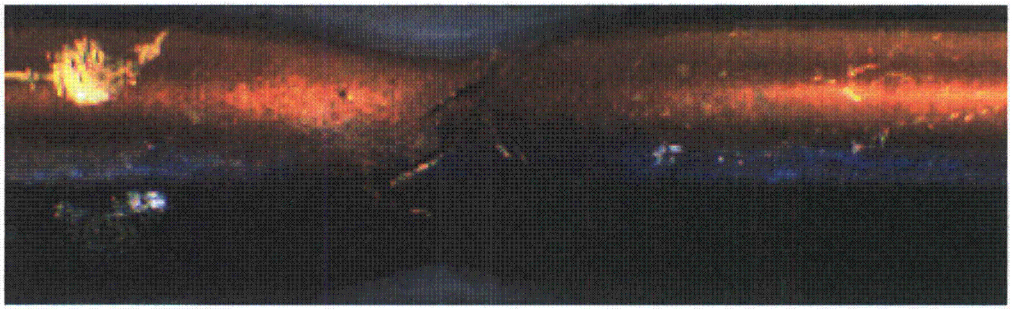
Figure 5-20 Fractured Tensile Specimens from Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Longitudinal Orientation)



Specimen CT7- Tested at 100°F

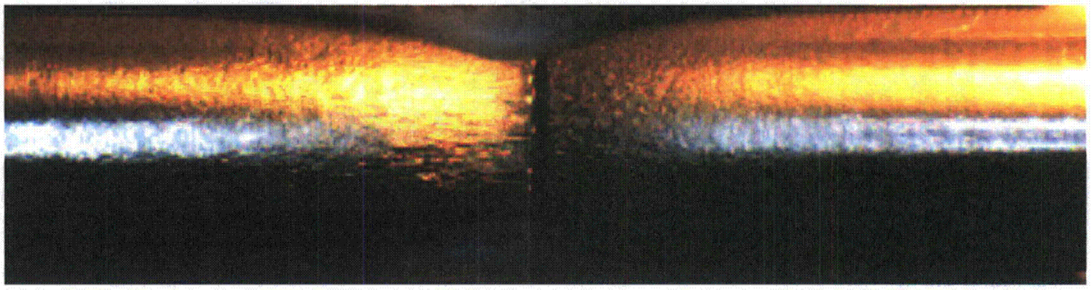


Specimen CT8- Tested at 200°F

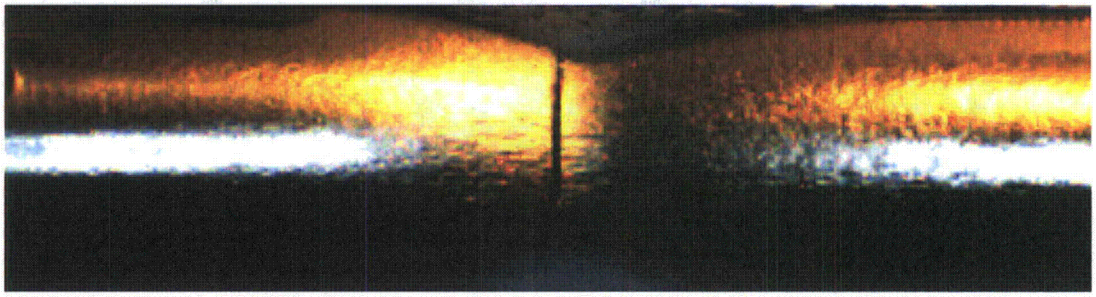


Specimen CT9- Tested at 550°F

Figure 5-21 Fractured Tensile Specimens from Comanche Peak Unit 2 Reactor Vessel Intermediate Shell Plate R3807-2 (Transverse Orientation)



Specimen CW7- Tested at 100°F



Specimen CW8- Tested at 200°F

Specimen CW9- Tested at 550°F

Figure 5-22 Fractured Tensile Specimens from the Comanche Peak Unit 2 Reactor Vessel Surveillance Program Weld Metal

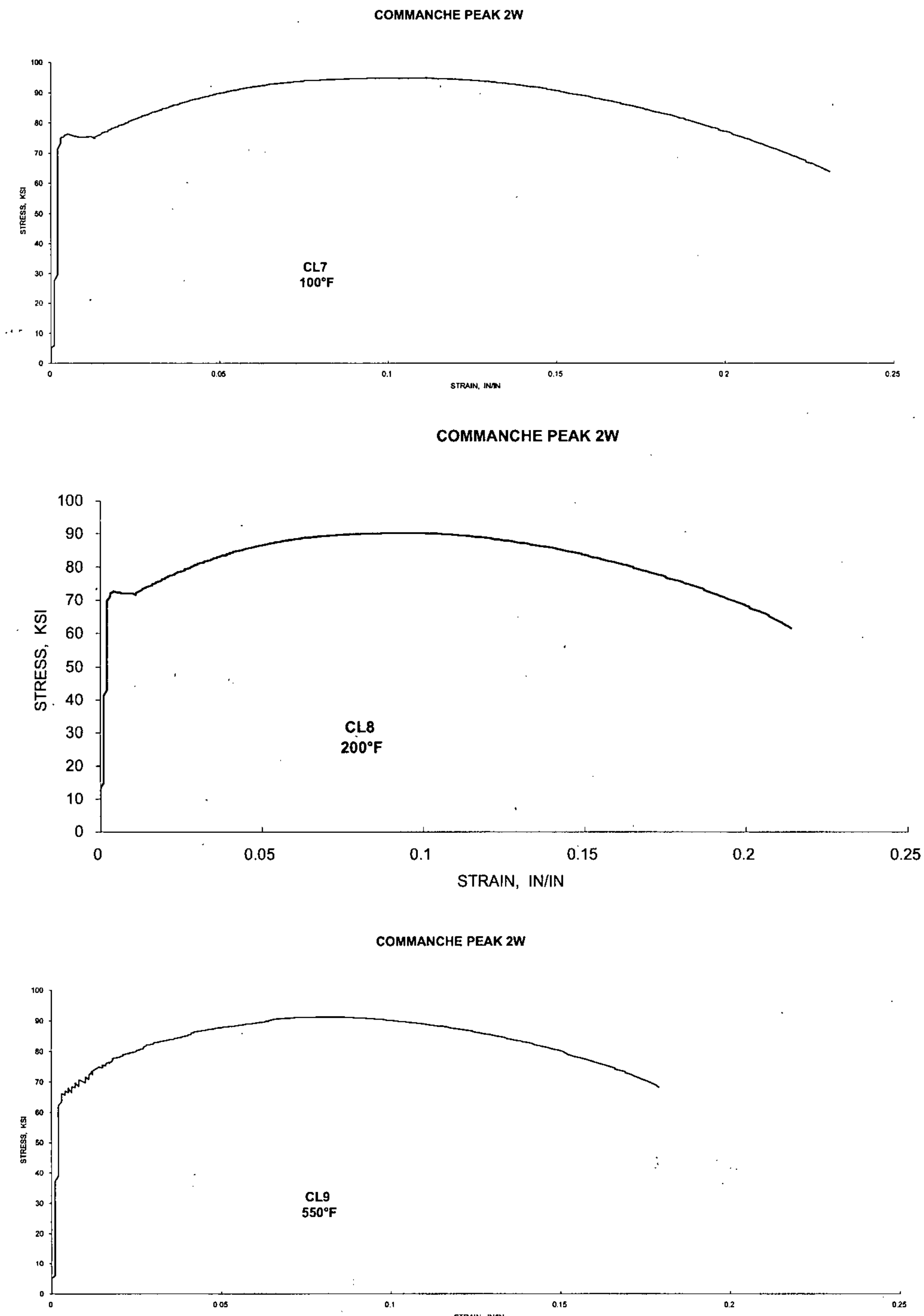


Figure 5-23 Engineering Stress-Strain Curves for Comanche Peak Unit 2 Intermediate Shell Plate R3807-2 Tensile Specimens CL7, CL8 and CL9 (Longitudinal Orientation)

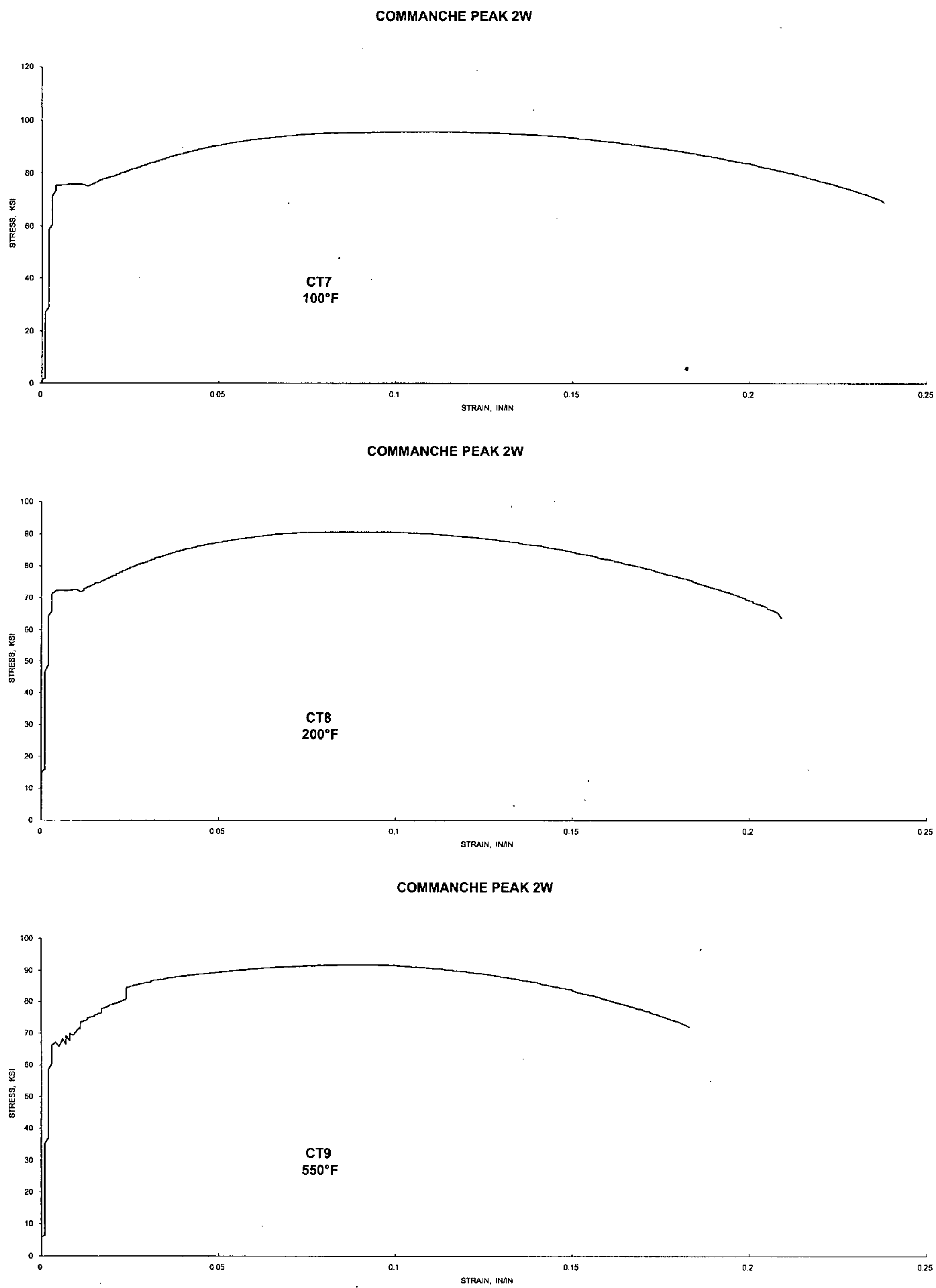


Figure 5-24 Engineering Stress-Strain Curves for Comanche Peak Unit 2 Intermediate Shell Plate R3807-2 Tensile Specimens CT7, CT8 and CT9 (Transverse Orientation)

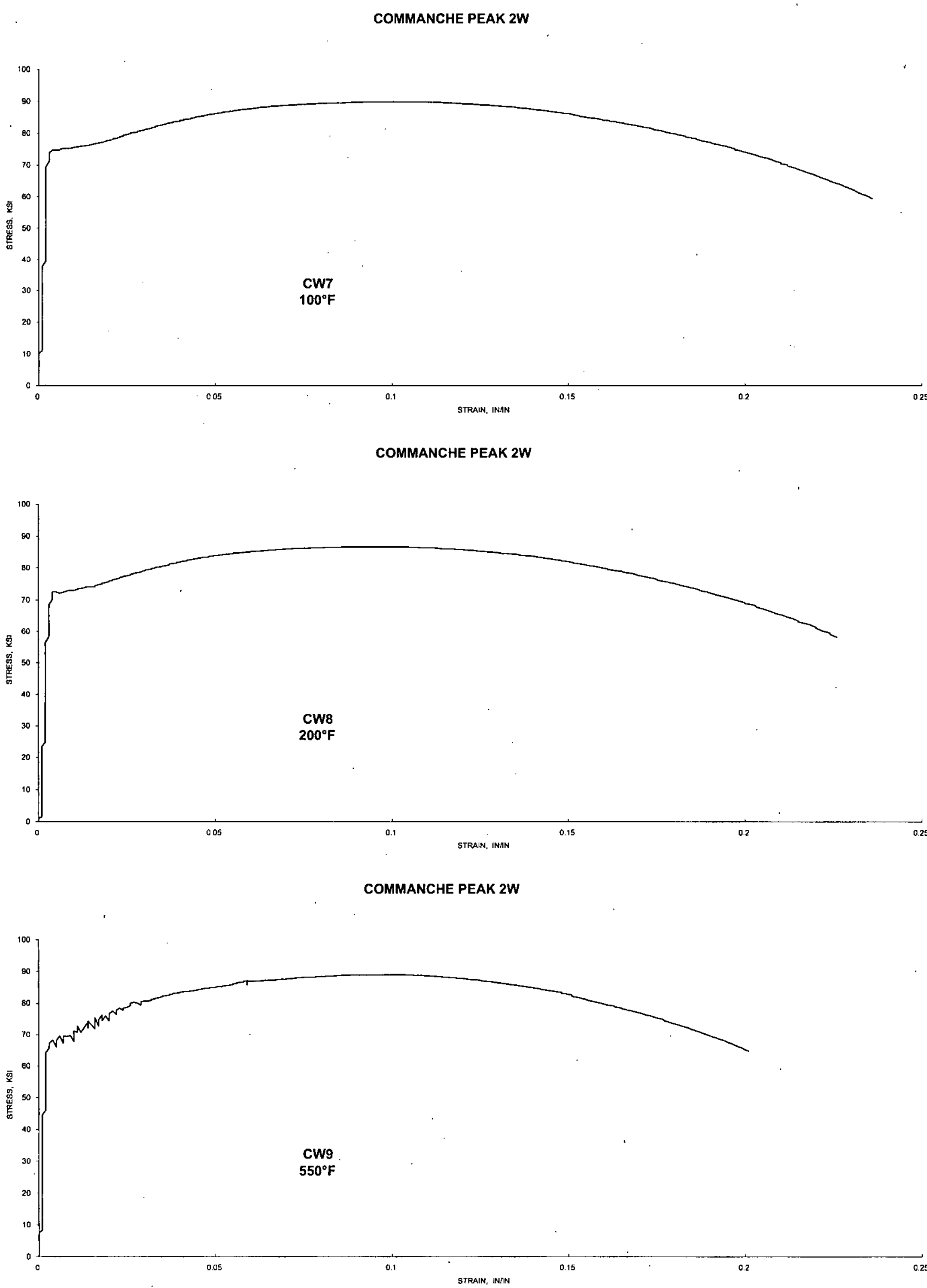


Figure 5-25 Engineering Stress-Strain Curves for Comanche Peak Unit 2 Surveillance Program Weld Metal Tensile Specimens CW7, CW8 and CW9

6 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION

This section describes a discrete ordinates S_n transport analysis performed for the Comanche Peak 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 W, withdrawn at the end of the eleventh plant operating cycle, is provided. In addition, to provide an up-to-date database applicable to the Comanche Peak Unit 2 reactor, the sensor sets from the previously withdrawn and analyzed capsules (U and X) were re-analyzed using the current dosimetry evaluation methodology. Capsules V and Y have been removed from the reactor vessel at the end of Cycle 7, Capsule Z has been removed from the reactor vessel at the end of Cycle 11, but all these three capsules have been stored in the spent fuel pool and have never been analyzed; therefore, their sensor sets were not analyzed in this analysis either. The updated dosimetry analysis results are presented in Appendix A of this report. Comparisons of the results from these dosimetry evaluations with the analytical predictions served to validate the plant-specific neutron transport calculations. These validated calculations subsequently formed the basis for providing projections of the neutron exposure of the reactor pressure vessel for operating periods extending to 60 Effective Full Power Years (EFPY).

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

Because of this potential shift away from a threshold fluence toward an energy-dependent damage function for data correlation, ASTM Standard Practice E853-01, "Analysis and Interpretation of Light-Water Reactor Surveillance Results" [Ref. 19], recommends reporting displacements per iron atom (dpa) along with fluence (E > 1.0 MeV) to provide a database for future reference. The energy-dependent dpa function to be used for this evaluation is specified in ASTM Standard Practice E693-01, "Standard Practice for Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements per Atom" [Ref. 20]. The application of the dpa parameter to the assessment of embrittlement gradients through the thickness of the reactor vessel wall has already been promulgated in Revision 2 to Regulatory Guide 1.99, "Radiation Embrittlement of Reactor Vessel Materials."

All of the calculations and dosimetry evaluations described in this section and in Appendix A were based on the nuclear cross-section data derived from ENDF/B-VI and made use of the latest available calculational tools. Furthermore, the neutron transport and dosimetry evaluation methodologies follow the guidance of Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence" [Ref. 21]. Additionally, the methods used to develop the calculated pressure vessel fluence are consistent with the NRC-approved methodology described in WCAP-14040-

A, Revision 4, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves," May 2004 [Ref. 22].

6.2 DISCRETE ORDINATES ANALYSIS

A plan view of the Comanche Peak Unit 2 reactor geometry at the core midplane 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°, 121.5°, 238.5°, 241°, and 301.5°, as shown in Figure 4-1. These full-core positions correspond to the following octant symmetric locations represented in Figures 6-1 through 6-3: 29° from the core cardinal axes (for the 61° and 241° dual surveillance capsule holder locations found in octants with a 22.5° neutron pad segment) and 31.5° from the core cardinal axes (for the 121.5° and 301.5° single surveillance capsule holder locations found in octants with a 20.0° neutron pad segment, and for the 58.5° and the 238.5° dual surveillance capsule holder locations found in octants with a 22.5° neutron pad segment). The stainless steel specimen containers are 1.182-inch by 1-inch and are approximately 56 inches in height. The containers are positioned axially such that the test specimens are centered on the core midplane, thus spanning the 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 marked effect on both the spatial distribution of neutron flux and the neutron energy spectrum in the water annulus between the neutron pads and the reactor vessel. In order to determine the neutron environment at the test specimen location, the capsules themselves must be included in the analytical model.

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

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

where $\phi(r,\theta,z)$ is the synthesized three-dimensional neutron flux distribution, $\phi(r,\theta)$ is the transport solution in r,θ geometry, $\phi(r,z)$ is the two-dimensional solution for a cylindrical reactor model using the actual axial core power distribution, and $\phi(r)$ is the one-dimensional solution for a cylindrical reactor model using the same source per unit height as that used in the r,θ two-dimensional calculation. This synthesis procedure was carried out for each operating cycle at Comanche Peak Unit 2.

For the Comanche Peak Unit 2 transport calculations, the r,θ models depicted in Figures 6-1 through 6-3 were utilized since, 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 models consisted of 183 radial by 99 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 Comanche Peak Unit 2 calculations is shown in Figure 6-4 and extends radially from the centerline of the reactor core out to a location interior to the primary biological shield and over an axial span from an elevation below the lower core plate to above the upper core plate. As in the case of the r,θ models, nominal design dimensions and full-power coolant densities were employed in the calculations. In this case, the homogenous core region was treated as an equivalent cylinder with a volume equal to that of the active core zone. The stainless steel former plates located between the core baffle and core barrel regions were also explicitly included in the model. The r,z geometric mesh description of these reactor models consisted of 153 radial by 188 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 Cycle 1 through Cycle 7 were provided by TXU, and Cycle 8 through Cycle 11 data were obtained from the Nuclear Fuels Division of Westinghouse. Specifically, the data utilized included cycle-dependent fuel assembly initial enrichments, burnups, and axial power distributions. This information was used to develop spatial- and energy-dependent core source distributions averaged over each individual fuel cycle. Therefore, the results from the neutron transport calculations provided data in terms of fuel-cycle-averaged neutron flux, which, when multiplied by the appropriate fuel cycle length, generated the incremental fast neutron exposure for each fuel cycle. In constructing these core source distributions, the energy distribution of the source was based on an appropriate fission split for uranium and plutonium isotopes based on the initial enrichment and burnup history of individual fuel assemblies. From these assembly-dependent fission splits, composite values of energy release per fission, neutron yield per fission, and fission spectrum were determined.

All of the transport calculations supporting this analysis were carried out using the DORT discrete ordinates code Version 3.2 [Ref. 23] and the BUGLE-96 cross-section library [Ref. 24]. The BUGLE-96 library provides a 67-group coupled neutron-gamma ray cross-section data set produced specifically for light water reactor (LWR) applications. In these analyses, anisotropic scattering was treated with a P_5 legendre expansion and angular discretization was modeled with an S_{16} order of angular quadrature. Energy- and space-dependent core power distributions, as well as system operating temperatures, were treated on a fuel-cycle-specific basis.

Selected results from the neutron transport analyses are provided in Tables 6-1 through 6-6. Cumulative irradiation times contained within these tables are expressed in terms of EFPY as well as Effective Full Power Seconds (EFPS). In Table 6-1, the calculated exposure rates and integrated exposures, expressed in terms of both neutron fluence (E > 1.0 MeV) and dpa, are given at the radial and azimuthal center of the octant symmetric surveillance capsule positions, i.e., for the 29° dual capsule, 31.5° dual capsule, and 31.5° single capsule. These results, representative of the axial midplane of the active core, establish the calculated exposure of the surveillance capsules withdrawn to date as well as projected into the future. Similar information is provided in Table 6-2 for the reactor vessel inner radius at five azimuthal locations and the overall maximum fluence (azimuthally and axially). The vessel data given in Table 6-2 were taken at the clad/base metal interface, and thus, represent maximum calculated exposure levels on the vessel.

From the data provided in Table 6-2 it is noted that the peak clad/base metal interface vessel fluence (E > 1.0 MeV) at the end of the eleventh fuel cycle (i.e., after 14.51 EFPY of plant operation) was 8.76×10^{18} n/cm^2.

Both calculated fluence (E > 1.0 MeV) and dpa data are provided in Tables 6-1 and 6-2. These data tabulations include both plant- and fuel-cycle-specific calculated neutron exposures at the end of the eleventh fuel cycle as well as future projections to 15.92, 20, 24, 30, 36, 42, 48, 54, and 60 EFPY. The calculations account for uprates from 3411 MWt to 3445 MWt that occurred during Cycle 5, and from 3445 MWt to 3458 MWt that occurred during Cycle 6. The projections were based on the assumption that the core power distributions and associated plant operating characteristics from Cycle 12 were representative of future plant operation. The future projections are also based on the current reactor power level of 3612 MWt.

Radial gradient information applicable to fast (E > 1.0 MeV) neutron fluence and dpa are given in Tables 6-3 and 6-4, respectively. The data, based on the cumulative integrated exposures from Cycles 1 through 11, are presented on a relative basis for each exposure parameter at several azimuthal locations. Exposure distributions through the vessel wall may be obtained by multiplying the calculated exposure at the vessel inner radius by the gradient data listed in Tables 6-3 and 6-4.

The calculated fast neutron exposures for the three surveillance capsules withdrawn and analyzed from Comanche Peak Unit 2 reactor are provided in Table 6-5. These assigned neutron exposure levels are based on the plant-and fuel-cycle-specific neutron transport calculations performed for the Comanche Peak Unit 2 reactor.

From the data provided in Table 6-5, Capsule W received a fluence (E > 1.0 MeV) of 3.38×10^{19} n/cm^2 after exposure through the end of the eleventh fuel cycle (i.e., after 14.51 EFPY of plant operation).

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

6.3 NEUTRON DOSIMETRY

The validity of the calculated neutron exposures previously reported in Section 6.2 is demonstrated by a direct comparison against the measured sensor reaction rates and via a least squares evaluation performed for each of the capsule dosimetry sets. However, since the neutron dosimetry measurement data merely serves to validate the calculated results, only the direct comparison of measured-to-calculated results for the most recent surveillance capsule removed from service is provided in this section of the report. For completeness, the assessment of all measured dosimetry removed to date, based on both direct and least squares evaluation comparisons are documented in Appendix A.

The direct comparison of measured versus calculated fast neutron threshold reaction rates for the sensors from Capsule W, which was withdrawn from Comanche Peak Unit 2 at the end of the fourteenth fuel cycle, is summarized below.

Reaction	Reaction Rates (rps/atom)		M/C Ratio
	Measured	Calculated	
$^{63}Cu(n,\alpha)^{60}Co$	4.70E-17	4.00E-17	1.18
$^{54}Fe(n,p)^{54}Mn$	4.76E-15	4.38E-15	1.09
$^{58}Ni(n,p)^{58}Co$	7.04E-15	6.13E-15	1.15
$^{238}U(n,f)^{137}Cs$ (Cd)	2.94E-14	2.33E-14	1.26
$^{237}Np(n,f)^{137}Cs$ (Cd)	2.48E-13	2.28E-13	1.09
		Average:	1.15
		% Standard Deviation:	6.1

The measured-to-calculated (M/C) reaction rate ratios for the Capsule W threshold reactions range from 1.09 to 1.26, and the average M/C ratio is 1.15 ± 6.1% (1σ). This direct comparison falls well within the ± 20% criterion specified in Regulatory Guide 1.190; furthermore, it is consistent with the full set of comparisons given in Appendix A for all measured dosimetry removed to date from the Comanche Peak Unit 2 reactor. These comparisons validate the current analytical results described in Section 6.2; therefore, the calculations are deemed applicable for Comanche Peak Unit 2.

6.4 CALCULATIONAL UNCERTAINTIES

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

The fourth phase of the uncertainty assessment (comparisons with Comanche Peak 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 Comanche Peak 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 24.

	Capsule	**Vessel IR**
PCA Comparisons	3%	3%
H. B. Robinson Comparisons	3%	3%
Analytical Sensitivity Studies	10%	11%
Additional Uncertainty for Factors not Explicitly Evaluated	5%	5%
Net Calculational Uncertainty	12%	13%

The net calculational uncertainty was determined by combining the individual components in quadrature. Therefore, the resultant uncertainty was treated as random and no systematic bias was applied to the analytical results.

The plant-specific measurement comparisons described in Appendix A support these uncertainty assessments for Comanche Peak Unit 2.

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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Flux (E > 1.0 MeV) [n/cm²-s]		
				Dual 29°	Dual 31.5°	Single 31.5°
1	2.87E+07	2.87E+07	0.91	1.01E+11	1.11E+11	1.09E+11
2	3.73E+07	6.60E+07	2.09	6.48E+10	7.16E+10	7.10E+10
3	4.42E+07	1.10E+08	3.49	7.47E+10	7.85E+10	7.76E+10
4	3.84E+07	1.49E+08	4.71	6.78E+10	7.20E+10	7.13E+10
5	4.52E+07	1.94E+08	6.14	6.68E+10	7.12E+10	7.05E+10
6	4.37E+07	2.37E+08	7.52	6.83E+10	7.15E+10	7.07E+10
7	4.12E+07	2.79E+08	8.83	7.12E+10	7.78E+10	7.70E+10
8	4.35E+07	3.22E+08	10.21	6.92E+10	7.32E+10	7.24E+10
9	4.52E+07	3.67E+08	11.64	6.99E+10	7.49E+10	7.41E+10
10	4.44E+07	4.12E+08	13.05	6.67E+10	7.00E+10	6.92E+10
11	4.60E+07	4.58E+08	14.51	5.69E+10	6.13E+10	6.07E+10
Future	4.64E+07	5.04E+08	15.92	6.63E+10	7.25E+10	7.18E+10
Future	1.27E+08	6.31E+08	20.00	6.63E+10	7.25E+10	7.18E+10
Future	1.26E+08	7.57E+08	24.00	6.63E+10	7.25E+10	7.18E+10
Future	1.89E+08	9.47E+08	30.00	6.63E+10	7.25E+10	7.18E+10
Future	1.89E+08	1.14E+09	36.00	6.63E+10	7.25E+10	7.18E+10
Future	1.89E+08	1.33E+09	42.00	6.63E+10	7.25E+10	7.18E+10
Future	1.89E+08	1.51E+09	48.00	6.63E+10	7.25E+10	7.18E+10
Future	1.89E+08	1.70E+09	54.00	6.63E+10	7.25E+10	7.18E+10
Future	1.89E+08	1.89E+09	60.00	6.63E+10	7.25E+10	7.18E+10

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Fluence (E > 1.0 MeV) [n/cm^2]		
				Dual 29°	Dual 31.5°	Single 31.5°
1	2.87E+07	2.87E+07	0.91	2.90E+18	3.17E+18	3.14E+18
2	3.73E+07	6.60E+07	2.09	5.31E+18	5.84E+18	5.79E+18
3	4.42E+07	1.10E+08	3.49	8.61E+18	9.31E+18	9.22E+18
4	3.84E+07	1.49E+08	4.71	1.12E+19	1.21E+19	1.20E+19
5	4.52E+07	1.94E+08	6.14	1.42E+19	1.53E+19	1.51E+19
6	4.37E+07	2.37E+08	7.52	1.72E+19	1.84E+19	1.82E+19
7	4.12E+07	2.79E+08	8.83	2.02E+19	2.16E+19	2.14E+19
8	4.35E+07	3.22E+08	10.21	2.32E+19	2.48E+19	2.46E+19
9	4.52E+07	3.67E+08	11.64	2.63E+19	2.82E+19	2.79E+19
10	4.44E+07	4.12E+08	13.05	2.93E+19	3.13E+19	3.10E+19
11	4.60E+07	4.58E+08	14.51	3.19E+19	3.41E+19	3.38E+19
Future	4.64E+07	5.04E+08	15.92	3.49E+19	3.73E+19	3.70E+19
Future	1.27E+08	6.31E+08	20.00	4.34E+19	4.67E+19	4.62E+19
Future	1.26E+08	7.57E+08	24.00	5.18E+19	5.58E+19	5.53E+19
Future	1.89E+08	9.47E+08	30.00	6.43E+19	6.95E+19	6.89E+19
Future	1.89E+08	1.14E+09	36.00	7.69E+19	8.33E+19	8.25E+19
Future	1.89E+08	1.33E+09	42.00	8.94E+19	9.70E+19	9.61E+19
Future	1.89E+08	1.51E+09	48.00	1.02E+20	1.11E+20	1.10E+20
Future	1.89E+08	1.70E+09	54.00	1.15E+20	1.24E+20	1.23E+20
Future	1.89E+08	1.89E+09	60.00	1.27E+20	1.38E+20	1.37E+20

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacement Rate [dpa/s]		
				Dual 29°	Dual 31.5°	Single 31.5°
1	2.87E+07	2.87E+07	0.91	1.99E-10	2.18E-10	2.15E-10
2	3.73E+07	6.60E+07	2.09	1.26E-10	1.40E-10	1.38E-10
3	4.42E+07	1.10E+08	3.49	1.46E-10	1.53E-10	1.51E-10
4	3.84E+07	1.49E+08	4.71	1.32E-10	1.40E-10	1.39E-10
5	4.52E+07	1.94E+08	6.14	1.30E-10	1.39E-10	1.37E-10
6	4.37E+07	2.37E+08	7.52	1.33E-10	1.39E-10	1.38E-10
7	4.12E+07	2.79E+08	8.83	1.39E-10	1.52E-10	1.51E-10
8	4.35E+07	3.22E+08	10.21	1.35E-10	1.43E-10	1.41E-10
9	4.52E+07	3.67E+08	11.64	1.37E-10	1.46E-10	1.45E-10
10	4.44E+07	4.12E+08	13.05	1.30E-10	1.36E-10	1.35E-10
11	4.60E+07	4.58E+08	14.51	1.11E-10	1.19E-10	1.18E-10
Future	4.64E+07	5.04E+08	15.92	1.30E-10	1.42E-10	1.40E-10
Future	1.27E+08	6.31E+08	20.00	1.30E-10	1.42E-10	1.40E-10
Future	1.26E+08	7.57E+08	24.00	1.30E-10	1.42E-10	1.40E-10
Future	1.89E+08	9.47E+08	30.00	1.30E-10	1.42E-10	1.40E-10
Future	1.89E+08	1.14E+09	36.00	1.30E-10	1.42E-10	1.40E-10
Future	1.89E+08	1.33E+09	42.00	1.30E-10	1.42E-10	1.40E-10
Future	1.89E+08	1.51E+09	48.00	1.30E-10	1.42E-10	1.40E-10
Future	1.89E+08	1.70E+09	54.00	1.30E-10	1.42E-10	1.40E-10
Future	1.89E+08	1.89E+09	60.00	1.30E-10	1.42E-10	1.40E-10

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacement [dpa]		
				Dual 29°	Dual 31.5°	Single 31.5°
1	2.87E+07	2.87E+07	0.91	5.70E-03	6.25E-03	6.19E-03
2	3.73E+07	6.60E+07	2.09	1.04E-02	1.14E-02	1.13E-02
3	4.42E+07	1.10E+08	3.49	1.69E-02	1.82E-02	1.80E-02
4	3.84E+07	1.49E+08	4.71	2.20E-02	2.36E-02	2.34E-02
5	4.52E+07	1.94E+08	6.14	2.78E-02	2.99E-02	2.96E-02
6	4.37E+07	2.37E+08	7.52	3.36E-02	3.60E-02	3.56E-02
7	4.12E+07	2.79E+08	8.83	3.94E-02	4.23E-02	4.18E-02
8	4.35E+07	3.22E+08	10.21	4.53E-02	4.85E-02	4.79E-02
9	4.52E+07	3.67E+08	11.64	5.15E-02	5.51E-02	5.45E-02
10	4.44E+07	4.12E+08	13.05	5.73E-02	6.11E-02	6.05E-02
11	4.60E+07	4.58E+08	14.51	6.24E-02	6.66E-02	6.59E-02
Future	4.64E+07	5.04E+08	15.92	6.81E-02	7.29E-02	7.21E-02
Future	1.27E+08	6.31E+08	20.00	8.48E-02	9.12E-02	9.02E-02
Future	1.26E+08	7.57E+08	24.00	1.01E-01	1.09E-01	1.08E-01
Future	1.89E+08	9.47E+08	30.00	1.26E-01	1.36E-01	1.34E-01
Future	1.89E+08	1.14E+09	36.00	1.50E-01	1.63E-01	1.61E-01
Future	1.89E+08	1.33E+09	42.00	1.75E-01	1.89E-01	1.87E-01
Future	1.89E+08	1.51E+09	48.00	1.99E-01	2.16E-01	2.14E-01
Future	1.89E+08	1.70E+09	54.00	2.24E-01	2.43E-01	2.41E-01
Future	1.89E+08	1.89E+09	60.00	2.48E-01	2.70E-01	2.67E-01

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Flux (E > 1.0 MeV) [n/cm²-s]					
				0°	15°	21°	30°	45°	Max
1	2.87E+07	2.87E+07	0.91	1.46E+10	2.16E+10	2.55E+10	2.54E+10	2.79E+10	2.79E+10
2	3.73E+07	6.60E+07	2.09	1.14E+10	1.41E+10	1.59E+10	1.66E+10	1.74E+10	1.74E+10
3	4.42E+07	1.10E+08	3.49	1.44E+10	2.09E+10	2.21E+10	1.91E+10	1.86E+10	2.22E+10
4	3.84E+07	1.49E+08	4.71	1.25E+10	1.85E+10	1.97E+10	1.76E+10	1.70E+10	1.97E+10
5	4.52E+07	1.94E+08	6.14	1.13E+10	1.64E+10	1.83E+10	1.71E+10	1.65E+10	1.83E+10
6	4.37E+07	2.37E+08	7.52	1.27E+10	1.77E+10	1.94E+10	1.73E+10	1.56E+10	1.94E+10
7	4.12E+07	2.79E+08	8.83	1.36E+10	1.81E+10	1.95E+10	1.82E+10	1.96E+10	1.96E+10
8	4.35E+07	3.22E+08	10.21	1.31E+10	1.85E+10	1.99E+10	1.78E+10	1.72E+10	1.99E+10
9	4.52E+07	3.67E+08	11.64	1.28E+10	1.82E+10	1.95E+10	1.78E+10	1.77E+10	1.95E+10
10	4.44E+07	4.12E+08	13.05	1.22E+10	1.74E+10	1.91E+10	1.71E+10	1.63E+10	1.91E+10
11	4.60E+07	4.58E+08	14.51	1.07E+10	1.42E+10	1.57E+10	1.53E+10	1.50E+10	1.58E+10
Future	4.64E+07	5.04E+08	15.92	9.38E+09	1.41E+10	1.67E+10	1.71E+10	1.82E+10	1.82E+10
Future	1.27E+08	6.31E+08	20.00	9.38E+09	1.41E+10	1.67E+10	1.71E+10	1.82E+10	1.82E+10
Future	1.26E+08	7.57E+08	24.00	9.38E+09	1.41E+10	1.67E+10	1.71E+10	1.82E+10	1.82E+10
Future	1.89E+08	9.47E+08	30.00	9.38E+09	1.41E+10	1.67E+10	1.71E+10	1.82E+10	1.82E+10
Future	1.89E+08	1.14E+09	36.00	9.38E+09	1.41E+10	1.67E+10	1.71E+10	1.82E+10	1.82E+10
Future	1.89E+08	1.33E+09	42.00	9.38E+09	1.41E+10	1.67E+10	1.71E+10	1.82E+10	1.82E+10
Future	1.89E+08	1.51E+09	48.00	9.38E+09	1.41E+10	1.67E+10	1.71E+10	1.82E+10	1.82E+10
Future	1.89E+08	1.70E+09	54.00	9.38E+09	1.41E+10	1.67E+10	1.71E+10	1.82E+10	1.82E+10
Future	1.89E+08	1.89E+09	60.00	9.38E+09	1.41E+10	1.67E+10	1.71E+10	1.82E+10	1.82E+10

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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Fluence (E > 1.0 MeV) [n/cm²]					
				0°	15°	21°	30°	45°	Max
1	2.87E+07	2.87E+07	0.91	4.18E+17	6.20E+17	7.33E+17	7.29E+17	8.01E+17	8.01E+17
2	3.73E+07	6.60E+07	2.09	8.40E+17	1.14E+18	1.32E+18	1.34E+18	1.44E+18	1.44E+18
3	4.42E+07	1.10E+08	3.49	1.48E+18	2.07E+18	2.30E+18	2.18E+18	2.26E+18	2.30E+18
4	3.84E+07	1.49E+08	4.71	1.95E+18	2.76E+18	3.03E+18	2.84E+18	2.90E+18	3.03E+18
5	4.52E+07	1.94E+08	6.14	2.45E+18	3.50E+18	3.86E+18	3.61E+18	3.64E+18	3.86E+18
6	4.37E+07	2.37E+08	7.52	3.01E+18	4.27E+18	4.70E+18	4.36E+18	4.32E+18	4.70E+18
7	4.12E+07	2.79E+08	8.83	3.57E+18	5.02E+18	5.51E+18	5.12E+18	5.14E+18	5.51E+18
8	4.35E+07	3.22E+08	10.21	4.13E+18	5.81E+18	6.36E+18	5.88E+18	5.87E+18	6.36E+18
9	4.52E+07	3.67E+08	11.64	4.70E+18	6.62E+18	7.23E+18	6.67E+18	6.66E+18	7.23E+18
10	4.44E+07	4.12E+08	13.05	5.23E+18	7.39E+18	8.07E+18	7.42E+18	7.37E+18	8.07E+18
11	4.60E+07	4.58E+08	14.51	5.70E+18	8.01E+18	8.76E+18	8.10E+18	8.03E+18	8.76E+18
Future	4.64E+07	5.04E+08	15.92	6.11E+18	8.63E+18	9.49E+18	8.84E+18	8.83E+18	9.49E+18
Future	1.27E+08	6.31E+08	20.00	7.32E+18	1.04E+19	1.16E+19	1.10E+19	1.12E+19	1.18E+19
Future	1.26E+08	7.57E+08	24.00	8.51E+18	1.22E+19	1.38E+19	1.32E+19	1.35E+19	1.41E+19
Future	1.89E+08	9.47E+08	30.00	1.03E+19	1.49E+19	1.69E+19	1.64E+19	1.69E+19	1.76E+19
Future	1.89E+08	1.14E+09	36.00	1.21E+19	1.75E+19	2.01E+19	1.97E+19	2.04E+19	2.10E+19
Future	1.89E+08	1.33E+09	42.00	1.38E+19	2.02E+19	2.32E+19	2.29E+19	2.38E+19	2.45E+19
Future	1.89E+08	1.51E+09	48.00	1.56E+19	2.29E+19	2.64E+19	2.61E+19	2.73E+19	2.79E+19
Future	1.89E+08	1.70E+09	54.00	1.74E+19	2.55E+19	2.96E+19	2.94E+19	3.07E+19	3.14E+19
Future	1.89E+08	1.89E+09	60.00	1.92E+19	2.82E+19	3.27E+19	3.26E+19	3.42E+19	3.48E+19

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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacement Rate [dpa/s]					
				0°	15°	21°	30°	45°	Max
1	2.87E+07	2.87E+07	0.91	2.26E-11	3.31E-11	3.91E-11	3.91E-11	4.41E-11	4.41E-11
2	3.73E+07	6.60E+07	2.09	1.77E-11	2.18E-11	2.44E-11	2.56E-11	2.74E-11	2.74E-11
3	4.42E+07	1.10E+08	3.49	2.23E-11	3.21E-11	3.39E-11	2.94E-11	2.94E-11	3.39E-11
4	3.84E+07	1.49E+08	4.71	1.94E-11	2.85E-11	3.02E-11	2.72E-11	2.69E-11	3.02E-11
5	4.52E+07	1.94E+08	6.14	1.75E-11	2.52E-11	2.81E-11	2.63E-11	2.61E-11	2.81E-11
6	4.37E+07	2.37E+08	7.52	1.96E-11	2.72E-11	2.97E-11	2.67E-11	2.47E-11	2.97E-11
7	4.12E+07	2.79E+08	8.83	2.11E-11	2.79E-11	2.99E-11	2.82E-11	3.10E-11	3.10E-11
8	4.35E+07	3.22E+08	10.21	2.04E-11	2.85E-11	3.05E-11	2.74E-11	2.71E-11	3.05E-11
9	4.52E+07	3.67E+08	11.64	1.98E-11	2.80E-11	2.99E-11	2.75E-11	2.80E-11	2.99E-11
10	4.44E+07	4.12E+08	13.05	1.88E-11	2.67E-11	2.93E-11	2.64E-11	2.57E-11	2.93E-11
11	4.60E+07	4.58E+08	14.51	1.65E-11	2.18E-11	2.41E-11	2.37E-11	2.36E-11	2.43E-11
Future	4.64E+07	5.04E+08	15.92	1.46E-11	2.16E-11	2.56E-11	2.64E-11	2.88E-11	2.88E-11
Future	1.27E+08	6.31E+08	20.00	1.46E-11	2.16E-11	2.56E-11	2.64E-11	2.88E-11	2.88E-11
Future	1.26E+08	7.57E+08	24.00	1.46E-11	2.16E-11	2.56E-11	2.64E-11	2.88E-11	2.88E-11
Future	1.89E+08	9.47E+08	30.00	1.46E-11	2.16E-11	2.56E-11	2.64E-11	2.88E-11	2.88E-11
Future	1.89E+08	1.14E+09	36.00	1.46E-11	2.16E-11	2.56E-11	2.64E-11	2.88E-11	2.88E-11
Future	1.89E+08	1.33E+09	42.00	1.46E-11	2.16E-11	2.56E-11	2.64E-11	2.88E-11	2.88E-11
Future	1.89E+08	1.51E+09	48.00	1.46E-11	2.16E-11	2.56E-11	2.64E-11	2.88E-11	2.88E-11
Future	1.89E+08	1.70E+09	54.00	1.46E-11	2.16E-11	2.56E-11	2.64E-11	2.88E-11	2.88E-11
Future	1.89E+08	1.89E+09	60.00	1.46E-11	2.16E-11	2.56E-11	2.64E-11	2.88E-11	2.88E-11

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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacement [dpa]					
				0°	15°	21°	30°	45°	Max
1	2.87E+07	2.87E+07	0.91	6.48E-04	9.52E-04	1.12E-03	1.12E-03	1.27E-03	1.27E-03
2	3.73E+07	6.60E+07	2.09	1.30E-03	1.75E-03	2.02E-03	2.07E-03	2.28E-03	2.28E-03
3	4.42E+07	1.10E+08	3.49	2.29E-03	3.17E-03	3.52E-03	3.37E-03	3.57E-03	3.57E-03
4	3.84E+07	1.49E+08	4.71	3.01E-03	4.24E-03	4.65E-03	4.38E-03	4.58E-03	4.65E-03
5	4.52E+07	1.94E+08	6.14	3.81E-03	5.38E-03	5.91E-03	5.57E-03	5.76E-03	5.92E-03
6	4.37E+07	2.37E+08	7.52	4.66E-03	6.56E-03	7.21E-03	6.73E-03	6.83E-03	7.21E-03
7	4.12E+07	2.79E+08	8.83	5.53E-03	7.71E-03	8.45E-03	7.90E-03	8.12E-03	8.44E-03
8	4.35E+07	3.22E+08	10.21	6.40E-03	8.92E-03	9.74E-03	9.07E-03	9.27E-03	9.74E-03
9	4.52E+07	3.67E+08	11.64	7.29E-03	1.02E-02	1.11E-02	1.03E-02	1.05E-02	1.11E-02
10	4.44E+07	4.12E+08	13.05	8.11E-03	1.13E-02	1.24E-02	1.15E-02	1.17E-02	1.24E-02
11	4.60E+07	4.58E+08	14.51	8.84E-03	1.23E-02	1.34E-02	1.25E-02	1.27E-02	1.34E-02
Future	4.64E+07	5.04E+08	15.92	9.48E-03	1.33E-02	1.46E-02	1.37E-02	1.40E-02	1.46E-02
Future	1.27E+08	6.31E+08	20.00	1.14E-02	1.60E-02	1.79E-02	1.70E-02	1.77E-02	1.83E-02
Future	1.26E+08	7.57E+08	24.00	1.32E-02	1.88E-02	2.11E-02	2.04E-02	2.13E-02	2.19E-02
Future	1.89E+08	9.47E+08	30.00	1.60E-02	2.29E-02	2.59E-02	2.54E-02	2.68E-02	2.73E-02
Future	1.89E+08	1.14E+09	36.00	1.87E-02	2.70E-02	3.08E-02	3.04E-02	3.22E-02	3.28E-02
Future	1.89E+08	1.33E+09	42.00	2.15E-02	3.11E-02	3.56E-02	3.53E-02	3.77E-02	3.83E-02
Future	1.89E+08	1.51E+09	48.00	2.42E-02	3.52E-02	4.05E-02	4.03E-02	4.31E-02	4.37E-02
Future	1.89E+08	1.70E+09	54.00	2.70E-02	3.93E-02	4.53E-02	4.53E-02	4.86E-02	4.92E-02
Future	1.89E+08	1.89E+09	60.00	2.97E-02	4.34E-02	5.02E-02	5.03E-02	5.40E-02	5.46E-02

Table 6-3 Relative Radial Distribution of Neutron Fluence (E > 1.0 MeV) Within the Reactor Vessel Wall

Radius (cm)	Azimuthal Angle				
	0°	15°	21°	30°	45°
220.11	1.000	1.000	1.000	1.000	1.000
225.59	0.571	0.566	0.564	0.562	0.557
231.06	0.281	0.276	0.274	0.273	0.268
236.54	0.132	0.129	0.128	0.128	0.123
242.01	0.061	0.059	0.058	0.059	0.054

Base Metal Inner Radius = 220.11 cm

Base Metal 1/4T = 225.59 cm

Base Metal 1/2T = 231.06 cm

Base Metal 3/4T = 236.54 cm

Base Metal Outer Radius = 242.01 cm

Note:
Relative radial distribution data are based on the cumulative integrated exposures from Cycles 1 through 11.

Table 6-4 Relative Radial Distribution of Iron Atom Displacements (dpa) Within the Reactor Vessel Wall

Radius (cm)	Azimuthal Angle				
	0°	15°	21°	30°	45°
220.11	1.000	1.000	1.000	1.000	1.000
225.59	0.641	0.636	0.635	0.638	0.643
231.06	0.385	0.381	0.379	0.385	0.389
236.54	0.228	0.227	0.225	0.231	0.229
242.01	0.129	0.128	0.126	0.132	0.122

Base Metal Inner Radius = 220.11 cm

Base Metal 1/4T = 225.59 cm

Base Metal 1/2T = 231.06 cm

Base Metal 3/4T = 236.54 cm

Base Metal Outer Radius = 242.01 cm

Note:

Relative radial distribution data are based on the cumulative integrated exposures from Cycles 1 through 11.

Table 6-5 Calculated Fast Neutron Exposure of Surveillance Capsules Withdrawn and Analyzed from Comanche Peak Unit 2

Capsule	Irradiation Time [EFPY]	Fluence (E > 1.0 MeV) [n/cm²]	Iron Displacements [dpa]
U	0.91	3.17E+18	6.25E-03
X	8.83	2.16E+19	4.23E-02
W	14.51	3.38E+19	6.59E-02

Table 6-6 Calculated Surveillance Capsule Lead Factors

Capsule ID And Location	Status	Lead Factor
U (31.5° Dual)	Withdrawn EOC 1	3.96
X (31.5° Dual)	Withdrawn EOC 7	3.92
W (31.5° Single)	Withdrawn EOC 11	3.86
V (29.0° Dual)	Stored in Spent Fuel Pool (Withdrawn EOC 7)	3.66
Y (29.0° Dual)	Stored in Spent Fuel Pool (Withdrawn EOC 7)	3.66
Z (31.5° Single)	Stored in Spent Fuel Pool (Withdrawn EOC 11)	3.86

Note:

Lead factors for capsules stored in the spent fuel pool are based on cycle-specific exposure calculations through their last completed fuel cycle, i.e., Cycle 7 for Capsules V and Y, Cycle 11 for Capsule Z.

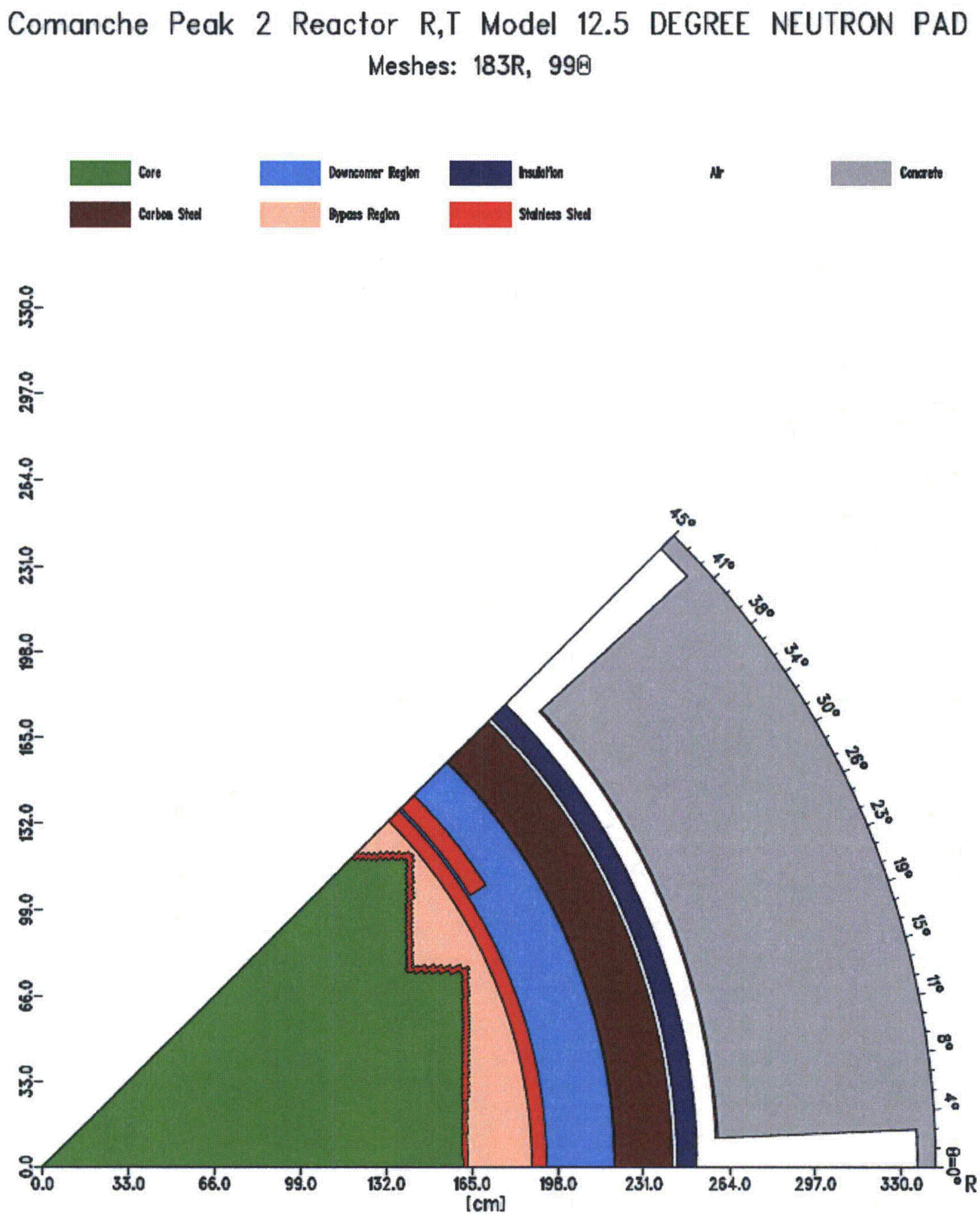


Figure 6-1 Comanche Peak Unit 2 r,θ Reactor Geometry with a 12.5° Neutron Pad Span at the Core Midplane

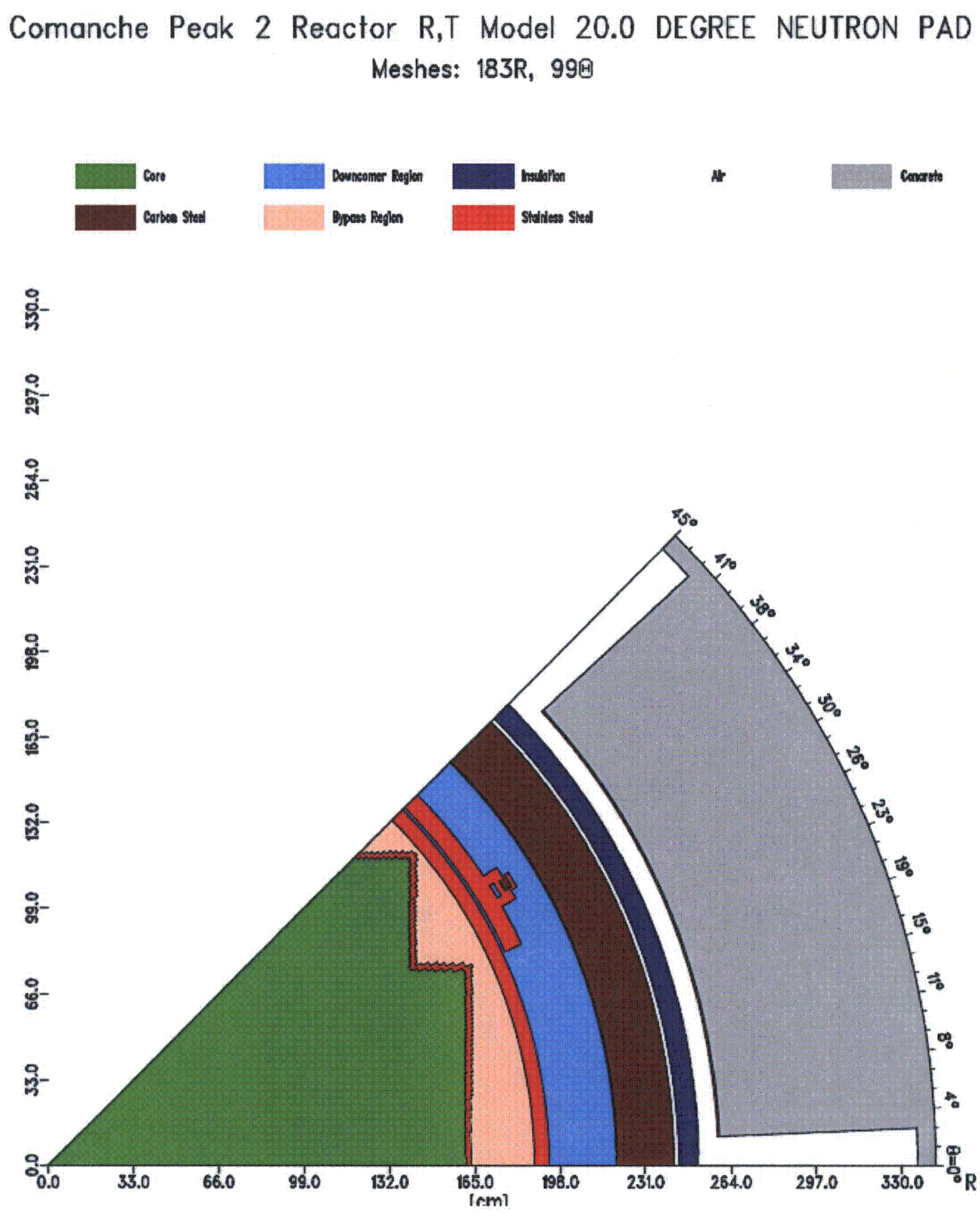


Figure 6-2 Comanche Peak Unit 2 r,θ Reactor Geometry with a 20.0° Neutron Pad Span at the Core Midplane

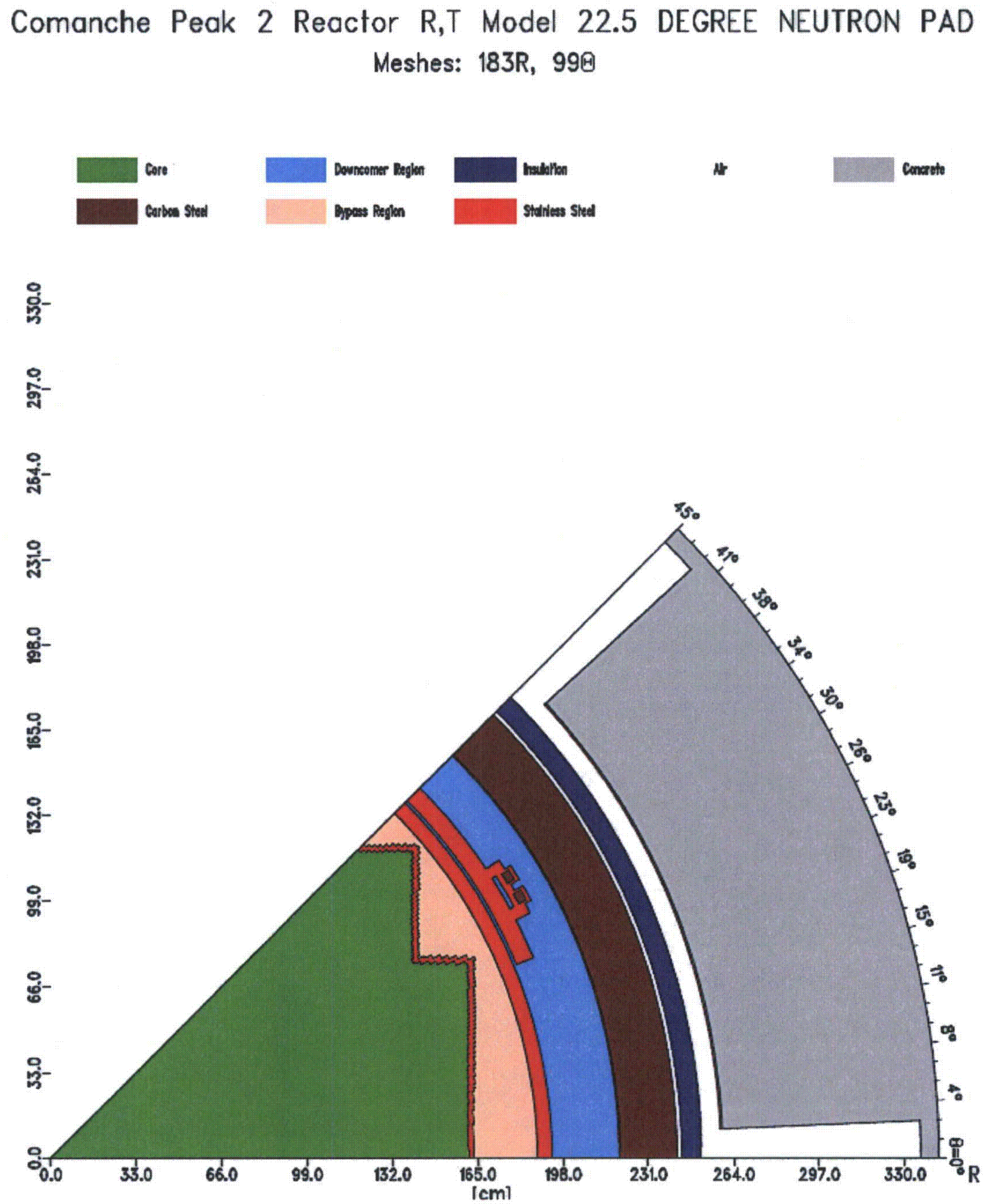


Figure 6-3 Comanche Peak Unit 2 r,θ Reactor Geometry with a 22.5° Neutron Pad Span at the Core Midplane

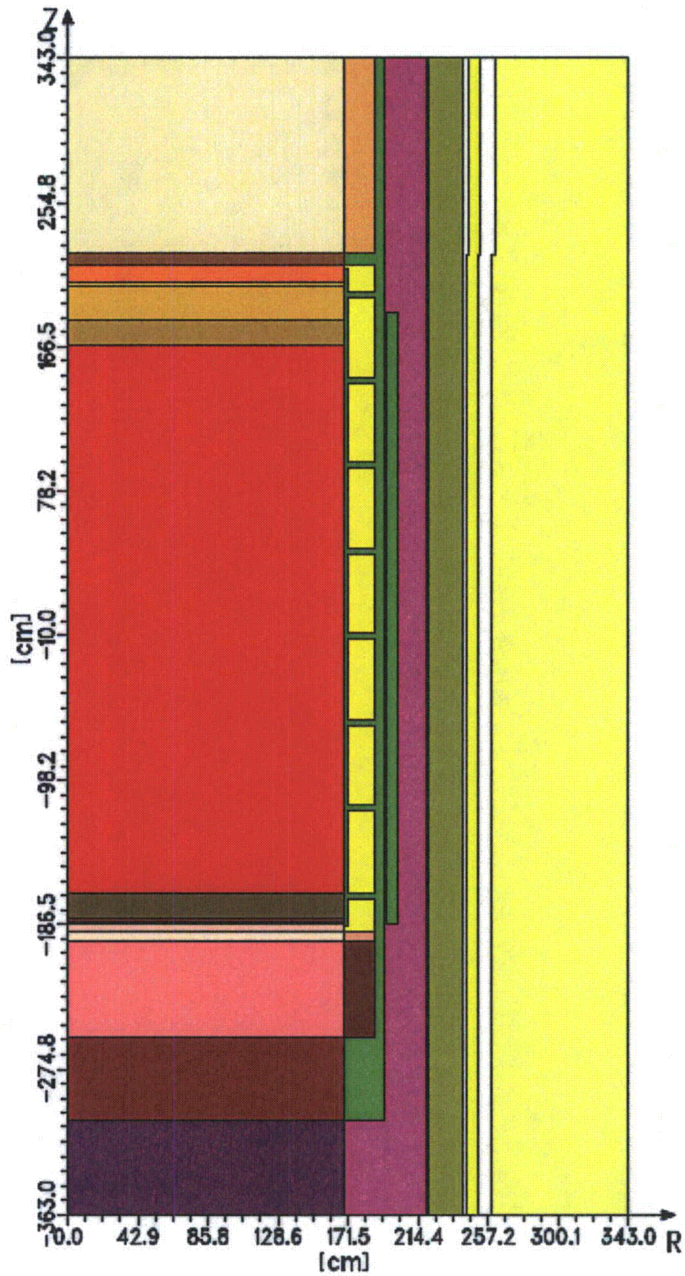


Figure 6-4 Comanche Peak Unit 2 r,z Reactor Geometry with Neutron Pad

7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following table summarizes the removal of the six surveillance capsules from the Comanche Peak Unit 2 reactor vessel, meeting the requirements of ASTM E185-82 [Ref. 4].

Table 7-1 Surveillance Capsule Withdrawal Summary

Capsule	Capsule Location	Lead Factor[a]	Withdrawal EFPY[b]	Fluence (n/cm^2)[c]
U	58.5°	3.96	0.91	0.317×10^{19}
X	238.5°	3.92	8.83	2.16×10^{19}
W	121.5°	3.86	14.51	3.38×10^{19}
Z[d]	301.5°	3.86	14.51[d]	3.38×10^{19}
V[d]	61.0°	3.66	8.83[d]	2.02×10^{19}
Y[d]	241.0°	3.66	8.83[d]	2.02×10^{19}

Notes:

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

(b) EFPY from plant startup.

(c) Updated in Capsule W dosimetry analysis; see Table 6-5.

(d) Standby Capsules Z, V, and Y were removed and placed in the spent fuel pool. No testing or analysis has been performed on these capsules. Reinsertion of one or more of these capsules may be considered in the future, especially if Comanche Peak Unit 2 plans to pursue a 40-year license renewal (72 EFPY or 80 years). However, since the current regulations may change between now and then, it is recommended that the schedule for reinsertion and subsequent withdrawal of an 80-year license capsule be revisited at a later time.

8 REFERENCES

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

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

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8. Westinghouse Science and Technology Department Procedure RMF 8402, *Surveillance Capsule Testing Program*, Revision 3, June 6, 2005.

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

A.1 NEUTRON DOSIMETRY

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

A.1.1 Sensor Reaction Rate Determinations

In this section, the results of the evaluations of the three neutron sensor sets analyzed to date as part of the Comanche Peak 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 ID	Azimuthal Location	Withdrawal Time	Irradiation Time [EFPY]
U	31.5° Dual	End of Cycle 1	0.91
X	31.5° Dual	End of Cycle 7	8.83
W	31.5° Single	End of Cycle 11	14.51

The azimuthal locations included in the above tabulation represent the first octant equivalent azimuthal angle of the geometric center of the respective surveillance capsules.

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

Sensor Material	Reaction Of Interest	Capsule U	Capsule X	Capsule W
Copper	$^{63}Cu(n,\alpha)^{60}Co$	X	X	X
Iron	$^{54}Fe(n,p)^{54}Mn$	X	X	X
Nickel	$^{58}Ni(n,p)^{58}Co$	X	X	X
Uranium-238	$^{238}U(n,f)^{137}Cs$	X	X	X
Neptunium-237	$^{237}Np(n,f)^{137}Cs$	X	X	X
Cobalt-Aluminum*	$^{59}Co(n,\gamma)^{60}Co$	X	X	X
*The cobalt-aluminum measurements for this plant include both bare wire and cadmium-covered sensors.				

Since all of the dosimetry monitors were located at the radial center of the material test specimen array, radial gradient corrections were not required for these reaction rates. Pertinent physical and nuclear characteristics of the passive neutron sensors are listed in Table A-1.

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

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

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

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

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

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

where:

R	=	Reaction rate averaged over the irradiation period and referenced to operation at a core power level of P_{ref} (rps/nucleus).
A	=	Measured specific activity (dps/g).
N_0	=	Number of target element atoms per gram of sensor.
F	=	Atom fraction of the target isotope in the target element.
Y	=	Number of product atoms produced per reaction.
P_j	=	Average core power level during irradiation period j (MW).
P_{ref}	=	Maximum or reference power level of the reactor (MW).
C_j	=	Calculated ratio of $\phi(E > 1.0 \text{ MeV})$ during irradiation period j to the time weighted average $\phi(E > 1.0 \text{ MeV})$ over the entire irradiation period.
λ	=	Decay constant of the product isotope (1/sec).
t_j	=	Length of irradiation period j (sec).
$t_{d,j}$	=	Decay time following irradiation period j (sec).

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

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

Section 6.2, accounts for the change in sensor reaction rates caused by variations in flux level induced by changes in core spatial power distributions from fuel cycle to fuel cycle. For a single-cycle irradiation, C_j is normally taken to be 1.0. However, for multiple-cycle irradiations, particularly those employing low leakage fuel management, the additional C_j term should be employed. The impact of changing flux levels for constant power operation can be quite significant for sensor sets that have been irradiated for many cycles in a reactor that has transitioned from non-low leakage to low leakage fuel management or for sensor sets contained in surveillance capsules that have been moved from one capsule location to another. The fuel-cycle-specific neutron flux values along with the computed values for C_j are listed in Table A-3. These flux values represent the cycle-dependent results at the radial and azimuthal center of the respective capsules at the axial elevation of the active fuel 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 measurements to account for the presence of ^{235}U impurities in the sensors as well as to adjust for the build-in of plutonium isotopes over the course of the irradiation. Corrections were also made to the ^{238}U and ^{237}Np sensor reaction rates to account for gamma ray induced fission reactions that occurred over the course of the capsule irradiations. The correction factors applied to the Comanche Peak Unit 2 fission sensor reaction rates are summarized as follows:

Correction	Capsule U	Capsule X	Capsule W
^{235}U Impurity/Pu Build-in	0.872	0.804	0.764
^{238}U(γ,f)	0.966	0.967	0.969
Net ^{238}U Correction	0.842	0.777	0.740
^{237}Np(γ,f)	0.990	0.990	0.991

These factors were applied in a multiplicative fashion to the decay corrected uranium and neptunium fission sensor reaction rates.

Results of the sensor reaction rate determinations for Capsules U, X, and W are given in Table A-4. In Table A-4, the measured specific activities, decay corrected saturated specific activities, and computed reaction rates for each sensor indexed to the radial center of the capsule are listed. The fission sensor reaction rates are listed both with and without the applied corrections for ^{238}U impurities, plutonium build-in, and gamma ray induced fission effects.

A.1.2 Least Squares Evaluation of Sensor Sets

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

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

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

For the least squares evaluation of the Comanche Peak Unit 2 surveillance capsule dosimetry, the FERRET code [Ref. A-4] was employed to combine the results of the plant-specific neutron transport calculations and sensor set reaction rate measurements to determine best-estimate values of exposure parameters ($\phi(E > 1.0$ MeV) and dpa) along with associated uncertainties for the three in-vessel capsules analyzed to date.

The application of the least squares methodology requires the following input:

1. The calculated neutron energy spectrum and associated uncertainties at the measurement location.

2. The measured reaction rates and associated uncertainty for each sensor contained in the multiple foil set.

3. The energy-dependent dosimetry reaction cross-sections and associated uncertainties for each sensor contained in the multiple foil sensor set.

For the Comanche Peak Unit 2 application, the calculated neutron spectrum was obtained from the results of plant-specific neutron transport calculations described in Section 6.2 of this report. The sensor reaction rates were derived from the measured specific activities using the procedures described in Section A.1.1. The dosimetry reaction cross-sections and uncertainties were obtained from the SNLRML dosimetry cross-section library (Reference A-5). The SNLRML library is an evaluated dosimetry reaction cross-section compilation recommended for use in LWR evaluations by ASTM Standard E1018, "Application of ASTM Evaluated Cross-Section Data File, Matrix E 706 (IIB)" [Ref. A-6].

The uncertainties associated with the measured reaction rates, dosimetry cross-sections, and calculated neutron spectrum were input to the least squares procedure in the form of variances and covariances. The assignment of the input uncertainties followed the guidance provided in ASTM Standard E 944, "Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance" [Ref. A-7].

The following provides a summary of the uncertainties associated with the least squares evaluation of the Comanche Peak Unit 2 surveillance capsule sensor sets.

Reaction Rate Uncertainties

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

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

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	5%
$^{54}Fe(n,p)^{54}Mn$	5%
$^{58}Ni(n,p)^{58}Co$	5%
$^{238}U(n,f)^{137}Cs$	10%
$^{237}Np(n,f)^{137}Cs$	10%
$^{59}Co(n,\gamma)^{60}Co$	5%

These uncertainties are given at the 1σ level.

Dosimetry Cross-Section Uncertainties

The reaction rate cross-sections used in the least squares evaluations were taken from the SNLRML library. This data library provides reaction cross-sections and associated uncertainties, including covariances, for 66 dosimetry sensors in common use. Both cross-sections and uncertainties are provided in a fine multigroup structure for use in least squares adjustment applications. These cross-sections were compiled from the most recent cross-section evaluations and they have been tested with respect to their accuracy and consistency for least squares evaluations. Further, the library has been empirically tested for use in fission spectra determination as well as in the fluence and energy characterization of 14 MeV neutron sources.

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

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	4.08-4.16%
$^{54}Fe(n,p)^{54}Mn$	3.05-3.11%
$^{58}Ni(n,p)^{58}Co$	4.49-4.56%
$^{238}U(n,f)^{137}Cs$	0.54-0.64%
$^{237}Np(n,f)^{137}Cs$	10.32-10.97%
$^{59}Co(n,\gamma)^{60}Co$	0.79-3.59%

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

Calculated Neutron Spectrum

The neutron spectra input to the least squares adjustment procedure were obtained directly from the results of plant-specific transport calculations for each surveillance capsule irradiation period and location. The spectrum for each capsule was input in an absolute sense (rather than as simply a relative spectral shape). Therefore, within the constraints of the assigned uncertainties, the calculated data were treated equally with the measurements.

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

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

where R_n specifies an overall fractional normalization uncertainty and the fractional uncertainties R_g and $R_{g'}$ specify additional random 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 Comanche Peak Unit 2 calculated spectra was as follows:

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

Short Range Correlation (θ)	
(E > 0.0055 MeV)	0.9
(0.68 eV < E < 0.0055 MeV)	0.5
(E < 0.68 eV)	0.5
Flux Group Correlation Range (γ)	
(E > 0.0055 MeV)	6
(0.68 eV < E < 0.0055 MeV)	3
(E < 0.68 eV)	2

A.1.3 Comparisons of Measurements and Calculations

Results of the least squares evaluations of the dosimetry from the Comanche Peak Unit 2 surveillance capsules withdrawn and analyzed to date are provided in Tables A-5 and A-6. In Table A-5, measured, calculated, and best-estimate values for sensor reaction rates are given for each capsule. Also provided in this tabulation are ratios of the measured reaction rates to both the calculated and least squares adjusted reaction rates. These ratios of M/C and M/BE illustrate the consistency of the fit of the calculated neutron energy spectra to the measured reaction rates both before and after adjustment. In Table A-6, comparison of the calculated and best-estimate values of neutron flux (E > 1.0 MeV) and iron atom displacement rate are tabulated along with the BE/C ratios observed for each of the capsules.

The data comparisons provided in Tables A-5 and A-6 show that the adjustments to the calculated spectra are relatively small and well within the assigned uncertainties for the calculated spectra, measured sensor reaction rates, and dosimetry reaction cross-sections. Further, these results indicate that the use of the least squares evaluation results in a reduction in the uncertainties associated with the exposure of the surveillance capsules. From Section 6.4 of this report, it may be noted that the uncertainty associated with the unadjusted calculation of neutron fluence (E > 1.0 MeV) and iron atom displacements at the surveillance capsule locations is specified as 12% at the 1σ level. From Table A-6, it is noted that the corresponding uncertainties associated with the least squares adjusted exposure parameters have been reduced to 6% for neutron flux (E > 1.0 MeV) and 7-8% for iron atom displacement rate. Again, the uncertainties from the least squares evaluation are at the 1σ level.

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

In the case of the direct comparison of measured and calculated sensor reaction rates, the M/C comparisons for fast neutron reactions range from 0.92 to 1.26 for the 15 samples included in the data set. The overall average M/C ratio for the entire set of Comanche Peak Unit 2 data is 1.08 with an associated standard deviation of 8.2%.

In the comparisons of best-estimate and calculated fast neutron exposure parameters, the corresponding BE/C comparisons for the capsule data sets range from 0.98 to 1.14 for neutron flux (E > 1.0 MeV) and from 1.01 to 1.13 for iron atom displacement rate. The overall average BE/C ratios for neutron flux (E > 1.0 MeV) and iron atom displacement rate are 1.05 with a standard deviation of 7.8% and 1.06 with a standard deviation of 6.1%, respectively.

Based on these comparisons, it is concluded that the calculated fast neutron exposures provided in Section 6.2 of this report are validated for use in the assessment of the condition of the materials comprising the beltline region of the Comanche Peak Unit 2 reactor pressure vessel.

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

Monitor Material	Reaction of Interest	Target Atom Fraction	90% Response Range (MeV)	Product Half-life	Fission Yield (%)
Copper	^{63}Cu (n,α)	0.6917	4.9 – 11.9	5.271 y	
Iron	^{54}Fe (n,p)	0.0585	2.1 – 8.5	312.1 d	
Nickel	^{58}Ni (n,p)	0.6808	1.5 – 8.3	70.82 d	
Uranium-238	^{238}U (n,f)	1.0000	1.3 – 6.9	30.07 y	6.02
Neptunium-237	^{237}Np (n,f)	1.0000	0.3 – 3.8	30.07 y	6.17
Cobalt-Aluminum	^{59}Co (n,γ)	0.0015	non-threshold	5.271 y	

Note:

The 90% response range is defined such that, in the neutron spectrum characteristic of the Comanche Peak 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.

Table A-2 Monthly Thermal Generation During the First Eleven Fuel Cycles of the Comanche Peak Unit 2 Reactor (Reactor Power of 3411 MWt from Startup through 10/7/99, 3445 MWt from 10/7/99 through 10/16/01, and 3458 MWt from 10/16/01 through the End of Cycle 11)

Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)
Mar-93	5239	Mar-95	2496279	Mar-97	2536640	Mar-99	1548126
Apr-93	665227	Apr-95	2291046	Apr-97	2450049	Apr-99	473690
May-93	499862	May-95	1551323	May-97	2144436	May-99	2536163
Jun-93	0	Jun-95	2414907	Jun-97	2368587	Jun-99	2446800
Jul-93	1398237	Jul-95	2537455	Jul-97	2530139	Jul-99	2533421
Aug-93	2506266	Aug-95	2533692	Aug-97	2536238	Aug-99	2535877
Sep-93	1317192	Sep-95	2451091	Sep-97	2451498	Sep-99	2454020
Oct-93	2397305	Oct-95	2537946	Oct-97	1958440	Oct-99	2547941
Nov-93	2066821	Nov-95	2447406	Nov-97	0	Nov-99	2478920
Dec-93	2512243	Dec-95	2116020	Dec-97	1470859	Dec-99	2561649
Jan-94	2471392	Jan-96	2528370	Jan-98	2532970	Jan-00	2558037
Feb-94	1545102	Feb-96	1731998	Feb-98	2227110	Feb-00	2396090
Mar-94	1165989	Mar-96	0	Mar-98	2428176	Mar-00	2559136
Apr-94	1225995	Apr-96	0	Apr-98	2450649	Apr-00	2476416
May-94	0	May-96	1738972	May-98	2533092	May-00	2561079
Jun-94	608905	Jun-96	2329301	Jun-98	2454480	Jun-00	2472280
Jul-94	2417607	Jul-96	2530637	Jul-98	2285176	Jul-00	2558036
Aug-94	1728640	Aug-96	2532626	Aug-98	2048721	Aug-00	2561286
Sep-94	2323301	Sep-96	2011808	Sep-98	2281630	Sep-00	2383888
Oct-94	342436	Oct-96	2353951	Oct-98	2532717	Oct-00	0
Nov-94	317387	Nov-96	2449903	Nov-98	2450886	Nov-00	1926717
Dec-94	2534919	Dec-96	2515648	Dec-98	2535523	Dec-00	2560103
Jan-95	2527469	Jan-97	2118763	Jan-99	2312036	Jan-01	2560732
Feb-95	2280649	Feb-97	2281115	Feb-99	2285274	Feb-01	2308856

Table A-2 (Continued) Monthly Thermal Generation During the First Eleven Fuel Cycles of the Comanche Peak Unit 2 Reactor (Reactor Power of 3411 MWt from Startupthrough 10/7/99, 3445 MWt from 10/7/99 through 10/16/01, and 3458 MWt from 10/16/01 through the End of Cycle 11)

Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)	Month-Year	Thermal Generation (MWt-hr)
Mar-01	2551290	May-03	1320086	Jul-05	2565762	Sep-07	2488899
Apr-01	2478855	Jun-03	2465264	Aug-05	2567525	Oct-07	2570046
May-01	2561154	Jul-03	111801	Sep-05	2487748	Nov-07	2492064
Jun-01	2474728	Aug-03	2547906	Oct-05	2564267	Dec-07	2571882
Jul-01	2431971	Sep-03	2473497	Nov-05	2488298	Jan-08	2569185
Aug-01	2560721	Oct-03	384321	Dec-05	2571074	Feb-08	2405943
Sep-01	2478056	Nov-03	2417397	Jan-06	2566082	Mar-08	2125790
Oct-01	2565724	Dec-03	2178790	Feb-06	2322771	Apr-08	932174
Nov-01	2486883	Jan-04	2548556	Mar-06	2567895	May-08	2567597
Dec-01	2569796	Feb-04	2385232	Apr-06	2485431	Jun-08	2486976
Jan-02	2563715	Mar-04	2544441	May-06	2571435	Jul-08	2571426
Feb-02	2320836	Apr-04	2479308	Jun-06	2488956	Aug-08	2571837
Mar-02	2419437	May-04	2565864	Jul-06	2567925	Sep-08	2488910
Apr-02	0	Jun-04	2476634	Aug-06	2571915	Oct-08	2571737
May-02	1996301	Jul-04	2567252	Sep-06	2478864	Nov-08	2482583
Jun-02	2333719	Aug-04	2569751	Oct-06	643723	Dec-08	2571908
Jul-02	2509555	Sep-04	2483501	Nov-06	2486122	Jan-09	2571027
Aug-02	2542003	Oct-04	2563599	Dec-06	2572531	Feb-09	2322983
Sep-02	2468447	Nov-04	2478648	Jan-07	2572442	Mar-09	2568015
Oct-02	2553421	Dec-04	2570238	Feb-07	2321329	Apr-09	2489118
Nov-02	2473948	Jan-05	2567214	Mar-07	2568423	May-09	2431026
Dec-02	2563144	Feb-05	2284203	Apr-07	2487473	Jun-09	2488797
Jan-03	2560486	Mar-05	2007877	May-07	2572745	Jul-09	2570769
Feb-03	2315079	Apr-05	148984	Jun-07	2489726	Aug-09	2571684
Mar-03	2567033	May-05	2537525	Jul-07	2568944	Sep-09	2488098
Apr-03	2475564	Jun-05	2488337	Aug-07	2571861	Oct-09	448292

Table A-3 Calculated C_j Factors at the Surveillance Capsule Center Core Midplane Elevation

Fuel Cycle	Cycle Length [EFPS]	φ(E > 1.0 MeV) [n/cm²-s]		
		Capsule U	Capsule X	Capsule W
1	2.87E+07	1.11E+11	1.11E+11	1.09E+11
2	3.73E+07		7.16E+10	7.10E+10
3	4.42E+07		7.85E+10	7.76E+10
4	3.84E+07		7.20E+10	7.13E+10
5	4.52E+07		7.12E+10	7.05E+10
6	4.37E+07		7.15E+10	7.07E+10
7	4.12E+07		7.78E+10	7.70E+10
8	4.35E+07			7.24E+10
9	4.52E+07			7.41E+10
10	4.44E+07			6.92E+10
11	4.60E+07			6.07E+10
Average		1.11E+11	7.76E+10	7.38E+10

Fuel Cycle	Cycle Length [EFPS]	C_j		
		Capsule U	Capsule X	Capsule W
1	2.87E+07	1.000	1.424	1.484
2	3.73E+07		0.923	0.962
3	4.42E+07		1.011	1.052
4	3.84E+07		0.928	0.966
5	4.52E+07		0.918	0.955
6	4.37E+07		0.921	0.958
7	4.12E+07		1.002	1.044
8	4.35E+07			0.982
9	4.52E+07			1.005
10	4.44E+07			0.939
11	4.60E+07			0.823
Average		1.000	1.000	1.000

Table A-4a Measured Sensor Activities and Reaction Rates Surveillance Capsule U

Reaction	Location	Measured Activity (dps/g)	Saturated Activity (dps/g)	Adjusted Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top	4.78E+04	4.56E+05	6.96E-17
	Middle	4.28E+04	4.09E+05	6.24E-17
	Bottom	4.29E+04	4.10E+05	6.25E-17
	Average			**6.48E-17**
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	1.39E+06	4.09E+06	6.49E-15
	Middle	1.27E+06	3.73E+06	5.93E-15
	Bottom	1.27E+06	3.73E+06	5.93E-15
	Average			**6.11E-15**
$^{58}Ni\ (n,p)\ ^{58}Co$	Top	1.30E+07	6.06E+07	8.68E-15
	Middle	1.21E+07	5.64E+07	8.08E-15
	Bottom	1.21E+07	5.64E+07	8.08E-15
	Average			**8.28E-15**
$^{238}U\ (n,f)\ ^{137}Cs$ (Cd)	Middle	1.37E+05	6.69E+06	4.39E-14
	Including ^{235}U, ^{239}Pu, and γ fission corrections:			**3.70E-14**
$^{237}Np\ (n,f)\ ^{137}Cs$ (Cd)	Middle	1.21E+06	5.91E+07	3.77E-13
	Including γ fission corrections:			**3.73E-13**
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	9.83E+06	9.39E+07	6.12E-12
	Middle	1.03E+07	9.84E+07	6.42E-12
	Bottom	1.03E+07	9.84E+07	6.42E-12
	Average			**6.32E-12**
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	5.29E+06	5.05E+07	3.30E-12
	Middle	5.65E+06	5.40E+07	3.52E-12
	Bottom	5.55E+06	5.30E+07	3.46E-12
	Average			**3.43E-12**

Notes:

1. Measured specific activities are indexed to a counting date of February 1, 1995.
2. The average ^{238}U (n,f) reaction rate of 3.70E-14 includes a correction factor of 0.872 to account for plutonium build-in and an additional factor of 0.966 to account for photo-fission effects in the sensor.
3. The average ^{237}Np (n,f) reaction rate of 3.73E-13 includes a correction factor of 0.990 to account for photo-fission effects in the sensor.
4. Reaction rates referenced to the Cycle 1 Rated Reactor Power of 3411 MWt.

Table A-4b Measured Sensor Activities and Reaction Rates Surveillance Capsule X

Reaction	Location	Measured Activity (dps/g)	Saturated Activity (dps/g)	Adjusted Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top	1.91E+05	3.06E+05	4.66E-17
	Middle	1.71E+05	2.74E+05	4.18E-17
	Bottom	1.68E+05	2.69E+05	4.10E-17
	Average			**4.31E-17**
^{54}Fe (n,p) ^{54}Mn	Top	2.44E+06	3.13E+06	4.97E-15
	Middle	2.23E+06	2.86E+06	4.54E-15
	Bottom	2.18E+06	2.80E+06	4.44E-15
	Average			**4.65E-15**
^{58}Ni (n,p) ^{58}Co	Top	2.48E+07	4.78E+07	6.84E-15
	Middle	2.29E+07	4.41E+07	6.31E-15
	Bottom	2.25E+07	4.33E+07	6.20E-15
	Average			**6.45E-15**
^{238}U (n,f) ^{137}Cs (Cd)	Middle	9.58E+05	5.31E+06	3.49E-14
	Including ^{235}U, ^{239}Pu, and γ fission corrections:			**2.71E-14**
^{237}Np (n,f) ^{137}Cs (Cd)	Middle	7.11E+06	3.94E+07	2.51E-13
	Including γ fission corrections:			**2.49E-13**
^{59}Co (n,γ) ^{60}Co	Top	3.84E+07	6.15E+07	4.01E-12
	Middle	3.91E+07	6.26E+07	4.08E-12
	Bottom	4.03E+07	6.45E+07	4.21E-12
	Average			**4.10E-12**
^{59}Co (n,γ) ^{60}Co (Cd)	Top	2.10E+07	3.36E+07	2.19E-12
	Middle	2.14E+07	3.43E+07	2.23E-12
	Bottom	2.20E+07	3.52E+07	2.30E-12
	Average			**2.24E-12**

Notes:

1. Measured specific activities are indexed to a counting date of November 26, 2003.
2. The average ^{238}U (n,f) reaction rate of 2.71E-14 includes a correction factor of 0.804 to account for plutonium build-in and an additional factor of 0.967 to account for photo-fission effects in the sensor.
3. The average ^{237}Np (n,f) reaction rate of 2.49E-13 includes a correction factor of 0.990 to account for photo-fission effects in the sensor.
4. Reaction rates referenced to the Cycles 1-7 Average Rated Reactor Power of 3428 MWt.

Table A-4c Measured Sensor Activities and Reaction Rates Surveillance Capsule W

Reaction	Location	Measured Activity (dps/g)	Saturated Activity (dps/g)	Adjusted Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top	2.15E+05	2.93E+05	4.47E-17
	Middle	2.17E+05	2.95E+05	4.51E-17
	Bottom	2.47E+05	3.36E+05	5.13E-17
	Average			**4.70E-17**
^{54}Fe (n,p) ^{54}Mn	Top	1.67E+06	2.89E+06	4.59E-15
	Middle	1.67E+06	2.89E+06	4.59E-15
	Bottom	1.86E+06	3.22E+06	5.11E-15
	Average			**4.76E-15**
^{58}Ni (n,p) ^{58}Co	Top	7.53E+06	4.74E+07	6.79E-15
	Middle	7.57E+06	4.77E+07	6.83E-15
	Bottom	8.32E+06	5.24E+07	7.50E-15
	Average			**7.04E-15**
^{238}U (n,f) ^{137}Cs (Cd)	Middle	1.67E+06	6.06E+06	3.98E-14
	Including ^{235}U, ^{239}Pu, and γ fission corrections:			**2.94E-14**
^{237}Np (n,f) ^{137}Cs (Cd)	Middle	1.08E+07	3.92E+07	2.50E-13
	Including γ fission corrections:			**2.48E-13**
^{59}Co (n,γ) ^{60}Co	Top	4.69E+07	6.39E+07	4.17E-12
	Middle	4.79E+07	6.52E+07	4.25E-12
	Bottom	4.69E+07	6.39E+07	4.17E-12
	Average			**4.19E-12**
^{59}Co (n,γ) ^{60}Co (Cd)	Top	2.52E+07	3.43E+07	2.24E-12
	Middle	2.51E+07	3.42E+07	2.23E-12
	Bottom	2.45E+07	3.34E+07	2.18E-12
	Average			**2.21E-12**

Notes:

1. Measured specific activities are indexed to a counting date of March 22, 2010.
2. The average ^{238}U (n,f) reaction rate of 2.94E-14 includes a correction factor of 0.764 to account for plutonium build-in and an additional factor of 0.969 to account for photo-fission effects in the sensor.
3. The average ^{237}Np (n,f) reaction rate of 2.48E-13 includes a correction factor of 0.991 to account for photo-fission effects in the sensor.
4. Reaction rates referenced to the Cycles 1-11 Average Rated Reactor Power of 3440 MWt.

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

Capsule U					
Reaction	Reaction Rate [rps/atom]			M/C	M/BE
	Measured	Calculated	Best Estimate		
$^{63}Cu(n,\alpha)^{60}Co$	6.48E-17	5.59E-17	6.13E-17	1.16	1.05
$^{54}Fe(n,p)^{54}Mn$	6.11E-15	6.38E-15	6.32E-15	0.96	0.97
$^{58}Ni(n,p)^{58}Co$	8.28E-15	8.97E-15	8.75E-15	0.92	0.94
$^{238}U(n,f)^{137}Cs$ (Cd)	3.70E-14	3.48E-14	3.42E-14	1.06	1.09
$^{237}Np(n,f)^{137}Cs$ (Cd)	3.73E-13	3.44E-13	3.58E-13	1.08	1.04
$^{59}Co(n,\gamma)^{60}Co$	6.32E-12	4.95E-12	6.20E-12	1.28	1.02
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	3.42E-12	3.44E-12	3.47E-12	0.99	0.99

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

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

Capsule X					
Reaction	Reaction Rate [rps/atom]			M/C	M/BE
	Measured	Calculated	Best Estimate		
$^{63}Cu(n,\alpha)^{60}Co$	4.31E-17	4.19E-17	4.28E-17	1.03	1.01
$^{54}Fe(n,p)^{54}Mn$	4.65E-15	4.61E-15	4.69E-15	1.01	0.99
$^{58}Ni(n,p)^{58}Co$	6.45E-15	6.46E-15	6.55E-15	1.00	0.98
$^{238}U(n,f)^{137}Cs$ (Cd)	2.71E-14	2.46E-14	2.53E-14	1.10	1.06
$^{237}Np(n,f)^{137}Cs$ (Cd)	2.49E-13	2.40E-13	2.49E-13	1.04	1.00
$^{59}Co(n,\gamma)^{60}Co$	4.10E-12	3.39E-12	4.03E-12	1.21	1.02
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	2.24E-12	2.36E-12	2.27E-12	0.95	0.99

Note:

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

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

Capsule W					
Reaction	Reaction Rate [rps/atom]			M/C	M/BE
	Measured	Calculated	Best Estimate		
$^{63}Cu(n,\alpha)^{60}Co$	4.70E-17	4.00E-17	4.62E-17	1.18	1.02
$^{54}Fe(n,p)^{54}Mn$	4.76E-15	4.38E-15	4.94E-15	1.09	0.96
$^{58}Ni(n,p)^{58}Co$	7.04E-15	6.13E-15	7.01E-15	1.15	1.00
$^{238}U(n,f)^{137}Cs$ (Cd)	2.94E-14	2.33E-14	2.67E-14	1.26	1.10
$^{237}Np(n,f)^{137}Cs$ (Cd)	2.48E-13	2.28E-13	2.54E-13	1.09	0.98
$^{59}Co(n,\gamma)^{60}Co$	4.19E-12	2.92E-12	4.10E-12	1.43	1.02
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	2.21E-12	2.07E-12	2.25E-12	1.07	0.99

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

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

Capsule ID	$\varphi(E > 1.0\ MeV)$ [n/cm²-s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
U	1.11E+11	1.09E+11	6%	0.98
X	7.77E+10	8.03E+10	6%	1.03
W	7.39E+10	8.42E+10	6%	1.14

Note:
Calculated results are based on the synthesized transport calculations taken at the core midplane following the completion of each respective capsules irradiation period and are the average neutron exposure over the irradiation period for each capsule. See Section A.1.2 for details describing the Best-Estimate (BE) exposure rates.

Capsule ID	Iron Atom Displacement Rate [dpa/s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
U	2.14E-10	2.17E-10	8%	1.01
X	1.49E-10	1.55E-10	8%	1.03
W	1.42E-10	1.61E-10	7%	1.13

Note:
Calculated results are based on the synthesized transport calculations taken at the core midplane following the completion of each respective capsules irradiation period and are the average neutron exposure over the irradiation period for each capsule. See Section A.1.2 for details describing the Best-Estimate (BE) exposure rates.

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

Reaction	M/C Ratio		
	Capsule U	Capsule X	Capsule W
$^{63}Cu(n,\alpha)^{60}Co$	1.16	1.03	1.18
$^{54}Fe(n,p)^{54}Mn$	0.96	1.01	1.09
$^{58}Ni(n,p)^{58}Co$	0.92	1.00	1.15
$^{238}U(n,f)^{137}Cs$ (Cd)	1.06	1.10	1.26
$^{237}Np(n,f)^{137}Cs$ (Cd)	1.08	1.04	1.09
Average	1.04	1.04	1.15
% Standard Deviation	9.3	3.8	6.1

Note:
The overall average M/C ratio for the set of 15 sensor measurements is 1.08 with an associated standard deviation of 8.2%.

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

Capsule ID	BE/C Ratio	
	ϕ(E > 1.0 MeV)	dpa/s
U	0.98	1.01
X	1.03	1.03
W	1.14	1.13
Average	1.05	1.06
% Standard Deviation	7.8	6.1

A.2 REFERENCES

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

A-2 WCAP-14315, "Analysis of Capsule U from the Texas Utilities Electric Company Comanche Peak Steam Electric Station Unit No. 2 Reactor Vessel Radiation Surveillance Program," July 1995.

A-3 WCAP-16277-NP, "Analysis of Capsule X from the TXU Energy Comanche Peak Unit 2 Reactor Vessel Radiation Surveillance Program," September 2004.

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

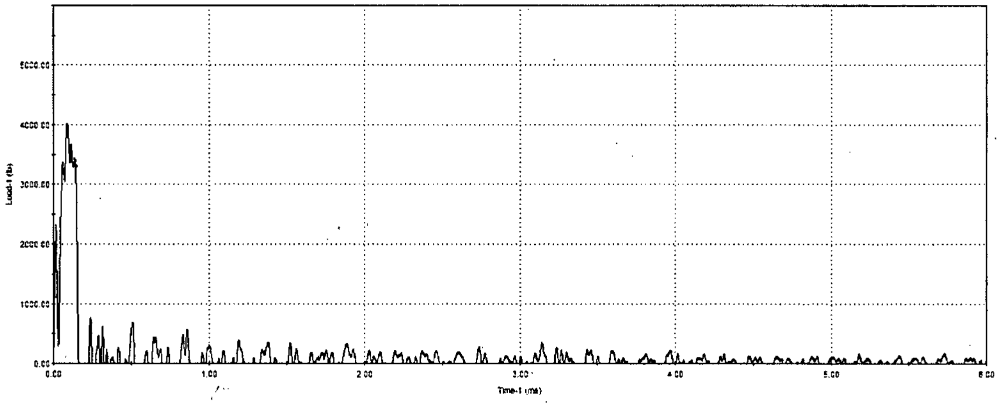
A-5 RSICC Data Library Collection DLC-178, "SNLRML Recommended Dosimetry Cross-Section Compendium," July 1994.

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

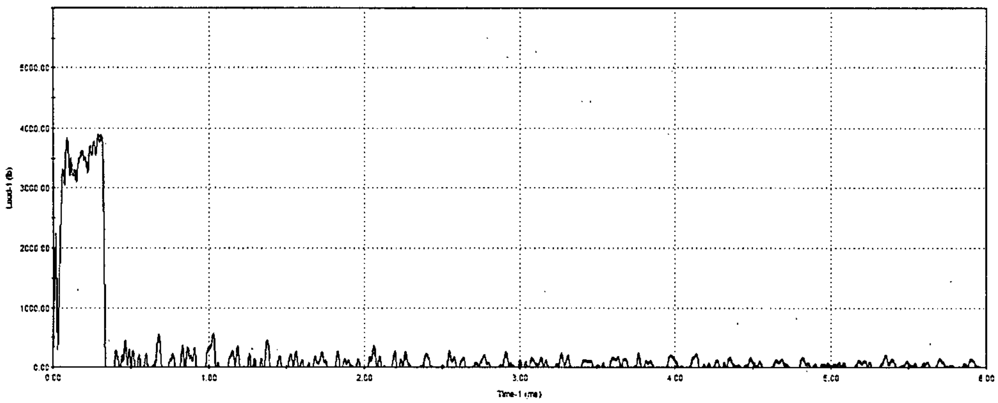
A-7 ASTM Standard E944, *Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance.*

APPENDIX B
LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

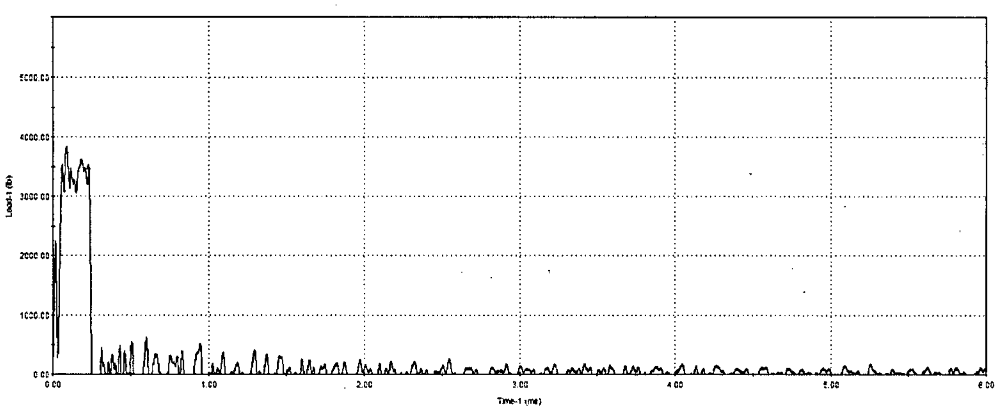
- Specimen prefix "CL" denotes Intermediate Shell Plate R3807-2, Longitudinal Orientation
- Specimen prefix "CT" denotes Intermediate Shell Plate R3807-2, Transverse Orientation
- Specimen prefix "CW" denotes Surveillance Program Weld Metal
- Specimen prefix "CH" denotes Heat-Affected Zone Material



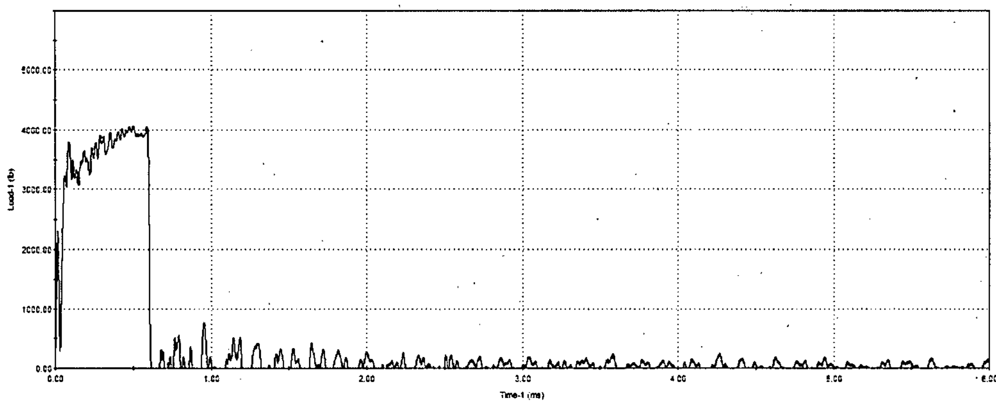
CL36, -50°F



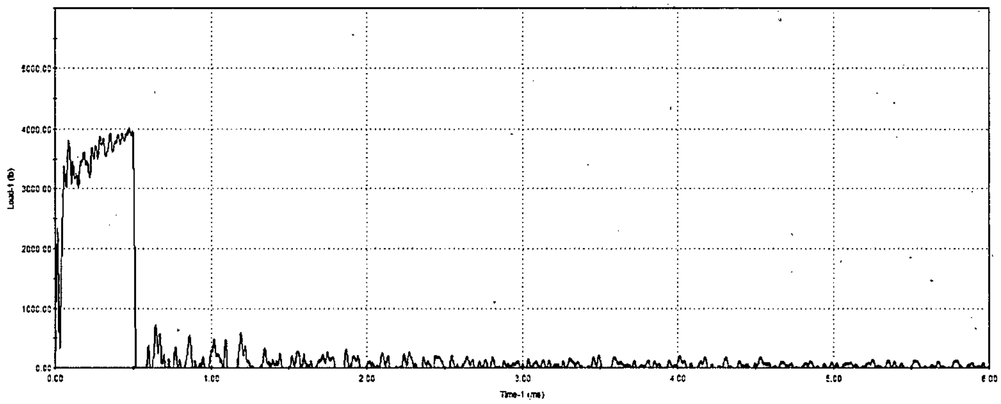
CL38, -20°F



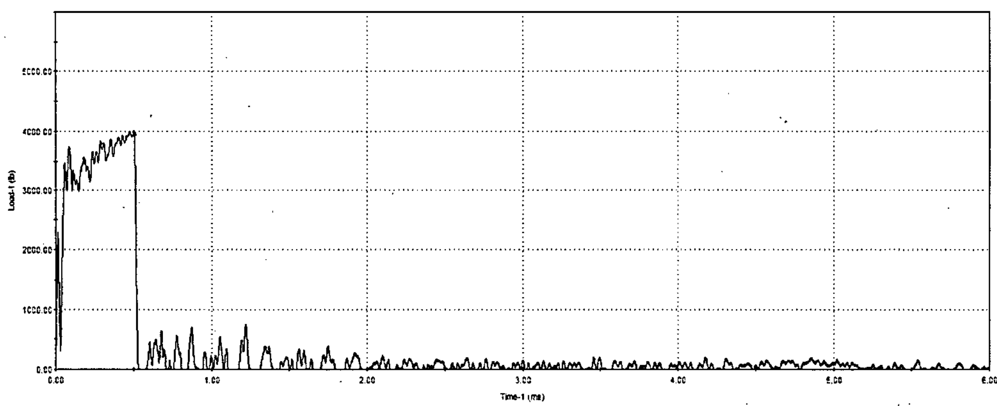
CL44, -15°F



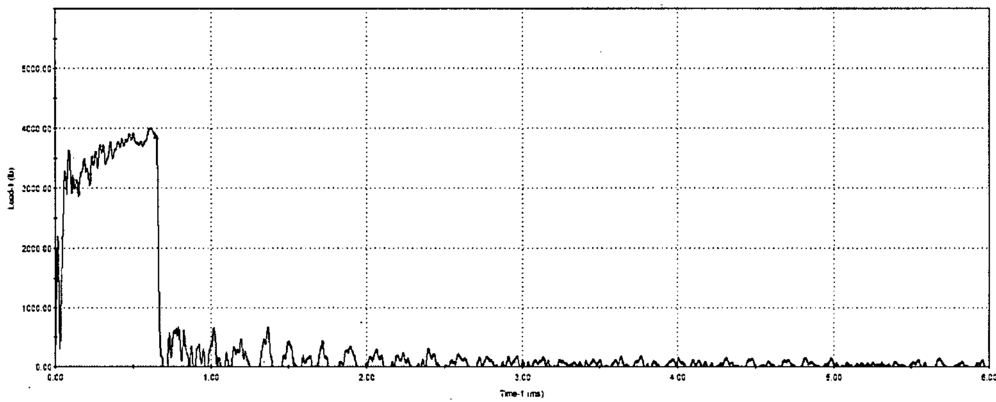
CL33, -10°F



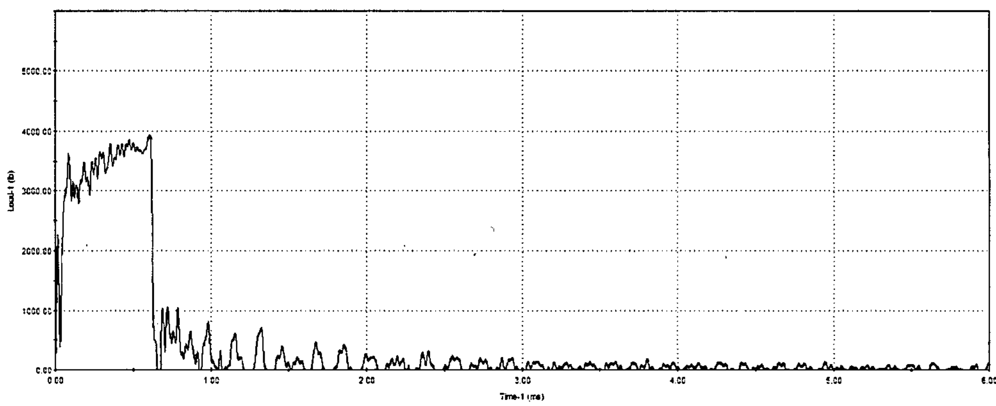
CL39, 0°F



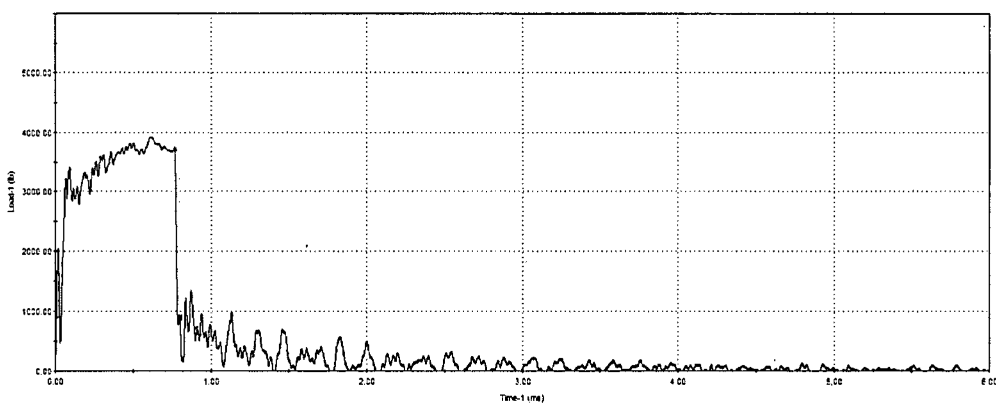
CL41, 25°F



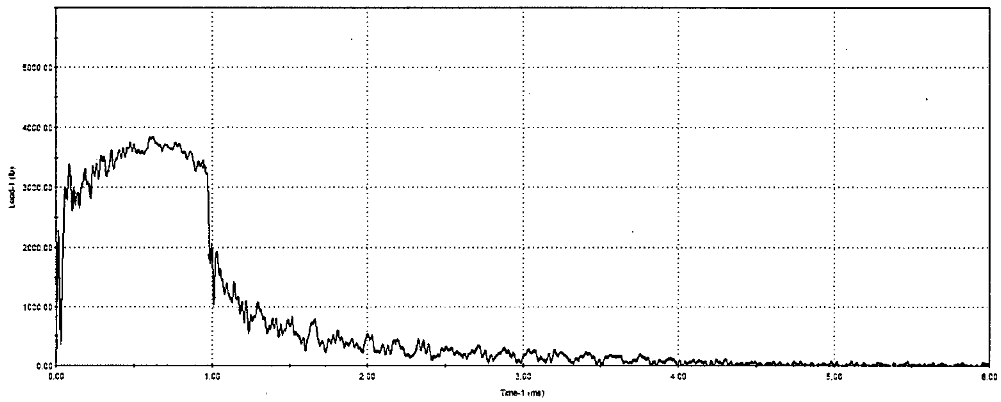
CL42, 40°F



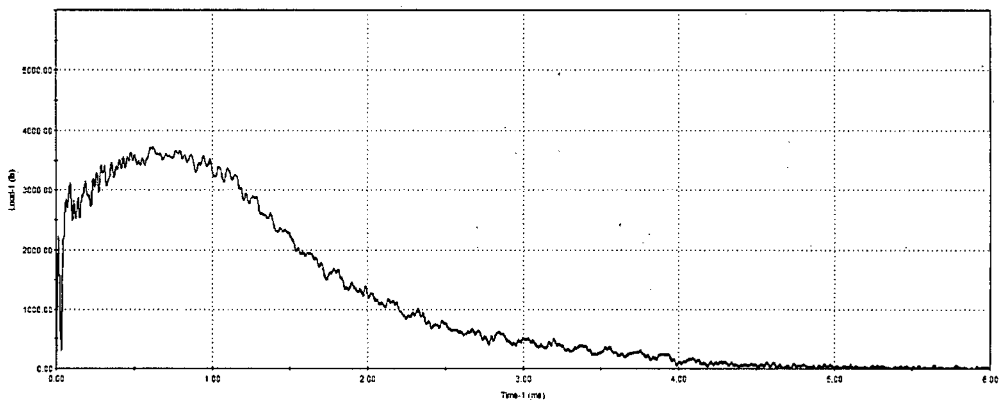
CL45, 60°F



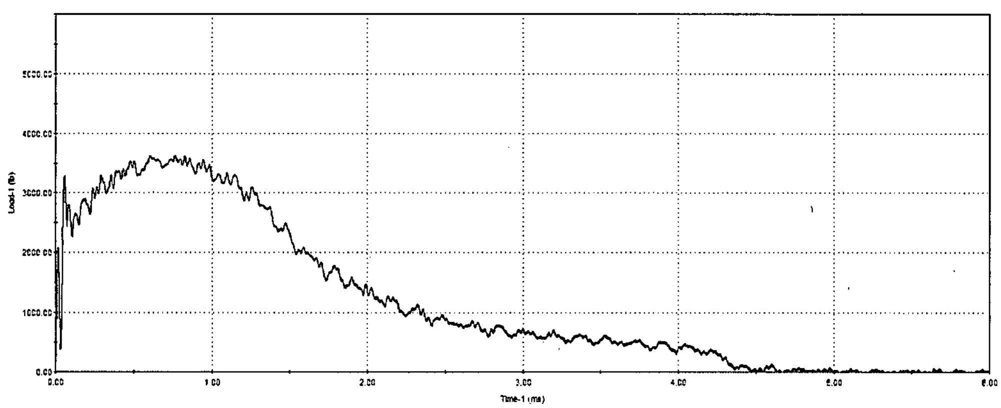
CL34, 80°F



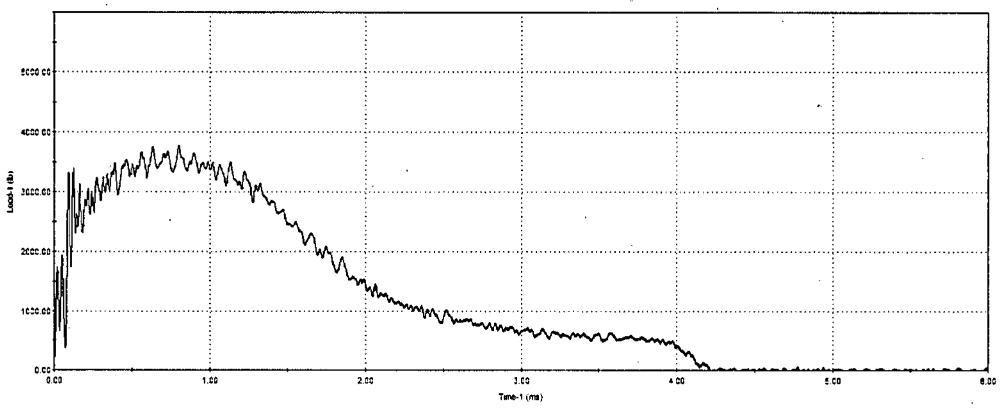
CL31, 125°F



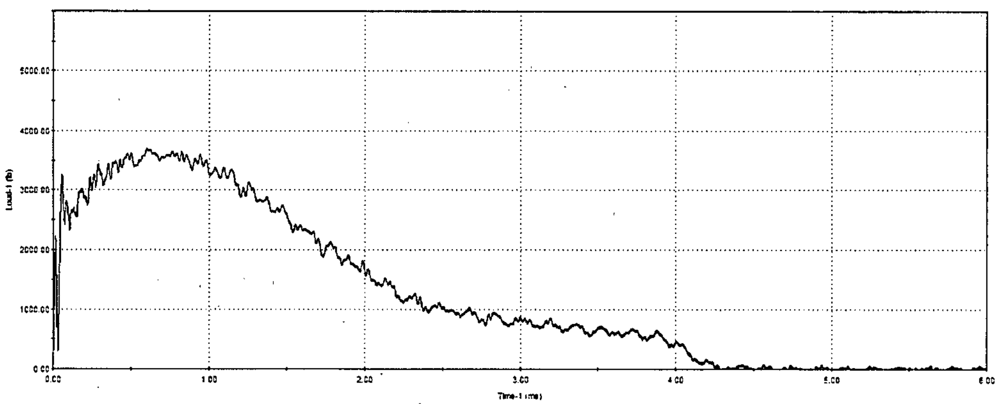
CL35, 200°F



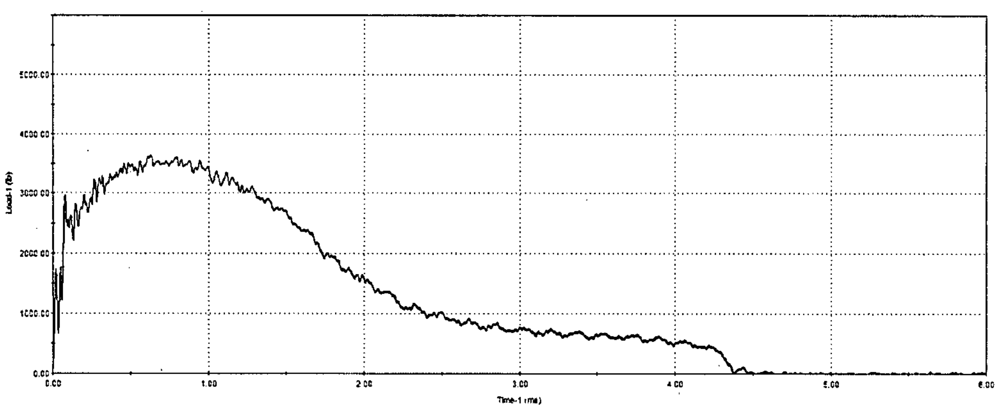
CL43, 275°F



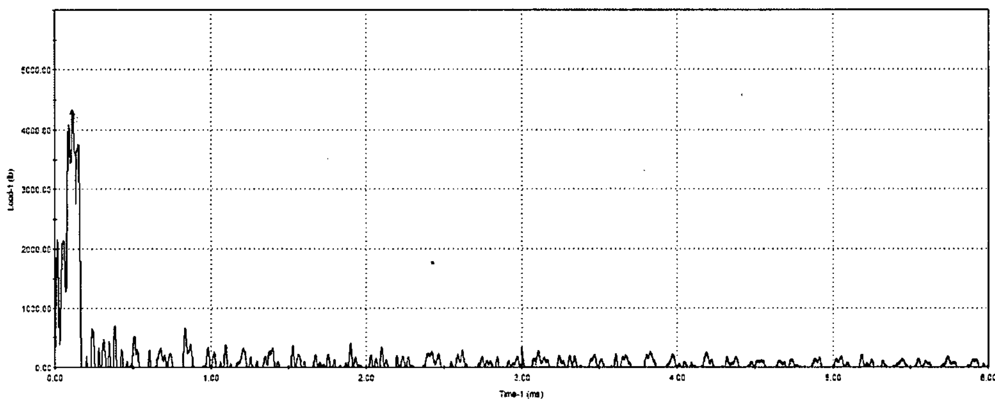
CL40, 300°F



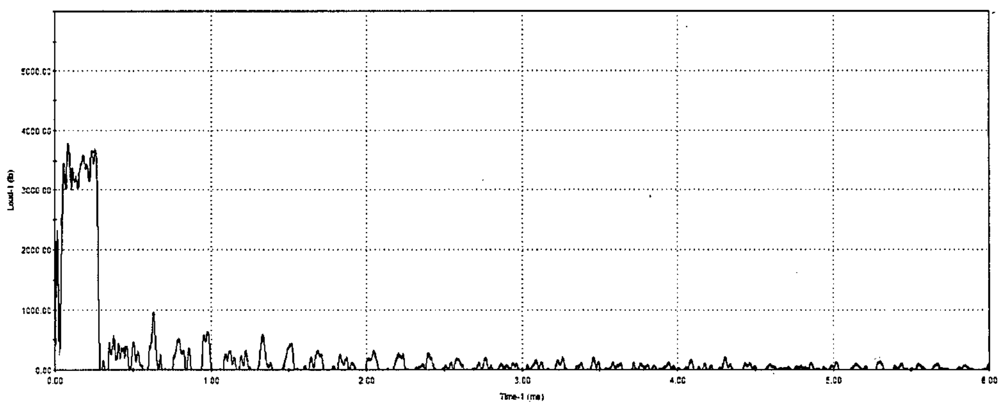
CL32, 325°F



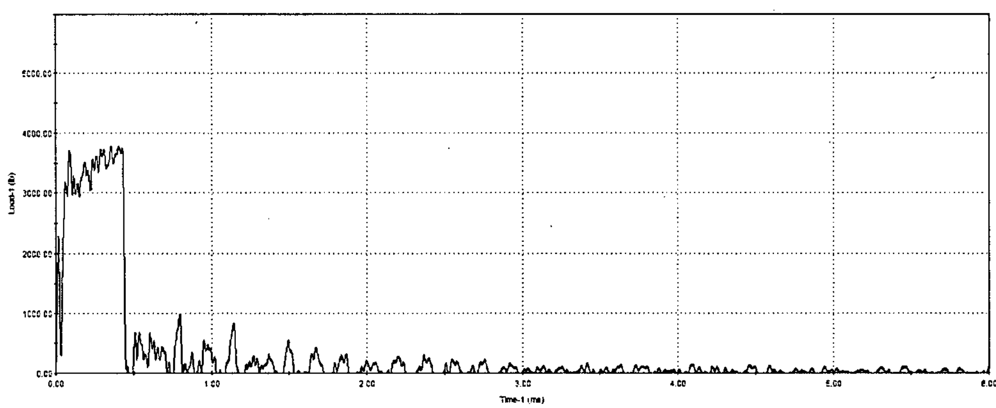
CL37, 350°F



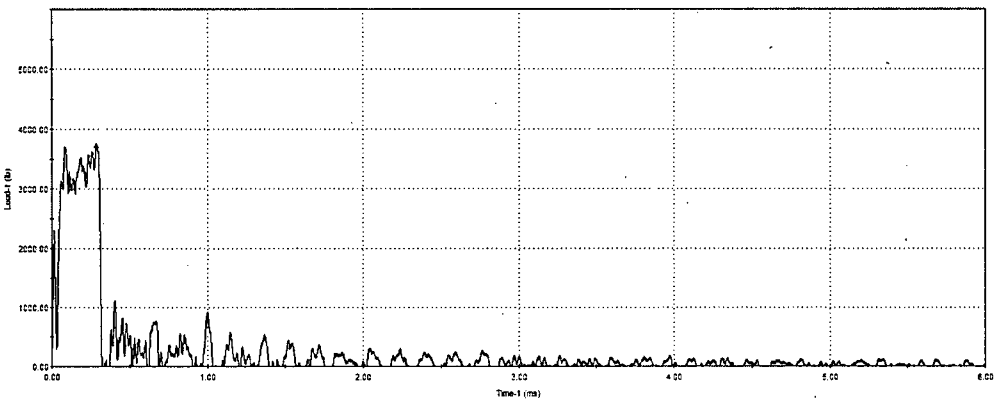
CT43, -90°F



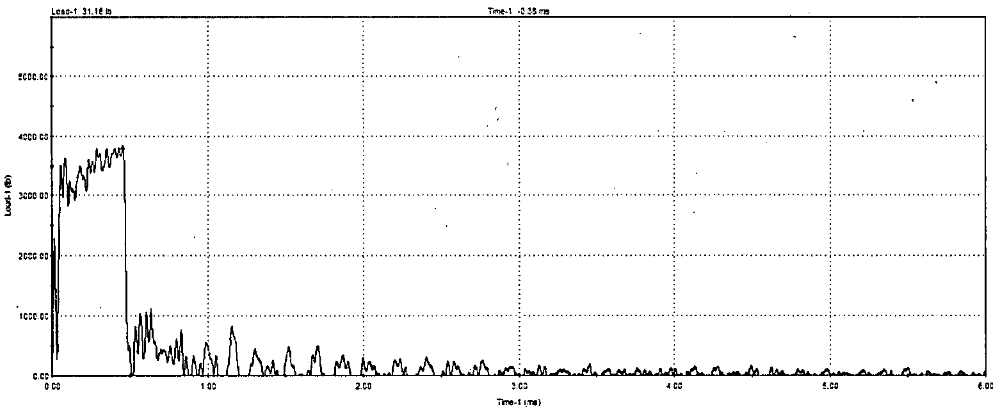
CT39, 30°F



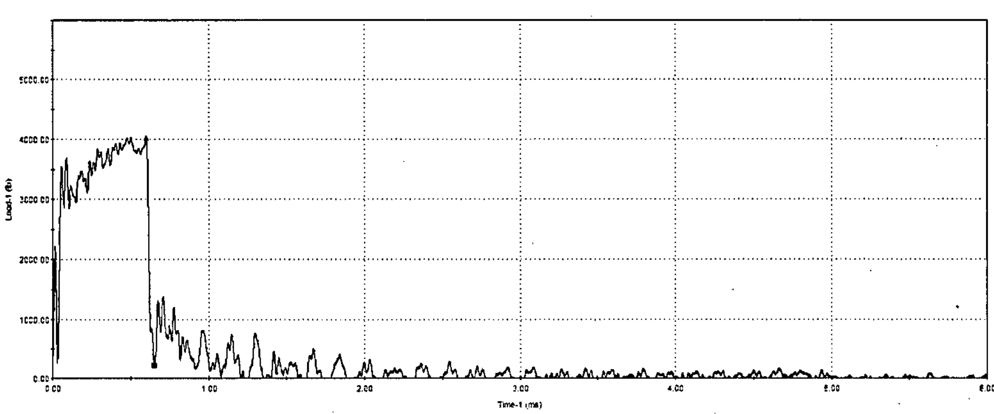
CT31, 50°F



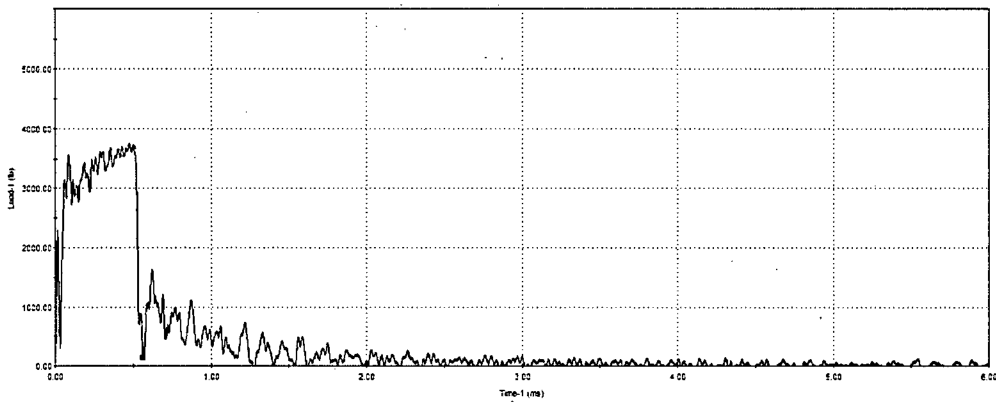
CT34, 55°F



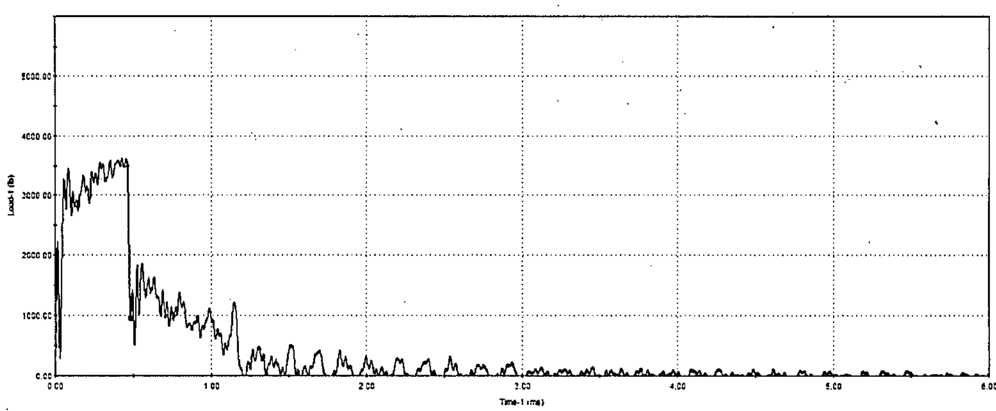
CT41, 65°F



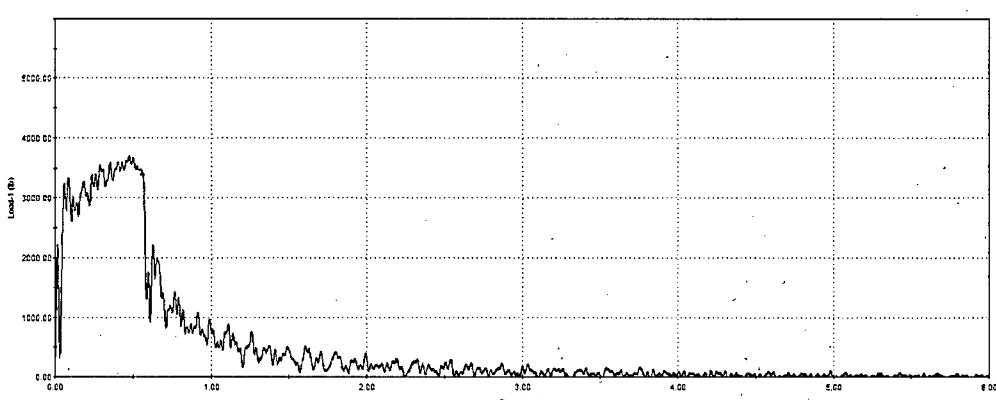
CT44, 75°F



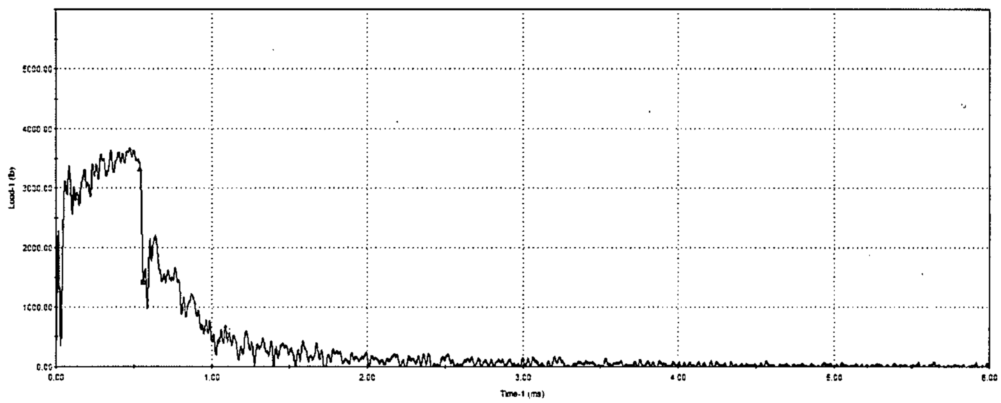
CT38, 100°F



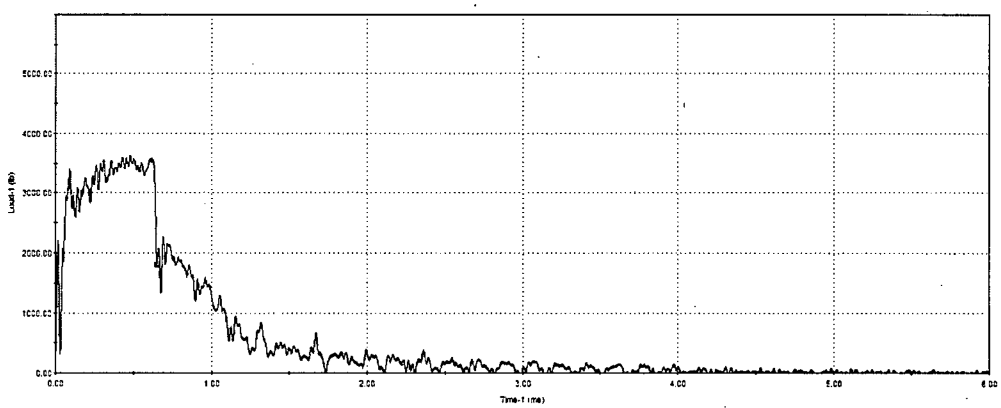
CT33, 125°F



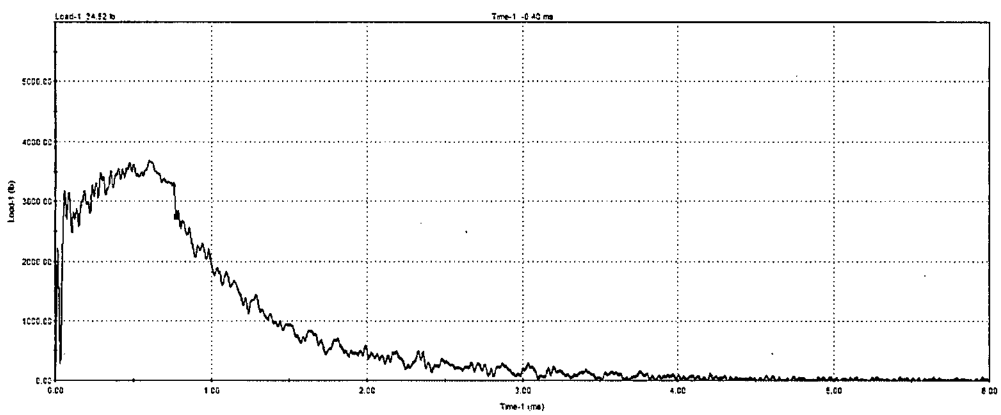
CT42, 130°F



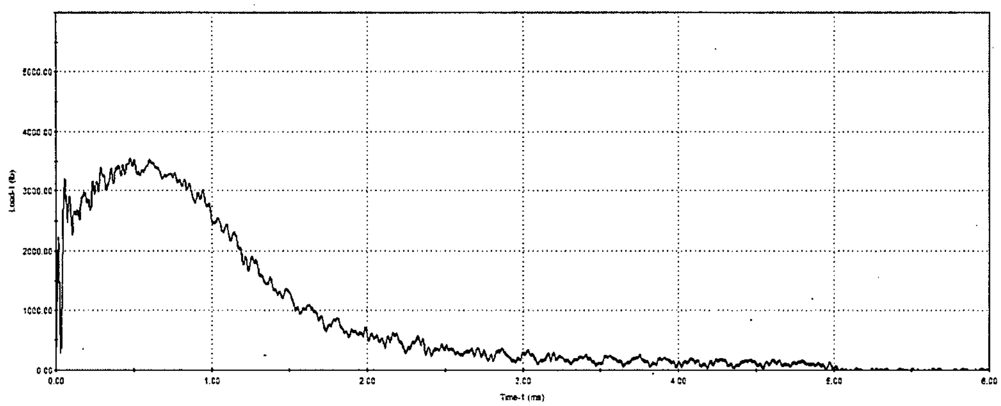
CT45, 140°F



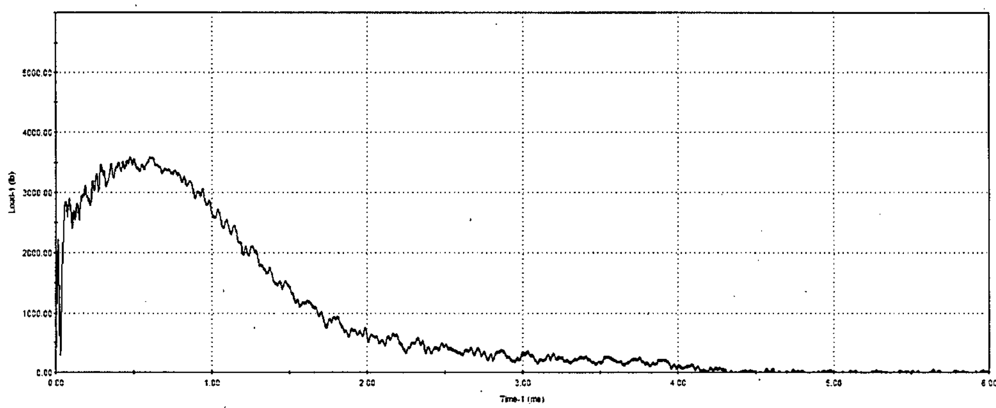
CT32, 150°F



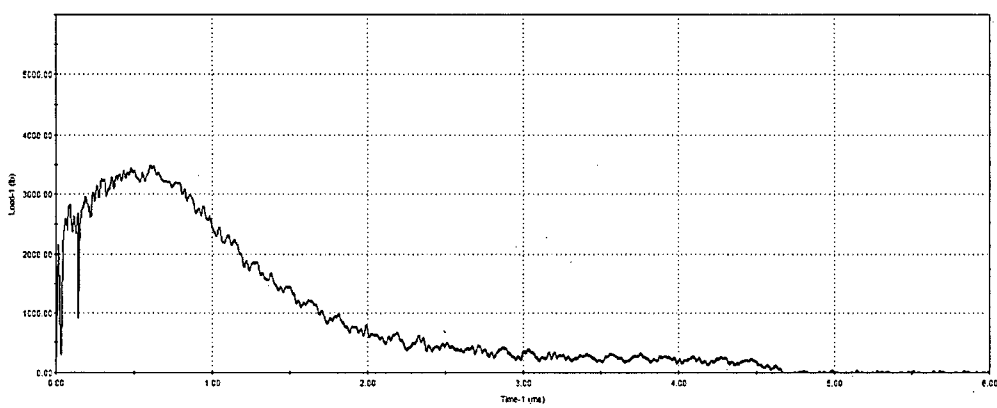
CT36, 200°F



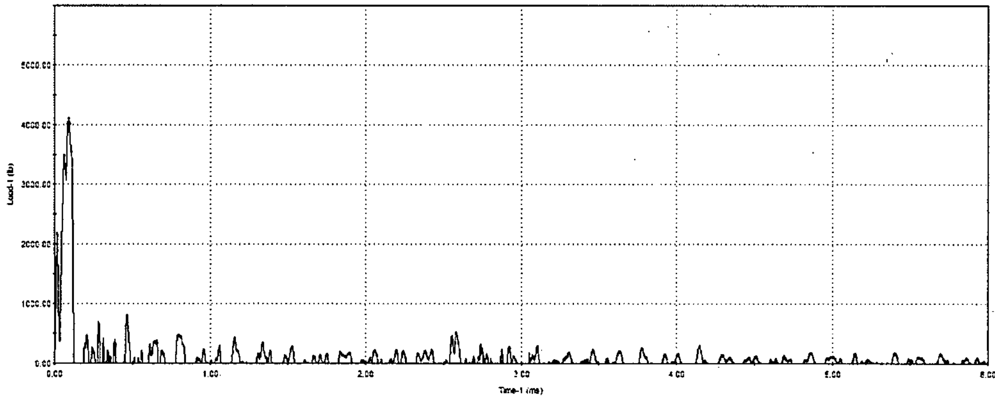
CT35, 275°F



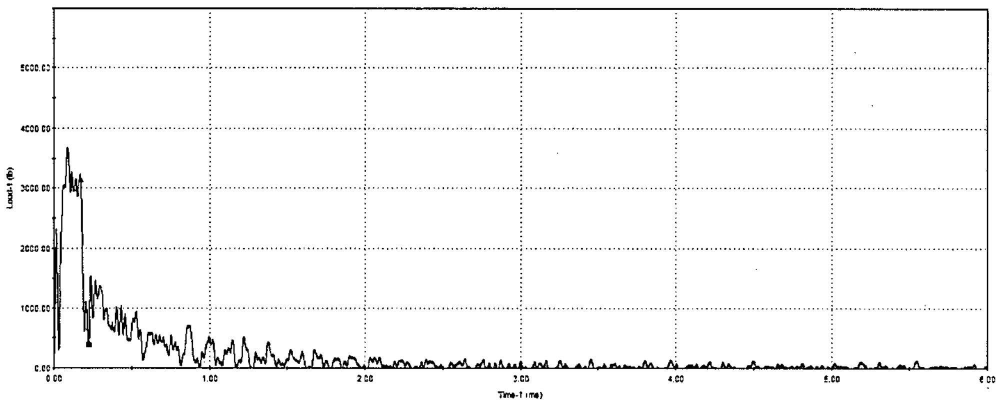
CT40, 300°F



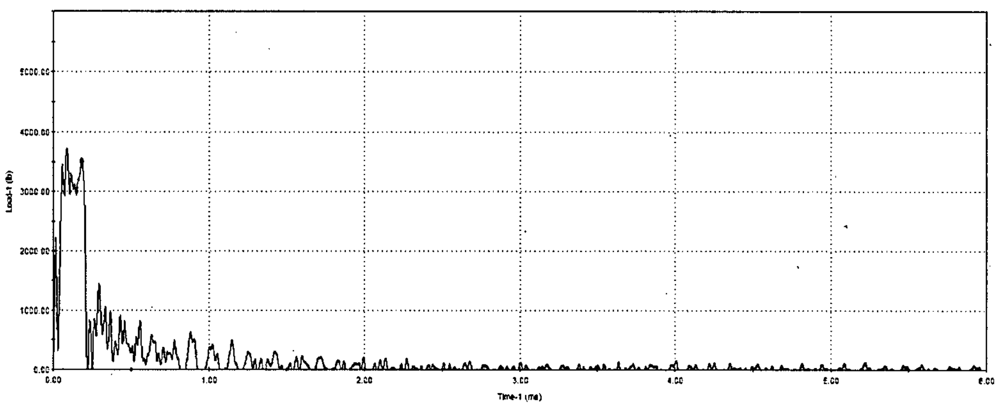
CT37, 325°F



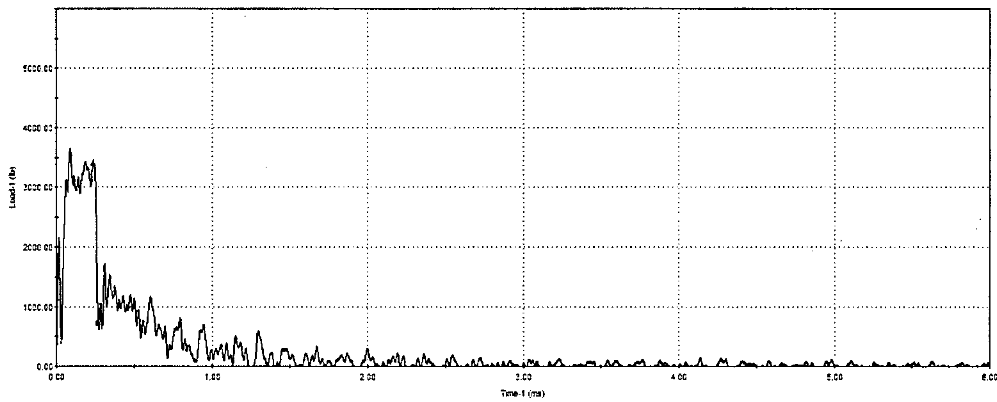
CW38, -90°F



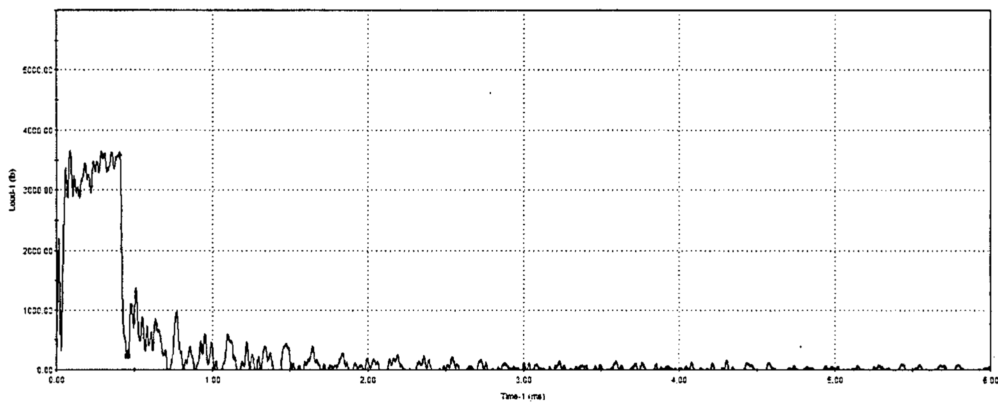
CW40, 25°F



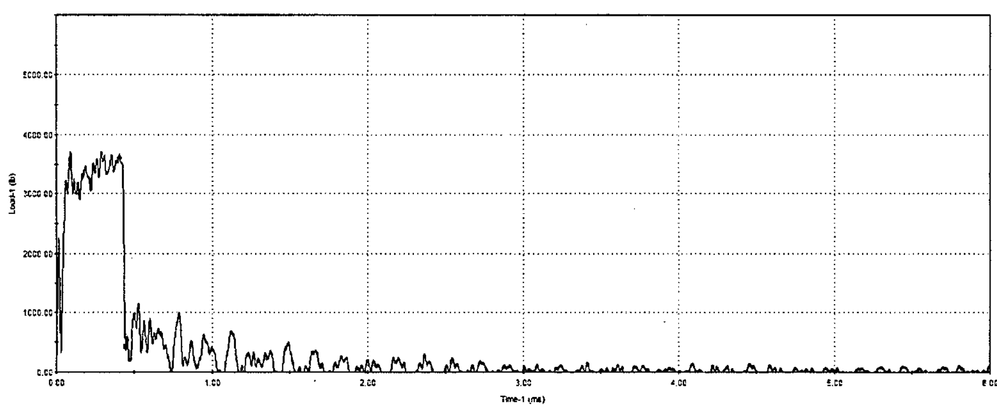
CW45, 30°F



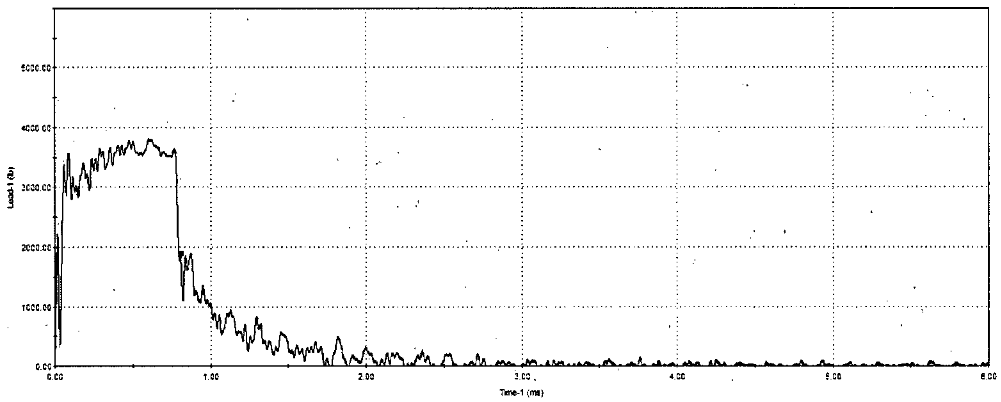
CW33, 30°F



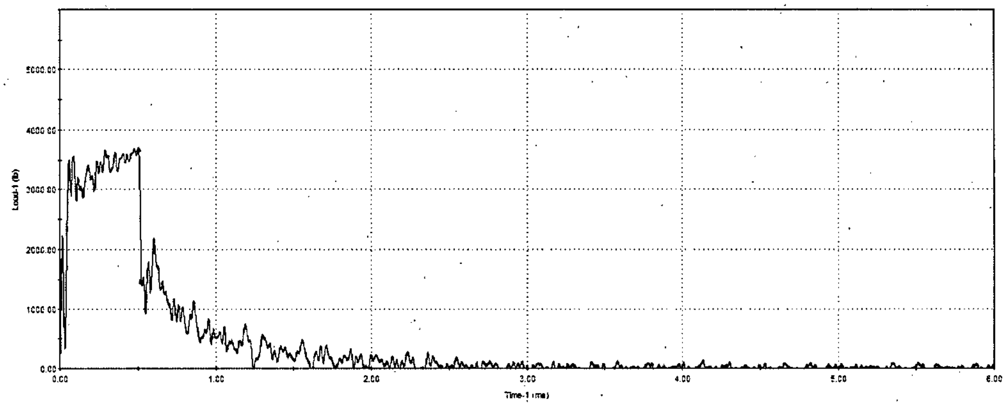
CW43, 35°F



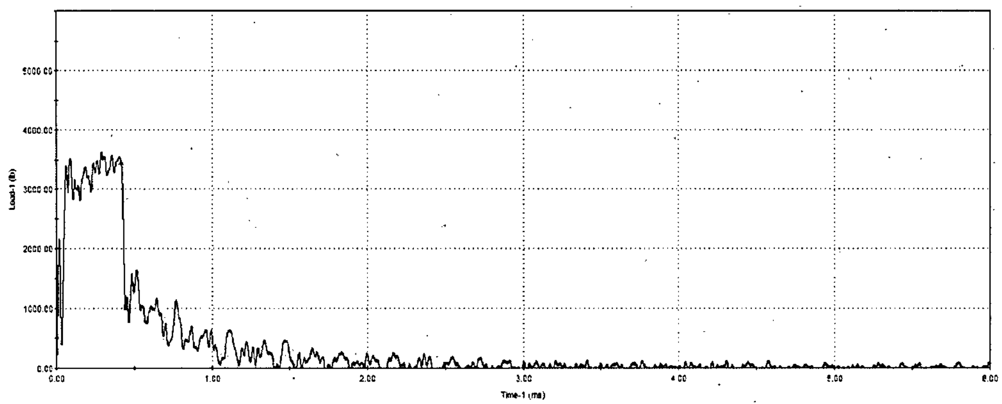
CW42, 40°F



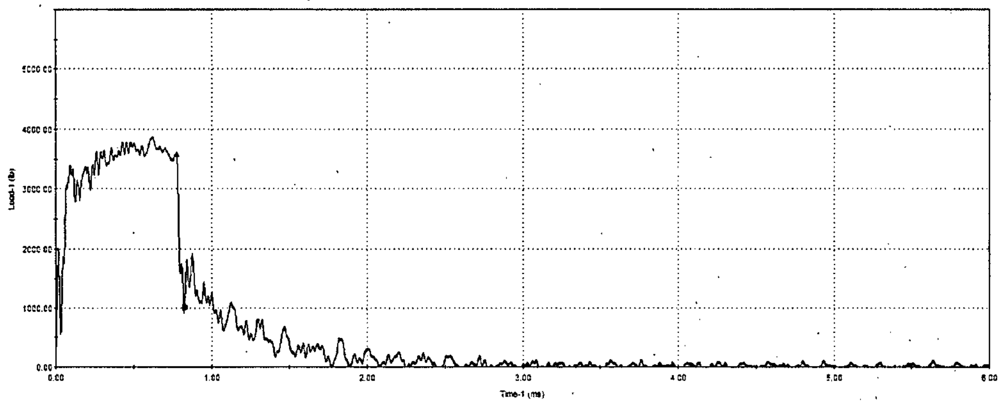
CW31, 45°F



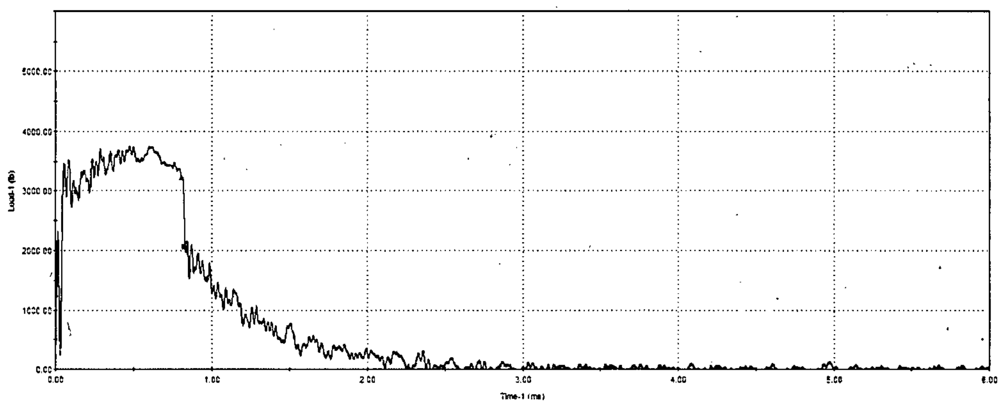
CW35, 45°F



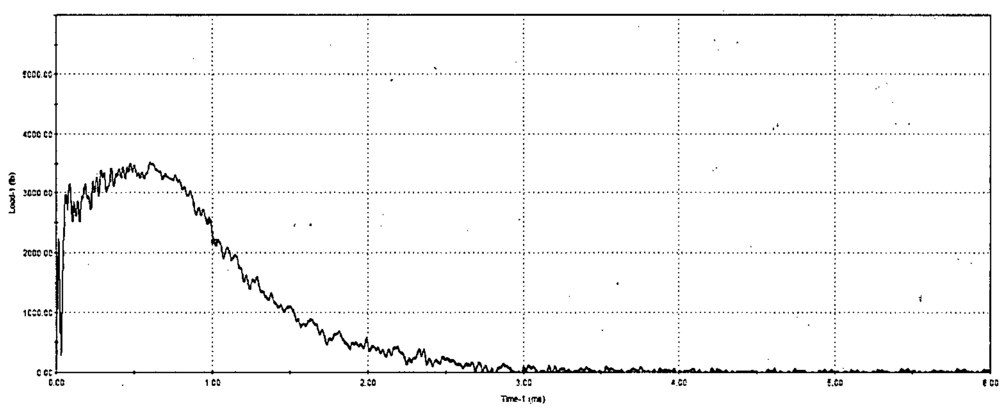
CW41, 50°F



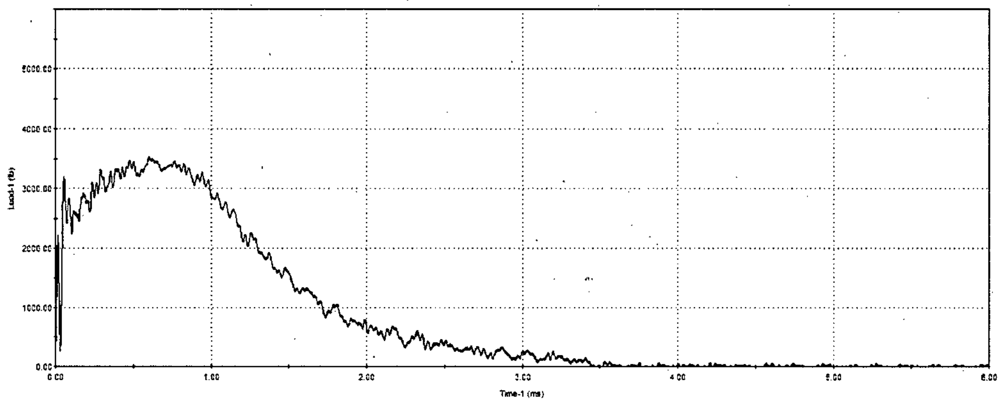
CW32, 50°F



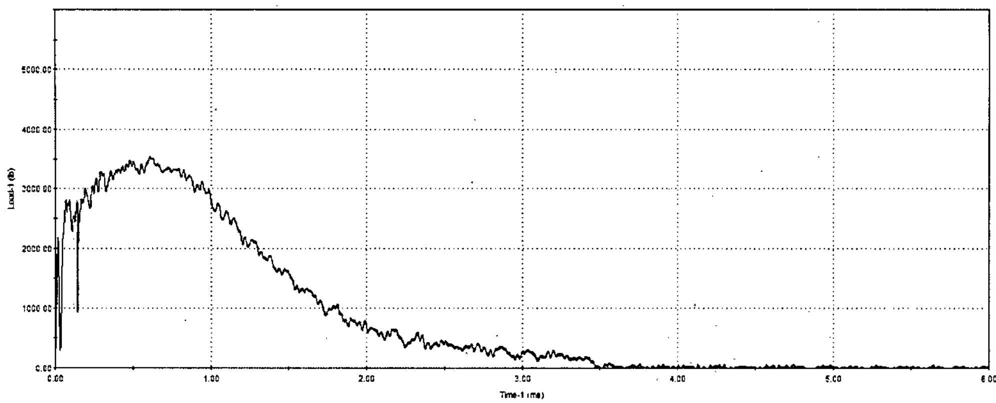
CW36, 75°F



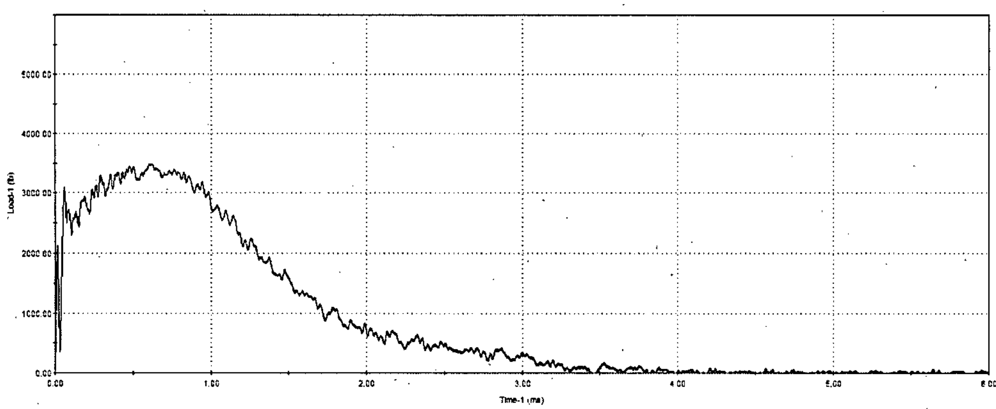
CW44, 175°F



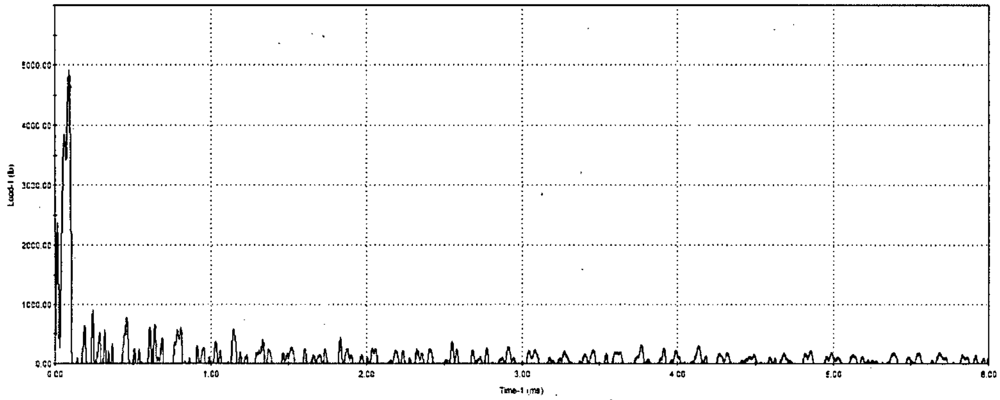
CW37, 275°F



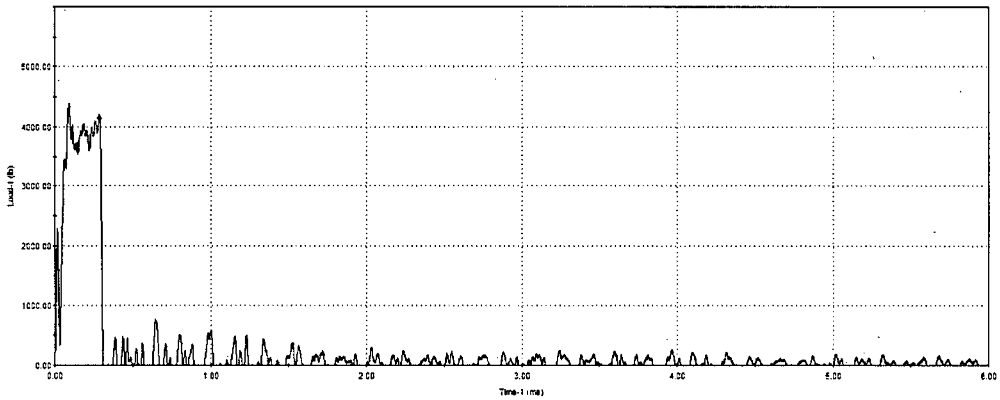
CW39, 300°F



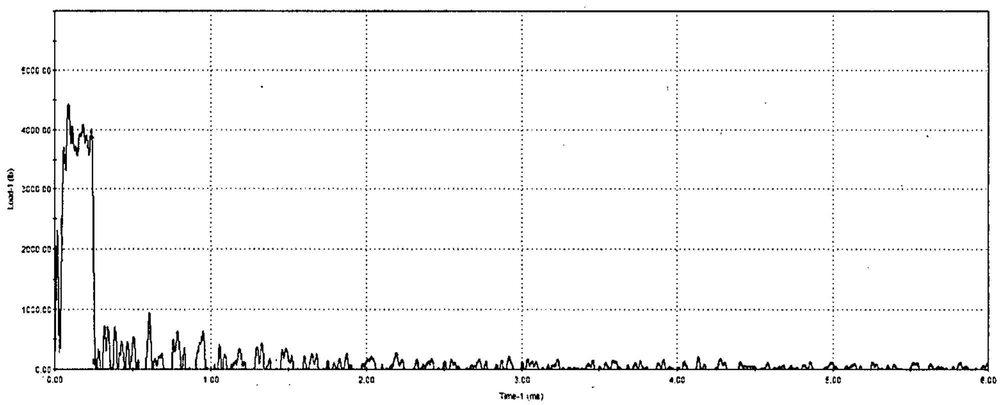
CW34, 325°F



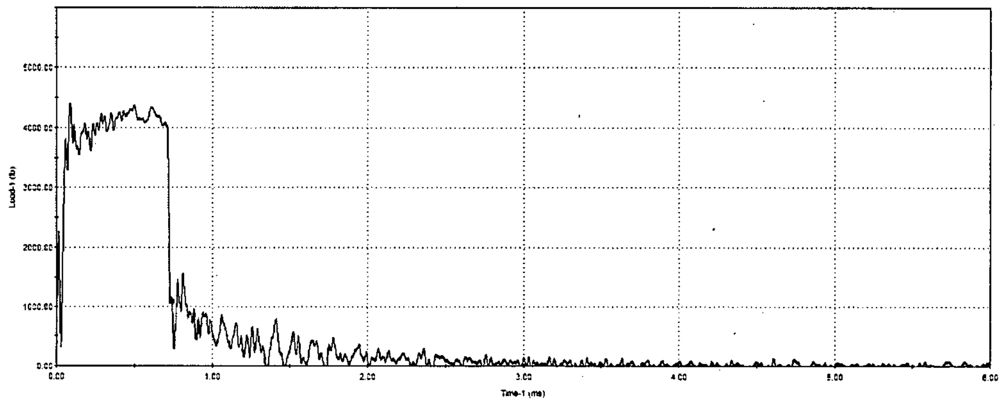
CH31, -175°F



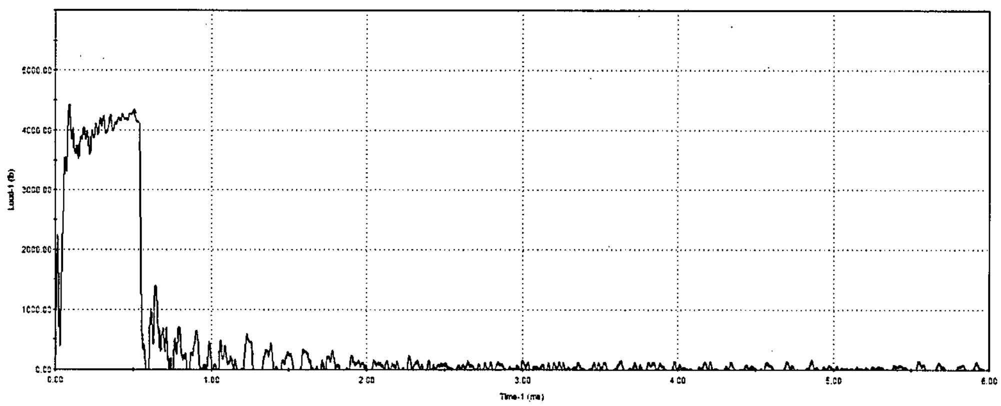
CH39, -90°F



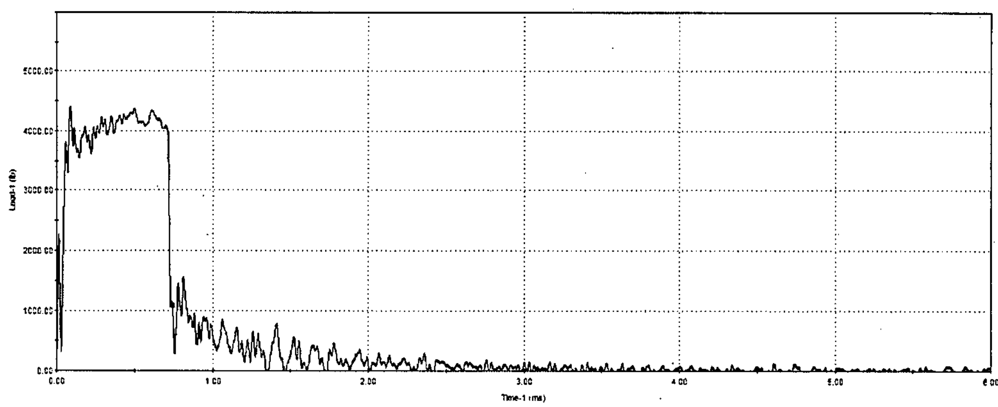
CH44, -80°F



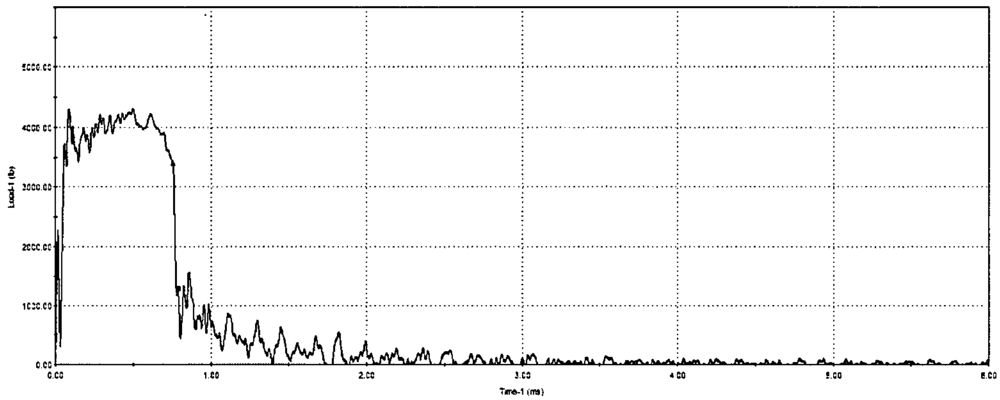
CH42, -75°F



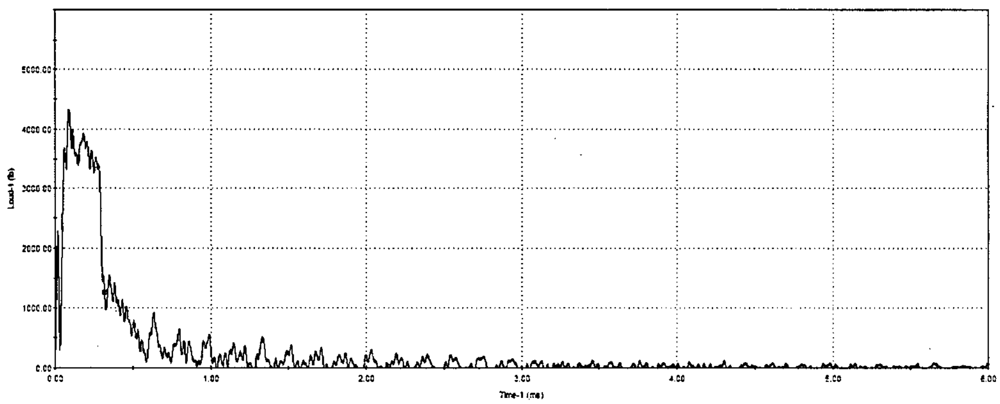
CH33, -75°F



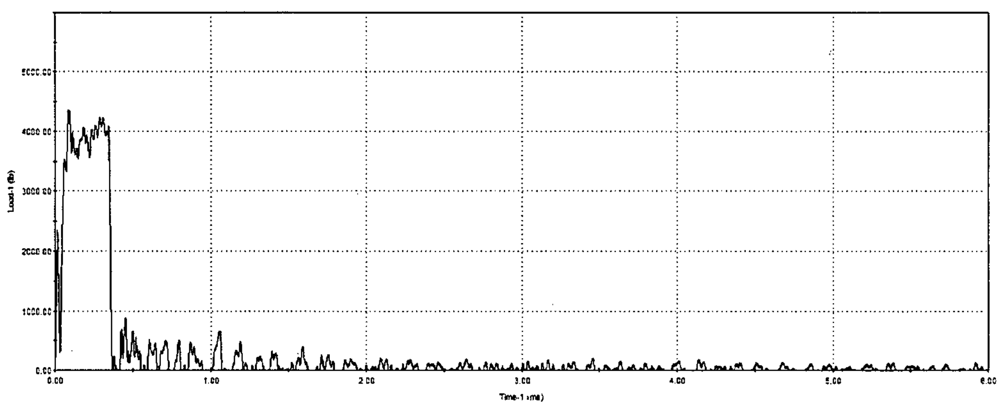
CH37, -70°F



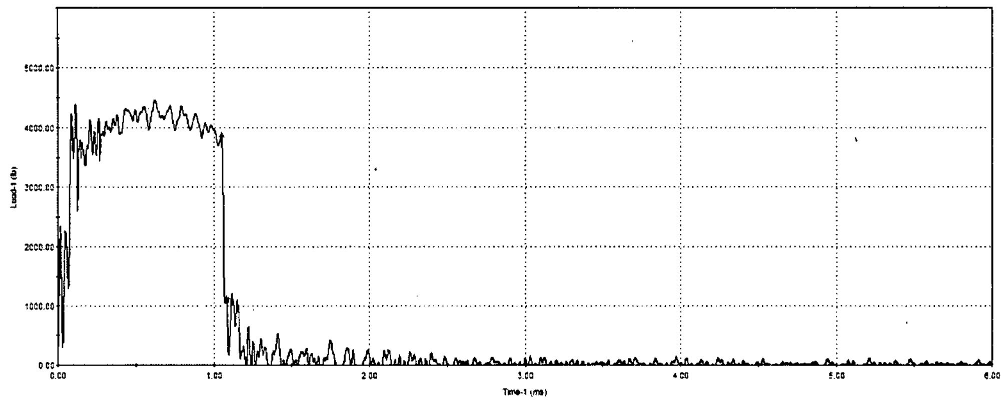
CH43, -65°F



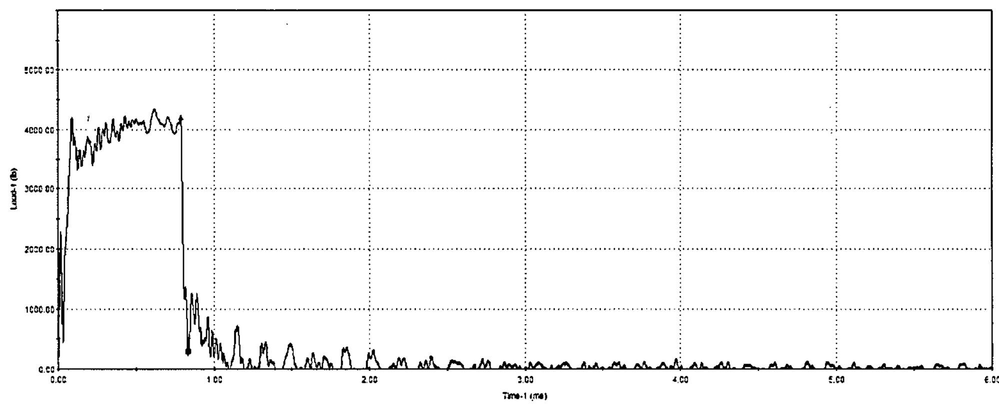
CH34, -60°F



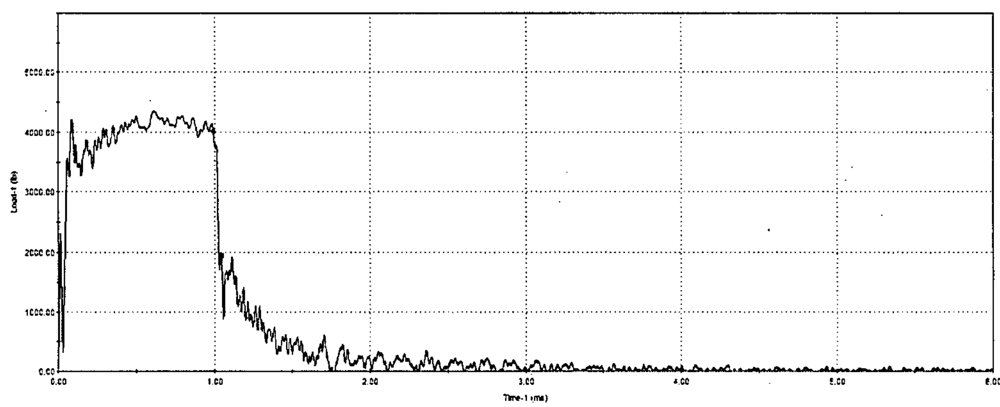
CH36, -60°F



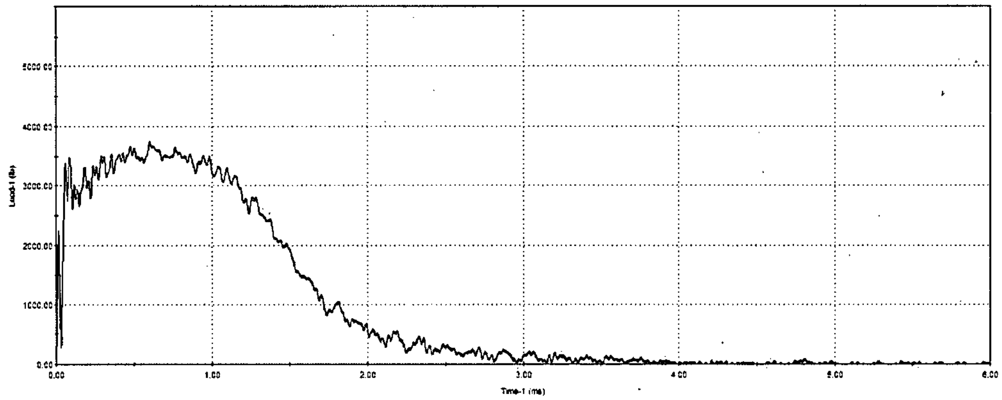
CH41, -60°F



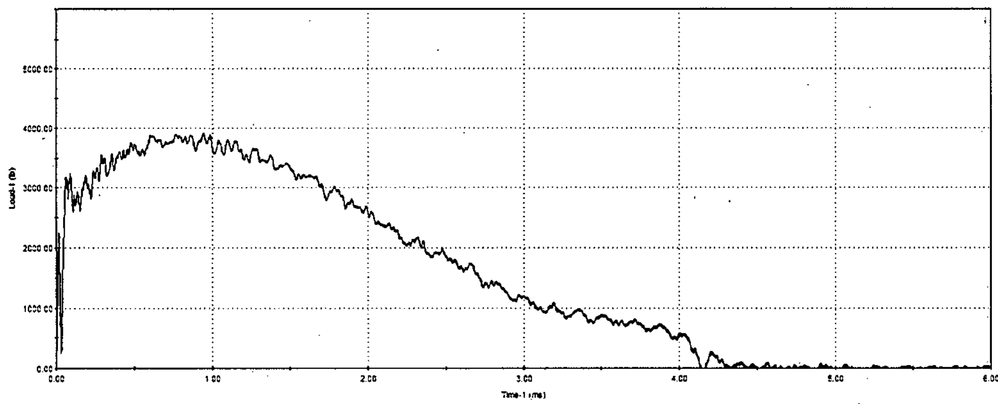
CH38, -50°F



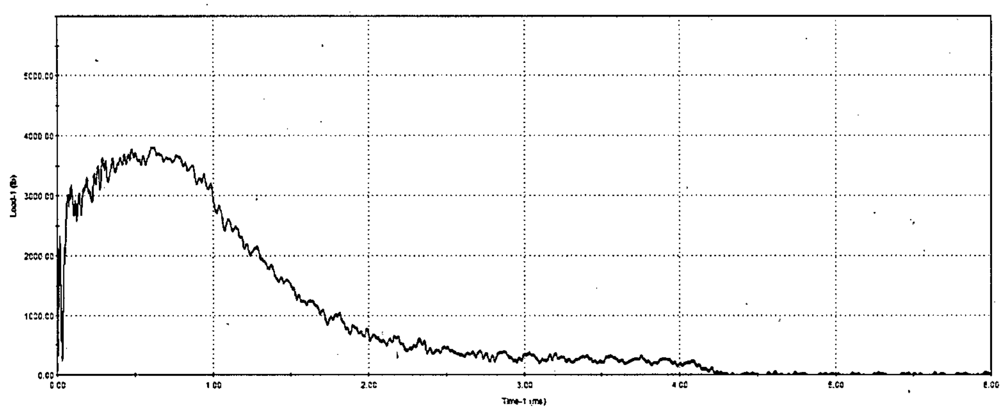
CH32, -25°F



CH45, 200°F



CH40, 225°F



CH35, 275°F

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

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

If there are specimens tested in sets of three at each temperature, Westinghouse typically reports the set having the highest average energy as the USE (usually unirradiated material). If the specimens were not tested in sets of three at each temperature, Westinghouse reports the average of all Charpy data (≥ 95% shear) as the USE, excluding any values that are deemed outliers using engineering judgment. Hence, the Capsule W 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 and X, were imported directly from Reference C-2. 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 0.0 mils in order to be consistent with the previous capsule analysis [Ref. C-2].

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

Material	Capsule			
	Unirradiated	U	X	W
Intermediate Shell Plate R3807-2 Longitudinal Orientation	115	118	120	118.4
Intermediate Shell Plate R3807-2 Transverse Orientation	84	88	91	84.0
Surveillance Program Weld Metal (Heat # 89833)	94	85	96	83.5
HAZ Material	116	127	116	111.0

CVGRAPH Version 5.3 plots of all surveillance data are provided in this appendix, on the pages following the reference list.

C.1 REFERENCES

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

C-2 WCAP-16277-NP, Revision 0, *Analysis of Capsule X from the TXU Energy Comanche Peak Unit 2 Reactor Vessel Radiation Surveillance Program*, September 2004.

C.2 CVGRAPH VERSION 5.3 INDIVIDUAL PLOTS

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 11:16 AM

Page 1

Coefficients of Curve 1

A = 58.6 B = 56.4 C = 93.38 T0 = 42.7 D = 0.00E+00

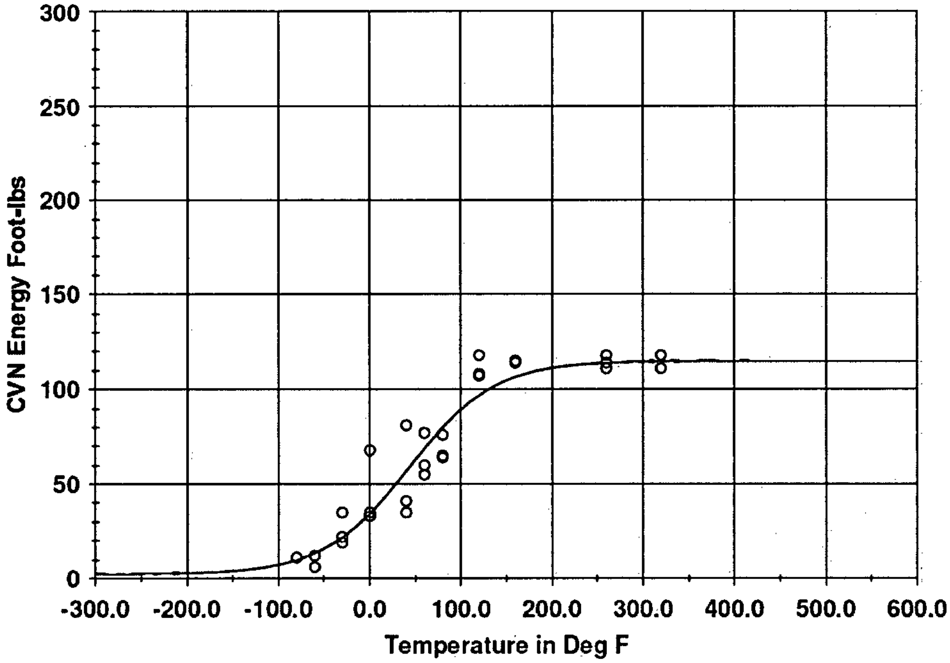
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=115.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-9.4 Deg F Temp@50 ft-lbs=28.4 Deg F

Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-80.00	11.00	9.80	1.20
-60.00	6.00	13.45	-7.45
-60.00	12.00	13.45	-1.45
-30.00	19.00	21.83	-2.83
-30.00	22.00	21.83	.17
-30.00	35.00	21.83	13.17
.00	33.00	34.47	-1.47
.00	33.00	34.47	-1.47
.00	35.00	34.47	.53

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

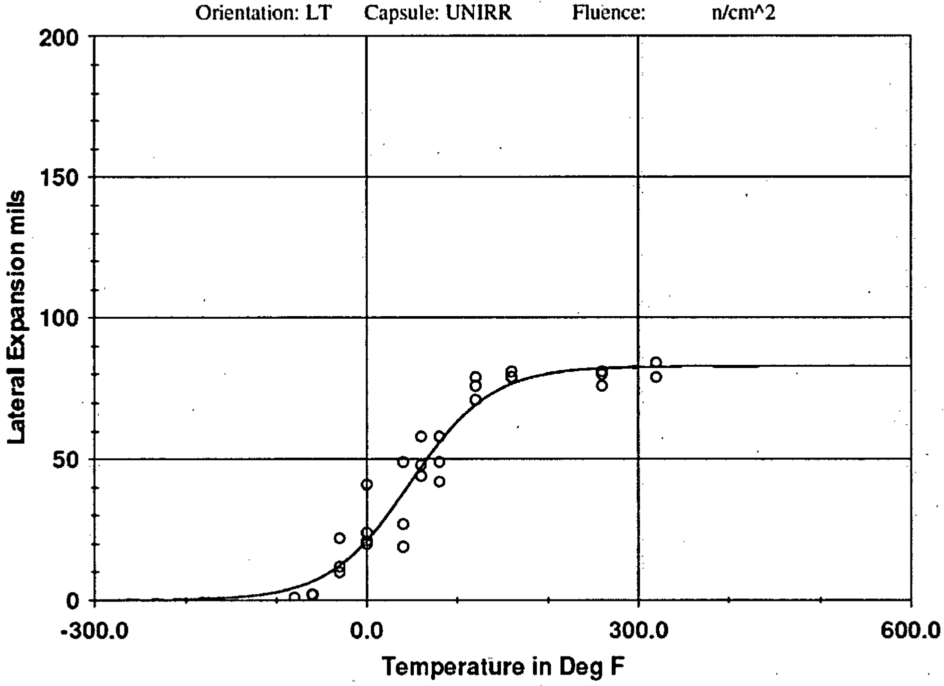
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	68.00	34.47	33.53
40.00	35.00	56.97	-21.97
40.00	41.00	56.97	-15.97
40.00	81.00	56.97	24.03
60.00	55.00	68.93	-13.93
60.00	60.00	68.93	-8.93
60.00	77.00	68.93	8.07
80.00	64.00	80.00	-16.00
80.00	65.00	80.00	-15.00
80.00	76.00	80.00	-4.00
120.00	107.00	96.91	10.09
120.00	108.00	96.91	11.09
120.00	118.00	96.91	21.09
160.00	114.00	106.54	7.46
160.00	115.00	106.54	8.46
160.00	115.00	106.54	8.46
260.00	111.00	113.94	-2.94
260.00	114.00	113.94	.06
260.00	118.00	113.94	4.06
320.00	111.00	114.70	-3.70
320.00	118.00	114.70	3.30

Correlation Coefficient = .950

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 11:19 AM
Page 1
Coefficients of Curve 1
A = 41.42 B = 41.42 C = 89.07 T0 = 47.28 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=82.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=33.4 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-80.00	1.00	4.50	-3.50
-60.00	2.00	6.83	-4.83
-60.00	2.00	6.83	-4.83
-30.00	10.00	12.42	-2.42
-30.00	12.00	12.42	-.42
-30.00	22.00	12.42	9.58
.00	21.00	21.29	-.29
.00	24.00	21.29	2.71
.00	20.00	21.29	-1.29

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

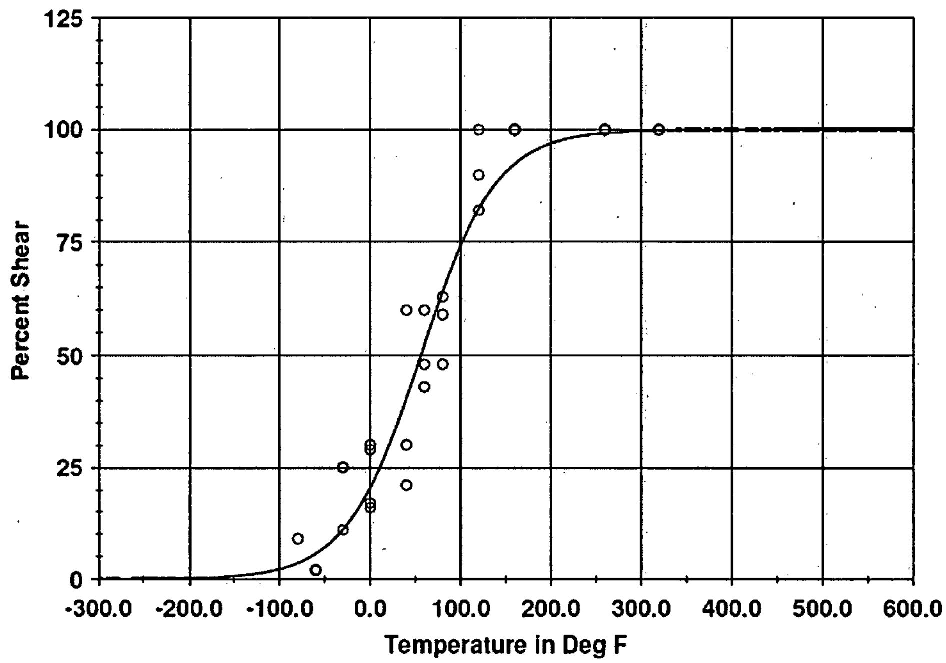
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	41.00	21.29	19.71
40.00	19.00	38.04	-19.04
40.00	27.00	38.04	-11.04
40.00	49.00	38.04	10.96
60.00	48.00	47.30	.70
60.00	44.00	47.30	-3.30
60.00	58.00	47.30	10.70
80.00	49.00	55.99	-6.99
80.00	42.00	55.99	-13.99
80.00	58.00	55.99	2.01
120.00	76.00	69.30	6.70
120.00	71.00	69.30	1.70
120.00	79.00	69.30	9.70
160.00	81.00	76.74	4.26
160.00	79.00	76.74	2.26
160.00	79.00	76.74	2.26
260.00	76.00	82.15	-6.15
260.00	80.00	82.15	-2.15
260.00	81.00	82.15	-1.15
320.00	79.00	82.66	-3.66
320.00	84.00	82.66	1.34

Correlation Coefficient = .962

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 02:03 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 82.77 T0 = 55.95 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 56.0
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-80.00	9.00	3.61	5.39
-60.00	2.00	5.72	-3.72
-60.00	2.00	5.72	-3.72
-30.00	25.00	11.14	13.86
-30.00	11.00	11.14	-.14
-30.00	25.00	11.14	13.86
.00	29.00	20.55	8.45
.00	17.00	20.55	-3.55
.00	16.00	20.55	-4.55

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

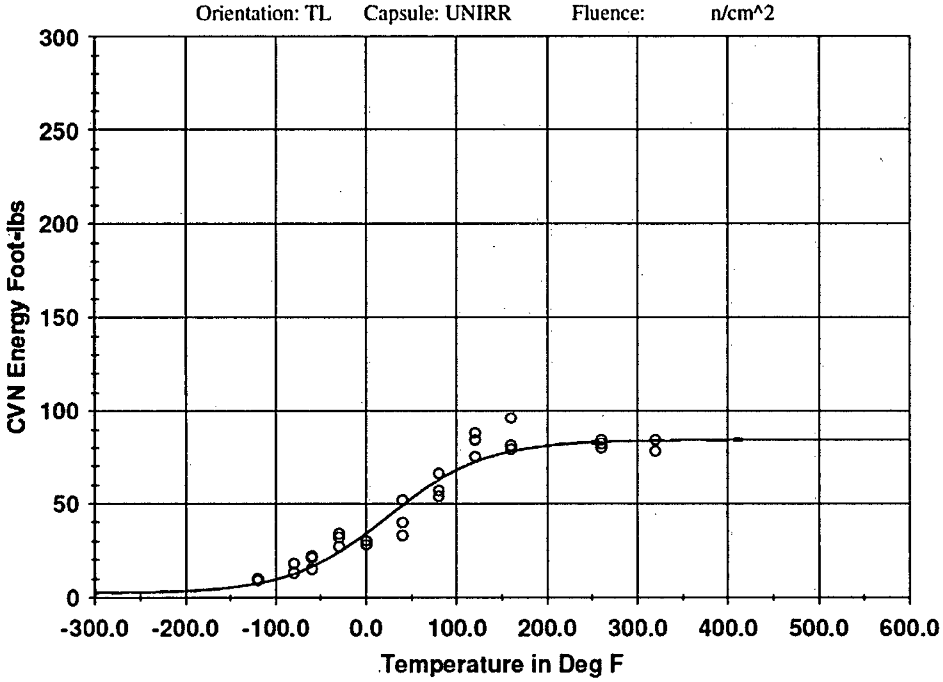
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	30.00	20.55	9.45
40.00	21.00	40.48	-19.48
40.00	30.00	40.48	-10.48
40.00	60.00	40.48	19.52
60.00	60.00	52.44	7.56
60.00	48.00	52.44	-4.44
60.00	43.00	52.44	-9.44
80.00	48.00	64.13	-16.13
80.00	59.00	64.13	-5.13
80.00	63.00	64.13	-1.13
120.00	90.00	82.46	7.54
120.00	82.00	82.46	-.46
120.00	100.00	82.46	17.54
160.00	100.00	92.51	7.49
160.00	100.00	92.51	7.49
160.00	100.00	92.51	7.49
260.00	100.00	99.28	.72
260.00	100.00	99.28	.72
260.00	100.00	99.28	.72
320.00	100.00	99.83	.17
320.00	100.00	99.83	.17

Correlation Coefficient = .968

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/30/2010 04:03 PM
Page 1
Coefficients of Curve 1
A = 43.1 B = 40.9 C = 107.72 T0 = 23.65 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=84.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-12.1 Deg F Temp@50 ft-lbs=42.1 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-120.00	9.00	7.51	1.49
-120.00	10.00	7.51	2.49
-80.00	13.00	12.62	.38
-80.00	18.00	12.62	5.38
-60.00	15.00	16.48	-1.48
-60.00	21.00	16.48	4.52
-60.00	22.00	16.48	5.52
-30.00	27.00	24.26	2.74
-30.00	32.00	24.26	7.74

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

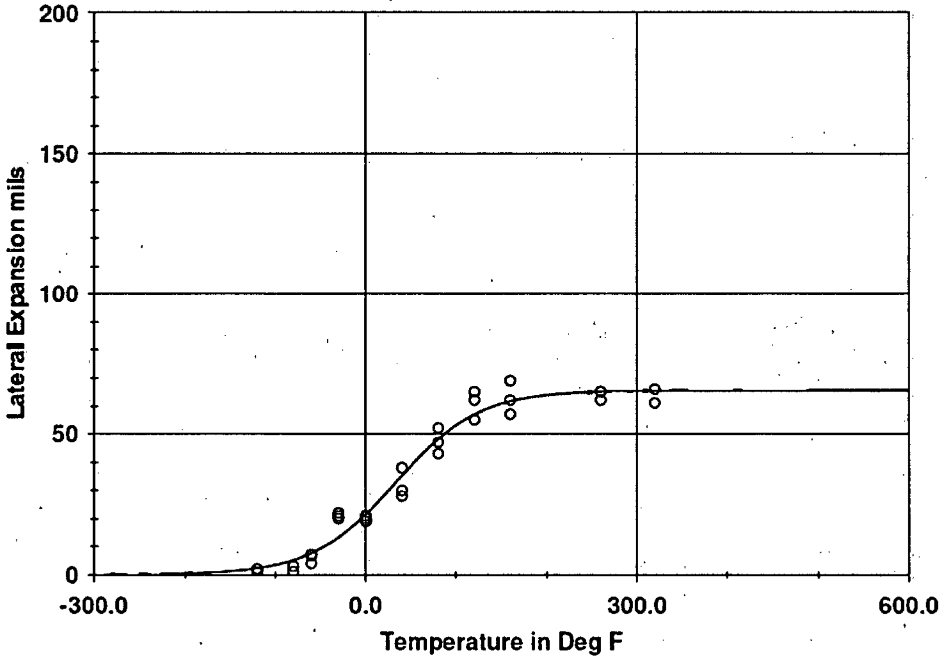
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-30.00	34.00	24.26	9.74
.00	28.00	34.26	-6.26
.00	30.00	34.26	-4.26
.00	30.00	34.26	-4.26
40.00	33.00	49.26	-16.26
40.00	40.00	49.26	-9.26
40.00	52.00	49.26	2.74
80.00	54.00	62.73	-8.73
80.00	57.00	62.73	-5.73
80.00	66.00	62.73	3.27
120.00	75.00	72.28	2.72
120.00	84.00	72.28	11.72
120.00	88.00	72.28	15.72
160.00	79.00	77.97	1.03
160.00	81.00	77.97	3.03
160.00	96.00	77.97	18.03
260.00	80.00	83.00	-3.00
260.00	82.00	83.00	-1.00
260.00	84.00	83.00	1.00
320.00	78.00	83.67	-5.67
320.00	84.00	83.67	.33

Correlation Coefficient = .967

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/30/2010 04:04 PM
Page 1
Coefficients of Curve 1
A = 32.79 B = 32.79 C = 92.46 T0 = 32.86 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=65.6 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=39.1 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-120.00	2.00	2.32	-.32
-120.00	1.00	2.32	-1.32
-80.00	3.00	5.25	-2.25
-80.00	1.00	5.25	-4.25
-60.00	7.00	7.76	-.76
-60.00	7.00	7.76	-.76
-60.00	4.00	7.76	-3.76
-30.00	21.00	13.40	7.60
-30.00	20.00	13.40	6.60

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

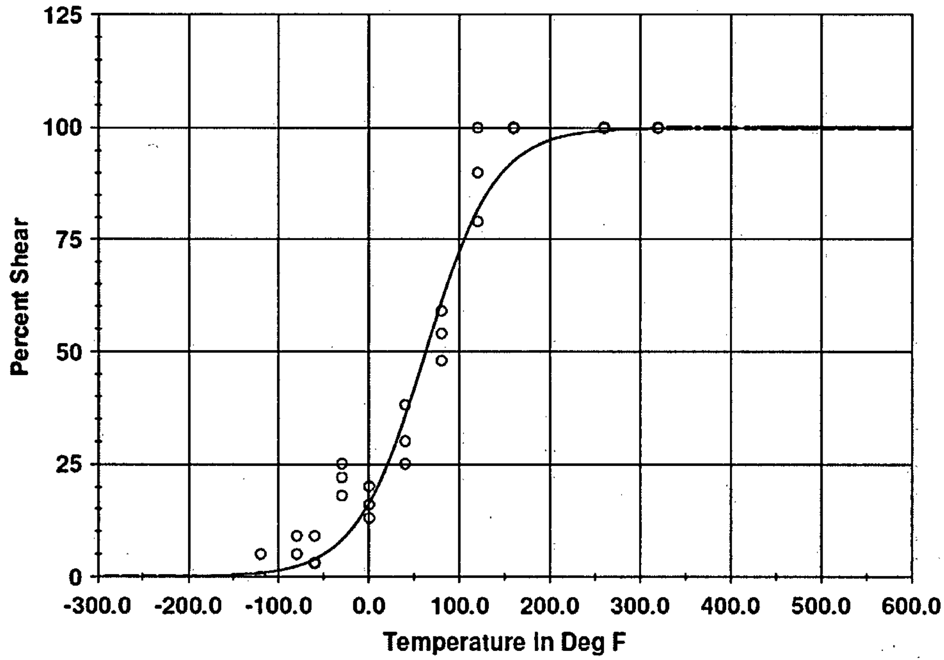
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-30.00	22.00	13.40	8.60
.00	21.00	21.61	-.61
.00	19.00	21.61	-2.61
.00	20.00	21.61	-1.61
40.00	28.00	35.32	-7.32
40.00	30.00	35.32	-5.32
40.00	38.00	35.32	2.68
80.00	43.00	48.20	-5.20
80.00	47.00	48.20	-1.20
80.00	52.00	48.20	3.80
120.00	55.00	56.94	-1.94
120.00	62.00	56.94	5.06
120.00	65.00	56.94	8.06
160.00	57.00	61.64	-4.64
160.00	62.00	61.64	.36
160.00	69.00	61.64	7.36
260.00	65.00	65.11	-.11
260.00	62.00	65.11	-3.11
260.00	65.00	65.11	-.11
320.00	61.00	65.45	-4.45
320.00	66.00	65.45	.55

Correlation Coefficient = .984

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 02:06 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 76.68 T0 = 62.67 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 62.7
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-120.00	5.00	.85	4.15
-120.00	.00	.85	-.85
-80.00	5.00	2.36	2.64
-80.00	9.00	2.36	6.64
-60.00	3.00	3.92	-.92
-60.00	9.00	3.92	5.08
-60.00	3.00	3.92	-.92
-30.00	22.00	8.19	13.81
-30.00	18.00	8.19	9.81

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

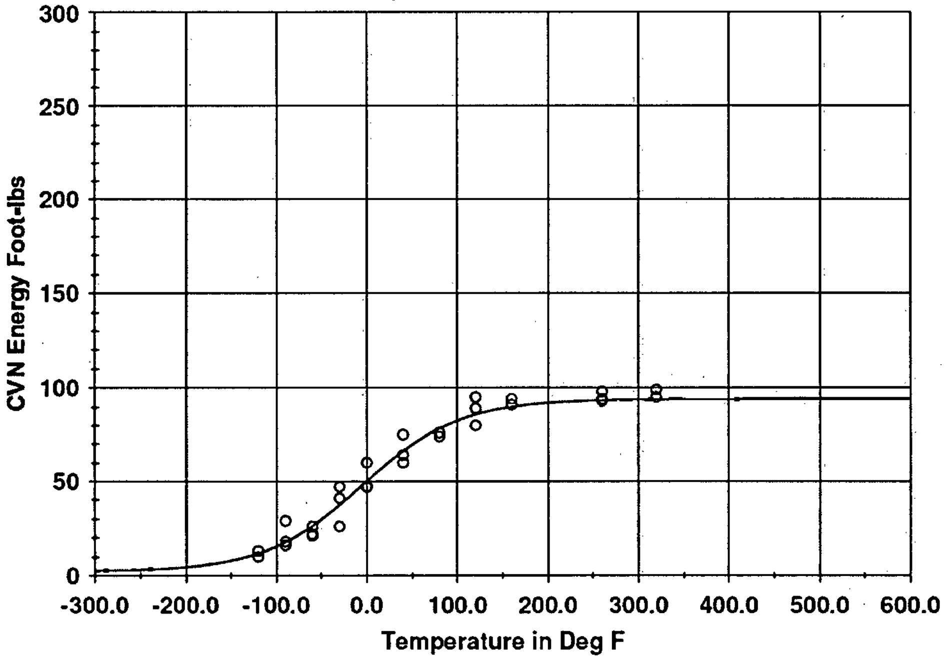
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-30.00	25.00	8.19	16.81
.00	13.00	16.32	-3.32
.00	20.00	16.32	3.68
.00	16.00	16.32	-.32
40.00	38.00	35.63	2.37
40.00	25.00	35.63	-10.63
40.00	30.00	35.63	-5.63
80.00	48.00	61.11	-13.11
80.00	54.00	61.11	-7.11
80.00	59.00	61.11	-2.11
120.00	79.00	81.69	-2.69
120.00	90.00	81.69	8.31
120.00	100.00	81.69	18.31
160.00	100.00	92.68	7.32
160.00	100.00	92.68	7.32
160.00	100.00	92.68	7.32
260.00	100.00	99.42	.58
260.00	100.00	99.42	.58
260.00	100.00	99.42	.58
320.00	100.00	99.88	.12
320.00	100.00	99.88	.12

Correlation Coefficient = .984

UNIRRADIATED (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 02:55 PM
Page 1
Coefficients of Curve 1
A = 48.1 B = 45.9 C = 107.15 T0 = -4.93 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=94.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-49.6 Deg F Temp@50 ft-lbs=-.4 Deg F
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-120.00	10.00	11.80	-1.80
-120.00	13.00	11.80	1.20
-90.00	16.00	17.78	-1.78
-90.00	18.00	17.78	.22
-90.00	29.00	17.78	11.22
-60.00	21.00	26.39	-5.39
-60.00	22.00	26.39	-4.39
-60.00	26.00	26.39	-.39
-30.00	26.00	37.55	-11.55

UNIRRADIATED (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

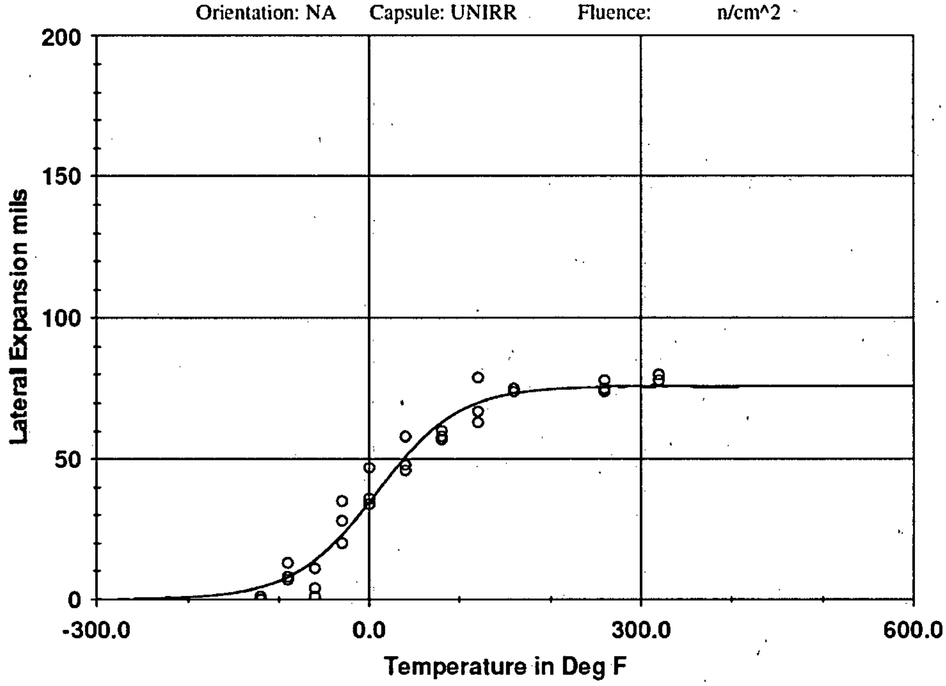
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-30.00	41.00	37.55	3.45
-30.00	47.00	37.55	9.45
.00	47.00	50.21	-3.21
.00	47.00	50.21	-3.21
.00	60.00	50.21	9.79
40.00	60.00	66.29	-6.29
40.00	64.00	66.29	-2.29
40.00	75.00	66.29	8.71
80.00	74.00	78.39	-4.39
80.00	76.00	78.39	-2.39
80.00	76.00	78.39	-2.39
120.00	80.00	85.87	-5.87
120.00	89.00	85.87	3.13
120.00	95.00	85.87	9.13
160.00	91.00	89.96	1.04
160.00	94.00	89.96	4.04
260.00	93.00	93.35	-.35
260.00	94.00	93.35	.65
260.00	98.00	93.35	4.65
320.00	95.00	93.79	1.21
320.00	99.00	93.79	5.21

Correlation Coefficient = .984

UNIRRADIATED (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 02:56 PM
Page 1
Coefficients of Curve 1
A = 38.02 B = 38.02 C = 91.24 T0 = 7.89 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=76.0 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=.7 Deg F
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-120.00	.00	4.34	-4.34
-120.00	1.00	4.34	-3.34
-90.00	8.00	7.96	.04
-90.00	7.00	7.96	-.96
-90.00	13.00	7.96	5.04
-60.00	4.00	14.00	-10.00
-60.00	1.00	14.00	-13.00
-60.00	11.00	14.00	-3.00
-30.00	20.00	23.08	-3.08

UNIRRADIATED (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-30.00	28.00	23.08	4.92
-30.00	35.00	23.08	11.92
.00	34.00	34.74	-.74
.00	36.00	34.74	1.26
.00	47.00	34.74	12.26
40.00	46.00	50.87	-4.87
40.00	48.00	50.87	-2.87
40.00	58.00	50.87	7.13
80.00	58.00	63.06	-5.06
80.00	57.00	63.06	-6.06
80.00	60.00	63.06	-3.06
120.00	63.00	70.04	-7.04
120.00	67.00	70.04	-3.04
120.00	79.00	70.04	8.96
160.00	74.00	73.42	.58
160.00	75.00	73.42	1.58
260.00	75.00	75.73	-.73
260.00	74.00	75.73	-1.73
260.00	78.00	75.73	2.27
320.00	80.00	75.96	4.04
320.00	78.00	75.96	2.04

Correlation Coefficient = .979

UNIRRADIATED (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 02:10 PM

Page 1

Coefficients of Curve 1

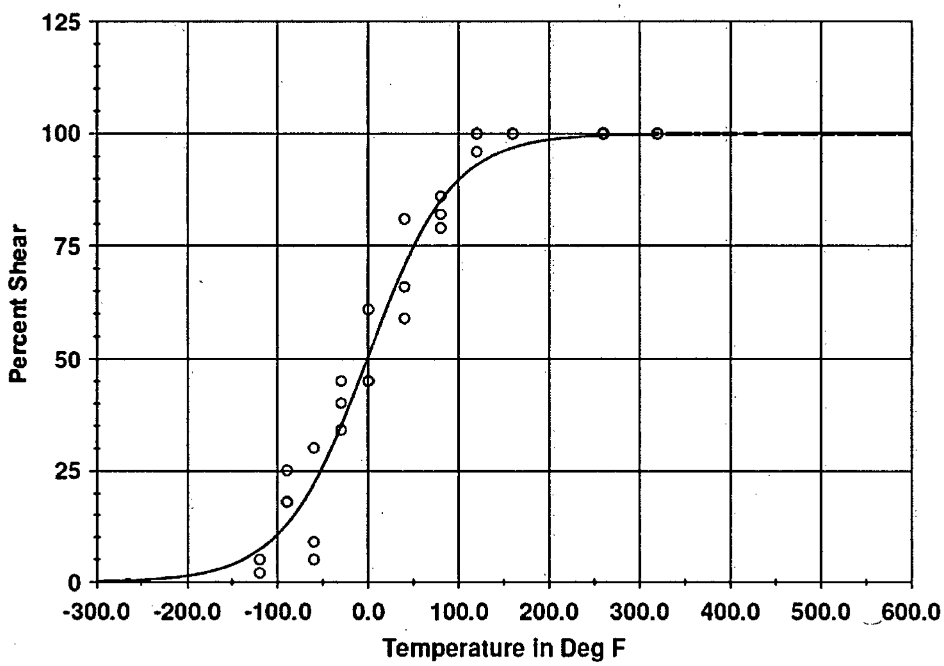
A = 50. B = 50. C = 93.39 T0 = -1.21 D = 0.00E+00

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

Temperature at 50% Shear = -1.2

Plant: Comanche Peak 2 Material: SAW Heat: 89833

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-120.00	5.00	7.28	-2.28
-120.00	2.00	7.28	-5.28
-90.00	18.00	12.99	5.01
-90.00	18.00	12.99	5.01
-90.00	25.00	12.99	12.01
-60.00	9.00	22.11	-13.11
-60.00	5.00	22.11	-17.11
-60.00	30.00	22.11	7.89
-30.00	34.00	35.06	-1.06

UNIRRADIATED (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

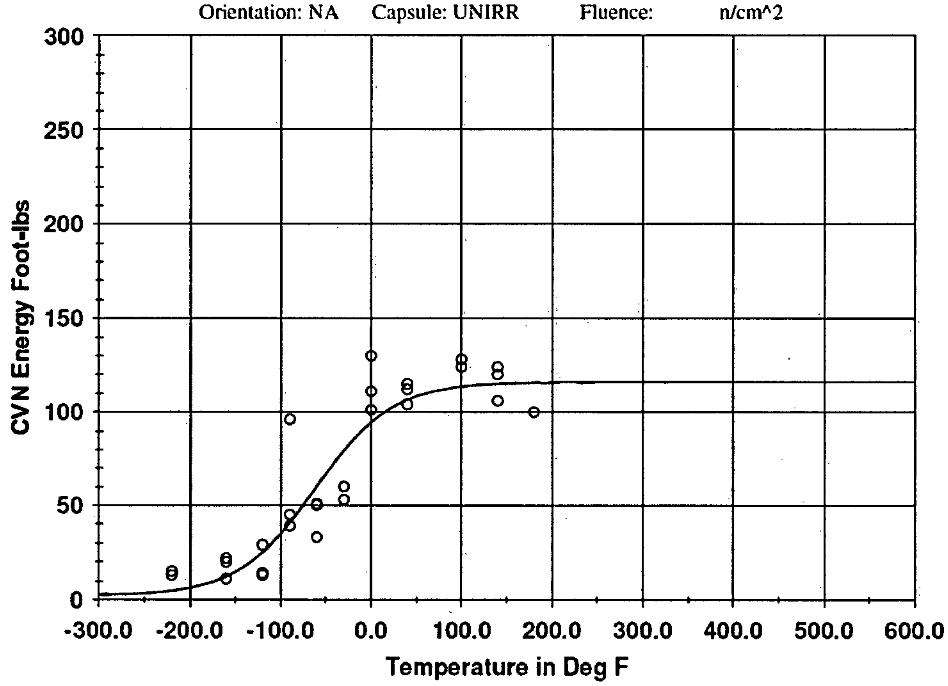
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-30.00	40.00	35.06	4.94
-30.00	45.00	35.06	9.94
.00	45.00	50.65	-5.65
.00	45.00	50.65	-5.65
.00	61.00	50.65	10.35
40.00	59.00	70.73	-11.73
40.00	66.00	70.73	-4.73
40.00	81.00	70.73	10.27
80.00	82.00	85.06	-3.06
80.00	86.00	85.06	.94
80.00	79.00	85.06	-6.06
120.00	96.00	93.06	2.94
120.00	100.00	93.06	6.94
120.00	100.00	93.06	6.94
160.00	100.00	96.93	3.07
160.00	100.00	96.93	3.07
260.00	100.00	99.63	.37
260.00	100.00	99.63	.37
260.00	100.00	99.63	.37
320.00	100.00	99.90	.10
320.00	100.00	99.90	.10

Correlation Coefficient = .980

UNIRRADIATED (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 02:58 PM
Page 1
Coefficients of Curve 1
A = 59.1 B = 56.9 C = 84.54 T0 = -61.79 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=116.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-109.5 Deg F Temp@50 ft-lbs=-75.4 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-220.00	13.00	4.83	8.17
-220.00	15.00	4.83	10.17
-160.00	11.00	12.35	-1.35
-160.00	20.00	12.35	7.65
-160.00	22.00	12.35	9.65
-120.00	13.00	25.13	-12.13
-120.00	14.00	25.13	-11.13
-120.00	29.00	25.13	3.87
-90.00	39.00	40.79	-1.79

UNIRRADIATED (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

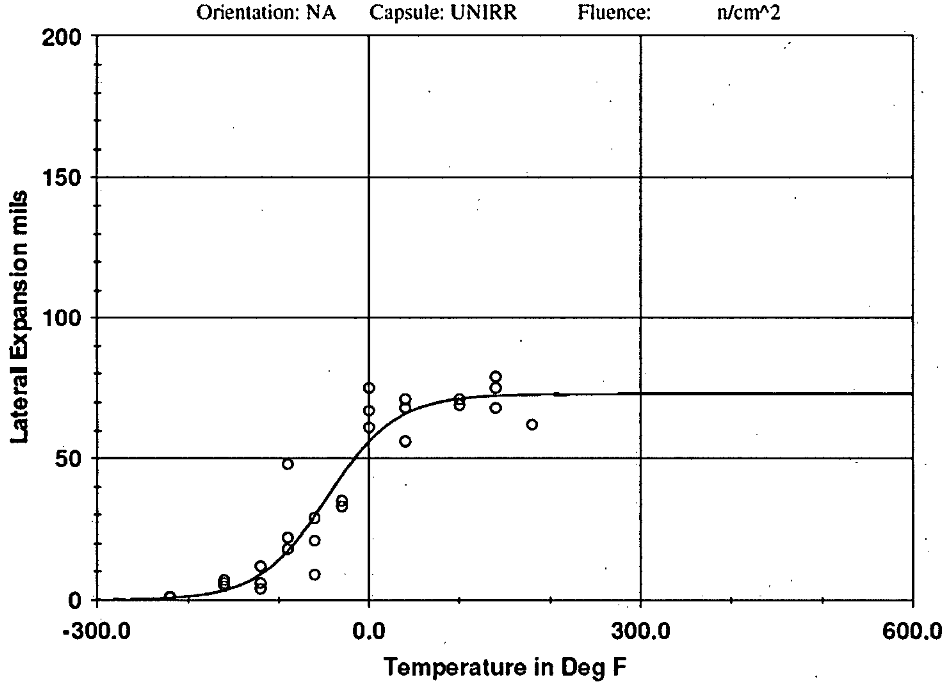
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-90.00	45.00	40.79	4.21
-90.00	96.00	40.79	55.21
-60.00	33.00	60.31	-27.31
-60.00	50.00	60.31	-10.31
-60.00	51.00	60.31	-9.31
-30.00	53.00	79.54	-26.54
-30.00	60.00	79.54	-19.54
.00	101.00	94.59	6.41
.00	111.00	94.59	16.41
.00	130.00	94.59	35.41
40.00	104.00	106.61	-2.61
40.00	112.00	106.61	5.39
40.00	115.00	106.61	8.39
100.00	124.00	113.58	10.42
100.00	128.00	113.58	14.42
140.00	106.00	115.05	-9.05
140.00	120.00	115.05	4.95
140.00	124.00	115.05	8.95
180.00	100.00	115.63	-15.63

Correlation Coefficient = .921

UNIRRADIATED (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 02:59 PM
Page 1
Coefficients of Curve 1
A = 36.41 B = 36.41 C = 76.16 T0 = -46.04 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=72.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=-48.9 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-220.00	1.00	.75	.25
-220.00	1.00	.75	.25
-160.00	6.00	3.48	2.52
-160.00	7.00	3.48	3.52
-160.00	5.00	3.48	1.52
-120.00	6.00	9.13	-3.13
-120.00	4.00	9.13	-5.13
-120.00	12.00	9.13	2.87
-90.00	18.00	17.45	..55

UNIRRADIATED (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

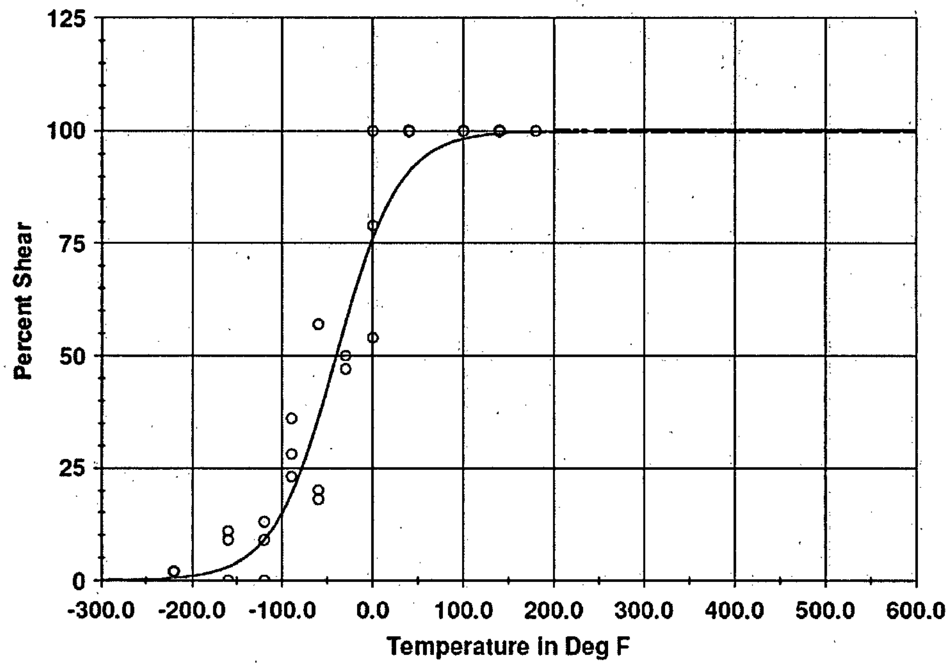
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-90.00	22.00	17.45	4.55
-90.00	48.00	17.45	30.55
-60.00	9.00	29.81	-20.81
-60.00	29.00	29.81	-.81
-60.00	21.00	29.81	-8.81
-30.00	33.00	43.97	-10.97
-30.00	35.00	43.97	-8.97
.00	61.00	56.08	4.92
.00	67.00	56.08	10.92
.00	75.00	56.08	18.92
40.00	56.00	65.94	-9.94
40.00	68.00	65.94	2.06
40.00	71.00	65.94	5.06
100.00	69.00	71.28	-2.28
100.00	71.00	71.28	-.28
140.00	68.00	72.27	-4.27
140.00	79.00	72.27	6.73
140.00	75.00	72.27	2.73
180.00	62.00	72.63	-10.63

Correlation Coefficient = .941

UNIRRADIATED (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 02:12 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 69.21 T0 = -40.34 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -40.3
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-220.00	2.00	.55	1.45
-220.00	2.00	.55	1.45
-160.00	.00	3.05	-3.05
-160.00	9.00	3.05	5.95
-160.00	11.00	3.05	7.95
-120.00	.00	9.10	-9.10
-120.00	13.00	9.10	3.90
-120.00	9.00	9.10	-.10
-90.00	28.00	19.23	8.77

UNIRRADIATED (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

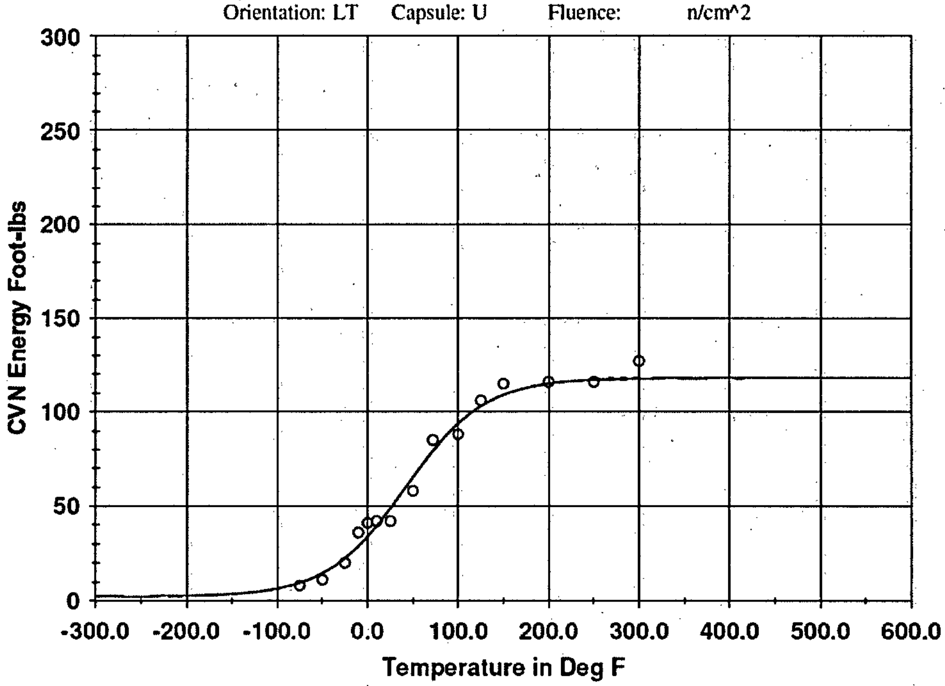
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-90.00	23.00	19.23	3.77
-90.00	36.00	19.23	16.77
-60.00	18.00	36.17	-18.17
-60.00	57.00	36.17	20.83
-60.00	20.00	36.17	-16.17
-30.00	50.00	57.41	-7.41
-30.00	47.00	57.41	-10.41
.00	54.00	76.24	-22.24
.00	79.00	76.24	2.76
.00	100.00	76.24	23.76
40.00	100.00	91.06	8.94
40.00	100.00	91.06	8.94
40.00	100.00	91.06	8.94
100.00	100.00	98.30	1.70
100.00	100.00	98.30	1.70
140.00	100.00	99.46	.54
140.00	100.00	99.46	.54
140.00	100.00	99.46	.54
180.00	100.00	99.83	.17

Correlation Coefficient = .966

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:00 PM
Page 1
Coefficients of Curve 1
A = 60.1 B = 57.9 C = 86.68 T0 = 42.11 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=118.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-7.8 Deg F Temp@50 ft-lbs=26.9 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-75.00	8.00	9.48	-1.48
-50.00	11.00	14.55	-3.55
-25.00	20.00	22.50	-2.50
-10.00	36.00	28.96	7.04
.00	41.00	34.00	7.00
10.00	42.00	39.58	2.42
25.00	42.00	48.82	-6.82
50.00	58.00	65.36	-7.36
72.00	85.00	79.31	5.69

CAPSULE U (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: U Fluence: n/cm^2

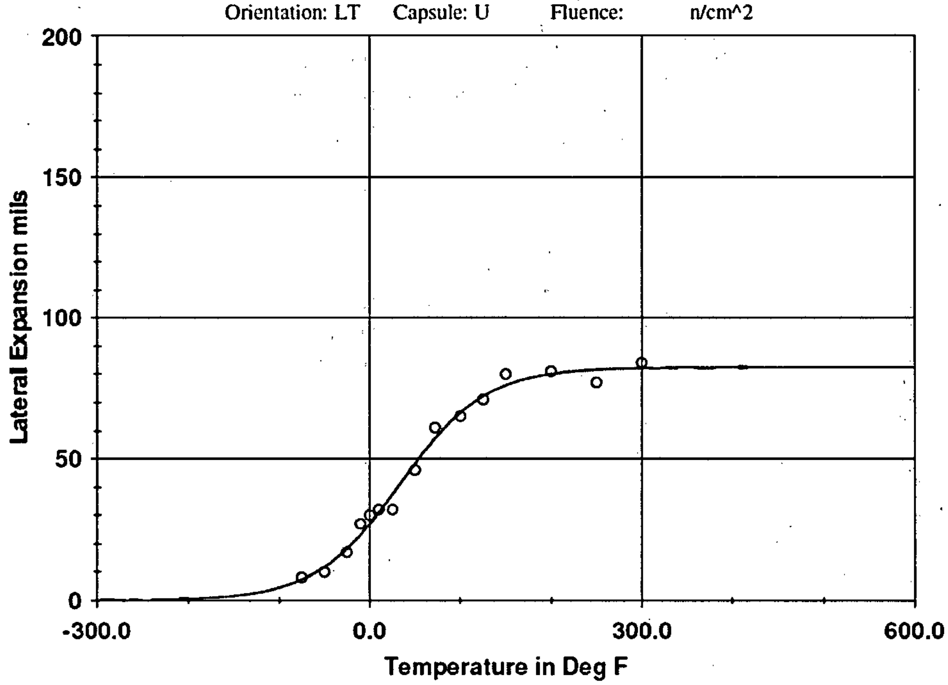
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
100.00	88.00	93.89	-5.89
125.00	106.00	103.10	2.90
150.00	115.00	109.13	5.87
200.00	116.00	115.05	.95
250.00	116.00	117.05	-1.05
300.00	127.00	117.70	9.30

Correlation Coefficient = .992

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:01 PM
Page 1
Coefficients of Curve 1
A = 41.23 B = 41.23 C = 93.56 T0 = 33.6 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=82.5 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=19.4 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-75.00	8.00	7.37	.63
-50.00	10.00	11.83	-1.83
-25.00	17.00	18.32	-1.32
-10.00	27.00	23.29	3.71
.00	30.00	27.03	2.97
10.00	32.00	31.04	.96
25.00	32.00	37.45	-5.45
50.00	46.00	48.38	-2.38
72.00	61.00	57.26	3.74

CAPSULE U (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: U Fluence: n/cm^2

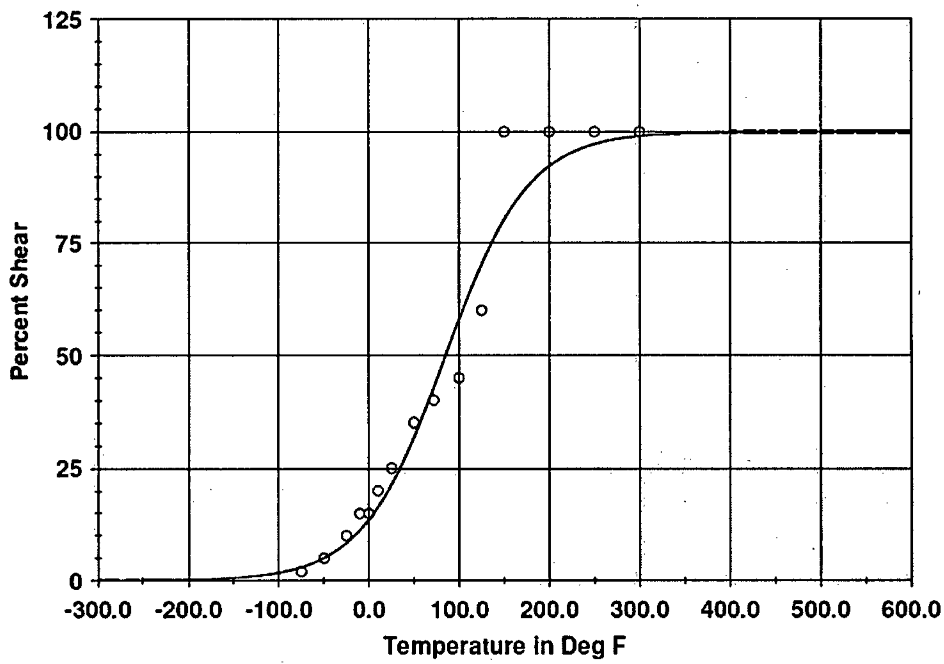
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
100.00	65.00	66.40	-1.40
125.00	71.00	72.22	-1.22
150.00	80.00	76.13	3.87
200.00	81.00	80.17	.83
250.00	77.00	81.65	-4.65
300.00	84.00	82.18	1.82

Correlation Coefficient = .994

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 02:04 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 92.29 T0 = 84.98 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 85.0
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75.00	2.00	3.03	-1.03
-50.00	5.00	5.09	-.09
-25.00	10.00	8.45	1.55
-10.00	15.00	11.32	3.68
.00	15.00	13.69	1.31
10.00	20.00	16.45	3.55
25.00	25.00	21.42	3.58
50.00	35.00	31.91	3.09
72.00	40.00	43.01	-3.01

CAPSULE U (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: U Fluence: n/cm^2

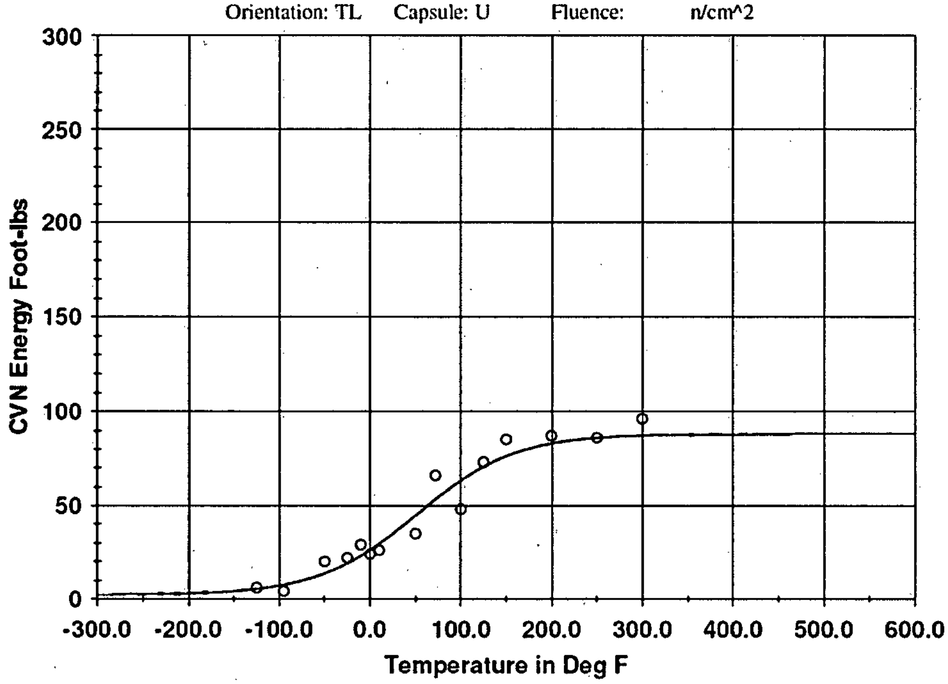
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100.00	45.00	58.07	-13.07
125.00	60.00	70.42	-10.42
150.00	100.00	80.36	19.64
200.00	100.00	92.36	7.64
250.00	100.00	97.28	2.72
300.00	100.00	99.06	.94

Correlation Coefficient = .981

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:03 PM
Page 1
Coefficients of Curve 1
A = 45.1 B = 42.9 C = 107.61 T0 = 50.81 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=88.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=11.3 Deg F Temp@50 ft-lbs=63.2 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-125.00	6.00	5.35	.65
-95.00	4.00	7.55	-3.55
-50.00	20.00	13.62	6.38
-25.00	22.00	19.05	2.95
-10.00	29.00	23.14	5.86
.00	24.00	26.22	-2.22
10.00	26.00	29.57	-3.57
50.00	35.00	44.78	-9.78
72.00	66.00	53.44	12.56

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: U Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
100.00	48.00	63.45	-15.45
125.00	73.00	70.74	2.26
150.00	85.00	76.28	8.72
200.00	87.00	82.95	4.05
250.00	86.00	85.93	.07
300.00	96.00	87.17	8.83

Correlation Coefficient = .974

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:04 PM

Page 1

Coefficients of Curve 1

A = 35.8 B = 35.8 C = 117.55 T0 = 45.7 D = 0.00E+00

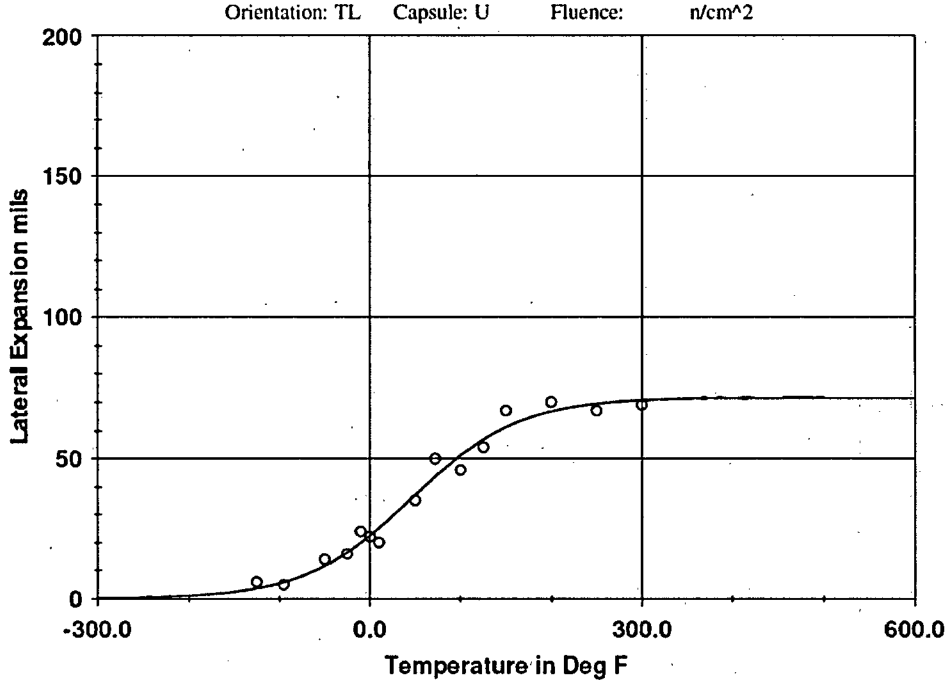
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=71.6 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=43.1 Deg F

Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-125.00	6.00	3.72	2.28
-95.00	5.00	5.99	-.99
-50.00	14.00	11.75	2.25
-25.00	16.00	16.54	-.54
-10.00	24.00	20.00	4.00
.00	22.00	22.55	-.55
10.00	20.00	25.25	-5.25
50.00	35.00	37.11	-2.11
72.00	50.00	43.68	6.32

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: U Fluence: n/cm^2

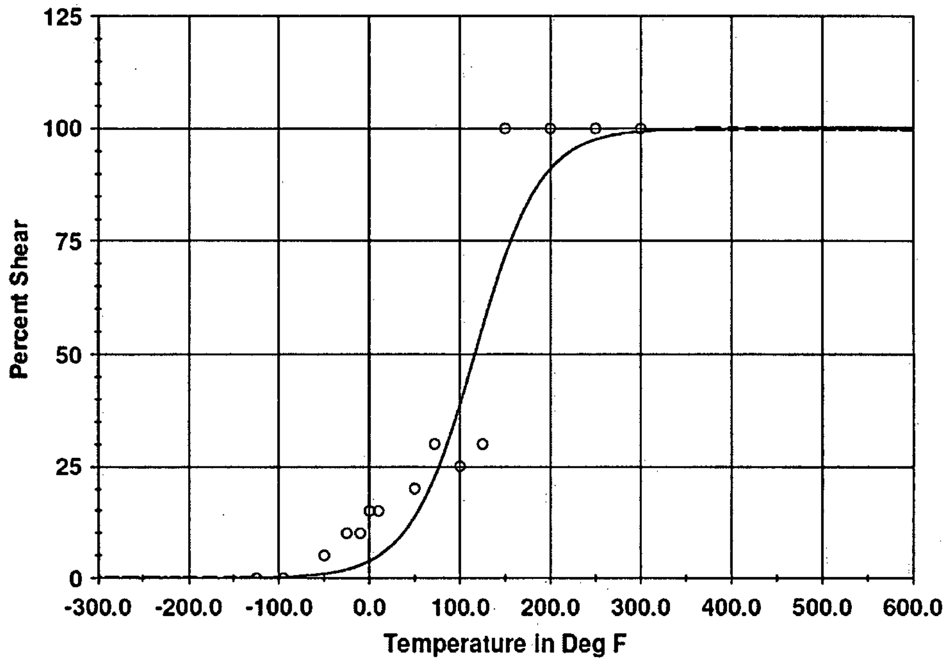
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
100.00	46.00	51.26	-5.26
125.00	54.00	56.86	-2.86
150.00	67.00	61.23	5.77
200.00	70.00	66.77	3.23
250.00	67.00	69.46	-2.46
300.00	69.00	70.68	-1.68

Correlation Coefficient = .988

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 02:08 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 72.02 T0 = 116.15 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 116.2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-125.00	.00	.12	-.12
-95.00	.00	.28	-.28
-50.00	5.00	.98	4.02
-25.00	10.00	1.95	8.05
-10.00	10.00	2.92	7.08
.00	15.00	3.82	11.18
10.00	15.00	4.98	10.02
50.00	20.00	13.74	6.26
72.00	30.00	22.69	7.31

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: U Fluence: n/cm^2

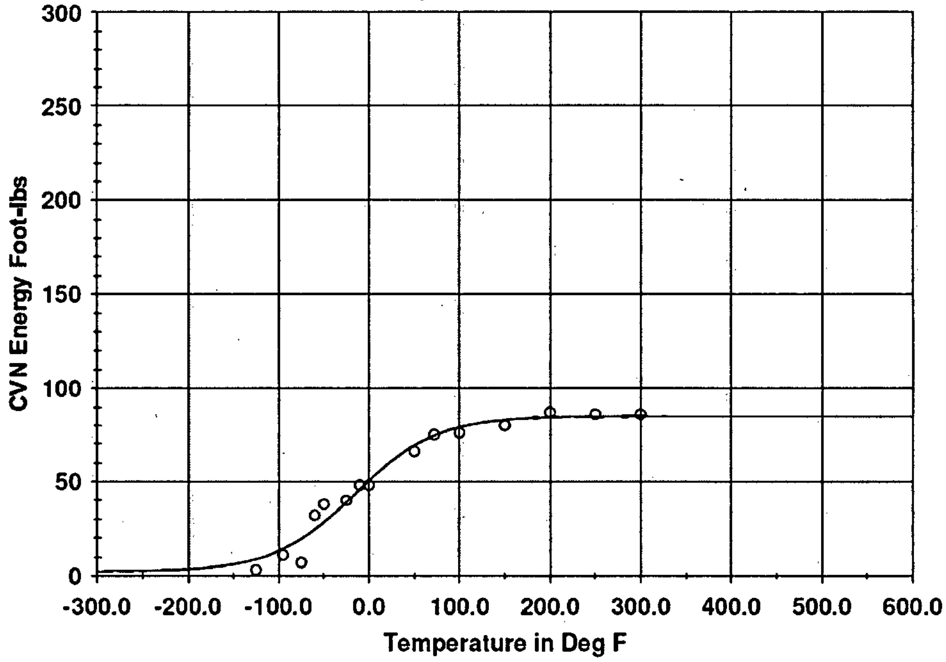
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100.00	25.00	38.97	-13.97
125.00	30.00	56.11	-26.11
150.00	100.00	71.91	28.09
200.00	100.00	91.12	8.88
250.00	100.00	97.63	2.37
300.00	100.00	99.40	.60

Correlation Coefficient = .955

CAPSULE U (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:06 PM
Page 1
Coefficients of Curve 1
A = 43.6 B = 41.4 C = 90.09 T0 = -15.27 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=85.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-46.0 Deg F Temp@50 ft-lbs=-1.2 Deg F
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-125.00	3.00	8.86	-5.86
-95.00	11.00	14.25	-3.25
-75.00	7.00	19.57	-12.57
-60.00	32.00	24.58	7.42
-50.00	38.00	28.39	9.61
-25.00	40.00	39.15	.85
-10.00	48.00	46.02	1.98
.00	48.00	50.55	-2.55
50.00	66.00	69.25	-3.25

CAPSULE U (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: U Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
72.00	75.00	74.57	.43
100.00	76.00	79.05	-3.05
150.00	80.00	82.94	-2.94
200.00	87.00	84.31	2.69
250.00	86.00	84.77	1.23
300.00	86.00	84.92	1.08

Correlation Coefficient = .984

CAPSULE U (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:06 PM

Page 1

Coefficients of Curve 1

A = 33.05 B = 33.05 C = 92. T0 = -22.16 D = 0.00E+00

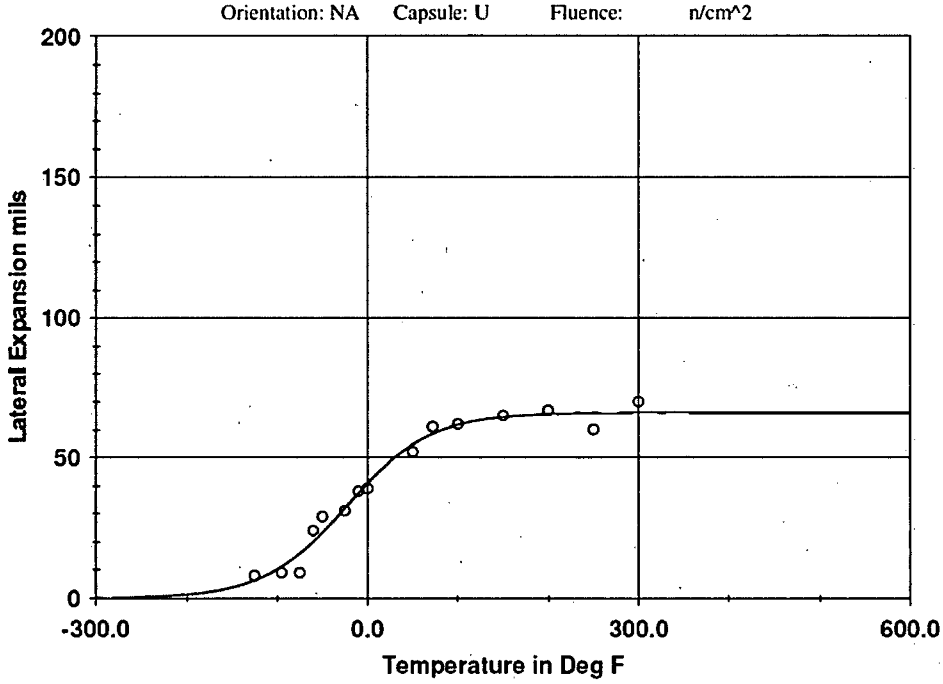
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=66.1 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=-16.7 Deg F

Plant: Comanche Peak 2 Material: SAW Heat: 89833

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-125.00	8.00	6.39	1.61
-95.00	9.00	11.26	-2.26
-75.00	9.00	15.91	-6.91
-60.00	24.00	20.17	3.83
-50.00	29.00	23.34	5.66
-25.00	31.00	32.03	-1.03
-10.00	38.00	37.39	.61
.00	39.00	40.86	-1.86
50.00	52.00	54.71	-2.71

CAPSULE U (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: U Fluence: n/cm^2

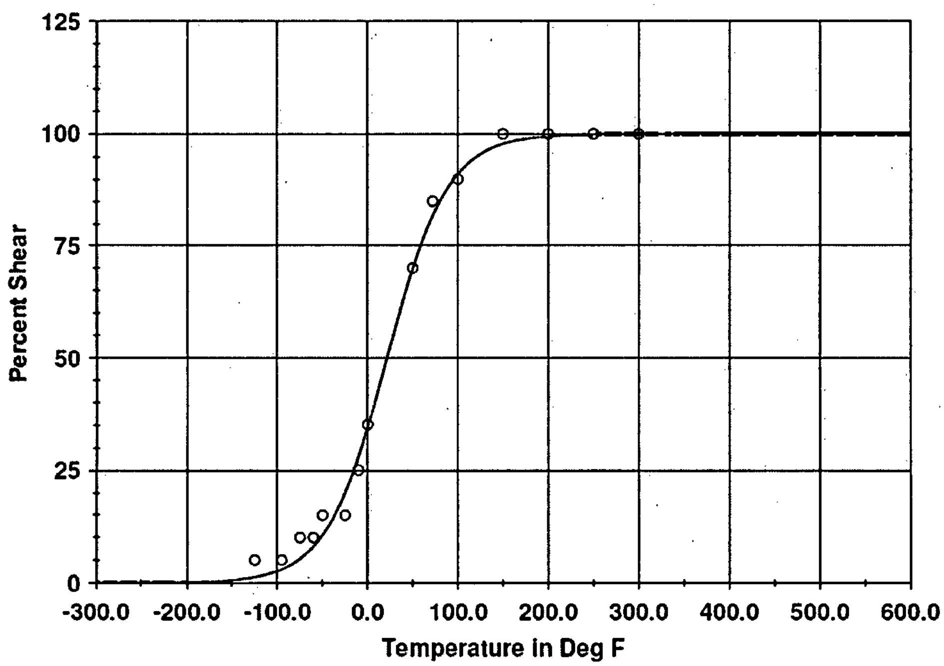
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
72.00	61.00	58.54	2.46
100.00	62.00	61.76	.24
150.00	65.00	64.57	.43
200.00	67.00	65.58	1.42
250.00	60.00	65.92	-5.92
300.00	70.00	66.04	3.96

Correlation Coefficient = .988

CAPSULE U (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 05:35 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 67.17 T0 = 21.52 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 21.6
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-125.00	5.00	1.26	3.74
-95.00	5.00	3.02	1.98
-75.00	10.00	5.35	4.65
-60.00	10.00	8.11	1.89
-50.00	15.00	10.63	4.37
-25.00	15.00	20.02	-5.02
-10.00	25.00	28.12	-3.12
.00	35.00	34.51	.49
50.00	70.00	70.01	-.01

CAPSULE U (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: U Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
72.00	85.00	81.80	3.20
100.00	90.00	91.19	-1.19
150.00	100.00	97.87	2.13
200.00	100.00	99.51	.49
250.00	100.00	99.89	.11
300.00	100.00	99.97	.03

Correlation Coefficient = .998

CAPSULE U (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:07 PM

Page 1

Coefficients of Curve 1

A = 64.6 B = 62.4 C = 136.19 T0 = -37.65 D = 0.00E+00

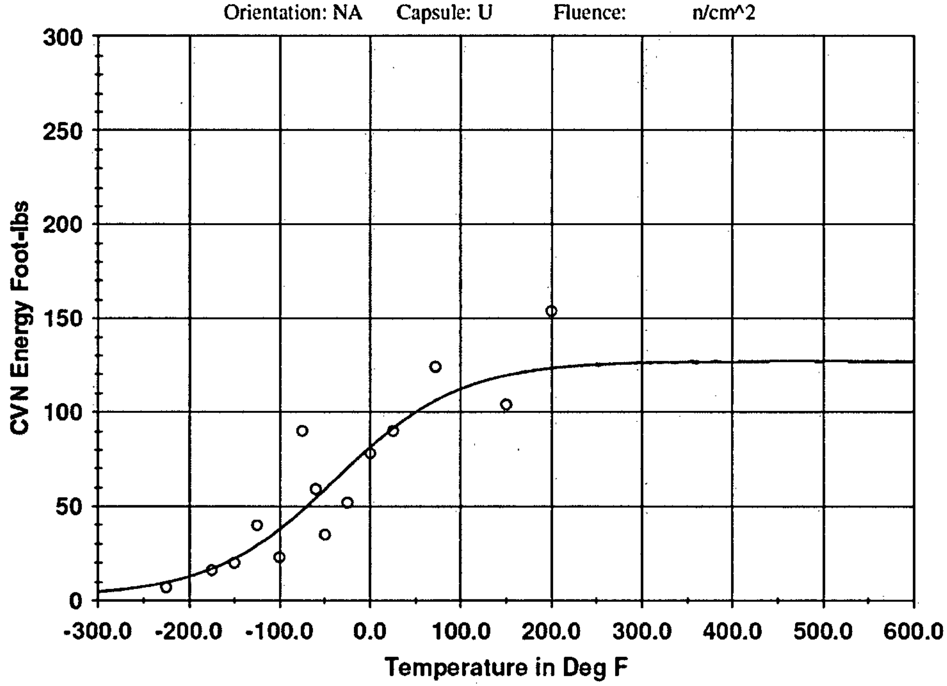
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=127.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-122.7 Deg F Temp@50 ft-lbs=-70.1 Deg F

Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-225.00	7.00	9.69	-2.69
-175.00	16.00	16.86	-.86
-150.00	20.00	22.31	-2.31
-125.00	40.00	29.29	10.71
-100.00	23.00	37.88	-14.88
-75.00	90.00	47.91	42.09
-60.00	59.00	54.45	4.55
-50.00	35.00	58.96	-23.96
-25.00	52.00	70.38	-18.38

CAPSULE U (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: U Fluence: n/cm^2

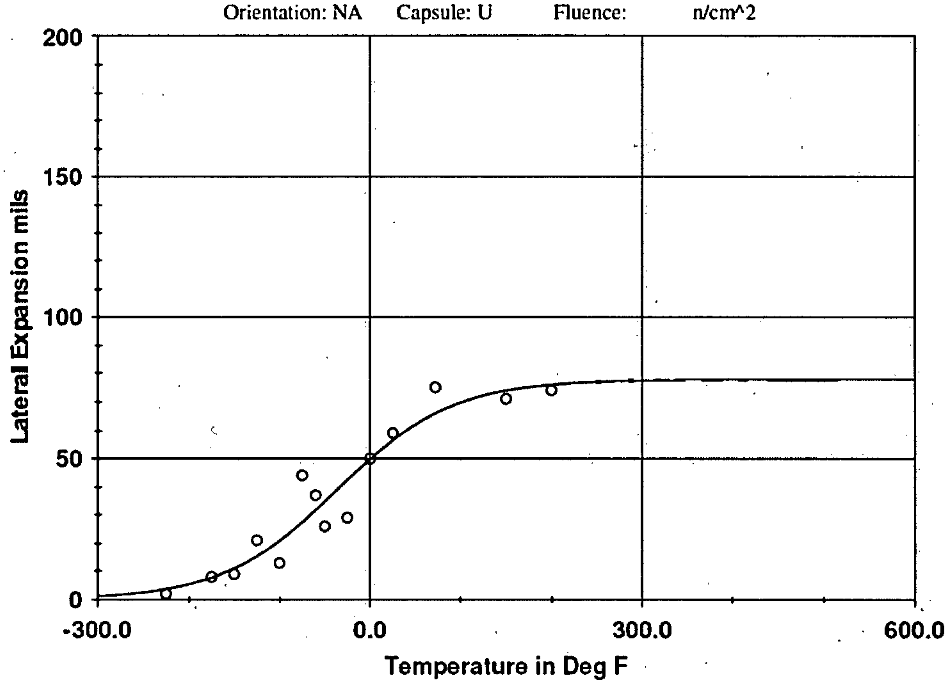
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	78.00	81.43	-3.43
25.00	90.00	91.44	-1.44
72.00	124.00	106.22	17.78
150.00	104.00	119.54	-15.54
200.00	154.00	123.31	30.69

Correlation Coefficient = .909

CAPSULE U (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:07 PM
Page 1
Coefficients of Curve 1
A = 38.9 B = 38.9 C = 126.43 T0 = -36.72 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=77.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=-49.4 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-225.00	2.00	3.77	-1.77
-175.00	8.00	7.85	.15
-150.00	9.00	11.11	-2.11
-125.00	21.00	15.43	5.57
-100.00	13.00	20.91	-7.91
-75.00	44.00	27.47	16.53
-60.00	37.00	31.82	5.18
-50.00	26.00	34.83	-8.83
-25.00	29.00	42.50	-13.50

CAPSULE U (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: U Fluence: n/cm^2

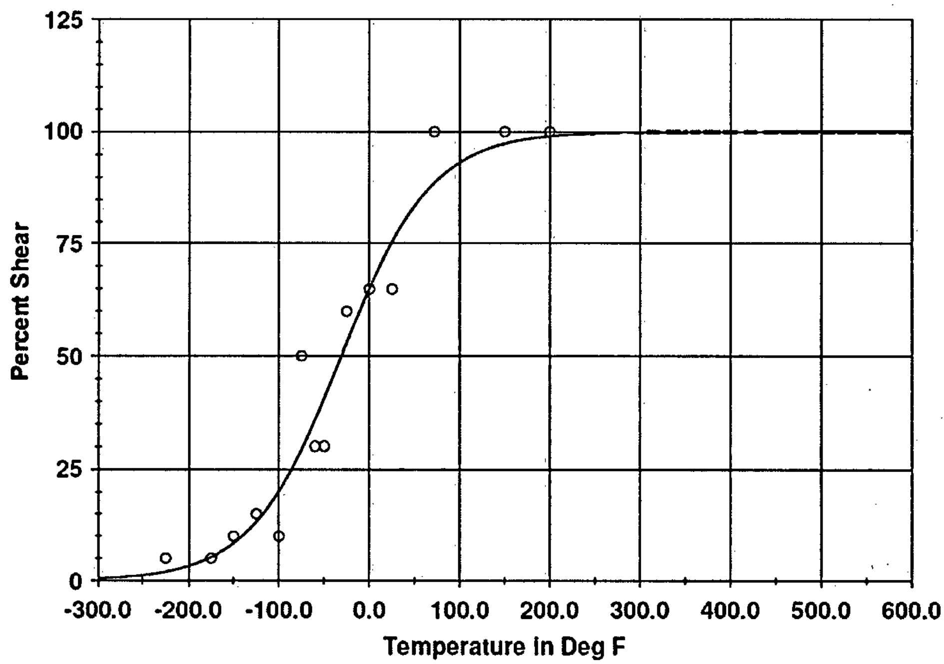
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	50.00	49.89	.11
25.00	59.00	56.51	2.49
72.00	75.00	65.98	9.02
150.00	71.00	73.95	-2.95
200.00	74.00	76.00	-2.00

Correlation Coefficient = .954

CAPSULE U (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 02:13 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 99.81 T0 = -31.2 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -31.1
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-225.00	5.00	2.02	2.98
-175.00	5.00	5.31	-.31
-150.00	10.00	8.47	1.53
-125.00	15.00	13.24	1.76
-100.00	10.00	20.12	-10.12
-75.00	50.00	29.37	20.63
-60.00	30.00	35.96	-5.96
-50.00	30.00	40.69	-10.69
-25.00	60.00	53.10	6.90

CAPSULE U (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: U Fluence: n/cm^2

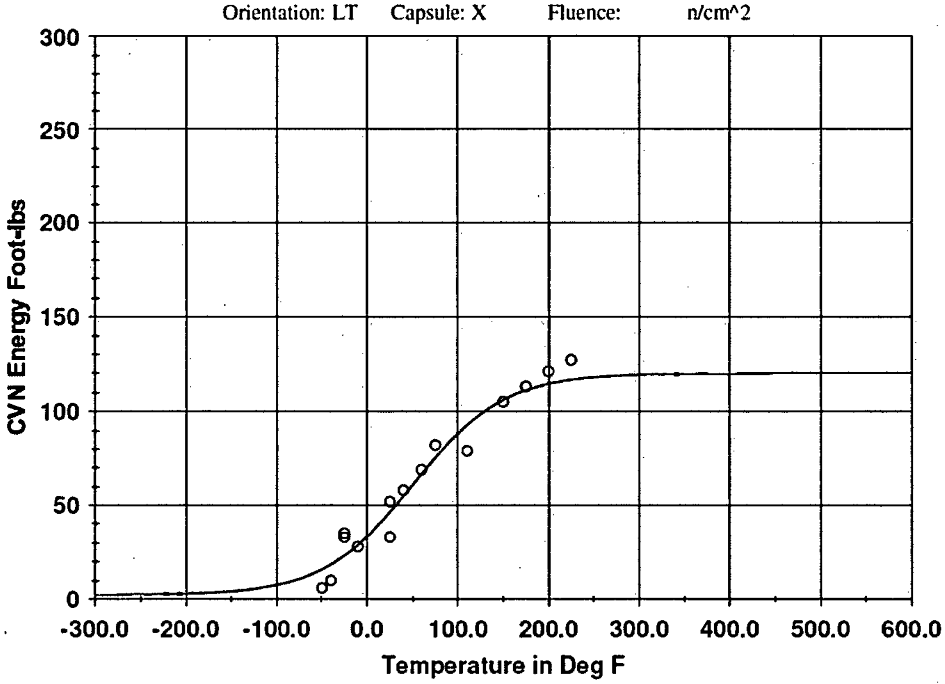
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	65.00	65.14	-.14
25.00	65.00	75.51	-10.51
72.00	100.00	88.77	11.23
150.00	100.00	97.42	2.58
200.00	100.00	99.04	.96

Correlation Coefficient = .971

CAPSULE X (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:09 PM
Page 1
Coefficients of Curve 1
A = 61.1 B = 58.9 C = 98.97 T0 = 50.28 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=120.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-7.8 Deg F Temp@50 ft-lbs=31.5 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	6.00	15.92	-9.92
-40.00	10.00	18.56	-8.56
-25.00	33.00	23.32	9.68
-25.00	35.00	23.32	11.68
-10.00	28.00	29.09	-1.09
25.00	33.00	46.37	-13.37
25.00	52.00	46.37	5.63
40.00	58.00	55.00	3.00
60.00	69.00	66.86	2.14

CAPSULE X (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: X Fluence: n/cm^2

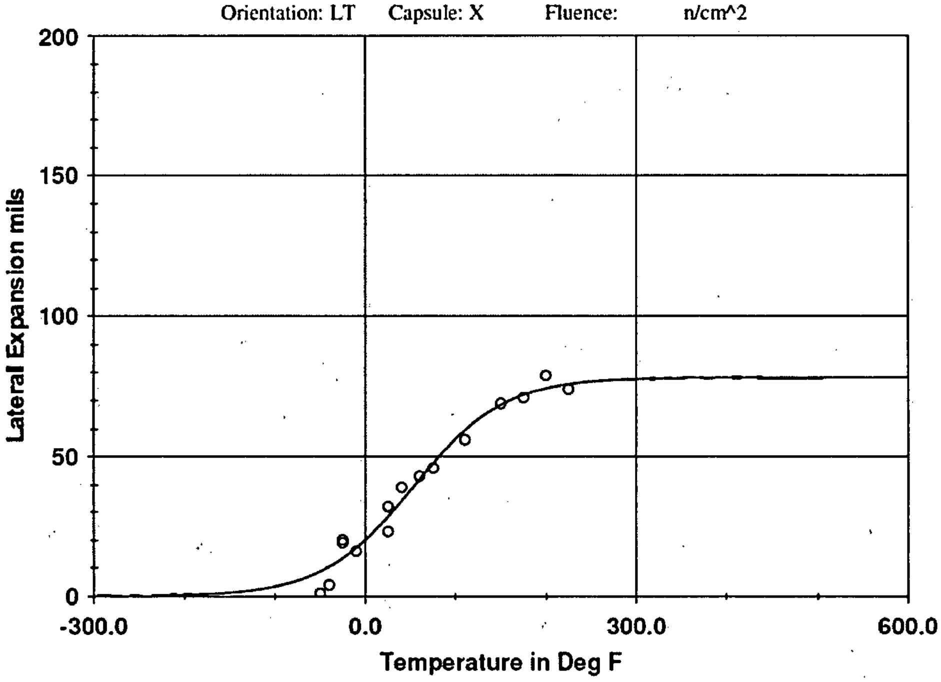
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
75.00	82.00	75.51	6.49
110.00	79.00	92.87	-13.87
150.00	105.00	106.14	-1.14
175.00	113.00	111.23	1.77
200.00	121.00	114.55	6.45
225.00	127.00	116.65	10.35

Correlation Coefficient = .978

CAPSULE X (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:10 PM
Page 1
Coefficients of Curve 1
A = 39.15 B = 39.15 C = 99.41 T0 = 52.76 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=78.3 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=42.2 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	1.00	8.79	-7.79
-40.00	4.00	10.49	-6.49
-25.00	20.00	13.55	6.45
-25.00	19.00	13.55	5.45
-10.00	16.00	17.26	-1.26
25.00	23.00	28.49	-5.49
25.00	32.00	28.49	3.51
40.00	39.00	34.15	4.85
60.00	43.00	42.00	1.00

CAPSULE X (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: X Fluence: n/cm^2

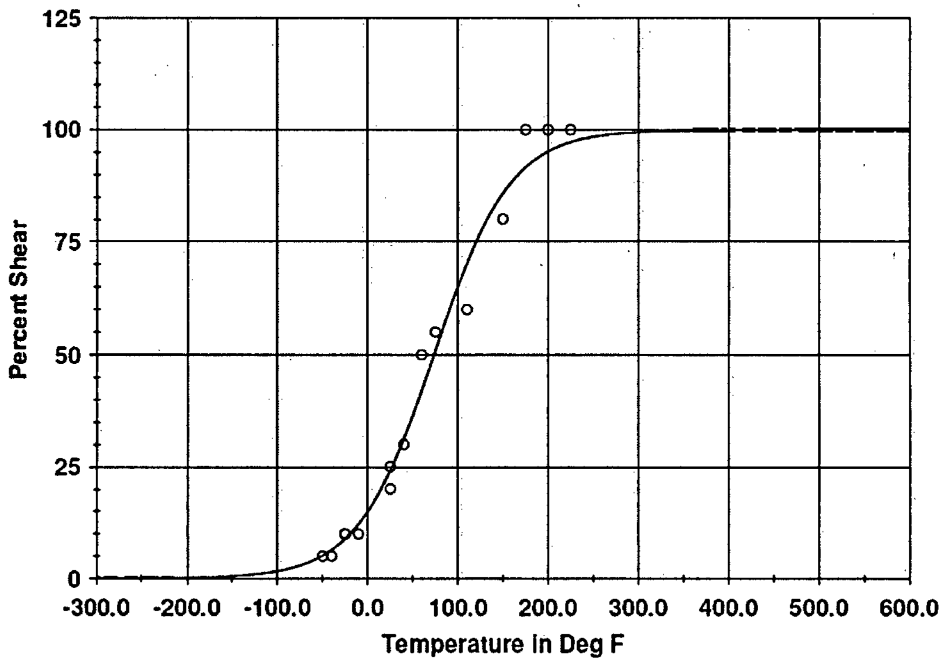
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
75.00	46.00	47.76	-1.76
110.00	56.00	59.49	-3.49
150.00	69.00	68.60	.40
175.00	71.00	72.13	-1.13
200.00	79.00	74.45	4.55
225.00	74.00	75.93	-1.93

Correlation Coefficient = .985

CAPSULE X (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 02:05 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 84.87 T0 = 73.51 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 73.6
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	5.00	5.16	-.16
-40.00	5.00	6.45	-1.45
-25.00	10.00	8.93	1.07
-25.00	10.00	8.93	1.07
-10.00	10.00	12.26	-2.26
25.00	20.00	24.17	-4.17
25.00	25.00	24.17	.83
40.00	30.00	31.22	-1.22
60.00	50.00	42.10	7.90

CAPSULE X (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: X Fluence: n/cm^2

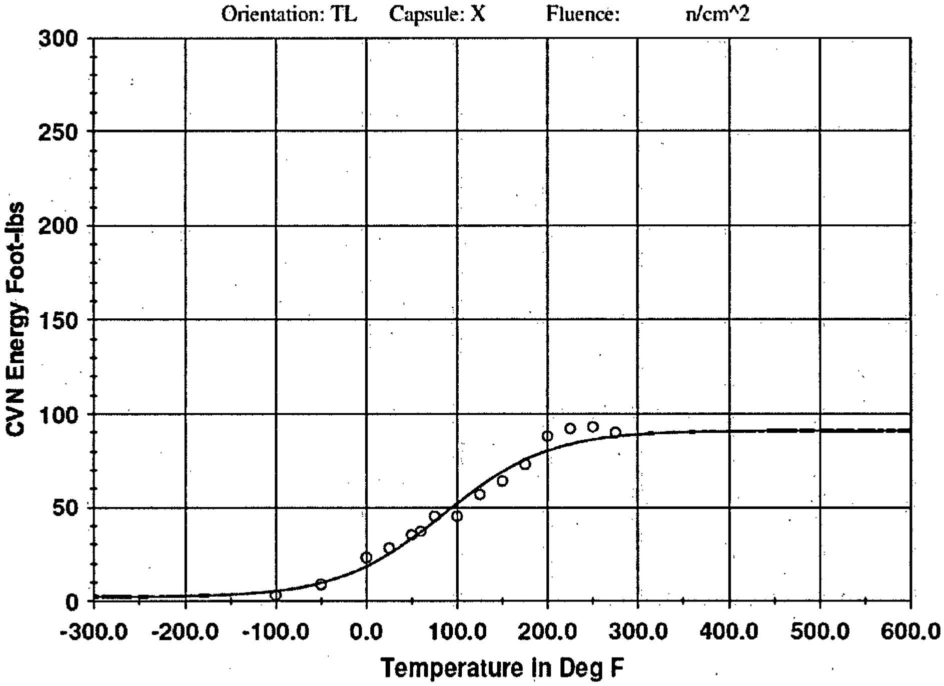
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75.00	55.00	50.88	4.12
110.00	60.00	70.26	-10.26
150.00	80.00	85.85	-5.85
175.00	100.00	91.62	8.38
200.00	100.00	95.17	4.83
225.00	100.00	97.26	2.74

Correlation Coefficient = .991

CAPSULE X (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:12 PM
Page 1
Coefficients of Curve 1
A = 46.6 B = 44.4 C = 114.54 T0 = 85.75 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=91.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=40.8 Deg F Temp@50 ft-lbs=94.6 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-100.00	3.00	5.54	-2.54
-50.00	9.00	9.79	-.79
.00	23.00	18.44	4.56
25.00	28.00	25.04	2.96
50.00	35.00	33.18	1.82
60.00	37.00	36.78	.22
75.00	45.00	42.45	2.55
100.00	45.00	52.10	-7.10
125.00	57.00	61.25	-4.25

CAPSULE X (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: X Fluence: n/cm^2

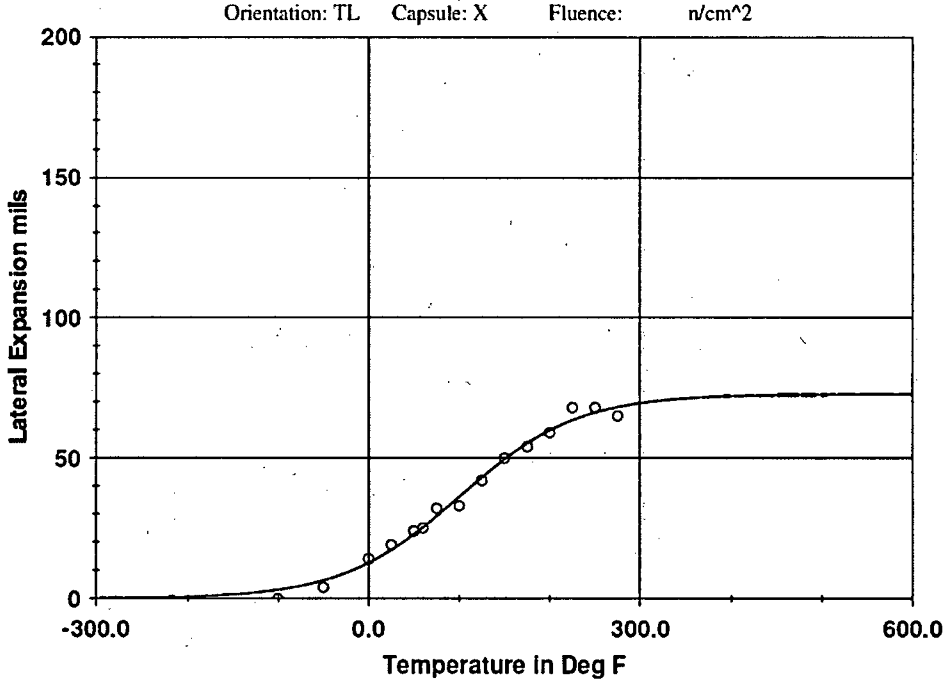
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
150.00	64.00	69.19	-5.19
175.00	73.00	75.56	-2.56
200.00	88.00	80.37	7.63
225.00	92.00	83.82	8.18
250.00	93.00	86.23	6.77
275.00	90.00	87.85	2.15

Correlation Coefficient = .989

CAPSULE X (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:12 PM
Page 1
Coefficients of Curve 1
A = 36.44 B = 36.44 C = 129.38 T0 = 100.68 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=72.9 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=95.6 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-100.00	.00	3.14	-3.14
-50.00	4.00	6.47	-2.47
.00	14.00	12.69	1.31
25.00	19.00	17.26	1.74
50.00	24.00	22.86	1.14
60.00	25.00	25.35	-.35
75.00	32.00	29.30	2.70
100.00	33.00	36.25	-3.25
125.00	42.00	43.21	-1.21

CAPSULE X (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: X Fluence: n/cm^2

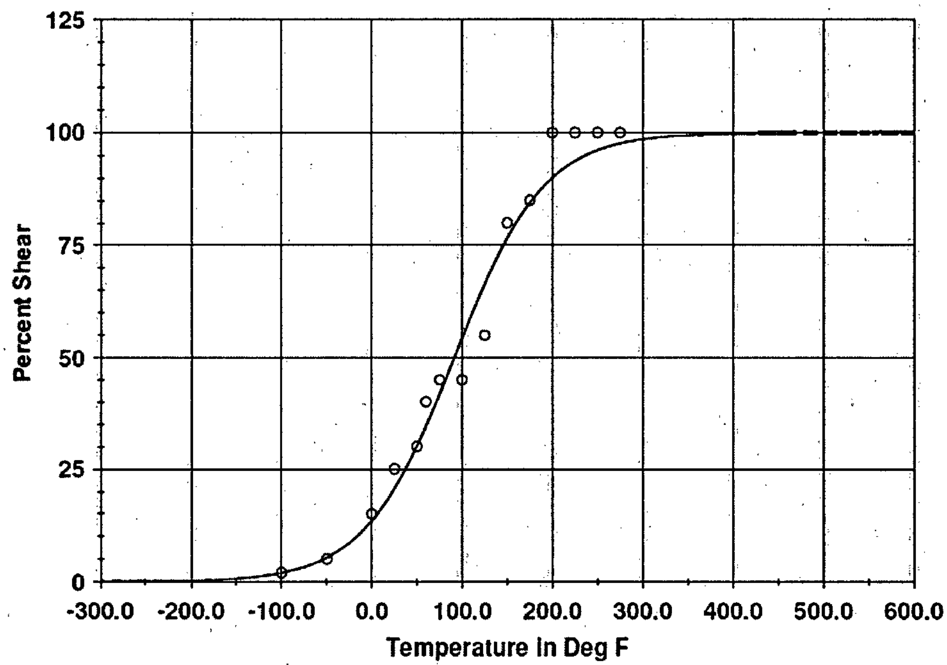
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
150.00	50.00	49.70	.30
175.00	54.00	55.34	-1.34
200.00	59.00	59.97	-.97
225.00	68.00	63.58	4.42
250.00	68.00	66.29	1.71
275.00	65.00	68.27	-3.27

Correlation Coefficient = .995

CAPSULE X (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 02:09 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 98.48 T0 = 91.27 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 91.3
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100.00	2.00	2.01	-.01
-50.00	5.00	5.37	-.37
.00	15.00	13.54	1.46
25.00	25.00	20.65	4.35
50.00	30.00	30.19	-.19
60.00	40.00	34.63	5.37
75.00	45.00	41.81	3.19
100.00	45.00	54.42	-9.42
125.00	55.00	66.48	-11.48

CAPSULE X (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: X Fluence: n/cm^2

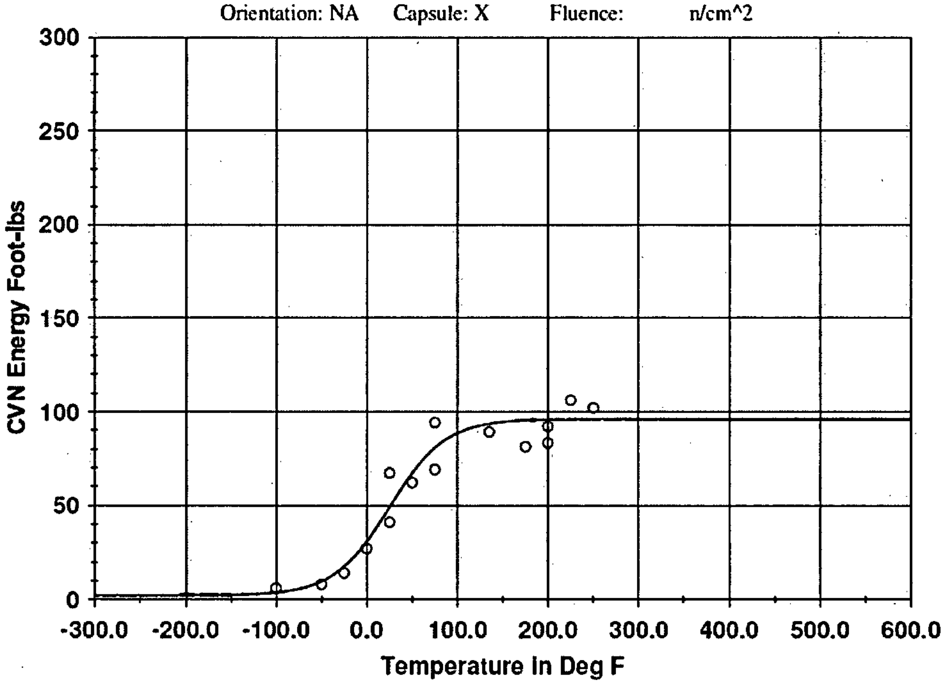
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150.00	80.00	76.72	3.28
175.00	85.00	84.56	.44
200.00	100.00	90.10	9.90
225.00	100.00	93.80	6.20
250.00	100.00	96.17	3.83
275.00	100.00	97.66	2.34

Correlation Coefficient = .989

CAPSULE X (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:13 PM
Page 1
Coefficients of Curve 1
A = 49.1 B = 46.9 C = 61.35 T0 = 25.12 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=96.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-1.4 Deg F Temp@50 ft-lbs=26.3 Deg F
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-100.00	6.00	3.76	2.24
-50.00	8.00	9.66	-1.66
-25.00	14.00	17.52	-3.52
.00	27.00	30.90	-3.90
25.00	67.00	49.01	17.99
25.00	41.00	49.01	-8.01
50.00	62.00	67.14	-5.14
75.00	94.00	80.58	13.42
75.00	69.00	80.58	-11.58

CAPSULE X (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: X Fluence: n/cm^2

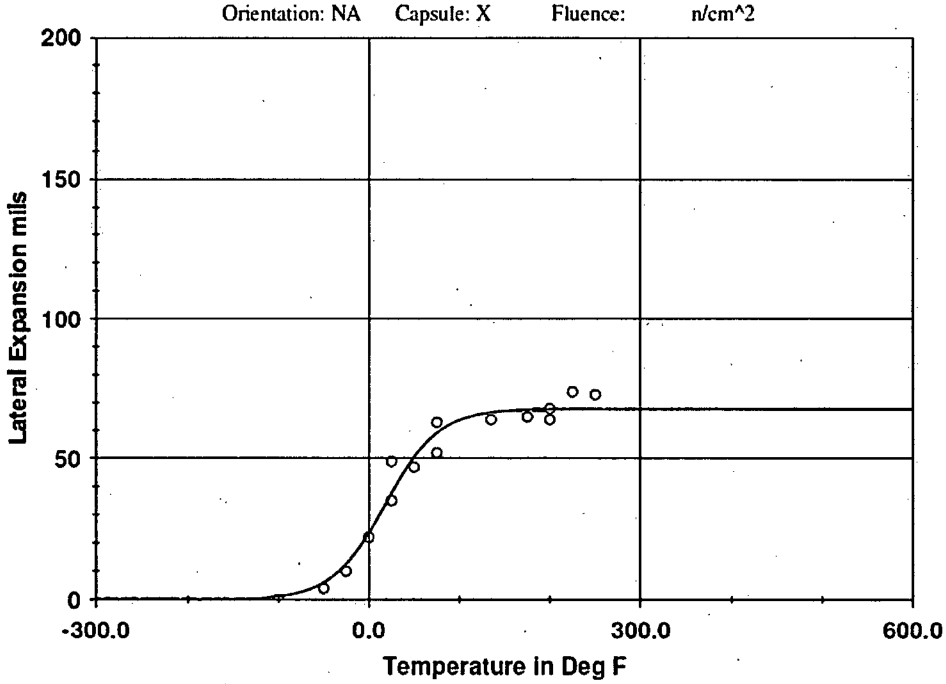
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
135.00	89.00	93.46	-4.46
175.00	81.00	95.30	-14.30
200.00	83.00	95.69	-12.69
200.00	92.00	95.69	-3.69
225.00	106.00	95.86	10.14
250.00	102.00	95.94	6.06

Correlation Coefficient = .962

CAPSULE X (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 01/29/2010 03:13 PM
Page 1
Coefficients of Curve 1
A = 33.97 B = 33.97 C = 58.82 T0 = 18.45 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=67.9 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=20.3 Deg F
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-100.00	.00	1.19	-1.19
-50.00	4.00	6.04	-2.04
-25.00	10.00	12.62	-2.62
.00	22.00	23.65	-1.65
25.00	49.00	37.74	11.26
25.00	35.00	37.74	-2.74
50.00	47.00	50.63	-3.63
75.00	63.00	59.28	3.72
75.00	52.00	59.28	-7.28

CAPSULE X (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: X Fluence: n/cm^2

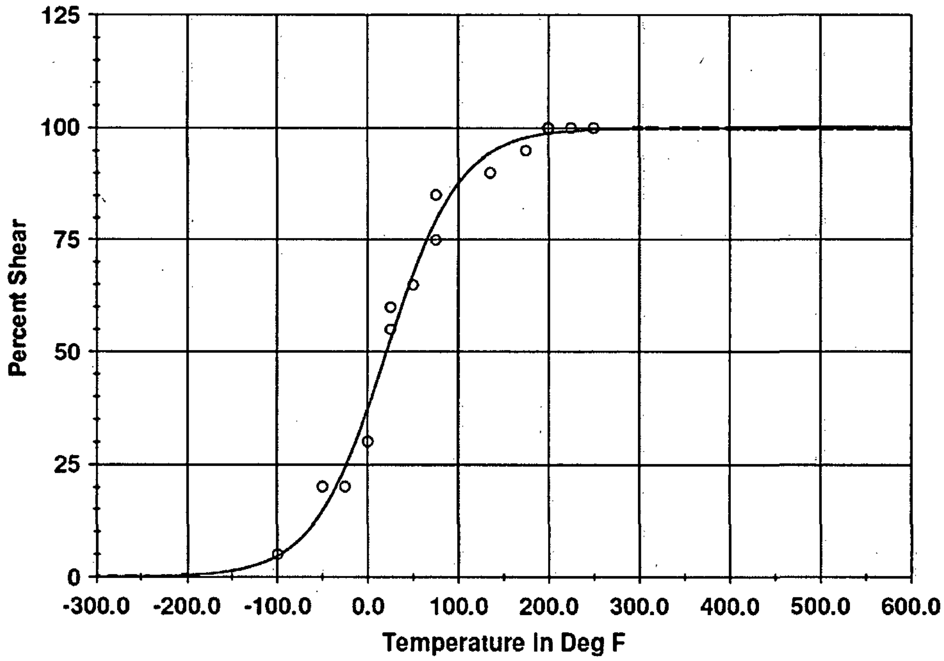
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
135.00	64.00	66.68	-2.68
175.00	65.00	67.62	-2.62
200.00	64.00	67.81	-3.81
200.00	68.00	67.81	.19
225.00	74.00	67.89	6.11
250.00	73.00	67.92	5.08

Correlation Coefficient = .983

CAPSULE X (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 05:36 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 80.55 T0 = 20.76 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 20.8
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100.00	5.00	4.75	.25
-50.00	20.00	14.72	5.28
-25.00	20.00	24.30	-4.30
.00	30.00	37.39	-7.39
25.00	60.00	52.63	7.37
25.00	55.00	52.63	2.37
50.00	65.00	67.40	-2.40
75.00	85.00	79.36	5.64
75.00	75.00	79.36	-4.36

CAPSULE X (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: X Fluence: n/cm^2

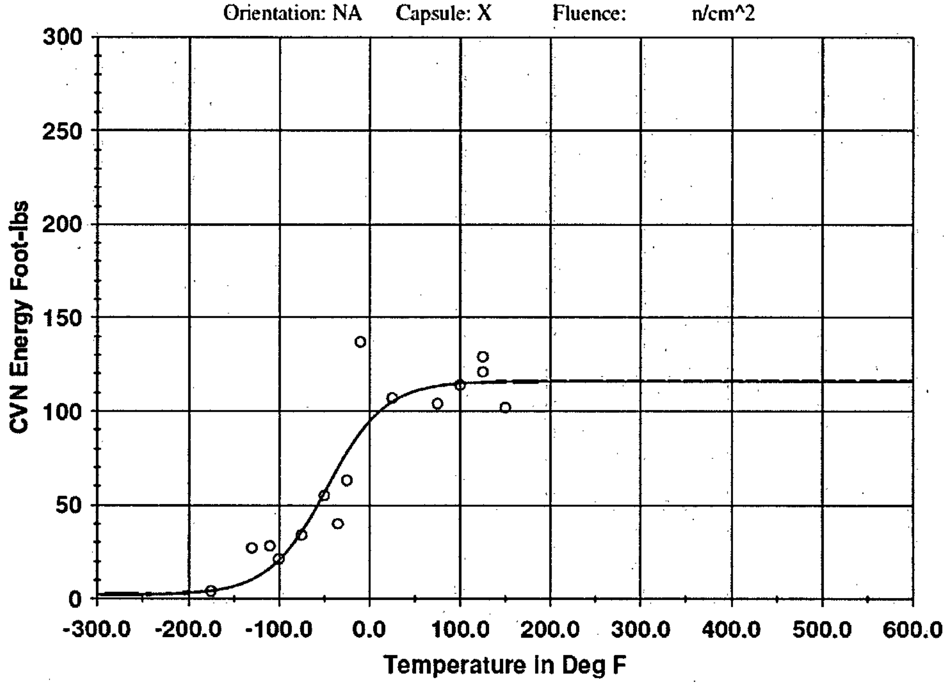
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
135.00	90.00	94.46	-4.46
175.00	95.00	97.87	-2.87
200.00	100.00	98.85	1.15
200.00	100.00	98.85	1.15
225.00	100.00	99.38	.62
250.00	100.00	99.66	.34

Correlation Coefficient = .992

CAPSULE X (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 02/04/2010 04:53 PM
Page 1
Coefficients of Curve 1
A = 59.1 B = 56.9 C = 64.25 T0 = -47.07 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=116.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-83.3 Deg F Temp@50 ft-lbs=-57.4 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-175.00	4.00	4.28	-.28
-130.00	27.00	10.20	16.80
-110.00	28.00	16.26	11.74
-100.00	21.00	20.57	.43
-75.00	34.00	35.81	-1.81
-50.00	55.00	56.51	-1.51
-35.00	40.00	69.67	-29.67
-25.00	63.00	77.91	-14.91
-10.00	137.00	88.72	48.28

CAPSULE X (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2   Material: SA533B1   Heat: C5522-2
Orientation: NA   Capsule: X   Fluence: n/cm^2

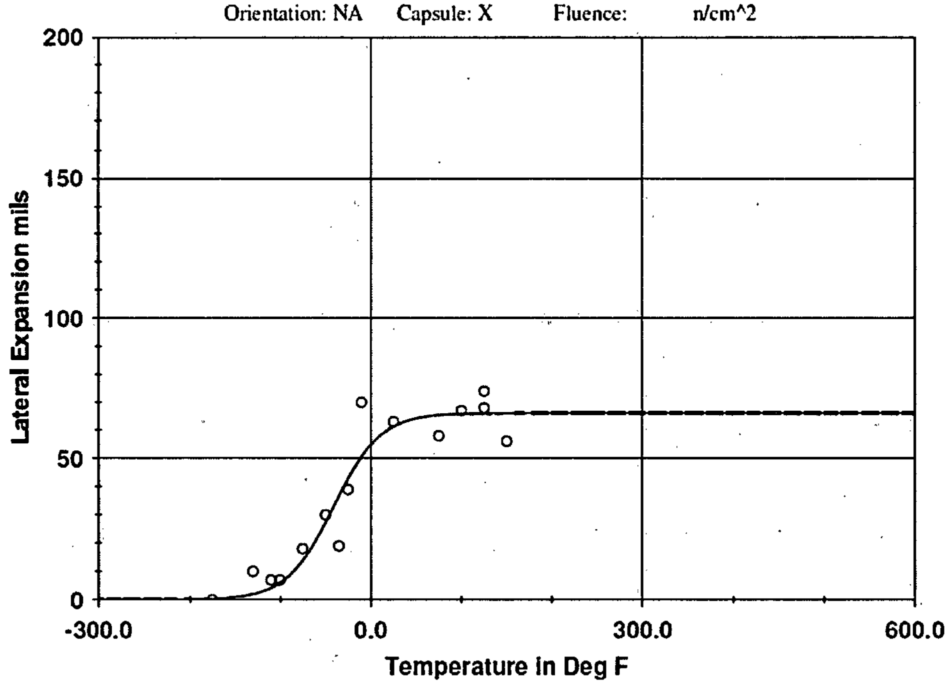
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
25.00	107.00	105.09	1.91
75.00	104.00	113.51	-9.51
100.00	114.00	114.84	-.84
125.00	129.00	115.47	13.53
125.00	121.00	115.47	5.53
150.00	102.00	115.75	-13.75

Correlation Coefficient = .923

CAPSULE X (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 02/04/2010 04:54 PM
Page 1
Coefficients of Curve 1
A = 33.07 B = 33.07 C = 51.65 T0 = -40.87 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=66.1 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=-37.8 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-175.00	.00	.37	-.37
-130.00	10.00	2.03	7.97
-110.00	7.00	4.26	2.74
-100.00	7.00	6.08	.92
-75.00	18.00	13.93	4.07
-50.00	30.00	27.28	2.72
-35.00	19.00	36.81	-17.81
-25.00	39.00	42.92	-3.92
-10.00	70.00	50.77	19.23

CAPSULE X (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: X Fluence: n/cm^2

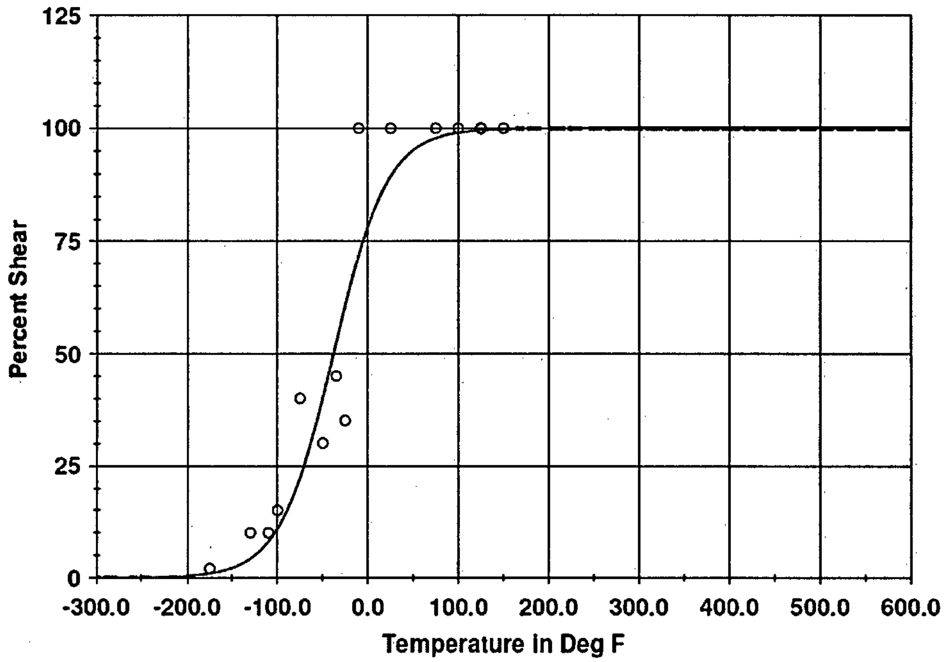
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
25.00	63.00	61.35	1.65
75.00	58.00	65.40	-7.40
100.00	67.00	65.85	1.15
125.00	74.00	66.03	7.97
125.00	68.00	66.03	1.97
150.00	56.00	66.09	-10.09

Correlation Coefficient = .950

CAPSULE X (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 02:13 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 59.24 T0 = -38.14 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -38.1
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-175.00	2.00	.98	1.02
-130.00	10.00	4.31	5.69
-110.00	10.00	8.12	1.88
-100.00	15.00	11.02	3.98
-75.00	40.00	22.37	17.63
-50.00	30.00	40.12	-10.12
-35.00	45.00	52.65	-7.65
-25.00	35.00	60.91	-25.91
-10.00	100.00	72.11	27.89

CAPSULE X (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: X Fluence: n/cm^2

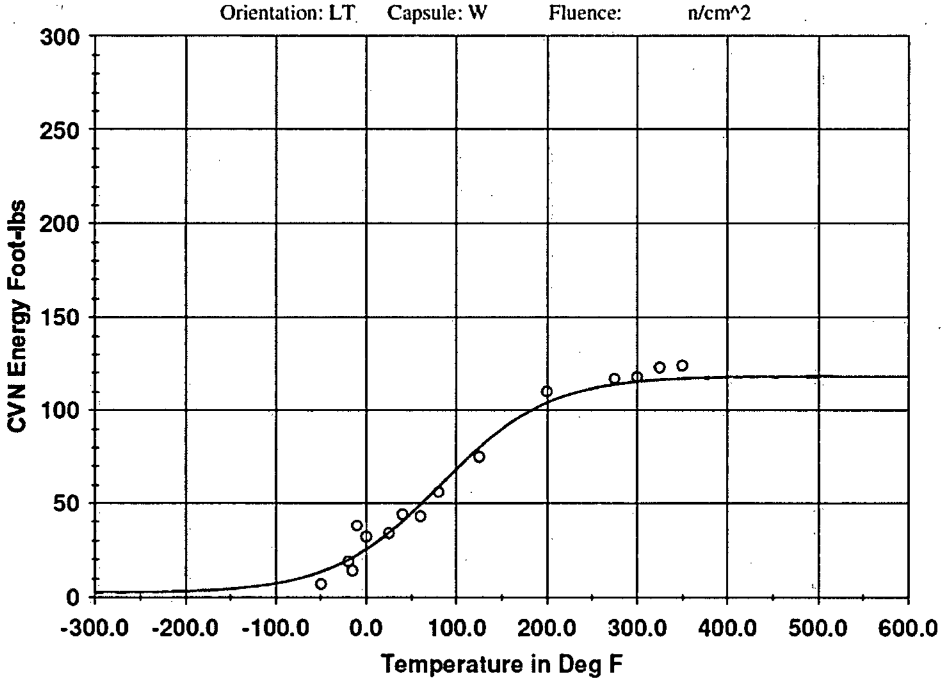
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25.00	100.00	89.39	10.61
75.00	100.00	97.85	2.15
100.00	100.00	99.07	.93
125.00	100.00	99.60	.40
125.00	100.00	99.60	.40
150.00	100.00	99.83	.17

Correlation Coefficient = .956

CAPSULE W (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:17 AM
Page 1
Coefficients of Curve 1
A = 60.3 B = 58.1 C = 119.24 T0 = 82.71 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=118.4(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=13.8 Deg F Temp@50 ft-lbs=61.4 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	7.00	13.52	-6.52
-20.00	19.00	19.81	-.81
-15.00	14.00	21.10	-7.10
-10.00	38.00	22.46	15.54
.00	32.00	25.42	6.58
25.00	34.00	34.19	-.19
40.00	44.00	40.34	3.66
60.00	43.00	49.37	-6.37
80.00	56.00	58.98	-2.98

CAPSULE W (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: W Fluence: n/cm^2

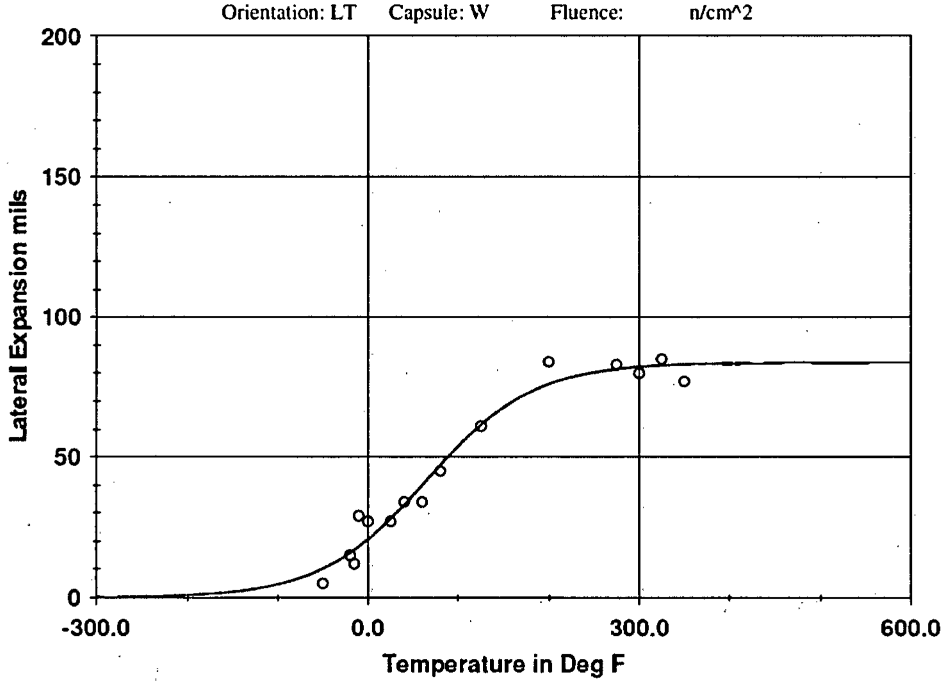
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
125.00	75.00	80.08	-5.08
200.00	110.00	104.14	5.86
275.00	117.00	113.96	3.04
300.00	118.00	115.44	2.56
325.00	123.00	116.44	6.56
350.00	124.00	117.10	6.90

Correlation Coefficient = .990

CAPSULE W (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:23 AM
Page 1
Coefficients of Curve 1
A = 41.89 B = 41.89 C = 116.94 T0 = 65.19 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=83.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=45.8 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	5.00	10.25	-5.25
-20.00	15.00	15.83	-.83
-15.00	12.00	16.95	-4.95
-10.00	29.00	18.14	10.86
.00	27.00	20.69	6.31
25.00	27.00	28.03	-1.03
40.00	34.00	33.00	1.00
60.00	34.00	40.03	-6.03
80.00	45.00	47.16	-2.16

CAPSULE W (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
125.00	61.00	61.62	-.62
200.00	84.00	76.18	7.82
275.00	83.00	81.52	1.48
300.00	80.00	82.29	-2.29
325.00	85.00	82.80	2.20
350.00	77.00	83.13	-6.13

Correlation Coefficient = .984

CAPSULE W (LONGITUDINAL ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:20 AM

Page 1

Coefficients of Curve 1

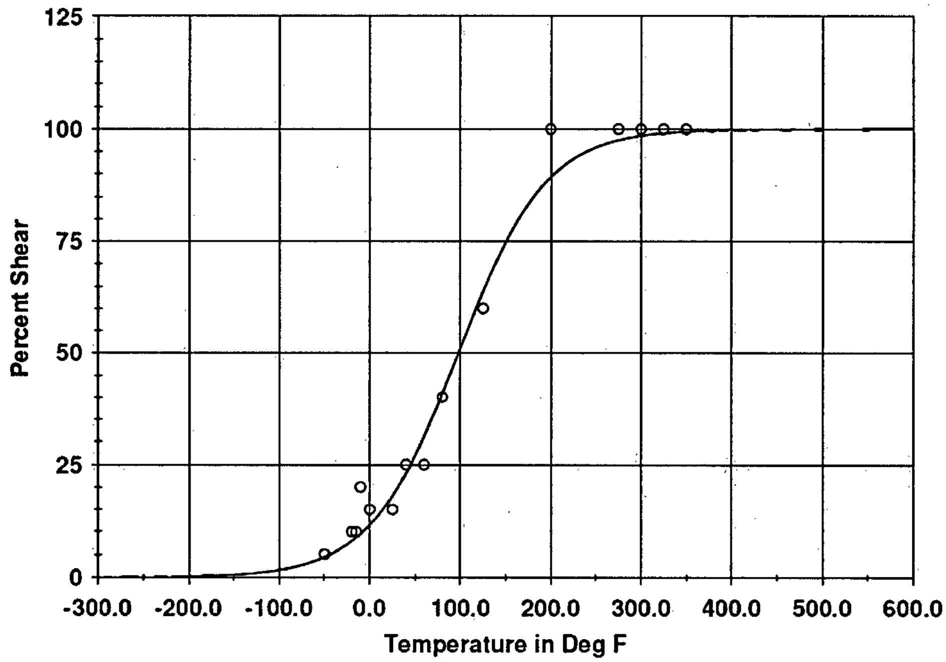
A = 50. B = 50. C = 95.99 T0 = 97.59 D = 0.00E+00

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

Temperature at 50% Shear = 97.6

Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	5.00	4.41	.59
-20.00	10.00	7.94	2.06
-15.00	10.00	8.74	1.26
-10.00	20.00	9.61	10.39
.00	15.00	11.57	3.43
25.00	15.00	18.06	-3.06
40.00	25.00	23.15	1.85
60.00	25.00	31.36	-6.36
80.00	40.00	40.94	-.94

CAPSULE W (LONGITUDINAL ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: LT Capsule: W Fluence: n/cm^2

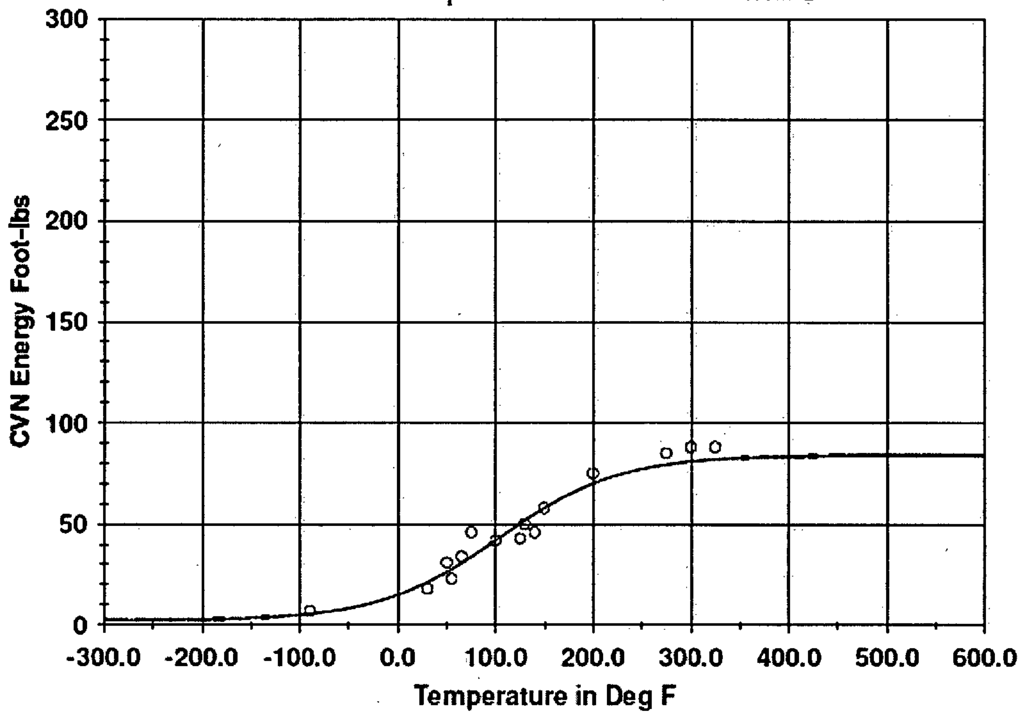
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125.00	60.00	63.90	-3.90
200.00	100.00	89.41	10.59
275.00	100.00	97.58	2.42
300.00	100.00	98.55	1.45
325.00	100.00	99.13	.87
350.00	100.00	99.48	.52

Correlation Coefficient = .994

CAPSULE W (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:28 AM
Page 1
Coefficients of Curve 1
A = 43.1 B = 40.9 C = 122.5 T0 = 102.96 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=84.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=62.3 Deg F Temp@50 ft-lbs=123.9 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-90.00	7.00	5.56	1.44
30.00	18.00	21.26	-3.26
50.00	31.00	26.44	4.56
55.00	23.00	27.86	-4.86
65.00	34.00	30.82	3.18
75.00	46.00	33.92	12.08
100.00	42.00	42.11	-.11
125.00	43.00	50.38	-7.38
130.00	50.00	51.99	-1.99

CAPSULE W (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
140.00	46.00	55.10	-9.10
150.00	58.00	58.08	-.08
200.00	75.00	70.08	4.92
275.00	85.00	79.35	5.65
300.00	88.00	80.85	7.15
325.00	88.00	81.88	6.12

Correlation Coefficient = .975

CAPSULE W (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:29 AM
Page 1
Coefficients of Curve 1

A = 34.08 B = 34.08 C = 130.86 T0 = 85.99 D = 0.00E+00

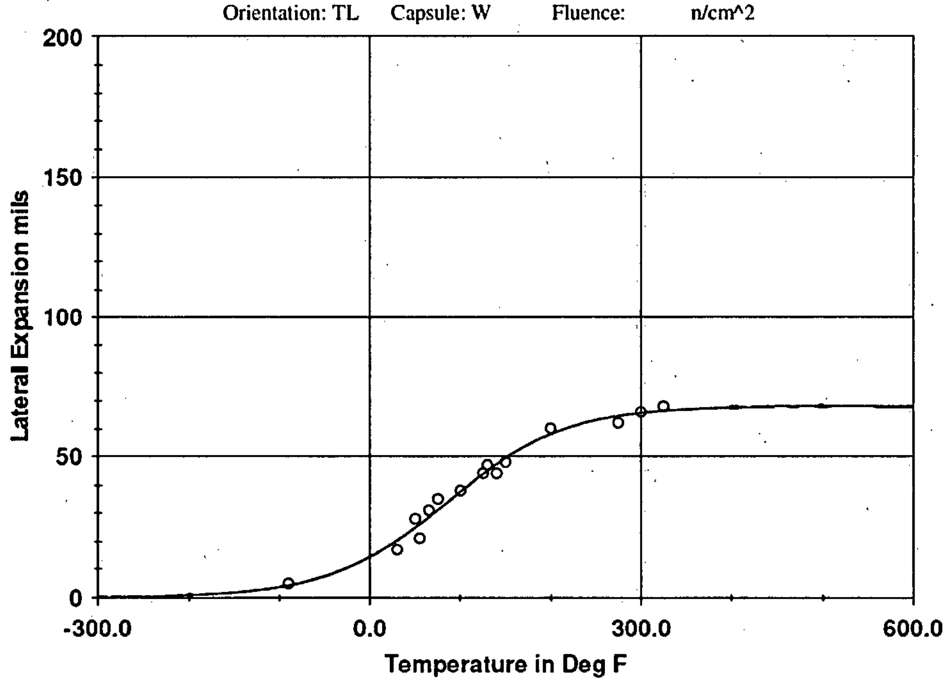
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=68.2 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=89.6 Deg F

Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-90.00	5.00	4.33	.67
30.00	17.00	20.33	-3.33
50.00	28.00	24.93	3.07
55.00	21.00	26.16	-5.16
65.00	31.00	28.66	2.34
75.00	35.00	31.22	3.78
100.00	38.00	37.71	.29
125.00	44.00	43.95	.05
130.00	47.00	45.13	1.87

CAPSULE W (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: W Fluence: n/cm^2

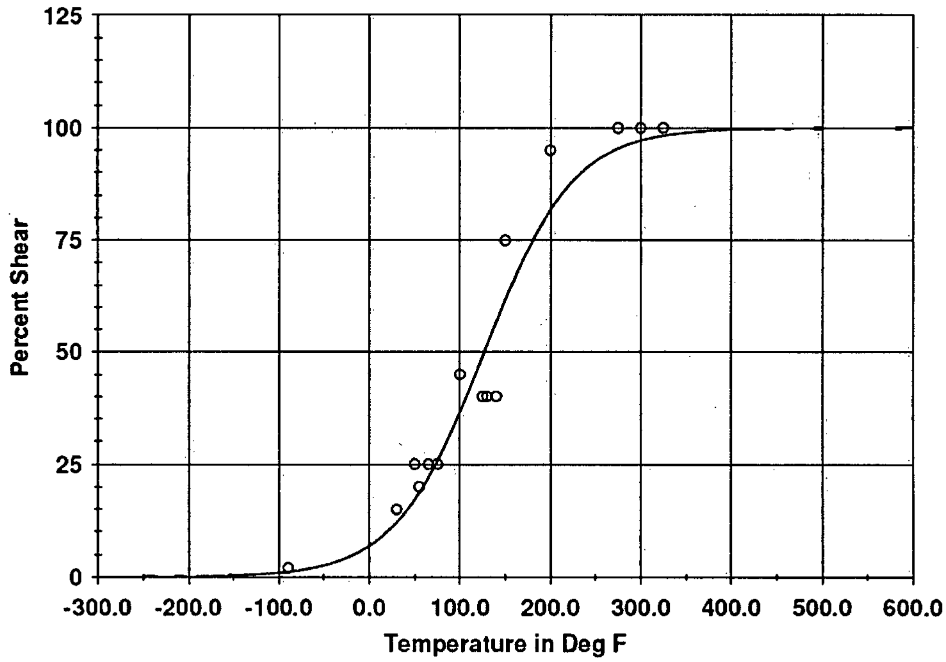
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
140.00	44.00	47.39	-3.39
150.00	48.00	49.53	-1.53
200.00	60.00	58.00	2.00
275.00	62.00	64.56	-2.56
300.00	66.00	65.66	.34
325.00	68.00	66.43	1.57

Correlation Coefficient = .990

CAPSULE W (TRANSVERSE ORIENTATION)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:28 AM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 97.7 T0 = 126.68 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 126.7
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-90.00	2.00	1.17	.83
30.00	15.00	12.14	2.86
50.00	25.00	17.23	7.77
55.00	20.00	18.73	1.27
65.00	25.00	22.05	2.95
75.00	25.00	25.77	-.77
100.00	45.00	36.68	8.32
125.00	40.00	49.14	-9.14
130.00	40.00	51.70	-11.70

CAPSULE W (TRANSVERSE ORIENTATION)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: TL Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
140.00	40.00	56.78	-16.78
150.00	75.00	61.71	13.29
200.00	95.00	81.77	13.23
275.00	100.00	95.42	4.58
300.00	100.00	97.20	2.80
325.00	100.00	98.30	1.70

Correlation Coefficient = .970

CAPSULE W (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:37 AM

Page 1

Coefficients of Curve 1

A = 42.85 B = 40.65 C = 32.64 T0 = 45.05 D = 0.00E+00

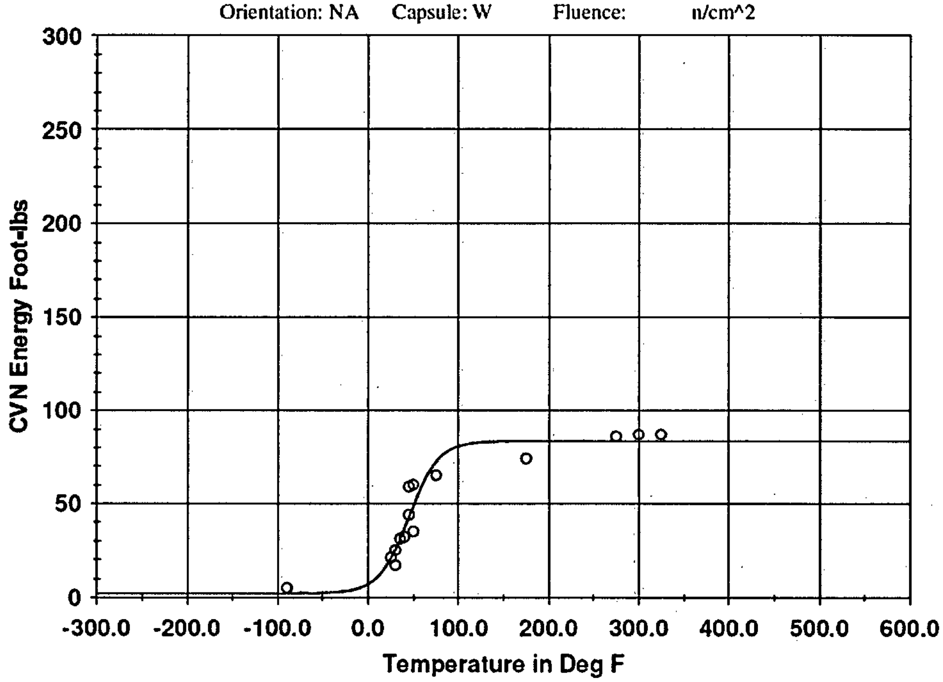
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=83.5(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=34.4 Deg F Temp@50 ft-lbs=50.9 Deg F

Plant: Comanche Peak 2 Material: SAW Heat: 89833

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-90.00	5.00	2.22	2.78
25.00	21.00	20.62	.38
30.00	17.00	25.34	-8.34
30.00	25.00	25.34	-.34
35.00	31.00	30.72	.28
40.00	32.00	36.62	-4.62
45.00	44.00	42.79	1.21
45.00	59.00	42.79	16.21
50.00	60.00	48.97	11.03

CAPSULE W (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
50.00	35.00	48.97	-13.97
75.00	65.00	72.31	-7.31
175.00	74.00	83.47	-9.47
275.00	86.00	83.50	2.50
300.00	87.00	83.50	3.50
325.00	87.00	83.50	3.50

Correlation Coefficient = .959

CAPSULE W (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:35 AM

Page 1

Coefficients of Curve 1

A = 35.93 B = 35.93 C = 38.16 T0 = 40.25 D = 0.00E+00

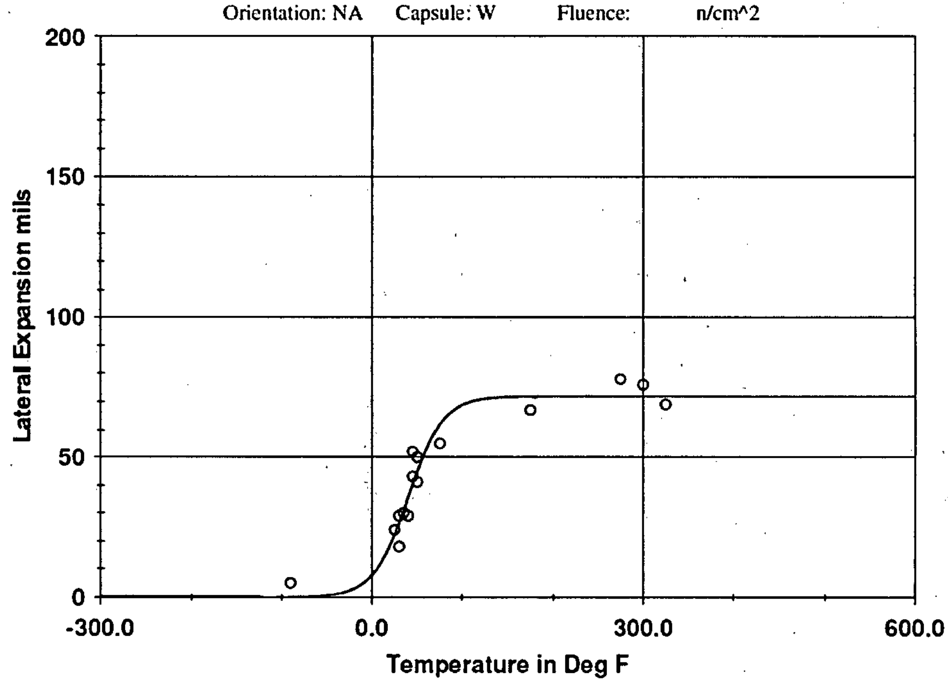
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=71.9 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=39.3 Deg F

Plant: Comanche Peak 2 Material: SAW Heat: 89833

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-90.00	5.00	.08	4.92
25.00	24.00	22.29	1.71
30.00	18.00	26.51	-8.51
30.00	29.00	26.51	2.49
35.00	30.00	31.02	-1.02
40.00	29.00	35.70	-6.70
45.00	43.00	40.38	2.62
45.00	52.00	40.38	11.62
50.00	50.00	44.92	5.08

CAPSULE W (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: W Fluence: n/cm^2

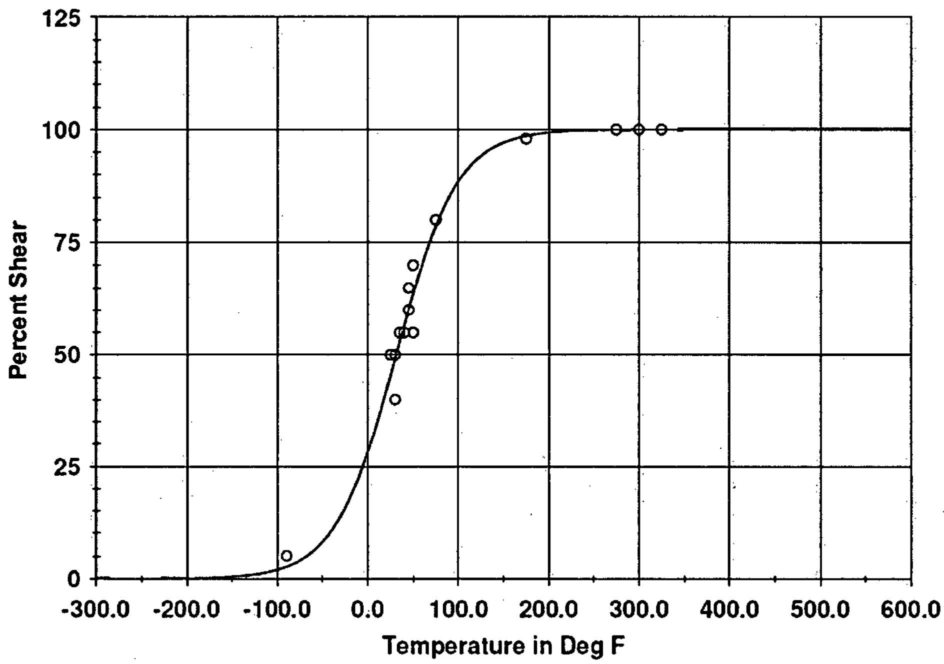
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
50.00	41.00	44.92	-3.92
75.00	55.00	61.85	-6.85
175.00	67.00	71.80	-4.80
275.00	78.00	71.86	6.14
300.00	76.00	71.86	4.14
325.00	69.00	71.86	-2.86

Correlation Coefficient = .965

CAPSULE W (WELD)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:37 AM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 67.19 T0 = 31.11 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 31.2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-90.00	5.00	2.65	2.35
25.00	50.00	45.46	4.54
30.00	40.00	49.17	-9.17
30.00	50.00	49.17	.83
35.00	55.00	52.89	2.11
40.00	55.00	56.58	-1.58
45.00	60.00	60.19	-.19
45.00	65.00	60.19	4.81
50.00	70.00	63.70	6.30

CAPSULE W (WELD)

Page 2
Plant: Comanche Peak 2 Material: SAW Heat: 89833
Orientation: NA Capsule: W Fluence: n/cm^2

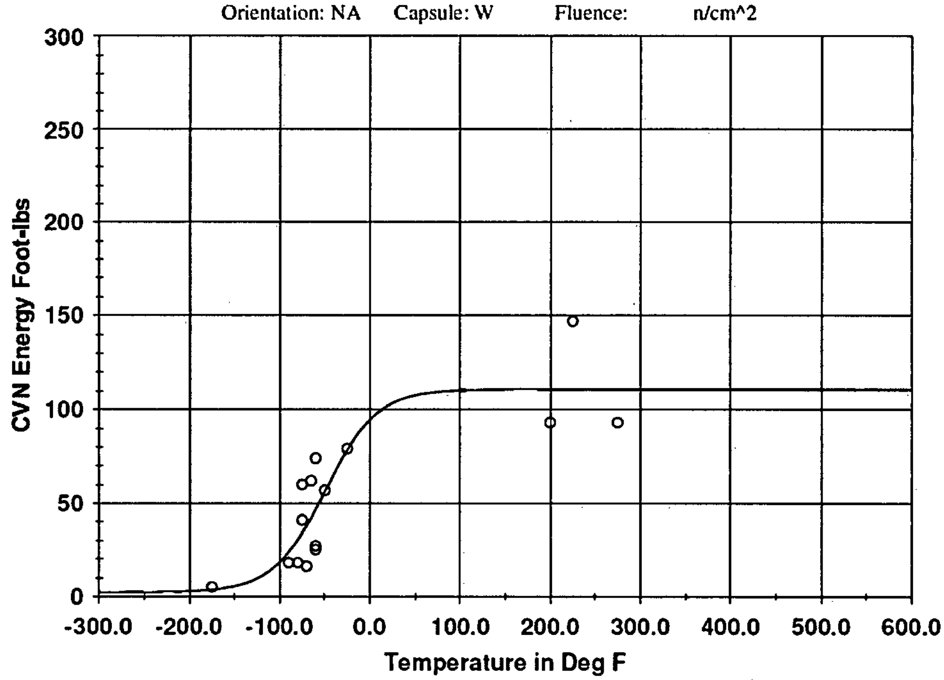
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50.00	55.00	63.70	-8.70
75.00	80.00	78.69	1.31
175.00	98.00	98.64	-.64
275.00	100.00	99.93	.07
300.00	100.00	99.97	.03
325.00	100.00	99.98	.02

Correlation Coefficient = .987

CAPSULE W (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:38 AM
Page 1
Coefficients of Curve 1
A = 56.6 B = 54.4 C = 57.45 T0 = -49.64 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=111.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-80.3 Deg F Temp@50 ft-lbs=-56.6 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-175.00	5.00	3.57	1.43
-90.00	18.00	23.63	-5.63
-80.00	18.00	30.26	-12.26
-75.00	41.00	34.03	6.97
-75.00	60.00	34.03	25.97
-70.00	16.00	38.09	-22.09
-65.00	62.00	42.39	19.61
-60.00	74.00	46.89	27.11
-60.00	27.00	46.89	-19.89

CAPSULE W (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: W Fluence: n/cm^2

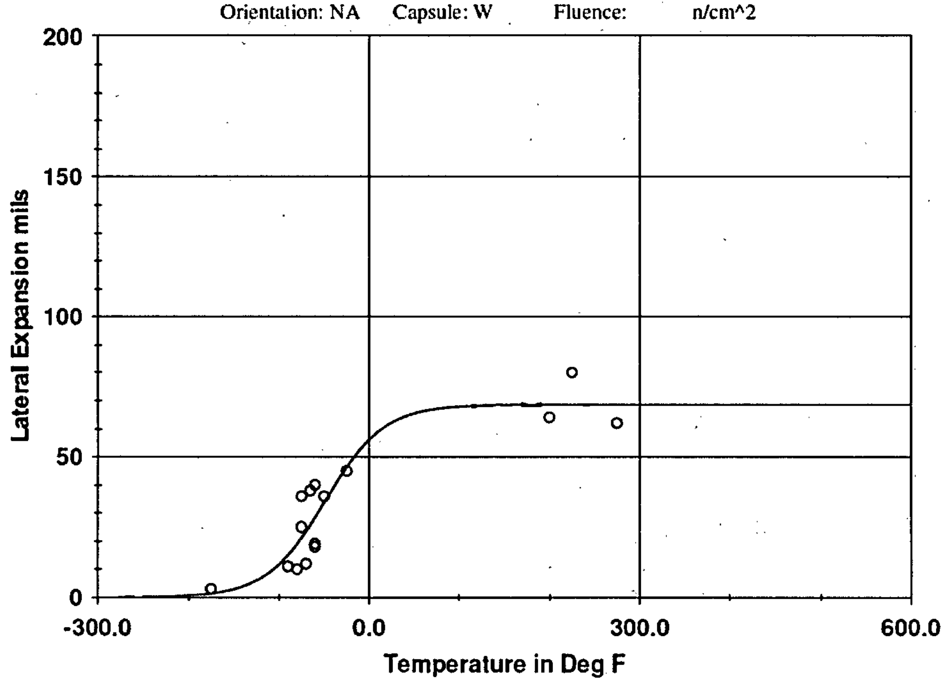
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-60.00	25.00	46.89	-21.89
-50.00	57.00	56.26	.74
-25.00	79.00	78.60	.40
200.00	93.00	110.98	-17.98
225.00	147.00	110.99	36.01
275.00	93.00	111.00	-18.00

Correlation Coefficient = .864

CAPSULE W (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:33 AM
Page 1
Coefficients of Curve 1
A = 34.3 B = 34.3 C = 64.75 T0 = -48.88 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=68.6 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=-47.5 Deg F
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-175.00	3.00	1.37	1.63
-90.00	11.00	15.04	-4.04
-80.00	10.00	18.98	-8.98
-75.00	25.00	21.17	3.83
-75.00	36.00	21.17	14.83
-70.00	12.00	23.49	-11.49
-65.00	38.00	25.93	12.07
-60.00	40.00	28.47	11.53
-60.00	19.00	28.47	-9.47

CAPSULE W (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: W Fluence: n/cm^2

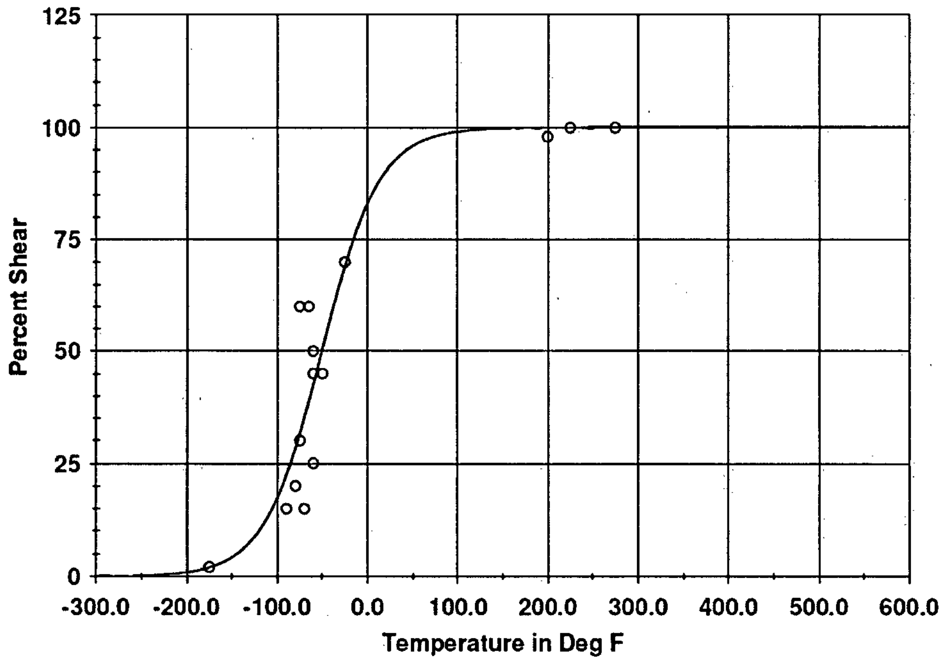
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-60.00	18.00	28.47	-10.47
-50.00	36.00	33.71	2.29
-25.00	45.00	46.40	-1.40
200.00	64.00	68.56	-4.56
225.00	80.00	68.58	11.42
275.00	62.00	68.59	-6.59

Correlation Coefficient = .916

CAPSULE W (HEAT AFFECTED ZONE)

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 04/27/2010 09:39 AM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 63.51 T0 = -50.63 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -50.6
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-175.00	2.00	1.95	.05
-90.00	15.00	22.45	-7.45
-80.00	20.00	28.40	-8.40
-75.00	30.00	31.71	-1.71
-75.00	60.00	31.71	28.29
-70.00	15.00	35.21	-20.21
-65.00	60.00	38.88	21.12
-60.00	50.00	42.68	7.32
-60.00	45.00	42.68	2.32

CAPSULE W (HEAT AFFECTED ZONE)

Page 2
Plant: Comanche Peak 2 Material: SA533B1 Heat: C5522-2
Orientation: NA Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60.00	25.00	42.68	-17.68
-50.00	45.00	50.50	-5.50
-25.00	70.00	69.15	.85
200.00	98.00	99.96	-1.96
225.00	100.00	99.98	.02
275.00	100.00	100.00	.00

Correlation Coefficient = .922

APPENDIX D
COMANCHE PEAK UNIT 2 SURVEILLANCE PROGRAM CREDIBILITY EVALUATION

D.1 INTRODUCTION

Regulatory Guide 1.99, Revision 2 [Ref. D-1] describes general procedures acceptable to the NRC staff for calculating the effects of neutron radiation embrittlement of the low-alloy steels currently used for light-water-cooled reactor vessels. Positions 2.1 and 2.2 of Regulatory Guide 1.99, Revision 2, describe the method for calculating the adjusted reference temperature and Charpy upper shelf energy of reactor vessel beltline materials using surveillance capsule data. The methods of Positions 2.1 and 2.2 can only be applied when two or more credible surveillance data sets become available from the reactor in question.

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

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

D.2 EVALUATION

Criterion 1: Materials in the capsules should be those judged most likely to be controlling with regard to radiation embrittlement.

The beltline region of the reactor vessel is defined in Appendix G to 10 CFR Part 50, "Fracture Toughness Requirements" [Ref. D-2], as follows:

> *"the region of the reactor vessel (shell material including welds, heat affected zones, and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage."*

The Comanche Peak Unit 2 reactor vessel consists of the following beltline region materials:

- Intermediate Shell Plates R3807-1, 2, and 3 (Heat # C5522-1, C5522-2, and B9566-1)
- Lower Shell Plates R3816-1, 2, and 3 (Heat # NR64435-1, NR64439-1, and NR64443-1)
- Intermediate to Lower Shell Circumferential Weld Seam (Heat # 89833)
- Intermediate & Lower Shell Longitudinal Weld Seams (Heat # 89833)

At the time when the Comanche Peak Unit 2 surveillance program material was selected it was believed that copper and phosphorus were the elements most important to embrittlement of the reactor vessel steels. Since all the plates had essentially the same weight percent copper, the choice for the surveillance plate was based on the plate that had the lowest initial USE, which was Intermediate Shell Plate R3807-2 (initial USE = 101 ft-lbs). In addition, this material also has the highest initial RT_{NDT} (initial RT_{NDT} = 10°F) of all the plates in the beltline region. Therefore, based on the highest initial RT_{NDT} and the lowest initial USE, Intermediate Shell Plate R3807-2 was chosen for the surveillance program.

The weld material in the Comanche Peak Unit 2 surveillance program was made of the same weld wire (Heat # 89833) as all the reactor vessel beltline welds. Thus, it was chosen as the surveillance weld material.

Hence, Criterion 1 is met for the Comanche Peak Unit 2 surveillance program.

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

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

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

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

The Comanche Peak Unit 2 Intermediate Shell Plate R3807-2 and surveillance weld material will be evaluated for credibility. The weld is made from weld wire Heat # 89833; Comanche Peak Unit 2 does not have a sister plant that shares the same weld wire heat and thus, does not utilize data from other surveillance programs. Therefore, the method of Regulatory Guide 1.99, Revision 2 will be followed for determining credibility of the weld as well as the plate material.

Credibility Assessment:

Since all surveillance data is from one vessel (Comanche Peak Unit 2), the measured ΔRT_{NDT} and fluence factor (FF) should be used to calculate the chemistry factors to determine if the Comanche Peak Unit 2 surveillance material test results are credible.

The chemistry factors for the Comanche Peak Unit 2 surveillance plate and weld material contained in the surveillance program were calculated in accordance with Regulatory Guide 1.99, Revision 2, Position 2.1

and are presented in Table D-1. The scatter of ΔRT_{NDT} values about the functional form of a best-fit line drawn as described in Regulatory Position 2.1 is presented in Table D-2.

Table D-1 Calculation of Chemistry Factors using Comanche Peak Unit 2 Surveillance Capsule Data

Material	Capsule	Capsule f ($x10^{19}$ n/cm^2)	FF	ΔRT_{NDT} (°F)	FF*ΔRT_{NDT} (°F)	FF^2
Intermediate Shell Plate R3807-2 (Longitudinal)	U	0.317	0.685	1.6	1.10	0.469
	X	2.16	1.209	1.6	1.93	1.462
	W	3.38	1.319	23.2	30.59	1.739
Intermediate Shell Plate R3807-2 (Transverse)	U	0.317	0.685	23.4	16.02	0.469
	X	2.16	1.209	52.9	63.96	1.462
	W	3.38	1.319	74.4	98.11	1.739
				SUM:	211.71	7.339
	$CF_{R3807-2} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (211.71) \div (7.339) = 28.8°F$					
Surveillance Weld Material	U	0.317	0.685	3.6	2.46	0.469
	X	2.16	1.209	48.2	58.28	1.462
	W	3.38	1.319	84.0	110.76	1.739
				SUM:	171.51	3.669
	$CF_{Surv. Weld} = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (171.51) \div (3.669) = 46.7°F$					

Table D-2 Comanche Peak Unit 2 Surveillance Capsule Data Scatter about the Best-Fit Line

Material	Capsule	CF (Slope$_{best\ fit}$) (°F)	Capsule f ($x10^{19}$ n/cm^2)	FF	Measured ΔRT_{NDT} (°F)	Predicted ΔRT_{NDT} (°F)	Scatter ΔRT_{NDT} (°F)	<17°F (Base Metal) <28°F (Weld)
Intermediate Shell Plate R3807-2 (Longitudinal)	U	28.8	0.317	0.685	1.6	19.7	18.1	No
	X	28.8	2.16	1.209	1.6	34.8	33.2	No
	W	28.8	3.38	1.319	23.2	38.0	14.8	Yes
Intermediate Shell Plate R3807-2 (Transverse)	U	28.8	0.317	0.685	23.4	19.7	3.7	Yes
	X	28.8	2.16	1.209	52.9	34.8	18.1	No
	W	28.8	3.38	1.319	74.4	38.0	36.4	No
Surveillance Weld Material	U	46.7	0.317	0.685	3.6	32.0	28.4	No
	X	46.7	2.16	1.209	48.2	56.5	8.3	Yes
	W	46.7	3.38	1.319	84.0	61.6	22.4	Yes

From a statistical point of view, +/- 1σ would be expected to encompass 68% of the data. Table D-2 indicates that four of the six surveillance data points fall outside the +/- 1σ of 17°F scatter band for surveillance base metals; therefore, the plate data is deemed "not credible" per the third criterion.

Table D-2 indicates that one of the three surveillance data points falls outside the +/- 1σ of 28°F scatter band for surveillance weld materials. The Comanche Peak Unit 2 surveillance weld material only has three data points. In order for the weld material to fully satisfy this requirement literally, all three data points would have to fall within the +/- 1σ scatter band. Since 66.7% (two-thirds) of the weld data fall within the +/- 1σ scatter band, it is concluded that this is approximately 68% and meets the intent of the requirement. Also note that the surveillance weld data point (Capsule U) that falls outside the scatter band is only slightly outside the criteria by approximately 0.4°F. Therefore, the surveillance weld data is deemed "credible" per the third criterion.

Note that although Intermediate Shell Plate R3807-2 did not meet Criterion 3, both materials (Intermediate Shell Plate R3807-2 and the surveillance weld material) may still be used in determining the upper shelf energy decrease in accordance with Regulatory Guide 1.99, Revision 2, Position 2.2.

Criterion 4: The irradiation temperature of the Charpy specimens in the capsule should match the vessel wall temperature at the cladding/base metal interface within +/- 25°F.

The capsule specimens are located in the reactor between the neutron pad and the vessel wall and are positioned opposite the center of the core. The test capsules are in baskets attached to the neutron pad. The location of the specimens with respect to the reactor vessel beltline provides assurance that the reactor vessel wall and the specimens experience equivalent operating conditions such that the temperatures will not differ by more than 25°F. Hence, this criterion is met.

Criterion 5: The surveillance data for the correlation monitor material in the capsule should fall within the scatter band of the database for that material.

The Comanche Peak Unit 2 surveillance program does not contain correlation monitor material. Therefore, this criterion is not applicable to the Comanche Peak Unit 2 surveillance program.

D.3 CONCLUSION

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B, the Comanche Peak Unit 2 surveillance data is deemed credible for the weld specimens and non-credible for the plate specimens.

D.4 REFERENCES

D-1 Regulatory Guide 1.99, Revision 2, *Radiation Embrittlement of Reactor Vessel Materials*, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, May 1998.

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

D-3 ASTM E185-82, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels, E706(IF)*, ASTM, 1982.

APPENDIX E
COMANCHE PEAK UNIT 2 UPPER SHELF ENERGY EVALUATION

Per Regulatory Guide 1.99, Revision 2 [Ref. E-1], the Charpy upper shelf energy (USE) is assumed to decrease as a function of fluence and copper content as indicated in Figure 2 of the Guide (Figure E-1 of this appendix) when surveillance data is not used. Linear interpolation is permitted. In addition, if surveillance data is to be used, the decrease in upper shelf energy may be obtained by plotting the reduced plant surveillance data on Figure 2 of the Guide (Figure E-1 of this appendix) and fitting the data with a line drawn parallel to the existing lines as the upper bound of all the data. This line should be used in preference to the existing graph.

The 36 EFPY (end-of-license) and 54 EFPY (end-of-license renewal) upper shelf energy of the vessel materials can be predicted using the corresponding 1/4T fluence projection, the copper content of the beltline materials and/or the results of the capsules tested to date using Figure 2 in Regulatory Guide 1.99, Revision 2. The maximum vessel clad/base metal interface fluence value was used to determine the corresponding 1/4T fluence value at 36 and 54 EFPY.

The Comanche Peak Unit 2 reactor vessel beltline region minimum thickness is 8.63 inches. Calculation of the 1/4T vessel surface fluence values at 36 and 54 EFPY for the beltline materials is shown as follows:

Maximum Vessel Fluence @ 36 EFPY = 2.10×10^{19} n/cm^2 (E > 1.0 MeV)

1/4T Fluence @ 36 EFPY = $(2.10 \times 10^{19}$ n/cm$^2) * e^{(-0.24 * (8.63 / 4))}$

= 1.251×10^{19} n/cm^2 (E > 1.0 MeV)

Maximum Vessel Fluence @ 54 EFPY = 3.14×10^{19} n/cm^2 (E > 1.0 MeV)

1/4T Fluence @ 54 EFPY = $(3.14 \times 10^{19}$ n/cm$^2) * e^{(-0.24 * (8.63 / 4))}$

= 1.871×10^{19} n/cm^2 (E > 1.0 MeV)

The following pages present the Comanche Peak Unit 2 upper shelf energy evaluation. Figure E-1, as indicated above, is used in making predictions in accordance with Regulatory Guide 1.99, Revision 2. Table E-1 provides the predicted upper shelf energy values for 36 EFPY (end-of-license). Table E-2 provides the predicted upper shelf energy values for 54 EFPY (end-of-license renewal).

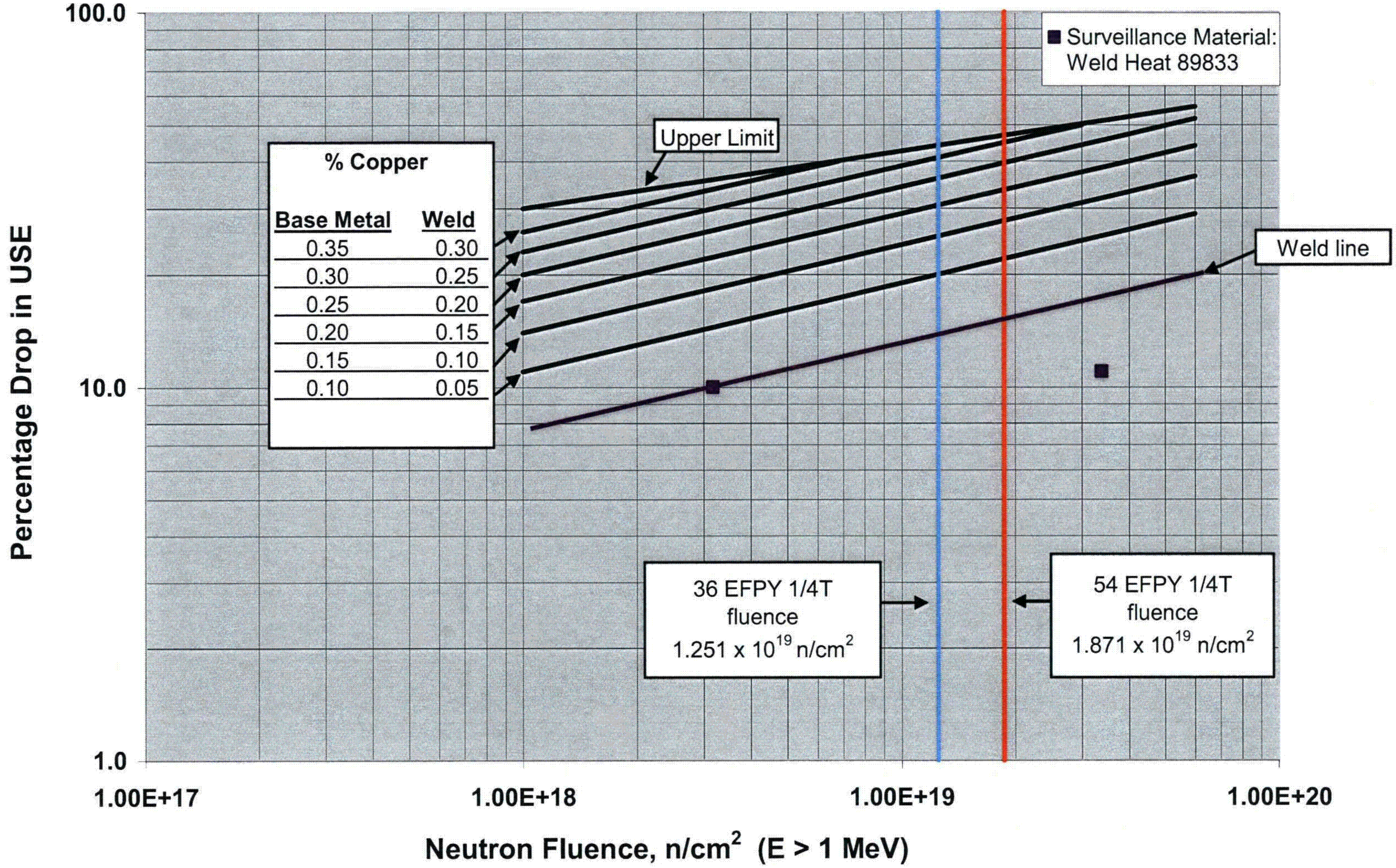


Figure E-1 **Regulatory Guide 1.99, Revision 2 Predicted Decrease in Upper Shelf Energy as a Function of Copper and Fluence**

Table E-1 Predicted Positions 1.2 and 2.2 Upper Shelf Energy Values at 36 EFPY

Material	Weight % of Cu	1/4T EOL Fluence ($x10^{19}$ n/cm^2, E > 1.0 MeV)	Unirradiated USE (ft-lb)	Projected USE Decrease (%)	Projected EOL USE (ft-lb)
Position 1.2					
Intermediate Shell Plate R3807-1	0.06	1.251	108	20	86.4
Intermediate Shell Plate R3807-2	0.06	1.251	101	20	80.8
Intermediate Shell Plate R3807-3	0.05	1.251	105	20	84
Lower Shell Plate R3816-1	0.05	1.251	107	20	85.6
Lower Shell Plate R3816-2	0.03	1.251	106	20	84.8
Lower Shell Plate R3816-3	0.04	1.251	108	20	86.4
Intermediate & Lower Shell Longitudinal Welds (Heat # 89833)	0.046	1.251[(a)]	172	20	137.6
Intermediate to Lower Shell Circumferential Weld (Heat # 89833)	0.046	1.251	96	20	76.8
Position 2.2[(b)]					
Intermediate Shell Plate R3807-2	0.06	1.251	101	2[(c)]	99.0
Intermediate & Lower Shell Longitudinal Welds (Heat # 89833)	0.046	1.251[(a)]	172	14	147.9
Intermediate to Lower Shell Circumferential Weld (Heat # 89833)	0.046	1.251	96	14	82.6

Notes:

(a) The fluence values listed for the intermediate and lower shell longitudinal welds conservatively pertain to the maximum vessel fluence value, though the welds vary in location.

(b) Calculated using surveillance capsule measured percent decrease in USE from Table 5-10 and Regulatory Guide 1.99, Revision 2, Position 2.2; see Figure E-1.

(c) The most limiting surveillance data point for Intermediate Shell Plate R3807-2 is a measured decrease of 0% at a fluence of 3.38×10^{19} n/cm^2 pertaining to Capsule W. A parallel line cannot be drawn in accordance with the guidelines of Position 2.2 of Regulatory Guide 1.99, Revision 2 using this limiting data point. Therefore, a Position 2.2 projected USE decrease of 2% is conservatively used.

Table E-2 Predicted Positions 1.2 and 2.2 Upper Shelf Energy Values at 54 EFPY

Material	Weight % of Cu	1/4T EOLR Fluence ($x10^{19}$ n/cm^2, E > 1.0 MeV)	Unirradiated USE (ft-lb)	Projected USE Decrease (%)	Projected EOLR USE (ft-lb)
Position 1.2					
Intermediate Shell Plate R3807-1	0.06	1.871	108	22	84.2
Intermediate Shell Plate R3807-2	0.06	1.871	101	22	78.8
Intermediate Shell Plate R3807-3	0.05	1.871	105	22	81.9
Lower Shell Plate R3816-1	0.05	1.871	107	22	83.5
Lower Shell Plate R3816-2	0.03	1.871	106	22	82.7
Lower Shell Plate R3816-3	0.04	1.871	108	22	84.2
Intermediate & Lower Shell Longitudinal Welds (Heat # 89833)	0.046	1.871[a]	172	22	134.2
Intermediate to Lower Shell Circumferential Weld (Heat # 89833)	0.046	1.871	96	22	74.9
Position 2.2[b]					
Intermediate Shell Plate R3807-2	0.06	1.871	101	2[c]	99.0
Intermediate & Lower Shell Longitudinal Welds (Heat # 89833)	0.046	1.871[a]	172	16	144.5
Intermediate to Lower Shell Circumferential Weld (Heat # 89833)	0.046	1.871	96	16	80.6

Notes:

(a) The fluence values listed for the intermediate and lower shell longitudinal welds conservatively pertain to the maximum vessel fluence value, though the welds vary in location.

(b) Calculated using surveillance capsule measured percent decrease in USE from Table 5-10 and Regulatory Guide 1.99, Revision 2, Position 2.2; see Figure E-1.

(c) The most limiting surveillance data point for Intermediate Shell Plate R3807-2 is a measured decrease of 0% at a fluence of 3.38 x 10^{19} n/cm^2 pertaining to Capsule W. A parallel line cannot be drawn in accordance with the guidelines of Position 2.2 of Regulatory Guide 1.99, Revision 2 using this limiting data point. Therefore, a Position 2.2 projected USE decrease of 2% is conservatively used.

USE Conclusion

All of the beltline materials in the Comanche Peak Unit 2 reactor vessel are projected to remain above the USE screening criterion value of 50 ft-lb (per 10 CFR 50, Appendix G) at 36 and 54 EFPY.

E.1 REFERENCES

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