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# Analysis of Capsule Z from the Tennessee Valley Authority, Watts Bar Unit 1 Reactor Vessel Radiation Surveillance Program

Westinghouse

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# Analysis of Capsule Z from the Tennessee Valley Authority, Watts Bar Unit 1 Reactor Vessel Radiation Surveillance Program

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## EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of Surveillance Capsule Z from Watts Bar Unit 1. Capsule Z was removed at the end of Cycle 7 and post irradiation mechanical tests of the Charpy V-notch and tensile specimens were performed. A fluence evaluation utilizing the recently released neutron transport and dosimetry cross-section libraries was derived from the ENDF/B-VI data-base. Capsule Z received a fluence of 2.40 x $10^{19}$n/cm$^2$ after irradiation to 9.37 EFPY. The peak clad/base metal interface vessel fluence after 9.37 EFPY of plant operation was 4.74 x $10^{18}$n/cm$^2$.

This evaluation lead to the following conclusions: 1) The measured 30 ft-lb shift in transition temperature values of the Intermediate Shell Forging 05 contained in Capsule Z (Tangential & Axial) is less than the Regulatory Guide 1.99, Revision 2[1], predictions. 2) The measured 30 ft-lb shift in transition temperature values of the weld metal contained in Capsule Z is less than the Regulatory Guide 1.99, Revision 2, predictions. 3) The measured percent decrease in upper shelf energy for all the surveillance materials of Capsule Z contained in the Watts Bar Unit 1 surveillance program are less than the Regulatory 1.99, Revision 2 predictions. 4) The lower shell forging and the intermediate shell to lower shell girth weld 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 life of the vessel (32 EFPY) as required by 10 CFR 50, Appendix G[2]. 5) The intermediate shell forging 05 is predicted to drop below 50 ft-lbs by 32 EFPY, however, it still remains above the 43 ft-lb lower bound as determined in WCAP-13587, Rev. 1[3]. 6) The Watts Bar Unit 1 surveillance weld data was found to be credible, while the surveillance forging 05 material was found to be not-credible. This evaluation can be found in Appendix D.

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

# 1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in Surveillance Capsule Z, the fourth capsule removed and tested from the Watts Bar Unit 1 reactor pressure vessel, led to the following conclusions:

- Charpy V-notch test data were plotted using symmetric hyperbolic tangent curve-fitting program. Appendix C presents the CVGRAPH, Version 5.0.2, Charpy V-notch plots for Capsule Z and previous capsules, along with the program input data.

- Capsule Z received an average fast neutron fluence (E> 1.0 MeV) of 2.40 x $10^{19}$n/cm$^2$ after 9.37 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel Intermediate Shell Forging 05 (heat number 527536) Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (tangential orientation), resulted in an irradiated 30 ft-lb transition temperature of 87.4°F and an irradiated 50 ft-lb transition temperature of 137.9°F. This results in a 30 ft-lb transition temperature increase of 145°F and a 50 ft-lb transition temperature increase of 153°F for the tangential orientation specimens. See Table 5-9.

- Irradiation of the reactor vessel Intermediate Shell Forging 05 (heat number 527536) Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (axial orientation), resulted in an irradiated 30 ft-lb transition temperature of 150.1°F and an irradiated 50 ft-lb transition temperature of 225.6°F. This results in a 30 ft-lb transition temperature increase of 105°F and a 50 ft-lb transition temperature increase of 111°F for the axial orientation specimens. See Table 5-9.

- Irradiation of the weld metal (heat number 895075) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -17.3°F and an irradiated 50 ft-lb transition temperature of 28.0°F. This results in a 30 ft-lb transition temperature increase of 14°F and a 50 ft-lb transition temperature increase of 34°F. See Table 5-9.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 11.5°F and an irradiated 50 ft-lb transition temperature of 74.9°F. This results in a 30 ft-lb transition temperature increase of 68°F and a 50 ft-lb transition temperature increase of 84°F. See Table 5-9.

- The average upper shelf energy of the Intermediate Shell Forging 05 (tangential orientation) resulted in an average energy decrease of 31 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 101 ft-lb for the tangential orientation specimens. See Table 5-9.

- The average upper shelf energy of the Intermediate Shell Forging 05 (axial orientation) resulted in no energy decrease after irradiation. This results in an irradiated average upper shelf energy of 62 ft-lb for the axial orientation specimens. See Table 5-9.

- The average upper shelf energy of the weld metal Charpy specimens resulted in no energy decrease after irradiation, rather the irradiated weld USE was measured to be 14 ft-lb higher than

the unirradiated material test results. This results in an irradiated average upper shelf energy of 145 ft-lb for the weld metal specimens. See Table 5-9.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy decrease of 10 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 79 ft-lb for the weld HAZ metal. See Table 5-9.

- A comparison, as presented in Table 5-10, of the Watts Bar Unit 1 reactor vessel surveillance material test results with the Regulatory Guide 1.99, Revision 2[1] predictions led to the following conclusions:

  - The measured 30 ft-lb shift in transition temperature values of the Intermediate Shell Forging 05 contained in Capsule Z (longitudinal & transverse) are less than the Regulatory Guide 1.99, Revision 2, predictions.

  - The measured 30 ft-lb shift in transition temperature value of the weld metal contained in Capsule Z is less than the Regulatory Guide 1.99, Revision 2, predictions.

  - The measured percent decrease in upper shelf energy for all the surveillance materials of Capsules Z contained in the Watts Bar Unit 1 surveillance program are less than the Regulatory Guide 1.99, Revision 2 predictions.

- The calculated end-of-license (32 EFPY) neutron fluence (E> 1.0 MeV) at the core midplane for the Watts Bar Unit 1 reactor vessel using the Regulatory Guide 1.99, Revision 2[1] attenuation formula (i.e., Equation #3 in the guide) are as follows:

| | | |
|---|---|---|
| Calculated: | Vessel inner radius* | $= 1.75 \times 10^{19} n/cm^2$ |
| | Vessel 1/4 thickness | $= 1.05 \times 10^{19} n/cm^2$ |
| | Vessel 3/4 thickness | $= 3.81 \times 10^{18} n/cm^2$ |

*Clad/base metal interface. (From Table 6-2)

- All beltline materials, with exception to the intermediate shell forging 05, are expected to have an upper shelf energy (USE) greater than 50 ft-lb through end of license (EOL, 32 EFPY) as required by 10 CFR 50, Appendix G[2].

  In September of 1993, Westinghouse completed an evaluation to demonstrate that all Westinghouse Owners Group (WOG) Plant reactor vessels have a margin of safety, relative to USE, equivalent to that required by Appendix G of the ASME Code[4]. This was accomplished by performing generic bounding evaluations per the proposed ASME Section XI, Appendix X[5]. This evaluation is documented in WCAP-13587, Revision 1[3], "Reactor Vessel Upper Shelf Energy Bounding Evaluation for Westinghouse Pressurized Water Reactors" and provides the minimum USE for a four loop Westinghouse NSSS plant. The minimum acceptable USE for a 4 loop plant is 43 ft-lb. The projected minimum EOL USE for the Watts Bar Unit 1 intermediate shell forging 05 is greater than 43 ft-lb. Hence, the bounding WOG evaluation shows that the Watts Bar Unit 1 intermediate shell forging 05 will maintain an equivalent margin, with respect to

USE per the requirements of 10 CFR Part 50, Appendix G, through EOL (i.e., Maintain this margin through EOL).

In addition, Westinghouse completed an evaluation of Watts Bar Unit 1 Capsule X compact tension specimens (of intermediate shell forging 05) to demonstrate that plant-specific J-R curves met the requirements for ductile tearing as presented in ASME Section XI, Appendix X[5]. This evaluation, contained in WCAP-16333-NP[6], indicates that the Watts Bar Unit 1 test data from Capsule X maintained sufficient fracture toughness to meet the requirements for plant service conditions. It should also be noted that the results of Capsule Z testing indicate that the measured EOL USE for the axially-oriented Charpy specimens for intermediate shell forging 05 (which is the limiting orientation for unirradiated USE in this surveillance material) showed no decrease in USE.

- The credibility evaluation of the Watts Bar Unit 1 surveillance program is presented in Appendix D of this report. The evaluation concluded that the Watts Bar Unit 1 surveillance data is deemed credible for the weld specimens and non-credible for the forging specimens.

# 2 INTRODUCTION

This report presents the results of the examination of Capsule Z, the fourth capsule removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the Watts Bar Unit 1 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Watts Bar Unit 1 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-9298, "Tennessee Valley Authority Watts Bar Unit No. 1 Reactor Vessel Radiation Surveillance Program"[7]. The surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-73[8], "Standard Recommended Practice Surveillance Tests for Nuclear Reactor Vessels." Capsule Z was removed from the reactor after 9.37 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 and the post-irradiation data obtained from Surveillance Capsule Z removed from the Watts Bar Unit 1 reactor vessel and discusses the analysis of the data.

# 3 BACKGROUND

The ability of the large steel pressure vessel containing the reactor core and its primary coolant to resist fracture constitutes an important factor in ensuring safety in the nuclear industry. The beltline region of the reactor pressure vessel is the most critical region of the vessel because it is subjected to significant fast neutron bombardment. The overall effects of fast neutron irradiation on the mechanical properties of low alloy, ferritic pressure vessel steels such as A508 Class 2 Forging (base material of the Watts Bar Unit 1 reactor pressure vessel beltline) are well documented in the literature. Generally, low alloy ferritic materials show an increase in hardness and tensile properties and a decrease in ductility and toughness during high-energy irradiation.

A method for ensuring the integrity of reactor pressure vessels has been presented in "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code[4]. 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[9]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (transverse) to the major working direction of the plate. The $RT_{NDT}$ of a given material is used to index that material to a reference stress intensity factor curve ($K_{Ic}$ curve) which appears in Appendix G to the ASME Code[4]. 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 Watts Bar Unit 1 reactor vessel radiation surveillance program[7], in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens tested. The increase in the average Charpy V-notch 30 ft-lb temperature ($\Delta RT_{NDT}$) 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 ($RT_{NDT}$ initial + M + $\Delta RT_{NDT}$) 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 Watts Bar Unit 1 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant start-up. 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.

Capsule Z was removed after 9.37 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch and tensile specimens made from intermediate shell forging 05 (heat number 527536) and submerged arc weld metal identical to the reactor vessel beltline region weld. In addition, this capsule contained Charpy V-notch specimens from the weld Heat-Affected-Zone (HAZ) metal of intermediate shell forging 05.

Test material obtained from the intermediate shell forging 05 (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 1/4 thickness location of the plate after performing a simulated post-weld stress-relieved weldment joining intermediate shell forging 05 and adjacent lower shell forging 04. All heat-affected-zone specimens were obtained from the weld heat-affected-zone of the intermediate shell forging 05.

Charpy V-notch impact specimens from intermediate shell forging 05 were machined in the tangential orientation (longitudinal axis of the specimen parallel to the major working direction) and also in the axial orientation (longitudinal axis of the specimen perpendicular to the major working direction). The core region weld Charpy impact specimens were machined from the weldment such that the long dimension of each Charpy specimen was perpendicular 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 the intermediate shell forging 05 were machined in both the tangential and axial orientations. Tensile specimens from the weld metal were oriented with the long dimension of the specimen perpendicular to the weld direction.

Bend bar specimens were machined from the intermediate shell forging 05 with the longitudinal axis of the specimen oriented in the rolling direction of the forging such that the simulated crack would propagate in a direction normal to the rolling direction of the forging. Compact tension test specimens from intermediate shell forging 05 were machined in the tangential and axial orientations. Compact tension test specimens from the weld metal were machined perpendicular to the weld direction with the notch oriented in the direction of welding. These specimens should be fatigue pre-cracked in accordance with ASTM E399[10].

Initial chemical composition data and heat treatment of the unirradiated surveillance materials are presented in Tables 4-1 and 4-2, respectively. The data in Tables 4-1 and 4-2 was obtained from the unirradiated surveillance program report, WCAP-9298, Rev. 3, Appendix A[7].

Capsule Z 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

($Np^{237}$) and uranium ($U^{238}$) were placed in the capsule to measure the integrated flux at specific neutron energy levels.

The capsule contained thermal monitors made from two low-melting-point eutectic alloys and 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) |
| 1.75% Ag, 0.75% Sn, 97.5% Pb | Melting Point: 590°F (310°C) |

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

**Table 4-1 Chemical Composition (wt%) of the Watts Bar Unit 1 Reactor Vessel Surveillance Materials (Unirradiated)[a]**

| Element | Intermediate Shell Forging 05[a & c] | | Weld Metal[b & c] | |
|---|---|---|---|---|
| C | 0.20 | 0.21 | 0.080 | 0.069 |
| S | 0.016 | 0.014 | 0.007 | 0.010 |
| N | 0.009 | --- | 0.019 | --- |
| Co | <0.01 | 0.012 | 0.007 | --- |
| Cu | 0.17 | 0.14 | 0.031 | 0.05 |
| Si | 0.25 | 0.25 | 0.27 | 0.22 |
| Mo | 0.57 | 0.61 | 0.54 | 0.56 |
| Ni | 0.80 | 0.79 | 0.75 | 0.70 |
| Mn | 0.73 | 0.68 | 1.94 | 1.97 |
| Cr | 0.32 | 0.34 | 0.023 | 0.05 |
| V | <0.01 | <0.02 | 0.001 | --- |
| P | 0.012 | 0.013 | 0.015 | 0.010 |
| Al | <0.019 | 0.049 | 0.019 | --- |
| Sn | 0.010 | --- | 0.003 | --- |

Notes:

a. All analysis except for N and Sn were conducted by Rotterdam Dockyard Company/Krupp ladle analysis; N and Sn analysis were performed by Westinghouse.

b. The surveillance weldment is identical to the closing girth seam weldment between forging 04 and 05. The closing seam used weld wire heat number 895075 with Grau L.O. (LW320) flux, lot P46, except for the 1-inch root pass at the ID of the vessel. This root pass used weld wire heat number 899680 with type Grau L.O. (LW320) flux, lot P23, with an as-deposited copper and phosphorus content of 0.03 and 0.009, respectively. The surveillance weldment specimens were not removed from this root area.

c. The left column results were obtained from Westinghouse analyses, while the results in the right column results were obtained from analyses conducted by Rotterdam Dockyard Company.

**Table 4-2 Heat Treatment History of the Watts Bar Unit 1 Reactor Vessel Surveillance Materials[a]**

| Material | Temperature (°F) | Time (hr) | Coolant |
|---|---|---|---|
| Intermediate Shell Forging 05 | 1675 - 1700 | 3 ½ | Water-quenched |
| | 1230 - 1240 | 6 | Air Cooled |
| | 1140 +/- 25 | 21 | Furnace Cooled |
| Weldment | 1140 +/- 25 | 14 hr., 56 min | Furnace Cooled |

Note:

a. This table was taken from WCAP-9298, Rev. 3[7].

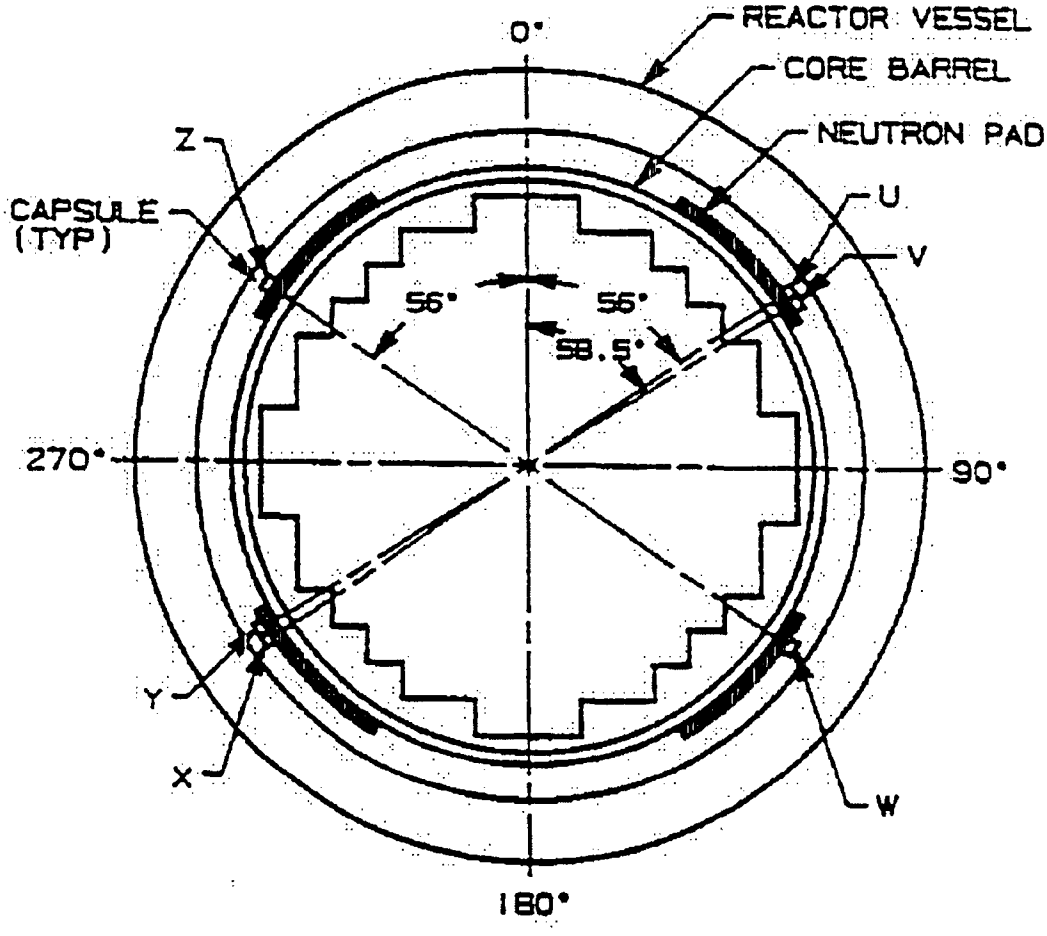



**Figure 4-1 Arrangement of Surveillance Capsules in the Watts Bar Unit 1 Reactor Vessel**

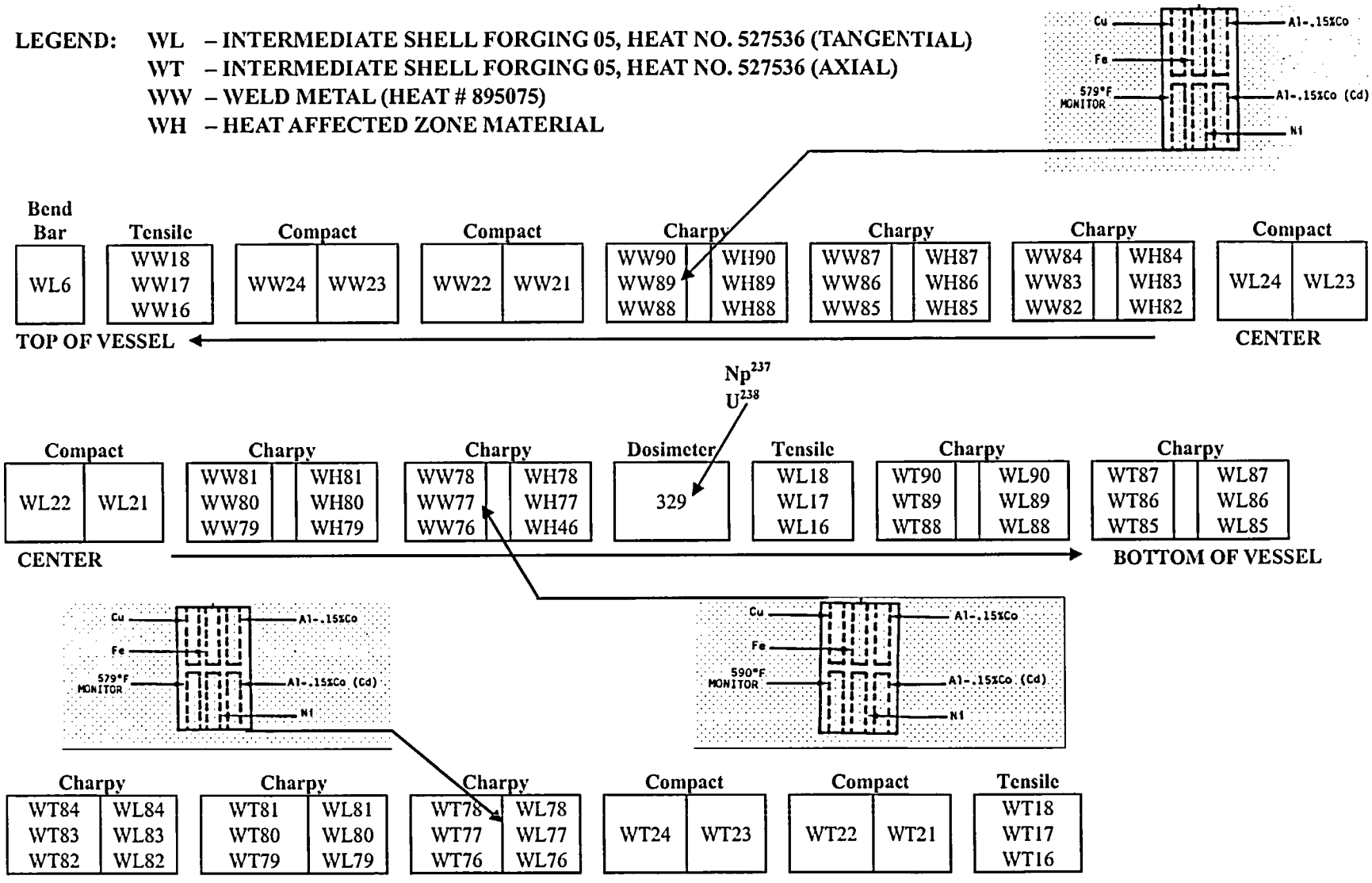



**Figure 4-2 Capsule Z Diagram Showing the Location of Specimens, Thermal Monitors, and Dosimeters**

# 5 TESTING OF SPECIMENS FROM CAPSULE Z

## 5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed in the Remote Metallographic Facility (RMF) at the Westinghouse Science and Technology Center.

Upon receipt of the capsule at the laboratory, the capsule was opened per Procedure RMF 8804[11]. The specimens and spacer blocks were carefully removed, inspected for identification number and checked against the master list in WCAP-9298, Revision 3[7].

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

The testing of the Charpy V-notch and tensile specimens was performed in accordance with ASTM Specification E185-82[12] and Westinghouse Procedures RMF 8402[13] as detailed by Westinghouse Procedures RMF 8102[14] and RMF 8103[15].

The Charpy impact tests were performed per ASTM Specification E23-06[16] and Procedure RMF 8103[15] 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 ($\sigma_Y$) was calculated from the three-point bend formula having the following expression[17]:

$$\sigma_Y = P_{GY} \frac{L}{B(W-a)^2 C} \tag{1}$$

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 ($\varphi$), notch root radius ($\rho$)

and the type of loading (i.e., pure bending or three-point bending). In three-point bending, for a Charpy specimen in which $\varphi = 450$ and $\rho = 0.010$ in., Equation 1 is valid with C = 1.21.

Therefore, (for L = 4W),

$$\sigma_Y = P_{GY} \frac{L}{B(W-a)^2\, 1.21} = \frac{3.305\, P_{GY} W}{B(W-a)^2} \tag{2}$$

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

$$\sigma_Y = 33.3\, P_{GY} \tag{3}$$

where $\sigma_Y$ 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:

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

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM E23-06[16] and A370-07[18]. The lateral expansion was measured using a dial gage rig similar to that shown in the same specifications.

Tensile tests were performed on a 20,000 pound Instron, split console test machine (Model 1115) per ASTM Specification E8-04[19] and E21-05[20] and Procedure RMF 8102[14]. 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 RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule Z, which received a fluence of $2.40 \times 10^{19}$ n/cm$^2$ (E> 1.0 MeV) in 9.37 EFPY of operation, are presented in Tables 5-1 through 5-10 and are compared with unirradiated results shown in Figures 5-1 through 5-12.

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

- Irradiation of the reactor vessel Intermediate Shell Forging 05 (heat number 527536) Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (tangential orientation), resulted in an irradiated 30 ft-lb transition temperature of 87.4°F and an irradiated 50 ft-lb transition temperature of 137.9°F. This results in a 30 ft-lb transition temperature increase of 145°F and a 50 ft-lb transition temperature increase of 153°F for the tangential orientation specimens. See Table 5-9.

- Irradiation of the reactor vessel Intermediate Shell Forging 05 (heat number 527536) Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (axial orientation), resulted in an irradiated 30 ft-lb transition temperature of 150.1°F and an irradiated 50 ft-lb transition temperature of 225.6°F. This results in a 30 ft-lb transition temperature increase of 105°F and a 50 ft-lb transition temperature increase of 111°F for the axial orientation specimens. See Table 5-9.

- Irradiation of the weld metal (heat number 895075) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -17.3°F and an irradiated 50 ft-lb transition temperature of 28.0°F. This results in a 30 ft-lb transition temperature increase of 14°F and a 50 ft-lb transition temperature increase of 34°F. See Table 5-9.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 11.5°F and an irradiated 50 ft-lb transition temperature of 74.9°F. This results in a 30 ft-lb transition temperature increase of 68°F and a 50 ft-lb transition temperature increase of 84°F. See Table 5-9.

- The average upper shelf energy of the Intermediate Shell Forging 05 (tangential orientation) resulted in an average energy decrease of 31 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 101 ft-lb for the tangential orientation specimens. See Table 5-9.

- The average upper shelf energy of the Intermediate Shell Forging 05 (axial orientation) resulted in no energy decrease after irradiation. This results in an irradiated average upper shelf energy of 62 ft-lb for the axial orientation specimens. See Table 5-9.

- The average upper shelf energy of the weld metal Charpy specimens resulted in no energy decrease after irradiation, rather the irradiated weld USE was measured to be 14 ft-lb higher than the unirradiated material test results. This results in an irradiated average upper shelf energy of 145 ft-lb for the weld metal specimens. See Table 5-9.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy decrease of 10 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 79 ft-lb for the weld HAZ metal. See Table 5-9.

- A comparison, as presented in Table 5-10, of the Watts Bar Unit 1 reactor vessel surveillance material test results with the Regulatory Guide 1.99, Revision 2[1] predictions led to the following conclusions:

  - The measured 30 ft-lb shift in transition temperature values of the Intermediate Shell Forging 05 contained in Capsule Z (longitudinal & transverse) are less than the Regulatory Guide 1.99, Revision 2, predictions.

  - The measured 30 ft-lb shift in transition temperature value of the weld metal contained in Capsule Z is less than the Regulatory Guide 1.99, Revision 2, predictions.

  - The measured percent decrease in upper shelf energy for all the surveillance materials of Capsules Z contained in the Watts Bar Unit 1 surveillance program are less than the Regulatory Guide 1.99, Revision 2 predictions.

All beltline materials, with exception to the intermediate shell forging 05, are expected to have an upper shelf energy (USE) greater than 50 ft-lb through end of license (EOL, 32 EFPY) as required by 10 CFR 50, Appendix G[2].

In September of 1993, Westinghouse completed an evaluation to demonstrate that all Westinghouse Owners Group (WOG) Plant reactor vessels have a margin of safety, relative to USE, equivalent to that required by Appendix G of the ASME Code. This was accomplished by performing generic bounding evaluations per the proposed ASME Section XI, Appendix X. This evaluation is documented in WCAP-13587, Revision 1[3], "Reactor Vessel Upper Shelf Energy Bounding Evaluation for Westinghouse Pressurized Water Reactors" and provides the minimum USE for a four loop Westinghouse NSSS plant. The minimum acceptable USE for a 4 loop plant is 43 ft-lb. The projected minimum EOL USE for the Watts Bar Unit 1 intermediate shell forging 05 is greater than 43 ft-lb. Hence, the bounding WOG evaluation shows that the Watts Bar Unit 1 intermediate shell forging 05 will maintain an equivalent margin, with respect to USE per the requirements of 10 CFR Part 50, Appendix G[2], through EOL (i.e., Maintain this margin through EOL).

In addition, Westinghouse completed an evaluation of Watts Bar Unit 1 Capsule X compact tension specimens (of intermediate shell forging 05) to demonstrate that plant-specific J-R curves met the requirements for ductile tearing as presented in ASME Section XI, Appendix X[5]. This evaluation, contained in WCAP-16333-NP[6], indicates that the Watts Bar Unit 1 test data from Capsule X maintained sufficient fracture toughness to meet the requirements for plant service conditions. It should also be noted that the results of Capsule Z testing indicate that the measured EOL USE for the axially-oriented Charpy specimens for intermediate shell forging 05 (which is the limiting orientation for unirradiated USE in this surveillance material) showed no decrease in USE.

The fracture appearance of each irradiated Charpy specimen from the various surveillance Capsule Z materials is shown in Figures 5-13 through 5-16 and shows an increasingly ductile or tougher appearance with increasing test temperature.

The load-time records for individual instrumented Charpy specimen tests are shown in Appendix B. Appendix C presents the individual CVGRAPH, Version 5.0.2, Charpy V-notch plots for each surveillance capsule and the program input data.

## 5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in Capsule Z irradiated to 2.40 x $10^{19}$n/cm$^2$ (E> 1.0 MeV) are presented in Table 5-11 and are compared with unirradiated results[7] as shown in Figures 5-17 through 5-19.

The results of the tensile tests performed on the Intermediate Shell Forging 05 (tangential orientation) at 550°F indicated that irradiation to 2.40 x $10^{19}$n/cm$^2$ (E> 1.0 MeV) caused approximately a 13 ksi increase in the 0.2 percent offset yield strength and approximately a 10 ksi increase in the ultimate tensile strength when compared to unirradiated data[7]. See Figure 5-17.

The results of the tensile tests performed on the Intermediate Shell Forging 05 (axial orientation) at 550°F indicated that irradiation to 2.40 x $10^{19}$n/cm$^2$ (E> 1.0 MeV) caused approximately a 9 ksi increase in the 0.2 percent offset yield strength and approximately a 9 ksi increase in the ultimate tensile strength when compared to unirradiated data[7]. See Figure 5-18.

The results of the tensile tests performed on the surveillance weld metal at 550°F indicated that irradiation to 2.40 x $10^{19}$n/cm$^2$ (E> 1.0 MeV) caused approximately a 5 ksi increase in the 0.2 percent offset yield strength and approximately a 5 ksi increase in the ultimate tensile strength when compared to unirradiated data[4]. See Figure 5-19.

The fractured tensile specimens for the Intermediate Shell Forging 05 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 with the Tennessee Valley Authority Nuclear Power Group, the 1/2T specimens were not tested. These specimens are stored at Westinghouse's Science and Technology Center.

**Table 5-1 Charpy V-notch Data for the Watts Bar Unit 1 Intermediate Shell Forging 05 Irradiated to a Fluence of 2.40 x $10^{19}$n/cm$^2$ (E> 1.0 MeV) (Tangential Orientation)**

| Sample Number | Temperature | | Impact Energy | | Lateral Expansion | | Shear |
|---|---|---|---|---|---|---|---|
| | °F | °C | ft-lbs | Joules | mils | mm | % |
| WL90 | -100 | -73 | 6 | 8 | 9 | 0.23 | 0 |
| WL83 | 25 | -4 | 15 | 20 | 15 | 0.38 | 2 |
| WL84 | 60 | 16 | 21 | 28 | 15 | 0.38 | 10 |
| WL87 | 75 | 24 | 27 | 37 | 23 | 0.58 | 25 |
| WL80 | 80 | 27 | 25 | 34 | 22 | 0.56 | 20 |
| WL79 | 85 | 29 | 16 | 22 | 17 | 0.43 | 40 |
| WL77 | 95 | 35 | 32 | 43 | 30 | 0.76 | 40 |
| WL85 | 100 | 38 | 45 | 61 | 36 | 0.91 | 45 |
| WL88 | 125 | 52 | 53 | 72 | 41 | 1.04 | 45 |
| WL76 | 150 | 66 | 60 | 81 | 44 | 1.12 | 65 |
| WL81 | 175 | 79 | 56 | 76 | 50 | 1.27 | 55 |
| WL78 | 200 | 93 | 70 | 95 | 50 | 1.27 | 80 |
| WL82 | 300 | 149 | 104 | 141 | 77 | 1.96 | 100 |
| WL86 | 350 | 177 | 101 | 137 | 76 | 1.93 | 100 |
| WL89 | 375 | 191 | 97 | 132 | 71 | 1.80 | 100 |

| Table 5-2 | Charpy V-notch Data for the Watts Bar Unit 1 Intermediate Shell Forging 05 Irradiated to a Fluence of 2.40 x $10^{19}$n/cm$^2$ (E> 1.0 MeV) (Axial Orientation) | | | | | | |
|---|---|---|---|---|---|---|---|
| Sample Number | Temperature | | Impact Energy | | Lateral Expansion | | Shear |
| | °F | °C | ft-lbs | Joules | mils | mm | % |
| WT82 | -50 | -46 | 7 | 9 | 6 | 0.15 | 2 |
| WT89 | 75 | 24 | 18 | 24 | 19 | 0.48 | 20 |
| WT86 | 100 | 38 | 24 | 33 | 36 | 0.91 | 25 |
| WT85 | 125 | 52 | 18 | 24 | 25 | 0.64 | 20 |
| WT88 | 140 | 60 | 27 | 37 | 32 | 0.81 | 40 |
| WT77 | 150 | 66 | 28 | 38 | 31 | 0.79 | 40 |
| WT83 | 165 | 74 | 33 | 45 | 35 | 0.89 | 45 |
| WT79 | 175 | 79 | 35 | 47 | 34 | 0.86 | 50 |
| WT81 | 190 | 88 | 36 | 49 | 42 | 1.07 | 50 |
| WT76 | 200 | 93 | 35 | 47 | 38 | 0.97 | 60 |
| WT90 | 210 | 99 | 58 | 79 | 60 | 1.52 | 95 |
| WT78 | 225 | 107 | 55 | 75 | 50 | 1.27 | 100 |
| WT84 | 300 | 149 | 66 | 89 | 56 | 1.42 | 100 |
| WT87 | 350 | 177 | 69 | 94 | 57 | 1.45 | 100 |
| WT80 | 375 | 191 | 64 | 87 | 52 | 1.32 | 100 |

**Table 5-3 Charpy V-notch Data for the Watts Bar Unit 1 Surveillance Weld Metal Irradiated to a Fluence of 2.40 x $10^{19}$ n/cm$^2$ (E> 1.0 MeV)**

| Sample Number | Temperature | | Impact Energy | | Lateral Expansion | | Shear |
|---|---|---|---|---|---|---|---|
| | °F | °C | ft-lbs | Joules | mils | mm | % |
| WW89 | -100 | -73 | 4 | 5 | 4 | 0.10 | 10 |
| WW83 | -25 | -32 | 27 | 37 | 24 | 0.61 | 20 |
| WW86 | -15 | -26 | 37 | 50 | 33 | 0.84 | 30 |
| WW78 | 0 | -18 | 31 | 42 | 30 | 0.76 | 25 |
| WW90 | 15 | -9 | 27 | 37 | 30 | 0.76 | 35 |
| WW87 | 25 | -4 | 51 | 69 | 42 | 1.07 | 50 |
| WW82 | 40 | 4 | 64 | 87 | 48 | 1.22 | 55 |
| WW85 | 50 | 10 | 72 | 98 | 59 | 1.50 | 50 |
| WW80 | 75 | 24 | 77 | 104 | 56 | 1.42 | 50 |
| WW84 | 100 | 38 | 97 | 132 | 71 | 1.80 | 70 |
| WW88 | 125 | 52 | 100 | 136 | 76 | 1.93 | 80 |
| WW81 | 150 | 66 | 101 | 137 | 85 | 2.16 | 85 |
| WW79 | 300 | 149 | 151 | 205 | 94 | 2.39 | 100 |
| WW77 | 350 | 177 | 148 | 201 | 91 | 2.31 | 100 |
| WW76 | 375 | 191 | 136 | 184 | 92 | 2.34 | 100 |

**Table 5-4 Charpy V-notch Data for the Watts Bar Unit 1 Heat-Affected-Zone (HAZ) Material Irradiated to a Fluence of 2.40 x $10^{19}$n/cm$^2$ (E> 1.0 MeV)**

| Sample Number | Temperature | | Impact Energy | | Lateral Expansion | | Shear |
|---|---|---|---|---|---|---|---|
| | °F | °C | Ft-lbs | Joules | mils | mm | % |
| WH79 | -100 | -73 | 9 | 12 | 6 | 0.15 | 2 |
| WH83 | -25 | -32 | 22 | 30 | 16 | 0.41 | 15 |
| WH85 | 0 | -18 | 34 | 46 | 24 | 0.61 | 15 |
| WH76 | 15 | -9 | 27 | 37 | 23 | 0.58 | 40 |
| WH78 | 25 | -4 | 31 | 42 | 26 | 0.66 | 40 |
| WH88 | 40 | 4 | 30 | 41 | 27 | 0.69 | 60 |
| WH80 | 50 | 10 | 40 | 54 | 33 | 0.84 | 50 |
| WH86 | 60 | 16 | 46 | 62 | 36 | 0.91 | 70 |
| WH82 | 75 | 24 | 62 | 84 | 40 | 1.02 | 80 |
| WH89 | 125 | 52 | 62 | 84 | 56 | 1.42 | 85 |
| WH87 | 175 | 79 | 69 | 94 | 54 | 1.37 | 100 |
| WH77 | 300 | 149 | 68 | 92 | 46 | 1.17 | 100 |
| WH90 | 325 | 163 | 83 | 113 | 75 | 1.91 | 100 |
| WH84 | 350 | 177 | 80 | 108 | 55 | 1.40 | 100 |
| WH81 | 375 | 191 | 96 | 130 | 75 | 1.91 | 100 |

**Table 5-5 Instrumented Charpy Impact Test Results for the Watts Bar Unit 1 Intermediate Shell Forging 05 Irradiated to a Fluence of 2.40 x $10^{19}$n/cm$^2$ (E>1.0 MeV) (Tangential Orientation)**

| Sample No. | Test Temp. (°F) | Charpy Energy $E_D$ (ft-lb) | Normalized Energies (ft-lb/in$^2$) | | | Yield Load $P_{GY}$ (lb) | Time to Yield $t_{GY}$ (msec) | Max. Load $P_M$ (lb) | Time to Max. $t_M$ (msec) | Fast Fract. Load $P_F$ (lb) | Arrest Load $P_A$ (lb) | Yield Stress $\sigma_Y$ (ksi) | Flow Stress (ksi) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Charpy $E_D/A$ | Max. $E_M/A$ | Prop. Ep/A | | | | | | | | |
| WL90 | -100 | 6 | 48 | 27 | 22 | 2964 | 0.13 | 3042 | 0.14 | 3042 | 0 | 99 | 100 |
| WL83 | 25 | 15 | 121 | 71 | 50 | 3436 | 0.15 | 4270 | 0.23 | 4250 | 0 | 114 | 128 |
| WL84 | 60 | 21 | 169 | 123 | 46 | 2962 | 0.14 | 4225 | 0.33 | 4061 | 0 | 99 | 120 |
| WL87 | 75 | 27 | 218 | 162 | 55 | 3258 | 0.15 | 4630 | 0.39 | 4630 | 0 | 109 | 131 |
| WL80 | 80 | 25 | 201 | 150 | 52 | 3045 | 0.14 | 4339 | 0.38 | 4258 | 0 | 101 | 123 |
| WL79 | 85 | 16 | 129 | 56 | 73 | 2794 | 0.13 | 3799 | 0.21 | 3786 | 115 | 93 | 110 |
| WL77 | 95 | 32 | 258 | 198 | 60 | 3090 | 0.14 | 4419 | 0.47 | 4406 | 0 | 103 | 125 |
| WL85 | 100 | 45 | 363 | 243 | 120 | 3336 | 0.16 | 4583 | 0.54 | 4461 | 0 | 111 | 132 |
| WL88 | 125 | 53 | 427 | 230 | 197 | 3221 | 0.15 | 4514 | 0.52 | 4214 | 0 | 107 | 129 |
| WL76 | 150 | 60 | 483 | 226 | 257 | 2928 | 0.14 | 4347 | 0.53 | 4044 | 433 | 97 | 121 |
| WL81 | 175 | 56 | 451 | 293 | 158 | 2989 | 0.14 | 4316 | 0.67 | 4110 | 580 | 100 | 122 |
| WL78 | 200 | 70 | 564 | 290 | 274 | 2800 | 0.14 | 4299 | 0.67 | 4086 | 1827 | 93 | 118 |
| WL82 | 300 | 104 | 838 | 221 | 617 | 2588 | 0.13 | 4293 | 0.55 | n/a | n/a | 86 | 115 |
| WL86 | 350 | 101 | 814 | 294 | 520 | 2949 | 0.15 | 4269 | 0.67 | n/a | n/a | 98 | 120 |
| WL89 | 375 | 97 | 782 | 209 | 573 | 3239 | 0.17 | 4310 | 0.53 | n/a | n/a | 108 | 126 |

**Table 5-6 Instrumented Charpy Impact Test Results for the Watts Bar Unit 1 Intermediate Shell Forging 05 Irradiated to a Fluence of 2.40 x $10^{19}$n/cm$^2$ (E>1.0 MeV) (Axial Orientation)**

| Sample No. | Test Temp. (°F) | Charpy Energy $E_D$ (ft-lb) | Normalized Energies (ft-lb/in$^2$) | | | Yield Load $P_{GY}$ (lb) | Time to Yield $t_{GY}$ (msec) | Max. Load $P_M$ (lb) | Time to Max. $t_M$ (msec) | Fast Fract. Load $P_F$ (lb) | Arrest Load $P_A$ (lb) | Yield Stress $\sigma_Y$ (ksi) | Flow Stress (ksi) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Charpy $E_D/A$ | Max. $E_M/A$ | Prop. Ep/A | | | | | | | | |
| WT82 | -50 | 7 | 56 | 36 | 21 | 3245 | 0.19 | 3245 | 0.19 | 3245 | 0 | 108 | 108 |
| WT89 | 75 | 18 | 145 | 71 | 74 | 3254 | 0.14 | 4109 | 0.23 | 4052 | 0 | 108 | 123 |
| WT86 | 100 | 24 | 193 | 126 | 68 | 2999 | 0.14 | 4216 | 0.34 | 4216 | 0 | 100 | 120 |
| WT85 | 125 | 18 | 145 | 49 | 96 | 3326 | 0.15 | 3788 | 0.19 | 3780 | 584 | 111 | 118 |
| WT88 | 140 | 27 | 218 | 120 | 97 | 3096 | 0.14 | 3967 | 0.34 | 3967 | 593 | 103 | 118 |
| WT77 | 150 | 28 | 226 | 99 | 127 | 2708 | 0.13 | 3996 | 0.30 | 3991 | 1003 | 90 | 112 |
| WT83 | 165 | 33 | 266 | 139 | 127 | 3110 | 0.13 | 4152 | 0.36 | 4144 | 1006 | 104 | 121 |
| WT79 | 175 | 35 | 282 | 146 | 136 | 2883 | 0.14 | 4200 | 0.39 | 4189 | 788 | 96 | 118 |
| WT81 | 190 | 36 | 290 | 148 | 142 | 2935 | 0.14 | 4134 | 0.39 | 4134 | 1222 | 98 | 118 |
| WT76 | 200 | 35 | 282 | 129 | 153 | 2961 | 0.15 | 4058 | 0.36 | 4016 | 1596 | 99 | 117 |
| WT90 | 210 | 58 | 467 | 184 | 283 | 2985 | 0.14 | 4247 | 0.45 | 2670 | 1822 | 99 | 120 |
| WT78 | 225 | 55 | 443 | 145 | 298 | 3001 | 0.14 | 4191 | 0.38 | n/a | n/a | 100 | 120 |
| WT84 | 300 | 66 | 532 | 197 | 335 | 2863 | 0.15 | 4308 | 0.48 | n/a | n/a | 95 | 119 |
| WT87 | 350 | 69 | 556 | 222 | 334 | 2490 | 0.17 | 4175 | 0.58 | n/a | n/a | 83 | 111 |
| WT80 | 375 | 64 | 516 | 176 | 340 | 2996 | 0.16 | 4054 | 0.45 | n/a | n/a | 100 | 117 |

**Table 5-7 Instrumented Charpy Impact Test Results for the Watts Bar Unit 1 Surveillance Weld Metal Irradiated to a Fluence of 2.40 x $10^{19}$n/cm$^2$ (E>1.0 MeV)**

| Sample No. | Test Temp. (°F) | Charpy Energy $E_D$ (ft-lb) | Normalized Energies (ft-lb/in$^2$) | | | Yield Load $P_{GY}$ (lb) | Time to Yield $t_{GY}$ (msec) | Max. Load $P_M$ (lb) | Time to Max. $t_M$ (msec) | Fast Fract. Load $P_F$ (lb) | Arrest Load $P_A$ (lb) | Yield Stress $\sigma_Y$ (ksi) | Flow Stress (ksi) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Charpy $E_D/A$ | Max. $E_M/A$ | Prop. Ep/A | | | | | | | | |
| WW89 | -100 | 4 | 32 | 11 | 21 | 1211 | 0.09 | 1346 | 0.11 | 1336 | 0 | 40 | 43 |
| WW83 | -25 | 27 | 218 | 148 | 69 | 3144 | 0.14 | 4207 | 0.38 | 4186 | 355 | 105 | 122 |
| WW86 | -15 | 37 | 298 | 181 | 117 | 3102 | 0.14 | 4301 | 0.45 | 4257 | 1430 | 103 | 123 |
| WW78 | 0 | 31 | 250 | 157 | 93 | 2862 | 0.13 | 4122 | 0.41 | 4117 | 1210 | 95 | 116 |
| WW90 | 15 | 27 | 218 | 117 | 100 | 3021 | 0.14 | 3816 | 0.33 | 3813 | 1218 | 101 | 114 |
| WW87 | 25 | 51 | 411 | 224 | 187 | 3050 | 0.15 | 4210 | 0.54 | 4106 | 1794 | 102 | 121 |
| WW82 | 40 | 64 | 516 | 301 | 214 | 2959 | 0.14 | 4272 | 0.68 | 4085 | 1223 | 99 | 120 |
| WW85 | 50 | 72 | 580 | 299 | 281 | 2822 | 0.14 | 4219 | 0.69 | 3853 | 1664 | 94 | 117 |
| WW80 | 75 | 77 | 620 | 311 | 309 | 3197 | 0.15 | 4376 | 0.69 | 3986 | 1427 | 106 | 126 |
| WW84 | 100 | 97 | 782 | 295 | 487 | 2969 | 0.14 | 4150 | 0.69 | 3376 | 889 | 99 | 119 |
| WW88 | 125 | 100 | 806 | 291 | 515 | 2738 | 0.14 | 4106 | 0.70 | 3000 | 1971 | 91 | 114 |
| WW81 | 150 | 101 | 814 | 283 | 531 | 2781 | 0.15 | 4011 | 0.69 | 1308 | 585 | 93 | 113 |
| WW79 | 300 | 151 | 1217 | 266 | 951 | 2509 | 0.15 | 3851 | 0.68 | n/a | n/a | 84 | 106 |
| WW77 | 350 | 148 | 1192 | 266 | 926 | 2565 | 0.14 | 3825 | 0.68 | n/a | n/a | 85 | 106 |
| WW76 | 375 | 136 | 1096 | 255 | 840 | 2340 | 0.14 | 3667 | 0.69 | n/a | n/a | 78 | 100 |

**Table 5-8 Instrumented Charpy Impact Test Results for the Watts Bar Unit 1 Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 2.40 x $10^{19}$n/cm$^2$ (E>1.0 MeV)**

| Sample No. | Test Temp. (°F) | Charpy Energy $E_D$ (ft-lb) | Normalized Energies (ft-lb/in$^2$) | | | Yield Load $P_{GY}$ (lb) | Time to Yield $t_{GY}$ (msec) | Max. Load $P_M$ (lb) | Time to Max. $t_M$ (msec) | Fast Fract. Load $P_F$ (lb) | Arrest Load $P_A$ (lb) | Yield Stress $\sigma_Y$ (ksi) | Flow Stress (ksi) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Charpy $E_D$/A | Max. $E_M$/A | Prop. Ep/A | | | | | | | | |
| WH79 | -100 | 9 | 73 | 44 | 28 | 4116 | 0.16 | 4200 | 0.17 | 4200 | 0 | 137 | 138 |
| WH83 | -25 | 22 | 177 | 74 | 104 | 3286 | 0.13 | 4487 | 0.22 | 4484 | 489 | 109 | 129 |
| WH85 | 0 | 34 | 274 | 187 | 87 | 3239 | 0.15 | 4610 | 0.44 | 4545 | 395 | 108 | 131 |
| WH76 | 15 | 27 | 218 | 126 | 92 | 3179 | 0.14 | 4358 | 0.33 | 4358 | 543 | 106 | 126 |
| WH78 | 25 | 31 | 250 | 162 | 88 | 3425 | 0.15 | 4410 | 0.39 | 4397 | 278 | 114 | 130 |
| WH88 | 40 | 30 | 242 | 74 | 168 | 3347 | 0.14 | 4137 | 0.23 | 4108 | 1113 | 111 | 125 |
| WH80 | 50 | 40 | 322 | 165 | 157 | 3335 | 0.15 | 4369 | 0.40 | 4317 | 1567 | 111 | 128 |
| WH86 | 60 | 46 | 371 | 194 | 177 | 3199 | 0.14 | 4314 | 0.46 | 4275 | 2350 | 107 | 125 |
| WH82 | 75 | 62 | 500 | 237 | 263 | 3116 | 0.14 | 4624 | 0.52 | 4593 | 2750 | 104 | 129 |
| WH89 | 125 | 62 | 500 | 199 | 300 | 3000 | 0.14 | 4275 | 0.48 | 3256 | 1574 | 100 | 121 |
| WH87 | 175 | 69 | 556 | 214 | 342 | 3049 | 0.15 | 4196 | 0.52 | n/a | n/a | 102 | 121 |
| WH77 | 300 | 68 | 548 | 207 | 341 | 2808 | 0.14 | 4102 | 0.52 | n/a | n/a | 94 | 115 |
| WH90 | 325 | 83 | 669 | 198 | 470 | 2813 | 0.14 | 3886 | 0.51 | n/a | n/a | 94 | 112 |
| WH84 | 350 | 80 | 645 | 208 | 436 | 2727 | 0.14 | 4073 | 0.52 | n/a | n/a | 91 | 113 |
| WH81 | 375 | 96 | 774 | 283 | 490 | 2950 | 0.16 | 4047 | 0.68 | n/a | n/a | 98 | 117 |

**Table 5-9 Effect of Irradiation to 2.40 x $10^{19}$n/cm$^2$ (E>1.0 MeV) on the Capsule V Notch Toughness Properties of the Watts Bar Unit 1 Reactor Vessel Surveillance Capsule Z Materials**

| Material | Average 30 (ft-lb)[a] Transition Temperature (°F) | | | Average 35 mil Lateral[b] Expansion Temperature (°F) | | | Average 50 ft-lb[a] Transition Temperature (°F) | | | Average Energy Absorption[a] at Full Shear (ft-lb) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Unirradiated | Irradiated | ΔT | Unirradiated | Irradiated | ΔT | Unirradiated | Irradiated | ΔT | Unirradiated | Irradiated | ΔE |
| Intermediate Shell Forging 05 (Tang.) | -57.1 | 87.4 | 145 | -9.4 | 121.2 | 131 | -15.4 | 137.9 | 153 | 132 | 101 | -31 |
| Intermediate Shell Forging 05 (Axial) | 45.2 | 150.1 | 105 | 84.6 | 150.0 | 65 | 114.2 | 225.6 | 111 | 62 | 62 | 0 |
| Weld Metal (Heat # 895075) | -31.2 | -17.3 | 14 | -9.9 | 8.9 | 19 | -5.9 | 28.0 | 34 | 131 | 145 | 14 |
| HAZ Metal | -56.2 | 11.5 | 68 | -0.6 | 56.9 | 58 | -8.6 | 74.9 | 84 | 89 | 79 | -10 |

Notes:
a. "Average" is defined as the value derived from the curve fit through the data points of the Charpy tests (see Figures 5-1, 5-4, 5-7 and 5-10).
b. "Average" is defined as the value derived from the curve fit through the data points of the Charpy tests (see Figures 5-2, 5-5, 5-8 and 5-11).

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

| | | | 30 ft-lb Transition Temperature Shift | | Upper Shelf Energy Decrease | |
|---|---|---|---|---|---|---|
| Material | Capsule | Fluence[d] (x $10^{19}$n/cm$^2$, E > 1.0 MeV) | Predicted (°F) [a] | Measured (°F) [b] | Predicted (%) [a] | Measured (%)[c] |
| Intermediate Shell Forging 05 (Tangential) | U | 0.447 | 95.4 | 98.3 | 21 | 19 |
| | W | 1.08 | 125.6 | 111.4 | 26 | 26 |
| | X | 1.71 | 141.2 | 94.7 | 29 | 20 |
| | Z | 2.40 | 152.0 | 144.5 | 31 | 23 |
| Intermediate Shell Forging 05 (Axial) | U | 0.447 | 95.4 | 28.7 | 21 | -- |
| | W | 1.08 | 125.6 | 79.0 | 26 | 3.2 |
| | X | 1.71 | 141.2 | 115.9 | 29 | -- |
| | Z | 2.40 | 152.0 | 104.9 | 31 | 0 |
| Surveillance Program Weld Metal | U | 0.447 | 31.8 | 0.0[e] | 16 | -- |
| | W | 1.08 | 41.9 | 30.5 | 19 | 15 |
| | X | 1.71 | 47.1 | 25.8 | 22 | -- |
| | Z | 2.40 | 50.7 | 13.9 | 23 | -- |
| Heat Affected Zone Material | U | 0.447 | --- | 50.9 | --- | 11 |
| | W | 1.08 | --- | 48.8 | --- | 13 |
| | X | 1.71 | --- | 74.5 | --- | 7.9 |
| | Z | 2.40 | --- | 67.7 | --- | 11 |

**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 using measured Charpy data plotted using CVGRAPH, Version 5.0.2 (See Appendix C)

c. Values are based on the definition of upper shelf energy given in ASTM E185-82.

d. The fluence values presented here are the "calculated" values.

e. Due to the scatter in the Capsule U Weld Charpy test results, a true Hyperbolic Tangent Curve fit resulted in $\Delta T_{30}$ values of –6.4°F when compared to unirradiated Charpy test data. A conservative value of 0°F was used in $RT_{NDT}$ calculations.

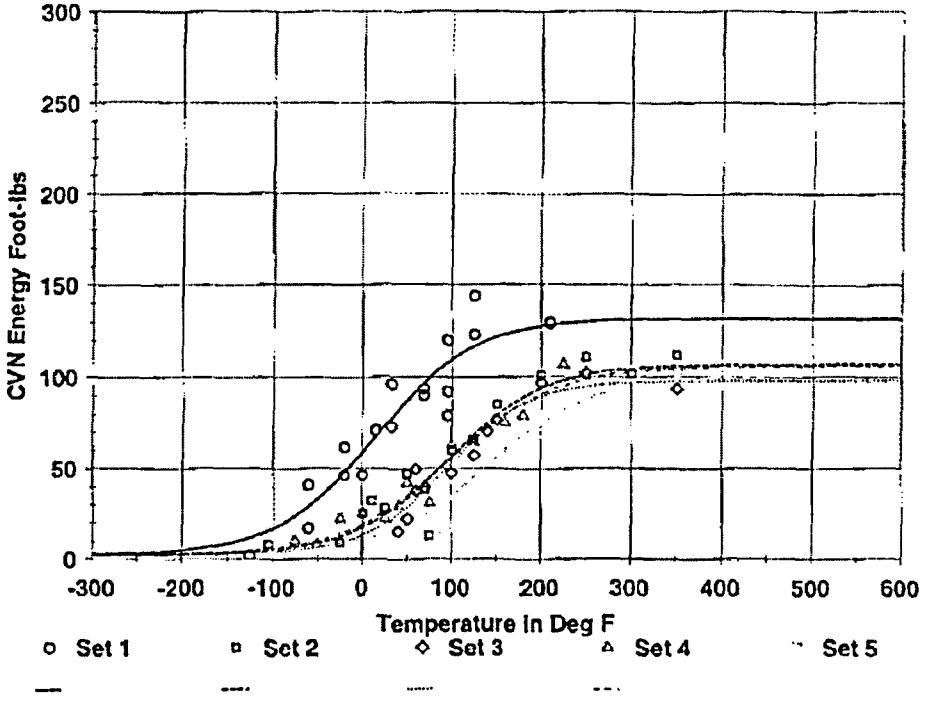
**Table 5-11 Tensile Properties of the Watts Bar Unit 1 Capsule Z Reactor Vessel Surveillance Materials Irradiated to 2.40 x $10^{19}$n/cm$^2$ (E > 1.0 MeV)**

| Material | Sample Number | Test Temp. (°F) | 0.2% Yield Strength (ksi) | Ultimate Strength (ksi) | Fracture Load (kip) | Fracture Stress (ksi) | Fracture Strength (ksi) | Uniform Elongation (%) | Total Elongation (%) | Reduction in Area (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Intermediate Shell Forging 05 (Tang.) | WL16 | 125 | 86.1 | 104.4 | 3.45 | 187.6 | 70.3 | 10.5 | 23.4 | 63 |
| | WL17 | 325 | 80.0 | 99.3 | 3.30 | 184.3 | 67.2 | 10.5 | 22.7 | 64 |
| | WL18 | 550 | 79.5 | 100.8 | 3.53 | 175.3 | 71.8 | 9.8 | 20.7 | 59 |
| Intermediate Shell Forging 05 (Axial) | WT16 | 170 | 85.1 | 102.9 | 3.90 | 167.8 | 79.5 | 10.5 | 20.7 | 53 |
| | WT17 | 325 | 80.5 | 98.8 | 3.60 | 129.7 | 73.3 | 10.2 | 17.9 | 43 |
| | WT18 | 550 | 76.4 | 100.3 | 4.15 | 129.5 | 84.5 | 9.8 | 17.4 | 35 |
| Weld Metal | WW16 | 70 | 77.1 | 91.7 | 2.80 | 198.5 | 57.0 | 12.0 | 28.2 | 71 |
| | WW17 | 325 | 70.3 | 82.5 | 2.50 | 182.7 | 50.9 | 11.6 | 24.8 | 72 |
| | WW18 | 550 | 65.2 | 85.1 | 2.70 | 165.8 | 55.0 | 10.5 | 22.7 | 67 |

## INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:34 PM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SA508CL2 | LT | 527536 |
| 2 | WATTS BAR 1 | U | SA508CL2 | LT | 527536 |
| 3 | WATTS BAR 1 | W | SA508CL2 | LT | 527536 |
| 4 | WATTS BAR 1 | X | SA508CL2 | LT | 527536 |
| 5 | WATTS BAR 1 | Z | SA508CL2 | LT | 527536 |




Results

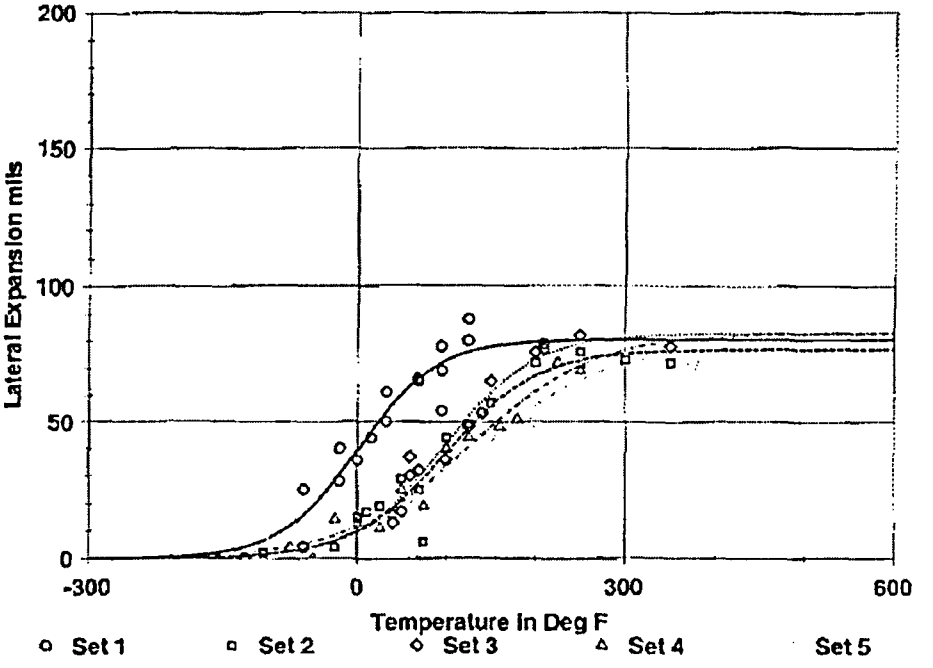
| Curve | Fluence | LSE | USE | d-USE | T @30 | d-T @30 | T @50 | d-T @50 |
|---|---|---|---|---|---|---|---|---|
| 1 | | 2.2 | 132.0 | .0 | -57.1 | .0 | -15.4 | .0 |
| 2 | | 2.2 | 107.0 | -25.0 | 41.2 | 98.3 | 86.4 | 101.8 |
| 3 | | 2.2 | 98.0 | -34.0 | 54.3 | 111.4 | 95.0 | 110.4 |
| 4 | | 2.2 | 106.0 | -26.0 | 37.6 | 94.7 | 87.2 | 102.6 |
| 5 | | 2.2 | 101.0 | -31.0 | 87.4 | 144.5 | 137.9 | 153.3 |

**Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)**

## INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:54 PM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SA508CL2 | LT | 527536 |
| 2 | WATTS BAR 1 | U | SA508CL2 | LT | 527536 |
| 3 | WATTS BAR 1 | W | SA508CL2 | LT | 527536 |
| 4 | WATTS BAR 1 | X | SA508CL2 | LT | 527536 |
| 5 | WATTS BAR 1 | Z | SA508CL2 | LT | 527536 |




Results

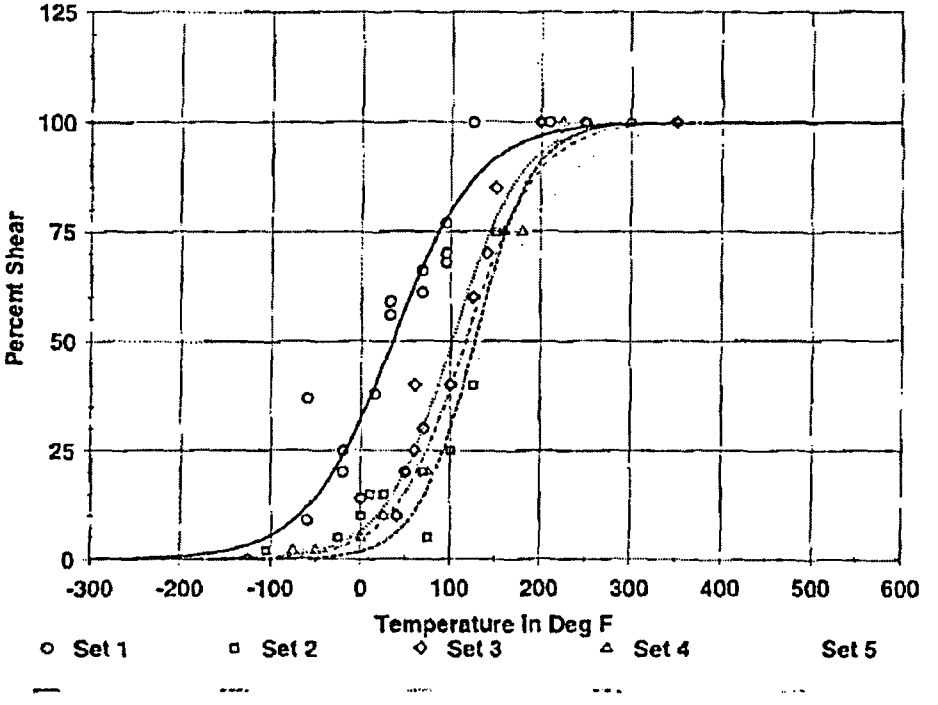
| Curve | Fluence | LSE | USE | d-USE | T @35 | d-T @35 |
|---|---|---|---|---|---|---|
| 1 | | .0 | 80.5 | .0 | -9.4 | .0 |
| 2 | | .0 | 76.9 | -3.6 | 91.0 | 100.4 |
| 3 | | .0 | 82.6 | 2.1 | 84.3 | 93.7 |
| 4 | | .0 | 83.1 | 2.6 | 106.6 | 116.0 |
| 5 | | .0 | 77.9 | -2.6 | 121.2 | 130.6 |

**Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)**

## INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:44 PM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SA508CL2 | LT | 527536 |
| 2 | WATTS BAR 1 | U | SA508CL2 | LT | 527536 |
| 3 | WATTS BAR 1 | W | SA508CL2 | LT | 527536 |
| 4 | WATTS BAR 1 | X | SA508CL2 | LT | 527536 |
| 5 | WATTS BAR 1 | Z | SA508CL2 | LT | 527536 |




Results

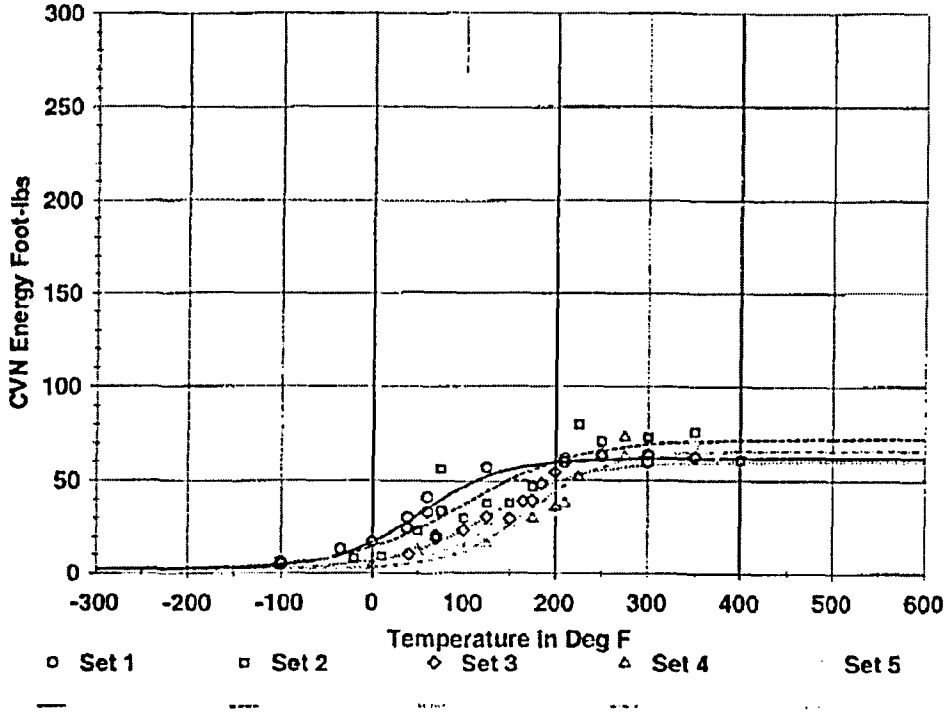
| Curve | Fluence | LSE | USE | d-USE | T @50 | d-T @50 |
|---|---|---|---|---|---|---|
| 1 | | .0 | 100.0 | .0 | 34.8 | .0 |
| 2 | | .0 | 100.0 | .0 | 126.6 | 91.8 |
| 3 | | .0 | 100.0 | .0 | 102.3 | 67.5 |
| 4 | | .0 | 100.0 | .0 | 116.6 | 81.8 |
| 5 | | .0 | 100.0 | .0 | 131.2 | 96.4 |

**Figure 5-3** **Charpy V-Notch Percent Shear vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)**

## INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:38 AM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SA508CL2 | TL | 527536 |
| 2 | WATTS BAR 1 | U | SA508CL2 | TL | 527536 |
| 3 | WATTS BAR 1 | W | SA508CL2 | TL | 527536 |
| 4 | WATTS BAR 1 | X | SA508CL2 | TL | 527536 |
| 5 | WATTS BAR 1 | Z | SA508CL2 | TL | 527536 |




Results

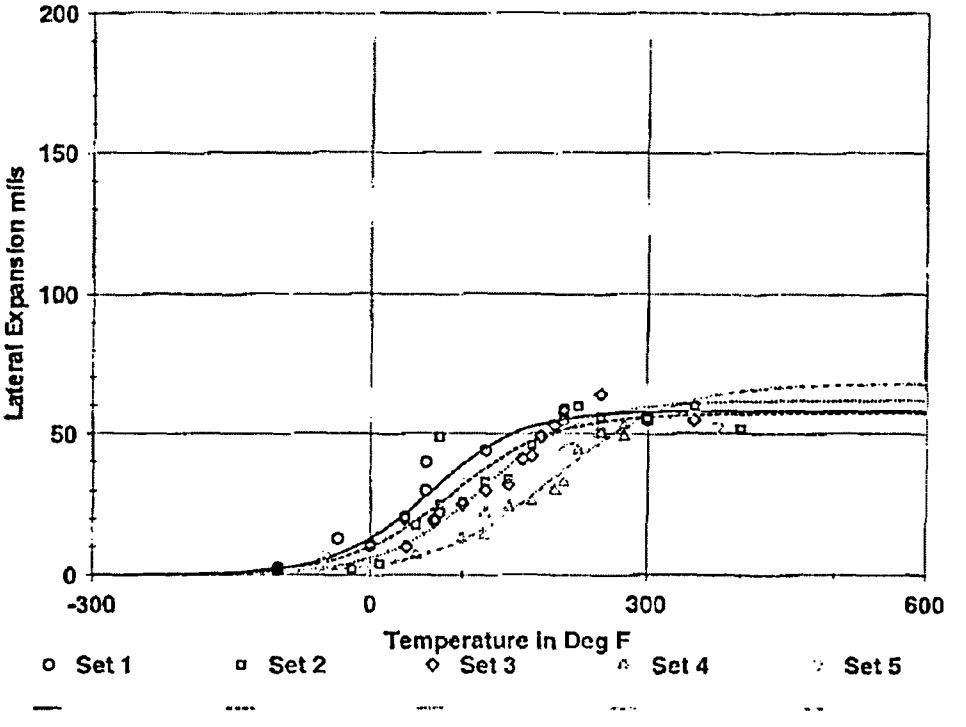
| Curve | Fluence | LSE | USE | d-USE | T @30 | d-T @30 | T @50 | d-T @50 |
|---|---|---|---|---|---|---|---|---|
| 1 | | 2.2 | 62.0 | .0 | 45.2 | .0 | 114.2 | .0 |
| 2 | | 2.2 | 72.0 | 10.0 | 73.9 | 28.7 | 148.7 | 34.5 |
| 3 | | 2.2 | 60.0 | -2.0 | 124.2 | 79.0 | 206.2 | 92.0 |
| 4 | | 2.2 | 66.0 | 4.0 | 161.1 | 115.9 | 218.3 | 104.1 |
| 5 | | 2.2 | 62.0 | .0 | 150.1 | 104.9 | 225.6 | 111.4 |

**Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)**

## INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:54 AM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SA508CL2 | TL | 527536 |
| 2 | WATTS BAR 1 | U | SA508CL2 | TL | 527536 |
| 3 | WATTS BAR 1 | W | SA508CL2 | TL | 527536 |
| 4 | WATTS BAR 1 | X | SA508CL2 | TL | 527536 |
| 5 | WATTS BAR 1 | Z | SA508CL2 | TL | 527536 |




Results

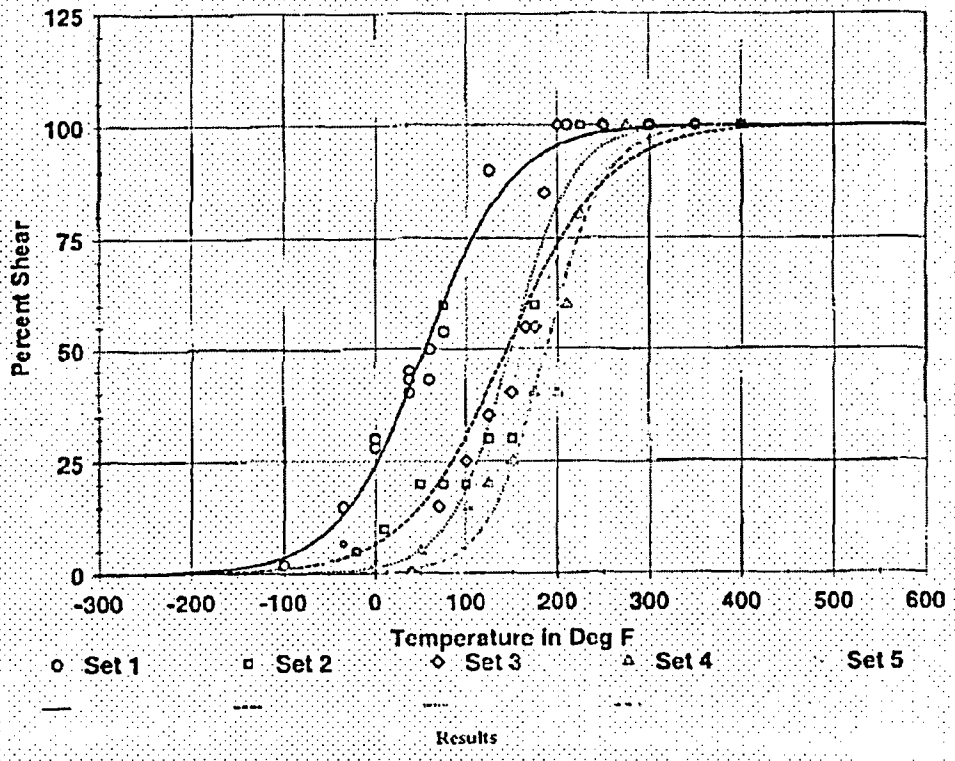
| Curve | Fluence | LSE | USE | d-USE | T @35 | d-T @35 |
|---|---|---|---|---|---|---|
| 1 | | .0 | 58.3 | .0 | 84.6 | .0 |
| 2 | | .0 | 57.3 | -1.0 | 113.4 | 28.8 |
| 3 | | .0 | 61.8 | 3.5 | 138.1 | 53.5 |
| 4 | | .0 | 68.1 | 9.8 | 201.6 | 117.0 |
| 5 | | .0 | 58.8 | .4 | 150.0 | 65.4 |

**Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)**

## INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:45 AM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SA508CL2 | TL | 527536 |
| 2 | WATTS BAR 1 | U | SA508CL2 | TL | 527536 |
| 3 | WATTS BAR 1 | W | SA508CL2 | TL | 527536 |
| 4 | WATTS BAR 1 | X | SA508CL2 | TL | 527536 |
| 5 | WATTS BAR 1 | Z | SA508CL2 | TL | 527536 |




Results

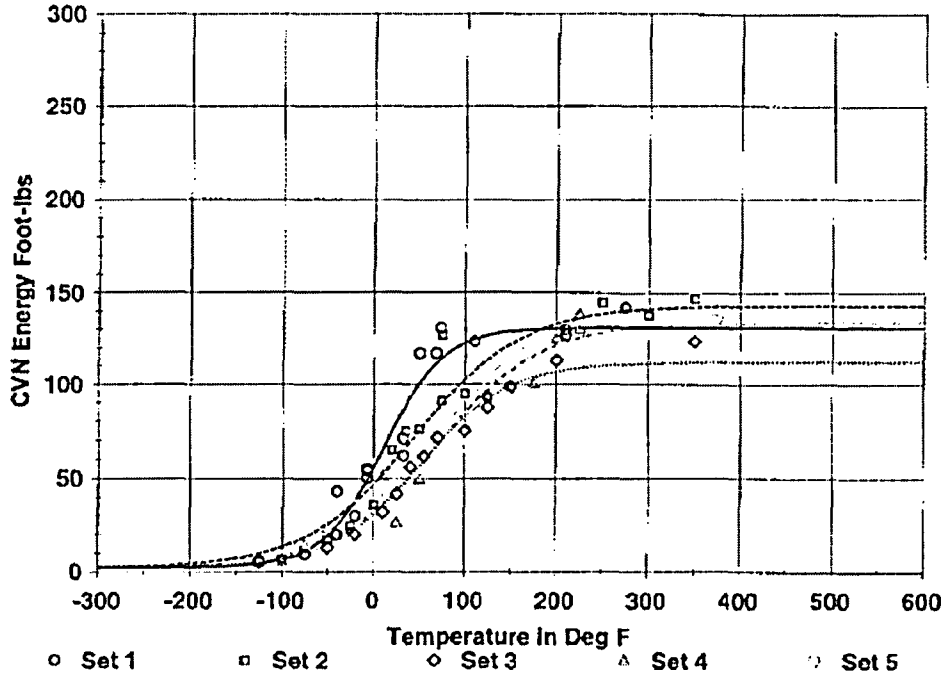
| Curve | Fluence | LSE | USE | d-USE | T @50 | d-T @50 |
|---|---|---|---|---|---|---|
| 1 | | .0 | 100.0 | .0 | 54.9 | .0 |
| 2 | | .0 | 100.0 | .0 | 144.3 | 89.4 |
| 3 | | .0 | 100.0 | .0 | 149.1 | 94.2 |
| 4 | | .0 | 100.0 | .0 | 187.3 | 132.4 |
| 5 | | .0 | 100.0 | .0 | 165.5 | 110.6 |

**Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)**

## SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:43 AM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SAW | NA | 895075 |
| 2 | WATTS BAR 1 | U | SAW | NA | 895075 |
| 3 | WATTS BAR 1 | W | SAW | NA | 895075 |
| 4 | WATTS BAR 1 | X | SAW | NA | 895075 |
| 5 | WATTS BAR 1 | Z | SAW | NA | 895075 |




Results

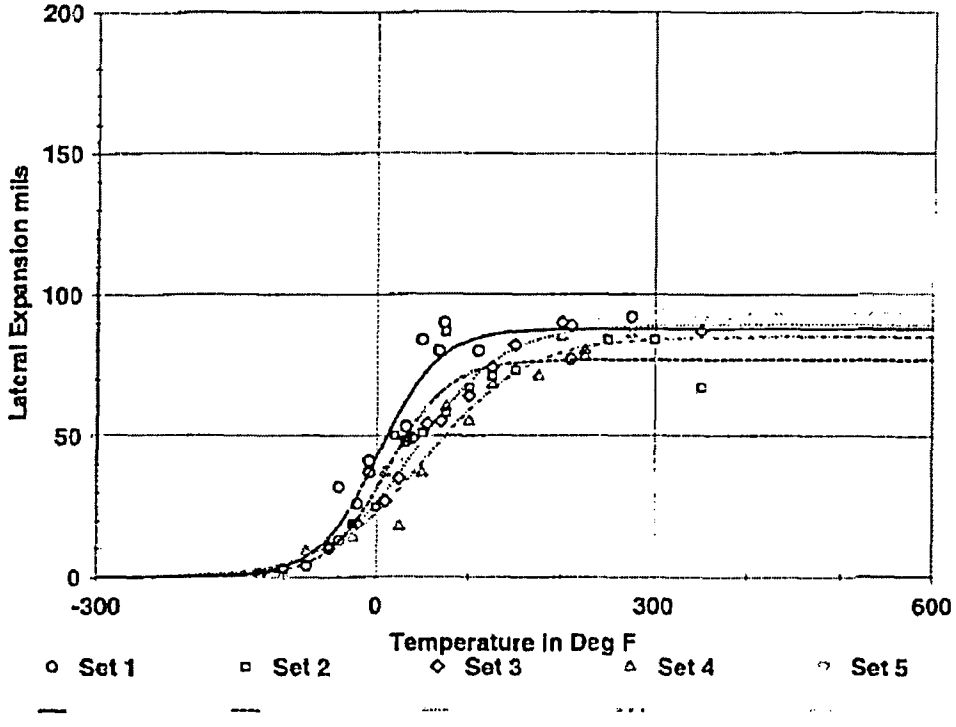
| Curve | Fluence | LSE | USE | d-USE | T @30 | d-T @30 | T @50 | d-T @50 |
|---|---|---|---|---|---|---|---|---|
| 1 | | 2.2 | 131.0 | .0 | -31.2 | .0 | -5.9 | .0 |
| 2 | | 2.2 | 143.0 | 12.0 | -37.6 | -6.4 | 6.3 | 12.2 |
| 3 | | 2.2 | 112.0 | -19.0 | -.7 | 30.5 | 39.4 | 45.3 |
| 4 | | 2.2 | 134.0 | 3.0 | -5.4 | 25.8 | 37.9 | 43.8 |
| 5 | | 2.2 | 145.0 | 14.0 | -17.3 | 13.9 | 28.0 | 33.9 |

**Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for Watts Bar Unit 1 Reactor Vessel Weld Metal**

## SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:57 AM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SAW | NA | 895075 |
| 2 | WATTS BAR 1 | U | SAW | NA | 895075 |
| 3 | WATTS BAR 1 | W | SAW | NA | 895075 |
| 4 | WATTS BAR 1 | X | SAW | NA | 895075 |
| 5 | WATTS BAR 1 | Z | SAW | NA | 895075 |




Results

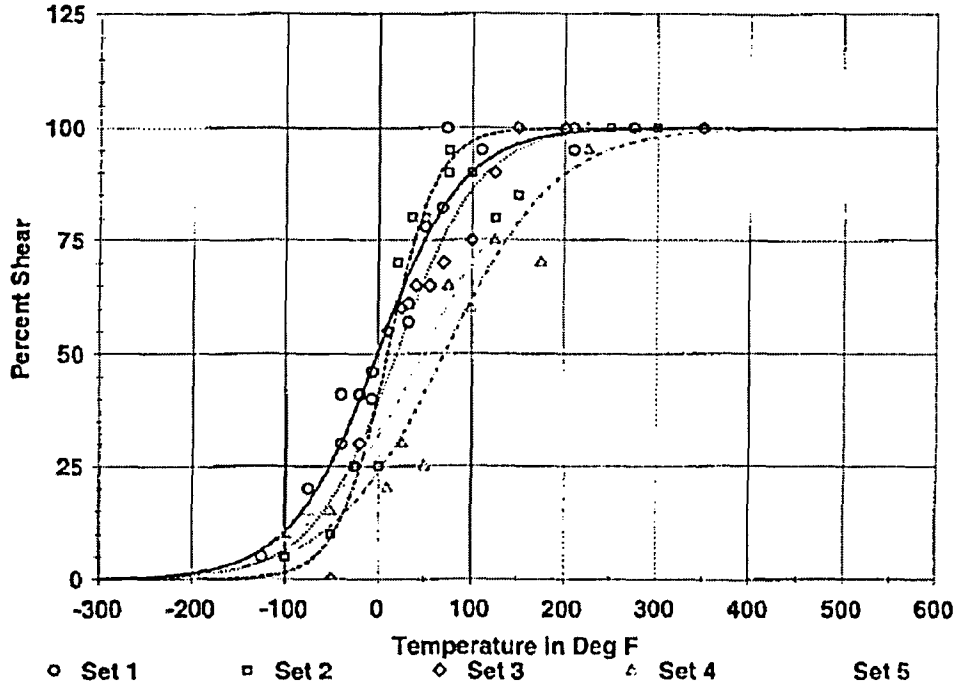
| Curve | Fluence | LSE | USE | d-USE | T @35 | d-T @35 |
|---|---|---|---|---|---|---|
| 1 | | .0 | 87.8 | .0 | -9.9 | .0 |
| 2 | | .0 | 76.9 | -10.9 | 7.4 | 17.3 |
| 3 | | .0 | 89.2 | 1.4 | 21.9 | 31.8 |
| 4 | | .0 | 85.0 | -2.8 | 35.9 | 45.8 |
| 5 | | .0 | 93.0 | 5.2 | 8.9 | 18.8 |

**Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for Watts Bar Unit 1 Reactor Vessel Weld Metal**

## SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:51 AM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SAW | NA | 895075 |
| 2 | WATTS BAR 1 | U | SAW | NA | 895075 |
| 3 | WATTS BAR 1 | W | SAW | NA | 895075 |
| 4 | WATTS BAR 1 | X | SAW | NA | 895075 |
| 5 | WATTS BAR 1 | Z | SAW | NA | 895075 |




Results

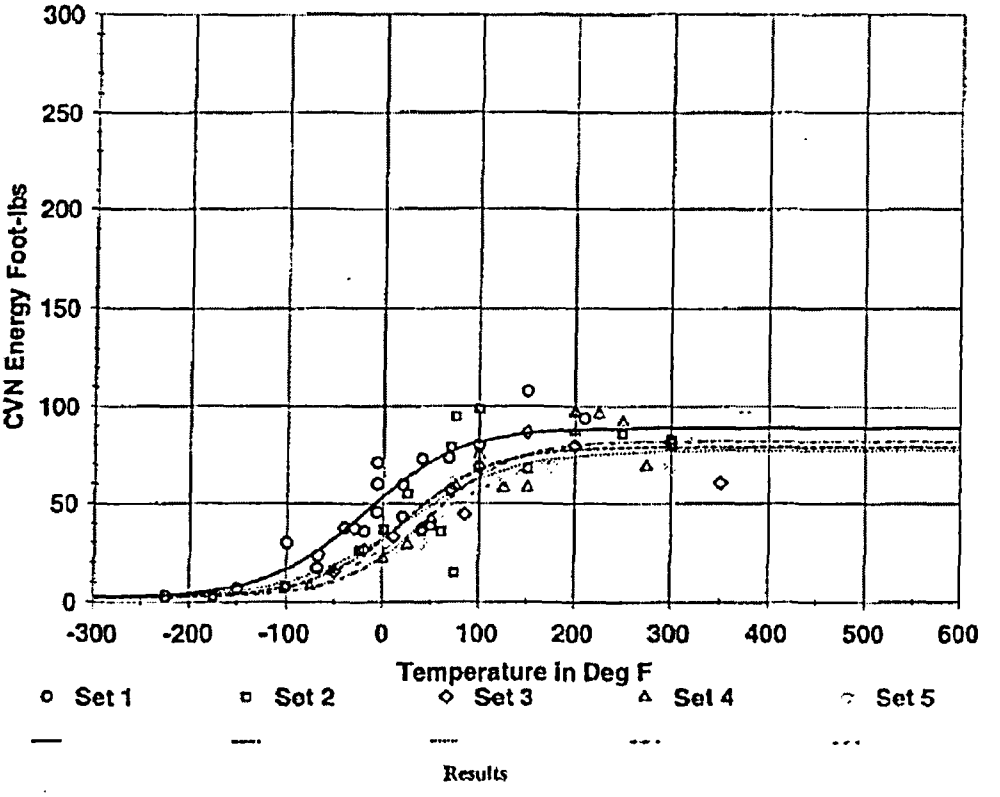
| Curve | Fluence | LSE | USE | d-USE | T @50 | d-T @50 |
|---|---|---|---|---|---|---|
| 1 | | .0 | 100.0 | .0 | -1.2 | .0 |
| 2 | | .0 | 100.0 | .0 | 9.6 | 10.8 |
| 3 | | .0 | 100.0 | .0 | 19.9 | 21.1 |
| 4 | | .0 | 100.0 | .0 | 70.9 | 72.1 |
| 5 | | .0 | 100.0 | .0 | 47.5 | 48.7 |

**Figure 5-9 Charpy V-Notch Percent Shear vs. Temperature for Watts Bar Unit 1 Reactor Vessel Weld Metal**

## HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 01:44 PM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SA508CL2 | NA | 527536 |
| 2 | WATTS BAR 1 | U | SA508CL2 | NA | 527536 |
| 3 | WATTS BAR 1 | W | SA508CL2 | NA | 527536 |
| 4 | WATTS BAR 1 | X | SA508CL2 | NA | 527536 |
| 5 | WATTS BAR 1 | Z | SA508CL2 | NA | 527536 |




Results

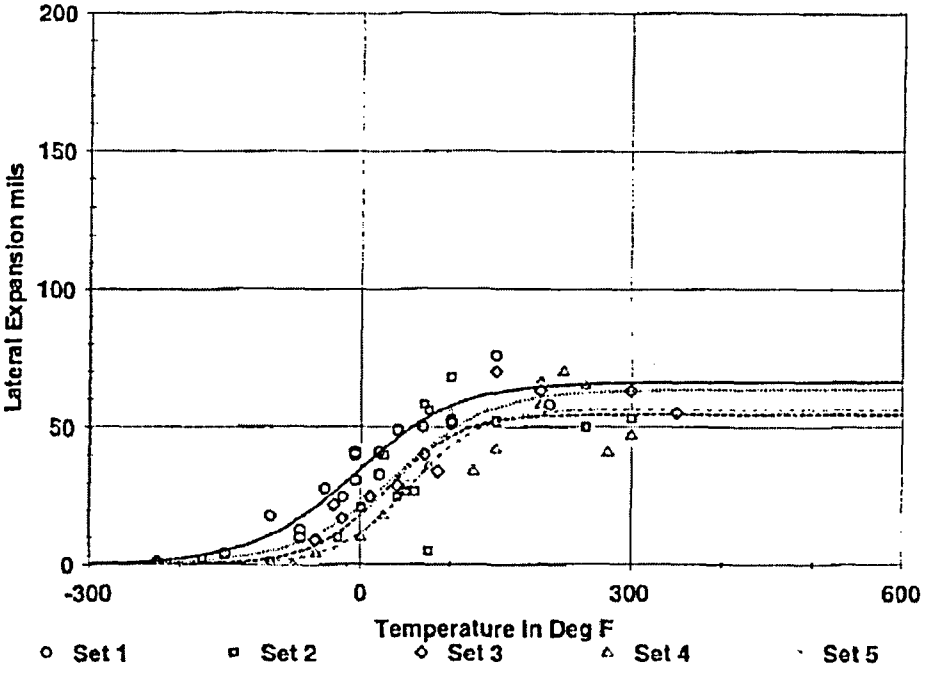
| Curve | Fluence | LSE | USE | d-USE | T @30 | d-T @30 | T @50 | d-T @50 |
|---|---|---|---|---|---|---|---|---|
| 1 | | 2.2 | 89.0 | .0 | -56.2 | .0 | -8.6 | .0 |
| 2 | | 2.2 | 79.0 | -10.0 | -5.3 | 50.9 | 43.7 | 52.3 |
| 3 | | 2.2 | 77.0 | -12.0 | -7.4 | 48.8 | 53.6 | 62.2 |
| 4 | | 2.2 | 82.0 | -7.0 | 18.3 | 74.5 | 63.7 | 72.3 |
| 5 | | 2.2 | 79.0 | -10.0 | 11.5 | 67.7 | 74.9 | 83.5 |

**Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Watts Bar Unit 1 Reactor Vessel Heat-Affected-Zone Material**

## HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 11:00 AM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SA508CL2 | NA | 527536 |
| 2 | WATTS BAR 1 | U | SA508CL2 | NA | 527536 |
| 3 | WATTS BAR 1 | W | SA508CL2 | NA | 527536 |
| 4 | WATTS BAR 1 | X | SA508CL2 | NA | 527536 |
| 5 | WATTS BAR 1 | Z | SA508CL2 | NA | 527536 |




Results

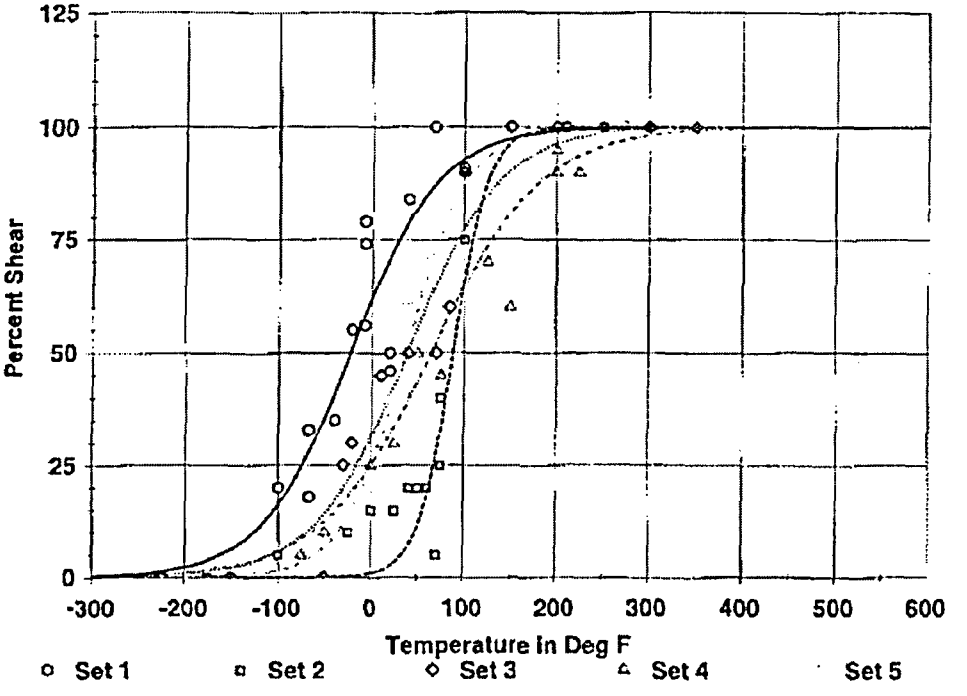
| Curve | Fluence | LSE | USE | d-USE | T @35 | d-T @35 |
|---|---|---|---|---|---|---|
| 1 | | .0 | 66.3 | .0 | -.6 | .0 |
| 2 | | .0 | 54.4 | -11.9 | 51.2 | 51.8 |
| 3 | | .0 | 63.6 | -2.7 | 48.0 | 48.6 |
| 4 | | .0 | 56.3 | -10.0 | 72.6 | 73.2 |
| 5 | | .0 | 63.6 | -2.7 | 56.9 | 57.5 |

**Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Watts Bar Unit 1 Reactor Vessel Heat-Affected-Zone Material**

## HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:54 AM
Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat # |
|---|---|---|---|---|---|
| 1 | WATTS BAR 1 | UNIRR | SA508CL2 | NA | 527536 |
| 2 | WATTS BAR 1 | U | SA508CL2 | NA | 527536 |
| 3 | WATTS BAR 1 | W | SA508CL2 | NA | 527536 |
| 4 | WATTS BAR 1 | X | SA508CL2 | NA | 527536 |
| 5 | WATTS BAR 1 | Z | SA508CL2 | NA | 527536 |




Results

| Curve | Fluence | LSE | USE | d-USE | T @50 | d-T @50 |
|---|---|---|---|---|---|---|
| 1 | | .0 | 100.0 | .0 | -22.2 | .0 |
| 2 | | .0 | 100.0 | .0 | 88.1 | 110.3 |
| 3 | | .0 | 100.0 | .0 | 39.6 | 61.8 |
| 4 | | .0 | 100.0 | .0 | 64.7 | 86.9 |
| 5 | | .0 | 100.0 | .0 | 37.0 | 59.2 |

**Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for Watts Bar Unit 1 Reactor Vessel Heat-Affected-Zone Material**

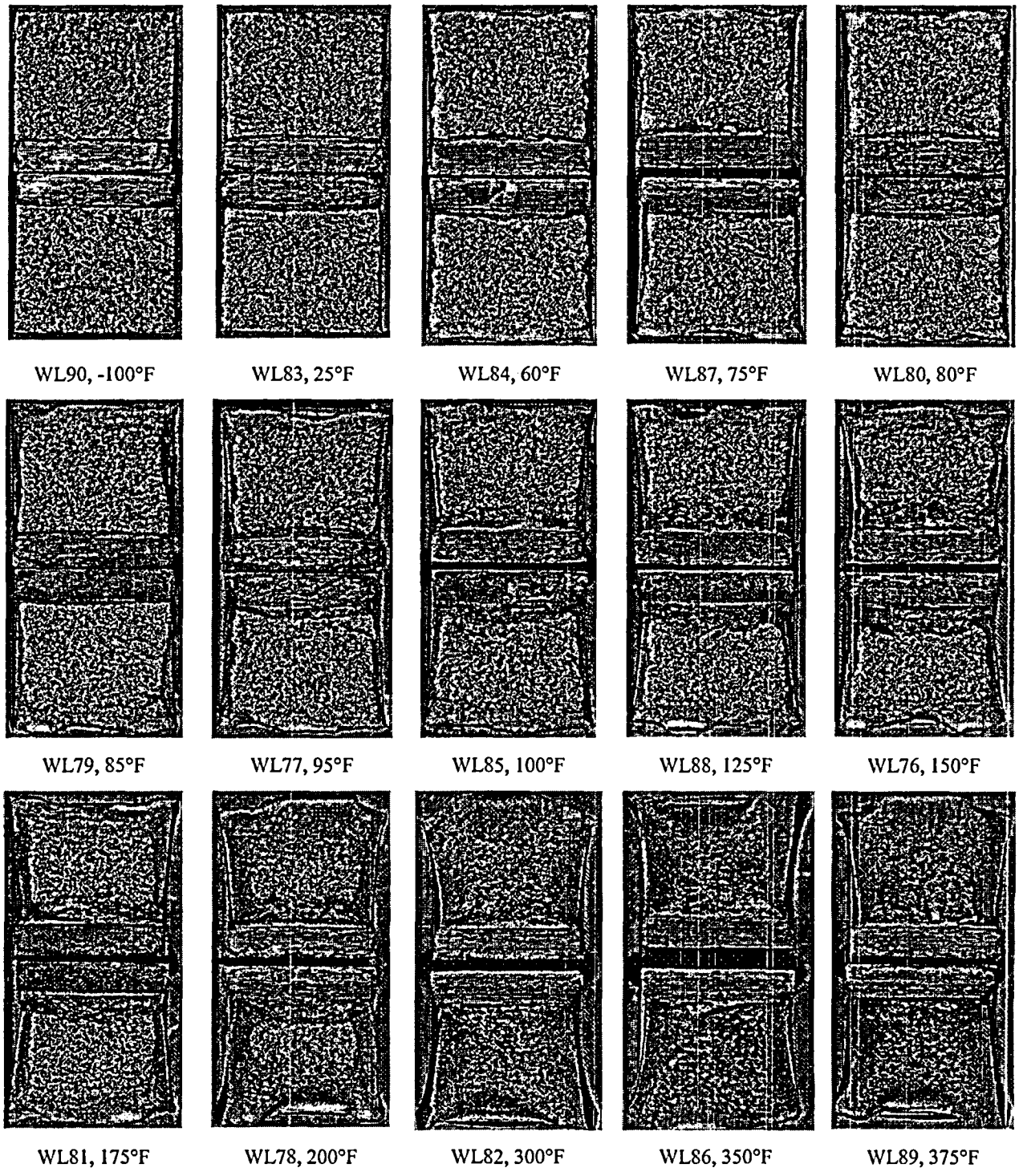



**Figure 5-13 Charpy Impact Specimen Fracture Surfaces for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging (Tangential Orientation)**

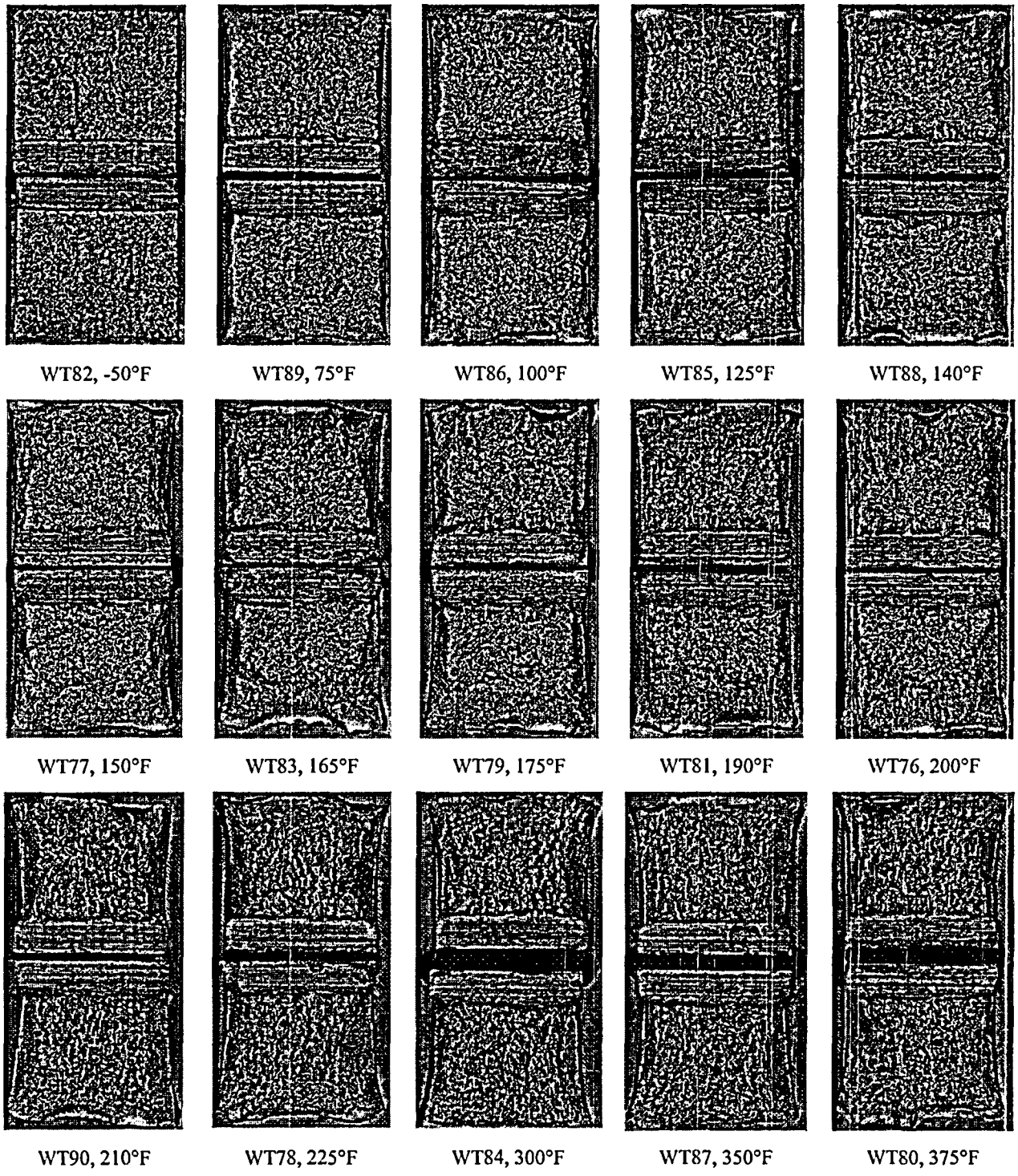



**Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)**

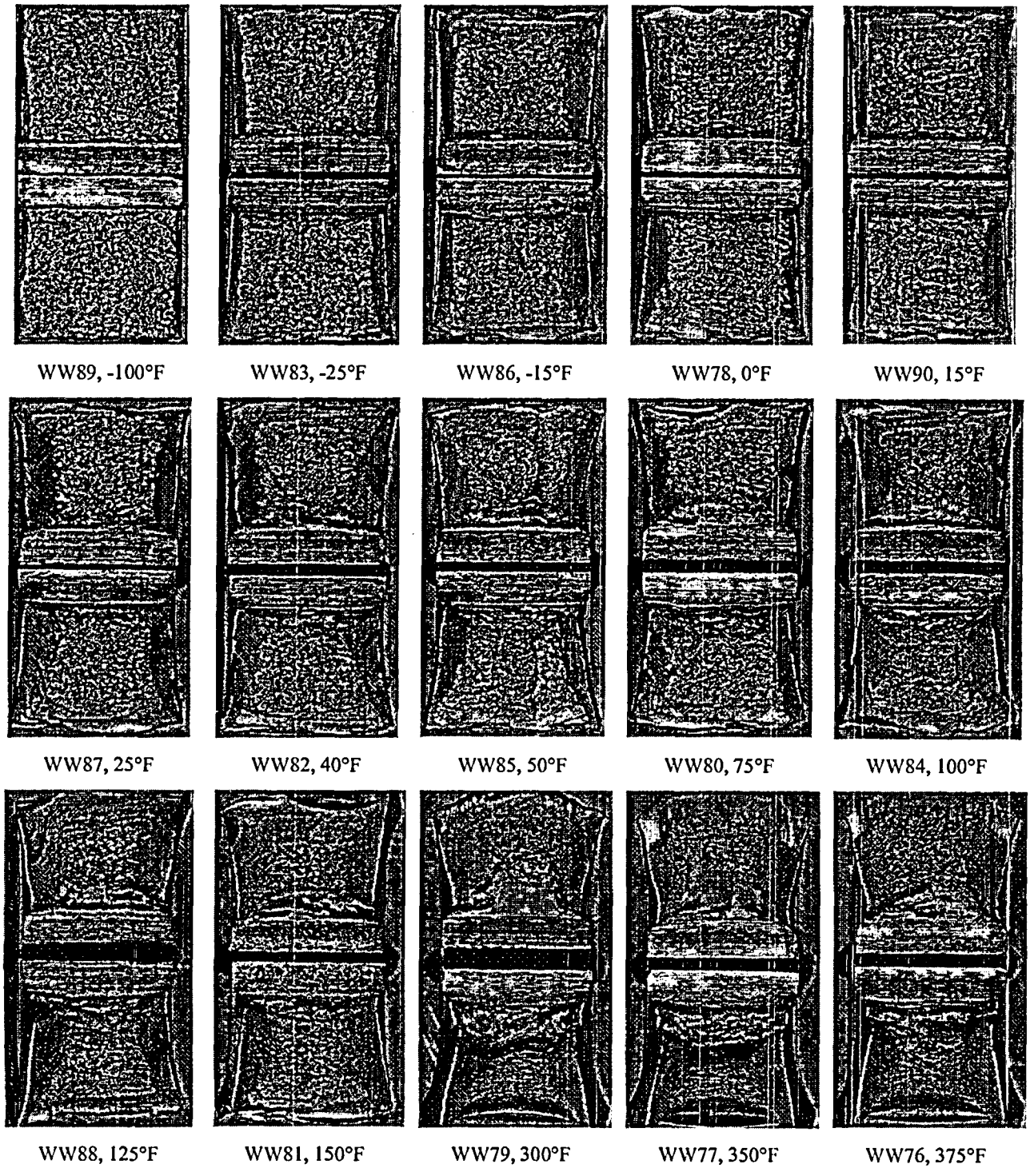



**Figure 5-15 Charpy Impact Specimen Fracture Surfaces for Watts Bar Unit 1 Reactor Vessel Weld Metal**

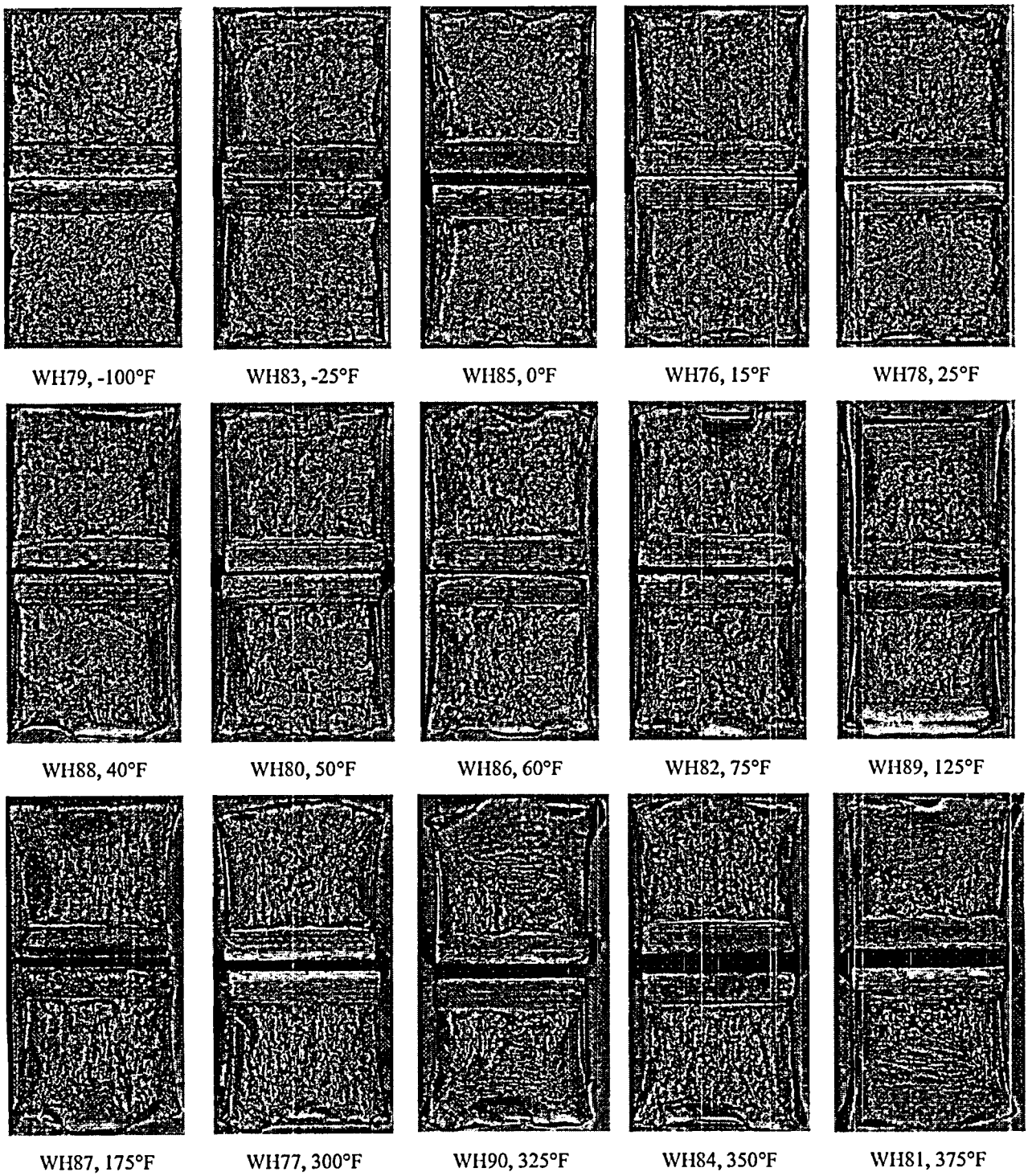
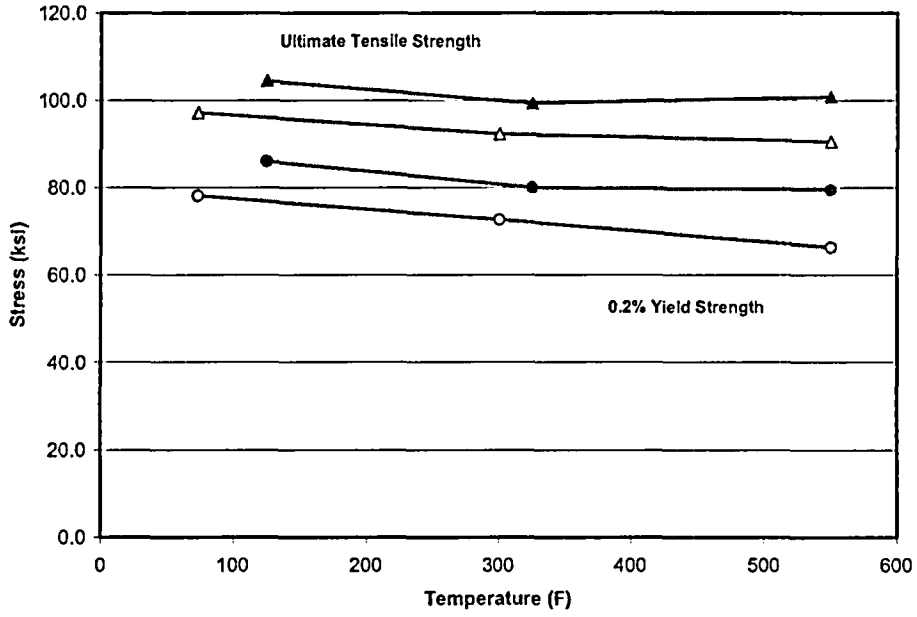



**Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Watts Bar Unit 1 Reactor Vessel Heat-Affected-Zone Metal**




Legend: Δ and ○ and □ are unirradiated
▲ and ● and ■ are irradiated to 2.40 x $10^{19}$n/cm$^2$ (E > 1.0 MeV)

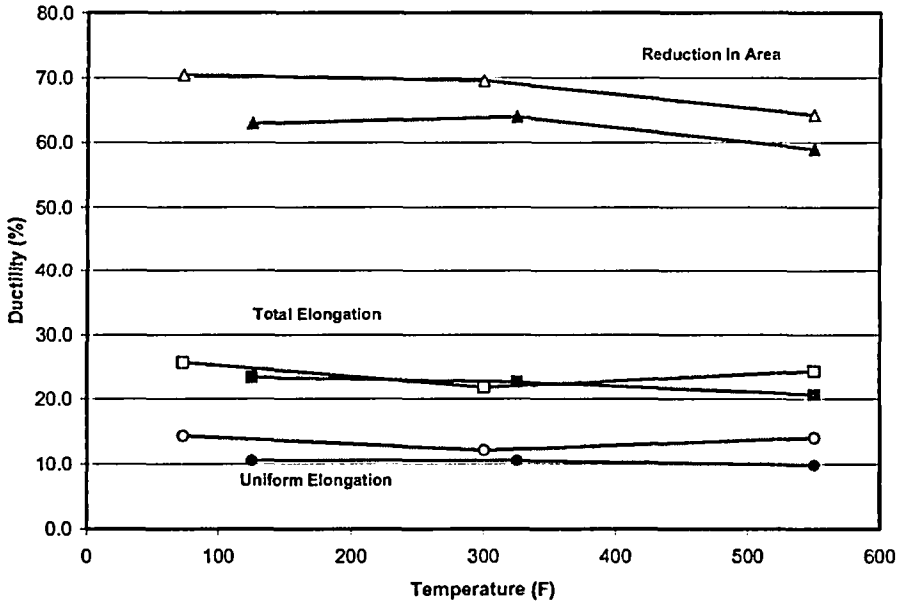
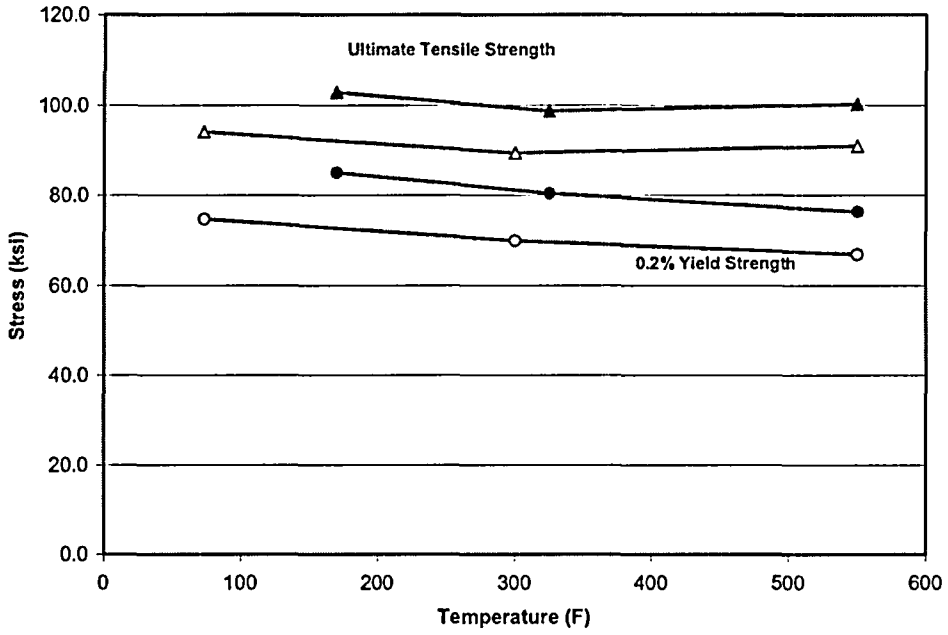



**Figure 5-17 Tensile Properties for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)**




Legend: Δ and ○ and □ are unirradiated
▲and ● and ■ are irradiated to 2.40 x $10^{19}$n/cm$^2$ (E > 1.0 MeV)

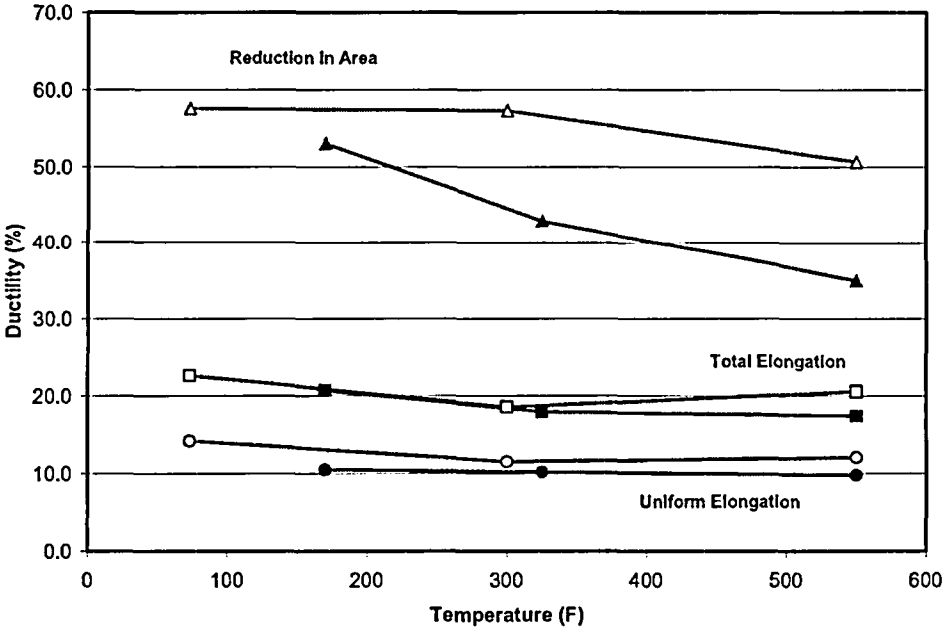
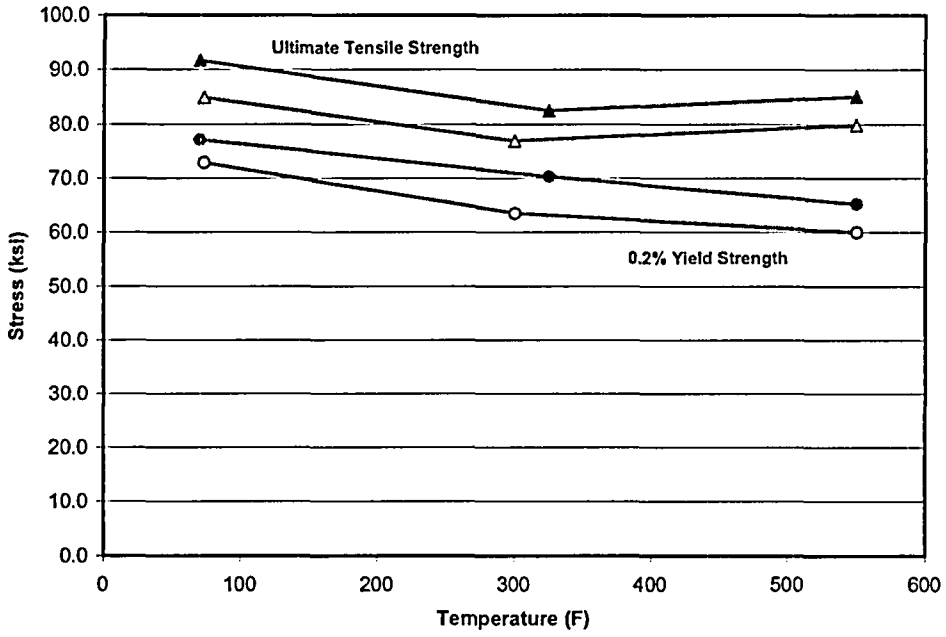



**Figure 5-18 Tensile Properties for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)**




Legend: Δ and ○ and □ are unirradiated
▲and ● and ■ are irradiated to 2.40 x $10^{19}$n/cm$^2$ (E > 1.0 MeV)

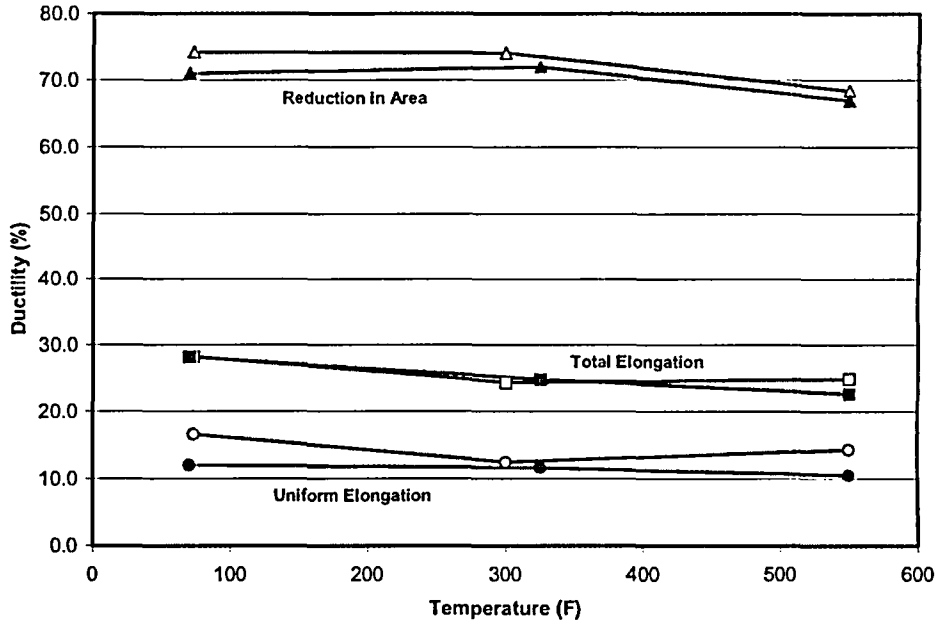
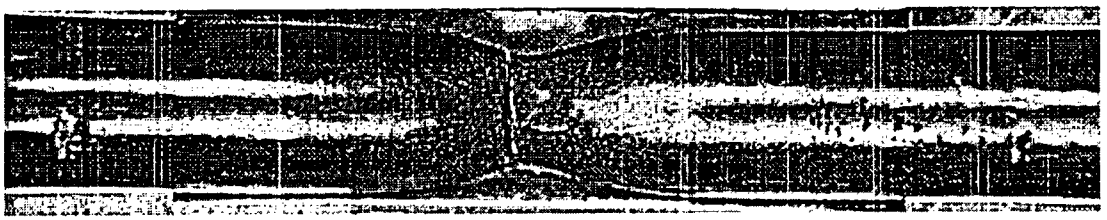
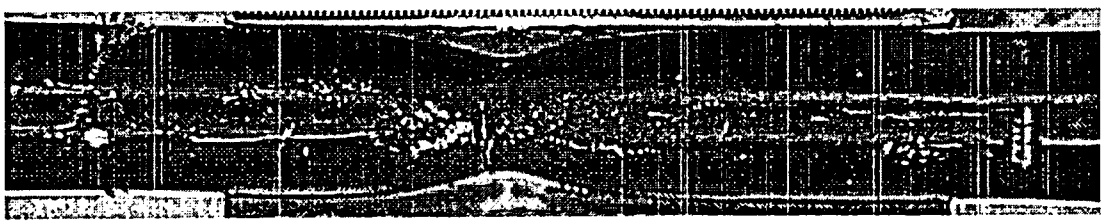



**Figure 5-19 Tensile Properties for Watts Bar Unit 1 Reactor Vessel Weld Metal**

Specimen WL16- Tested at 125°F



Specimen WL17- Tested at 325°F



Specimen WL18- Tested at 550°F

**Figure 5-20 Fractured Tensile Specimens from Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)**

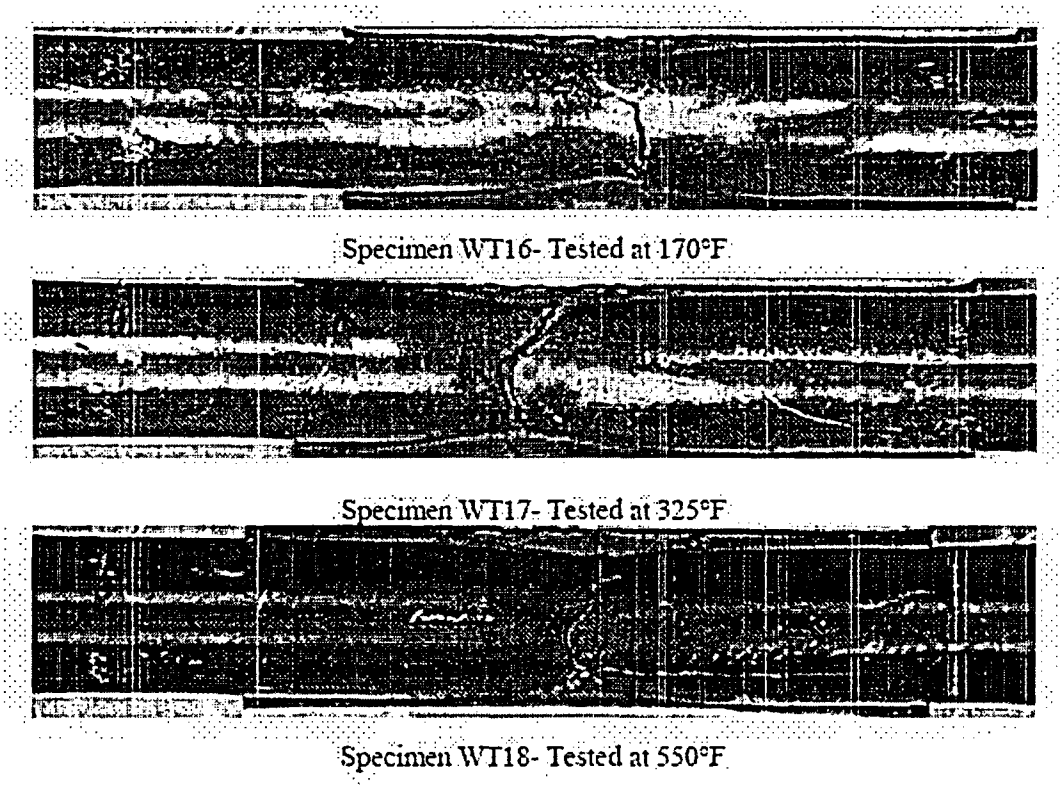



**Figure 5-21 Fractured Tensile Specimens from Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)**

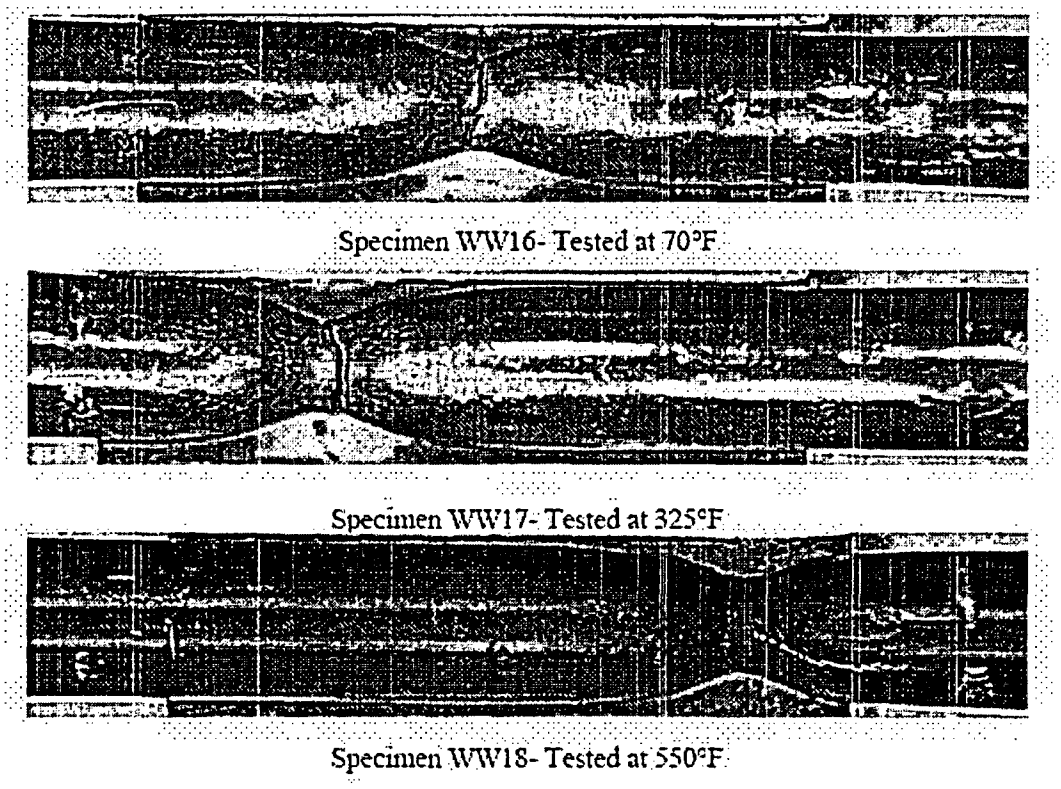
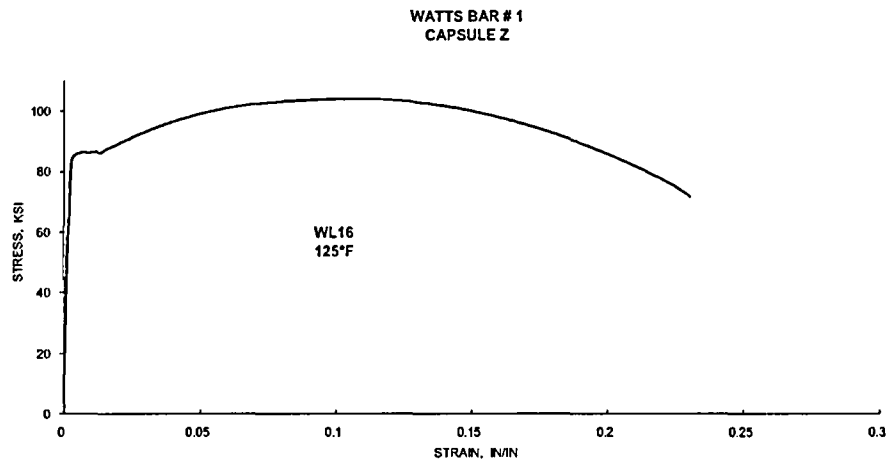
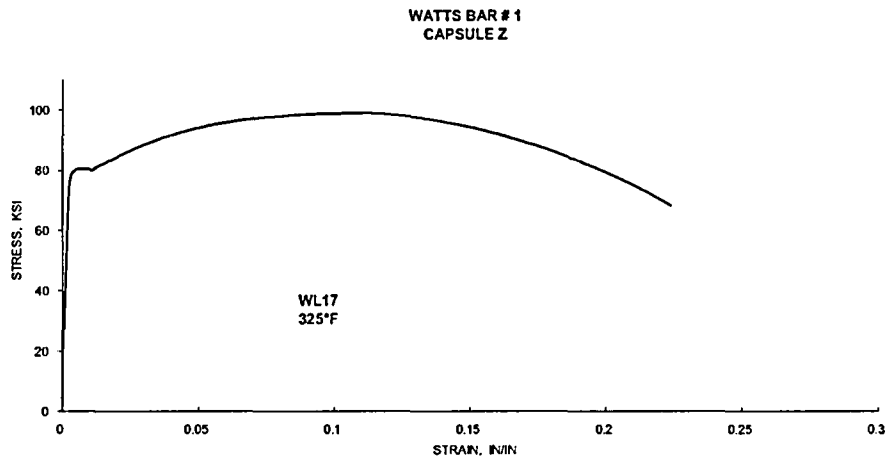



**Figure 5-22 Fractured Tensile Specimens from Watts Bar Unit 1 Reactor Vessel Weld Metal**



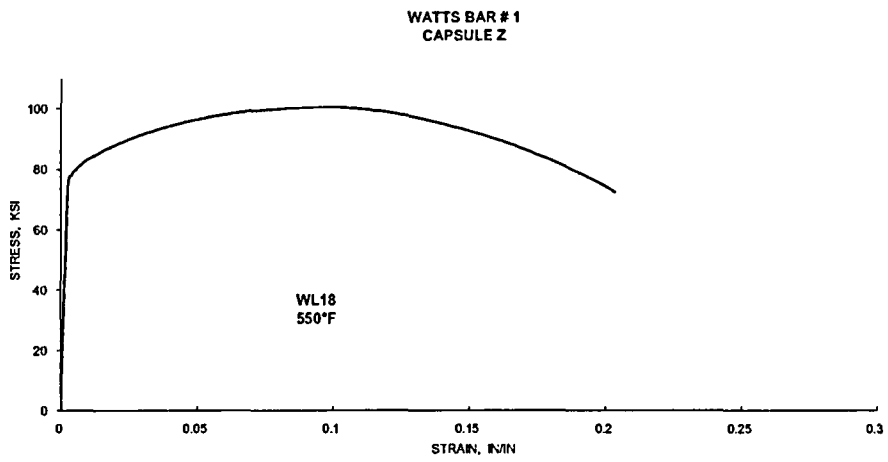
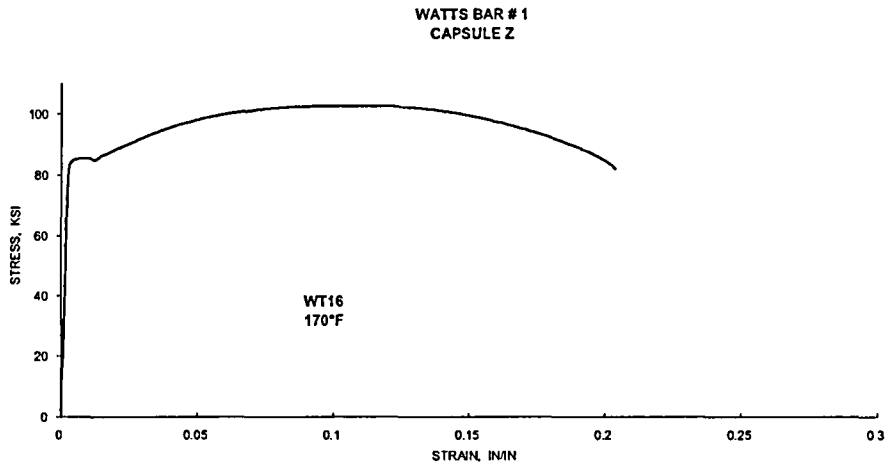
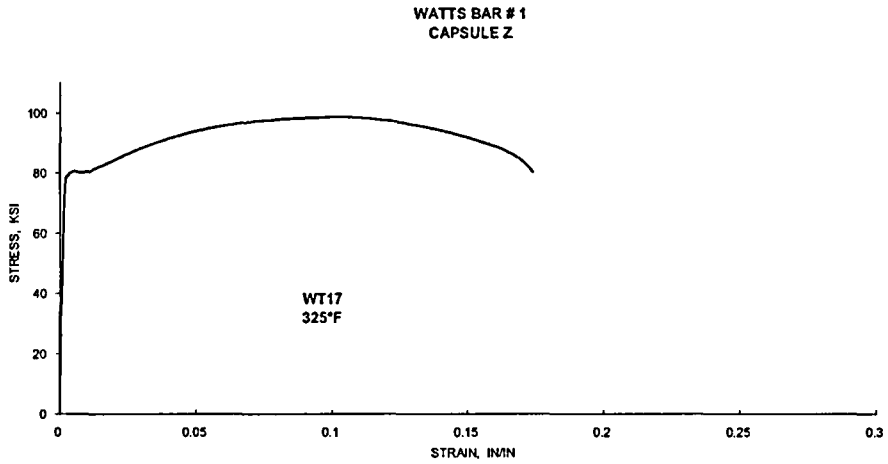




**Figure 5-23 Engineering Stress-Strain Curves for Watts Bar Unit 1 Intermediate Shell Forging 05 Tensile Specimens WL-16, WL-17 and WL-18 (Tangential Orientation)**



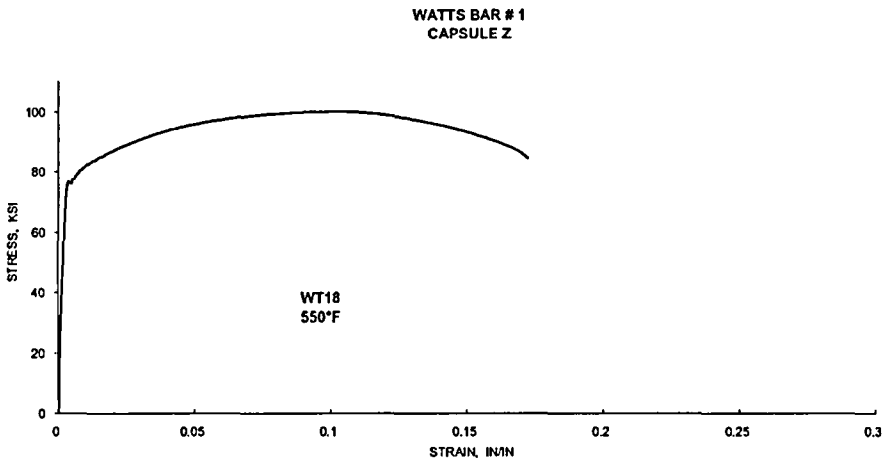
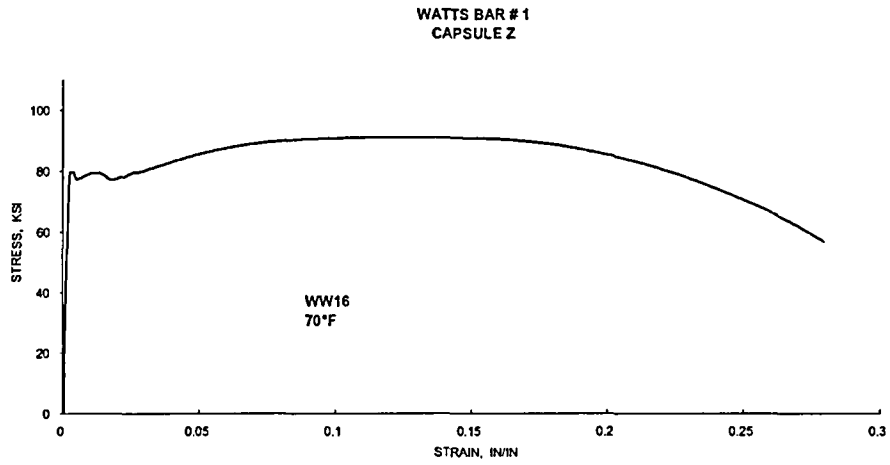
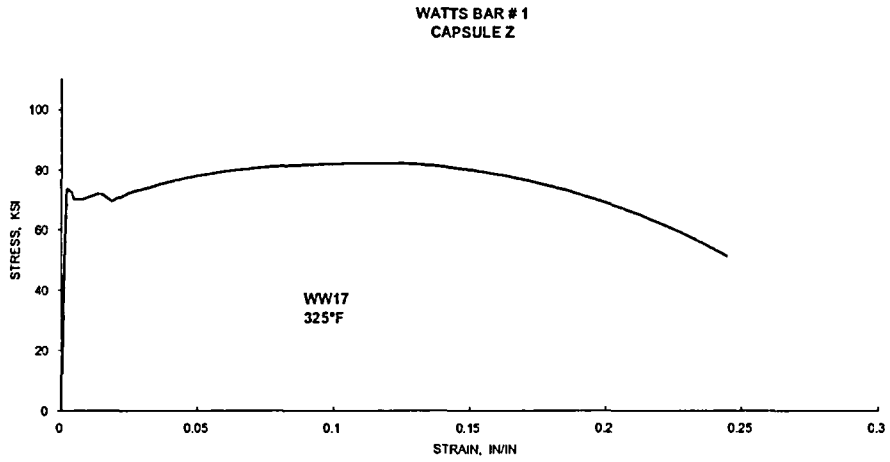




**Figure 5-24 Engineering Stress-Strain Curves for Watts Bar Unit 1 Intermediate Shell Forging 05 Tensile Specimens WT-16, WT-17 and WT-18 (Axial Orientation)**



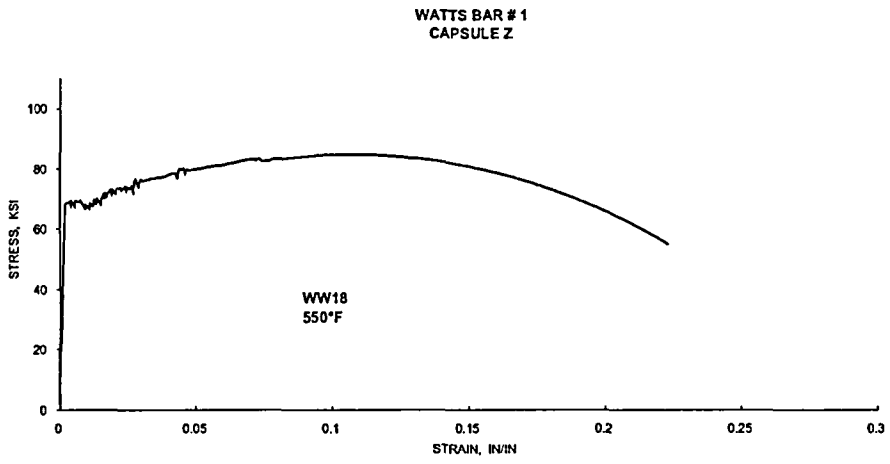




**Figure 5-25 Engineering Stress-Strain Curves for Weld Metal Tensile Specimens WW-16, WW-17 and WW-18**

# 6 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

## 6.1 INTRODUCTION

This section describes a discrete ordinates Sn transport analysis performed for the Watts Bar 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 Z, withdrawn at the end of the seventh plant operating cycle, is provided. 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, "Analysis and Interpretation of Light-Water Reactor Surveillance Results,"[22] 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, "Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements per Atom."[23] 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." [1]

All of the calculations and dosimetry evaluations described in this section and in Appendix A were based on the latest available 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."[35] Additionally, the methods used to develop the calculated pressure vessel fluence are consistent with the NRC approved methodology described in WCAP-14040-NP-A, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves," May 2004.[24]

## 6.2 DISCRETE ORDINATES ANALYSIS

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 Watts Bar 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:

$$\varphi(r,\theta,z) = \varphi(r,\theta) * \frac{\varphi(r,z)}{\varphi(r)}$$

where $\phi(r,\theta,z)$ is the synthesized three-dimensional neutron flux distribution, $\phi(r,\theta)$ is the transport solution in $r,\theta$ 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 $r,\theta$ two-dimensional calculation. This synthesis procedure was carried out for each operating cycle at Watts Bar.

For the Watts Bar transport calculations, the $r,\theta$ models depicted in Figures 6-1 and 6-2 were utilized since, with the exception of the neutron pads, the reactor is octant symmetric. These $r,\theta$ 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 31.5° and 34°, 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 $r,\theta$ reactor models consisted of 170 radial by 98 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 $r,\theta$ calculations was set at a value of 0.001.

The r,z model used for the Watts Bar calculations is shown in Figure 6-3. As in the case of the $r,\theta$ 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 90 axial intervals. As in the case of the $r,\theta$ 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 were taken from References 25 through 32 for each of the first eight fuel cycles at Watts Bar. 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[33] and the BUGLE-96 cross-section library.[34] 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 P5 legendre expansion and angular discretization was modeled with an S16 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. 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. 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 four azimuthal locations. The vessel data given in Table 6-2 were taken at the clad/base metal interface, and thus, represent maximum calculated exposure levels on the vessel.

Both calculated fluence (E > 1.0 MeV) and dpa data are provided in Table 6-1 and Table 6-2. These data tabulations include both plant and fuel cycle specific calculated neutron exposures at the end of the eighth fuel cycle as well as future projections to 15, 20, 25, 32, 36, 48, 54, and 60 EFPY. The projections were based on the assumption that the relative spatial core power distributions and associated plant operating characteristics from Cycles 6-8 were representative of future plant operation. The peripheral assembly powers in the representative model were then modified to include the effects of the tritium producing burnable absorbing rods (TPBARs) to be utilized in future cycles.

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 8, 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 surveillance capsules withdrawn from the Watts Bar 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 Watts Bar reactor.

From the data provided in Table 6-5 it is noted that Capsule Z received a fluence (E > 1.0 MeV) of $2.40 \times 10^{19}$ n/cm$^2$ after exposure through the end of the seventh fuel cycle (i.e., after 9.37 EFPY of plant operation).

Updated lead factors for the Watts Bar 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, W, X, and Z) were based on the calculated fluence values for the irradiation period corresponding to the time of withdrawal for the individual capsules. The remaining capsules V and Y are standby 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, is documented in Appendix A.

The direct comparison of measured versus calculated fast neutron threshold reaction rates for the sensors from Capsule Z, that was withdrawn from Watts Bar at the end of the seventh fuel cycle, is summarized below.

| | Reaction Rates | | | |
|---|---|---|---|---|
| | Measured | Calculated | Best Est. | M/C |
| Cu-63(n,a)Co-60 Cd | 4.15E-17 | 3.95E-17 | 4.06E-17 | 1.05 |
| Fe-54(n,p)Mn-54 | 4.20E-15 | 4.51E-15 | 4.26E-15 | 0.93 |
| Ni-58(n,p)Co-58 Cd | 5.78E-15 | 6.38E-15 | 5.95E-15 | 0.91 |
| U-238(n,f)Cs-137 Cd | 2.55E-14 | 2.52E-14 | 2.34E-14 | 1.01 |
| Np-237(n,f)Cs-137 Cd | 2.40E-13 | 2.62E-13 | 2.42E-13 | 0.92 |
| Co-59(n,g)Co-60 | 3.49E-12 | 3.47E-12 | 3.47E-12 | 1.01 |
| Co-59(n,g)C0-60 Cd | 1.94E-12 | 2.52E-12 | 2.52E-12 | 0.77 |
| Threshold Foil Average | | | | 0.96 |
| % std dev | | | | 6.68 |

The measured-to-calculated (M/C) reaction rate ratios for the Capsule Z threshold reactions range from 0.91 to 1.05, and the average M/C ratio is 1.96 ± 6.68% (1σ). This direct comparison falls 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 Watts Bar reactor.

These comparisons validate the current analytical results described in Section 6.2; therefore, the calculations are deemed applicable for Watts Bar.

## 6.4 CALCULATIONAL UNCERTAINTIES

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

The fourth phase of the uncertainty assessment (comparisons with Watts Bar 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 Watts Bar 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 2.

| | 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 Watts Bar.

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

| | | | | Fast Neutron Flux (E > 1.0 MeV) (n/cm^2-s) | | |
|---|---|---|---|---|---|---|
| | Cycle Length | Cumulative | Cumulative | Single | Dual | Dual |
| Cycle | EFPS | EFPS | EFPY | 34 degrees | 31.5 degrees | 34 degrees |
| 1 | 3.80E+07 | 3.80E+07 | 1.20 | 1.19E+11 | 9.97E+10 | 1.18E+11 |
| 2 | 4.07E+07 | 7.87E+07 | 2.49 | 7.44E+10 | 6.40E+10 | 7.34E+10 |
| 3 | 4.36E+07 | 1.22E+08 | 3.88 | 7.39E+10 | 6.34E+10 | 7.28E+10 |
| 4 | 4.22E+07 | 1.64E+08 | 5.21 | 8.48E+10 | 7.28E+10 | 8.36E+10 |
| 5 | 4.46E+07 | 2.09E+08 | 6.63 | 6.61E+10 | 5.63E+10 | 6.52E+10 |
| 6 | 4.59E+07 | 2.55E+08 | 8.08 | 7.15E+10 | 5.99E+10 | 7.05E+10 |
| 7 | 4.07E+07 | 2.96E+08 | 9.37 | 8.37E+10 | 7.07E+10 | 8.25E+10 |
| 8 | 4.07E+07 | 3.36E+08 | 10.66 | 7.56E+10 | 6.35E+10 | 7.45E+10 |
| 9* | 1.37E+08 | 4.73E+08 | 15.00 | 9.22E+10 | 7.71E+10 | 9.08E+10 |
| 10* | 1.58E+08 | 6.31E+08 | 20.00 | 9.22E+10 | 7.71E+10 | 9.08E+10 |
| 11* | 1.58E+08 | 7.89E+08 | 25.00 | 9.22E+10 | 7.71E+10 | 9.08E+10 |
| 12* | 2.21E+08 | 1.01E+09 | 32.00 | 9.22E+10 | 7.71E+10 | 9.08E+10 |
| 13* | 1.26E+08 | 1.14E+09 | 36.00 | 9.22E+10 | 7.71E+10 | 9.08E+10 |
| 14* | 1.26E+08 | 1.26E+09 | 40.00 | 9.22E+10 | 7.71E+10 | 9.08E+10 |
| 15* | 2.52E+08 | 1.51E+09 | 48.00 | 9.22E+10 | 7.71E+10 | 9.08E+10 |
| 16* | 1.89E+08 | 1.70E+09 | 54.00 | 9.22E+10 | 7.71E+10 | 9.08E+10 |
| 17* | 1.89E+08 | 1.89E+09 | 60.00 | 9.22E+10 | 7.71E+10 | 9.08E+10 |

Notes:

1. Neutron exposure values reported for the surveillance capsules are centered at the core midplane.
2. Future projections assume use of TPBARs.

* Indicates a projected cycle

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

| | | | Cumulative Fast Neutron Fluence (E > 1.0 MeV) (n/cm^2) | | | |
|---|---|---|---|---|---|---|
| | Cycle Length | Cumulative | Cumulative | Single | Dual | Dual |
| Cycle | EFPS | EFPS | EFPY | 34 degrees | 31.5 degrees | 34 degrees |
| 1 | 3.80E+07 | 3.80E+07 | 1.20 | 4.54E+18 | 3.79E+18 | 4.47E+18 |
| 2 | 4.07E+07 | 7.87E+07 | 2.49 | 7.57E+18 | 6.40E+18 | 7.46E+18 |
| 3 | 4.36E+07 | 1.22E+08 | 3.88 | 1.08E+19 | 9.16E+18 | 1.06E+19 |
| 4 | 4.22E+07 | 1.64E+08 | 5.21 | 1.44E+19 | 1.22E+19 | 1.42E+19 |
| 5 | 4.46E+07 | 2.09E+08 | 6.63 | 1.73E+19 | 1.47E+19 | 1.71E+19 |
| 6 | 4.59E+07 | 2.55E+08 | 8.08 | 2.06E+19 | 1.75E+19 | 2.03E+19 |
| 7 | 4.07E+07 | 2.96E+08 | 9.37 | 2.40E+19 | 2.04E+19 | 2.37E+19 |
| 8 | 4.07E+07 | 3.36E+08 | 10.66 | 2.71E+19 | 2.30E+19 | 2.67E+19 |
| 9* | 1.37E+08 | 4.73E+08 | 15.00 | 3.97E+19 | 3.35E+19 | 3.91E+19 |
| 10* | 1.58E+08 | 6.31E+08 | 20.00 | 5.43E+19 | 4.57E+19 | 5.35E+19 |
| 11* | 1.58E+08 | 7.89E+08 | 25.00 | 6.88E+19 | 5.79E+19 | 6.78E+19 |
| 12* | 2.21E+08 | 1.01E+09 | 32.00 | 8.92E+19 | 7.49E+19 | 8.79E+19 |
| 13* | 1.26E+08 | 1.14E+09 | 36.00 | 1.01E+20 | 8.46E+19 | 9.93E+19 |
| 14* | 1.26E+08 | 1.26E+09 | 40.00 | 1.12E+20 | 9.44E+19 | 1.11E+20 |
| 15* | 2.52E+08 | 1.51E+09 | 48.00 | 1.36E+20 | 1.14E+20 | 1.34E+20 |
| 16* | 1.89E+08 | 1.70E+09 | 54.00 | 1.53E+20 | 1.29E+20 | 1.51E+20 |
| 17* | 1.89E+08 | 1.89E+09 | 60.00 | 1.71E+20 | 1.43E+20 | 1.68E+20 |

Notes:

1. Neutron exposure values reported for the surveillance capsules are centered at the core midplane.
2. Future projections assume use of TPBARs.

*Indicates a projected cycle

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

| | | | | Iron Atom Displacement Rate (dpa/s) | | |
|---|---|---|---|---|---|---|
| | Cycle Length | Cumulative | Cumulative | Single | Dual | Dual |
| Cycle | EFPS | EFPS | EFPY | 34 degrees | 31.5 degrees | 34 degrees |
| 1 | 3.80E+07 | 3.80E+07 | 1.20 | 2.44E-10 | 1.96E-10 | 2.36E-10 |
| 2 | 4.07E+07 | 7.87E+07 | 2.49 | 1.50E-10 | 1.25E-10 | 1.45E-10 |
| 3 | 4.36E+07 | 1.22E+08 | 3.88 | 1.49E-10 | 1.23E-10 | 1.44E-10 |
| 4 | 4.22E+07 | 1.64E+08 | 5.21 | 1.71E-10 | 1.42E-10 | 1.65E-10 |
| 5 | 4.46E+07 | 2.09E+08 | 6.63 | 1.33E-10 | 1.10E-10 | 1.29E-10 |
| 6 | 4.59E+07 | 2.55E+08 | 8.08 | 1.45E-10 | 1.17E-10 | 1.40E-10 |
| 7 | 4.07E+07 | 2.96E+08 | 9.37 | 1.69E-10 | 1.38E-10 | 1.64E-10 |
| 8 | 4.07E+07 | 3.36E+08 | 10.66 | 1.53E-10 | 1.24E-10 | 1.48E-10 |
| 9* | 1.37E+08 | 4.73E+08 | 15.00 | 1.87E-10 | 1.51E-10 | 1.81E-10 |
| 10* | 1.58E+08 | 6.31E+08 | 20.00 | 1.87E-10 | 1.51E-10 | 1.81E-10 |
| 11* | 1.58E+08 | 7.89E+08 | 25.00 | 1.87E-10 | 1.51E-10 | 1.81E-10 |
| 12* | 2.21E+08 | 1.01E+09 | 32.00 | 1.87E-10 | 1.51E-10 | 1.81E-10 |
| 13* | 1.26E+08 | 1.14E+09 | 36.00 | 1.87E-10 | 1.51E-10 | 1.81E-10 |
| 14* | 1.26E+08 | 1.26E+09 | 40.00 | 1.87E-10 | 1.51E-10 | 1.81E-10 |
| 15* | 2.52E+08 | 1.51E+09 | 48.00 | 1.87E-10 | 1.51E-10 | 1.81E-10 |
| 16* | 1.89E+08 | 1.70E+09 | 54.00 | 1.87E-10 | 1.51E-10 | 1.81E-10 |
| 17* | 1.89E+08 | 1.89E+09 | 60.00 | 1.87E-10 | 1.51E-10 | 1.81E-10 |

Notes:

1. Neutron exposure values reported for the surveillance capsules are centered at the core midplane.
2. Future projections assume use of TPBARs.

* Indicates a projected cycle

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

| | | | | Cumulative Iron Atom Displacements (dpa) | | |
|---|---|---|---|---|---|---|
| | Cycle Length | Cumulative | Cumulative | Single | Dual | Dual |
| Cycle | EFPS | EFPS | EFPY | 34 degrees | 31.5 degrees | 34 degrees |
| 1 | 3.80E+07 | 3.80E+07 | 1.20 | 9.26E-03 | 7.46E-03 | 8.95E-03 |
| 2 | 4.07E+07 | 7.87E+07 | 2.49 | 1.54E-02 | 1.26E-02 | 1.49E-02 |
| 3 | 4.36E+07 | 1.22E+08 | 3.88 | 2.19E-02 | 1.79E-02 | 2.11E-02 |
| 4 | 4.22E+07 | 1.64E+08 | 5.21 | 2.91E-02 | 2.39E-02 | 2.81E-02 |
| 5 | 4.46E+07 | 2.09E+08 | 6.63 | 3.51E-02 | 2.88E-02 | 3.39E-02 |
| 6 | 4.59E+07 | 2.55E+08 | 8.08 | 4.17E-02 | 3.42E-02 | 4.03E-02 |
| 7 | 4.07E+07 | 2.96E+08 | 9.37 | 4.86E-02 | 3.98E-02 | 4.69E-02 |
| 8 | 4.07E+07 | 3.36E+08 | 10.66 | 5.48E-02 | 4.48E-02 | 5.29E-02 |
| 9* | 1.37E+08 | 4.73E+08 | 15.00 | 8.04E-02 | 6.55E-02 | 7.77E-02 |
| 10* | 1.58E+08 | 6.31E+08 | 20.00 | 1.10E-01 | 8.94E-02 | 1.06E-01 |
| 11* | 1.58E+08 | 7.89E+08 | 25.00 | 1.40E-01 | 1.13E-01 | 1.35E-01 |
| 12* | 2.21E+08 | 1.01E+09 | 32.00 | 1.81E-01 | 1.47E-01 | 1.75E-01 |
| 13* | 1.26E+08 | 1.14E+09 | 36.00 | 2.04E-01 | 1.66E-01 | 1.98E-01 |
| 14* | 1.26E+08 | 1.26E+09 | 40.00 | 2.28E-01 | 1.85E-01 | 2.20E-01 |
| 15* | 2.52E+08 | 1.51E+09 | 48.00 | 2.75E-01 | 2.23E-01 | 2.66E-01 |
| 16* | 1.89E+08 | 1.70E+09 | 54.00 | 3.11E-01 | 2.52E-01 | 3.00E-01 |
| 17* | 1.89E+08 | 1.89E+09 | 60.00 | 3.46E-01 | 2.80E-01 | 3.34E-01 |

Notes:

1. Neutron exposure values reported for the surveillance capsules are centered at the core midplane.
2. Future projections assume use of TPBARs.

* Indicates a projected cycle

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

| | | | | Maximum Fast Neutron Flux | | | (n/cm^2-s) |
|---|---|---|---|---|---|---|---|
| **Cycle** | **EFPY** | **EFPS** | **Total EFPY** | **0 deg** | **15 deg** | **30 deg** | **45 deg** |
| 1 | 1.20 | 3.80E+07 | 1.20 | 1.26E+10 | 1.92E+10 | 1.90E+10 | 2.35E+10 |
| 2 | 1.29 | 4.07E+07 | 2.49 | 8.17E+09 | 1.27E+10 | 1.32E+10 | 1.52E+10 |
| 3 | 1.38 | 4.36E+07 | 3.88 | 9.10E+09 | 1.25E+10 | 1.28E+10 | 1.49E+10 |
| 4 | 1.34 | 4.22E+07 | 5.21 | 8.54E+09 | 1.26E+10 | 1.39E+10 | 1.63E+10 |
| 5 | 1.41 | 4.46E+07 | 6.63 | 7.94E+09 | 1.06E+10 | 1.09E+10 | 1.32E+10 |
| 6 | 1.46 | 4.59E+07 | 8.08 | 7.61E+09 | 1.10E+10 | 1.15E+10 | 1.46E+10 |
| 7 | 1.29 | 4.07E+07 | 9.37 | 7.84E+09 | 1.24E+10 | 1.38E+10 | 1.67E+10 |
| 8 | 1.29 | 4.07E+07 | 10.66 | 7.34E+09 | 1.14E+10 | 1.21E+10 | 1.52E+10 |
| 9* | 4.34 | 1.37E+08 | 15.00 | 9.91E+09 | 1.47E+10 | 1.46E+10 | 1.81E+10 |
| 10* | 5.00 | 1.58E+08 | 20.00 | 9.91E+09 | 1.47E+10 | 1.46E+10 | 1.81E+10 |
| 11* | 5.00 | 1.58E+08 | 25.00 | 9.91E+09 | 1.47E+10 | 1.46E+10 | 1.81E+10 |
| 12* | 7.00 | 2.21E+08 | 32.00 | 9.91E+09 | 1.47E+10 | 1.46E+10 | 1.81E+10 |
| 13* | 4.00 | 1.26E+08 | 36.00 | 9.91E+09 | 1.47E+10 | 1.46E+10 | 1.81E+10 |
| 14* | 4.00 | 1.26E+08 | 40.00 | 9.91E+09 | 1.47E+10 | 1.46E+10 | 1.81E+10 |
| 15* | 8.00 | 2.52E+08 | 48.00 | 9.91E+09 | 1.47E+10 | 1.46E+10 | 1.81E+10 |
| 16* | 6.00 | 1.89E+08 | 54.00 | 9.91E+09 | 1.47E+10 | 1.46E+10 | 1.81E+10 |
| 17* | 6.00 | 1.89E+08 | 60.00 | 9.91E+09 | 1.47E+10 | 1.46E+10 | 1.81E+10 |

**Notes:**

1. Neutron exposure values reported for the pressure vessel are indexed to the axial location of the maximum exposure at each azimuthal angle.
2. Future projections assume use of TPBARs.

* Indicates a projected cycle

| Table 6-2 (cont.) | Calculated Azimuthal Variation of Maximum Exposure Rates and Integrated Exposures at the Reactor Vessel Clad/Base Metal Interface | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Maximum Cumulative Fast Neutron Fluence (n/cm^2) | | | |
| Cycle | EFPY | EFPS | Total EFPY | 0 deg | 15 deg | 30 deg | 45 deg |
| 1 | 1.20 | 3.80E+07 | 1.20 | 4.79E+17 | 7.28E+17 | 7.23E+17 | 8.94E+17 |
| 2 | 1.29 | 4.07E+07 | 2.49 | 7.96E+17 | 1.22E+18 | 1.24E+18 | 1.49E+18 |
| 3 | 1.38 | 4.36E+07 | 3.88 | 1.19E+18 | 1.77E+18 | 1.79E+18 | 2.14E+18 |
| 4 | 1.34 | 4.22E+07 | 5.21 | 1.55E+18 | 2.29E+18 | 2.37E+18 | 2.81E+18 |
| 5 | 1.41 | 4.46E+07 | 6.63 | 1.90E+18 | 2.76E+18 | 2.85E+18 | 3.39E+18 |
| 6 | 1.46 | 4.59E+07 | 8.08 | 2.25E+18 | 3.26E+18 | 3.38E+18 | 4.06E+18 |
| 7 | 1.29 | 4.07E+07 | 9.37 | 2.57E+18 | 3.77E+18 | 3.94E+18 | 4.74E+18 |
| 8 | 1.29 | 4.07E+07 | 10.66 | 2.85E+18 | 4.22E+18 | 4.41E+18 | 5.34E+18 |
| 9* | 4.34 | 1.37E+08 | 15.00 | 4.19E+18 | 6.20E+18 | 6.38E+18 | 7.79E+18 |
| 10* | 5.00 | 1.58E+08 | 20.00 | 5.74E+18 | 8.51E+18 | 8.67E+18 | 1.06E+19 |
| 11* | 5.00 | 1.58E+08 | 25.00 | 7.31E+18 | 1.08E+19 | 1.10E+19 | 1.35E+19 |
| 12* | 7.00 | 2.21E+08 | 32.00 | 9.49E+18 | 1.41E+19 | 1.42E+19 | 1.75E+19 |
| 13* | 4.00 | 1.26E+08 | 36.00 | 1.07E+19 | 1.60E+19 | 1.60E+19 | 1.98E+19 |
| 14* | 4.00 | 1.26E+08 | 40.00 | 1.20E+19 | 1.78E+19 | 1.79E+19 | 2.21E+19 |
| 15* | 8.00 | 2.52E+08 | 48.00 | 1.45E+19 | 2.15E+19 | 2.16E+19 | 2.66E+19 |
| 16* | 6.00 | 1.89E+08 | 54.00 | 1.64E+19 | 2.43E+19 | 2.43E+19 | 3.01E+19 |
| 17* | 6.00 | 1.89E+08 | 60.00 | 1.83E+19 | 2.71E+19 | 2.71E+19 | 3.35E+19 |

Notes:

1. Neutron exposure values reported for the pressure vessel are indexed to the axial location of the maximum exposure at each azimuthal angle.
2. Future projections assume use of TPBARs.

* Indicates a projected cycle

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

| | | | | Maximum Iron Atom Displacement Rate (dpa/s) | | | |
|---|---|---|---|---|---|---|---|
| **Cycle** | **EFPY** | **EFPS** | **Total EFPY** | **0 deg** | **15 deg** | **30 deg** | **45 deg** |
| 1 | 1.20 | 3.80E+07 | 1.20 | 1.95E-11 | 2.95E-11 | 2.97E-11 | 3.73E-11 |
| 2 | 1.29 | 4.07E+07 | 2.49 | 1.27E-11 | 1.96E-11 | 2.05E-11 | 2.41E-11 |
| 3 | 1.38 | 4.36E+07 | 3.88 | 1.41E-11 | 1.93E-11 | 1.99E-11 | 2.36E-11 |
| 4 | 1.34 | 4.22E+07 | 5.21 | 1.33E-11 | 1.95E-11 | 2.16E-11 | 2.57E-11 |
| 5 | 1.41 | 4.46E+07 | 6.63 | 1.23E-11 | 1.64E-11 | 1.70E-11 | 2.09E-11 |
| 6 | 1.46 | 4.59E+07 | 8.08 | 1.18E-11 | 1.69E-11 | 1.80E-11 | 2.31E-11 |
| 7 | 1.29 | 4.07E+07 | 9.37 | 1.22E-11 | 1.91E-11 | 2.14E-11 | 2.64E-11 |
| 8 | 1.29 | 4.07E+07 | 10.66 | 1.14E-11 | 1.76E-11 | 1.89E-11 | 2.40E-11 |
| 9* | 4.34 | 1.37E+08 | 15.00 | 1.54E-11 | 2.27E-11 | 2.28E-11 | 2.87E-11 |
| 10* | 5.00 | 1.58E+08 | 20.00 | 1.54E-11 | 2.27E-11 | 2.28E-11 | 2.87E-11 |
| 11* | 5.00 | 1.58E+08 | 25.00 | 1.54E-11 | 2.27E-11 | 2.28E-11 | 2.87E-11 |
| 12* | 7.00 | 2.21E+08 | 32.00 | 1.54E-11 | 2.27E-11 | 2.28E-11 | 2.87E-11 |
| 13* | 4.00 | 1.26E+08 | 36.00 | 1.54E-11 | 2.27E-11 | 2.28E-11 | 2.87E-11 |
| 14* | 4.00 | 1.26E+08 | 40.00 | 1.54E-11 | 2.27E-11 | 2.28E-11 | 2.87E-11 |
| 15* | 8.00 | 2.52E+08 | 48.00 | 1.54E-11 | 2.27E-11 | 2.28E-11 | 2.87E-11 |
| 16* | 6.00 | 1.89E+08 | 54.00 | 1.54E-11 | 2.27E-11 | 2.28E-11 | 2.87E-11 |
| 17* | 6.00 | 1.89E+08 | 60.00 | 1.54E-11 | 2.27E-11 | 2.28E-11 | 2.87E-11 |

**Notes:**

1. Neutron exposure values reported for the pressure vessel are indexed to the axial location of the maximum exposure at each azimuthal angle.
2. Future projections assume use of TPBARs.

* Indicates a projected cycle

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

| | | | | Maximum Cumulative Iron Atom Displacements (dpa) | | | |
|---|---|---|---|---|---|---|---|
| **Cycle** | **EFPY** | **EFPS** | **Total EFPY** | **0 deg** | **15 deg** | **30 deg** | **45 deg** |
| 1 | 1.20 | 3.80E+07 | 1.20 | 7.43E-04 | 1.12E-03 | 1.13E-03 | 1.42E-03 |
| 2 | 1.29 | 4.07E+07 | 2.49 | 1.24E-03 | 1.88E-03 | 1.93E-03 | 2.35E-03 |
| 3 | 1.38 | 4.36E+07 | 3.88 | 1.85E-03 | 2.72E-03 | 2.79E-03 | 3.38E-03 |
| 4 | 1.34 | 4.22E+07 | 5.21 | 2.40E-03 | 3.53E-03 | 3.69E-03 | 4.45E-03 |
| 5 | 1.41 | 4.46E+07 | 6.63 | 2.94E-03 | 4.25E-03 | 4.44E-03 | 5.37E-03 |
| 6 | 1.46 | 4.59E+07 | 8.08 | 3.49E-03 | 5.03E-03 | 5.26E-03 | 6.43E-03 |
| 7 | 1.29 | 4.07E+07 | 9.37 | 3.98E-03 | 5.80E-03 | 6.14E-03 | 7.51E-03 |
| 8 | 1.29 | 4.07E+07 | 10.66 | 4.43E-03 | 6.49E-03 | 6.88E-03 | 8.45E-03 |
| 9* | 4.34 | 1.37E+08 | 15.00 | 6.51E-03 | 9.56E-03 | 9.96E-03 | 1.23E-02 |
| 10* | 5.00 | 1.58E+08 | 20.00 | 8.92E-03 | 1.31E-02 | 1.35E-02 | 1.68E-02 |
| 11* | 5.00 | 1.58E+08 | 25.00 | 1.14E-02 | 1.67E-02 | 1.71E-02 | 2.13E-02 |
| 12* | 7.00 | 2.21E+08 | 32.00 | 1.48E-02 | 2.17E-02 | 2.22E-02 | 2.77E-02 |
| 13* | 4.00 | 1.26E+08 | 36.00 | 1.67E-02 | 2.46E-02 | 2.50E-02 | 3.13E-02 |
| 14* | 4.00 | 1.26E+08 | 40.00 | 1.86E-02 | 2.74E-02 | 2.79E-02 | 3.49E-02 |
| 15* | 8.00 | 2.52E+08 | 48.00 | 2.25E-02 | 3.31E-02 | 3.36E-02 | 4.22E-02 |
| 16* | 6.00 | 1.89E+08 | 54.00 | 2.54E-02 | 3.74E-02 | 3.80E-02 | 4.76E-02 |
| 17* | 6.00 | 1.89E+08 | 60.00 | 2.83E-02 | 4.17E-02 | 4.23E-02 | 5.30E-02 |

**Notes:**

1. Neutron exposure values reported for the pressure vessel are indexed to the axial location of the maximum exposure at each azimuthal angle.
2. Future projections assume use of TPBARs.

* Indicates a projected cycle

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

| RADIUS | AZIMUTHAL ANGLE | | | |
|---|---|---|---|---|
| (cm) | 0° | 15° | 30° | 45° |
| 220.35 | 1.000 | 1.000 | 1.000 | 1.000 |
| 225.87 | 0.561 | 0.557 | 0.558 | 0.547 |
| 231.39 | 0.275 | 0.271 | 0.273 | 0.262 |
| 236.90 | 0.129 | 0.126 | 0.128 | 0.119 |
| 242.42 | 0.059 | 0.056 | 0.058 | 0.051 |
| | | Base Metal Inner Radius = 220.35 cm | | |
| | | Base Metal 1/4T = 225.87 cm | | |
| | | Base Metal 1/2T = 231.39 cm | | |
| | | Base Metal 3/4T = 236.90 cm | | |
| | | Base Metal Outer Radius = 242.42 cm | | |

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

| RADIUS | AZIMUTHAL ANGLE | | | |
|---|---|---|---|---|
| (cm) | 0° | 15° | 30° | 45° |
| 220.35 | 1.000 | 1.000 | 1.000 | 1.000 |
| 225.87 | 0.634 | 0.630 | 0.645 | 0.637 |
| 231.39 | 0.381 | 0.377 | 0.396 | 0.384 |
| 236.90 | 0.226 | 0.223 | 0.240 | 0.225 |
| 242.42 | 0.127 | 0.124 | 0.137 | 0.117 |
| | | Base Metal Inner Radius = 220.35 cm | | |
| | | Base Metal 1/4T = 225.87 cm | | |
| | | Base Metal 1/2T = 231.39 cm | | |
| | | Base Metal 3/4T = 236.90 cm | | |
| | | Base Metal Outer Radius = 242.42 cm | | |

| Table 6-5 Calculated Fast Neutron Exposure of Surveillance Capsules Withdrawn from Watts Bar | | | |
|---|---|---|---|
| Capsule | Irradiation Time [EFPY] | Fluence (E > 1.0 MeV) [n/cm^2] | Iron Displacements [dpa] |
| U | 1.20 | 4.47E+18 | 8.95E-03 |
| W | 3.88 | 1.08E+19 | 2.19E-02 |
| X | 6.63 | 1.71E+19 | 3.39E-02 |
| Z | 9.37 | 2.40E+19 | 4.86E-02 |

| Table 6-6 Calculated Surveillance Capsule Lead Factors | | |
|---|---|---|
| Capsule ID And Location | Status | Lead Factor |
| U (34° Dual) | Withdrawn EOC 1 | 5.00 |
| W (34° Single) | Withdrawn EOC 3 | 5.05 |
| X (34° Dual) | Withdrawn EOC 5 | 5.03 |
| Z (34° Single) | Withdrawn EOC 7 | 5.06 |
| V (31.5° Dual) | Standby | 4.31 |
| Y (31.5° Dual) | Standby | 4.31 |

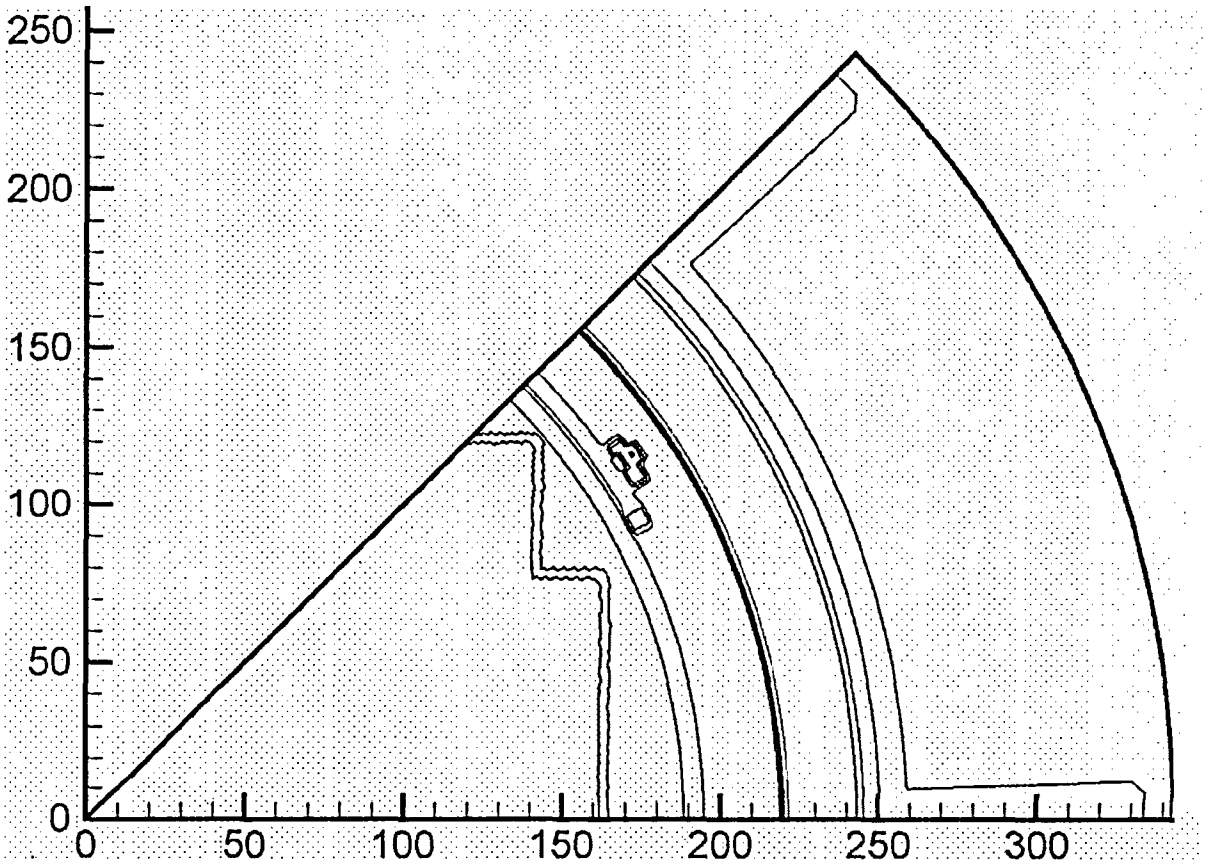



**Figure 6-1 Watts Bar r,θ Reactor Geometry with a Single Capsule Neutron Pad Span at the Core Midplane**

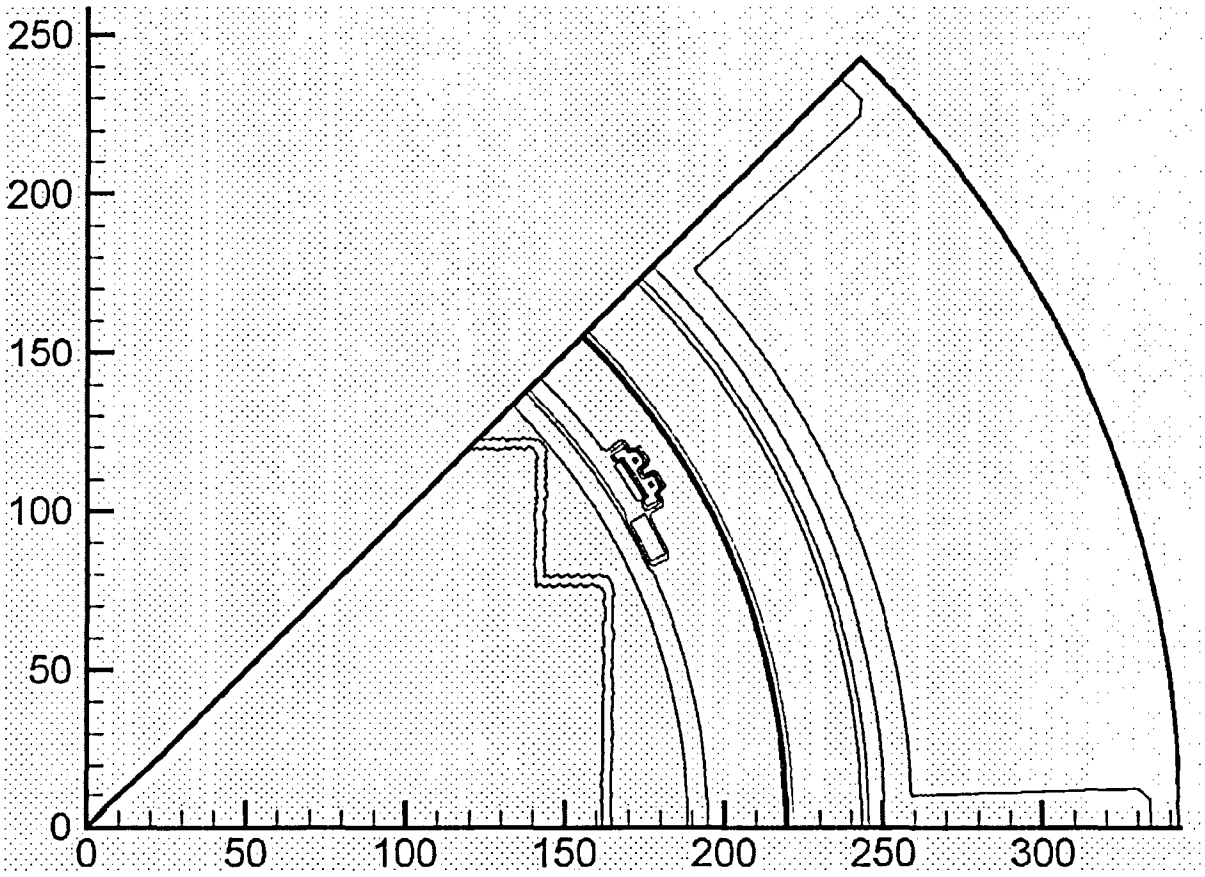



**Figure 6-2 Watts Bar r,θ Reactor Geometry with a Dual Capsule Neutron Pad Span at the Core Midplane**

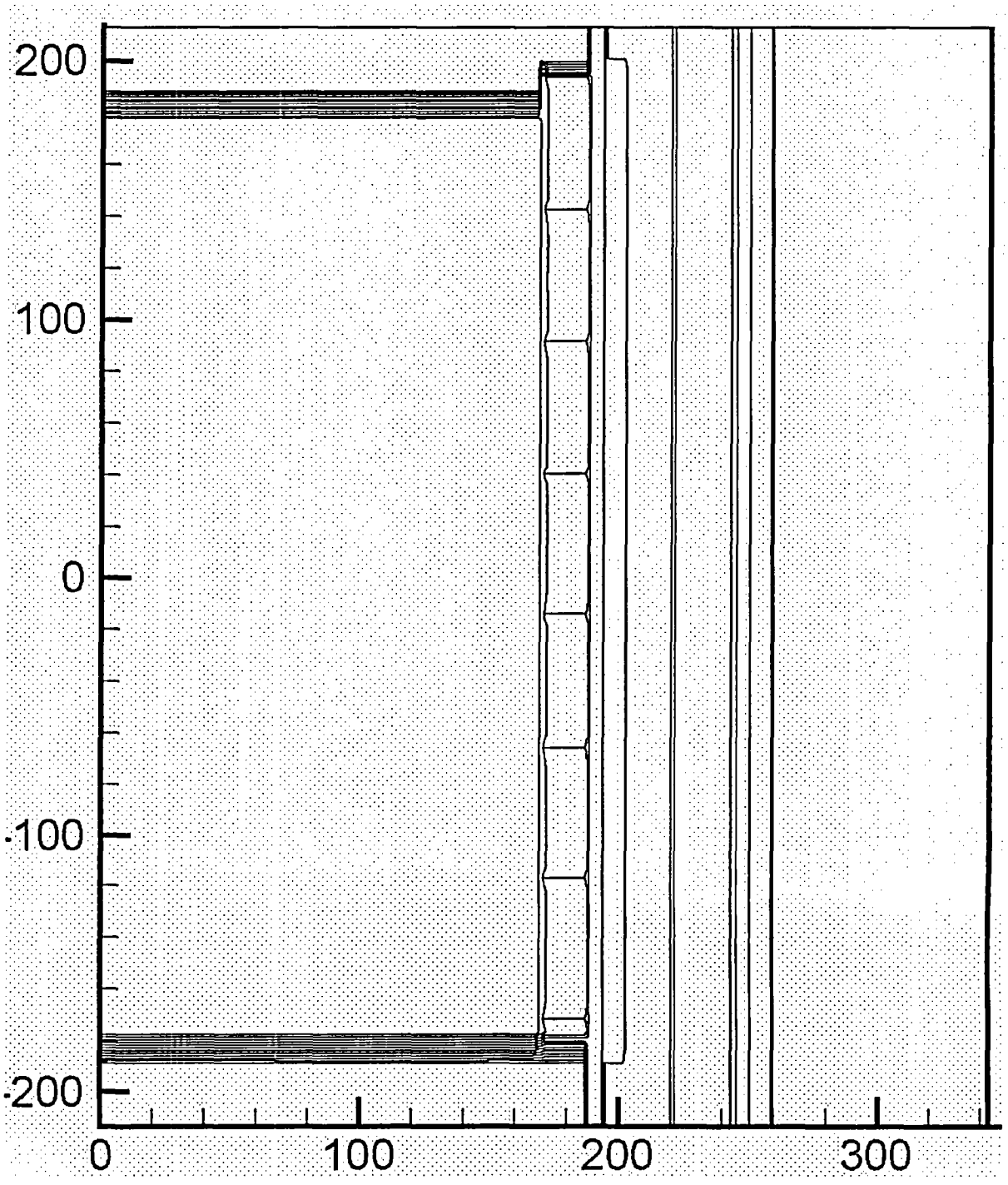



**Figure 6-3 Watts Bar r,z Reactor Geometry with Neutron Pad**

# 7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following surveillance capsule removal schedule meets the requirements of ASTM E185-82 [12] and is recommended for future capsules to be removed from the Watts Bar Unit 1 reactor vessel. This recommended removal schedule is applicable to 32 EFPY of operation.

**Table 7-1 Recommended Surveillance Capsule Withdrawal Schedule**

| Capsule | Capsule Location | Lead Factor[a] | Withdrawal EFPY[b] | Fluence (n/cm$^2$)[a] |
|---|---|---|---|---|
| U | 56° | 5.00 | 1.20 | $4.47 \times 10^{18}$[c] |
| W | 124° | 5.05 | 3.88 | $1.08 \times 10^{19}$[c] |
| X | 236° | 5.03 | 6.63 | $1.71 \times 10^{19}$[c] |
| Z | 304° | 5.06 | 9.37 | $2.40 \times 10^{19}$[c] |
| V | 58.5° | 4.31 | [d] | Standby |
| Y | 238.5° | 4.31 | [d] | Standby |

**Notes:**

a. Updated in Capsule Z dosimetry analysis.
b. Effective Full Power Years (EFPY) from plant startup.
c. Plant specific evaluation.
d. Section X1.M31, "Reactor Vessel Surveillance," of NUREG-1801[21] states that any surveillance capsules that are left in the reactor vessel should provide meaningful metallurgical data. The NRC specifically states that anything beyond 60 years of exposure is not meaningful metallurgical data. Capsules "V" and "Y" can be removed after 12.1 EFPY (Capsule exposure equivalent to 1 times the projected 48 EFPY Peak Vessel Fluence of $2.66 \times 10^{19}$n/cm$^2$, E > 1.0 MeV). It is recommended that these capsules be removed after approximately 15 EFPY of operation, with one capsule being tested to satisfy the requirements of the fourth capsule (in a four-capsule withdrawal schedule) for extended operating life, while the other should be placed in storage pending regulatory guidance for capsule reinsertion.

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

## A.1 NEUTRON DOSIMETRY

Comparisons of measured dosimetry results to both the calculated and least squares adjusted values for all surveillance capsules withdrawn from service to date at Watts Bar 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."[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 four neutron sensor sets analyzed to date as part of the Watts Bar 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 | 34° Dual | End of Cycle 1 | 1.20 |
| W | 34° Single | End of Cycle 3 | 3.88 |
| X | 34° Dual | End of Cycle 5 | 6.63 |
| Z | 34° Single | End of Cycle 7 | 9.37 |

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, W, and Z are summarized as follows:

| Sensor Material | Reaction Of Interest | Capsule U | Capsule W | Capsule X | Capsule Z |
|---|---|---|---|---|---|
| Copper | $^{63}Cu(n,\alpha)^{60}Co$ | X | X | X | X |
| Iron | $^{54}Fe(n,p)^{54}Mn$ | X | X | X | X |
| Nickel | $^{58}Ni(n,p)^{58}Co$ | X | X | X | X |
| Uranium-238 | $^{238}U(n,f)^{137}Cs$ | X | X | X | X |
| Neptunium-237 | $^{237}Np(n,f)^{137}Cs$ | X | X | X | X |
| Cobalt-Aluminum* | $^{59}Co(n,\gamma)^{60}Co$ | X | X | X | X |

Note:
* 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, 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, X, and W are documented in References A-2, A-3, and A-4, respectively. The radiometric counting of the sensors from Capsule Z was carried out by Pace Analytical Services, Inc., located at the Westinghouse Waltz Mill Site. 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, W, X, and Z was based on the monthly power generation of Watts Bar 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 Capsule Z 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:

$$R = \frac{A}{N_0 F Y \Sigma \frac{P_j}{P_{ref}} C_j [1 - e^{-\lambda t_j}][e^{-\lambda t_d}]}$$

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/gm).

$N_0$ = 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.

$\lambda$ = Decay constant of the product isotope (1/sec).

$t_j$ = Length of irradiation period j (sec).

$t_d$ = 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 Watts Bar fission sensor reaction rates are summarized as follows:

| Correction | Capsule U | Capsule W | Capsule X | Capsule Z |
|---|---|---|---|---|
| $^{235}U$ Impurity/Pu Build-in | 0.867 | 0.843 | 0.819 | 0.796 |
| $^{238}U(\gamma,f)$ | 0.964 | 0.964 | 0.964 | 0.966 |
| Net $^{238}U$ Correction | 0.836 | 0.813 | 0.789 | 0.769 |
| $^{237}Np(\gamma,f)$ | 0.990 | 0.990 | 0.990 | 0.990 |

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, W, X, and Z 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 $\phi(E > 1.0\ MeV)$ 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, $\phi_g$, through the multigroup dosimeter reaction cross-section, $\sigma_{ig}$, each with an uncertainty $\delta$. 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 Watts Bar surveillance capsule dosimetry, the FERRET code[A-5] 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 Watts Bar 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[A-6]. 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)". [A-7]

The uncertainties associated with the measured reaction rates, dosimetry cross-sections, and calculated neutron spectrum were input to the least squares procedure in the form of variances and covariances. The assignment of the input uncertainties followed the guidance provided in ASTM Standard E944, "Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance." [A-8]

The following provides a summary of the uncertainties associated with the least squares evaluation of the Watts Bar 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 $1\sigma$ 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 Watts Bar 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 $\gamma$ ($\theta$ specifies the strength of the latter term). The value of $\delta$ is 1.0 when $g = g'$, and is 0.0 otherwise.

The set of parameters defining the input covariance matrix for the Watts Bar 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) | 29% |
| (E < 0.68 eV) | 52% |

Short Range Correlation ($\theta$)

| | |
|---|---|
| (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 ($\gamma$)

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

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

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

In the case of the direct comparison of measured and calculated sensor reaction rates, the M/C comparisons for fast neutron reactions range from 0.92 to 1.29 for the 20 samples included in the data set. The overall average M/C ratio for the entire set of Watts Bar data is 1.05 with an associated standard deviation of 11.65%.

In the comparisons of best estimate and calculated fast neutron exposure parameters, the corresponding BE/C comparisons for the capsule data sets range from 0.92 to 1.15 for neutron flux (E > 1.0 MeV) and from 0.94 to 1.18 for iron atom displacement rate. The overall average BE/C ratios for neutron flux (E > 1.0 MeV) and iron atom displacement rate are 1.03 with a standard deviation of 9.82% and 1.06 with a standard deviation of 10.52%, 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 Watts Bar 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 Watts Bar 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 Cycles 6 and 7 of the Watts Bar Reactor

| Cycle 1 | | Cycle 2 | | Cycle 3 | |
|---|---|---|---|---|---|
| Month | Thermal Generation [MW-Hr] | Month | Thermal Generation [MW-Hr] | Month | Thermal Generation [MW-Hr] |
| Jan-96 | 9519 | Oct-97 | 709914 | Apr-99 | 1068631 |
| Feb-96 | 49773 | Nov-97 | 2449654 | May-99 | 2454763 |
| Mar-96 | 475248 | Dec-97 | 2527971 | Jun-99 | 2454685 |
| Apr-96 | 999029 | Jan-98 | 2523492 | Jul-99 | 2536887 |
| May-96 | 1713718 | Feb-98 | 2142012 | Aug-99 | 2526645 |
| Jun-96 | 2348718 | Mar-98 | 2180599 | Sep-99 | 2455157 |
| Jul-96 | 2523691 | Apr-98 | 2370444 | Oct-99 | 2540350 |
| Aug-96 | 2525629 | May-98 | 2535488 | Nov-99 | 2454874 |
| Sep-96 | 2184725 | Jun-98 | 2445551 | Dec-99 | 2536956 |
| Oct-96 | 1114619 | Jul-98 | 2531951 | Jan-00 | 2536601 |
| Nov-96 | 2202224 | Aug-98 | 2486237 | Feb-00 | 2373327 |
| Dec-96 | 2523130 | Sep-98 | 2429447 | Mar-00 | 2536915 |
| Jan-97 | 1956638 | Oct-98 | 2470835 | Apr-00 | 2451520 |
| Feb-97 | 2147746 | Nov-98 | 2452741 | May-00 | 2536436 |
| Mar-97 | 1645462 | Dec-98 | 2535907 | Jun-00 | 2455171 |
| Apr-97 | 2236507 | Jan-99 | 2280206 | Jul-00 | 2534880 |
| May-97 | 2519097 | Feb-99 | 1519605 | Aug-00 | 2279989 |
| Jun-97 | 2237128 | Mar-99 | 0 | Sep-00 | 570521 |
| Jul-97 | 2399891 | | | | |
| Aug-97 | 1934439 | | | | |
| Sep-97 | 262258 | | | | |
| Total | 36009189 | Total | 38592054 | Total | 41304308 |
| [EFPS] | 3.800E+07 | [EFPS] | 4.073E+07 | [EFPS] | 4.359E+07 |
| [EFPY] | 1.204 | [EFPY] | 1.291 | [EFPY] | 1.381 |
| To Date | | To Date | | To Date | |
| [EFPS] | 3.800E+07 | [EFPS] | 7.873E+07 | [EFPS] | 1.223E+08 |
| [EFPY] | 1.204 | [EFPY] | 2.495 | [EFPY] | 3.876 |

Table A-2 (cont.) Monthly Thermal Generation During Cycles 6 and 7 of the Watts Bar Reactor

| Cycle 4 | | Cycle 5 | |
|---|---|---|---|
| Month | Thermal Generation [MW-Hr] | Month | Thermal Generation [MW-Hr] |
| Oct-00 | 1906668 | Mar-02 | 759955 |
| Nov-00 | 2455222 | Apr-02 | 2486032 |
| Dec-00 | 2536907 | May-02 | 2041632 |
| Jan-01 | 2539043 | Jun-02 | 2489640 |
| Feb-01 | 2323719 | Jul-02 | 2440231 |
| Mar-01 | 2571100 | Aug-02 | 2572406 |
| Apr-01 | 2486145 | Sep-02 | 2489113 |
| May-01 | 2572676 | Oct-02 | 2573865 |
| Jun-01 | 2384162 | Nov-02 | 2489493 |
| Jul-01 | 1723109 | Dec-02 | 2547822 |
| Aug-01 | 2572727 | Jan-03 | 2572408 |
| Sep-01 | 2298210 | Feb-03 | 2322599 |
| Oct-01 | 2576028 | Mar-03 | 2052502 |
| Nov-01 | 2489629 | Apr-03 | 2485939 |
| Dec-01 | 2423020 | May-03 | 2572277 |
| Jan-02 | 2572218 | Jun-03 | 2487655 |
| Feb-02 | 1970262 | Jul-03 | 2570050 |
| | | Aug-03 | 2409124 |
| | | Sep-03 | 485359 |
| Total | 40400845 | Total | 42848102 |
| [EFPS] | 4.217E+07 | [EFPS] | 4.459E+07 |
| [EFPY] | 1.336 | [EFPY] | 1.413 |
| To Date | | To Date | |
| [EFPS] | 1.645E+08 | [EFPS] | 2.091E+08 |
| [EFPY] | 5.213 | [EFPY] | 6.626 |

| Table A-2 (cont.) Monthly Thermal Generation During Cycles 6 and 7 of the Watts Bar Reactor | | | |
|---|---|---|---|
| **Date** | **MW-Thermal** | | |
| Sep-2003 | 0 | Note September 2003 for cycle 6 was zero. | |
| Oct-2003 | 797,571 | | |
| Nov-2003 | 2,489,411 | | |
| Dec-2003 | 2,572,114 | | |
| Jan-2004 | 2,356,325 | | |
| Feb-2004 | 2,406,294 | | |
| Mar-2004 | 2,572,166 | | |
| Apr-2004 | 2,483,973 | | |
| May-2004 | 2,568,656 | | |
| Jun-2004 | 2,489,087 | | |
| Jul-2004 | 2,571,263 | | |
| Aug-2004 | 2,571,859 | | |
| Sep-2004 | 2,198,177 | | |
| Oct-2004 | 2,575,547 | | |
| Nov-2004 | 2,489,216 | | |
| Dec-2004 | 2,571,088 | | |
| Jan-2005 | 2,572,113 | Monthly Sum | EOC Report |
| Feb-2005 | 1,731,861 | 40,016,721 | 40,007,084 |
| CYCLE 6 ABOVE | | Note Round-off error is the difference between these two numbers. | |
| Mar-2005 | 3,388 | | |
| Apr-2005 | 2,375,517 | | |
| May-2005 | 2,571,958 | | |
| Jun-2005 | 2,488,183 | | |
| Jul-2005 | 2,572,181 | | |
| Aug-2005 | 2,572,139 | | |
| Sep-2005 | 2,361,712 | | |
| Oct-2005 | 2,575,678 | | |
| Nov-2005 | 2,489,136 | | |
| Dec-2005 | 2,572,013 | | |
| Jan-2006 | 2,570,408 | | |
| Feb-2006 | 2,147,690 | | |

| Table A-2 (cont.) Monthly Thermal Generation During Cycles 6 and 7 of the Watts Bar Reactor | | | |
|---|---|---|---|
| **Date** | **MW-Thermal** | | |
| Mar-2006 | 2,517,604 | | |
| Apr-2006 | 2,485,651 | | |
| May-2006 | 2,465,114 | | |
| Jun-2006 | 394,229 | | |
| Jul-2006 | 2,508,244 | | |
| Aug-2006 | 2,184,917 | Monthly Sum | EOC Report |
| Sep-2006 | 809,562 | 40,665,324 | 40,655,860 |
| CYCLE 7 ABOVE | | Note Round-off error is the difference between these two numbers. | |

| Table A-3 | Calculated $C_j$ Factors at the Surveillance Capsule Center Core Midplane Elevation | | | | |
|---|---|---|---|---|---|
| | Cycle Length | Fast Neutron Flux (E > 1.0 MeV) | | | |
| Cycle | EFPS | Capsule U | Capsule W | Capsule X | Capsule Z |
| 1 | 3.80E+07 | 1.18E+11 | 1.19E+11 | 1.18E+11 | 1.19E+11 |
| 2 | 4.07E+07 | | 7.44E+10 | 7.34E+10 | 7.44E+10 |
| 3 | 4.36E+07 | | 7.39E+10 | 7.28E+10 | 7.39E+10 |
| 4 | 4.22E+07 | | | 8.36E+10 | 8.48E+10 |
| 5 | 4.46E+07 | | | 6.52E+10 | 6.61E+10 |
| 6 | 4.59E+07 | | | | 7.15E+10 |
| 7 | 4.07E+07 | | | | 8.37E+10 |
| | Average | 1.18E+11 | 8.92E+10 | 8.25E+10 | 8.20E+10 |
| | Cycle Length | | | $C_j$ | |
| Cycle | EFPS | Capsule U | Capsule W | Capsule X | Capsule Z |
| 1 | 3.80E+07 | 1.00 | 1.34 | 1.42 | 1.46 |
| 2 | 4.07E+07 | | 0.83 | 0.89 | 0.91 |
| 3 | 4.36E+07 | | 0.83 | 0.88 | 0.90 |
| 4 | 4.22E+07 | | | 1.01 | 1.03 |
| 5 | 4.46E+07 | | | 0.79 | 0.81 |
| 6 | 4.59E+07 | | | | 0.87 |
| 7 | 4.07E+07 | | | | 1.02 |
| | Average | 1.00 | 1.00 | 1.00 | 1.00 |

| Table A-4 Measured Sensor Activities and Reaction Rates | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Surveillance Capsule Z | | | | | | | | |
| Capsule Z – 34 Degrees – Single Capsule Pad Segment – EOC 7 | | | | | | | | |
| Sample | Location | Target Isotope | Product Isotope | Measured Activity [dps/g] | Saturated Activity [dps/g] | Reaction Rate [rps/atom] | Average Reaction Rate [rps/atom] | Corrected Average Reaction Rate [rps/atom] |
| Cu | Top | Cu-63 | Co-60 | 1.62E+05 | 2.70E+05 | 4.11E-17 | | |
| Cu | Middle | Cu-63 | Co-60 | 1.67E+05 | 2.78E+05 | 4.24E-17 | | |
| Cu | Bottom | Cu-63 | Co-60 | 1.61E+05 | 2.68E+05 | 4.09E-17 | 4.15E-17 | 4.148E-17 |
| Iron | Top | Fe-54 | Mn-54 | 1.35E+06 | 2.63E+06 | 4.17E-15 | | |
| Iron | Middle | Fe-54 | Mn-54 | 1.38E+06 | 2.69E+06 | 4.27E-15 | | |
| Iron | Bottom | Fe-54 | Mn-54 | 1.35E+06 | 2.63E+06 | 4.17E-15 | 4.20E-15 | 4.203E-15 |
| Ni | Top | Ni-58 | Co-58 | 3.14E+06 | 4.05E+07 | 5.80E-15 | | |
| Ni | Middle | Ni-58 | Co-58 | 3.17E+06 | 4.09E+07 | 5.85E-15 | | |
| Ni | Bottom | Ni-58 | Co-58 | 3.09E+06 | 3.99E+07 | 5.70E-15 | 5.78E-15 | 5.784E-15 |
| U-238 (Cd) | Middle | U-238 (Cd) | Cs-137 | 9.49E+05 | 5.04E+06 | 3.31E-14 | 3.31E-14 | 2.467E-14 |
| Np-237 (Cd) | Middle | Np-237 (Cd) | Cs-137 | 7.14E+06 | 3.80E+07 | 2.42E-13 | 2.42E-13 | 2.397E-13 |
| Bare Co | Top | Co-59 | Co-60 | 3.60E+07 | 5.99E+07 | 3.91E-12 | | |
| Bare Co | Top | Co-59 | Co-60 | 2.99E+07 | 4.98E+07 | 3.25E-12 | | |
| Bare Co | Middle | Co-59 | Co-60 | 2.92E+07 | 4.86E+07 | 3.17E-12 | | |
| Bare Co | Middle | Co-59 | Co-60 | 3.28E+07 | 5.46E+07 | 3.56E-12 | | |
| Bare Co | Bottom | Co-59 | Co-60 | 3.02E+07 | 5.03E+07 | 3.28E-12 | | |
| Bare Co | Bottom | Co-59 | Co-60 | 3.47E+07 | 5.78E+07 | 3.77E-12 | 3.49E-12 | 3.490E-12 |
| Co (Cd) | Top | Co-59 (Cd) | Co-60 | 1.84E+07 | 3.06E+07 | 2.00E-12 | | |
| Co (Cd) | Middle | Co-59 (Cd) | Co-60 | 1.75E+07 | 2.91E+07 | 1.90E-12 | | |
| Co (Cd) | Bottom | Co-59 (Cd) | Co-60 | 1.78E+07 | 2.96E+07 | 1.93E-12 | 1.94E-12 | 1.944E-12 |

Notes: 1) Measured specific activities are indexed to a counting date of January 30, 1998.

2) The average U-238 (n,f) reaction rate includes a correction factor of 0.796 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 N-237 (n,f) reaction rate includes a correction factor of 0.990 to account for photo-fission effects in the sensor.

**Table A-4 (cont.) Measured Sensor Activities and Reaction Rates Surveillance Capsule U**

| Location | Target Isotope | Product Isotope | Measured Actitivy (dps/g) | Saturated Actitivy (dps/g) | Reaction Rate (rps/atom) | Averaged Reaction Rate (rps/atom) | Corrected Averaged Reaction Rate (rps/atom) |
|---|---|---|---|---|---|---|---|
| Top | Cu-63 | Co-60 | 5.05E+04 | 3.684E+05 | 5.620E-17 | | |
| Middle | Cu-63 | Co-60 | 5.34E+04 | 3.895E+05 | 5.942E-17 | | |
| Bottom | Cu-63 | Co-60 | 5.25E+04 | 3.829E+05 | 5.842E-17 | 5.801E-17 | 5.801E-17 |
| Top | Fe-54 | Mn-54 | 1.62E+06 | 3.855E+06 | 6.111E-15 | | |
| Middle | Fe-54 | Mn-54 | 1.71E+06 | 4.069E+06 | 6.450E-15 | | |
| Bottom | Fe-54 | Mn-54 | 1.71E+06 | 4.069E+06 | 6.450E-15 | 6.337E-15 | 6.337E-15 |
| Top | Ni-58 | Co-58 | 1.20E+07 | 5.968E+07 | 8.544E-15 | | |
| Middle | Ni-58 | Co-58 | 1.25E+07 | 6.217E+07 | 8.900E-15 | | |
| Bottom | Ni-58 | Co-58 | 1.26E+07 | 6.267E+07 | 8.971E-15 | 8.805E-15 | 8.805E-15 |
| Top | Co-59 | Co-60 | 1.55E+07 | 1.131E+08 | 7.376E-12 | | |
| Top | Co-59 | Co-60 | 1.28E+07 | 9.337E+07 | 6.091E-12 | | |
| Middle | Co-59 | Co-60 | 1.43E+07 | 1.043E+08 | 6.805E-12 | | |
| Middle | Co-59 | Co-60 | 1.19E+07 | 8.680E+07 | 5.663E-12 | | |
| Bottom | Co-59 | Co-60 | 1.41E+07 | 1.028E+08 | 6.710E-12 | | |
| Bottom | Co-59 | Co-60 | 1.22E+07 | 8.899E+07 | 5.806E-12 | 6.409E-12 | 6.409E-12 |
| Top | Co-59 Cd | Co-60 | 7.59E+06 | 5.536E+07 | 3.612E-12 | | |
| Middle | Co-59 Cd | Co-60 | 7.06E+06 | 5.150E+07 | 3.360E-12 | | |
| Bottom | Co-59 Cd | Co-60 | 7.10E+06 | 5.179E+07 | 3.379E-12 | 3.450E-12 | 3.450E-12 |
| | U-238 | Cs-137 | 2.34E+05 | 8.647E+06 | 5.678E-14 | 5.678E-14 | 4.744E-14 |
| | Np-237 | Cs-137 | 1.94E+06 | 7.169E+07 | 4.574E-13 | 4.574E-13 | 4.528E-13 |

Notes: 1) Measured specific activities are indexed to a counting date of January 30, 1998.
2) The average $^{238}U$ (n,f) reaction rate of 4.744E-14 includes a correction factor of 0.867 to account for plutonium build-in and an additional factor of 0.964 to account for photo-fission effects in the sensor.
3) The average $^{237}Np$ (n,f) reaction rate of 4.528E-13 includes a correction factor of 0.990 to account for photo-fission effects in the sensor.

**Table A-4 (cont.) Measured Sensor Activities and Reaction Rates Surveillance Capsule U**

| Location | Target Isotope | Product Isotope | Measured Actitivy (micro-Ci/g) | Measured Actitivy (dps/g) | Saturated Actitivy (dps/g) | Reaction Rate (rps/atom) | Averaged Reaction Rate (rps/atom) | Corrected Averaged Reaction Rate (rps/atom) |
|---|---|---|---|---|---|---|---|---|
| Top | Cu-63 | Co-60 | 4.975 | 1.84E+05 | 4.874E+05 | 5.143E-17 | | |
| Middle | Cu-63 | Co-60 | 5.265 | 1.95E+05 | 5.166E+05 | 5.451E-17 | | |
| Bottom | Cu-63 | Co-60 | 5.232 | 1.94E+05 | 5.139E+05 | 5.423E-17 | 5.339E-17 | 5.339E-17 |
| Top | Fe-54 | Mn-54 | 1251 | 4.63E+07 | 5.950E+07 | 5.519E-15 | | |
| Middle | Fe-54 | Mn-54 | 1308 | 4.84E+07 | 6.220E+07 | 5.769E-15 | | |
| Bottom | Fe-54 | Mn-54 | 1269 | 4.70E+07 | 6.040E+07 | 5.602E-15 | 5.630E-15 | 5.630E-15 |
| Top | Ni-58 | Co-58 | 1664 | 6.16E+07 | 7.787E+07 | 7.592E-15 | | |
| Middle | Ni-58 | Co-58 | 1713 | 6.34E+07 | 8.015E+07 | 7.814E-15 | | |
| Bottom | Ni-58 | Co-58 | 1665 | 6.16E+07 | 7.787E+07 | 7.592E-15 | 7.666E-15 | 7.666E-15 |
| Top | Co-59 | Co-60 | 5.483E+05 | 2.03E+10 | 5.378E+10 | 5.262E-12 | | |
| Top | Co-59 | Co-60 | 4.803E+05 | 1.78E+10 | 4.715E+10 | 4.614E-12 | | |
| Middle | Co-59 | Co-60 | 5.070E+05 | 1.88E+10 | 4.980E+10 | 4.874E-12 | | |
| Middle | Co-59 | Co-60 | 4.191E+05 | 1.55E+10 | 4.106E+10 | 4.018E-12 | | |
| Bottom | Co-59 | Co-60 | 5.247E+05 | 1.94E+10 | 5.139E+10 | 5.029E-12 | | |
| Bottom | Co-59 | Co-60 | 4.432E+05 | 1.64E+10 | 4.344E+10 | 4.251E-12 | 4.675E-12 | 4.675E-12 |
| Top | Co-59 Cd | Co-60 | 2.740E+05 | 1.01E+10 | 2.676E+10 | 2.618E-12 | | |
| Middle | Co-59 Cd | Co-60 | 2.616E+05 | 9.68E+09 | 2.564E+10 | 2.509E-12 | | |
| Bottom | Co-59 Cd | Co-60 | 2.690E+05 | 9.95E+09 | 2.636E+10 | 2.579E-12 | 2.569E-12 | 2.569E-12 |
| | U-238 | Cs-137 | 9.13 | 3.97E+05 | 4.694E+06 | 3.082E-14 | 3.082E-14 | 2.504E-14 |
| | Np-237 | Cs-137 | 124.8 | 4.62E+06 | 5.462E+07 | 3.485E-13 | 3.485E-13 | 3.450E-13 |

Notes: 1) Measured specific activities are indexed to a counting date of September 10. 2000.
2) The average $^{238}U$ (n,f) reaction rate of 2.504E-14 includes a correction factor of 0.843 to account for plutonium build-in and an additional factor of 0.964 to account for photo-fission effects in the sensor.
3) The average $^{237}Np$ (n,f) reaction rate of 3.450E-13 includes a correction factor of 0.990 to account for photo-fission effects in the sensor.

**Table A-4 (cont.) Measured Sensor Activities and Reaction Rates Surveillance Capsule U**

| Location | Target Isotope | Product Isotope | Measured Actitivy (dps/g) | Saturated Actitivy (dps/g) | Reaction Rate (rps/atom) | Averaged Reaction Rate (rps/atom) | Corrected Averaged Reaction Rate (rps/atom) |
|---|---|---|---|---|---|---|---|
| Top | Cu-63 | Co-60 | 1.52E+05 | 2.889E+05 | 4.408E-17 | | |
| Middle | Cu-63 | Co-60 | 1.55E+05 | 2.946E+05 | 4.495E-17 | | |
| Bottom | Cu-63 | Co-60 | 1.56E+05 | 2.965E+05 | 4.524E-17 | 4.476E-17 | 4.476E-17 |
| Top | Fe-54 | Mn-54 | 1.84E+06 | 2.723E+06 | 4.316E-15 | | |
| Middle | Fe-54 | Mn-54 | 1.96E+06 | 2.900E+06 | 4.597E-15 | | |
| Bottom | Fe-54 | Mn-54 | 1.90E+06 | 2.811E+06 | 4.456E-15 | 4.456E-15 | 4.456E-15 |
| Top | Ni-58 | Co-58 | 1.59E+07 | 4.495E+07 | 6.436E-15 | | |
| Middle | Ni-58 | Co-58 | 1.68E+07 | 4.750E+07 | 6.800E-15 | | |
| Bottom | Ni-58 | Co-58 | 1.69E+07 | 4.778E+07 | 6.840E-15 | 6.692E-15 | 6.692E-15 |
| Top | Co-59 | Co-60 | 3.13E+07 | 5.950E+07 | 3.882E-12 | | |
| Top | Co-59 | Co-60 | 3.54E+07 | 6.729E+07 | 4.390E-12 | | |
| Middle | Co-59 | Co-60 | 3.35E+07 | 6.748E+07 | 4.403E-12 | | |
| Middle | Co-59 | Co-60 | 2.75E+07 | 5.228E+07 | 3.411E-12 | | |
| Bottom | Co-59 | Co-60 | 2.93E+07 | 5.570E+07 | 3.634E-12 | | |
| Bottom | Co-59 | Co-60 | 3.41E+07 | 6.482E+07 | 4.229E-12 | 3.991E-12 | 3.991E-12 |
| Top | Co-59 Cd | Co-60 | 1.87E+07 | 3.555E+07 | 2.319E-12 | | |
| Middle | Co-59 Cd | Co-60 | 1.79E+07 | 3.403E+07 | 2.220E-12 | 2.270E-12 | 2.270E-12 |
| Bottom | Co-59 Cd | Co-60 | --- | | | | |
| | U-238 | Cs-137 | 6.61E+05 | 4.759E+06 | 3.125E-14 | 3.125E-14 | 2.467E-14 |
| | Np-237 | Cs-137 | 5.82E+06 | 4.190E+07 | 2.673E-13 | 2.673E-13 | 2.646E-13 |

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 2.467E-14 includes a correction factor of 0.819 to account for plutonium build-in and an additional factor of 0.964 to account for photo-fission effects in the sensor.
3) The average $^{237}Np$ (n,f) reaction rate of 2.646E-13 includes a correction factor of 0.990 to account for photo-fission effects in the sensor.

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

**Capsule U**

| Reaction | Reaction Rate [rps/atom] Measured | Calculated | Best Estimate | M/C | M/BE |
|---|---|---|---|---|---|
| $^{63}Cu(n,\alpha)^{60}Co$ | 5.80E-17 | 5.45E-17 | 5.65E-17 | 1.06 | 1.03 |
| $^{54}Fe(n,p)^{54}Mn$ | 6.34E-15 | 6.48E-15 | 6.50E-15 | 0.98 | 0.97 |
| $^{58}Ni(n,p)^{58}Co$ | 8.81E-15 | 9.18E-15 | 9.24E-15 | 0.96 | 0.95 |
| $^{238}U(n,f)^{137}Cs$ (Cd) | 4.74E-14 | 3.66E-14 | 3.99E-14 | 1.29 | 1.19 |
| $^{237}Np(n,f)^{137}Cs$ (Cd) | 4.53E-13 | 3.76E-13 | 4.49E-13 | 1.20 | 1.01 |
| $^{59}Co(n,\gamma)^{60}Co$ | 6.41E-12 | 5.58E-12 | 6.38E-12 | 1.15 | 1.00 |
| $^{59}Co(n,\gamma)^{60}Co$ (Cd) | 3.45E-12 | 3.90E-12 | 3.47E-12 | 0.89 | 1.00 |

**Note:**

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

**Capsule W**

| Reaction | Reaction Rate [rps/atom] Measured | Calculated | Best Estimate | M/C | M/BE |
|---|---|---|---|---|---|
| $^{63}Cu(n,\alpha)^{60}Co$ | 5.34E-17 | 4.20E-17 | 5.28E-17 | 1.27 | 1.01 |
| $^{54}Fe(n,p)^{54}Mn$ | 5.63E-15 | 4.86E-15 | 5.54E-15 | 1.16 | 1.02 |
| $^{58}Ni(n,p)^{58}Co$ | 7.67E-15 | 6.88E-15 | 7.70E-15 | 1.12 | 1.00 |
| $^{238}U(n,f)^{137}Cs$ (Cd) | 2.50E-14 | 2.73E-14 | 2.90E-14 | 0.92 | 0.86 |
| $^{237}Np(n,f)^{137}Cs$ (Cd) | 3.45E-13 | 2.85E-13 | 3.24E-13 | 1.21 | 1.06 |
| $^{59}Co(n,\gamma)^{60}Co$ | 4.67E-12 | 3.80E-12 | 4.65E-12 | 1.23 | 1.01 |
| $^{59}Co(n,\gamma)^{60}Co$ (Cd) | 2.57E-12 | 2.75E-12 | 2.58E-12 | 0.93 | 0.99 |

**Note:**

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

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

**Capsule X**

| | Reaction Rates [rps/atom] | | | | |
|---|---|---|---|---|---|
| | Measured | Calculated | Best Est. | M/C | M/BE |
| Cu-63(n,a)Co-60 Cd | 4.48E-17 | 4.07E-17 | 4.41E-17 | 1.10 | 1.02 |
| Fe-54(n,p)Mn-54 | 4.46E-15 | 4.65E-15 | 4.61E-15 | 0.96 | 0.97 |
| Ni-58(n,p)Co-58 Cd | 6.69E-15 | 6.55E-15 | 6.58E-15 | 1.02 | 1.02 |
| U-238(n,f)Cs-137 Cd | 2.47E-14 | 2.57E-14 | 2.50E-14 | 0.96 | 0.99 |
| Np-237(n,f)Cs-137 Cd | 2.65E-13 | 2.59E-13 | 2.60E-13 | 1.02 | 1.02 |
| Co-59(n,g)Co-60 | 3.99E-12 | 3.77E-12 | 3.98E-12 | 1.06 | 1.00 |
| Co-59(n,g)C0-60 Cd | 2.27E-12 | 2.63E-12 | 2.28E-12 | 0.86 | 1.00 |

**Note:**

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

Capsule Z

| | Reaction Rates | | | | | |
|---|---|---|---|---|---|---|
| | Measured | Calculated | Best Est. | M/C | BE/M | BE/C |
| Cu-63(n,a)Co-60 Cd | 4.15E-17 | 3.95E-17 | 4.06E-17 | 1.05 | 0.98 | 1.03 |
| Fe-54(n,p)Mn-54 | 4.20E-15 | 4.51E-15 | 4.26E-15 | 0.93 | 1.01 | 0.94 |
| Ni-58(n,p)Co-58 Cd | 5.78E-15 | 6.38E-15 | 5.95E-15 | 0.91 | 1.03 | 0.93 |
| U-238(n,f)Cs-137 Cd | 2.55E-14 | 2.52E-14 | 2.34E-14 | 1.01 | 0.92 | 0.93 |
| Np-237(n,f)Cs-137 Cd | 2.40E-13 | 2.62E-13 | 2.42E-13 | 0.92 | 1.01 | 0.92 |
| Co-59(n,g)Co-60 | 3.49E-12 | 3.47E-12 | 3.47E-12 | 1.01 | 0.99 | 1.00 |
| Co-59(n,g)C0-60 Cd | 1.94E-12 | 2.52E-12 | 1.95E-12 | 0.77 | 1.01 | 0.77 |

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

| Capsule ID | $\phi$(E > 1.0 MeV) [n/cm$^2$-s] | | | |
|---|---|---|---|---|
| | Calculated | Best Estimate | Uncertainty (1$\sigma$) | BE/C |
| U | 1.08E+11 | 1.35E+11 | 7% | 1.15 |
| W | 8.82E+10 | 9.35E+10 | 7% | 1.06 |
| X | 8.16E+10 | 8.02E+10 | 7% | 0.98 |
| Z | 8.19E+10 | 7.57E+10 | 7% | 0.92 |

**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 (1$\sigma$) | BE/C |
| U | 2.35E-10 | 2.78E-10 | 11% | 1.18 |
| W | 1.79E-10 | 1.96E-10 | 11% | 1.10 |
| X | 1.62E-10 | 1.62E-10 | 11% | 1.00 |
| Z | 1.64E-10 | 1.54E-10 | 11% | 0.94 |

**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**

| | | | M/C Ratio | |
|---|---|---|---|---|
| | **Capsule U** | **Capsule W** | **Capsule X** | **Capsule Z** |
| Cu-63(n,a)Co-60 Cd | 1.06 | 1.27 | 1.10 | 1.05 |
| Fe-54(n,p)Mn-54 | 0.98 | 1.16 | 0.96 | 0.93 |
| Ni-58(n,p)Co-58 Cd | 0.96 | 1.12 | 1.02 | 0.91 |
| U-238(n,f)Cs-137 Cd | 1.29 | 0.92 | 0.92 | 1.01 |
| Np-237(n,f)Cs-137 Cd | 1.20 | 1.21 | 1.02 | 0.92 |
| Average | 1.10 | 1.14 | 1.00 | 0.96 |
| % Standard Deviation | 14.29 | 13.32 | 6.84 | 6.68 |

**Note:**
The overall average M/C ratio for the set of 20 sensor measurements is 1.050 with an associated standard deviation of 11.65%.

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

| | BE/C Ratios | |
|---|---|---|
| **Capsule** | **Flux** | **Dpa/s** |
| U | 1.15 | 1.18 |
| W | 1.06 | 1.10 |
| X | 0.98 | 1.00 |
| Z | 0.92 | 0.94 |
| Average | 1.03 | 1.06 |
| % Standard Deviation | 9.82 | 10.52 |

## 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-15046, Revision 0, *Analysis of Capsule U from the Tennessee Valley Authority Watts Bar Unit 1 Reactor Vessel Radiation Surveillance Program*, June 1998.

A-3. WCAP-16245-NP, Revision 0, *Analysis of Capsule X from the Tennessee Valley Authority Watts Bar Unit 1 Reactor Vessel Radiation Surveillance Program,* April 2004.

A-4. BWXT Report, Analysis of Capsule W from Tennessee Valley Authority Watts Bar Unit 1 Reactor Vessel Radiation Surveillance Program, W.A. Pavinich, dated 9/10/01.

A-5. A. Schmittroth, *FERRET Data Analysis Core*, HEDL-TME 79-40, Hanford Engineering Development Laboratory, Richland, WA, September 1979.

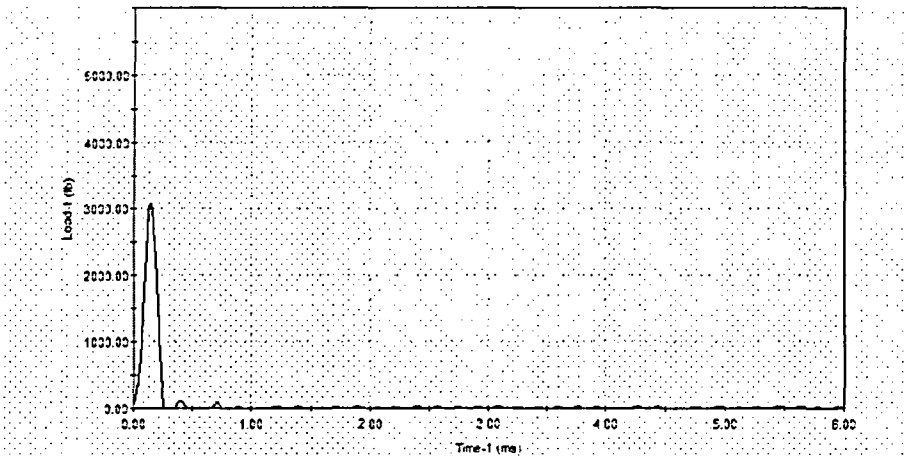
A-6. RSIC Data Library Collection DLC-178, *SNLRML Recommended Dosimetry Cross-Section Compendium,* July 1994.

A-7. ASTM E1018, *Application of ASTM Evaluated Cross-Section Data File, Matrix E 706 (IIB),* American Society for Testing and Materials.

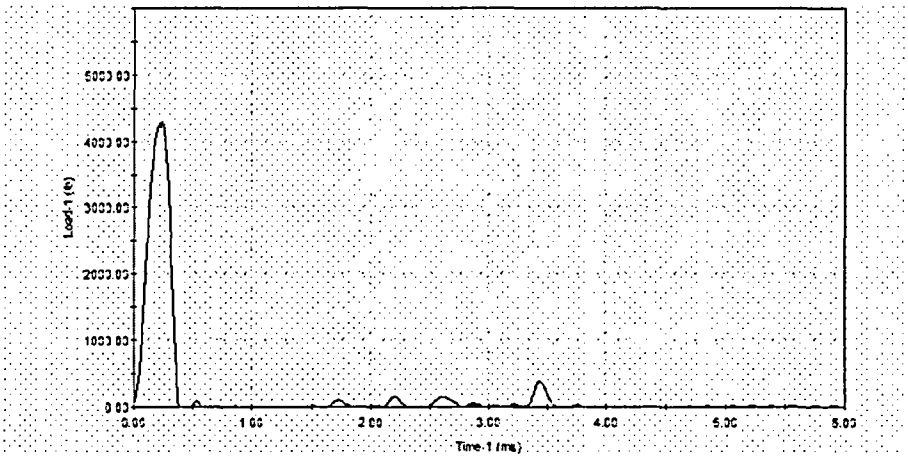
A-8. ASTM E944, *Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance,* American Society for Testing and Materials.

# APPENDIX B
# LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

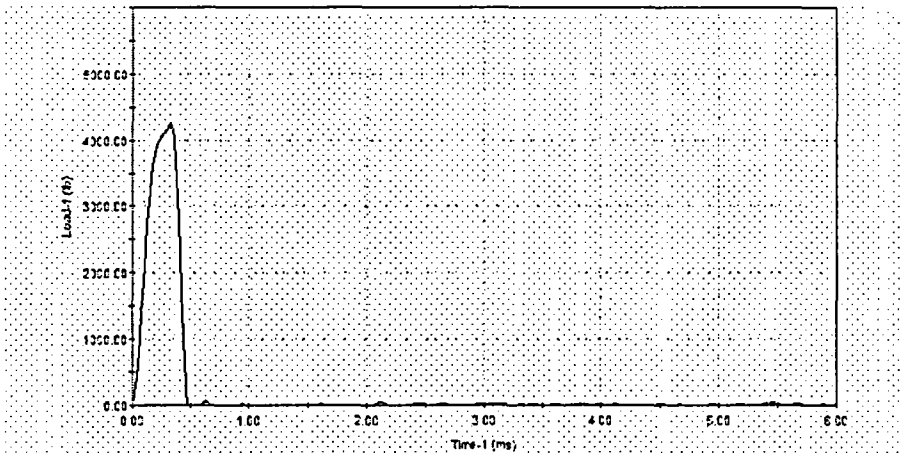
- Specimen prefix "WL" denotes Intermediate Shell Forging 05, Tangential Orientation
- Specimen prefix "WT" denotes Intermediate Shell Forging 05, Axial Orientation
- Specimen prefix "WW" denotes Weld Material
- Specimen prefix "WH" denotes Heat-Affected Zone material
- Load (1) is in units of lbs
- Time (1) is in units of milliseconds



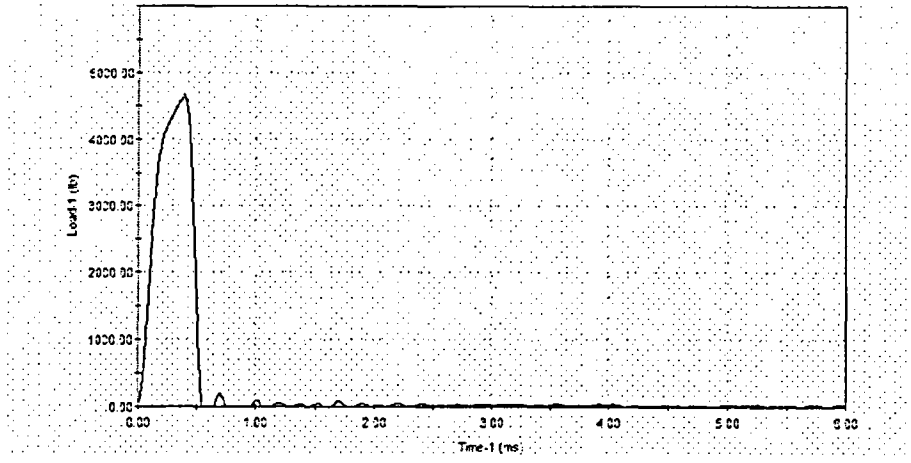

**WL90, -100°F**



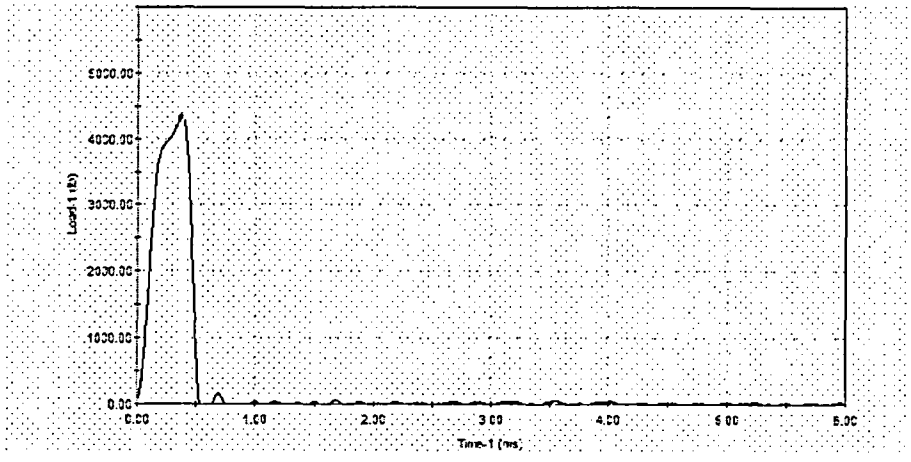

**WL83, 25°F**



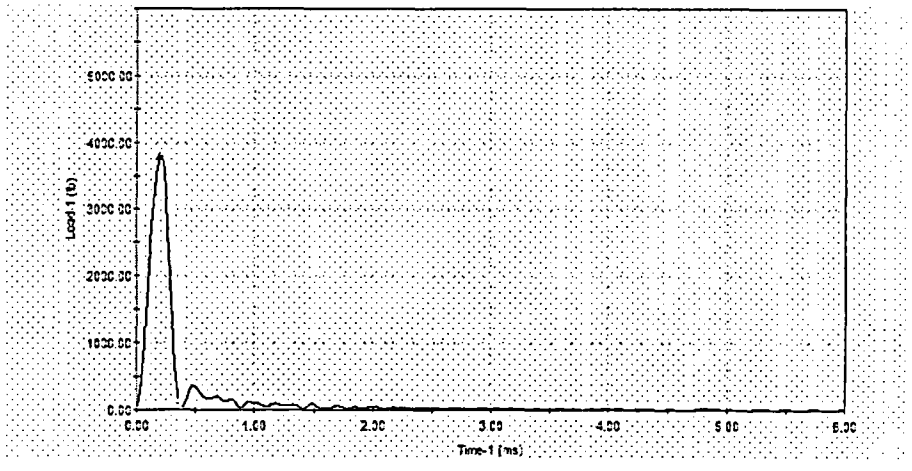

**WL84, 60°F**



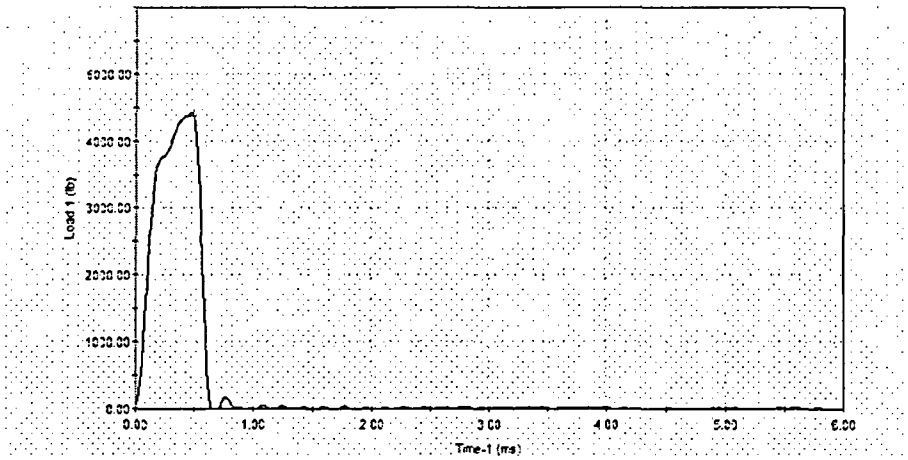

**WL87, 75°F**



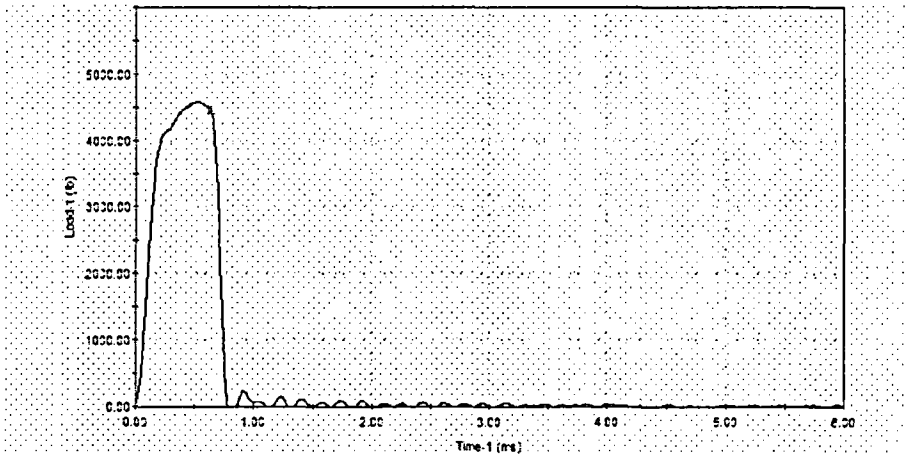

**WL80, 80°F**



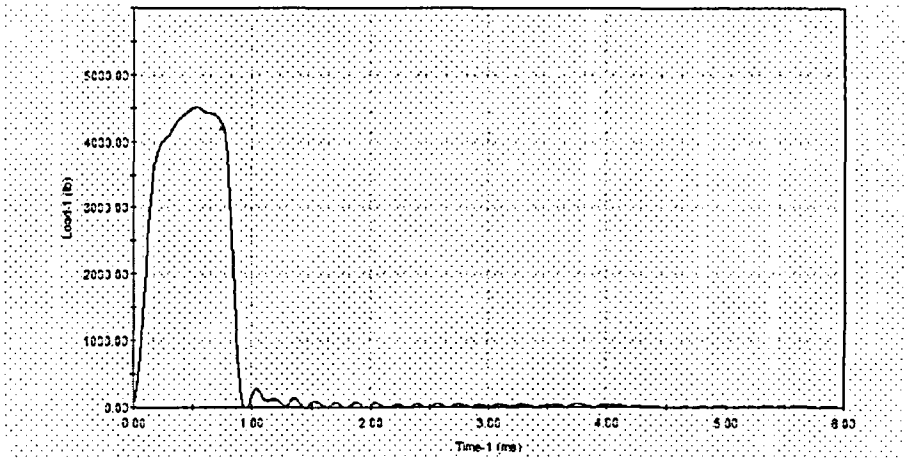

**WL79, 85°F**



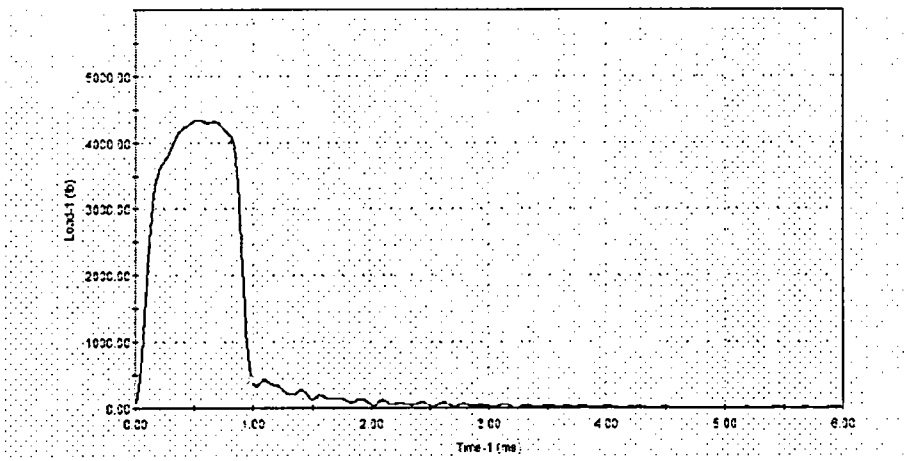

**WL77, 95°F**



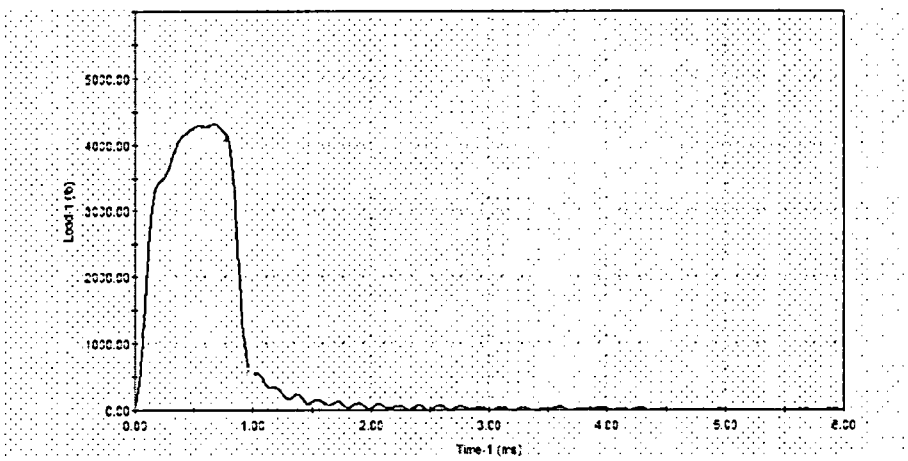

**WL85, 100°F**



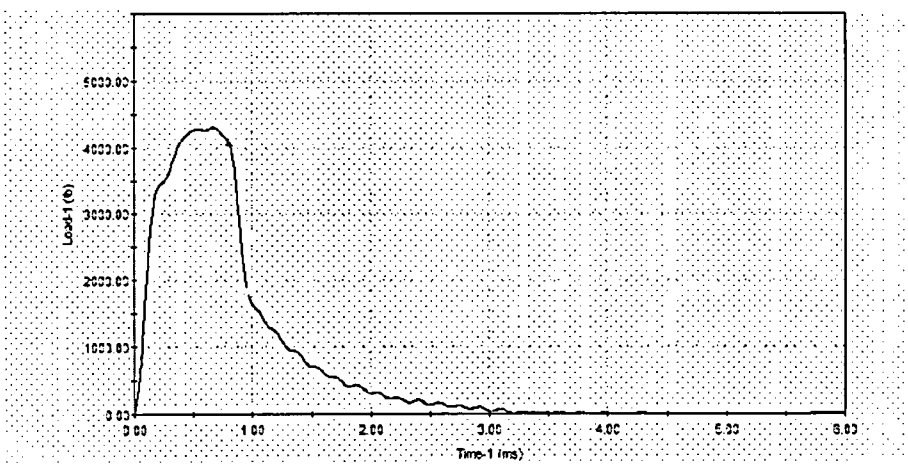

**WL88, 125°F**



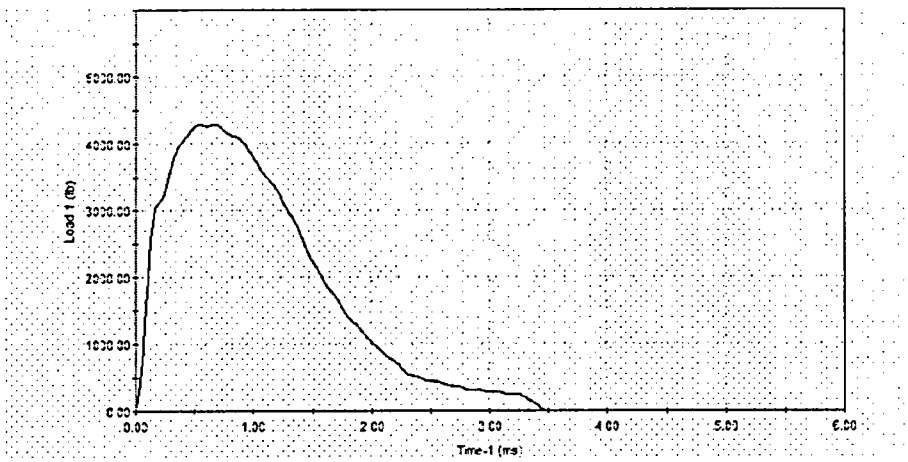

**WL76, 150°F**



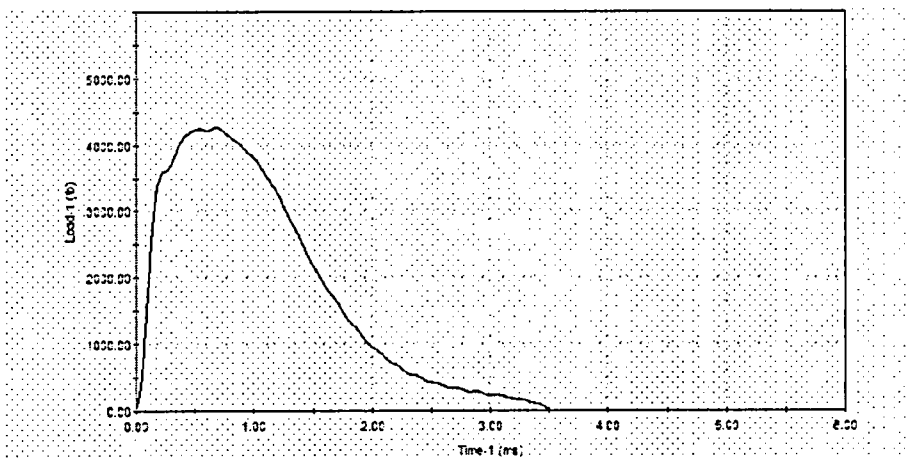

**WL81, 175°F**



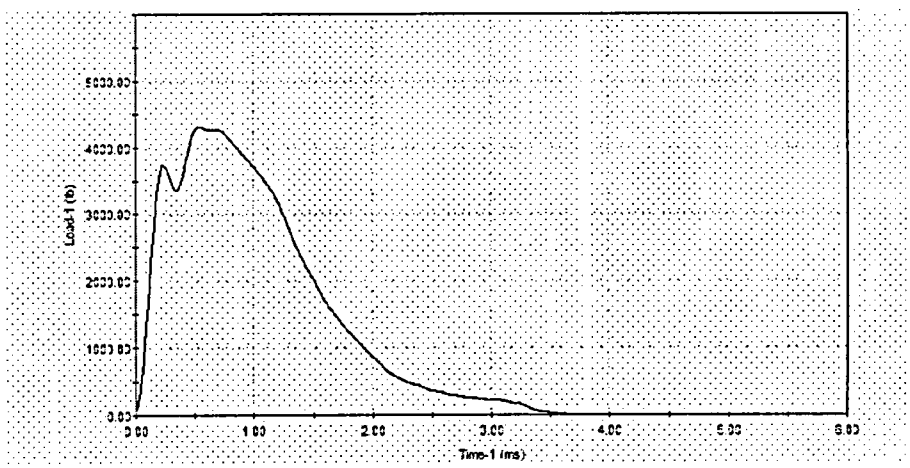

**WL78, 200°F**



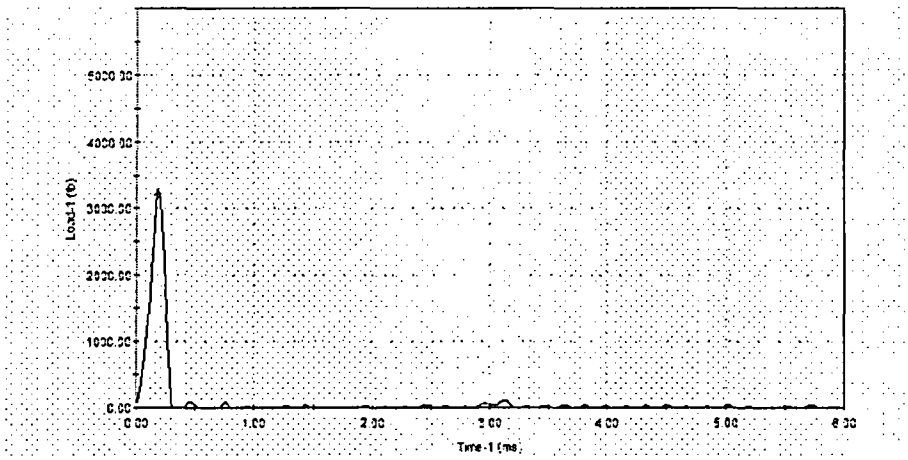

**WL82, 300°F**



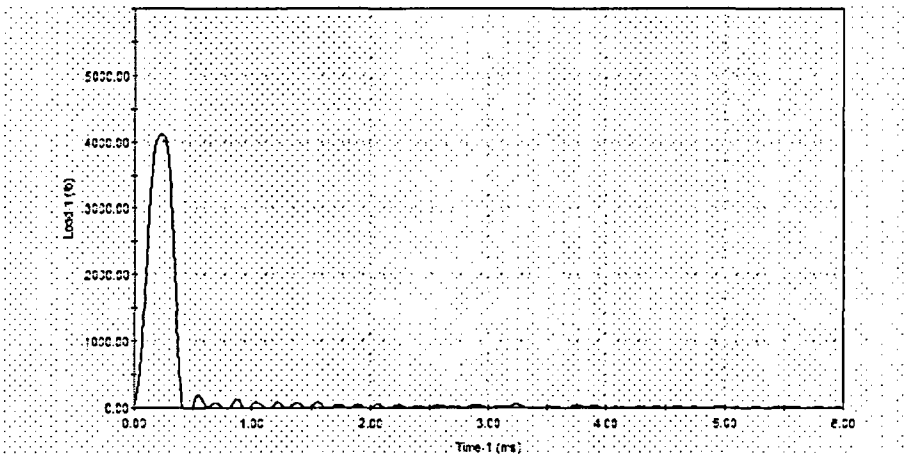

**WL86, 350°F**



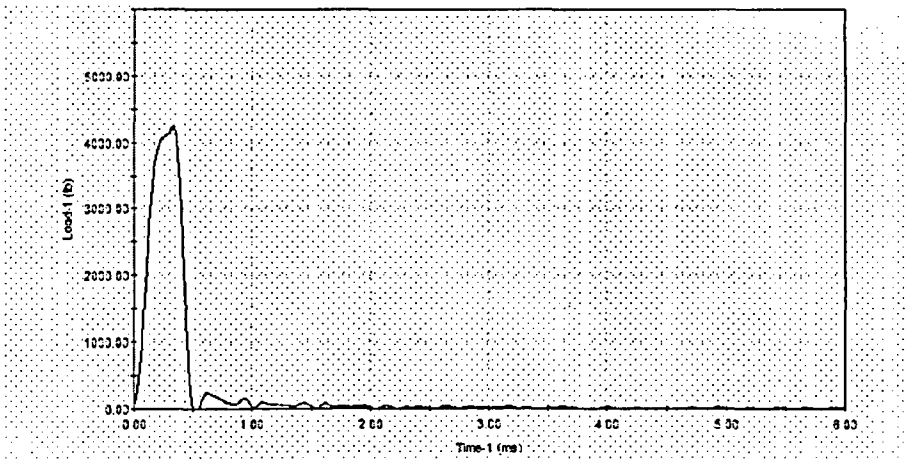

**WL89, 375°F**



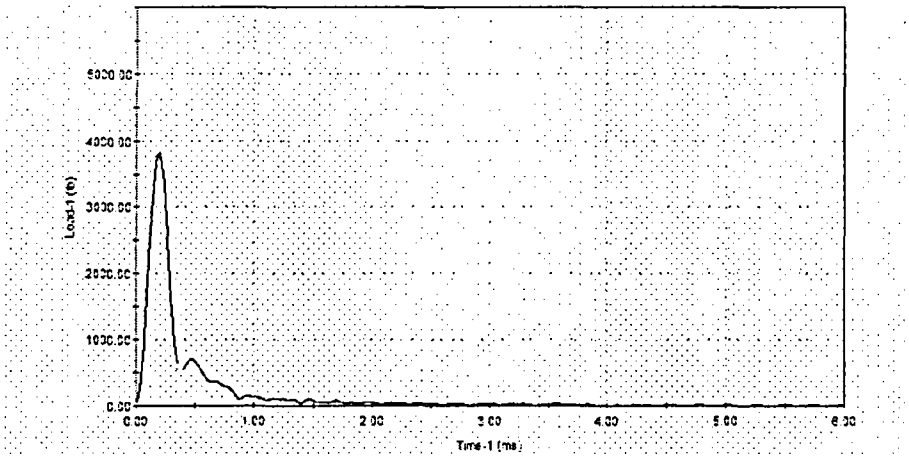

**WT82, -50°F**



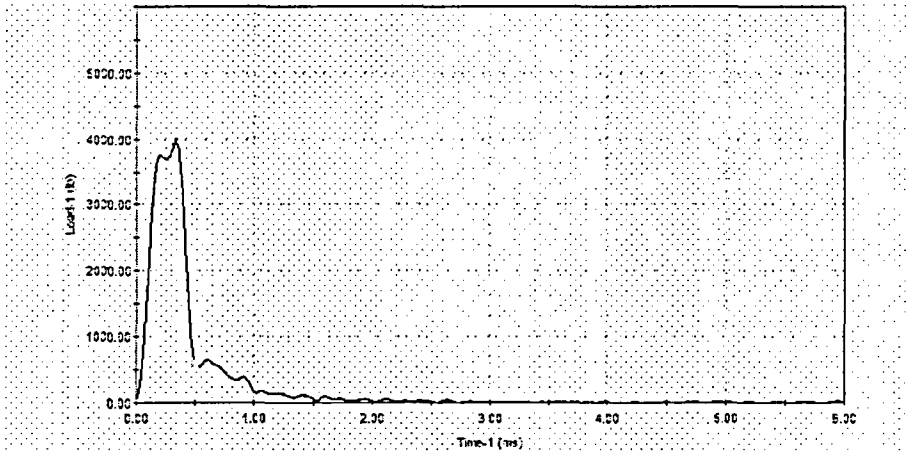

**WT89, 75°F**



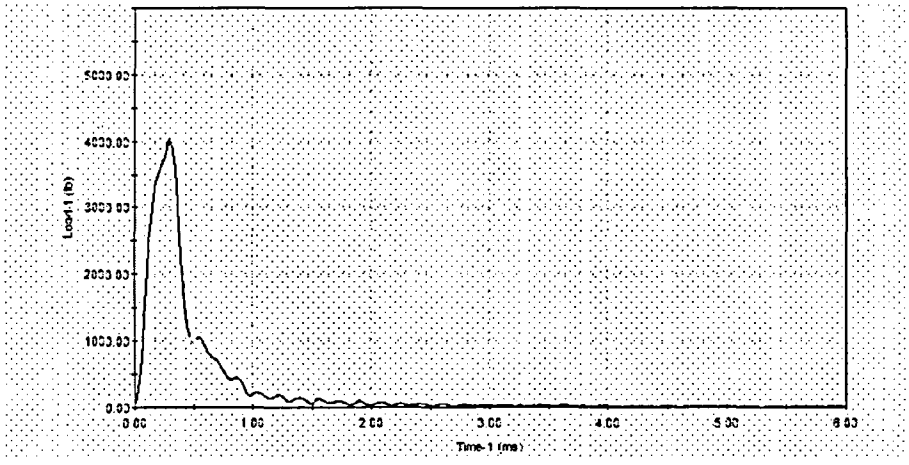

**WT86, 100°F**



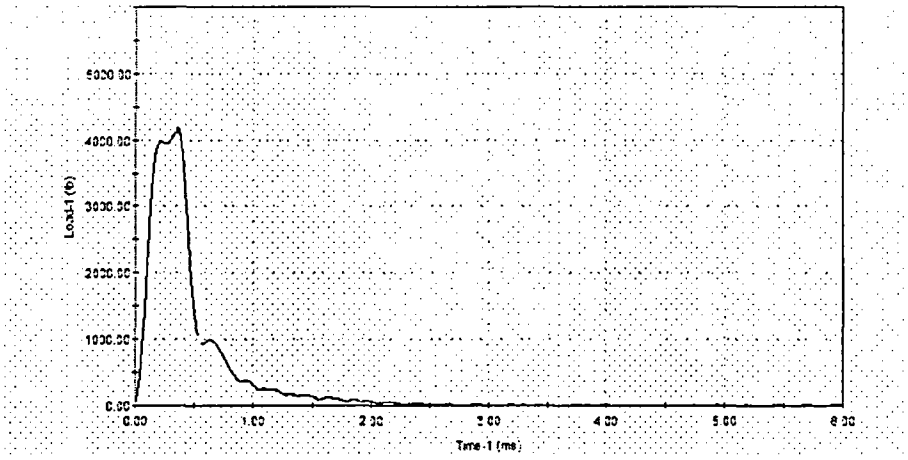

**WT85, 125°F**



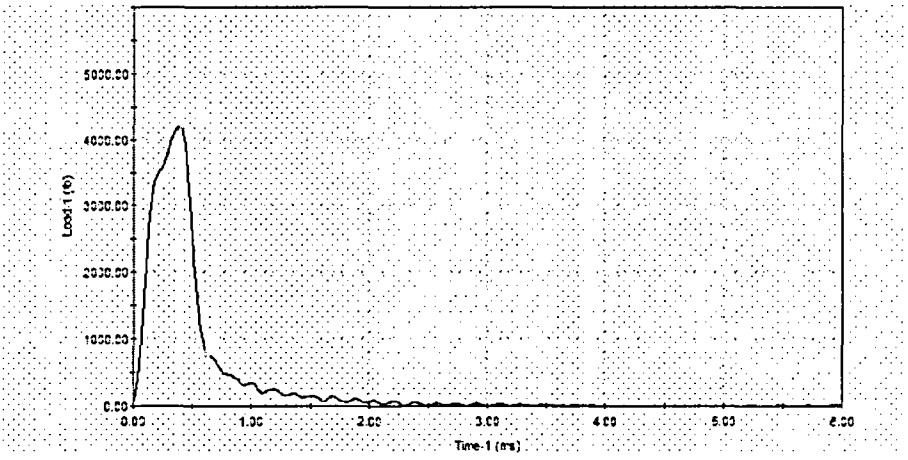

**WT88, 140°F**



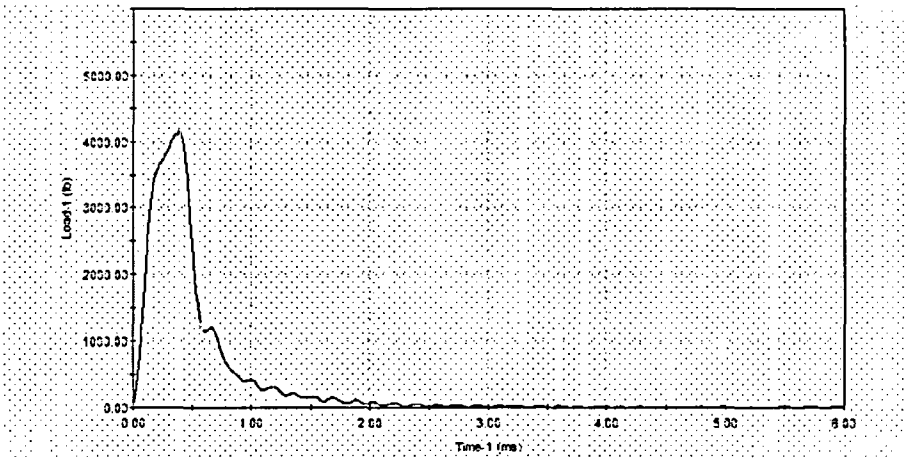

**WT77, 150°F**



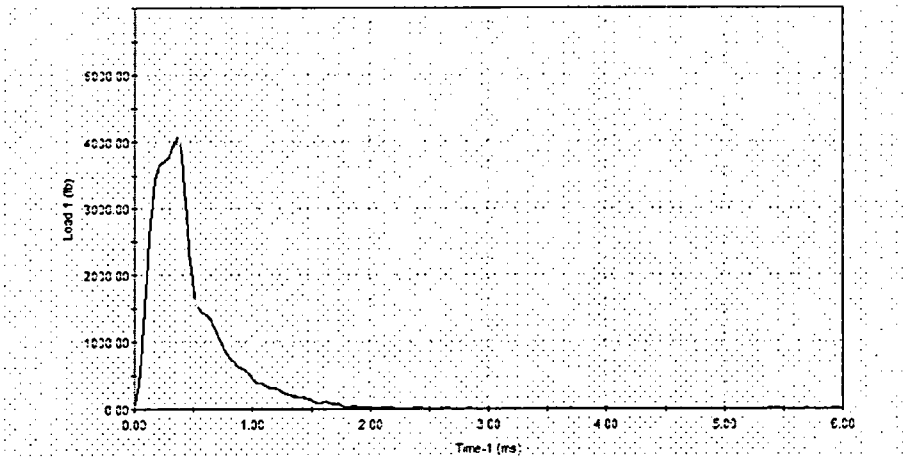

**WT83, 165°F**



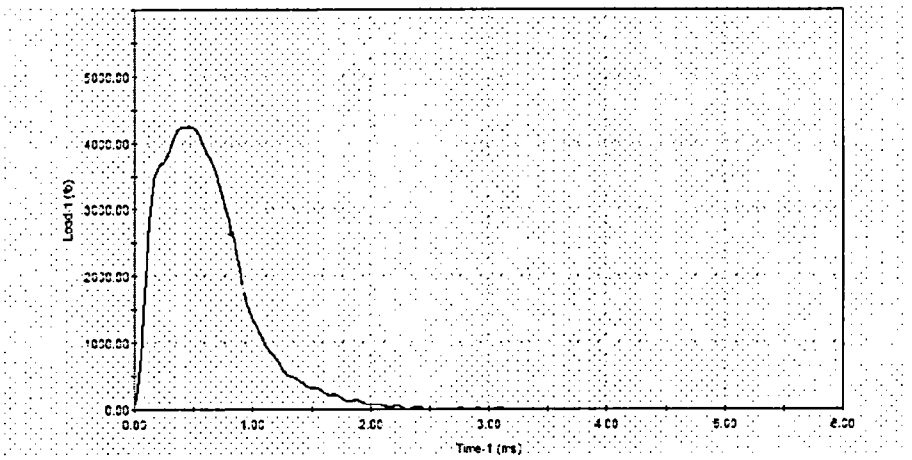

**WT79, 175°F**



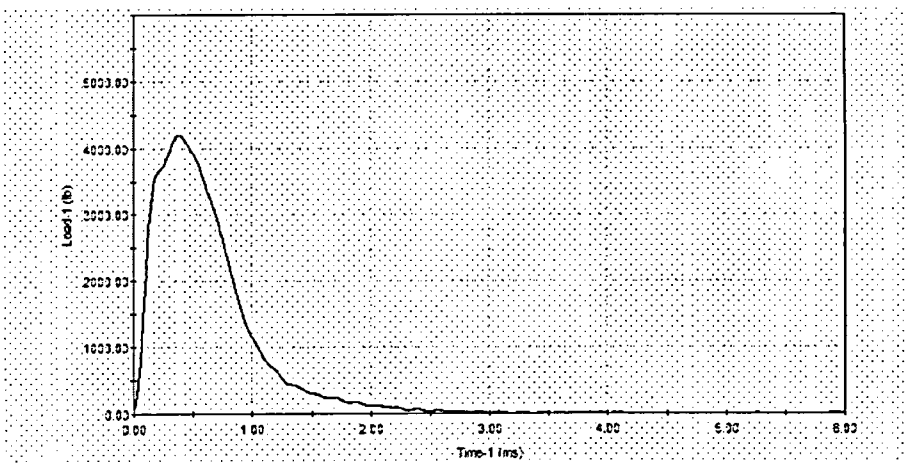

**WT81, 190°F**



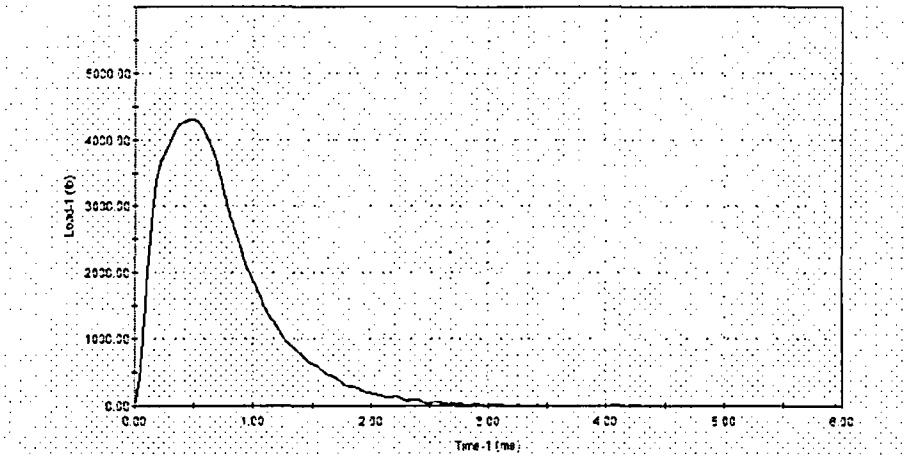

**WT76, 200°F**



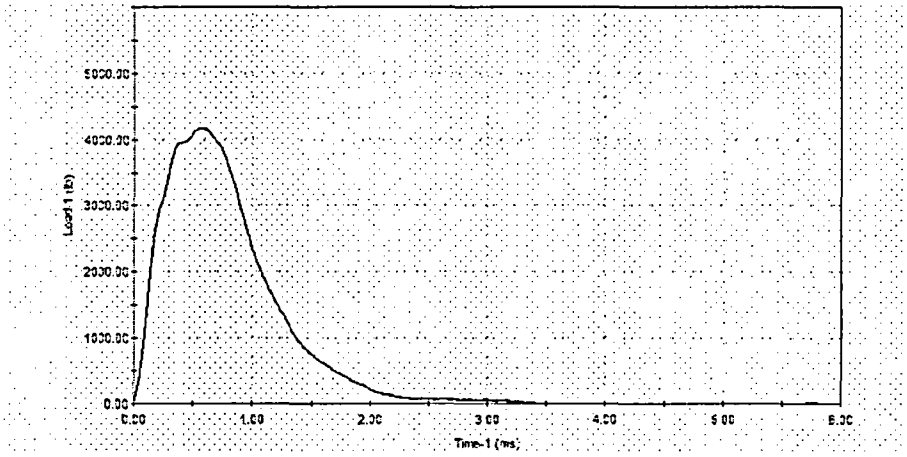

**WT90, 210°F**



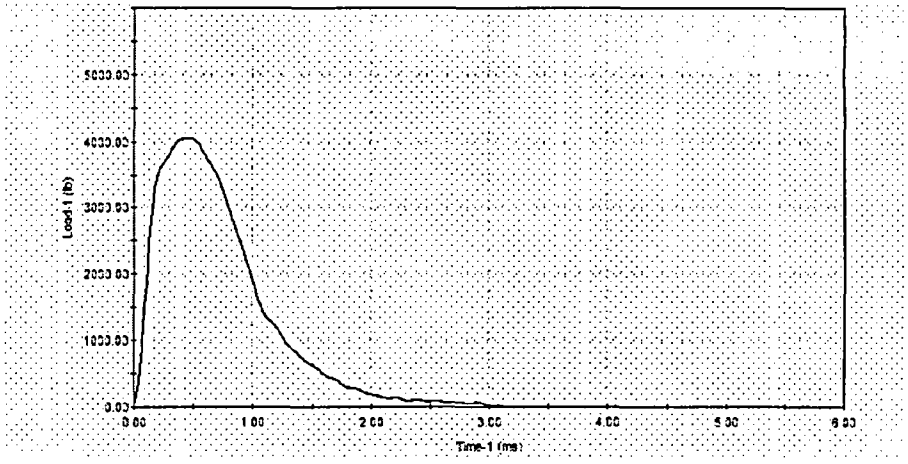

**WT78, 225°F**



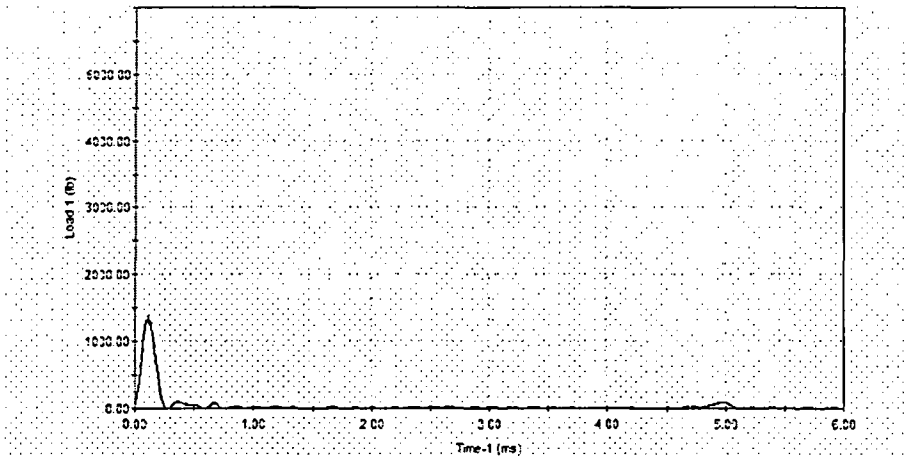

**WT84, 300°F**



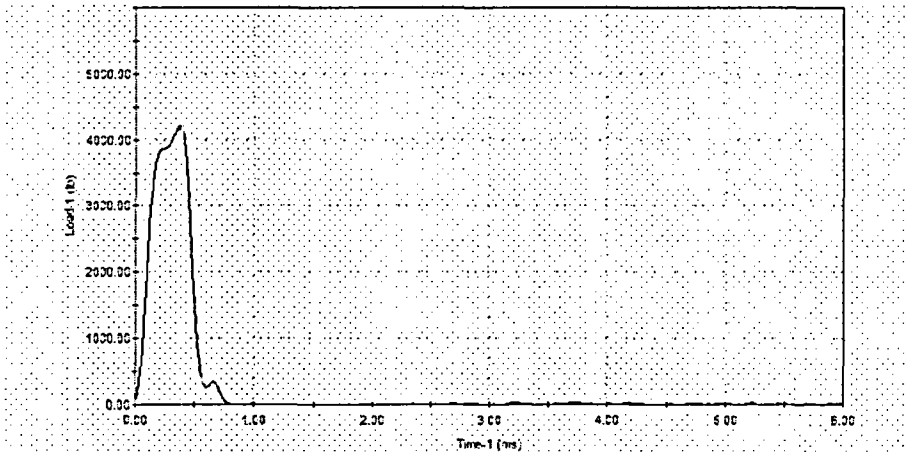

**WT87, 350°F**



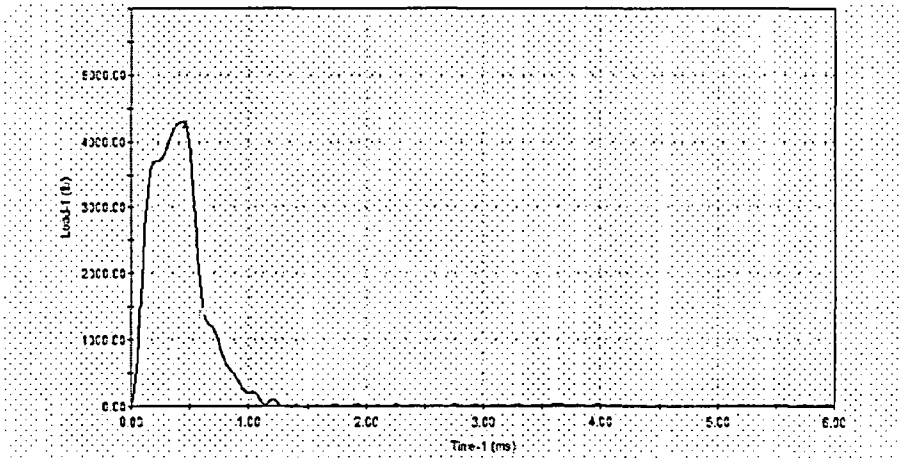

**WT80, 375°F**



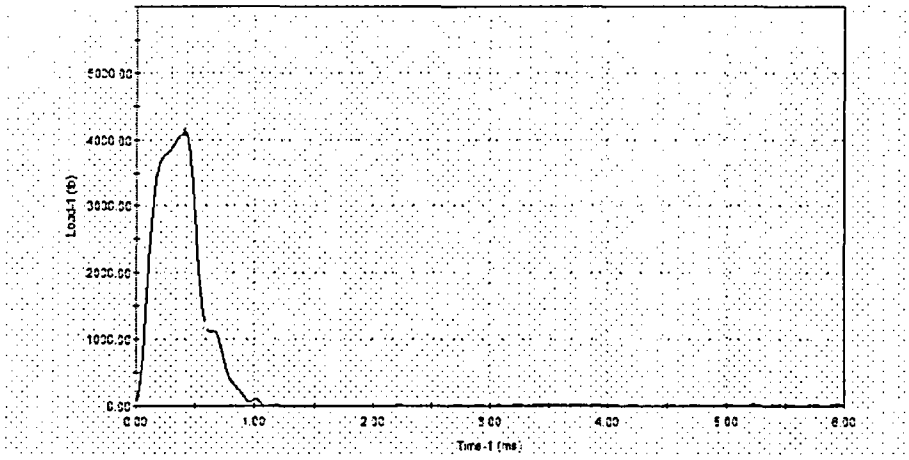

**WW89, -100°F**



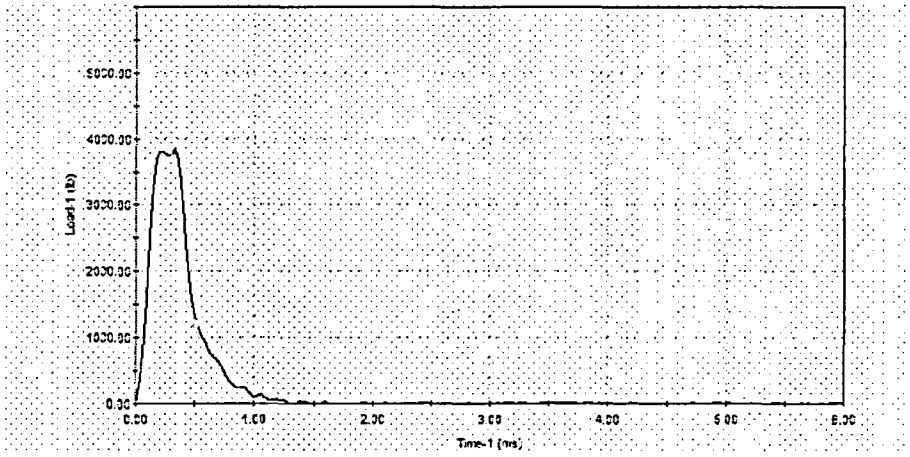

**WW83, -25°F**



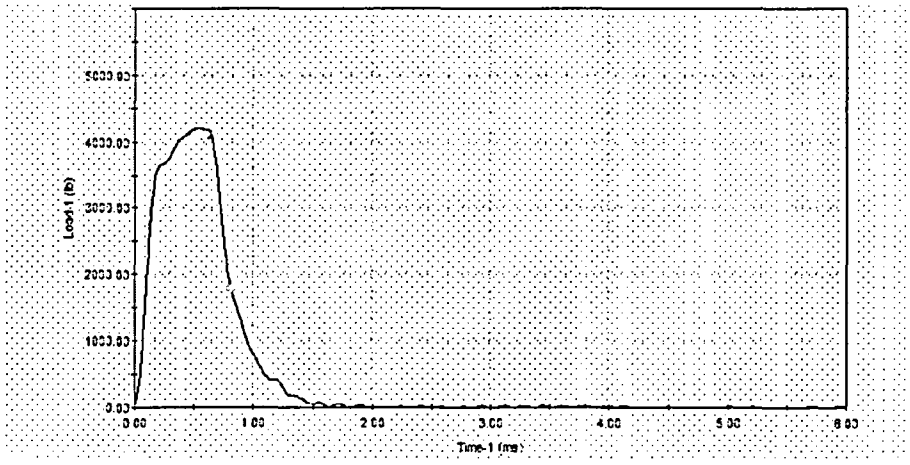

**WW86, -15°F**



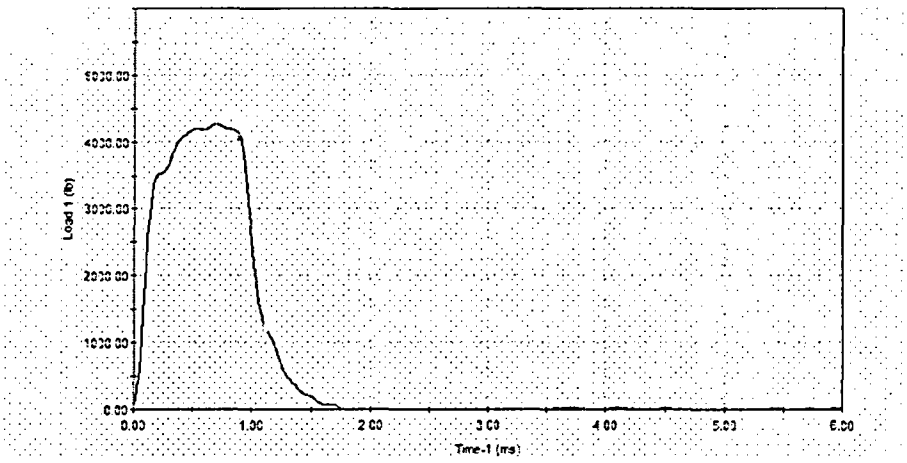

**WW78, 0°F**



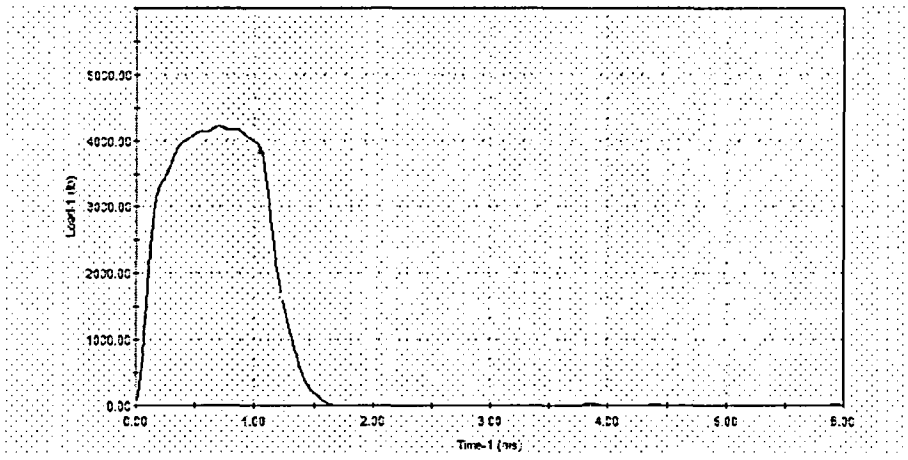

**WW90, 15°F**



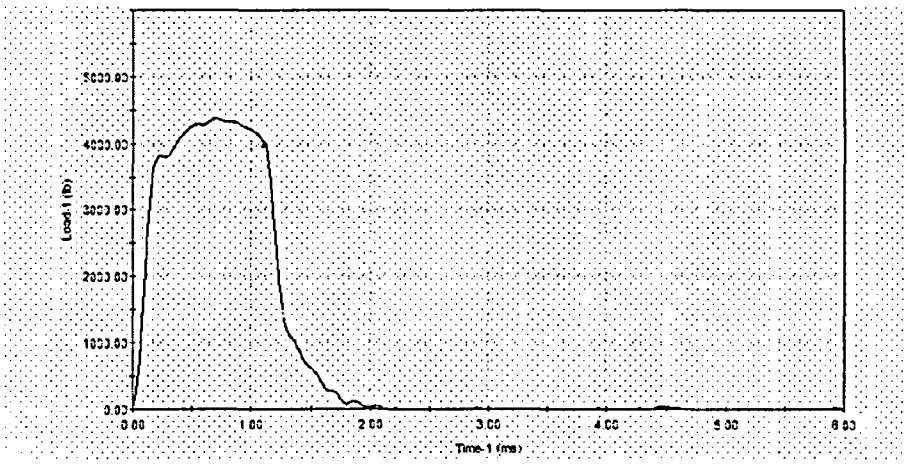

**WW87, 25°F**



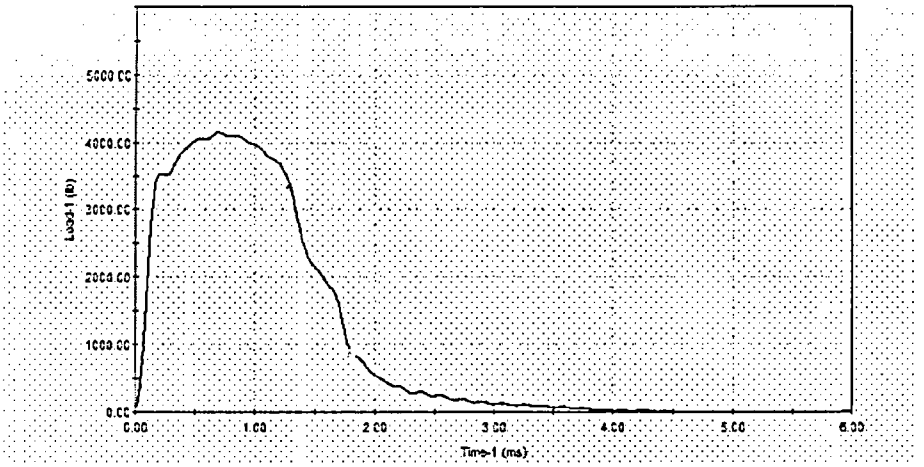

**WW82, 40°F**



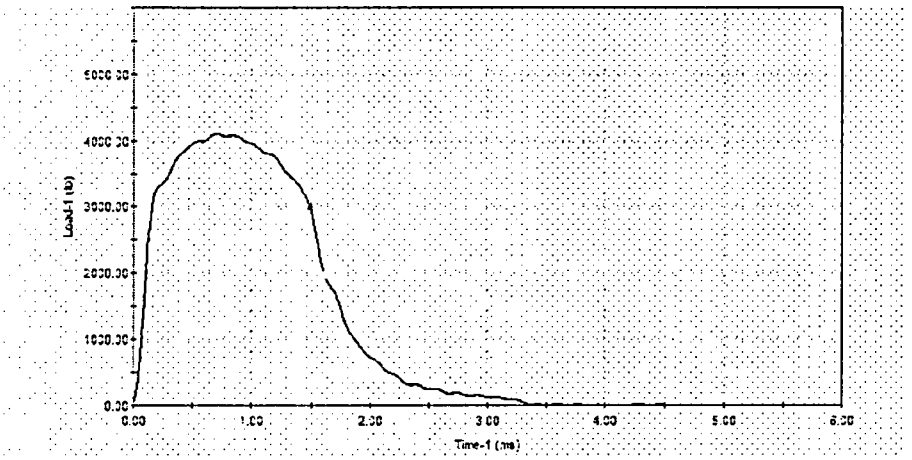

**WW85, 50°F**



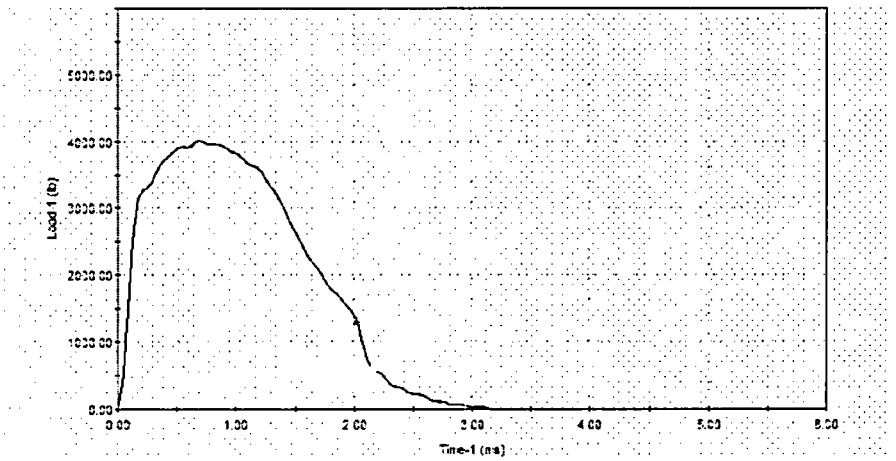

**WW80, 75°F**



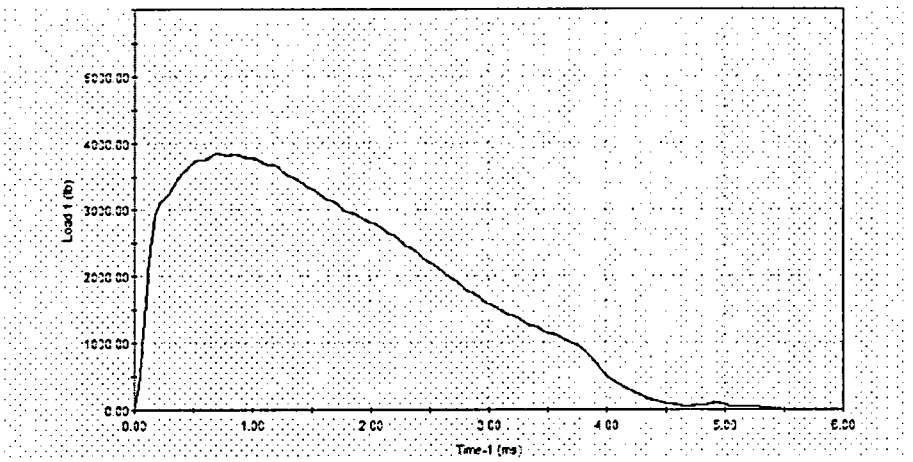

**WW84, 100°F**



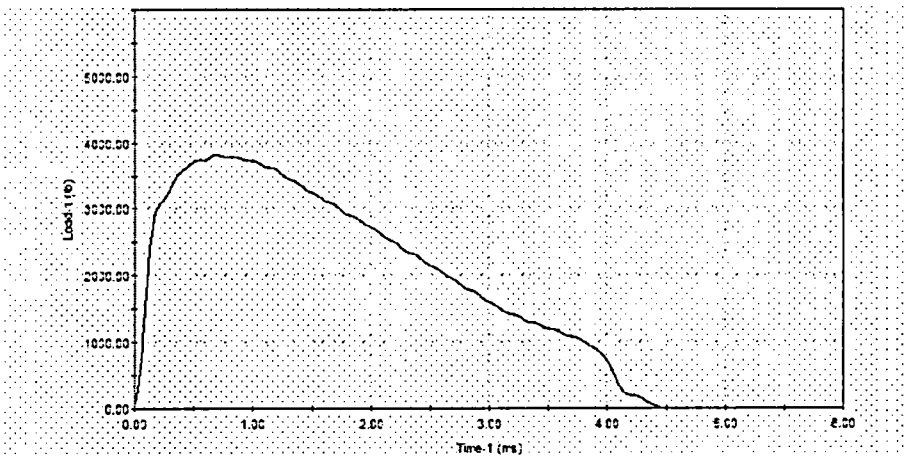

**WW88, 125°F**



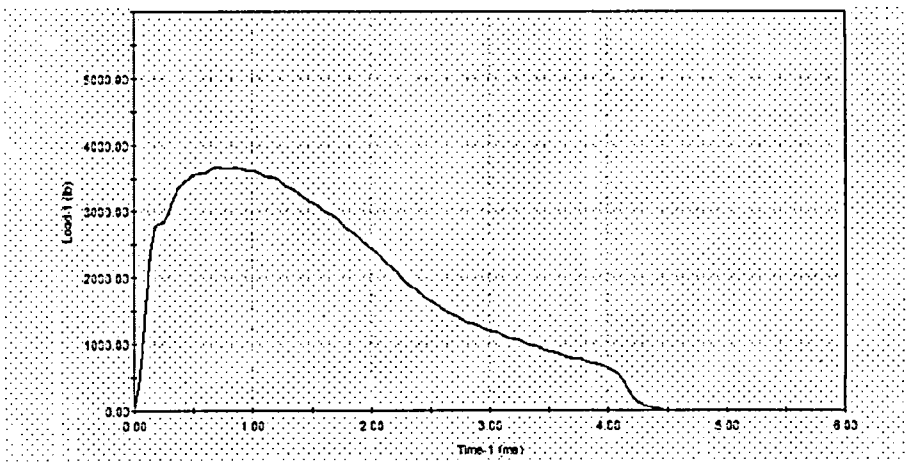

**WW81, 150°F**



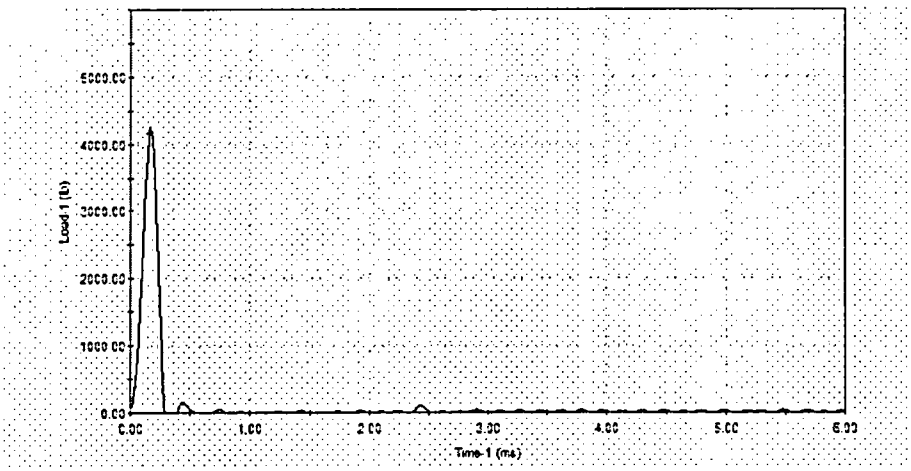

**WW79, 300°F**



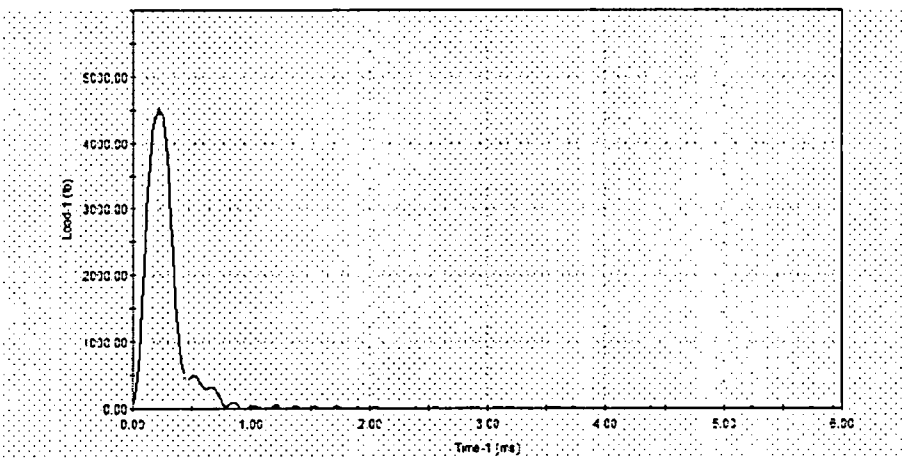

**WW77, 350°F**



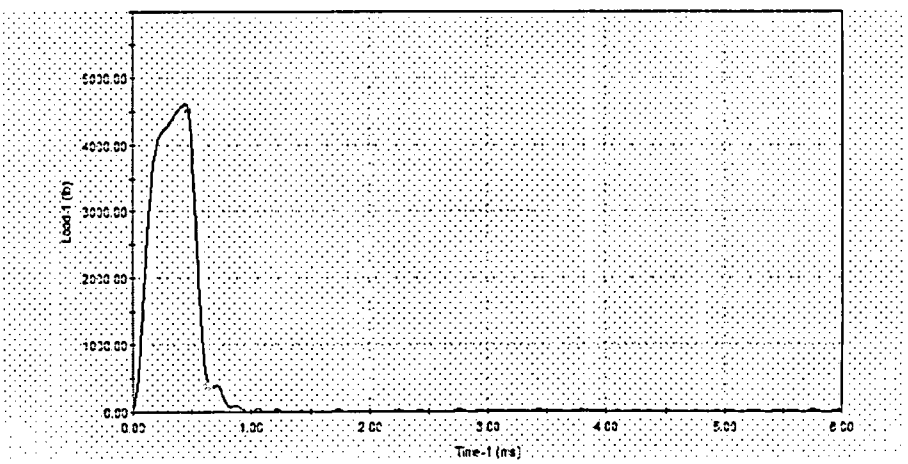

**WW76, 375°F**



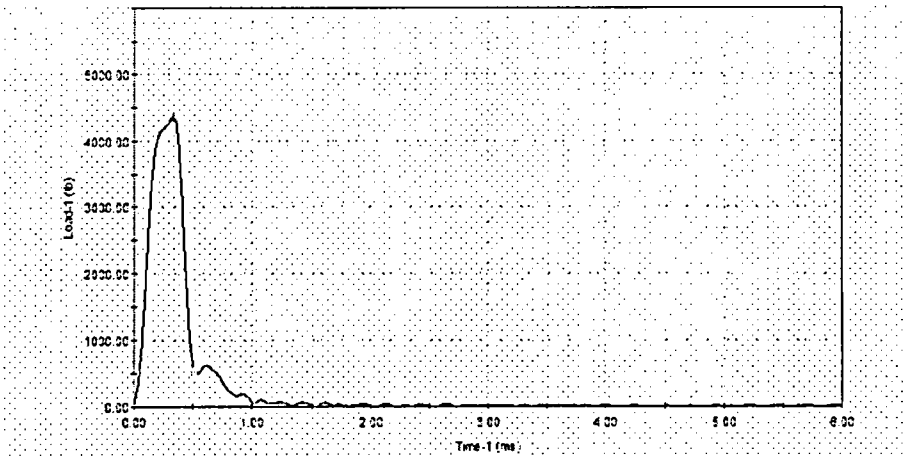

**WH79, -100°F**



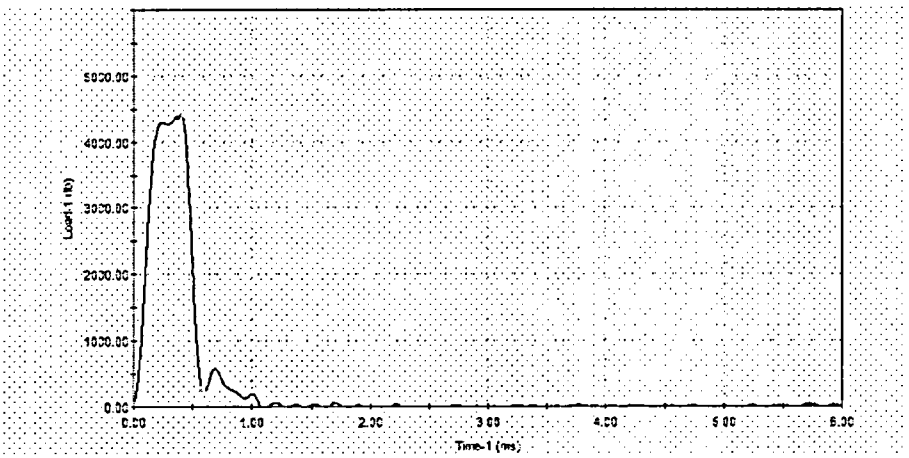

**WH83, -25°F**



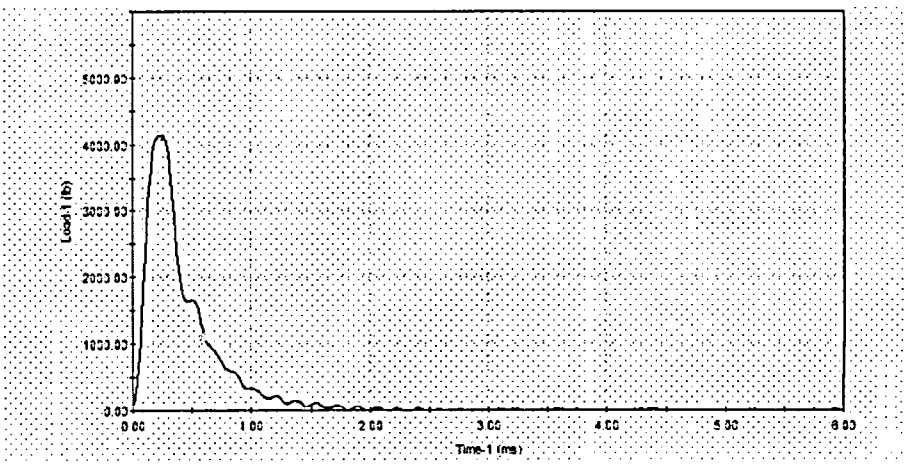

**WH85, 0°F**



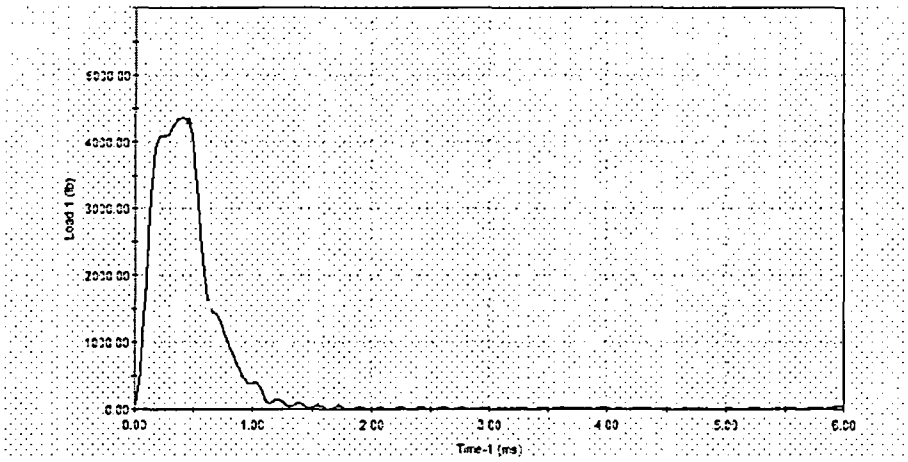

**WH76, 15°F**



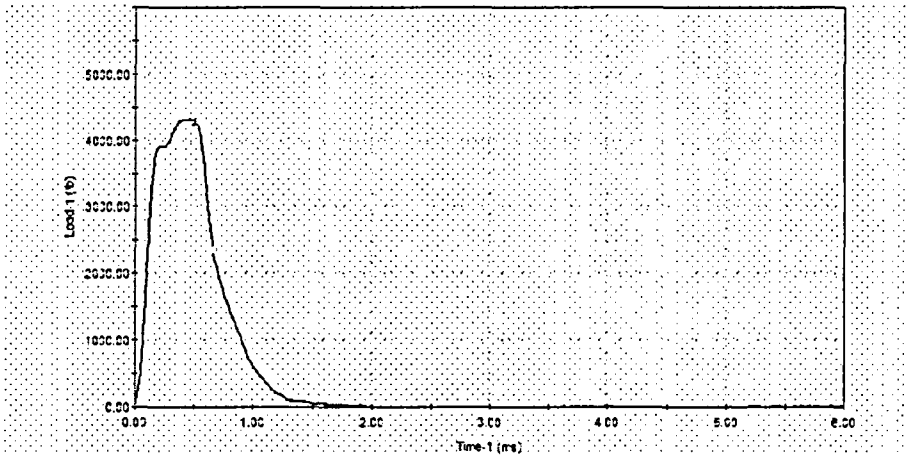

**WH78, 25°F**



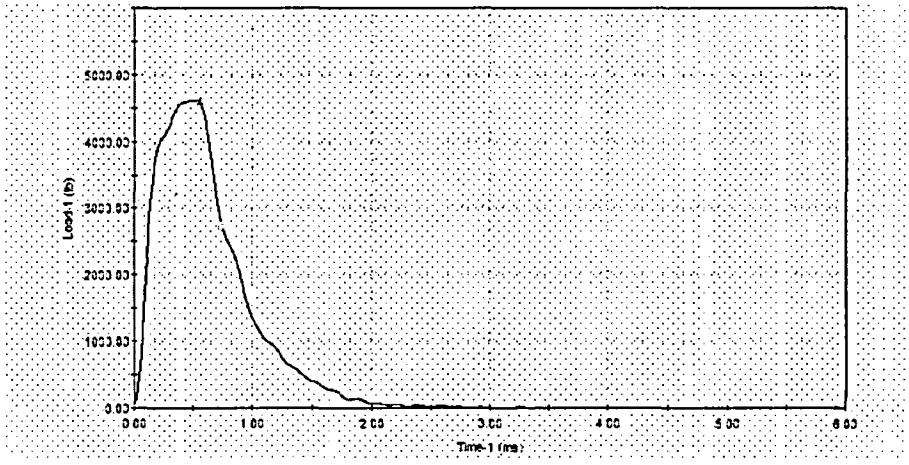

**WH88, 40°F**



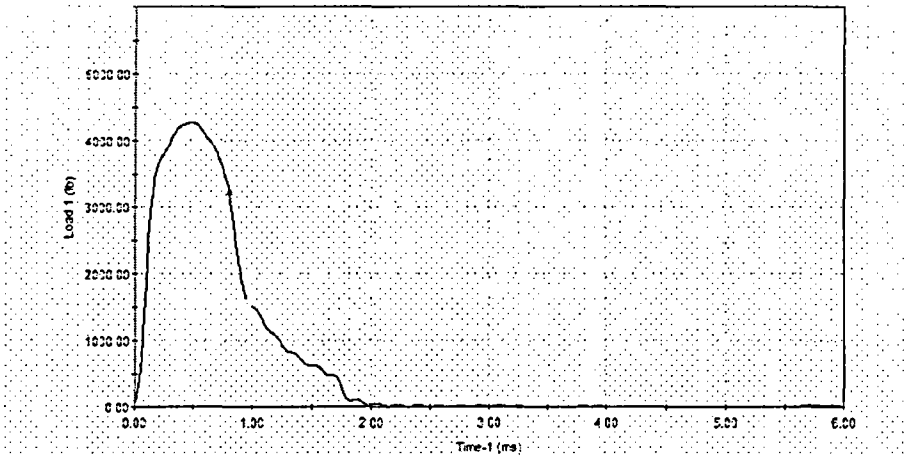

**WH80, 50°F**



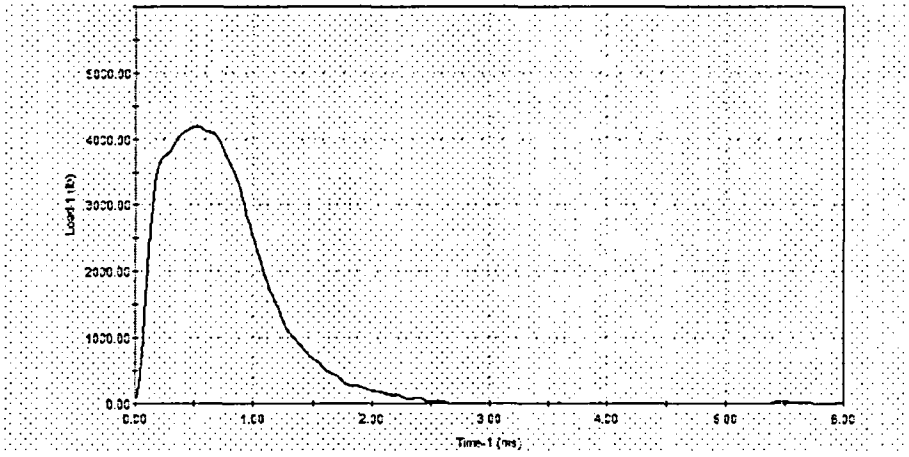

**WH86, 60°F**



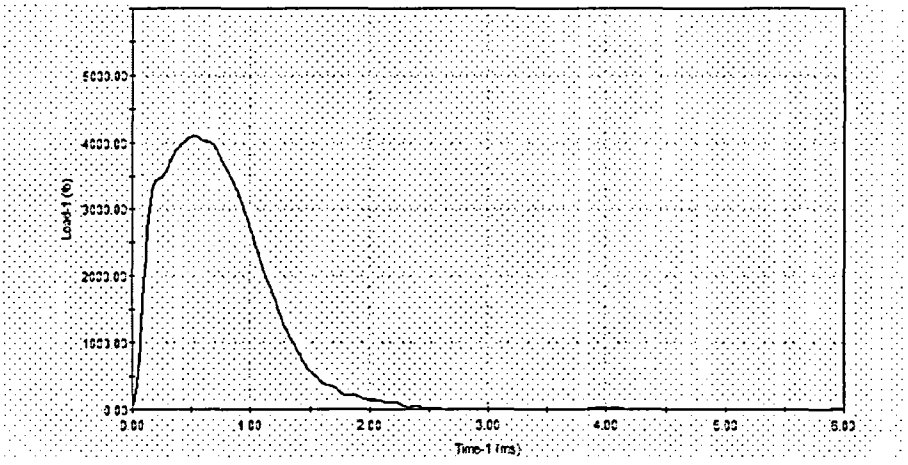

**WH82, 75°F**



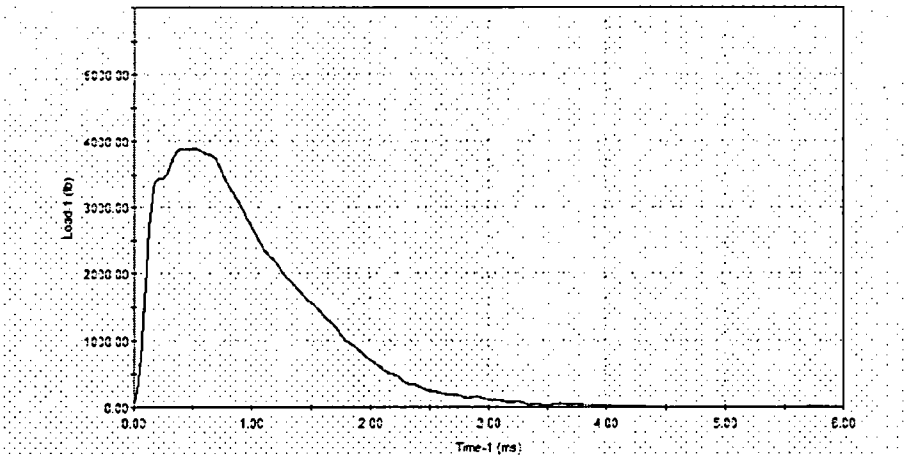

**WH89, 125°F**



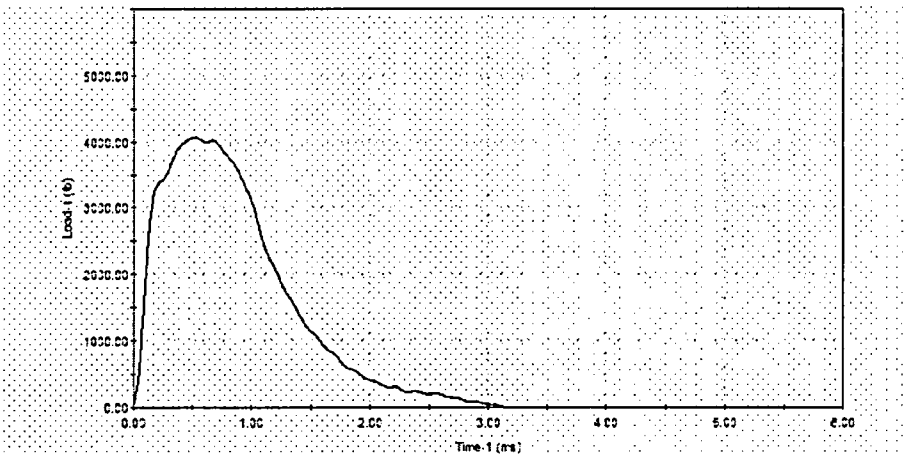

**WH87, 175°F**



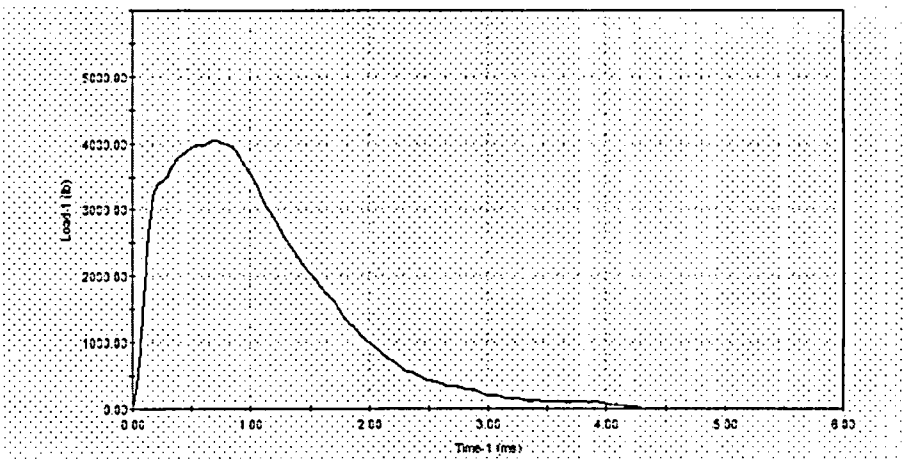

**WH77, 300°F**




**WH90, 325°F**




**WH84, 350°F**




**WH81, 375°F**

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

Contained in Table C-1 are the upper shelf energy values used as input for the generation of the Charpy V-notch plots using CVGRAPH, Version 5.0.2. The definition for Upper Shelf Energy (USE) is given in ASTM E185-82 [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 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. Hence, the USE values reported in Table C-1, which were used to generate the Charpy V-notch curves, were determined utilizing this methodology.

The lower shelf energy values were fixed at 2.2 ft-lb for all cases.

**Table C-1 Upper Shelf Energy Values Fixed in CVGRAPH [ft-lb]**

| Material | Unirradiated | Capsule U | Capsule W | Capsule X | Capsule Z |
|---|---|---|---|---|---|
| Intermediate Shell Forging 05 - Tangential Orientation | 132 | 107 | 98 | 106 | 101 |
| Intermediate Shell Forging 05 - Axial Orientation | 62 | 72 | 60 | 66 | 62 |
| Weld Metal (Heat # 895075) | 131 | 143 | 112 | 134 | 145 |
| HAZ Material | 89[a] | 79 | 77 | 82[b] | 79 |

**Notes:**

a. Re-tabulated CVN data using CVGRAPH v5.0.2 in the Capsule X analysis (WCAP-16245-NP [C-2]) utilized an USE value for the unirradiated HAZ of 89 ft-lbs, which incorporates a 91% shear test value from the unirradiated test data in the USE determination.

b. The USE value tabulated for the Capsule X HAZ in WCAP-16245-NP is 80 ft-lbs. If all Charpy V-Notch data with greater than or equal to 95% shear from Table 5-4 of WCAP-16245-NP were used in the determination of USE, the value should be 82 ft-lb instead of 80 ft-lb. Specimen WH48 was not incorporated in the previous calculation; however, HAZ materials are not utilized in the evaluation of surveillance data credibility or in the projection of USE decreases for vessel materials; therefore, this change has no impact on reactor vessel integrity analyses previously performed for Watts Bar Unit 1.

CVGRAPH v5.0.2 plots of all surveillance data are provided in this appendix, on the pages following the reference list.

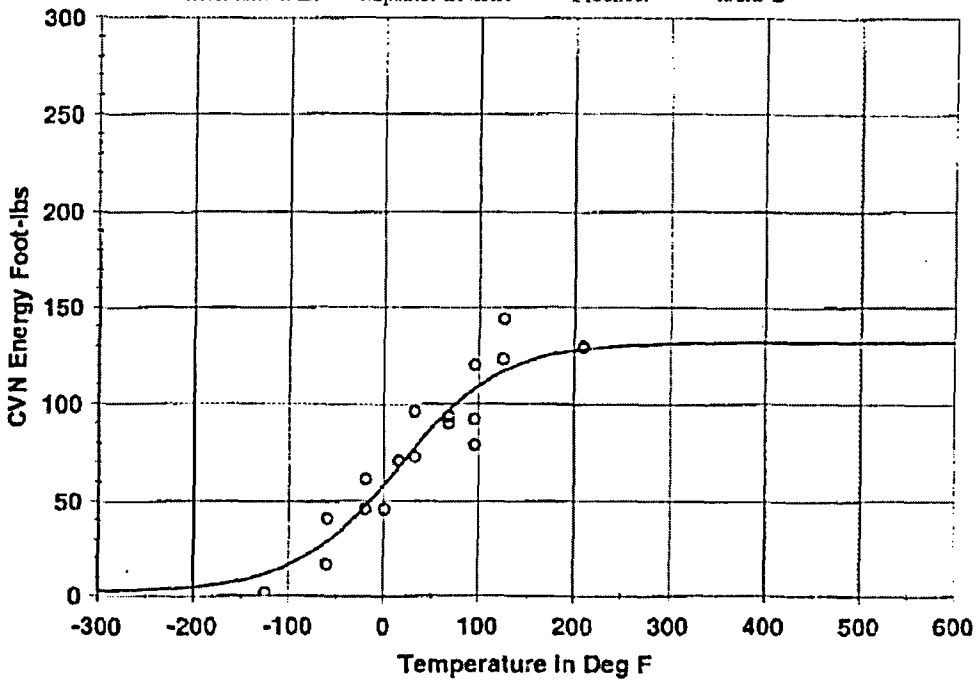
## C.1 REFERENCES

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

C-2 WCAP-16245-NP, Revision 0, "Analysis of Capsule X from the Tennessee Valley Authority, Watts Bar Unit 1 Reactor Vessel Radiation Surveillance Program," T. J. Laubham, April 2004.

# UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:24 PM
Page 1
Coefficients of Curve 1
**A = 67.1 B = 64.9 C = 109.84 T0 = 14.2 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=132.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-57.1 Deg F Temp@50 ft-lbs=-15.4 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -125.00 | 1.50 | 11.74 | -10.24 |
| -60.00 | 41.00 | 28.90 | 12.10 |
| -60.00 | 17.00 | 28.90 | -11.90 |
| -20.00 | 46.00 | 47.52 | -1.52 |
| -20.00 | 61.50 | 47.52 | 13.98 |
| .00 | 46.00 | 58.75 | -12.75 |
| 15.00 | 71.00 | 67.57 | 3.43 |
| 32.00 | 73.00 | 77.52 | -4.52 |
| 32.00 | 96.00 | 77.52 | 18.48 |

# UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

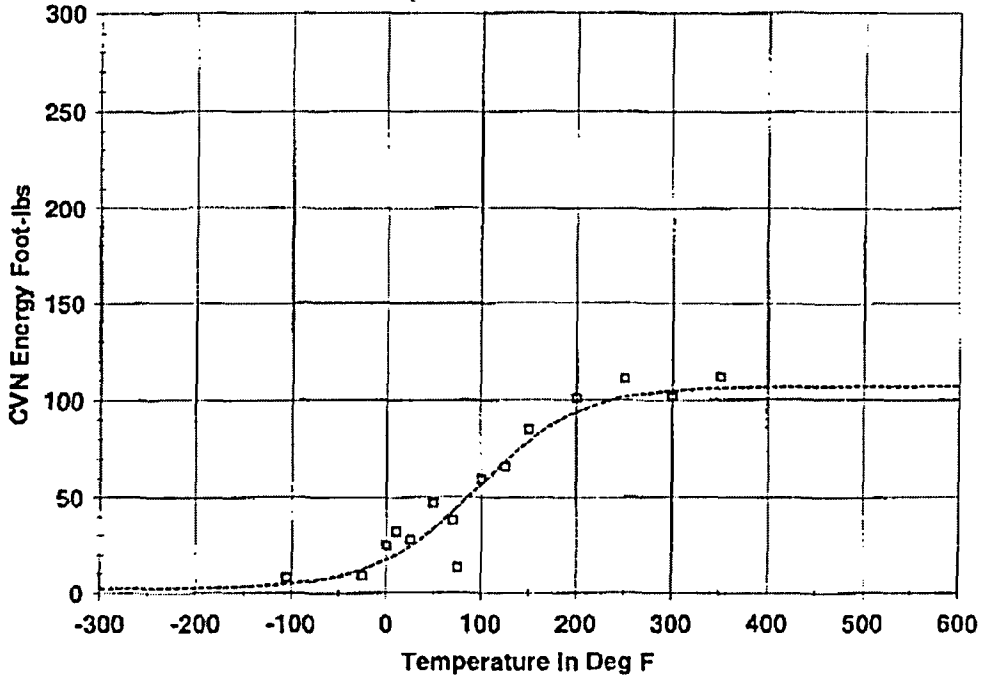
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 68.00 | 93.50 | 96.57 | -3.07 |
| 68.00 | 90.00 | 96.57 | -6.57 |
| 95.00 | 120.00 | 107.76 | 12.24 |
| 95.00 | 79.00 | 107.76 | -28.76 |
| 95.00 | 92.00 | 107.76 | -15.76 |
| 125.00 | 123.00 | 116.76 | 6.24 |
| 125.00 | 144.00 | 116.76 | 27.24 |
| 210.00 | 130.00 | 128.43 | 1.57 |
| 210.00 | 129.00 | 128.43 | .57 |

Correlation Coefficient = .941

# CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:24 PM
Page 1
Coefficients of Curve 2
**A = 54.6 B = 52.4 C = 107.38 T0 = 95.83 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=107.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=41.2 Deg F Temp@50 ft-lbs=86.4 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -105.00 | 8.00 | 4.63 | 3.37 |
| -25.00 | 9.00 | 12.19 | -3.19 |
| .00 | 25.00 | 17.26 | 7.74 |
| 10.00 | 32.00 | 19.83 | 12.17 |
| 25.00 | 28.00 | 24.31 | 3.69 |
| 50.00 | 47.00 | 33.50 | 13.50 |
| 70.00 | 38.00 | 42.23 | -4.23 |
| 75.00 | 13.00 | 44.56 | -31.56 |
| 100.00 | 60.00 | 56.64 | 3.36 |

# CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: n/cm^2

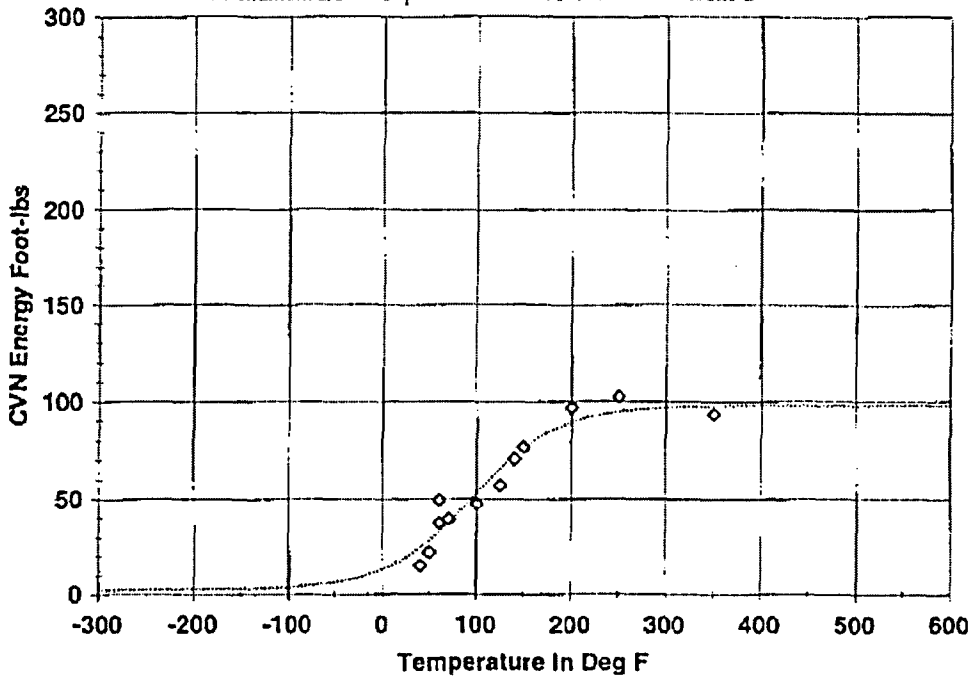
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 125.00 | 66.00 | 68.50 | -2.50 |
| 150.00 | 85.00 | 79.00 | 6.00 |
| 200.00 | 101.00 | 93.83 | 7.17 |
| 250.00 | 111.00 | 101.38 | 9.62 |
| 300.00 | 102.00 | 104.71 | -2.71 |
| 350.00 | 112.00 | 106.09 | 5.91 |

Correlation Coefficient = .959

# CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:24 PM
Page 1
Coefficients of Curve 3
**A = 50.1 B = 47.9 C = 91.41 T0 = 95.16 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=98.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=54.3 Deg F Temp@50 ft-lbs=95.0 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 40.00 | 15.00 | 24.26 | -9.26 |
| 50.00 | 22.00 | 28.19 | -6.19 |
| 60.00 | 37.50 | 32.53 | 4.97 |
| 60.00 | 49.50 | 32.53 | 16.97 |
| 70.00 | 39.50 | 37.24 | 2.26 |
| 100.00 | 47.50 | 52.63 | -5.13 |
| 125.00 | 57.00 | 65.20 | -8.20 |
| 140.00 | 70.50 | 71.88 | -1.38 |
| 150.00 | 76.50 | 75.82 | .68 |

# CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2

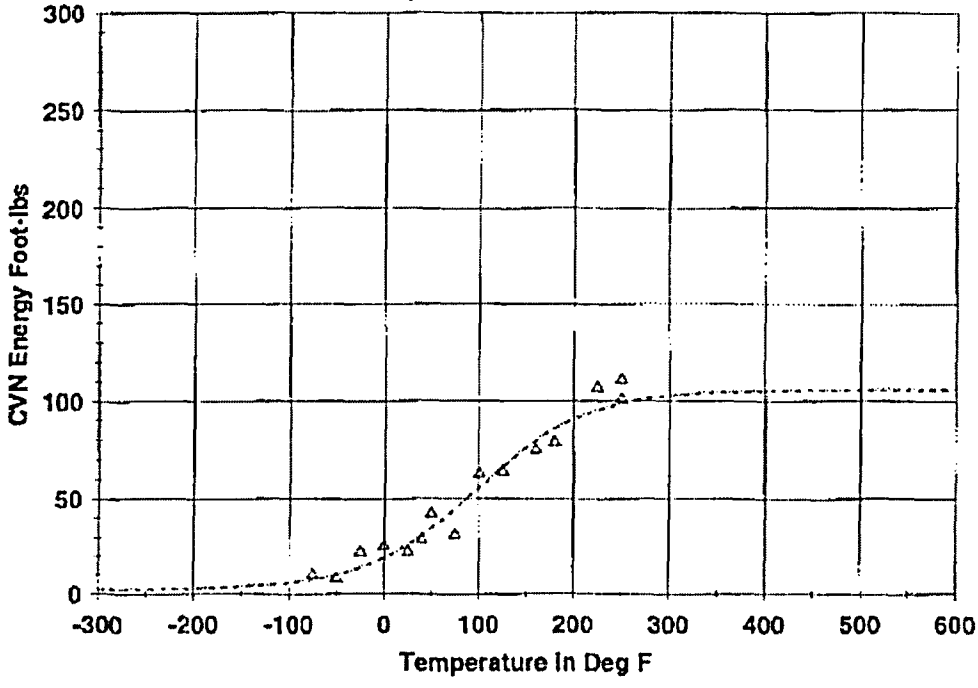
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 200.00 | 97.00 | 89.22 | 7.78 |
| 250.00 | 102.50 | 94.87 | 7.63 |
| 350.00 | 93.50 | 97.64 | -4.14 |

Correlation Coefficient = .964

# CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:25 PM
Page 1
Coefficients of Curve 4
**A = 54.1 B = 51.9 C = 117.15 T0 = 96.42 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=106.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=37.6 Deg F Temp@50 ft-lbs=87.2 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -75.00 | 10.00 | 7.48 | 2.52 |
| -50.00 | 8.00 | 10.08 | -2.08 |
| -25.00 | 22.00 | 13.80 | 8.20 |
| .00 | 25.00 | 18.98 | 6.02 |
| 25.00 | 22.00 | 25.87 | -3.87 |
| 40.00 | 29.00 | 30.87 | -1.87 |
| 50.00 | 42.00 | 34.55 | 7.45 |
| 75.00 | 31.00 | 44.71 | -13.71 |
| 100.00 | 63.00 | 55.69 | 7.31 |

# CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2

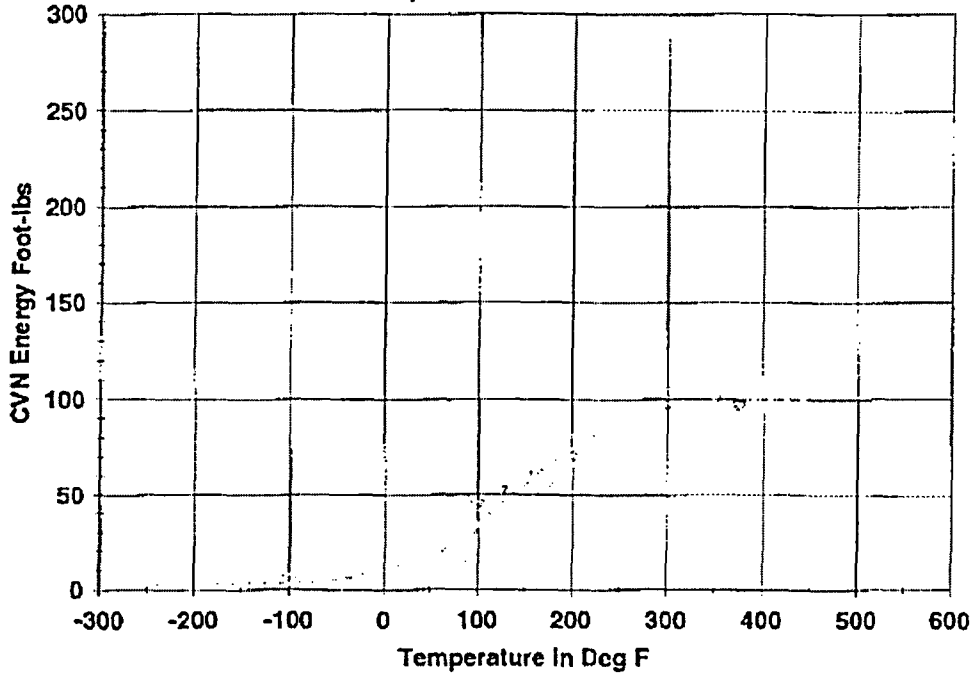
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 125.00 | 64.00 | 66.52 | -2.52 |
| 160.00 | 75.00 | 79.79 | -4.79 |
| 180.00 | 79.00 | 85.91 | -6.91 |
| 225.00 | 107.00 | 95.60 | 11.40 |
| 250.00 | 101.00 | 98.97 | 2.03 |
| 250.00 | 111.00 | 98.97 | 12.03 |

*Correlation Coefficient = .979*

# CAPSULE Z INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:25 PM
Page 1
Coefficients of Curve 5
**A = 51.6 B = 49.4 C = 115.79 T0 = 141.59 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=101.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=87.4 Deg F Temp@50 ft-lbs=137.9 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: Z Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -100.00 | 6.00 | 3.70 | 2.30 |
| 25.00 | 15.00 | 13.84 | 1.16 |
| 60.00 | 21.00 | 21.60 | -.60 |
| 75.00 | 27.00 | 25.96 | 1.04 |
| 80.00 | 25.00 | 27.55 | -2.55 |
| 85.00 | 16.00 | 29.21 | -13.21 |
| 95.00 | 32.00 | 32.73 | -.73 |
| 100.00 | 45.00 | 34.58 | 10.42 |
| 125.00 | 53.00 | 44.57 | 8.43 |

# CAPSULE Z INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: Z Fluence: n/cm^2

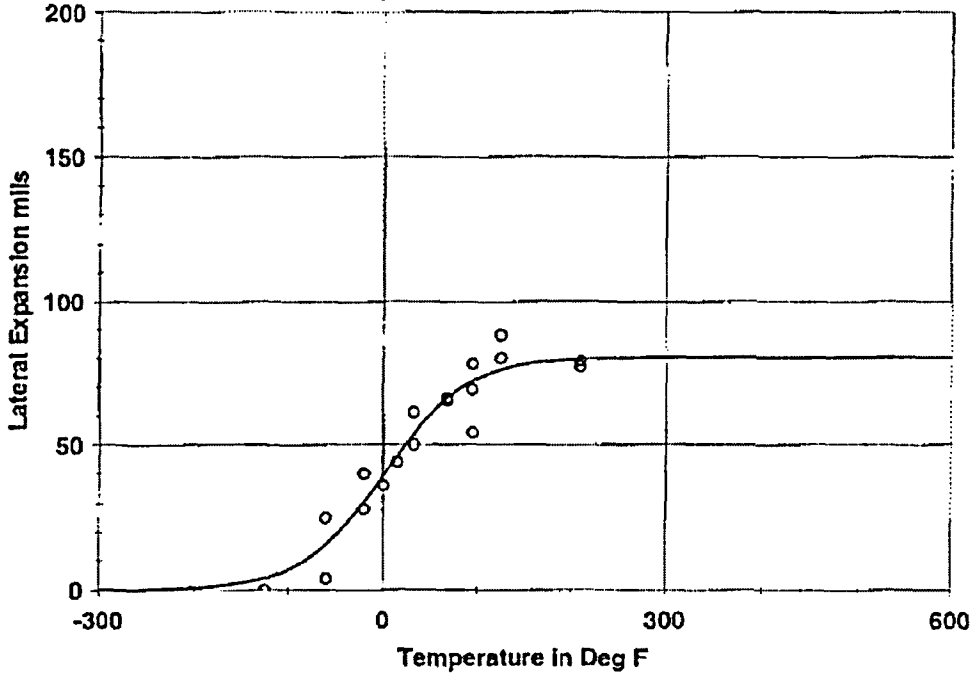
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 150.00 | 60.00 | 55.18 | 4.82 |
| 175.00 | 56.00 | 65.47 | -9.47 |
| 200.00 | 70.00 | 74.60 | -4.60 |
| 300.00 | 104.00 | 94.99 | 9.01 |
| 350.00 | 101.00 | 98.37 | 2.63 |
| 375.00 | 97.00 | 99.28 | -2.28 |

Correlation Coefficient = .980

# UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:53 PM
Page 1
Coefficients of Curve 1
**A = 40.26 B = 40.26 C = 87.82 T0 = 2.05 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=80.5 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=-9.4 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -125.00 | .00 | 4.23 | -4.23 |
| -60.00 | 25.00 | 15.76 | 9.24 |
| -60.00 | 4.00 | 15.76 | -11.76 |
| -20.00 | 28.00 | 30.35 | -2.35 |
| -20.00 | 40.00 | 30.35 | 9.65 |
| .00 | 36.00 | 39.31 | -3.31 |
| 15.00 | 44.00 | 46.15 | -2.15 |
| 32.00 | 50.00 | 53.47 | -3.47 |
| 32.00 | 61.00 | 53.47 | 7.53 |

# UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

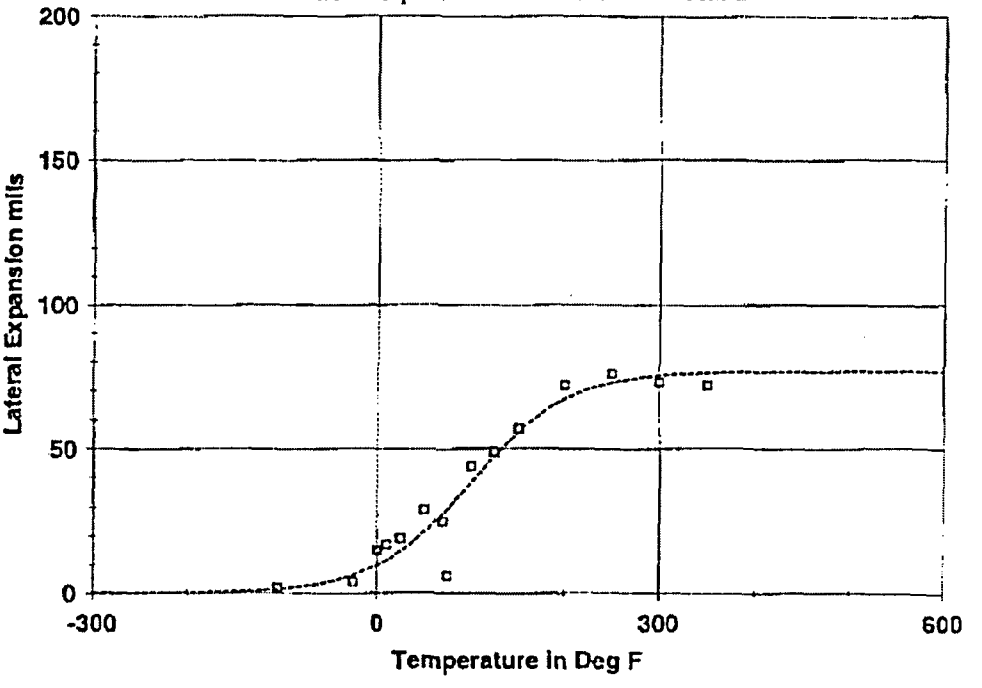
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 68.00 | 65.00 | 65.85 | -.85 |
| 68.00 | 66.00 | 65.85 | .15 |
| 95.00 | 78.00 | 71.86 | 6.14 |
| 95.00 | 54.00 | 71.86 | -17.86 |
| 95.00 | 69.00 | 71.86 | -2.86 |
| 125.00 | 80.00 | 75.89 | 4.11 |
| 125.00 | 88.00 | 75.89 | 12.11 |
| 210.00 | 77.00 | 79.81 | -2.81 |
| 210.00 | 79.00 | 79.81 | -.81 |

Correlation Coefficient = .958

# CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:53 PM
Page 1
Coefficients of Curve 2
**A = 38.44 B = 38.44 C = 103.11 T0 = 100.22 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=76.9 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=91.0 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -105.00 | 2.00 | 1.41 | .59 |
| -25.00 | 4.00 | 6.23 | -2.23 |
| .00 | 15.00 | 9.63 | 5.37 |
| 10.00 | 17.00 | 11.38 | 5.62 |
| 25.00 | 19.00 | 14.50 | 4.50 |
| 50.00 | 29.00 | 21.07 | 7.93 |
| 70.00 | 25.00 | 27.49 | -2.49 |
| 75.00 | 6.00 | 29.22 | -23.22 |
| 100.00 | 44.00 | 38.36 | 5.64 |

# CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: n/cm^2

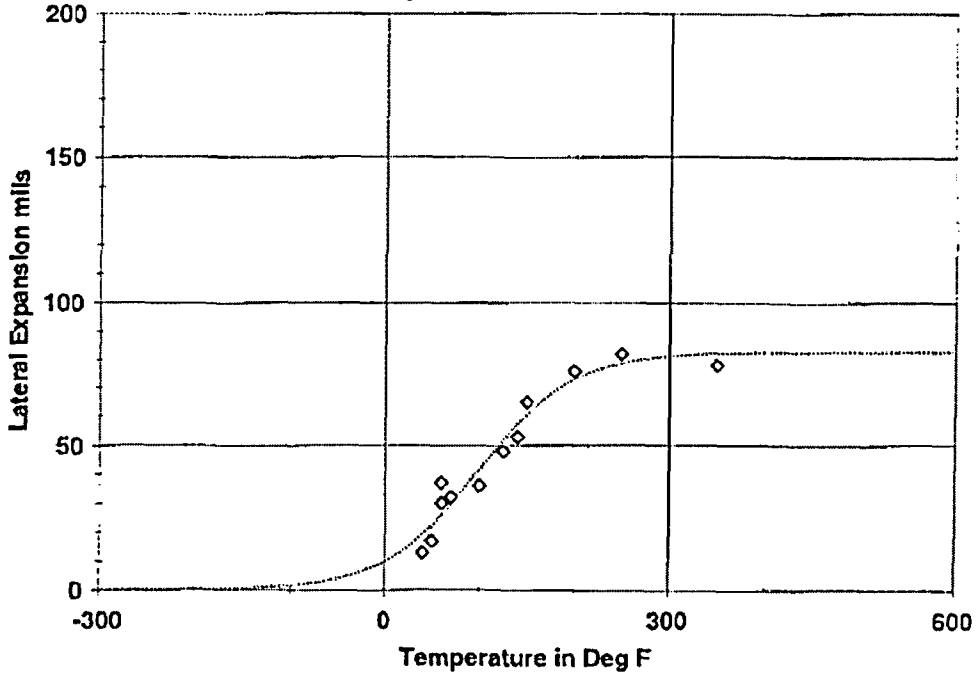
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 125.00 | 49.00 | 47.50 | 1.50 |
| 150.00 | 57.00 | 55.68 | 1.32 |
| 200.00 | 72.00 | 67.18 | 4.82 |
| 250.00 | 76.00 | 72.89 | 3.11 |
| 300.00 | 73.00 | 75.31 | -2.31 |
| 350.00 | 72.00 | 76.28 | -4.28 |

Correlation Coefficient = .962

# CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:53 PM
Page 1
Coefficients of Curve 3
**A = 41.32 B = 41.32 C = 99.72 T0 = 99.66 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=82.6 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=84.3 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 40.00 | 13.00 | 19.18 | -6.18 |
| 50.00 | 17.00 | 22.29 | -5.29 |
| 60.00 | 30.00 | 25.70 | 4.30 |
| 60.00 | 37.00 | 25.70 | 11.30 |
| 70.00 | 32.00 | 29.38 | 2.62 |
| 100.00 | 36.00 | 41.46 | -5.46 |
| 125.00 | 48.00 | 51.60 | -3.60 |
| 140.00 | 53.00 | 57.18 | -4.18 |
| 150.00 | 65.00 | 60.58 | 4.42 |

# CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2

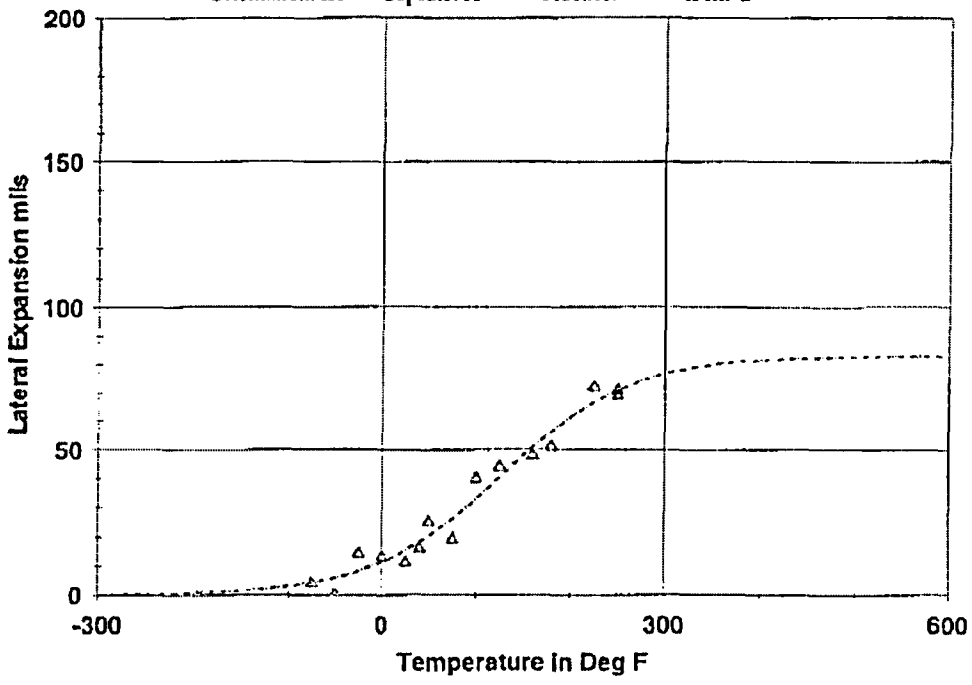
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 200.00 | 76.00 | 72.90 | 3.10 |
| 250.00 | 82.00 | 78.78 | 3.22 |
| 350.00 | 78.00 | 82.11 | -4.11 |

Correlation Coefficient = .972

# CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:53 PM
Page 1
Coefficients of Curve 4
**A = 41.57 B = 41.57 C = 138.42 T0 = 128.58 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=83.1 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=106.6 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -75.00 | 4.00 | 4.17 | -.17 |
| -50.00 | .00 | 5.85 | -5.85 |
| -25.00 | 14.00 | 8.15 | 5.85 |
| .00 | 13.00 | 11.22 | 1.78 |
| 25.00 | 11.00 | 15.21 | -4.21 |
| 40.00 | 16.00 | 18.09 | -2.09 |
| 50.00 | 25.00 | 20.22 | 4.78 |
| 75.00 | 19.00 | 26.24 | -7.24 |
| 100.00 | 40.00 | 33.10 | 6.90 |

# CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2

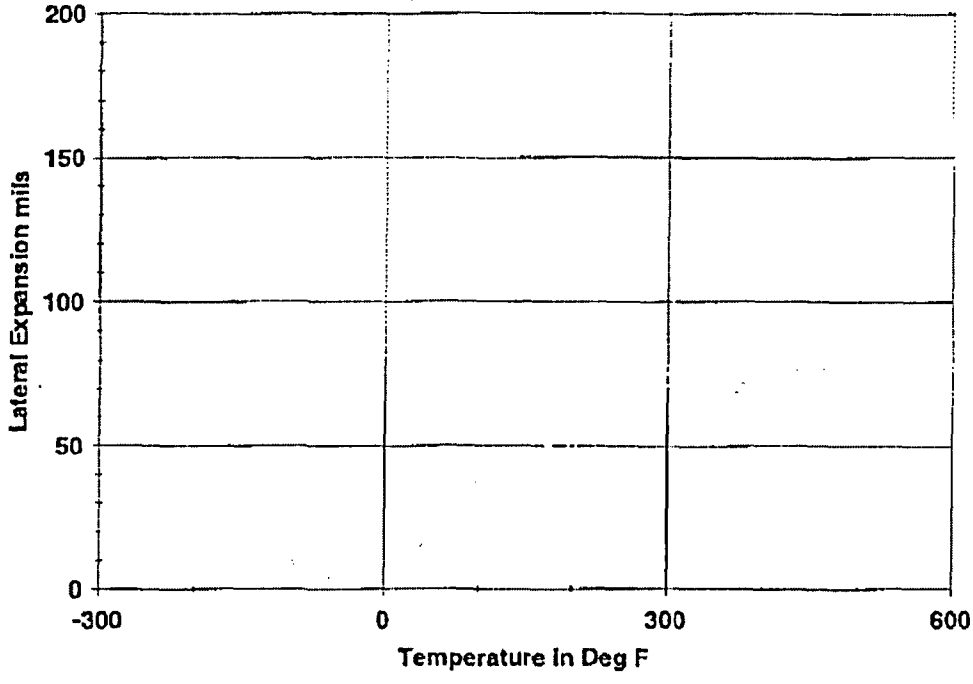
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 125.00 | 44.00 | 40.49 | 3.51 |
| 160.00 | 48.00 | 50.84 | -2.84 |
| 180.00 | 51.00 | 56.33 | -5.33 |
| 225.00 | 72.00 | 66.60 | 5.40 |
| 250.00 | 69.00 | 70.87 | -1.87 |
| 250.00 | 71.00 | 70.87 | .13 |

Correlation Coefficient = .983

# CAPSULE Z INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:54 PM
Page 1
Coefficients of Curve 5
A = 38.97 B = 38.97 C = 138.47 T0 = 135.34 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=77.9 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=121.2 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: Z Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -100.00 | 9.00 | 2.52 | 6.48 |
| 25.00 | 15.00 | 13.16 | 1.84 |
| 60.00 | 15.00 | 19.64 | -4.64 |
| 75.00 | 23.00 | 22.99 | .01 |
| 80.00 | 22.00 | 24.17 | -2.17 |
| 85.00 | 17.00 | 25.39 | -8.39 |
| 95.00 | 30.00 | 27.93 | 2.07 |
| 100.00 | 36.00 | 29.23 | 6.77 |
| 125.00 | 41.00 | 36.06 | 4.94 |

# CAPSULE Z INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: Z Fluence: n/cm^2

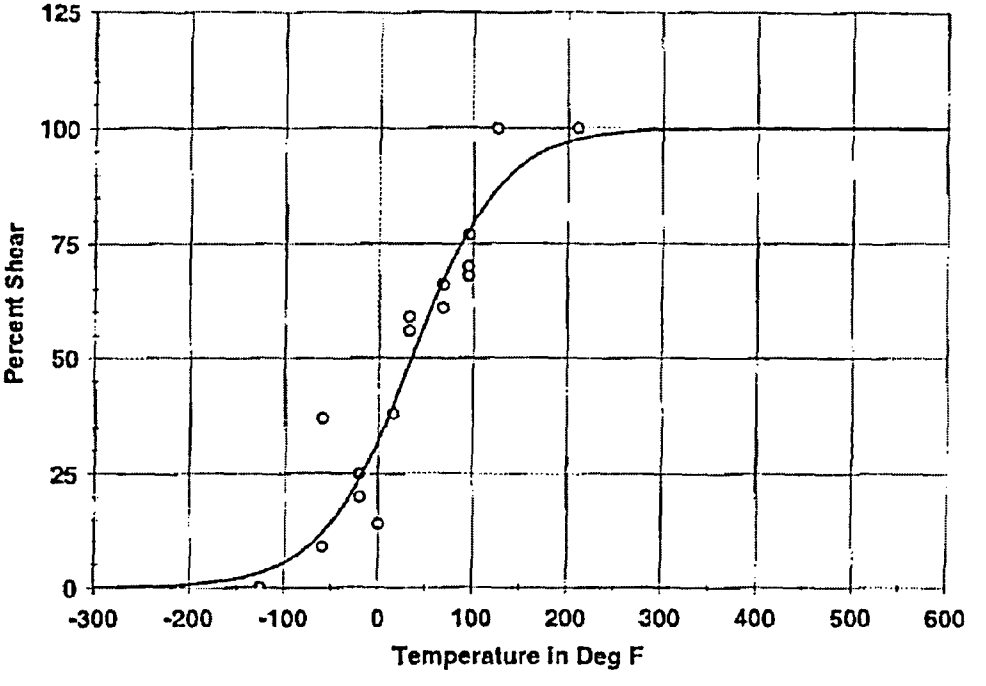
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 150.00 | 44.00 | 43.08 | .92 |
| 175.00 | 50.00 | 49.83 | .17 |
| 200.00 | 50.00 | 55.95 | -5.95 |
| 300.00 | 77.00 | 71.32 | 5.68 |
| 350.00 | 76.00 | 74.58 | 1.42 |
| 375.00 | 71.00 | 75.56 | -4.56 |

*Correlation Coefficient = .979*

# UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:42 PM
Page 1
Coefficients of Curve 1
**A = 50. B = 50. C = 94.86 T0 = 34.78 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 34.8
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -125.00 | .00 | 3.33 | -3.33 |
| -60.00 | 37.00 | 11.94 | 25.06 |
| -60.00 | 9.00 | 11.94 | -2.94 |
| -20.00 | 20.00 | 23.96 | -3.96 |
| -20.00 | 25.00 | 23.96 | 1.04 |
| .00 | 14.00 | 32.45 | -18.45 |
| 15.00 | 38.00 | 39.72 | -1.72 |
| 32.00 | 56.00 | 48.53 | 7.47 |
| 32.00 | 59.00 | 48.53 | 10.47 |

# UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

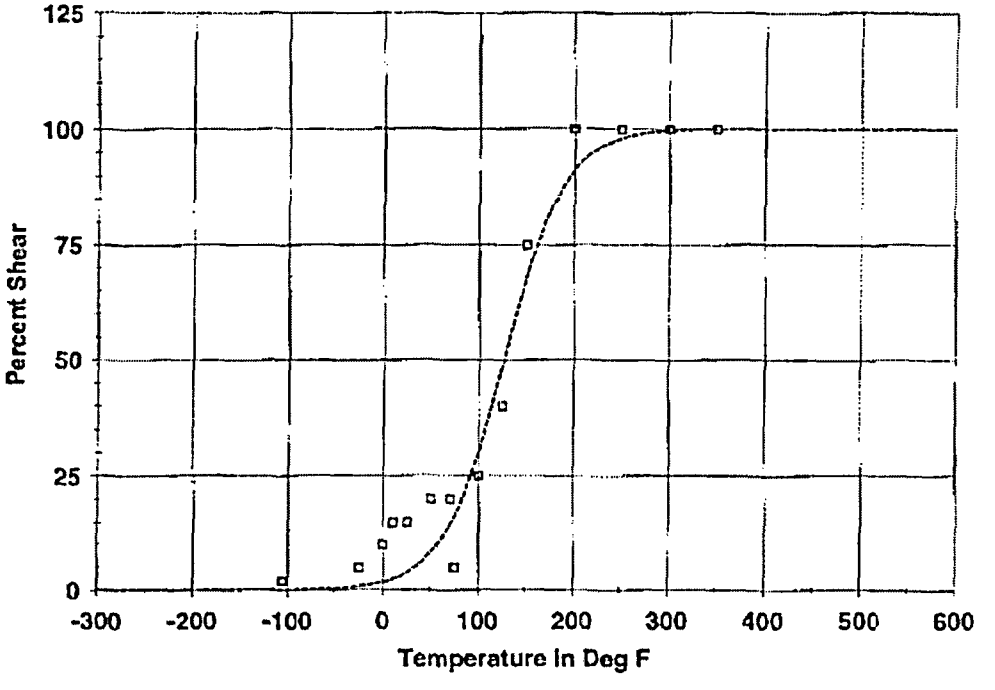
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 68.00 | 61.00 | 66.83 | -5.83 |
| 68.00 | 66.00 | 66.83 | -.83 |
| 95.00 | 77.00 | 78.07 | -1.07 |
| 95.00 | 70.00 | 78.07 | -8.07 |
| 95.00 | 68.00 | 78.07 | -10.07 |
| 125.00 | 100.00 | 87.01 | 12.99 |
| 125.00 | 100.00 | 87.01 | 12.99 |
| 210.00 | 100.00 | 97.57 | 2.43 |
| 210.00 | 100.00 | 97.57 | 2.43 |

Correlation Coefficient = .953

# CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:43 PM
Page 1
Coefficients of Curve 2
**A = 50. B = 50. C = 63.23 T0 = 126.56 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 126.6
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -105.00 | 2.00 | .07 | 1.93 |
| -25.00 | 5.00 | .82 | 4.18 |
| .00 | 10.00 | 1.79 | 8.21 |
| 10.00 | 15.00 | 2.44 | 12.56 |
| 25.00 | 15.00 | 3.87 | 11.13 |
| 50.00 | 20.00 | 8.15 | 11.85 |
| 70.00 | 20.00 | 14.32 | 5.68 |
| 75.00 | 5.00 | 16.37 | -11.37 |
| 100.00 | 25.00 | 30.15 | -5.15 |

# CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: n/cm^2

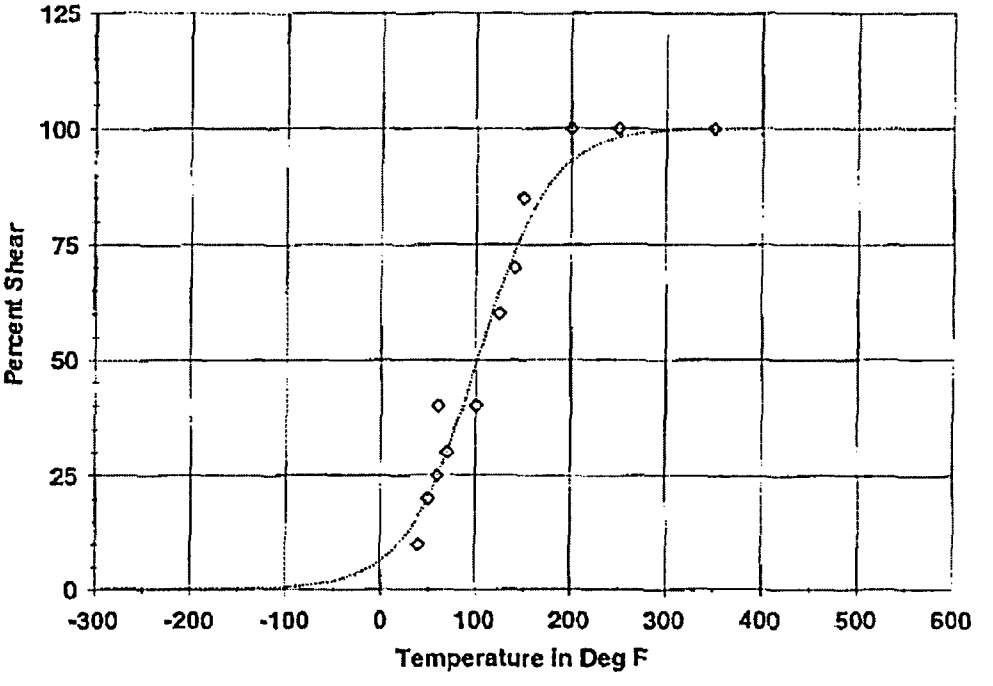
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 125.00 | 40.00 | 48.77 | -8.77 |
| 150.00 | 75.00 | 67.73 | 7.27 |
| 200.00 | 100.00 | 91.08 | 8.92 |
| 250.00 | 100.00 | 98.02 | 1.98 |
| 300.00 | 100.00 | 99.59 | .41 |
| 350.00 | 100.00 | 99.91 | .09 |

Correlation Coefficient = .984

# CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:43 PM
Page 1
Coefficients of Curve 3
**A = 50. B = 50. C = 75.89 T0 = 102.25 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 102.3
Plant: WATTS BAR 1 Material: SA508Cl.2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 40.00 | 10.00 | 16.24 | -6.24 |
| 50.00 | 20.00 | 20.15 | -.15 |
| 60.00 | 25.00 | 24.73 | .27 |
| 60.00 | 40.00 | 24.73 | 15.27 |
| 70.00 | 30.00 | 29.95 | .05 |
| 100.00 | 40.00 | 48.52 | -8.52 |
| 125.00 | 60.00 | 64.56 | -4.56 |
| 140.00 | 70.00 | 73.01 | -3.01 |
| 150.00 | 85.00 | 77.88 | 7.12 |

# CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2

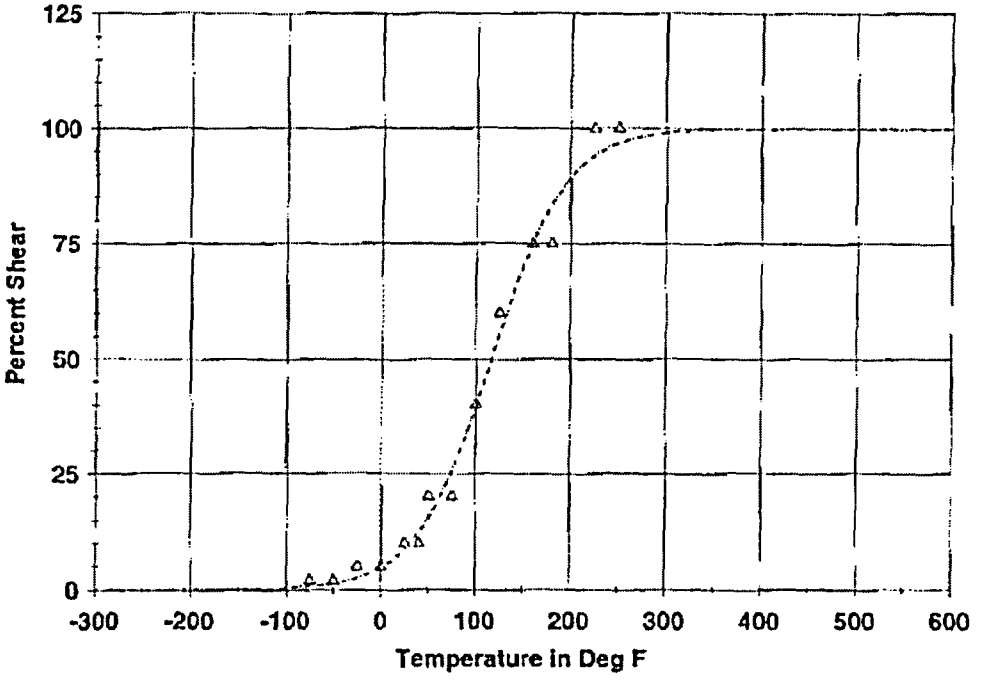
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200.00 | 100.00 | 92.93 | 7.07 |
| 250.00 | 100.00 | 98.00 | 2.00 |
| 350.00 | 100.00 | 99.85 | .15 |

Correlation Coefficient = .981

# CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:43 PM
Page 1
Coefficients of Curve 4
**A = 50. B = 50. C = 78.4 T0 = 116.58 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 116.6
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -75.00 | 2.00 | .75 | 1.25 |
| -50.00 | 2.00 | 1.41 | .59 |
| -25.00 | 5.00 | 2.63 | 2.37 |
| .00 | 5.00 | 4.86 | .14 |
| 25.00 | 10.00 | 8.82 | 1.18 |
| 40.00 | 10.00 | 12.42 | -2.42 |
| 50.00 | 20.00 | 15.47 | 4.53 |
| 75.00 | 20.00 | 25.72 | -5.72 |
| 100.00 | 40.00 | 39.58 | .42 |

# CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2

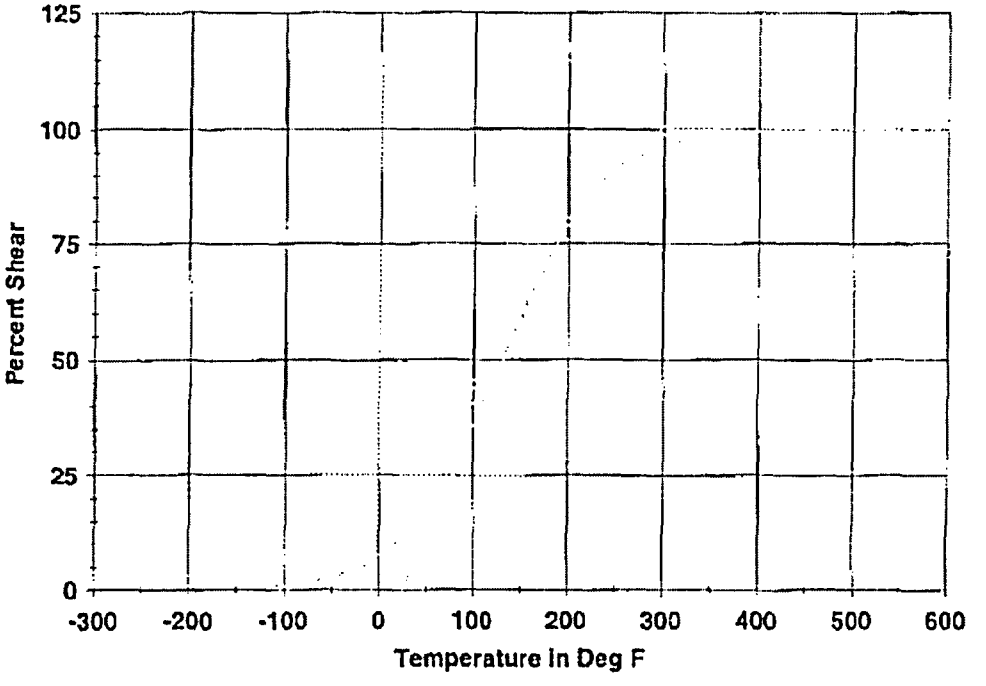
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 125.00 | 60.00 | 55.35 | 4.65 |
| 160.00 | 75.00 | 75.17 | -.17 |
| 180.00 | 75.00 | 83.45 | -8.45 |
| 225.00 | 100.00 | 94.08 | 5.92 |
| 250.00 | 100.00 | 96.78 | 3.22 |
| 250.00 | 100.00 | 96.78 | 3.22 |

Correlation Coefficient = .995

# CAPSULE Z INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/12/2007 03:43 PM
Page 1
Coefficients of Curve 5
**A = 50. B = 50. C = 103.54 T0 = 131.16 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 131.2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: Z Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100.00 | .00 | 1.14 | -1.14 |
| 25.00 | 2.00 | 11.40 | -9.40 |
| 60.00 | 10.00 | 20.19 | -10.19 |
| 75.00 | 25.00 | 25.26 | -.26 |
| 80.00 | 20.00 | 27.13 | -7.13 |
| 85.00 | 40.00 | 29.08 | 10.92 |
| 95.00 | 40.00 | 33.22 | 6.78 |
| 100.00 | 45.00 | 35.39 | 9.61 |
| 125.00 | 45.00 | 47.03 | -2.03 |

# CAPSULE Z INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: Z Fluence: n/cm^2

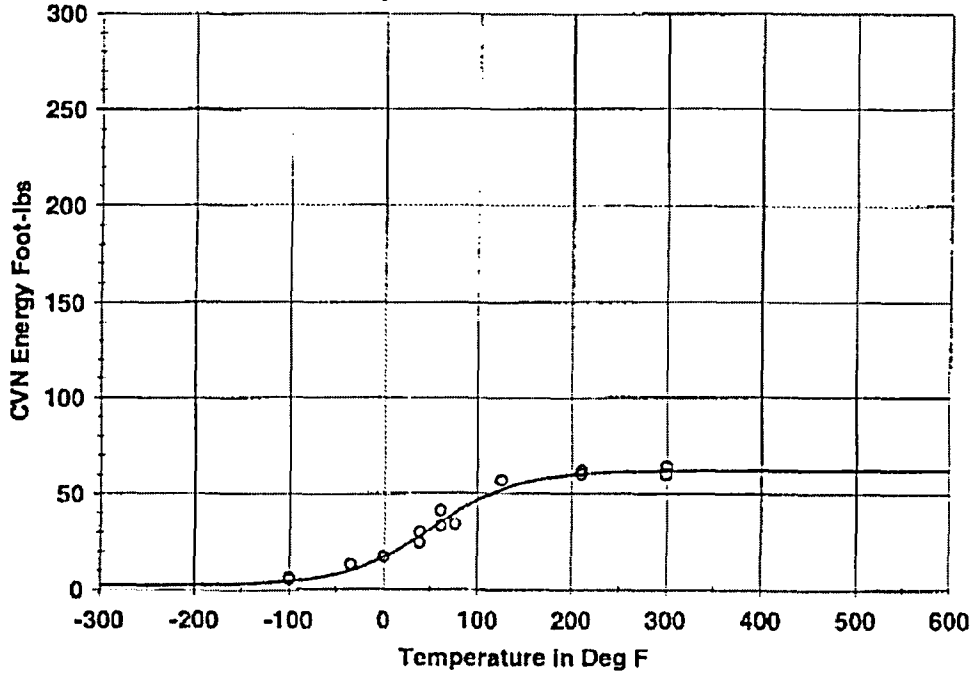
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 150.00 | 65.00 | 59.00 | 6.00 |
| 175.00 | 55.00 | 69.99 | -14.99 |
| 200.00 | 80.00 | 79.08 | .92 |
| 300.00 | 100.00 | 96.31 | 3.69 |
| 350.00 | 100.00 | 98.56 | 1.44 |
| 375.00 | 100.00 | 99.11 | .89 |

Correlation Coefficient = .977

# UNIRRADIATED INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:35 AM
Page 1
Coefficients of Curve 1
**A = 32.1 B = 29.9 C = 90.57 T0 = 51.57 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=62.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=45.2 Deg F Temp@50 ft-lbs=114.2 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -100.00 | 5.50 | 4.23 | 1.27 |
| -100.00 | 5.00 | 4.23 | .77 |
| -100.00 | 6.50 | 4.23 | 2.27 |
| -35.00 | 13.00 | 9.90 | 3.10 |
| .00 | 17.00 | 16.70 | .30 |
| .00 | 17.00 | 16.70 | .30 |
| 38.00 | 24.50 | 27.65 | -3.15 |
| 38.00 | 30.00 | 27.65 | 2.35 |
| 38.00 | 24.00 | 27.65 | -3.65 |

# UNIRRADIATED INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

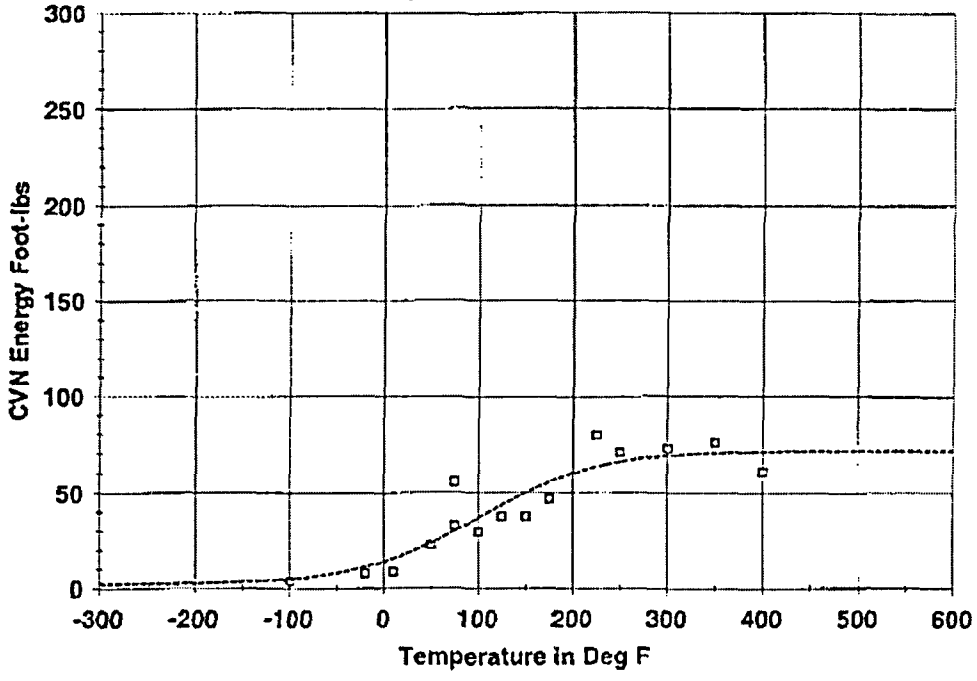
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 60.00 | 41.00 | 34.88 | 6.12 |
| 60.00 | 33.00 | 34.88 | -1.88 |
| 75.00 | 34.00 | 39.67 | -5.67 |
| 125.00 | 57.00 | 52.13 | 4.87 |
| 210.00 | 62.00 | 60.24 | 1.76 |
| 210.00 | 62.00 | 60.24 | 1.76 |
| 210.00 | 60.00 | 60.24 | -.24 |
| 300.00 | 60.00 | 61.75 | -1.75 |
| 300.00 | 64.00 | 61.75 | 2.25 |

Correlation Coefficient = .991

# CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:35 AM
Page 1
Coefficients of Curve 2
**A = 37.1 B = 34.9 C = 125.83 T0 = 99.81 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=72.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=73.9 Deg F Temp@50 ft-lbs=148.7 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -100.00 | 4.00 | 5.00 | -1.00 |
| -20.00 | 8.00 | 11.25 | -3.25 |
| 10.00 | 9.00 | 15.71 | -6.71 |
| 50.00 | 23.00 | 23.96 | -.96 |
| 75.00 | 33.00 | 30.31 | 2.69 |
| 75.00 | 56.00 | 30.31 | 25.69 |
| 100.00 | 30.00 | 37.15 | -7.15 |
| 125.00 | 38.00 | 43.99 | -5.99 |
| 150.00 | 38.00 | 50.33 | -12.33 |

# CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: U Fluence: n/cm^2

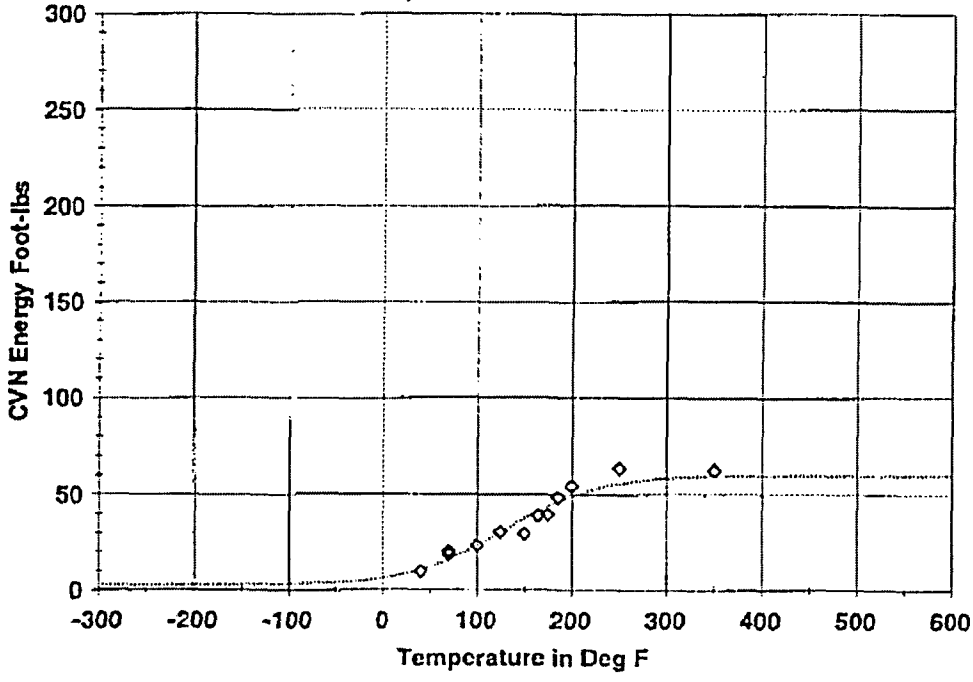
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 175.00 | 47.00 | 55.78 | -8.78 |
| 225.00 | 80.00 | 63.60 | 16.40 |
| 250.00 | 71.00 | 66.13 | 4.87 |
| 300.00 | 73.00 | 69.22 | 3.78 |
| 350.00 | 76.00 | 70.72 | 5.28 |
| 400.00 | 61.00 | 71.41 | -10.41 |

Correlation Coefficient = .917

# CAPSULE W INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:35 AM
Page 1
Coefficients of Curve 3
**A = 31.1 B = 28.9 C = 99.98 T0 = 127.92 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=60.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=124.2 Deg F Temp@50 ft-lbs=206.2 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 40.00 | 10.00 | 10.69 | -.69 |
| 70.00 | 18.50 | 16.01 | 2.49 |
| 70.00 | 20.50 | 16.01 | 4.49 |
| 100.00 | 23.50 | 23.23 | .27 |
| 125.00 | 30.50 | 30.26 | .24 |
| 150.00 | 29.50 | 37.38 | -7.88 |
| 165.00 | 39.00 | 41.35 | -2.35 |
| 175.00 | 39.50 | 43.78 | -4.28 |
| 185.00 | 48.50 | 46.01 | 2.49 |

# CAPSULE W INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2

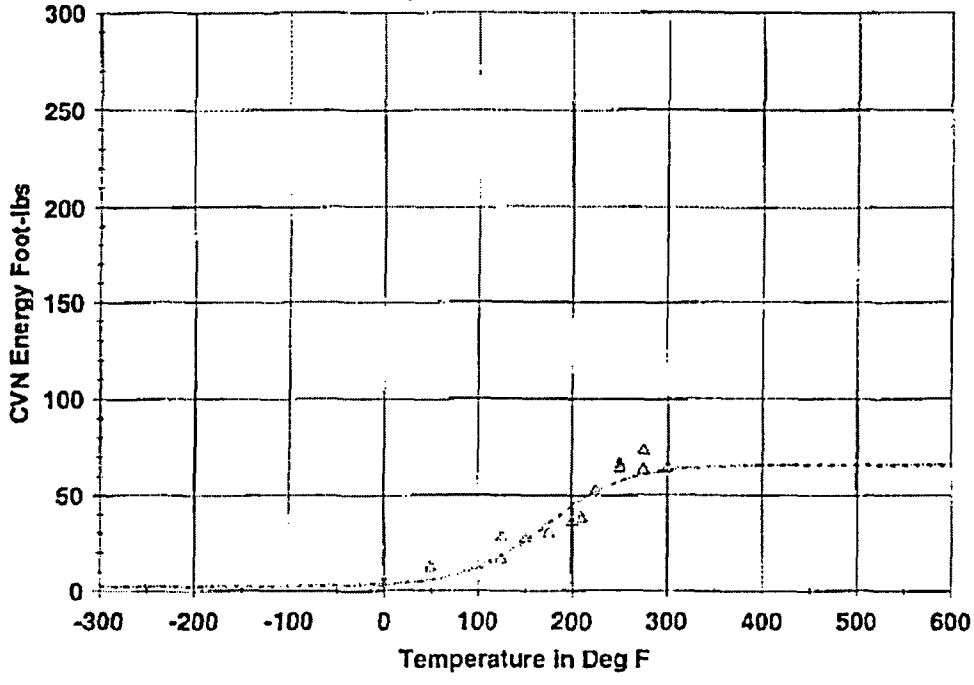
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 200.00 | 54.50 | 48.95 | 5.55 |
| 250.00 | 63.50 | 55.37 | 8.13 |
| 350.00 | 62.50 | 59.33 | 3.17 |

Correlation Coefficient = .969

# CAPSULE X INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:35 AM
Page 1
Coefficients of Curve 4
**A = 34.1 B = 31.9 C = 84.5 T0 = 172. D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=66.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=161.1 Deg F Temp@50 ft-lbs=218.3 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| .00 | 4.00 | 3.27 | .73 |
| 50.00 | 12.00 | 5.57 | 6.43 |
| 100.00 | 13.00 | 12.02 | .98 |
| 125.00 | 28.00 | 17.99 | 10.01 |
| 125.00 | 16.00 | 17.99 | -1.99 |
| 150.00 | 27.00 | 25.98 | 1.02 |
| 175.00 | 30.00 | 35.23 | -5.23 |
| 200.00 | 36.00 | 44.30 | -8.30 |
| 210.00 | 38.00 | 47.55 | -9.55 |

# CAPSULE X INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: X Fluence: n/cm^2

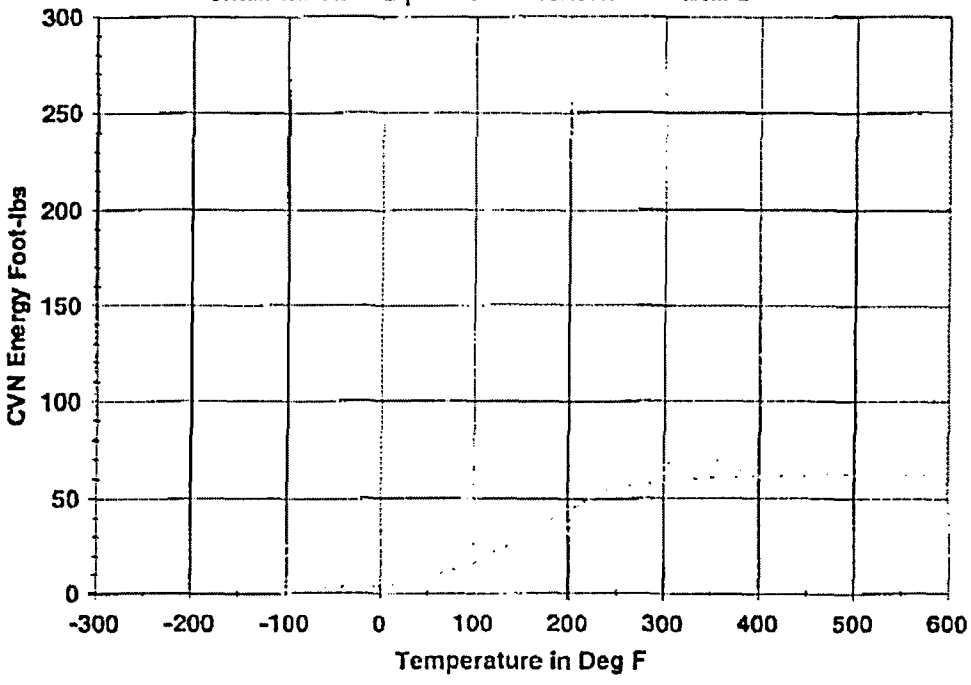
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 225.00 | 52.00 | 51.84 | .16 |
| 250.00 | 66.00 | 57.30 | 8.70 |
| 250.00 | 64.00 | 57.30 | 6.70 |
| 275.00 | 73.00 | 60.87 | 12.13 |
| 275.00 | 63.00 | 60.87 | 2.13 |
| 300.00 | 64.00 | 63.06 | .94 |

Correlation Coefficient = .961

# CAPSULE Z INTEMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:35 AM
Page 1
Coefficients of Curve 5
**A = 32.1 B = 29.9 C = 99.14 T0 = 156.99 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=62.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=150.1 Deg F Temp@50 ft-lbs=225.6 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: Z Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -50.00 | 7.00 | 3.10 | 3.90 |
| 75.00 | 18.00 | 11.80 | 6.20 |
| 100.00 | 24.00 | 16.58 | 7.42 |
| 125.00 | 18.00 | 22.77 | -4.77 |
| 140.00 | 27.00 | 27.02 | -.02 |
| 150.00 | 28.00 | 29.99 | -1.99 |
| 165.00 | 33.00 | 34.51 | -1.51 |
| 175.00 | 35.00 | 37.47 | -2.47 |
| 190.00 | 36.00 | 41.70 | -5.70 |

# CAPSULE Z INTEMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: Z Fluence: n/cm^2

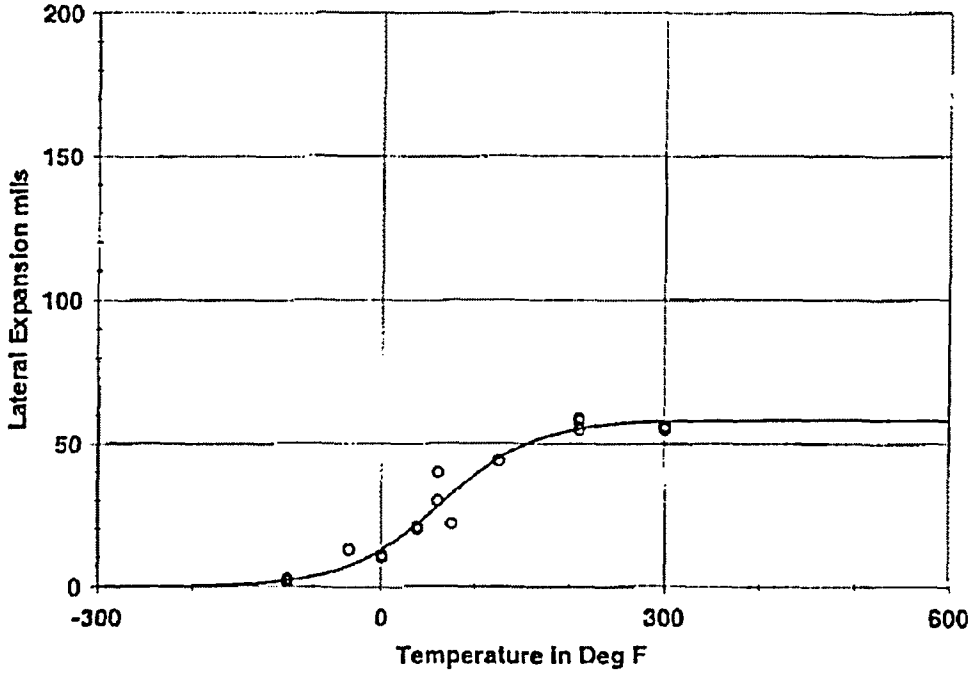
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 200.00 | 35.00 | 44.31 | -9.31 |
| 210.00 | 58.00 | 46.72 | 11.28 |
| 225.00 | 55.00 | 49.90 | 5.10 |
| 300.00 | 66.00 | 58.84 | 7.16 |
| 350.00 | 69.00 | 60.81 | 8.19 |
| 375.00 | 64.00 | 61.27 | 2.73 |

Correlation Coefficient = .953

# UNIRRADIATED INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:52 AM
Page 1
Coefficients of Curve 1
**A = 29.17 B = 29.17 C = 101.37 T0 = 63.98 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=58.3 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=84.6 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -100.00 | 2.00 | 2.21 | -.21 |
| -100.00 | 1.00 | 2.21 | -1.21 |
| -100.00 | 3.00 | 2.21 | .79 |
| -35.00 | 13.00 | 7.25 | 5.75 |
| .00 | 11.00 | 12.87 | -1.87 |
| .00 | 10.00 | 12.87 | -2.87 |
| 38.00 | 21.00 | 21.85 | -.85 |
| 38.00 | 21.00 | 21.85 | -.85 |
| 38.00 | 20.00 | 21.85 | -1.85 |

# UNIRRADIATED INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

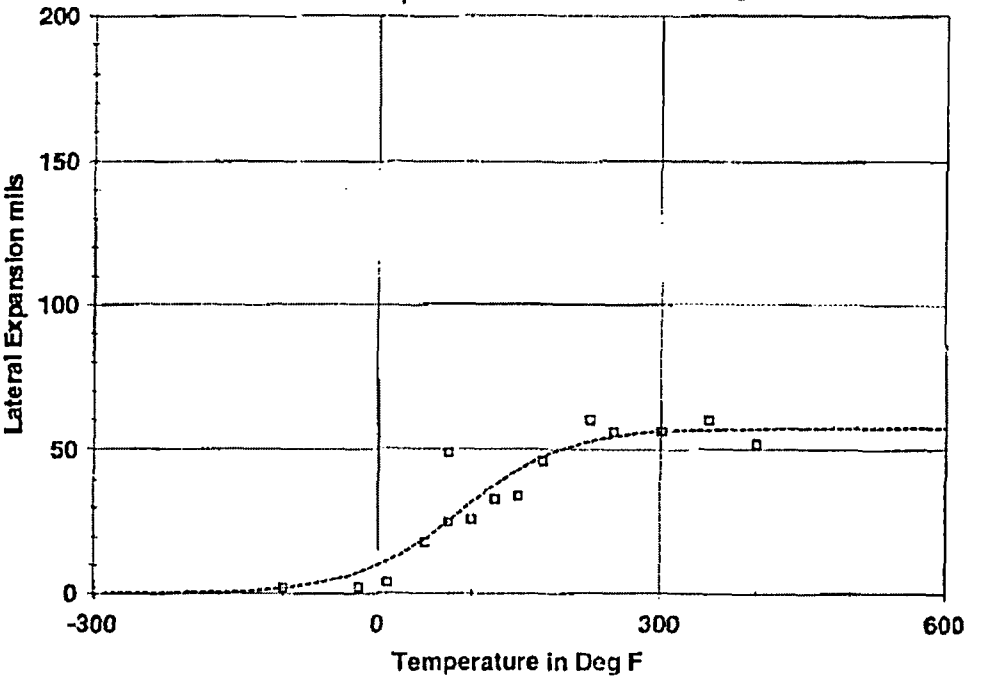
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 60.00 | 40.00 | 28.03 | 11.97 |
| 60.00 | 30.00 | 28.03 | 1.97 |
| 75.00 | 22.00 | 32.33 | -10.33 |
| 125.00 | 44.00 | 44.88 | -.88 |
| 210.00 | 58.00 | 55.24 | 2.76 |
| 210.00 | 59.00 | 55.24 | 3.76 |
| 210.00 | 55.00 | 55.24 | -.24 |
| 300.00 | 55.00 | 57.79 | -2.79 |
| 300.00 | 56.00 | 57.79 | -1.79 |

Correlation Coefficient = .977

# CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:52 AM
Page 1
Coefficients of Curve 2
**A = 28.65 B = 28.65 C = 111.9 T0 = 88.09 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=57.3 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=113.4 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -100.00 | 2.00 | 1.92 | .08 |
| -20.00 | 2.00 | 7.25 | -5.25 |
| 10.00 | 4.00 | 11.37 | -7.37 |
| 50.00 | 18.00 | 19.26 | -1.26 |
| 75.00 | 25.00 | 25.32 | -.32 |
| 75.00 | 49.00 | 25.32 | 23.68 |
| 100.00 | 26.00 | 31.69 | -5.69 |
| 125.00 | 33.00 | 37.77 | -4.77 |
| 150.00 | 34.00 | 43.06 | -9.06 |

# CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: U Fluence: n/cm^2

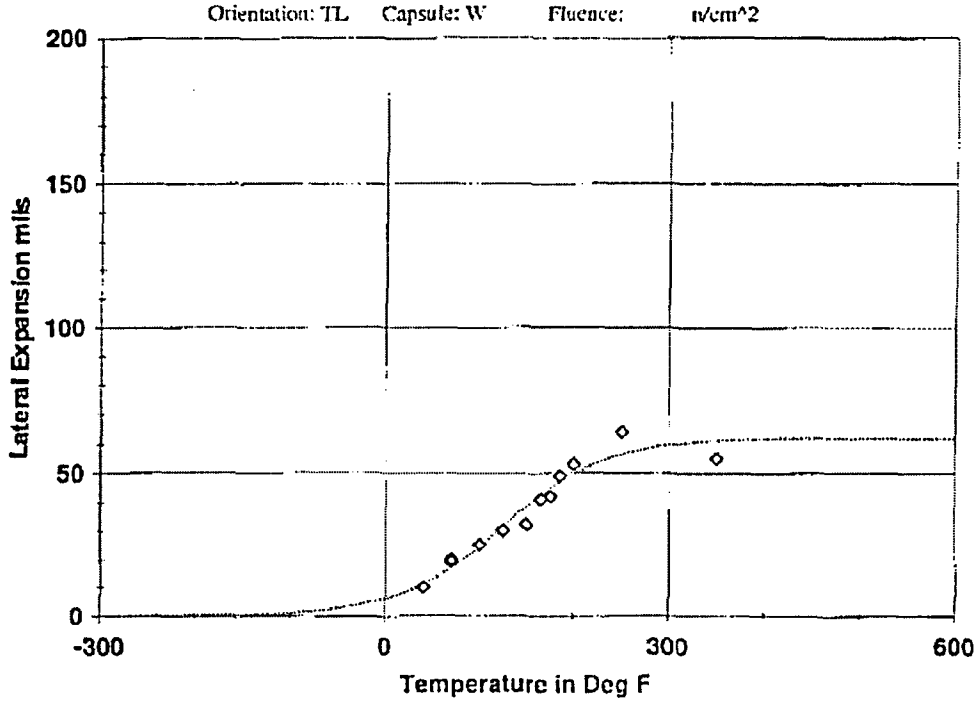
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 175.00 | 46.00 | 47.30 | -1.30 |
| 225.00 | 60.00 | 52.74 | 7.26 |
| 250.00 | 56.00 | 54.30 | 1.70 |
| 300.00 | 56.00 | 56.03 | -.03 |
| 350.00 | 60.00 | 56.78 | 3.22 |
| 400.00 | 52.00 | 57.09 | -5.09 |

Correlation Coefficient = .929

# CAPSULE W INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:53 AM
Page 1
Coefficients of Curve 3
**A = 30.92 B = 30.92 C = 108.86 T0 = 123.59 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=61.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=138.1 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 40.00 | 10.00 | 10.96 | -.96 |
| 70.00 | 20.00 | 16.82 | 3.18 |
| 70.00 | 19.00 | 16.82 | 2.18 |
| 100.00 | 25.00 | 24.32 | .68 |
| 125.00 | 30.00 | 31.32 | -1.32 |
| 150.00 | 32.00 | 38.28 | -6.28 |
| 165.00 | 41.00 | 42.15 | -1.15 |
| 175.00 | 42.00 | 44.53 | -2.53 |
| 185.00 | 49.00 | 46.72 | 2.28 |

# CAPSULE W INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA50SCL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2

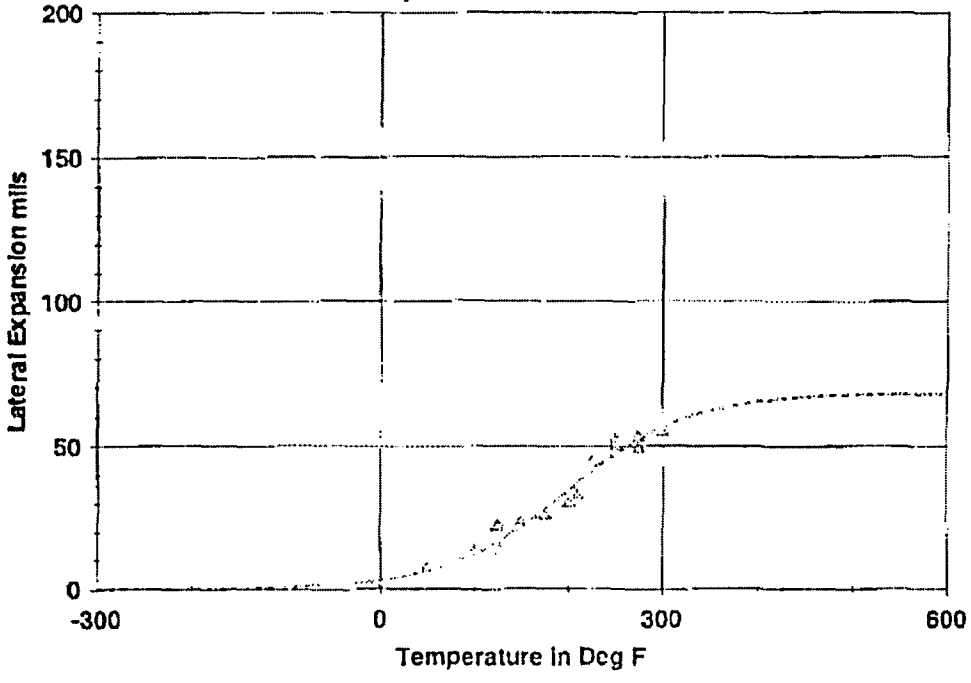
## Charpy V-Notch Data

| Temperature | Input L.E | Computed L.E. | Differential |
|---|---|---|---|
| 200.00 | 53.00 | 49.65 | 3.35 |
| 250.00 | 64.00 | 56.32 | 7.68 |
| 350.00 | 55.00 | 60.89 | -5.89 |

Correlation Coefficient = .971

# CAPSULE X INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:53 AM
Page 1
Coefficients of Curve 4
A = 34.07 B = 34.07 C = 129.63 T0 = 197.99 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=68.1 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=201.6 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| .00 | .00 | 3.07 | -3.07 |
| 50.00 | 7.00 | 6.30 | .70 |
| 100.00 | 13.00 | 12.31 | .69 |
| 125.00 | 22.00 | 16.69 | 5.31 |
| 125.00 | 14.00 | 16.69 | -2.69 |
| 150.00 | 24.00 | 22.00 | 2.00 |
| 175.00 | 26.00 | 28.09 | -2.09 |
| 200.00 | 30.00 | 34.60 | -4.60 |
| 210.00 | 33.00 | 37.22 | -4.22 |

# CAPSULE X INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: X Fluence: n/cm^2

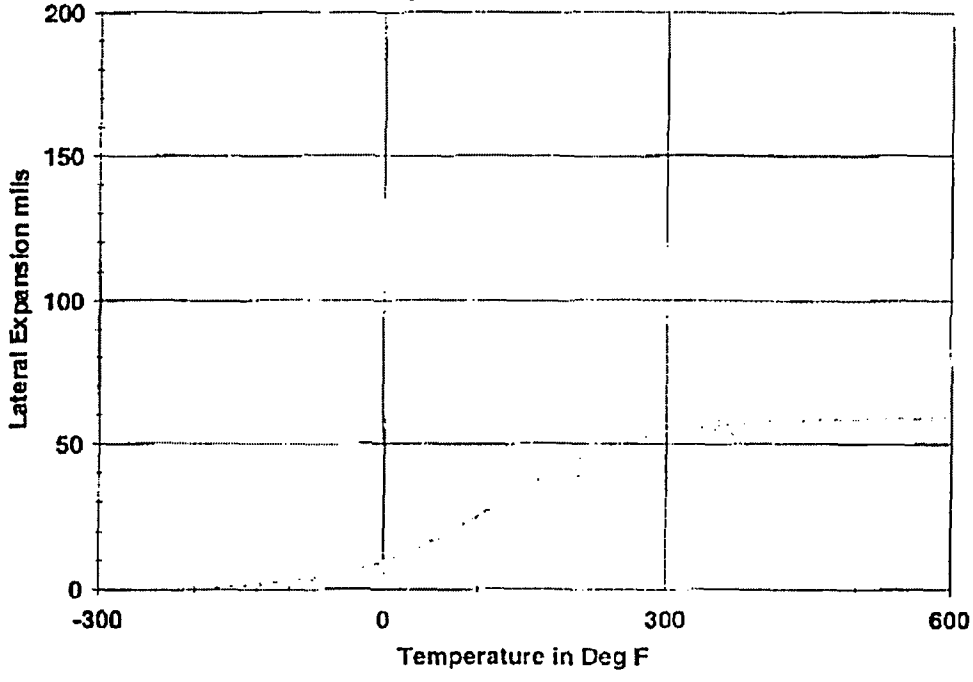
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 225.00 | 44.00 | 41.07 | 2.93 |
| 250.00 | 50.00 | 47.05 | 2.95 |
| 250.00 | 52.00 | 47.05 | 4.95 |
| 275.00 | 53.00 | 52.22 | .78 |
| 275.00 | 49.00 | 52.22 | -3.22 |
| 300.00 | 55.00 | 56.44 | -1.44 |

Correlation Coefficient = .984

# CAPSULE Z INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:53 AM
Page 1
Coefficients of Curve 5
**A = 29.38 B = 29.38 C = 146.82 T0 = 121.47 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=58.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=150.0 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: Z Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -50.00 | 6.00 | 5.18 | .82 |
| 75.00 | 19.00 | 20.38 | -1.38 |
| 100.00 | 36.00 | 25.11 | 10.89 |
| 125.00 | 25.00 | 30.08 | -5.08 |
| 140.00 | 32.00 | 33.06 | -1.06 |
| 150.00 | 31.00 | 35.01 | -4.01 |
| 165.00 | 35.00 | 37.84 | -2.84 |
| 175.00 | 34.00 | 39.63 | -5.63 |
| 190.00 | 42.00 | 42.17 | -.17 |

# CAPSULE Z INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: Z Fluence: n/cm^2

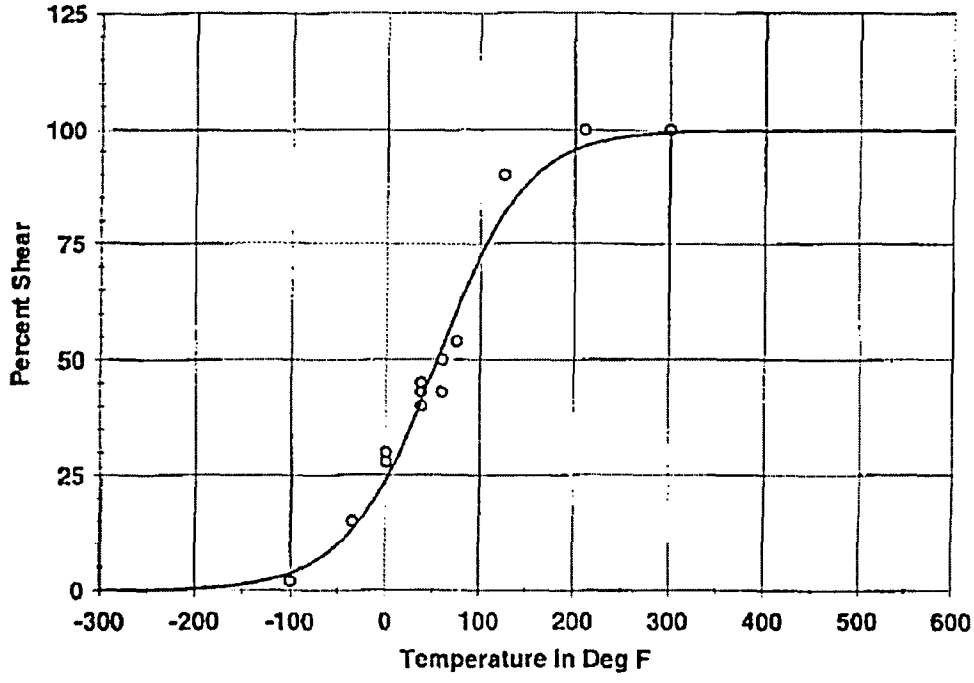
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 200.00 | 38.00 | 43.74 | -5.74 |
| 210.00 | 60.00 | 45.21 | 14.79 |
| 225.00 | 50.00 | 47.22 | 2.78 |
| 300.00 | 56.00 | 54.01 | 1.99 |
| 350.00 | 57.00 | 56.25 | .75 |
| 375.00 | 52.00 | 56.95 | -4.95 |

Correlation Coefficient = .920

# UNIRRADIATED INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:44 AM
Page 1
Coefficients of Curve 1
**A = 50. B = 50. C = 95.2 T0 = 54.88 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 54.9
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100.00 | 2.00 | 3.72 | -1.72 |
| -100.00 | 2.00 | 3.72 | -1.72 |
| -100.00 | 2.00 | 3.72 | -1.72 |
| -35.00 | 15.00 | 13.14 | 1.86 |
| .00 | 30.00 | 23.99 | 6.01 |
| .00 | 28.00 | 23.99 | 4.01 |
| 38.00 | 45.00 | 41.22 | 3.78 |
| 38.00 | 43.00 | 41.22 | 1.78 |
| 38.00 | 40.00 | 41.22 | -1.22 |

# UNIRRADIATED INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

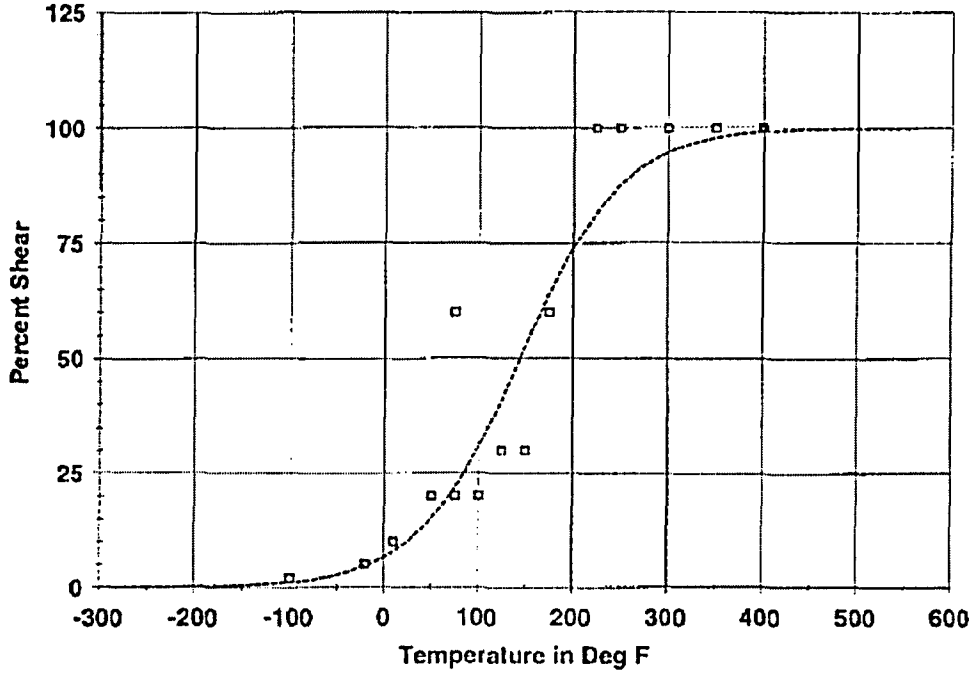
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 60.00 | 50.00 | 52.68 | -2.68 |
| 60.00 | 43.00 | 52.68 | -9.68 |
| 75.00 | 54.00 | 60.41 | -6.41 |
| 125.00 | 90.00 | 81.35 | 8.65 |
| 210.00 | 100.00 | 96.30 | 3.70 |
| 210.00 | 100.00 | 96.30 | 3.70 |
| 210.00 | 100.00 | 96.30 | 3.70 |
| 300.00 | 100.00 | 99.42 | .58 |
| 300.00 | 100.00 | 99.42 | .58 |

Correlation Coefficient = .993

# CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:44 AM
Page 1
Coefficients of Curve 2
**A = 50. B = 50. C = 108.6 T0 = 144.29 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 144.3
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100.00 | 2.00 | 1.10 | .90 |
| -20.00 | 5.00 | 4.63 | .37 |
| 10.00 | 10.00 | 7.78 | 2.22 |
| 50.00 | 20.00 | 14.98 | 5.02 |
| 75.00 | 20.00 | 21.82 | -1.82 |
| 75.00 | 60.00 | 21.82 | 38.18 |
| 100.00 | 20.00 | 30.67 | -10.67 |
| 125.00 | 30.00 | 41.21 | -11.21 |
| 150.00 | 30.00 | 52.63 | -22.63 |

# CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: U Fluence: n/cm^2

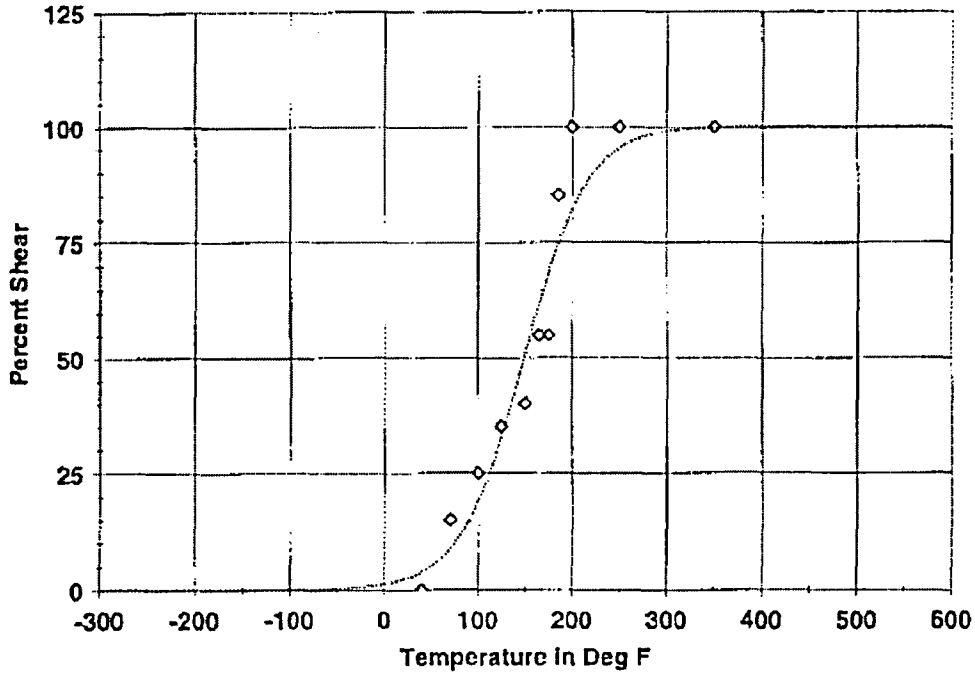
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 175.00 | 60.00 | 63.77 | -3.77 |
| 225.00 | 100.00 | 81.55 | 18.45 |
| 250.00 | 100.00 | 87.51 | 12.49 |
| 300.00 | 100.00 | 94.62 | 5.38 |
| 350.00 | 100.00 | 97.79 | 2.21 |
| 400.00 | 100.00 | 99.11 | .89 |

Correlation Coefficient = .937

# CAPSULE W INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:44 AM
Page 1
Coefficients of Curve 3
**A = 50. B = 50. C = 66.93 T0 = 149.07 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 149.1
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 40.00 | .00 | 3.70 | -3.70 |
| 70.00 | 15.00 | 8.60 | 6.40 |
| 70.00 | 15.00 | 8.60 | 6.40 |
| 100.00 | 25.00 | 18.75 | 6.25 |
| 125.00 | 35.00 | 32.75 | 2.25 |
| 150.00 | 40.00 | 50.69 | -10.69 |
| 165.00 | 55.00 | 61.68 | -6.68 |
| 175.00 | 55.00 | 68.45 | -13.45 |
| 185.00 | 85.00 | 74.53 | 10.47 |

# CAPSULE W INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2

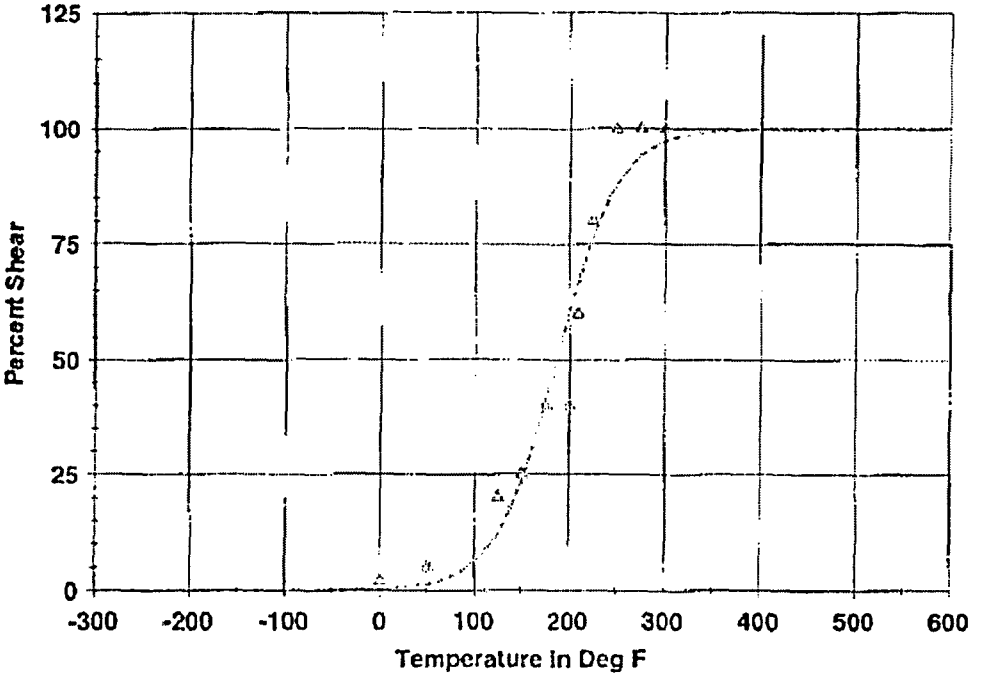
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200.00 | 100.00 | 82.08 | 17.92 |
| 250.00 | 100.00 | 95.33 | 4.67 |
| 350.00 | 100.00 | 99.75 | .25 |

Correlation Coefficient = .969

# CAPSULE X INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:44 AM
Page 1
Coefficients of Curve 4
**A = 50. B = 50. C = 63.84 T0 = 187.25 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 187.3
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| .00 | 2.00 | .28 | 1.72 |
| 50.00 | 5.00 | 1.34 | 3.66 |
| 100.00 | 15.00 | 6.10 | 8.90 |
| 125.00 | 20.00 | 12.45 | 7.55 |
| 125.00 | 20.00 | 12.45 | 7.55 |
| 150.00 | 25.00 | 23.74 | 1.26 |
| 175.00 | 40.00 | 40.52 | -.52 |
| 200.00 | 40.00 | 59.86 | -19.86 |
| 210.00 | 60.00 | 67.10 | -7.10 |

# CAPSULE X INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: X Fluence: n/cm^2

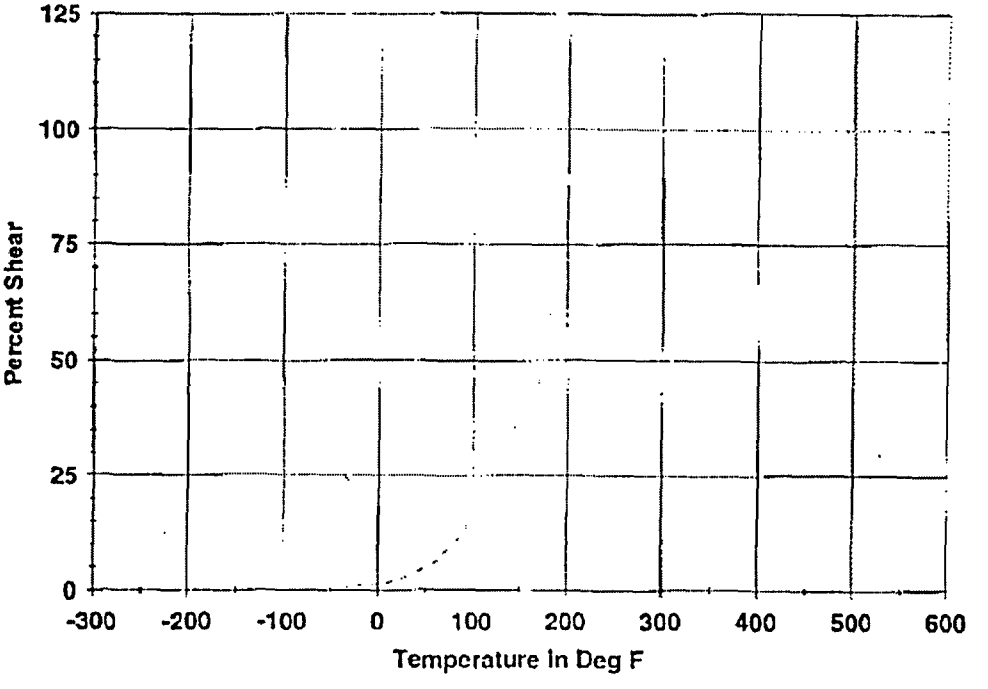
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 225.00 | 80.00 | 76.54 | 3.46 |
| 250.00 | 100.00 | 87.72 | 12.28 |
| 250.00 | 100.00 | 87.72 | 12.28 |
| 275.00 | 100.00 | 93.99 | 6.01 |
| 275.00 | 100.00 | 93.99 | 6.01 |
| 300.00 | 100.00 | 97.16 | 2.84 |

Correlation Coefficient = .979

# CAPSULE Z INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 08:44 AM
Page 1
Coefficients of Curve 5
**A = 50. B = 50. C = 77.78 T0 = 165.42 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 165.5
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: Z Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -50.00 | 2.00 | .39 | 1.61 |
| 75.00 | 20.00 | 8.91 | 11.09 |
| 100.00 | 25.00 | 15.68 | 9.32 |
| 125.00 | 20.00 | 26.13 | -6.13 |
| 140.00 | 40.00 | 34.22 | 5.78 |
| 150.00 | 40.00 | 40.22 | -.22 |
| 165.00 | 45.00 | 49.73 | -4.73 |
| 175.00 | 50.00 | 56.13 | -6.13 |
| 190.00 | 50.00 | 65.29 | -15.29 |

# CAPSULE Z INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: Z Fluence: n/cm^2

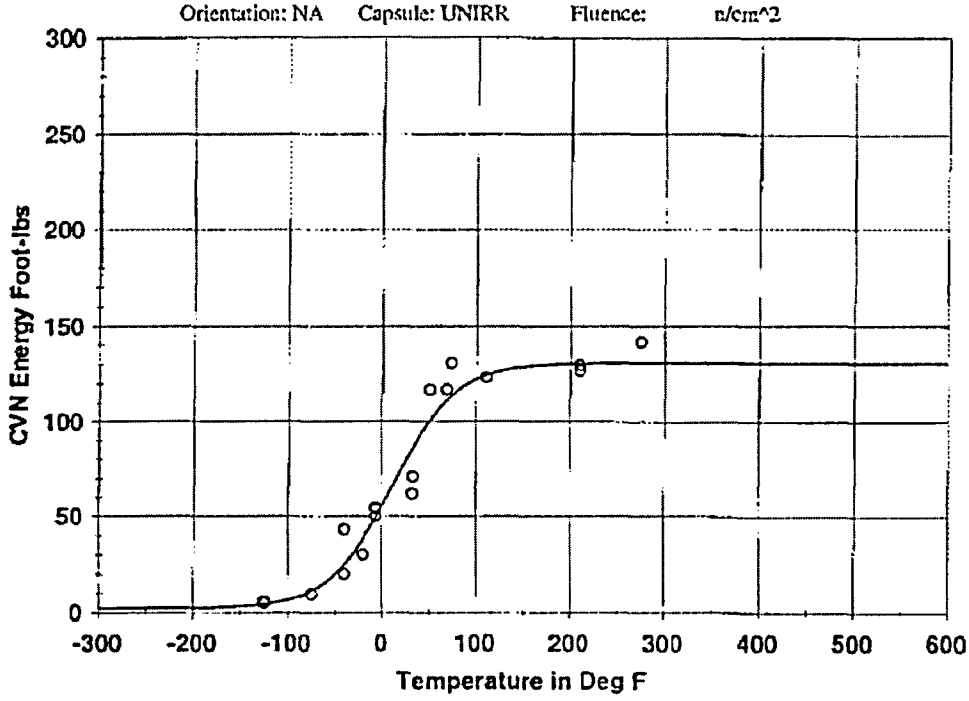
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200.00 | 60.00 | 70.87 | -10.87 |
| 210.00 | 95.00 | 75.88 | 19.12 |
| 225.00 | 100.00 | 82.23 | 17.77 |
| 300.00 | 100.00 | 96.95 | 3.05 |
| 350.00 | 100.00 | 99.14 | .86 |
| 375.00 | 100.00 | 99.55 | .45 |

Correlation Coefficient = .958

# UNIRRADIATED SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:16 AM
Page 1
Coefficients of Curve 1
**A = 66.6 B = 64.4 C = 66.29 T0 = 11.54 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=131.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-31.2 Deg F Temp@50 ft-lbs=-5.9 Deg F
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -125.00 | 6.00 | 4.26 | 1.74 |
| -125.00 | 5.00 | 4.26 | .74 |
| -75.00 | 9.50 | 11.01 | -1.51 |
| -40.00 | 20.00 | 24.66 | -4.66 |
| -40.00 | 43.00 | 24.66 | 18.34 |
| -20.00 | 30.00 | 38.08 | -8.08 |
| -7.00 | 50.00 | 49.04 | .96 |
| -7.00 | 54.00 | 49.04 | 4.96 |
| -7.00 | 55.00 | 49.04 | 5.96 |

# UNIRRADIATED SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

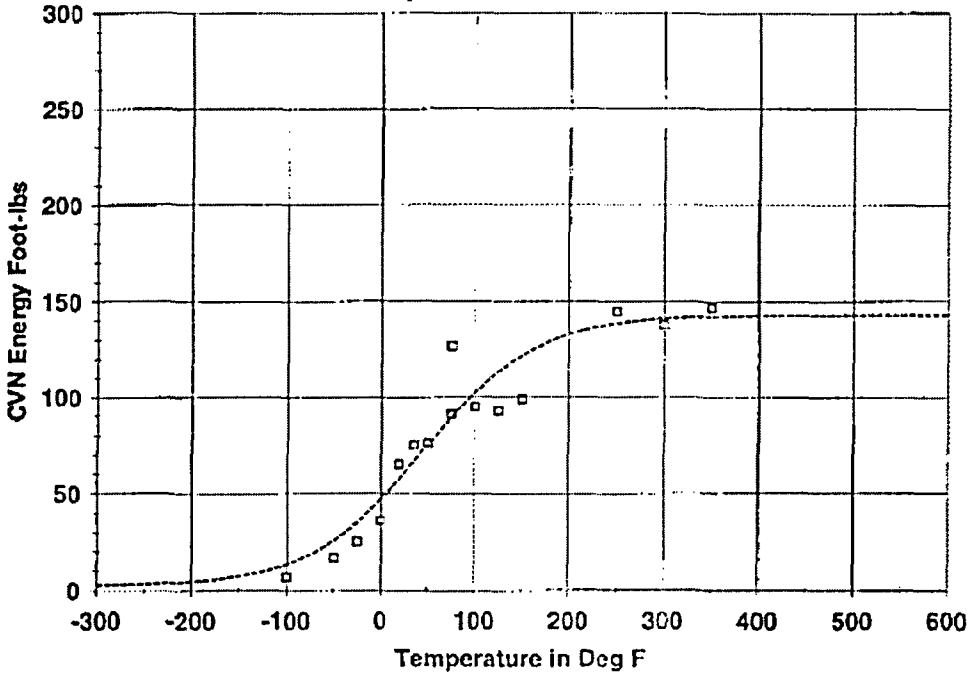
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 32.00 | 71.00 | 85.87 | -14.87 |
| 32.00 | 62.00 | 85.87 | -23.87 |
| 50.00 | 117.00 | 100.26 | 16.74 |
| 68.00 | 117.00 | 111.16 | 5.84 |
| 73.00 | 131.00 | 113.56 | 17.44 |
| 110.00 | 123.50 | 124.72 | -1.22 |
| 210.00 | 130.00 | 130.68 | -.68 |
| 210.00 | 127.00 | 130.68 | -3.68 |
| 275.00 | 142.00 | 130.95 | 11.05 |

Correlation Coefficient = .975

# CAPSULE U SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:16 AM
Page 1
Coefficients of Curve 2
**A = 72.6 B = 70.4 C = 119.21 T0 = 45.94 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=143.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-37.6 Deg F Temp@50 ft-lbs=6.3 Deg F
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -100.00 | 7.00 | 13.40 | -6.40 |
| -50.00 | 17.00 | 25.66 | -8.66 |
| -25.00 | 25.00 | 35.04 | -10.04 |
| .00 | 36.00 | 46.74 | -10.74 |
| 20.00 | 65.00 | 57.52 | 7.48 |
| 35.00 | 75.00 | 66.16 | 8.84 |
| 50.00 | 76.00 | 75.00 | 1.00 |
| 75.00 | 127.00 | 89.43 | 37.57 |
| 75.00 | 91.00 | 89.43 | 1.57 |

# CAPSULE U SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: U Fluence: n/cm^2

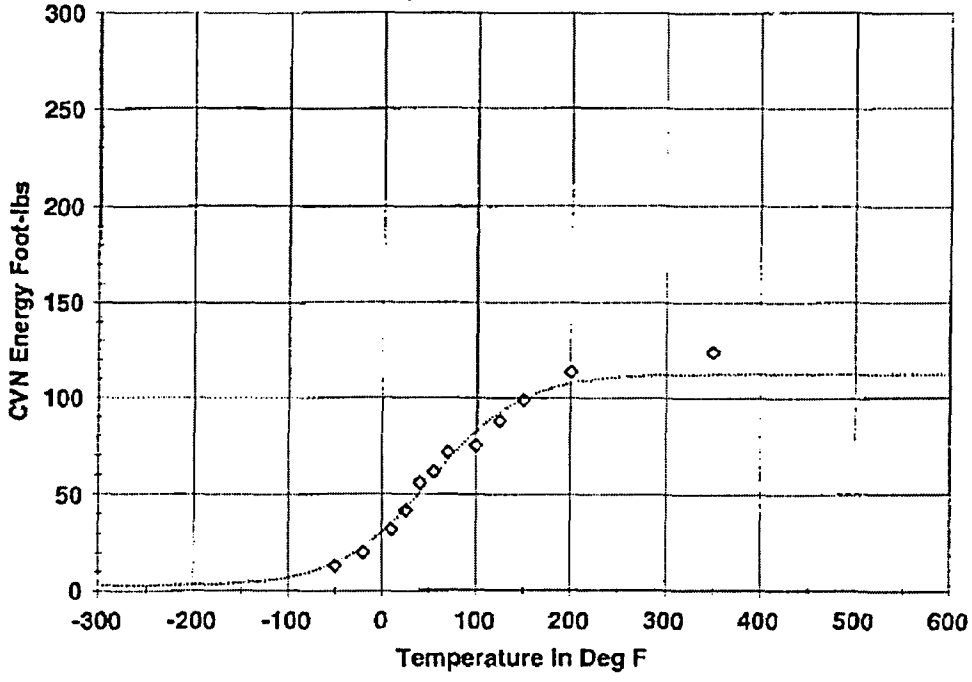
## Charpy V-Notch Data

| Temperature | Input CVN | Generated CVN | Differential |
|---|---|---|---|
| 100.00 | 95.00 | 102.50 | -7.50 |
| 125.00 | 93.00 | 113.47 | -20.47 |
| 150.00 | 99.00 | 122.08 | -23.08 |
| 250.00 | 145.00 | 138.56 | 6.44 |
| 300.00 | 138.00 | 141.04 | -3.04 |
| 350.00 | 147.00 | 142.15 | 4.85 |

Correlation Coefficient = .949

# CAPSULE W SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:41 AM
Page 1
Coefficients of Curve 3
**A = 57.1 B = 54.9 C = 97.49 T0 = 52.01 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=112.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-.7 Deg F Temp@50 ft-lbs=39.4 Deg F
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: W Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -50.00 | 13.00 | 14.26 | -1.26 |
| -20.00 | 20.00 | 22.61 | -2.61 |
| 10.00 | 32.00 | 34.81 | -2.81 |
| 25.00 | 41.50 | 42.27 | -.77 |
| 40.00 | 56.00 | 50.37 | 5.63 |
| 55.00 | 61.50 | 58.79 | 2.71 |
| 70.00 | 71.50 | 67.12 | 4.38 |
| 100.00 | 75.00 | 82.14 | -7.14 |
| 125.00 | 87.50 | 91.93 | -4.43 |

# CAPSULE W SURVIELLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: W Fluence: n/cm^2

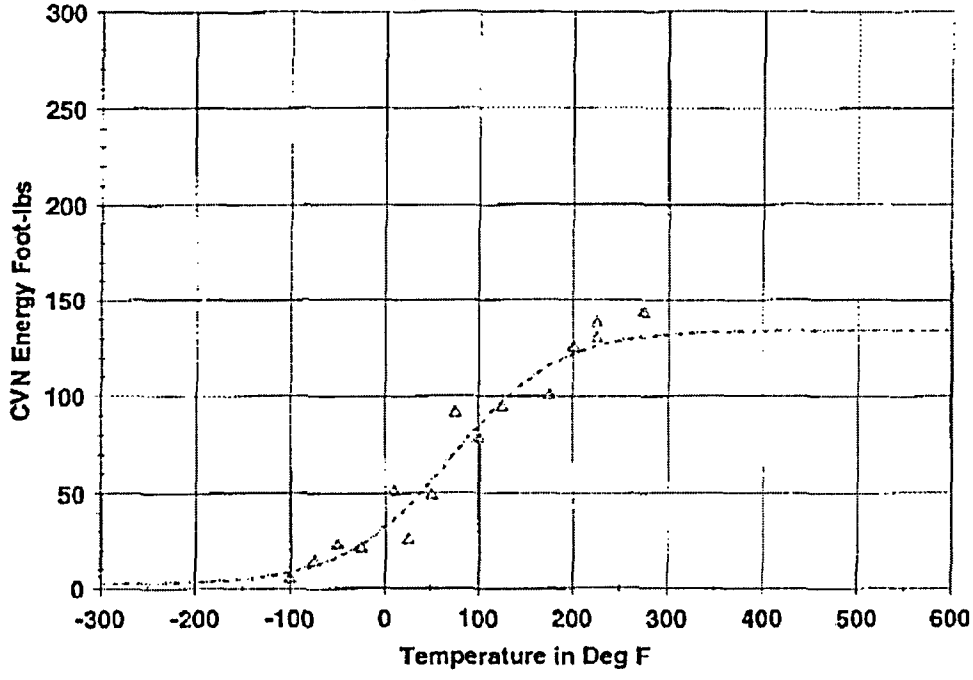
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 150.00 | 98.50 | 99.03 | -.53 |
| 200.00 | 113.00 | 106.97 | 6.03 |
| 350.00 | 123.50 | 111.76 | 11.74 |

Correlation Coefficient = .990

# CAPSULE X SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:41 AM
Page 1
Coefficients of Curve 4
**A = 68.1 B = 65.9 C = 114.7 T0 = 70.21 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=134.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-5.4 Deg F Temp@50 ft-lbs=37.9 Deg F
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -100.00 | 5.00 | 8.64 | -3.64 |
| -75.00 | 14.00 | 11.91 | 2.09 |
| -50.00 | 23.00 | 16.63 | 6.37 |
| -25.00 | 21.00 | 23.25 | -2.25 |
| 10.00 | 51.00 | 36.37 | 14.63 |
| 25.00 | 26.00 | 43.39 | -17.39 |
| 50.00 | 49.00 | 56.61 | -7.61 |
| 75.00 | 91.00 | 70.85 | 20.15 |
| 100.00 | 78.00 | 84.84 | -6.84 |

# CAPSULE X SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: X Fluence: n/cm^2

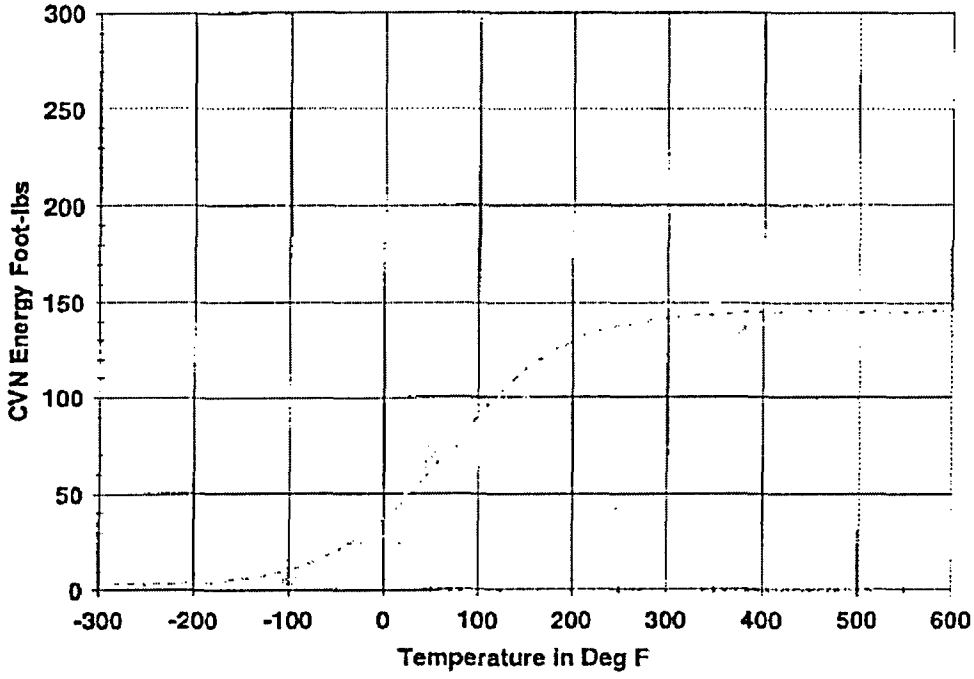
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 125.00 | 94.00 | 97.39 | -3.39 |
| 175.00 | 100.00 | 115.74 | -15.74 |
| 200.00 | 125.00 | 121.58 | 3.42 |
| 225.00 | 138.00 | 125.69 | 12.31 |
| 225.00 | 130.00 | 125.69 | 4.31 |
| 275.00 | 143.00 | 130.39 | 12.61 |

Correlation Coefficient = .975

# CAPSULE Z SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:41 AM
Page 1
Coefficients of Curve 5
**A = 73.6 B = 71.4 C = 123.68 T0 = 70.47 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=145.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-17.3 Deg F Temp@50 ft-lbs=28.0 Deg F
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: Z Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -100.00 | 4.00 | 10.73 | -6.73 |
| -25.00 | 27.00 | 27.33 | -.33 |
| -15.00 | 37.00 | 30.86 | 6.14 |
| .00 | 31.00 | 36.82 | -5.82 |
| 15.00 | 27.00 | 43.57 | -16.57 |
| 25.00 | 51.00 | 48.47 | 2.53 |
| 40.00 | 64.00 | 56.36 | 7.64 |
| 50.00 | 72.00 | 61.89 | 10.11 |
| 75.00 | 77.00 | 76.21 | .79 |

# CAPSULE Z SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: Z Fluence: n/cm^2

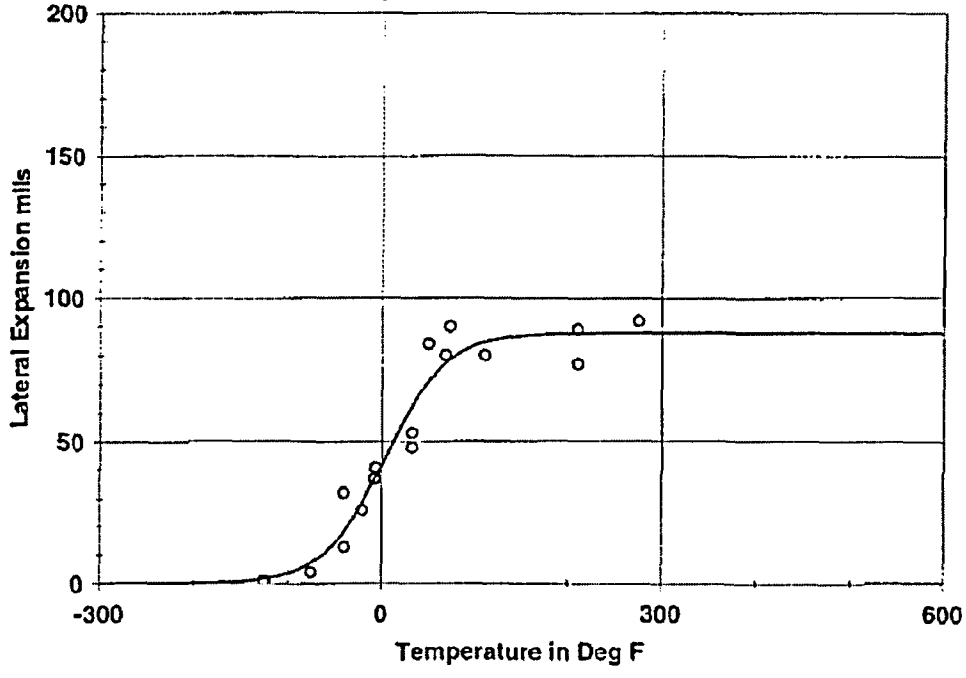
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 100.00 | 97.00 | 90.33 | 6.67 |
| 125.00 | 100.00 | 103.19 | -3.19 |
| 150.00 | 101.00 | 114.08 | -13.08 |
| 300.00 | 151.00 | 141.59 | 9.41 |
| 350.00 | 148.00 | 143.46 | 4.54 |
| 375.00 | 136.00 | 143.97 | -7.97 |

Correlation Coefficient = .984

# UNIRRADIATED SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:56 AM
Page 1
Coefficients of Curve 1
**A = 43.89 B = 43.89 C = 65.14 T0 = 3.4 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=87.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=-9.9 Deg F
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -125.00 | 1.00 | 1.67 | -.67 |
| -125.00 | 1.00 | 1.67 | -.67 |
| -75.00 | 4.00 | 7.25 | -3.25 |
| -40.00 | 13.00 | 18.32 | -5.32 |
| -40.00 | 32.00 | 18.32 | 13.68 |
| -20.00 | 26.00 | 28.77 | -2.77 |
| -7.00 | 37.00 | 36.94 | .06 |
| -7.00 | 37.00 | 36.94 | .06 |
| -7.00 | 41.00 | 36.94 | 4.06 |

# UNIRRADIATED SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

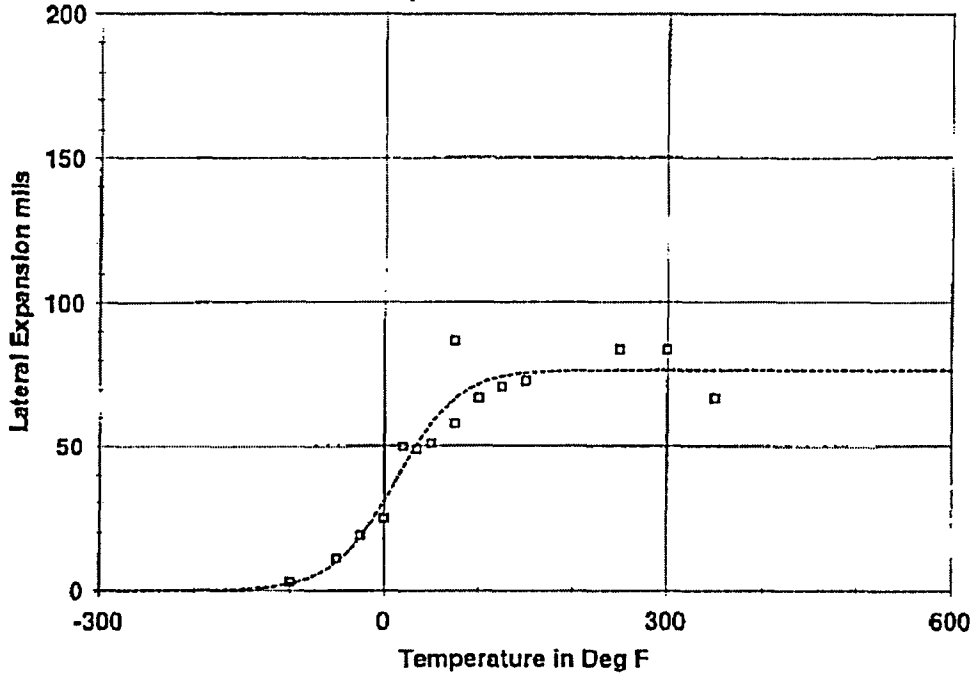
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 32.00 | 53.00 | 62.01 | -9.01 |
| 32.00 | 48.00 | 62.01 | -14.01 |
| 50.00 | 84.00 | 70.84 | 13.16 |
| 68.00 | 80.00 | 77.16 | 2.84 |
| 73.00 | 90.00 | 78.52 | 11.48 |
| 110.00 | 80.00 | 84.58 | -4.58 |
| 210.00 | 89.00 | 87.63 | 1.37 |
| 210.00 | 77.00 | 87.63 | -10.63 |
| 275.00 | 92.00 | 87.76 | 4.24 |

Correlation Coefficient = .972

# CAPSULE U SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:56 AM
Page 1
Coefficients of Curve 2
**A = 38.43 B = 38.43 C = 65.63 T0 = 13.24 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=76.9 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=7.4 Deg F
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -100.00 | 3.00 | 2.36 | .64 |
| -50.00 | 11.00 | 9.77 | 1.23 |
| -25.00 | 19.00 | 18.27 | .73 |
| .00 | 25.00 | 30.78 | -5.78 |
| 20.00 | 50.00 | 42.38 | 7.62 |
| 35.00 | 49.00 | 50.73 | -1.73 |
| 50.00 | 51.00 | 57.96 | -6.96 |
| 75.00 | 87.00 | 66.71 | 20.29 |
| 75.00 | 58.00 | 66.71 | -8.71 |

# CAPSULE U SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: U Fluence: n/cm^2

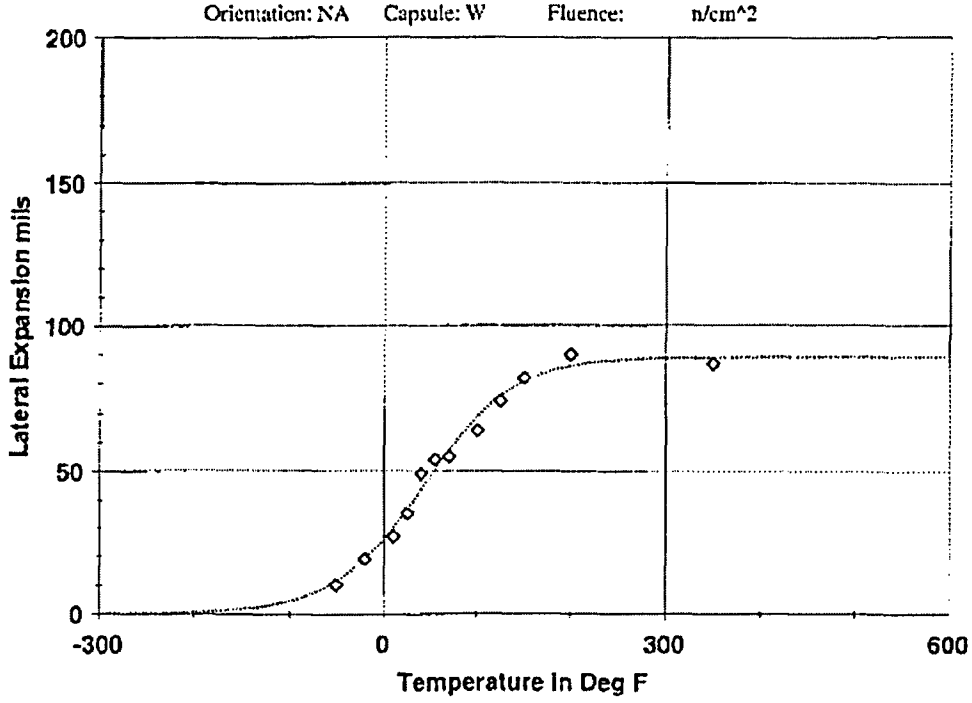
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 100.00 | 67.00 | 71.76 | -4.76 |
| 125.00 | 71.00 | 74.39 | -3.39 |
| 150.00 | 73.00 | 75.69 | -2.69 |
| 250.00 | 84.00 | 76.81 | 7.19 |
| 300.00 | 84.00 | 76.85 | 7.15 |
| 350.00 | 67.00 | 76.86 | -9.86 |

Correlation Coefficient = .957

# CAPSULE W SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:56 AM
Page 1
Coefficients of Curve 3
**A = 44.58 B = 44.58 C = 95.29 T0 = 42.68 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=89.2 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=21.9 Deg F
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: W Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -50.00 | 10.00 | 11.15 | -1.15 |
| -20.00 | 19.00 | 18.86 | .14 |
| 10.00 | 27.00 | 29.86 | -2.86 |
| 25.00 | 35.00 | 36.40 | -1.40 |
| 40.00 | 49.00 | 43.32 | 5.68 |
| 55.00 | 54.00 | 50.31 | 3.69 |
| 70.00 | 55.00 | 57.02 | -2.02 |
| 100.00 | 64.00 | 68.57 | -4.57 |
| 125.00 | 74.00 | 75.70 | -1.70 |

# CAPSULE W SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: W Fluence: n/cm^2

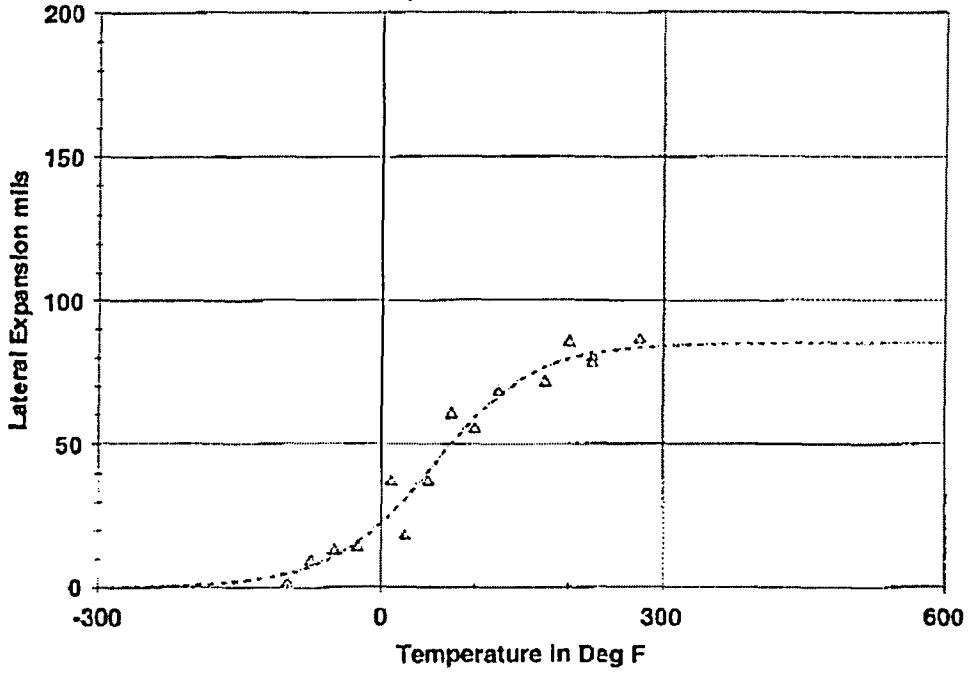
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 150.00 | 82.00 | 80.67 | 1.33 |
| 200.00 | 90.00 | 85.99 | 4.01 |
| 350.00 | 87.00 | 89.01 | -2.01 |

Correlation Coefficient = .993

# CAPSULE X SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:56 AM
Page 1
Coefficients of Curve 4
**A = 42.49 B = 42.49 C = 109.65 T0 = 55.42 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=85.0 Lower Shelf L.E.=0(Fixed)
Temp.@L.E. 35 mils=35.9 Deg F
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -100.00 | 1.00 | 4.71 | -3.71 |
| -75.00 | 9.00 | 7.21 | 1.79 |
| -50.00 | 13.00 | 10.84 | 2.16 |
| -25.00 | 14.00 | 15.93 | -1.93 |
| 10.00 | 37.00 | 25.83 | 11.17 |
| 25.00 | 18.00 | 31.00 | -13.00 |
| 50.00 | 37.00 | 40.39 | -3.39 |
| 75.00 | 60.00 | 50.00 | 10.00 |
| 100.00 | 55.00 | 58.87 | -3.87 |

# CAPSULE X SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: X Fluence: n/cm^2

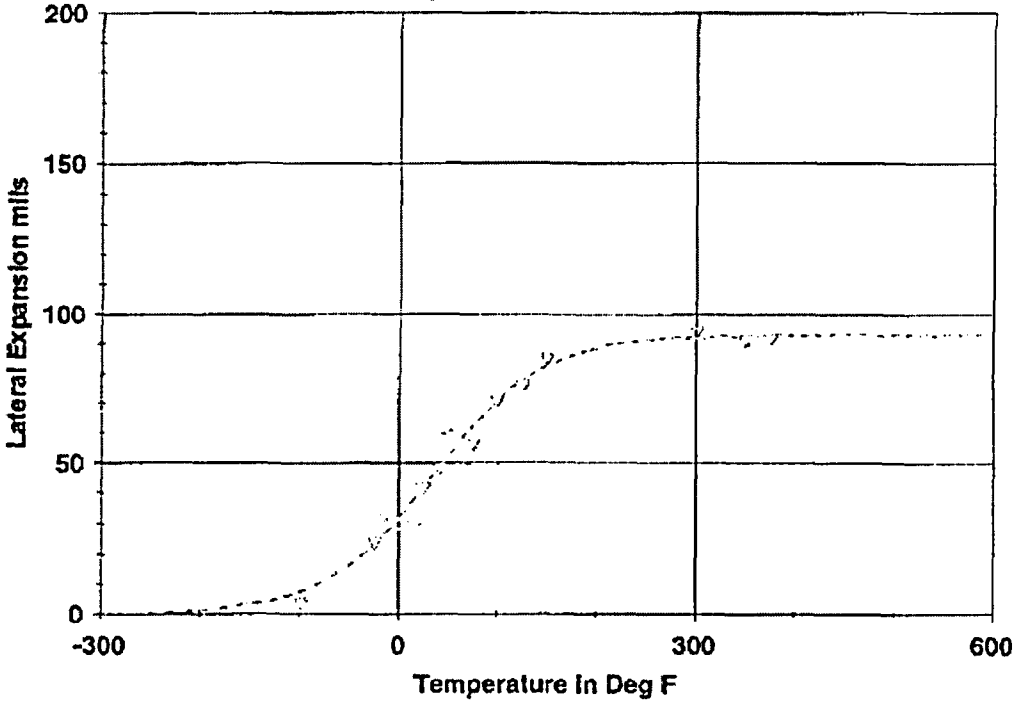
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 125.00 | 68.00 | 66.34 | 1.66 |
| 175.00 | 71.00 | 76.36 | -5.36 |
| 200.00 | 85.00 | 79.31 | 5.69 |
| 225.00 | 78.00 | 81.29 | -3.29 |
| 225.00 | 80.00 | 81.29 | -1.29 |
| 275.00 | 86.00 | 83.46 | 2.54 |

Correlation Coefficient = .980

# CAPSULE Z SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:56 AM
Page 1
Coefficients of Curve 5
**A = 46.49 B = 46.49 C = 111.11 T0 = 36.88 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=93.0 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=8.9 Deg F
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: Z Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -100.00 | 4.00 | 7.29 | -3.29 |
| -25.00 | 24.00 | 22.98 | 1.02 |
| -15.00 | 33.00 | 26.24 | 6.76 |
| .00 | 30.00 | 31.60 | -1.60 |
| 15.00 | 30.00 | 37.45 | -7.45 |
| 25.00 | 42.00 | 41.54 | .46 |
| 40.00 | 48.00 | 47.80 | .20 |
| 50.00 | 59.00 | 51.96 | 7.04 |
| 75.00 | 56.00 | 61.85 | -5.85 |

# CAPSULE Z SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: Z Fluence: n/cm^2

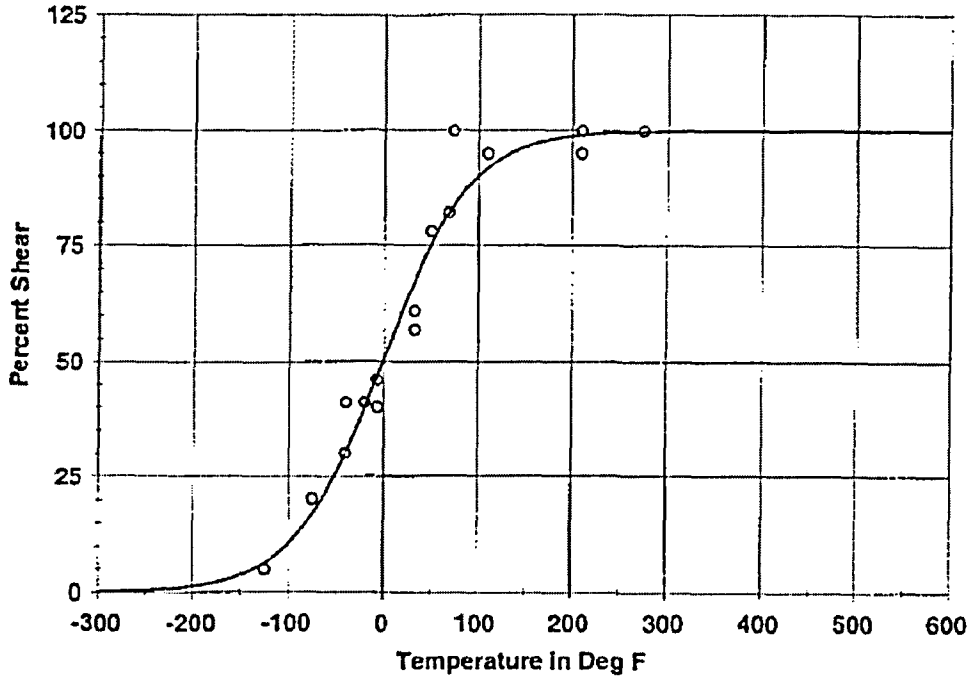
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 100.00 | 71.00 | 70.39 | .61 |
| 125.00 | 76.00 | 77.19 | -1.19 |
| 150.00 | 85.00 | 82.25 | 2.75 |
| 300.00 | 94.00 | 92.18 | 1.82 |
| 350.00 | 91.00 | 92.66 | -1.66 |
| 375.00 | 92.00 | 92.78 | -.78 |

Correlation Coefficient = .990

# UNIRRADIATED SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:49 AM
Page 1
Coefficients of Curve 1
**A = 50. B = 50. C = 91.87 T0 = -1.28 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -1.2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -125.00 | 5.00 | 6.34 | -1.34 |
| -125.00 | 5.00 | 6.34 | -1.34 |
| -75.00 | 20.00 | 16.73 | 3.27 |
| -40.00 | 30.00 | 30.09 | -.09 |
| -40.00 | 41.00 | 30.09 | 10.91 |
| -20.00 | 41.00 | 39.95 | 1.05 |
| -7.00 | 46.00 | 46.89 | -.89 |
| -7.00 | 40.00 | 46.89 | -6.89 |
| -7.00 | 46.00 | 46.89 | -.89 |

# UNIRRADIATED SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

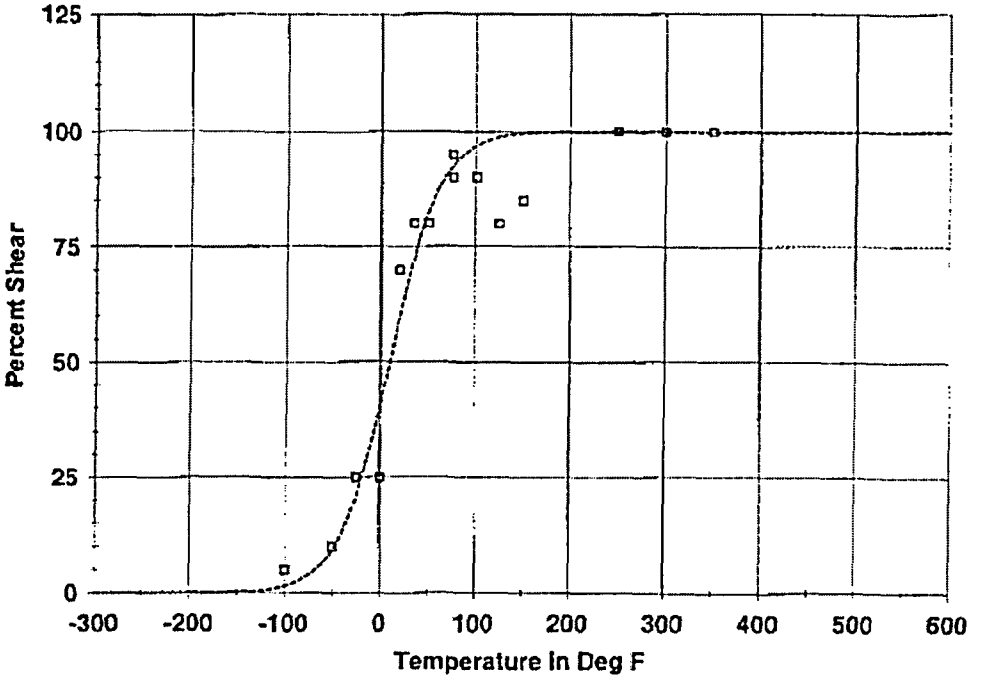
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 32.00 | 61.00 | 67.36 | -6.36 |
| 32.00 | 57.00 | 67.36 | -10.36 |
| 50.00 | 78.00 | 75.33 | 2.67 |
| 68.00 | 82.00 | 81.88 | .12 |
| 73.00 | 100.00 | 83.44 | 16.56 |
| 110.00 | 95.00 | 91.85 | 3.15 |
| 210.00 | 100.00 | 99.00 | 1.00 |
| 210.00 | 95.00 | 99.00 | -4.00 |
| 275.00 | 100.00 | 99.76 | .24 |

Correlation Coefficient = .982

# CAPSULE U SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:50 AM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 52.19 T0 = 9.58 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 9.6
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100.00 | 5.00 | 1.48 | 3.52 |
| -50.00 | 10.00 | 9.25 | .75 |
| -25.00 | 25.00 | 20.99 | 4.01 |
| .00 | 25.00 | 40.92 | -15.92 |
| 20.00 | 70.00 | 59.85 | 10.15 |
| 35.00 | 80.00 | 72.59 | 7.41 |
| 50.00 | 80.00 | 82.47 | -2.47 |
| 75.00 | 95.00 | 92.46 | 2.54 |
| 75.00 | 90.00 | 92.46 | -2.46 |

# CAPSULE U SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: U Fluence: n/cm^2

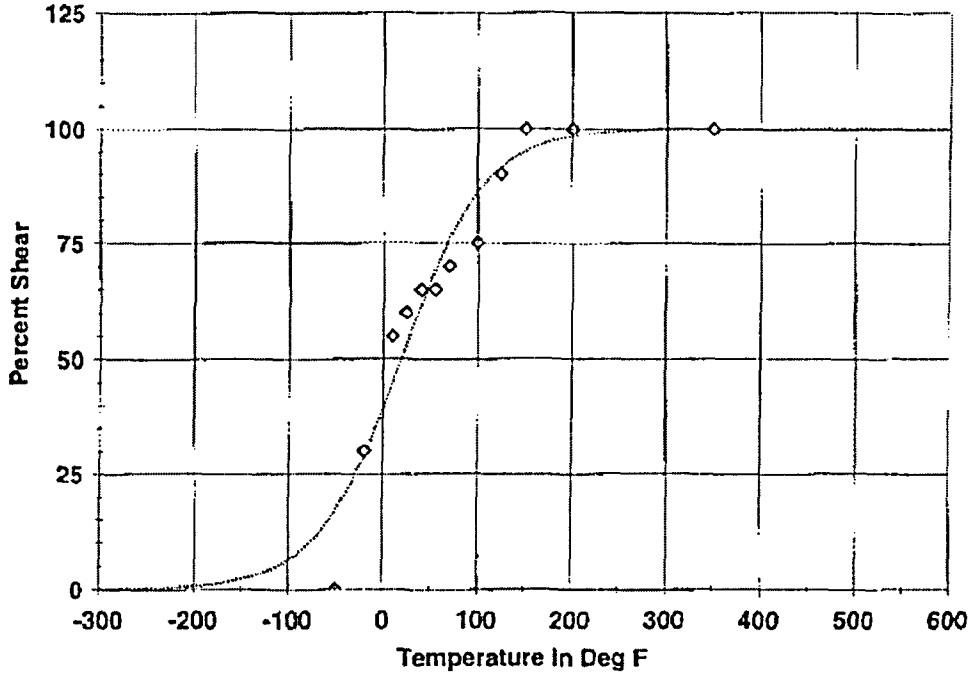
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 100.00 | 90.00 | 96.97 | -6.97 |
| 125.00 | 80.00 | 98.81 | -18.81 |
| 150.00 | 85.00 | 99.54 | -14.54 |
| 250.00 | 100.00 | 99.99 | .01 |
| 300.00 | 100.00 | 100.00 | .00 |
| 350.00 | 100.00 | 100.00 | .00 |

Correlation Coefficient = .972

# CAPSULE W SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:50 AM
Page 1
Coefficients of Curve 3
**A = 50. B = 50. C = 88.62 T0 = 19.8 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 19.9
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: W Fluence: n/cm^2




**Charpy V-Notch Data**

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -50.00 | .00 | 17.15 | -17.15 |
| -20.00 | 30.00 | 28.94 | 1.06 |
| 10.00 | 55.00 | 44.49 | 10.51 |
| 25.00 | 60.00 | 52.93 | 7.07 |
| 40.00 | 65.00 | 61.20 | 3.80 |
| 55.00 | 65.00 | 68.88 | -3.88 |
| 70.00 | 70.00 | 75.64 | -5.64 |
| 100.00 | 75.00 | 85.94 | -10.94 |
| 125.00 | 90.00 | 91.48 | -1.48 |

# CAPSULE W SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: W Fluence: n/cm^2

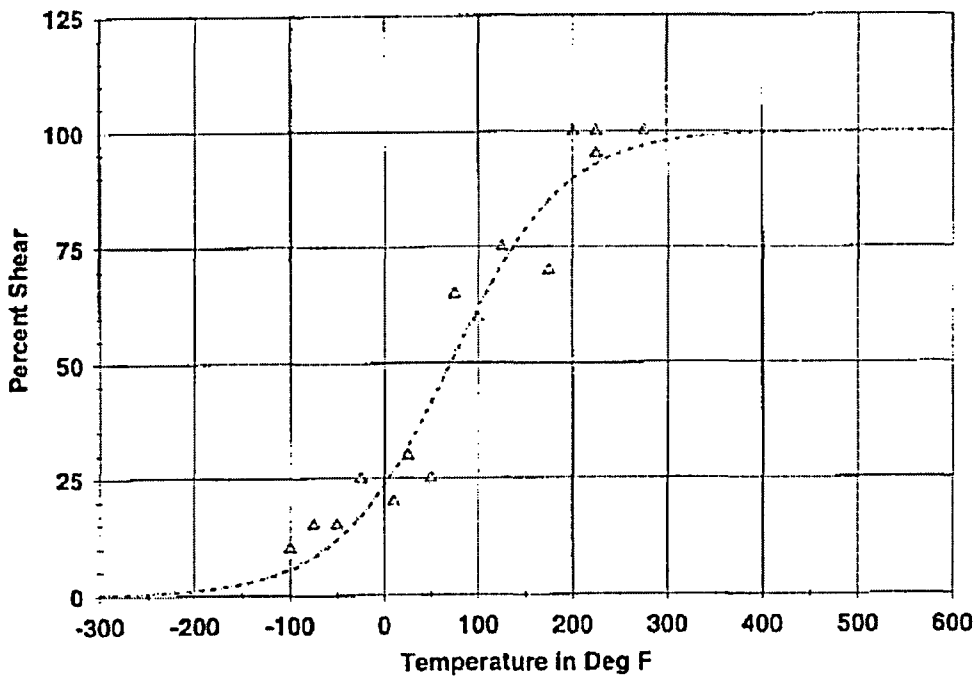
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 150.00 | 100.00 | 94.97 | 5.03 |
| 200.00 | 100.00 | 98.32 | 1.68 |
| 350.00 | 100.00 | 99.94 | .06 |

Correlation Coefficient = .967

# CAPSULE X SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:50 AM
Page 1
Coefficients of Curve 4
A = 50. B = 50. C = 120.09 T0 = 70.86 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 70.9
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100.00 | 10.00 | 5.49 | 4.51 |
| -75.00 | 15.00 | 8.10 | 6.90 |
| -50.00 | 15.00 | 11.79 | 3.21 |
| -25.00 | 25.00 | 16.85 | 8.15 |
| 10.00 | 20.00 | 26.63 | -6.63 |
| 25.00 | 30.00 | 31.78 | -1.78 |
| 50.00 | 25.00 | 41.40 | -16.40 |
| 75.00 | 65.00 | 51.72 | 13.28 |
| 100.00 | 60.00 | 61.90 | -1.90 |

# CAPSULE X SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: X Fluence: n/cm^2

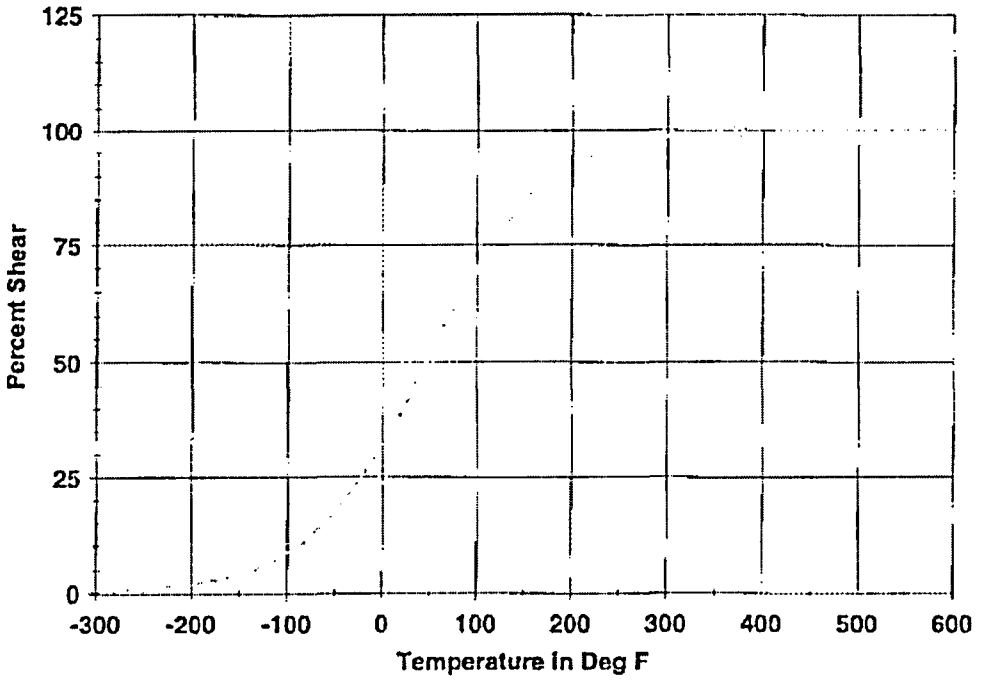
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 125.00 | 75.00 | 71.13 | 3.87 |
| 175.00 | 70.00 | 85.00 | -15.00 |
| 200.00 | 100.00 | 89.57 | 10.43 |
| 225.00 | 95.00 | 92.87 | 2.13 |
| 225.00 | 100.00 | 92.87 | 7.13 |
| 275.00 | 100.00 | 96.77 | 3.23 |

Correlation Coefficient = .970

# CAPSULE Z SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 09:50 AM
Page 1
Coefficients of Curve 5
**A = 50. B = 50. C = 124.26 T0 = 47.49 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 47.5
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: Z Fluence: n/cm^2




**Charpy V-Notch Data**

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100.00 | 10.00 | 8.52 | 1.48 |
| -25.00 | 20.00 | 23.74 | -3.74 |
| -15.00 | 30.00 | 26.78 | 3.22 |
| .00 | 25.00 | 31.77 | -6.77 |
| 15.00 | 35.00 | 37.21 | -2.21 |
| 25.00 | 50.00 | 41.05 | 8.95 |
| 40.00 | 55.00 | 46.99 | 8.01 |
| 50.00 | 50.00 | 51.01 | -1.01 |
| 75.00 | 50.00 | 60.89 | -10.89 |

# CAPSULE Z SURVEILLANCE PROGRAM WELD

Page 2
Plant: WATTS BAR 1 Material: SAW Heat: 895075
Orientation: NA Capsule: Z Fluence: n/cm^2

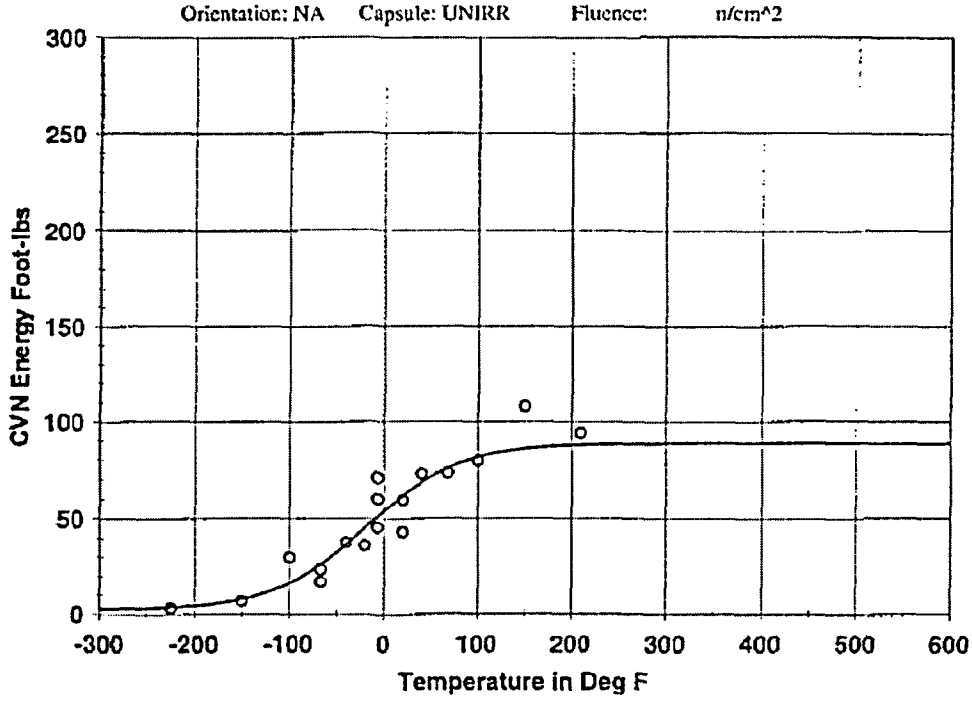
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 100.00 | 70.00 | 69.95 | .05 |
| 125.00 | 80.00 | 77.69 | 2.31 |
| 150.00 | 85.00 | 83.89 | 1.11 |
| 300.00 | 100.00 | 98.31 | 1.69 |
| 350.00 | 100.00 | 99.24 | .76 |
| 375.00 | 100.00 | 99.49 | .51 |

Correlation Coefficient = .986

# UNIRRADIATED HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 01:21 PM
Page 1
Coefficients of Curve 1
**A = 45.6 B = 43.4 C = 99.65 T0 = -18.8 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=89.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-56.2 Deg F Temp@50 ft-lbs=-8.6 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -225.00 | 3.00 | 3.56 | -.56 |
| -225.00 | 3.00 | 3.56 | -.56 |
| -150.00 | 7.00 | 8.02 | -1.02 |
| -100.00 | 30.00 | 16.42 | 13.58 |
| -67.00 | 17.00 | 26.10 | -9.10 |
| -67.00 | 23.50 | 26.10 | -2.60 |
| -40.00 | 37.50 | 36.50 | 1.00 |
| -20.00 | 36.00 | 45.08 | -9.08 |
| -7.00 | 71.00 | 50.71 | 20.29 |

# UNIRRADIATED HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

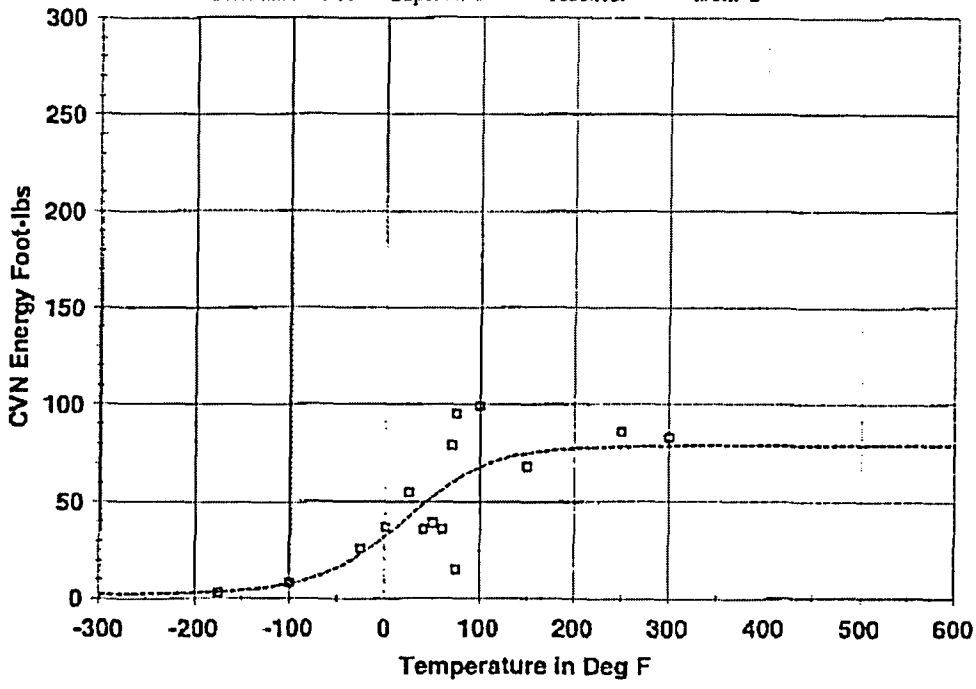
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -7.00 | 45.50 | 50.71 | -5.21 |
| -7.00 | 60.00 | 50.71 | 9.29 |
| 20.00 | 43.00 | 61.69 | -18.69 |
| 20.00 | 59.50 | 61.69 | -2.19 |
| 40.00 | 73.00 | 68.60 | 4.40 |
| 68.00 | 73.50 | 76.06 | -2.56 |
| 100.00 | 80.00 | 81.68 | -1.68 |
| 150.00 | 108.00 | 86.16 | 21.84 |
| 210.00 | 94.00 | 88.13 | 5.87 |

Correlation Coefficient = .948

# CAPSULE U HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 01:21 PM
Page 1
Coefficients of Curve 2
**A = 40.6 B = 38.4 C = 91.79 T0 = 20.68 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=79.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-5.3 Deg F Temp@50 ft-lbs=43.7 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -175.00 | 3.00 | 3.27 | -.27 |
| -100.00 | 8.00 | 7.37 | .63 |
| -25.00 | 26.00 | 22.93 | 3.07 |
| .00 | 37.00 | 32.09 | 4.91 |
| 25.00 | 55.00 | 42.41 | 12.59 |
| 40.00 | 36.00 | 48.56 | -12.56 |
| 50.00 | 39.00 | 52.46 | -13.46 |
| 60.00 | 36.00 | 56.11 | -20.11 |
| 70.00 | 79.00 | 59.45 | 19.55 |

# CAPSULE U HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: U Fluence: n/cm^2

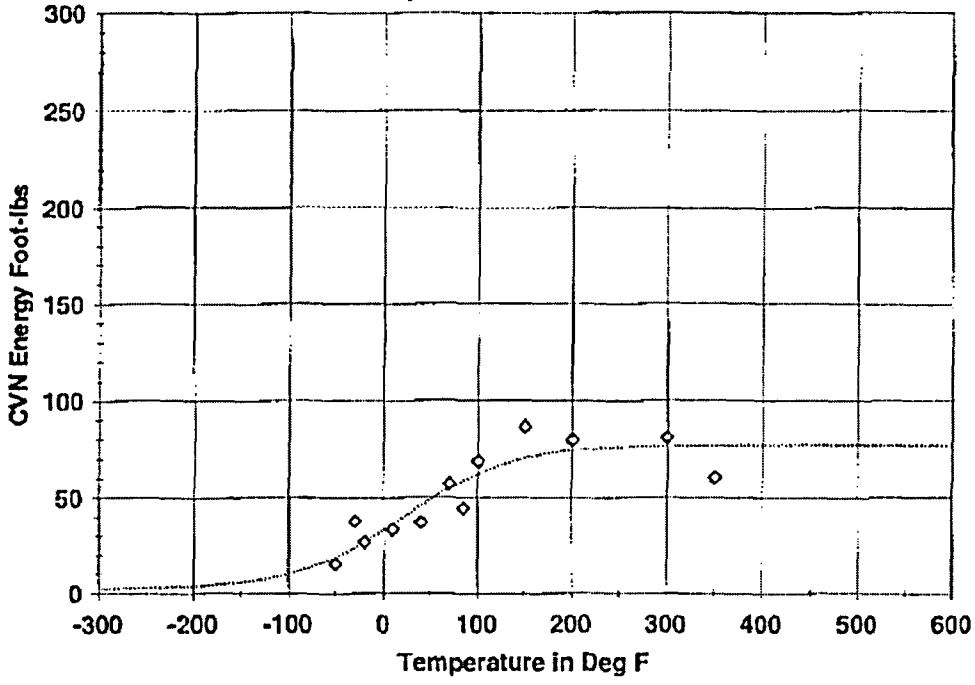
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 75.00 | 95.00 | 61.00 | 34.00 |
| 75.00 | 15.00 | 61.00 | -46.00 |
| 100.00 | 99.00 | 67.42 | 31.58 |
| 150.00 | 68.00 | 74.67 | -6.67 |
| 250.00 | 86.00 | 78.48 | 7.52 |
| 300.00 | 83.00 | 78.83 | 4.17 |

Correlation Coefficient = .780

# CAPSULE W HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 01:21 PM
Page 1
Coefficients of Curve 3
**A = 39.6 B = 37.4 C = 111.37 T0 = 21.74 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=77.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-7.4 Deg F Temp@50 ft-lbs=53.6 Deg F
Plant: WATTS BAR 1 Material: SA508Cl.2 Heat: 527536
Orientation: NA Capsule: W Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -50.00 | 15.00 | 18.37 | -3.37 |
| -30.00 | 37.50 | 23.38 | 14.12 |
| -20.00 | 26.50 | 26.20 | .30 |
| 10.00 | 33.00 | 35.67 | -2.67 |
| 40.00 | 37.00 | 45.68 | -8.68 |
| 70.00 | 57.00 | 54.86 | 2.14 |
| 85.00 | 44.50 | 58.82 | -14.32 |
| 100.00 | 69.00 | 62.27 | 6.73 |
| 150.00 | 86.50 | 70.20 | 16.30 |

# CAPSULE W HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: W Fluence: n/cm^2

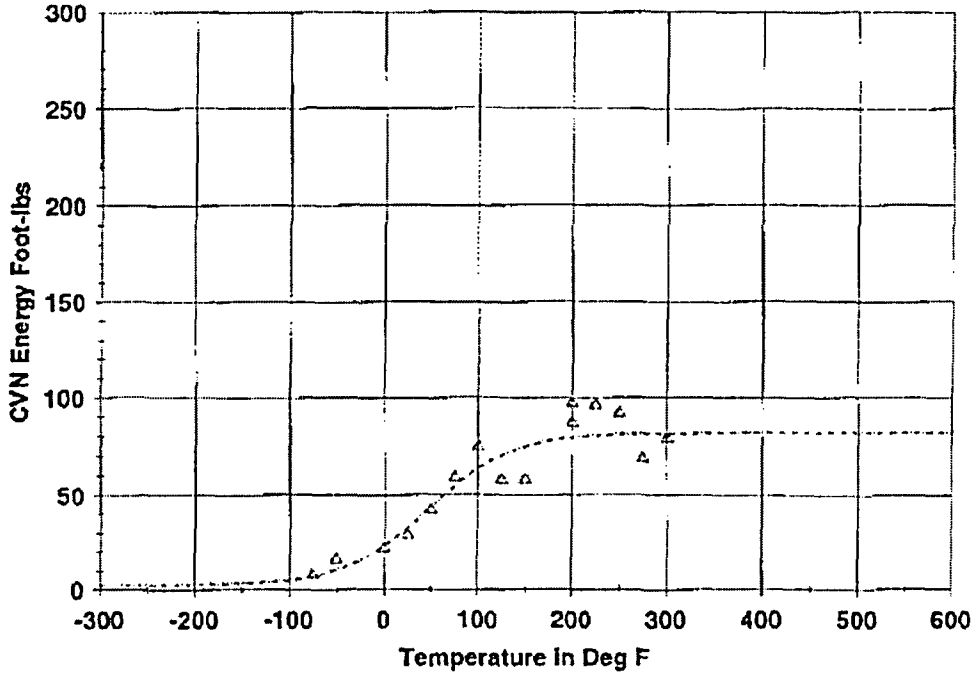
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 200.00 | 79.50 | 74.07 | 5.43 |
| 300.00 | 81.00 | 76.50 | 4.50 |
| 350.00 | 60.50 | 76.79 | -16.29 |

Correlation Coefficient = .902

# CAPSULE X HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 01:22 PM
Page 1
Coefficients of Curve 4
**A = 42.1 B = 39.9 C = 88.37 T0 = 45.95 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=82.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=18.3 Deg F Temp@50 ft-lbs=63.7 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -75.00 | 8.00 | 7.05 | .95 |
| -50.00 | 16.00 | 10.37 | 5.63 |
| .00 | 22.00 | 23.04 | -1.04 |
| 25.00 | 29.00 | 32.81 | -3.81 |
| 50.00 | 42.00 | 43.93 | -1.93 |
| 75.00 | 59.00 | 54.76 | 4.24 |
| 100.00 | 75.00 | 63.86 | 11.14 |
| 125.00 | 58.00 | 70.57 | -12.57 |
| 150.00 | 58.00 | 75.08 | -17.08 |

# CAPSULE X HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: X Fluence: n/cm^2

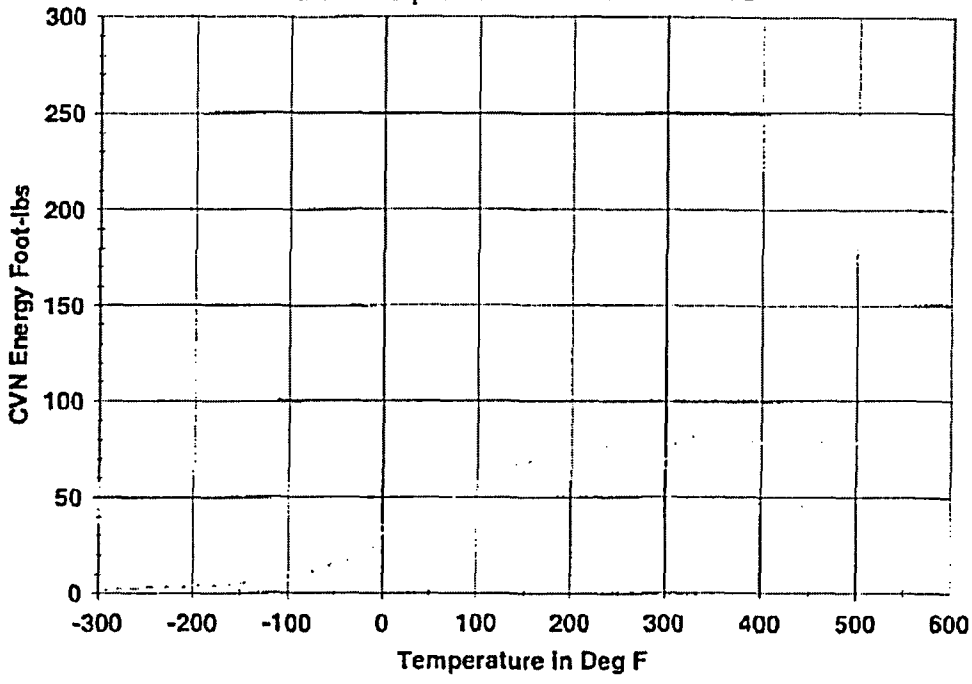
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 200.00 | 87.00 | 79.63 | 7.37 |
| 200.00 | 97.00 | 79.63 | 17.37 |
| 225.00 | 96.00 | 80.64 | 15.36 |
| 250.00 | 92.00 | 81.22 | 10.78 |
| 275.00 | 69.00 | 81.56 | -12.56 |
| 300.00 | 79.00 | 81.75 | -2.75 |

Correlation Coefficient = .939

# CAPSULE Z HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 01:22 PM
Page 1
Coefficients of Curve 5
**A = 40.6 B = 38.4 C = 118.89 T0 = 45.11 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=79.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=11.5 Deg F Temp@50 ft-lbs=74.9 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: Z Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| -100.00 | 9.00 | 8.35 | .65 |
| -25.00 | 22.00 | 20.26 | 1.74 |
| .00 | 34.00 | 26.69 | 7.31 |
| 15.00 | 27.00 | 31.08 | -4.08 |
| 25.00 | 31.00 | 34.17 | -3.17 |
| 40.00 | 30.00 | 38.95 | -8.95 |
| 50.00 | 40.00 | 42.18 | -2.18 |
| 60.00 | 46.00 | 45.38 | .62 |
| 75.00 | 62.00 | 50.06 | 11.94 |

# CAPSULE Z HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: Z Fluence: n/cm^2

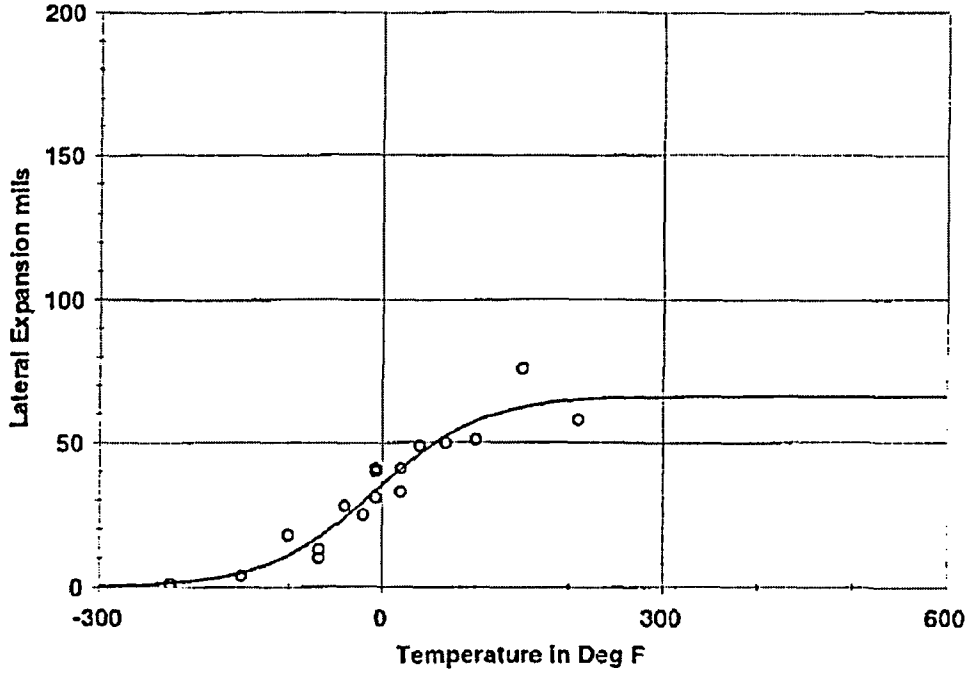
## Charpy V-Notch Data

| Temperature | Input CVN | Computed CVN | Differential |
|---|---|---|---|
| 125.00 | 62.00 | 63.11 | -1.11 |
| 175.00 | 69.00 | 71.23 | -2.23 |
| 300.00 | 68.00 | 77.96 | -9.96 |
| 325.00 | 83.00 | 78.31 | 4.69 |
| 350.00 | 80.00 | 78.55 | 1.45 |
| 375.00 | 96.00 | 78.70 | 17.30 |

Correlation Coefficient = .960

# UNIRRADIATED HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:58 AM
Page 1
Coefficients of Curve 1
**A = 33.16 B = 33.16 C = 114.43 T0 = -7. D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=66.3 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=-.6 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -225.00 | 1.00 | 1.44 | -.44 |
| -225.00 | 1.00 | 1.44 | -.44 |
| -150.00 | 4.00 | 5.03 | -1.03 |
| -100.00 | 18.00 | 10.91 | 7.09 |
| -67.00 | 10.00 | 17.21 | -7.21 |
| -67.00 | 13.00 | 17.21 | -4.21 |
| -40.00 | 28.00 | 23.85 | 4.15 |
| -20.00 | 25.00 | 29.41 | -4.41 |
| -7.00 | 41.00 | 33.16 | 7.84 |

# UNIRRADIATED HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

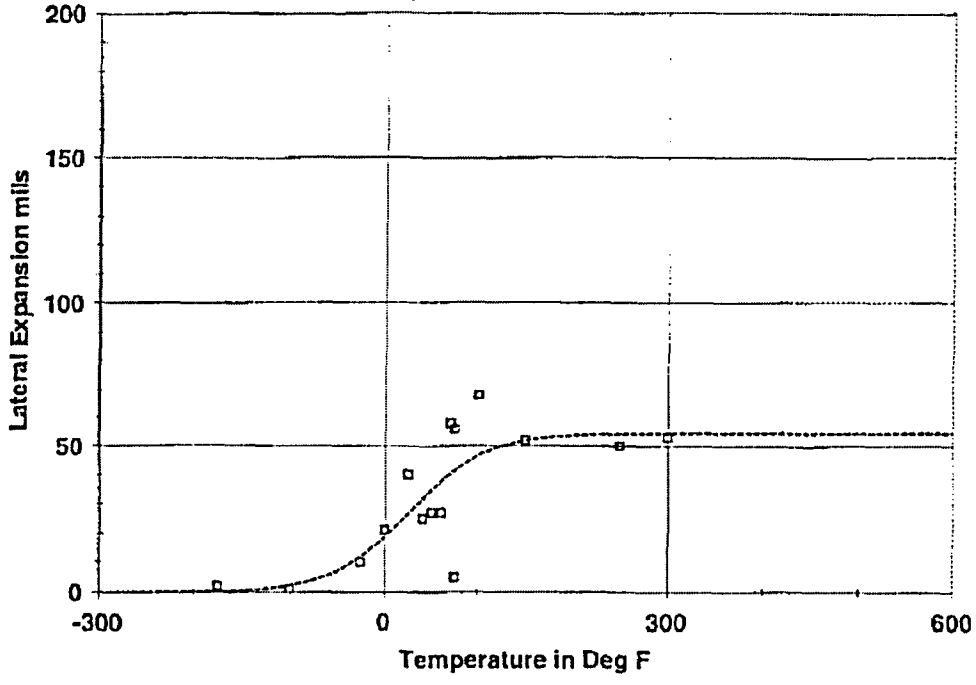
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -7.00 | 31.00 | 33.16 | -2.16 |
| -7.00 | 40.00 | 33.16 | 6.84 |
| 20.00 | 33.00 | 40.84 | -7.84 |
| 20.00 | 41.00 | 40.84 | .16 |
| 40.00 | 49.00 | 46.06 | 2.94 |
| 68.00 | 50.00 | 52.24 | -2.24 |
| 100.00 | 51.00 | 57.46 | -6.46 |
| 150.00 | 76.00 | 62.31 | 13.69 |
| 210.00 | 58.00 | 64.86 | -6.86 |

Correlation Coefficient = .958

# CAPSULE U HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:59 AM
Page 1
Coefficients of Curve 2
**A = 27.21 B = 27.21 C = 80.96 T0 = 27.31 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=54.4 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=51.2 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: U Fluence: n/cm^2




**Charpy V-Notch Data**

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -175.00 | 2.00 | .37 | 1.63 |
| -100.00 | 1.00 | 2.25 | -1.25 |
| -25.00 | 10.00 | 11.73 | -1.73 |
| .00 | 21.00 | 18.37 | 2.63 |
| 25.00 | 40.00 | 26.44 | 13.56 |
| 40.00 | 25.00 | 31.44 | -6.44 |
| 50.00 | 27.00 | 34.65 | -7.65 |
| 60.00 | 27.00 | 37.64 | -10.64 |
| 70.00 | 58.00 | 40.37 | 17.63 |

# CAPSULE U HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: U Fluence: n/cm^2

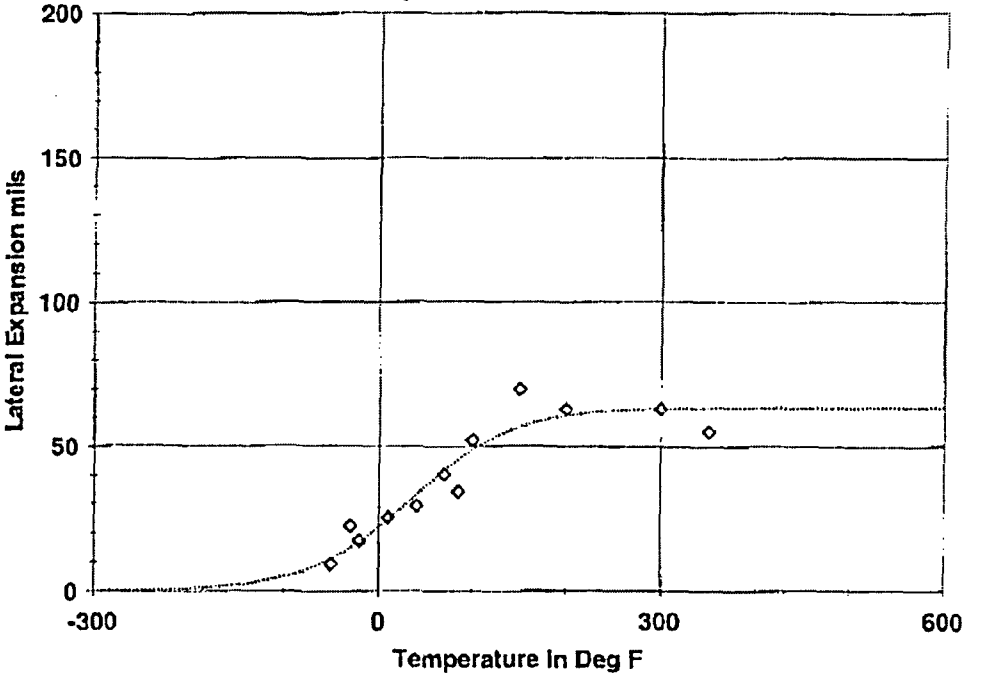
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 75.00 | 56.00 | 41.62 | 14.38 |
| 75.00 | 5.00 | 41.62 | -36.62 |
| 100.00 | 68.00 | 46.68 | 21.32 |
| 150.00 | 52.00 | 51.92 | .08 |
| 250.00 | 50.00 | 54.21 | -4.21 |
| 300.00 | 53.00 | 54.36 | -1.36 |

Correlation Coefficient = .782

# CAPSULE W HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:59 AM
Page 1
Coefficients of Curve 3
**A = 31.8 B = 31.8 C = 108.76 T0 = 36.94 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=63.6 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=48.0 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: W Fluence: n/cm^2




**Charpy V-Notch Data**

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -50.00 | 9.00 | 10.70 | -1.70 |
| -30.00 | 22.00 | 14.37 | 7.63 |
| -20.00 | 17.00 | 16.52 | .48 |
| 10.00 | 25.00 | 24.08 | .92 |
| 40.00 | 29.00 | 32.70 | -3.70 |
| 70.00 | 40.00 | 41.18 | -1.18 |
| 85.00 | 34.00 | 45.00 | -11.00 |
| 100.00 | 52.00 | 48.42 | 3.58 |
| 150.00 | 70.00 | 56.53 | 13.47 |

# CAPSULE W HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: W Fluence: n/cm^2

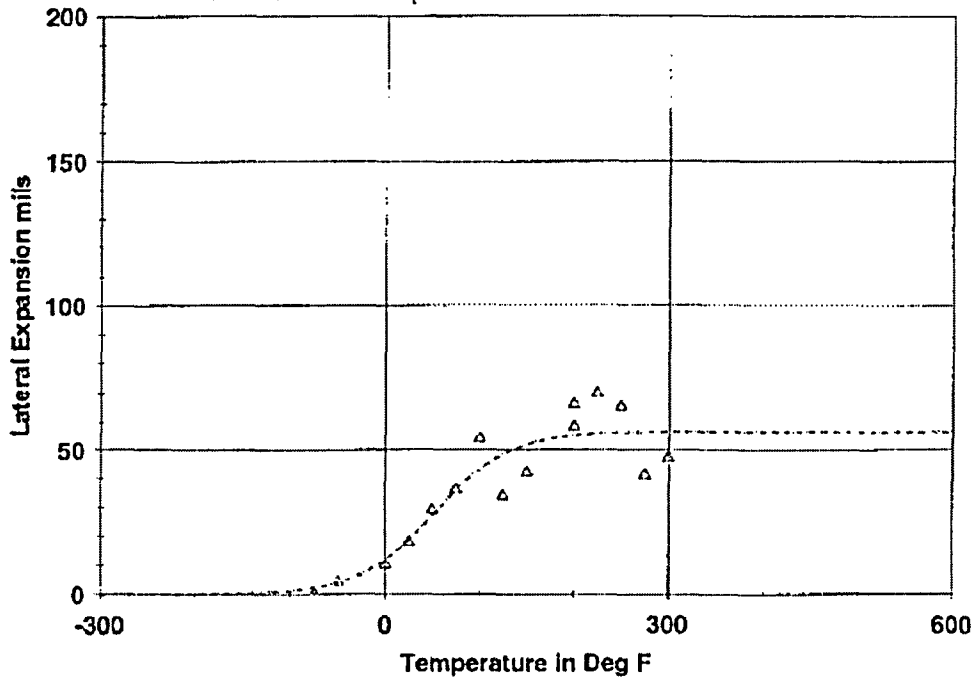
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 200.00 | 63.00 | 60.58 | 2.42 |
| 300.00 | 63.00 | 63.10 | -.10 |
| 350.00 | 55.00 | 63.40 | -8.40 |

Correlation Coefficient = .947

# CAPSULE X HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:59 AM
Page 1
Coefficients of Curve 4
**A = 28.15 B = 28.15 C = 79.27 T0 = 52.89 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=56.3 Lower Shelf L.E.=0(Fixed)
Temp.@L.E. 35 mils=72.6 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -75.00 | .00 | 2.15 | -2.15 |
| -50.00 | 4.00 | 3.91 | .09 |
| .00 | 10.00 | 11.74 | -1.74 |
| 25.00 | 18.00 | 18.64 | -.64 |
| 50.00 | 29.00 | 27.13 | 1.87 |
| 75.00 | 36.00 | 35.81 | .19 |
| 100.00 | 54.00 | 43.16 | 10.84 |
| 125.00 | 34.00 | 48.45 | -14.45 |
| 150.00 | 42.00 | 51.83 | -9.83 |

# CAPSULE X HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: X Fluence: n/cm^2

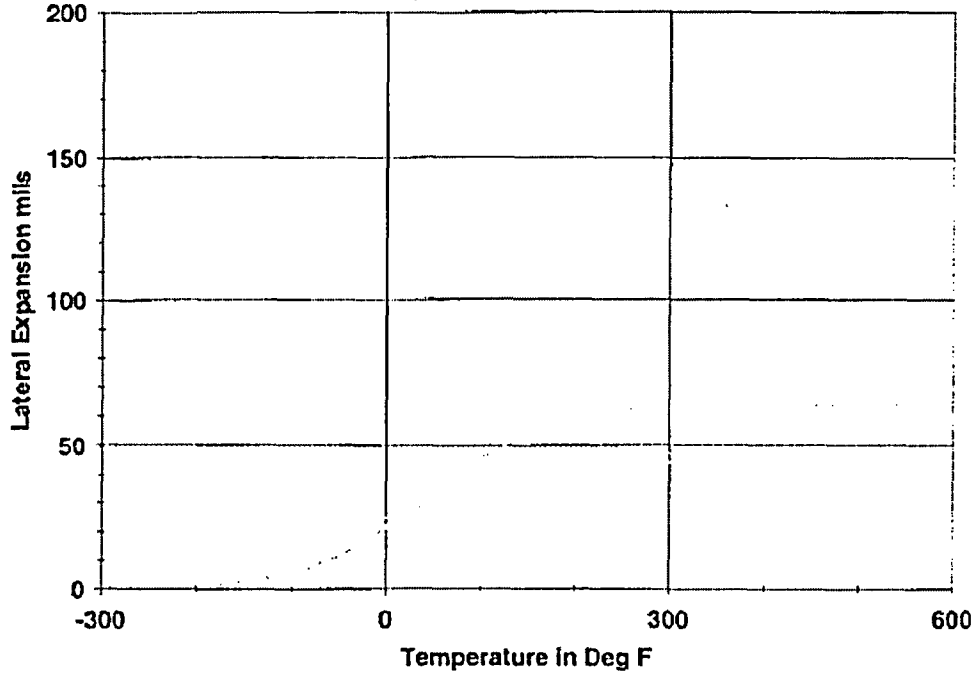
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 200.00 | 66.00 | 54.96 | 11.04 |
| 200.00 | 58.00 | 54.96 | 3.04 |
| 225.00 | 70.00 | 55.58 | 14.42 |
| 250.00 | 65.00 | 55.92 | 9.08 |
| 275.00 | 41.00 | 56.10 | -15.10 |
| 300.00 | 47.00 | 56.19 | -9.19 |

Correlation Coefficient = .915

# CAPSULE Z HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:59 AM
Page 1
Coefficients of Curve 5
**A = 31.82 B = 31.82 C = 124.1 T0 = 44.39 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=63.6 Lower Shelf L.E.=.0(Fixed)
Temp. @L.E. 35 mils=56.9 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: Z Fluence: n/cm^2




**Charpy V-Notch Data**

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| -100.00 | 6.00 | 5.66 | .34 |
| -25.00 | 16.00 | 15.68 | .32 |
| .00 | 24.00 | 20.90 | 3.10 |
| 15.00 | 23.00 | 24.42 | -1.42 |
| 25.00 | 26.00 | 26.89 | -.89 |
| 40.00 | 27.00 | 30.70 | -3.70 |
| 50.00 | 33.00 | 33.26 | -.26 |
| 60.00 | 36.00 | 35.80 | .20 |
| 75.00 | 40.00 | 39.52 | .48 |

# CAPSULE Z HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: Z Fluence: n/cm^2

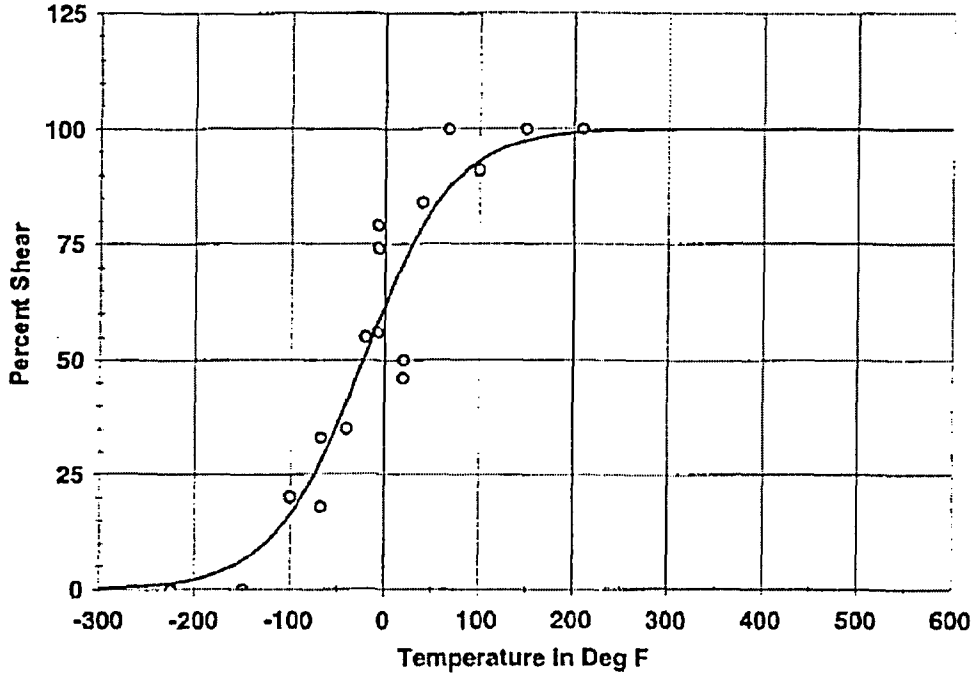
## Charpy V-Notch Data

| Temperature | Input L.E. | Computed L.E. | Differential |
|---|---|---|---|
| 125.00 | 56.00 | 50.00 | 6.00 |
| 175.00 | 54.00 | 56.73 | -2.73 |
| 300.00 | 46.00 | 62.63 | -16.63 |
| 325.00 | 75.00 | 62.96 | 12.04 |
| 350.00 | 55.00 | 63.19 | -8.19 |
| 375.00 | 75.00 | 63.34 | 11.66 |

Correlation Coefficient = .939

# UNIRRADIATED HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:53 AM
Page 1
Coefficients of Curve 1
**A = 50. B = 50. C = 94.74 T0 = -22.26 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -22.2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: UNIRR Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -225.00 | .00 | 1.37 | -1.37 |
| -225.00 | .00 | 1.37 | -1.37 |
| -150.00 | .00 | 6.32 | -6.32 |
| -100.00 | 20.00 | 16.23 | 3.77 |
| -67.00 | 18.00 | 28.00 | -10.00 |
| -67.00 | 33.00 | 28.00 | 5.00 |
| -40.00 | 35.00 | 40.75 | -5.75 |
| -20.00 | 55.00 | 51.19 | 3.81 |
| -7.00 | 79.00 | 57.99 | 21.01 |

# UNIRRADIATED HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

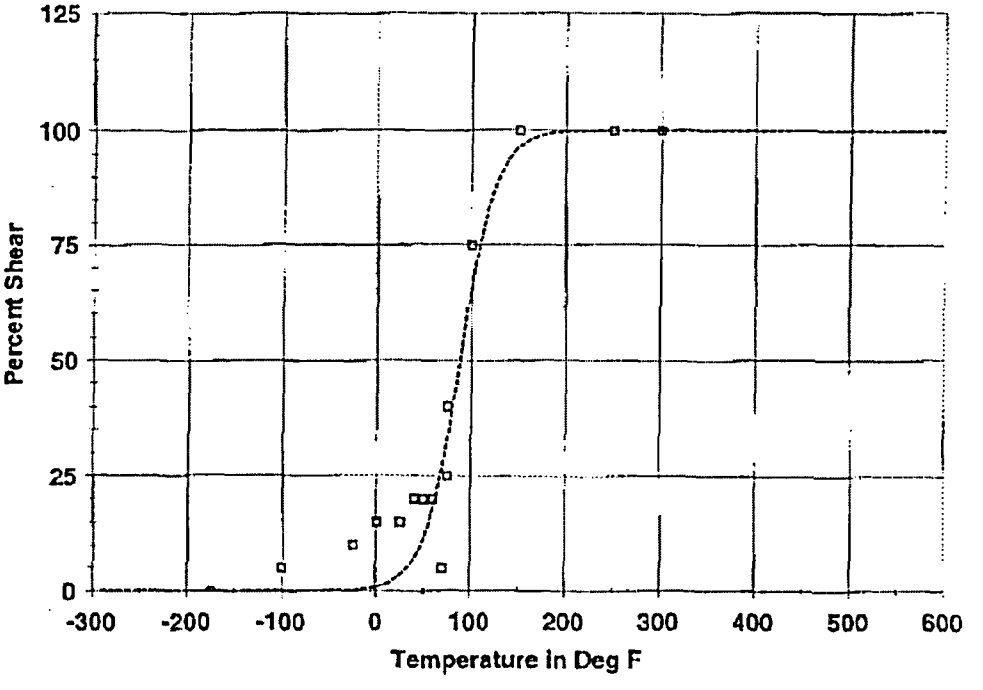
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -7.00 | 56.00 | 57.99 | -1.99 |
| -7.00 | 74.00 | 57.99 | 16.01 |
| 20.00 | 50.00 | 70.93 | -20.93 |
| 20.00 | 46.00 | 70.93 | -24.93 |
| 40.00 | 84.00 | 78.82 | 5.18 |
| 68.00 | 100.00 | 87.05 | 12.95 |
| 100.00 | 91.00 | 92.96 | -1.96 |
| 150.00 | 100.00 | 97.43 | 2.57 |
| 210.00 | 100.00 | 99.26 | .74 |

Correlation Coefficient = .948

# CAPSULE U HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:53 AM
Page 1
Coefficients of Curve 2
**A = 50. B = 50. C = 37.41 T0 = 88.1 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 88.1
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: U Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -175.00 | .00 | .00 | .00 |
| -100.00 | 5.00 | .00 | 5.00 |
| -25.00 | 10.00 | .24 | 9.76 |
| .00 | 15.00 | .89 | 14.11 |
| 25.00 | 15.00 | 3.31 | 11.69 |
| 40.00 | 20.00 | 7.10 | 12.90 |
| 50.00 | 20.00 | 11.54 | 8.46 |
| 60.00 | 20.00 | 18.21 | 1.79 |
| 70.00 | 5.00 | 27.54 | -22.54 |

# CAPSULE U HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: U Fluence: n/cm^2

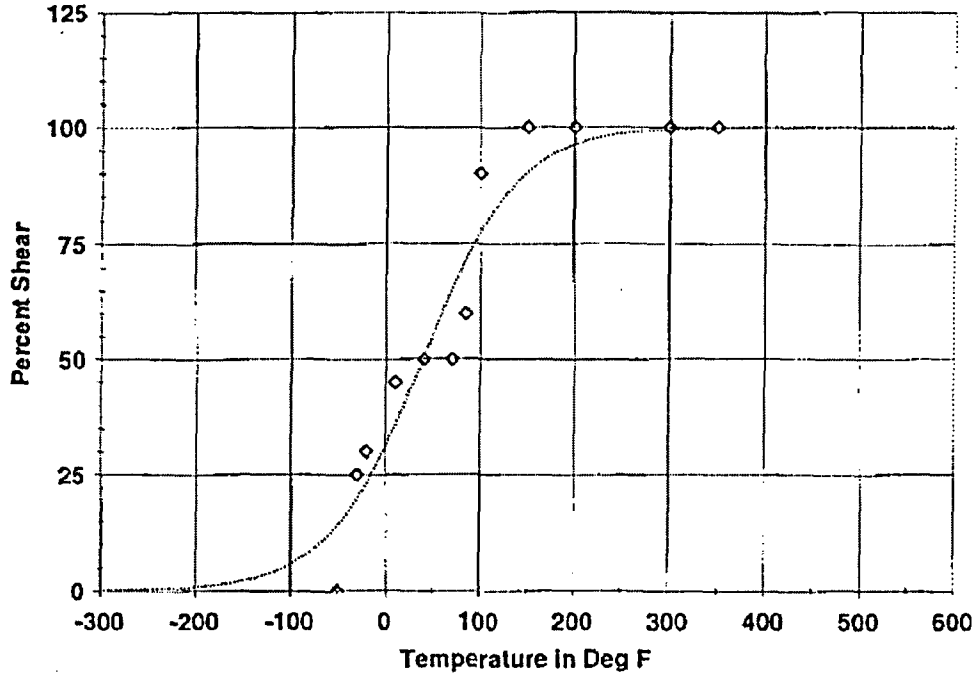
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 75.00 | 25.00 | 33.18 | -8.18 |
| 75.00 | 40.00 | 33.18 | 6.82 |
| 100.00 | 75.00 | 65.39 | 9.61 |
| 150.00 | 100.00 | 96.48 | 3.52 |
| 250.00 | 100.00 | 99.98 | .02 |
| 300.00 | 100.00 | 100.00 | .00 |

Correlation Coefficient = .970

# CAPSULE W HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:54 AM
Page 1
Coefficients of Curve 3
**A = 50. B = 50. C = 99.03 T0 = 39.58 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 39.6
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: W Fluence: n/cm^2




**Charpy V-Notch Data**

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -50.00 | .00 | 14.07 | -14.07 |
| -30.00 | 25.00 | 19.70 | 5.30 |
| -20.00 | 30.00 | 23.09 | 6.91 |
| 10.00 | 45.00 | 35.49 | 9.51 |
| 40.00 | 50.00 | 50.21 | -.21 |
| 70.00 | 50.00 | 64.89 | -14.89 |
| 85.00 | 60.00 | 71.45 | -11.45 |
| 100.00 | 90.00 | 77.21 | 12.79 |
| 150.00 | 100.00 | 90.29 | 9.71 |

# CAPSULE W HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR I Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: W Fluence: n/cm^2

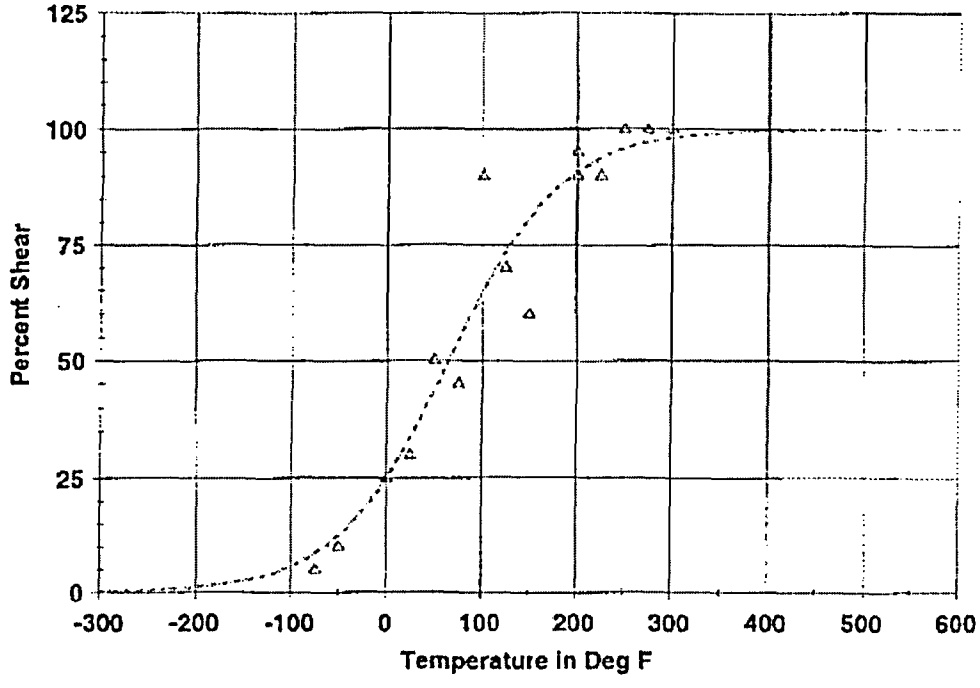
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200.00 | 100.00 | 96.23 | 3.77 |
| 300.00 | 100.00 | 99.48 | .52 |
| 350.00 | 100.00 | 99.81 | .19 |

Correlation Coefficient = .963

# CAPSULE X HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:54 AM
Page 1
Coefficients of Curve 4
**A = 50. B = 50. C = 117.85 T0 = 64.64 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 64.7
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: X Fluence: n/cm^2




## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -75.00 | 5.00 | 8.55 | -3.55 |
| -50.00 | 10.00 | 12.50 | -2.50 |
| .00 | 25.00 | 25.03 | -.03 |
| 25.00 | 30.00 | 33.79 | -3.79 |
| 50.00 | 50.00 | 43.82 | 6.18 |
| 75.00 | 45.00 | 54.38 | -9.38 |
| 100.00 | 90.00 | 64.57 | 25.43 |
| 125.00 | 70.00 | 73.58 | -3.58 |
| 150.00 | 60.00 | 80.98 | -20.98 |

# CAPSULE X HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: X Fluence: n/cm^2

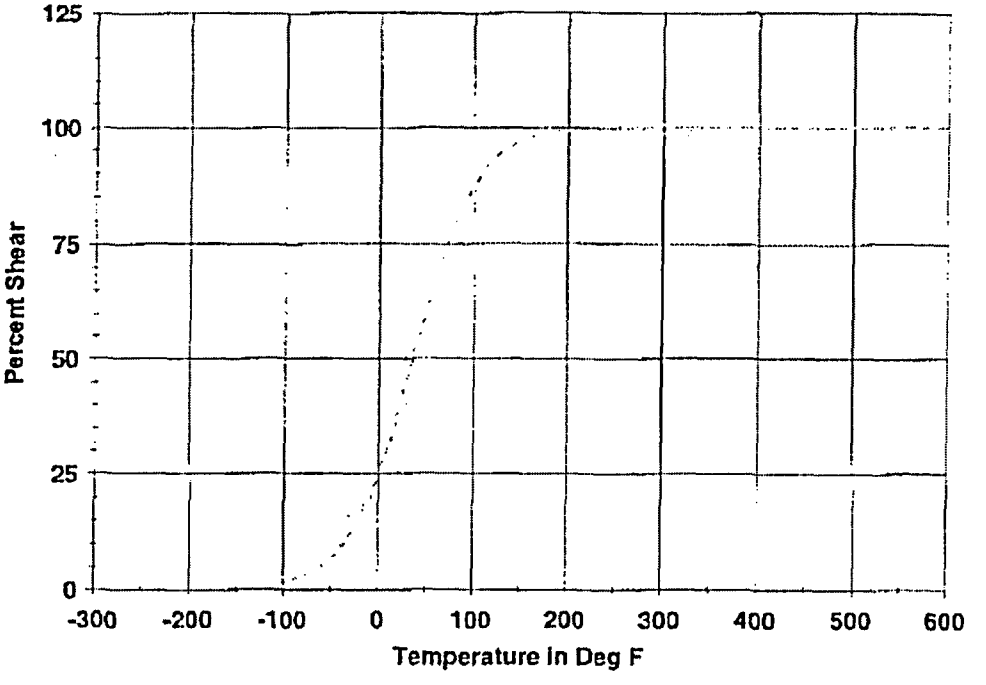
## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200.00 | 95.00 | 90.86 | 4.14 |
| 200.00 | 90.00 | 90.86 | -.86 |
| 225.00 | 90.00 | 93.83 | -3.83 |
| 250.00 | 100.00 | 95.87 | 4.13 |
| 275.00 | 100.00 | 97.26 | 2.74 |
| 300.00 | 100.00 | 98.19 | 1.81 |

Correlation Coefficient = .960

# CAPSULE Z HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 07/13/2007 10:54 AM
Page 1
Coefficients of Curve 5
**A = 50. B = 50. C = 65.72 T0 = 36.9 D = 0.00E+00**
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 37.0
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: Z Fluence: n/cm^2




**Charpy V-Notch Data**

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100.00 | 2.00 | 1.53 | .47 |
| -25.00 | 15.00 | 13.20 | 1.80 |
| .00 | 15.00 | 24.55 | -9.55 |
| 15.00 | 40.00 | 33.93 | 6.07 |
| 25.00 | 40.00 | 41.04 | -1.04 |
| 40.00 | 60.00 | 52.35 | 7.65 |
| 50.00 | 50.00 | 59.83 | -9.83 |
| 60.00 | 70.00 | 66.88 | 3.12 |
| 75.00 | 80.00 | 76.12 | 3.88 |

# CAPSULE Z HEAT AFFECTED ZONE

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: Z Fluence: n/cm^2

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 125.00 | 85.00 | 93.59 | -8.59 |
| 175.00 | 100.00 | 98.53 | 1.47 |
| 300.00 | 100.00 | 99.97 | .03 |
| 325.00 | 100.00 | 99.98 | .02 |
| 350.00 | 100.00 | 99.99 | .01 |
| 375.00 | 100.00 | 100.00 | .00 |

Correlation Coefficient = .989

# APPENDIX D
# WATTS BAR UNIT 1 SURVEILLANCE PROGRAM CREDIBILITY EVALUATION

## D.1 INTRODUCTION

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

To date there have been four surveillance capsules removed from the Watts Bar Unit 1 reactor vessel. To use these surveillance data sets, they must be shown to be credible. In accordance with the discussion of Regulatory Guide 1.99, Revision 2, there are five requirements that must be met for the surveillance data to be judged credible.

The purpose of this evaluation is to apply the credibility requirements of Regulatory Guide 1.99, Revision 2, to the Watts Bar Unit 1 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" [Reference D-2], as follows:

> *"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 Watts Bar Unit 1 reactor vessel consists of the following beltline region materials:

- Intermediate Shell Forging 05
- Lower Shell Forging 04
- Intermediate to Lower Shell Circumferential Weld Seam (Heat # 895075)

The vessel forging material selected for inclusion in the surveillance program was Intermediate Shell Forging 05, which had the highest initial $RT_{NDT}$ (Initial $RT_{NDT}$ = 47°F per Appendix B of Reference D-3, and lowest initial USE (which was below the 75 ft-lbs limit from 10 CFR 50 Appendix G). Thus, it was selected as the surveillance base metal.

The weld material in the Watts Bar Unit 1 surveillance program was made of the same wire as the reactor vessel beltline circumferential weld, thus it was chosen as the surveillance weld material. Hence, Criterion 1 is met for the Watts Bar Unit 1 reactor vessel.

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

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

**Criterion 3:** When there are two or more sets of surveillance data from one reactor, the scatter of $\Delta RT_{NDT}$ values about a best-fit line drawn as described in Regulatory Position 2.1 normally should be less than 28°F for welds and 17°F for base metal. Even if the fluence range is large (two or more orders of magnitude), the scatter should not exceed twice those values. Even if the data fail this criterion for use in shift calculations, they may be credible for determining decrease in upper shelf energy if the upper shelf can be clearly determined, following the definition given in ASTM E185-82 [Reference D-4].

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

The Watts Bar intermediate to lower circumferential weld will be evaluated for credibility. This weld is made from weld wire heat 895075. This weld metal is also contained in the Catawba Unit 1 and McGuire Unit 2 surveillance programs. Since the welds in question utilize data from other surveillance programs, the recommended NRC methods for determining credibility will be followed. The NRC methods for credibility determination were presented to industry at a meeting held by the NRC on February 12 and 13, 1998. At these meetings the NRC presented five cases. Of the five cases, Case 4 most closely represents the situation listed above for Watts Bar Unit 1 surveillance weld metal. Note, for the forging material, the straightforward method of Regulatory Guide 1.99, Revision 2 will be followed.

The Watts Bar intermediate to lower circumferential weld is made from weld wire heat 895075. This weld metal is also contained in the Catawba Unit 1 and McGuire Unit 2 surveillance programs. It should be noted that a credibility evaluation for this weld heat has already been performed for Catawba in Appendix D of WCAP-15117 [Reference D-5]. This evaluation is adapting the information provided in Appendix C of WCAP-16339-NP [Reference D-6], which was based upon the Reference D-5 credibility evaluation, to include the additional Watts Bar Unit 1 surveillance data from Capsule Z.

**Credibility assessment – Watts Bar Data Only**

Since all data is from one source (Watts Bar Unit 1), the measured $\Delta RT_{NDT}$ and fluence factor (FF) should be used to calculate the chemistry factor to determine if the Watts Bar Unit 1 surveillance material test results are credible.

Table D-1 contains the calculation of chemistry factors for the Watts Bar Unit 1 surveillance forging and weld material contained in the surveillance program. These chemistry factors are calculated per Regulatory Guide 1.99, Revision 2, Position 2.1. [Note that when evaluating surveillance weld data, an adjustment called the "Ratio Procedure" is applied. This "Ratio" is not required when determining the credibility of the surveillance weld data.]

**Table D-1 Calculation of Chemistry Factors using Watts Bar Unit 1 Surveillance Capsule Data**

| Material | Capsule | Capsule f | FF | $\Delta RT_{NDT}$ | $FF*\Delta RT_{NDT}$ | $FF^2$ |
|---|---|---|---|---|---|---|
| Inter. Shell Forging 05 (Tangential) | U | 0.447 | 0.776 | 98.3 | 76.28 | 0.602 |
| | W | 1.08 | 1.022 | 111.4 | 113.80 | 1.044 |
| | X | 1.71 | 1.148 | 94.7 | 108.68 | 1.317 |
| | Z | 2.40 | 1.236 | 144.5 | 178.60 | 1.528 |
| Inter. Shell Forging 05 (Axial) | U | 0.447 | 0.776 | 28.7 | 22.27 | 0.602 |
| | W | 1.08 | 1.022 | 79.0 | 80.70 | 1.044 |
| | X | 1.71 | 1.148 | 115.9 | 133.01 | 1.317 |
| | Z | 2.40 | 1.236 | 104.9 | 129.65 | 1.528 |
| | | | | SUM: | 842.99 | 8.982 |
| | $CF05 = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (842.99) \div (8.982) = 93.9°F$ | | | | | |
| Surveillance Weld | U | 0.447 | 0.776 | 0[(a)] | 0 | 0.602 |
| | W | 1.08 | 1.022 | 30.5 | 31.16 | 1.044 |
| | X | 1.71 | 1.148 | 25.8 | 29.61 | 1.317 |
| | Z | 2.40 | 1.236 | 13.9 | 17.18 | 1.528 |
| | | | | SUM: | 77.95 | 4.491 |
| | $CF\ Surv.\ Weld = \Sigma(FF * \Delta RT_{NDT}) \div \Sigma(FF^2) = (77.95) \div (4.490) = 17.4°F$ | | | | | |

**Note:**
A. Actual value is -6.4°F, but for conservatism a value of zero is used.

The scatter of $\Delta RT_{NDT}$ values about the functional form of a best-fit line drawn as described in Regulatory Position 2.1 is presented in Table D-2. Table D-2 indicates that three of the eight surveillance data points fall outside the +/- 1σ of 17°F scatter band for surveillance forging materials, therefore the forging data is deemed "not credible" per the third criterion. Table D-2 indicates that all of the four surveillance data points are within the +/- 1σ of 28°F scatter band for surveillance weld materials, therefore the surveillance weld data is deemed "credible" per the third criterion.

| Table D-2 Watts Bar Unit 1 Surveillance Capsule Data Scatter about the Best-Fit Line | | | | | | | |
|---|---|---|---|---|---|---|---|
| Material | Capsule | CF (Slope best fit) | FF | Measured $\Delta RT_{NDT}$ | Predicted $\Delta RT_{NDT}$ | Scatter $\Delta RT_{NDT}$ | <17°F (Base Metal) <28°F (Weld) |
| Inter. Shell Forging 05 (Tangential) | U | 93.9°F | 0.7760 | 98.3°F | 72.9°F | 25.4°F | NO |
| | W | 93.9°F | 1.0215 | 111.4°F | 95.9°F | 15.5°F | YES |
| | X | 93.9°F | 1.1477 | 94.7°F | 107.8°F | 13.1°F | YES |
| | Z | 93.9°F | 1.2360 | 144.5°F | 116.1°F | 28.4°F | NO |
| Inter. Shell Forging 05 (Axial) | U | 93.9°F | 0.7760 | 28.7°F | 72.9°F | 44.2°F | NO |
| | W | 93.9°F | 1.0215 | 79.0°F | 95.9°F | 16.9°F | YES |
| | X | 93.9°F | 1.1477 | 115.9°F | 107.8°F | 8.1°F | YES |
| | Z | 93.9°F | 1.2360 | 104.9°F | 116.1°F | 11.2°F | YES |
| Girth Seam Surveillance Weld | U | 17.4°F | 0.7760 | -6.4°F | 13.5°F | 19.9°F | YES |
| | W | 17.4°F | 1.0215 | 30.5°F | 17.8°F | 12.8°F | YES |
| | X | 17.4°F | 1.1477 | 25.8°F | 20.0°F | 5.8°F | YES |
| | Z | 17.4°F | 1.2360 | 13.9°F | 21.5°F | 7.6°F | YES |

Since surveillance data were used in determining the chemistry factor in Section 6 for calculating the shift in $RT_{NDT}$, and presumably for calculating pressurized thermal shock reference temperatures in the future, the credibility assessments of the surveillance data from Catawba Unit 1 and McGuire Unit 2 should be consulted. Appendix D of WCAP-15117 [Reference D-5] indicates that the Catawba Unit 1 surveillance data is credible. WCAP-14799 [Reference D-7] failed to include a credibility evaluation of the McGuire surveillance data.

**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 Watts Bar Unit 1 surveillance program does not contain correlation monitor material. Therefore, this criterion is not applicable to the Watts Bar surveillance program.

## D.3 CONCLUSION

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B, the Watts Bar Unit 1 surveillance data is deemed credible for the weld specimens and non-credible for the forging specimens. Credibility of surveillance data is used to determine the appropriate margin term for calculation of adjusted reference temperature in accordance with Reference D-1. Credible forging and weld surveillance data have reduced $\sigma_\Delta$ terms of 8.5°F and 14°F, respectively, in calculation of the margin term for determining the respective vessel materials' Position 2.1 adjusted reference temperatures.

## 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 Code of Federal Regulations, 10 CFR 50, Appendix G, *Fracture Toughness Requirements*, and Appendix H, *Reactor Vessel Material Surveillance Program Requirements*, U.S. Nuclear Regulatory Commission, Washington, D.C.

D-3 WCAP-9298, Revision 3, *Tennessee Valley Authority Watts Bar Unit No. 1 Reactor Vessel Radiation Surveillance Program*, P. A. Peter, August 1995.

D-4 ASTM E185-82, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels*, American Society for Testing and Materials.

D-5 WCAP-15117, Revision 0, *Analysis of Capsule V and the Dosimeter from Capsule U and X From the Catawba Unit 1 Reactor Vessel Radiation Surveillance Program*, E. Terek, et. al., October 1998.

D-6 WCAP-16333-NP, Revision 0, *Fracture Toughness Testing of Compact Tension Specimens from Watts Bar Unit 1 Surveillance Capsule X*, Randy Lott, August 2004.

D-7 WCAP-14799, Revision 0, *Analysis of Capsule W from the Duke Power Company McGuire Unit 2 Reactor Vessel Radiation Surveillance Program*, E. Terek, et. al., March 1997.