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Analysis of Capsule N from the Xcel Energy Prairie Island Unit 2 Reactor Vessel Radiation Surveillance Program

Westinghouse

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EXECUTIVE SUMMARY

The purpose of this report is to document the testing results of surveillance Capsule N from Prairie Island Unit 2. Capsule N was removed at 40.64 effective full-power years (EFPY) and post-irradiation mechanical tests of the Charpy V-notch and tensile specimens were performed. A fluence evaluation utilizing the neutron transport and dosimetry cross-section libraries was derived from the Evaluated Nuclear Data File (ENDF) database (specifically, ENDF/B-VI). Capsule N received a fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV) after irradiation to 40.64 EFPY. The peak clad/base metal interface vessel fluence at 54 EFPY (end-of-license extension) of plant operation is projected to be 5.66 x 10^{19} n/cm^2 (E > 1.0 MeV).

This evaluation led to the following conclusions: (1) The measured shifts in the 30 ft-lb transition temperature of all the surveillance materials, i.e., the surveillance forging (tangential and axial orientations), the surveillance weld material, and Correlation Monitor Material (CMM) contained in Prairie Island Unit 2 Capsule N are higher than the Regulatory Guide 1.99, Revision 2 [1], Position 1.1 predictions. (2) The measured percent decreases in upper-shelf energy of all the surveillance materials, i.e., the Lower Shell Forging D (Heat # 22642) (tangential and axial orientations), surveillance weld material (Heat # 2721), and CMM, are less than the Regulatory Guide 1.99, Rev. 2, Position 1.2 predictions. (3) The Prairie Island Unit 2 surveillance forging data is deemed "non-credible", while the surveillance weld data is deemed to be "credible". This credibility 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 N, the fifth capsule removed and tested from the Prairie Island Unit 2 reactor pressure vessel, led to the following conclusions:

- Charpy V-notch test data were plotted using a symmetric hyperbolic tangent curve-fitting program. Appendix C presents the CVGRAPH, Version 6.02, Charpy V-notch plots for Capsule N, along with data from the program baseline and previous capsules.

- Capsule N received an average fast neutron fluence (E > 1.0 MeV) of 8.41 x 10^{19} n/cm^2 after 40.64 effective full-power years (EFPY) of plant operation.

- Irradiation of the reactor vessel Lower Shell Forging D (Heat # 22642) 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 148.2°F. This results in a 30 ft-lb transition temperature increase of 176.5°F for the tangentially oriented specimens.

- Irradiation of the reactor vessel Lower Shell Forging D (Heat # 22642) 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 152.9°F. This results in a 30 ft-lb transition temperature increase of 154.1°F for the axially oriented specimens.

- Irradiation of the surveillance program weld material (Heat # 2721, Flux Type UM89, Lot # 1263) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 59.5°F. This results in a 30 ft-lb transition temperature increase of 135.6°F for the surveillance program weld material specimens.

- Irradiation of the reactor vessel heat-affected zone (HAZ) material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 10.9°F. This results in a 30 ft-lb transition temperature increase of 145.5°F for the HAZ material specimens.

- Irradiation of the reactor vessel Correlation Monitor Material (CMM) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 259.9°F. This results in a 30 ft-lb transition temperature increase of 212.9°F for the CMM specimens.

- The average upper-shelf energy of Lower Shell Forging D (Heat # 22642) (tangential orientation) resulted in an average energy decrease of 22.7 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 125 ft-lb for the tangentially oriented specimens.

- The average upper-shelf energy of Lower Shell Forging D (Heat # 22642) (axial orientation) resulted in an average energy decrease of 17.2 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 89 ft-lb for the axially oriented specimens.

- The average upper-shelf energy of the surveillance program weld material (Heat # 2721) Charpy specimens resulted in an average energy decrease of 8.3 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 95 ft-lb for the surveillance program weld material specimens.

- The average upper-shelf energy of the HAZ material Charpy specimens resulted in an average energy decrease of 32 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 82 ft-lb for the HAZ material.

- The average upper-shelf energy of the CMM Charpy specimens resulted in an average energy decrease of 41.4 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 79 ft-lb for the CMM specimens.

- Comparisons of the measured 30 ft-lb shift in transition temperature values and upper-shelf energy decreases to those predicted by Regulatory Guide 1.99, Rev. 2 [1] for the Prairie Island Unit 2 reactor vessel surveillance materials are presented in Table 5-12.

- Based on the credibility evaluation presented in Appendix D, the Prairie Island Unit 2 surveillance plate data is deemed "non-credible", while the surveillance weld material data is deemed "credible".

- The maximum calculated 54 EFPY (end-of-license extension) neutron fluence (E > 1.0 MeV) for the Prairie Island Unit 2 reactor vessel beltline using the Regulatory Guide 1.99, Rev. 2 [1] attenuation formula (i.e., Equation # 3 in the Guide) and a vessel thickness of 6.692 inches are as follows:

Calculated (54 EFPY): Vessel peak clad/base metal interface fluence* = 5.66 x 10^{19} n/cm^2
Vessel peak quarter-thickness (1/4T) fluence = 3.79 x 10^{19} n/cm^2
Vessel peak three-quarter thickness (3/4T) fluence = 1.70 x 10^{19} n/cm^2

*This fluence value is determined from data in Table 6-5.

2 INTRODUCTION

This report presents the results of the examination of Capsule N, the fifth capsule removed and tested in the continuing surveillance program, which monitors the effects of neutron irradiation on the Xcel Energy Prairie Island Unit 2 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Prairie Island Unit 2 reactor pressure vessel materials was designed and recommended by Westinghouse Electric Company LLC. A detailed description of the surveillance program is contained in WCAP-8193 [2], "Northern States Power Co. Prairie Island Unit No. 2 Reactor Vessel Radiation Surveillance Program." The surveillance program was originally planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-70 [3], "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels." Capsule N was removed from the reactor at 40.64 effective full-power years (EFPY) of exposure and shipped to the Westinghouse Churchill Laboratory, where the post-irradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

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

A method for ensuring the integrity of reactor pressure vessels has been presented in "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code [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 American Society of Testing and Materials (ASTM) E208 [5] or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (axial) to the major working direction of the plate. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ic} curve) which appears in Appendix G to Section XI of the ASME Code [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, are 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, are monitored by a reactor vessel surveillance program, such as the Prairie Island Unit 2 reactor vessel radiation surveillance program, in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens are tested. The increase in the average Charpy V-notch 30 ft-lb temperature (ΔRT_{NDT}) due to irradiation is added to the initial RT_{NDT}, along with a margin (M) to cover uncertainties, to adjust the RT_{NDT} (ART) for radiation embrittlement. This ART (initial RT_{NDT} + M + ΔRT_{NDT}) is used to index the material to the K_{Ic} curve and, in turn, to set operating limits for the nuclear power plant that take into account the effects of irradiation on the reactor vessel materials.

4 DESCRIPTION OF PROGRAM

Six surveillance capsules for monitoring the effects of neutron exposure on the Prairie Island Unit 2 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant startup. The six capsules were positioned in the reactor vessel between the thermal shield and the vessel wall as shown in Figure 4-1. The test capsules are in baskets attached to the thermal shield. The vertical center of the capsules is opposite the vertical center of the core. The capsules contain specimens made from the following:

- Lower Shell Forging D (Heat # 22642) – Tangential Orientation
- Lower Shell Forging D (Heat # 22642) – Axial Orientation
- Surveillance Weld Metal (Weld Wire Type UM40, Heat # 2721, Flux Type UM89, Lot # 1263)
- Heat Affected Zone material of Lower Shell Forging D (Heat # 22642)
- Correlation Monitor Material

Test material from Lower Shell Forging D (Heat # 22642) was heat-treated with the shell. All test specimens were machined from the 1/4 thickness location of the forging after performing a simulated post-weld stress-relieving treatment on the test material. Test material was taken at least one forging thickness (6.692 inches) from the quenched edges of the forging. Test specimens were also machined from weld metal and the heat affected zone metal of stress-relieved weldment joining sections of the Intermediate and Lower Shell forgings. All heat-affected zone specimens were obtained from the weld heat-affected zone of Lower Shell Forging D (Heat # 22642). The A533 Grade B Class 1 material (HSST Plate 02) for the CMM test specimens was supplied by the Oak Ridge Laboratory from a 12-inch thick plate.

Charpy V-notch impact specimens from Lower Shell Forging D (Heat # 22642) were machined in both the tangential orientation (the longitudinal axis of the specimen parallel to the major working direction) and also in the axial orientation (the longitudinal axis of the specimen perpendicular to the major working direction). The weld specimens were machined from the weldment such that the long dimension of the Charpy was normal to the weld direction where the notch was machined such that the direction of crack propagation was in the weld direction.

Tensile test specimens from the surveillance forging were machined with the longitudinal axis of the specimen in the hoop direction (tangential) and also normal to the hoop direction (axial) of the shell ring forging.

Wedge Opening Loading (WOL) test specimens were machined in a tangential direction so that the loading of the specimen would be in the major working direction of the forging with the simulated crack propagating in the axial direction. In addition, axial specimens were machined so that the loading of the specimens would be in the axial direction of the forging with the simulated crack propagating in the major working direction. All specimens were fatigue pre-cracked per ASTM E399 [6].

Capsule N contained dosimeters of pure iron, copper, nickel, and aluminum-0.15 weight percent cobalt wire (cadmium-shielded and unshielded). In addition, cadmium-shielded dosimeters of neptunium (^{237}Np)

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

Thermal monitors comprised of low melting-point eutectic alloy specimens sealed in Pyrex tubes were also included in the capsule. 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 chemical composition and the heat treatment of the various mechanical specimens in Capsule N are presented in Table 4-1 and Table 4-2, respectively. The data in the tables was obtained from surveillance capsule report WCAP-14613 [16].

Capsule N was removed after 40.64 EFPY of plant operation. The capsule contained Charpy V-notch specimens, tensile specimens, WOL specimens, dosimeters, and thermal monitors.

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

Table 4-1 Chemical Composition (wt. %) of the Prairie Island Unit 2 Reactor Vessel Surveillance Materials (Unirradiated)(1)

Element(2)	Lower Shell Forging D (Heat # 22642)	Weld Metal (Heat # 2721)	Correlation Monitor Material
C	0.175	0.045	0.22
Mn	1.22	1.37	1.48
P	0.011	0.019	0.012
S	0.013	0.014	0.018
Si	---	0.47	0.25
Mo	0.445	0.51	0.52
Ni	0.70	0.072	0.68
Cr	0.14	0.020	---
V	<0.008	0.001	---
Cu	0.085	0.082	0.14
Co	0.026	0.013	---
Al	0.036	0.007	---
N_2	0.017	0.026	---
Sn	0.011	0.002	---

Notes:
1. Data obtained from WCAP-14613 [16] and duplicated herein for completeness.
2. A qualitative spectrographic analysis was made for elements greater than 0.010 weight percent.

Table 4-2 Heat Treatment History of the Prairie Island Unit 2 Reactor Vessel Surveillance Materials[1]

<table>
<tr><th>Material</th><th>Temperature (°F)</th><th>Time (hrs.)</th><th>Coolant</th></tr>
<tr><td rowspan="6">Lower Shell Forging D
(Heat # 22642)</td><td>Heated to 1652/1715</td><td>5</td><td>Water quenched</td></tr>
<tr><td>Tempered at 1175/1238</td><td>5</td><td>Furnace cooled</td></tr>
<tr><td>Heated to 1652/1724</td><td>5.5</td><td>Water quenched</td></tr>
<tr><td>Tempered at 1202/1238</td><td>5</td><td>Furnace cooled</td></tr>
<tr><td>Stress relieved at 1022</td><td>11.5</td><td>Furnace cooled</td></tr>
<tr><td>Stress relieved at 1112</td><td>7</td><td>Furnace cooled</td></tr>
<tr><td rowspan="2">Weldment</td><td>Stress relieved at 1022</td><td>5</td><td>Furnace cooled</td></tr>
<tr><td>Stress relieved at 1112</td><td>7</td><td>Furnace cooled</td></tr>
<tr><td rowspan="4">Correlation Monitor Material</td><td>1675 ± 25</td><td>4</td><td>Air cooled</td></tr>
<tr><td>1600 ± 25</td><td>4</td><td>Water quenched</td></tr>
<tr><td>1125 ± 25</td><td>4</td><td>Furnace cooled</td></tr>
<tr><td>1150 ± 25</td><td>40</td><td>Furnace cooled to 600ºF</td></tr>
</table>

Note:
1. Data obtained from WCAP-14613 [16] and duplicated herein for completeness.

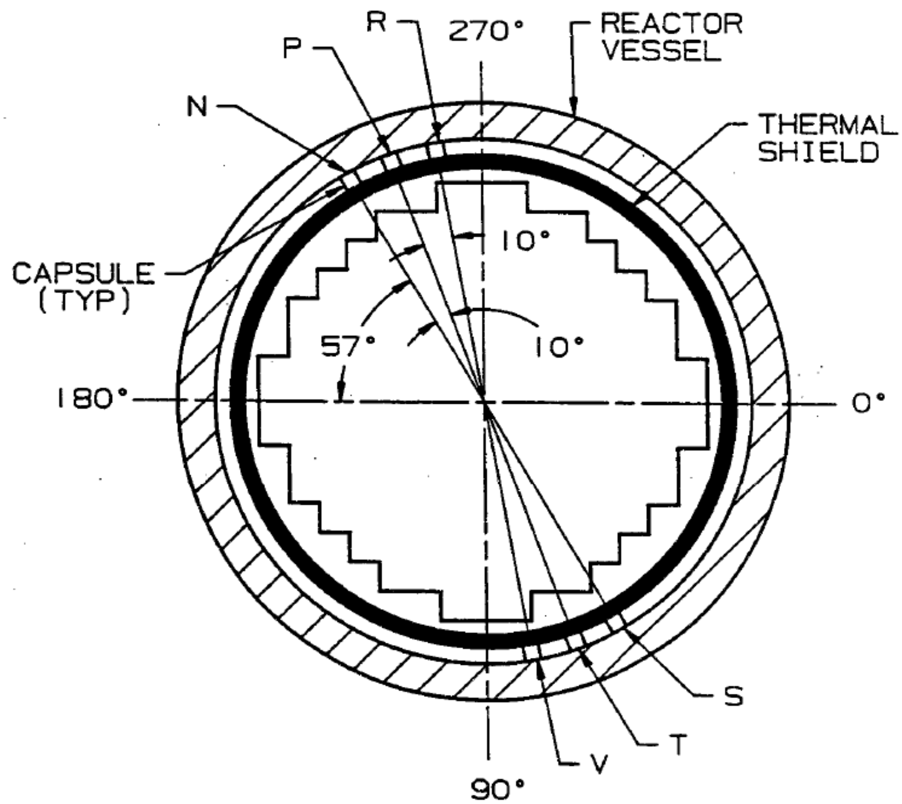

Figure 4-1 Arrangement of Surveillance Capsules in the Prairie Island Unit 2 Reactor Vessel

LEGEND:
NLxx – LOWER SHELL COURSE RING FORGING D (Heat # 22642) (TANGENTIAL)
NTxx – LOWER SHELL COURSE RING FORGING D (Heat # 22642) (AXIAL)
NWxx – WELD METAL
NHxx – HEAT AFFECTED ZONE
Rxx – CORRELATION MONITOR MATERIAL

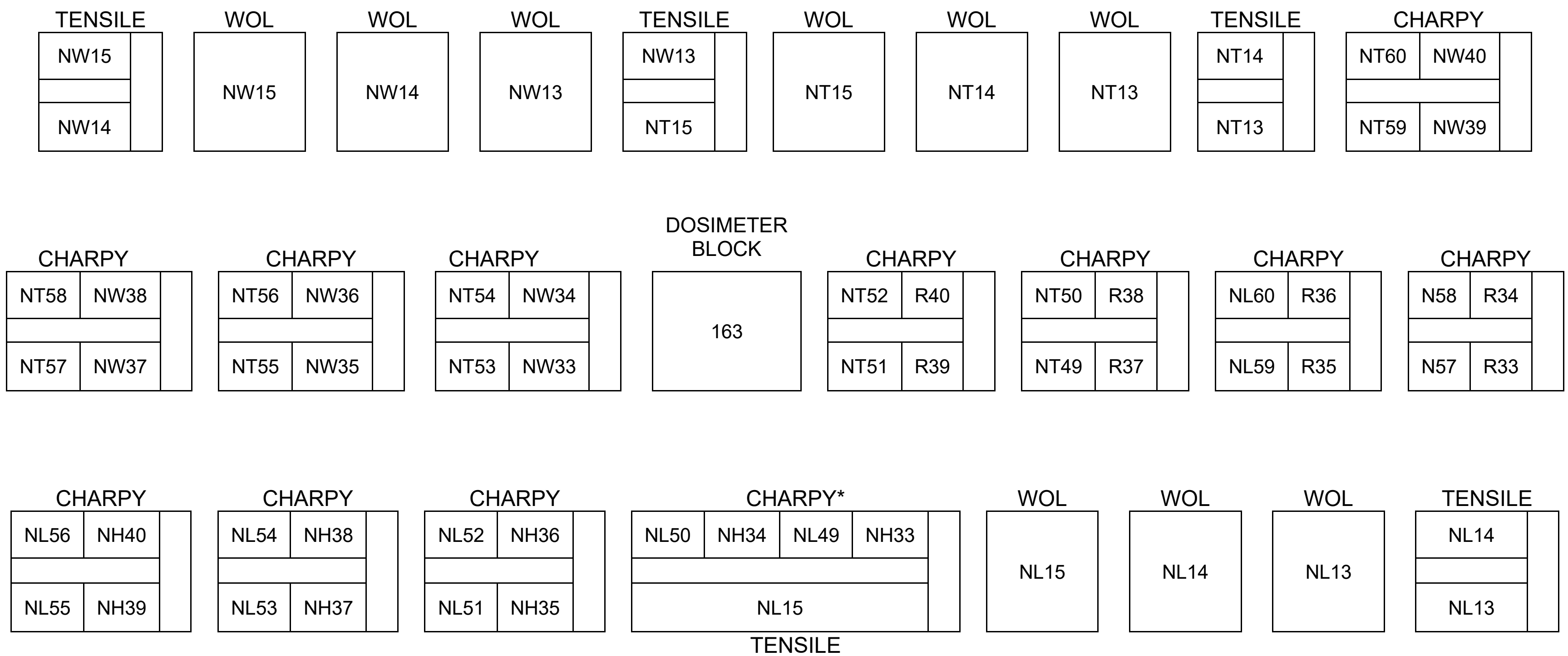

Figure 4-2 Prairie Island Unit 2 Surveillance Capsule N Specimen Locations per WCAP-8193 [2]

5 TESTING OF SPECIMENS FROM CAPSULE N

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed at the Westinghouse Churchill Hot Cell Facility. Testing was performed in accordance with 10 CFR 50, Appendix H [9] and ASTM Specification E185-82 [10].

Capsule N was opened upon receipt at the hot cell laboratory. The specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in WCAP-8193 [2] and shown in Figure 4-2. All of the items were in their proper locations.

The temperature monitors were removed from the capsule compartments and were photographed and visually examined for evidence of melting. Visual examination revealed no definitive evidence indicating that the capsule experienced temperatures in excess of 579°F.

Charpy V-notch testing was performed per ASTM E185-82 [10] and ASTM E23-18 [11] on a Tinius-Olsen Model 74, with 358J capacity impact test machine. The Charpy machine striker was instrumented with an Instron®[1] Impulse system. Instrumented testing and calibration were performed to ASTM E2298-18 [12].

The instrumented striker load signal data acquisition rate was 819 kHz with data acquired for 10 ms. From the load-time curve, the load of general yield load (F_{gy}), the maximum load (F_m) and the time to maximum load were determined. Under some test conditions, a sharp drop in load, indicative of fast fracture, was observed. The load at which fast fracture was initiated is identified as the load at brittle fracture initiation/load at initiation of unstable crack propagation (F_{bf}). The termination load after the fast load drop is identified as the arrest load/load at end of unstable crack propagation (F_a). F_{gy}, F_m, F_{bf}, and F_a were determined per the guidance in ASTM Standard E2298-18 [12].

The maximum load energy (W_m) was determined by integrating the load-time record to the maximum load point via the instrumented Charpy software. The maximum load energy is approximately equivalent to the energy required to initiate a crack in the specimen. The integrated total impact energy (W_t) is compared to the absorbed energy measured from the dial energy (KV).

Percent shear was determined from post-fracture photographs using the ratio-of-areas method in compliance with ASTM E23-18 [11] and A370-18 [13]. The lateral expansion was measured using a dial gage rig similar to that shown in the same ASTM Standards.

Tensile tests were performed on a 250 kN capacity Instron® screw driven tensile machine (Model 5985) equipped with Instron Bluehill 3 Software and an Instron 22.48 kip load cell per ASTM E185-82 [10].

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1 Instron® is a registered trademark of Instron Corporation. Other product and company names used herein are trademarks or trade names of their respective companies.

Testing met ASTM Specifications E8/E8M-16a [14] for room temperature or E21-17 [15] for elevated temperatures.

The tensile specimens were, nominally, 4.2 inches long with a 1.00 inch gauge section and a reduced section of 1.25 inches long by 0.250 inches in diameter, as noted in WCAP-8193 [2]. Strain measurements were made using an extensometer (equipped with a Columbia Research Labs LVDT), which was attached to the 1.00 inch gauge section of the tensile specimen. The strain rate (crosshead speed controlled) obtained met the requirements of ASTM E8/E8M-16a [14] and ASTM E21-17 [15].

Elevated test temperatures were obtained with a three-zone electric resistance split-tube Instron SF-16 furnace with an 11-inch hot zone with an Instron TCS 3203 temperature controller. For the elevated temperature tests, two Type-N thermocouples were placed in contact with the specimens on both ends of the gauge-length section of the specimen per ASTM E21-17 [15]. Tensile specimens were soaked at temperature (± 5ºF) for a minimum of 20 minutes before testing. All testing was conducted in air.

The yield load, ultimate load, fracture load, uniform elongation, and elongation at fracture were determined directly from the load-extension curve. The yield strength (0.2% offset method), ultimate tensile strength, and fracture strength were calculated using the original cross-sectional area. Yield point elongation (YPE) was calculated as the difference in strain between the upper yield strength and the onset of uniform strain hardening using the methodology described in ASTM E8/E8M-16a [14]. The final diameter and final gauge length were determined from post-fracture photographs. This final diameter measurement was used to calculate the fracture stress (fracture true stress) and the percent reduction in area. The reported total elongation is the elongation at fracture.

All testing equipment was calibrated per Westinghouse procedures and in accordance with the ASTM standards cited herein. Records of calibration are available at Westinghouse.

5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule N, which received a fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV) in 40.64 EFPY of operation, are presented in Tables 5-1 through 5-10 and are compared with the unirradiated and previously withdrawn capsule results as shown in Figures 5-1 through 5-15. The unirradiated capsule results were taken from WCAP-8193 [2]. Results from the previous capsules were obtained from WCAP-14613 [16] and confirmed to be applicable or updated as appropriate. The previous capsules, along with the original program unirradiated material input data, were updated using CVGRAPH, Version 6.02.

The transition temperature increases and decreases in upper-shelf energies for the Capsule N materials are summarized in Table 5-11 and led to the following results:

- Irradiation of the reactor vessel Lower Shell Forging D (Heat # 22642) 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 148.2°F and an irradiated 50 ft-lb transition temperature of 170.7°F. This results in a 30 ft-lb transition temperature increase of 176.5°F and a 50 ft-lb transition temperature increase of 177.5°F for the tangentially oriented specimens.

- Irradiation of the reactor vessel Lower Shell Forging D (Heat # 22642) 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 152.9°F and an irradiated 50 ft-lb transition temperature of 184.7°F. This results in a 30 ft-lb transition temperature increase of 154.1°F and a 50 ft-lb transition temperature increase of 150.1°F for the axially oriented specimens.

- Irradiation of the surveillance program weld material (Heat # 2721) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 59.5°F and an irradiated 50 ft-lb transition temperature of 112°F. This results in a 30 ft-lb transition temperature increase of 135.6°F and a 50 ft-lb transition temperature increase of 154.1°F.

- Irradiation of the Heat Affected Zone (HAZ) material Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 10.9°F and an irradiated 50 ft-lb transition temperature of 50.4°F. This results in a 30 ft-lb transition temperature increase of 145.5°F and a 50 ft-lb transition temperature increase of 148.4°F.

- Irradiation of the Correlation Monitor Material (CMM) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 259.9°F and an irradiated 50 ft-lb transition temperature of 310.3°F. This results in a 30 ft-lb transition temperature increase of 212.9°F and a 50 ft-lb transition temperature increase of 232.3°F.

- The average upper-shelf energy of Lower Shell Forging D (Heat # 22642) (tangential orientation) resulted in an average energy decrease of 22.7 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 125.0 ft-lb for the tangentially oriented specimens.

- The average upper-shelf energy of Lower Shell Forging D (Heat # 22642) (axial orientation) resulted in an average energy decrease of 17.2 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 89.0 ft-lb for the axially oriented specimens.

- The average upper-shelf energy of the surveillance program weld material (Heat # 2721) Charpy specimens resulted in an average energy decrease of 8.3 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 95.0 ft-lb for the weld specimens.

- The average upper-shelf energy of the HAZ material Charpy specimens resulted in an average energy decrease of 32.0 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 82.0 ft-lb for the HAZ specimens.

- The average upper-shelf energy of the CMM Charpy specimens resulted in an average energy decrease of 41.4 ft-lb after irradiation. This decrease results in an irradiated average upper-shelf energy of 79.0 ft-lb for the CMM specimens.

- Comparisons of the measured 30 ft-lb shift in transition temperature values and upper-shelf energy decreases to those predicted by Regulatory Guide 1.99, Rev. 2 [1] for the Prairie Island Unit 2 reactor vessel surveillance materials are presented in Table 5-12.

The fracture appearance of each irradiated Charpy specimen from the various materials is shown in Figure 5-16 through Figure 5-20. The fractures show an increasingly ductile or tougher appearance with increasing test temperature. Load-time records for the individual instrumented Charpy specimens are contained in Appendix B.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in Capsule N irradiated to 8.41×10^{19} n/cm^2 (E > 1.0 MeV) are presented in Table 5-13 and are compared with unirradiated results as shown in Figure 5-21 through Figure 5-23.

The results of the tensile tests performed on the Lower Shell Forging D (Heat # 22642) (tangential orientation) indicated that irradiation to 8.41×10^{19} n/cm^2 (E > 1.0 MeV) caused increases in the 0.2 percent offset yield strength and the ultimate tensile strength when compared to unirradiated data in WCAP-8193 [2]. See Figure 5-21.

The results of the tensile tests performed on the Lower Shell Forging D (Heat # 22642) (axial orientation) indicated that irradiation to 8.41×10^{19} n/cm^2 (E > 1.0 MeV) caused increases in the 0.2 percent offset yield strength and the ultimate tensile strength when compared to unirradiated data in WCAP-8193 [2]. See Figure 5-22.

The results of the tensile tests performed on the surveillance program weld material (Heat # 2721) indicated that irradiation to 8.41×10^{19} n/cm^2 (E > 1.0 MeV) caused increases in the 0.2 percent offset yield strength and the ultimate tensile strength when compared to unirradiated data in WCAP-8193 [2]. See Figure 5-23.

The fractured tensile specimens for the Lower Shell Forging D (Heat # 22642) (tangential orientation) material are shown in Figure 5-24; the fractured tensile specimens for the Lower Shell Forging D (Heat # 22642) (axial orientation) are shown in Figure 5-25; and the fracture tensile specimens for the surveillance program weld material are shown in Figure 5-26. The engineering stress-strain curves for the tensile tests are shown in Figure 5-27 through Figure 5-35.

Table 5-1 Charpy V-notch Data for the Prairie Island Unit 2 Capsule N Lower Shell Forging D (Heat # 22642) (Tangential Orientation) Irradiated to a Fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Specimen ID	Temperature		Impact Energy		Lateral Expansion		Shear %
	°F	°C*	ft-lbs	Joules*	mils	mm*	
NL59	73	23	20	27	13	0.3	5
NL56	120	49	11	15	11	0.3	10
NL53	130	54	14	19	13	0.3	15
NL57	140	60	36	49	27	0.7	15
NL51	155	68	20	27	20	0.5	10
NL49	165	74	45	61	34	0.9	20
NL58	175	79	57	77	42	1.1	30
NL55	200	93	97	132	57	1.4	60
NL60	225	107	77	104	54	1.4	55
NL52	250	121	126	171	78	2.0	100
NL54	300	149	127	172	85	2.2	100
NL50	325	163	122	165	79	2.0	100

*Calculated conversion values.

Table 5-2 Charpy V-notch Data for the Prairie Island Unit 2 Capsule N Lower Shell Forging D (Heat # 22642) (Axial Orientation) Irradiated to a Fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Specimen ID	Temperature		Impact Energy		Lateral Expansion		Shear %
	°F	°C*	ft-lbs	Joules*	mils	mm*	
NT54	100	38	19	26	16	0.4	5
NT56	120	49	24	33	20	0.5	10
NT49	140	60	27	37	19	0.5	10
NT59	155	68	20	27	18	0.5	15
NT58	165	74	31	42	24	0.6	20
NT53	170	77	31	42	26	0.7	20
NT60	175	79	57	77	38	1.0	30
NT57	200	93	56	76	42	1.1	35
NT55	225	107	78	106	56	1.4	65
NT51	275	135	93	126	63	1.6	100
NT50	300	149	84	114	66	1.7	100
NT52	325	163	90	122	61	1.5	100

*Calculated conversion values.

Table 5-3 Charpy V-notch Data for the Prairie Island Unit 2 Capsule N Surveillance Program Weld Material Irradiated to a Fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Specimen ID	Temperature		Impact Energy		Lateral Expansion		Shear %
	°F	°C*	ft-lbs	Joules*	mils	mm*	
NW36	30	-1	22	30	17	0.4	15
NW39	50	10	29	39	21	0.5	20
NW38	73	23	51	69	34	0.9	30
NW40	100	38	26	35	17	0.4	25
NW37	175	79	69	94	44	1.1	55
NW35	225	107	91	123	73	1.9	95
NW33	275	135	95	129	69	1.8	100
NW34	300	149	99	134	83	2.1	100

*Calculated conversion values.

Table 5-4 Charpy V-notch Data for the Prairie Island Unit 2 Capsule N Heat Affected Zone (HAZ) Irradiated to a Fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Specimen ID	Temperature		Impact Energy		Lateral Expansion		Shear %
	°F	°C*	ft-lbs	Joules*	mils	mm*	
NH39	-25	-32	26	35	15	0.4	20
NH33	25	-4	33	45	19	0.5	25
NH36	30	-1	28	38	19	0.4	30
NH40	60	16	64	87	40	1.0	60
NH37	90	32	72	98	49	1.2	70
NH34	120	49	67	91	42	1.1	55
NH35	175	79	85	115	62	1.6	98
NH38	275	135	79	107	49	1.2	100

* Calculated conversion values.

Table 5-5 Charpy V-notch Data for the Prairie Island Unit 2 Capsule N Correlation Monitor Material (CMM) Irradiated to a Fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Specimen ID	Temperature		Impact Energy		Lateral Expansion		Shear %
	°F	°C*	ft-lbs	Joules*	mils	mm*	
R37	200	93	16	22	10	0.3	15
R35	225	107	27	37	16	0.4	20
R34	240	116	12	16	10	0.3	18
R33	275	135	37	50	28	0.7	35
R36	320	160	54	73	39	1.0	50
R38	375	191	66	89	39	1.0	65
R39	425	218	84	114	51	1.3	100
R40	450	232	74	100	63	1.6	100

* Calculated conversion values.

Table 5-6 Instrumented Charpy Impact Test Results for the Prairie Island Unit 2 Capsule N Lower Shell Forging D (Heat # 22642) (Tangential Orientation) Irradiated to a Fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Specimen ID	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, (KV-W_t)/KV (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Brittle Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
NL59	73	20	19	4	15.9	4265	0.29	3413	4015	None
NL56	120	11	8	26(1)	3.2	3767	0.09	2193	3256	None
NL53	130	14	9	33(1)	3.3	3727	0.09	3289	3443	None
NL57	140	36	30	16(1)	28.6	4102	0.51	3118	4039	None
NL51	155	20	15	27(1)	11.7	3723	0.24	3104	3540	None
NL49	165	45	37	18(1)	34.1	4130	0.60	3103	4050	None
NL58	175	57	52	9	34.9	4188	0.61	3120	3956	1391
NL55	200	97	90	7	34.6	4184	0.60	3050	3557	2031
NL60	225	77	67	13	33.2	4055	0.60	2919	3788	1790
NL52	250	126	118	7	34.4	4156	0.60	2962	0	None
NL54	300	127	118	7	33.3	4018	0.61	2938	0	None
NL50	325	122	114	7	33.9	4040	0.61	2993	0	None

Note:

1. The difference between instrumented Charpy and Dial values was greater than 15%. The values were not adjusted as required by ASTM E2298-18 [12] since this data is not required, but is presented for informational purposes only.

Table 5-7 Instrumented Charpy Impact Test Results for the Prairie Island Unit 2 Capsule N Lower Shell Forging D (Heat # 22642) (Axial Orientation) Irradiated to a Fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Specimen ID	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, (KV-W_t)/KV (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Brittle Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
NT54	100	19	17	12	15.3	4015	0.29	3142	3934	None
NT56	120	24	22	10	18.9	4004	0.36	3234	3810	None
NT49	140	27	23	14	19.0	4013	0.36	3084	3971	None
NT59	155	20	16	19(1)	14.8	3879	0.29	3116	3770	None
NT58	165	31	25	21(1)	18.5	3914	0.36	3047	3840	451
NT53	170	31	26	17(1)	3.6	4111	0.11	3039	3981	415
NT60	175	57	51	11	35.8	4253	0.61	3146	4078	1526
NT57	200	56	47	15	26.9	4079	0.48	3154	3964	1766
NT55	225	78	71	9	34.3	4074	0.61	3055	3656	2506
NT51	275	93	87	6	33.7	4011	0.60	2966	0	None
NT50	300	84	77	9	26.6	3823	0.51	2883	0	None
NT52	325	90	84	7	33.2	3932	0.60	2905	0	None

Note:

1. The difference between instrumented Charpy and Dial values was greater than 15%. The values were not adjusted as required by ASTM E2298-18 [12] since this data is not required, but is presented for informational purposes only.

Table 5-8 Instrumented Charpy Impact Test Results for the Prairie Island Unit 2 Capsule N Surveillance Program Weld Material Irradiated to a Fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Specimen ID	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, $(KV-W_t)/KV$ (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Brittle Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
NW36	30	22	19	15	3.4	3973	0.09	3346	3564	461
NW39	50	29	26	10	18.5	3807	0.36	3143	3730	1097
NW38	73	51	47	8	34.7	4083	0.60	3332	3829	952
NW40	100	26	22	15	18.8	3883	0.36	3256	3763	761
NW37	175	69	61	11	33.2	3884	0.60	2957	3319	1563
NW35	225	91	83	8	31.3	3764	0.60	2870	2790	2124
NW33	275	95	87	8	32.1	3819	0.60	2870	0	None
NW34	300	99	91	9	31.4	3761	0.60	2780	0	None

Table 5-9 Instrumented Charpy Impact Test Results for the Prairie Island Unit 2 Capsule N Heat Affected Zone (HAZ) Irradiated to a Fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Specimen ID	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, (KV-W_t)/KV (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Brittle Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
NH39	-25	26	23	10	21.5	4512	0.36	3524	4361	None
NH33	25	33	30	10	20.9	4338	0.36	3647	4148	1529
NH36	30	28	21	24(1)	16.6	4342	0.29	3529	4180	591
NH40	60	64	58	10	36.7	4339	0.60	3426	4034	2612
NH37	90	72	67	7	37.0	4357	0.61	3360	3216	2043
NH34	120	67	62	7	20.0	4228	0.36	3408	2091	1190
NH35	175	85	78	8	24.0	4358	0.44	3304	2553	2091
NH38	275	79	74	7	24.0	4312	0.44	3333	0	None

Note:

1. The difference between instrumented Charpy and Dial values was greater than 15%. The value was not adjusted as required by ASTM E2298-18 [12] since this data is not required, but is presented for informational purposes only.

Table 5-10 Instrumented Charpy Impact Test Results for Prairie Island Unit 2 Capsule N Correlation Monitor Material (CMM) Irradiated to a Fluence of 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Specimen ID	Test Temp (°F)	Total Dial Energy, KV (ft-lb)	Total Instrumented Energy, W_t (ft-lb)	Difference, $(KV-W_t)/KV$ (%)	Energy to Max Load, W_m (ft-lb)	Maximum Load, F_m (lb)	Time to F_m (msec)	General Yield Load, F_{gy} (lb)	Brittle Fracture Load, F_{bf} (lb)	Arrest Load, F_a (lb)
R37	200	16	15	8	9.8	4212	0.19	3638	4086	None
R35	225	27	23	15	15.8	4253	0.29	3365	4155	730
R34	240	12	10	16(1)	9.3	3928	0.19	3324	3809	365
R33	275	37	33	12	15.5	4287	0.30	3353	4062	2158
R36	320	54	49	9	27.4	4158	0.48	3132	3972	2587
R38	375	66	62	7	20.5	4311	0.38	3232	3671	2220
R39	425	84	77	8	24.0	4253	0.44	3280	0	None
R40	450	74	70	6	14.9	4065	0.29	3081	0	None

Note:

1. The difference between instrumented Charpy and Dial values was greater than 15%. The value was not adjusted as required by ASTM E2298-18 [12] since this data is not required, but is presented for informational purposes only.

Table 5-11 Effect of Irradiation to 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV) on the Charpy V-notch Toughness Properties of the Prairie Island Unit 2 Reactor Vessel Surveillance Capsule N Materials

Material	Average 30 ft-lb Transition Temperature(1) (°F)			Average 35 mil Lateral Expansion Temperature(1) (°F)			Average 50 ft-lb Transition Temperature(1) (°F)			Average Energy Absorption ≥ 95% Shear(2) (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Lower Shell Forging D (Heat # 22642) (Tangential Orientation)	-28.3	148.2	176.5	-10.0	169.2	179.2	-6.8	170.7	177.5	147.7	125.0	-22.7
Lower Shell Forging D (Heat # 22642) (Axial Orientation)	-1.2	152.9	154.1	23.0	181.3	158.3	34.6	184.7	150.1	106.2	89.0	-17.2
Surveillance Weld Material (Heat # 2721)	-76.1	59.5	135.6	-47.6	124.8	172.4	-42.1	112.0	154.1	103.3	95.0	-8.3
Heat-Affected Zone (HAZ) Material	-134.6	10.9	145.5	-86.2	58.7	144.9	-98.0	50.4	148.4	114.0	82.0	-32.0
Correlation Monitor Material (CMM)	47.0	259.9	212.9	59.1	330.6	271.5	78.0	310.3	232.3	120.4	79.0	-41.4

Notes:

1. Average value is determined by CVGRAPH (see Appendix C).
2. USE values are a calculated average from unirradiated and Capsule N Charpy test results for specimens that achieved greater than or equal to 95% shear.

Table 5-12 Comparison of the Prairie Island Unit 2 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper-Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions

Material	Capsule	Capsule Fluence (x 10^{19} n/cm^2, E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		Upper-Shelf Energy Decrease	
			Predicted(1) (°F)	Measured(2) (°F)	Predicted(1) (%)	Measured(2) (%)
Lower Shell Forging D (Heat # 22642) (Tangential Orientation)	V	0.598	43.7	33.8	17	0(3)
	T	1.10	52.4	54.4	20	10
	R	4.11	69.5	89.6	26	14
	P	4.27	69.9	99.6	27	13
	N	8.41	76.0	176.5	32	15
Lower Shell Forging D (Heat # 22642) (Axial Orientation)	V	0.598	43.7	35.0	17	0(3)
	T	1.10	52.4	27.9	20	13
	R	4.11	69.5	84.3	26	7
	P	4.27	69.9	103.5	27	11
	N	8.41	76.0	154.1	32	16
Surveillance Weld Material (Heat # 2721)	V	0.598	44.2	69.3	20	6
	T	1.10	53.0	57.7	23	8
	R	4.11	70.3	100.3	31	12
	P	4.27	70.7	96.2	32	5
	N	8.41	76.9	135.6	37	8
Heat Affected Zone (HAZ)	V	0.598	---	42.9	---	0(3)
	T	1.10	---	48.9	---	13
	R	4.11	---	127.6	---	23
	P	4.27	---	81.2	---	16
	N	8.41	---	145.5	---	28
Correlation Monitor Material (CMM)	V	0.598	109.6	123.5	20	15
	T	1.10	131.1	158.0	23	27
	R	4.11	174.3	183.2	32	36
	P	4.27	175.4	196.8	33	20
	N	8.41	190.8	212.9	38	34

Notes:
1. Based on Regulatory Guide 1.99, Revision 2 [1], methodology using the capsule fluence and best-estimate weight percent values of copper and nickel of the surveillance material. For the predicted USE decrease determinations, the Cu weight percentages were conservatively rounded up to the lowest line (Cu weight % of 0.10 for base metal and 0.05 for weld metal) in Regulatory Guide 1.99, Revision 2, Figure 2. Also note that for Capsule N, the fluence value is slightly beyond the scale in Figure 2; therefore, the predicted USE was extrapolated from the available data in the figure.
2. Calculated using measured Charpy data (See Appendix C).
3. Physically, an increase in USE should not occur after irradiation. Therefore, a conservative 0% decrease value is shown here instead of the measured increase.

Table 5-13 Tensile Test Properties of the Prairie Island Unit 2 Capsule N Reactor Vessel Surveillance Materials Irradiated to 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

Material	Specimen ID	Test Temp (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Strength (ksi)	Fracture True Stress (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
Lower Shell Forging D (Heat # 22642) (Tangential)	NL13	78	91.1	106.5	3.5	71.3	210	10.4	22.7	66.1
	NL14	300	82.1	98.2	3.3	67.2	195	10.1	21.6	65.6
	NL15	550	76.9	98.3	3.4	70.3	178	7.9	18.5	60.4
Lower Shell Forging D (Heat # 22642) (Axial)	NT13	78	93.0	108.2	3.7	77.4	202	9.6	20.7	61.6
	NT 14	300	78.7	98.2	3.6	73.9	173	6.9	14.9(1)	57.1
	NT 15	550	82.5	101.7	3.8	78.5	170	7.8	16.7	53.7
Surveillance Weld (Heat # 2721)	NW13	78	100.2	109.3	4.0	82.7	205	8.3	19.0	59.7
	NW14	300	80.7	92.4	2.9	60.9	204	5.9	18.6	70.1
	NW15	550	77.2	94.0	3.4	70.1	179	8.8	19.0	60.9

Note:

1. Elongation at fracture value is low compared to the elongation after fracture for that specimen. May be an indication of the specimen gauge slipping.

Lower Shell Forging D (Tangential)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 7/12/2022 12:37 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	SA508CL3	Tangential	22642
2	Prairie Island 2	V	SA508CL3	Tangential	22642
3	Prairie Island 2	T	SA508CL3	Tangential	22642
4	Prairie Island 2	R	SA508CL3	Tangential	22642
5	Prairie Island 2	P	SA508CL3	Tangential	22642
6	Prairie Island 2	N	SA508CL3	Tangential	22642

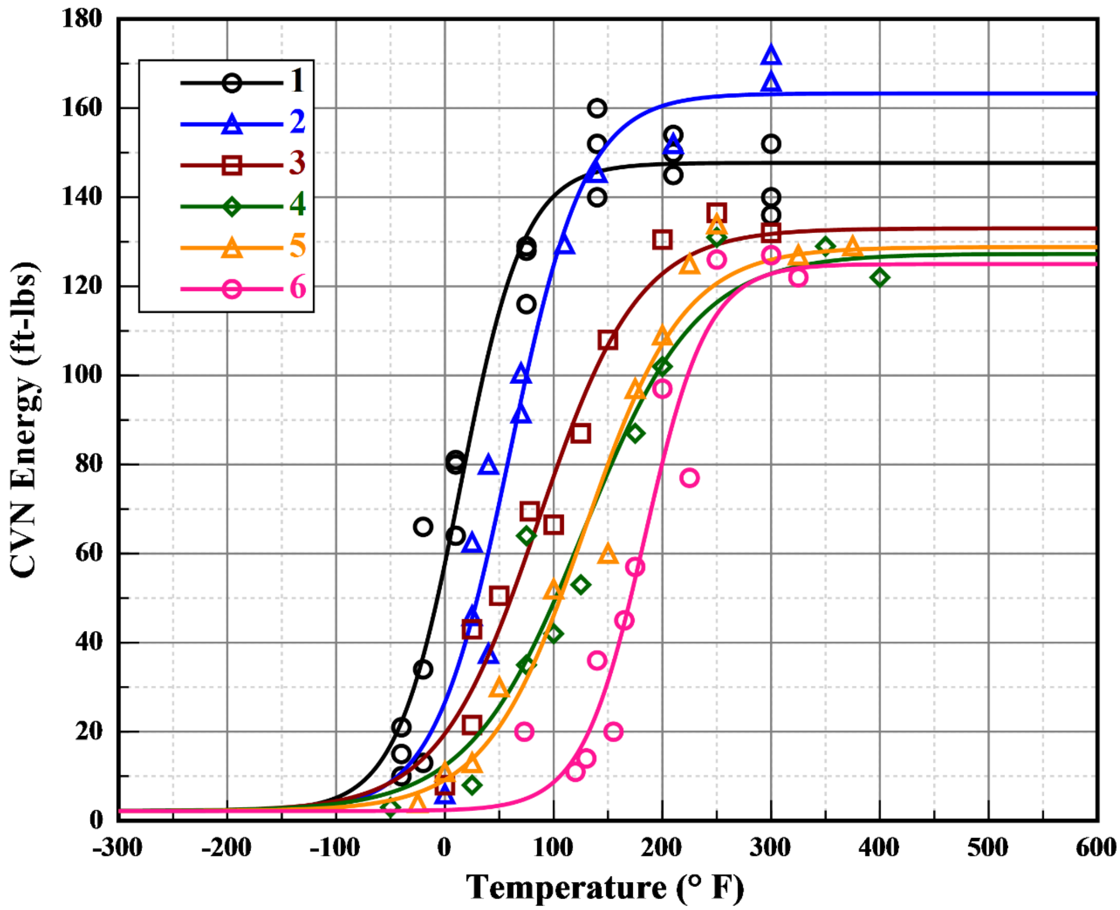


Figure 5-1 Charpy V-notch Impact Energy vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Tangential Orientation)

Lower Shell Forging D (Tangential)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 7/12/2022 12:37 PM

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	0.00E+000	2.2	147.7	0	-28.3	0	-6.8	0
2	5.98E+018	2.2	163.3	15.6	5.5	33.8	29.9	36.7
3	1.10E+019	2.2	133	-14.7	26.1	54.4	61	67.8
4	4.11E+019	2.2	127.3	-20.4	61.3	89.6	101.8	108.6
5	4.27E+019	2.2	128.8	-18.9	71.3	99.6	106.1	112.9
6	8.41E+019	2.2	125	-22.7	148.2	176.5	170.7	177.5

Figure 5-1 Charpy V-notch Impact Energy vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Tangential Orientation) (cont.)

Lower Shell Forging D (Tangential)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 7/12/2022 12:40 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	SA508CL3	Tangential	22642
2	Prairie Island 2	V	SA508CL3	Tangential	22642
3	Prairie Island 2	T	SA508CL3	Tangential	22642
4	Prairie Island 2	R	SA508CL3	Tangential	22642
5	Prairie Island 2	P	SA508CL3	Tangential	22642
6	Prairie Island 2	N	SA508CL3	Tangential	22642

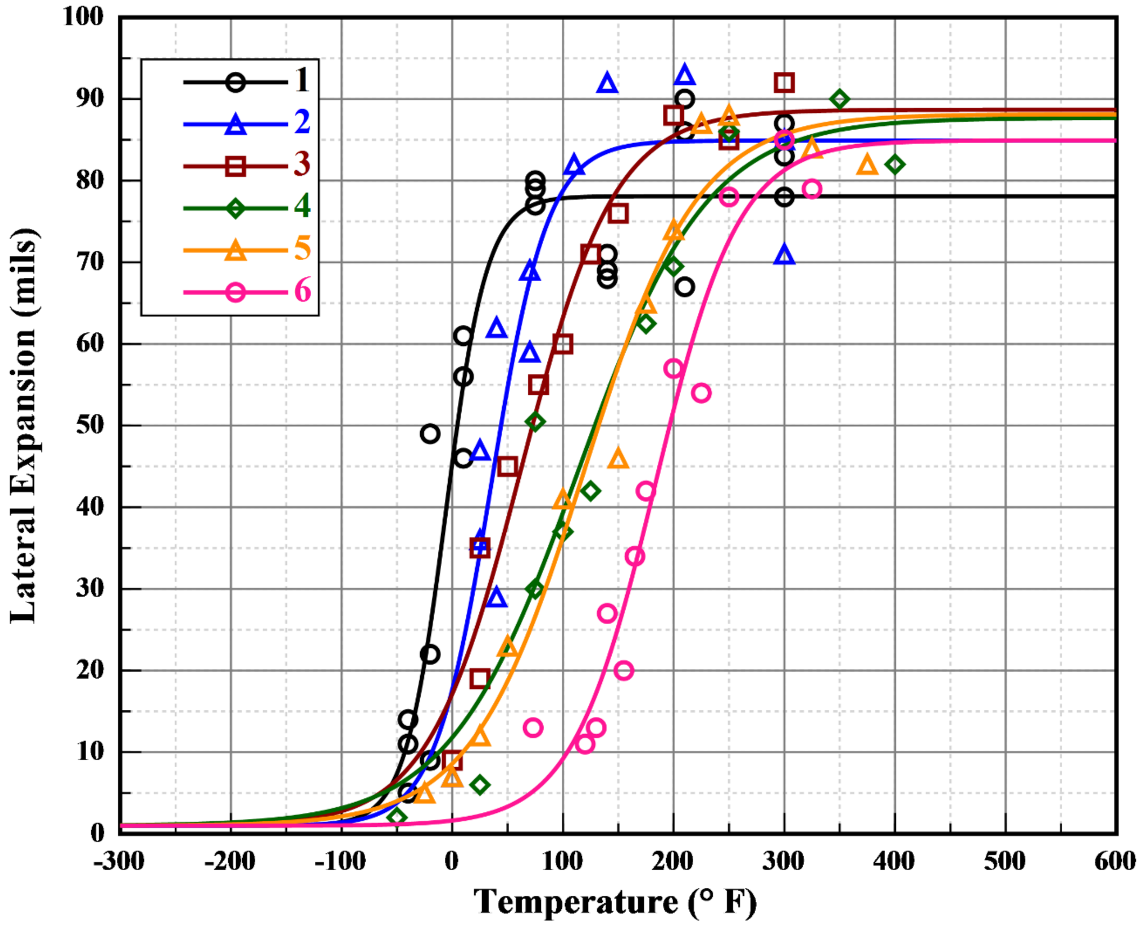


Figure 5-2 Charpy V-notch Lateral Expansion vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Tangential Orientation)

Lower Shell Forging D (Tangential)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 7/12/2022 12:40 PM

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	0.00E+000	1	78.1	0	-10	0
2	5.98E+018	1	84.9	6.80	25.7	35.7
3	1.10E+019	1	88.69	10.59	43.3	53.3
4	4.11E+019	1	87.68	9.58	88	98
5	4.27E+019	1	88.11	10.01	96.7	106.7
6	8.41E+019	1	84.93	6.83	169.2	179.2

Figure 5-2 Charpy V-notch Lateral Expansion vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Tangential Orientation) (cont.)

Lower Shell Forging D (Tangential)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 10:19 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	SA508CL3	Tangential	22642
2	Prairie Island 2	V	SA508CL3	Tangential	22642
3	Prairie Island 2	T	SA508CL3	Tangential	22642
4	Prairie Island 2	R	SA508CL3	Tangential	22642
5	Prairie Island 2	P	SA508CL3	Tangential	22642
6	Prairie Island 2	N	SA508CL3	Tangential	22642

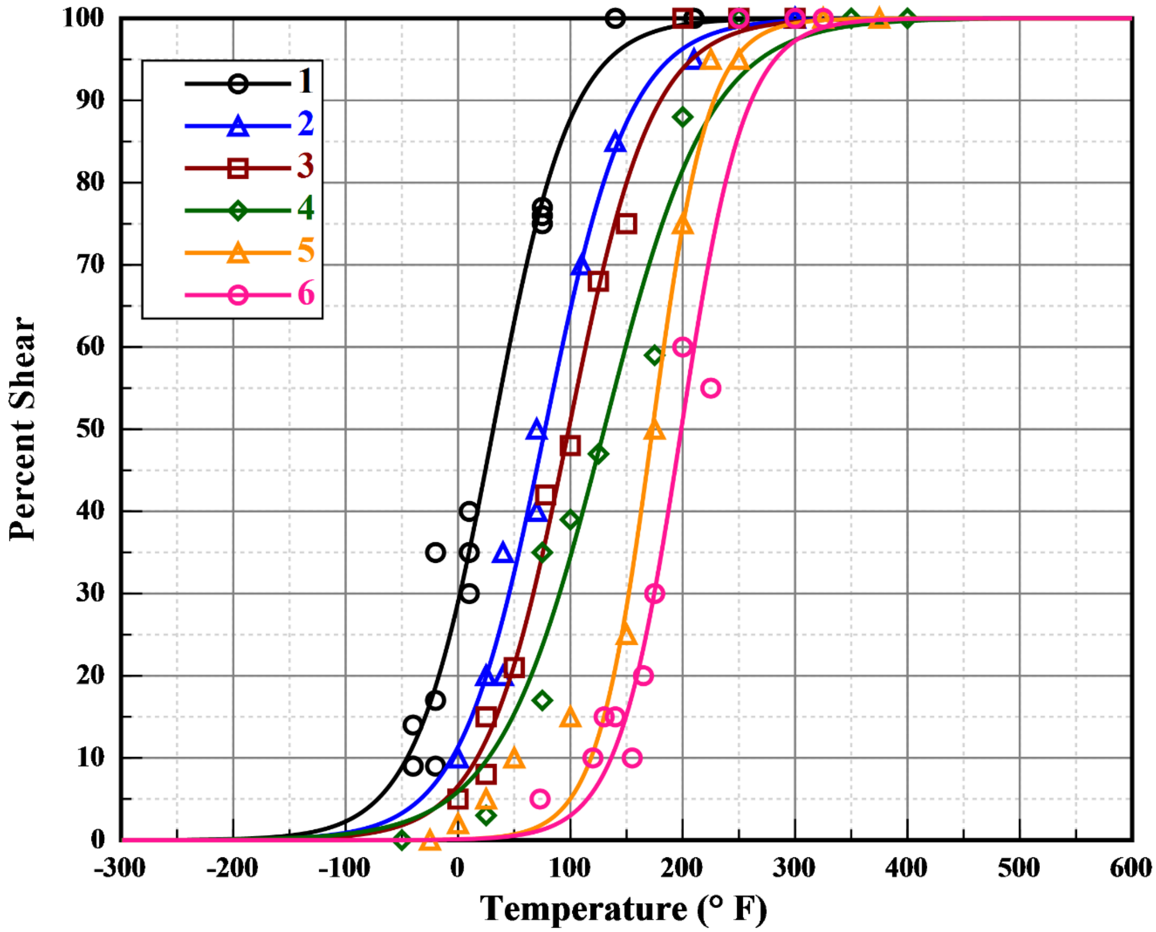


Figure 5-3 Charpy V-notch Percent Shear vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Tangential Orientation)

Lower Shell Forging D (Tangential)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 10:19 AM

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	0.00E+000	0	100	0	31.4	0
2	5.98E+018	0	100	0	77.4	46
3	1.10E+019	0	100	0	98.6	67.2
4	4.11E+019	0	100	0	130.2	98.8
5	4.27E+019	0	100	0	173.1	141.7
6	8.41E+019	0	100	0	198.7	167.3

Figure 5-3 Charpy V-notch Percent Shear vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Tangential Orientation) (cont.)

Lower Shell Forging D (Axial)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 9/21/2022 8:24 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	SA508CL3	Axial	22642
2	Prairie Island 2	V	SA508CL3	Axial	22642
3	Prairie Island 2	T	SA508CL3	Axial	22642
4	Prairie Island 2	R	SA508CL3	Axial	22642
5	Prairie Island 2	P	SA508CL3	Axial	22642
6	Prairie Island 2	N	SA508CL3	Axial	22642

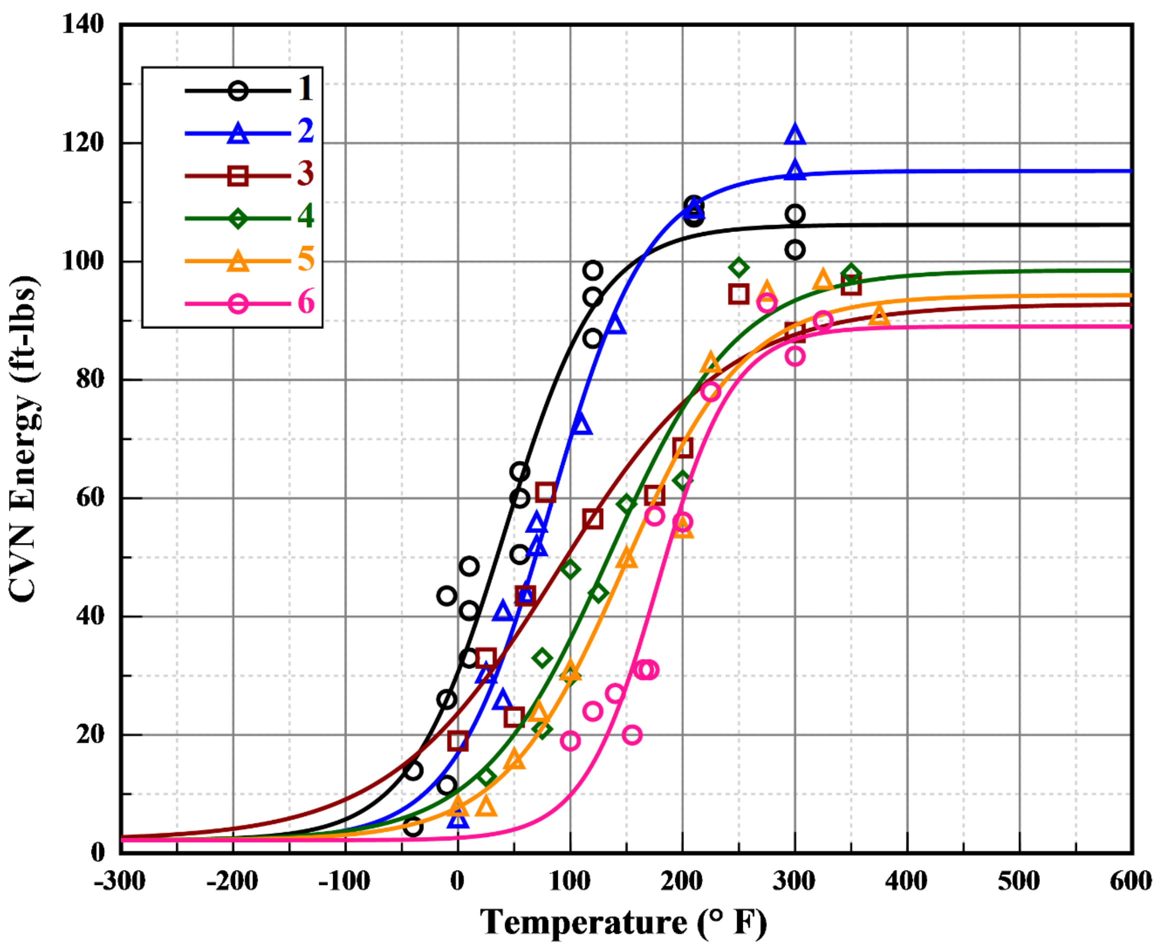


Figure 5-4 Charpy V-notch Impact Energy vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Axial Orientation)

Lower Shell Forging D (Axial)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 9/21/2022 8:24 PM

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	0.00E+000	2.2	106.2	0	-1.2	0	34.6	0
2	5.98E+018	2.2	115.3	9.10	33.8	35	68.9	34.3
3	1.10E+019	2.2	92.8	-13.4	26.7	27.9	96.5	61.9
4	4.11E+019	2.2	98.5	-7.7	83.1	84.3	133.9	99.3
5	4.27E+019	2.2	94.3	-11.9	102.3	103.5	151.5	116.9
6	8.41E+019	2.2	89	-17.2	152.9	154.1	184.7	150.1

Figure 5-4 Charpy V-notch Impact Energy vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Axial Orientation) (cont.)

Lower Shell Forging D (Axial)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 7/12/2022 1:09 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	SA508CL3	Axial	22642
2	Prairie Island 2	V	SA508CL3	Axial	22642
3	Prairie Island 2	T	SA508CL3	Axial	22642
4	Prairie Island 2	R	SA508CL3	Axial	22642
5	Prairie Island 2	P	SA508CL3	Axial	22642
6	Prairie Island 2	N	SA508CL3	Axial	22642

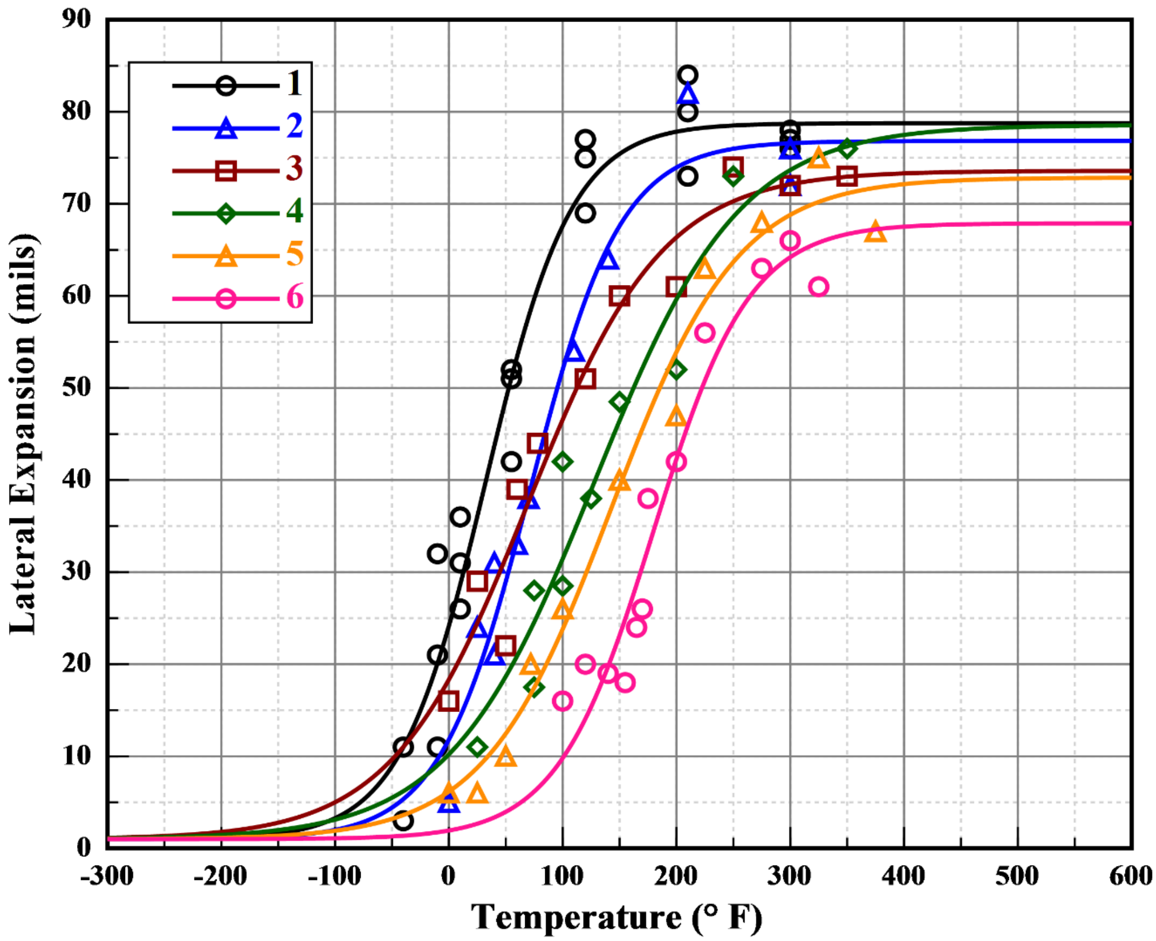


Figure 5-5 Charpy V-notch Lateral Expansion vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Axial Orientation)

Lower Shell Forging D (Axial)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 7/12/2022 1:09 PM

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	0.00E+000	1	78.76	0	23	0
2	5.98E+018	1	76.82	-1.94	63.2	40.2
3	1.10E+019	1	73.59	-5.17	61.5	38.5
4	4.11E+019	1	78.56	-0.20	112.1	89.1
5	4.27E+019	1	72.85	-5.91	136.8	113.8
6	8.41E+019	1	67.88	-10.88	181.3	158.3

Figure 5-5 Charpy V-notch Lateral Expansion vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Axial Orientation) (cont.)

Lower Shell Forging D (Axial)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 9/27/2022 5:31 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	SA508CL3	Axial	22642
2	Prairie Island 2	V	SA508CL3	Axial	22642
3	Prairie Island 2	T	SA508CL3	Axial	22642
4	Prairie Island 2	R	SA508CL3	Axial	22642
5	Prairie Island 2	P	SA508CL3	Axial	22642
6	Prairie Island 2	N	SA508CL3	Axial	22642

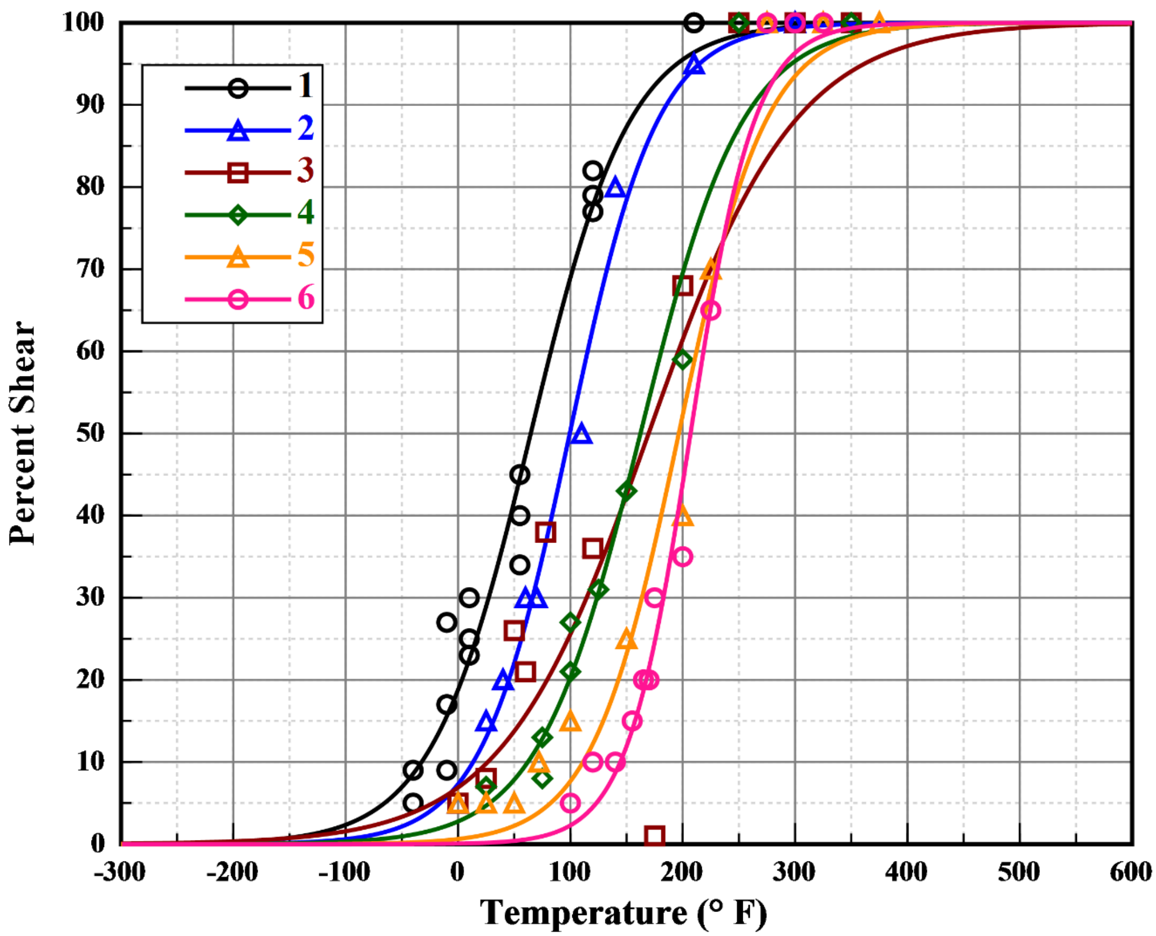


Figure 5-6 Charpy V-notch Percent Shear vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Axial Orientation)

Lower Shell Forging D (Axial)

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 9/27/2022 5:31 AM

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	0.00E+000	0	100	0	64.7	0
2	5.98E+018	0	100	0	99.5	34.8
3	1.10E+019	0	100	0	169.7	105
4	4.11E+019	0	100	0	162.4	97.7
5	4.27E+019	0	100	0	196.5	131.8
6	8.41E+019	0	100	0	207	142.3

Figure 5-6 Charpy V-notch Percent Shear vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Lower Shell Forging D (Heat # 22642) (Axial Orientation) (cont.)

Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 7/12/2022 1:15 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	Weld	NA	2721
2	Prairie Island 2	V	Weld	NA	2721
3	Prairie Island 2	T	Weld	NA	2721
4	Prairie Island 2	R	Weld	NA	2721
5	Prairie Island 2	P	Weld	NA	2721
6	Prairie Island 2	N	Weld	NA	2721

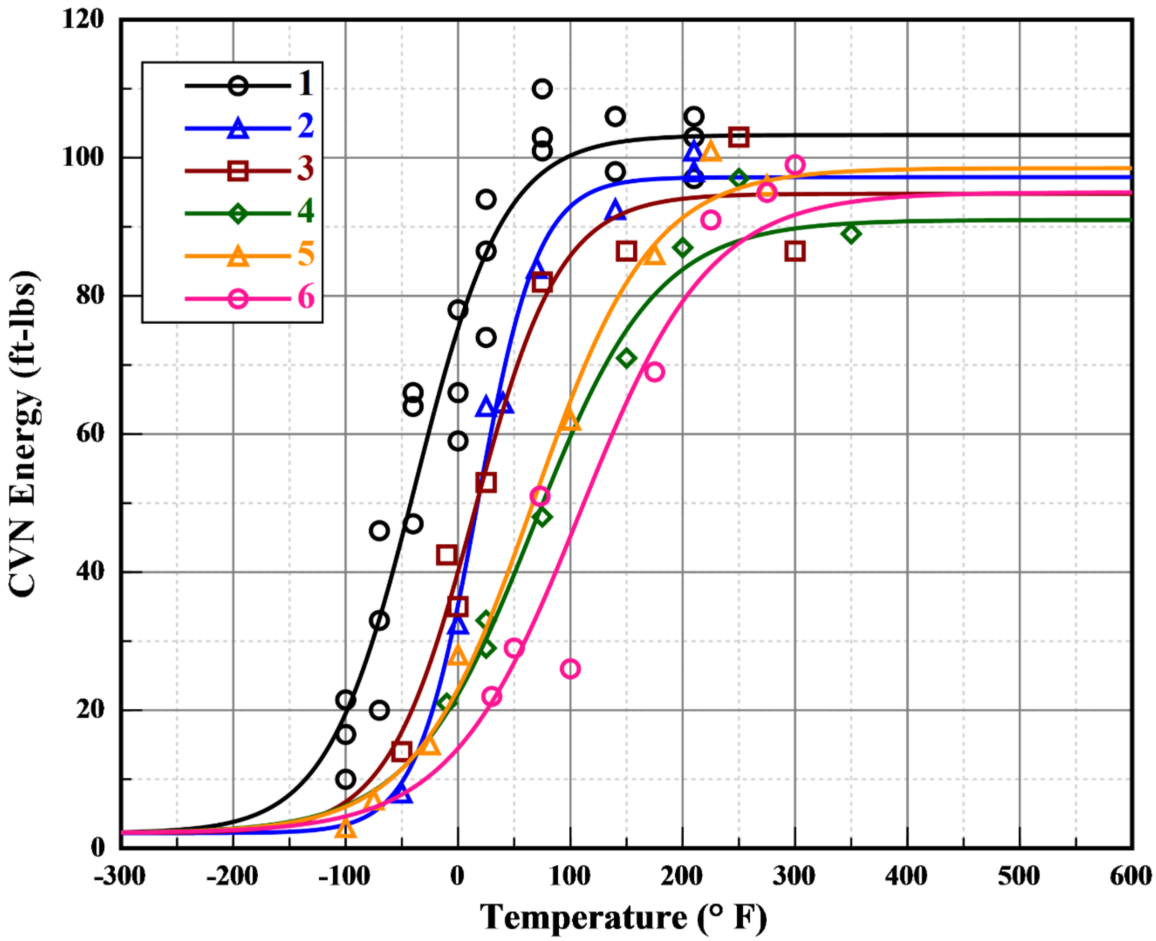


Figure 5-7 Charpy V-notch Impact Energy vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Weld Material

Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 7/12/2022 1:15 PM

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	0.00E+000	2.2	103.3	0	-76.1	0	-42.1	0
2	5.98E+018	2.2	97.2	-6.10	-6.8	69.3	17.4	59.5
3	1.10E+019	2.2	94.8	-8.5	-18.4	57.7	16.7	58.8
4	4.11E+019	2.2	91	-12.3	24.2	100.3	75.5	117.6
5	4.27E+019	2.2	98.5	-4.8	20.1	96.2	66.7	108.8
6	8.41E+019	2.2	95	-8.3	59.5	135.6	112	154.1

Figure 5-7 Charpy V-notch Impact Energy vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Weld Material (cont.)

Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 7/12/2022 1:18 PM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	Weld	NA	2721
2	Prairie Island 2	V	Weld	NA	2721
3	Prairie Island 2	T	Weld	NA	2721
4	Prairie Island 2	R	Weld	NA	2721
5	Prairie Island 2	P	Weld	NA	2721
6	Prairie Island 2	N	Weld	NA	2721

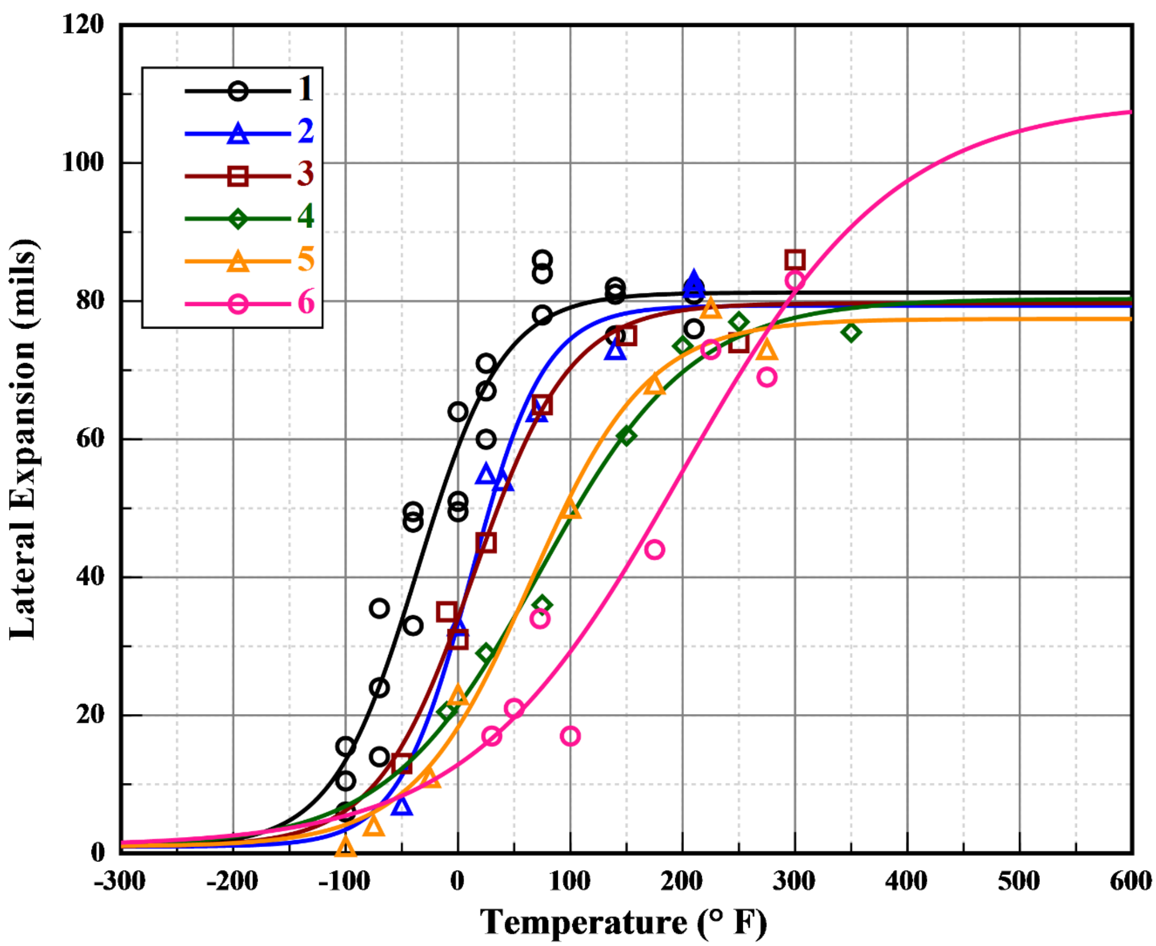


Figure 5-8 Charpy V-notch Lateral Expansion vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Weld Material

Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 7/12/2022 1:18 PM

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	0.00E+000	1	81.24	0	-47.6	0
2	5.98E+018	1	79.34	-1.90	2.9	50.5
3	1.10E+019	1	79.7	-1.54	2.1	49.7
4	4.11E+019	1	80.33	-0.91	52.9	100.5
5	4.27E+019	1	77.42	-3.82	52.8	100.4
6	8.41E+019	1	108.98	27.74	124.8	172.4

Figure 5-8 Charpy V-notch Lateral Expansion vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Weld Material (cont.)

Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 9:21 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	Weld	NA	2721
2	Prairie Island 2	V	Weld	NA	2721
3	Prairie Island 2	T	Weld	NA	2721
4	Prairie Island 2	R	Weld	NA	2721
5	Prairie Island 2	P	Weld	NA	2721
6	Prairie Island 2	N	Weld	NA	2721

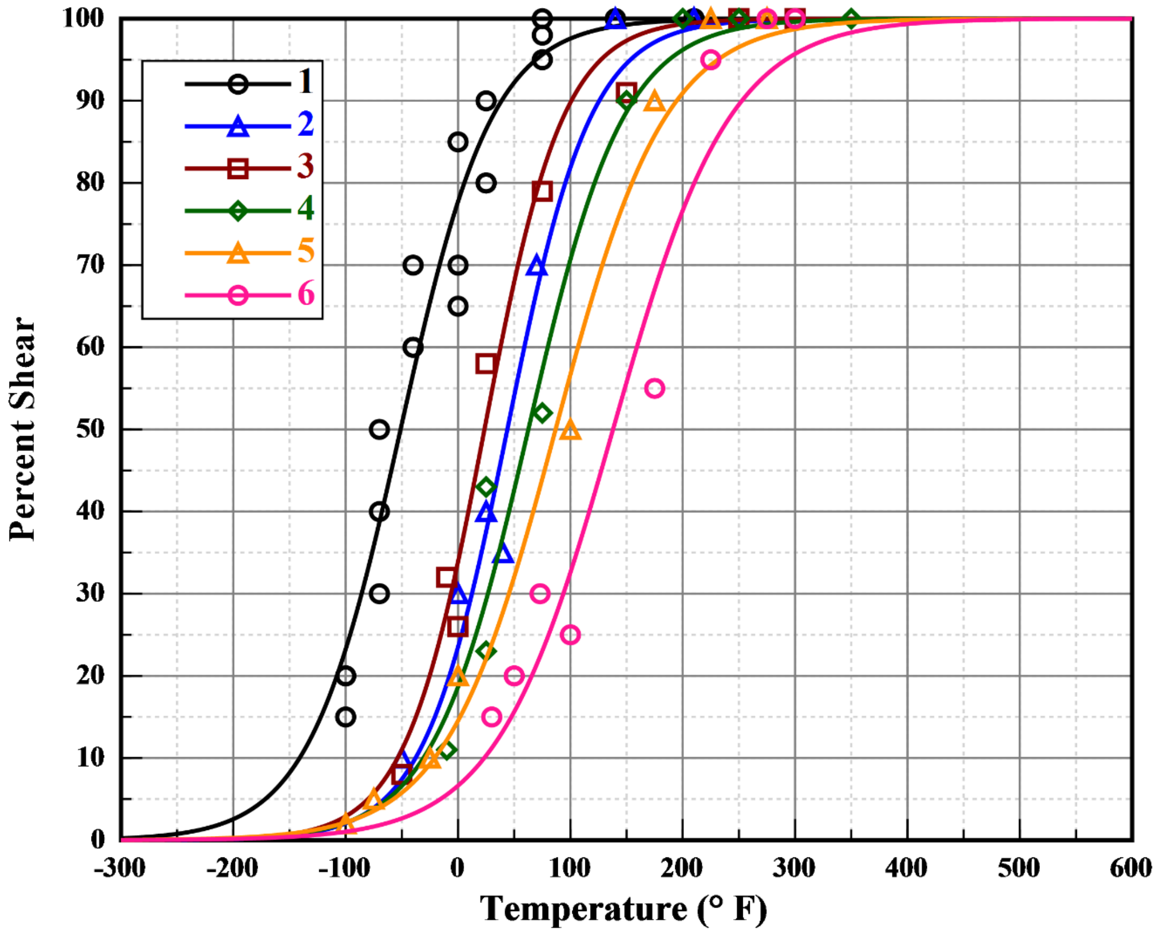


Figure 5-9 Charpy V-notch Percent Shear vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Weld Material

Weld Metal

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 9:21 AM

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	0.00E+000	0	100	0	-51.1	0
2	5.98E+018	0	100	0	43.9	95
3	1.10E+019	0	100	0	23.6	74.7
4	4.11E+019	0	100	0	62.6	113.7
5	4.27E+019	0	100	0	86.9	138
6	8.41E+019	0	100	0	138	189.1

Figure 5-9 Charpy V-notch Percent Shear vs. Temperature for Prairie Island Unit 2 Reactor Vessel Surveillance Program Weld Material (cont.)

Heat Affected Zone

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 9:27 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	SA508CL3	NA	22642
2	Prairie Island 2	V	SA508CL3	NA	22642
3	Prairie Island 2	T	SA508CL3	NA	22642
4	Prairie Island 2	R	SA508CL3	NA	22642
5	Prairie Island 2	P	SA508CL3	NA	22642
6	Prairie Island 2	N	SA508CL3	NA	22642

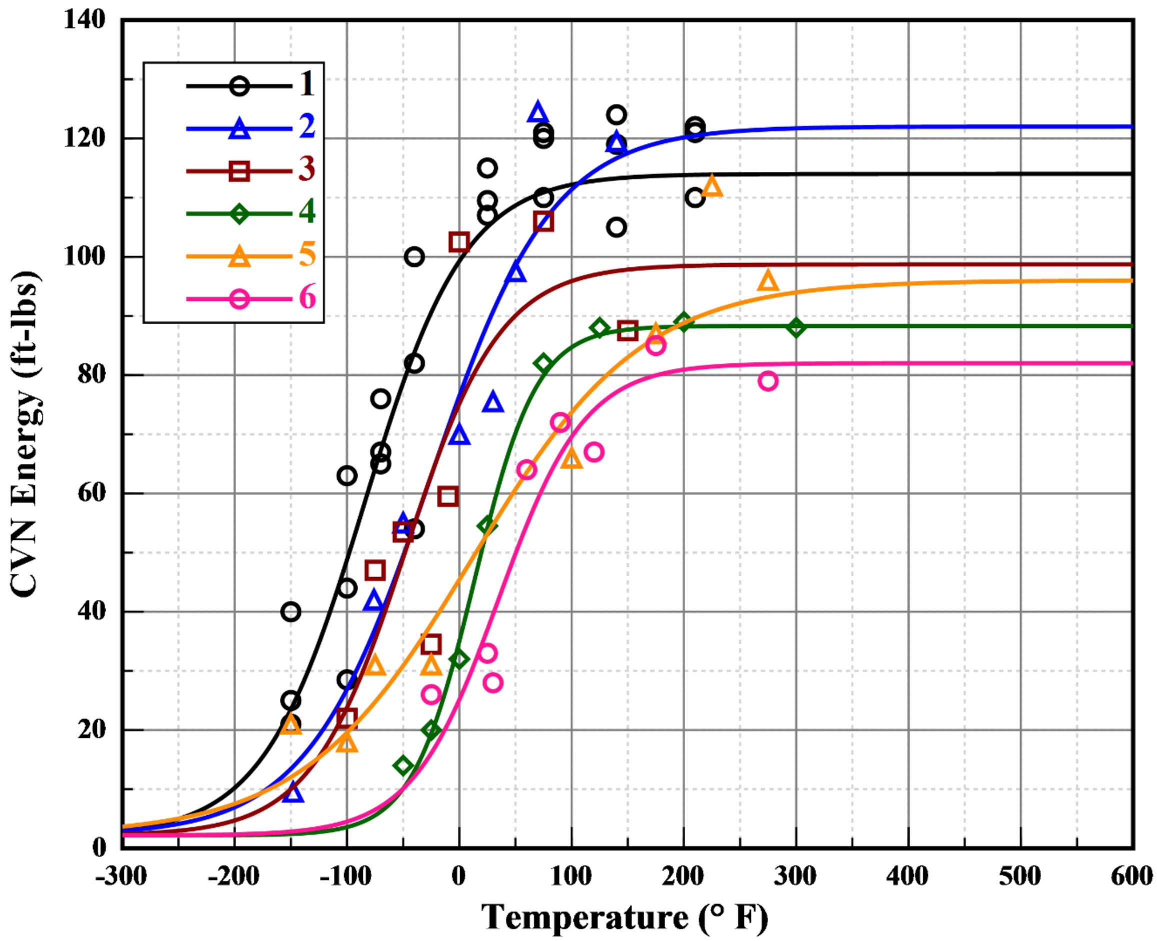


Figure 5-10 Charpy V-notch Impact Energy vs. Temperature for Prairie Island Unit 2 Reactor Vessel Heat-Affected Zone Material

Heat Affected Zone

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 9:27 AM

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	0.00E+000	2.2	114	0	-134.6	0	-98	0
2	5.98E+018	2.2	122	8	-91.7	42.9	-48.9	49.1
3	1.10E+019	2.2	98.7	-15.3	-85.7	48.9	-48.4	49.6
4	4.11E+019	2.2	88.3	-25.7	-7	127.6	19.6	117.6
5	4.27E+019	2.2	96	-18	-53.4	81.2	14.8	112.8
6	8.41E+019	2.2	82	-32	10.9	145.5	50.4	148.4

Figure 5-10 Charpy V-notch Impact Energy vs. Temperature for Prairie Island Unit 2 Reactor Vessel Heat-Affected Zone Material (cont.)

Heat Affected Zone

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 11/8/2022 9:37 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	SA508CL3	NA	22642
2	Prairie Island 2	V	SA508CL3	NA	22642
3	Prairie Island 2	T	SA508CL3	NA	22642
4	Prairie Island 2	R	SA508CL3	NA	22642
5	Prairie Island 2	P	SA508CL3	NA	22642
6	Prairie Island 2	N	SA508CL3	NA	22642

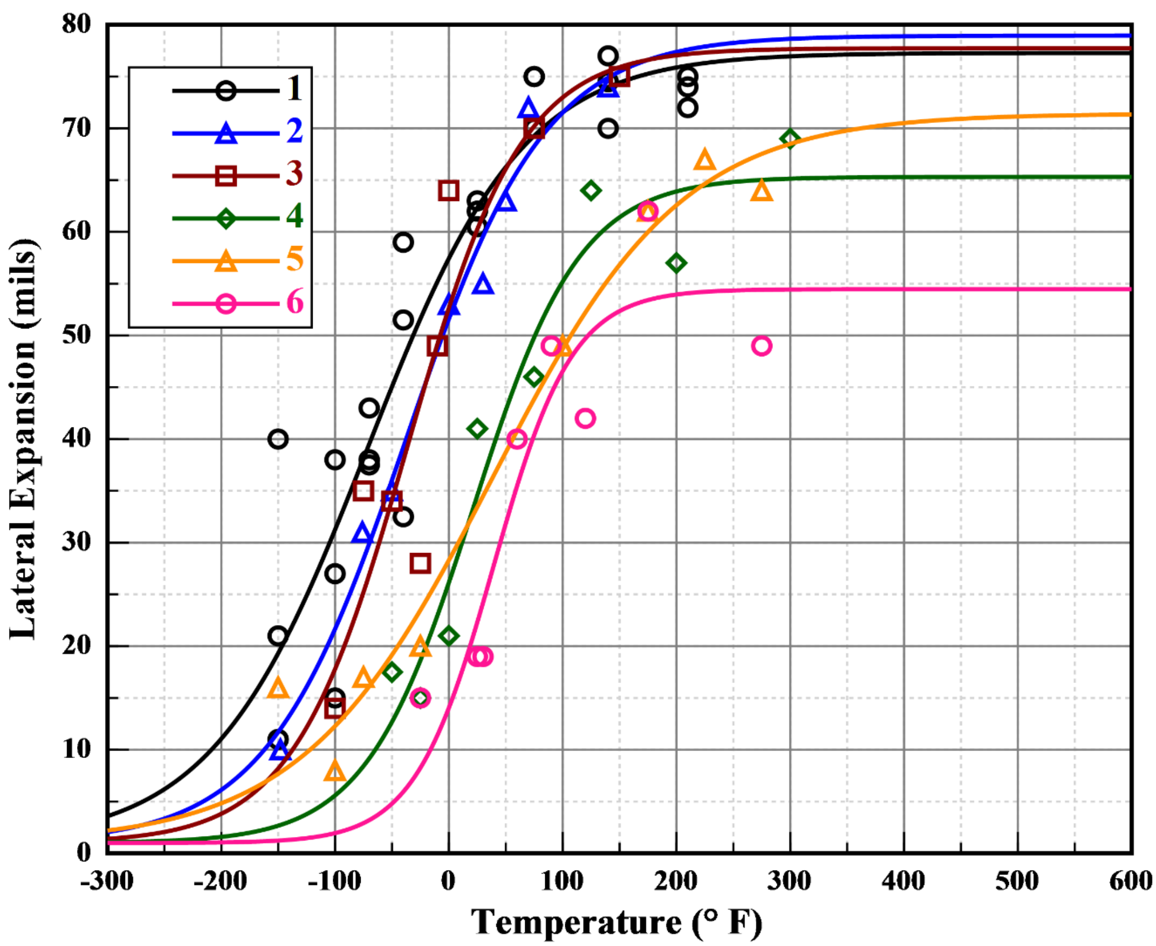


Figure 5-11 Charpy V-notch Lateral Expansion vs. Temperature for Prairie Island Unit 2 Reactor Vessel Heat-Affected Zone Material

Heat Affected Zone

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 11/8/2022 9:37 AM

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	0.00E+000	1	77.28	0	-86.2	0
2	5.98E+018	1	78.95	1.67	-53.2	33
3	1.10E+019	1	77.73	0.45	-47.6	38.6
4	4.11E+019	1	65.31	-11.97	26.4	112.6
5	4.27E+019	1	71.42	-5.86	32.5	118.7
6	8.41E+019	1	54.47	-22.81	58.7	144.9

Figure 5-11 Charpy V-notch Lateral Expansion vs. Temperature for Prairie Island Unit 2 Reactor Vessel Heat-Affected Zone Material (cont.)

Heat Affected Zone

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 11/8/2022 9:36 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	SA508CL3	NA	22642
2	Prairie Island 2	V	SA508CL3	NA	22642
3	Prairie Island 2	T	SA508CL3	NA	22642
4	Prairie Island 2	R	SA508CL3	NA	22642
5	Prairie Island 2	P	SA508CL3	NA	22642
6	Prairie Island 2	N	SA508CL3	NA	22642

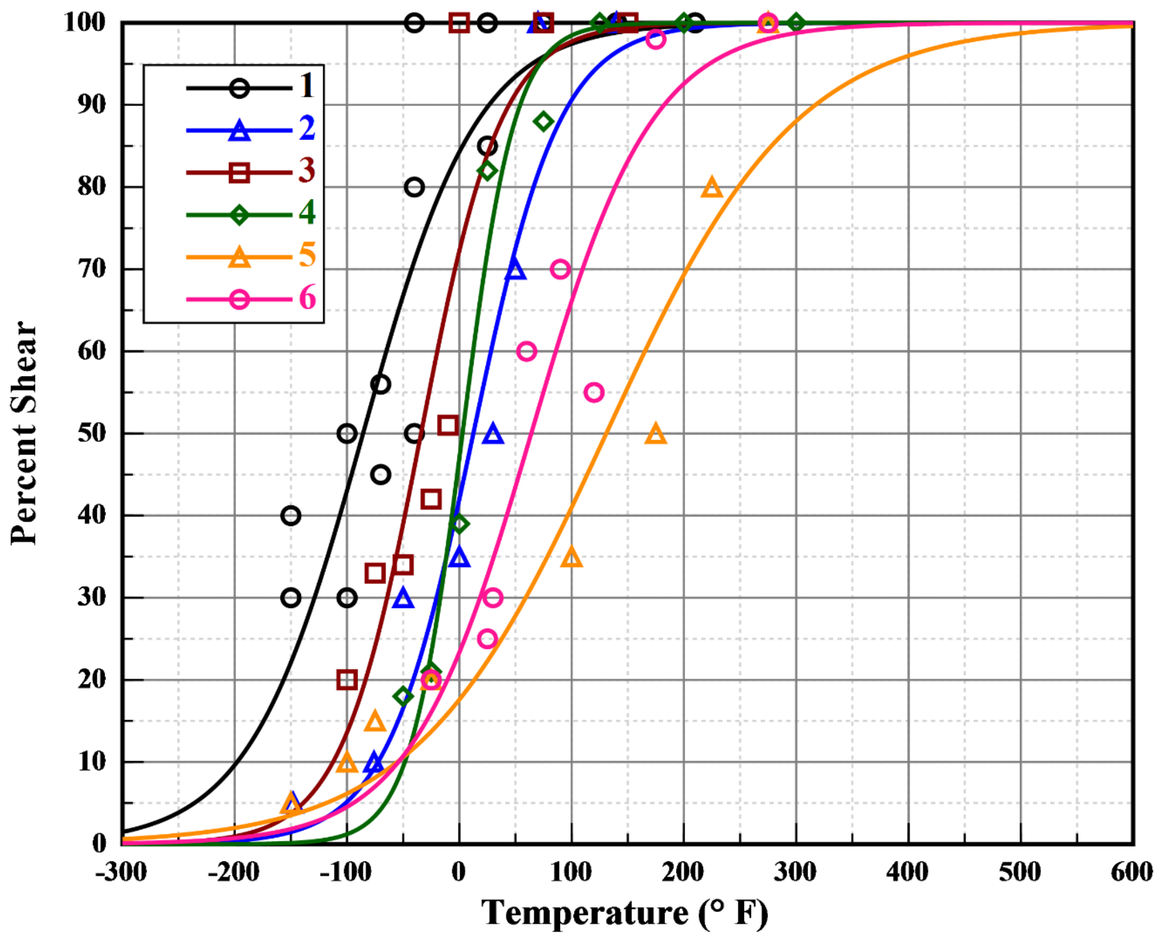


Figure 5-12 Charpy V-notch Percent Shear vs. Temperature for Prairie Island Unit 2 Reactor Vessel Heat-Affected Zone Material

Heat Affected Zone

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 11/8/2022 9:36 AM

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	0.00E+000	0	100	0	-85.7	0
2	5.98E+018	0	100	0	12.5	98.2
3	1.10E+019	0	100	0	-34	51.7
4	4.11E+019	0	100	0	2.9	88.6
5	4.27E+019	0	100	0	130.9	216.6
6	8.41E+019	0	100	0	64.1	149.8

Figure 5-12 Charpy V-notch Percent Shear vs. Temperature for Prairie Island Unit 2 Reactor Vessel Heat-Affected Zone Material (cont.)

Correlation Monitor Material

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 9:48 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	A533B1	NA	HSST 02
2	Prairie Island 2	V	A533B1	NA	HSST 02
3	Prairie Island 2	T	A533B1	NA	HSST 02
4	Prairie Island 2	R	A533B1	NA	HSST 02
5	Prairie Island 2	P	A533B1	NA	HSST 02
6	Prairie Island 2	N	A533B1	NA	HSST 02

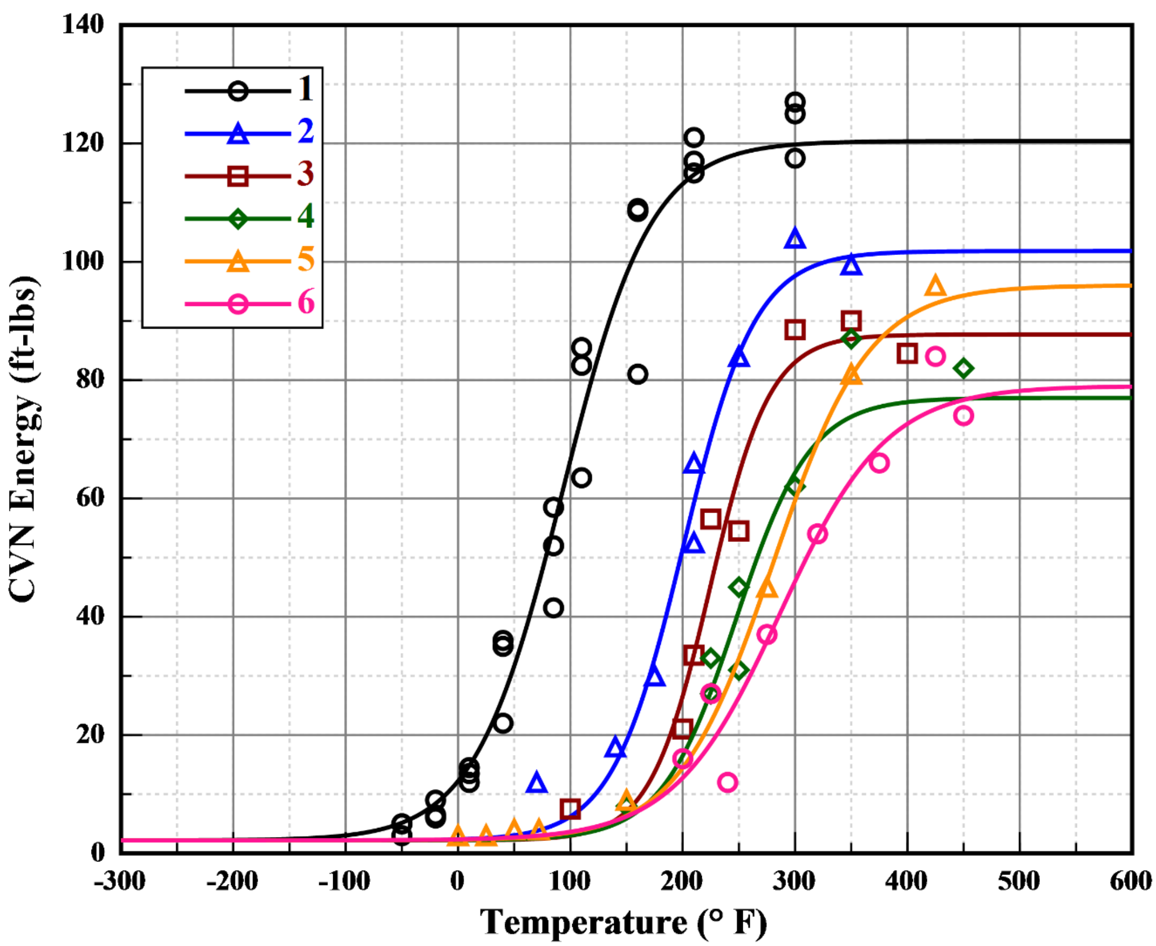


Figure 5-13 Charpy V-notch Impact Energy vs. Temperature for Prairie Island Unit 2 Reactor Vessel Correlation Monitor Material

Correlation Monitor Material

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 9:48 AM

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	0.00E+000	2.2	120.4	0	47	0	78	0
2	5.98E+018	2.2	101.8	-18.6	170.5	123.5	198.1	120.1
3	1.10E+019	2.2	87.7	-32.7	205	158	230.7	152.7
4	4.11E+019	2.2	77	-43.4	230.2	183.2	266.4	188.4
5	4.27E+019	2.2	96	-24.4	243.8	196.8	282.2	204.2
6	8.41E+019	2.2	79	-41.4	259.9	212.9	310.3	232.3

Figure 5-13 Charpy V-notch Impact Energy vs. Temperature for Prairie Island Unit 2 Reactor Vessel Correlation Monitor Material (cont.)

Correlation Monitor Material

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 9:51 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	A533B1	NA	HSST 02
2	Prairie Island 2	V	A533B1	NA	HSST 02
3	Prairie Island 2	T	A533B1	NA	HSST 02
4	Prairie Island 2	R	A533B1	NA	HSST 02
5	Prairie Island 2	P	A533B1	NA	HSST 02
6	Prairie Island 2	N	A533B1	NA	HSST 02

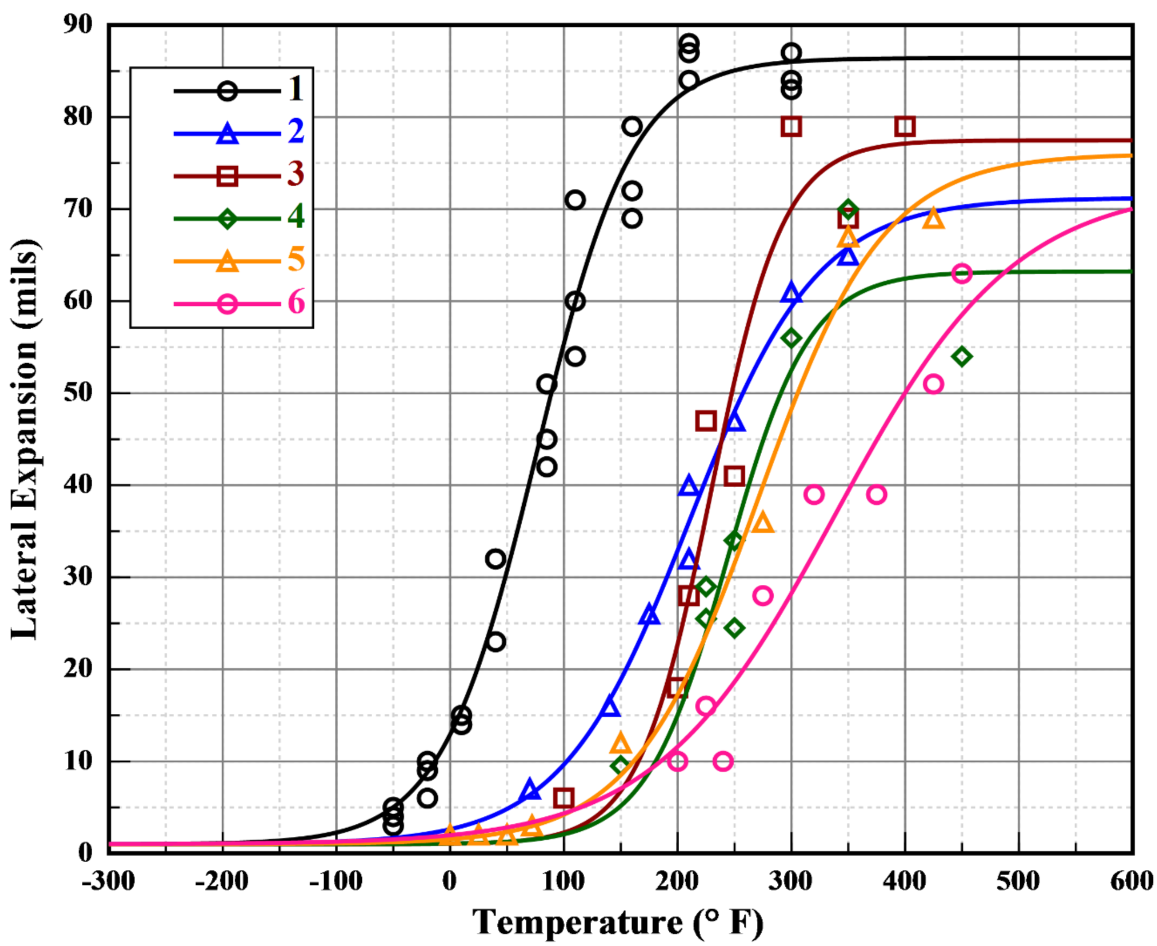


Figure 5-14 Charpy V-notch Lateral Expansion vs. Temperature for Prairie Island Unit 2 Reactor Vessel Correlation Monitor Material

Correlation Monitor Material

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 9:51 AM

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	0.00E+000	1	86.42	0	59.1	0
2	5.98E+018	1	71.21	-15.21	206.8	147.7
3	1.10E+019	1	77.47	-8.95	222.3	163.2
4	4.11E+019	1	63.23	-23.19	250.7	191.6
5	4.27E+019	1	76.02	-10.4	260.5	201.4
6	8.41E+019	1	72.57	-13.85	330.6	271.5

Figure 5-14 Charpy V-notch Lateral Expansion vs. Temperature for Prairie Island Unit 2 Reactor Vessel Correlation Monitor Material (cont.)

Correlation Monitor Material

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 9:55 AM

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Prairie Island 2	Unirrad	A533B1	NA	HSST 02
2	Prairie Island 2	V	A533B1	NA	HSST 02
3	Prairie Island 2	T	A533B1	NA	HSST 02
4	Prairie Island 2	R	A533B1	NA	HSST 02
5	Prairie Island 2	P	A533B1	NA	HSST 02
6	Prairie Island 2	N	A533B1	NA	HSST 02

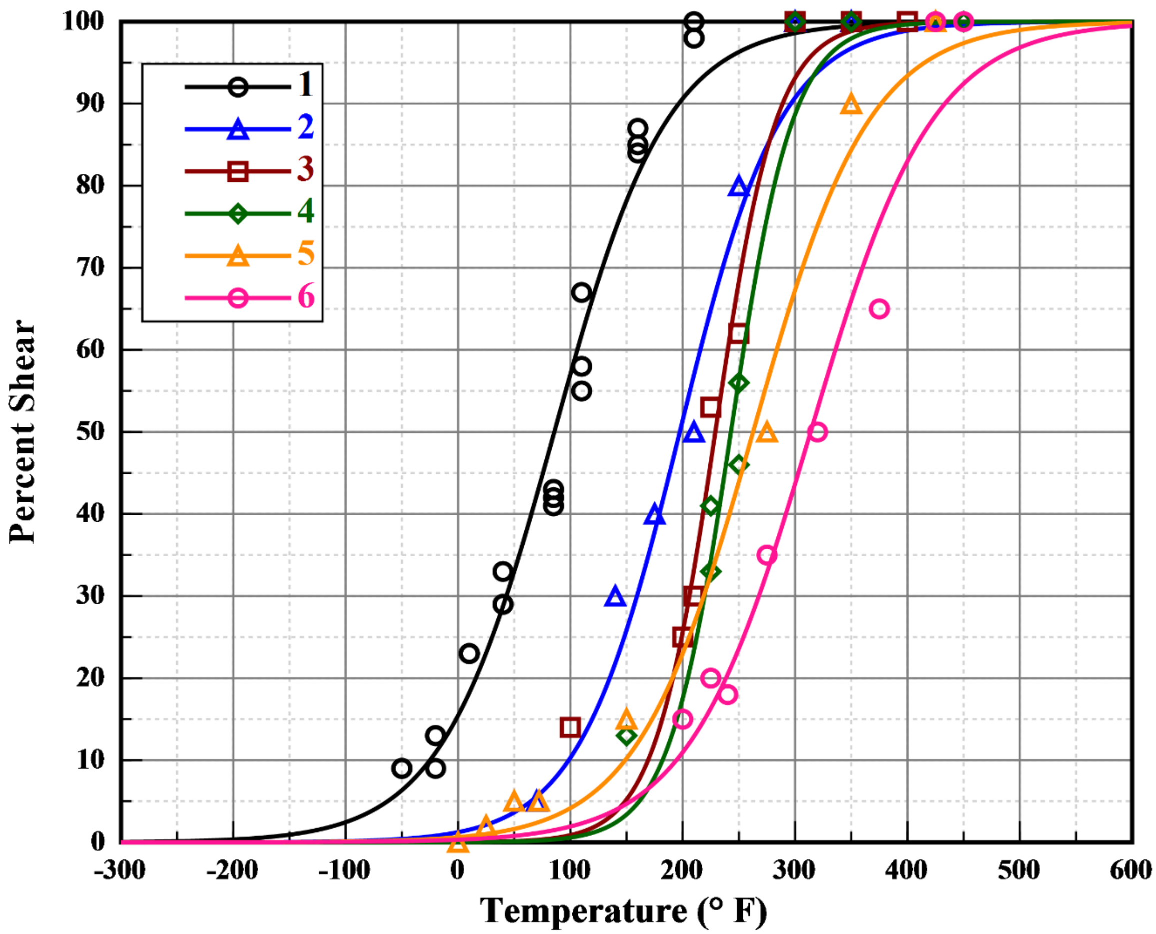


Figure 5-15 Charpy V-notch Percent Shear vs. Temperature for Prairie Island Unit 2 Reactor Vessel Correlation Monitor Material

Correlation Monitor Material

CVGraph 6.02: Hyperbolic Tangent Curve Printed on 8/23/2022 9:55 AM

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	0.00E+000	0	100	0	85.7	0
2	5.98E+018	0	100	0	197.4	111.7
3	1.10E+019	0	100	0	229.1	143.4
4	4.11E+019	0	100	0	242.9	157.2
5	4.27E+019	0	100	0	262.6	176.9
6	8.41E+019	0	100	0	313.9	228.2

Figure 5-15 Charpy V-notch Percent Shear vs. Temperature for Prairie Island Unit 2 Reactor Vessel Correlation Monitor Material (cont.)

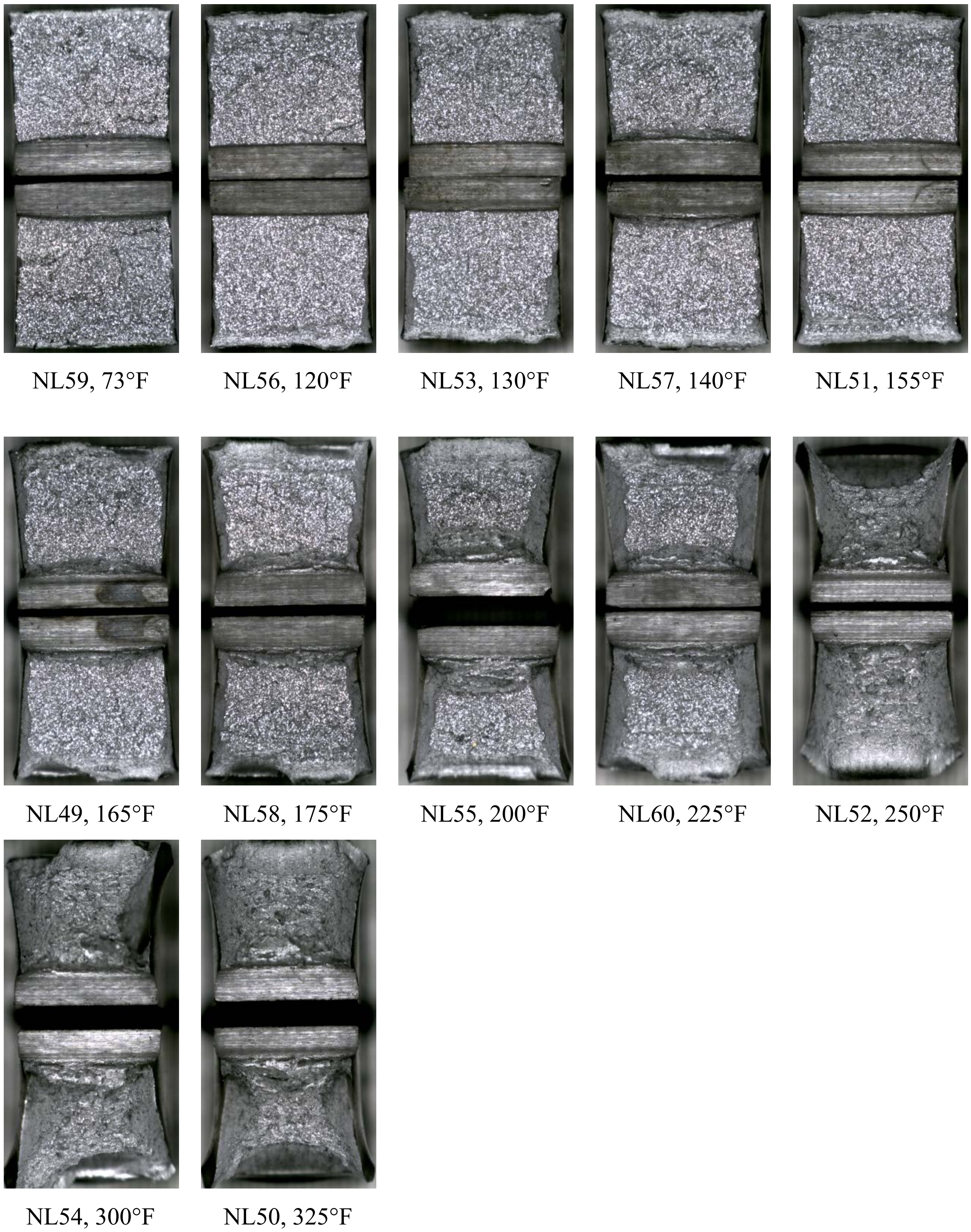


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Prairie Island Unit 2 Capsule N Lower Shell Forging D (Heat # 22642) (Tangential Orientation)


NT54, 100°F


NT56, 120°F


NT49, 140°F


NT59 155°F


NT58, 165°F


NT53, 170°F


NT60, 175°F


NT57, 200°F


NT55, 225°F

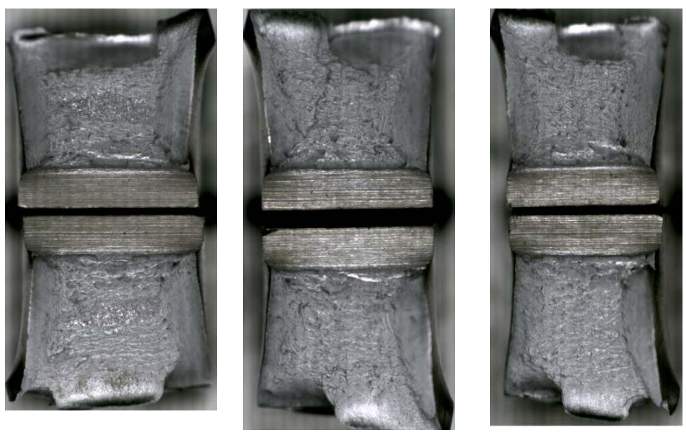

NT51, 275°F


NT50, 300°F


NT52, 325°F

Figure 5-17 Charpy Impact Specimen Fracture Surfaces for Prairie Island Unit 2 Capsule N Lower Shell Forging D (Heat # 22642) (Axial Orientation)

NW36, 30°F NW39, 50°F NW38, 73°F NW40, 100°F NW37, 175°F



NW35, 225°F NW33, 275°F NW34, 300°F

Figure 5-18 Charpy Impact Specimen Fracture Surfaces for the Prairie Island Unit 2 Capsule N Weld Material

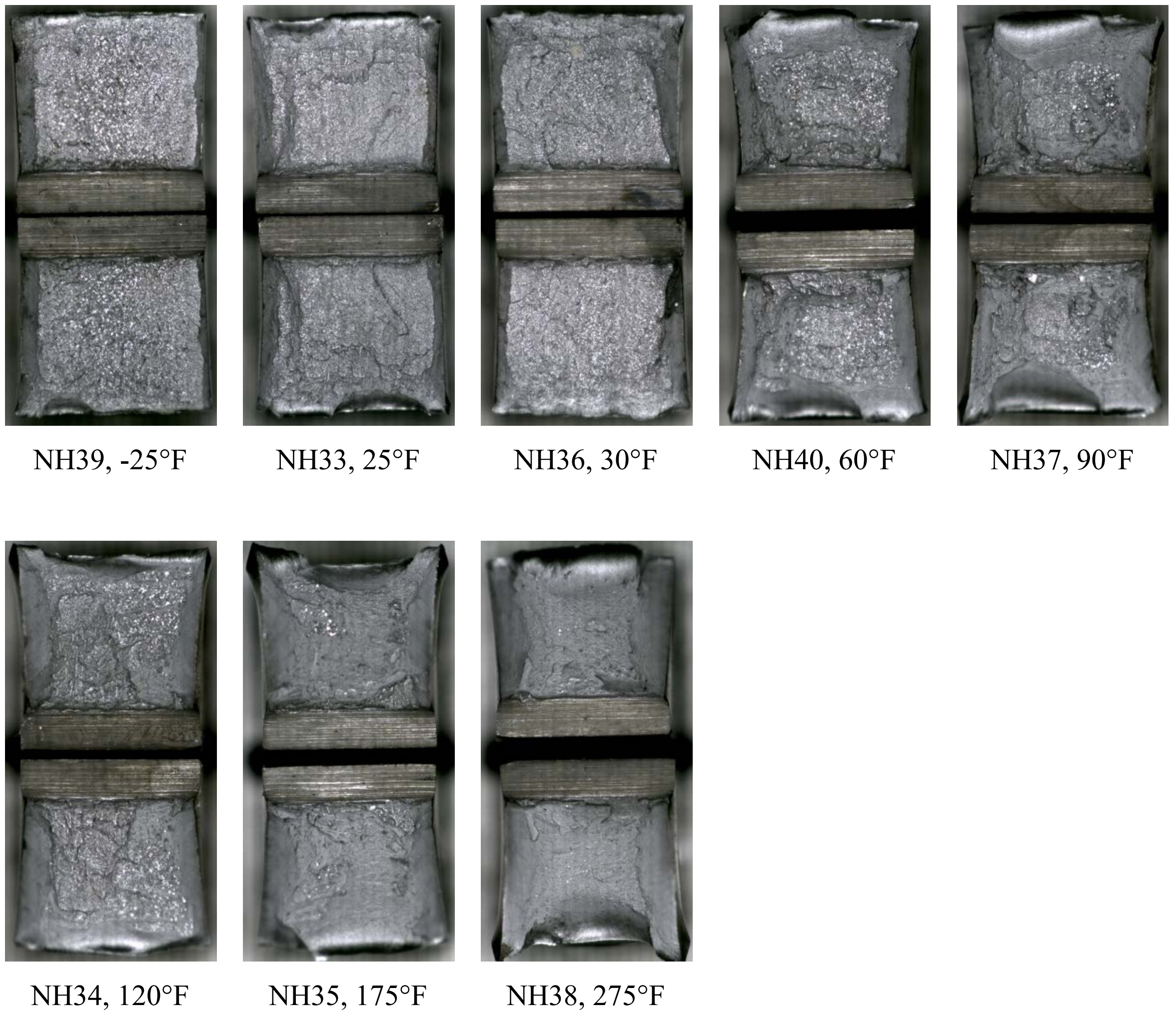
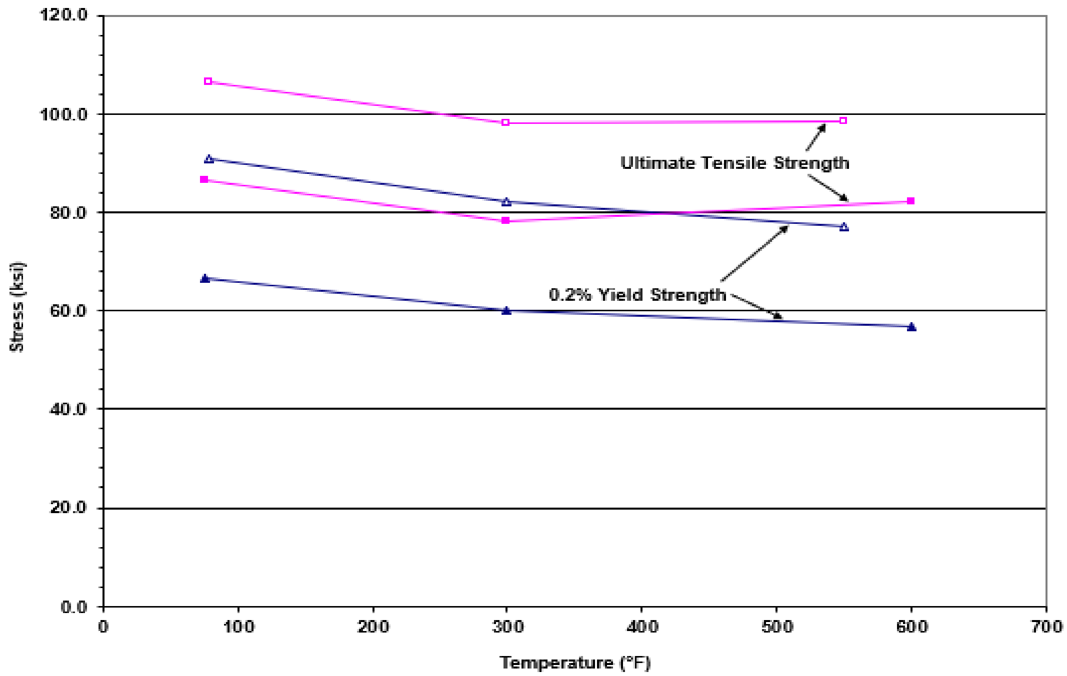


Figure 5-19 Charpy Impact Specimen Fracture Surfaces for the Prairie Island Unit 2 Capsule N Heat-Affected Zone (HAZ) Material

Figure 5-20 Charpy Impact Specimen Fracture Surfaces of the Prairie Island Unit 2 Capsule N Correlation Monitor Material (CMM)



Legend: ▲, ●, and ■ are unirradiated
Δ, ○, and □ are irradiated to 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

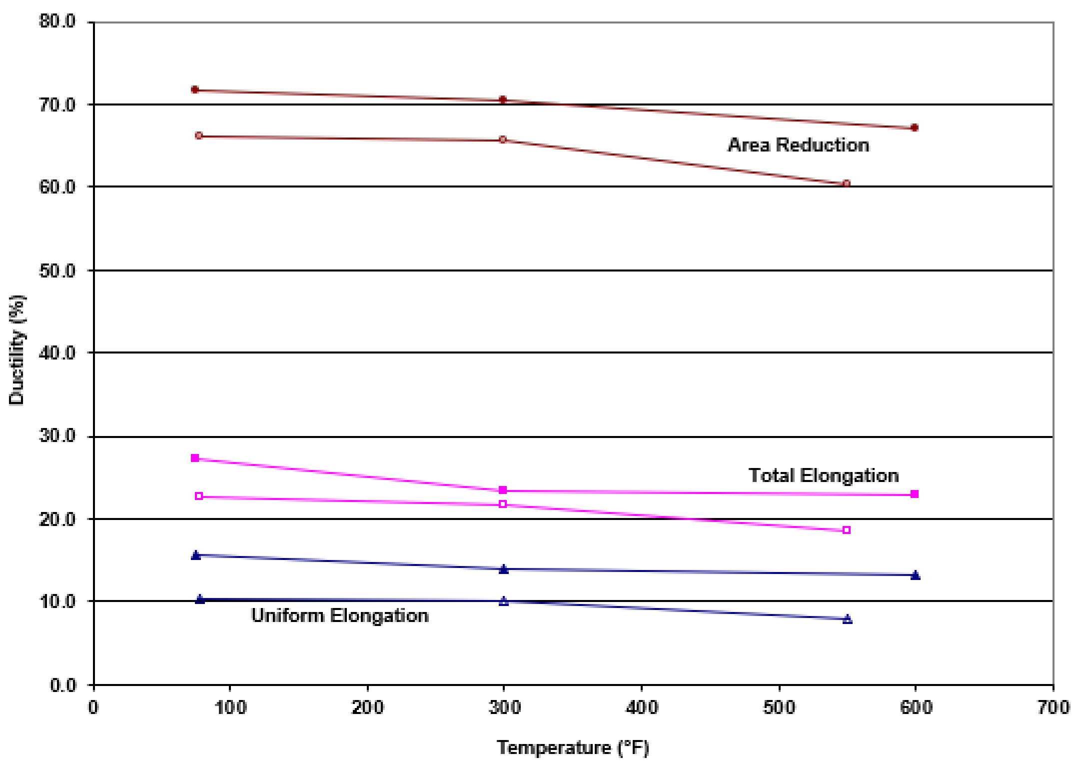
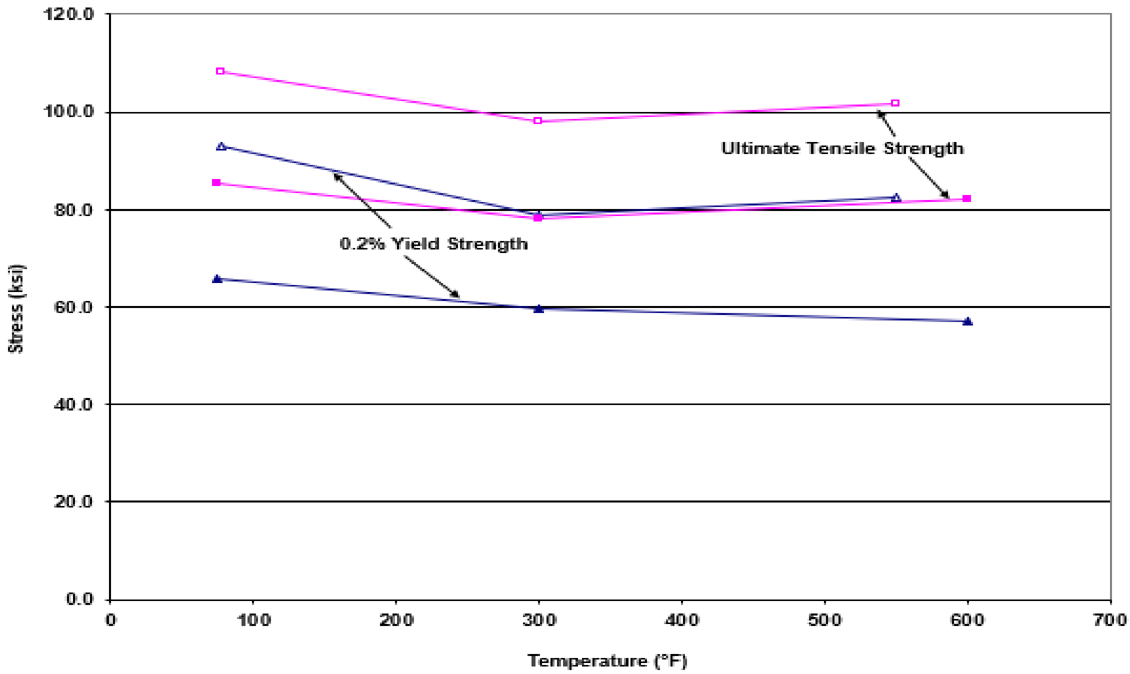


Figure 5-21 Tensile Properties for Prairie Island Unit 2 Reactor Vessel Lower Shell Forging D (Heat # 22642) (Tangential Orientation)



Legend: ▲, ●, and ■ are unirradiated
Δ, ○, and □ are irradiated to 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

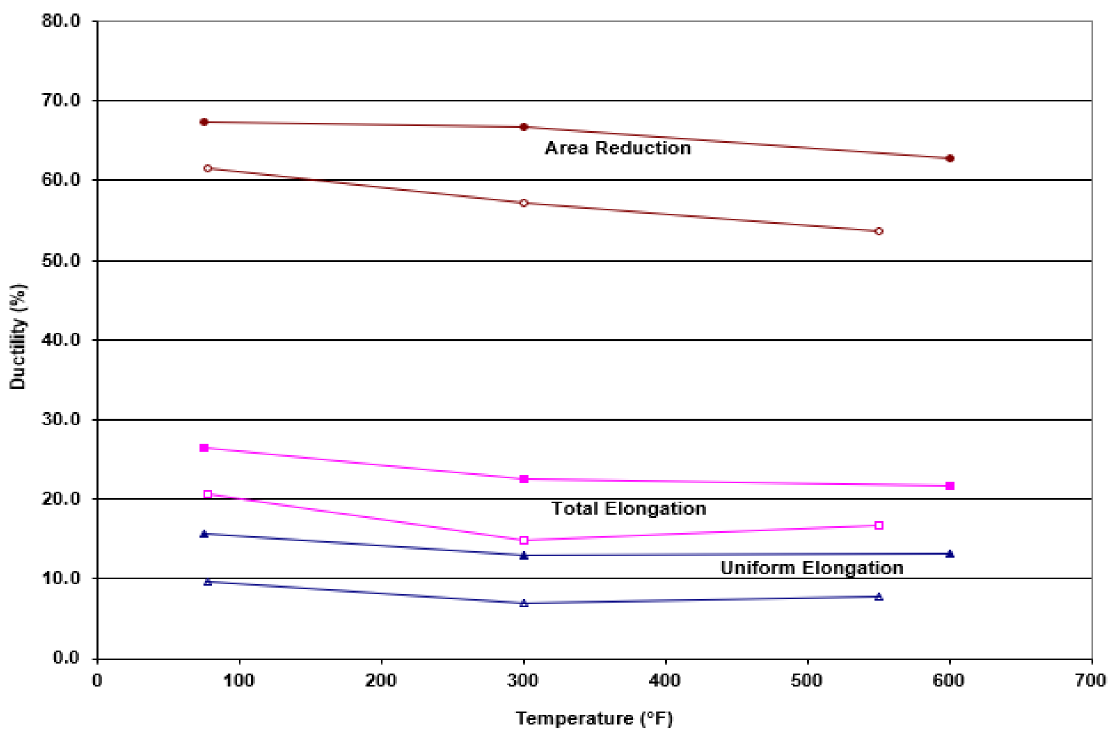
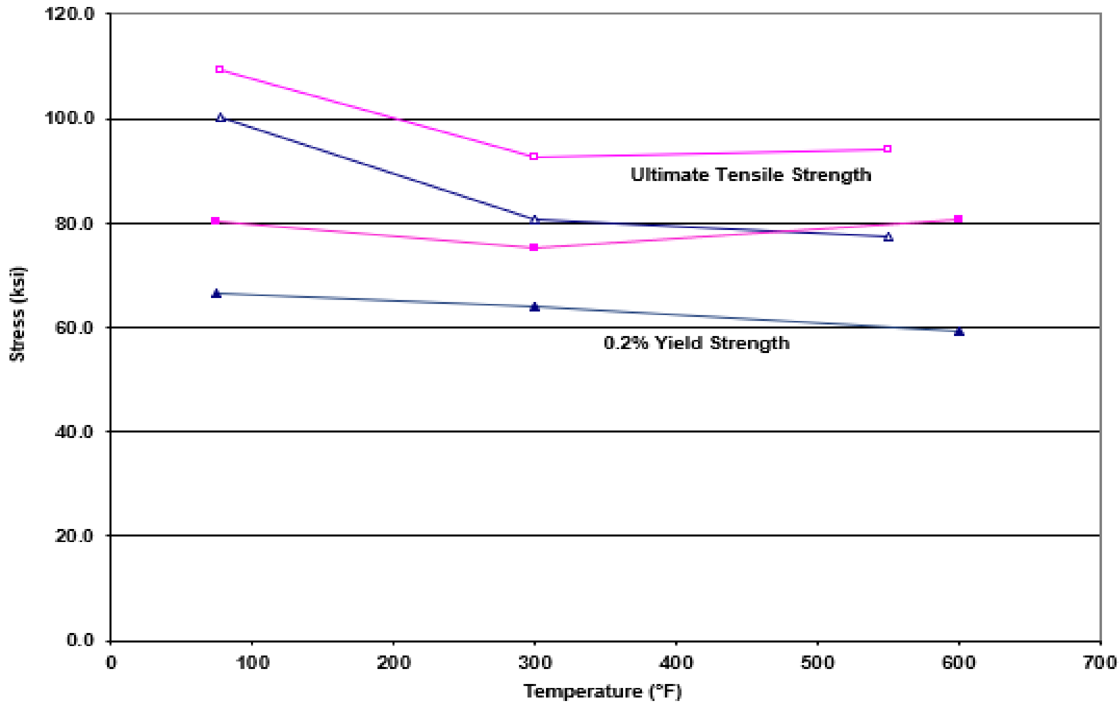


Figure 5-22 Tensile Properties for Prairie Island Unit 2 Reactor Vessel Lower Shell Forging D (Heat # 22642) (Axial Orientation)



Legend: ▲, ●, and ■ are unirradiated
Δ, ○, and □ are irradiated to 8.41 x 10^{19} n/cm^2 (E > 1.0 MeV)

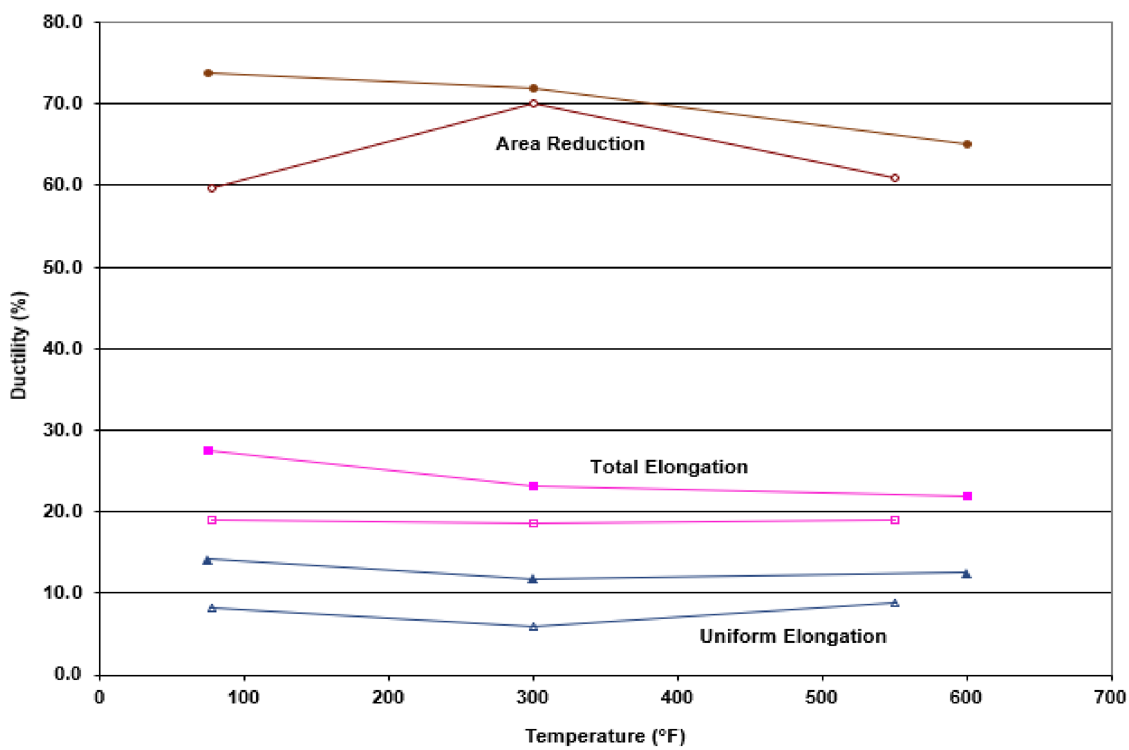
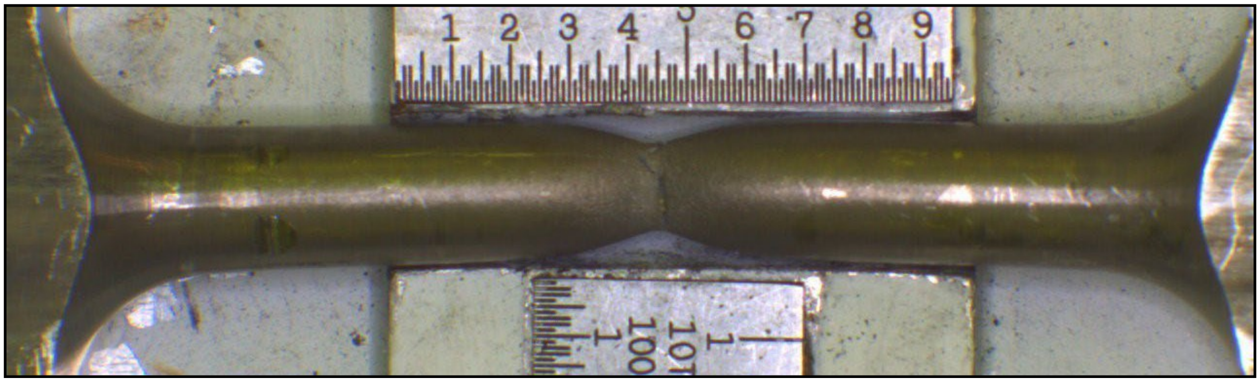
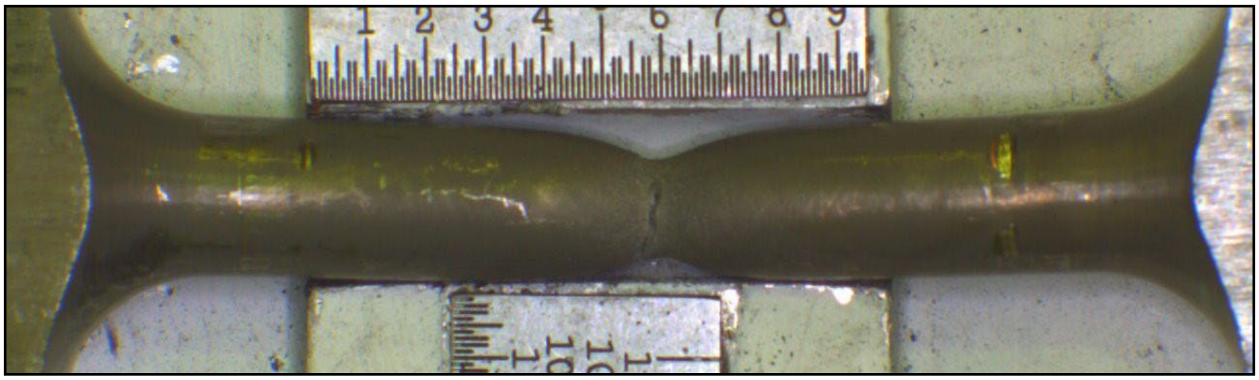


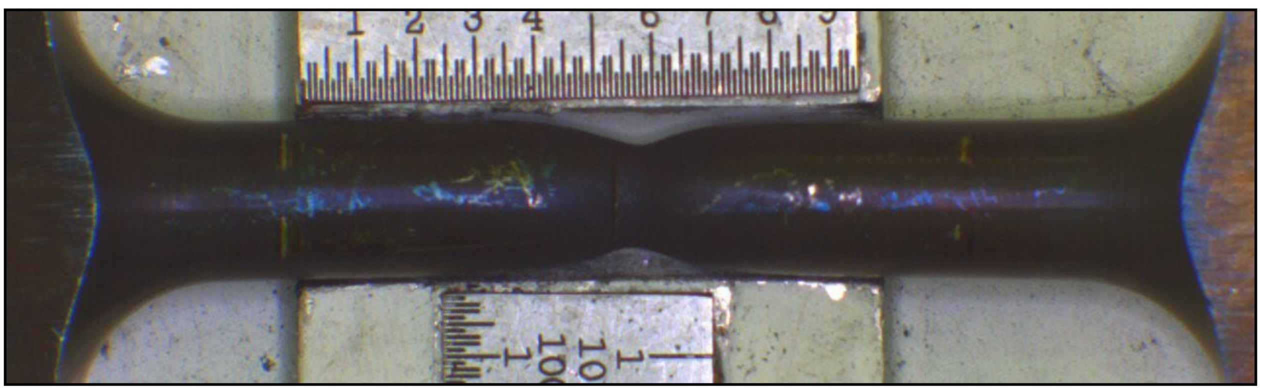
Figure 5-23 Tensile Properties for Prairie Island Unit 2 Reactor Vessel Surveillance Program Weld Material



NL13 tested at 78°F.

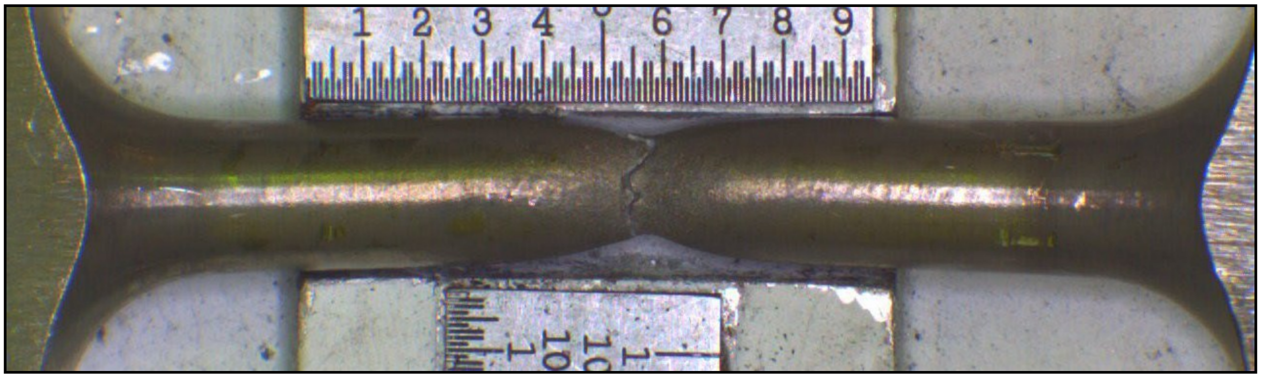


NL14 tested at 300°F.

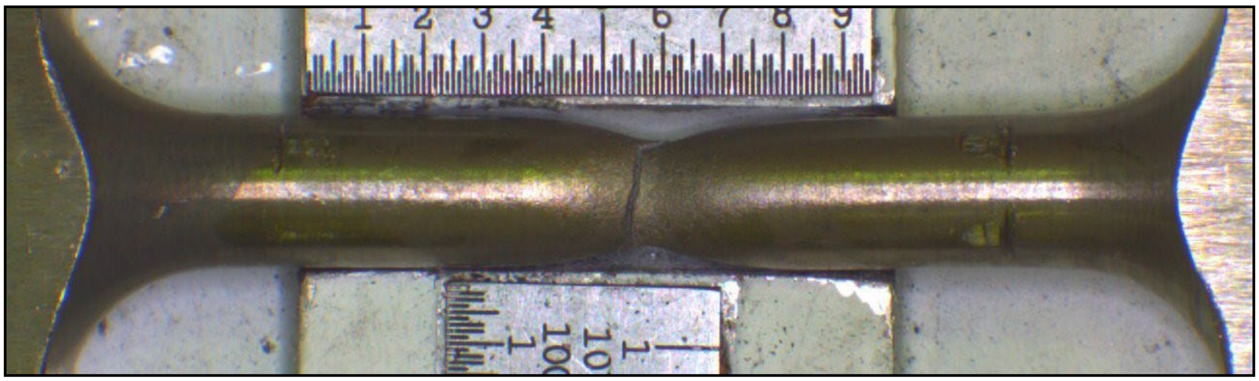


NL15 tested at 550°F.

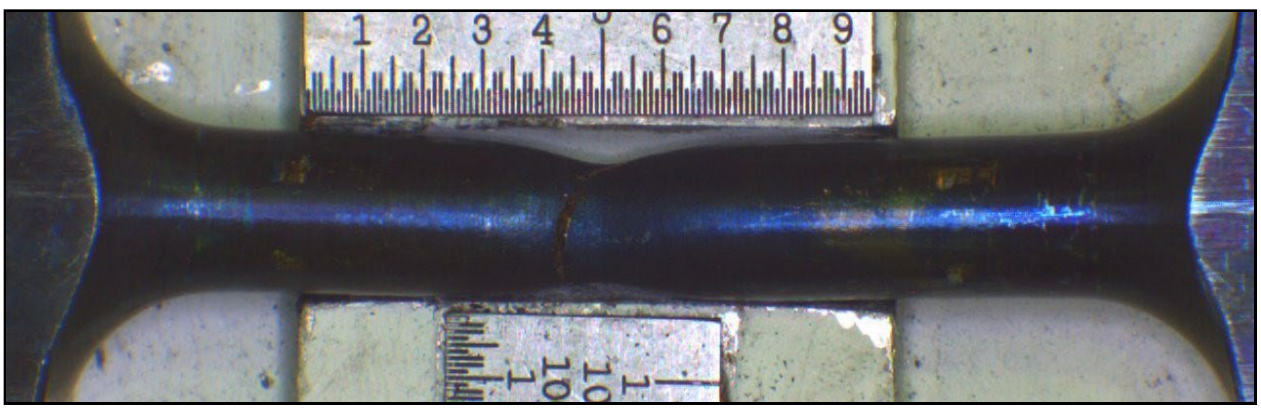
Figure 5-24 Fractured Tensile Specimens from Prairie Island Unit 2 Capsule N Lower Shell Forging D (Heat # 22642) (Tangential Orientation) [Scale in 1/10th of inch]



NT13 tested at 78°F.

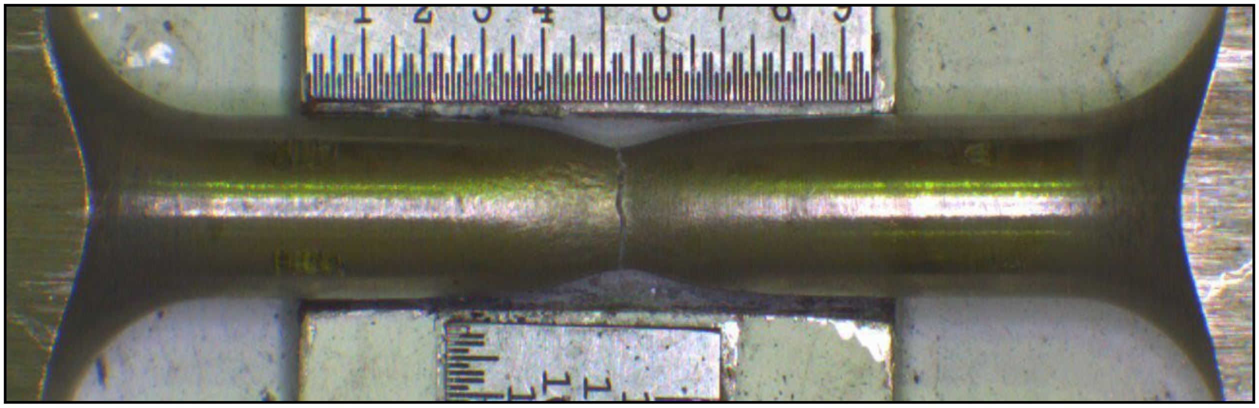


NT14 tested at 300°F.

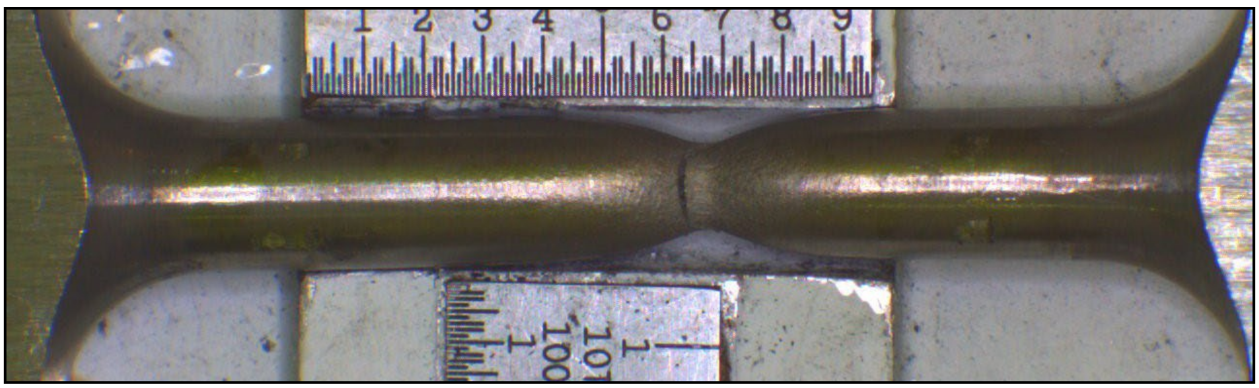


NT15 tested at 550°F.

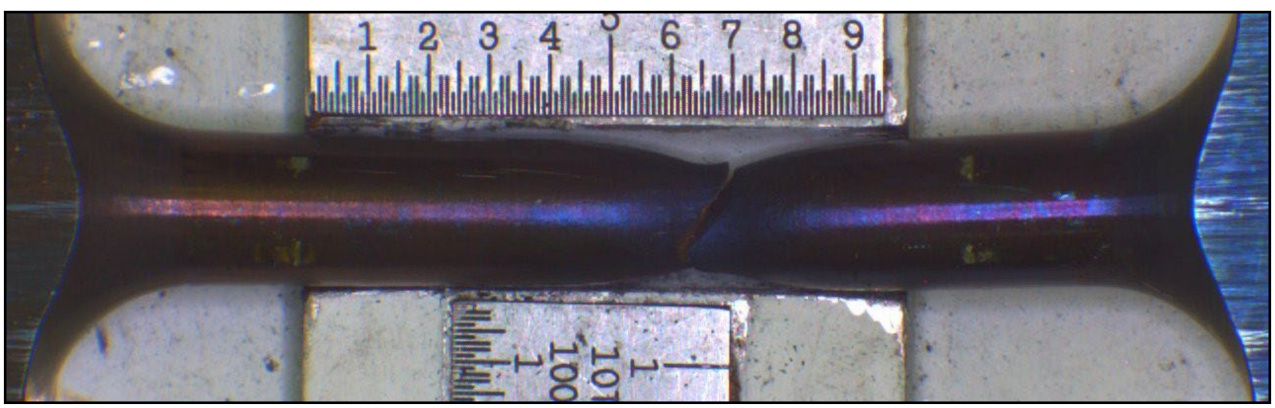
Figure 5-25 Fractured Tensile Specimens from Prairie Island Unit 2 Capsule N Lower Shell Forging D (Heat # 22642) (Axial Orientation) [Scale in 1/10^th^ of inch]



NW13 tested at 78°F.



NW14 tested at 300°F.



NW15 tested at 550°F.

Figure 5-26 Fractured Tensile Specimens from Prairie Island Unit 2 Capsule N Weld Metal [Scale in 1/10th of inch]

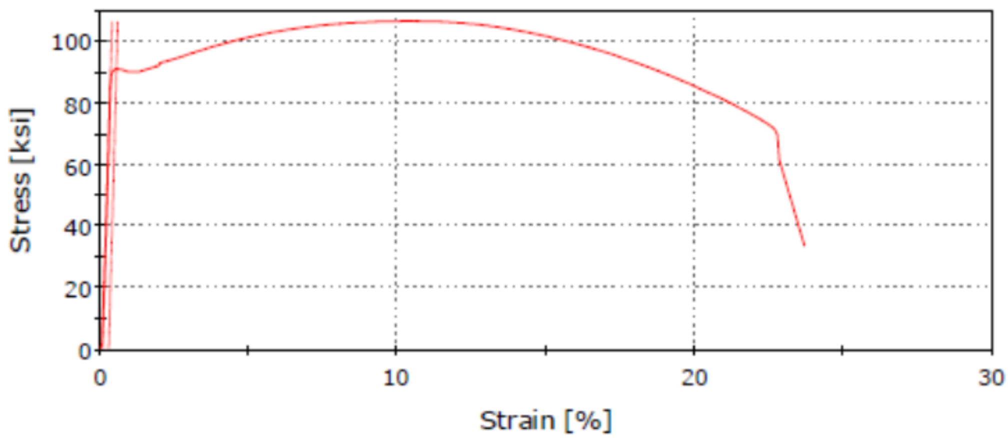


Figure 5-27 Engineering Stress-Strain Curve for Prairie Island Unit 2, Capsule N, Tensile Specimen NL13 (Tangential Orientation), Tested at 78°F

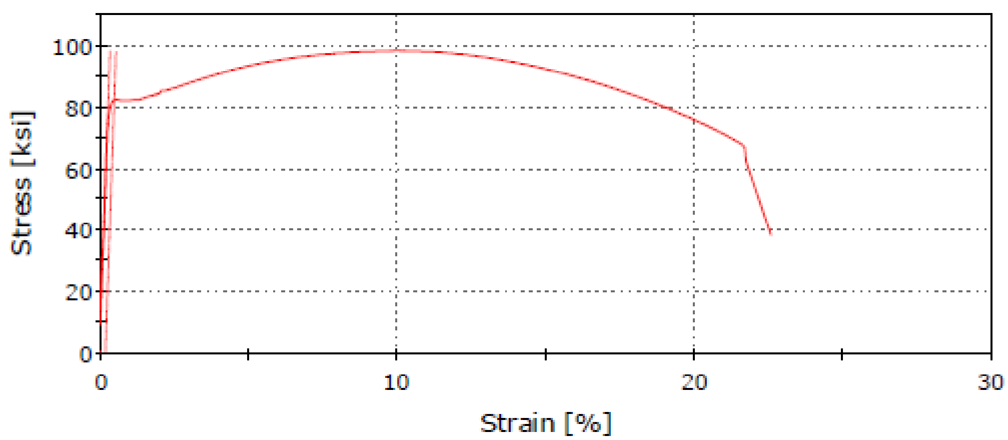


Figure 5-28 Engineering Stress-Strain Curve for Prairie Island Unit 2, Capsule N, Tensile Specimen NL14 (Tangential Orientation), Tested at 300°F

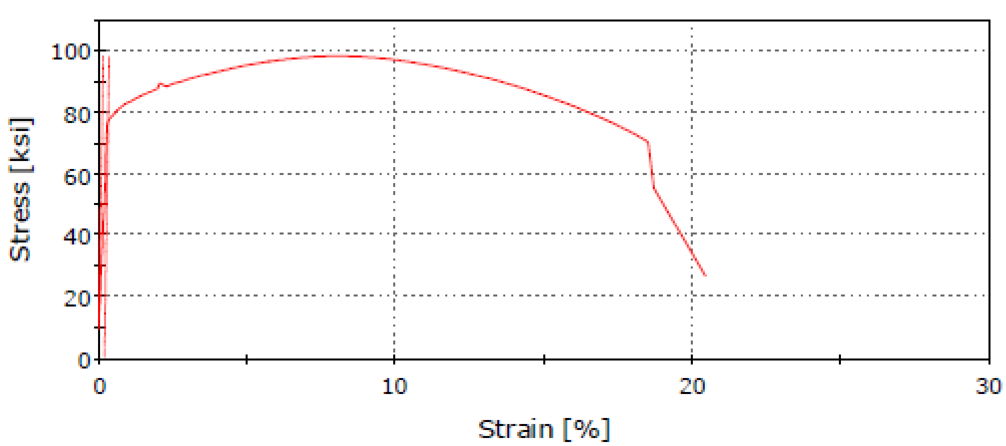


Figure 5-29 Engineering Stress-Strain Curve for Prairie Island Unit 2, Capsule N, Tensile Specimen NL15 (Tangential Orientation), Tested at 550°F

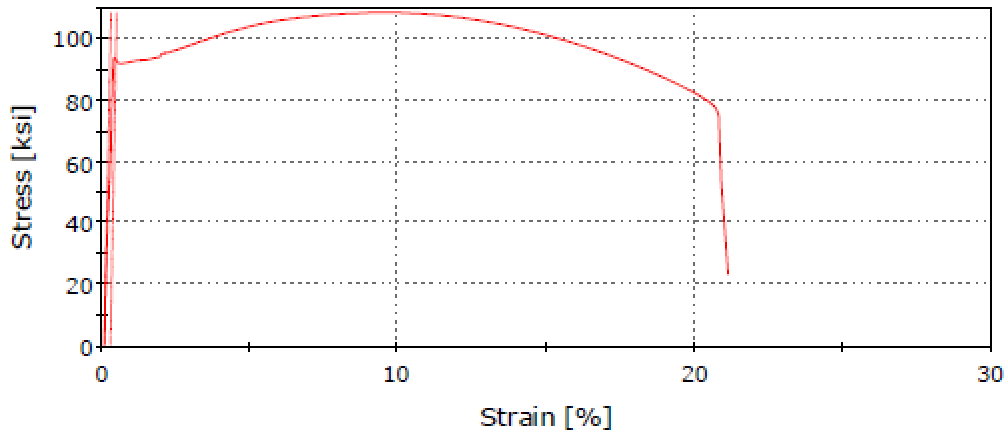


Figure 5-30 Engineering Stress-Strain Curve for Prairie Island Unit 2, Capsule N, Tensile Specimen NT13 (Axial Orientation), Tested at 78°F

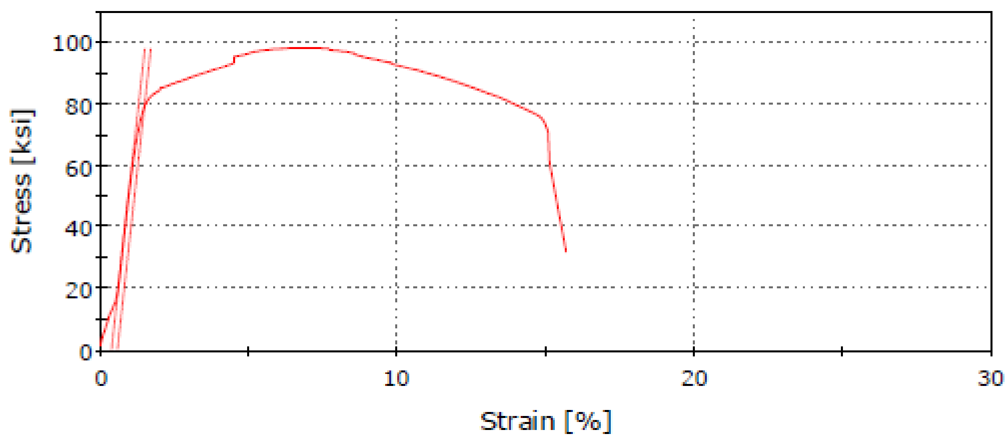


Figure 5-31 Engineering Stress-Strain Curve for Prairie Island Unit 2, Capsule N, Tensile Specimen NT14 (Axial Orientation), Tested at 300°F

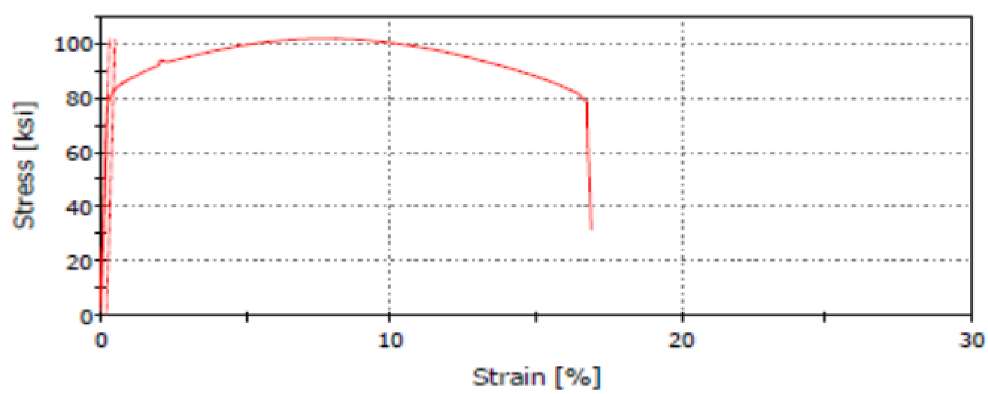


Figure 5-32 Engineering Stress-Strain Curve for Prairie Island Unit 2, Capsule N, Tensile Specimen NT15 (Axial Orientation), Tested at 550°F

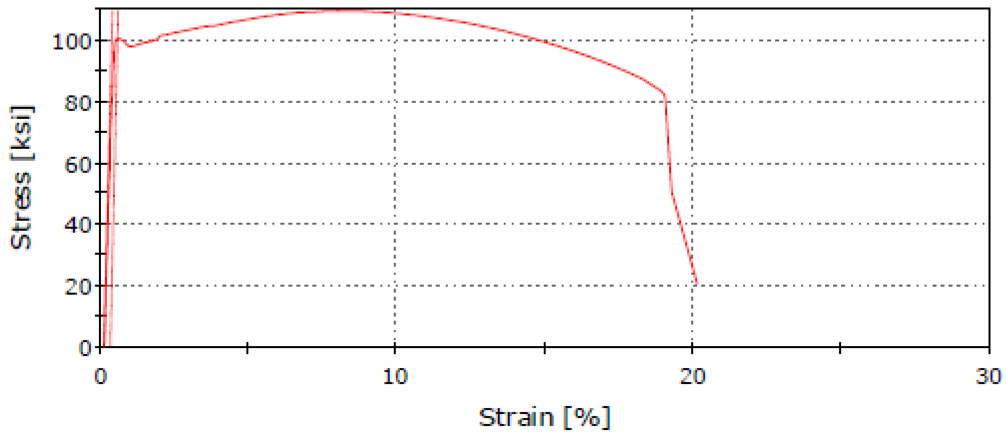


Figure 5-33 Engineering Stress-Strain Curve for Prairie Island Unit 2, Capsule N, Tensile Specimen NW13 (Weld), Tested at 78°F

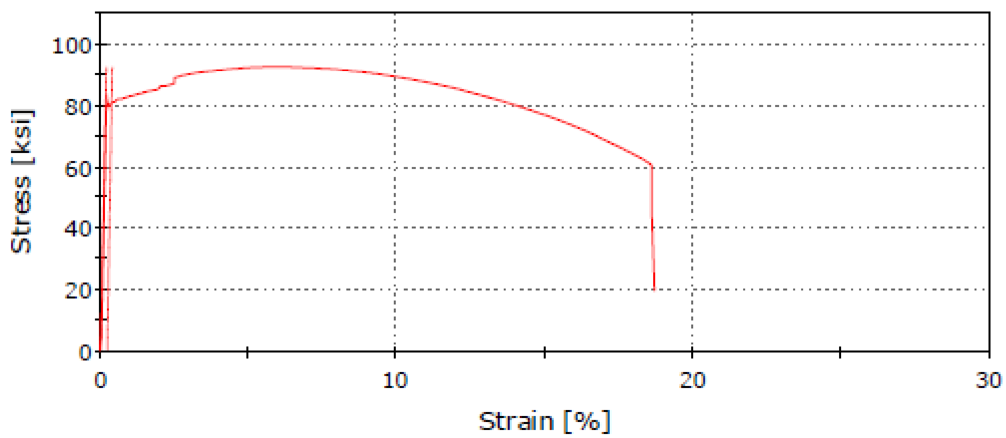


Figure 5-34 Engineering Stress-Strain Curve for Prairie Island Unit 2, Capsule N, Tensile Specimen NW14 (Weld), Tested at 300°F

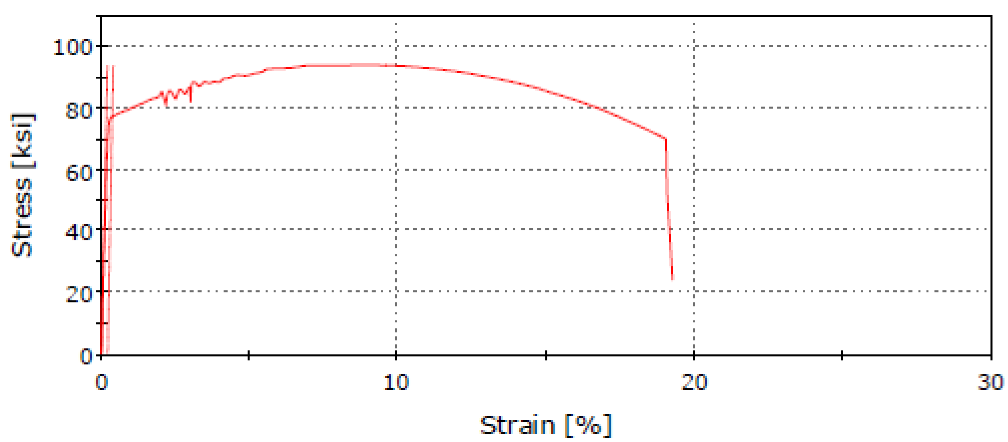


Figure 5-35 Engineering Stress-Strain Curve for Prairie Island Unit 2, Capsule N, Tensile Specimen NW15 (Weld), Tested at 550°F