ATTACHMENT 2

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REVISED PRESSURIZED THERMAL SHOCK EVALUATION FOR THE PALISADES REACTOR PRESSURE VESSEL

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Revised Pressurized Thermal Shock Evaluation for the Palisades Reactor Pressure Vessel

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EXECUTIVE SUMMARY

This updated analysis was performed to review the previous Pressurized Thermal Shock (PTS) evaluation for Palisades and incorporate new data and information that could affect the date to reach the PTS screening limit in 10CFR50.61. A previous analysis performed for the Palisades vessel in 2000 determined that the PTS screening criteria limit of 270°F for weld heat No. W5214 would not be reached until January 2014. That evaluation was based on the fluence projections and weld material chemistry for weld heat No. W5214 available at that time; no credit was given for surveillance data to improve the RT_{PTS} projection. In the fall of 2009 it became apparent to Entergy that new information was available that could affect the RT_{NDT} of the limiting Palisades vessel beltline material. The new data included revised fluence calculations and additional surveillance capsules containing weld data matching the Palisades vessel beltline materials. This report examines the updated fluence calculations performed by Westinghouse and all known surveillance data relevant to the Palisades reactor pressure vessel weld heat numbers W5214 and 27204. The scope of this new evaluation includes all of the materials located in the Palisades reactor vessel beltline region. This report is an extension of the earlier Structural Integrity Associates Report that only evaluated weld heat No. W5214 [5]. Using the revised fluences and chemistry factors based on the refitted surveillance data for limiting weld heat No. W5214, this re-evaluation shows that the projected date to reach the PTS screening criteria limit using the surveillance weld data would be approximately April 2017 or later. Revised chemistry factors based on surveillance capsule results were also calculated for weld heat No. 27204 and plate heat No. C-1279. This further evaluation of PTS confirms that the limiting vessel beltline material in the Palisades reactor vessel for evaluation of PTS remains the axial weld heat No. W5214.

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1.0 INTRODUCTION

The PTS Rule in 10CFR50.61 [1] specifies that all PWRs must monitor the reactor vessel beltline materials for comparison to the PTS screening criteria limits of 270°F for axial weld and base metal, and 300°F for circumferential welds.

The Palisades Nuclear Plant submitted to NRC a Pressurized Thermal Shock (PTS) evaluation in 2000 that projected the value for RT_{PTS}, or maximum Adjusted Reference Temperature (ART) of the limiting vessel weld or plate, based on the calculated fluences and material properties available at that time [2]. These inputs to the PTS Rule equations were used to calculate RT_{PTS}, and the Palisades vessel was projected to reach the screening criterion limit of 270°F for the limiting axial weld (heat no. W5214) in January 2014. Since the time that the previous PTS evaluation was performed for the Palisades vessel, ten years have passed and more data and information are available now to update the projected RT_{NDT} value for the limiting Palisades vessel beltline material. This evaluation is being performed as a part of Palisades' TLAA process under 10 CFR 54.21 (c)(1)(iii) for the NRC approved license renewal application.

The PTS Rule establishes the following requirements for all domestic, operating PWRs:

- All plants must submit projected values of RT_{PTS} for reactor vessel beltline materials. The PTS submittal must be updated whenever there are changes in core loadings, surveillance measurements or other information that indicates a significant change in projected RT_{PTS} values.
- The submittal must include the following:
    1. The basis for the projection (including assumptions regarding core loading pattern)
    2. Copper and nickel content and fluence values used in the calculations for each of the vessel beltline materials (if those values differ from those previously submitted to the NRC, justification must be provided).
- All values of RT_{PTS} must be verified to be bounding values for the specific reactor vessel. In doing so, each plant should consider plant-specific information that could affect the level of embrittlement.

The PTS Rule provides two methods for calculating the adjusted reference temperature of the reactor vessel beltline materials. The first method is described in 10CFR50.61, paragraph (c)(1) and uses the copper and nickel chemistry to determine a chemistry factor. The second method is described in 10CFR50.61, paragraphs (c)(2) and (c)(3), for use of surveillance data. These procedures can only be applied when two or more credible data sets become available. Both methods have been used to update the PT_{PTS} values for the Palisades vessel.

2.0 TECHNICAL APPROACH

Pressurized Thermal Shock (PTS) is a condition that could challenge the integrity of the reactor pressure vessel (RPV). PTS may occur during a severe transient such as a Loss of Coolant Accident (LOCA) or a steam line break. Such transients can challenge the RPV integrity under the following conditions:

- Severe overcooling of the inner surface of the RPV followed by high repressurization
- Radiation embrittlement of RPV materials causing a shift in the nil-ductility reference temperature and a decrease in the fracture toughness as measured by the material parameter RT_{PTS}.
- Presence of a flaw/defect of a critical size in the vessel wall

The RT_{PTS} values obtained from this evaluation are compared against the PTS screening limits for plates, forgings and axial welds, and circumferential welds to justify the continued operation until the End-of-Life-Extended (EOLE) fluence is achieved. The PTS screening criterion is 270°F for plates, forgings, and axial weld materials, and 300°F for circumferential weld materials.

The materials used to fabricate the Palisades vessel, the associated best-estimate copper (Cu) and nickel (Ni) chemistries, the corresponding chemistry factors as well as the method used to calculate the chemistry factor, and the corresponding RT_{PTS} values from the previous PTS submittal [2] are documented in Table 1 for the current operating license expiration date (March 24, 2011). The estimated date to reach the PTS screening criteria limit was previously determined to be January 2014, as shown in Table 2. This date has been reevaluated using updated fluence and materials data to determine revised projections to reach the PTS screening criteria limit. The guidance provided by the NRC Staff for the use of surveillance capsule data for determining chemistry factors (as published in Reference 6) has been implemented in this evaluation.

3.0 RT_{PTS} CALCULATION METHOD

RT_{PTS} must be calculated for each beltline material using a fluence value, *f*, which is the EOLE fluence for the material. RT_{PTS} has been evaluated using the same procedures used to calculate RT_{NDT}, as indicated in paragraph (c)(1) of Reference 1, except that the fluence values at the clad/base metal interface is used instead of the 1/4T fluence. The RT_{PTS} is evaluated using the following equation:

$$RT_{PTS} = RT_{NDT(U)} + M + \Delta RT_{PTS} \quad (1)$$

$$\Delta RT_{PTS} = CF \times FF \quad (2)$$

where:

$RT_{NDT(U)}$ = Reference temperature of nil ductility transition for the unirradiated material

M = Margin term to cover for uncertainties in the value of initial RT_{NDT} and the scatter in the shift

$$Margin = 2 * \sqrt{\sigma_I^2 + \sigma_\Delta^2} \quad (3)$$

σ_I = the standard deviation for the initial RT_{NDT} (°F). For non-Linde 80 type welds, if a generic initial RT_{NDT} value is used, σ_I = 17°F, if a measured value is used for the initial RT_{NDT}, σ_I = 0°F

σ_Δ = the standard deviation for ΔRT_{NDT} (°F). The values for σ_Δ are 28°F for welds and 17° for base metal (plates or forgings)

ΔRT_{PTS} = the mean value of the transition temperature shift due to irradiation, and

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

where:

f = Neutron fluence, in units of 10^{19} n/cm^2 (E > 1 MeV), at the clad/base metal interface, and

CF = Chemistry factor in °F, which is a function of the copper and nickel content, obtained from either the tables or a fitted CF value from surveillance data.

10 CFR 50.61 [1] states that σ_Δ need not exceed 0.5 times the mean reference temperature shift (0.5* ΔRT_{NDT}), or the standard value of σ_Δ of 28 °F for welds and 17 °F for base metal (plates or forgings), whichever is lower. Note: the margin term, M, may be reduced by half if credit is obtained for credible surveillance data.

4.0 FLUENCE PROJECTIONS AND FLUENCE METHODOLOGY

Westinghouse performed a detailed fluence evaluation of the Palisades vessel in 2000 [3]. This previous evaluation determined that the peak fluence at the clad-to-base-metal interface at the 60° location of the limiting axial weld was 1.158×10^{19} n/cm^2 (E > 1 MeV) at the end of Cycle 14 (i.e., October 1999). That evaluation provided the basis for fluence projections in the vessel through the end of license (EOL) period of March 24, 2011. A linear projection of fluence beyond EOL showed that the Palisades vessel could operate within the PTS screening criteria limit through January 2014 (as shown in Figure 1). Since December 1999, the Palisades plant has been operating with an Ultra-Low Leakage core strategy and stainless steel shielding of the limiting vessel weld at 60° azimuthal angle. The reactor vessel fluence reduction associated with the Ultra-Low Leakage core design requires that the flux suppression assemblies be loaded in specific core design locations and oriented with the stainless steel rods facing the reactor vessel. This configuration has been maintained to minimize flux at the limiting vessel weld location. It was observed that the flux at the limiting weld location may vary slightly from cycle to cycle because of limitations in the core loading patterns for each fuel reload. Recognizing that the flux and operating history of the Palisades plant may have changed over the years from the earlier projections, Westinghouse performed an updated fluence assessment for the Palisades vessel beltline region in 2010 [4]. This revised fluence evaluation provided an updated fluence assessment for the vessel beltline region that included cycle specific analyses for known core configuration through operating

Cycles 15 through 21, and projections for future operation based on the best available knowledge as a function of EFPY. The calculated and projected neutron fluence values for the limiting 60° weld location and the peak (75°) fluence location are given in Table 3 [4]. The projected fluence values at the EOLE date of March 24, 2031 is shown in Table 4. Note: the cycle specific projections for the designs of Cycle 21 and beyond were provided by Entergy and include an assumed load factor of 95% for future plant operation.

The calculated fluences in the vessel were interpolated to determine the limiting axial weld and peak (60° and 75°) fluences for the end of license renewal date of March 24, 2031 as shown in Table 4.

5.0 REVISED VESSEL MATERIAL PROPERTIES

The Palisades reactor vessel consists of the following beltline region materials [2, 20]:

- Intermediate Shell, Axial Welds 2-112 A/B/C, material heat No. W5214,
- Lower Shell, Axial Welds 3-112 A/B/C, material heat No. W5214 and 34B009,
- Intermediate to Lower Shell, Circumferential Weld 9-112, material heat No. 27204,
- Intermediate Shell, Plate D-3803-1, material heat No. C-1279,
- Intermediate Shell, Plate D-3803-2, material heat No. A-0313,
- Intermediate Shell, Plate D-3803-3, material heat No. C-1279,
- Lower Shell, Plate D-3804-1, material heat No. C-1308A,
- Lower Shell, Plate D-3804-2, material heat No. C-1308B,
- Lower Shell, Plate D-3804-3, material heat No. B-5294.

5.1 Weld Heat No. W5214

Weld heat no. W5214 was used in the intermediate shell axial welds 2/112A/B/C. The limiting vessel beltline material for PTS was determined to be the welds made from weld heat No. W5214 at the 60° azimuthal location [2]. Previously this weld was projected to reach the PTS screening criterion in January 2014, before any other beltline region material. This determination considered the fluence analysis and relevant surveillance data available at that time. In particular, seven surveillance capsules containing weld heat No. W5214 were evaluated, the data fitted to determine a revised CF value. However, the previous results were not used to adjust the RT_{PTS} value because the data were deemed to be non-credible [12].

A more accurate determination of the vessel beltline materials was recently performed to consider additional surveillance data, revised fluences, and other available information that could improve the embrittlement predictions for the limiting weld material. A more complete evaluation of the surveillance data for weld heat no. W5214 is given in Reference 5. The results of that study are summarized here.

5.1.1 Surveillance Data for Weld Heat No. W5214

Surveillance capsule data from eleven capsule reports were found to contain this weld heat. These data were obtained from the Palisades supplemental capsules, and additional data from H. B. Robinson 2, Indian Point Unit 2, and Indian Point Unit 3 was evaluated using the credibility requirements in 10CFR50.61. The NRC guidance for evaluation and use of other plant's surveillance data is contained in Reference 6. The data were adjusted to account for difference in specimen chemistry and plant operating temperatures, and the irradiated Charpy shift results were fitted using the least squares fit relation given in Equation (4) [6].

$$CF = \frac{\sum_{i=1}^{n} \left[A_i \times f_i^{(0.28 - 0.10 \log f_i)} \right]}{\sum_{i=1}^{n} \left[f_i^{(0.56 - 0.20 \log f_i)} \right]} \qquad (4)$$

where "n" = the number of surveillance data points,
"A_i" = the measured value of ΔT_{30} from the Charpy specimens, and
"f_i" = the fluence for each surveillance capsule data point.

The results of this evaluation are given in Table 5 and the results are plotted in Figure 2. It is noted that the fitted CF value = 227.74°F for weld heat no. W5214. Further analyses based on Palisades surveillance data only showed that the two plant-specific data points yield a lower CF value with a scatter from a mean fit less than 28°F (i.e., within the range for credible data); however, these results for weld heat No. W5214 have not been credited since all surveillance data were used to develop a revised CF value as given above.

5.2 Weld Heat No. 27204

In the September 1998 RAI response [12], the best estimate chemistry for weld heat No. 27204 was reevaluated. A study performed by the Combustion Engineering Owners Group (CEOG), CE NPSD-1039, Rev. 02 [7], determined the best estimate chemistry values of 0.203% Cu and 1.018% Ni for welds fabricated with weld wire heat number 27204. Given that the values reported in CE NPSD-1039, Rev. 02 are comparable to those that had been calculated previously, it was concluded the best estimate chemistry for the Palisades reactor vessel beltline welds fabricated with weld wire heat number 27204 is 0.203% Cu and 1.018% Ni as reported in CE NPSD-1039, Rev. 02. Using Table 1 in 10CFR50.61, a chemistry factor (CF) of 226.8°F was determined based on the best estimate chemistry for the surveillance data for Weld Heat No. 27204.

5.2.1 Surveillance Data for Weld Heat No. 27204

The previous analysis of surveillance data for weld heat No. 27204 [12] included only two capsule data points from Diablo Canyon Unit 1, Capsule S [8] and Capsule Y [9]. That analysis performed a least-squares fit to the surveillance data results and determined the data to not be credible because the scatter exceeded the allowable scatter for credible surveillance data (i.e., $1\sigma > 28°F$). Since then, two new data surveillance data points were obtained from the Palisades supplemental capsules SA-60-1 [10] and SA-240-1 [11] and one from Diablo Canyon Unit 1, Capsule V [25]. The surveillance data results for the capsules containing weld heat No. 27204 are shown in Appendix B. It is noted that the Charpy V-notch test data had been fitted with the TANH function to determine the ΔT_{30}, or RT_{NDT} shift values. The measured RT_{NDT} shift values from the fitted surveillance capsules were considered for projection of embrittlement in the Palisades vessel weld. The two (2) surveillance capsules from Palisades were found to be credible. The Palisades supplemental surveillance data were combined with the Diablo Canyon 1 surveillance data and the results are shown in Table 6. The analysis of the surveillance data was performed using Case 4 of the NRC guidance, "Surveillance Data from Plant and Other Sources" [6]. Adjustments were made to the measured shift values to account for chemistry differences and temperature differences between the capsules and the vessel, as shown in Table 6. The irradiation temperatures for the Diablo Canyon Unit 1 capsules were obtained from Reference 27. Using the least-squares fitting method in Eq. (4), a fitted CF value of 216.13°F was obtained for weld heat No. 27204 for application to the Palisades circumferential weld, 9-112. A discussion of data credibility for weld heat No. 27204 is given in Appendix A. A plot of all the capsule data for weld heat No. 27204 is shown in Figure 4 along with the 1-sigma (28°F) scatter bound for weld materials. These additional surveillance capsule data were included for completeness. As a result, the (measured – predicted) scatter for the surveillance data was found to fall within the 28°F band rendering the data to be credible and applicable to improve the projected RT_{PTS} value for the circumferential weld by taking advantage for the reduced margin term, as discussed in Appendix B.

5.3 Weld Heat No. 34B009

The technical basis for the weld heat No. 34B009 material properties has been reviewed and no changes are proposed. This technical basis has been reviewed and approved by the NRC as a part of the Palisades Safety Evaluation Report [20]. In examining the basis, it was noted that CE NPSD-1039, Rev. 02 specifies best estimate values of 0.192% Cu and 1.038% Ni for weld fabricated with weld wire heat No. 34B009 [7]. In the submittal dated September 8, 1998, it was determined that a copper value of 0.192% is the best estimate value for the welds made from heat No. 34B009 in the Palisades vessel [12]. However, it was also determined at that time that the best estimate chemistry value for nickel recommended in CE NPSD-1039, Rev. 02 for nickel addition welds could not be endorsed for the Palisades vessel welds. The value of 1.038% Ni was determined by finding the mean of 144 nickel measurements. It was noted that 45 of those measurements were from the retired Palisades steam generators, and the calculated mean was dominated heavily by just two welds. A new evaluation of the nickel content using a coil-weighted average was performed by the CEOG in "Updated Analysis for Combustion Engineering Fabricated Reactor Vessel Welds Best Estimate Copper and Nickel Content," CE NPSD-1119, Revision 01, July 1998 [13]. The best estimate value of 1.007% nickel derived using a sample weighted mean was considered a technically superior approach to that used in CE NPSD-1039, Rev. 02. Further studies were performed after the CEOG work was completed in order to establish the best estimate nickel value to be used for this weld in the Palisades vessel. These were described in Reference 14. 10CFR50.61(c)(1)(iv)(A) states "For a weld, the best estimate values will normally be the mean of the measured values for a weld deposit made using the same weld wire heat number as the critical vessel weld." The concept of determining the best estimate nickel from all nickel addition welds made from the same heat is a reasonable technical assumption. The multiple measurements of nickel from samples of weld heat No. 34B009 were averaged (i.e., average of the averages) to obtain the mean nickel value, as shown in Table 7 [14]. Therefore, the best estimate value of 0.98% Ni reported in the December 20, 1995 and November 17, 1995 submittals [14, 15] is considered more representative of the best estimate for nickel provided in CE NPSD-1119, Rev. 01. It was concluded that the best estimate chemistry for the Palisades reactor vessel beltline welds fabricated with weld wire heat No. 34B009 (with nickel addition) is 0.192% Cu and 0.98% Ni. Using Table 1 in 10CFR50.61, a chemistry factor (CF) of 217.7°F was determined based on the best estimate chemistry for this weld. Thus, there is no change from the previously reported values for this weld.

5.3.1 Surveillance Data for Weld Heat No. 34B009

The only surveillance program results known to contain weld wire heat No. 34B009 are from the Millstone 1 reactor vessel. These data were evaluated previously and found to not have relevance to Palisades because Millstone 1 is a Boiling Water Reactor [12]. No further analysis of the surveillance data for this weld heat was performed.

5.4 Vessel Beltline Plate Materials

The reported copper and nickel chemistry values and calculated chemistry factors for the beltline plates are shown in Table 1. There is no additional capsule data for the Palisades vessel beltline plate materials. However, there is new fluence data for the Palisades surveillance capsules containing the surveillance plate heat No. C-1279. The Palisades surveillance capsules containing base metal include A-240 [21], W-290 [22], W-110 [23], and W-100 [26]. The Charpy test results and the evaluated ΔT_{30} shift values from these capsule test reports are given in Appendix C. Updated surveillance capsule fluence values were obtained from WCAP-15353, Supplement 1 [4], and the least-squares fit to the data using the revised fluence values is given in Table 8. The least-squares fit to these data is determined to be CF = 147.71°F, and a plot of the data and fitted results is given in Figure 5. However, it is observed that three data points fall outside the 1-sigma bound and one data point falls outside the 2-sigma bound for plate materials and, therefore, the data were determined to not be credible and a fitted CF value should not be used for projections of the vessel RT_{PTS} for the beltline plates with the same heat number. The projection of RT_{PTS} for the vessel beltline plates made from plate heat No. C-1279 used a CF value of 157.5°F (from the Reg. Guide 1.99, Rev. 2 tables) and a full margin term of 34°F.

6.0 DISCUSSION

Additional surveillance capsule data and fluence calculations were considered that could affect the projection of embrittlement in the Palisades vessel beltline materials. The results have been evaluated to determine the effect on the date to reach the PTS screening criteria limit for the materials with the highest RT_{PTS} values. These are the axial weld heat No. W5214 at the 60°F azimuthal locations, and weld heat No. 27204 with a peak fluence at the 75° azimuthal location. The projected date for the limiting axial weld to reach the PTS screening criteron limit of 270°F is shown in Table 9 based on a maximum fluence for this locations of 1.685×10^{19} n/cm^2. The date to reach this limit is April 2017, as has been confirmed by the evaluation of surveillance data for weld heat No. W5214 in Reference 5. The next closest material to the PTS screening criterion is axial weld heat No. 34B009. For the circumferential weld heat No. 27204, using a fitted CF value of 216.13°F based on surveillance data with a 1-sigma margin term (i.e., 44°F) and revised projections of fluence in the vessel [4], the maximum fluence for the circumferential weld to remain below the PTS screening criterion limit of 300°F is determined to be 6.24×10^{19} n/cm^2 (see Table 12). Table 10 shows the updated RT_{PTS} values for all the vessel beltline materials at the EOLE date of March 24, 2031, including use of best available data and revised fluence calculations for the Palisades reactor pressure vessel. Table 11 shows how the maximum fluence value for the axial weld at the 60° location was determined. Similarly, Table 12 gives the details for estimating the maximum (peak) fluence in the circumferential weld at the 75° location. New data has been included for the Palisades vessel beltline materials, and the results shown in Table 10 confirm that the limiting vessel beltline material for PTS is the axial weld made from heat No. W5214. This analysis provides the basis to assure that the Palisades vessel remains below the limits defined in 10CFR50.61 through April 2017 or beyond.

7.0 CONCLUSIONS

The results for all available surveillance capsules have been evaluated for applicability to the Palisades limiting vessel welds. A thorough examination of the use of surveillance data for weld heat No. W5214 was previously performed for the limiting axial welds [5]. The results of that study have been confirmed to be the applicable for the limiting beltline material since the other weld and base materials would not overtake this weld. Updates to the surveillance capsule fluences and the projected fluence in the Palisades vessel were also reviewed and included in these analyses. The methods of 10CFR50.61 were applied including options for considering the effects of surveillance data on the projected RT_{NDT} values. Reference 5 showed that by using Position 1 of the PTS Rule (without the use of surveillance data), the projected date to reach the PTS screening criteria limit would be as late as July 2014. To summarize the results from Reference 5, use of the weld heat No. W5214 surveillance data can improve the projections of embrittlement and significantly changes the date to reach the screening criteria limit. Since weld heat No. W5214 is currently identified as the limiting material, the projections for RT_{PTS} using the Palisades supplemental surveillance data show that the PTS screening criteria limit of 270°F would not be reached until after 2034 if the data were fully credible; however, other vessel beltline materials would become limiting and that would change that date. By comparison, considering an evaluation of the surveillance data available from the plant and other sources, the surveillance data results for weld heat No. W5214 were shown to be credible for determination of the CF value, but the scatter in the data would not permit a reduction in the margin term. Using all the available weld heat No. W5214 surveillance data, a CF value of 227.74°F was determined for limiting axial weld and a projected date to reach the screening criteria limit of approximately April 2017 (or later) was estimated. The other vessel beltline materials have been shown to be less sensitive to neutron irradiation effects, so the April 2017 date is the revised projected RT_{PTS} limiting date for the Palisades vessel to stay below the screening criteria limits in 10CFR50.61. Palisades plans to inspect the reactor vessel beltline region in 2012, following which, the results of the NDE will be used to perform a new PTS evaluation to ensure that the reference toughness values per 10CFR50.61a [24] are satisfied throughout the period of extended operation.

8.0 REFERENCES

1. Code of Federal Regulations, Title 10, Part 50, Section 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events," U. S. Nuclear Regulatory Commission. (SI File No. 0901025.201).

2. Letter from Darl S. Hood (USNRC) to Nathan Haskell (Palisades), "Palisades Plant – Reactor Vessel Neutron Fluence Evaluation and Revised Schedule for Reaching Pressurized Thermal Shock Screening Criteria (TAC No. MA8250)," November 14, 2000. (SI File No. 0901025.206).

3. "Palisades Reactor Pressure Vessel Neutron Fluence Evaluation," WCAP-15353, Rev. 0, January, 2000 (SI File No. 0901025.203).

4. "Palisades Reactor Pressure Vessel Neutron Fluence Evaluation," WCAP-15353-Supplement 1-NP, May, 2010 (SI File No. 1000915.211).

5. "Evaluation of Surveillance Data for Weld Heat No. W5214 for Application to Palisades PTS Analysis," SI Report No. 0901132.402, Rev. 0, April 2010.

6. "Generic Letter 92-01 and RPV Integrity Assessment," NRC/Industry Workshop on RPV Integrity Issues, February 12, 1998. (SI File No. 0901132.213).

7. "Best Estimate Copper and Nickel Values in CE Fabricated Reactor Vessel Welds," CE NPSD-1039, Rev. 02, Combustion Engineering Owners Group, June 1997. (SI File No. 1000915.202)

8. Westinghouse Report, WCAP-11567, "Analysis of Capsule S from the Pacific Gas and Electric Company Diablo Canyon Unit 1 Reactor Vessel Radiation Surveillance Program," December 1987. (SI File No. 1000915.209)

9. Westinghouse Report, WCAP-13750, "Analysis of Capsule Y from the Pacific Gas and Electric Company Diablo Canyon Unit 1 Reactor Vessel Radiation Surveillance Program," July 1993. (SI File No. 1000915.210)

10. Framatome ANP Report, "Test Results of Capsule SA-60-1 Consumers Energy Palisades Nuclear Plant – Reactor Vessel Material Surveillance Program," BAW-2341, Revision 2, May 2001. (SI File No. 0901132.210).

11. Framatome ANP Report, "Test Results of Capsule SA-240-1 Consumers Energy Palisades Nuclear Plant – Reactor Vessel Material Surveillance Program," BAW-2398, May 2001. (SI File No. 0901132.209).

12. Haskell (Consumers Energy) to NRC, "Docket 50-255 -License DPR-20 -Palisades Plant Response to Request for Additional Information Regarding Reactor Pressure Vessel Integrity (TAC No. MA0560)," September 8, 1998. (SI File No. 0901132.217)

13. "Updated Analysis for Combustion Engineering Fabricated Reactor Vessel Welds Best Estimate Copper and Nickel Content," Combustion Engineering Owners Group, CEOG Task 1054, CE NPSD-1119, Rev. 01, July 1998. (SI File No. 0901025.204)

14. Smedley (Consumers Energy) to NRC, "Docket 50-255-License DPR-20 –Palisades Plant Response to NRC Generic Letter 92-01, Revision 1, Supplement 1: Reactor Vessel Structural Integrity," November 17, 1995. (SI File No. 1000915.212)

15. Smedley (Consumers Energy) to NRC, "Docket 50-255-License DPR-20 –Palisades Plant Response to NRC Generic Letter 92-01, Revision 1, Supplement 1: Reactor Vessel Structural Integrity – Correction of Typographical Errors," December 20, 1995. (SI File No. 1000915.213)

16. ASME Boiler and Pressure Vessel Code, Section III, 1965 Edition, including all addenda through Winter 1965, American Society of Mechanical Engineers.

17. ASTM E185-66, "Recommended Practice for Surveillance Tests on Structural Materials in Nuclear Reactors."

18. Design Input Record from Thomas Allen (Entergy) to Timothy Griesbach (SIA) for basis/reference for adjusting the Palisades Cycle 1 through 12's cycle length expressed as Effective Full Power Day (EFPD) & unadjusted cycle lengths and operating dates, April 15, 2010. (SI File No. 0901132.224)

19. ORNL Report, "Analysis of the Irradiation Data for A302B and A533B Correlation Monitor Materials," Oak Ridge National Laboratory, NUREG/CR-6413, ORNL/TM-13133, April 1996. (SI File No. 1000915.215)

20. "Evaluation of Palisades Nuclear Plant Reactor Pressure Vessel Through the Period of Extended Operation," Constellation Nuclear Services Report, CNS-04-02-01, Rev. 1, June 2004. (SI File No. 0901132.219)

21. Perrin, J. S., et al., "Palisades Nuclear Plant Reactor Pressure Vessel Surveillance Program Capsule A-240," BCL-585-12, March 13, 1979. (SI File No. 1000915.216)

22. Kunka, M. K., Cheney, C. A., "Analysis of Capsules T-330 and W-290 from the Consumers Power Company Palisades Reactor Vessel Radiation Surveillance Program," WCAP-10637, September 1984. (SI File No. 1000915.217)

23. Peter, P. A., et al., "Analysis of Capsule W-110 from the Consumers Power Company Palisades Reactor Vessel Radiation Surveillance Program," WCAP-14014. (SI File No. 1000915.218)

24. Federal Register/ Vol. 75, No. 1/ Monday, January 4, 2010/ Rules and Regulations, 10 CFR Part 50, "Alternate Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events."

25. Westinghouse Report WCAP-15958, Revision 0, "Analysis of Capsule V from Pacific Gas and Electric Company Diablo Canyon Unit 1 Reactor Vessel Radiation Surveillance Program," January 2003. (SI File No. 1000915.219).

26. BWXT Services Report No. 1295-001-03-08:00, "Analysis of Capsule W-100 from the Nuclear Management Company Palisades Reactor Vessel Material Surveillance Program," February 2004. (SI File No. 1000915.220).

27. Westinghouse Letter Report No. CPAL-10-34 Dated October 15, 2010, "Westinghouse Review of Structural Integrity Associates Reports on Pressurized Thermal Shock for Palisades." (SI File No. 1000915.221).

Table 1: Palisades Vessel Beltline Material Properties on Operating License Expiration Date (3/24/11) (from Ref. 2)

RPV Material	Heat No.	Cu%	Ni%	CF (°F)	Surface Fluence (E19)	FF	$RT_{NDT}(U)$ (°F)	RT_{NDT} Shift (°F)	Margin (°F)	RT_{PTS} (°F)
Axial Weld 2-112A/B/C	W5214	0.213	1.01	231.08	1.492	1.111	-56	256.7	65.5	266
Axial Weld 3-112A/B/C	W5214	0.213	1.01	231.08	1.492	1.111	-56	256.7	65.5	266
	34B009	0.192	0.98	217.7	1.492	1.111	-56	241.8	65.5	251
Circ Weld 9-112	27204	0.203	1.018	226.8	2.061	1.197	-56	271.5	65.5	281
Plate D-3803-1	C-1279	0.24	0.50	153.3	2.061	1.197	-5	183.5	17	195
Plate D-3803-2	A-0313	0.24	0.52	160.4	2.061	1.197	-30	192.0	34	196
Plate D-3803-3	C-1279	0.24	0.50	153.3	2.061	1.197	-5	183.5	17	195
Plate D-3804-1	C-1308A	0.19	0.48	128.8	2.061	1.197	0	154.2	34	188
Plate D-3804-2	C-1308B	0.19	0.50	131	2.061	1.197	-30	156.8	34	161
Plate D-3804-3	B-5294	0.12	0.55	82	2.061	1.197	-25	98.2	34	107

Table 2. Original Estimated Date for Weld Heat No. W5214 to Reach PTS Screening Criterion Limit (RT_{PTS} = 270°F)*

RPV Material	Heat No.	Cu%	Ni%	CF (°F)	Surface Fluence* (E19)	FF	$RT_{NDT}(U)$ (°F)	RT_{NDT} Shift (°F)	Margin (°F)	RT_{PTS} (°F)
Axial Weld 3-112A/B/C	W5214	0.213	1.007	231.08	1.584	1.127	-56	260.5	65.5	270

***Limiting weld heat no. W5214 w/original projected fluence and CF (Estimated date to reach PTS screening criterion limit = January 2014) [2]**

Table 3. Calculated Clad-to-Base Metal Interface Fluence in Palisades Vessel [4]

End of Fuel Cycle	Estimated Calendar Date	Cumulative Time (EFPY)	Fluence (n/cm^2, E > 1 MeV)*	
			60°	75°
21	10/2010	23.4	1.472E+19	2.157E+19
22	4/2012	24.7	1.520E+19	2.252E+19
23	10/2013	26.1	1.571E+19	2.345E+19
24	4/5/2015	27.4	1.619E+19	2.433E+19
25	10/2016	28.8	1.670E+19	2.527E+19
26	4/2018	30.2	1.721E+19	2.621E+19
27	10/2019	31.5	1.772E+19	2.714E+19
28	4/2021	32.9	1.823E+19	2.808E+19
29	10/2022	34.3	1.874E+19	2.902E+19
30	4/2024	35.7	1.925E+19	2.995E+19
31	10/2025	37.1	1.976E+19	3.089E+19
32	4/2027	38.4	2.027E+19	3.182E+19
33	10/2028	39.8	2.078E+19	3.276E+19
34	4/2030	41.2	2.129E+19	3.370E+19
35	10/2031	42.6	2.180E+19	3.463E+19
36	4/2033	44.0	2.231E+19	3.557E+19

*Source WCAP-15353-Supplement 1-NP, Rev. 0 [4]

Table 4. Calculated Fluence at End of License Renewal Date (March 24, 2031)

	Estimated Calendar Date	Fluence at Axial Weld* @60°	Peak Fluence* @75°
End of Cycle 34	4/1/2030	2.129E+19	3.370E+19
Start of Cycle 35	5/1/2030	2.129E+19	3.370E+19
	6/1/2030	2.132E+19	3.375E+19
	7/1/2030	2.135E+19	3.381E+19
	8/1/2030	2.138E+19	3.386E+19
	9/1/2030	2.141E+19	3.392E+19
	10/1/2030	2.144E+19	3.397E+19
	11/1/2030	2.147E+19	3.403E+19
	12/1/2030	2.150E+19	3.408E+19
	1/1/2031	2.153E+19	3.414E+19
	2/1/2031	2.156E+19	3.419E+19
	3/1/2031	2.159E+19	3.425E+19
EOLE Date	**3/24/2031**	**2.161E+19**	**3.429E+19**
	4/1/2031	2.162E+19	3.430E+19
	5/1/2031	2.165E+19	3.436E+19
	6/1/2031	2.168E+19	3.441E+19
	7/1/2031	2.171E+19	3.447E+19
	8/1/2031	2.174E+19	3.452E+19
	9/1/2031	2.177E+19	3.458E+19
End of Cycle 35	10/1/2031	2.180E+19	3.463E+19

*Source WCAP-15353-Supplement 1-NP, Rev. 0 [4]

Table 5. Evaluation of all Surveillance Capsule Results Containing Weld Heat No. W5214 [5]

Capsule	%Cu	%Ni	Table CF (F)	Revised Fluence (n/cm^2)	Fluence Factor FF	Irrad. Temp. Ti (F)	Measured (Refitted) ΔRTndt (F)	Ratio Adjusted ΔRTndt (F)	Chem. & Temp. Adj. ΔRTndt (F)	Predicted ΔRTndt (F)	Adjusted - Predicted (F)
SA-60-1	0.307	1.045	266.5	1.50E+19	1.11	535	259	224.2	224.0	253.3	-29.27
SA-240-1	0.307	1.045	266.5	2.38E+19	1.23	535.7	280.1	242.5	243.0	281.0	-38.00
HB2 T	0.34	0.66	217.7	3.87E+19	1.35	547	289.1	306.4	318.2	307.2	10.97
HB2 V	0.34	0.66	217.7	5.30E+18	0.82	547	208.8	221.3	233.1	187.3	45.75
HB2 X	0.34	0.66	217.7	4.49E+19	1.38	547	265.6	281.5	293.3	314.4	-21.14
IP2 V	0.20	1.03	226.3	4.92E+18	0.80	524	197.5	201.4	190.2	182.7	7.48
IP2 Y	0.20	1.03	226.3	4.55E+18	0.78	529.1	193.9	197.7	191.6	177.8	13.77
IP3 T	0.16	1.12	206.2	2.63E+18	0.64	539.4	149.8	167.6	171.8	145.0	26.81
IP3 Y	0.16	1.12	206.2	6.92E+18	0.90	539.5	171.1	191.5	195.8	204.2	-8.48
IP3 Z	0.16	1.12	206.2	1.04E+19	1.01	538.9	228.3	255.5	259.2	230.2	28.92
IP3 X	0.16	1.12	206.2	8.74E+18	0.96	539.7	192.5	215.4	219.9	219.1	0.76
Vessel Best Estimate CF =			**230.73**		**Mean T =**	**535.2**					
								Least Squares Fitted CF =		**227.74**	

Table 6. Evaluation of Surveillance Capsule Results Containing Weld Heat No. 27204

Capsule	%Cu	%Ni	Table CF (F)	Revised Fluence (n/cm^2)	Fluence Factor FF	Irrad. Temp. Ti (F)	Measured ΔRTndt (F)	Ratio Adjusted ΔRTndt (F)	Chem. & Temp. Adj. ΔRTndt (F)	Predicted ΔRTndt (F)	Adjusted - Predicted (F)
CAP Y (DCPP)	0.198	0.999	222.26	1.05E+19	1.01	542	232.59	237.3	244.1	219.1	25.06
CAP S (DCPP)	0.198	0.999	222.26	2.84E+18	0.66	544	110.79	113.1	121.9	141.8	-19.97
SA-240-1 (PNP)	0.194	1.067	227.8	2.38E+19	1.23	535.7	267.8	266.7	267.2	266.7	0.49
SA-60-1 (PNP)	0.194	1.067	227.8	1.50E+19	1.11	535	253.1	252.0	251.8	240.4	11.43
CAP V (DCPP)	0.198	0.999	222.26	1.37E+19	1.09	541.5	201.07	205.2	211.5	235.0	-23.56
Vessel Best Estimate CF =			**226.8**		**Mean T =**	**535.2**					
								Least Squares Fitted CF =		**216.13**	

Table 7. Weight Percent Nickel in Heat 34B009 Welds [14]

Sample Description	Average Ni%
Millstone 1 Surveillance Weld	1.05
H.B. Robinson 2 Torus-Dome Weld	0.80
Palisades Steam Generator Weld	1.09
Mean Value	0.98

Table 8. Evaluation of Surveillance Capsule Results Containing Plate Heat No. C-1279

Material I.D.	Capsule	Capsule fluence* (n/cm^2)	FF	Measured ΔRTndt (°F)	Predicted ΔRTndt (°F)	Measured - Predicted ΔRTndt (°F)
D3803-1 (Longitudinal)	A-240 [21]	4.09E+19	1.361	205.0	201.0	4.0
D3803-1 (Transverse)	A-240 [21]	4.09E+19	1.361	205.0	201.0	4.0
D3803-1 (Longitudinal)	W-290 [22]	9.38E+18	0.982	155.0	145.1	9.9
D3803-1 (Transverse)	W-290 [22]	9.38E+18	0.982	175.0	145.1	29.9
D3803-1 (Longitudinal)	W-110 [23]	1.64E+19	1.136	180.0	167.9	12.1
D3803-1 (Transverse)	W-100 [26]	2.09E+19	1.201	142.5	177.3	-34.8
D3803-1 (Longitudinal)	W-100 [26]	2.09E+19	1.201	159.1	177.3	-18.2

Fitted CF = 147.71

*Revised fluence values from WCAP-15353, Supplement 1-NP [4]

Table 9. Calculation of PTS Limit Date Based on Limiting Fluence for Axial Weld Heat No. W5214 @ 60° Location

Date	Neutron Fluence @ 60° n/cm^2 (E > 1 MeV)
November 2016	1.670E+19
December 2016	1.673E+19
January 2017	1.676E+19
February 2017	1.679E+19
March 2017	1.682E+19
April 2017	1.685E+19*
May 2017	1.688E+19
June 2017	1.691E+19
July 2017	1.694E+19
August 2017	1.697E+19
September 2017	1.700E+19
October 2017	1.703E+19
November 2017	1.706E+19
December 2017	1.709E+19
January 2018	1.712E+19
February 2018	1.715E+19
March 2018	1.718E+19
April 2018	1.721E+19

* Maximum fluence limit = 1.685×10^{19} n/cm^2 using revised fluence and W5214 surveillance data with fitted CF = 227.74°F and full (2-sigma) margin term

Note: Further analyses based on Palisades surveillance data only showed that the date to reach the PTS screening limit could be beyond April 2017 [5]. However, these capsule results for weld heat No. W5214 have not been fully credited since all surveillance data were used to develop a revised CF but without a reduced margin term.

Table 10: Palisades Vessel Beltline Material Properties on Extended Operating License Expiration Date (3/24/31)

RPV Material	Heat No.	Cu%	Ni%	CF (°F)	Surface Fluence (E19)	FF	$RT_{NDT}(U)$ (°F)	RT_{NDT} Shift (°F)	Margin (°F)	RT_{PTS} (°F)
Axial Weld 2-112A/B/C	W5214	0.213	1.007	227.74*	2.161	1.209	-56	275.4	65.5	284.9
Axial Weld 3-112A/B/C	W5214	0.213	1.007	227.74*	2.161	1.209	-56	275.4	65.5	284.9
	34B009	0.192	0.98	217.7	2.161	1.209	-56	263.2	65.5	272.7
Circ Weld 9-112	27204	0.203	1.018	216.13*	3.429	1.322	-56	285.7	44	273.7
Plate D-3803-1	C-1279	0.24	0.50	157.5	3.429	1.322	-5	209.5	34	238.5
Plate D-3803-2	A-0313	0.24	0.52	160.4	3.429	1.322	-30	212.0	34	216.0
Plate D-3803-3	C-1279	0.24	0.50	157.5	3.429	1.322	-5	209.5	34	238.5
Plate D-3804-1	C-1308A	0.19	0.48	128.8	3.429	1.322	0	170.3	34	204.3
Plate D-3804-2	C-1308B	0.19	0.50	131	3.429	1.322	-30	173.2	34	177.2
Plate D-3804-3	B-5294	0.12	0.55	82	3.429	1.322	-25	108.4	34	117.4

* Fitted CF values based on use of plant-specific surveillance data from all available sources

Table 11. Revised Estimated Date for Weld Heat No. W5214 to Reach PTS Screening Criterion Limit (RT_{PTS} = 270°F)

RPV Material	Heat No.	Cu%	Ni%	CF (°F)	Surface Fluence* (E19)	FF	$RT_{NDT}(U)$ (°F)	RT_{NDT} Shift (°F)	Margin (°F)	RT_{PTS} (°F)
Axial Weld 3-112A/C	W5214	0.213	1.007	227.74	1.685	1.144	-56	260.5	65.5	270

*** Limiting weld heat no. W5214 w/revised fluence and CF value (Estimated date to reach PTS screening criterion limit = April 2017) [5]**

Table 12. Revised Estimated Date for Weld Heat No. 27204 to Reach PTS Screening Criterion Limit (RT_{PTS} = 300°F)*

RPV Material	Heat No.	Cu%	Ni%	CF (°F)	Surface Fluence* (E19)	FF	$RT_{NDT}(U)$ (°F)	RT_{NDT} Shift (°F)	Margin (°F)	RT_{PTS} (°F)
Circ Weld 9-112	27204	0.203	1.018	216.13	6.24	1.444	-56	312.2	44	300

***Weld heat no. 27204 projected fluence to reach PTS screening criteria limit = 300°F (Estimated date > March 2031)**

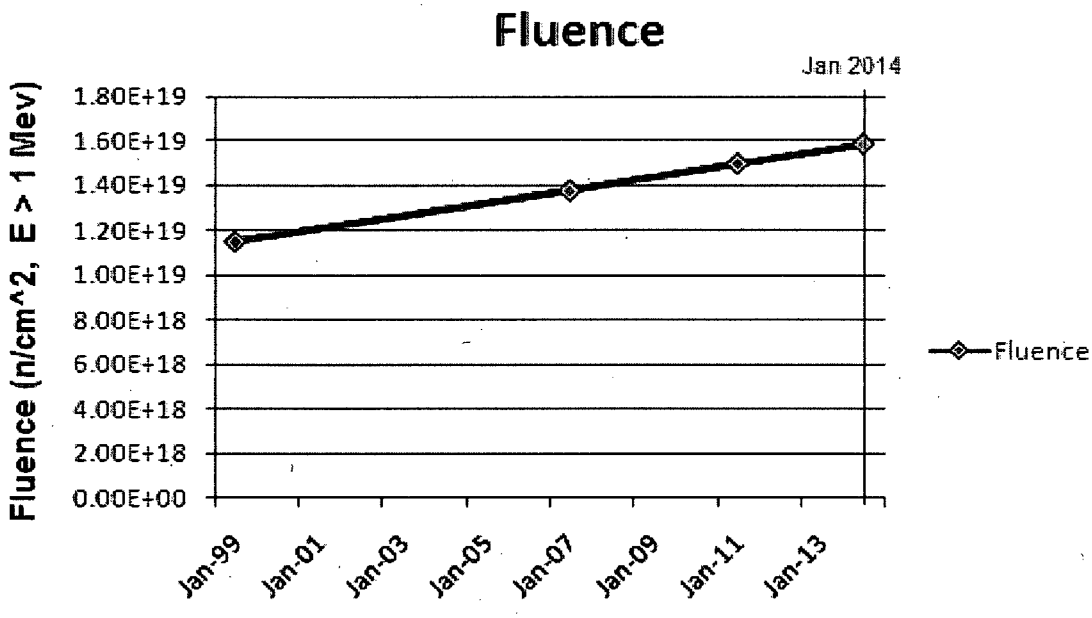

Figure 1. Projected Fluence at Limiting Vessel Axial Weld (60°) Using Previous Palisades Vessel Fluence Calculation (from Reference 3)

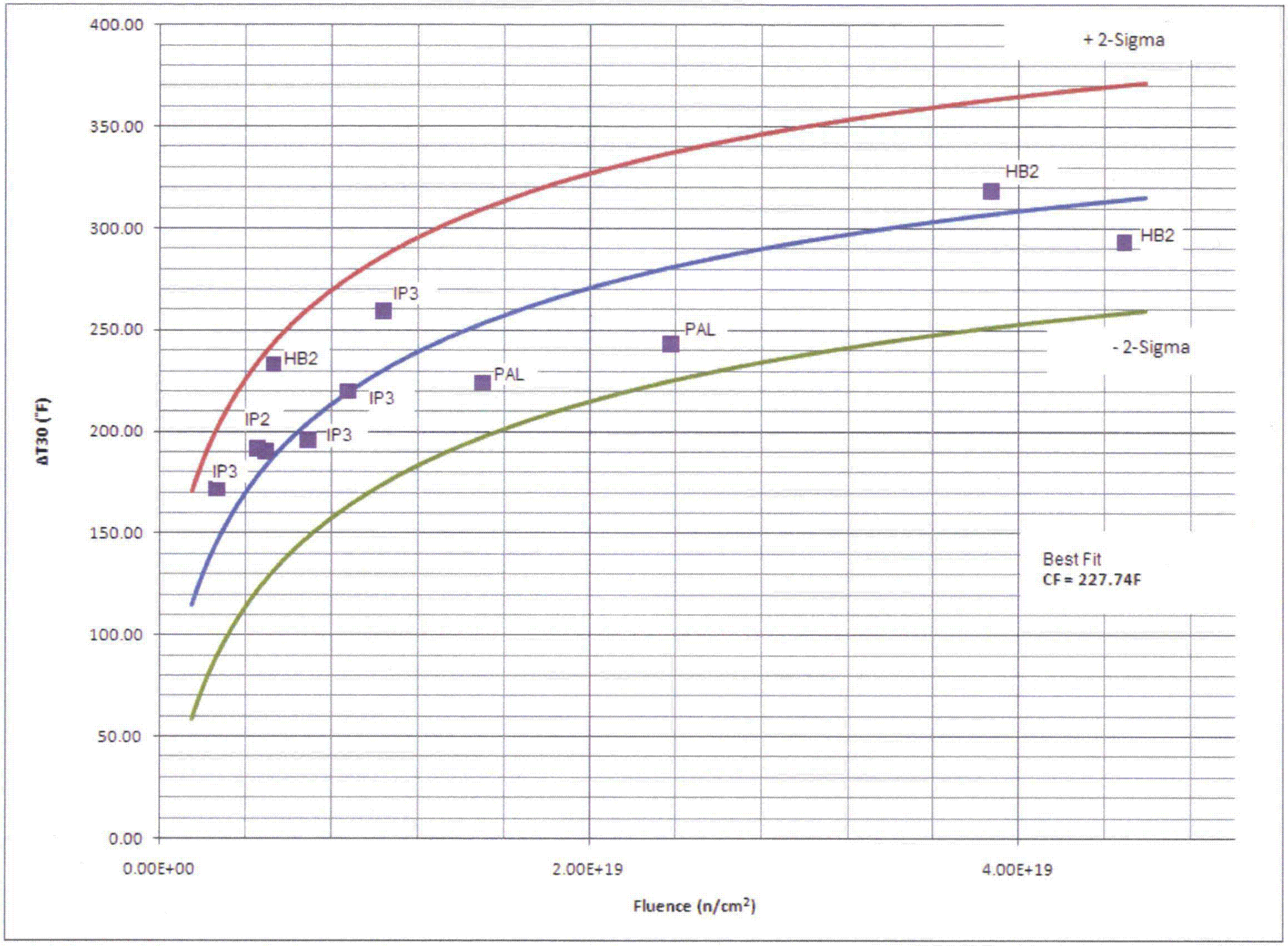

Figure 2. Best Fit for all W5214 Surveillance Data with Revised Fluence and Refitted Shift

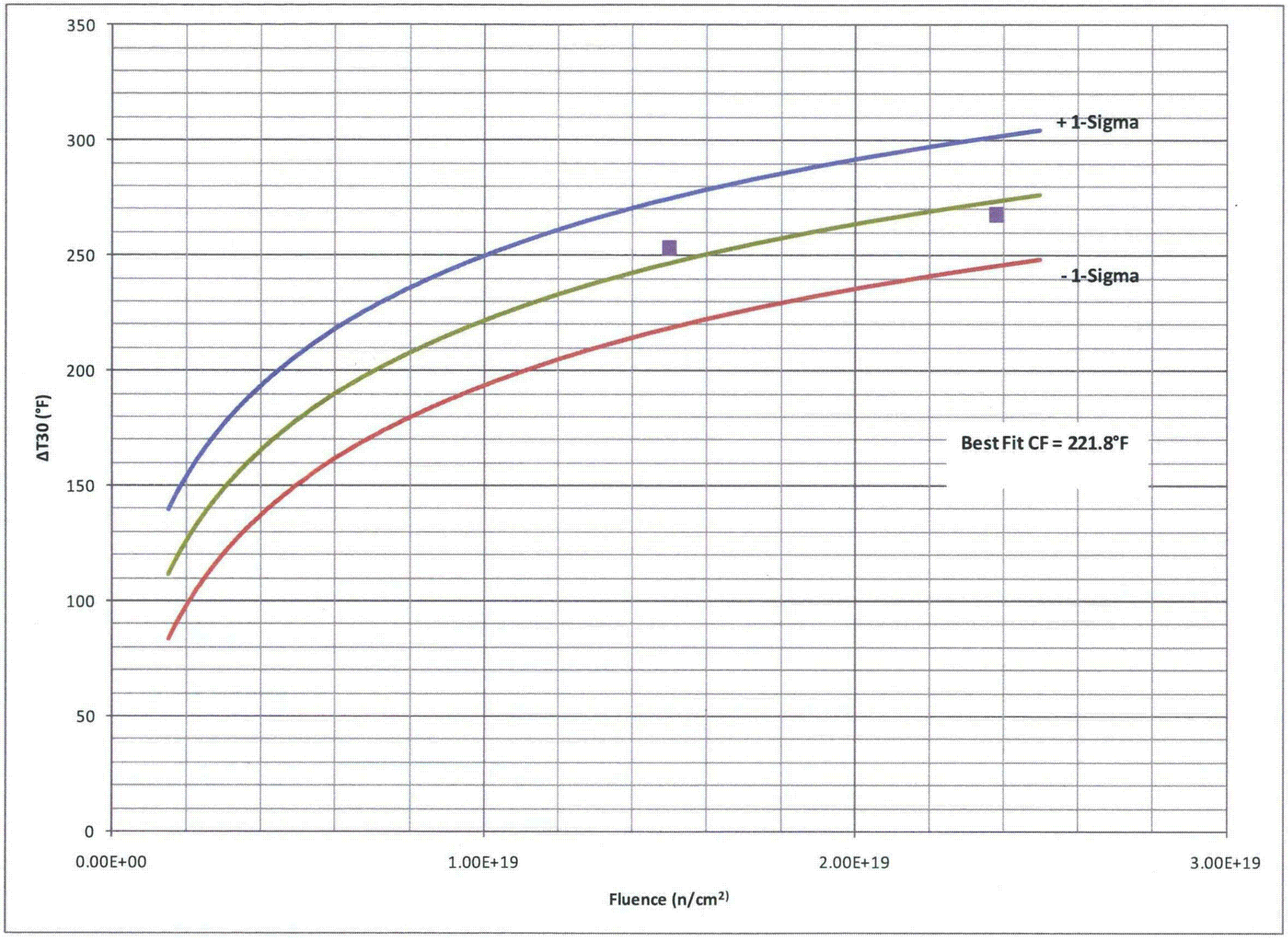

Figure 3. Best Fit for Palisades Weld Heat No. 27204 Surveillance Data

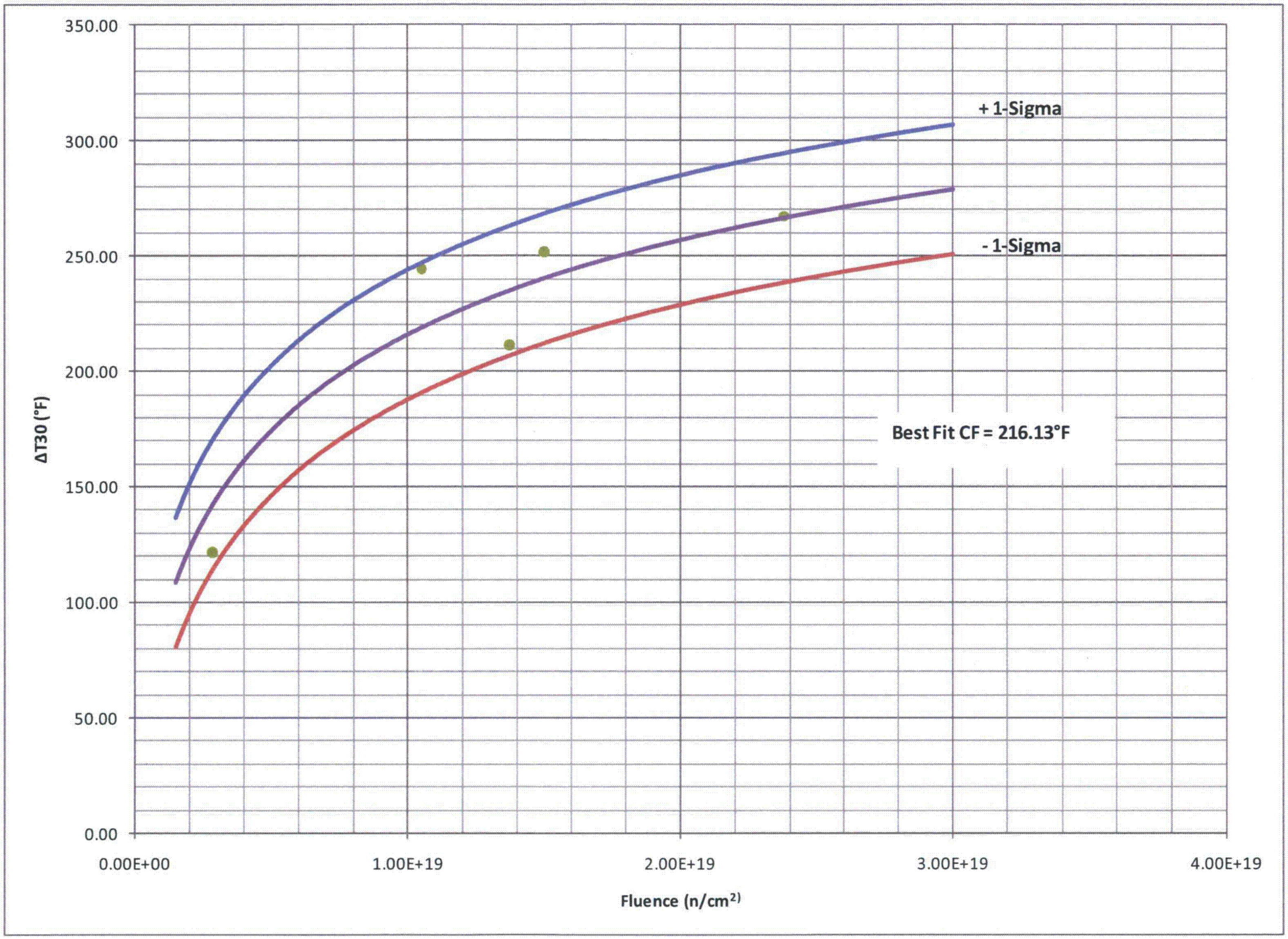

Figure 4. Best Fit for all Weld Heat No. 27204 Surveillance Data

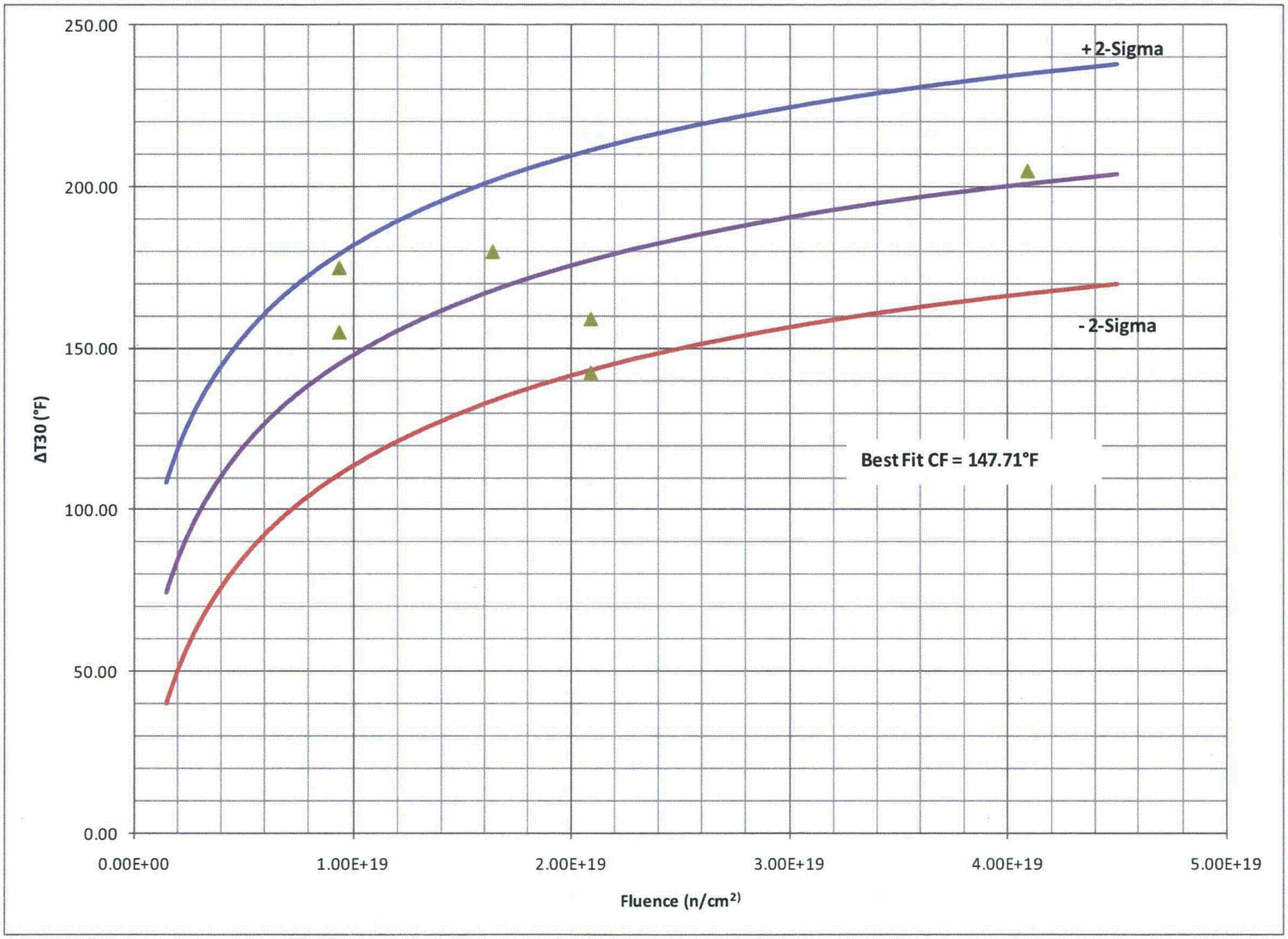

Figure 5. Best Fit for all Base Metal Heat No. C-1279 Surveillance Data

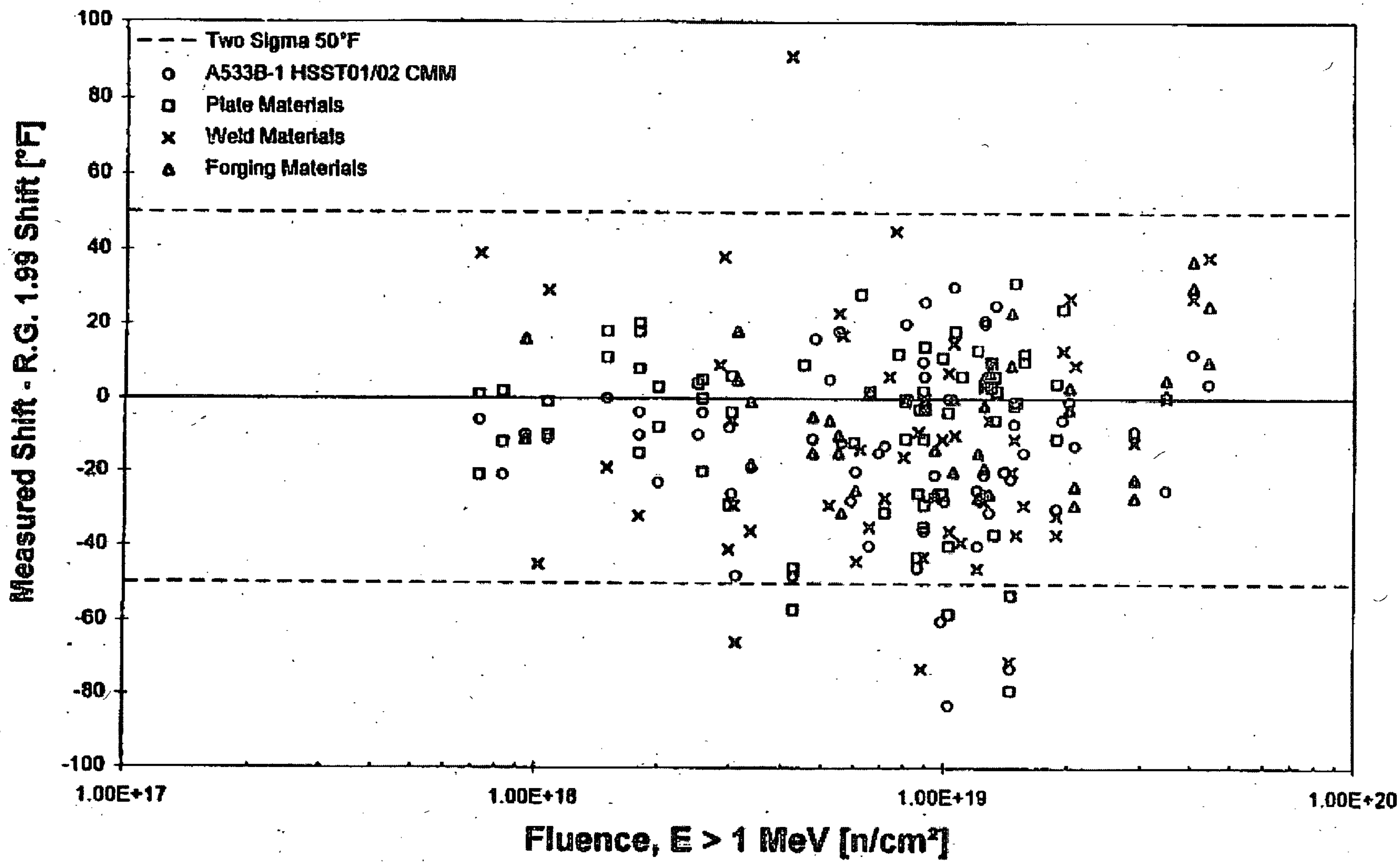

Figure 6. Plot of Residual vs. Fast Fluence for A533B-1 HSST-01/HSST-02 CMM with Companion Materials, the Overall 2-Sigma Scatter is 50°F [19].

Appendix A

DATA CREDIBILITY ASSESSMENT FOR WELD HEAT NO. 27204

DATA CREDIBILITY ASSESSMENT FOR WELD HEAT NO. 27204

The purpose of this evaluation is to apply the credibility requirements in 10CFR50.61 to the Palisades, and Diablo Canyon 1 surveillance capsule data and to determine if the surveillance capsule data is credible and can be used to improve the RT_{NDT} predictions for the vessel circumferential weld heat No. 27204.

10CFR50.61 describes general procedures acceptable to the NRC staff for calculating the effects of neutron radiation embrittlement of low-alloy steels currently used for light-water-cooled reactor vessels. 10CFR50.61 provides two methods for calculating the adjusted reference temperature of the reactor vessel beltline materials. The first method is described in paragraph (c)(1). The second method is described in paragraphs (c)(2) and (c)(3). The procedures in paragraphs (c)(2) and (c)(3) can only be applied when two or more credible surveillance data sets become available.

NRC provided additional guidance for evaluation and use of surveillance data in Reference 6. The evaluation presented herein is organized like Case 4 from this guidance document, the case for plants with surveillance data for their plant and from other sources.

Credibility Evaluation:

Criterion 1: The materials in the surveillance capsules must be those which are the controlling materials with regard to radiation embrittlement.

The beltline region of the reactor vessel is defined in Appendix G to 10 CFR 50, "Fracture Toughness Requirements" 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 and regard to radiation damage."

The Palisades reactor vessel consists of the following beltline region materials:

- Intermediate Shell, Axial Welds 2-112 A/B/C, material heat No. W5214,
- Lower Shell, Axial Welds 3-112 A/B/C, material heat No. W5214 and 34B009,
- Intermediate to Lower Shell, Circumferential Weld 9-112, material heat No. 27204,
- Intermediate Shell, Plate D-3803-1, material heat No. C-1279,
- Intermediate Shell, Plate D-3803-2, material heat No. A-0313,

- Intermediate Shell, Plate D-3803-3, material heat No. C-1279,
- Lower Shell, Plate D-3804-1, material heat No. C-1308A,
- Lower Shell, Plate D-3804-2, material heat No. C-1308B,
- Lower Shell, Plate D-3804-3, material heat No. B-5294.

The Palisades reactor vessel was designed and fabricated in accordance with the ASME Boiler and Pressure Vessel Code, Section III, 1965 Edition, including all addenda through Winter 1965 [16]. The Palisades reactor vessel surveillance program was originally developed with the intent to comply, where possible, with the guidance of ASTM E185-66, "Recommended Practice for Surveillance Tests on Structural Materials in Nuclear Reactors" [17]. At the time that the Palisades surveillance capsules were built, 10 CFR50 Appendices G and H did not exist.

Palisades supplemental capsules SA-240-1 and SA-60-1 were reinserted into the Palisades vessel at the end of Cycle 11 and removed for testing at the end of Cycle 13. The capsules contain reconstituted Charpy specimens made from weld heat No. 27204 obtained from Fort Calhoun, another C-E designed plant with the same weld heat. The weld material was carefully chosen, including the post weld heat treatment condition, in order to match the Palisades vessel beltline weld. Because weld heat No. 27204 in the capsules matches the limiting circumferential weld, the beltline material with the highest adjusted reference temperature and the limiting material for P-T curves, Criterion 1 is met for the Palisades 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.

Criterion 2 is satisfied if the Charpy energy data for the surveillance capsules containing weld heat No. 27204 can be fitted to determine the 30 ft-lb temperature (T_{30}) and upper shelf energy (USE) unambiguously. The data and Charpy energy curve fits for weld heat No. 27204 are shown in Appendix B. It was determined that the Charpy curve-fits have produced accurate 30 ft-lb temperatures and USE values. Hence, Criterion 2 is met for all the surveillance capsules evaluated here which contain weld metal heat No. 27204.

Criterion 3: When there are two or more sets of surveillance data from one reactor, the scatter of ΔRT_{NDT} values about a best-fit line drawn as described in Position 2 (surveillance data available) 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 fails 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 in ASTM E185.

The functional form of the least squares method as described in paragraph (c)(2) of 10CFR 50.61 will be utilized. A best-fit line is generated for this data to determine if the scatter of the ΔRT_{NDT} values about this line is less than 28°F for weld metal heat No. 27204.

The Palisades limiting weld metal will be evaluated for credibility using the NRC recommended guidelines [6]. Of the recommended methods, Case 4 most closely represents the situation for the Palisades surveillance weld metal where data is available from the plant of interest and from other plants.

Case 4a Credibility Assessment – Palisades 27204 Data Only

The data most representative for the Palisades limiting vessel weld are the supplemental surveillance capsules containing weld heat No. 27204 since the irradiation environment of the surveillance capsules and the reactor vessel are the same. The data requires the least adjustment since the radiation conditions are the same as the vessel. The Palisades weld heat No. 27204 capsule data are shown in Table A-1 and in Figure 3, along with the fitted solution (i.e., mean shift prediction) result, and the comparison of the measured – predicted scatter from the fitted CF of 221.8°F. A plot of the measured ΔT_{30} vs. fluence results for the Palisades supplemental capsule weld (27204) is shown in Figure 3 along with the +/- 1σ bounds for credible data scatter. The data clearly fall within the 1-sigma scatter band for credible surveillance data and the margin term can be reduced when using credible data.

Based on criterion 3, the Palisades surveillance data is credible since the scatter is less than 28°F for both of these surveillance capsules.

Table A-1. Evaluation of Palisades Surveillance Data Results for Weld Heat No. 27204

	Material	Capsule	Heat	Capsule fluence	FF	ΔRTndt	FF*ΔRTndt	FF^2
Weld	27204	SA-240-1 (PNP)	27204	2.38E+19	1.234	267.8	330	1.52
	27204	SA-60-1 (PNP)	27204	1.50E+19	1.112	253.1	282	1.24
				CF (SumSqrs)	Measured ΔRTndt	Predicted ΔRTndt	Scatter ΔRTndt	
	27204	SA-240-1 (PNP)	27204	221.8	267.8	273.6	-5.8	
	27204	SA-60-1 (PNP)	27204	221.8	253.1	246.7	6.4	

	FF*ΔRTndt	FF^2
Sum	611.9	2.8
Fitted CF	221.8	

Case 4b Credibility Assessment - All 27204 Surveillance Capsule Data

Following the guidance in Case 4 [6], the data from all sources should also be considered. For weld heat No. 27204 there are a total of five surveillance capsules, two from Palisades and three from Diablo Canyon Unit 1. Since data are from multiple sources, the data must be adjusted first for chemical composition differences and then for irradiation temperature differences before determining the least-squares fit.

The five capsule results and the fitted CF value, as shown in Table A-2, is determined to be 216.13°F for this case. The results for (measured – predicted) scatter for all the 27204 surveillance data results are also shown in Table A-2. The results for all the surveillance capsule data are plotted in Figure 4 along with the +/- 1σ scatter bands. The scatter in the measured – predicted values does not exceed 28°F (1-sigma). According to 10CFR50.61 paragraph (c)(2)(iv), the use of results from the plant-specific surveillance program may result in an RT_{NDT} that is higher or lower than that determined from the chemistry of the weld and a chemistry factor using the tables. If the CF value is higher, it must be used for vessel RT_{PTS} predictions, if the CF value is lower, it may be used. In this case the fitted CF value is lower.

The chemistry factor from the tables in paragraph (c)(1) is 226.8°F, and the adjusted chemistry factor using the Palisades surveillance capsule data is 216.13°F. It is noted that per NRC guidance that it is possible to use a lower value of chemistry factor based upon all sources of surveillance capsule data with a reduced margin term if the data is also credible in all other ways.

Therefore, the weld data meets this criterion, and the Palisades surveillance program weld metal chemistry factor to be used for determining RT_{PTS} and RT_{NDT} is 216.13°F in combination with a reduced (1-sigma) margin term of 44°F.

Table A-2. Evaluation of all Surveillance Capsule Results Containing Weld Heat No. 27204

Capsule	%Cu	%Ni	Table CF (F)	Revised Fluence (n/cm^2)	Fluence Factor FF	Irrad. Temp. Ti (F)	Measured ΔRTndt (F)	Ratio Adjusted ΔRTndt (F)	Chem. & Temp. Adj. ΔRTndt (F)	Predicted ΔRTndt (F)	Adjusted - Predicted (F)
CAP Y (DCPP)	0.198	0.999	222.26	1.05E+19	1.01	542	232.59	237.3	244.1	219.1	25.06
CAP S (DCPP)	0.198	0.999	222.26	2.84E+18	0.66	544	110.79	113.1	121.9	141.8	-19.97
SA-240-1 (PNP)	0.194	1.067	227.8	2.38E+19	1.23	535.7	267.8	266.7	267.2	266.7	0.49
SA-60-1 (PNP)	0.194	1.067	227.8	1.50E+19	1.11	535	253.1	252.0	251.8	240.4	11.43
CAP V (DCPP)	0.198	0.999	222.26	1.37E+19	1.09	541.5	201.07	205.2	211.5	235.0	-23.56
Vessel Best Estimate CF =			**226.8**		**Mean T =**	**535.2**					
							Least Squares Fitted CF =			**216.13**	

Note: None of the five (measured – predicted) data points exceed the 1 standard deviation of 28°F for credible data for welds.

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 Palisades supplemental surveillance capsules SA-60-1 and SA-240-1 were located in the reactor vessel between the core barrel and the vessel wall opposite the center of the core. These supplemental surveillance capsules were installed in the capsule holders located on the core support barrel. Table A-3 provides a history of the time-weighted temperature for the Palisades supplemental surveillance capsules and reactor vessel wall.

Table A-3. History of Time-Weighted Operating Temperature for Palisades

Operating Cycle Number	Cycle Length[a] (EFPD)	Cycle Average Vessel Temp.[b] (°F)	Surveillance Capsule Removed	Time Weighted Capsule Avg. T (°F)	Time Weighted Vessel Avg. T (°F)
1	371.7	523			
2	440.1	529	A-240	526	
3	342.5	534			
4	321.0	536			
5	386.7	536	W-290	531	
6	326.7	536			
7	362.5	536			
8	366.1	537			
9	292.5	534			
10	349.7	534	W-110	533	
11	421.9	533			
12	399.3	534			
13	419.6	536	SA-60-1	535.0	
14	449.3	537	SA-240-1	535.7	
15	401.3	537			
16	444.3	537			
17	493.1	537			
18	472	537			
19	459.2	537			
20	499.8	537			
21	519.2	537			
22	498.8	537			535.2

(a) Cycle length (EFPD) values obtained from Reference 18

(b) Cycle average vessel temperatures obtained from Reference 20

(c) Cycles 1-12 EFPDs are reduced by 2% to account for power reduction factor per the guidance in [18]

The location of the specimens with respect to the reactor vessel beltline assured that the reactor vessel wall and the specimens have experienced equivalent operating conditions such that the temperatures did not differ by more than 25°F. Therefore, this criterion is satisfied for the Palisades capsules.

The Diablo Canyon 1 capsule irradiation temperatures are shown in Table A-2 [12]. These temperatures are also within 25°F of the Palisades average vessel irradiation temperature of 535.2°F.

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

The Palisades supplemental surveillance capsules, SA-60-1 and SA-240-1, both contain standard reference material HSST02 plate. Plots of the Charpy energy versus temperature for the irradiated condition of correlation monitoring material (HSST Plate 02, Heat A1195-1) from SA-60-1 and SA-240-1 are documented in BAW-2341 Rev 2 [10] and BAW-2398 [11], respectively. Charpy energy versus temperature for the unirradiated correlation monitoring material (HSST Plate 02, Heat A1195-1) is taken from NUREG/CR-6413, ORNL/TM-13133 [19]. Tables A-4 and A-5 provide the updated calculation of (measured – predicted) scatter versus fast fluence in the correlation monitor material (HSST 02) data. Figure 6 (from Reference 19) shows that the measured scatter band for the correlation monitor materials is 50°F.

Table A-4. Correlation Monitor Material HSST Plate 02
Calculation of Fitted CF

Capsule	Fluence ($x\ 10^{19}$) (a)	Fluence Factor (FF) (b)	ΔRT_{NDT} (c) (°F)	FF * ΔRT_{NDT}	FF^2
SA-60-1	1.5	1.112	113.7	126.4344	1.2365
SA-240-1	2.38	1.234	140.9	173.871	1.5223
			Sum	300.305	2.7588
CF Surveillance weld = Σ (FF x RT_{NDT}) / Σ (FF^2)= 300.305/2.7588 = 108.853					
Slope of best fit line is 108.853					
Notes: (a) Calculated fluence (x 10^{19} n/cm^2, E>1.0 MeV) (b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$ (c) Irradiated values of 30 ft-lb Transition Temperature From BAW-2341 Rev 2 and BAW-2398 [10, 11]					

Table A-5. Correlation Monitor Material HSST Plate 02
Calculation of Measured – Predicted Scatter

Capsule	Fluence (x 10^{19}) [a]	Fluence Factor (FF) [b]	ΔRT_{NDT} [c]	Predicted ΔRT_{NDT}	(Measured – Predicted) ΔRT_{NDT}
SA-60-1	1.5	1.112	113.7	121.044	-7.344
SA-240-1	2.38	1.234	140.9	134.324	6.575
Where predicted ΔRT_{NDT} = (slope $_{\text{best fit}}$)*(Fluence Factor) Slope of best fit line is 108.853					
Notes: (a) Calculated fluence (x 10^{19} n/cm^2, E>1.0 MeV) (b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$ (c) Irradiated values of 30 ft-lb Transition Temperature From BAW-2341 Rev 2 and BAW-2398 [10, 11]					

Table A-5 shows that the scatter in these data is less than 50°F, which is the allowable scatter in NUREG/CR-6413, ORNL/TM-13133 [19]. Thus, criterion 5 is satisfied for the correlation monitor materials.

Appendix B

SURVEILLANCE CAPSULE DATA FOR WELD HEAT NO. 27204

BAW-2341, Revision 2
May 2001

Test Results of Capsule SA-60-1
Consumers Energy
Palisades Nuclear Plant

-- Reactor Vessel Material Surveillance Program --

by

M. J. DeVan

FTI Document No. 77-2341-02
(See Section 7 for document signatures.)

Prepared for

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Executive Summary

This report describes the results of the test specimens from the first supplemental capsule (Capsule SA-60-1) of the Consumers Energy Palisades Nuclear Plant as part of their reactor vessel surveillance program. The objective of the program is to monitor the effects of neutron irradiation on the mechanical properties of the reactor vessel materials by testing and evaluation of Charpy impact specimens.

Supplemental Capsule SA-60-1 was removed from the Palisades reactor vessel at the end-of-cycle 13 (EOC-13) for testing and evaluation. The capsule contents were removed from Capsule SA-60-1 for testing and examination. The test specimens included modified 18mm Charpy V-notch inserts for three weld metals fabricated with weld wire heats W5214, 34B009, and 27204 and standard Charpy V-notch specimens fabricated from the correlation monitor plate material, HSST Plate 02. The weld metal Charpy inserts were reconstituted to full size Charpy V-notch specimens. The reconstituted weld metals along with HSST Plate 02 material were Charpy impact tested.

Following the initial Charpy V-notch impact testing, the laboratory performed a calibration of the temperature indicator used in the Palisades Capsule SA-60-1 testing. The results of the laboratory calibration indicated the instrument was out-of-tolerance. Based on the results of this calibration test, the laboratory revised the Charpy impact test temperatures accordingly. Revision 1 corrects the test temperatures for the Supplemental Capsule SA-60-1 reconstituted weld metal Charpy V-notch impact specimens and the HSST Plate 02 Charpy V-notch impact specimens.

Revision 2 provides an update to the hyperbolic tangent curve fits of the Charpy impact curves by restraining the upper-shelf energy. For these curve fits, the lower-shelf energy was fixed at 2.2 ft-lbs for all cases, and for each materials the upper-shelf energy was fixed at the average of all test energies exhibiting 100% shear, consistent with ASTM Standard E 185-82. 2

of full size Type A Charpy V-notch specimens in accordance with ASTM Standard E 23-91. The reconstituted Charpy specimen dimensions for each specimen are shown in Table 4-2. Upon completion of the machining of the reconstituted Charpy specimens, twelve (12) specimens were selected from each weld metal for Charpy impact testing.

4.5. Charpy V-Notch Impact Test Results

The Charpy V-notch impact testing was performed in accordance with the applicable requirements of ASTM Standard E 23-91. Impact energy, lateral expansion, and percent shear fracture were measured at numerous test temperatures and recorded for each specimen. The impact energy was measured using a certified Satec S1-1K Impact tester (traceable to NIST Standard) with 240 ft-lb of available energy. The lateral expansion was measured using a certified dial indicator. The specimen percent shear was estimated by video examination and comparison with the visual standards presented in ASTM Standard E 23-91. In addition, all Charpy V-notch impact testing was performed using instrumentation to record a load-versus-time trace and energy-versus-time trace for each impact event. The load-versus-time traces were analyzed to determine time, load, and impact energy for general yielding, maximum load, fast fracture, and crack arrest properties during the test. The dynamic yield stress is calculated from the three-point bend formula:

$$\sigma_y = 33.33 * (\textit{general yielding load})$$

The dynamic flow stress is calculated from the average of the yield and maximum loads, also using the three-point bend formula:

$$\sigma_{flow} = 33.33 * \left(\frac{(\textit{general yielding load} + \textit{maximum load})}{2}\right)$$

The results of the Charpy V-notch impact testing are shown in Tables 4-3 through 4-10 and Figures 4-2 through 4-5, and the individual load-versus-time traces for the instrumented Charpy V-notch impact tests are presented in Appendix B. The curves were generated using a hyperbolic tangent curve-fitting program to produce the best-fit curve through the data. The hyperbolic tangent (TANH) function (test response, i.e., absorbed energy, lateral expansion, and percent shear fracture, "R," as a function of test temperature, "T") used to evaluate the surveillance data is as follows:

$$R = A + B * \tanh\left[\frac{(T - To)}{C}\right]$$

For the absorbed (impact) energy curves, the lower-shelf energy was fixed at 2.2 ft-lbs for all materials, and the upper-shelf energy was fixed at the average of all test energies exhibiting 100 percent shear for each material, consistent with the ASTM Standard E 185-82. The lateral expansion curves were generated with the lower-shelf mils lateral expansion fixed at 1 mil and the upper-shelf mils lateral expansion not constrained (i.e., not fixed). The percent shear fracture curves for each material were generated with the lower-shelves and upper-shelves fixed at 0 and 100 respectively. 2

The Charpy V-notch data was entered, and the coefficients *A*, *B*, *To*, and *C* are determined by the program minimizing the sum of the errors squared (least-squares fit) of the data points about the fitted curve. Using these coefficients and the above TANH function, a smooth curve is generated through the data for interpretation of the material transition region behavior. The coefficients determined for irradiated materials in Capsule SA-60-1 are shown in Table 4-11.

The transition temperature shifts and upper-shelf energy decreases for the Capsule SA-60-1 materials with respect to the unirradiated material properties are summarized in Table 4-12.

Photographs of the Charpy V-notch specimen fracture surfaces are presented in Figures 4-6 through 4-9.

Table 4-5. Charpy Impact Results for Palisades Capsule SA-60-1 Irradiated Weld Metal 27204

Specimen ID	Test Temperature, °F	Impact Energy, ft-lbs	Lateral Expansion, mil	Shear Fracture, %
PB68	74	12.5	7	0
PB56	129	16.5	13	40
PB81	154	17	10	30
PB78	204	25	19	45
PB93	229	28	27	70
PB91	254	39.5	35	85
PB28	279	44.5	39	95
PB96	329	52.5*	48	100
PB94	329	52*	50	100
PB15	404	57*	53	100
PB42	454	55*	49	100
PB95	479	48.5*	43	100

* Value used to determine upper-shelf energy (USE) in accordance with ASTM Standard E 185-82.[15]

Table 4-11. Hyperbolic Tangent Curve Fit Coefficients for the Palisades Capsule SA-60-1 Surveillance Materials

Material Description	Hyperbolic Tangent Curve Fit Coefficients		
	Absorbed Energy	Lateral Expansion	Percent Shear Fracture
Weld Metal W5214	A: 28.4 B: 26.2 C: 158.1 T0: 188.8	A: 25.0 B: 24.0 C: 160.0 T0: 239.6	A: 50.0 B: 50.0 C: 80.5 T0: 214.9
Weld Metal 34B009	A: 28.7 B: 26.5 C: 123.8 T0: 161.8	A: 25.3 B: 24.3 C: 97.6 T0: 196.4	A: 50.0 B: 50.0 C: 89.6 T0: 179.6
Weld Metal 27204	A: 27.6 B: 25.4 C: 111.4 T0: 201.4	A: 25.9 B: 24.9 C: 101.8 T0: 214.4	A: 50.0 B: 50.0 C: 92.1 T0: 187.1
Correlation Monitor Plate, HSST Plate 02 (Heat No. A1195-1)	A: 44.3 B: 42.1 C: 95.1 T0: 193.0	A: 41.3 B: 40.3 C: 104.9 T0: 208.6	A: 50.0 B: 50.0 C: 85.2 T0: 183.7

2

Table 4-12. Summary of Charpy Impact Test Results for the Palisades Capsule SA-60-1 Surveillance Materials

Material Description	30 ft-lb Transition Temperature, °F			50 ft-lb Transition Temperature, °F			35 mil Lateral Expansion Transition Temperature, °F			Upper-Shelf Energy, ft-lb		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	Decrease
Weld Metal W5214	-60.2[a]	198.8	259.0	-17.4[a]	375.6	393.0	-29.6[a]	310.1	339.7	102.7[a]	54.5	48.2
Weld Metal 34B009	-82.0[a]	167.8	249.8	-45.0[a]	298.6	343.6	-51.6[a]	237.5	289.1	113.9[a]	55.25	58.65
Weld Metal 27204	-41.2[b]	211.9	253.1	-6.1[b]	355.6	361.7	Not available.	249.4	---	108.4[b]	53.0	55.4
HSST Plate 02 Heat No A1195-1	45.7[c]	159.4	113.7	78.3[c]	206.0	127.7	Not available.	187.9	---	120.3[c]	86.3	34.0

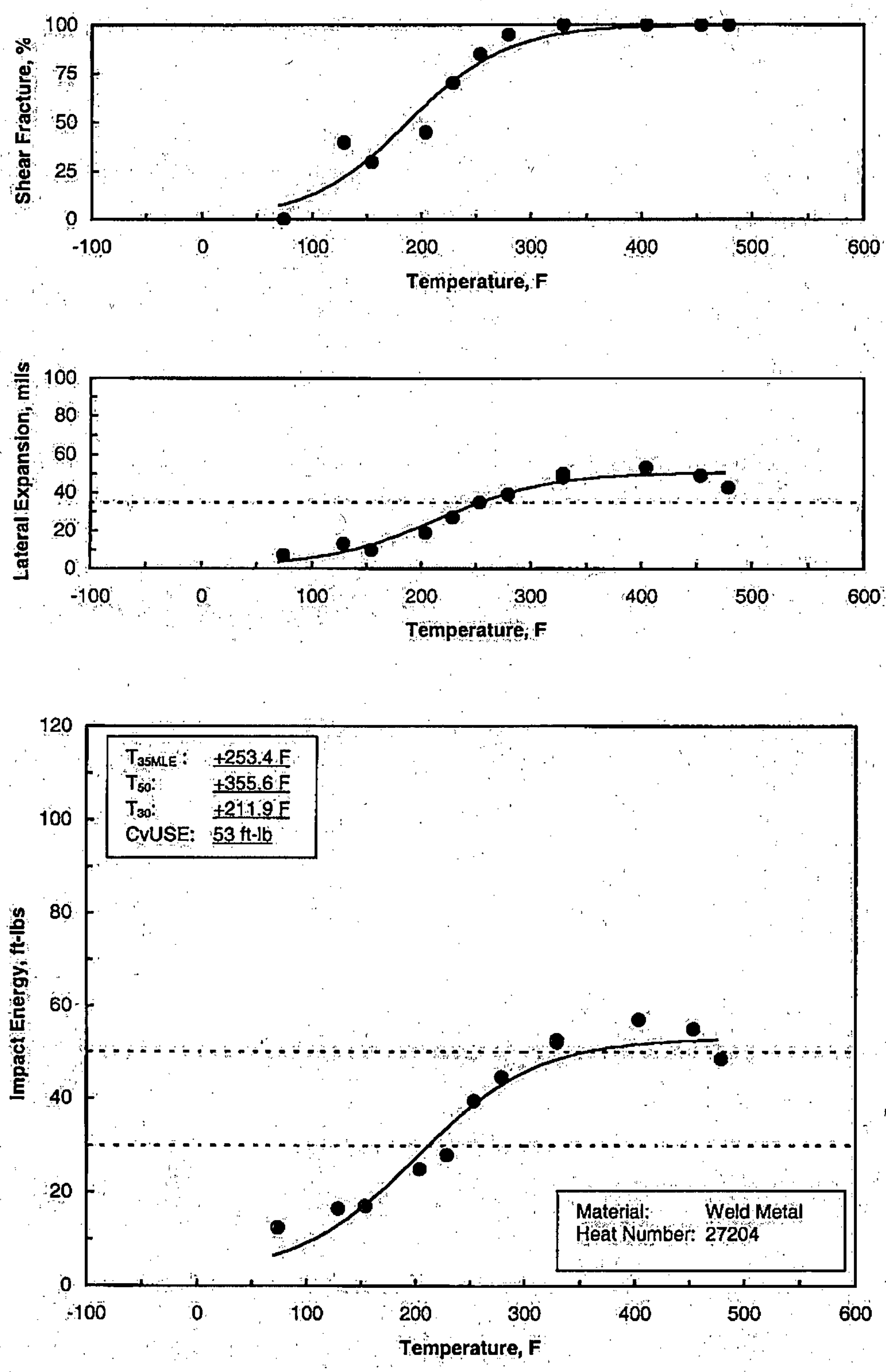
2

(a) Data reported in AEA Technology Report AEA-TSD-0774.[8]

(b) Data reported in CE Report No. TR-MCC-189.[16]

(c) Data reported in NUREG/CR-6413.[10]

Figure 4-4. Charpy Impact Data for Irradiated Weld Metal 27204



2

BAW-2398
May 2001

Test Results of Capsule SA-240-1
Consumers Energy
Palisades Nuclear Plant

-- Reactor Vessel Material Surveillance Program --

by

M. J. DeVan

FTI Document No. 77-2398-00
(See Section 7 for document signatures.)

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Executive Summary

This report describes the results of the tests performed on the specimens contained in the second supplemental reactor vessel surveillance capsule (Capsule SA-240-1) from the Consumers Energy Palisades Nuclear Plant. The objective of the program is to monitor the effects of neutron irradiation on the mechanical properties of the reactor vessel materials by testing and evaluation of Charpy impact specimens.

Supplemental Capsule SA-240-1 was removed from the Palisades reactor vessel at the end-of-cycle 14 (EOC-14) for testing and evaluation. The test specimens included modified 18mm Charpy V-notch inserts for three weld metals fabricated with weld wire heats W5214, 34B009, and 27204 and standard Charpy V-notch specimens fabricated from the correlation monitor plate material, HSST Plate 02. The weld metal Charpy inserts were reconstituted to full size Charpy V-notch specimens. The reconstituted weld metals along with HSST Plate 02 material were Charpy impact tested. The results of these tests are presented in this document.

the center position of the temperature verification mockup insert ranged from 347°F to 511°F, which is less than the Palisades reactor vessel cold-leg temperature and meets the temperature requirement of ASTM Standard E 1253-88.

Twelve (12) stud-welded inserts were then selected from each of the weld metals W5214, 34B009, and 27204 for machining of full size Type A Charpy V-notch specimens in accordance with ASTM Standard E 23-91. The reconstituted Charpy specimen dimensions for each specimen are shown in Table 4-2.

4.5. Charpy V-Notch Impact Test Results

The Charpy V-notch impact testing was performed in accordance with the applicable requirements of ASTM Standard E 23-91. Prior to testing, the specimens were temperature-controlled in liquid immersion baths, capable of covering the temperature range -100°F to +550°F. Specimens remain immersed in the liquid medium at the test temperature ±2°F for at least 10 minutes before testing to assure achievement of thermal equilibrium. A certified Omega Model 462 device was used to measure the temperature. Impact energy, lateral expansion, and percent shear fracture were measured at numerous test temperatures and recorded for each specimen. The impact energy was measured using a certified Satec S1-1K Impact tester (traceable to NIST Standard[a]) with a striker velocity of 16.90 ft/sec and 240 ft-lb of available energy. The lateral expansion was measured using a certified dial indicator. The specimen percent shear was estimated by video examination and comparison with the visual standards presented in ASTM Standard E 23-91. In addition, all Charpy V-notch impact testing was performed using instrumentation to record a load-versus-time trace and energy-versus-time trace for each impact event. The load-versus-time traces were analyzed to determine time, load, and impact energy for general yielding, maximum load, fast fracture, and crack arrest properties during the test. The dynamic yield stress is calculated from the three-point bend formula:

$$\boxed{\sigma_y = \mathbf{33.33} * (\textbf{\textit{general yielding load}})}$$

The dynamic flow stress is calculated from the average of the yield and maximum loads, also using the three-point bend formula:

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[a] Each year, two sets of Charpy specimens are purchased from NIST and tested on the Charpy test machine. The results are then sent to NIST for evaluation. A letter is then issued by NIST certifying the calibration of the Charpy test machine. The accuracy of the Charpy tester is ±1 ft-lb or 5% of the dial reading whichever is greater.

$$\sigma_{flow} = 33.33 * \left(\frac{(general\ yielding\ load + maximum\ load)}{2} \right)$$

The results of the Charpy V-notch impact testing are shown in Tables 4-3 through 4-10 and Figures 4-2 through 4-5, and the individual load-versus-time traces for the instrumented Charpy V-notch impact tests are presented in Appendix B. The curves were generated using a hyperbolic tangent curve-fitting program to produce the best-fit curve through the data. The hyperbolic tangent (TANH) function (test response, i.e., absorbed energy, lateral expansion, and percent shear fracture, "R," as a function of test temperature, "T") used to evaluate the surveillance data is as follows:

$$R = A + B * \tanh\left[\frac{(T - To)}{C}\right]$$

For the absorbed (impact) energy curves, the lower-shelf energy was fixed at 2.2 ft-lbs for all materials, and the upper-shelf energy was fixed at the average of all test energies exhibiting 100 percent shear for each material, consistent with the ASTM Standard E 185-82. The lateral expansion curves were generated with the lower-shelf mils lateral expansion fixed at 1 mil and the upper-shelf mils lateral expansion not constrained (i.e., not fixed). The percent shear fracture curves for each material were generated with the lower-shelves and upper-shelves fixed at 0 and 100 respectively.

The Charpy V-notch data was entered, and the coefficients *A, B, To,* and *C* are determined by the program minimizing the sum of the errors squared (least-squares fit) of the data points about the fitted curve. Using these coefficients and the above TANH function, a smooth curve is generated through the data for interpretation of the material transition region behavior. The coefficients determined for irradiated materials in Capsule SA-240-1 are shown in Table 4-11.

The transition temperature shifts and upper-shelf energy decreases for the Capsule SA-240-1 materials with respect to the unirradiated material properties are summarized in Table 4-12.

Photographs of the Charpy V-notch specimen fracture surfaces are presented in Figures 4-6 through 4-9.

Table 4-5. Charpy Impact Results for Palisades Capsule SA-240-1 Irradiated Weld Metal 27204

Specimen ID	Test Temperature, °F	Impact Energy, ft-lbs	Lateral Expansion, mil	Shear Fracture, %
PB45	70	5.5	3	0
PB62	125	16.5	12	10
PB71	175	16	18	30
PB54	200	26.5	29	55
PB07	200	33.5	27	60
PB73	225	29	24	65
PB52	250	34.5	26	55
PB35	300	36	32	65
PB06	350	44.5	43	95
PB58	400	49.5*	42	100
PB57	450	59*	52	100
PB61	500	53*	47	100

* Value used to determine upper-shelf energy (USE) in accordance with ASTM Standard E 185-82.[17]

Table 4-11. Hyperbolic Tangent Curve Fit Coefficients for the Palisades Capsule SA-240-1 Surveillance Materials

Material Description	Hyperbolic Tangent Curve Fit Coefficients		
	Absorbed Energy	Lateral Expansion	Percent Shear Fracture
Weld Metal W5214	A: 27.4 B: 25.2 C: 111.6 T0: 208.1	A: 22.8 B: 21.8 C: 83.5 T0: 231.7	A: 50.0 B: 50.0 C: 72.5 T0: 223.2
Weld Metal 34B009	A: 29.8 B: 27.6 C: 111.7 T0: 176.6	A: 22.9 B: 21.9 C: 88.0 T0: 184.3	A: 50.0 B: 50.0 C: 109.8 T0: 192.6
Weld Metal 27204	A: 28.0 B: 25.8 C: 145.7 T0: 215.3	A: 25.6 B: 24.6 C: 169.2 T0: 225.9	A: 50.0 B: 50.0 C: 118.4 T0: 210.1
Correlation Monitor Plate, HSST Plate 02 (Heat No. A1195-1)	A: 43.3 B: 41.1 C: 75.3 T0: 211.8	A: 35.8 B: 34.8 C: 83.1 T0: 222.2	A: 50.0 B: 50.0 C: 75.9 T0: 206.5

Table 4-12. Summary of Charpy Impact Test Results for the Palisades Capsule SA-240-1 Surveillance Materials

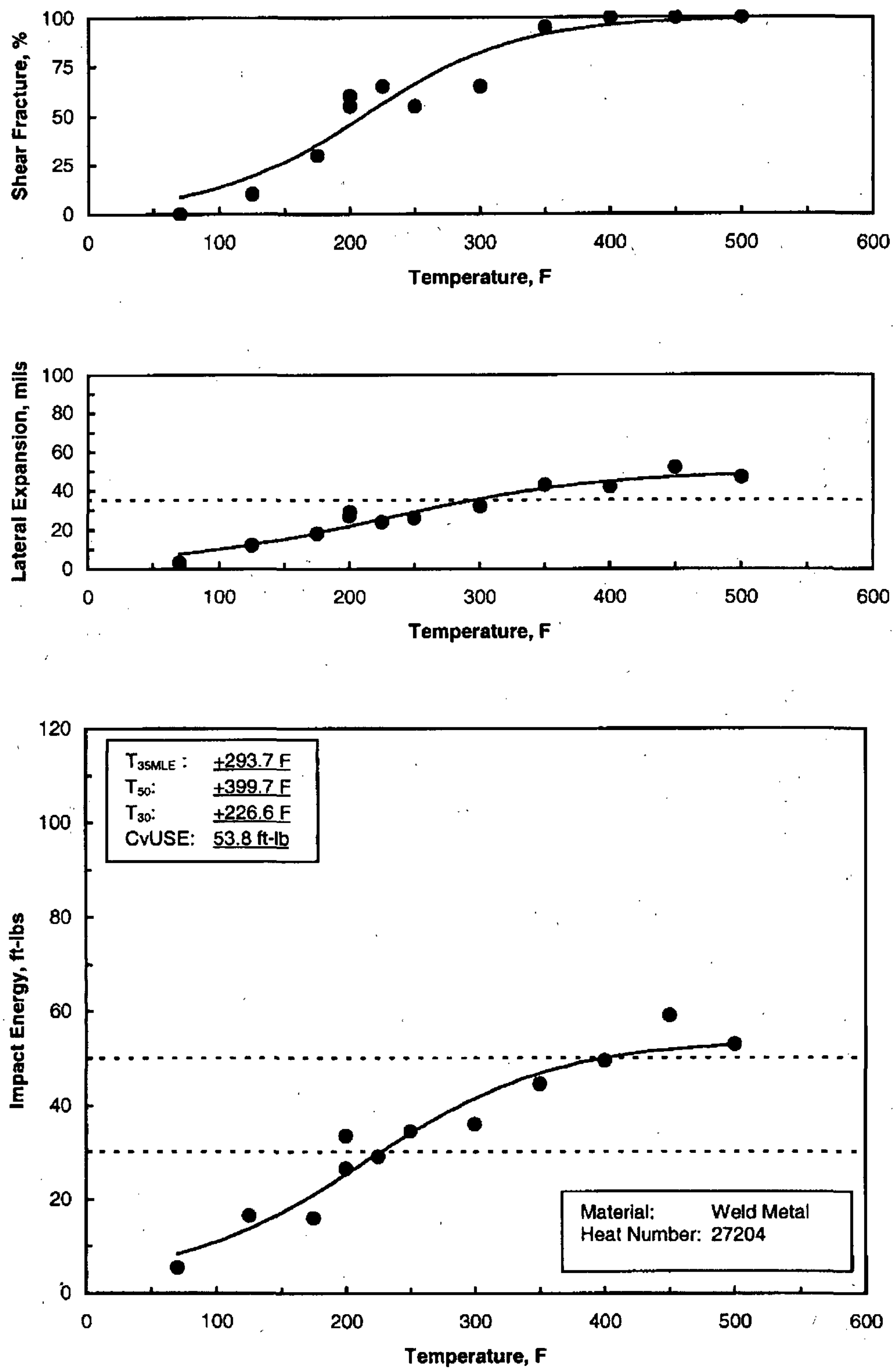
Material Description	*30 ft-lb Transition Temperature, °F*			*50 ft-lb Transition Temperature, °F*			*35 mil Lateral Expansion* Transition Temperature, °F			Upper-Shelf Energy, ft-lb		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	Decrease
Weld Metal W5214	-60.2[(a)]	219.9	280.1	-17.4[(a)]	372.7	390.1	-29.6[(a)]	284.3	313.9	102.7[(a)]	52.5	50.2
Weld Metal 34B009	-82.0[(a)]	177.4	259.4	-45.0[(a)]	280.8	325.8	-51.6[(a)]	238.6	290.2	113.9[(a)]	57.4	56.5
Weld Metal 27204	-41.2[(b)]	226.6	267.8	-6.1[(b)]	399.7	405.8	Not available.	293.7	---	108.4[(b)]	53.8	54.6
HSST Plate 02 Heat No A1195-1	45.7[(c)]	186.6	140.9	78.3[(c)]	224.2	145.9	Not available.	220.3	---	120.3[(c)]	84.4	35.9

(a) Data reported in AEA Technology Report AEA-TSD-0774.[9]

(b) Data reported in CE Report No. TR-MCC-189.[18]

(c) Data reported in NUREG/CR-6413.[11]

Figure 4-4. Palisades Capsule SA-240-1 Charpy Impact Data for Irradiated Weld Metal 27204



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WCAP-11567

ANALYSIS OF CAPSULE S FROM THE PACIFIC GAS AND ELECTRIC COMPANY DIABLO CANYON UNIT 1 REACTOR VESSEL RADIATION SURVEILLANCE PROGRAM

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DECEMBER 1987

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SECTION 1
SUMMARY OF RESULTS

The analysis of the reactor vessel material contained in surveillance Capsule S, the first capsule to be removed from the Pacific Gas and Electric Company Diablo Canyon Unit 1 reactor pressure vessel, led to the following conclusions:

- o The capsule received an average fast neutron fluence (E > 1.0 MeV) of 2.98×10^{18} n/cm^2.

- o Irradiation of specimens made from the reactor vessel intermediate shell plate B4106-3 to 2.98×10^{18} n/cm^2 resulted in 30 and 50 ft-lb transition temperature shifts of -2°F and 4°F respectively, for specimens oriented parallel to the major working direction (longitudinal orientation).

- o Specimens made from weld metal irradiated to 2.98×10^{18} n/cm^2 resulted in 30 and 50 ft-lb transition temperature increases of 110°F and 148°F respectively.

- o Irradiation to 2.98×10^{18} n/cm^2 resulted in a 11 ft-lb decrease in the upper shelf energy of the weld metal specimens and no decrease in the upper shelf of the shell plate B4106-3 specimens. Both materials exhibit a more than adequate upper shelf level for continued safe plant operation.

- o Comparison of the 30 ft-lb transition temperature increases for the Diablo Canyon Unit 1 surveillance material with predicted increases using the methods of NRC Regulatory Guide 1.99 proposed Revision 2 shows that the plate material and weld metal transition temperature increase are less than predicted.

- o Capsule S contained specimens from the same heat of weld wire (Heat 27204) as the limiting reactor vessel weld seam. The surveillance program is therefore representative of the limiting reactor vessel material.

SECTION 5

TESTING OF SPECIMENS FROM CAPSULE S

5.1 Overview

The postirradiation mechanical testing of the Charpy V-notch and tensile specimens was performed at the Westinghouse Research and Development Laboratory with consultation by Westinghouse Power Systems Division personnel. Testing was performed in accordance with 10CFR50, Appendices G and H,[2] ASTM Specification E185-82, and Westinghouse Procedure RMF-8402, Revision 0 as modified by RMF Procedures 8102 and 8103.

Upon receipt of the capsule at the laboratory, the specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in WCAP-8465.[1] No discrepancies were found.

Examination of the two low-melting point 304°C (579°F) and 310°C (590°F) eutectic alloys indicated no melting of either type of thermal monitor. Based on this examination, the maximum temperature to which the test specimens were exposed was less than 304°C (579°F).

The Charpy impact tests were performed per ASTM Specification E23-82 and RMF Procedure 8103 on a Tinius-Olsen Model 74,358J machine. The tup (striker) of the Charpy machine is instrumented with an Effects Technology Model 500 instrumentation system. 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. The load at which fast fracture was initiated is identified as the fast fracture load (P_F), and the load at which fast fracture terminated 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 roughly 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.

The yield stress (σ_Y) is calculated from the three-point bend formula. The flow stress is calculated from the average of the yield and maximum loads, also using the three-point bend formula.

Percent shear was determined from postfracture photographs using the ratio-of-areas methods in compliance with ASTM Specification A370-77. The lateral expansion was measured using a dial gage rig similar to that shown in the same specification.

Tension tests were performed on a 20,000-pound Instron, split-console test machine (Model 1115) per ASTM Specifications E8-83 and E21-79, and RMF Procedure 8102. All pull rods, grips, and pins were made of Inconel 718 hardened to Rc 45. The upper pull rod was connected through a universal joint to improve axiality of loading. The tests were conducted at a constant crosshead speed of 0.05 inches per minute throughout the test.

Deflection measurements were made with a linear variable displacement transducer (LVDT) extensometer. The extensometer knife edges were spring-loaded to the specimen and operated through specimen failure. The extensometer gage length is 1.00 inch. The extensometer is rated as Class B-2 per ASTM E83-67.

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.

Because of the difficulty in remotely attaching a thermocouple directly to the specimen, the following procedure was used to monitor specimen temperature. Chromel-alumel thermocouples were inserted in shallow holes in the center and each end of the gage section of a dummy specimen and in each grip. In the test configuration, with a slight load on the specimen, a plot of specimen temperature versus upper and lower grip and controller temperatures was developed over the range room temperature to 550°F (288°C). The upper grip was used to control the furnace temperature. During the actual testing the grip temperatures were used to obtain desired specimen temperatures. Experiments indicated that this method is accurate to $\pm$ 2°F.

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 and final gage length were determined from post-fracture photographs. The fracture area used to calculate the fracture stress (true stress at fracture) and percent reduction in area was computed using the final diameter measurement.

5.2 Charpy V-Notch Impact Test Results

The results of Charpy V-notch impact tests performed on the various materials contained in Capsule S irradiated at 2.98 x 10^{18} n/cm^2 are presented in tables 5-1 through 5-6 and figures 5-1 through 5-4. Initial and irradiated transition temperature and upper shelf energy levels were determined using a hyperbolic tangent (TANH) curve fitting model as used by Oldfield [3] to fit the data. Tables containing the results of the curve fitting were supplied to Westinghouse by the Pacific Gas and Electric Company for use in determining the impact property changes. The transition temperature increases and upper shelf energy decreases for the Capsule S material are summarized in table 5-7.

Irradiation of vessel intermediate shell plate B4106-3 material (longitudinal orientation) specimens to 2.98 x 10^{18} n/cm^2 (figure 5-1) resulted in a 30 and 50 ft-lb transition temperature shift of -2 and 4°F, respectively, and an average upper shelf energy increase of 4 ft-lb. The small increase in upper shelf energy is not unusual and is considered to be the result of data scatter.

Weld metal irradiated to 2.98 x 10^{18} n/cm^2 (figure 5-2) resulted in 30 and 50 ft-lb transition temperature increases of 110 and 148°F respectively and an average upper shelf energy decrease of 11 ft-lb.

Weld HAZ metal irradiated to 2.98 x 10^{18} n/cm^2 (figure 5-3) resulted in 30 and 50 ft-lb transitions temperature increases of 77 and 56°Frespectively and an average upper shelf energy decrease of 22 ft-lb.

HSST plate 02 correlation monitor material irradiated to 2.98 x 10^{18} n/cm^2 (figure 5-4) resulted in a 30 and 50 ft-lb transition temperature increase of 66 and 68°F, respectively, and an average upper shelf energy decrease of 1 ft-lb, which fall within the data base for this material.

The fracture appearance of each irradiated Charpy specimen from the various materials is shown in figure 5-5 through 5-8 and show an increasing ductile or tougher appearance with increasing test temperature.

Table 5-8 shows a comparison of the 30 ft-lb transition temperature increases for the various Diablo Canyon Unit 1 surveillance materials with predicted increases using the methods of proposed NRC Regulatory Guide 1.99 Revision 2.[4] This comparison shows that the transition temperature increase resulting from irradiation to 2.98 x 10^{18} n/cm^2 is less than predicted by the Guide for plate B4106-3, weld metal and correlation monitor material.

Four weld metal Charpy V-notch impact specimens from Capsule S were reconstituted by Westinghouse to obtain additional impact toughness data to better define the transition region and the upper shelf of the weld metal. A separate report [5] describes the reconstitution procedure and discusses the analysis of the test data. Two of the four reconstituted specimens were notched too deep and therefore were considered inappropriate for obtaining reliable test data. Table 5-9 shows the results of the impact tests performed at 125 and 400°F on the other two reconstituted specimens. The toughness results for these two tests when compared to the original irradiated weld metal test results shown in figure 5-2 appear to be questionable since they do not fit the irradited energy and lateral expansion transition curves. A review of the reconstitution and testing techniques used in this progmam was conducted which did not identify any obvious abnormalities that could have produced the lower than expected toughness values. The reconstituted Charpy data points have not been included in the development of the Charpy transition curves. Only two of the four reconstituted specimens were successful in

TABLE 5-7

EFFECT OF 550°F IRRADIATION AT 2.98 x 10^{18} n/cm^2 (E > 1.0 MeV)

ON NOTCH TOUGHNESS PROPERTIES OF DIABLO CANYON UNIT 1 REACTOR VESSEL MATERIALS

	Average 50 ft-lb Temperature (°F)			Average 35 mil Lateral Expansion Temperature (°F)			Average 30 ft-lb Temperature (°F)			Average Upper Shelf Energy (ft-lb)		
Material	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	Δ(ft-lb)
Plate B4106-3 (Longitudinal)	41	45	4	29	29	0	5	3	-2	122	126	+4
Weld Metal	-23	125	148	-46	96	142	-67	43	110	98	87	-11
HAZ Metal	-111	-55	56	-107	-64	43	-168	-91	77	147	125	-22
Correlation Monitor Mt'l	78	146	68	59	124	65	46	112	66	124	123	-1

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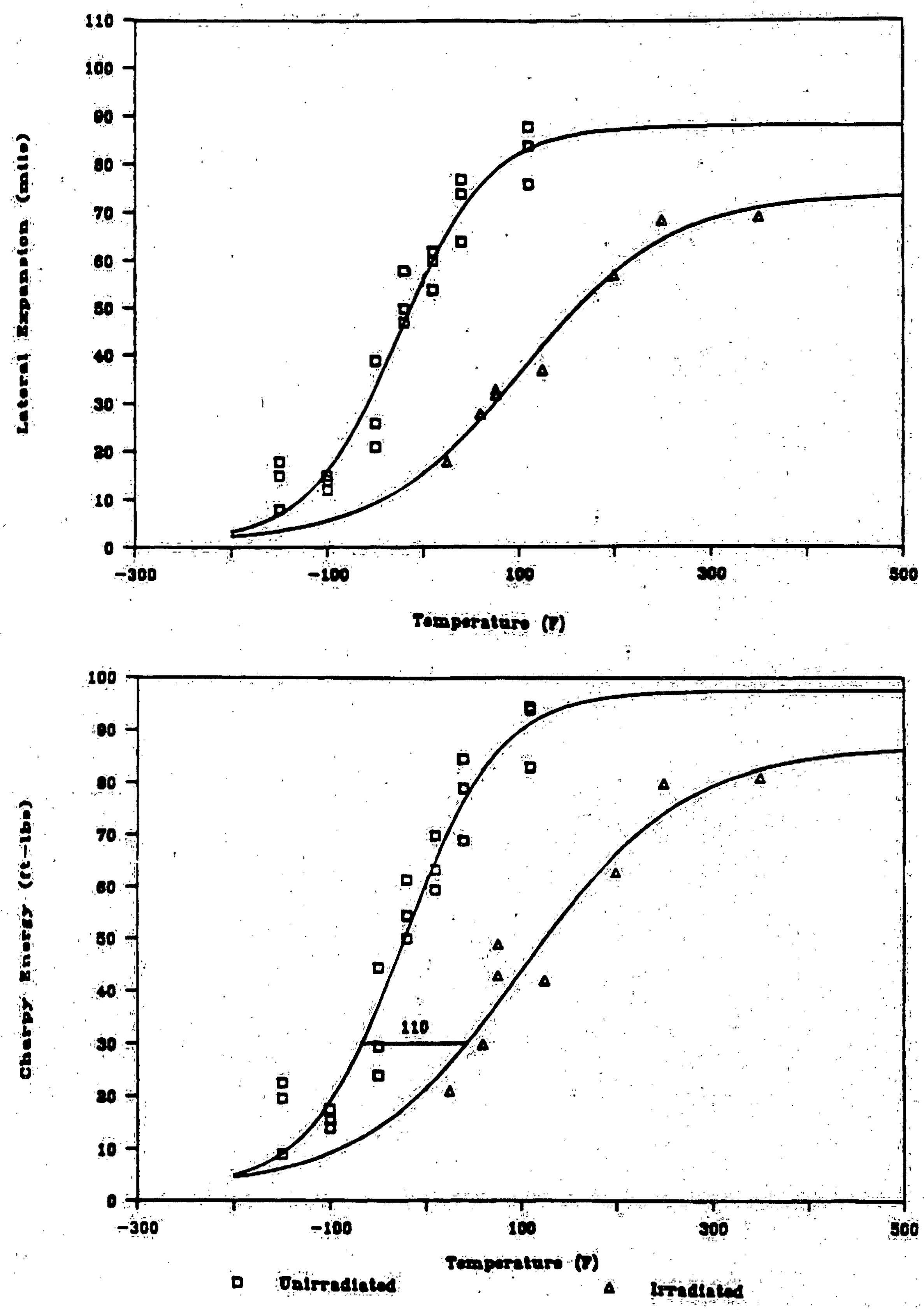

Figure 5-2. Irradiated Charpy V-Notch Impact Properties for Diablo Canyon Unit 1 Reactor Vessel Weld Metal

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ANALYSIS OF CAPSULE Y FROM THE PACIFIC GAS AND ELECTRIC COMPANY DIABLO CANYON UNIT 1 REACTOR VESSEL RADIATION SURVEILLANCE PROGRAM

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SECTION 1.0
SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance Capsule Y, the second capsule to be removed from the Pacific Gas and Electric Company Diablo Canyon Unit 1 reactor pressure vessel, led to the following conclusions:

- The capsule received an average fast neutron fluence (E > 1.0 MeV) of 1.02×10^{19} n/cm^2 after 5.86 EFPY of plant operation.

- Irradiation of the reactor vessel intermediate shell plate B4106-3 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (longitudinal orientation), to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 47°F and a 50 ft-lb transition temperature increase of 53°F. This results in a 30 ft-lb transition temperature of 52°F and a 50 ft-lb transition temperature of 94°F for the longitudinally oriented specimens.

- Irradiation of the weld metal Charpy specimens to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 234°F and a 50 ft-lb transition temperature increase of 276°F. This results in a 30 ft-lb transition temperature of 167°F and a 50 ft-lb transition temperature of 253°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 84°F and a 50 ft-lb transition temperature increase of 75°F. This results in a 30 ft-lb transition temperature of -84°F and a 50 ft-lb transition temperature of -36°F.

- Irradiation of the Correlation Monitor Material Plate HSST 02 Charpy specimens to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) resulted in 30 and 50 ft-lb transition temperature increases of 112°F. This results in a 30 ft-lb transition temperature of 158°F and a 50 ft-lb transition temperature of 190°F.

- o The surveillance Capsule Y test results indicate that the Correlation Monitor Plate HSST 02 material 30 ft-lb transition temperature shift is 10°F greater than the Regulatory Guide 1.99, Revision 2 prediction. This increase is bounded by the 2 sigma allowance for shift prediction of 34°F. The average upper shelf energy decrease of the Correlation Monitor Material is less than the Regulatory Guide 1.99, Revision 2 prediction.

- o The surveillance capsule materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are expected to maintain an upper shelf energy of no less than 50 ft-lb throughout the life (32 EFPY) of the vessel as required by 10CFR50, Appendix G.

- o The calculated end-of-life (32 EFPY) maximum neutron fluence (E > 1.0 MeV) for the Diablo Canyon Unit 1 reactor vessel is as follows:

  Vessel inner radius* = 1.54×10^{19} n/cm^2
  Vessel 1/4 thickness = 8.10×10^{18} n/cm^2
  Vessel 3/4 thickness = 1.62×10^{18} n/cm^2

  * Clad/base metal interface

- o Based on the criteria given in Regulatory Guide 1.99, Revision 2, the Diablo Canyon Unit 1 Surveillance Program is judged to be credible.

SECTION 5.0

TESTING OF SPECIMENS FROM CAPSULE Y

5.1 Overview

The post-irradiation mechanical testing of the Charpy V-notch and tensile specimens was performed at the Westinghouse Science and Technology Center hot cell with consultation by Westinghouse Power Systems personnel. Testing was performed in accordance with 10CFR50, Appendices G and H[3], ASTM Specification E185-82[7], and Westinghouse Remote Metallographic Facility (RMF) Procedure 8402, Revision 2 as modified by RMF Procedures 8102, Revision 1 and 8103, Revision 1.

Upon receipt of the capsule 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-8465[1]. No discrepancies were found.

Examination of the two low-melting point 579°F (304°C) and 590°F (310°C) eutectic alloys indicated no melting of either type of thermal monitor. Based on this examination, the maximum temperature to which the test specimens were exposed was less than 579°F (304°C).

The Charpy impact tests were performed per ASTM Specification E23-92[8] and RMF Procedure 8103, Revision 1 on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy machine is instrumented with a GRC 830I instrumentation system, feeding into an IBM XT 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 (Appendix A), 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), and the load at which fast fracture terminated 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 roughly equivalent to the energy required to initiate a crack in the specimen. Therefore, the propagation energy for the crack (E_p) is the difference between the total energy to fracture (E_D) and the energy at maximum load (E_M).

The yield stress (σ_Y) was calculated from the three-point bend formula having the following expression:

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

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 (Φ), notch root radius (ρ), and the type of loading (i.e., pure bending or three-point bending).

In three-point bending a Charpy specimen in which $\Phi = 45°$ and $\rho = 0.010"$, Equation 1 is valid with C = 1.21. Therefore (for L = 4W),

$$\sigma_Y = P_{GY} * \{ L / [B * (W - a)^2 * 1.21] \} = [3.3\ P_{GY}\ W] / [B (W - a)^2] \tag{2}$$

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

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM Specification A370-92[9]. The lateral expansion was measured using a dial gage rig similar to that shown in the same specification.

Tension tests were performed on a 20,000-pound Instron Model 1115, split-console test machine, per ASTM Specification E8-91[10] and E21-79 (1988)[11], and RMF Procedure 8102, Revision 1. All pull rods, grips, and pins were made of Inconel 718 hardened to HRC45. The upper pull rod was connected through a universal joint to improve axiality of loading. The tests were conducted at a constant crosshead speed of 0.05 inches per minute throughout the test.

Deflection measurements were made with a linear variable displacement transducer (LVDT) extensometer. The extensometer knife edges were spring-loaded to the specimen and operated through specimen failure. The extensometer gage length is 1.00 inch. The extensometer is rated as Class B-2 per ASTM E83-92[12].

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.

Because of the difficulty in remotely attaching a thermocouple directly to the specimen, the following procedure was used to monitor specimen temperature. Chromel-alumel thermocouples were inserted in shallow holes in the center and each end of the gage section of a dummy specimen and in each grip. In the test configuration, with a slight load on the specimen, a plot of specimen temperature versus upper and lower grip and controller temperatures was developed over the range of room temperature to 550°F (288°C). The upper grip was used to control the furnace temperature. During the actual testing the grip temperatures were used to obtain desired specimen temperatures. Experiments indicated that this method is accurate to ± 2°F.

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 and final gage length were determined from post-fracture photographs. The fracture area used to calculate the fracture stress (true stress at fracture) and percent reduction in area was computed using the final diameter measurement.

5.2 Charpy V-Notch Impact Test Results

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule Y, which was irradiated to 1.02×10^{19} n/cm^2 (E > 1.0 MeV), are presented in Tables 5-1 through 5-8 and are compared with unirradiated results[1] as shown in Figures 5-1 through 5-12. The transition temperature increases and upper shelf energy decreases for the Capsule Y materials are summarized in Table 5-9.

Irradiation of the reactor vessel intermediate shell plate B4106-3 Charpy specimens oriented with the longitudinal axis of the specimen parallel to the major rolling direction of the plate (longitudinal orientation) to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) at 550°F (Figure 5-1) resulted in a 30 ft-lb transition temperature increase of 47°F and a 50 ft-lb transition temperature increase of 53°F. This resulted in a 30 ft-lb transition temperature of 52°F and a 50 ft-lb transition temperature of 94°F (longitudinal orientation).

The average upper shelf energy (USE) of the intermediate shell plate B4106-3 Charpy specimens (longitudinal orientation) resulted in a energy decrease of 3 ft-lb after irradiation to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) at 550°F. This results in an average USE of 119 ft-lb (Figure 5-1).

Irradiation of the surveillance weld metal Charpy specimens to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) at 550°F (Figure 5-4) resulted in a 30 ft-lb transition temperature shift of 234°F and a 50 ft-lb transition temperature increase of 276°F. This results in a 30 ft-lb transition temperature of 167°F and a 50 ft-lb transition temperature of 253°F.

The average upper shelf energy (USE) of the surveillance weld metal resulted in an energy decrease of 32 ft-lb after irradiation to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) at 550°F. This resulted in an average USE of 66 ft-lb (Figure 5-4).

Irradiation of the reactor vessel weld HAZ metal Charpy specimens to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) at 550°F (Figure 5-7) resulted in a 30 ft-lb transition temperature increase of 84°F and a 50 ft-lb transition temperature increase of 75°F. This resulted in a 30 ft-lb transition temperature of -84°F and a 50 ft-lb transition temperature of -36°F.

The average upper shelf energy (USE) of the weld HAZ metal resulted in an energy decrease of 37 ft-lb after irradiation to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) at 550°F. This resulted in an average USE of 110 ft-lb (Figure 5-7).

Irradiation of the HSST 02 correlation monitor material Charpy specimens to 1.02×10^{19} n/cm^2 (E > 1.0 MeV) at 550°F (Figure 5-10) resulted in 30 and 50 ft-lb transition temperature increases of 112°F. This results in a 30 ft-lb transition temperature of 158°F and a 50 ft-lb transition temperature of 190°F.

The average upper shelf energy of the HSST 02 correlation monitor material experienced an energy decrease of 2 ft-lb after irradiation to 1.02 x 10^{19} n/cm^2 (E > 1.0 MeV) at 550°F. This resulted in an average USE of 122 ft-lb (Figure 5-10).

Plots of the Capsule Y Charpy test results are presented in Figures 5-13 through 5-24.

The fracture appearance of each irradiated Charpy specimen from the various materials is shown in Figures 5-25 through 5-28 and show an increasingly ductile or tougher appearance with increasing test temperature.

A comparison of the 30 ft-lb transition temperature increases and upper shelf energy decreases for the various Diablo Canyon Unit 1 surveillance materials with predicted values using the methods of NRC Regulatory Guide 1.99, Revision 2[4] is presented in Table 5-10 and led to the following conclusions:

- This comparison indicates that the transition temperature increases and the USE decreases for intermediate shell Plate B4106-3 resulting from irradiation to 1.02 x 10^{19} n/cm^2 (E > 1.0 MeV) are less than the Regulatory Guide predictions.

- This comparison indicates that the surveillance weld metal 30 ft-lb shift in transition temperature is 10°F greater than the Regulatory Guide 1.99, Revision 2 prediction. However, this increase is bounded by the 2 sigma allowance for shift prediction of 56°F. The average upper shelf energy decrease of the surveillance weld metal is less than the Regulatory Guide 1.99, Revision 2 prediction.

- This comparison indicates that the HSST 02 correlation monitor material 30 ft-lb shift in transition temperature is 10°F greater than the Regulatory Guide 1.99, Revision 2 prediction. However, this increase is bounded by the 2 sigma allowance for shift prediction of 34°F. The average upper shelf energy decrease of the HSST 02 correlation monitor material is less than the Regulatory Guide 1.99, Revision 2 prediction.

The load-time records for the individual instrumented Charpy specimen tests are presented in Appendix A.

TABLE 5-9

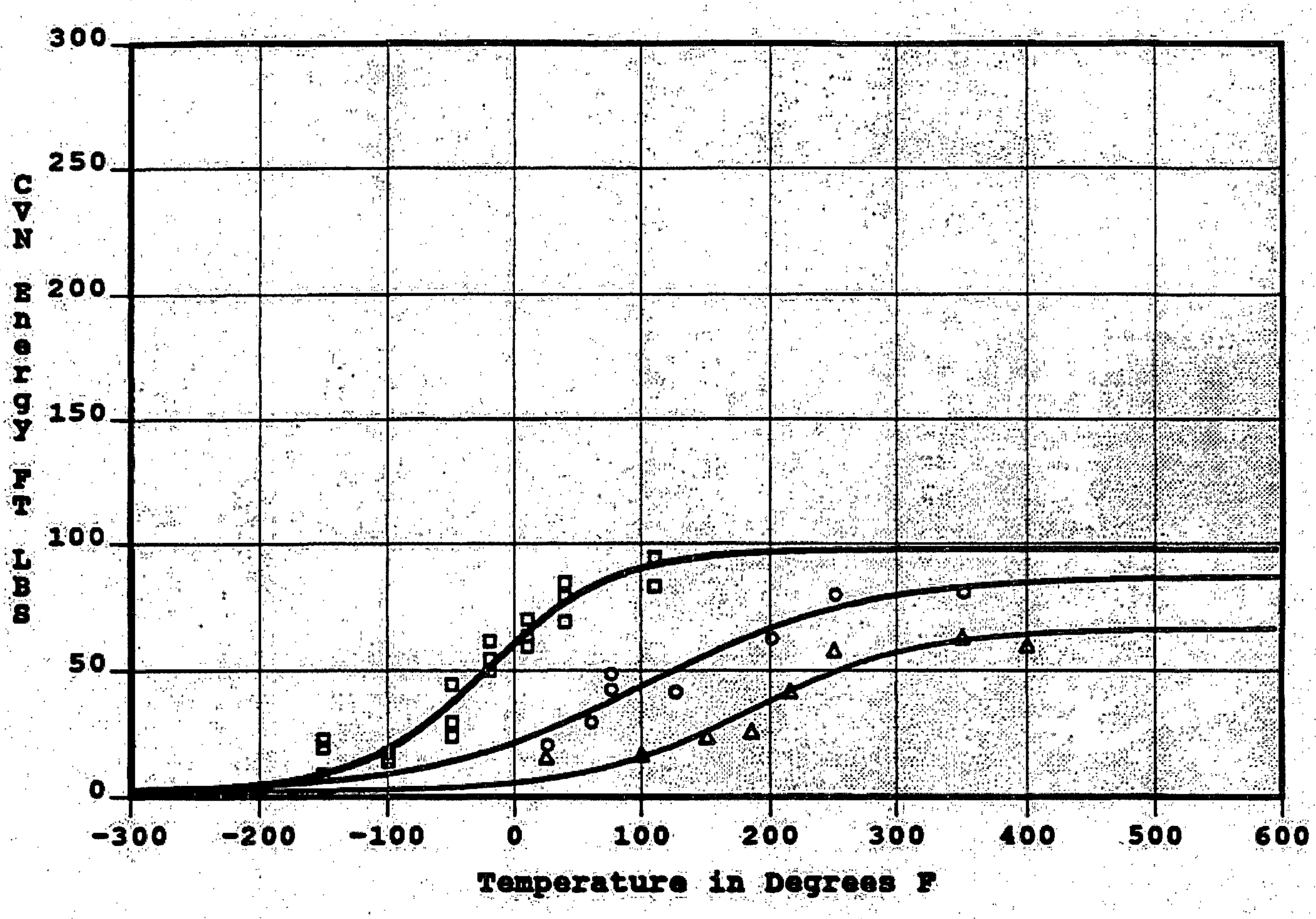
Effect of 550°F Irradiation to 1.02 X 10^{19} n/cm^2 (E > 1.0 MeV) on the Notch Toughness Properties of the Diablo Canyon Unit 1 Reactor Vessel Surveillance Materials[b]

Material	Average 30 (ft-lb) [a] Transition Temperature (°F)			Average 35 mil Lateral [a] 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	Δ
Plate B4106-3 (longitudinal)	5	52	47	29	75	46	41	94	53	122	119 (110)	-3 (-12)
Weld Metal	-67	167	234	-46	195	241	-23	253	276	98	66 (60)	-32 (-38)
HAZ Metal	-168	-84	84	-107	-36	71	-111	-36	75	147	110 (109)	-37 (-38)
Correlation Monitor Mt'l	46	158	112	59	178	119	78	190	112	124	122 (112)	-2 (-12)

(a) "Average" is defined as the value read from the curve fit through the data points of the Charpy tests (see Figures 5-1 through 5-4)
(b) The data were fit by PG&E using the EPRI Hyperbolic Tangent Curve Fitting Routine, Revision 2.0[13]
(c) Values in parenthesis were calculated per the definition of Upper Shelf Energy given in ASTM E185-82[7]
(d) Unirradiated values presented here are from the Capsule "S" Analysis[2]

TABLE 5-10						
Comparison of the Diablo Canyon 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 ($X\ 10^{19}$ n/cm^2)	Predicted [a] (°F)	Measured (°F)	Predicted [a] (%)	Measured[b] (%)
Plate B4106-3 (Longitudinal)	S	0.305	35	-2	14	0
	Y	1.02	52	47	19	3 (10)
Surveillance Weld Metal	S	0.305	150	110	26	11
	Y	1.02	224	234	34	33 (39)
Heat Affected Zone Metal	S	0.305	--	77	--	15
	Y	1.02	--	84	--	26 (26)
Correlation Monitor Plate HSST 02	S	0.305	68	66	18	2
	Y	1.02	102	112	23	2 (10)

(a) Based on Regulatory Guide 1.99, Revision 2 methodology using Mean wt. % values of Cu and Ni.
(b) Values in parenthesis were calculated per the definition of Upper Shelf Energy given in ASTM E185-82[7]



□ Unirradiated Test Data

○ Capsule S Test Data

△ Capsule Y Test Data

Figure 5-16 Charpy V-Notch Impact Energy vs. Temperature for Diablo Canyon Unit 1 Surveillance Weld Metal

Westinghouse Non-Proprietary Class 3

WCAP-15958
Revision 0

January 2003

Analysis of Capsule V from Pacific Gas and Electric Company Diablo Canyon Unit 1 Reactor Vessel Radiation Surveillance Program

Westinghouse

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15958, Revision 0

Analysis of Capsule V from Pacific Gas and Electric Company Diablo Canyon Unit 1 Reactor Vessel Radiation Surveillance Program

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January 2003

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EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of surveillance Capsule V from Diablo Canyon Unit 1. Capsule V was removed at 14.27 EFPY 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 database. Capsule V received a fluence of 1.37×10^{19} n/cm^2 after irradiation to 14.27 EFPY. This is equivalent to a vessel fluence at the end of the current license (32 EFPY). The peak clad/base metal interface vessel fluence after 14.27 EFPY of plant operation was 6.07×10^{18} n/cm^2. This evaluation lead to the following conclusions: Specimen results are behaving in accordance with predictions. The surveillance program, however, does not meet the regulatory criteria for credibility. Regulatory Guide 1.99 requires that all five criteria for credibility be met. For the Diablo Canyon Unit 1 surveillance program, four out of five of the criteria for credibility were met. A brief summary of the Charpy V-notch testing can be found in Section 1. All Charpy V-notch data was plotted using a symmetric hyperbolic tangent curve fitting program.

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance Capsule V, the fifth capsule removed (third capsule tested) from the Diablo Canyon Unit 1 reactor pressure vessel, led to the following conclusions:

- The Charpy V-notch data presented in WCAP-8465[3], WCAP-11567[4] and WCAP-13750[5] were based on Charpy curves using a hyperbolic tangent curve-fitting routine. The results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1. which is a symmetric hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on previous fit vs. symmetric hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

- Capsule V received an average fast neutron fluence (E> 1.0 MeV) of 1.37 x 10^{19} n/cm^2 after 14.27 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel intermediate shell plate B4106-3 (heat number C2793-1) Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (longitudinal orientation), resulted in an irradiated 30 ft-lb transition temperature of 39.46°F and an irradiated 50 ft-lb transition temperature of 77.51°F. This results in a 30 ft-lb transition temperature increase of 34.32°F and a 50 ft-lb transition temperature increase of 38.19°F for the longitudinal oriented specimens. See Table 5-9.

- Irradiation of the weld metal (heat number 27204) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 135.45°F and an irradiated 50 ft-lb transition temperature of 219.26°F. This results in a 30 ft-lb transition temperature increase of 201.07°F and a 50 ft-lb transition temperature increase of 243.43°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 -52.65°F and an irradiated 50 ft-lb transition temperature of -1.98°F. This results in a 30 ft-lb transition temperature increase of 110.9°F and a 50 ft-lb transition temperature increase of 109.77°F. See Table 5-9.

- Irradiation of the Correlation Monitor Material Plate HSST02 Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 163.05°F and an irradiated 50 ft-lb transition temperature of 197.42°F. This results in a 30 ft-lb transition temperature increase of 116.61°F and a 50 ft-lb transition temperature increase of 119.12°F. See Table 5-9.

- The average upper shelf energy of the intermediate shell plate B4106-3 (longitudinal orientation) resulted in no energy decrease after irradiation. This results in an irradiated average upper shelf energy of 118 ft-lb for the longitudinal oriented specimens. See Table 5-9.

- The average upper shelf energy of the weld metal Charpy specimens resulted in an average energy decrease of 25 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 66 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 20 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 116 ft-lb for the weld HAZ metal. See Table 5-9.

- The average upper shelf energy of the Correlation Monitor Material Plate HSST02 Charpy specimens resulted in an average energy decrease of 6 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 117 ft-lb for the weld correlation monitor metal. See Table 5-9.

- A comparison, as presented in Table 5-10, of the Diablo Canyon 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 for all the surveillance materials of Capsule V contained in the Diablo Canyon Unit 1 surveillance program are in good agreement or 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 V contained in the Diablo Canyon Unit 1 surveillance program are less than the Regulatory Guide 1.99, Revision 2 predictions.

- The credibility evaluation of the Diablo Canyon Unit 1 surveillance program presented in Appendix D of this report indicates that the surveillance results are not credible. This is based on not satisfying the third criterion for credibility.

- All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are predicted to maintain an upper shelf energy greater than 50 ft-lb throughout the life of the vessel (32 EFPY) as required by 10CFR50, Appendix G [2].

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

<u>Calculated:</u> Vessel inner radius* = 1.26×10^{19} n/cm^2

Vessel 1/4 thickness = 7.51×10^{18} n/cm^2

Vessel 3/4 thickness = 2.67×10^{18} n/cm^2

Table 4-3 Chemical Composition (wt%) of the Diablo Canyon Unit 1 Reactor Vessel Surveillance Materials (Unirradiated)[c]

Element	Intermediate Shell Plate B4106-3	Weld Metal [b]	HSST 02	
			Ladle	Check
N	0.010	0.009	-	-
C	0.200	0.140	0.22	0.22
Si	0.250	0.450	0.22	0.25
Mo	0.460	0.480	0.53	0.52
Cu	0.077	0.210	-	0.14
Ni	0.460	0.980	0.62	0.68
Mn	1.330	1.360	1.45	1.48
Cr	0.035	0.060	-	-
V	0.001	0.001	-	-
Co	0.001[a]	0.001[a]	-	-
Sn	0.007	0.010	-	-
Zn	0.001[a]	0.056	-	-
Ti	0.001[a]	0.010	-	-
Zr	0.001[a]	0.030	-	-
As	0.009	0.016	-	-
Sb	0.001	0.003	-	-
S	0.012	0.025	0.019	0.018
P	0.011	0.016	0.011	0.012
Al	0.036	0.018	-	-
B	0.003[a]	0.03[a]	-	-

Notes:

(a) Not detected, the number represents the minimum of detection.

(b) Surveillance weld was made of the same weld wire Heat 27204 and Linde 1092 Flux as the beltline region reactor vessel intermediate and lower shell longitudinal weld seams. Linde 1092 flux lot 3714 was used to fabricate the surveillance weld whereas flux lot 3724 and 3774 was used to fabricate the intermediate and lower shell longitudinal weld seams respectively.

(c) This table was taken from WCAP-13750[5].

The best estimate copper and nickel weight percent remains as presented in the Diablo Canyon Unit 1 FSAR. The values used for the intermediate shell plate B4106-3 (Heat Number C2793-1) in all calculations documented in this report are as follows:

Cu wt. % = 0.086, and

Ni wt. % = 0.476

The values used for the surveillance weld (Heat Number 27204)* in all calculations documented in this report are as follows:

Cu wt. % = 0.198, and

Ni wt. % = 0.999

* The overall best estimate Cu and Ni for heat 27204 is 0.203 Cu and 1.018 Ni. These values are documented in the Diablo Canyon Unit 1 FSAR.

calculated using the original cross-sectional area. The final diameter and final gage length were determined from post-fracture photographs. The fracture area used to calculate the fracture stress (true stress at fracture) and percent reduction in area was computed using the final diameter measurement.

5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule V, which received a fluence of 1.37 x 10^{19} n/cm^2(E> 1.0 MeV) in 14.27 EFPY of operation, are presented in Tables 5-1 through 5-8 and are compared with unirradiated results[3] as shown in Figures 5-1 through 5-12.

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

Irradiation of the reactor vessel Intermediate Shell Plate B4106-3 (heat number C2793-1) Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (longitudinal orientation) resulted in an irradiated 30 ft-lb transition temperature of 39.46°F and an irradiated 50 ft-lb transition temperature of 77.51°F. This results in a 30 ft-lb transition temperature increase of 34.32°F and a 50 ft-lb transition temperature increase of 38.19°F for the longitudinal oriented specimens. See Table 5-9.

Irradiation of the weld metal (heat number 27204) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 135.45°F and an irradiated 50 ft-lb transition temperature of 219.26°F. This results in a 30 ft-lb transition temperature increase of 201.07°F and a 50 ft-lb transition temperature increase of 243.43°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 –52.65°F and an irradiated 50 ft-lb transition temperature of –1.98°F. This results in a 30 ft-lb transition temperature increase of 110.9°F and a 50 ft-lb transition temperature increase of 109.77°F. See Table 5-9.

Irradiation of the Correlation Monitor Material Plate HSST02 Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 163.05°F and an irradiated 50 ft-lb transition temperature of 197.42°F. This results in a 30 ft-lb transition temperature increase of 116.61°F and a 50 ft-lb transition temperature increase of 119.12°F. See Table 5-9.

The average upper shelf energy of the Intermediate Shell Plate B4106-3 (longitudinal orientation) resulted in no energy decrease after irradiation. This results in an irradiated average upper shelf energy of 118 ft-lb for the longitudinal oriented specimens. See Table 5-9.

The average upper shelf energy of the weld metal Charpy specimens resulted in an average energy decrease of 25 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 66 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 20 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 116 ft-lb for the weld HAZ metal. See Table 5-9.

The average upper shelf energy of the weld correlation monitor metal Charpy specimens resulted in an average energy decrease of 6 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 117 ft-lb for the weld correlation monitor metal. See Table 5-9.

A comparison, as presented in Table 5-10, of the Diablo Canyon Unit 1 reactor vessel beltline 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 for all the surveillance materials of Capsule V contained in the Diablo Canyon Unit 1 surveillance program are in good agreement or 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 V contained in the Diablo Canyon Unit 1 surveillance program are less than the Regulatory Guide 1.99, Revision 2 predictions.

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

All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are predicted to maintain an upper shelf energy greater than 50 ft-lb throughout the life of the vessel (32 EFPY) as required by 10CFR50, Appendix G [2].

The load-time records for individual instrumented Charpy specimen tests are shown in Appendix A.

The Charpy V-notch data presented in WCAP-8465[3], WCAP-11567[4] and WCAP-13750[5] were based on hyperbolic tangent curve fitting. The results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1[14], which is a symmetric hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on previous fit vs. symmetric hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

Table 5-2 Charpy V-notch Data for the Diablo Canyon Unit 1 Surveillance Weld Metal Irradiated to a Fluence of 1.37×10^{19} n/cm^2 (E> 1.0 MeV)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	°F	°C	ft-lbs	Joules	mils	mm	%
W11	25	-4	11	15	1	0.03	5
W13	100	38	23	31	13	0.33	15
W12	150	66	36	49	25	0.64	25
W9	200	93	37	50	24	0.61	30
W10	225	107	52	71	37	0.94	80
W15	300	149	71	96	51	1.30	100
W14	325	163	60	81	50	1.27	100
W16	350	177	66	89	48	1.22	100

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

Material	Capsule	Fluence[d] ($\times 10^{19}$ n/cm^2, E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F) [a]	Measured (°F) [b]	Predicted (%) [a]	Measured (%)[c]
Inter. Shell Plate	S	0.284	36.2	-1.78	14	0
B4106-3	Y	1.05	56.0	48.66	19	6.8
(Longitudinal)	V	1.37	60.0	34.32	20	0
Weld Metal	S	0.284	145.8	110.79	25.5	11.0
(heat # 27204)	Y	1.05	225.4	232.59	34.5	34.1
	V	1.37	241.6	201.07	36.5	27.5
HAZ Metal	S	0.284	--	72.31	--	8.1
	Y	1.05	--	79.77	--	19.9
	V	1.37	--	110.9	--	14.7
Correlation Monitor	S	0.284	73.01	65.62	--	2.4
Material	Y	1.05	112.9	115.79	--	8.9
	V	1.37	121.0	116.61	--	4.9

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 4.1 (See Appendix C)

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

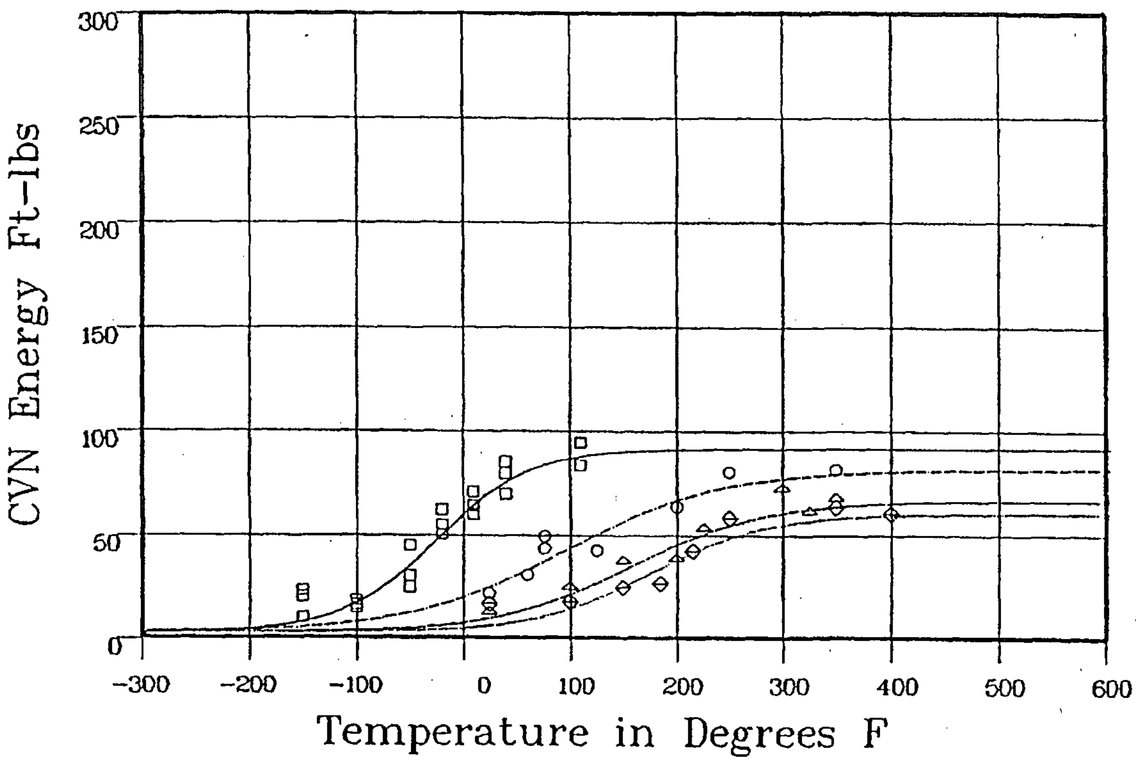
(d) The fluence values presented here are the calculated fluence values, not the best estimate. For best estimate values see Section 6 of this report.

SURVEILLANCE WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:20:17 on 08-19-2002

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T o 30	d-T o 30	T o 50	d-T o 50
1	0	2.19	0	91	0	-65.62	0	-24.16	0
2	2.84E+18	2.19	0	81	-10	45.17	110.79	120.38	144.54
3	1.05E+19	2.2	0	60	-31	166.97	232.59	255.73	279.9
4	1.37E+19	2.19	0	66	-25	135.45	201.07	219.26	243.43



Curve Legend

1 □——— 2 ○--------- 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material		Ori.	Heat#
1	DC1	UNIRR	WELD	LINDE 1092		27204 FLUX LOT 3714
2	DC1	S	WELD	LINDE 1092		27204 FLUX LOT 3714
3	DC1	Y	WELD	LINDE 1092		27204 FLUX LOT 3714
4	DC1	V	WELD	LINDE 1092		27204 FLUX LOT 3714

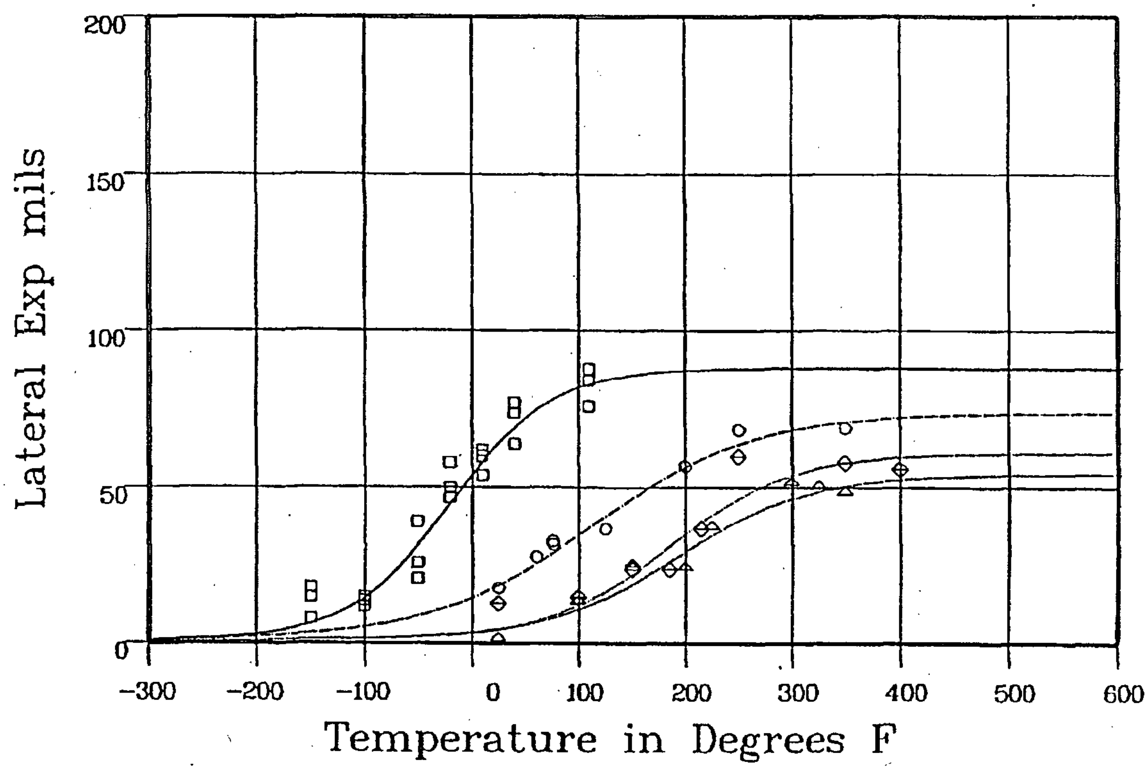
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Diablo Canyon Unit 1 Reactor Vessel Weld Metal

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:30:39 on 08-19-2002

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	88.17	0	-46.52	0
2	2.84E+18	73.91	-14.25	95.28	141.81
3	1.05E+19	61.24	-26.93	194.25	240.77
4	1.37E+19	54.47	-33.7	220.66	267.19



Curve Legend

1 □——— 2 ○---------- 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	DC1	UNIRR	WELD LINDE 1092		27204 FLUX LOT 3714
2	DC1	S	WELD LINDE 1092		27204 FLUX LOT 3714
3	DC1	Y	WELD LINDE 1092		27204 FLUX LOT 3714
4	DC1	V	WELD LINDE 1092		27204 FLUX LOT 3714

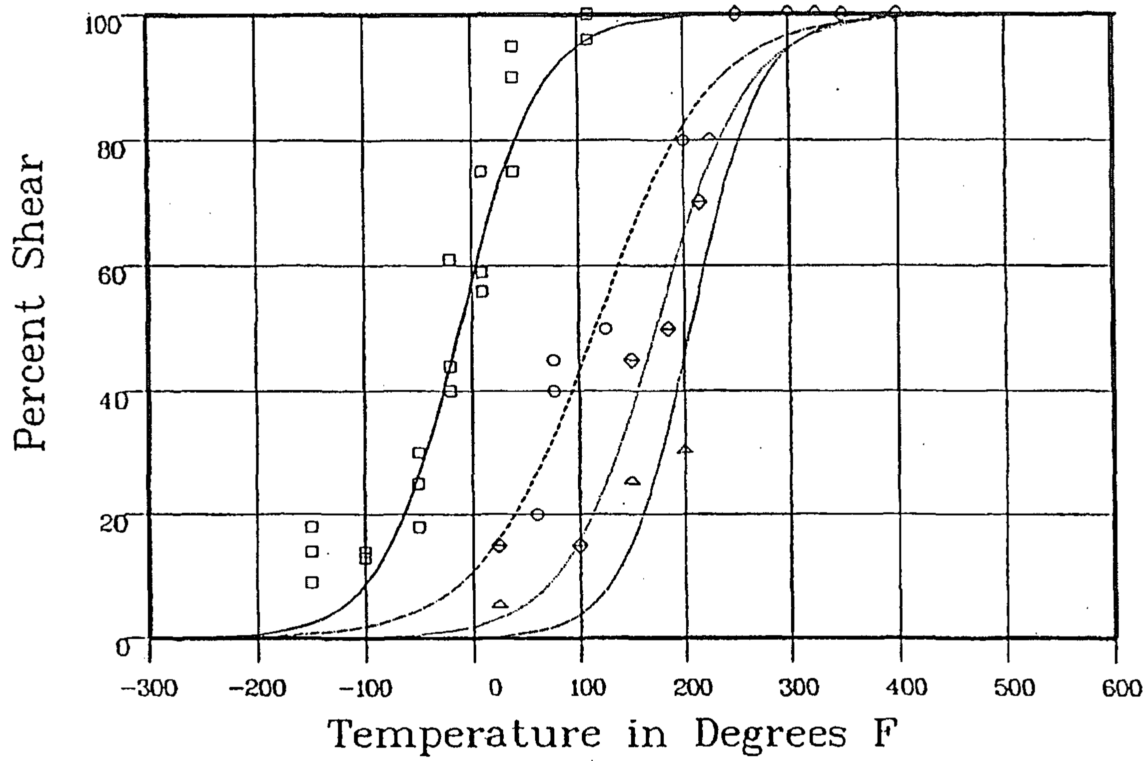
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Diablo Canyon Unit 1 Reactor Vessel Weld Metal

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:44:50 on 08-19-2002

Results

Curve	Fluence	T o 50% Shear	d-T o 50% Shear
1	0	-15.93	0
2	2.84E+18	110.74	126.67
3	1.05E+19	168.75	184.68
4	1.37E+19	201.56	217.5



Curve Legend

1 2 3 4

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	DC1	UNIRR	WELD LINDE 1092		27204 FLUX LOT 3714
2	DC1	S	WELD LINDE 1092		27204 FLUX LOT 3714
3	DC1	Y	WELD LINDE 1092		27204 FLUX LOT 3714
4	DC1	V	WELD LINDE 1092		27204 FLUX LOT 3714

Figure 5-6 Charpy V-Notch Percent Shear vs Temperature for Diablo Canyon Unit 1 Reactor Vessel Weld Metal

Appendix C

SURVEILLANCE CAPSULE DATA FOR PLATE HEAT NO. C-1279

BCL-585-12

FINAL REPORT

on

PALISADES NUCLEAR PLANT REACTOR PRESSURE VESSEL SURVEILLANCE PROGRAM: CAPSULE A-240

to

CONSUMERS POWER COMPANY

March 13, 1979

by

J. S. Perrin, E. O. Fromm, D. R. Farmelo,
R. S. Denning, and R. G. Jung

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

OCL 585-12

FINAL REPORT

on

PALISADES NUCLEAR PLANT REACTOR PRESSURE VESSEL SURVEILLANCE PROGRAM: CAPSULE A-240

to

CONSUMERS POWER COMPANY

from

BATTELLE
Columbus Laboratories

March 13, 1979

SUMMARY

Capsule A-240 was removed from the Palisades Nuclear Power Plant after 2.26 equivalent full power years of reactor operation. The capsule was sent to the Battelle Columbus Hot Laboratory for examination and evaluation.

The irradiation temperature did not exceed 536 F as indicated by the examination of the 12 thermal monitors. The neutron fluence at the location of the specimens was determined to be 4.4×10^{19} nvt (E>1 MeV), using neutron dosimeters from within the capsule. At the vessel wall the maximum exposure was determined to be 3.2×10^{19} n/cm^2 at 32 full power years.

The radiation-induced changes in the mechanical properties of pressure vessel material specimens were determined. Charpy impact specimens were used to determine changes in the impact behavior, including the shifts in the transition temperature region and the drops in the upper shelf energy level. Evaluation of the tensile property specimens included the yield and ultimate strengths as well as elongation and reduction in area.

Charpy Impact Properties

This section contains results and discussion pertaining to the Charpy impact testing. Appendix A contains further results and discussion relating to the instrumented procedures used during the impact testing.

The impact properties determined as a function of temperature are listed in Tables 9 through 12. In addition to the impact energy values, the tables also list the measured values of lateral expansion and the estimated fracture appearance for each specimen. The lateral expansion is a measure of the deformation produced by the striking edge of the impact machine hammer when it impacts the specimen; it is the change in specimen thickness directly adjacent to the notch location. The fracture appearance is a visual estimate of the amount of shear or ductile type of fracture appearing on the specimen fracture surface.

The impact data are graphically shown in Figures 11 through 14. These figures show the change in impact properties as a function of temperature, including both the impact energy and the lateral expansion. Figures 15 through 18 show the fracture surfaces of the Charpy specimens.

Table 13 summarizes the Palisades 30 and 50 ft-lb transition temperature, the 35 mils lateral expansion temperature, and the upper shelf energy for the present program and for the earlier unirradiated program. As indicated previously in the neutron dosimetry section, the Charpy specimens received a fairly uniform exposure. The neutron exposures based on the iron dosimeters ranged from 4.3 to 4.6×10^{19} n/cm^2 (>1 MeV). Particular exposure values can be assigned to each of the four Charpy materials since specimens of a particular material were all located in a given Charpy compartment. Using a conservative approach, the four Charpy materials from Capsule A-240 received exposures estimated as follows:

Base longitudinal,	4.5×10^{19} n/cm^2 (>1 MeV)
Base transverse,	4.4×10^{19} n/cm^2 (>1 MeV)
Weld,	4.6×10^{19} n/cm^2 (>1 MeV)
HAZ,	4.3×10^{19} n/cm^2 (>1 MeV)

The impact properties of the Palisades base metal, weld metal, and HAZ metal are all significantly affected by irradiation, as can be seen in the figures of impact energy and lateral expansion versus temperature (Figures 11 through 14).

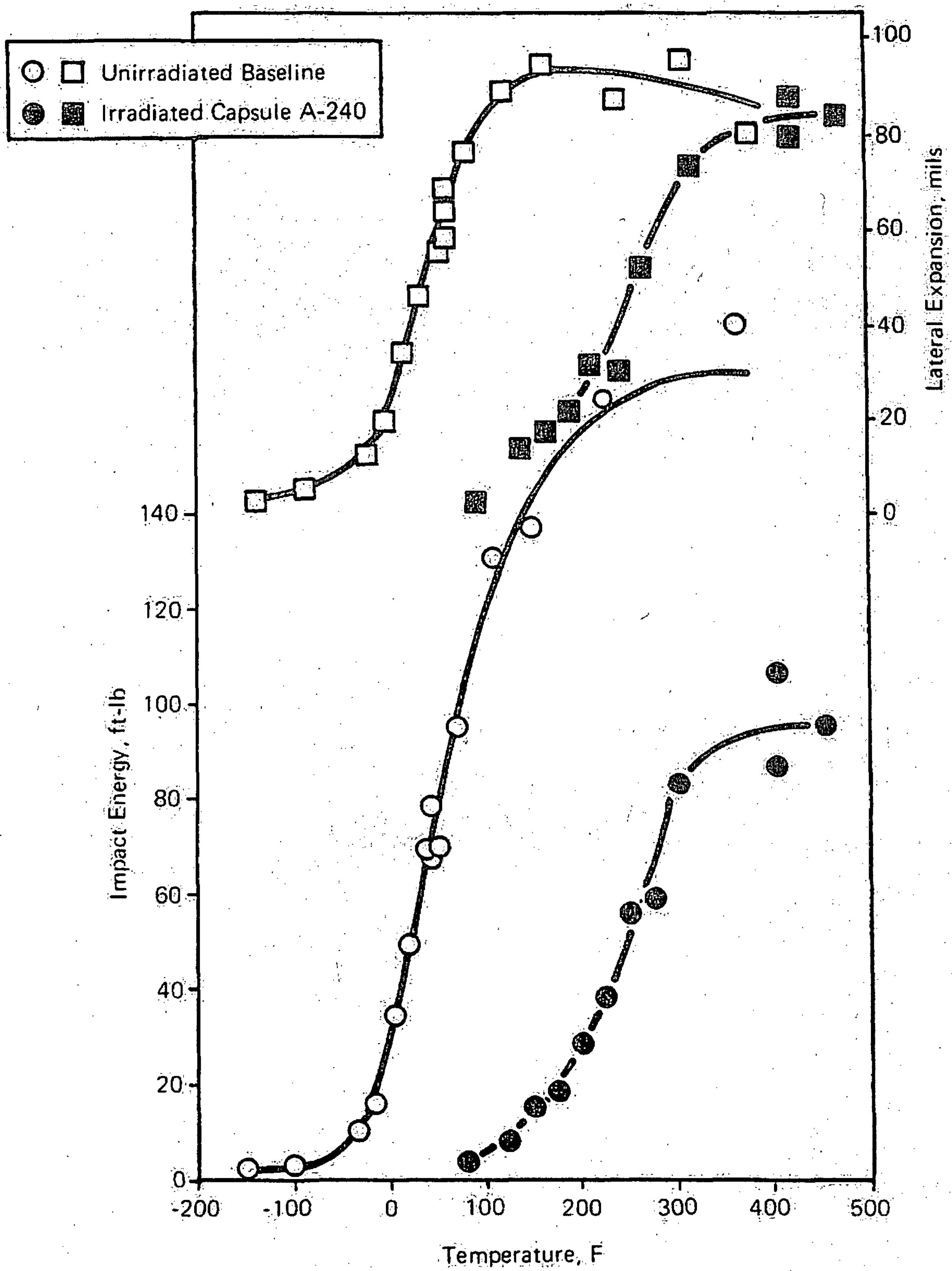


FIGURE 11. CHARPY IMPACT PROPERTIES FOR BASE METAL, PLATE NO. D3803-1, LONGITUDINAL ORIENTATION

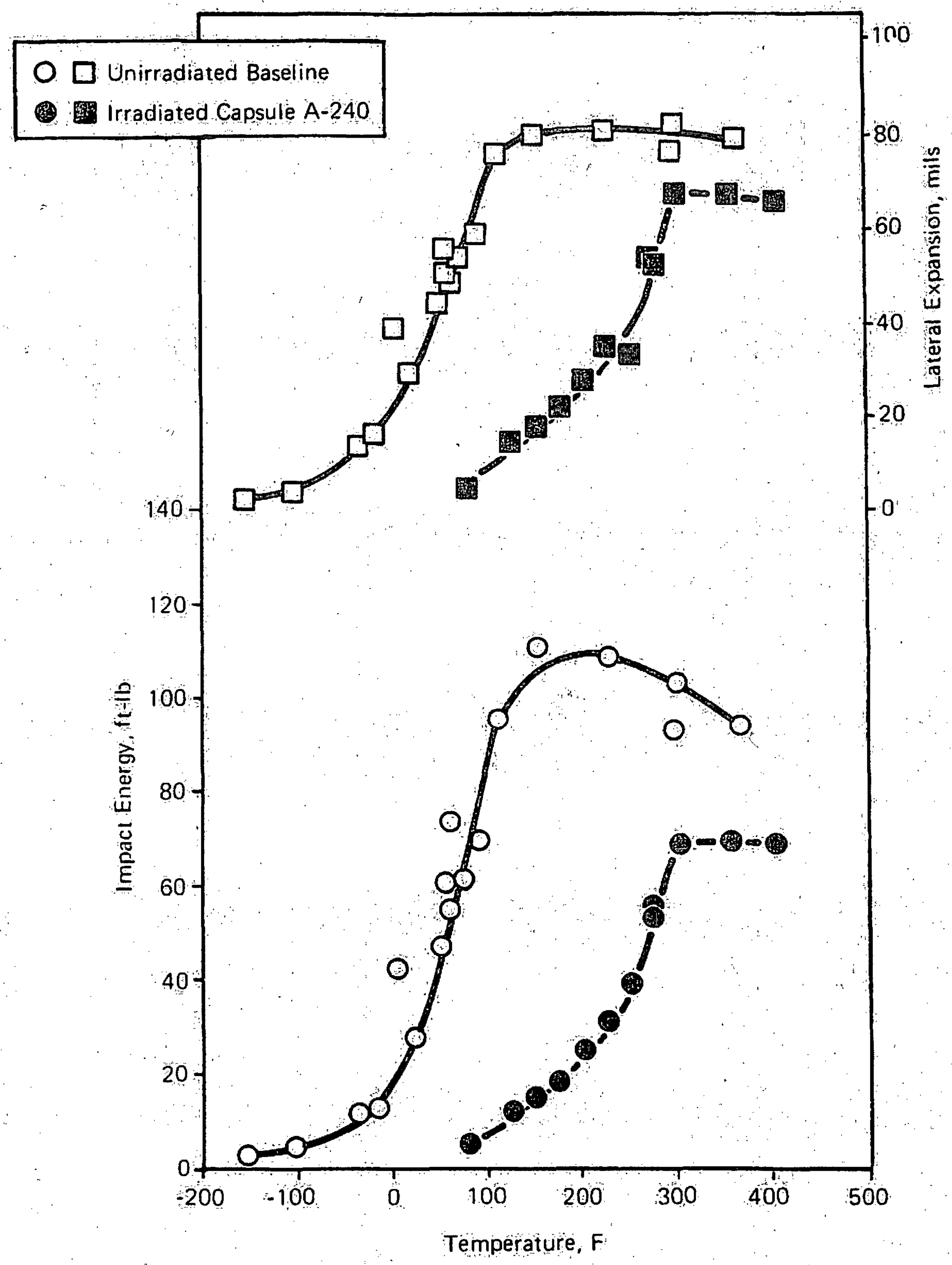


FIGURE 12. CHARPY IMPACT PROPERTIES FOR BASE METAL, PLATE NO. D3803-1, TRANSVERSE ORIENTATION

BCL 585-12

TABLE 13. SUMMARY OF CHARPY IMPACT PROPERTIES FOR PALISADES

Material	Program	Fluence E>1 MeV, x 10^{19} n/cm^2	30 ft-lb Transition Temp, F	50 ft-lb Transition Temp, F	Upper Shelf Energy, ft-lb	35-Mil Lateral Expansion Temp, F
Base L[(a)]	Ref 10	0	0	+20	165	+5
Base L[(a)]	Present	4.5	+205	+250	95	+220
Base T[(b)]	Ref 10	0	25	+55	105	+40
Base T[(b)]	Present	4.4	+230	+270	68	+235
Weld	Ref 10	0	-85	-50	120	-85
Weld	Present	4.6	+265	+305	54	+285
HAZ	Ref 10	0	-90	-65	125	-55
HAZ	Present	4.3	+200	+240	60	+205

(a) Base metal, longitudinal orientation.
(b) Base metal, transverse orientation.

For the four materials in Capsule A-240, the 50 ft-lb and 30 ft-lb transition temperatures range from 240 F to 305 F and 200 F to 265 F, respectively. The 35-mil lateral expansion temperature ranges from 205 F to 285 F, and the upper shelf energy levels range from 54 to 95 ft-lb. The upper shelf energy levels were taken as being the highest point of the curve drawn through the points.

Table 14 is a comparison of the 50 ft-lb and 30 ft-lb transition temperature shifts and the 35-mil lateral expansion temperature shift due to irradiation for the present program. The 50 ft-lb transition temperature shift is defined as the increase in the irradiated 50 ft-lb temperature with respect to the unirradiated 50 ft-lb temperature. The 30 ft-lb transition temperature shift and the 35-mil lateral expansion temperature shift are similarly defined. As can be seen, the greatest shift occurs for the weld material in all three cases.

TABLE 14. 50 FT-LB, 30 FT-LB, AND 35-MIL LATERAL EXPANSION TEMPERATURE SHIFTS DUE TO IRRADIATION FOR PALISADES CAPSULE A-240

Material	Fluence, E>1 MeV, x 10^{19} n/cm^2	30 ft-lb Transition Temperature Shift, F	50 ft-lb Transition Temperature Shift, F	35-Mil Lateral Expansion Temperature Shift, F
Base L[(a)]	4.5	+205	230	215
Base T[(b)]	4.4	+205	215	195
Weld	4.6	+350	355	370
HAZ	4.3	+290	305	260

(a) Base longitudinal orientation.
(b) Base transverse orientation.

In comparing the 50 ft-lb shift to the 35-mil lateral expansion shift for each of the four materials, note that the weld metal 35-mil lateral expansion shift is greater than the weld metal 50 ft-lb shift, but the reverse is true for the other three materials.

In considering the Charpy results, it should be realized that this surveillance capsule is an accelerated one, and has a very high lead factor of 19.4. This means the flux the specimens in the capsule receive is much higher than any point in the vessel wall. Further Palisades capsules to be examined include ones with significantly lower lead factors, more closely approximately the vessel wall. The actual location of the various surveillance capsules inside the pressure vessel are given in Figure C-1 of Appendix C.

The reference temperature, RT_{NDT}, was determined previously for the unirradiated base transverse material to be 0 F[23]. The procedure for the determination of the RT_{NDT} is defined by the ASME Boiler and Pressure Vessel Code[24]. Appendix H, "Reactor Vessel Material Surveillance Program Requirements", to 10CFR50 specifies how an adjusted reference temperature for irradiated specimens can be determined.[25] This temperature can be used in revising the plant pressure-temperature operating curves in those cases where the fluence of the irradiated specimens is in the range to be experienced by the pressure vessel. The adjusted reference temperature defined by Appendix H is determined by adding to the reference temperature the amount of the temperature shift in the Charpy curves between the unirradiated material and the irradiated material, measured at the 50 ft-lb level, or that measured at the 35-mil lateral expansion level, whichever temperature shift is greater.

Tensile Properties

The tensile properties determined for the tensile specimen contained in the Palisades capsule A-240 are listed in Table 15. The table lists test temperature, fluence, 0.2 percent offset yield strength, ultimate tensile strength, uniform elongation, total elongation, and reduction in area for the present program as well as for the unirradiated baseline program. Post-test photographs of the tensile specimens are shown in Figure 19. These photographs show the necked down region of the gage length and the fracture. A typical tensile test curve is shown in Figure 20; the particular test shown is for base metal specimen 1D4 tested at 72 F.

Tensile tests were run at room temperature (69 to 73 F), 535 and 565 F. The higher temperature tests exhibited a decrease in 0.2 percent offset yield strength and a decrease in ultimate tensile strength for each material with respect to the room temperature tests. In general, ductility values (as determined by total elongation and reduction in area) decreased at higher temperatures as compared to room temperature for each material.

Palisades tensile specimens were located in the vicinity of iron dosimeters which received fluences ranging from 4.3 to 4.6 x 10^{19} n/cm^2 (E>1 MeV). When the tensile data for Capsule A-240 is compared to the unirradiated baseline data (Table 5) it can be seen that as fluence increases, the yield strength and tensile strength increase while ductility decreases.

WCAP-10637

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ANALYSIS OF CAPSULES T-330 AND W-290 FROM THE CONSUMERS POWER COMPANY PALISADES REACTOR VESSEL RADIATION SURVEILLANCE PROGRAM

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September 1984

Work performed under Shop Order Nos. ENVJ-106 and ENVJ-450

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WCAP 10637

SECTION 1
SUMMARY OF RESULTS

The analysis of the material contained in Capsule T-330, the first thermal surveillance capsule removed from the Consumers Power Company's Palisades reactor pressure vessel, led to the following conclusions:

- o The weld and heat-affected zone metal has experienced a 60-70°F shift in the ductile to brittle transition temperatures due to exposure to elevated temperature.

The analysis of the material contained in Capsule W-290, the second irradiated surveillance capsule to be removed from the Consumers Power Company Palisades reactor pressure vessel, led to the following conclusions:

- o The capsule received an average fast neutron fluenc (E>1.0Mev) of 1.09×10^{19} n/cm^2.

- o Irradiation of the reactor vessel intermediate shell course plate D-3803-1, to 1.09×10^{19} n/cm, resulted in 30 and 50 ft-lb transition temperature increases of 155 and 160°F, respectively, for specimens oriented perpendicular to the principal rolling direction (transverse orientation), and 175°F and 180°F, respectively, for specimens oriented parallel to the principal rolling direction (longitudinal orientation).

- o Weld metal irradiated to 1.09×10^{19} n/cm^2 resulted in 30 and 50 ft-lb transition temperature increase of 290 and 300°F, respectively.

- o The average upper shelf energy of all the surveillance materials remained above 50 ft-lbs, thereby providing adequate toughness for continued safe plant operation.

- Comparison of the 30 ft-lb transition temperature increases for the Palisades surveillance material with predicted increases using the methods of NRC Regulatory Guide 1.99, Revision 1, shows that the weld metal transition temperature increase was greater than predicted. It is suspected that the relatively high nickel content of the weld metal contributed to the greater than predicted transition temperature increase experienced by the weld metal.

these test results it appears that a mixup in monitors occurred during the initial loading of the capsules and therefore a reliable estimate of the capsule temperature cannot be determined from the thermal monitors.

5-3. CHEMICAL ANALYSIS

Chemical analyses were performed on fractured Charpy V-notch specimens in order to confirm the chemical composition of the surveillance plate and weld materials. The chemical analysis results are summarized in Table 5-1. The most notable feature of these analyses is the great variance measured in the nickel content, specifically from .95 to 1.60 wt. %. From the high nickel content, it is evident that a Nickel-200 addition was made to the surveillance weldment, and from the nickel variances observed it can be concluded that the rate of Nickel-200 addition was varied during welding.

5-4. CHARPY V-NOTCH IMPACT TEST RESULTS

Capsule T-330:

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule T-330, the thermal capsule, are presented in Tables 5-2 through 5-9 and Figures 5-1 through 5-4. From the Charpy V-notch plots based on best engineering judgement it appears that the weld and heat-affected zone metals have experienced a 60 to 70°F shift in the ductile to brittle transition temperatures due to exposure to elevated temperature, but no decrease in upper shelf energy.

The fracture appearance of each Charpy specimen from the various materials is shown in Figures 5-5 through 5-8, and show an increasing ductile or tougher appearance with increasing test temperature.

A typical instrumented Charpy curve, representing the curves of both Capsule T-330 and Capsule W-290, is presented in Figure 5-9.

Capsule W-290:

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule W-290, irradiated at 1.09 x 10^{19} n/cm^2, are presented in Tables 5-10 through 5-17 and Figures 5-10 through 5-13. A summary of the transition temperature increases and upper shelf energy decreases for the Capsule W-290 material is shown in Table 5-18.

Irradiation of the vessel intermediate shell course plate D-3803-1 (transverse orientation) to 1.09 x 10^{19} n/cm^2 (Figure 5-10) resulted in 30 and 50 ft-lb transition temperature increases of 155 and 160°F, respectively, and an upper shelf energy decrease of 18 ft-lb. Irradiation of the vessel intermediate shell plate material (longitudinal orientation) to 1.09 x 10^{19} n/cm^2 (Figure 5-11) resulted in 30 and 50 ft-lb transition temperature increases of 175 and 180°F, respectively, and an upper shelf energy decrease of 43 ft-lb.

Weld metal irradiated to 1.09 x 10^{19} n/cm^2 (Figure 5-12) resulted in 30 and 50 ft-lb transition temperature increases of 290 and 300°F, respectively, and an upper shelf energy decrease of 54 ft-lb.

Weld HAZ metal irradiated to 1.09 x 10^{19} n/cm^2 (Figure 5-13) resulted in 30 and 50 ft-lb transition temperature increases of 235 and 245°F, respectively, and an upper shelf energy decrease of 44 ft-lb.

The fracture appearance of each irradiated Charpy specimen from the various materials is shown in Figures 5-14 through 5-17 and show an increasing ductile or tougher appearance with increasing test temperature.

Figure 5-18 shows a comparison of the 30 ft-lb transition temperature increases for the various Palisades surveillance materials with predicted increases using the methods of NRC Regulatory Guide 1.99, Revision 1.[3]

The regulatory curves used for comparison were developed from the average copper and phosphorus contents (averages of the analyses presented in Tables 4-1 and 5-1) of plate D-3803-1 and the weld metal. This comparison shows that the plate transition temperature increases resulting from irradiation to 1.09 x 10^{19} n/cm^2 are less than predicted by the Guide for plate D-3803-1. The weld metal transition temperature increase resulting from 1.09 x 10^{19} n/cm^2 is greater than predicted by the Guide. This can be explained by the high nickel content of the weld metal. It is widely recognized today that nickel has a profound effect upon the irradiation damage of reactor vessel materials, whereas the current revision of Regulatory Guide 1.99 does not incorporate this important variable.

5-5. TENSION TEST RESULTS

Capsule T-330:

The results of the thermal capsule tension tests performed on plate D-3803-1 (longitudinal orientation) and weld metal are shown in Table 5-19 and Figures 5-19 and 5-20, respectively. These results show that the thermal environment produced little change in the 0.2 percent yield strength of the plate and weld material. Fractured tension specimens for each of the materials are shown in Figures 5-22 through 5-24. A typical stress-strain curve for the tension specimens, representing the curves of both Capsule T-330 and Capsule W-290, is shown in Figure 5-25.

Capsule W-290:

The results of the irradiated capsule tension tests performed on plate D-3803-1 (longitudinal orientation) and weld metal irradiated to 1.09 x 10^{19} n/cm^2 are show in Table 5-20 and Figures 5-26 and 5-27, respectively. These results show that irradiation produced an increase in the 0.2 percent yield strength of approximately 20 ksi for plate D-3803-1 and of approximately 30 ksi for the weld metal. Fractured tension specimens for each of the materials are shown in Figures 5-29 through 5-31.

TABLE 5-18

EFFECT OF IRRADIATION AT 1.09 x 10^{19} (E > 1 MeV) ON THE NOTCH TOUGHNESS PROPERTIES OF THE PALISADES SURVEILLANCE VESSEL MATERIALS

	Average 30 ft-lb Temp (°F)			Average 35 mil Lateral Expansion Temp (°F)			Average 50 ft-lb Temp (°F)			Average Energy Absorption at Full Shear (ft-lb)		
Material	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	Δ (ft-lb)
Plate D-3803-1 (Transverse)	25	180	155	25	195	170	55	215	160	102	84	18
Plate D-3803-1 (Longitudinal)	0	175	175	5	190	185	20	200	180	155	112	43
Weld Metal	-85	205	290	-75	240	315	-50	250	300	118	64	54
HAZ Metal	-90	145	235	-55	160	215	-65	180	245	116	72	44

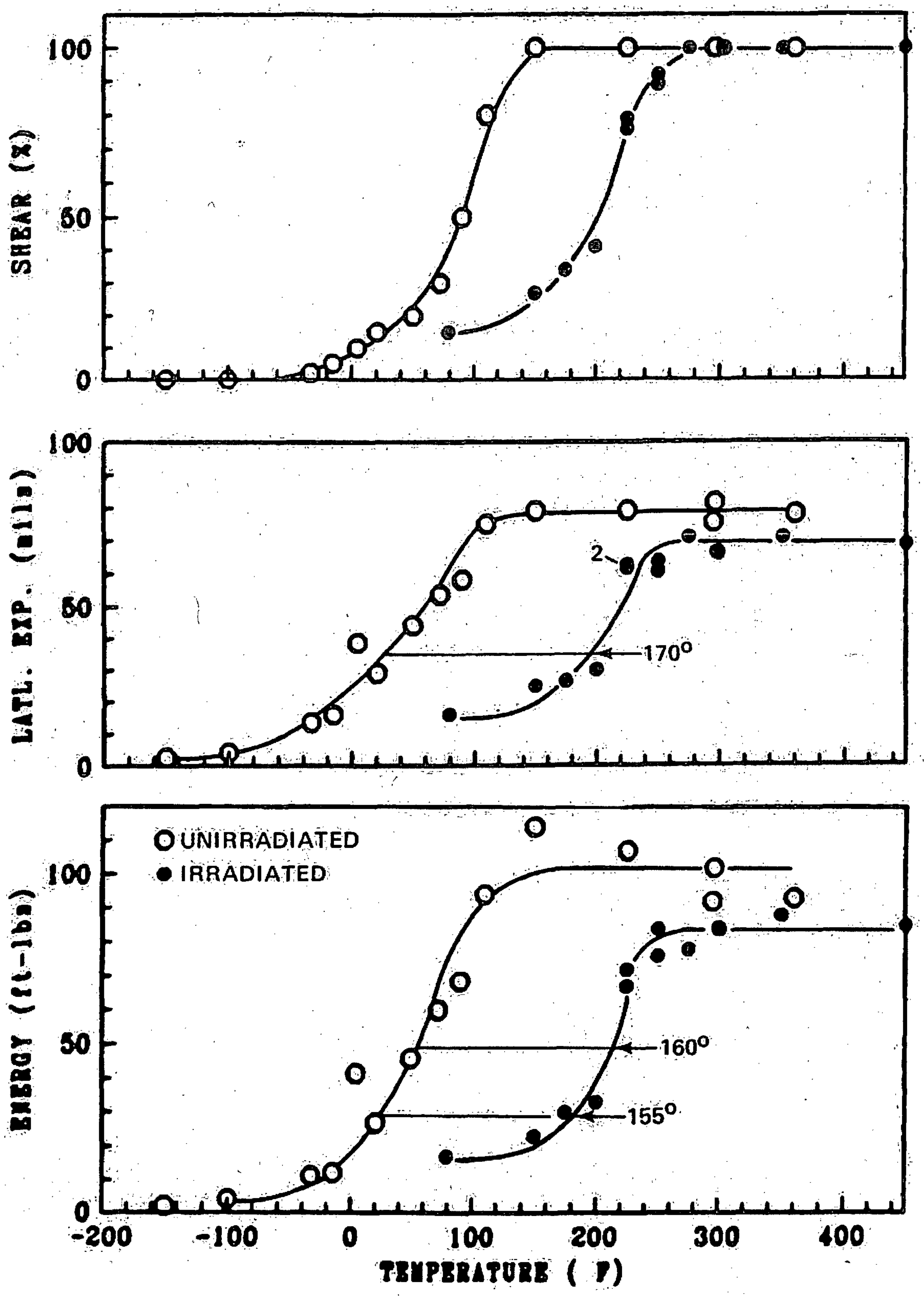

Figure 5-10. Irradiated Capsule Charpy V-Notch Impact Properties for Palisades Intermediate Shell Plate D-3803-1 (Transverse Orientation)

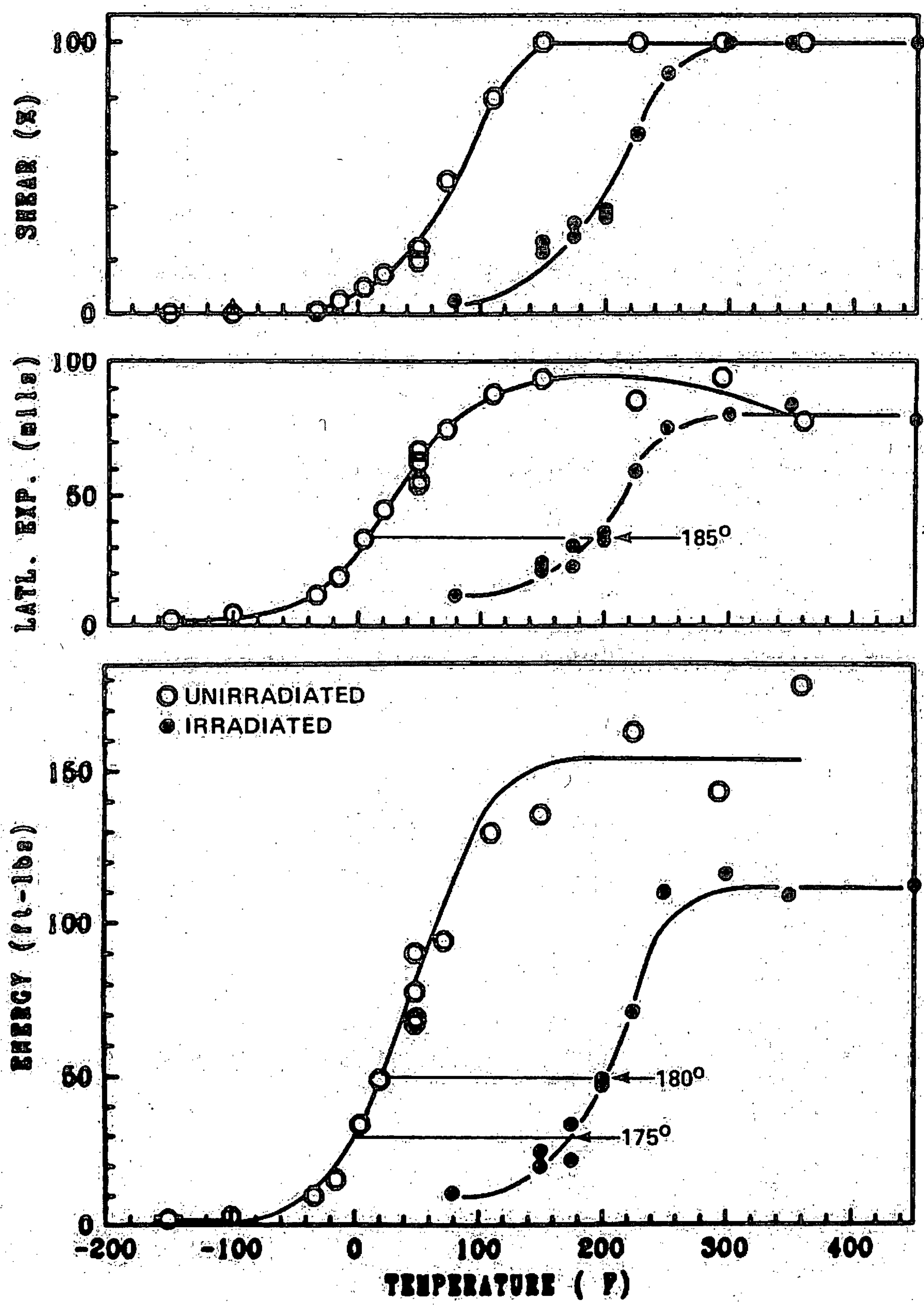

Figure 5-11. Irradiated Capsule Charpy V-Notch Impact Properties for Palisades Intermediate Shell Plate D-3803-1 (Longitudinal Orientation)

WCAP-14014

WESTINGHOUSE CLASS 3 (Non-Proprietary)

ANALYSIS OF CAPSULE W-110 FROM THE CONSUMERS POWER COMPANY PALISADES REACTOR VESSEL RADIATION SURVEILLANCE PROGRAM

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SECTION 1.0
SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance Capsule W-110, the second vessel wall capsule assembly to be removed from the Consumers Power Company Palisades reactor pressure vessel, led to the following conclusions:

- o The capsule received an average fast neutron fluence of 1.779×10^{19} n/cm² (E > 1.0 MeV) after 9.95 EFPY of plant operation.

- o Irradiation of the reactor vessel intermediate shell plate D-3803-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (longitudinal orientation), to 1.779×10^{19} n/cm² (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 180°F and a 50 ft-lb transition temperature increase of 190°F. This results in an irradiated 30 ft-lb transition temperature of 180°F and an irradiated 50 ft-lb transition temperature of 210°F for longitudinally oriented specimens.

- o Irradiation of the surveillance weld metal Charpy specimens to 1.779×10^{19} n/cm² (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 314°F and a 50 ft-lb transition temperature increase of 355°F. This results in an irradiated 30 ft-lb transition temperature of 229°F and an irradiated 50 ft-lb transition temperature of 305°F for the weld metal.

- o Irradiation of the reactor vessel weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 1.779×10^{19} n/cm² (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 240°F and a 50 ft-lb transition temperature increase of 275°F. This results in an irradiated 30 ft-lb transition temperature of 150°F and an irradiated 50 ft-lb transition temperature of 210°F for the weld HAZ metal.

- o Irradiation of the reactor vessel Correlation Monitor Standard Reference Material (SRM) metal Charpy specimens to 1.779×10^{19} n/cm² (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 148°F and a 50 ft-lb transition temperature increase of 158°F. This results in an irradiated 30 ft-lb transition temperature of 163°F and an irradiated 50 ft-lb transition temperature of 203°F for the weld HAZ metal.

- o Irradiation of intermediate shell plate D-3803-1 (longitudinal orientation) to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in an irradiated average upper shelf energy decrease of 52 ft-lbs, resulting in an irradiated upper shelf energy of 103 ft-lbs.

- o The average upper shelf energy of the weld metal decreased 56 ft-lb after irradiation to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated upper shelf energy of 62 ft-lb for the weld metal specimens.

- o The average upper shelf energy of the weld HAZ metal decreased 35 ft-lb after irradiation to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated upper shelf energy of 81 ft-lb for the weld HAZ metal.

- o Irradiation of SRM metal to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in an irradiated average upper shelf energy decrease of 34 ft-lbs, resulting in an irradiated upper shelf energy of 99 ft-lbs.

- o The surveillance Capsule W-110 test results indicate that the 30 ft-lb transition temperature shift of the surveillance materials is in good agreement with Regulatory Guide 1.99, Revision 2 predictions and that the upper shelf energy decrease of the surveillance materials, except for the weld metal, is less than the Regulatory Guide 1.99, Revision 2 predictions (Table 5-8).

- o Per Reference 6, the Surveillance Capsule Removal Schedule will not be generated as part of this analysis.

The extensometer gage length is 1.00 inch. The extensometer is rated as Class B-2 per ASTM E83-93[17].

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. Because of the difficulty in remotely attaching a thermocouple directly to the specimen, the following procedure was used to monitor specimen temperature. Chromel-alumel thermocouples were inserted in shallow holes in the center and each end of the gage section of a dummy specimen and in each grip. In the test configuration, with a slight load on the specimen, a plot of specimen temperature versus upper and lower grip and controller temperatures was developed over the range of room temperature to 550°F (288°C). The upper grip was used to control the furnace temperature. During the actual testing the grip temperatures were used to obtain desired specimen temperatures. Experiments indicated that this method is accurate to ± 2°F[41].

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 and final gage length were determined from post-fracture photographs. The fracture area used to calculate the fracture stress (true stress at fracture) and percent reduction in area was computed using the final diameter measurement.

5.2 Charpy V-Notch Impact Test Results

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule W-110, which was irradiated to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV), are presented in Tables 5-1 through 5-6 and are compared with unirradiated results[2] as shown in Figures 5-2 through 5-5. The transition temperature increases and upper shelf energy decreases for the Capsule W-110 materials are summarized in Table 5-7.

Irradiation of the reactor vessel intermediate shell plate D-3803-1 Charpy specimens oriented with the longitudinal axis of the specimen parallel to the major rolling direction of the plate (longitudinal orientation) to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV) (Figure 5-1) resulted in a 30 ft-lb transition temperature increase of 180°F and in a 50 ft-lb transition temperature increase of 190°F. This results in an irradiated 30 ft-lb transition temperature of 180°F and an irradiated 50 ft-lb transition temperature of 210°F (longitudinal orientation).

The average Upper Shelf Energy (USE) of the intermediate shell plate D-3803-1 Charpy specimens (longitudinal orientation) resulted in an energy decrease of 52 ft-lb after irradiation to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average USE of 103 ft-lb (Figure 5-2).

Irradiation of the surveillance weld metal Charpy specimens to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV) (Figure 5-3) resulted in a 314°F increase in 30 ft-lb transition temperature and a 50 ft-lb transition temperature increase of 355°F. This results in an irradiated 30 ft-lb transition temperature of 229°F and an irradiated 50 ft-lb transition temperature of 305°F.

The average USE of the reactor vessel core region weld metal resulted in an energy decrease of 56 ft-lb after irradiation to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average USE of 62 ft-lb (Figure 5-3).

Irradiation of the reactor vessel weld Heat-Affected-Zone (HAZ) metal specimens to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV) (Figure 5-4) resulted in a 30 ft-lb transition temperature increase of 240°F and a 50 ft-lb transition temperature increase of 275°F. This results in an irradiated 30 ft-lb transition temperature of 150°F and an irradiated 50 ft-lb transition temperature of 210°F.

The average USE of the reactor vessel weld HAZ metal experienced an energy decrease of 35 ft-lb after irradiation to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average USE of 81 ft-lb (Figure 5-4).

Irradiation of the reactor vessel Correlation Monitor Standard Reference Material (SRM) specimens to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV) (Figure 5-5) resulted in a 30 ft-lb transition temperature increase of 148°F and a 50 ft-lb transition temperature increase of 158°F. This results in an irradiated 30 ft-lb transition temperature of 163°F and an irradiated 50 ft-lb transition temperature of 203°F.

The average USE of the reactor vessel Correlation Monitor Standard Reference Material (SRM) experienced an energy decrease of 34 ft-lb after irradiation to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average USE of 99 ft-lb (Figure 5-5).

The fracture appearance of each irradiated Charpy specimen from the various materials is shown in Figures 5-6 through 5-9 and show an increasingly ductile or tougher appearance with increasing test temperature.

A comparison of the 30 ft-lb transition temperature increases and upper shelf energy decreases for the various Palisades surveillance materials with predicted values using the methods of NRC Regulatory Guide 1.99, Revision 2[9] is presented in Table 5-8. This comparison indicates that the 30 ft-lb transition temperature shift of the surveillance materials is in good agreement with the Regulatory Guide 1.99, Revision 2 predictions and the USE decrease of the surveillance materials, except the weld metal, is less than the Regulatory Guide 1.99, Revision 2 predictions.

The load-time records for the individual instrumented Charpy specimen tests are shown in Appendix A.

5.3 Tension Test Results

The results of the tension tests performed on the various materials contained in Capsule W-110 irradiated to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV) are presented in Table 5-9 and are compared with unirradiated results[2] as shown in Figures 5-10 through 5-12.

The results of the tension tests performed on the intermediate shell plate D-3803-1 (longitudinal orientation) indicated that irradiation to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV) caused an 18 to 23 ksi increase in the 0.2 percent offset yield strength and a 12 to 15 ksi increase in the ultimate tensile strength when compared to unirradiated data[2] (Figure 5-10).

The results of the tension tests performed on the surveillance weld metal indicated that irradiation to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV) caused a 17 to 35 ksi increase in the 0.2 percent offset yield strength and a 17 to 27 ksi increase in the ultimate tensile strength when compared to unirradiated data[2] (Figure 5-11).

The results of the tension tests performed on the heat-affected zone (HAZ) metal indicated that irradiation to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV) caused a 12 to 20 ksi increase in the 0.2 percent offset yield strength and a 15 to 17 ksi increase in the ultimate tensile strength when compared to unirradiated data[2] (Figure 5-12).

The fractured tension specimens for the surveillance materials are shown in Figures 5-13 through 5-15.

The engineering stress-strain curves for the tensile tests are shown in Figures 5-16 through 5-21.

TABLE 5-7

Effect of Irradiation to 1.779 x 10^{19} n/cm^2 (E > 1.0 MeV)

on the Notch Toughness Properties of the Palisades Reactor Vessel Surveillance Materials

Material	Average 30 ft-lb (a) Transition Temperature (°F)			Average 35 mil (a) Lateral Expansion Temperature (°F)			Average 50 ft-lb (a) Transition Temperature (°F)			Average Energy Absorption at Full Shear (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Plate D-3803-1	0	180	180	5	200	195	20	210	190	155	103	-52
Weld Metal	-85	229	314	-75	280	355	-50	305	355	118	62	-56
HAZ Metal	-90	150	240	-55	187	242	-65	210	275	116	81	-35
SRM 01MY	15	163	148	25	192	167	45	203	158	133	99	-34

(a) "Average" is defined as the value read from the curve fit through the data points of the Charpy tests (see Figures 5-1 through 5-4).

TABLE 5-8

Comparison of the Palisades 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 (10^{19} n/cm^2, E>1.0MeV)**	**Predicted (a) (°F)**	**Measured (°F)**	**Predicted (a) (%)**	**Measured (%)**
Plate D-3803-1 (Transverse)	A-240	6.0*	223	205	48	35
	W-290	1.09	159	155	33	18
	W-110	1.779	180	--	37	--
Plate D-3803-1 (Longitudinal)	A-240	6.0*	223	205	48	42
	W-290	1.09	159	175	33	28
	W-110	1.779	180	180	37	34
Weld Metal	A-240	6.0*	423	350	56	55
	W-290	1.09	302	290	40	46
	W-110	1.779	341	314	44	47
HAZ Metal	A-240	6.0*	--	290	--	52
	W-290	1.09	--	235	--	38
	W-110	1.779	--	240	--	30
SRM	W-110	1.779	158	148	31	26

(a) Based on Regulatory Guide 1.99, Revision 2 methodology.

* See Reference 42.

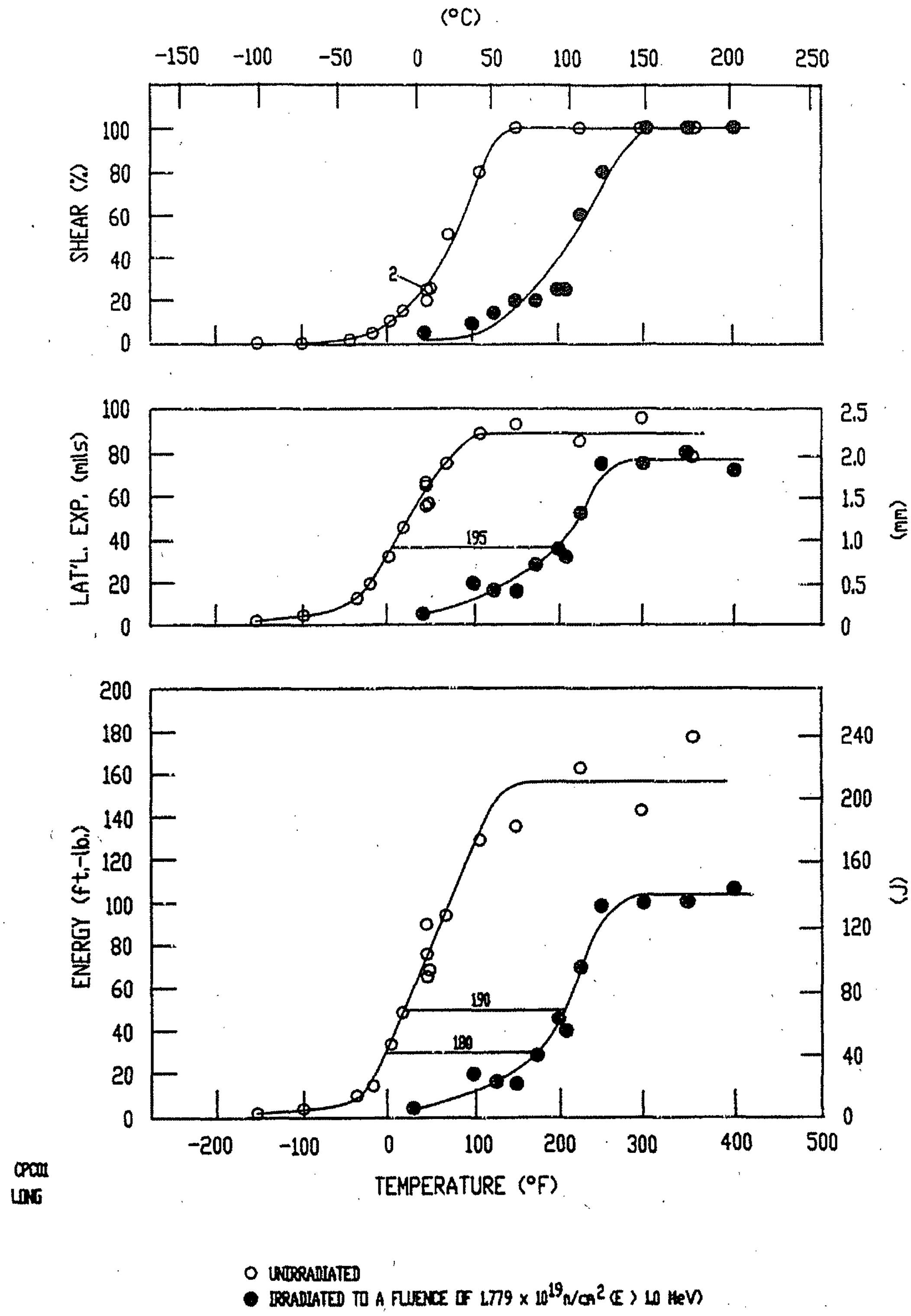


Figure 5-2 Charpy V-Notch Impact Properties for Palisades Reactor Vessel Intermediate Shell Plate D-3803-1 (longitudinal orientation)

BWXT Services, Inc.

ANALYSIS OF CAPSULE W-100 FROM THE NUCLEAR MANAGEMENT COMPANY PALISADES REACTOR VESSEL MATERIAL SURVEILLANCE PROGRAM

FEBRUARY 2004

4.0 DESCRIPTION OF THE PALISADES REACTOR VESSEL SURVEILLANCE PROGRAM

Prior to initial plant start-up, ten surveillance capsules were inserted into the Palisades reactor vessel near the reactor vessel wall as shown in Figure 4-1. The capsules contain specimens made from intermediate shell plate D-3803-1, heat-affected-zone (HAZ) metal fabricated by welding intermediate shell plates D-3803-2 and D-3803-3 with submerged arc process using Linde 1092 flux, and weld metal fabricated by welding intermediate shell plates D-3803-1 and D-3803-2 with submerged arc process using Linde 1092 flux and a MIL-B4 electrode and a 1/16-inch diameter Nickel-200 wire feed. Capsule W-100 was removed after 16.93 effective full power years (EFPY) of plant operation. This capsule contained Charpy impact and tensile specimens made of intermediate shell plate D-3803-1, submerged arc weld metal, and HAZ metal as describe above. All test specimens were machined from material taken at least one plate thickness from any water quenched edge.

The surveillance plate material was cut directly from the intermediate shell course plate after being subjected to 1.75 hours of interstage and 30 hours of final heat treatment at 1150 ± 25°F. Charpy impact specimens from surveillance plate D-3803-1 were machined in the longitudinal orientation (longitudinal axis of the specimen longitudinal to the major working direction). The 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 surveillance plate D-3803-1 were machined with the major axis both in the tangential and longitudinal orientations. Tensile specimens from the weld metal were oriented with the long dimension of the specimen perpendicular to the weld direction.

The chemical compositions of the surveillance materials are presented in Table 4-1. The chemical analysis reported in Table 4-1 was obtained from unirradiated material used in the surveillance program [3].

Capsule W-100 contained dosimeter wires of uranium, sulfur, iron, nickel, titanium, and copper. Cadmium covers were used for materials that have competing thermal activities (i.e., uranium, nickel, and copper). Dosimeters are used to determine flux spectrum and flux attenuation through the thickness of the Charpy specimens.

The temperature monitor assemblies consist of four separate coil-shaped monitors, each of different composition and thus having different melting points. They are identified by varying capsule lengths, with melting temperatures increasing with increasing capsule length. The alloys compositions and melting points are listed as follows.

Composition	Melting Point
92.5% Pb, 5.0% Sn, 2.5% Ag	536°F
90.0% Pb, 5.0% Sn, 5.0% Ag	558°F
97.5% Pb, 2.5% Ag	580°F
97.5% Pb, 0.75% Sn, 1.75% Ag	590°F

The arrangement of the various mechanical specimens, dosimeters, and thermal monitors contained in Capsule W-100 is shown in Figure 4-2.

TABLE 4-1
Chemical Composition (wt%) of the Palisades Reactor Vessel Surveillance Materials[3]

Element	D-3803-1	D-3803-2	D-3803-3	Weld D-3803-3/ D-3803-2 Root	Weld D-3803-3/ D-3803-2 Face	Weld D-3803-2/ D-3803-2 Root	Weld D-3803-2/ D-3803-1 Face
Si	0.23	0.32	0.24	0.24	0.25	0.25	0.22
S	0.019	0.021	0.020	0.009	0.010	0.010	0.010
P	0.011	0.12	0.010	0.011	0.012	0.011	0.011
Mn	1.55	1.43	1.56	1.08	1.03	1.01	1.02
C	0.22	0.23	0.21	0.098	0.080	0.088	0.086
Cr	0.13	0.42	0.13	0.05	0.04	0.05	0.03
Ni	0.53	0.55	0.53	0.43	1.28	0.63	1.27
Mo	0.58	0.58	0.59	0.54	0.53	0.55	0.52
Al(T)	0.037	0.022	0.037	Nil	Nil	Nil	Nil
V	0.003	0.003	0.003	Nil	Nil	Nil	Nil
Cu	0.25	0.25	0.25	0.25	0.20	0.26	0.22

Table 6-1.
Charpy Impact Data for the Palisades W-100 Capsule Plate D-3803-1

Specimen Number	Temperature, °F	Impact Energy, ft-lb	Lateral Expansion, mils	Shear Fracture, %
		Transverse		
213	70	9.5	2	0
255	110	14.0	7	5
25E	150	27.5	19	20
25B	200	44.0	32	40
25D	225	52.5	39	50
211	240	50.0	36	50
257	250	71.5	54	70
256	260	69.0	47	90
214	270	71.0	54	95
25A	285	77.0	56	100
25C	300	76.5	63	100
212	325	67.5	56	100
		Longitudinal		
152	70	5.5	1	0
151	110	14.0	7	5
153	130	29.5	18	25
157	175	44.0	27	40
15A	200	45.0	34	45
154	225	74.4	51	70
15Y	250	86.5	50	85
156	260	73.0	50	80
15C	270	102.0	57	95
15B	280	100.5	58	100
15U	300	104.5	72	100
155	325	101.0	68	100

Table 6-3.
Comparison of Palisades Surveillance Material (Capsule W-100) 30 ft-lb Transition Temperature Shifts (Position 2.1) and Upper Shelf Energy Decreases with Regulatory Guide 1.99 Revision 2 Predictions

Material	Unirradiated 30 ft-lb Temp. (°F)	Capsule W-100 30 ft-lb Temp. (°F)	Measured 30 ft-lb Temp. Shift (°F)	Predicted 30 ft-lb Temp. Shift (°F)	Unirradiated USE (ft-lb)	Capsule W-100 USE (ft-lb)	Predicted USE (ft-lb)
D-3803-1 Transverse	18.3	160.8	142.5	189.1	101.6	73.0	61.7
D-3803-1 Longitudinal	-0.5	158.6	159.1	189.1	154.8	102.0	93.8
Weld Metal	-86.6	218.8	305.4	*	117.7	51.8	63.7
HAZ Metal	-89.6	101.4	191.0	**	115.5	59.7	**

*Could not be calculated because RG 1.99 Rev 2 Table 2 does not provide chemistry factors for base metals with Ni content greater than 1.2 wt%.
** The RG 1.99 Rev 2 CF tables do not cover HAZ metal

Table 6-4.
Tensile Properties of the Palisades Capsule W-100 Materials

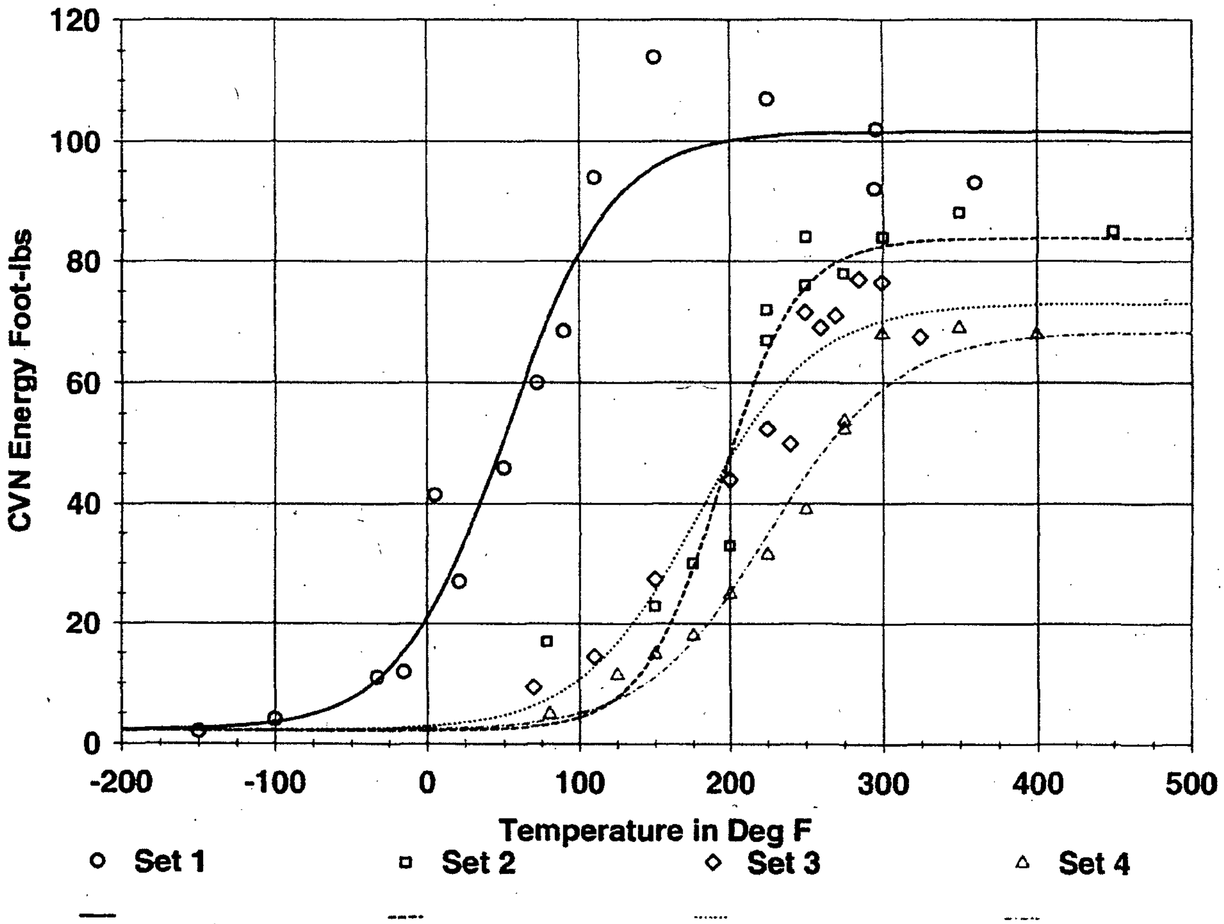
Material	Specimen Number	Test Temp. (°F)	0.2% Yield Strength (Ksi)	Ultimate Strength (Ksi)	Fracture Load (Kip)	Fracture Stress (Ksi)	Fracture Strength (Ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
HAZ	4JK	70	92.0	106.3	3.60	175.9	73.4	6.0	N/A	58.3
	4JJ	200	88.6	101.3	3.47	171.4	70.7	4.9	N/A	58.8
	4JE	550	83.1	98.9	3.84	146.8	78.2	4.3	N/A	46.7
D-3803-1 (Long.)	1J1	70	89.8	108.2	3.51	190.6	71.4	10.8	23.8	62.5
	1EY	250	83.0	101.7	3.35	169.9	68.3	9.9	21.6	59.8
	1E7	550	76.7	98.3	3.53	150.1	71.9	8.8	19.2	52.1
Weld Metal	3DT	70	101.7	115.0	4.52	192.1	92.0	11.7	23.5	52.1
	3DP	300	96.4	109.7	4.59	167.1	93.5	9.4	16.6	44.0
	3DM	550	92.9	109.8	4.78	178.6	97.3	7.9	13.6	45.5

NA: Specimen failed outside the gage length.

Palisades Nuclear Plant - Base (Transverse)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 02/03/2004 10:22 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	PALISADES	UNIRR	SA302BM	TL	C-1279-3
2	PALISADES	W-290	SA302BM	TL	C-1279-3
3	PALISADES	W-100	SA302BM	TL	C-1279-3
4	PALISADES	A-240	SA302BM	TL	C-1279-3



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	0	2.2	101.6	.0	18.3	.0	49.1	.0
2	9.26E18	2.2	83.8	-17.8	176.3	158.0	202.5	153.4
3	2.09E19	2.2	73.0	-28.6	160.8	142.5	206.3	157.2
4	4.01E19	2.2	68.4	-33.2	212.6	194.3	265.1	216.0

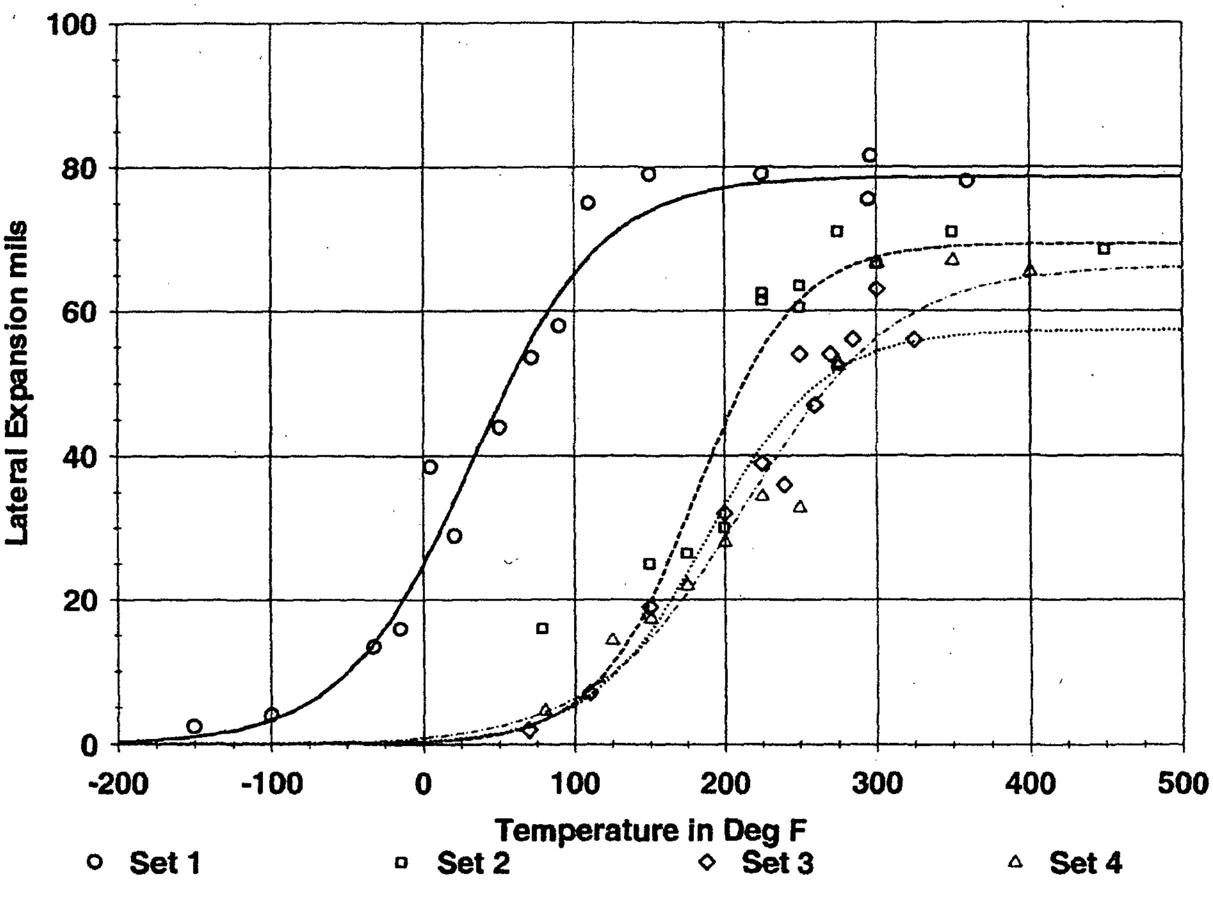
Figure 6-1. Charpy Impact Energy vs. Temperature for Palisades Surveillance Plate D-3803-1 (Transverse Orientation)

C01

Palisades Nuclear Plant - Base (Transverse)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 02/03/2004 10:25 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	PALISADES	UNIRR	SA302BM	TL	C-1279-3
2	PALISADES	W-290	SA302BM	TL	C-1279-3
3	PALISADES	W-100	SA302BM	TL	C-1279-3
4	PALISADES	A-240	SA302BM	TL	C-1279-3



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	0	.0	78.6	.0	23.5	.0
2	9.26E18	.0	69.3	-9.3	181.7	158.2
3	2.09E19	.0	57.3	-21.3	205.9	182.4
4	4.01E19	.0	66.3	-12.3	219.2	195.7

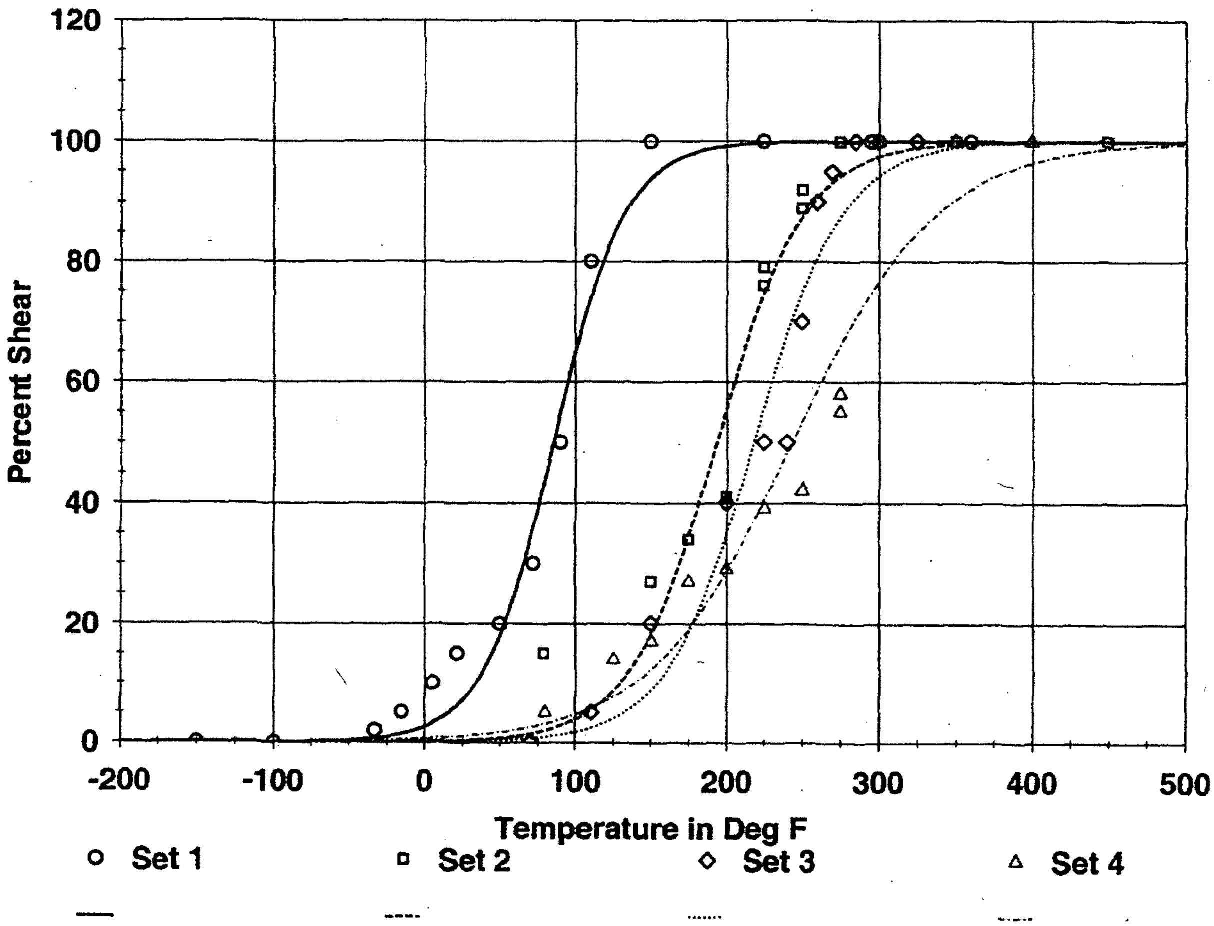
Figure 6-2. Lateral Expansion vs. Temperature for Palisades Surveillance Plate D-3803-1 (Transverse Orientation)

C02

Palisades Nuclear Plant - Base (Transverse)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 02/03/2004 10:23 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	PALISADES	UNIRR	SA302BM	TL	C-1279-3
2	PALISADES	W-290	SA302BM	TL	C-1279-3
3	PALISADES	W-100	SA302BM	TL	C-1279-3
4	PALISADES	A-240	SA302BM	TL	C-1279-3



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	0	.0	100.0	.0	85.5	.0
2	9.26E18	.0	100.0	.0	193.6	108.1
3	2.09E19	.0	100.0	.0	218.7	133.2
4	4.01E19	.0	100.0	.0	243.5	158.0

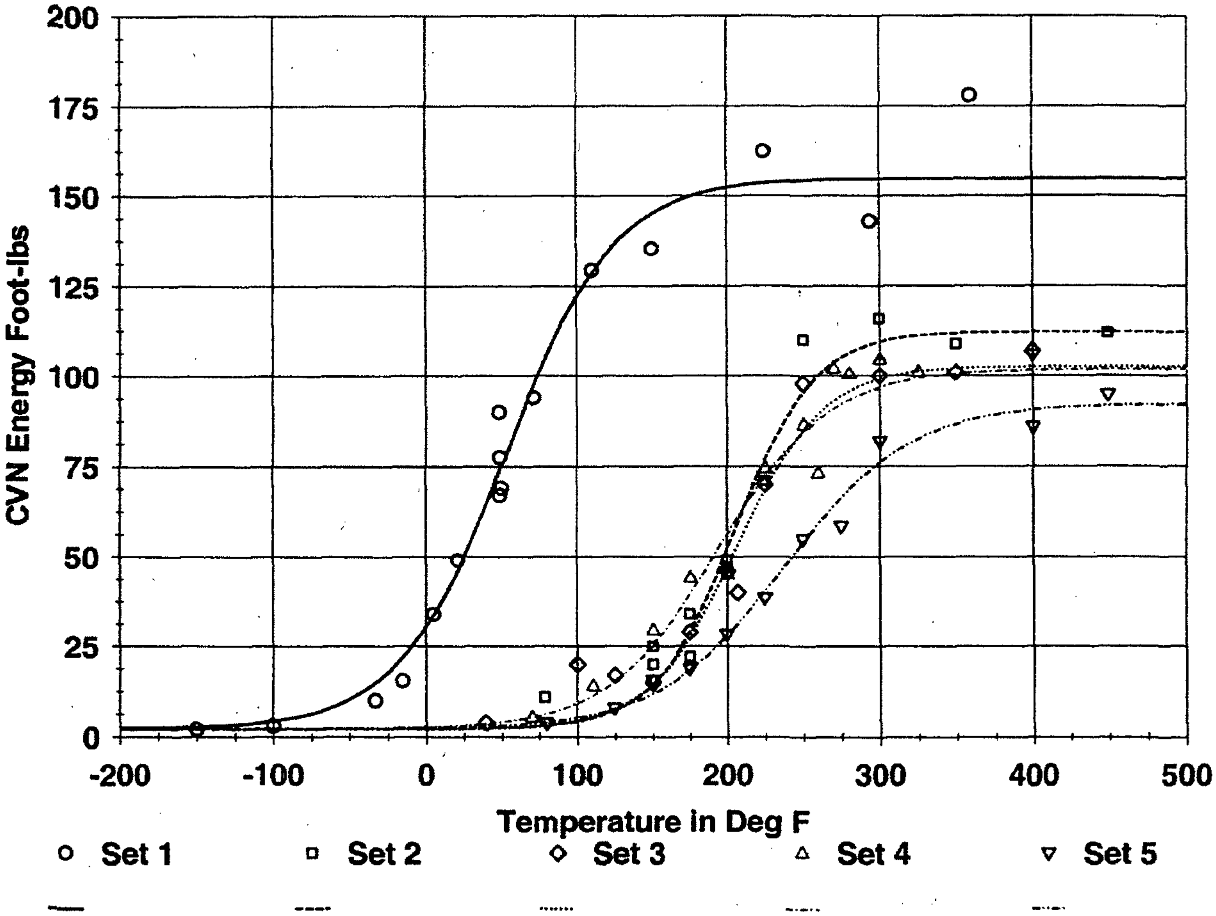
Figure 6-3. Percent Shear vs. Temperature for Palisades Surveillance Plate D-3803-1 (Transverse Orientation)

C03

Palisades Nuclear Plant - Base (Long.)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 02/03/2004 09:49 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	PALISADES	UNIRR	SA302BM	LT	C-1279-3
2	PALISADES	W-290	SA302BM	LT	C-1279-3
3	PALISADES	W-110	SA302BM	LT	C-1279-3
4	PALISADES	W-100	SA302BM	LT	C-1279-3
5	PALISADES	A-240	SA302BM	LT	C-1279-3



Results

Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	0	2.2	154.8	.0	-.5	.0	25.3	.0
2	9.26E18	2.2	112.3	-42.5	176.3	176.8	198.0	172.7
3	1.66E19	2.1	102.7	-52.1	179.0	179.5	203.5	178.2
4	2.09E19	2.2	102.0	-52.8	158.6	159.1	190.4	165.1
5	4.01E19	2.1	92.3	-62.5	204.6	205.1	243.0	217.7

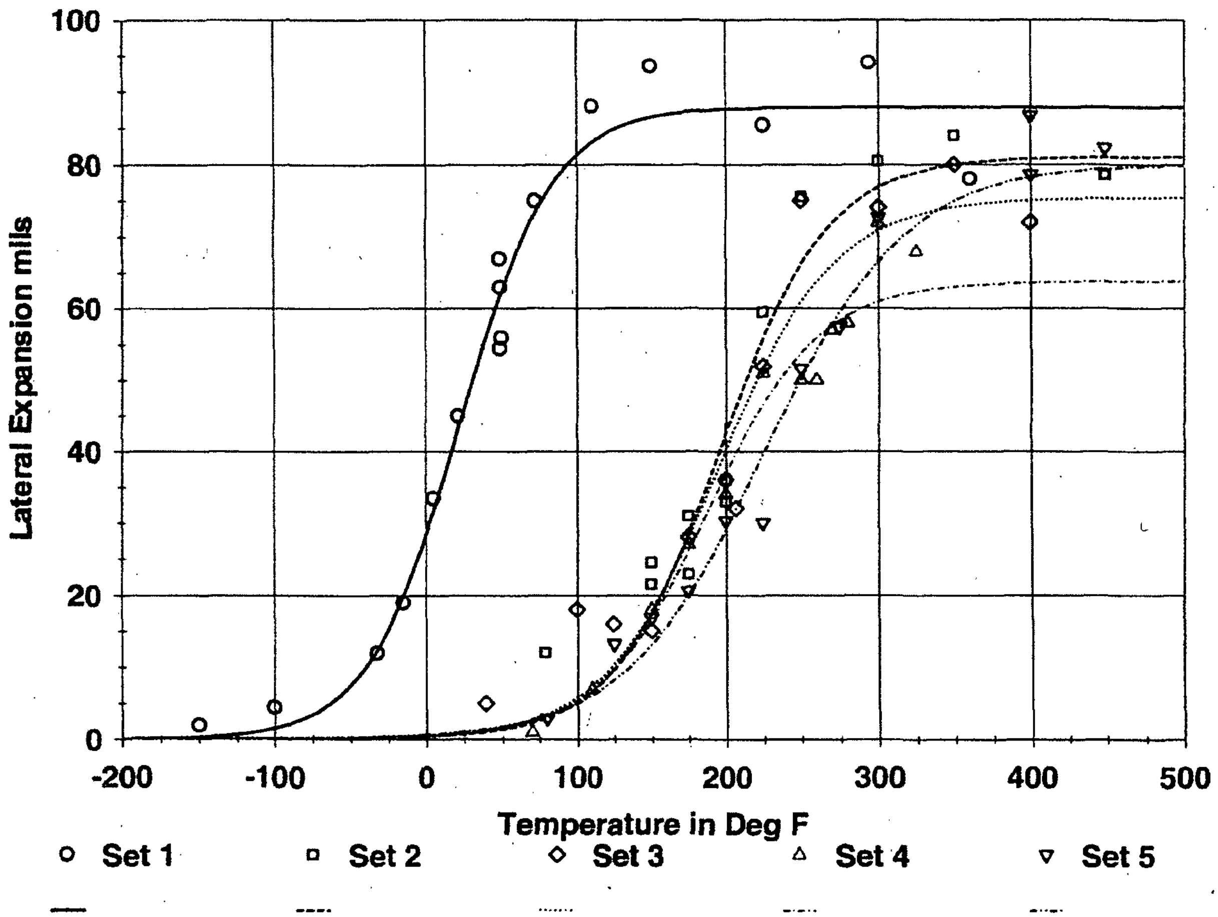
Figure 6-4. Charpy Impact Energy vs. Temperature for Palisades Surveillance Plate D-3803-1 (Longitudinal Orientation)

C04

Palisades Nuclear Plant - Base (Long.)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 02/03/2004 09:51 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	PALISADES	UNIRR	SA302BM	LT	C-1279-3
2	PALISADES	W-290	SA302BM	LT	C-1279-3
3	PALISADES	W-110	SA302BM	LT	C-1279-3
4	PALISADES	W-100	SA302BM	LT	C-1279-3
5	PALISADES	A-240	SA302BM	LT	C-1279-3



Results

Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	0	.0	87.8	.0	10.0	.0
2	9.26E18	.0	81.0	-6.8	186.9	176.9
3	1.66E19	.0	75.3	-12.5	190.0	180.0
4	2.09E19	.0	63.8	-24.0	195.7	185.7
5	4.01E19	.0	80.0	-7.8	214.4	204.4

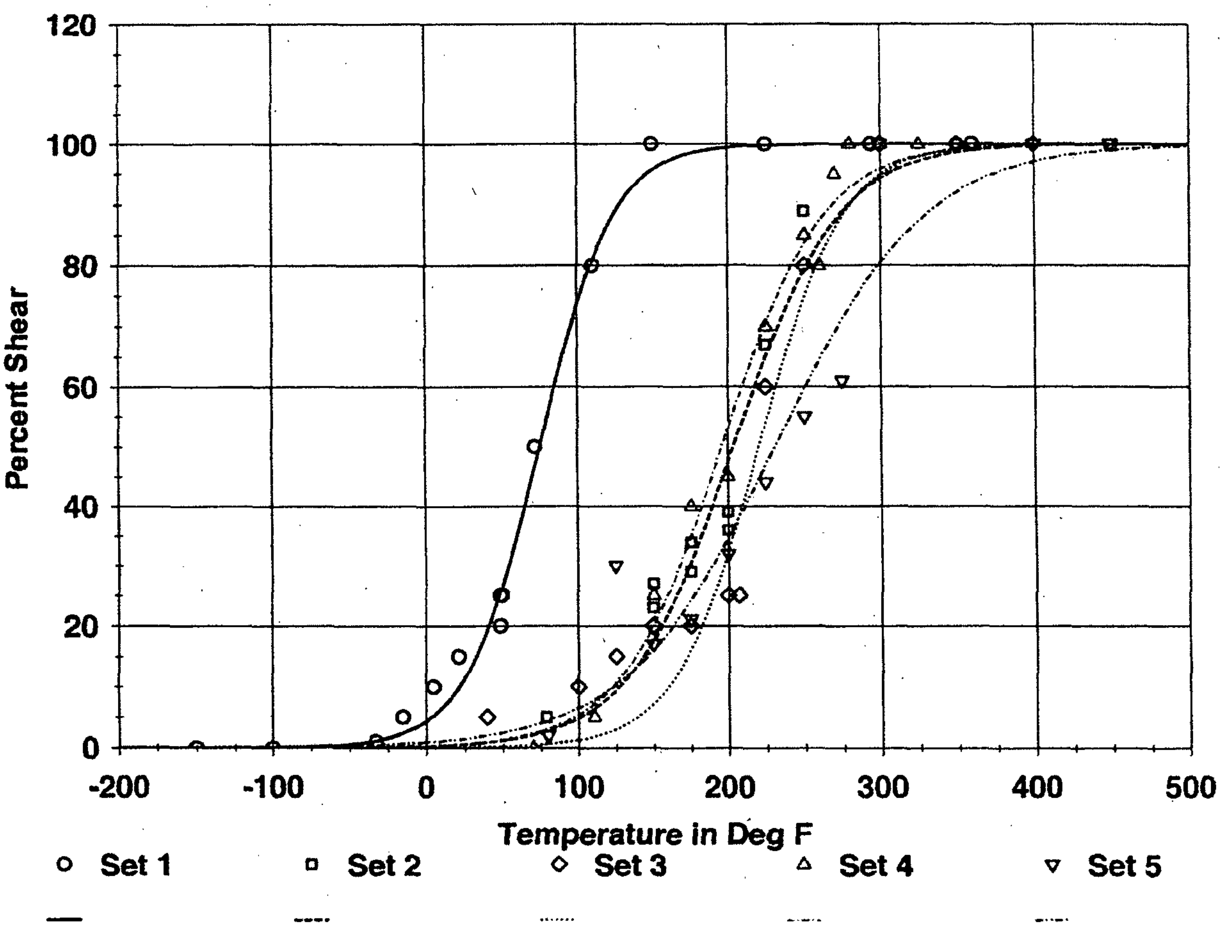
Figure 6-5. Lateral Expansion vs. Temperature for Palisades Surveillance Plate D-3803-1 (Longitudinal Orientation)

r05

Palisades Nuclear Plant - Base (Long.)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 02/03/2004 09:50 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	PALISADES	UNIRR	SA302BM	LT	C-1279-3
2	PALISADES	W-290	SA302BM	LT	C-1279-3
3	PALISADES	W-110	SA302BM	LT	C-1279-3
4	PALISADES	W-100	SA302BM	LT	C-1279-3
5	PALISADES	A-240	SA302BM	LT	C-1279-3



Results

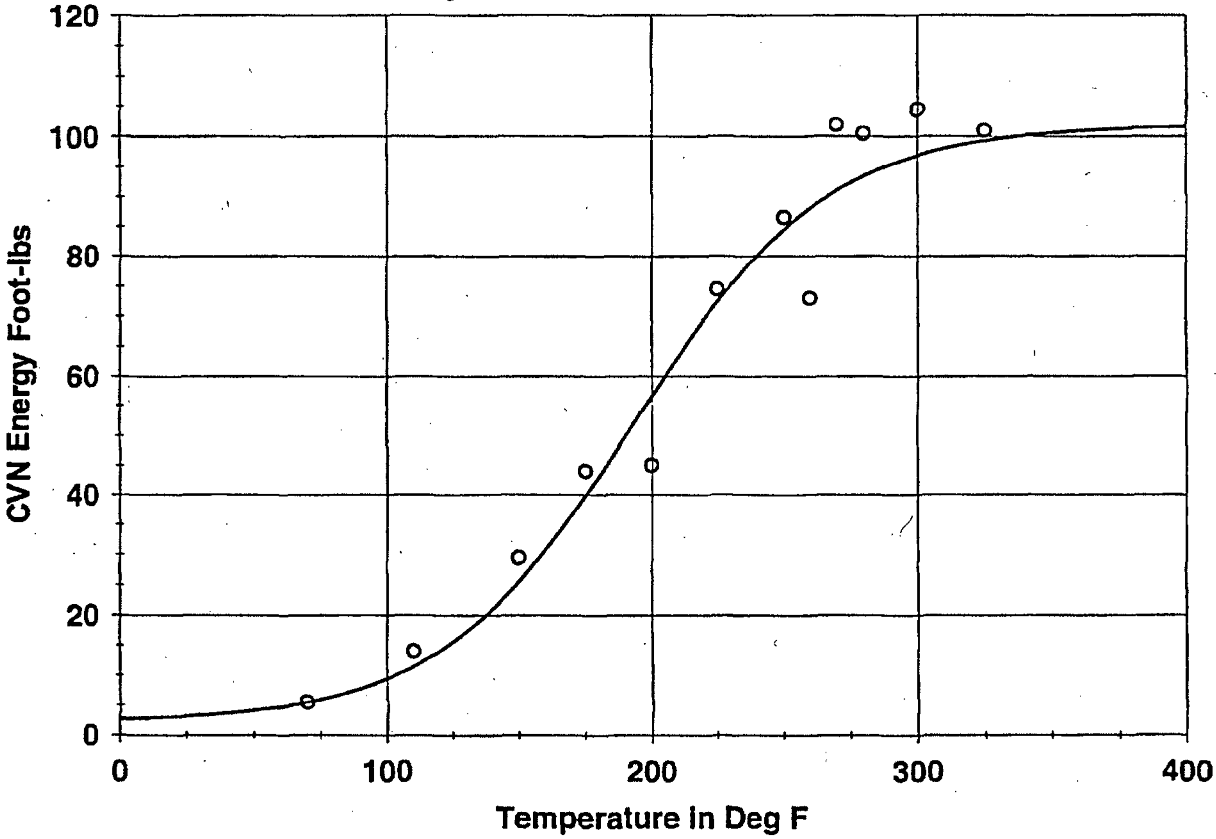
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	0	.0	100.0	.0	75.0	.0
2	9.26E18	.0	100.0	.0	203.5	128.5
3	1.66E19	.0	100.0	.0	220.5	145.5
4	2.09E19	.0	100.0	.0	195.7	120.7
5	4.01E19	.0	100.0	.0	231.0	156.0

Figure 6-6. Percent Shear vs. Temperature for Palisades Surveillance Plate D-3803-1 (Longitudinal Orientation)

C06

W-100 PLATE (LONGITUDINAL)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 01/08/2004 10:29 AM
Page 1
Coefficients of Curve 1
A = 52.1 B = 49.9 C = 73.2 T0 = 193.41 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=102.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=158.6 Deg F Temp@50 ft-lbs=190.4 Deg F
Plant: PALISADES Material: D-3803-1 Heat: C-1279
Orientation: LT Capsule: W-100 Fluence: 2.09E19 n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	5.50	5.51	-.01
110.00	14.00	11.47	2.53
150.00	29.50	25.55	3.95
175.00	44.00	39.81	4.19
200.00	45.00	56.58	-11.58
225.00	74.50	72.39	2.11
250.00	86.50	84.47	2.03
260.00	73.00	88.08	-15.08
270.00	102.00	91.04	10.96

W-100 PLATE (LONGITUDINAL)

Plant: PALISADES Material: D-3803-1 Heat: C-1279
Orientation: LT Capsule: W-100 Fluence: 2.09E19 n/cm^2

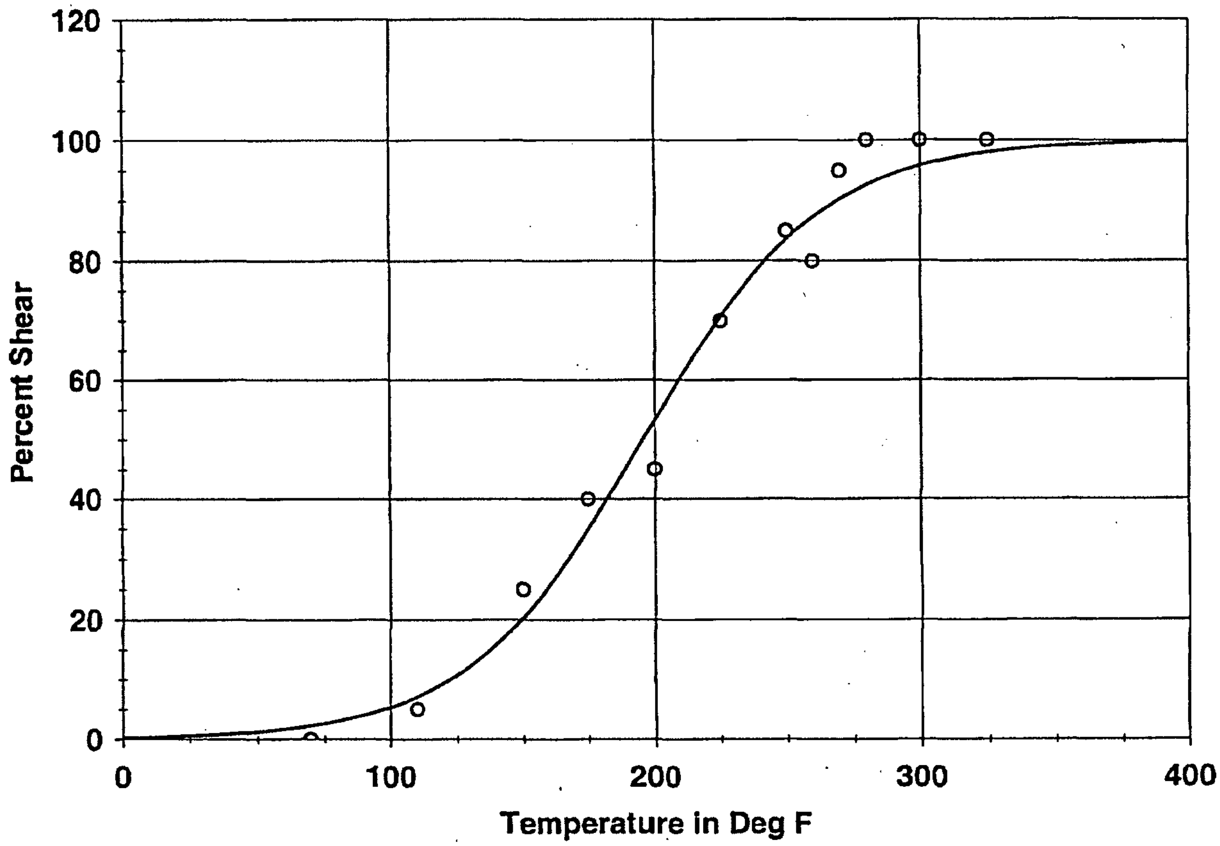
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
280.00	100.50	93.44	7.06
300.00	104.50	96.86	7.64
325.00	101.00	99.33	1.67

Correlation Coefficient = .978

W-100 PLATE (LONGITUDINAL)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 01/08/2004 10:30 AM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 66.65 T0 = 195.62 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 195.7
Plant: PALISADES Material: D-3803-1 Heat: C-1279
Orientation: LT Capsule: W-100 Fluence: 2.09E19 n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	.00	2.25	-2.25
110.00	5.00	7.11	-2.11
150.00	25.00	20.28	4.72
175.00	40.00	35.01	4.99
200.00	45.00	53.28	-8.28
225.00	70.00	70.71	-.71
250.00	85.00	83.64	1.36
260.00	80.00	87.34	-7.34
270.00	95.00	90.31	4.69

W-100 PLATE (LONGITUDINAL)

Plant: PALISADES Material: D-3803-1 Heat: C-1279
Orientation: LT Capsule: W-100 Fluence: 2.09E19 n/cm^2

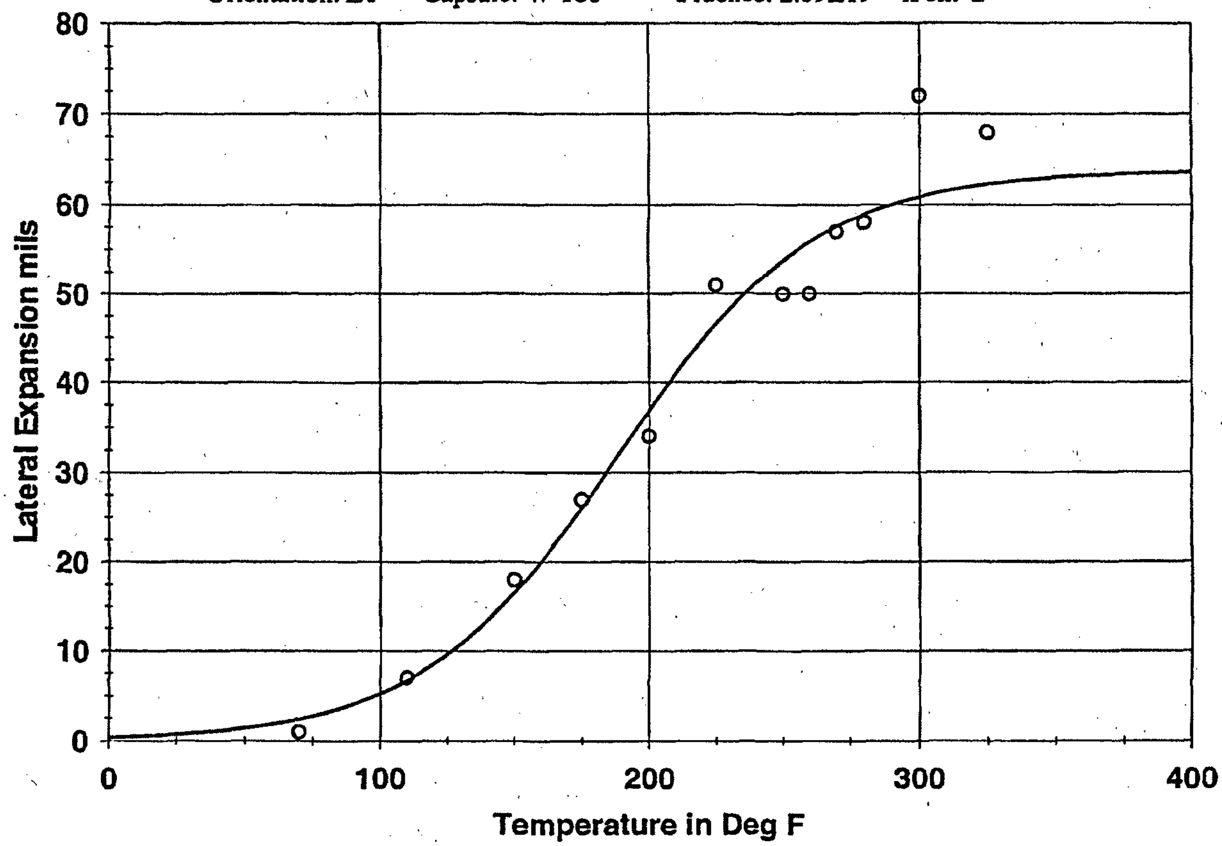
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
280.00	100.00	92.63	7.37
300.00	100.00	95.82	4.18
325.00	100.00	97.98	2.02

Correlation Coefficient = .992

W-100 PLATE (LONGITUDINAL)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 01/08/2004 10:35 AM
Page 1
Coefficients of Curve 1
A = 31.9 B = 31.9 C = 73.39 T0 = 188.47 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=63.8(Fixed) Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=195.7 Deg F
Plant: PALISADES Material: D-3803-1 Heat: C-1279
Orientation: LT Capsule: W-100 Fluence: 2.09E19 n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	1.00	2.43	-1.43
110.00	7.00	6.73	.27
150.00	18.00	16.56	1.44
175.00	27.00	26.11	.89
200.00	34.00	36.87	-2.87
225.00	51.00	46.59	4.41
250.00	50.00	53.75	-3.75
260.00	50.00	55.85	-5.85
270.00	57.00	57.56	-.56

W-100 PLATE (LONGITUDINAL)

Plant: PALISADES Material: D-3803-1 Heat: C-1279
Orientation: LT Capsule: W-100 Fluence: 2.09E19 n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
280.00	58.00	58.94	-.94
300.00	72.00	60.89	11.11
325.00	68.00	62.29	5.71

Correlation Coefficient = .981

W-100 PLATE (TRANSVERSE)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 01/08/2004 10:37 AM

Page 1

Coefficients of Curve 1

A = 37.6 B = 35.4 C = 77.92 T0 = 177.79 D = 0.00E+00

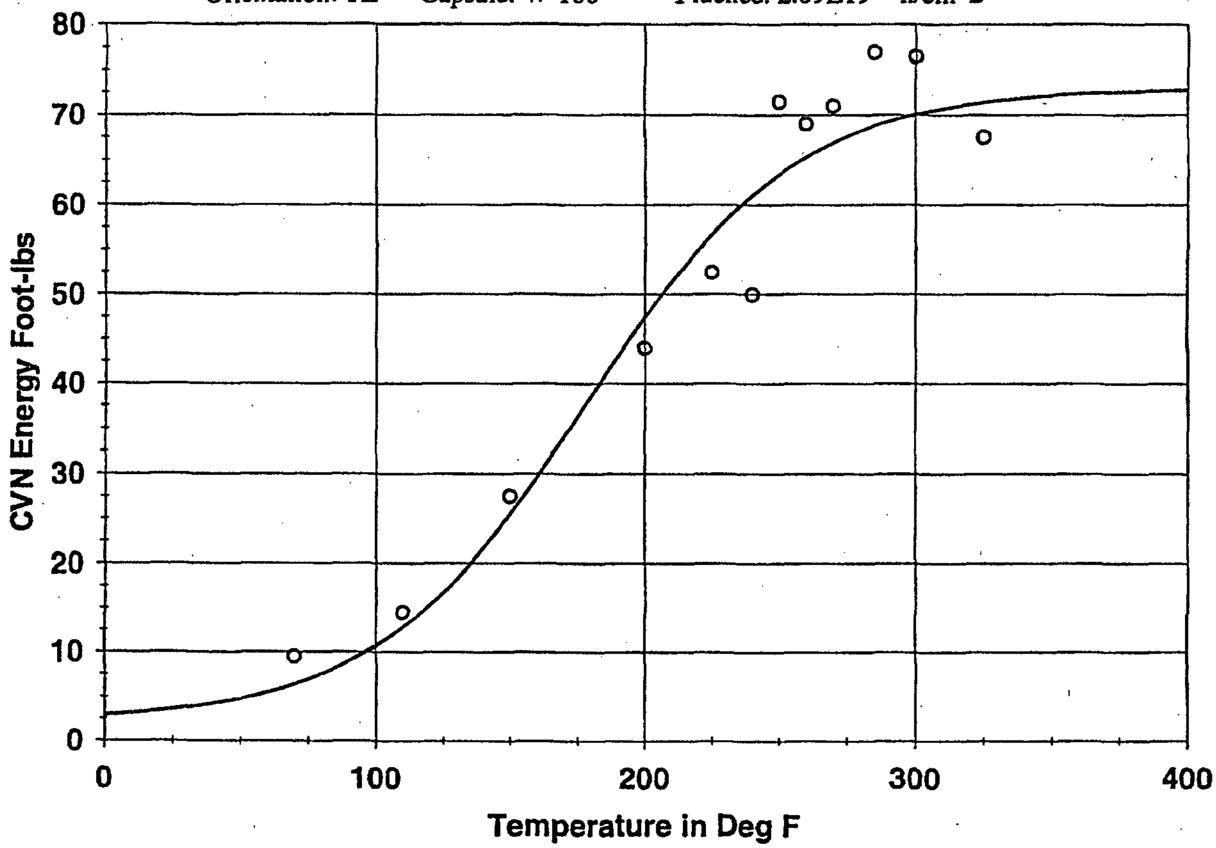
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=73.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=160.8 Deg F Temp@50 ft-lbs=206.3 Deg F

Plant: PALISADES Material: D-3803-1 Heat: C-1279

Orientation: TL Capsule: W-100 Fluence: 2.09E19 n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	9.50	6.39	3.11
110.00	14.50	12.77	1.73
150.00	27.50	25.48	2.02
200.00	44.00	47.42	-3.42
225.00	52.50	56.76	-4.26
240.00	50.00	61.07	-11.07
250.00	71.50	63.41	8.09
260.00	69.00	65.34	3.66
270.00	71.00	66.93	4.07

W-100 PLATE (TRANSVERSE)

Plant: PALISADES Material: D-3803-1 Heat: C-1279
Orientation: TL Capsule: W-100 Fluence: 2.09E19 n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
285.00	77.00	68.75	8.25
300.00	76.50	70.05	6.45
325.00	67.50	71.42	-3.92

Correlation Coefficient = .970

W-100 PLATE (TRANSVERSE)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 01/08/2004 10:38 AM

Page 1

Coefficients of Curve 1

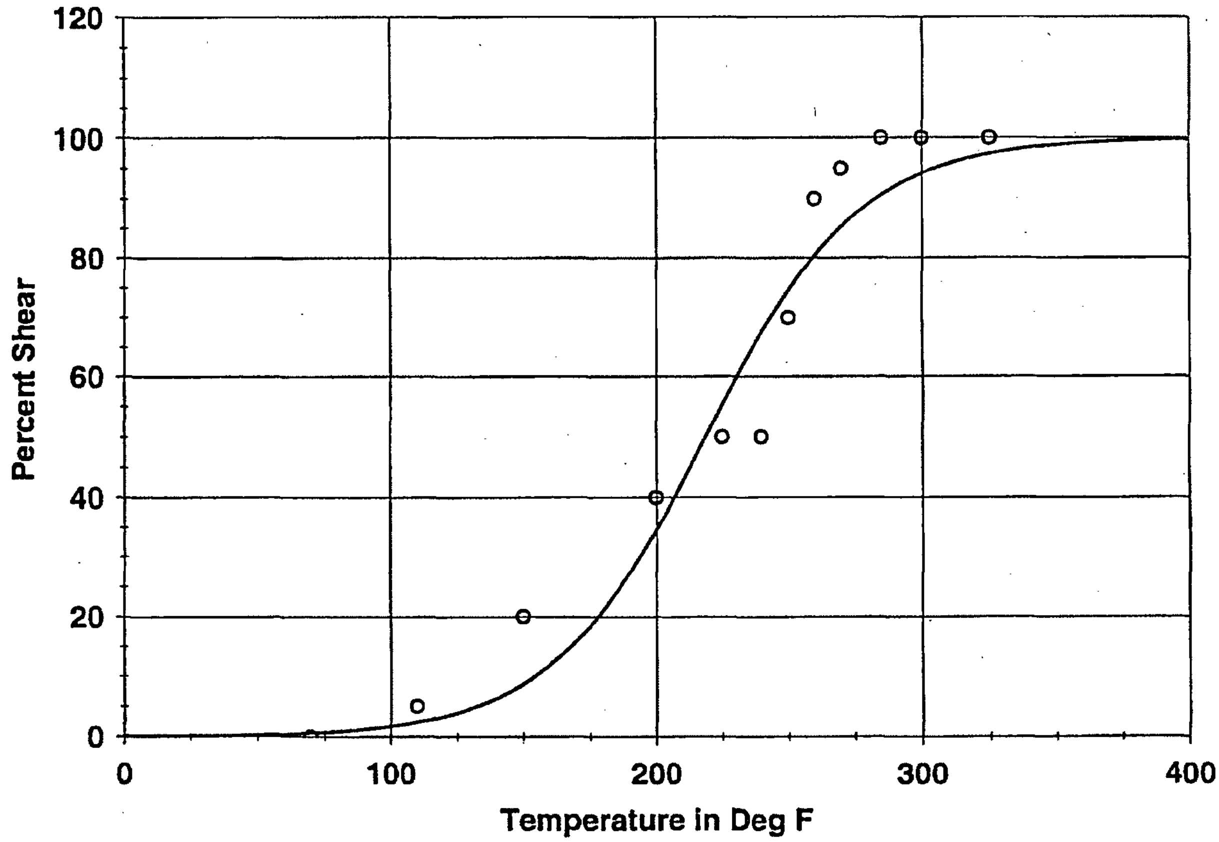
A = 50. B = 50. C = 58.39 T0 = 218.6 D = 0.00E+00

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

Temperature at 50% Shear = 218.7

Plant: PALISADES Material: D-3803-1 Heat: C-1279

Orientation: TL Capsule: W-100 Fluence: 2.09E19 n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	.00	.61	-.61
110.00	5.00	2.37	2.63
150.00	20.00	8.71	11.29
200.00	40.00	34.59	5.41
225.00	50.00	55.46	-5.46
240.00	50.00	67.55	-17.55
250.00	70.00	74.56	-4.56
260.00	90.00	80.50	9.50
270.00	95.00	85.33	9.67

W-100 PLATE (TRANSVERSE)

Plant: PALISADES Material: D-3803-1 Heat: C-1279
Orientation: TL Capsule: W-100 Fluence: 2.09E19 n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
285.00	100.00	90.67	9.33
300.00	100.00	94.20	5.80
325.00	100.00	97.45	2.55

Correlation Coefficient = .975

W-100 PLATE (TRANSVERSE)

CVGRAPH 5.0.1 Hyperbolic Tangent Curve Printed on 01/08/2004 10:39 AM

Page 1

Coefficients of Curve 1

A = 28.65 B = 28.65 C = 77.19 T0 = 188.4 D = 0.00E+00

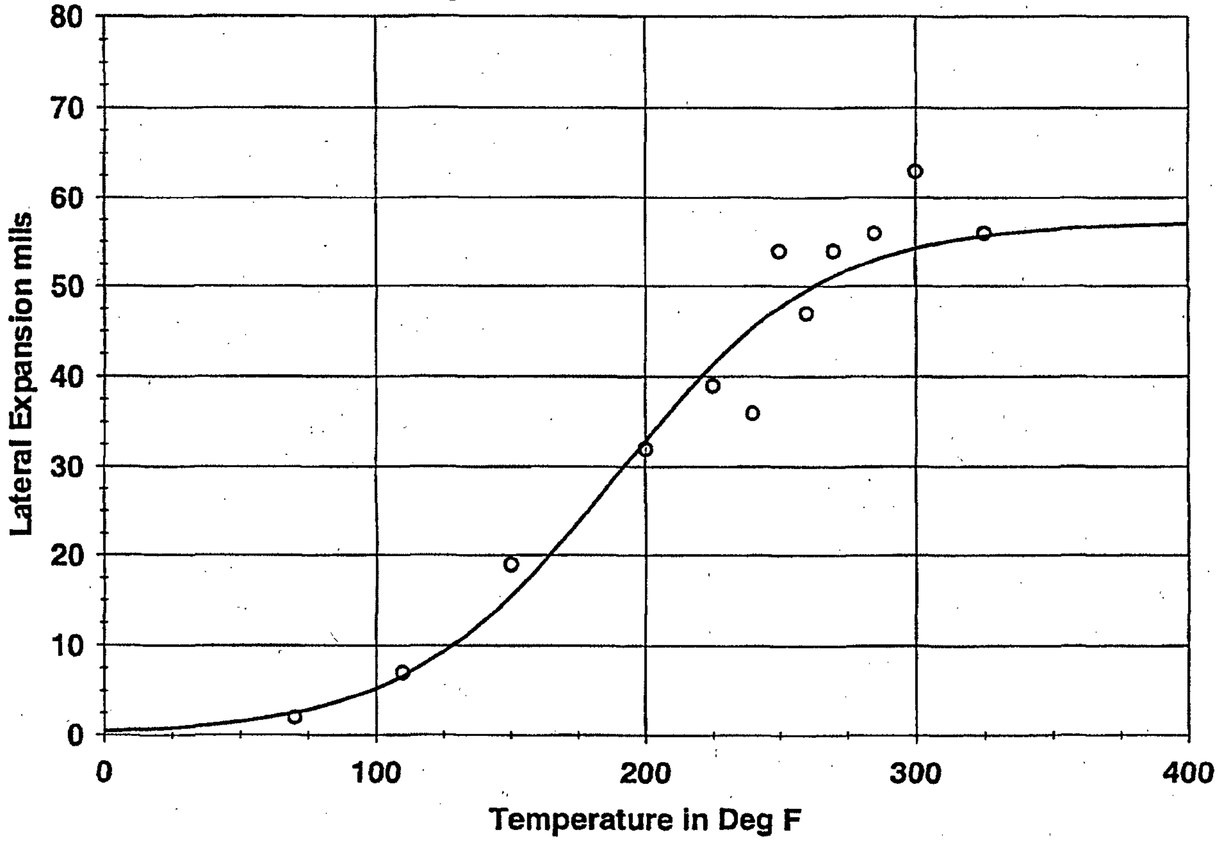
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=57.3(Fixed) Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=205.9 Deg F

Plant: PALISADES Material: D-3803-1 Heat: C-1279

Orientation: TL Capsule: W-100 Fluence: 2.09E19 n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	2.00	2.55	-.55
110.00	7.00	6.64	.36
150.00	19.00	15.47	3.53
200.00	32.00	32.92	-.92
225.00	39.00	41.30	-2.30
240.00	36.00	45.38	-9.38
250.00	54.00	47.64	6.36
260.00	47.00	49.55	-2.55
270.00	54.00	51.13	2.87

W-100 PLATE (TRANSVERSE)

Plant: PALISADES Material: D-3803-1 Heat: C-1279
Orientation: TL Capsule: W-100 Fluence: 2.09E19 n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
285.00	56.00	52.96	3.04
300.00	63.00	54.29	8.71
325.00	56.00	55.68	.32

Correlation Coefficient = .973