ATTACHMENT 1

WESTINGHOUSE WCAP-17403-NP
REVISION 1

PALISADES NUCLEAR POWER PLANT
EXTENDED BELTLINE REACTOR VESSEL INTEGRITY EVALUATION

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Palisades Nuclear Power Plant Extended Beltline Reactor Vessel Integrity Evaluation

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Palisades Nuclear Power Plant Extended Beltline Reactor Vessel Integrity Evaluation

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RECORD OF REVISION

Revision 0: Original Issue

Revision 1: This revision is being issued to correct the intermediate shell axial weld designations on Figures 1-1 and 1-2. In Revision 0, these welds are incorrectly labeled as 2-112 C – B – A, reading from left to right. The correct order is 2-112 B – C – A. No other changes were made to this report as a result of this correction; therefore, change bars are omitted.

TABLE OF CONTENTS

LIST OF TABLES iv

LIST OF FIGURES v

EXECUTIVE SUMMARY vi

1 INTRODUCTION 1-1
2 METHOD DISCUSSION 2-1
2.1 INITIAL MATERIAL PROPERTY DETERMINATION METHODOLOGY 2-1
2.1.1 Branch Technical Position 5-3 of NUREG-0800, Revision 2 2-1
2.1.2 Charpy V-Notch Surveillance Data Curve Fitting 2-2
2.2 REACTOR VESSEL INTEGRITY EVALUATIONS METHODOLOGY 2-4
2.2.1 Pressurized Thermal Shock (PTS) 2-4
2.2.2 Upper-Shelf Energy (USE) 2-5
2.2.3 Adjusted Reference Temperature (ART) 2-6
2.2.4 Supplemental Surveillance Data Guidance 2-7
2.2.5 Pressure-Temperature (P-T) Limit Curve Applicability 2-8
3 CALCULATED FLUENCE 3-1
4 FRACTURE TOUGHNESS PROPERTIES 4-1
5 CHEMISTRY FACTORS AND UPPER-SHELF ENERGY SURVEILLANCE DATA 5-1
6 PRESSURIZED THERMAL SHOCK CALCULATIONS 6-1
7 UPPER-SHELF ENERGY CALCULATIONS 7-1
8 PRESSURE-TEMPERATURE LIMIT CURVE APPLICABILITY 8-1
9 REFERENCES 9-1
APPENDIX A CVGRAPH PLOTS USED IN THE DETERMINATION OF THE INITIAL RT_{NDT} FOR THE PALISADES UPPER SHELL PLATES A-1
A.1 US PLATE D-3802-1 (HEAT # C-1279) A-2
A.2 US PLATE D-3802-2 (HEAT # C-1308) A-6
A.3 US PLATE D-3802-3 (HEAT # C-1281) A-10

LIST OF TABLES

Table 1-1 Palisades Reactor Vessel Materials and Analyses 1-2

Table 3-1 Palisades Surface, 1/4T and 3/4T Fluence and Fluence Factor Values at 42.1 EFPY 3-2

Table 4-1 Extended Beltline Material Properties for the Palisades Reactor Vessel 4-2

Table 5-1 Summary of Palisades Positions 1.1 and 2.1 Chemistry Factors 5-2

Table 5-2 Summary of Palisades Capsule Fluence Values and Measured USE Percent Decrease Data 5-3

Table 6-1 RT_{PTS} Calculations for the Palisades Reactor Vessel Extended Beltline Materials at 42.1 EFPY 6-2

Table 7-1 Palisades Predicted Positions 1.2 and 2.2 USE Values at 42.1 EFPY 7-3

Table 8-1 Summary of the Limiting Beltline ART Values Used in the Generation of the Palisades Heatup/Cooldown Curves at 42.1 EFPY 8-3

Table 8-2 1/4T ART Calculations for the Palisades Reactor Vessel Extended Beltline Materials at 42.1 EFPY 8-4

Table 8-3 3/4T ART Calculations for the Palisades Reactor Vessel Extended Beltline Materials at 42.1 EFPY 8-5

Table 8-4 Summary of the Limiting ART Values for the Palisades Reactor Vessel Extended Beltline at 42.1 EFPY 8-6

Table 8-5 Summary of the Available Margin Between the Palisades Reactor Vessel Beltline and Extended Beltline ART Values at 42.1 EFPY 8-6

Table A-1 Summary of the USE Values Fixed in CVGraph for the Palisades Upper Shell Plates .. A-1

LIST OF FIGURES

Figure 1-1 Extent of the Neutron Fluence Analysis for the Palisades Reactor Vessel (FIO) 1-3

Figure 1-2 Extent of the 1 x 10^{17} n/cm^2 (E > 1.0 MeV) Neutron Fluence Threshold for the Palisades Reactor Vessel (FIO) 1-4

Figure 4-1a CVGraph Unconstrained Fit of US Plate D-3802-3 Charpy Data for Use in Determination of the Initial USE Value 4-4

Figure 4-1b CVGraph Unconstrained Fit of US Plate D-3802-3 Charpy Data for Use in Determination of the Initial USE Value 4-5

Figure 7-1 Regulatory Guide 1.99, Revision 2 Predicted Decrease in USE for Welds as a Function of Copper and Fluence for Palisades 7-4

Figure 7-2 Regulatory Guide 1.99, Revision 2 Predicted Decrease in USE for Plates as a Function of Copper and Fluence for Palisades 7-5

EXECUTIVE SUMMARY

This report presents the Pressurized Thermal Shock (PTS), Upper-Shelf Energy (USE) and Adjusted Reference Temperature (ART) evaluations for the extended beltline region of the Palisades reactor vessel. PTS and USE evaluations must be shown to meet the applicable Nuclear Regulatory Commission (NRC) requirements through the end of the licensed operating period. Additionally, the calculated ART values must be shown to be less than those used in the current Palisades Analysis-of-Record (AOR) for Pressure-Temperature (P-T) limit curves. Palisades is currently licensed for 60 years of operation, which pertains to 42.1 effective full power years (EFPY). This is deemed end-of-license-extension (EOLE). Therefore, the PTS, USE and ART evaluations were performed at 42.1 EFPY in this report. The 42.1 EFPY extended beltline fluence values were determined by Westinghouse and are documented in WCAP-15353 – Supplement 2-NP. The conclusions to the PTS, USE and ART evaluations are as follows:

Extended Beltline Materials

Fluence calculations were performed for the Palisades reactor vessel upper (nozzle) shell plates, nozzle forgings, along with the associated upper shell and nozzle welds, and the lower shell to lower head weld to determine if any of these materials will exceed the 1.0×10^{17} n/cm^2 (E > 1.0 MeV) extended beltline material threshold at 42.1 EFPY. The Palisades reactor vessel materials that were identified as extended beltline materials in this report are the upper shell plates, the upper shell axial welds and the upper to intermediate shell circumferential weld. See Sections 3 and 4 for more details.

EOLE PTS Values

All of the extended beltline materials in the Palisades reactor vessel are projected to remain below the PTS screening criteria values of 270°F, for axially oriented welds and plates / forgings, and 300°F, for circumferentially oriented welds (per 10 CFR 50.61), through EOLE (42.1 EFPY). Additionally, the conclusions of this report, with regards to PTS, confirm that the traditional beltline materials remain limiting when compared to the extended beltline materials. This validates the conclusions of Structural Integrity Associates (SIA), Inc. Report No. 1000915.401. See Section 6 for more details.

EOLE USE Values

The limiting material in the Palisades extended beltline, Upper Shell (US) Plate D-3802-3, is predicted to drop below the USE screening criterion value of 50 ft-lb (per 10 CFR 50, Appendix G) through EOLE (42.1 EFPY) when considering an initial USE value based only on the available 95% shear Charpy V-Notch data for this material. However, this material is predicted to remain above the USE screening criterion value through EOLE when considering an initial USE value based on a CVGraph curve-fit of the available Charpy V-Notch data.

While US Plate D-3802-3 marginally meets the USE requirements at EOLE, based on a CVGraph curve-fit of the available Charpy V-Notch data, it is recommended that an Equivalent Margins Analysis (EMA) be performed for this material. It is recognized that two other materials located in the traditional beltline region of the reactor vessel are projected to drop below the 50 ft-lb screening criteria, which requires that an EMA be performed for these two materials. In addition, Palisades may elect to perform an uprate or submit for a second license extension in the future. Therefore, considering that an EMA will be performed for the two materials in the traditional beltline region of the Palisades reactor vessel that are

projected to drop below the 50 ft-lb screening criteria and future operation at Palisades may include higher flux levels, it is recommended that the EMA for the Palisades reactor vessel also include US Plate D-3802-3.

All of the remaining extended beltline materials in the Palisades reactor vessel are projected to remain above the USE screening criterion value of 50 ft-lb (per 10 CFR 50, Appendix G) through EOLE (42.1 EFPY). Therefore, the conclusions of Appendix D of WCAP-17341-NP, Revision 0 and this report confirm that three materials in the Palisades reactor vessel require a plant-specific EMA. See Section 7 for more details.

EOLE ART Values and P-T Limit Curve Applicability

The ART values for the extended beltline materials in the Palisades reactor vessel were calculated using the guidance provided in Regulatory Guide 1.99, Revision 2 through EOLE (42.1 EFPY). All of the ART values for the extended beltline materials are predicted to remain below those used in the AOR (WCAP-17341-NP, Revision 0) through EOLE (42.1 EFPY). Therefore, the P-T limit curves contained in the AOR for Palisades continue to be governed by the traditional beltline only. See Section 8 for more details.

1 INTRODUCTION

The definition of reactor vessel beltline, as given in the PTS Rule, 10 CFR 50.61 (Reference 1), is "*the region of the reactor vessel (shell material including welds, heat affected zones and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage.*" Historically, only those materials directly adjacent to the active core, commonly referred to as the traditional beltline, have been evaluated with respect to Reactor Vessel Integrity (RVI).

The materials in the traditional beltline region of the Palisades reactor vessel, have been previously analyzed as part of several RVI evaluations including Pressurized Thermal Shock (PTS), Upper-Shelf Energy (USE) decrease, Adjusted Reference Temperature (ART) and Pressure-Temperature (P-T) limit curves. These RVI analyses for the traditional beltline have been completed and are documented in Structural Integrity Associates (SIA), Inc. Report No.'s 0901132.401, Revision 0 and 1000915.401, Revision 1 (References 2 and 3) for RT_{PTS} and Westinghouse Report WCAP-17341-NP, Revision 0 (Reference 4) for USE, ART and P-T limit curves.

As plants, such as Palisades, obtain License Renewal, additional materials are now being included in RVI analyses. The Generic Aging Lessons Learned (GALL) Report (NUREG-1801, Revision 2 (Reference 5)) states that any materials exceeding 1.0×10^{17} n/cm^2 (E > 1.0 MeV) must be monitored to evaluate the changes in fracture toughness. Any materials not previously evaluated for RVI that have predicted fluence levels greater than 1.0×10^{17} n/cm^2 (E > 1.0 MeV) are now commonly referred to as the extended beltline.

Therefore, the purpose of this report is to evaluate the materials in the extended beltline region of the Palisades reactor vessel with respect to RVI. These materials are evaluated to determine their RT_{PTS}, USE and ART values at the end of life extension (EOLE), which corresponds to 42.1 Effective Full Power Years (EFPY). The applicability period of the current Palisades P-T limit curves is also analyzed to ensure that the curves applicability period is not impacted by the extended beltline materials.

Table 1-1 below gives a summary of the Palisades reactor vessel materials that have been previously analyzed and those that are considered for evaluation in this report. Figure 1-1 below shows the extent of the neutron fluence analysis of the Palisades reactor vessel per WCAP-15353 – Supplement 2-NP (Reference 6). Figure 1-2 below shows the extent of the 1×10^{17} n/cm^2 (E > 1.0 MeV) neutron fluence threshold for the Palisades reactor vessel. Note that these figures are for information only (FIO), and are not meant to delineate the exact, to scale, limits of the fluence analysis.

Section 2 of this report discusses the methodologies used to evaluate the various RVI analyses. The methodologies used to determine initial material property values are also given in this section. Section 3 identifies the materials in the Palisades reactor vessel extended beltline region that should be evaluated, and provides their associated neutron fluence values. Section 4 provides the extended beltline region material properties for Palisades. The material chemistry factors used in this analysis, along with applicable surveillance data are summarized in Section 5. The RT_{PTS}, USE, and ART values are determined in Sections 6 through 8, respectively. The P-T limit curve applicability period determination is also shown in Section 8.

Table 1-1 Palisades Reactor Vessel Materials and Analyses

Reactor Vessel Material[a]		Reference of RVI Analyses		
		RT_{PTS}[b]	USE[c]	ART and P-T Limit Curves[d]
Potential Extended Beltline Region[e]	Outlet Nozzle to Upper Shell Welds – Lowest Extent	This report	This report	This report
	Inlet Nozzle to Upper Shell Welds – Lowest Extent			
	Upper Shell Plates			
	Upper Shell Longitudinal Welds			
	Upper Shell to Intermediate Shell Circumferential Weld			
	Lower Shell to Lower Vessel Head Circumferential Weld			
Traditional Beltline Region	Intermediate Shell Plates	Ref. 3	Ref. 4	Ref. 4
	Intermediate Shell Longitudinal Welds	Refs. 2, 3		
	Intermediate to Lower Shell Circumferential Weld	Ref. 3		
	Lower Shell Plates	Ref. 3		
	Lower Shell Longitudinal Welds	Refs. 2, 3		

Notes for Table 1-1:

(a) The extent of the neutron fluence analysis (Reference 6) of the Palisades reactor vessel is shown on Figure 1-1 below.

(b) The RT_{PTS} methodology is defined in Section 2.2.1 of this report. In addition, supplemental information for this methodology is given in Section 2.2.4.

(c) The USE methodology is defined in Section 2.2.2 of this report.

(d) The ART methodology is defined in Section 2.2.3 of this report. The P-T limit curve applicability analysis methodology is defined in Section 2.2.5 of this report. Reference 4 documents the complete P-T limit curve development methodology.

(e) Extended beltline material properties were determined using the methodologies defined in Sections 2.1.1 and 2.1.2 of this report. The extent of the extended beltline is shown on Figure 1-2 below and defined in Section 3 of this report.

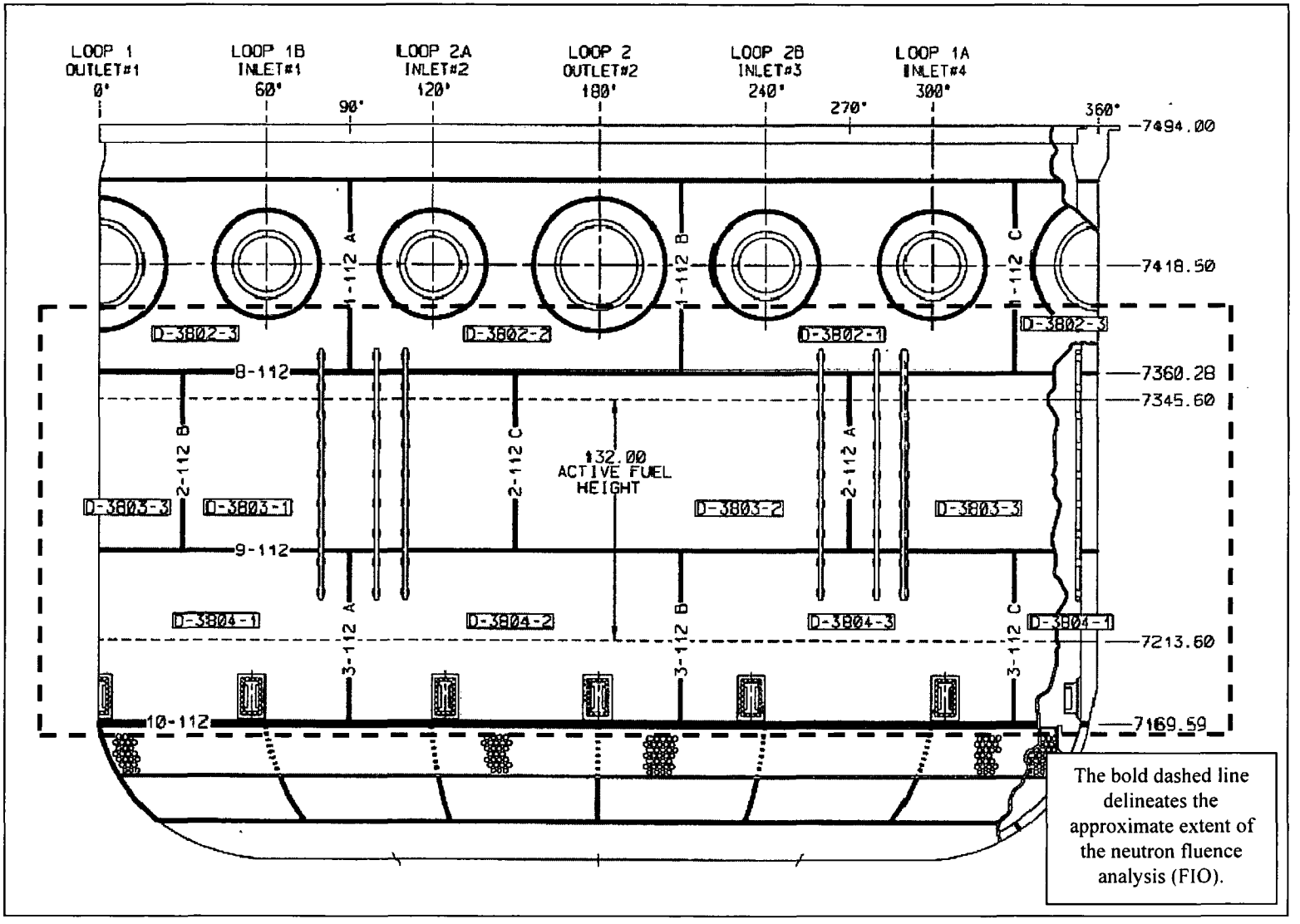


Figure 1-1 Extent of the Neutron Fluence Analysis for the Palisades Reactor Vessel (FIO)

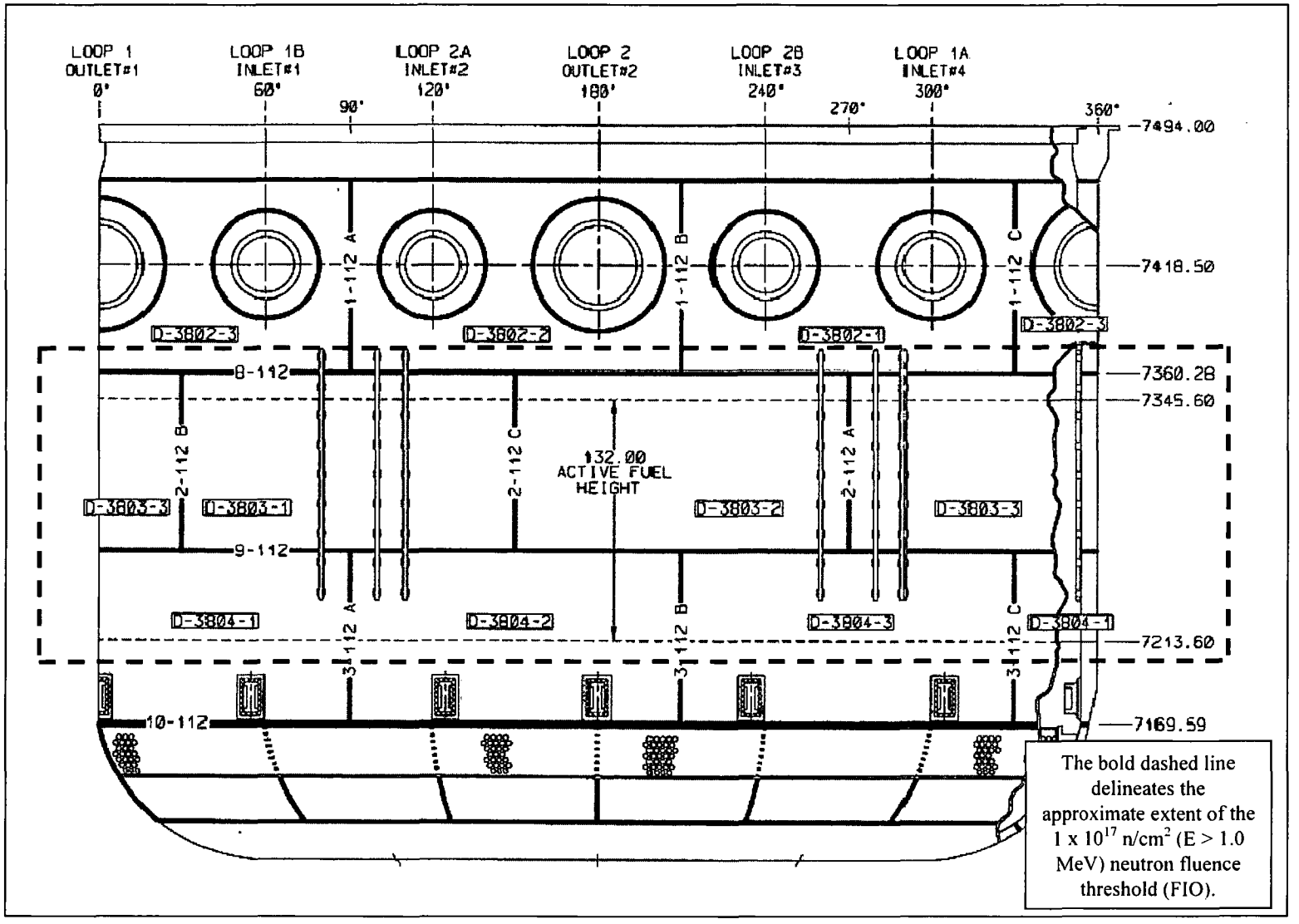


Figure 1-2 Extent of the 1 x 10^{17} n/cm^2 (E > 1.0 MeV) Neutron Fluence Threshold for the Palisades Reactor Vessel (FIO)

2 METHOD DISCUSSION

2.1 INITIAL MATERIAL PROPERTY DETERMINATION METHODOLOGY

2.1.1 Branch Technical Position 5-3 of NUREG-0800, Revision 2

Per NUREG-0800, Revision 2 Branch Technical Position MTEB 5-3 (Reference 7), the following equations and methodologies are to be used for determining initial (unirradiated) RT_{NDT} and USE values for ferritic materials.

Determination of RT_{NDT} for Vessel Materials

Temperature limitations are determined in relation to a characteristic temperature of the material, RT_{NDT}, that is established from the results of fracture toughness tests. Both drop-weight nil-ductility transition temperature (T_{NDT}) tests and Charpy V-Notch tests should be run to determine the RT_{NDT}. The T_{NDT} temperature, as determined by drop-weight tests (ASTM E-208-1969) is the RT_{NDT} if, at 60°F above the T_{NDT}, at least 50 ft-lbs of energy and 35 mils lateral expansion (LE) are obtained in Charpy V-Notch tests on specimens oriented in the weak direction (transverse to the direction of maximum working).

In most cases, the fracture toughness testing performed on vessel material for older plants did not include all tests necessary to determine the RT_{NDT} in this manner. Acceptable estimation methods for the most common cases, based on correlations of data from a large number of heats of vessel material, are provided below for guidance in determining RT_{NDT} when measured values are not available.

(1) If drop-weight tests were not performed, but full Charpy V-Notch curves were obtained, the T_{NDT} for SA-533 Grade B, Class 1 plate and weld material may be assumed to be the temperature at which 30 ft-lbs was obtained in Charpy V-Notch tests, or 0°F, whichever was higher.

(2) If drop-weight tests were not performed on SA-508, Class II forgings, the T_{NDT} may be estimated as the lowest of the following temperatures:

(a) 60°F.
(b) The temperatures of the Charpy V-Notch upper shelf.
(c) The temperature at which 100 ft-lbs was obtained on Charpy V-Notch tests if the upper-shelf energy values were above 100 ft-lbs.

(3) If transversely-oriented Charpy V-Notch specimens were not tested, the temperature at which 50 ft-lbs and 35 mils LE would have been obtained on transverse specimens may be estimated by one of the following criteria:

(a) Test results from longitudinally-oriented specimens reduced to 65% of their value to provide conservative estimates of values expected from transversely oriented specimens.
(b) Temperatures at which 50 ft-lbs and 35 mils LE were obtained on longitudinally-oriented specimens increased 20°F to provide a conservative estimate of the temperature that would have been necessary to obtain the same values on transversely-oriented specimens.

(4) If limited Charpy V-Notch tests were performed at a single temperature to confirm that at least 30 ft-lbs was obtained, that temperature may be used as an estimate of the RT_{NDT} provided that at least 45 ft-lbs was obtained if the specimens were longitudinally oriented. If the minimum value obtained was less than 45 ft-lbs, the RT_{NDT} may be estimated as 20°F above the test temperature.

Estimation of Charpy V-Notch Upper-Shelf Energies

For the beltline region of reactor vessels, the upper-shelf toughness must account for the effects of neutron radiation. Reactor vessel beltline materials must have Charpy upper-shelf energy, in the transverse direction for base material and along the weld for weld material according to the ASME Code, of no less than 75 ft-lbs initially and must maintain Charpy upper-shelf energy throughout the life of the vessel of no less than 50 ft-lbs.

If Charpy upper-shelf energy values were not obtained, conservative estimates should be made using results of tests on specimens from the first surveillance capsule removed.

If tests were only made on longitudinal specimens, the values should be reduced to 65% of the longitudinal values to estimate the transverse properties.

2.1.2 Charpy V-Notch Surveillance Data Curve Fitting

The hyperbolic tangent (TANH) curve approach is the most widely used model for determining the mean behavior of the Charpy energy-temperature relationship for reactor pressure vessel steels. The TANH fit provides parameters that have physical significance relative to the S-shape of the Charpy energy-temperature curve. For the symmetric TANH fit:

$$\textbf{Energy} = A + B\ \tanh\left[\frac{T-T_0}{C}\right]$$

Where,

A + B is the upper shelf

A – B is the lower shelf

T_0 is the mid-transition temperature at the energy level A

B/C is the slope of the mid-transition temperature T_0.

The computer code CVGraph (Version 5.3) is commonly used to determine the Charpy energy-temperature curve-fit parameters, and allows the engineering analyst flexibility in helping to provide the most meaningful fit to the Charpy energy data. Guidance for fitting Charpy energy data was developed in WCAP-14370 (Reference 8), and even though there is no standard method for using the TANH fit, some recommended guidance has been provided. This guidance starts first with fitting the lower shelf to a reasonably small number (i.e., A – B is set to either zero or some value slightly higher than zero (typically 2.2 ft-lb)); this assures that the curve does not extend below zero energy or give some excessively high level of lower shelf if there are little data at lower temperatures indicative of the lower shelf and the start of the transition region. Fixing the lower shelf reduces the fit to only three parameters.

The USE also can be fixed based upon some other definition of upper shelf using ASTM E185-82 (Reference 9), as an example. Following the ASTM E185-82 guidance, the USE can be determined for cases where there are ideally a minimum of three Charpy energy values that are on the upper shelf. Upper shelf generally means a fracture appearance of 100% shear, but for conservative estimates of USE, 95% shear data can be used. When evaluating USE, many different scenarios can arise. One scenario involves many data on the upper shelf, and one interpretation of ASTM E185-82 would allow the use of any three values (normally tested at one temperature) to define the USE. More typically, all data on the upper shelf are generally averaged (which can include data with 95% shear). One common problem with reactor pressure vessel surveillance data is not enough data with 100% shear, so that it is difficult to set an actual fixed USE (A + B).

When using the TANH model in CVGraph, the analyst can try different approaches which include a free fit upper shelf or some other predefined upper shelf levels. The recommendation for these limited data cases in WCAP-14370 is to fit the curve first fixing the lower shelf and leaving the upper shelf free to see what the curve fit predicts for the USE. If the USE value from this free upper shelf fit is within 3-5 ft-lb of some other estimate of USE, then the free fit parameters can be used for subsequent analyses. If the free upper shelf fit does not reasonably agree with the other estimate of USE, the analyst should choose a reasonable or conservative USE estimate and refit the data accordingly. The guidance in WCAP-14370 has been used in the USE analyses presented in this report.

2.2 REACTOR VESSEL INTEGRITY EVALUATIONS METHODOLOGY

2.2.1 Pressurized Thermal Shock (PTS)

The PTS Rule, 10 CFR 50.61 (Reference 1), requires that for each pressurized water nuclear power reactor for which an operating license has been issued, the licensee shall have projected pressurized thermal shock reference temperature (RT_{PTS}) values accepted by the NRC for each reactor vessel material at the end-of-life fluence of the plant. This includes any reactor vessel material with an end-of-life fluence (E > 1.0 MeV) exceeding 1 x 10^{17} n/cm^2. This assessment must specify the basis for the projected value of RT_{PTS} for each vessel material, including the assumptions regarding core-loading patterns, and must specify the copper and nickel contents and the fluence value used in the calculation. This assessment must be updated whenever there is a significant change in projected values of RT_{PTS}, or upon request for a change in the expiration date for operation of the facility. Changes to RT_{PTS} values are considered significant if either the previous value or the current value, or both values, exceed the screening criterion prior to the expiration of the operating license, including any renewed term, if applicable, for the plant.

Per 10 CFR 50.61 (Reference 1), the following equations and variables are to be used for calculating RT_{PTS} values at the clad/base metal interface of the vessel. RT_{PTS} is also referred to as the EOL RT_{NDT} (reference nil-ductility transition temperature).

RT_{PTS} (°F) = Initial RT_{NDT} + M + ΔRT_{NDT}

Where,

Initial RT_{NDT} (°F) = $RT_{NDT(U)}$ = Initial Unirradiated RT_{NDT} value

M = Margin (°F) = $2 * \sqrt{\sigma_U^2 + \sigma_\Delta^2}$

Where,

σ_U = 0°F when $RT_{NDT(U)}$ is a measured value

σ_U = 17°F when $RT_{NDT(U)}$ is a generic value

For plates and forgings:

σ_Δ = 17°F when surveillance capsule data is not credible or not used**

σ_Δ = 8.5°F when credible surveillance capsule data is used**

For welds:

σ_Δ = 28°F when surveillance capsule data is not credible or not used**

σ_Δ = 14°F when credible surveillance capsule data is used**

** σ_Δ not to exceed 0.5*ΔRT_{NDT} per 10 CFR 50.61 (Reference 1)

$$\Delta RT_{NDT} (^{\circ}F) = CF * FF$$

Where,

CF = chemistry factor (°F) calculated generically for copper (Cu) and nickel (Ni) content based on Tables 1 and 2 in Reference 1 for welds and plates, respectively (also referred to as Position 1.1). It can also be calculated using credible surveillance capsule data per Equation 5 of Reference 1 (also referred to as Position 2.1).

FF = fluence factor = $f^{(0.28 - 0.10*\log(f))}$, where the normalized neutron fluence at the clad/base metal interface on the inside surface of the vessel is $f = \Phi / (1.0 \times 10^{19})$. The units for Φ are n/cm^2, $E > 1.0$ MeV.

The RT_{PTS} screening criteria values are 270°F for plates, forgings and axial weld materials and 300°F for circumferential weld materials. All available surveillance data must be considered in the evaluation.

2.2.2 Upper-Shelf Energy (USE)

The predicted decrease in USE is determined as a function of fluence and copper content using either of the following:

- Figure 2 of Regulatory Guide 1.99, Revision 2 (Reference 10), Position 1.2, or
- Surveillance program test results and Figure 2 of Regulatory Guide 1.99, Revision 2, Position 2.2. Credibility Criterion 3 of Regulatory Guide 1.99, Revision 2 indicates that even if the surveillance data are not considered credible for determination of ΔRT_{NDT}, "they may be credible for determining decrease in upper-shelf energy if the upper shelf can be clearly determined, following the definition given in ASTM E185-82" (Reference 9).

Both methods require the use of the 1/4 thickness (1/4T) vessel fluence. Per Regulatory Guide 1.99, Revision 2, the following equation and variables are to be used for calculating 1/4T fluence values, which are then used to determine the predicted decrease in USE.

$$f = f_{surf} * e^{-0.24*(x)}$$

Where:

f = Vessel 1/4T fluence, $x10^{19}$ n/cm^2 ($E > 1.0$ MeV),

f_{surf} = Vessel inner wall surface fluence, $x10^{19}$ n/cm^2 ($E > 1.0$ MeV), and

x = The depth into the vessel wall from the inner surface, inches.

2.2.3 Adjusted Reference Temperature (ART)

Per Regulatory Guide 1.99, Revision 2 (Reference 10), the following equations and variables are to be used for calculating ART values at the clad/base metal interface and at the 1/4T and 3/4T locations.

ART (°F) = Initial RT_{NDT} + ΔRT_{NDT} + Margin

Where:

Initial RT_{NDT} (°F) = $RT_{NDT(U)}$ = Reference temperature of the unirradiated material

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

Where:

σ_I = 0°F when $RT_{NDT(U)}$ is a measured value

σ_I = 17°F when $RT_{NDT(U)}$ is a generic value

For plates and forgings:

σ_Δ = 17°F when surveillance capsule data is not credible or not used**

σ_Δ = 8.5°F when credible surveillance capsule data is used**

For welds:

σ_Δ = 28°F when surveillance capsule data is not credible or not used**

σ_Δ = 14°F when credible surveillance capsule data is used**

** σ_Δ not to exceed $0.5*\Delta RT_{NDT}$ per Regulatory Guide 1.99, Revision 2 (Reference 10)

ΔRT_{NDT} = CF * FF, (°F)

Where:

CF (°F) = chemistry factor based on the copper (Cu) and nickel (Ni) weight % of the material or based on the results of surveillance capsule test data. If the weight percent of copper and nickel is used to determine the CF, then the Position 1.1 CF is obtained from either Table 1 or 2 of Regulatory Guide 1.99, Revision 2. If surveillance capsule data is used to determine the CF, then the Position 2.1 CF is determined as follows:

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

Where:

n = The number of surveillance data points

A_i = The measured value of ΔRT_{NDT}***

f_i = fluence for each surveillance data point

*** If the surveillance weld copper and nickel content differs from that of the vessel weld, then the measured values of ΔRT_{NDT} (A_i in the preceding equation for CF) shall be adjusted by multiplying them by the ratio of the chemistry factor for the vessel weld (CF_{VW}) to that for the surveillance weld (CF_{SW}) based on the copper and nickel content of the materials. In this case, ΔRT_{NDT} is determined as follows:

$$\Delta RT_{NDT} = (\text{measured } \Delta RT_{NDT}) * (CF_{VW} / CF_{SW})$$

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

Where:

f = Vessel inner wall surface fluence, 1/4T fluence, 3/4T fluence, or capsule fluence, $x10^{19}$ n/cm^2 (E > 1.0 MeV). The neutron fluence at any depth in the vessel wall is calculated as follows:

$$f = f_{surf} * e^{-0.24 (x)}$$

Where:

f	=	Vessel 1/4T or 3/4T fluence, $x10^{19}$ n/cm^2 (E > 1.0 MeV)
f_{surf}	=	Vessel inner wall surface fluence, $x10^{19}$ n/cm^2 (E > 1.0 MeV)
x	=	The depth into the vessel wall from the inner surface, inches

2.2.4 Supplemental Surveillance Data Guidance

Guidance was presented by the Nuclear Regulatory Commission (NRC) to industry at a meeting held by the NRC on February 12 and 13, 1998 (Reference 11), regarding adjustments of surveillance data for irradiation temperature and chemical composition differences when applying surveillance data from one plant to a different plant. This guidance also detailed how plants can determine the credibility status of their surveillance data, with or without consideration of sister plant data.

The guidance contained in Reference 11 was used by Structural Integrity Associates, Inc. in References 2 and 3 to determine the Position 2.1 chemistry factor values and credibility status of the Palisades surveillance materials. The information contained in those reports was directly utilized in WCAP-17341-NP, Revision 0 (Reference 4) and will be followed in the calculations detailed in this report.

2.2.5 Pressure-Temperature (P-T) Limit Curve Applicability

P-T limit curves, also referred to as Heatup and Cooldown limit curves, are based on the most limiting 1/4T and 3/4T adjusted reference temperature values for a given reactor vessel. Westinghouse has previously calculated P-T limit curves for Palisades under normal operating conditions through 42.1 EFPY in WCAP-17341-NP, Revision 0 (Reference 4), considering only the materials contained in the traditional beltline region. This current evaluation determines if the applicability period is affected by any materials in the extended beltline by comparing the ART values contained in the AOR with the ART values calculated for the extended beltline materials. If the ART values used in the previous analysis are *higher* than the ART values calculated for the extended beltline materials, the applicability period of the current curves will remain bounding. If the ART values used in the previous analysis are *lower* than the ART values calculated for the extended beltline materials, the applicability period of the current curves will be shortened. This new period of applicability is calculated based on a comparison of the ART values via linear interpolation.

3 CALCULATED FLUENCE

Fast neutron fluence (E > 1.0 MeV) values for the Palisades extended beltline were calculated in WCAP-15353 – Supplement 2-NP (Reference 6). The assessment was performed based on the guidance specified in Regulatory Guide 1.190 (Reference 12). The use of Regulatory Guide 1.190 has been approved by the NRC for the Palisades reactor vessel in an NRC Safety Evaluation Report (SER) from November of 2000 (Reference 13).

The industry accepted definition of "extended beltline" is given in Item IV.A2.R-84 of NUREG-1801, Revision 2 (Reference 5), and states that any materials exceeding 1.0×10^{17} n/cm^2 (E > 1.0 MeV) must be monitored to evaluate the changes in fracture toughness. Reactor vessel materials that are not traditionally thought of as being plant limiting because of low levels of neutron radiation must now be evaluated to determine the accumulated fluence at EOLE (42.1 EFPY). Therefore, fluence calculations were performed for the Palisades reactor vessel upper (nozzle) shell plates, nozzle forgings, along with the associated upper shell and nozzle welds, and the lower shell to lower head weld to determine if they will exceed 1.0×10^{17} n/cm^2 (E > 1.0 MeV) at 42.1 EFPY. The materials that exceed this threshold are referred to as extended beltline materials in this report and are evaluated to assure that the PTS and USE acceptance criteria are met through EOLE. Additionally, ART values are calculated in this report to assure that no material's ART values exceed those used in the current Palisades P-T limit curve analysis of record.

For the PTS, USE and ART evaluations, the surface, 1/4T and 3/4T fluence values and fluence factors are needed. These values are summarized in Table 3-1 for the Palisades extended beltline materials. The neutron fluence information is summarized at 42.1 EFPY (EOLE). Note that the inlet and outlet nozzles and nozzle to shell welds, along with the lower shell to lower head circumferential weld did not reach the 1.0×10^{17} n/cm^2 (E > 1.0 MeV) fluence threshold; therefore, they are not included in Table 3-1 or any subsequent RVI evaluations contained in this report.

The reactor vessel thickness for Palisades is 8.79 inches (Reference 6). Hence, for the 1/4T and 3/4T fluence calculations, the depth into the vessel wall is as follows:

$x_{1/4T} = (0.25 * 8.79 \text{ inches}) = 2.20 \text{ inches}$

$x_{3/4T} = (0.75 * 8.79 \text{ inches}) = 6.59 \text{ inches}$

Table 3-1 Palisades Surface, 1/4T and 3/4T Fluence and Fluence Factor Values at 42.1 EFPY

Material Description	Surface fluence, f[(a)] ($x10^{19}$ n/cm^2, E > 1.0 MeV)	Surface FF	1/4T f ($x10^{19}$ n/cm^2, E > 1.0 MeV)	1/4T FF	3/4T f ($x10^{19}$ n/cm^2, E > 1.0 MeV)	3/4T FF
Extended Beltline Materials						
Upper Shell Plates (D-3802-1, D-3802-2, D-3802-3)	0.1529	0.5071	0.0902	0.3966	0.0314	0.2256
Upper Shell Axial Welds 1-112 A/B/C	0.09707	0.4109	0.0573	0.3148	0.0200	0.1718
Upper Shell to Intermediate Shell Circumferential Weld 8-112	0.1529	0.5071	0.0902	0.3966	0.0314	0.2256

Note for Table 3-1:

(a) All values taken from WCAP-15353 – Supplement 2-NP (Reference 6).

4 FRACTURE TOUGHNESS PROPERTIES

The fracture toughness properties of the ferritic materials in the reactor coolant pressure boundary are determined in accordance with the fracture toughness requirements in NUREG-0800, Revision 2, Branch Technical Position MTEB 5-3 (Reference 7) and the requirements of Subparagraph NB-2331 of Section III of the ASME B&PV Code (Reference 14), as specified by Paragraph II – D of 10 CFR Part 50, Appendix G (Reference 15). The extended beltline unirradiated material properties of the Palisades reactor vessel are presented in Table 4-1.

Table 4-1 Extended Beltline Material Properties for the Palisades Reactor Vessel[a]

Material Description	Heat Number	Chemical Composition		Fracture Toughness Properties	
		Cu Wt. %	Ni Wt. %	Initial RT_{NDT} (°F)	Initial USE (ft-lb)
Extended Beltline Materials					
Upper Shell (US) Plate D-3802-1	C-1279[b]	0.21	0.48	10[e]	75[f]
US Plate D-3802-2	C-1308	0.19	0.52	19[e]	73[f]
US Plate D-3802-3	C-1281	0.25	0.57	10[e]	62.2/59[g]
US Axial Welds 1-112 A/B/C	W5214[c]	0.213	1.007	-56[d]	118
US to Intermediate Shell (IS) Circumferential (Circ.) Weld 8-112	34B009[c]	0.192	0.98	-56[d]	111

Notes for Table 4-1:

(a) All values obtained from P-PENG-ER-006, Revision 0 (Reference 16), unless otherwise noted.

(b) US Plate D-3802-1 is the same heat of material (C-1279) as the traditional beltline region Intermediate Shell Plates D-3803-1 and D-3803-3 per WCAP-17341-NP, Revision 0 (Reference 4). Non-credible surveillance data, for use in the ΔRT_{NDT} determination, is available for this material. However, per Credibility Criterion 3 of Regulatory Guide 1.99, Revision 2, the surveillance data, for use in the percent decrease in USE determination, is deemed credible for this material.

(c) Weld Heat #'s W5214 and 34B009 are contained in the traditional beltline region of the Palisades reactor vessel. Their chemical composition and fracture toughness properties were taken from WCAP-17341-NP, Revision 0 (Reference 4). These welds were fabricated with Linde 1092 flux type. Note that weld Heat # W5214 has 'not fully credible' surveillance data associated with it per Reference 4, for use in the ΔRT_{NDT} determination. However, per Credibility Criterion 3 of Regulatory Guide 1.99, Revision 2, the surveillance data, for use in the percent decrease in USE determination, is deemed credible for both weld heats.

(d) Generic initial RT_{NDT} values for weld Heat #'s W5214 and 34B009 were taken from WCAP-17341-NP, Revision 0 (Reference 4).

(e) Initial RT_{NDT} values were determined using the Charpy V-Notch data contained in the Certified Material Test Reports (CMTRs) and in accordance with the requirements of Subparagraph NB-2331 of Section III of the ASME B&PV Code (Reference 14), as specified by Paragraph II – D of 10 CFR Part 50, Appendix G (Reference 15). Furthermore, portions of the fracture toughness requirements in NUREG-0800, Revision 2, Branch Technical Position MTEB 5-3 (Reference 7) were used in the determination of the initial RT_{NDT} values. Following the guidance provided in MTEB 5-3, Section 1.1(3)(b), the initial RT_{NDT} values associated with the longitudinal (strong) orientation were increased by 20°F to provide a conservative estimate for a transversely-oriented specimen. Lastly, per Reference 7, the determined Charpy V-Notch initial RT_{NDT} was compared to the T_{NDT} as reported in the P-PENG-ER-006 report (Reference 16) because the initial RT_{NDT} must be greater than or equal to the T_{NDT}. Appendix A of this report contains the Charpy V-Notch plots, which were refitted from the CMTRs using a hyperbolic tangent curve fitting program and were used to obtain the initial RT_{NDT} values.

(f) Initial USE values were determined using the guidance contained in ASTM E185-82 (Reference 9) and the data contained in P-PENG-ER-006, Revision 0 (Reference 16). Note that the Charpy V-Notch Tests were performed on longitudinally (strong direction) oriented specimens. Following the guidance provided in MTEB 5-3, Section 1.2, the upper-shelf energy values were reduced to 65% of the values associated with the strong direction (longitudinally-oriented) in order to approximate the properties in the weak direction (transversely-oriented).

(g) Initial USE value for US Plate D-3802-3 was determined using an unconstrained TANH fit to the available Charpy energy data in P-PENG-ER-006, Revision 0 (Reference 16) as described below. The initial upper-shelf energy value of 62.2 ft-lb, after the 65% reduction in Note (f), is reasonable when comparisons are made with the two other plate materials in the extended beltline, which had data available at 100% shear fracture appearance resulting in much higher initial USE levels. If the data were treated as described above in Note (f) using 95% shear data, the corresponding initial USE value would be 59 ft-lb.

Determination of an Initial Curve-Fit USE Value for US Plate D-3802-3

The definition for USE is given in ASTM E185-82 (Reference 9), Sections 4.17 and 4.18, and reads as follows:

> *"Charpy transition curve* – a graphic representation of Charpy data, including absorbed energy, lateral expansion, and fracture appearance, extending over a range including the lower shelf energy (<5 % shear), transition region, and the upper shelf energy (>95 % shear)."
>
> "*upper shelf energy level* – the average energy value for all Charpy specimens (normally three) whose test temperature is above the upper end of the transition region. For specimens tested in sets of three at each test temperature, the set having the highest average may be regarded as defining the upper shelf energy."

Using engineering judgment and ASTM E185-82, Sections 4.17 and 4.18, "Above the upper end of the transition region" is considered to be > 95% shear. Per P-PENG-ER-006, Revision 0 (Reference 16), the Charpy testing for US Plate D-3802-3 did not achieve 100% Shear values; a maximum of 95% Shear was reached. It is probable that the 95% shear data is indicative of the onset of upper shelf, but not the actual upper shelf, which would be > 95% shear. In addition, the actual upper-shelf energy is likely to have been greater than the average shown (91 ft-lbs, pre-MTEB 5-3 reduction) if Charpy impact tests were performed at a temperature above 160°F. Finally, the correlation coefficient of the unconstrained CVGraph curve fit of the available data for this material is very high (0.987), such that if this unirradiated Charpy data was actually surveillance capsule Charpy data, it would satisfy Credibility Criterion 2 of Regulatory Guide 1.99, Revision 2 (Reference 10).

Therefore, considering the above, the Charpy impact data was refitted using a hyperbolic tangent curve fitting program (CVGraph, Version 5.3) to predict the upper-shelf energy at 100% shear. To do this, the upper-shelf energy, which is typically fixed in the program (See Appendix A), was allowed to float such that a new upper-shelf energy was calculated by the curve fit. Figures 4-1a and 4-1b present the CVGraph figure, which documents the predicted initial USE value.

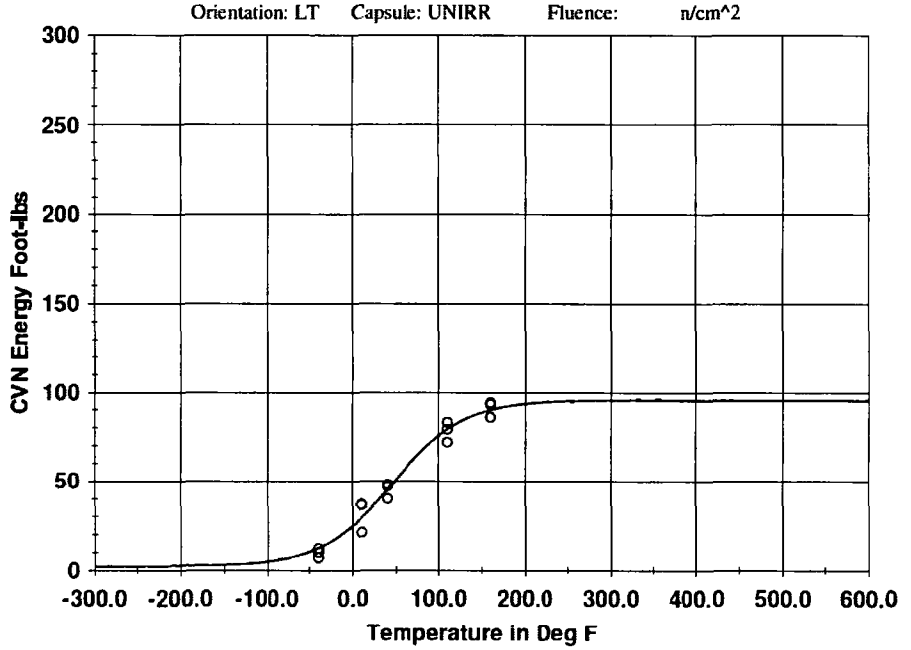
Initial Curve-Fit USE Value for US Plate D-3802-3 Conclusion

The initial curve-fit USE value based on longitudinal Charpy data was determined to be 95.7 ft-lbs by CVGraph, Version 5.3. This value is reasonable when compared with the as measured average initial USE value of 91 ft-lbs, which considered 95% shear Charpy data points determined from longitudinal specimens. The initial curve-fit USE value, after reduction to 65% per MTEB 5-3, is 62.2 ft-lbs.

Therefore, an initial curve-fit USE value of 62.2 ft-lb will also be assigned to US Plate D-3802-3. This initial USE value of 62.2 ft-lb will be used in Section 7 in order to calculate the projected EOLE USE for this material.

US PLATE D-3802-3 - IMPACT ENERGY - LT - UNIRRADIATED

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 07/01/2011 07:25 AM
Page 1
Coefficients of Curve 1
A = 48.95 B = 46.75 C = 82.04 T0 = 46.6 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=95.7 Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=11.4 Deg F Temp@50 ft-lbs=48.5 Deg F
Plant: Palisades Material: SA302BM Heat: C-1281-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-40.00	7.00	12.30	-5.30
-40.00	10.00	12.30	-2.30
-40.00	12.00	12.30	-.30
10.00	21.00	29.38	-8.38
10.00	36.50	29.38	7.12
10.00	37.00	29.38	7.62
40.00	48.00	45.20	2.80
40.00	40.00	45.20	-5.20
40.00	47.00	45.20	1.80

Figure 4-1a CVGraph Unconstrained Fit of US Plate D-3802-3 Charpy Data for Use in Determination of the Initial USE Value

US PLATE D-3802-3 - IMPACT ENERGY - LT - UNIRRADIATED

Page 2
Plant: Palisades Material: SA302BM Heat: C-1281-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
110.00	79.00	79.26	-.26
110.00	83.00	79.26	3.74
110.00	72.00	79.26	-7.26
160.00	86.00	90.15	-4.15
160.00	94.00	90.15	3.85
160.00	93.00	90.15	2.85

Correlation Coefficient = .987

Figure 4-1b CVGraph Unconstrained Fit of US Plate D-3802-3 Charpy Data for Use in Determination of the Initial USE Value

5 CHEMISTRY FACTORS AND UPPER-SHELF ENERGY SURVEILLANCE DATA

As described in Section 2 of this report, Position 1.1 chemistry factors for each reactor vessel extended beltline material are calculated using the best-estimate copper and nickel weight percent values of the material and Tables 1 and 2 of 10 CFR 50.61. The best-estimate copper and nickel weight percent values for the Palisades reactor vessel extended beltline materials were provided in Table 4-1 of this report. The Position 2.1 chemistry factors are calculated for the materials that have available surveillance program results. The calculation is performed using the method described in 10 CFR 50.61 and Regulatory Guide 1.99, Revision 2, as summarized in Sections 2.2.1 and 2.2.3 of this report, respectively.

Normally, no surveillance data exists for materials in the extended beltline region of reactor pressure vessels. However, for Palisades, the material heats for US Plate D-3802-1 (Heat # C-1279), US Axial Welds 1-112 A/B/C (Heat # W5214) and US to IS Circumferential Weld 8-112 (Heat # 34B009) are also contained in the traditional beltline region of the Palisades reactor vessel. The capsule Charpy data from all of the capsules withdrawn and tested to date were used in the calculation of the Position 2.1 chemistry factors. In addition to the chemistry factor data, measured USE percent decrease data is also available for the three material heats shared between the extended and traditional beltline.

The Position 1.1 chemistry factors are summarized along with the Position 2.1 chemistry factors in Table 5-1 for Palisades. The measured USE decrease data for Palisades is summarized in Table 5-2.

Table 5-1 Summary of Palisades Positions 1.1 and 2.1 Chemistry Factors

Material Description	Chemistry Factor (°F)	
	Position 1.1[(a)]	Position 2.1[(b)]
Extended Beltline Materials		
US Plate D-3802-1[(c)]	139.4	147.71
US Plate D-3802-2	133.2	- - -
US Plate D-3802-3	171.8	- - -
US Axial Welds 1-112 A/B/C (Heat # W5214)	230.73[(b)]	227.74
US to IS Circ. Weld 8-112 (Heat # 34B009)	217.7[(b)]	- - -

Notes for Table 5-1:

(a) Position 1.1 Chemistry Factors for the extended beltline materials were calculated using the copper and nickel weight percents presented in Table 4-1 of this report and Tables 1 and 2 of 10 CFR 50.61 (Reference 1), unless otherwise noted.

(b) Position 1.1 Chemistry Factors for the extended beltline welds and the Position 2.1 Chemistry Factors are consistent with the values documented in Table 2-3 of WCAP-17341-NP, Revision 0 (Reference 4).

(c) The Cu and Ni wt. % values used to calculate the Position 1.1 Chemistry Factor were taken from as measured data summarized in P-PENG-ER-006, Revision 0 (Reference 16). These Cu and Ni wt. % values for the US Plate D-3802-1 are slightly different from the two plates that share this material heat # in the traditional beltline (Reference 4); however, since the upper shell plate is still the same heat of material, the Position 2.1 Chemistry Factor will still be applied to this material.

Table 5-2 Summary of Palisades Capsule Fluence Values and Measured USE Percent Decrease Data[a]

Material	Capsule	Capsule Fluence ($x10^{19}$ n/cm^2, E > 1.0 MeV)	Measured USE Decrease (%)
Weld Heat # W5214[b]	SA-60-1	1.50	46.9
	SA-240-1	2.38	48.9
Weld Heat # 34B009[b]	SA-60-1	1.50	51.5
	SA-240-1	2.38	49.6
Plate Heat # C-1279[b] (Longitudinal)	A-240	4.09	42.4
	W-290	0.938	27.7
	W-110	1.64	33.5
	W-100	2.09	34.1
Plate Heat # C-1279[b] (Transverse)	A-240	4.09	35.2
	W-290	0.938	17.6
	W-100	2.09	28.1

Notes for Table 5-2:

(a) Information taken from Table D-2 of WCAP-17341-NP, Revision 0 (Reference 4).

(b) Per Credibility Criterion 3 of Regulatory Guide 1.99, Revision 2, the surveillance data, for use in the percent decrease in USE determination, has been deemed credible for the weld and plate materials.

6 PRESSURIZED THERMAL SHOCK CALCULATIONS

A limiting condition on reactor vessel integrity known as PTS may occur during a severe system transient such as a loss-of-coolant accident or steam line break. Such transients may challenge the integrity of the reactor vessel under the following conditions: severe overcooling of the inside surface of the vessel wall followed by high repressurization; significant degradation of vessel material toughness caused by radiation embrittlement; and the presence of a critical-size defect anywhere within the vessel wall.

In 1985, the U.S. NRC issued a formal ruling (10 CFR 50.61) on PTS (Reference 1) that established screening criteria on reactor vessel embrittlement, as measured by the maximum reference nil-ductility transition temperature in the limiting reactor vessel component at the end-of-license, termed RT_{PTS}. RT_{PTS} screening values were set by the U.S. NRC for axial welds, forgings or plates, and circumferential weld seams for plant operation to the end of plant license. All domestic PWR vessels have been required to evaluate vessel embrittlement in accordance with the criteria through the end-of-license. The U.S. NRC revised 10 CFR 50.61 in 1991 and 1995 to change the procedure for calculating radiation embrittlement. These revisions make the procedure for calculating the reference temperature for pressurized thermal shock (RT_{PTS}) values consistent with the methods given in Regulatory Guide 1.99, Revision 2 (Reference 10).

These accepted methods were used with the surface fluence of Section 3 to calculate the following RT_{PTS} values for the Palisades reactor vessel extended beltline materials at 42.1 EFPY (EOLE). The EOLE RT_{PTS} calculations are summarized in Table 6-1.

PTS Conclusion

For Palisades, the limiting extended beltline RT_{PTS} values at 42.1 EFPY are 131.1°F and 119.9°F (see Table 6-1); these values correspond to US Plate D-3802-3 using Position 1.1 (Axially oriented welds and plates) and US to IS Circumferential Weld 8-112 (Heat # 34B009) using Position 1.1 (Circumferentially oriented weld). Therefore, all of the extended beltline materials in the Palisades reactor vessel are below the RT_{PTS} screening criteria values of 270°F, for axially oriented welds and plates / forgings, and 300°F, for circumferentially oriented welds through EOLE (42.1 EFPY).

The PTS conclusion confirms that the traditional beltline materials remain limiting when compared to the extended beltline materials. This validates the conclusions of Structural Integrity Associates (SIA), Inc. Report No. 1000915.401 (Reference 3).

Table 6-1 RT_{PTS} Calculations for the Palisades Reactor Vessel Extended Beltline Materials at 42.1 EFPY[a]

Material Description	CF[b] (°F)	Fluence[c] ($x10^{19}$ n/cm^2, E > 1.0 MeV)	FF[c]	$RT_{NDT(U)}$[d] (°F)	ΔRT_{NDT} (°F)	σ_U[d] (°F)	σ_Δ[f] (°F)	Margin (°F)	RT_{PTS} (°F)
Extended Beltline Materials									
US Plate D-3802-1	139.4	0.1529	0.5071	10	70.7	0	17	34.0	114.7
Using Non-Credible Surveillance Data	147.71	0.1529	0.5071	10	74.9	0	17	34.0	118.9
US Plate D-3802-2	133.2	0.1529	0.5071	19	67.5	0	17	34.0	120.5
US Plate D-3802-3	171.8	0.1529	0.5071	10	87.1	0	17	34.0	131.1
US Axial Welds 1-112 A/B/C (Heat # W5214)	230.73	0.09707	0.4109	-56[e]	94.8	17[e]	28	65.5	104.3
Using Not Fully Credible Surveillance Data	227.74	0.09707	0.4109	-56[e]	93.6	17[e]	28	65.5	103.1
US to IS Circ. Weld 8-112 (Heat # 34B009)	217.7	0.1529	0.5071	-56[e]	110.4	17[e]	28	65.5	119.9

Notes for Table 6-1:

(a) The 10 CFR 50.61 methodology was utilized in the calculation of the RT_{PTS} values. See Section 2.2.1 of this report for details.
(b) Taken from Table 5-1 of this report.
(c) Taken from Table 3-1 of this report.
(d) Initial RT_{NDT} values are taken from Table 4-1 of this report and are measured values, unless otherwise noted. For measured initial RT_{NDT} values, $\sigma_U = 0°F$.
(e) Initial RT_{NDT} values are generic; therefore, $\sigma_U = 17°F$.
(f) Per WCAP-17341-NP, Revision 0 (Reference 4), surveillance data of the plate material and weld Heat # W5214 were considered to be non-credible and not fully credible, respectively. Per the guidance of 10 CFR 50.61, the base metal $\sigma_\Delta = 17°F$ for plate materials without surveillance data as well as for the plate material with non-credible surveillance data. The weld metal $\sigma_\Delta = 28°F$ for welds without surveillance data as well as for the weld metal with not fully credible surveillance data. However, σ_Δ need not exceed $0.5*\Delta RT_{NDT}$.

7 UPPER-SHELF ENERGY CALCULATIONS

The requirements for USE are contained in 10 CFR 50, Appendix G (Reference 15). 10 CFR 50, Appendix G requires utilities to submit an analysis at least 3 years prior to the time that the USE of any reactor vessel material is predicted to drop below 50 ft-lb.

Regulatory Guide 1.99, Revision 2 defines two methods that can be used to predict the decrease in USE due to irradiation. The method to be used depends on the availability of credible surveillance capsule data. For vessel materials that are not in the surveillance program or are not credible, the Charpy USE (Position 1.2) is assumed to decrease as a function of fluence and copper content, as indicated in Regulatory Guide 1.99, Revision 2 (Reference 10).

When two or more credible surveillance data sets become available from the reactor vessel, they may be used to determine the Charpy USE of the surveillance materials. The surveillance data are then used in conjunction with Figure 2 of the Regulatory Guide to predict the decrease in USE (Position 2.2) of the reactor vessel materials due to irradiation.

The 42.1 EFPY (EOLE) Position 1.2 USE values of the vessel materials can be predicted using the corresponding 1/4T fluence projection, the copper content, and Figure 2 in Regulatory Guide 1.99, Revision 2. In applying either Position 1.2 or 2.2, the TANH fitted Charpy energy data followed the general principles described in Section 2.1.2 of this report.

The predicted Position 2.2 USE values are determined for the extended beltline materials whose heat numbers are contained in the surveillance program by using the reduced plant surveillance data along with the corresponding 1/4T fluence projection. The reduced plant surveillance data for the Palisades weld materials are contained in Appendix D of WCAP-17341-NP, Revision 0 (Reference 4). The reduced plant surveillance data for the Palisades plate materials are also contained in Appendix D of WCAP-17341-NP, Revision 0. This data is summarized in Table 5-2 of this report. The weld and plate reduced surveillance data were plotted on Regulatory Guide 1.99, Revision 2, Figure 2 (see Figures 7-1 and 7-2 of this report) using the surveillance capsule fluence values from WCAP-17341-NP, Revision 0. This data was fitted by drawing a line parallel to the existing lines as the upper bound of all the surveillance data. These reduced lines were used instead of the existing lines to determine the Position 2.2 EOLE USE values.

The projected USE values were calculated to determine if the Palisades reactor vessel extended beltline materials remain above the 50 ft-lb limit at EOLE. These calculations are summarized in Table 7-1.

USE Conclusion

All of the extended beltline materials are projected to have USE values greater than 50 ft-lb at 42.1 EFPY. However, it is noted that the initial USE for US Plate D-3802-3 has been determined using two approaches. The first approach used to project the USE at 100% shear is similar to the determination of the 30 ft-lb transition temperature (T_{30}) using a best fit TANH curve through all of the available data. By allowing a free, or unconstrained, fit to the upper shelf (since no data at 100% shear were measured), and only fixing the lower shelf level, a calculated initial upper-shelf energy can be obtained. This method of initial USE determination along with the orientation and projected drop in USE adjustments, per NUREG-0800, Revision 2 and Regulatory Guide 1.99, Revision 2, projects that the USE value for US Plate D-3802-3 is 50.1 ft-lb at EOLE fluence. It is noted that the correlation coefficient from CVGraph for the fit is equal to 0.987.

The second approach conservatively determines the USE for this plate from the highest temperature tested Charpy data, which corresponds to only 95% shear. Averaging these data and then making the orientation and projected drop in USE adjustments, per NUREG-0800, Revision 2 and Regulatory Guide 1.99, Revision 2, the USE at EOLE fluence will be below 50 ft-lbs at 42.1 EFPY.

It is noted that generic EMA evaluations for both the Westinghouse and Combustion Engineering fleets, WCAP-13587, Revision 1 (Reference 17) and CE NPSD-993 (Reference 18), respectively, predict that a lower-bound USE value below 50 ft-lb is justified. These evaluations show that there is considerable margin between the actual 10 CFR 50, Appendix G 50 ft-lb limit and the calculated lower-bound values. Therefore, using engineering judgment, the increase gained in the projected EOLE USE value by curve-fitting the Charpy data is minimal when compared to the margin that an EMA would justify. A plant-specific EMA should be completed on this material, as concluded above, in order to document the exact lower-bound USE value for this material at EOLE.

Reference 4 indicates that the USE at EOLE fluence will fall below the 50 ft-lb limitation for two materials in the traditional beltline region of the Palisades reactor vessel. Therefore, an Equivalent Margins Analysis (EMA) is to be performed for the Intermediate to Lower Shell Circumferential Weld 9-112 (Heat #27240) and the Lower Shell Plate D-3804-1. This EMA should also include the US Plate D-3802-3 material to provide a bounding case for all suspect reactor vessel materials.

Table 7-1 Palisades Predicted Positions 1.2 and 2.2 USE Values at 42.1 EFPY

Material Description		Wt. % Cu[a]	1/4T EOLE Fluence[b] ($x10^{19}$ n/cm^2, E > 1.0 MeV)	Unirradiated USE[a] (ft-lb)	Projected USE Decrease[c] (%)	Projected EOLE USE (ft-lb)
Extended Beltline Materials						
US Plate D-3802-1		0.21	0.0902	75	17	62.3
Using Surveillance Data[f]		0.21	0.0902	75	17[d]	62.3
US Plate D-3802-2		0.19	0.0902	73	16	61.3
US Plate D-3802-3	Using CVGraph Refitted Initial USE	0.25	0.0902	62.2	19.5	50.1[g]
	Using 95% Shear Initial USE	0.25	0.0902	59	19.5	47.5[g]
US Axial Welds 1-112 A/B/C (Heat # W5214)		0.213	0.0573	118	18.5	96.2
Using Surveillance Data		0.213	0.0573	118	30[d,e]	82.6
US to IS Circ. Weld 8-112 (Heat # 34B009)		0.192	0.0902	111	19	89.9
Using Surveillance Data		0.192	0.0902	111	35[d,e]	72.2

Notes for Table 7-1:

(a) From Table 4-1 of this report.

(b) From Table 3-1 of this report.

(c) Unless otherwise noted, percentage USE decrease values are based on Position 1.2 of Regulatory Guide 1.99, Revision 2 and calculated by plotting the 1/4T fluence values on Figure 2 of the Guide. The percent USE decrease values that corresponded to each material's specific Cu wt. % value were determined using interpolation between the existing Weld or Base Metal lines on Figure 2.

(d) Percentage USE decrease is based on Position 2.2 of Regulatory Guide 1.99, Revision 2, using data from Table 5-2 of this report. Credibility Criterion 3 in the Discussion section of Regulatory Guide 1.99, Revision 2, indicates that even if the surveillance data are not considered credible for determination of ΔRT_{NDT}, "they may be credible for determining decrease in upper-shelf energy if the upper shelf can be clearly determined, following the definition given in ASTM E 185-82." Regulatory Guide 1.99, Revision 2, Position 2.2 indicates that an upper-bound line drawn parallel to the existing lines (in Figure 2 of the Guide) through the surveillance data points should be used in preference to the existing graph lines for determining the decrease in USE.

(e) Since the limiting surveillance data fell above the limiting line on Figure 2 of the Guide, the upper-bound line was drawn parallel to the "upper limit" line, and not the "% copper" lines. This was considered to be a conservative approach for the fluence levels being used in this evaluation.

(f) Plate surveillance data for these capsules used material from IS Plate D-3803-1; however, US Plate D-3802-1 is made from the same heat of material. Therefore, this USE data was used for US Plate D-3802-1 (Heat # C-1279) in this USE evaluation.

(g) The projected EOLE USE was determined for this material using an unconstrained TANH curve fit since there were no available data at 100% shear fracture appearance. Consistent with Credibility Criterion 2 of Regulatory Guide 1.99, Revision 2, if this unirradiated Charpy data was actually surveillance capsule Charpy data, it would be considered credible based on a very high correlation coefficient from CVGraph (0.987). However, a more conservative value could be calculated which would fall below 50 ft-lb. Therefore, an EMA is needed in the future for this material.

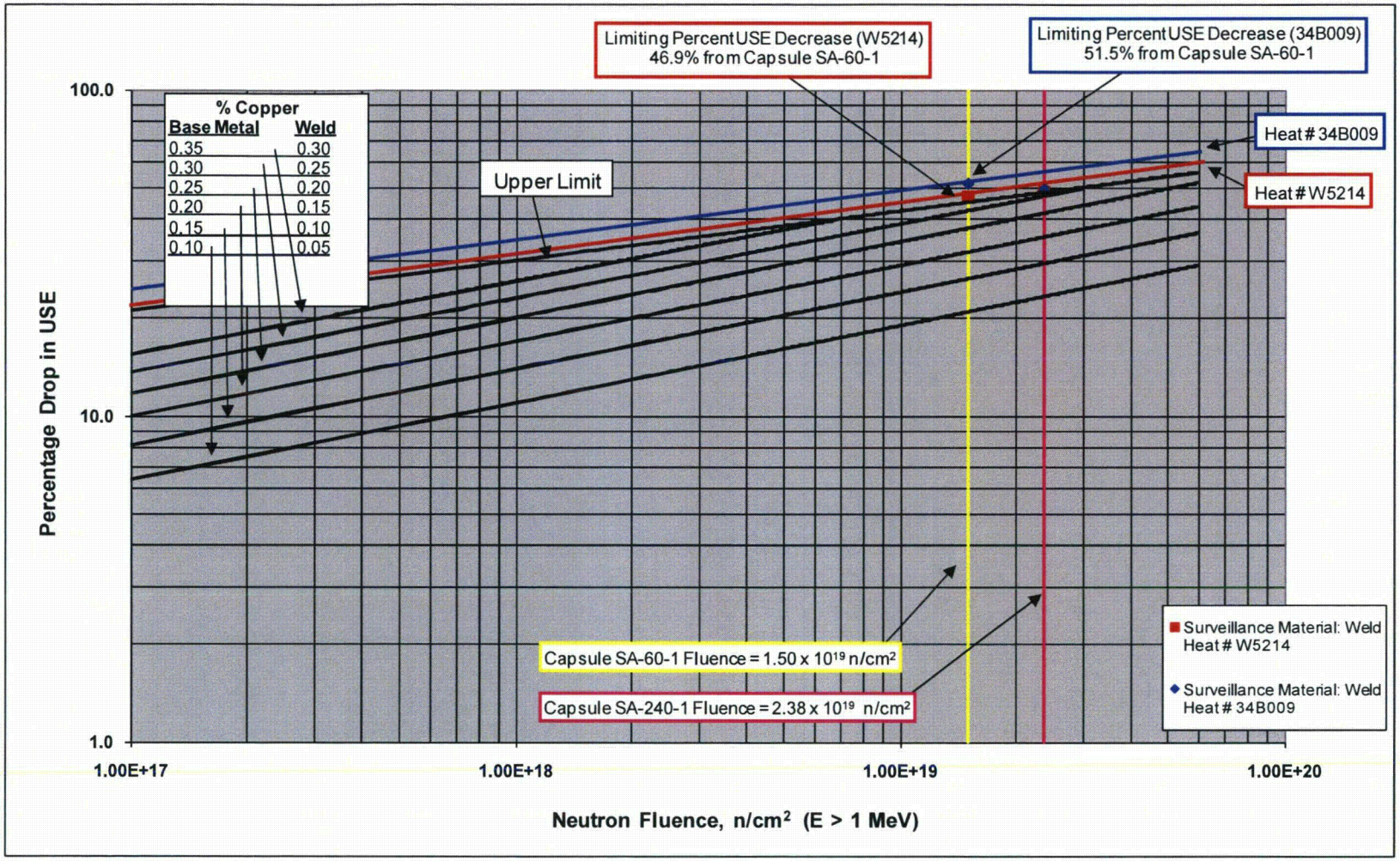


Figure 7-1 Regulatory Guide 1.99, Revision 2 Predicted Decrease in USE for Welds as a Function of Copper and Fluence for Palisades

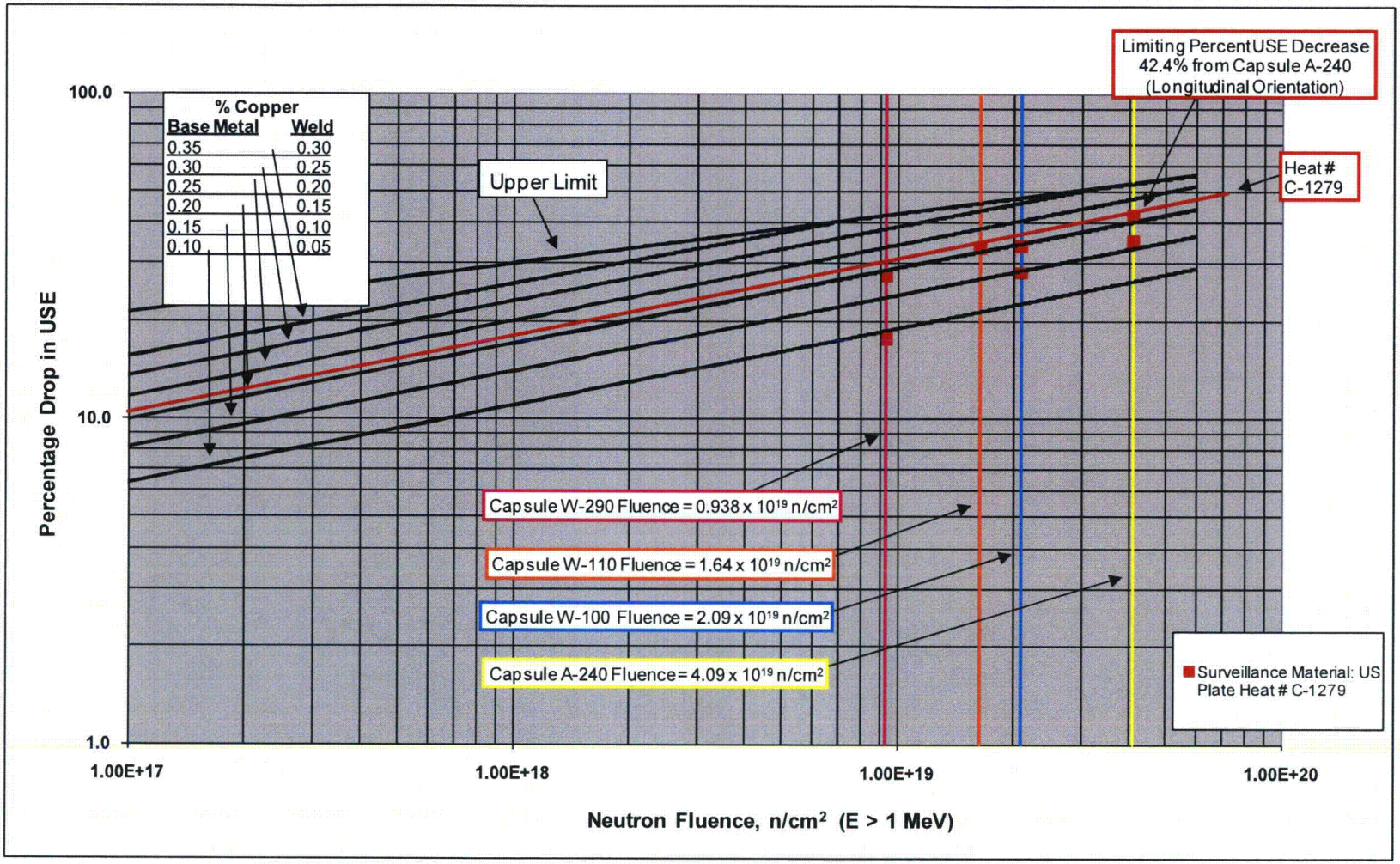


Figure 7-2 Regulatory Guide 1.99, Revision 2 Predicted Decrease in USE for Plates as a Function of Copper and Fluence for Palisades

8 PRESSURE-TEMPERATURE LIMIT CURVE APPLICABILITY

Heatup and cooldown limit curves are calculated using the most limiting values of RT_{NDT} (reference nil ductility transition temperature) corresponding to the limiting reactor vessel material. The most limiting reactor vessel material RT_{NDT} values are determined by using the unirradiated reactor vessel material fracture toughness properties and estimating the irradiation-induced shift (ΔRT_{NDT}).

RT_{NDT} increases as the material is exposed to fast-neutron irradiation; therefore, to find the most limiting RT_{NDT} at any time period in the reactor's life, ΔRT_{NDT} due to the radiation exposure associated with that time period must be added to the original unirradiated RT_{NDT}. Using the adjusted reference temperature (ART) values, pressure-temperature (P-T) limit curves are determined in accordance with the requirements of 10 CFR Part 50, Appendix G (Reference 15), as augmented by Appendix G to Section XI of the ASME Boiler and Pressure Vessel (B&PV) Code (Reference 19).

The P-T limit curves for normal heatup and cooldown of the primary reactor coolant system for Palisades were previously developed in WCAP-17341-NP, Revision 0 (Reference 4) for 42.1 EFPY. The existing 42.1 EFPY P-T limit curves are based on the limiting beltline material ART values, which are influenced by both the fluence and the initial material properties of that material. The Palisades P-T limit curves were developed by calculating ART values utilizing the clad/base metal interface fluence that corresponded to each reactor vessel beltline material. The limiting ART values correspond to the Intermediate and Lower Shell Axial Welds 2-112 and 3-112 (Heat # W5214 using the Position 2.1 chemistry factor value based on not fully credible surveillance data with full margin term). Table 8-1 contains a summary of the limiting beltline material ART values at 42.1 EFPY.

To confirm the applicability of the P-T limit curves developed in WCAP-17341-NP, Revision 0 (Reference 4), the limiting extended beltline material ART values must be shown to be less than the limiting beltline material ART values summarized in Table 8-1. The accepted methods of Regulatory Guide 1.99, Revision 2 (Reference 10) were used along with the surface fluence of Section 3 to calculate the following ART values for the Palisades reactor vessel extended beltline materials at 42.1 EFPY (EOLE). The EOLE ART calculations are summarized below in Tables 8-2 and 8-3 at the 1/4T and 3/4T locations, respectively, for Palisades.

Per Regulatory Guide 1.99, Revision 2, σ_Δ need not exceed one half of ΔRT_{NDT} (See Section 2.2.3); however, for conservatism and consistency with References 2, 3 and 4, a full margin term will be used for all the Palisades extended beltline materials for the 3/4T ART calculations shown in Table 8-3. A full margin term was already necessary for the 1/4T ART calculations shown in Table 8-2. Note that the use of this conservative margin term, for the 3/4T location, caused the limiting material for the Palisades extended beltline to change from US Plate D-3802-3 for the 1/4T location to US Plate D-3802-2 for the 3/4T location.

Table 8-4 contains a summary of the limiting extended beltline materials ART values at 42.1 EFPY. Table 8-5 details the available margin between the limiting extended beltline and traditional beltline materials.

Existing P-T Limit Curve Applicability Conclusion

It is concluded that the Palisades reactor vessel extended beltline material ART values are bounded by the traditional beltline material ART values used in the development of the existing 42.1 EFPY P-T limit curves; therefore, the existing P-T limit curves remain valid as documented in WCAP-17341-NP (Reference 4).

Table 8-1 Summary of the Limiting Beltline ART Values Used in the Generation of the Palisades Heatup/Cooldown Curves at 42.1 EFPY

Limiting ART – Beltline Materials[a]	
Axial Welds 2-112 and 3-112 (Heat # W5214) Using the Position 2.1 Chemistry Factor Value Based on Not Fully Credible Surveillance Data with Full Margin Term (Limiting Axial Flaw Material)	
1/4T	**3/4T**
252.7°F	185.8°F

Note for Table 8-1:

(a) Values obtained from Table 4-4 of WCAP-17341-NP, Revision 0 (Reference 4).

Table 8-2 1/4T ART Calculations for the Palisades Reactor Vessel Extended Beltline Materials at 42.1 EFPY[(a)]

Material Description	CF[(b)] (°F)	1/4T Fluence[(c)] ($x10^{19}$ n/cm^2, E > 1.0 MeV)	FF[(c)]	$RT_{NDT(U)}$[(d)] (°F)	ΔRT_{NDT} (°F)	σ_I[(d)] (°F)	σ_Δ[(f)] (°F)	Margin (°F)	ART (°F)
Extended Beltline Materials									
US Plate D-3802-1	139.4	0.0902	0.3966	10	55.3	0	17	34.0	99.3
Using Non-Credible Surveillance Data	147.71	0.0902	0.3966	10	58.6	0	17	34.0	102.6
US Plate D-3802-2	133.2	0.0902	0.3966	19	52.8	0	17	34.0	105.8
US Plate D-3802-3	171.8	0.0902	0.3966	10	68.1	0	17	34.0	**112.1**
US Axial Welds 1-112 A/B/C (Heat # W5214)	230.73	0.0573	0.3148	-56[(e)]	72.6	17[(e)]	28	65.5	82.1
Using Not Fully Credible Surveillance Data	227.74	0.0573	0.3148	-56[(e)]	71.7	17[(e)]	28	65.5	81.2
US to IS Circ. Weld 8-112 (Heat # 34B009)	217.7	0.0902	0.3966	-56[(e)]	86.3	17[(e)]	28	65.5	95.9

Notes for Table 8-2:

(a) The Regulatory Guide 1.99, Revision 2 methodology was utilized in the calculation of the ART values. See Section 2.2.3 of this report for details.
(b) Taken from Table 5-1 of this report.
(c) Taken from Table 3-1 of this report.
(d) Initial RT_{NDT} values are taken from Table 4-1 of this report and are measured values, unless otherwise noted. For measured initial RT_{NDT} values, $\sigma_I = 0°F$.
(e) Initial RT_{NDT} values are generic; therefore, $\sigma_I = 17°F$.
(f) Per WCAP-17341-NP, Revision 0 (Reference 4), surveillance data of the plate material and weld Heat # W5214 were considered to be non-credible and not fully credible, respectively. Per the guidance of Reg. Guide 1.99, Revision 2, the base metal $\sigma_\Delta = 17°F$ for both Positions 1.1 and 2.1 with non-credible surveillance data, and the weld metal $\sigma_\Delta = 28°F$ for both Positions 1.1 and 2.1 with not fully credible surveillance data. However, σ_Δ need not exceed $0.5*\Delta RT_{NDT}$.

Table 8-3 3/4T ART Calculations for the Palisades Reactor Vessel Extended Beltline Materials at 42.1 EFPY[(a)]

Material Description	CF[(b)] (°F)	3/4T Fluence[(c)] ($x10^{19}$ n/cm^2, E > 1.0 MeV)	FF[(c)]	$RT_{NDT(U)}$[(d)] (°F)	ΔRT_{NDT} (°F)	σ_I[(d)] (°F)	σ_Δ[(f)] (°F)	Margin (°F)	ART (°F)
Extended Beltline Materials									
US Plate D-3802-1	139.4	0.0314	0.2256	10	31.5	0	17	34.0	75.5
Using Non-Credible Surveillance Data	147.71	0.0314	0.2256	10	33.3	0	17	34.0	77.3
US Plate D-3802-2	133.2	0.0314	0.2256	19	30.1	0	17	34.0	**83.1**
US Plate D-3802-3	171.8	0.0314	0.2256	10	38.8	0	17	34.0	82.8
US Axial Welds 1-112 A/B/C (Heat # W5214)	230.73	0.0200	0.1718	-56[(e)]	39.6	17[(e)]	28	65.5	49.1
Using Not Fully Credible Surveillance Data	227.74	0.0200	0.1718	-56[(e)]	39.1	17[(e)]	28	65.5	48.6
US to IS Circ. Weld 8-112 (Heat # 34B009)	217.7	0.0314	0.2256	-56[(e)]	49.1	17[(e)]	28	65.5	58.6

Notes for Table 8-3:

(a) The Regulatory Guide 1.99, Revision 2 methodology was utilized in the calculation of the ART values. See Section 2.2.3 of this report for details.
(b) Taken from Table 5-1 of this report.
(c) Taken from Table 3-1 of this report.
(d) Initial RT_{NDT} values are taken from Table 4-1 of this report and are measured values, unless otherwise noted. For measured initial RT_{NDT} values, $\sigma_I = 0°F$.
(e) Initial RT_{NDT} values are generic; therefore, $\sigma_I = 17°F$.
(f) Per WCAP-17341-NP, Revision 0 (Reference 4), surveillance data of the plate material and weld Heat # W5214 were considered to be non-credible and not fully credible, respectively. Per the guidance of Reg. Guide 1.99, Revision 2, the base metal $\sigma_\Delta = 17°F$ for both Positions 1.1 and 2.1 with non-credible surveillance data, and the weld metal $\sigma_\Delta = 28°F$ for both Positions 1.1 and 2.1 with not fully credible surveillance data. Per Reg. Guide 1.99, Revision 2, σ_Δ need not exceed $0.5*\Delta RT_{NDT}$; however, for conservatism and consistency with References 2, 3 and 4, a full margin term will be used for all Palisades extended beltline materials.

Table 8-4 Summary of the Limiting ART Values for the Palisades Reactor Vessel Extended Beltline at 42.1 EFPY

Limiting 1/4T ART	Limiting 3/4T ART
US Plate D-3802-3 using Position 1.1 Chemistry Factor Value with Full Margin Term	**US Plate D-3802-2 using Position 1.1 Chemistry Factor Value with Full Margin Term**
112.1°F	83.1°F

Table 8-5 Summary of the Available Margin Between the Palisades Reactor Vessel Beltline and Extended Beltline ART Values at 42.1 EFPY

Reactor Vessel Location	Limiting Material	Limiting ART Value (°F)	
		1/4T Location	3/4T Location
Traditional Beltline[(a)]	Axial Welds 2-112 and 3-112 (Heat # W5214) Using the Position 2.1 Chemistry Factor Value Based on Not Fully Credible Surveillance Data with Full Margin Term	252.7	185.8
Extended Beltline[(b)]	US Plate D-3802-3 using Position 1.1 Chemistry Factor Value with Full Margin Term	112.1	- - -
	US Plate D-3802-2 using Position 1.1 Chemistry Factor Value with Full Margin Term	- - -	83.1
Available Margin (°F)		140.6	102.7

Notes for Table 8-5:

(a) Traditional beltline limiting ART values used in development of the Palisades P-T limit curves, as documented in WCAP-17341-NP, Revision 0 (Reference 4), were taken from Table 8-1 of this report.

(b) Extended beltline limiting ART values were taken from Table 8-4 of this report.

9 REFERENCES

1. Code of Federal Regulations, 10 CFR Part 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events," U.S. Nuclear Regulatory Commission, Washington, D.C., Federal Register, Volume 60, No. 243, dated December 19, 1995.

2. Structural Integrity Associates, Inc. Report No. 0901132.401, Revision 0, "Evaluation of Surveillance Data for Weld Heat No. W5214 for Application to Palisades PTS Analysis," Timothy J. Griesbach, April 2010.

3. Structural Integrity Associates, Inc. Report No. 1000915.401, Revision 1, "Revised Pressurized Thermal Shock Evaluation for the Palisades Reactor Pressure Vessel," Timothy J. Griesbach and Vikram Marthandam, November 12, 2010.

4. WCAP-17341-NP, Revision 0, "Palisades Nuclear Power Plant Heatup and Cooldown Limit Curves for Normal Operation and Upper-Shelf Energy Evaluation," E. J. Long and S. T. Byrne, February 2011.

5. NUREG-1801, Revision 2, "Generic Aging Lessons Learned (GALL) Report," U.S. Nuclear Regulatory Commission, December 2010.

6. WCAP-15353 – Supplement 2-NP, Revision 0, "Palisades Reactor Pressure Vessel Fluence Evaluation," S. L. Anderson, July 2011.

7. "Fracture Toughness Requirements," Branch Technical Position 5-3, Revision 2, Contained in Chapter 5 of Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, NUREG-0800, March 2007.

8. WCAP-14370, Revision 0, "Use of the Hyperbolic Tangent Function for Fitting Transition Temperature Toughness Data," Thomas R. Mager et al., May 1995.

9. ASTM E185-82, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels," American Society for Testing and Materials, 1982.

10. Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials," U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, May 1988.

11. K. Wichman, M. Mitchel and A. Hiser, USNRC, Generic Letter 92-01 and RPV Integrity Workshop Handouts, *NRC/Industry Workshop on RPV Integrity Issues,* February 12, 1998.

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

13. NRC SER, Carl S. Hood (NRC) to Nathan L. Haskell (Palisades), "Palisades Plant – Reactor Vessel Neutron Fluence Evaluation and revised Schedule for Reaching Pressurized Thermal Shock Screening Criteria," November 14, 2000.

14. ASME Boiler and Pressure Vessel (B&PV) Code, Section III, Division 1, Subsection NB, Section NB-2300, "Fracture Toughness Requirements for Material."

15. Code of Federal Regulations, 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements," U.S. Nuclear Regulatory Commission, Washington, D.C., Federal Register, Volume 60, No. 243, dated December 19, 1995.

16. Combustion Engineering Report P-PENG-ER-006, Revision 0, "The Reactor Vessel Group Records Evaluation Program Phase II Final Report for the Palisades Reactor Pressure Vessel Plates, Forgings, Welds and Cladding," Combustion Engineering, Inc., October 1995.

17. WCAP-13587, Revision 1, "Reactor Vessel Upper Shelf Energy Bounding Evaluation for Westinghouse Pressurized Water Reactors," S. Tandon et al., September 1993.

18. Combustion Engineering Report CE NPSD-993, Revision 0, "Evaluation of Low Upper Shelf Energy for Reactor Vessel Beltline Weld and Base Metal Materials for Combustion Engineering Nuclear Steam Supply Systems Reactor Pressure Vessels," CEOG Task 821, C-E Owners Group, May 1995.

19. Appendix G to the 1998 through the 2000 Addenda Edition of the ASME Boiler and Pressure Vessel (B&PV) Code, Section XI, Division 1, "Fracture Toughness Criteria for Protection Against Failure."

APPENDIX A CVGRAPH PLOTS USED IN THE DETERMINATION OF THE INITIAL RT_{NDT} FOR THE PALISADES UPPER SHELL PLATES

The temperature representing a minimum of 50 ft-lbs and 35 mils lateral expansion (L.E.) is needed in order to determine initial RT_{NDT} values for the Palisades extended beltline plate material. The following CVGraph plots for Charpy V-Notch Impact Energy and L.E. were used, along with the methodology described in Table 4-1 footnote (e), to determine the initial RT_{NDT} values for the three plates.

Table A-1 contains the initial upper-shelf energy values used as input for the generation of the Charpy V-Notch plots in CVGraph, Version 5.3. The values shown in Table A-1 were fixed in the program. The lower-shelf energy values were fixed at 2.2 ft-lb for all cases. The lower-shelf Lateral Expansion values were fixed at 1.0 mils in all cases. Finally, note that all Charpy V-Notch data, obtained from P-PENG-ER-006, Revision 0 (Reference A-1), was tested in the strong-direction (longitudinal-orientation (LT)).

Table A-1 Summary of the USE Values Fixed in CVGraph for the Palisades Upper Shell Plates

Reactor Vessel Material	Unirradiated Initial USE (ft-lb)
US Plate D-3802-1	115[(a)]
US Plate D-3802-2	113[(b)]
US Plate D-3802-3	91[(c)]

Notes for Table A-1:

(a) Unirradiated initial USE value was determined based on one data point at 100% shear per Reference A-1.
(b) Unirradiated initial USE value was determined based on three data points at 100% shear per Reference A-1.
(c) Unirradiated initial USE value was determined based on three data points at 95% shear per Reference A-1.

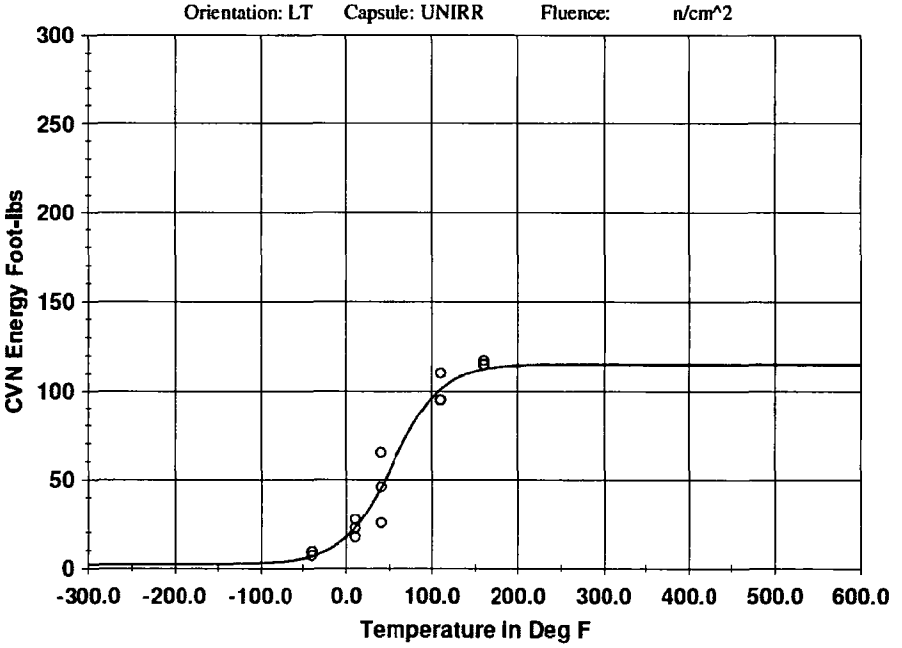
Appendix A Reference

A-1 Combustion Engineering Report P-PENG-ER-006, Revision 0, "The Reactor Vessel Group Records Evaluation Program Phase II Final Report for the Palisades Reactor Pressure Vessel Plates, Forgings, Welds and Cladding," Combustion Engineering, Inc., October 1995.

A.1 US PLATE D-3802-1 (HEAT # C-1279)

US PLATE D-3802-1 - IMPACT ENERGY - LT - UNIRRADIATED

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/11/2011 09:42 AM
Page 1
Coefficients of Curve 1
A = 58.6 B = 56.4 C = 57.79 T0 = 53.89 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=115.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=21.6 Deg F Temp@50 ft-lbs=45.1 Deg F
Plant: Palisades Material: SA302BM Heat: C-1279-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-40.00	7.00	6.41	.59
-40.00	9.00	6.41	2.59
-40.00	9.00	6.41	2.59
10.00	22.00	22.46	-.46
10.00	27.00	22.46	4.54
10.00	17.00	22.46	-5.46
40.00	25.00	45.30	-20.30
40.00	65.00	45.30	19.70
40.00	46.00	45.30	.70

US PLATE D-3802-1 - IMPACT ENERGY - LT - UNIRRADIATED

Page 2
Plant: Palisades Material: SA302BM Heat: C-1279-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

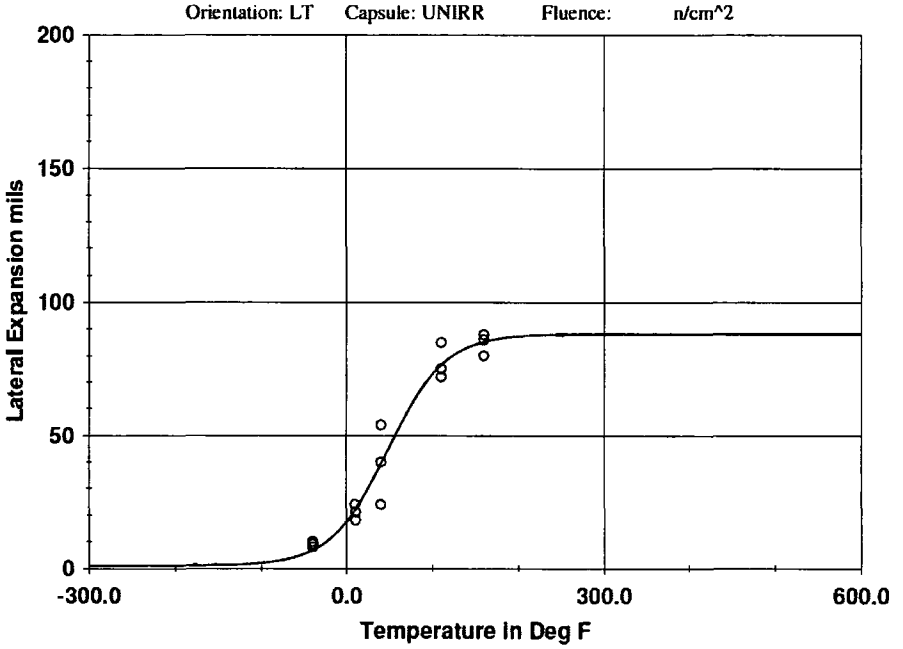
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
110.00	95.00	100.85	-5.85
110.00	95.00	100.85	-5.85
110.00	110.00	100.85	9.15
160.00	115.00	112.20	2.80
160.00	117.00	112.20	4.80
160.00	115.00	112.20	2.80

Correlation Coefficient = .981

US PLATE D-3802-1 - L. E. - LT - UNIRRADIATED

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/11/2011 09:43 AM
Page 1
Coefficients of Curve 1
A = 44.62 B = 43.62 C = 66.71 T0 = 48.05 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=88.2 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=33.1 Deg F
Plant: Palisades Material: SA302BM Heat: C-1279-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-40.00	8.00	6.81	1.19
-40.00	9.00	6.81	2.19
-40.00	10.00	6.81	3.19
10.00	21.00	22.13	-1.13
10.00	24.00	22.13	1.87
10.00	18.00	22.13	-4.13
40.00	24.00	39.38	-15.38
40.00	54.00	39.38	14.62
40.00	40.00	39.38	.62

US PLATE D-3802-1 - L. E. - LT - UNIRRADIATED

Page 2
Plant: Palisades Material: SA302BM Heat: C-1279-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

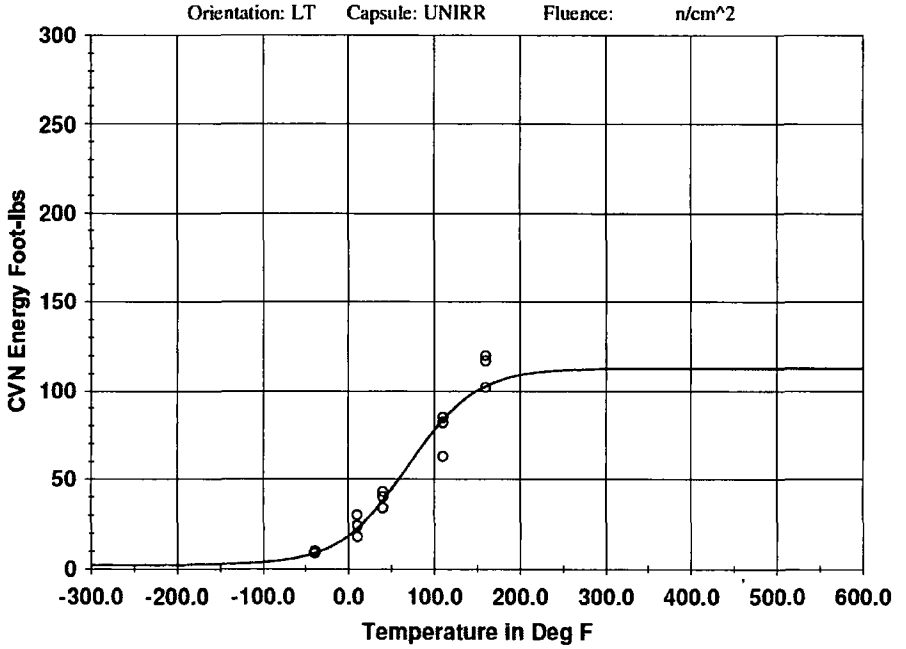
Temperature	Input L.E.	Computed L.E.	Differential
110.00	72.00	76.46	-4.46
110.00	75.00	76.46	-1.46
110.00	85.00	76.46	8.54
160.00	88.00	85.30	2.70
160.00	86.00	85.30	.70
160.00	80.00	85.30	-5.30

Correlation Coefficient = .978

A.2 US PLATE D-3802-2 (HEAT # C-1308)

US PLATE D-3802-2 - IMPACT ENERGY - LT - UNIRRADIATED

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/11/2011 08:03 AM
Page 1
Coefficients of Curve 1
A = 57.6 B = 55.4 C = 79.47 T0 = 69.48 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=113.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=26.1 Deg F Temp@50 ft-lbs=58.6 Deg F
Plant: Palisades Material: SA302BM Heat: C-1308-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-40.00	10.00	8.82	1.18
-40.00	9.00	8.82	.18
-40.00	9.00	8.82	.18
10.00	18.00	22.46	-4.46
10.00	24.00	22.46	1.54
10.00	30.00	22.46	7.54
40.00	34.00	37.94	-3.94
40.00	43.00	37.94	5.06
40.00	40.00	37.94	2.06

US PLATE D-3802-2 - IMPACT ENERGY - LT - UNIRRADIATED

Page 2
Plant: Palisades Material: SA302BM Heat: C-1308-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

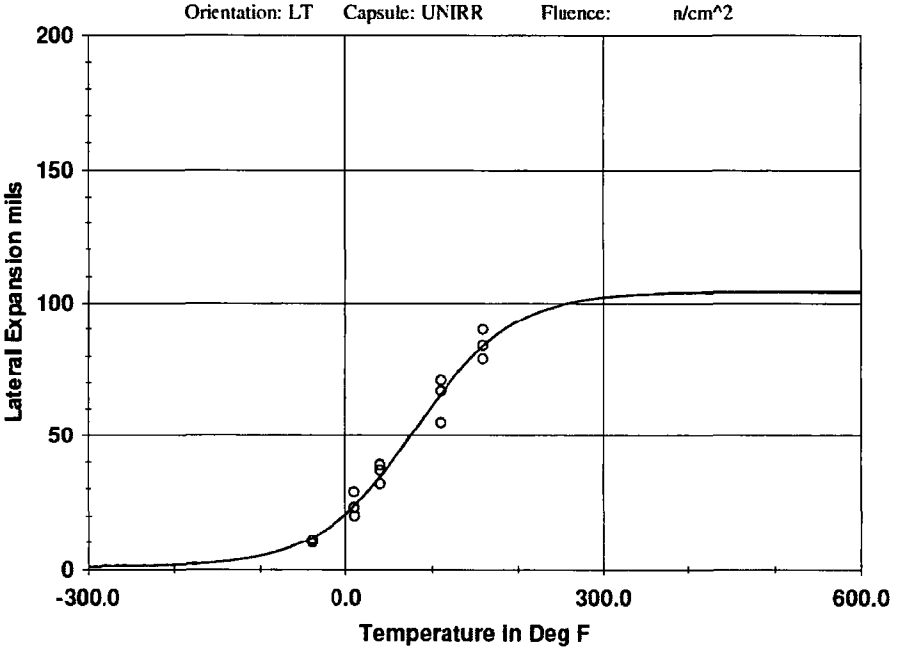
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
110.00	85.00	83.63	1.37
110.00	63.00	83.63	-20.63
110.00	82.00	83.63	-1.63
160.00	120.00	102.70	17.30
160.00	117.00	102.70	14.30
160.00	102.00	102.70	-.70

Correlation Coefficient = .977

US PLATE D-3802-2 - L. E. - LT - UNIRRADIATED

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/11/2011 08:03 AM
Page 1
Coefficients of Curve 1
A = 52.69 B = 51.69 C = 113. T0 = 81.31 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=104.4 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=41.1 Deg F
Plant: Palisades Material: SA302BM Heat: C 1308 2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-40.00	10.00	11.82	-1.82
-40.00	11.00	11.82	-.82
-40.00	10.00	11.82	-1.82
10.00	20.00	23.81	-3.81
10.00	23.00	23.81	-.81
10.00	29.00	23.81	5.19
40.00	32.00	34.60	-2.60
40.00	39.00	34.60	4.40
40.00	37.00	34.60	2.40

US PLATE D-3802-2 - L. E. - LT - UNIRRADIATED

Page 2
Plant: Palisades Material: SA302BM Heat: C-1308-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

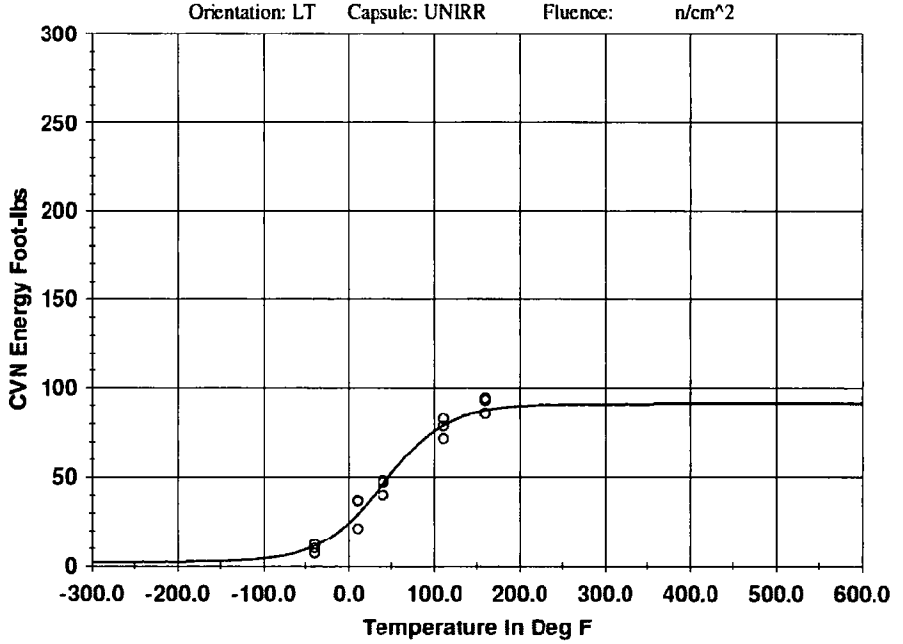
Temperature	Input L.E.	Computed L.E.	Differential
110.00	71.00	65.55	5.45
110.00	55.00	65.55	-10.55
110.00	67.00	65.55	1.45
160.00	90.00	83.82	6.18
160.00	79.00	83.82	-4.82
160.00	84.00	83.82	.18

Correlation Coefficient = .987

A.3 US PLATE D-3802-3 (HEAT # C-1281)

US PLATE D-3802-3 - IMPACT ENERGY - LT - UNIRRADIATED

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/11/2011 09:44 AM
Page 1
Coefficients of Curve 1
A = 46.6 B = 44.4 C = 73.63 T0 = 40.51 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=91.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=11.6 Deg F Temp@50 ft-lbs=46.2 Deg F
Plant: Palisades Material: SA302BM Heat: C-1281-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-40.00	7.00	11.16	-4.16
-40.00	10.00	11.16	-1.16
-40.00	12.00	11.16	.84
10.00	21.00	29.19	-8.19
10.00	36.50	29.19	7.31
10.00	37.00	29.19	7.81
40.00	48.00	46.29	1.71
40.00	40.00	46.29	-6.29
40.00	47.00	46.29	.71

US PLATE D-3802-3 - IMPACT ENERGY - LT - UNIRRADIATED

Page 2
Plant: Palisades Material: SA302BM Heat: C-1281-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

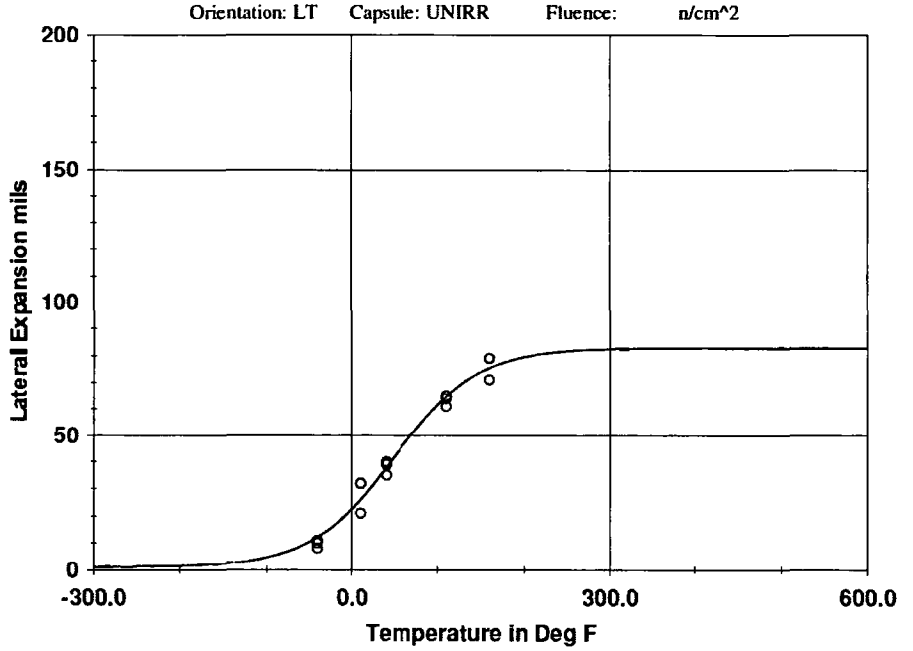
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
110.00	79.00	79.32	-.32
110.00	83.00	79.32	3.68
110.00	72.00	79.32	-7.32
160.00	86.00	87.67	-1.67
160.00	94.00	87.67	6.33
160.00	93.00	87.67	5.33

Correlation Coefficient = .986

US PLATE D-3802-3 - L. E. - LT - UNIRRADIATED

CVGRAPH 5.3 Hyperbolic Tangent Curve Printed on 05/11/2011 09:44 AM
Page 1
Coefficients of Curve 1
A = 41.99 B = 40.99 C = 96.52 T0 = 49.4 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=83.0 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=32.8 Deg F
Plant: Palisades Material: SA302BM Heat: C-1281-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-40.00	8.00	12.11	-4.11
-40.00	10.00	12.11	-2.11
-40.00	11.00	12.11	-1.11
10.00	21.00	26.13	-5.13
10.00	32.00	26.13	5.87
10.00	32.00	26.13	5.87
40.00	40.00	38.01	1.99
40.00	35.00	38.01	-3.01
40.00	39.00	38.01	.99

US PLATE D-3802-3 - L. E. - LT - UNIRRADIATED

Page 2
Plant: Palisades Material: SA302BM Heat: C-1281-1
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
110.00	65.00	64.80	.20
110.00	64.00	64.80	-.80
110.00	61.00	64.80	-3.80
160.00	71.00	75.45	-4.45
160.00	79.00	75.45	3.55
160.00	79.00	75.45	3.55

Correlation Coefficient = .989