Consumers Power

POWERING MICHIGAN'S PROGRESS

Palisades Nuclear Plant: 27780 Blue Star Memorial Highway, Covert, MI 49043

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DOCKET 50-255 - LICENSE DPR-20 - PALISADES PLANT
PRELIMINARY THERMAL ANNEALING REPORT SECTION 3

At a meeting on June 6, 1995, we discussed with the staff our plan to anneal the Palisades reactor vessel (RV) during the refueling outage currently scheduled for May, 1998. In support of this effort, we plan to submit the final Thermal Annealing Report (TAR) in the third quarter of 1996 after the results of the Marble Hill reactor vessel annealing demonstration have been evaluated. The TAR will include the information recommended in Draft Regulatory Guide DG-1027, Format and Content of Application For Approval For Thermal Annealing of Reactor Pressure Vessels. To permit NRC review of the TAR to begin before the Marble Hill results are known, we will make a series of submittals of preliminary TAR sections as they are developed. This letter provides the first of those submittals.

The attachment to this letter contains the preliminary TAR Section 3 entitled "Fracture Toughness Recovery and Reembrittlement Assurance Program". The information is presented in the format recommended by Section C.3 of DG-1027.

SUMMARY OF COMMITMENTS

This letter contains no new commitments and no revisions to existing commitments.

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Manager, Licensing

CC Administrator, Region III, USNRC
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Attachment

A001

ATTACHMENT 1

CONSUMERS POWER COMPANY
PALISADES PLANT
DOCKET 50-255

THERMAL ANNEALING REPORT
SECTION 3
FRACTURE TOUGHNESS RECOVERY AND REEMBRITTLEMENT ASSURANCE PROGRAM

3 FRACTURE TOUGHNESS RECOVERY AND REEMBRITTLEMENT ASSURANCE PROGRAMS

3.1 FRACTURE TOUGHNESS RECOVERY PROGRAM

The Palisades fracture toughness recovery assurance program will be based on a combination of testing of credible surveillance materials and use of generic computational methods. The primary method for predicting the recovery of the Palisades materials will be the generic computational model. Results from the original surveillance materials will be used to verify the predictions from the generic equations outlined in NUREG CR-6327. Employing this combination of approaches should allow demonstration of adequate recovery without the need to remove and test material from the reactor beltline. The original Palisades surveillance program has been supplemented with additional material and the supplemental surveillance program will provide further confirmation of the adequacy of the computational model for predicting recovery of toughness properties.

3.1.1 Vessel Surveillance Program Method

The vessel surveillance program method for determining the projected percentage recovery of both RT_{NDT} and Charpy upper shelf energy (USE) will be used to validate the equations used in the computation model for annealing recovery. Initially, broken specimens from the original Palisades surveillance program will be annealed and reconstituted using the procedures outlined in Section 3.1.4. The weld included in the original Palisades surveillance program does not satisfy the definition of a credible surveillance material as outlined in 10 CFR 50.61 since it was not fabricated from the same weld wire heat as any weld in the vessel. The plate material does match one of the vessel plate materials and is therefore a credible surveillance material. The annealing verification test program includes the irradiation of supplemental surveillance capsules, incorporating three surrogate welds that meet the requirements of credible surveillance material. These supplemental capsules contain specimens suitable for annealing and reconstitution. Measured annealing data on the original Palisades surveillance materials will be submitted in parallel with the Thermal Annealing Report (TAR). This data will be used to verify the predictions of the generic model outlined in NUREG CR-6327. The supplemental surveillance capsules have been installed in the Palisades reactor vessel. The first set of irradiated and annealed data on those specimens (corresponding to a fluence level of 0.85×10^{19} n/cm^2, E > 1 MeV) will be submitted in parallel with the Certification of Annealing Report. It is currently anticipated that all of this data will be used to verify the generic model. If statistically significant differences between the generic model and the measurements are detected, the projected fracture toughness values will be adjusted as detailed in Section 3.1.6.

The material included in the annealing verification test program are shown in Table 3.1.3-1. One plate and four welds are included in this program. A total of 12 Charpy curves will be generated to verify recovery of the transition temperature and upper shelf energy. Material from the original surveillance program (Weld Heat No. 3277 and Plate D-3803-1) has been selected from the available capsules (one high fluence [accelerated] capsule (A-240) and two low lead factor capsules (W-290 and W-110)). Supplemental surveillance material will be irradiated in two accelerated capsules. The first supplemental capsule (SA-60-1) will be exposed for one fuel cycle and is expected to accumulate a nominal fluence of 0.85 x 10^{19} n/cm^2 (E > 1 MeV). The second supplemental capsule (SA-240-1) will be exposed for two fuel cycles and is expected to accumulate a fluence of 1.7 x 10^{19} n/cm^2 (E > 1 MeV). The latter fluence level is higher than the estimated peak vessel fluence at the time of annealing for the axial welds (i.e., 1.45 x 10^{19} n/cm^2) and slightly lower than the peak vessel fluence for the circumferential weld at the time of annealing (i.e., 1.93 x 10^{19} n/cm^2). The transverse orientation plate material from capsule W-100 will be removed and tested prior to annealing. The irradiation level for this capsule is estimated to be 2.00 x 10^{19} n/cm^2, which is close to the peak vessel fluence for the plate material prior to annealing (i.e., 1.93 x 10^{19} n/cm^2). The test plan for this program is outlined in Figure 3.1.1-1.

The Charpy 30-ft-lb transition temperature and Charpy upper shelf energy will be determined by testing surveillance material. General material handling and testing procedures are outlined in Sections 3.1.4 and 3.1.5. These procedures are consistent with the requirements of ASTM E-185. The percent recovery of the Charpy transition temperature shift, R_t, is defined as:

$$R_t = 100\,(TT_i - TT_{ia})/(TT_i - TT_u) \qquad (3.1\text{-}1)$$

where,
TT_u = unirradiated Charpy 30 ft-lb transition temperature,
TT_i = irradiated Charpy 30 ft-lb transition temperature, and
TT_{ia} = irradiated and annealed Charpy 30 ft-lb transition temperature.

Similarly, the percent recovery of the Charpy upper shelf energy, R_U, is defined as:

$$R_U = 100\,(C_VUSE_{ia} - C_VUSE_i)/(C_VUSE_u - C_VUSE_i) \qquad (3.1\text{-}2)$$

where,
C_VUSE_u = unirradiated Charpy upper shelf energy,
C_VUSE_i = irradiated Charpy upper shelf energy, and
C_VUSE_{ia} = irradiated and annealed Charpy upper shelf energy.

R_t and R_U will be limited to values which do not exceed 100 percent.

3.1.2 Irradiated Vessel Material Method

There are no plans to use this alternative method for determining the percent recovery.

3.1.3 Computational Method

The prediction procedures and equations described in NUREG CR-6327 will be used as the generic computational method for determining annealing recovery. These equations were developed from a detailed analysis of the available literature and data on annealing of irradiated pressure vessel steels. This method is based on the analysis of a large number of data points and is not subject to the uncertainties that may arise from measurement errors associated with a small sample set. Since there is a significant level of uncertainty when a determination of annealing recovery is based on three or fewer data points, the annealing recovery data generated in the surveillance program will be compared to the normal statistical uncertainty associated with the predictive equations. If the surveillance data falls within the predicted uncertainty, recovery will be determined using the computational method. The predicted recovery will be adjusted when the data falls outside the normal uncertainty band as outlined in Section 3.1.6.

3.1.3.a Computation of Transition Temperature

The models outlined in NUREG CR-6327 provide the basis for performing generic predictions of the transition temperature shift for the Palisades reactor vessel materials. The prediction model is:

$$TT_{ia} = TT_i - \Delta TT_i \left[0.5 + 0.5 \tanh \left(\frac{a_1 T_a - a_2}{a_3} \right) \right] \qquad (3.1\text{-}3)$$

TT_{ia}	=	irradiated and annealed Charpy transition temperature @ 30 ft-lb
TT_i	=	irradiated Charpy transition temperature (prior to anneal) @ 30 ft-lb
ΔTT_i	=	irradiation induced shift in Charpy transition temperature @ 30 ft-lb
T_a	=	annealing temperature
a_1	=	$1 + 0.0151 \ln t_a - 0.424\, Cu^{(3.28-0.00306T_a)}$
a_2	=	$\begin{cases} 0.584(T_i + 637) & T_a \geq 800°F \\ 0.584T_i - 15.5 \ln\phi + 833 & T_a \leq 750°F \end{cases}$
a_3	=	95.7
t_a	=	annealing time (hours)
T_i	=	irradiation temperature (°F)
ϕ	=	neutron flux (n/cm^2 - sec, E > 1MeV)
Cu	=	minimum value { Copper Concentration (wt%); 0.3 or higher measured solubility value }

where all of the temperatures are expressed in °F. The NUREG CR-6327 models represent the most comprehensive available analysis of the annealing response of reactor pressure vessel steels. These models incorporate all available annealing data on steels similar to those used in the construction of the Palisades reactor vessel and covers the annealing conditions proposed for the Palisades vessel. Therefore, this model is expected to describe the behavior of the Palisades vessel materials.

T_i will be calculated for each surveillance capsule and will be a time weighted average of the temperature at which the irradiation occurred. This average would be obtained using the values in Table 1.1.4-1 and the following equation:

$$T_i = \frac{[T_{c1} \times EFPD_{c1} + T_{c2} \times EFPD_{c2} + \ldots + T_{cn} \times EFPD_{cn}]}{EFPD_{total}} \quad (3.1\text{-}4)$$

T_{cn} = temperature of surveillance capsule irradiation for the applicable core cycle
$EFPD_n$ = effective full power days for the applicable core cycle
$EFPD_{total}$ = total effective full power days for the surveillance capsule

3.1.3.b Computation of Charpy Upper Shelf Energy

The models outlined in NUREG CR-6327 provide a suitable basis for performing generic predictions of the Charpy upper shelf energy (USE). The prediction model is:

$$CvUSE_{ia} = CvUSE_i + [1\text{-}0.586\exp(-t_a/15.9)]x[0.570\Delta CvUSE_i + (0.120T_a\text{-}104)Cu + 0.0389T_a\text{-}17.6] \quad (3.1\text{-}5)$$

where,

$CvUSE_i$ = irradiated shelf energy (ft-lb),
$CvUSE_{ia}$ = irradiated & annealed shelf energy (ft-lb),
$\Delta CvUSE_i$ = irradiated induced decrease in shelf energy (ft-lb),
T_a = annealing temperature (°F)
t_a = annealing time (hours), and
Cu = wt% copper

This equation may be rearranged and used with equation 3.1-2 to give the percentage recovery, R_U:

$$R_U = [1\text{-}0.586\exp(-t_a/15.9)]x[0.570\Delta CvUSE_i + (0.120T_a\text{-}104)Cu + 0.0389T_a\text{-}17.6]x100/\Delta CvUSE_i \quad (3.1\text{-}6)$$

This equation provides the basis for predicting the annealing recovery of the Charpy upper shelf energy. NUREG CR-6327 states that the standard error for this method is 5.1 ft-lb. The data set used to develop this model was obtained from the same set of experiments used to develop the transition temperature model. Therefore, this model is expected to describe the behavior of the Palisades vessel materials.

3.1.4 Specimen Handling & Preparation

3.1.4.1 Specimen Handling Procedures

Only full size Charpy specimens, whether original or reconstituted, will be tested. Some specimens from the original surveillance program will be taken from the archives of broken surveillance specimens. The broken specimen halves are all identified by numbers stamped in the ends. All available broken Charpy specimens will be located and inventoried; specimens that have been cut for chemical analysis or dosimetry measurements will be identified.

Specimen identity will be positively maintained throughout the process of cutting specimen blanks and reconstituting specimens. The orientation of specimens will be retained. Upon completion of the reconstitution process, the specimens will be permanently marked with new identification numbers.

3.1.4.2 Specimen Orientation

Reconstituted specimens will be tested in the same orientation as the original surveillance specimens. Selection preference will be given to specimens in the transverse direction. The original orientation will be determined from the location of the notch in the broken Charpy half. The notched side of the specimen will be marked before the fracture face is removed. It will be demonstrated that the marking procedure will survive the welding process.

3.1.4.3 Reconstitution of Charpy Specimens

Charpy specimens will be reconstituted according to the procedures described in ASTM Standard E 1253-88. The maximum temperature in the central, notched portion of the specimen should not exceed the most recent processing temperature of the material. Therefore, the maximum permissible temperature for the annealed specimens is the annealing temperature (850°F) and the maximum permissible temperature for irradiated and reirradiated specimens is the reactor operating temperature (533°F).

3.1.5 Specimen Testing

3.1.5.1 Test Procedures

3.1.5.1.a Specimen Annealing Procedure

The surveillance program specimens will be annealed in a laboratory furnace. Prior to performing the anneal, it will be demonstrated that the furnace is capable of maintaining a stable, uniform temperature throughout the zone containing the specimens. During the anneal, the temperature will be monitored using calibrated thermocouples and will be recorded in a data logging system.

3.1.5.1.b Charpy Testing Procedure

Charpy testing will be performed according to surveillance program test procedures as outlined in ASTM Standards E185-82 and E23-91.

3.1.5.2 Test Plan

3.1.5.2.a Material Selection

The reconstitution portion of the surveillance test plan includes specimens from surveillance capsules A-240, W-110, W-290 and W-100. The first three capsules were tested as part of the original reactor vessel surveillance program. Capsule W-100 is scheduled for removal and testing at the end of fuel cycle 12 (1997). The specimen halves will be inspected to determine their suitability for reconstitution and testing. Specimen halves with extensive evidence of plastic deformation will be eliminated from further consideration. In addition, specimen halves that have been cut for chemistry or dosimetry specimens and are consequently too small for reconstitution will be eliminated from further consideration. Weld specimens will be etched to reveal the weld/plate interface. Specimen halves containing inadequate amounts of weld metal will also be eliminated from further consideration.

Reconstitution specimen blanks will be fabricated from the remaining specimens. Where feasible, 12 broken Charpy specimen halves will be selected for reconstitution. However, preliminary studies indicate that as many as 50% of the broken halves from Weld 3277 may be unsuitable for further studies due to the lack of an adequate amount of sound weld metal. This limitation, combined with the fact that some specimens were cut for chemical analysis, will reduce the number of available specimen halves. Eight specimens are adequate for determining the Charpy curve since some of the existing industry surveillance programs rely on only eight specimens (as was acceptable by earlier versions of ASTM E185). Weld specimens from the supplemental surveillance capsules will not require examination for suitability.

The test program will follow the procedures for testing Charpy specimens from reactor pressure vessel surveillance programs outlined in ASTM Procedure E185-82. The test temperatures will be selected using the guidelines outlined in that procedure.

3.1.5.2.b Selection of Annealing Temperature For Surveillance Test Specimens

The annealing specifications for the surveillance materials will be 850°F±25°F for a time greater than 160 hours, not to exceed 168 hours. The heatup and cooldown rate on the vessel will be limited by the large mass of the vessel and the thermal stresses generated by the temperature transients. Because annealing is a strong function of temperature, it is anticipated that the final time at temperature will be more important than the heatup and cooldown rates. To allow heatup and cooldown in a controlled manner, the rate for surveillance material annealing operations will be limited to 50°F/hour in the range 500°F to 850°F. Below 500°F, the rate of heatup and cool down will be determined by the response of the annealing furnace.

The surveillance specimens from Capsules W-100 and SA-60-1 which will be tested prior to the vessel anneal, will be annealed as described in the preceding paragraph. Specimens from capsule SA-240-1 will be tested following the vessel anneal. The annealing parameters for the SA-240-1 specimens will be modified such that they are representative of the actual annealing conditions.

3.1.6 Quantification of Post-Anneal Initial Properties

The surveillance program data will be used to verify the predictions of the NUREG CR-6327 models of annealing recovery. If significant differences between the models and the surveillance data are observed, correction procedures will be applied to the models. The annealing recovery models are the preferred method for determining the post-anneal properties because they represent a full body of information regarding annealing and the models are less subject to the measurement uncertainties associated with a limited number of measurements. The use of a model also facilitates the application of the measured surveillance data to the determination of the recovery in actual pressure vessel materials, with slightly different values for the composition and exposure variables.

Statistical models will be used to compare the surveillance program data to the model predictions. In any predictive model variance between the measurement and the prediction is expected. This variance gives rise to the scatter band normally expected when measured values are plotted as a function of predicted values. To verify the model, statistical methods will be applied to test whether or not the surveillance data falls within the expected scatter band. If the data falls within the normal scatter band, there is no reason to believe that the model is in error. In statistical terms, this procedure tests the "null hypothesis" that the model is applicable (i.e. there is no compelling reason to reject the model). The width of the scatter band can be expressed in terms of confidence limits. The confidence limits are directly related to the standard error associated with the models, which are stated in NUREG CR-6327.

The value of RT_{NDT} and C_vUSE for each of the reactor vessel beltline materials will be calculated using the NUREG/CR-6327 model. Input to this calculation will include the actual time and temperature of the anneal. Should the surveillance program indicate that a correction factor (K) or bias (B) be applied, the calculated recovery would be adjusted accordingly. The results of this determination will be included in Section 4.3 of the annealing certification. Projections of this recovery are detailed in 1.10.

3.1.6.a Verification of Transition Temperature Recovery

The recovery of the Palisades reactor vessel materials will be confirmed through the testing of irradiated and annealed surveillance specimens. The structure of the Palisades surveillance program is described above. Data on irradiated and annealed materials will be generated on four weldments and one plate material. The test matrix includes testing of materials at fluences that bound the peak vessel fluence at the time of the anneal. The projected transition temperature recovery values using equation 3.1-3 for these surveillance materials are summarized in Table 3.1.6-1.

The primary goal of the testing of the annealed surveillance materials is to verify the NUREG CR-6327 model. The standard error of the model is stated as 17.2°F. This implies that for any individual measurement of the annealing recovery, there is a 95% chance that the measured value will fall within ±34°F of the predicted value. For multiple measurements, the average difference between the measured and predicted values should decrease. If there are no systematic differences between the surveillance data and the NUREG CR-6327 model, the average prediction error should follow a normal distribution. In this case, the mean prediction error should be zero and the confidence interval in the determination of the mean prediction error should be controlled by the standard deviation of the model. With a 95% confidence level, the average prediction error should fall within:

$$\pm 1.96\, S/\sqrt{n} \qquad (3.1\text{-}7)$$

where,

S = standard deviation, and
n = number of observations.

The 95% confidence intervals for the determination of the mean error as a function of the number of observations are indicated in Table 3.1.6-2. The confidence level for one observation corresponds to the previously noted ±34°F band indicated for a single determination.

To verify the NUREG CR-6327 model, the mean prediction errors should fall inside the confidence intervals indicated in Table 3.1.6-2. These verification criteria may be applied either to the data on a material-by-material basis or to the data set as a whole. If the model contains a systematic error in its treatment of the primary material related variables (composition, etc.), it might be expected that individual material data sets would begin to fall outside the confidence band as data is accumulated. However, if the model contains a systematic error in its treatment of the irradiation or annealing variables (fluence, T_i, T_a, etc.), the average prediction error for the data set considered as a whole would begin to fall outside of the confidence interval.

The annealing recovery measurements on the surveillance materials will be compared to the values predicted by the NUREG CR-6327 model. The average prediction error for each material will be compared to confidence limits indicated in Table 3.1.6-2. If the average prediction error for any material falls within the confidence limits, the generic equation (3.1-3) will be used to determine the annealing recovery in the transition temperature. If the average prediction error for any material falls outside the confidence limit, a correction factor or a bias will be applied to the predictions. To determine the correction factor, the ratio of the measured recovery to the predicted recovery will be calculated for each measurement of recovery made on that material. The correction factor, K, will then be defined as the average value of this ratio:

$$K = \Sigma_n[R_{mn}/R_{pn}]/N, \qquad (3.1\text{-}8)$$

where,
R_{mn} = measured fractional recovery for data point n,
R_{pn} = predicted fractional recovery for data point n and
N = number of measurements.

The bias, B, will then be defined as the average value of the deviation between the measurements and the predictions:

$$B = \Sigma_n[R_{mn} - R_{pn}]/N \qquad (3.1\text{-}9)$$

As a second test, the average prediction error for the combined, uncorrected surveillance data set will be compared to the confidence limits indicated in Table 3.1.6-2. Only materials that pass the first, material specific test will be included in the combined data set evaluation. If this combined data set mean prediction error falls outside the predicted confidence interval, a correction factor, or bias, will be determined. The process for determining a correction factor or bias for the combined data set will be completely analogous to the procedure outlined above for the material specific data sets. The annealing response for all materials in the combined data set will be determined by taking the product of the original predicted fractional recovery and the correction factor or the sum of the original predicted fractional recovery plus the bias. If the average prediction error for the combined data set falls within the confidence interval, the annealing recovery will be determined directly from the NUREG CR-6327 model.

3.1.6.b Verification of Upper Shelf Recovery

The predicted recovery values for the Charpy Upper Shelf Energy will also be verified by the testing of surveillance materials. The upper shelf recovery assurance program is summarized in Table 3.1.6-3 using equation 3.1-6.

The primary objective of the surveillance program is to verify the predictions of the NUREG CR-6327 model. The stated standard error of the model is 5.1 ft-lb. There is a 95% probability that any individual measurement of the Charpy Upper Shelf will be within ± 10ft-lb of the prediction. For multiple measurements, the mean residual error should begin to approach zero as the number of measurements increases.

The verification scheme for the Charpy Upper Shelf Energy will follow the same strategy as the transition temperature verification procedure. The measured values of the Charpy Upper Shelf Energy will be compared to the predicted values. If the data fall within reasonable confidence bands, the model will be used for all determinations of recovery on the upper shelf. If the data indicate a significant variance from the model, appropriate adjustments will be made. A summary of the confidence bands for the prediction of Upper Shelf Energy is provided in Table 3.1.6-4.

If the annealing data for any individual material fall outside of the confidence band indicated in Table 3.1.6-4, a correction factor or bias will be applied to the predictions in the same manner as described in 3.1.6.a.

A combined data set, including all materials that met the material specific criteria, will be constructed for the second verification test. The average residual error for the combined data set will be compared to the confidence band indicated in Table 3.1.6-4. If the average residual error for the data set falls outside the indicated confidence band, a correction factor, or bias, will be applied to the predictions in the same manner as described in 3.1.6.a. If the predictions meet both verification criteria, the upper shelf annealing recovery will be determined directly from the NUREG CR-6327 model.

PALISADES RECOVERY AND REEMBRITTLEMENT PROGRAM

Cycle	12	13	14	15	16	17	18	19	20	21
Vessel Condition	I	I	IAR	IAR	IAR	IAR	IAR	IAR	IAR	IAR
Vessel Peak Fluence -axial welds	1.38	1.45	1.52	1.59	1.66	1.73	1.80	1.87	1.94	2.01
-circumferential welds and plates	1.84	1.93	2.02	2.10	2.19	2.28	2.36	2.45	2.54	2.63
Material Available *Original Surveillance* -Welds 3277	A-240/W-290/W-110 IA (I=**6.0**/1.09/1.78)	W-100 I (I=2.00)					W-280 IAR (R=0.36) (I=2.09)			
-Plate (TL)	A-240/W-290 IA (I=**6.0**/1.09)	W-100 I;IA (I=2.00)			SA-60-2 IAR (R=**0.85**) (I=2.00)		W-280 IAR (R=0.36) (I=2.09)			
-Plate (LT)		W-100 I (I=2.00)					W-280 IAR (R=0.36) (I=2.09)			
Supplemental Program -Weld W5214		SA-60-1 I;IA (I=**0.85**)	SA-240-1 I;IA (I=**1.7**)		SA-60-2 IAR (R=**0.5/0.85**) (I=**1.7**)					
-Weld 34B009		SA-60-1 I;IA (I=**0.85**)	SA-240-1 I;IA (I=**1.7**)		SA-60-2 IAR (R=**0.5/0.85**) (I=**1.7**)					
-Weld 27204		SA-60-1 I;IA (I=**0.85**)	SA-240-1 I;IA (I=**1.7**)		SA-60-2 IAR (R=**0.5/0.85**) (I=**1.7**)					
-HSST02 (LT)		SA-60-1 I (I=**0.85**)	SA-240-1 I (I=**1.7**)							
		Vessel Anneal (EOC 13)								
	Today							2007		

CYCLE

NOTE:

I=Irradiated
IA=Irradiated and Anneal
IAR=Irradiated, Anneal and Reembrittlement

1. Boxes indicate when data will be available.
2. Numbers in parentheses indicate fluence ($x10^{19}n/cm^2$). bolded numbers indicate higher accelerated flux.
3. Previously Tested Capsules:
   A-240 (**6.0**)
   W-110 (1.78)
   W-290 (1.09)
4. Capsules To Be Tested:
   W-100 (2.00)
   W-280 (2.09) - IAR (0.36)
   W-80 (2.02) - IAR Reserved
   W-260 (2.02) - IAR Reserved
5. Supplemental Capsules:
   SA-60-1 (**0.85**)
   SA-240-1 (**1.7**)
   SA-60-2 (**1.7**/2.00) - IAR (**0.5/0.85**)

FIGURE 3.1.1-1

Material	Fluence n/cm^2 (E>1MeV)	Cu wt%	Ni wt%	Test Program (Capsule)
Weld 3277	1.09×10^{19}	0.246	1.388	Original/Reconstitution (W-290)
Weld 3277	1.78×10^{19}	0.246	1.388	Original/Reconstitution (W-110)
Weld 3277	6.0×10^{19}#	0.246	1.388	Original/Reconstitution (A-240)
Plate D-3803-1 (TL)	1.09×10^{19}	0.232	0.510	Original/Reconstitution (W-290)
Plate D-3803-1 (TL)	2.00×10^{19}	0.232	0.510	Original/Reconstitution (W-100)
Plate D-3803-1 (TL)	6.0×10^{19}#	0.232	0.510	Original/Reconstitution (A-240)
Weld W5214*	0.85×10^{19}	0.307	1.045	Supplemental (SA-60-1)
Weld W5214*	1.7×10^{19}	0.307	1.045	Supplemental (SA-240-1)
Weld 34B009*	0.85×10^{19}	0.185	1.121	Supplemental (SA-60-1)
Weld 34B009*	1.7×10^{19}	0.185	1.121	Supplemental (SA-240-1)
Weld 27204	0.85×10^{19}	0.194	1.067	Supplemental (SA-60-1)
Weld 27204	1.7×10^{19}	0.194	1.067	Supplemental (SA-240-1)

* Note that these welds were taken from the higher copper or higher nickel chemistry region of the steam generator welds and bound the best estimate for the RPV.

\# Fluence value presently being evaluated.

TABLE 3.1.3-1 Materials Included in Palisades Annealing Verification Program

Material	Fluence, n/cm² (E > 1 MeV)	TT_u (°F)	TT_i (°F)	Capsule Time-Wt. Temp. (°F)	Predicted Recovery	Predicted TT_{ia} (°F)	Lower 95% Conf. Limit (°F)	Upper 95% Conf. Limit (°F)
Weld 3277	1.09×10^{19}	-87	199	530	88%	-53	-87	-19
Weld 3277	1.78×10^{19}	-87	218	533	88%	-49	-83	-15
Weld 3277	6.0×10^{19}#	-87	255	524	89%	-48	-82	-14
Weld 3277	2.00×10^{19}	-87	234**	533	88%	-47	-81	-13
Plate D-3803-1 (TL)	1.09×10^{19}	18	176	530	89%	35	1	69
Plate D-3803-1 (TL)	2.00×10^{19}	18	201*	533	89%	38	4	72
Plate D-3803-1 (TL)	6.0×10^{19}#	18	212	524	90%	37	3	71
Weld W5214	0.85×10^{19}	-60	194*	533	82%***	-13	-47	21
Weld W5214	1.7×10^{19}	-60	246*	533	82%***	-3	-37	31
Weld 34B009	0.85×10^{19}	-82	135*	533	92%	-65	-99	-31
Weld 34B009	1.7×10^{19}	-82	178*	533	92%	-62	-96	-28
Weld 27204	0.85×10^{19}	-41	176*	533	92%	-23	-57	11
Weld 27204	1.7×10^{19}	-41	220*	533	92%	-19	-53	15

Fluence value presently being evaluated.

* Estimated from Regulatory Guide 1.99, Revision 2 based upon the chemistry values in Table 3.1.3-1.

** Weld 3277 based upon surveillance data (The high nickel of this weld prevents interpolation of CF from 10CFR50.61 Table 1).

*** Based upon a copper solubility level of 0.307 rather than 0.30 as indicated in Equation 3.1-3.

TABLE 3.1.6-1 Projected Transition Temperature Annealing Response of Palisades Surveillance Materials

Number of Observations	95% Confidence Interval (Based on Average of Observation Values) (°F)
1	33.7
2	23.8
3	19.5
4	16.9
5	15.1
6	13.6
7	12.7
8	11.9
9	11.2
10	10.7
11	10.2
12	9.7
13	9.3
14	9.0
15	8.7

TABLE 3.1.6-2 Confidence Interval for Predictions of Annealed Transition Temperature

Material	Fluence n/cm^2 (E > 1MeV)	CvUSE (ft-lb)	$CvUSE_i$ (ft-lb)	Predicted Recovery (%)	$CvUSE_{ia}$ (ft-lbs)	Lower 95% Conf. Limit (ft-lbs)	Upper 95% Conf. Limit (ft-lbs)
Weld 3277	1.09×10^{19}	118	63	84	109	99	118
Weld 3277	1.78×10^{19}	118	58	82	107	97	117
Weld 3277	6.0×10^{19}#	118	51	79	104	94	114
Weld 3277	2.00×10^{19}	118	64*	85	110	100	118
Plate D-3803-1 (TL)	1.09×10^{19}	102	84	100	102	92	102
Plate D-3803-1 (TL)	2.00×10^{19}	102	63 *	95	100	90	102
Plate D-3803-1 (TL)	6.0×10^{19}#	102	68	100	102	92	102
Weld W5214	0.85×10^{19}	103	61 *	92	100	90	103
Weld W5214	1.7×10^{19}	103	56 *	89	98	88	103
Weld 34B009	0.85×10^{19}	114	78 *	100	114	104	114
Weld 34B009	1.7×10^{19}	114	71 *	92	111	101	114
Weld 27204	0.85×10^{19}	104	71 *	100	104	94	104
Weld 27204	1.7×10^{19}	104	65 *	96	102	92	104

Fluence value presently being evaluated
* Estimated from Regulatory Guide 1.99, Revision 2

TABLE 3.1.6-3 Projected Upper Shelf Annealing Response of Palisades Surveillance Materials

Number of Observations	95% Confidence Interval (Based on Average of Observation Values) (ft-lb)
1	10.0
2	7.1
3	5.8
4	5.0
5	4.5
6	4.1
7	3.8
8	3.5
9	3.3
10	3.2
11	3.0
12	2.9
13	2.8
14	2.7
15	2.6

TABLE 3.1.6-4 Confidence Interval for Predictions of Annealed Charpy Upper Shelf Energy

3.2 REEMBRITTLEMENT RATE ASSURANCE PROGRAM

The Palisades Reembrittlement Rate Assurance Program will be based on a combination of surveillance data and the "lateral shift" model. The surveillance program has been designed to provide credible embrittlement data on the irradiated, annealed and reirradiated materials. These materials are shown in Table 3.2-1. The completion of the post-anneal irradiation program will require several fuel cycles beyond the anneal. The surveillance program has one reembrittlement capsule (W-280) to be installed prior to cycle 14 and removed after cycle 17. A second reembrittlement capsule (SA-60-2) will be installed for cycle 15 and will be removed after cycle 15. The projected results of the program are summarized in Table 3.2-2. While awaiting the results of the reembrittlement data from these capsules, the Reembrittlement Rate Assurance Program will be based on the "lateral shift" model.

3.2.1 Lateral Shift Method

The "lateral shift" approach was chosen because it provides a conservative bound on the reembrittlement rate. When the surveillance data becomes available, the use of the "lateral shift" approach will be reevaluated. While the conservative nature of the "lateral shift" approach is not expected to limit operation during the current period of licensed operation, it could limit operation if license renewal is obtained.

3.2.1.1 Reembrittlement of Transition Temperature

The application of the "lateral shift" model is done in the following manner. The base curve for the prediction of the irradiation-induced change in Charpy transition temperature, ΔTT_i is given by Regulatory Guide 1.99 Rev. 2:

$$\Delta TT_i = CF \ \phi t^{(0.28-0.1\log(\phi t))} \qquad (3.2\text{-}1)$$

where,

CF = chemistry factor,
ϕt = neutron fluence (10^{19} n/cm^2, E > 1 MeV).

The post-annealing shift, ΔTT_{ia} (ΔTT_{resid} in NUREG/CR-6327), is defined as

$$\Delta TT_{ia} = TT_{ia} - TT_u \qquad (3.2\text{-}2)$$

where,

TT_{ia} = Charpy transition temperature in annealed material
TT_u = Charpy transition temperature in unirradiated material

The lateral shift model defines a new base fluence for the annealed material, ϕt_A, such that the shift calculated using the Reg. Guide 1.99 Rev. 2 equation equals ΔTT_{ia}, i.e.,

$$\Delta TT_{ia} = CF\ \phi t_A^{(0.28-0.1\log(\phi t_A))} \tag{3.2-3}$$

The post-annealing transition temperature shift, ΔTT_{iar}, is then calculated using the Reg. Guide 1.99, Rev. 2 equation and an equivalent fluence, ϕt_{iar}, defined as:

$$\phi t_{iar} = \phi t_A + \phi t_R \tag{3.2-4}$$

where

ϕt_R = post-anneal fluence

Per 10 CFR Part 50.61, RT_{NDT} is determined by the equation:

$$RT_{NDT} = RT_{NDT(U)} + M + \Delta RT_{NDT} \tag{3.2-5}$$

where

$RT_{NDT(U)}$	=	unirradiated reference temperature
ΔRT_{NDT}	=	change in Charpy transition temperature, and
M	=	margin term

The margin term is the root mean square of the uncertainties in the two primary values:

$$M = 2 \times \sqrt{\sigma_U^2 + \sigma_\Delta^2} \tag{3.2-6}$$

where,

σ_U = standard deviation of $RT_{NDT(U)}$, and
σ_Δ = standard deviation of ΔRT_{NDT},

Additional uncertainty for annealing recovery is not required.

For purposes of consistency with projections for the reactor vessel beltline materials listed in Section 1.10, RT_{NDT} for the surveillance materials will be calculated assuming:

$RT_{NDT(u)}$	=	-56°F for welds
	=	0°F for base metal
σ_U	=	17°F for welds
	=	0°F for base metal
σ_Δ	=	28°F for welds
	=	17°F for base metal

The results of these calculations are listed in Table 3.2-2.

3.2.1.2 Reembrittlement of Charpy Upper Shelf Energy

The "lateral shift" model requires a pre-determined model for the prediction of embrittlement in the irradiated material. The model supplies a procedure for applying the pre-anneal trend curve to the post-anneal condition. This procedure works well for the

Charpy transition temperature because the embrittlement trend curve provided in 10 CFR Part 50.61 is widely accepted. The application of the "lateral shift" model to the Charpy upper shelf energy is more difficult because there is no generally accepted model of embrittlement.

DG-1027 suggests a particular model of irradiation induced decreases in Charpy upper shelf energy. While that model was used, it is believed to overestimate the amount of reembrittlement and there is a high probability that improved models will be available in the near future. When improved models for the Charpy upper shelf energy become available, this issue will be reconsidered.

The predicted Charpy upper shelf energy following reirradiation of the surveillance material is detailed in Table 3.2-2.

3.2.2 Surveillance Method

The reembrittlement rate assurance program for the Palisades reactor vessel builds on the original surveillance capsules and the supplemental surveillance capsules as described above. Many of the materials used in the annealing verification program will also be used in the reembrittlement rate assurance program. At least one irradiated and annealed supplemental surveillance capsule will be utilized and inserted at the end of cycle 14 in an accelerated fluence location to obtain at least two separate reembrittlement fluence points for each of the supplemental welds (W5214, 34B009, and 27204). Reembrittlement data will be generated on the three supplemental surveillance welds and the one original surveillance program plate (see Figure 3.1.1-1). The three wall capsules from the original surveillance program will be annealed after the vessel anneal and, if possible, reinserted prior to restart. The plan is to pull one of these capsules (W-280) at the end of cycle 17 at a fluence of about 0.36 x 10^{19} n/cm^2 to primarily evaluate the base metal reembrittlement. Irradiated weld metal (Heat No. 3277) will also be available for research interests.

The goal of the reembrittlement surveillance program will be to provide a realistic assessment of the reembrittlement rate in the Palisades vessel materials. This approach differs from the annealing verification program because the projection procedures for predicting reembrittlement rates are not as well developed. It is possible to conduct a verification program for the annealing recovery predictions because the projection procedures are statistically based and well documented. In contrast, the "lateral shift" approach was chosen for reembrittlement because it is believed to consistently over-estimate the amount of reembrittlement. The supplemental surveillance program should verify the conservative nature of these assumptions. However, sufficient data will be generated in Palisades supplemental surveillance program to allow a more realistic, material-specific projection of the reembrittlement rate.

Procedures for applying the surveillance data for the determination of the post-anneal embrittlement curve are not well established. There are a number of ongoing research programs that may provide significant improvements in these procedures before the Palisades reirradiation program is completed. At this time, it is presumed that the programs that may provide significant improvements in these procedures before the Palisades reirradiation program is completed. At this time, it is presumed that the procedures outlined in 10CFR50.61 for the determination of a chemistry factor from credible surveillance data would be used. The calculation of a new chemistry factor recognizes that annealing may alter the sensitivity of the materials to radiation embrittlement and the post-anneal chemistry factor may be different than the original chemistry factor. In this procedure, it is assumed that the shape (fluence factor) of the post anneal embrittlement curve is unchanged by irradiation. In order to use the 10CFR50.61 procedure, an appropriate definition of post-anneal fluence must be established. At this time, it is assumed that the value ϕt_{iar}, as defined originally by the lateral shift model, will be used to determine the chemistry factor. This procedure should allow the annealed data point to be included in the calculation as a measurement made at a fluence of ϕt_A.

These procedures for applying the surveillance data in the reembrittlement rate assurance program should be viewed as provisional. Improvements are expected as technology advances.

Material	Anneal Fluence (n/cm²) (E > 1MeV)	Cu wt%	Ni wt%	Test Program (Capsule)
Plate D-3803-1 (TL)	2.00×10^{19}	0.232	0.510	Supplemental (SA60-2)
Plate D-3803-1 (TL)	2.09×10^{19}	0.232	0.510	Original (W-280)
Plate D-3803-1 (LT)*	2.09×10^{19}	0.232	0.510	Original (W-280)
Weld W5214	1.70×10^{19}	0.307	1.045	Supplemental (SA60-2)
Weld W5214	1.70×10^{19}	0.307	1.045	Supplemental (SA60-2)
Weld 34B009	1.70×10^{19}	0.185	1.121	Supplemental (SA60-2)
Weld 34B009	1.70×10^{19}	0.185	1.121	Supplemental (SA60-2)
Weld 27204	1.7×10^{19}	0.194	1.067	Supplemental (SA60-2)
Weld 27204	1.7×10^{19}	0.194	1.067	Supplemental (SA60-2)
Weld 3277*	2.09×10^{19}	0.246	1.388	Original (W-280)

* Information only

TABLE 3.2-1 Materials Included in Palisades Reembrittlement Rate Assurance Program

Material	Anneal Fluence (n/cm^2) (E>1MeV)	RT_{NDT} @ Anneal (°F)	R_{NDT} After Anneal (°F)	USE @ Anneal (ft-lb)	USE After Anneal (ft-lb)	Reirradiated Fluence (n/cm^2) (E>1MeV)	RT_{NDT} After Reirrad. (°F)	USE After Reirrad. (ft-lb)
Plate D-3803-1 (TL)	2.00×10^{19}	217	54	63	100	0.85×10^{19}	182	70
Plate D-3803-1 (TL)	2.09×10^{19}	219	55	62	100	0.36×10^{19}	146	76
Plate D-3803-1 (LT)*	2.09×10^{19}	N/A	N/A	N/A	N/A	0.36×10^{19}	N/A	N/A
Weld W5214	1.70×10^{19}	315	65	56	98	0.50×10^{19}	229	64
Weld W5214	1.70×10^{19}	315	65	56	98	0.85×10^{19}	267	61
Weld 34B009	1.70×10^{19}	270	31	71	111	0.50×10^{19}	195	82
Weld 34B009	1.70×10^{19}	270	31	71	111	0.85×10^{19}	228	78
Weld 27204	1.70×10^{19}	271	31	65	102	0.50×10^{19}	195	75
Weld 27204	1.70×10^{19}	271	31	65	102	0.85×10^{19}	228	71
Weld 3277*	2.09×10^{19}	N/A	N/A	N/A	N/A	0.36×10^{19}	N/A	N/A

* Information only

TABLE 3.2-2 Projected Results of Palisades Reembrittlement Surveillance Program for RT_{NDT} and Upper Shelf Energy

3.3 USE OF MATERIALS TEST REACTOR (MTR) IRRADIATIONS

There are no plans to use Materials Test Reactor (MTR) irradiations in the Palisades reactor vessel fracture toughness recovery and reembrittlement assurance program.