GE Nuclear Energy

GE Nuclear Energy

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DEMONSTRATION OF COMPLIANCE WITH 10CFR50 APPENDIX G FOR THE LASALLE UNIT 2 PLATE MATERIAL

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ABSTRACT

The surveillance capsule at the 300° azimuthal location (which had 120° capsule identification and contents) was removed from the LaSalle Unit 2 reactor in the Spring 1995 at 6.98 EFPY for surveillance testing and analysis. In 1994 an archive materials records search was conducted for LaSalle Units 1 and 2 to gather all available material fabrication and testing records. In this search it was discovered that transverse Charpy specimens had been tested for the LaSalle 2 unirradiated surveillance plate material, whereas longitudinal specimens were present in the surveillance capsule. To demonstrate compliance with 10CFR50 Appendix G requirements for the adjusted reference temperature (ART) and the upper shelf energy (USE), alternative analyses have been conducted.

In the alternative analyses, two different approaches are applied to generate an unirradiated baseline Charpy curve. The first method uses the six 40°F longitudinal data points. For this method, the irradiated curve is shifted left to pass through the mean value of the six data points. The second method converts the unirradiated transverse data set to longitudinal values using a combination of the MTEB 5-2 USE conversion factor and a GE alternate position to 10CFR50 Appendix G for the reference temperature shift.

The results of these methods, in conjunction with the results from other plants of similar vintage, are compared with the predictions of Regulatory Guide 1.99, Revision 2 to determine an estimated ART and USE. In addition, to evaluate the USE, applicability of the equivalent margin analysis (EMA) was conducted to determine applicability to LaSalle 2.

The results of all analyses indicate that the LaSalle Unit 2 beltline plate materials are currently in compliance with 10CFR50 Appendix G requirements and will remain in compliance throughout the life of the plant.

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1. INTRODUCTION

Part of the effort to assure reactor vessel integrity involves evaluation of the fracture toughness of the vessel ferritic materials. The key values which characterize a material's fracture toughness are the adjusted reference (ART) and the upper shelf energy (USE) per the requirements of 10CFR50 Appendix G [1]. In a standard RPV surveillance analysis, the unirradiated data is compared to the irradiated data to determine the shift in reference temperature and decrease in USE as a result of irradiation over time. To conduct this analysis most effectively, complete sets of unirradiated and irradiated data should be obtained from specimens cut in a consistent orientation.

For the LaSalle 2 RPV Surveillance Analysis [7], a full set of baseline data, from specimens cut in consistent orientation, were available for the weld material but not for the base material. The unirradiated specimens for the weld material were of transverse orientation, whereas the irradiated specimens removed in the Spring 1995 outage were of longitudinal orientation. The only longitudinal baseline plate data were 6 points at 40 °F. Thus, to develop a full range Charpy curve to demonstrate 10CFR50 Appendix G compliance with respect to shift in reference temperature and decrease in USE, alternative analysis methods were conducted as described in this report.

2. SUMMARY AND CONCLUSIONS

2.1 Summary of Results

To demonstrate compliance with 10CFR50 Appendix G [1] requirements for the adjusted reference temperature (ART) and the upper shelf energy (USE), alternative analysis methods of the beltline surveillance plate material were applied.

The significant results of the evaluation are as follows:

1. The first method uses the six 40°F longitudinal data points. For this method, the irradiated curve is shifted left to pass through the mean value of the six data points. The results of this method estimates a shift in reference temperature (ΔRT_{ndt}) of 25.0°F. Due to the assumptions made, an estimated decrease in USE could not be determined by this method.

2. The second method converts the transverse data to longitudinal values using a combination of the MTEB 5-2 USE conversion factor and a GE alternate position to 10CFR50 Appendix G for the reference temperature shift. This method estimates a ΔRT_{ndt} of 19.3°F and a 15.1% decrease in USE.

3. Regulatory Guide 1.99, Revision 2 (Reg. Guide 1.99) [6] predicts a ΔRT_{ndt} of 7.8 and a USE decrease of 7%.

4. An evaluation to determine the applicability of the Equivalent Margin Analysis (EMA) [8] was conducted for Method 2 only, because Method 1 did not provide a useful correlation to determine USE. The EMA for Method 2 was well within the bounds of the acceptability criteria (adjusted % decrease = 17% ≤ 21%).

5. The comparisons of ΔRT_{ndt} and USE to data from plants of similar vintage show that the LaSalle 2 plate material is behaving like other similar plants.

2.2 Conclusions

The requirements of 10CFR50 Appendix G [1] deal with vessel design life conditions and with limits of operation designed to prevent brittle fracture. Based on the evaluation of the analysis methods and their results, the following conclusions are made:

1. The 30 ft-lb shifts and changes in USE for all analysis methods are consistent with Reg. Guide 1.99 predictions and expected standard deviations.

2. The 30 ft-lb shifts and changes in USE for all analysis methods are consistent with measured 30 ft-lb shifts and changes in USE for other plants of similar vintage.

3. Results from the evaluation to determine applicability of the EMA show that the beltline plate materials are bounded by the EMA.

The results of all analyses conducted in this study indicate that the LaSalle Unit 2 beltline plate materials are currently in compliance with 10CFR50 Appendix G requirements and will remain in compliance throughout the life of the plant.

3. ANALYSIS

Two methods were used to estimate nil-ductility transition shift (ΔRT_{ndt}) and decrease in USE for the LaSalle 2 plate material. Each method represents a separate way of approaching the problem and also develop a range of results which can be compared to Reg. Guide 1.99 predictions and measured trends from plants of similar vintage. An evaluation to determine the applicability of the equivalent margin analysis (EMA) was also conducted to demonstrate that the LaSalle 2 plates will meet the requirements of 10CFR50 Appendix G [1].

3.1 Estimated Unirradiated Charpy Transition Curves

An archive materials records search was conducted for LaSalle Units 1 and 2 to gather all available material fabrication and testing records [2]. In this search it was discovered that transverse Charpy data were available for the LaSalle 2 unirradiated plate material, whereas longitudinal specimens were present in the surveillance capsule. Thus, to generate a baseline curve for comparison with the irradiated longitudinal surveillance test data, two approaches were used. Each approach provides an indication of ΔRT_{ndt} and decrease in USE for the plate material as summarized in Table 3-1. All available Charpy data for the LaSalle 2 plate material are shown in Appendix A Tables A-1 through A-3.

3.1.1 Method 1: Manual Shift

The only available longitudinal Charpy plate data for the LaSalle 2 unirradiated specimens was found in the certified material test report (CMTR) as six points at 40°F for plate heat C9481-1 [2]. The range of this data does not allow for development of a full Charpy curve for the unirradiated material by standard procedures. However, Method 1 uses this data in an attempt to develop a baseline curve and an indication of ΔRT_{ndt}.

Method 1 consists of shifting the irradiated hyperbolic tangent curve [3] so that it passes through the average of the six data points at 40°F as shown in Figure 3-1. To develop this curve, the coefficients which determine the shape of the irradiated hyperbolic tangent fit (A, B, and C) are maintained and the curve is shifted until the curve passes through the average of the six available unirradiated longitudinal baseline Charpy data points while maintaining the shape of the curve.

This method shows a shift in reference temperature of 25.0 °F at 30 ft-lbs. Because the shape of the irradiated curve is maintained, this method does not provide any estimation of the decrease in USE.

3.1.2 Method 2: Transverse to Longitudinal Conversion (65%)

The second analysis converts the transverse baseline plate data into longitudinal data using a combination of the NRC Branch Technical Position MTEB 5-2 [4] and a GE alternate position [5] to 10CFR50 Appendix G [1]. The MTEB 5-2 recommends that the transverse USE be estimated by taking 65% of the longitudinal value. In the case of LaSalle 2, no unirradiated longitudinal USE data was available. Thus, the MTEB 5-2 position was applied inversely to the unirradiated transverse USE data. That is, the longitudinal USE was estimated by increasing the transverse value by 1/0.65.

To determine an estimate for ΔRT_{ndt}, the GE alternate position to 10CFR50 Appendix G was applied providing a conservative temperature shift in the conversion from transverse to longitudinal data. The GE alternate position states that the data should be shifted forward 30°F when converting from longitudinal to transverse, therefore the temperature for each transverse data point was shifted back 30°F to obtain the longitudinal values. The shift value of 30°F from reference [5] is more conservative than the MTEB 5-2 shift of 20°F and has been accepted by the NRC [9].

An overall summary of the Method 2 procedure is as follows:

1. The three 200°F USE data points from the transverse data set were averaged to represent the USE for the transverse data.
2. This value of the transverse USE was then multiplied by 1/0.65 to obtain an estimate for the longitudinal unirradiated USE. This new value is used to fix the USE in the hyperbolic tangent program.
3. Next, each transverse unirradiated baseline data point [2] was shifted mathematically by -30°F, except for the three USE data points which were used to set the longitudinal USE.
4. The hyperbolic tangent curve fitting procedure was then used to plot the shifted data with the USE fixed at the value obtained in #2.

Plots of the transverse curve and the converted longitudinal curve are shown in Figures 3-2 and 3-3. The converted longitudinal curve (the new baseline curve) is plotted together with the irradiated surveillance curve as shown in Figure 3-4. This method provides a 15.1% estimated decrease in USE and a 19.3°F estimated shift in the 30 ft-lb reference temperature. These results are summarized in Table 3-1.

3.2 Regulatory Guide 1.99 Predictions

3.2.1 Predicted Irradiation Shift

Measured transition temperature shifts for plate materials are typically compared to the predictions calculated according to Reg. Guide 1.99. Because there was insufficient unirradiated data to measure the ΔRT_{ndt} and decrease in USE for the LaSalle 2 surveillance plate, the estimated values based on the alternative methods of this report will be compared to the Reg. Guide predictions.

The inputs and calculated values for the Reg. Guide 1.99 irradiated shift of the surveillance plate are as follows:

Plate:	Copper =	0.10%
	Nickel =	0.48%
	CF =	65
	fluence =	1.15×10^{17} n/cm^2
	Reg. Guide 1.99 ΔRT_{NDT} = 7.8°F	
	Reg. Guide 1.99 $\Delta RT_{NDT} \pm 2\sigma_{\Delta}$(34°F) = 41.8°F max, -26.2°F min	

The weight percents of Cu and Ni are best estimates based on averaging (see Table 3-3 of [7]). The chemistry factor (CF) shown above was obtained from Table 2 of Reg. Guide 1.99. The fluence was obtained from the first surveillance capsule report [7]. The fluence factor for the Reg. Guide calculation of 30 ft-lb shift may either be calculated according to the Reg. Guide definition,

$$\text{fluence factor} = f^{(0.28 - 0.10 \log f)} \qquad (3\text{-}1)$$

or it may be obtained from the Reg. Guide Figure 1 [6]. Using equation 3-1, the fluence factor was calculated to be 0.12. The values listed above are used to calculate the Reg. Guide 1.99 prediction for 30 ft-lb shift and USE decrease for the irradiated surveillance materials. The predicted 30 ft-lb temperature shift (ΔRT_{ndt}) was calculated according to the Reg. Guide using the equation

$$\Delta RT_{ndt} = (CF)\, f^{(0.28 - 0.10 \log f)} \qquad (3\text{-}2)$$

3.2.2 Predicted Change in USE

Using the copper and fluence data above with Figure 2 of Reg. Guide 1.99 [6], a decrease in USE of approximately 7% is predicted for the plate material. The Charpy curves generated by Methods 1 and 2 for the plate material provide the percent changes in USE shown in Table 3-1. From this table it can be observed that the more conservative method is Method 2 with a predicted decrease in USE of 15.1%.

Table 3-1: SUMMARY OF CORRELATION RESULTS

Method	RTndt Shift (°F)	USE (ft-lbs.)	% Decrease USE
1	25.0	125	0
2 [a]	19.3	147	15.1
Reg. Guide 1.99	7.8	-	7

[a] Increase trans. USE by 1/0.65, shift trans. data (-30°F)

3.3 Equivalent Margin Analysis

Commonwealth Edison is a participant in a BWR Owners' Group program to perform analyses to demonstrate equivalent margin in cases where a minimum of 50 ft-lb USE cannot be demonstrated [8]. The calculations in Appendix A indicate that, for the methods used to determine a baseline Charpy curve, the EMA is applicable for LaSalle 2.

The EMA was conducted for Method 2 only, because Method 1 did not provide any useful information on the baseline USE. A summary of the results of the EMA are as follows:

Method 2 (65%): 17% $\leq$ 21% so vessel plates are bounded by EMA

The 17% adjusted percent decrease in USE demonstrates equivalent margin when compared to the EMA criteria.

The *Surveillance Plate USE* segment of the EMA (Appendix B), was conducted using the decrease in USE for Method 2 as the estimated % decrease (typically known as the measured % decrease). The Method 2 estimated percent decrease was a conservative value at 15% as previously discussed.

The *Limiting Beltline Plate USE* analysis used the most limiting copper content of all beltline plates (%Cu = 0.12). The adjusted % decrease results for Method 2, as determined from Reg. Guide 1.99 Figure 2, show a 17% decrease in USE at 32 EFPY. If this % decrease is applied to the Method 2 longitudinal USE value of 147 ft-lbs, the end of life USE becomes 122 ft-lbs, which is well above the minimum allowable longitudinal USE, 59 ft-lbs, as demonstrated in the EMA study [10]. Similarly, the 17% USE decrease can be applied to the LaSalle 2 transverse USE value of 95.5 ft-lbs resulting in an end of life USE of 79.3 ft-lbs. This is also well above the minimum allowable transverse USE of 35 ft-lbs [10]. Scatter plots from the EMA study [10] are reproduced here to illustrate the implications of these results with respect to other plants and the bounding values of the EMA.

3.4 Industry Comparisons

An additional study has been conducted on plants of similar vintage to LaSalle 2 to summarize and compare the results from the analyses of sections 3.1 and 3.2. Predicted shift, measured shift, and USE information from these plants has been tabulated and graphed in Table C-1 in Appendix C, and Figures 3-4 and 3-5 respectively. The graphs are useful to show the compliance of LaSalle 2 with the requirements of 10CFR50 Appendix G as compared to plants of similar vintage.

The criteria for selection of similar vintage plants are the following:

- Plant type (BWR 3, 4 and 5)
- RPV inner diameter (251")
- Surveillance capsule fluence (0.52×10^{17} - 1.80×10^{17} n/cm^2)
- Plate material (SA533, B-1 and 302, B-Modified low alloy steel)

The RT_{ndt} shift and USE decreases for the similar vintage plants are shown in Figures 3-7 and 3-8 respectively. Figure 3-7 shows that the Method 1 and 2 RT_{ndt} shift estimation techniques yield results that are consistent with the vintage plant data. Figure 3-8 shows that the Method 2 USE percent decrease estimation technique is conservative with respect to the vintage plant data. (NOTE: The Method 1 technique does not provide an USE percent decrease and therefore was not plotted in Figure 3-8.)

Figure 3-1

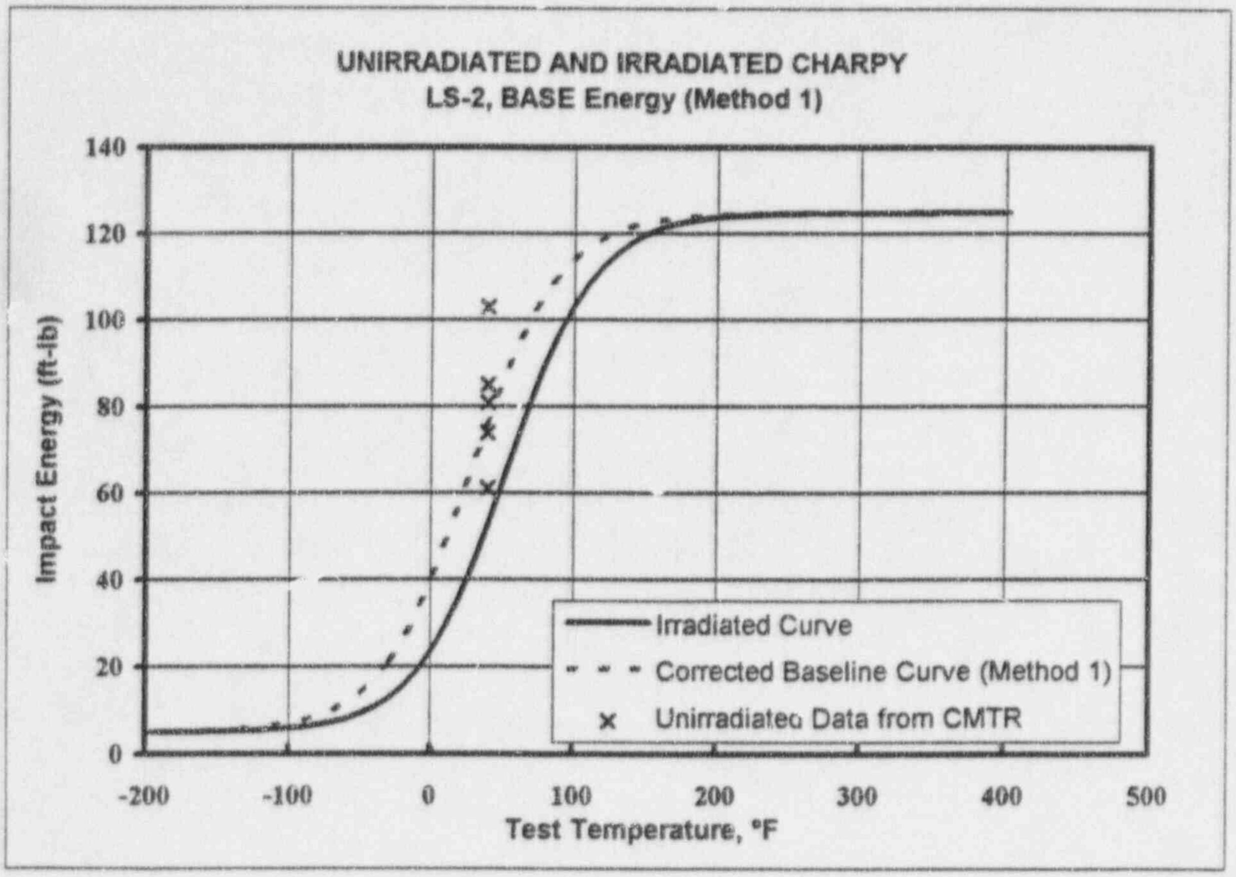

UNIRRADIATED AND IRRADIATED CHARPY
LS-2, BASE Energy (Method 1)
Impact Energy (ft-lb)
140
120
100
80
60
40
20
0
-200
-100
0
100
200
300
400
500
Test Temperature, °F
Irradiated Curve
Corrected Baseline Curve (Method 1)
Unirradiated Data from CMTR

Figure 3-2

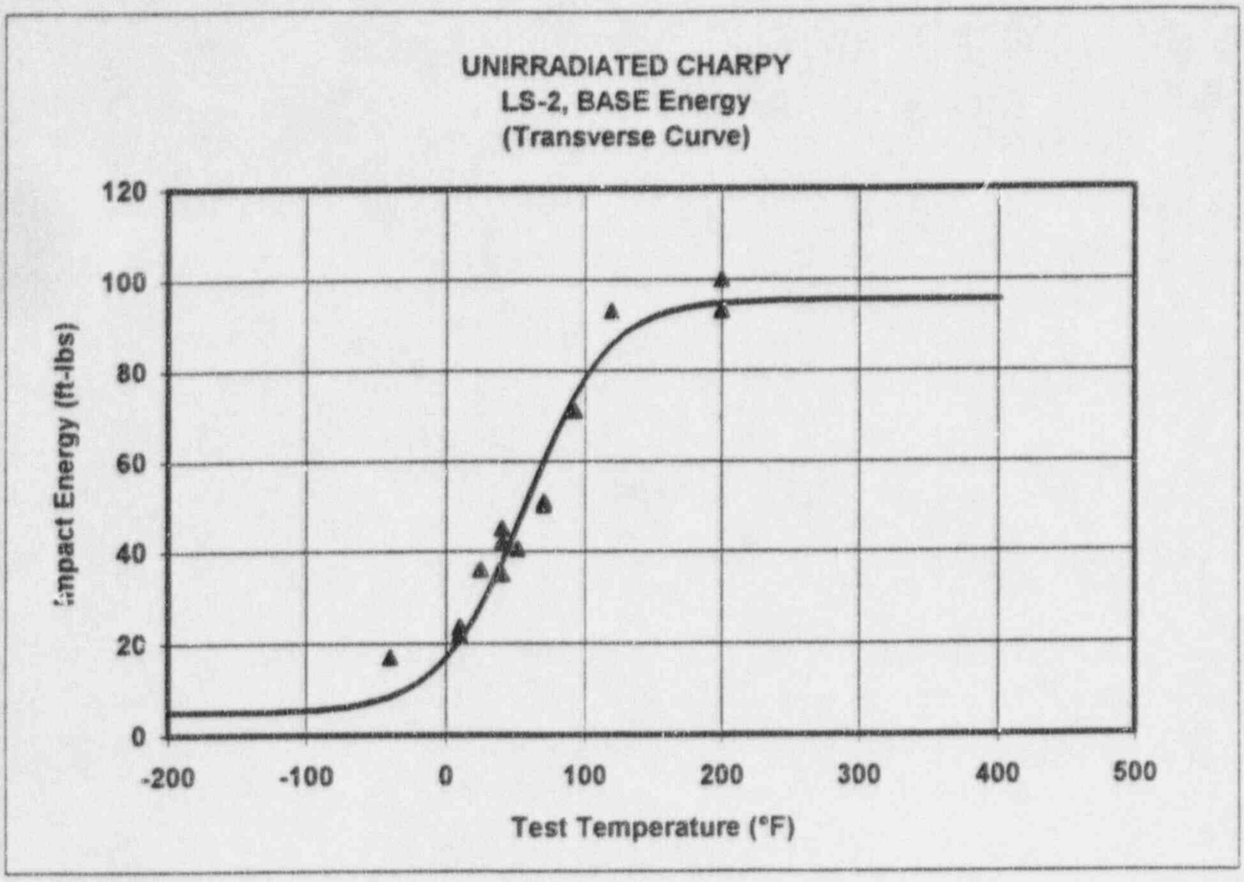

UNIRRADIATED CHARPY
LS-2, BASE Energy
(Transverse Curve)
Impact Energy (ft-lbs)
0
20
40
60
80
100
120
-200
-100
0
100
200
300
400
500
Test Temperature (°F)

Figure 3-3

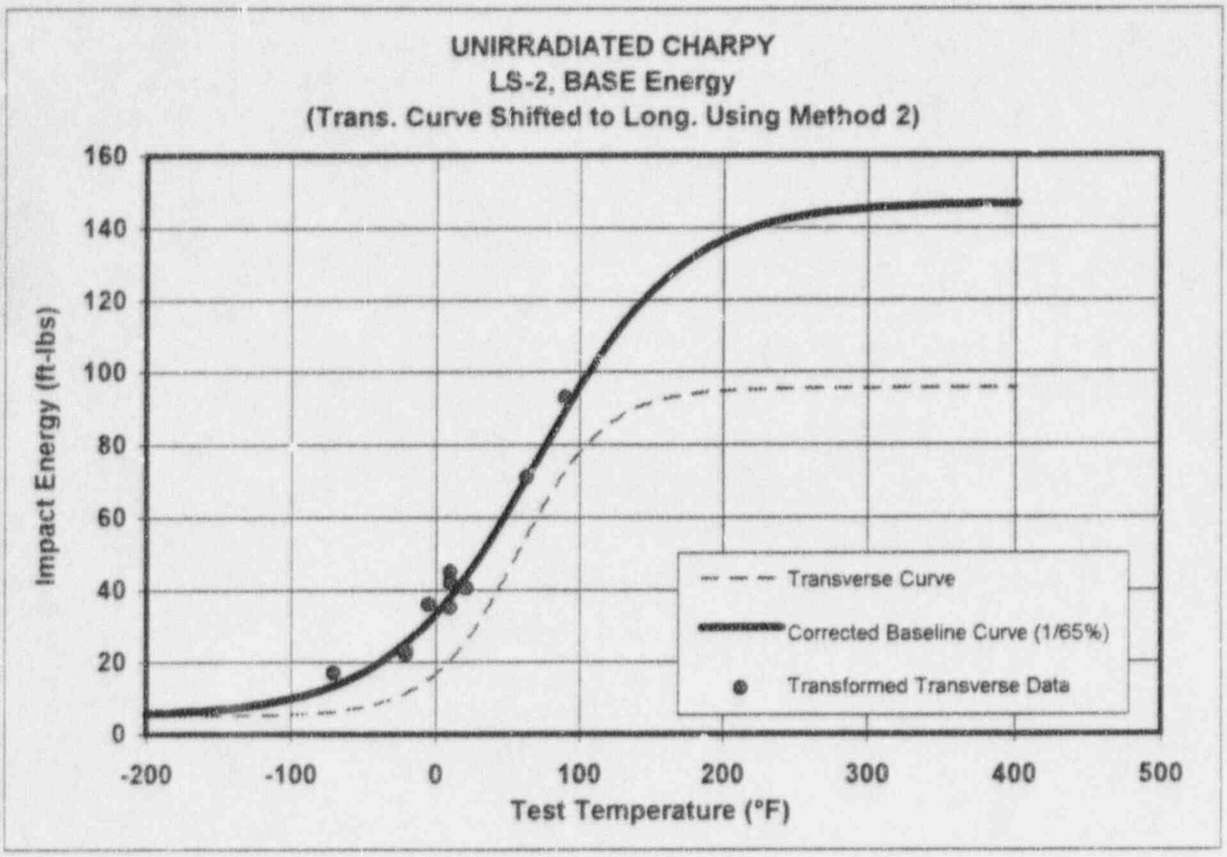
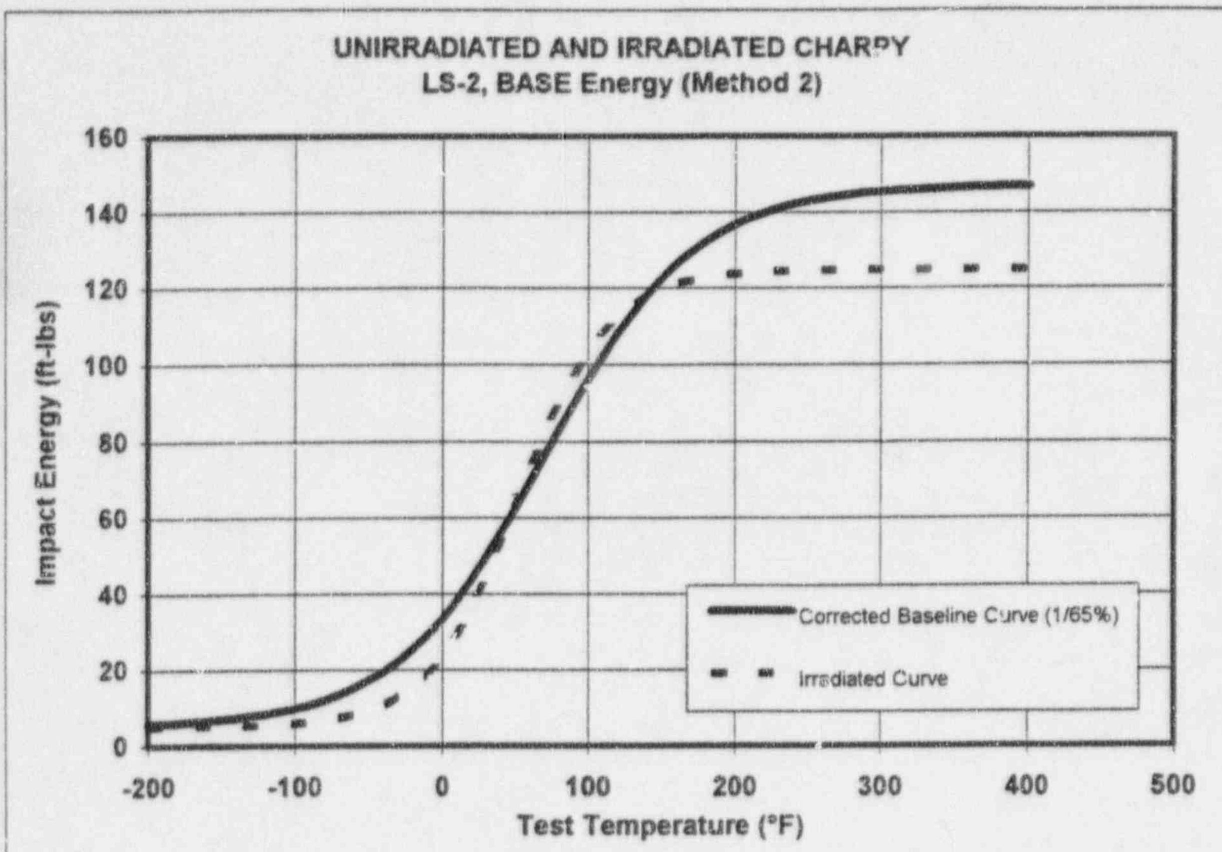

UNIRRADIATED CHARPY
LS-2, BASE Energy
(Trans. Curve Shifted to Long. Using Method 2)
Impact Energy (ft-lbs)
160
140
120
100
80
60
40
20
0
-200
-100
0
100
200
300
400
500
Test Temperature (°F)
Transverse Curve
Corrected Baseline Curve (1/65%)
Transformed Transverse Data

Figure 3-4


UNIRRADIATED AND IRRADIATED CHARPY
LS-2, BASE Energy (Method 2)
Impact Energy (ft-lbs)
160
140
120
100
80
60
40
20
0
-200
-100
0
100
200
300
400
500
Test Temperature (°F)
Corrected Baseline Curve (1/65%)
Irradiated Curve

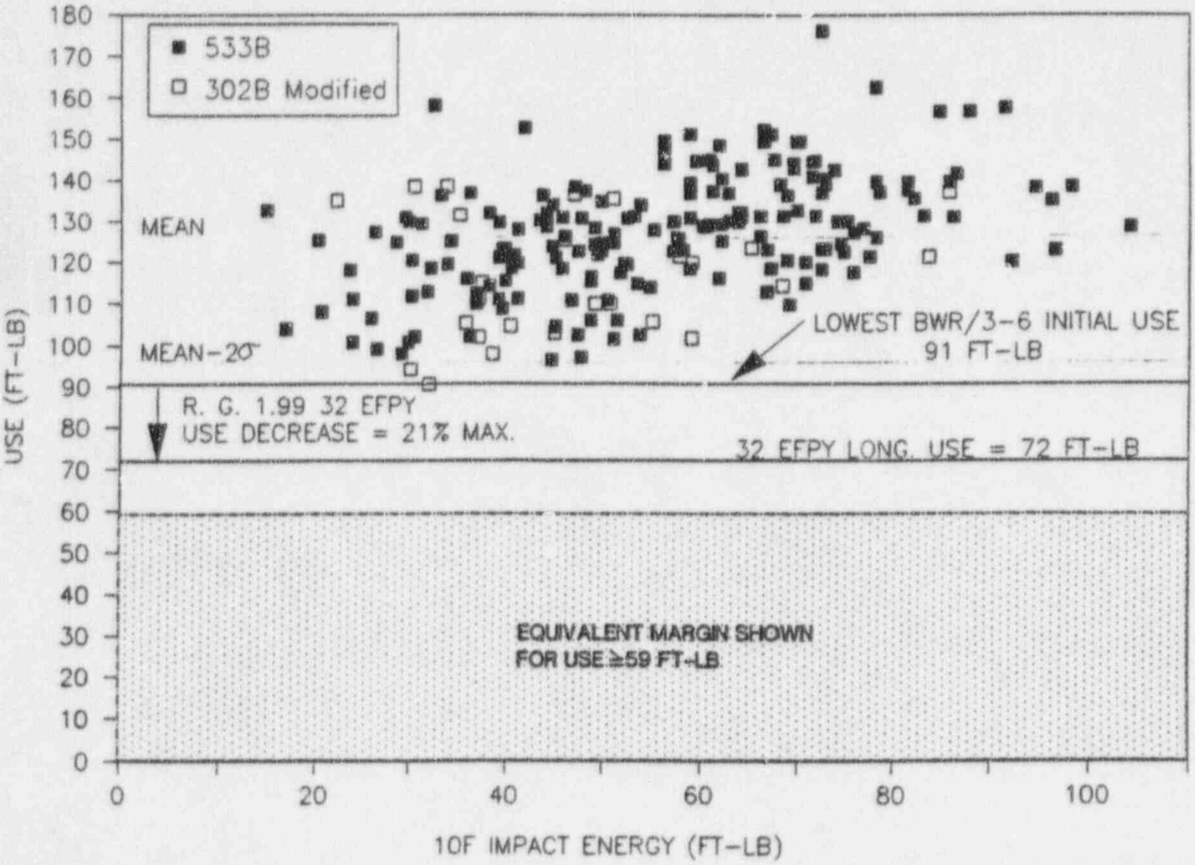


Figure 3-5: BWR/3-6 Plates (Longitudinal) Meet Equivalent Margin Requirements [10]

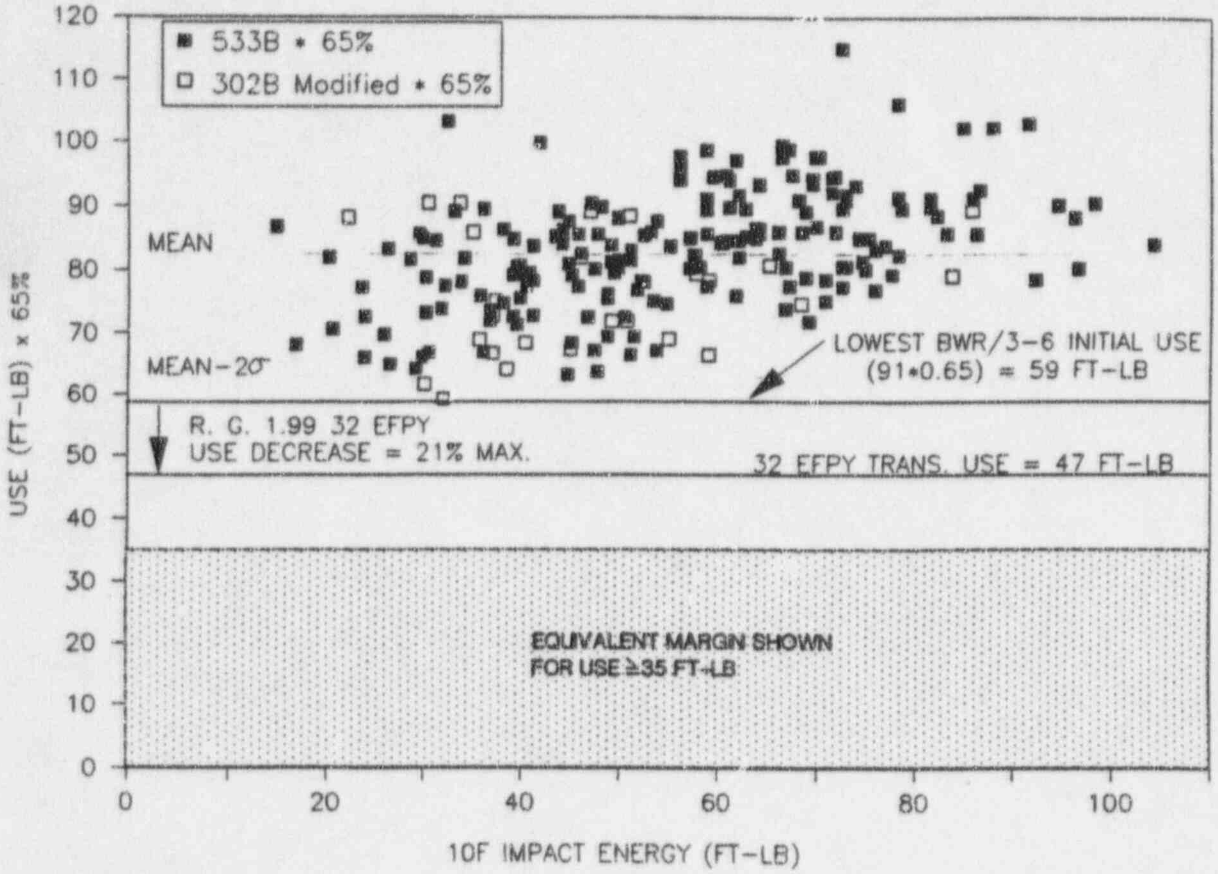


Figure 3-6: BWR/3-6 Plates (Transverse) Meet Equivalent Margin Requirements [10]

Figure 3-7:

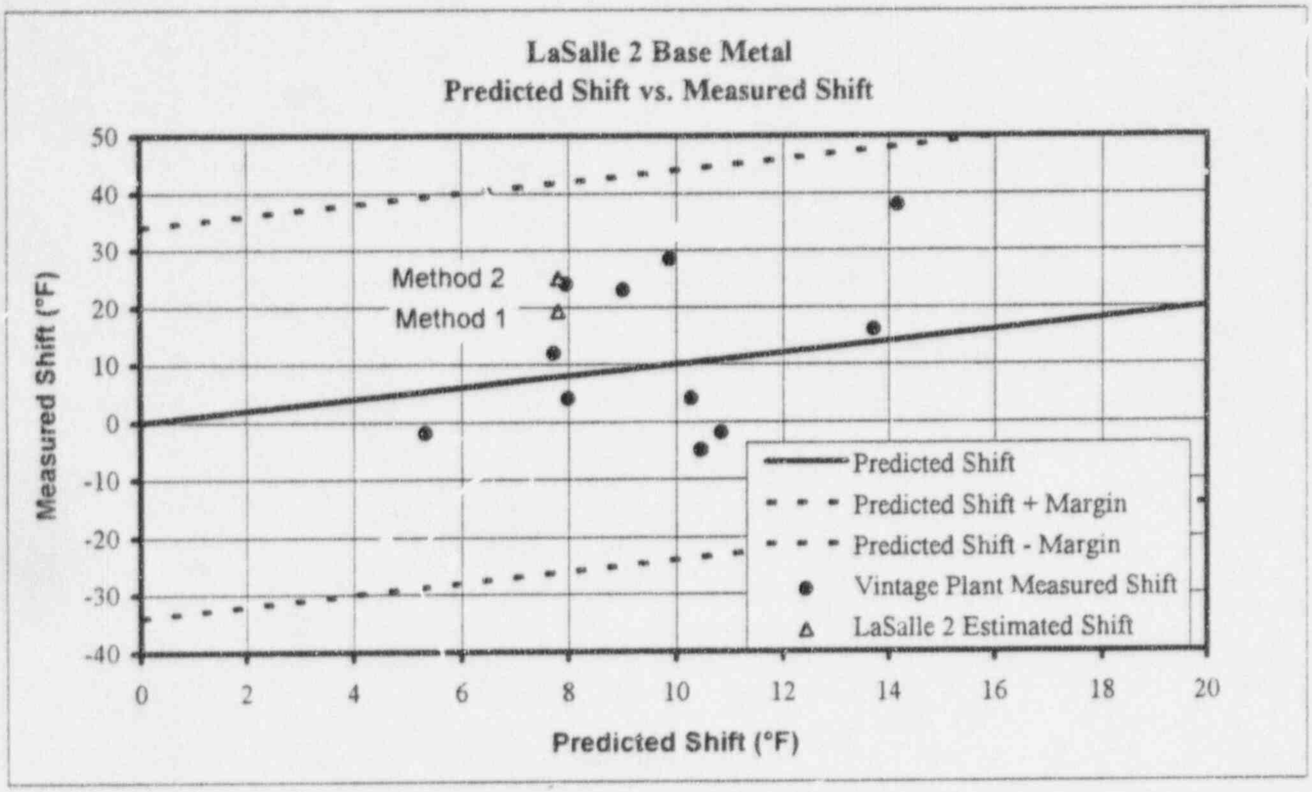
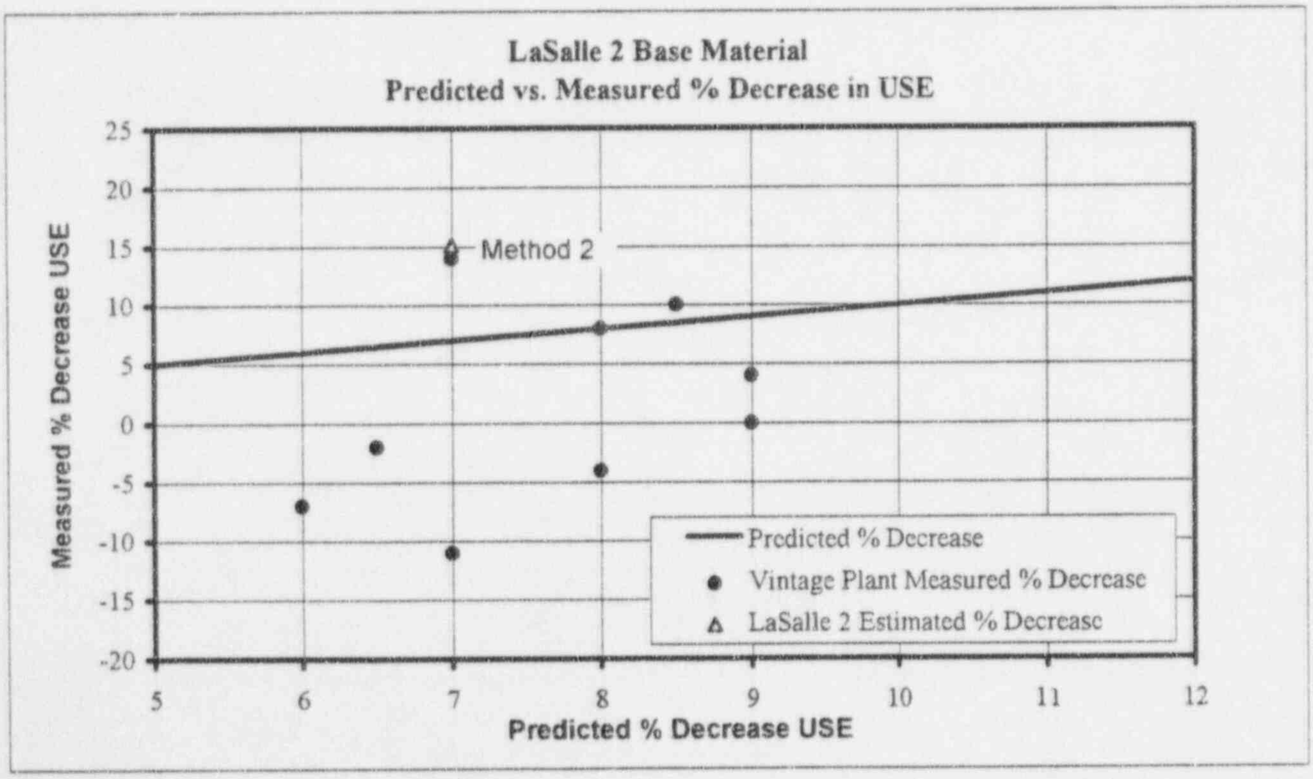


Figure 3-8:



4. REFERENCES

[1] "Fracture Toughness Requirements," Appendix G to Part 50 of Title 10 of the Code of Federal Regulations, July 1983.

[2] Letter from G.W. Contreras, GE San Jose, to R. Willems, GE Oak Brook, "LaSalle RPV Archive Material Records Search," 3/16/94 (GENE-523-37-0394).

[3] "Nuclear Plant Irradiated Steel Handbook," EPRI Report NP-4797, September 1986.

[4] "Fracture Toughness Requirements," USNRC Branch Technical Position MTEB 5-2, Revision 1, July 1981.

[5] "Methods For Establishing Initial Reference Temperatures (RT_{ndt}) For Vessel Steels For Certain Plants," GE Design Procedure, (GE-NEBO-Y1006A006).

[6] "Radiation Embrittlement of Reactor Vessel Materials," USNRC Regulatory Guide 1.99, Revision 2, May 1988.

[7] E. W. Sleight, "LaSalle Unit 2 RPV Surveillance Materials Testing and Analysis," GENE, San Jose, CA, January 1996 (GE-NE-B01301786-01).

[8] H. S. Mehta, T. A. Caine, and S. E. Plaxton, "10CFR50 Appendix G Equivalent Margin Analysis for Low Upper Shelf Energy in BWR/2 through BWR/6 Vessels," GENE, San Jose, CA, February 1994, (NEDO-32205-A, Rev. 1).

[9] GE Nuclear Energy, NEDC-32399-P, "Basis for GE RT_{ndt} Estimation Method," Report for BWR Owners' Group, San Jose, CA, September 1994 (proprietary).

[10] H. S. Mehta, T. A. Caine, and S. E. Plaxton, " 10CFR50 Appendix G Equivalent Margin Analysis for Low Upper Shelf Energy in BWR/2 through BWR/6 Vessels," GENE, San Jose, CA, February 1994, (NEDO-32205-A, Rev. 1).

APPENDIX A

LaSalle Unit 2 Surveillance Data Tables:

Table A-1: Irradiated Longitudinal Charpy V-Notch Impact Test Results

Table A-2: Unirradiated Longitudinal Charpy Data From Fabrication Test Records

Table A-3: Unirradiated Transverse Charpy V-Notch Impact Test Results

Table A-1:
IRRADIATED LONGITUDINAL CHARPY V-NOTCH IMPACT TEST RESULTS

	Specimen Identification[a]	Test Temperature (°F)	Fracture Energy (ft-lb)	Lateral Expansion (mils)	Percent Shear (Method 1) (%)
Base:	28823	-60	7	5	0
Heat C9481-1,	28824	-20	7.5	6	17.6
Longitudinal,	28825	0	23	21	49.4
	28826	20	58	41.5	53.8
	28827	30	32	30	44.3
	28828	40	47.5	31.5	43.7
	28829	50	44	36.5	40.2
	28830	65	99.5	74	67.7
	28831	80	101.5	59	70.3
	28832	120	88.5	66	82.4
	28833	200	126	84.5	100
	28834	300	123.5	87.5	100

Table A-2:
UNIRRADIATED LONGITUDINAL CHARPY DATA FROM FABRICATION TEST RECORDS

	Specimen Identification[a]	Test Temperature (°F)	Fracture Energy (ft-lb)	Lateral Expansion (mils)	Percent Shear (Method 1) (%)
Plate[b]:	1	40	74	61	50
Heat C9481-1,	2	40	74	53	50
Unirradiated	3	40	81	60	50
	4	40	103	48	40
	5	40	61	66	50
	6	40	85	72	60

[a] I.D.'s are listed for numbering only (I.D.'s were not preassigned)
[b] Fabrication Charpy specimen data from Materials Certification Reports in [2]

Table A-3:
UNIRRADIATED TRANSVERSE CHARPY V-NOTCH IMPACT TEST RESULTS

	Specimen Identification[a]	Test Temperature (°F)	Fracture Energy (ft-lb)	Lateral Expansion (mils)	Percent Shear (Method 1) (%)
Base:	12	-40	17.0	15.0	5
Heat C9481-1,	10	10	23.5	21.0	10
Transverse,	11	10	22.0	20.5	10
	14	25	36.0	31.0	20-25
	8	40	45.0	42.0	30-35
	9	40	35.0	34.2	30
	13	40	42.0	38.0	30-35
	15	51	40.5	35.0	30
	1	70	51.0	44.5	40
	2	70	50.0	42.5	40
	7	93	71.0	58.5	70
	3	120	93.0	69.5	90-95
	4	200	93.5	74.0	95
	5	200	100.0	72.0	95
	6	200	93.0	69.0	95

APPENDIX B

Equivalent Margin Analysis:

Method 2

EQUIVALENT MARGIN ANALYSIS
PLANT APPLICABILITY VERIFICATION FORM
FOR LASALLE UNIT 2 - BWR 5/MK II at 100% Current Power Condtion

BWR/3-6 PLATE

Surveillance Plate USE:

%Cu = 0.10 (Ave. value from Table 3-3 of [7])

Capsule Fluence = 1.15×10^{17} n/cm^2 (6.98 EFPY on p.20 of [7])

Estimated % Decrease = 15 (from 65% USE Method 2)

R.G. 1.99 Predicted % Decrease = 7.0 (R.G. 1.99, Figure 2)

Limiting Beltline Plate USE:

%Cu = 0.12 (highest Cu of beltline plates, Table 7-1 of [7])

32 EFPY (1/4 T) Fluence = 3.7×10^{17} n/cm^2 (Calc. on p. 18 of [7])

R.G. 1.99 Predicted % Decrease = 9.8 (R.G. 1.99, Figure 2)

Adjusted % Decrease = 17 (R.G. 1.99, Position 2.2)

17% ≤ 21%, so vessel plates are bounded by equivalent margin analysis

APPENDIX C

Vintage Plant Data:

LaSalle 1

Browns Ferry 2

Peach Bottom 2, 3

Susquehanna 1, 2

Dresden 2, 3

Quad Cities 1, 2

TABLE C-1. BWR BASE MATERIAL SURVEILLANCE DATA

PLANT NAME	RPV ID (in)	Capsule I.D. (deg)	Cu	Ni	CF	>1 MeV FLUENCE (x10^17) (n/cm^2)	@EFPY	1.99,REV2 DELTA RTNDT	REV2 DELTA+ MARGIN	30 FT-LB TEST SHIFT	1.99,REV2 USE DECREASE	TEST USE DECREASE
BWR/3												
DRESDEN 2	251	215	0.20	0.45	131.0	0.52	6.23	9.0	43.0	23	9	4
DRESDEN 3	251	215	0.12	0.54	89.5	0.71	5.98	7.7	41.7	12	7	-11
QUAD 1	251	215	0.20	0.55	143.0	0.55	6.64	10.3	44.3	4	9	0
QUAD 2	251	215	0.10	0.54	65.0	0.66	5.63	5.3	39.3	-2	6	-7
BWR/4												
BROWNS FERRY 2	251	30	0.14	0.55	98.0	1.52	8.20	14.2	48.2	38	9	4
HOPE CREEK	251	30	0.09	0.64	58.0	1.42	6.01	8.0	42.0	4	7	14
PEACH BOT 2	251	120	0.10	0.54	65.0	1.80	7.53	10.5	44.5	-5	7.5	N/A
PEACH BOT 3	251	30	0.13	0.63	91.8	1.60	7.58	13.7	47.7	16	8.5	10
SUSQU'NNA 1	251	30	0.09	0.61	58.0	1.40	6.68	8.0	42.0	24	6.5	-2
SUSQU'NNA 2	251	30	0.12	0.63	83.0	1.30	6.20	10.8	44.8	-2	8	-4
BWR/5												
LASALLE 1	251	300	0.14	0.54	97.0	0.90	6.50	9.9	43.9	28	8	8

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