Enclosure 1

Calculation No. VSC-04.3205, Revision 0,
Palisades MSB #4 Crack Growth Analysis Inputs
(1 paper copy)

ENERGYSOLUTIONS Spent Fuel Division	CALCULATION PACKAGE	Calc. Pkg No. VSC-04.3205 File No.: VSC-04.3205 Revision: 0

PROJECT/CUSTOMER:

VSC-04/VSC-24 General Licensees

TITLE:

Palisades MSB #4 Crack Growth Analysis Inputs

SCOPE:

Product:	☐ FuelSolutions™	☒ VSC-24		☐ Other ______
Service:	☒ Storage	☐ Transportation		☐ Other ______
Conditions:	☒ Normal	☒ Off-Normal	☒ Accident	☐ Other ______

Component(s):

Palisades MSB #4 Shell

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[signature] 06/13/2012

Verified by:

James E. Hopf 6/13/12

Approved by Engineering Manager:

[signature] 06/13/2012

RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (Print or Type)	
				PREPARER	CHECKER
0	All	None	Initial Issue	S. Sisley	J. Hopf

RECORD OF VERIFICATION

	YES	NO	N/A
(a) The objective is clear and consistent with the analysis.	☑	☐	
(b) The inputs are correctly selected and incorporated into the design.	☑	☐	☐
(c) References are complete, accurate, and retrievable.	☑	☐	☐
(d) Basis for engineering judgments is adequately documented.	☑	☐	☐
(e) The assumptions necessary to perform the design activity are adequately described and reasonable.	☑	☐	☐
(f) Assumptions and references, which are preliminary, are noted as being preliminary.	☐	☐	☑
(g) Methods and units are clearly identified.	☑	☐	☐
(h) Any limits of applicability are identified.	☑	☐	☐
(i) Computer calculations are properly identified.	☐	☐	☑
(j) Computer codes used are under configuration control.	☐	☐	☑
(k) Computer codes used are applicable to the calculation.	☐	☐	☑
(l) Input parameters and boundary conditions are appropriate and correct.	☑	☐	
(m) An appropriate design method is used.	☑	☐	
(n) The output is reasonable compared to the inputs.	☑	☐	
(o) Conclusions are clear and consistent with analysis results.	☑	☐	

COMMENTS:

All comments resolved

Verifier:

James E. Hopf 6/13/12

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1. INTRODUCTION

A weld flaw crack growth analysis was previously performed by Sargent and Lundy (Reference 3.2.1) for specific flaws identified in the longitudinal seam weld of Palisades MSB #4. The analysis determined the amount of fatigue crack growth in the weld flaws over a 50-year service period (i.e., the original design life of the VSC-24 storage system.) For the VSC-24 CoC renewal, the service period is to be extended to 60-years. This calculation determines the stress inputs to be used for the weld flaw crack growth analysis of Palisades MSB #4 for the extended service period of 60-years. The Palisades MSB #4 weld flaw crack growth analysis is presented in a separate document.

1.1 Objective

The objective of this calculation package is to determine the maximum membrane and bending stress intensities in the MSB shell for the range of normal, off-normal, and accident conditions that are considered in the crack growth analysis. The MSB shell stresses are based on the current licensing basis calculations for the VSC-24 storage system. In addition, the MSB shell stresses account for a 0.18-inch maximum corrosion allowance on the MSB shell for the 60-year, as determined in Reference 3.1.1.

1.2 Purpose

The purpose of this calculation package is to provide the stress inputs required to perform the weld flaw crack growth analysis of Palisades MSB #4.

1.3 Scope

This calculation package is specific to the shell of Palisades MSB #4.

2. <u>REQUIREMENTS</u>

2.1 Design Inputs

None.

2.2 Regulatory Commitments

None.

3. REFERENCES

3.1 BFS Calculation Packages

3.1.1. VSC-04.3200, Revision 1, "MSB-24 Corrosion Analysis."

3.1.2. VSC02.6.2.3.04, Revision 4, "MSB-24 Pressure Stress Analysis."

3.1.3. VSC02.6.2.3.05, Revision 2, "Normal, Off-Normal, and Maximum Accident Pressure in the MSB."

3.1.4. VSC02.6.2.3.07, Revision 2, "MSB Thermal Stress Analysis."

3.1.5. VSC02.6.2.3.02, Revision 4, "MSB-24 Load Combination Evaluation."

3.2 General References

3.2.1. Sargent & Lundy Calculation No. 2007-20168, Revision 00, "Palisades Weld Flaw Analysis for Loaded Spent Fuel Cask MSB No. 4."

3.2.2. DBD-7.09, Revision 0, "Palisades Nuclear Plant Design Basis Document."

4. ASSUMPTIONS

4.1 Design Configuration

The MSB shell has a 62.5-inch nominal outside diameter and a 1.0-inch nominal thickness. Per Reference 3.1.1, the amount of corrosion predicted on the MSB shell over a 60-year service period in a marine environment, conservatively neglecting the coating on the MSB shell, is 0.18 inches. Therefore, the corroded MSB shell after 60-years has an outside diameter of 62.14 inches and a thickness of 0.82 inches.

4.2 Design Criteria

Not Applicable.

4.3 Calculation Assumptions

The following assumptions are used in this calculation package:

1. The MSB shell stresses are conservatively based on the initial design basis heat load of 24 kW. The actual initial heat load for Palisades MSB #4 was only 9.38 kW (Reference 3.2.2). Therefore, the stresses in the MSB #4 shell are considerably lower than those calculated for the 24 kW design basis heat load. In addition, no credit is taken for decay of the heat load during the storage period.

2. For cyclic loading that occurs during the service life of the MSB (i.e., after loading operations) the higher stresses for the corroded shell condition are conservatively assumed throughout the entire service life. In reality, the reduction in heat load over the service life offsets the increase in the MSB shell stresses due to thickness reduction from corrosion. However, this effect is conservatively neglected.

5. CALCULATION METHODOLOGY

The stresses in the MSB #4 shell are taken from the current licensing basis calculations for the VSC-24 storage system. Available stresses are scaled to determine the stresses for intermediate conditions. In addition, stresses are scaled by the appropriate factors to account for the corrosion allowance of the MSB shell.

6. CALCULATIONS

6.1 Flaw Growth Analysis Inputs

The membrane and bending stresses in the MSB shell due to cyclic loading conditions that must be considered in the flaw crack growth analysis are discussed in the following sections and summarized in Table 1.

6.1.1 Internal Pressure Stresses

6.1.1.1 Pressure Test

The MSB shell is subjected to a 7.3 psig (i.e., 0.5 atm.) hydrostatic internal pressure test load. The stresses in the MSB shell due to the 7.3 psig test pressure load are determined by scaling the maximum stresses calculated for a 10 psig internal pressure load by the ratio of the pressure loads (i.e., 7.3/10.0). Per Table 4-1 of Reference 3.1.2, the maximum membrane and membrane plus bending stress intensities in the MSB shell for a 10 psig normal operating pressure are 1.17 ksi and 4.35 ksi, respectively. Therefore, the maximum membrane and bending stress intensities in the MSB shell for the 7.3 psig test pressure load are:

$$\sigma_m = 1.17 \times (7.3/10.0) = 0.85 \text{ ksi}$$

$$\sigma_b = 4.35 \times (7.3/10) - 0.85 = 2.33 \text{ ksi}$$

Pressure test loads are applied to the MSB shell prior to being placed into service. Therefore, these stresses need not be adjusted for the effects of MSB shell corrosion. For the flaw crack growth analysis, two (2) cycles of pressure test loading are assumed.

6.1.1.2 Vacuum Drying

During the MSB loading operation, the MSB shell is subjected to a vacuum drying internal pressure of 3 mm Hg (-14.6 psig). The stresses in the MSB shell due to the vacuum drying pressure load are determined by scaling the maximum stresses calculated for a 10 psig internal pressure load by the ratio of the pressure loads (i.e., -14.6/10.0). Per Table 4-1 of Reference 3.1.2, the maximum membrane and membrane plus bending stress intensities in the MSB shell for a 10 psig normal operating pressure are 1.17 ksi and 4.35 ksi, respectively. Therefore, the maximum membrane and bending stress intensities in the MSB shell for the vacuum drying pressure load are:

$$\sigma_m = 1.17 \times (-14.6/10.0) = -1.71 \text{ ksi}$$

$$\sigma_b = 4.35 \times (-14.6/10) - (-1.71) = -4.64 \text{ ksi}$$

The vacuum drying pressure load is applied to the MSB shell prior to being placed into service. Therefore, these stresses need not be adjusted for the effects of MSB shell corrosion. For the flaw crack growth analysis, one (1) cycles of vacuum drying pressure loading is assumed.

6.1.1.3 Off-Normal Extreme Pressure Fluctuations

The MSB internal pressure fluctuates with changes in the ambient air temperatures. Extreme fluctuations in ambient air temperature from -40°F to 125°F are conservatively postulated to occur 10 times per year. The maximum MSB internal pressure resulting from the 125°F off-normal hot thermal condition is 10.0 psig (Ref. 3.1.3, Table 7-1), or 24.7 psia. This internal pressure load is based on the assumption of a maximum decay heat load of 24 kW and that 10% of the fuel rods have failed. The average temperature of the MSB cavity gas for this condition is 436°F (Ref. 3.1.3, Section 6.4.1), or 896R. Per Table 4-1 of Reference 3.1.2, the maximum membrane and membrane plus bending stress intensities in the MSB shell for a 10 psig normal operating pressure are 1.17 ksi and 4.35 ksi, respectively. These stresses are based on the nominal MSB shell thickness of 1.0-inches. For the minimum shell thickness of 0.82-inches, the membrane and bending stresses are determined as follows:

$$\sigma_m = 1.17 \text{ ksi} \times (1.0''/0.82'') = 1.43 \text{ ksi}$$

$$\sigma_b = (4.35 \text{ ksi} - 1.17 \text{ ksi}) \times (1.0''/0.82'')^2 = 4.73 \text{ ksi}$$

The minimum MSB internal pressure resulting from the -40°F off-normal cold thermal condition is -7.53 psig (Ref. 3.1.3, Table 7-1). This pressure load is based on the assumptions of zero (0) decay heat load and that 0% of the fuel rods have failed. Therefore, while this is theoretically the lowest internal pressure that can occur in the MSB, it cannot exist in combination with the maximum pressure conditions for the extreme hot condition. Therefore, for the purpose of this calculation, the corresponding minimum internal pressure for the -40°F off-normal cold thermal condition is determined based on the ideal gas law. It is assumed that the change in the average temperature of the MSB cavity gas is equal to the change in the ambient air temperature. This is conservative because the fluctuation in MSB cavity gas temperature will be less than the fluctuation in external ambient temperature, due to the fact that the MSB interior effective thermal conductivity increases with increasing temperature, due to the strong non-linear dependence of radiation heat transfer on temperature. Thus, the average temperature of the MSB cavity gas for this condition is 271°F (i.e., 436°F – 165°F), or 731R. Therefore, the MSB internal pressure load at an ambient air temperature of -40°F is:

$$P_{-40F} = (24.7 \text{ psia})(731R)/(896R) = 20.15 \text{ psia } (5.45 \text{ psig})$$

The stresses in the MSB shell due to the 5.45 psig off-normal cold pressure load are determined by scaling the maximum stresses calculated for a 10 psig internal pressure load by the ratio of the pressure loads (i.e., 5.45/10.0), as follows:

$$\sigma_m = 1.43 \times (5.45/10.0) = 0.78 \text{ ksi}$$

$$\sigma_b = 4.73 \times (5.45/10.0) = 2.58 \text{ ksi}$$

For the flaw crack growth analysis, 10 cycles of extreme pressure fluctuation loading are assumed each year for the full 60-year period, or 600 cycles total.

6.1.1.4 Daily Pressure Fluctuations

The maximum internal pressure load for the MSB shell for the 75°F normal thermal condition is 5.23 psig (Ref. 3.1.3, Section 6.3.1), or 19.93 psia. This pressure is based on the assumptions of a maximum decay heat of 24 kW and 1% fuel rod failures. The average temperature of the MSB cavity gas for this condition is 439°F (Ref. 3.1.3, Section 6.3.1), or 899R. Per Section 2.3.4 of Reference 3.2.1, the average daily temperature range of 57°F to 93°F (i.e., 75°F ± 18°F) is used for the fatigue crack growth analysis. The range of MSB internal pressures resulting from the fluctuation of the ambient air temperature is determined based on the ideal gas law. As discussed in Section 6.1.1.3, it is conservatively assumed that the change in the average temperature of the MSB cavity gas is equal to the change in the ambient air temperature. Thus, the temperature of the gas inside the MSB cavity is conservatively assumed to cycle up and down daily by 18°F (i.e., 18R) from the 439°F average temperature. Therefore, the MSB internal pressure loads at ambient air temperatures of 57°F to 93°F are:

$$P_{57F} = (19.93 \text{ psia})(881R)/(899R) = 19.53 \text{ psia } (4.83 \text{ psig})$$

$$P_{93F} = (19.93 \text{ psia})(917R)/(899R) = 20.33 \text{ psia } (5.63 \text{ psig})$$

The stresses in the MSB shell due to the range of daily pressure fluctuation are determined by scaling the maximum stresses calculated for a 10 psig internal pressure load by the ratio of the pressure loads, as follows:

$$\sigma_{m,57F} = 1.43 \times (4.83/10.0) = 0.69 \text{ ksi}$$

$$\sigma_{b,57F} = 4.73 \times (4.83/10.0) = 2.28 \text{ ksi}$$

$$\sigma_{m,93F} = 1.43 \times (5.63/10.0) = 0.81 \text{ ksi}$$

$$\sigma_{b,93F} = 4.73 \times (5.63/10.0) = 2.66 \text{ ksi}$$

For the flaw crack growth analysis, 365 cycles of daily pressure fluctuation loading are assumed each year for the full 60-year period, or 21,900 cycles total.

6.1.2 Thermal Stresses

6.1.2.1 Off-Normal Extreme Ambient Temperature Fluctuations

The MSB thermal gradients and thermal stresses fluctuate with changes in the ambient air temperatures. Extreme fluctuations in ambient air temperature from -40°F to 100°F are conservatively postulated to occur 10 times per year. As discussed in Reference 3.1.4, the maximum temperature gradients and thermal stress in the MSB shell are due to the -40°F extreme cold condition. The maximum thermal stress in the MSB shell for this condition is 1.374 ksi. As discussed in Section 2.4 of Reference 3.2.1, the thermal stress in the MSB shell is bending stress caused by temperature gradients. This thermal stress is based on the nominal shell thickness of 1.0 inches. As discussed in Section 6.2 of Reference 3.1.4, the MSB shell thermal stress calculated for a minimum shell thickness of 0.75 inches (i.e., 1.031 ksi) is directly proportional to the ratio of the shell thickness since thermal stress is controlled by displacement. Therefore, the thermal stress in the corroded MSB shell with a thickness of 0.82 inches is:

$$Q = 1.031 \text{ ksi} \times (0.82"/0.75") = 1.13 \text{ ksi}$$

As discussed in Section 2.4.1 of Reference 3.2.1, the thermal stress in the MSB shell is proportional to the radial thermal gradient in the MSB, which is shown to vary linearly with the ambient air temperature. The MSB shell thermal stress for the 100°F ambient condition is determined by multiplying the thermal stress from the -40°F ambient condition by the ratio of the radial thermal gradients (i.e., by 400°F/423°F.) Thus, the MSB shell thermal stress for the 100°F ambient condition is 1.07 ksi.

For the flaw crack growth analysis, 10 cycles of extreme thermal fluctuation loading are assumed each year for the full 60-year period, or 600 cycles total.

6.1.2.2 Daily Ambient Temperature Fluctuations

As discussed in Section 2.4.2 of Reference 3.2.1, the daily fluctuations in ambient air temperature from 57°F to 93°F will not significantly change the MSB temperature gradient and the associated MSB shell thermal stress. The range of thermal stress due to the daily ambient temperature fluctuation will be roughly ¼ (i.e., 36°F/140°F) of the change due to the off-normal extreme ambient temperature fluctuations, or less than 0.02 ksi.

6.1.3 Seismic and Handling Loads

As discussed in Section 2.5 of Reference 3.2.1, although handling loads associated with moving the MSB and seismic loads are not required to be included in the fatigue analysis, they are conservatively considered in the flaw propagation analysis. The seismic load was determined to be enveloped by the handling loads. Therefore, the MSB shell stresses due to the handling load, which bound those due to seismic loading, are used. Per Table 3-1 of Reference 3.1.5, the maximum membrane and membrane plus bending stress intensities in the MSB shell for handling, which result from the vertical normal handling condition (which conservatively includes dead weight), are 1.02 ksi and 3.74 ksi, respectively. The bending stress in the MSB shell for handling is taken as the difference between these values, or 2.72 ksi. These stresses are based on the nominal MSB shell thickness of 1.0-inches. For the minimum shell thickness of 0.82-inches, the membrane and bending stresses are determined as follows:

$$\sigma_m = 1.02 \text{ ksi} \times (1.0"/0.82") = 1.24 \text{ ksi}$$

$$\sigma_b = 2.72 \text{ ksi} \times (1.0"/0.82")^2 = 4.05 \text{ ksi}$$

As discussed in Section 2.5 of Reference 3.2.1, the enveloping seismic and handling loadings were conservatively assumed to occur once every 10 years (i.e., 5 times during a 50-year design life) with 10 stress cycles associated with each occurrence. Therefore, for the extended 60-year service life, a total of 60 stress cycles (i.e., 1 occurrence every 10 years x 10 stress cycles per occurrence x 60 year service life) of enveloping seismic and handling loadings is assumed.

6.1.4 Residual Stress in Weld

As explained in Section 2.6 of Reference 3.2.1, the residual stress in the MSB shell material is assumed to be equal to the yield strength of the shell material, or 54 ksi. This stress is added to the bending stresses for the MSB weld.

Table 1 - Summary of MSB Shell Loading Stress Ranges

Loading Condition	Total Cycles[1]	Stress Type	Stress Range (ksi)		Reference Section
			Minimum Stress	Maximum Stress	
Pressure Test	2	Membrane	0.00	0.85	6.1.1.1
		Bending	0.00	2.33	
Vacuum Drying	1	Membrane	-1.71	0.85	6.1.1.2
		Bending	-4.64	2.33	
Off-Normal Ambient Temperature Fluctuation[2]	600	Membrane	0.78	1.43	6.1.1.3 and 6.1.2.1
		Bending	3.71[3]	5.80[4]	
Daily Ambient Temperature Fluctuation[2]	21,900	Membrane	0.69	0.81	6.1.1.4 and 6.1.2.2
		Bending	2.28	2.66	
Seismic and Handling	60	Membrane	-1.24	1.24	6.1.3
		Bending	-4.05	4.05	
Residual Weld Stress	N/A	Bending	54.0	54.0	6.1.4

Notes:

(1) Total for 60-year service period.

(2) Combined effects of pressure and thermal stress.

(3) Minimum stress results from the -40°F ambient condition. The bending stress for this case is the combination of 2.58 ksi for internal pressure and 1.13 ksi for thermal stress.

(4) Maximum stress results from the 125°F ambient condition. The bending stress for this case is the combination of 4.73 ksi for internal pressure and 1.07 ksi for thermal stress.

6.2 Flaw Stability Analysis Inputs

The maximum stresses in the MSB shell for the controlling normal, off-normal, and accident load combinations that are used in the MSB shell flaw stability analysis are discussed in this section.

Normal Conditions:

For normal conditions, the controlling load combination is dead load plus normal internal pressure plus normal handling plus thermal. The combined stress intensities in the MSB shell for this load combination from Table 3-1 of Reference 3.1.5 are summarized as follows:

P_m = 1.71 ksi
P_L+P_b = 5.35 ksi
P_L+P_b+Q = 6.72 ksi

Since these stresses were calculated for the nominal MSB shell thickness of 1.0 inches, they are scaled to determine the stresses for a corroded shell with a thickness of 0.82 inches as follows:

$P_m = 1.71 \times (1.0/0.82) = 2.09$ ksi
$P_L+P_b = 2.09 + (5.35 - 1.71) \times (1.0/0.82)^2 = 7.50$ ksi
$P_L+P_b+Q = 2.09 + (6.72 - 1.71) \times (1.0/0.82)^2 = 9.54$ ksi

Off-Normal Conditions:

For off-normal conditions, the controlling load combination is dead load plus off-normal internal pressure plus normal handling plus thermal. The combined stress intensities in the MSB shell for this load combination from Table 3-2 of Reference 3.1.5 are summarized as follows:

P_m = 2.86 ksi
P_L+P_b = 8.96 ksi
P_L+P_b+Q = 10.33 ksi

Since these stresses were calculated for the nominal MSB shell thickness of 1.0 inches, they are scaled to determine the stresses for a corroded shell with a thickness of 0.82 inches as follows:

$P_m = 2.86 \times (1.0/0.82) = 3.49$ ksi
$P_L+P_b = 3.49 + (8.96 - 2.86) \times (1.0/0.82)^2 = 12.56$ ksi
$P_L+P_b+Q = 3.49 + (10.33 - 2.86) \times (1.0/0.82)^2 = 14.60$ ksi

Accident Conditions:

For accident conditions, the controlling load combination is normal internal pressure plus vertical drop. The combined stress intensities in the MSB shell (including a corrosion allowance of 0.18 inches) for this load combination from Section 6.1 of Reference 3.1.1 are summarized as follows:

P_m = 47.0 ksi
P_L+P_b = 47.3 ksi

7. <u>CONCLUSIONS</u>

7.1 Results

The MSB shell stresses to be used in the flaw growth analysis are summarized in Table 1. The MSB shell stresses to be used in the flaw stability analysis are summarized in Section 6.2.

7.2 Compliance With Requirements

Not applicable.

7.3 Range of Validity

The results of this calculation are applicable to Palisades MSB #4 for an extended storage period of 60 years.

7.4 Summary of Conservatism

Conservative assumptions used in this calculation are summarized in Section 4.3.

7.5 Limitations or Special Instructions

None.