Entergy Nuclear Operations, Inc.
Palisades Nuclear Plant
27780 Blue Star Memorial Highway
Covert, MI 49043
Tel 269 764 2000

Paula Anderson
Licensing Manager

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U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

SUBJECT: Response to Request for Additional Information Regarding Multi-Assembly Sealed Basket (MSB) No. 4 Weld Flaw Analysis

Palisades Nuclear Plant
Docket 50-255
License No. DPR-20

Reference: 1. NRC letter dated February 18, 2009, "Follow-Up Information Regarding Multi-Assembly Sealed Basket (MSB) #4 Weld Flaw Analysis"

Dear Sir or Madam:

The Nuclear Regulatory Commission requested additional information in Reference 1 as part of their ongoing evaluation of a weld flaw analysis of a loaded spent fuel cask, MSB No. 4. Attachment 1 to this letter provides the requested information.

Summary of Commitments

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

Sincerely,

pka/jlk

Attachment: 1. Response to Request for Additional Information Regarding Palisades Weld Flaw Analysis for Loaded Spent Fuel Cask, MSB No. 4

cc: Administrator, Region III, USNRC
Project Manager, Palisades, USNRC
Resident Inspector, Palisades, USNRC

ATTACHMENT 1

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION REGARDING PALISADES WELD FLAW ANALYSIS FOR LOADED SPENT FUEL CASK, MSB NO. 4

In letter dated February 18, 2009, (Reference 1 in cover letter) the Nuclear Regulatory Commission (NRC) issued a request for additional information (RAI) as part of their ongoing evaluation of a weld flaw analysis of a loaded spent fuel cask, MSB No. **4.** For completeness, the NRC's reference, background and requested information from the RAI letter enclosure are provided below along with the Entergy Nuclear Operations, Inc. (ENO) RAI responses.

Reference

Description and summary results of calculation EA-FC-864-50-01 Issue:

The original calculation EA-FC-864-50, "MSB #4 Structural Integrity Assessment," Appendix 2, evaluated flaws in this longitudinal weld in Spent Fuel Cask Multi-Assembly Sealed Basket (MSB) No. 4. This calculation was preformed conservatively, assuming a uniform welding residual of 54 ksi (base material yield stress) and the parameter R=0.9 for the crack in the MSB longitudinal shim weld.

The parameter R for stress in the MSB longitudinal crack in the range of 0.9 <R <1.0. Reassessment using a value of R=1.0 would yield a higher fatigue crack growth rate.

Calculation EA-FC-864-50-01, "Palisades Weld Flaw Analysis for Loaded VSC Spent Fuel Cask MSB No. 4," performed this reassessment to determine the flaw size at the end of 50-year life using the R value of 1.0 which is conservative.

Background

The Division of Spent Fuel and Storage and Transportation (SFST) staff reviewed the fatigue crack growth calculation for an initial semi-circular surface crack present in the MSB No. 4, considering 50 years of cyclic service conditions. The calculations assumed all loading cycles had an R value of 0.9 < R < 1.0. However, the data for the specific American Society of Testing and Materials (ASTM) material specification was not used in the calculations.

It should be noted that there exists a number of fatigue crack growth models in the open literature, including the model adopted by ASME Article A-4000, Material Properties. See Barnford, W. H. and Jones, D. P., "The Use of Fatigue Crack Growth Technology in Fracture Control Plans in Nuclear Components," *Fatigue Crack Growth Data Analysis Measurement and Data Analysis, ASTM STP 738, S. J. Hudak, Jr., and R. J. Bucci, Eds., American Society for Testing and Materials, 1981, pp. 281-299. Refer to the heading "Crack Growth Rate Law Considerations," Table 1 and Table 2. Comparisons on the crack growth rate between these models show that the ASME model is less conservative.*

NRC Request

A) The licensee should obtain fatigue crack growth data for a semi-circular surface crack in ASME SA-516, Grade 70 ferritic steel for the R-range (0.9 < R < 1.0), in air, at room temperature to mimic the cask material and environmental conditions. Using such data, a new analysis should be performed to show that the final calculated crack sizes at the end of a 50 year service life remain stable.

Absent such data and re-analysis, the SFST staff are unable to determine if the flaw propagation after 50 years of cyclic loads would remain stable, thus assuring the integrity of the cask.

ENO Response

A) The analysis performed is an ASME Section XI, Appendix A, Code analysis to the 1992 Code, 1994 Addendum. The fatigue information was developed and peer-reviewed by the ASME Code consensus process, which included NRC participation. We agree that there is substantial data available in the open literature, but in general, such data does not reflect the industry ASME Code consensus process. Therefore, there is reluctance to use such data that is not known to have been included in the consensus process or accepted by the NRC.

A semi-circular surface crack has been assumed, and a peak residual stress of 54 ksi was conservatively added to the stress field in the fatigue crack growth analysis. Use of this maximum residual stress value in the analysis results in a stress ratio (R ratio) of 1.O.

Using the results of the fatigue crack growth analysis (50 year growth) a linear elastic fracture mechanics (LEFM) flaw stability analysis was performed as required by ASME Section XI, Appendix A. Residual stress (54 ksi) was included in this analysis. The results of this analysis illustrate that the crack size remains stable for the 50 year service life. The use of a modeled surface crack is conservative as compared to the observed subsurface crack. This is because a subsurface crack experiences greater constraint than does a surface crack.

The fatigue correlation contained in Appendix A of Section XI is directly applicable to carbon steels such as SA-516 Grade 70. This is confirmed in Rao, K. R. (ed), <u>Companion Guide to the ASME Boiler and Pressure Vessel Code</u>, Volume 2, Chapter 31, section 31.1.5, Authored by W. Bamford. © 2002, American Society of Mechanical Engineers.

NRC Request

B) Refer to "Indication Evaluation Report #: EA-F[C]A-864-050, Appendix 2, Revision 0"

1. Material Test Reports: Provide justification for achieving brittle fracture conditions at the listed temperature levels to determine minimum fracture energy levels. As defined, nil-ductility temperature (NDT) is the highest temperature that the standard specimen breaks in a brittle manner.

Appendix 2 of EA-FC-864-050 Material Test Reports: la-Order #: 9094, dated: 04/4/1991 for ASTM A-285 @ 0°F and lb-Project #: 2941 5, dated: 01/17/92 for ASME SA-516, Gr. 70 @-50°F

ENO Response

B) 1. Evaluating flaws such as that reported using the methods of linear elastic fracture mechanics (LEFM) is conservative and appropriate for materials such as the MSB shell. Although the material exhibits significant toughness, review of the Charpy test data demonstrates that this material is in the toughness transition region, but not on the upper shelf of the material toughness curve, and thus the use of LEFM is appropriate. Referring to the reported fracture surface data, it may be seen that the percent shear of the fracture surfaces was in some cases around 30% shear, which illustrates that significant brittle fracture modes are present. As noted in calculation EA-FC-864-50-01, page 12 of 34, "Since the lowest MSB shell temperature is 5°F, section 11.1.1.3 of Reference 8.1 and the MSB will not be transported when the ambient temperature less than O°F, the minimum CVN [Charpy V-notch] value for the weld metal at 0°F (54 ft-lbs) is used to calculate K_{Ic} and K_{Id}."

NRC Request

B) 2. Material Test Reports: Provide justification(s) for not using the lowest Charpy V-Notch (CVN) test results (18 ft-# at weld metal) to determine the fracture toughness values in Section 5.3 ($K_{Ic} = (2^*E^*CVN^{1.5})^{1/2}$ and $K_{Id} = (5^*E^*CVN)^{1/2}$) of the report. The staff states that the mechanical properties of the weld should be considered in the evaluation given that the indications were identified in the weld.

The minimum CVN values of materials from the test reports: Order #: 9094, dated: 04/4/1991 for ASTM A-285 @ 0°F: 54 ft-# and Project #: 29415, dated: 01/17/92 for ASME SA-516, Gr. 70 @ -50°F: 18 ft-# at weld & 52 ft-# at HAZ.

The CVN values of materials from the report: Sections 4.1.2 Weld Metal: CVN= 64, 65, 54, ft-# @ O°F, Section 4.1.3 Weld test coupon: Weld Metal CVN= 24, 20, 18 ft-# @ -50°F and HAZ CVN= 56, 69, 52 ft-# @ -50°F.

ENO Response

B) 2. The lowest operating temperature is 5°F, so the CVN value for the weld metal at 0°F (54 ft-lbs) is used to calculate K_{Ic} and K_{Id}. The value of 18 ft-lb at -50°F is far below the temperature at which the vessel is expected to operate. The purpose of taking Charpy tests over a broad temperature range for ferritic materials is to effectively characterize the toughness transition curve. The evidence from the reported data, in the calculation, demonstrate that at the lower end of operating temperatures for the MSB, the material is in the transition region of the toughness curve, and not on the upper shelf.

NRC Request

B) 3. Section 2.2: Provide justification(s) and discussion(s) for assuming a semi-elliptical inside surface indication would provide conservative results as compared to the identified sub-surface indication[.]?

In Section 2.2 Flaw Model for Analysis- it is stated that "three (3) indications were identified." One of them (the sub-surface indication) was chosen to the most critical (2l= 3/4", a= 3/16"). The indication was assumed as a semi-elliptical inside surface indication with dimensions of (2l= 1.0", a= 0.5").

ENO Response

B) 3. In general, a surface connected flaw is more severe than a subsurface flaw, because the subsurface flaw experiences greater constraint than does the equivalent surface connected flaw. This difference is acknowledged in the ASME Code, Section XI, for example, in the flaw acceptance standards of IWB-3500. By reviewing those tables, it may be seen that for a given flaw length, a subsurface flaw that is approximately double the size (measured in the cross-flaw or depth direction) of the same length surface flaw would be acceptable. Consequently an inside surface flaw is assumed as a conservative bounding flaw.

NRC Request

B) 4. Section 2.6: Provide justification for formation of compressive residual stress in the weld-root area for double V butt-welds.

Fabrication by welding induces complex three-dimensional residual stresses that are caused by heating and cooling effects of welding. The residual stress distribution in the vicinity of welds can be as high as the yield strength of the base material, and can be categorized as a secondary localized self-equilibrating (self-limiting) stress distribution through the weld length in two principal directions (longitudinal and transverse) in thin plate/shell structures. In the longitudinal direction, the weld residual stress should be in tension (membrane stress) throughout the thickness for all welding configurations. On the other hand, in the transverse direction based on the location, the weld residual stress can be alternating throughout the length of the weld. Therefore, considering weld residual stress in the bending stress may <u>not</u> be appropriate for thin plate/shell structures.

Thus a "double V butt-weld" application may <u>not</u> provide <u>significantly less</u> residual stress distribution than a "single V butt-weld" as it was stated in section 2.6, thin plate shell structures. Therefore, the weld residual stress may have to be categorized as a membrane stress in a conservative fatigue/fracture mechanics evaluation(s). Finally, a large tensile secondary stress can contribute on flaw growth even to fractures of a structure under plane-stress and or plane strain conditions on subsequent to fatigue-flaw growth.

Section 2.6: Residual Stress in the Longitudinal Weld - the licensee stated that the MSB shell material yield strength is 54 ksi, and refers to Section 4.0. In the same section, the licensee provided discussions of weld residual stress due to double V weld configurations and considered adding welding residual stress as a bending stress, in Section 5.3, to be used as a conservative application.

ENO Response

B) 4. The wording in the calculation is not clear, and we believe that led to the staff question above. The actual residual stress in the weld would be expected to be less severe than the 54 ksi yield level stress, which is assumed in this calculation. A previous calculation by the company that designed the MSB (Sierra Nuclear) suggests that the residual stress would be negligible.

With regard to the treatment of weld residual stresses in the flaw stability analysis, the contract firm that provided the calculation has provided the following comment: "Also as stated in section 5.1.2, K_I for a linear stress distribution (0 at the shell ID and Sb at the shell OD) was used in the calculation. The peak welding residual stress of 54 ksi was added to maximum bending stress Sb."

NRC Request

€3) 5. Sections 3.3 and 4.1.1 : Revise the calculations accordingly, based on the literature check the minimum yield strength for base metal of ASTM A-516, Gr. 70, is 260 MPa = 37.7 ksi.

In Section 3.0, Item 3.3, the licensee assumes the weld residual stress level as the yield stress of 54.0 ksi and in Section 4.1.I the yield strength of ASME SA-516, Gr. 70 was listed as 53.23 ksi.

ENO Response

B) 5. Use of the ASME Code minimum yield stress (e.g., 37.7 ksi as stated in the NRC question) rather than the more representative values used in the calculation (e.g., 54 ksi) would be non-conservative. The larger yield stress is taken to represent the weld residual stress magnitude. Weld residual stresses are steady state secondary stresses that are not limited by the ASME Code. They are included in fatigue crack growth calculations only as non-cyclic mean stresses, and the higher the value used for yield stress, the higher such mean stresses become.

NRC Request

B) 6. Section 5.3: Provide the technical basis for the calculated (summed) final predicted indications (a and b) after 50 year of service life.

Section 5.3: "Flaw Stability Calculation"- the licensee calculated the predicted crack sizes (a and b) after 50 years of service life.

ENO Response

B) 6. The calculation performed an ASME Section XI Code analysis to determine the fatigue life of the spent fuel cask using the methodology of the code and using bounding conservative values for material properties, a conservative initial crack configuration, bounding temperatures and yield level residual stress with a stress ratio R of 1.0. Safety factors in accordance with the ASME Code were used and the results of the analysis demonstrated insignificant crack growth for the 50 year design lifetime.

NRC Request

B) 7. Section 5.3: Provide the effects of neutron irradiation for fracture toughness values (K_{Ic} and K_{Id}) as irradiation effects on materials were not considered discussed in the evaluation.

ENO Response

B) 7. The fluence expectations for this component are addressed in the design documentation for the VSC-24, and evaluated by the NRC in the documentation supporting the Certificate of Conformance. However, since the fuel in MSB-04 was loaded prior to 1997, and since that fuel had been in the spent fuel pool and not in an active core for more than ten years before MSB fuel loading, neutron fluence over the service life of the MSB is not expected to significantly impact toughness.

NRC Request

NOTE: The licensee conservatively considered the worst sub-surface indication as a surface indication, considered a conservative postulated flaw dimensions of 1.0" X 0.5", assumed higher weld residual stress level (54 ksi) of base metal and ASME Section XI, IWB-3612 (a) & (b) acceptance criteria, applies additional margins of safety of $(2)^{1/2}$ *and* $(10)^{1/2}$ *for* K_{Ic} *and* K_{Id} *respectively. However, the licensee considered the weld residual stress as the bending stress, contrary to the conservatism applied in the above stated assumptions.*

ENO Response

As noted in response to item B) 4. above, the firm that provided the calculation has indicated that "as stated in section 5.1.2, K_I for a linear stress distribution (0 at the shell ID and Sb at the shell OD) was used in the calculation. The peak welding residual stress of 54 ksi was added to maximum bending stress Sb."

NRC Request

The licensee may consider employing less restrictive code applications as follows: Appendices C and H of ASME Section XI apply to piping and include somewhat undemanding flaw assessments based on a combination of linear-elastic and elastic-plastic methods. In addition, consider ASME Code Case N494-4, which uses a "failure assessment diagram (FAD)" approach.

ENO Response

The limited toughness data available does not justify use of elastic-plastic or limit load methods at the low end of the operating temperature range. Such evaluation methods would be considerably less conservative than the LEFM methods used.