Request for Additional Information
for the
Model No. CR3MP Package
Docket No. 71-9393

By letter dated September 1, 2021 (Agencywide Documents Access and Management System [ADAMS] Accession No. ML21244A485), Orano Federal Services LLC submitted an application for approval of the Crystal River 3 Middle Package (CR3MP).

On February 14, 2022, staff accepted the application for review after receiving on January 6, 2022 (ADAMS No. ML22006A365), responses to the October 14, 2021, request for supplemental information (ADAMS No. ML21286A798).

This request for additional information (RAI) identifies information needed by the staff in connection with its detailed review of the CR3MP.

CHAPTER 2 STRUCTURAL AND MATERIALS EVALUATION

2-1 Explain why the guidance of ASTM C869 was not followed to determine the significant properties of the Low-Density Cellular Concrete (LDCC).

In chapter 2, “Materials,” subsection 2.2.1, the applicant describes the different standards used to manufacture the LDCC. The applicant, in the same subsection, establishes the properties of LDCC by assuming values of density and compressive strength. The LDCC was prepared in accordance with ACI 523.1R using a foaming agent per ASTM C869.

The guidance of ASTM C869 states that “this is accomplished by using the foaming agent in making a standard cellular concrete test batch (see Method C796) from which test specimens are cast. Then, significant properties of the concrete are determined by tests and compared with the requirements of Section 3.”

This information is required to support staff conclusions about the properties used in the non-linear analyses performed to satisfy the requirement of Title 10 of the *Code of Federal Regulations* (10 CFR), Section 71.71 and 10 CFR 71.73

2-2 Explain, in SAR subsection 2.5.2, how the contact surface loads, between the skid and the CR3MP, and between the tiedown frame and CR3MP, are addressed in the structural analysis for normal conditions of transport (NCT).

In chapter 7, “Package Operations,” the applicant states that the CR3MP package is secured in place on the barge and during transport by the heavy haul trailer by a configuration using a skid at the bottom and a tiedown frame at the top. The frame contacts the CR3MP package at the top and the skid with its lateral restraints at the bottom.

This information is required to support staff conclusions on the structural integrity of CR3MP steel shell in meeting the requirements of 10 CFR 71.71 (c)(1),(2),(3) and (4).

2-3 Provide an assessment of other drop orientations to explain how it was determined that the governing drop orientations bound all other drop orientations.

In section 2.6.7, “Free Drop,” the applicant states that only three governing drop orientations were considered for the free drop analysis under NCT conditions. However, the applicant did not assess other drop orientations, nor did it explain how it was determined that the governing drop orientations bound all other drop orientations.

This information is required to support staff conclusions on the structural integrity of CR3MP steel shell in meeting the requirements of 10 CFR 71.71.

2-4 Provide a plot of the material behavior simulation with those of the ASTM material test curves for A516 steel using the same time steps used in the analysis. Demonstrate how effectively the selected approach simulates the stress-strain behavior of the ASTM A516 Grade 70 steel through the entire range of the simulated drop.

In section 2.6.7, “Free Drop,” the applicant describes the methodology adopted to simulate the stress-strain behavior of the modeled material using a piecewise linear stress-strain curve. However, the applicant has not demonstrated how effectively this approach simulates the stress-strain behavior of the ASTM A516 Grade 70 steel through the entire range of the simulated drop. Also, the applicant did not provide a plot of the material behavior simulation with those of the ASTM material test curves for A516 steel using the same time steps used in the analysis.

This information is required to support staff conclusions on the ability of the material model to simulate the material non-linearity during a drop condition required by 10 CFR 71.71 and 71.73.

2-5 Provide details on the material properties of the grout used in the analysis. Provide a comparison of the results from the material model used in the simulation to the actual grout properties from testing data.

The finite element model (FEM) includes the contents of the cask which is the grouted mass of the RPV mid-section and pieces of the RPV internals. However, the applicant did not present information as to how this mass of the model participates in the drop. Also, the applicant did not explain how the internal mass participates in the drop analysis and its role in energy dissipation on impact, if any; and did not provide details on the material properties of the grout used in the analysis.

This information is required to support staff conclusions on the ability of the material model to simulate the material non-linearity during a drop condition required by 10 CFR 71.71 and 71.73.

2-6 Explain why the simplifications made are reflective of the non-linear behavior of the material during the different drop scenarios considered in the NCT and HAC analyses, providing a basis for the simplified strain-based analysis approach. Describe why a biaxial tension state of stress may be assumed beforehand to determine an acceptance criterion for all elements in the containment vessel.

The applicant, in section 2.6.7, has used a strain-based analysis that is based on the one described in ASME BPVC, Section VIII, Division 2, Article 5.3.3, for protection against local failure using a local strain limit (ASME 2017c). The implementation of this methodology in the SAR is performed using a simplified approach, wherein a worst-case (bounding) loading condition is assumed to apply to all elements within the containment vessel. As a result, a plastic strain limit (i.e., “limiting triaxial strain”) is derived beforehand, instead of the derivation of a plastic strain limit at the conclusion of the analysis using resultant stresses “for each point in the component” (ASME 2017c, Article 5.3.3.1, Step 2).

The applicant did not explain why such a simplification would be reflective of the non-linear behavior of the material during the different drop scenarios considered in the NCT and HAC analysis, providing a basis for the simplified strain-based analysis approach. In particular, the SAR should describe why a biaxial tension (“balanced uniaxial tension”) state of stress may be assumed beforehand to determine an acceptance criterion for all elements in the containment vessel. Additionally, the SAR should verify that the state of stress in the FE model at each element in the containment vessel meets the stated assumption.

This information is required by the staff to evaluate compliance with 10 CFR 71.71 and 71.73 drop tests.

2-7 Justify why the erosion feature was applied only to the welds and not extended to the peripheral elements of the attached parts.

The applicant, in section 2.6.7, cites the use of element erosion of the weld between the cover plates and the cylindrical shell. The elements used for the attachment welds between the individual elements of the weld are deleted if the effective plastic strain within the element exceeded the plastic strain limit.

The deleted elements expose openings (gaps) between the welded parts initiating a discontinuous deformation sequence.

This information is required by the staff to evaluate compliance with 10 CFR 71.71 and 71.73 drop tests

2-8 Explain the choice of the modeling approach and discuss its influence on the non-linear behavior of the weld when subject to different drop conditions.

In section 2.12.2.4 regarding the Model, the applicant presented information on different aspects of the FEM. However, the applicant did not justify why the attachment welds in the model were simplified to two rows of elements through the 3.75 -in thickness, without definition of the compound V-groove geometry.

This information is required by the staff to evaluate compliance with 10 CFR 71.71 and 71.73 drop tests

2-9 Provide a dimensional check for the model and model weights.

In section 2.12.4 the applicant did not provide any basic checks of the model to the information in the SAR. The staff’s review identified that the total height of the package (i.e., length of the cylindrical shell) is 178.63 in in the FE models, though the SAR describes it as 178.1 in multiple locations.

For the NCT free drop and HAC combined free drop center of gravity (CG) over top corner impact orientations, the FE models have the package oriented with an angle of 42.2° between the axial centerline of the package and the horizontal drop pad instead of the 47.8° as defined in the SAR.

This information is required by the staff to evaluate compliance with 10 CFR 71.71 and 71.73 drop tests

2-10 Provide an explanation for the elements selected for the different parts of the package and the types of controls used to integrate non-linear behavior that may result from the different drop conditions.

In section 2.12.4, the applicant does not discuss element formulation and discretization. The SAR does not state if a mesh sensitivity was performed during the development of the FE models.

This information is required by the staff to evaluate compliance with 10 CFR 71.71 and 71.73 drop tests

2-11 Explain the approach taken for the modeling of the package.

The drop surface is a rigid surface compared to the cask package material and hence no surface deformation is expected. However, the model shows hourglass control for all components except for the horizontal pad.

This information is required by the staff to evaluate compliance with 10 CFR 71.71 and 71.73 drop tests.

2-12 Justify the non-degradation of the base materials due to the excessive plastic strain.

The SAR identifies locations of local failure but does not provide any justifications for why they were then deemed to be acceptable and why they were not included in the maximum gap generated for the containment analysis. Justify why the base materials were not further degraded (i.e., through possible development of through-thickness cracks) because of the excessive plastic strain.

The response to this issue should also be considered in the containment analysis; similar issues are discussed and should be resolved in the other structural RAIs.

This information is required by the staff to evaluate compliance with 10 CFR 71.71 and 71.73 drop tests.

2-13 Provide an assessment of the model energies and justification for any unexpected values to demonstrate that the model correctly captured the containment vessel's damage and the value is maximized.

This information is required by the staff to evaluate compliance with 10 CFR 71.71 and 71.73 drop tests.

2-14 Explain why the material properties of the grout were not selected based on material test data.

The material models used for the packaging grout and reactor fill grouts were a simplified elastic-plastic material model, which allowed for dramatic component deformations, resulting in some plastic strain (up to 4.06 in/in in one location).

For the HAC combined free drop side impact orientation, the internal energy for the reactor middle fill grout exceeded 21% of the total energy in the FE analysis, though the same value for the other two reactor fills and the packaging grout were no greater than 6% and 10%, respectively. Concrete-like materials are typically believed to fail by brittle fracture prior to measurable plastic deformation.

This information is required by the staff to evaluate compliance with 10 CFR 71.71 and 71.73 drop tests

2-15 Clarify in the SAR that the design of the welded closed vent plug port includes a recessed cover plate or some other means to ensure there are no detrimental effects during operations and transport.

SAR section 4.1.1 indicated that a vent plug port may be part of the containment boundary. However, there was little discussion or pictorial to show that the closure design would not affect operations. The issue of snagging applies to all six of the holes; five of these are plugged or covered for transportation while the sixth one is having the threaded rod and grove weld.

The applicant did not explain the closure process to ensure that the final closure surface is prepared to eliminate these locations as potential points of attachment or that could cause any snagging during transportation and placement in its final location.

This information is needed to determine compliance with 10 CFR 71.43.

2-16 Provide the basis for the low temperature yield strength values used in the calculation for the required brittle fracture performance of the alloy steel package components.

The calculation for the nil ductility temperature in SAR section 2.1.2.1.1, “Brittle Fracture” includes the following assumptions:

- yield strength does not increase with reduction of temperature (the calculation uses the code minimum strength at room temperature)
- the material will have the minimum required yield strength to meet the code specification (vs the typical yield strength of the supplied material which will be higher than the code specified minimum value).

Both of these assumptions make the nil ductility temperature calculation less conservative. Revise the SAR to include additional details about these assumptions

This information is needed to determine compliance with 10 CFR 71.33.

CHAPTER 3 THERMAL EVALUATION

3-1 Clarify the inputs to the pressure and radiolysis calculations in appendix 3.5.2 and SAR section 5.4 and confirm they are bounding.

The assumption in SAR appendix 3.5.2 was that the reference “air” volume for the pressure calculation (and radiolysis calculation) was a portion of the LDCC volume with a 40% void fraction. For example, SAR tables 3.5-1 through 3.5-3 indicate volumes associated with LDCC and HDCC are considered, however the total volumes change with each table. It is unclear whether the radiolysis and pressure calculations account for the water vapor released from the entire amount of grout within the package.

This information is needed to determine compliance with 10 CFR 71.41, 71.51.

3-2 Provide a detailed discussion and justification of the boundary conditions applied during the 30-minute engulfing fire analysis and subsequent cool-down period.

a. The description of the fire test boundary conditions appeared to indicate that the heat flux from the fire to the package was a function of a fire thermal component that was “reduced” due to a convection component. However, a clear definition in equation form of each thermal input of the fire thermal inputs was not clearly described. In addition, the analysis should reflect the engulfing nature of the fire condition, which includes a component due to the radiation heat transfer from the 800 deg C fire and the convection heat transfer component from the engulfing fire.

b. The discussion should include an energy balance calculation of the package surface in order to understand the derivation of the thermal input to the ANSYS model and in order to derive the package surface temperature. This calculation is a function of package decay heat, convection and radiation heat transfer into the package, and radiation heat transfer leaving the package.

c. Provide details and discussion related to the boundary conditions and modes of heat transfer associated with the CR3MP HAC post-fire steady-state temperatures provided in figure 3.4-3.

This information is needed to determine compliance with 10 CFR 71.41.

3-3 Provide package temperatures (e.g., interior, package surface) as function of time during the HAC fire, including the initial conditions.

Temperatures of package components (e.g., interior grout, air, package surface) are often used in the SAR calculations (e.g., radiolysis, pressure). Although some temperatures were noted within the SAR text, it was unclear as to which component and point in time the particular temperature was chosen as an input to the calculations.

This information is needed to determine compliance with 10 CFR 71.41.

3-4 Provide the mesh sensitivity study mentioned in SAR section 3.3 and discuss the results of a time step sensitivity study.

Section 3.3 mentioned that a mesh sensitivity study was performed; however, details of the study and its results were not provided. In addition, there was no mention that a time step sensitivity analysis of the transient HAC was performed to confirm adequate numerical time steps were applied.

This information is needed to determine compliance with 10 CFR 71.41.

3-5 Demonstrate in the SAR that there is no free water in the package grout material in order to confirm that the water vapor contribution to radiolysis and pressure is bounding and clarify and update the calculations and discussion in SAR appendix 3.5.2 to result in the appropriate amount of grout, and correspondingly, the water vapor that is to be used in the pressure and radiolysis analyses.

SAR section 3.5.2.1 indicated that there is no free water within the package’s LDCC and HDCC. However, there was no data or discussion within the SAR that demonstrated there would be no free water. The staff notes that, in practice, the grout slurry will contain more water than necessary to cure the concrete - to ensure sufficient water is present to hydrate all the cement and to aid workability/flow of the slurry. The evaporation of this free water from thick sections can take several months (Castro, 1998).

SAR section 3.5.2.1 states that there is no free water because the concrete is cured after 28 days; however, concrete curing is not related to the release of the excess (free) water that does not participate in the curing reaction.

In addition, the calculations in SAR appendix 3.5.2 (e.g., page 3.5-4, SAR table 3.5-5) appear to result in a total mass of LDCC and HDCC (i.e., total mass of package grout) that is below the grout amounts indicated in SAR table 2.1-2 which prevents staff from reviewing the analyses. As noted in SAR chapter 3 and chapter 5, the quantity of water vapor is an important parameter when calculating pressure and radiolysis effects and, therefore, the calculations and their inputs (e.g., fraction of cement in LDCC and HDCC, mass of grout) should be verified.

This information is needed to determine compliance with 10 CFR 71.43.

Castro, J. Master’s Thesis Dissertation, “Experimental Study of Drying Cellular Concrete,” University of Porto (Portugal), 1998 (summary available at https://www.irbnet.de/daten/iconda/CIB15459.pdf)

3-6 Provide the references associated with the convection heat transfer correlations listed in appendix 3.5.3.

Convection heat transfer is an important parameter for transferring the decay heat to the ambient. Although correlations were provided, the references for those correlations were not provided and their relevance to the particular surface orientation and Ra number could not be determined.

This information is needed to determine compliance with 10 CFR 71.41.

CHAPTER 4 CONTAINMENT EVALUATION

4-1 Provide the calculations for determining the quantity of "energy emitted by source", "energy absorbed in grout", "total gas generated" (moles) and "quantity of hydrogen gas generated" (moles) when performing the radiolysis calculation.

Although SAR table 5.4-3 included a number of quantities, there were no corresponding calculations that demonstrated certain equation inputs (e.g., energy absorbed in grout) would result in the values found in the table for a 405 day evaluation period and, therefore, a review confirming the 5% concentration limit could not be performed.

This information is needed to determine compliance with 10 CFR 71.43.

4-2 Demonstrate in the SAR that the G(H2) value should be reduced from its nominal value due to dose.

SAR section 5.4.4 noted that G(H2) values were reduced from nominal values to account for varying absorbed doses throughout the payload based on SAR chapter 5 Reference 11 (i.e., BNL-NUREG-50957). However, the reference indicates that G(H2) would not be expected to decrease with dose for systems that allow diffusion (such as the package interior according to SAR section 5.4.4). If a reduced G(H2) value is demonstrated to be appropriate, then provide the calculation package, including inputs, for determining the 0.23 G(H2) value. Although an equation was provided relating dose and G values in SAR section 5.4.4, it was unclear as to which dose and G values were used as input to the equation and, therefore, a review could not be performed.

This information is needed to determine compliance with 10 CFR 71.43.