UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

FINAL SAFETY EVALUATION REPORT

DOCKET NO. 72-1042
TN AMERICAS LLC
CERTIFICATE OF COMPLIANCE NO. 1042
NUHOMS® EOS SYSTEM
AMENDMENT NO. 1

SUMMARY

This safety evaluation report (SER) documents the U.S. Nuclear Regulatory Commission (NRC) staff's review and evaluation of the amendment request to amend Certificate of Compliance (CoC) No. 1042 for the NUHOMS® EOS System. By letter dated February 15, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession Number ML18053A220), as supplemented on June 14, 2018 (ADAMS Accession Number ML18178A029), August 30, 2018 (ADAMS Accession Number ML18255A124), February 19, 2019 (ADAMS Accession Number ML19058A410), March 21, 2019 (ADAMS Accession Number ML19084A054), June 19, 2019 (ADAMS Accession Number ML19176A315), July 16, 2019 (ADAMS Accession Number ML19204A228), July 17, 2019 (ADAMS Accession Number ML19220A177), August 29, 2019 (ADAMS Accession Number ML19248C254), and October 1, 2019 (ADAMS Accession Number ML19274B914), TN Americas LLC, from here on referred to as the "applicant," requested that NRC amend the CoC to include the following changes:

Change No. 1:
For the EOS-37PTH Dry Shielded Canister (DSC), add a new basket type (Type 4) with staggered alignment of the steel, aluminum, and poison basket plates. This change allows for the loading of intact, damaged or failed fuel – with up to eight damaged fuel assemblies, or four compartments containing failed fuel rods, with the remaining locations containing intact fuel assemblies. An option is also introduced for the Type 4 basket crediting a low emissivity option for the basket steel plates, and low conductivity for the basket poison plates. When equipped with the low emissivity coating and low conductivity poison, this basket type is identified as "4L." When equipped with the standard poison and coating identical to that of Type 1, 2 and 3 baskets, this basket type is identified as "4H." The Type 4 basket may be stored in either the EOS horizontal storage module (EOS-HSM) or the new NUHOMS® MATRIX design (described in Change No. 4 below). The Type 4 basket may be transferred onsite in either the EOS Transfer Cask (EOS-TC)125 or the EOS-TC135.

Change No. 2:
For the EOS-37PTH DSC, add a new basket type (Type 5) that is comparable in geometry to existing Types 1, 2 and 3 baskets, but with the low conductivity poison and low emissivity option of the Type 4 basket with the ability to be stored in either the EOS-HSM or the new NUHOMS® MATRIX design (described in Change No. 4 below). The Type 5 basket may be transferred onsite in either the EOS-TC125, or the EOS-TC135.

Change No. 3:
For the EOS-37PTH DSC, some locations within the basket are now able to accept fuel

Enclosure

assemblies with a minimum cooling time of two years.

Change No. 4:
Add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel canistered in an EOS-37PTH or an EOS-89BTH DSC. The HSM-MX provides a staggered two-tiered self-contained modular structure for storage of these spent fuel DSCs. The HSM-MX is designed to store the DSCs that are authorized for storage in the EOS-HSM Short and EOS-HSM Medium HSMs.

Change No. 5:
Certain CoC and TS items are revised for consistency and clarity, as described further in the application package.

The amended CoC, when codified through rulemaking, will be denoted as Amendment No. 1 to CoC No. 1042. This SER documents the review and evaluation of the proposed amendment. The staff followed the guidance of NUREG-1536, Revision 1, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility" and ISG-23, "Application of ASTM Standard Practice C1671-07" when performing technical reviews of spent fuel storage and transportation packaging licensing actions.

The staff's evaluation is based on a review of the application to determine whether the amended CoC meets the applicable requirements of 10 CFR Part 72 for dry storage of spent nuclear fuel. The staff's evaluation focused only on the modifications to the CoC and Technical Specifications (TS) requested in the amendment as supported by the submitted revised Updated Final Safety Analysis Report (UFSAR) (see ADAMS Accession Numbers ML18053A234, ML18053A235, ML18178A024, ML18255A101, ML19058A286, ML19176A311 and ML19274B914) and did not reassess previous revisions of the UFSAR nor previous amendments to the CoC.

1.0 GENERAL DESCRIPTION

The objective of this chapter is to review the changes requested to CoC No. 1042 for the NUHOMS® EOS System to ensure that the applicant provided an adequate description of the pertinent features of the storage system and the changes requested in the application. The specific changes requested by the applicant are described and evaluated in the following sections of this SER.

2.0 PRINCIPAL DESIGN CRITERIA EVALUATION

The applicant did not propose any changes that affect the staff's principal design criteria evaluation provided in the previous safety evaluation for CoC No. 1042, Amendment No. 0. Therefore, the staff determined that a new evaluation was not required.

3.0 STRUCTURAL EVALUATION

The staff reviewed the information provided by the applicant and found the four following changes requested in Amendment No. 1 to require structural evaluation:

1. Change No. 1, add a new basket type (Type 4) with staggered alignment of the steel, aluminum, and poison basket plates to the EOS-37PTH DSC. This change allows for the loading of intact, damaged or failed fuel.
2. Change No. 2, add a new basket type (Type 5) that is comparable in geometry to existing Types 1, 2 and 3 baskets but with the low conductivity poison and low emissivity option of the Type 4 basket with the ability to be stored in either the EOS-HSM or the new NUHOMS® MATRIX design for the EOS-37PTH DSC.
3. Change No. 4, add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel in an EOS-37PTH or an EOS-89BTH DSC.
4. Change No. 5, revised certain CoC and TS conditions for consistency and clarity, as described further in the application package.

3.1 Addition of EOS-37PTH DSC Type 4 Basket

Basket Type 4 is one of the five (5) EOS-37PTH DSC baskets (Types 1, 2, 3, 4 and 5). The design of the Type 4 is identical to the design of Type 1, 2 and 3 baskets except that it incorporates a plate configuration that offsets the aluminum plates to allow for damaged/failed fuel storage in the EOS-37PTH DSC. The primary design change of the Type 4 basket is a modification to stagger the alignment of the steel, aluminum and poison basket plates to ensure no continuous gaps across the compartments. The key basket dimensions and materials are provided in Drawing EOS01-1010-SAR in Section 1.3.1 of the UFSAR.

The applicant stated in Section 3.9.2.3A *NUHOMS® EOS-37PTH Type 4 Basket Evaluation* in Appendix 3.9.2 of the UFSAR that no structural analysis is required for the Type 4 basket because there were no changes in (i) allowable weight, (ii) overall length, thickness or other structural dimensions, (iii) design criteria, and (iv) loadings that were used in the structural evaluations for the Type 1 through Type 3 baskets, which were previously reviewed and accepted by the staff, and therefore the current structural evaluations in Section 3.9.2.1 and Section 3.9.2.3 of the UFSAR remain valid for the Type 4 basket. The applicant's analytical approach is the same as what has been previously evaluated and found acceptable. Since there is no change to this approach for Amendment No. 1, the staff finds the evaluation performed by the applicant to be acceptable.

3.2 Addition of EOS-37PTH DSC Type 5 Basket

Basket Type 5 is one of the five (5) EOS-37PTH DSC baskets (Types 1, 2, 3, 4 and 5). The design of the Type 5 is identical to the design of Type 1, 2 and 3 baskets except that it incorporates the low emissivity coated steel plates and low conductivity poison plate.

The applicant stated in Section 3.9.2.3B *NUHOMS® EOS-37PTH Type 5 Basket Evaluation* in Appendix 3.9.2 of the UFSAR that no structural analysis is required for the Type 5 basket because there were no changes in (i) allowable weight, (ii) overall length, thickness or other structural dimensions, (iii) design criteria, and (iv) loadings that were used in the structural evaluations for the Type 1 through 3 baskets, which were previously reviewed and accepted by the staff, and therefore the current structural evaluations in Section 3.9.2.1 and Section 3.9.2.3 of the UFSAR remain valid for the Type 5 basket. The applicant's analytical approach is the same as what has been previously evaluated and found acceptable. Since there is no change to this approach for Amendment No. 1, the staff finds the evaluation performed by the applicant to be acceptable.

3.3 Addition of NUHOMS® MATRIX

The applicant proposed to add a new storage system, NUHOMS® MATRIX (HSM-MX), as an alternative to the EOS horizontal storage module (EOS-HSM). Doing so will reduce the footprint of the current EOS-HSM, which will allow more storage capability on an independent spent fuel storage installation (ISFSI) pad.

3.3.1 General Description

The HSM-MX is a reinforced concrete monolithic modular structure, which is similar to the EOS-HSM reinforced concrete modular structure except that the HSM-MX is a staggered, two-tiered modular structure. The HSM-MX provides storage for the spent fuels in a canister (EOS-37PTH DSC or EOS-89BTH DSC), and it is installed on a load bearing foundation, which consists of a reinforced concrete basemat on a subgrade suitable to support the loads. Table A.1-1 of the UFSAR lists the key design parameters of the HSM-MX and Section A.1.3 of the UFSAR provides the drawings of the HSM-MX.

The HSM-MX contains compartments to accommodate DSCs and provides a means of removing spent fuel decay heat by a combination of radiation, conduction, and convection. Ambient air enters into the HSM-MX through ventilation inlet openings located on the lower tier of the HSM-MX, circulates around the DSC and the heat shields, then exits through the outlets of the HSM-MX. Decay heat is rejected from the DSC to the HSM-MX air space by convection and then removed from the HSM-MX by natural circulation airflow. Heat is also radiated from the DSC surface to the heat shields and HSM-MX walls and roof, where the natural convection airflow and conduction through the walls and roof aid in the removal of the decay heat. The passive cooling system for the HSM-MX is designed to preserve fuel cladding integrity by maintaining spent fuel assemblies (SFAs) peak cladding temperatures below acceptable limits during a long-term storage.

The HSM-MX is designed to offer self-shielding and it is capable of withstanding all normal condition loads, as well as the off-normal condition loads created by earthquakes, tornadoes, flooding, and other natural phenomena hazards.

3.3.2 Design Criteria

The applicant stated in Section A.3.9.4.3 of the UFSAR that the design criteria used for the evaluation of the HSM-MX is identical to the design criteria used for the evaluation of the EOS-HSM, which were previously reviewed and accepted by the staff. Both, HSM-MX and EOS-HSM, structures are reinforced concrete modular structures that are designed in accordance with the requirements of American Concrete Institute (ACI) 349-06 and the American Institute of Steel Construction (AISC) Manual of Steel Construction. The staff reviewed the design criteria and found the designs of the HSM-MX and EOS-HSM to be consistent with the ACI and AISC codes and standards.

3.3.3 Design Loads

The applicant stated in Section A.3.9.4.4 of the UFSAR that the design loads used for the evaluation of the HSM-MX are similar to the design loads used for the evaluation of the EOS-HSM, which were previously reviewed and accepted by the staff except that minor editorial changes in the definitions of the normal handling load and off-normal handling load were made to reflect the design parameters more appropriately. The magnitudes of 140 kips and 135 kips for the normal handling load and off-normal handling load, respectively, are not changed for the HSM-MX from the previous use of the magnitudes of the loads for the EOS-HSM. Table A.3.9.4-4 of the UFSAR provides the applicable codes and standards for the design loads. The staff reviewed the design loads and found them acceptable because the limits for the normal and off-normal handling load requirements are not changed and the applicant's analytical approach is consistent with what has been previously approved.

3.3.4 Load Combinations

The load combinations used for the evaluation of the HSM-MX are identical to the load combinations used for the evaluation of the EOS-HSM. Table 3.3.4-1 of this SER below provides a summary of the seven (7) load combinations (C1 through C7) used for the structural evaluations of the HSM-MX and EOS-HSM. The staff reviewed the load combinations and found that they comply with the requirements of 10 CFR 72.122 and ANSI 57.9-84, and therefore are acceptable.

Table 3.3.4-1 Load Combination for HSM-MX Concrete Components Evaluation

Combination	Load Combination	Event
C1	1.4 DL + 1.7 (LL + R_o)	Normal
C2	1.05 DL + 1.275 (LL + T_o + W)	Off-Normal – Wind
C3	1.05 DL + 1.275 (LL + T_o + R_a)	Off-Normal – Handling
C4	DL + LL + T_o + E	Accident – Earthquake
C5	DL + LL + T_o + W_t	Accident – Tornado
C6	DL + LL + T_o + FL	Accident – Flood
C7	DL + LL + Ta	Accident – Thermal

3.3.5 Methodology for Structural Analysis

The applicant used the finite element (FE) method for structural analysis of the HSM-MX that is the same method used for the structural analysis of the EOS-HSM, which was previously reviewed and accepted by the staff. The applicant used the commercially available FE software program, ANSYS, for the computer-based analysis of the HSM-MX. The applicant developed a 3-D FE model for the HSM-MX storage arranged in a back-to-back row array, where each row consists of three lower compartments and two upper compartments. The applicant applied ten (10) different design loads (Table A.3.9.4-4 of the UFSAR) with seven (7) load combinations

(Table A.3.9.4-5 of the UFSAR) to the HSM-MX reinforced concrete structure that encompass the various conditions of the HSM-MX during loading and storage for normal, off-normal and accident conditions. The staff confirmed that all aspects of the applicant's computer-based FE models were consistent with standard practices described in NUREG-1536, Revision 1.

3.3.6 Structural Analysis for Normal and Off-Normal Conditions

The applicant presented the results of the FE structural analysis of the HSM-MX under the normal and off-normal conditions of loading in Table A.3.9.4-6 of the UFSAR. In this table, the applicant reported the eighteen (18) reinforced concrete structural components of the HSM-MX with: (i) the required and provided reinforcement areas; and (ii) the calculated demand-to-capacity ratios for the combined axial force and bending moment in two orthogonal directions (Asx and Asy) and for the in-plane shear (Asip), where the term of demand-to-capacity (D/C) is defined as a ratio to equate the required reinforcement area of the concrete member (Demand) to the provided reinforcement area of that member (Capacity). The staff summarized Table A.3.9.4-6 of the UFSAR and provided a simplified table, as Table 3.3.6-1 of this SER below, for the staff's evaluations.

For load combination C1 (normal condition), the loads included the weight of the concrete components, the live load and the normal handling load. For load combination C2 (off-normal condition), the loads included the weight of the concrete components, the live load, normal thermal load and the wind load. For load combination C3 (off-normal condition), the loads included the weight of the concrete components, the live load, the thermal load and the off-normal handling load. For all normal and off-normal load combinations, the applicant reported the analysis results in terms of the D/C ratios for the individual structural components.

The staff reviewed the results of the normal and off-normal load conditions and finds that the design of the reinforced concrete structural components of the HSM-MX is adequate for normal and off-normal loading conditions based on the calculated D/C ratios. The staff finds that the applicant's analysis results are acceptable because under all load combinations the demand-to-capacity (D/C) ratio remains less than 1.0, which indicate that the load-carrying capacity of the structural members of the HSM-MX is greater than the maximum load combinations applied, and therefore the staff concludes that the HSM-MX structure will perform its intended functions under the normal and off-normal load conditions.

Table 3.3.6-1 Demand to Capacity Ratios for HSM-MX Reinforcement Areas

Component Name	Thickness (in)	A_{sx}		A_{sy}		A_{sip}	
		D/C	Governing Load Combination	D/C	Governing Load Combination	D/C	Governing Load Combination
Bottom Unit Front Wall Bottom	51	0.91	C4	0.49	C4	0.45	C1
Top Unit Front Wall Bottom	51	0.68	C4	0.68	C4	0.51	C1
Front Wall Top	39	0.82	C4	0.91	C4	0.64	C4
Bottom Unit Vent Wall	11.5	0.43	C4	0.38	C4	0.37	C1
Top Unit Side Vent Wall	11	0.31	C5	0.44	C7	0.36	C1
Bottom Unit Side Wall	37	0.44	C4	0.43	C4	0.84	C1
Bottom Unit End Side Wall	44	0.79	C4	0.57	C7	0.44	C1
Top Unit End Side Wall	82	0.36	C4	0.46	C4	0.82	C1
Bottom Unit Rear Wall Bottom	78	0.56	C4	0.12	C4	0.78	C1
Rear Wall	30	0.07	C4	0.00	C1	0.54	C4
Roof Top Panel	24	0.48	C2	0.87	C5	0.45	C1
Roof Bottom Panel	10	0.34	C5	0.21	C7	0.37	C3
Roof Side Panel	11	0.17	C5	0.19	C2	0.36	C1
Roof Side Panel	10.5	0.11	C5	0.37	C7	0.80	C5
Roof Side Wall	44	0.24	C5	0.83	C2	0.44	C1
Roof	50	0.78	C2	0.57	C5	0.50	C1
Inclined Slab	11.5	0.37	C4	0.38	C4	0.37	C1
Pedestal	23.89	0.32	C4	0.55	C4	0.40	C1

3.3.7 Structural Analysis for Accident Conditions

The applicant also presented the results of the FE structural analysis of the HSM-MX under the accident conditions of loading in Table A.3.9.4-6 of the UFSAR, where the applicant reported the eighteen (18) reinforced concrete structural components of the HSM-MX with the required and provided reinforcement areas and the D/C ratios. From Table 3.3.6-1 of this SER, (i) load combination C4 (accident-earthquake) includes the weight of the concrete components, the live load, the normal thermal load and the seismic load; (ii) load combination C5 (accident-tornado) is similar to load combination C4 except the seismic load is replaced with the tornado load; (iii) load combination C6 (accident-flood) is similar to load combination C4 except the seismic load is replaced with the flood load; and (iv) load combination C7 (accident-thermal) includes the weight of the concrete components, the live load and the accident thermal load due to a blocked vent.

As was the case in Section 3.3.6 of this SER, the staff reviewed the results of the accident load conditions and finds that the design of the reinforced concrete structural components of the HSM-MX is adequate under the accident loading conditions based on the calculated D/C ratios. The staff finds that the reported results are acceptable because under all load combinations the demand-to-capacity (D/C) ratio remains less than 1.0. These D/C ratios indicate that the load-carrying capacity of the structural members of the HSM-MX is greater than maximum load combinations applied, and therefore the staff concludes that the HSM-MX structure will perform its intended functions under the accident load conditions.

3.3.8 Structural Analysis for Missile Impacts

In Sections A.3.9.4.10.2 and A.3.9.4.10.5 of the UFSAR, the applicant evaluated the shield door and the concrete structural components of the HSM-MX for local damage due to a tornado generated missile impact. The applicant used the modified National Defense Research Committee (NDRC) formula to calculate the effects of a nondeforming projectile penetrating a massive concrete target. This is the same analytical approach taken for the evaluation of the EOS-HSM, which the staff previously reviewed and accepted.

The applicant calculated the maximum penetration depth of 7.6 inches of the HSM-MX concrete components using the NDRC formula as a result of the 12-inch diameter, Schedule 40 steel pipe striking the HSM-MX. Since none of the HSM-MX concrete targets are less than 10 inches thick, the staff finds that the structural performance of the HSM-MX against local damage due to a tornado generated missile is adequate.

In Section A.3.9.4.10.5.2 of the UFSAR, the applicant analyzed the global response of the HSM-MX due to tornado-generated missiles. Reinforced concrete components that meet the rebar placement provisions of ACI 318-06 provide the prescribed ductile failure mode under all applied loads. Ductile failure is preferable because it indicates a failure before it actually occurs. Because of the dynamic nature of an impulsive load, ACI 349-06 code defines a ductility ratio that characterizes the ductile response of a reinforced concrete member to an impulsive load. In this case, the code recommends that the ductility ratio be no more than 10 to ensure a margin for the ductile failure mode for impulsive loads.

The applicant calculated the ductility ratio of each concrete component by calculating the peak interface force and the yield resistance based on the duration of impact and the fundamental period of vibration for individual components. The applicant stated that the calculated ductility ratios for all concrete components are less than 10.0, meaning the ductility provided (capacity) is greater than the ductility demand. The staff reviewed the applicant's approach to calculate the ductility ratio and finds it acceptable because the method is consistent with that of ACI 349-06. Furthermore, because all the calculated ductility ratios are less than 10.0, the staff concludes that the structural performance of the HSM-MX is adequate with respect to the global response of the components impacted by impulsive loads from tornado generated missiles.

3.3.9 Stability Analysis

The staff reviewed the results of the applicant's stability evaluation of the HSM-MX with respect to overturning and sliding under the accident conditions. To assess whether the HSM-MX adequately resists overturning, the applicant compared the overturning moment (the rotational force causing the component to tip over, known as Demand) to the resisting moment (the rotational force resisting the tip over, known as Capacity). In order to determine the adequacy of the HSM-MX to resist sliding, the applicant compared the sliding force (also known as Demand) to the resisting force (also known as Capacity). Table 3-3 of NUREG-1536, Revision 1, provides the formula for calculating a factor of safety (FS) with 10% increased margin, where the FS against overturning and sliding is defined as: $FS = Capacity/Demand \geq 1.00$. The staff used this FS as the basis to evaluate the stability performance of the HSM-MX.

In Section A.3.9.7.2.1 of the UFSAR, the applicant conducted a static analysis of the HSM-MX under tornado wind. The applicant calculated a safety factor (M_{st}/M_{ot}) of 3.28 by taking a ratio of the stabilizing moment (M_{st}) using gravity loads and compared it to the overturning moment (M_{ot}) from tornado wind. Because the calculated FS is greater than 1.0, consistent with the provisions of NUREG-1536, Revision 1, the staff finds that the HSM-MX will not overturn as a result of tornado wind.

In the same section of the UFSAR, the applicant also conducted two dynamic overturning analyses for tornado wind concurrent with a massive missile impact load: one based on the conservation of energy and the other based on a time-dependent overturning analysis. The applicant calculated that the HSM-MX will rotate a maximum of 0.000029 degrees based on the principle of the conservation of energy and will not rotate (0.0 degree) based on the time dependent analysis. Both values are less than 37.9 degrees, which is the angle at which the center of gravity is directly above the point of rotation. Based on these angles, the applicant concluded that there is no overturning of the HSM-MX due to tornado wind concurrent with a massive missile impact load. The staff evaluated the applicant's dynamic overturning analyses and finds it acceptable because the applicant has made a reasonable assumption that there will be no overturning based on the calculated angles.

The applicant also conducted two sliding analyses for tornado wind and missile impact: one using the conservation of energy and the other using a time-dependent sliding analysis. Based on the conservation of energy, the applicant calculated that the HSM-MX will slide about 0.15 inches, while the time-dependent analysis presents that the HSM-MX will not slide (0.0 inch). With respect to the sliding distance of 0.15 inches, the applicant indicated that additional storage modules will be added to the HSM-MX array, and thereby the weight of additional storage modules will significantly increase the resistance to sliding of the HSM-MX on the ISFSI pad. Because of (i) no slide by a detailed realistic time-dependent analysis, (ii) small sliding distance of 0.15 inches compared with the large dimension of the HSM-MX, and (iii) significant sliding resistance due to the weight of additional storage modules, the staff finds that there is reasonable assurance that the HSM-MX array will not experience excessive sliding as a result of combined tornado effects.

In Section A.3.9.7.2.2 of the UFSAR, the applicant conducted a static overturning analysis against flood load by summing the moments about the bottom outside corner of the HSM-MX module. For the most limiting module length, the applicant calculated that the minimum factor of safety of the HSM-MX against overturning is about 1.98. Because this is greater than 1.0, consistent with the provisions of NUREG 1536, Revision 1, the staff finds that the HSM-MX will not overturn as a result of the design basis flood. For the sliding analysis for flood load, the applicant calculated a minimum safety factor against sliding to be 1.42. Because this is greater than 1.0, consistent with the provisions of NUREG 1536, Revision 1, the staff finds that the HSM-MX will not slide as a result of the design basis flood.

In Section A.3.9.7.2.3 of the UFSAR, the applicant conducted a stability analysis of the HSM-MX under high seismic loads. The overturning and sliding seismic stability analysis of the HSM-MX was performed using the LS-DYNA explicit dynamics FE computer program. The staff reviewed the seismic stability analysis including the LS-DYNA computer files. The staff found that the seismic stability analysis conforms to (i) the guidance provided in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" Section 3.7.1 "Seismic Design Parameters" for performing a nonlinear seismic analysis; and (ii) the methodology in NUREG/CR-6865, "Parametric Evaluation of Seismic Behavior of Freestanding Spent Fuel Dry Cask Storage Systems."

The nonlinear dynamic analyses for seismic loads were performed for a range of friction coefficients (CoF) for concrete against concrete, varying from 0.8 as the upper bound, 0.6 as the nominal CoF for concrete poured directly on the ISFSI pad and 0.4 as the lower bound. For the nonlinear dynamic time history analyses, impact damping coefficients were included in all contact definitions to obtain a coefficient of restitution (COR) of at least 0.8.

The LS-DYNA FE model of the HSM-MX monolithic expansion single array design loaded with five (5) DSCs was constructed with solid 4-node tetrahedral elements in a mesh, whereas the ISFSI pad was modeled with 8-node solid elements. All components were modeled with rigid materials for the stability analysis. Gaps between components were also modeled. Mass properties of concrete (150pcf) were used throughout the model.

The earthquake input motions were in the form of acceleration time histories whose response spectra match Regulatory Guide 1.60, “Design Response Spectra for Seismic Design of Nuclear Power Plants,” at 5% damping anchored at 0.85g zero period acceleration (ZPA) in both horizontal directions and 0.80 in the vertical direction. Seven input time history sets (3 component directions) were chosen. Each set met the spectral matching requirements of NUREG/CR-6728, “Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-consistent Ground Motion Spectra Guidelines”.

In all, 21 nonlinear dynamic analyses were run [seven (7) time history sets x three (3) CoF]. The nonlinear seismic analyses results showed no overturning, a maximum resultant sliding of 12.5 inches, and a maximum uplift of 0.13 inches of the HSM-MX from all 21 analyses. Regarding the sliding and uplift movements, the applicant indicated that additional HSM-MX storage modules will be added to the array, and thereby the weight of additional storage modules will significantly increase the resistance to sliding and uplifting of the HSM-MX modules on the ISFSI pad. Because of (i) no overturning, (ii) negligible uplift of 0.13 inches, (iii) relatively small sliding distance of 12.5 inches compared with the large dimension of the HSM-MX, and (iv) significant sliding resistance due to the weight of additional storage modules, the staff finds that there is reasonable assurance that the HSM-MX array will not experience excessive sliding and uplifting as a result of the high seismic loads.

3.4 Technical Specification Changes

The staff reviewed Technical Specification (TS) Sections 1.1 Definitions and 4.2 Storage System Features, where the HSM-MX structural storage system was described. Based on the staff's review of TS Sections 1.1 and 4.2, the staff found that the information provided in TS Sections 1.1 and 4.2 regarding the HSM-MX is consistent with the information provided in Appendix A.3 Structural Evaluation and Appendix A.3.9.4 HSM-MX Structural Analysis, and therefore is acceptable.

3.5 Evaluation Findings

F3.1 On the basis of the review of the statements and representations in the application, the staff finds that the UFSAR adequately describes the HSM-MX in Appendix A.3 Structural Evaluation and Appendix A.3.9.4 HSM-MX Structural Analysis of the UFSAR to enable an evaluation of its structural performance and effectiveness.

F3.2 The staff finds that the applicant has met the requirements of 10 CFR 72.236(b). The HSM- MX is designed to accommodate the combined loads of normal or off-normal operating conditions and accidents or natural phenomena events with an adequate margin of safety. Stresses at various locations of the cask for various design loads are determined by analysis. Total stresses for the combined loads of normal, off-normal, accident, and natural phenomena events are acceptable and are found to be within the limits given in applicable codes, standards, and specifications.

The staff concludes that the structural performance of the HSM-MX that comprises the NUHOMS® EOS dry storage system is in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria in Section 3.4 of NUREG-1536, Revision 1, have been satisfied. The evaluation of structural performance provides reasonable assurance that the NUHOMS® EOS dry storage system will allow for the safe storage of SNF for the licensed period. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

4.0 THERMAL EVALUATION

The staff reviewed the information provided by the applicant and found the four following changes requested in Amendment No. 1 to require thermal evaluation:

1. Change No. 1, add a new basket type (Type 4) with staggered alignment of the steel, aluminum, and poison basket plates to the EOS-37PTH DSC. This change allows for the loading of intact, damaged or failed fuel
2. Change No. 2, add a new basket type (Type 5) that is comparable in geometry to existing Types 1, 2 and 3 baskets but with the low conductivity poison and low emissivity

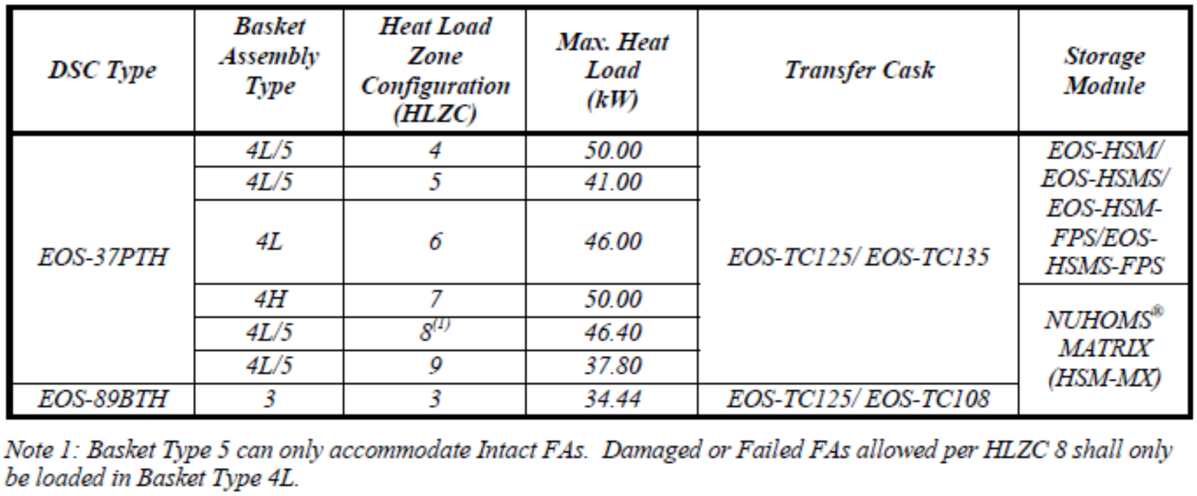
option of the Type 4 basket with the ability to be stored in either the EOS-HSM or the new NUHOMS® MATRIX design for the EOS-37PTH DSC.

3. Change No. 4, add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel in an EOS-37PTH or an EOS-89BTH DSC.
4. Change No. 5, revised certain CoC and TS conditions for consistency and clarity, as described further in the application package.

4.1 Addition of Type 4H, 4L and 5 Basket Assemblies in the EOS-37PTH DSC

The applicant provided a summary of the EOS-37PTH and EOS-89BTH DSC configurations analyzed in Chapter 4, “THERMAL EVALUATION,” that include the Type 4H, Type 4L, and Type 5 basket assemblies which is shown on Page 4-1 of the UFSAR and in Table 4-1, “EOS-37PTH and EOS-89BTH DSC Configurations,” of this SER.

Table 4-1 EOS-37PTH and EOS-89BTH DSC Configurations



DSC Type	*Basket Assembly Type*	*Heat Load Zone Configuration (HLZC)*	*Max. Heat Load (kW)*	*Transfer Cask*	*Storage Module*
EOS-37PTH	*4L/5*	*4*	*50.00*	*EOS-TC125/ EOS-TC135*	*EOS-HSM/ EOS-HSMS/ EOS-HSM-FPS/EOS-HSMS-FPS*
	4L/5	*5*	*41.00*		
	4L	*6*	*46.00*		
	4H	*7*	*50.00*		*NUHOMS® MATRIX (HSM-MX)*
	4L/5	*8*[1]	*46.40*		
	4L/5	*9*	*37.80*		
EOS-89BTH	*3*	*3*	*34.44*	*EOS-TC125/ EOS-TC108*	

Note 1: Basket Type 5 can only accommodate Intact FAs. Damaged or Failed FAs allowed per HLZC 8 shall only be loaded in Basket Type 4L.

4.1.1 Type 4H, 4L, and 5 Basket Emissivity and Conductivity

The applicant described in Section 1.1, “Introduction,” of the UFSAR that the Type 4L and Type 5 baskets have lower emissivity and conductivity values compared to the Type 4H basket that has higher emissivity and conductivity values. The staff confirmed that the Type 4 basket has a coating on steel plates, that it was approved in the initial issuance of the Certificate of Compliance No. 1042, as described in the NUHOMS EOS System UFSAR and that the applicant changed the name of the Type 4 basket to the Type 4H basket in this amendment request. The applicant described in Section 4.2, “Material and Design Limits,” of the UFSAR the EOS-37PTH Type 4L and Type 5 basket emissivity. Based on the staff’s review of Type 4H, Type 4L, and Type 5 basket emissivities, the staff concludes the Type 4L and Type 5 baskets have a lower emissivity compared to the Type 4H basket and the use of baskets with lower emissivity values in the thermal model provides higher predicted temperatures. The applicant described in Section 4.2.2, “Neutron Absorber Plate Conductivity Requirements,” of the UFSAR the Type 4L and Type 5 baskets have a neutron absorber with a higher boron carbide density and with a lower thermal conductivity compared to the Type 4H basket. Based on the staff's review of the Type 4H, Type 4L, and Type 5 basket thermal conductivities, the staff concludes that the thermal conductivity of the Type 4L and Type 5 baskets is lower than the thermal conductivity for the Type 4H basket and the use of baskets with lower thermal conductivity values in the thermal model provides higher predicted temperatures. The applicant states in Section 4.9.1.4, "Effective Thermal Properties for PWR Spent Fuel Assemblies in EOS-37PTH DSC with Low Emissivity Basket Coating," of the UFSAR that only the transverse effective conductivity for the bounding fuel assembly (FA) with the low emissivity basket coating is recomputed with a low emissivity and presented in Table 4.9.1-6, "Bounding Transverse Effective Thermal Conductivity of Fuel Assemblies in EOS-37PTH DSC with Low Emissivity Basket Coating," of the UFSAR. Based on the staff's review of use of low emissivity basket coating, the staff finds the calculation of the bounding transverse effective thermal conductivity of fuel assemblies in the EOS-37PTH DSC with the low emissivity basket coating to be acceptable.

The applicant showed in Section 4.9.6.1.1, "Discussion on Basket Assembly Types for EOS-37PTH DSC," of the UFSAR that the Type 4L basket has a staggered arrangement of basket plates, whereas the Type 5 basket plate arrangement is non-staggered. The applicant described that the staggered plate design reduces the overall thermal resistance along the axial direction and improves heat transfer performance. Therefore, the applicant used the thermal model from Section 4.4.2.1, "Computer-Aided Design Model of EOS-37PTH DSC Basket Assembly," of the UFSAR (ADAMS Accession Number ML18043A206), developed for the EOS-37PTH DSC basket assembly type without staggered basket plates to evaluate the EOS-37PTH DSC basket assembly with staggered plates. Because the thermal model with the use of non-staggered basket plates provides greater thermal resistance and reduces heat transfer, staff finds this to be acceptable.

4.1.2 Evaluation of Intact FAs in Heat Load Zone Configuration (HLZC) 4, 5, and 6 During Normal, Off-normal, and Accident Conditions

The applicant described in Section 4.9.6, "Thermal Evaluation of EOS-37PTH DSC for HLZC 4 through HLZC 9," of the UFSAR the thermal evaluation of the EOS-37PTH DSC for HLZC 4 (50 kilowatts (kW)), HLZC 5 (41 kW), and HLZC 6 (46 kW) storage and transfer operations. The applicant provided in Section 4.9.6.1.3, "Evaluation for Intact FAs in HLZC 4, 5, and 6," of the UFSAR the evaluation of intact FAs in HLZC 4, 5, and 6 where the bounding load case was evaluated along with an ambient temperature identical to that in Section 4.3, "Thermal Loads and Environmental Conditions," of the UFSAR (ADAMS Accession Number ML18043A206), and consideration of impact of wind on the maximum fuel cladding temperature resulting in the use of wind deflectors on the EOS-HSM.

The applicant's results summarized in Section 4.9.6.1.3.5, "Results and Conclusions," of the UFSAR show that the maximum fuel temperatures remain below the allowable temperature limit in both the EOS-HSM and the EOS-HSM flat plate support structure; component temperatures are lower compared to the design basis temperatures; and that slight changes in average temperatures will not impact the internal pressure. The applicant also described that for off-normal and accident conditions, with the same increases in fuel cladding temperatures as normal conditions of storage, there is large margin for the fuel cladding temperature limit. For these reasons, the staff finds the applicant’s evaluation of intact FAs in HLZCs 4, 5, and 6 during normal, off-normal, and accident conditions to be acceptable.

4.1.3 Evaluation of Intact FAs in HLZCs 4, 5, and 6 During Transfer Operations

The applicant provided in Section 4.9.6.1.4, “Transfer Evaluation,” of the UFSAR the transfer evaluation of intact FAs in HLZC 4, 5, and 6 where the bounding load case was evaluated along with ambient operating conditions identical to those in Section 4.5, “Thermal Evaluation for Transfer in EOS-TC125 or EOS-TC135,” of the UFSAR (ADAMS Accession Number ML18043A206). The applicant showed in Table 4.9.6-5, “Maximum Component Temperatures for EOS-TC125 Loaded with EOS-37PTH DSC (HLZCs 4, 5, and 6) for the Bounding Normal Conditions,” of the UFSAR that the maximum fuel cladding temperature at 13 hours for bounding normal conditions is below the allowable temperature limit; component temperatures are lower compared to the design basis temperatures for normal and off-normal conditions; and there is no impact on the internal pressure. The applicant showed in Table 4.9.6-6, “Maximum Component Temperature for EOS-TC125 Loaded with EOS-37PTH DSC (HLZCs 4, 5, and 6) for the Bounding Accident Condition,” of the UFSAR that the maximum fuel cladding temperature increased; however, it remained below the allowable temperature limit during accident conditions. The applicant also recalculated a higher internal pressure based on a higher average helium temperature; however, the maximum accident internal pressure is below the maximum internal pressure limit for accident conditions. Based on the staff review of the statements described above, the staff finds the applicant’s evaluation of intact FA in HLZCs 4, 5, and 6 during transfer operations to be acceptable.

4.1.4 Evaluation of Damaged FAs in HLZC 6

The applicant described in Section 4.9.6.1.2, “Description of HLZCs 4, 5, 6,” of the UFSAR that HLZCs 4 and 5 only allow intact fuel assemblies, while HLZC 6 can accommodate up to 8 damaged or 4 failed FAs along with intact FAs; however, damaged and failed fuel assemblies cannot be stored together. The applicant described in Section 4.9.6.1.5, “Evaluation for Damaged FAs in HLZC 6,” the thermal evaluation of the EOS-37PTH DSC with the Type 4L basket for HLZC 6 with intact and damaged FAs during storage and transfer conditions. The applicant showed in Table 4.9.6-9, “Maximum Component Temperature of EOS-37PTH DSC with 8 Damaged FA,” of the UFSAR that the maximum temperatures of the intact fuel cladding remains below the allowable temperature limit for accident conditions. The applicant also described in Section 4.9.6.1.5 of the UFSAR that the maximum internal pressure during the bounding accident condition with damaged FAs is bounded by the evaluation performed with intact FAs in Table 4-45, “Maximum Internal Pressures in the EOS-37PTH DSC” of the UFSAR. Based on the staff review of the statements described above, the staff finds the applicant’s evaluation of damaged FAs in HLZC 6 to be acceptable.

4.1.5 Evaluation of Failed FAs in HLZC 6

The applicant described in Section 4.9.6.1.6.4, “Results and Conclusions,” of the UFSAR that the maximum temperatures for HLZC 6 with failed FAs are lower compared to HLZC 4; therefore, the time limits for transfer operations described in Section 4.9.6.1.4.4 of the UFSAR are also applicable for transfer operations of HLZC 6 with failed FAs. The applicant also described that the average helium temperature within the DSC is lower compared to the design basis value, and the applicant concluded there is no impact on the internal pressure for normal and off-normal conditions. The applicant also described in Section 4.9.6.1.6.4 of the UFSAR that the failed FAs are conservatively modeled as helium for normal and off-normal conditions; therefore, because no other changes are expected for accident conditions, the maximum accident temperatures determined for HLZC 4 in Section 4.9.6.1.4 of the UFSAR are bounding for HLZC 6. Because the applicant's predicted temperatures for failed FAs in HLZC4 are bounding for HLZC 6, the staff finds the applicant's evaluation of failed FAs in HLZC 6 to be acceptable.

4.1.6 Evaluation of EOS-37PTH DSC for HLZCs 7, 8, and 9

The applicant summarized the transfer operation time limits of the EOS-37PTH DSC with HLZCs 7, 8, and 9 in Table 4.9.6-11, "Time Limit for Transfer Operations for HLZCs 7, 8, and 9," of the UFSAR. The applicant described in Section 4.9.6.2, "Thermal Evaluation of EOS-37PTH DSC for HLZCs 7, 8, and 9," of the UFSAR how the transfer time limits for the EOS-37PTH DSC with HLZCs 7, 8, and 9 were determined based on bounding total decay heat, basket performance, intact or failed FAs, and / or decay heat per FA in each HLZC zone. Based on the justification provided in Section 4.9.6.2, of the UFSAR the staff found the transfer time limits in Table 4.9.6-11 of the UFSAR to be acceptable.

4.2 Addition of NUHOMS MATRIX Design, HSM-MX, for Storage of Spent Fuel Canistered in EOS-37PTH or EOS-89BTH DSC

The applicant provided a summary table in Section A.4, "THERMAL EVALUATION," of the application that described the EOS-37PTH and EOS-89BTH DSC configurations for storage in the HSM-MX. The table is also shown in Table 4-2, "EOS-37PTH and EOS-89BTH DSC Configurations for Storage in HSM-MX," of this SER.

Table 4-2 EOS-37PTH and EOS-89BTH DSC Configurations for Storage in HSM-MX

DSC Type	Basket Assembly Type	HLZC	Max. Heat Load (kW)	Transfer Cask	Storage Module
EOS-37PTH	4H	7	50.00	EOS-TC125/ EOS-TC135	HSM-MX
	4L/5	8(1)	46.40(2)		
	4L/5	9	37.80		
EOS-89BTH	3	3	34.44	EOS-TC125/ EOS-TC108	

Note:

(1) Basket Type 5 can only accommodate Intact FAs. Therefore, damaged or Failed FAs allowed per HLZC 8 shall only be loaded in Basket Type 4L.

(2) The maximum decay heat per DSC is limited to 41.8 kW when a damaged or failed FA is loaded

4.2.1 Decay Heat Removal System

The applicant described in Section A.4.1, “Discussion of Decay Heat Removal System,” of the UFSAR that the decay heat removal system described for storage operations in the EOS-HSM is also applicable for storage operations in the HSM-MX. Section 4.1, “Discussion of Decay Heat Removal System,” of the UFSAR (ADAMS Accession Number ML18043A206) provides a description of the decay heat removal system within the EOS-37PTH and EOS-89BTH DSCs during storage operations in the EOS-HSM. The applicant also described in Section A.4.1 of the UFSAR that no instrumentation is required to monitor the thermal performance if daily visual inspection of the air inlet and outlet vents are performed, which is the same for the EOS-HSM. Additionally, in lieu of daily visual inspection, a direct measurement of the HSM-MX temperature would provide an indication of thermal performance and may be used for monitoring in accordance with the requirements in Technical Specification 5.1.3.2, “HSM-MX Thermal Monitoring Program.” Based on the staff’s previous review of the decay heat removal system for the initial certificate of the NUHOMS EOS storage system (ADAMS Accession Number ML17215A159) the staff finds the description of the decay heat removal to be acceptable.

4.2.2 Material and Design Limits

The applicant described in Section A.4.2, “Material and Design Limits,” of the UFSAR that there is no change to the design criteria for the EOS-37PTH and EOS-89BTH DSCs compared to Section 4.2, “Material and Design Limits” of the UFSAR. The applicant also described that the Type 4L/5 basket properties are discussed in Section 4.9.6.1.1, “Discussion on Basket Assembly Types for EOS-37PTH DSC,” of the UFSAR, which the staff evaluated in Section 4.1.1 of this SER.

4.2.3 Thermal Loads and Environmental Conditions

The applicant described in Section A.4.3, “Thermal Loads and Environmental Conditions,” of the UFSAR that for normal conditions of storage a daily average ambient temperature of 90 degrees Fahrenheit (°F) (32 degrees Celsius (°C)) is used in the thermal analysis, which corresponds to a daily maximum temperature of 100 °F (38 °C) for normal hot storage conditions and is consistent with Section 4.3, “Thermal Loads and Environmental Conditions,” of the UFSAR (ADAMS Accession Number ML18043A206). The applicant also described in Section A.4.3 of the UFSAR that for off-normal and accident conditions a daily average ambient temperature of 103 °F (39 °C) is used in the thermal analysis, which corresponds to a daily maximum temperature of 117 °F (47 °C) for off-normal and accident conditions of storage. The staff finds this to be consistent with Section 4.3 of the UFSAR. The applicant also described that wind is a normal environment variable and for the HSM-MX, a low speed wind in the range of 0 to 15 mph is considered for normal storage conditions. The staff finds this to be consistent with Section 2.5, “Wind,” of NUREG-2174, “Impact of Variation in Environmental Conditions on the Thermal Performance of Dry Storage Casks.” Based on the use of thermal loads and conditions that were consistent with the initial certificate of the NUHOMS EOS storage system (ADAMS Accession Number ML17215A159), the staff finds the description of the thermal loads and environmental conditions to be acceptable.

4.2.4 Thermal Evaluation for Storage

The applicant described that Section A.4.4, “Thermal Evaluation for Storage,” of the UFSAR provides a summary of the thermal performance of the EOS-37PTH DSC within the HSM-MX for normal, off-normal, and accident conditions. Specifically, Sections A.4.4.1 through A.4.4.3 of the UFSAR provide the thermal evaluation for the Type 4H basket within the EOS-37PTH DSC that is within the HSM-MX at a decay heat of 50 kW using HLZC 7. The maximum allowable heat load in the HSM-MX upper compartment is 41.8 kW and in the lower compartment it is 50 kW. The applicant also described that Section A.4.4.4 of the UFSAR provides the thermal evaluation for the Type 4L/5 basket within the EOS-37PTH DSC that is within the HSM-MX using HLZCs 8 and 9. The maximum allowable heat load in the HSM-MX upper compartment is 41.8 kW and in the lower compartment it is 46.4 kW. Lastly, the applicant described that Section A.4.4.5 of the UFSAR provides the thermal evaluation of the EOS-89BTH DSC in the HSM-MX with a maximum allowable heat load of 34.44 kW. The staff finds that Section A.4.4 of the UFSAR adequately summarizes the maximum decay heat evaluated.

4.2.4.1 EOS-37PTH DSC and Type 4H Basket – Description of Load Cases for Storage

The applicant described in Section A.4.4.1, “EOS-37PTH DSC and Basket Type 4H – Description of Load Cases for Storage,” of the UFSAR how the peak cladding temperature is maximized based on a study of the loading patterns for a given decay heat. Based on the staff review of the statements from Section A.4.4.1 of the UFSAR, the staff finds the description of the EOS-37PTH DSC and Type 4H basket description of load cases to be acceptable.

4.2.4.2 EOS-37PTH DSC with Type 4H Basket Thermal Model for Storage in HSM-MX

The applicant described that to analyze the thermal performance of the HSM-MX loaded with the EOS-37PTH DSC, the applicant developed a three-dimensional (3D) half-symmetric computational fluid dynamics (CFD) model in ANSYS FLUENT. The applicant described that no changes were required for the thermal model of the EOS-37PTH DSC Type 4H basket assembly, the staff finds this to be acceptable based on the staff’s review of the Type 4H basket in Section 4.1.1 of this SER.

4.2.4.2.1 CFD Model of EOS-37PTH DSC in HSM-MX

The applicant described in Section A.4.4.2.2, “Model of HSM-MX,” of the UFSAR that the HSM-MX is a staggered, two-tiered array of horizontal storage modules (HSMs) with upper and lower compartments which can be arranged in a single row, or back-to-back row arrays. Figure A.4-1, “CFD Model for HSM-MX with EOS-37PTH DSC,” of the UFSAR shows that the CFD model consists of one complete lower compartment and two half upper compartments. The applicant described in Section A.4.4.2.2 of the UFSAR that conservatisms in the HSM-MX CFD model include the application of: various boundary conditions on the boundaries of the CFD model, heat load, and ambient conditions for a sufficient duration to establish steady state conditions, the appropriate size of the external air domain, no application of insolation, and simplifications on the outlet ducts and bird screens. Based on the staff’s review of the description of the thermal model of the HSM-MX, the conservatisms, and the assumptions described in Section A.4.4.2.2 of the UFSAR, the staff finds the description to be acceptable, except for the use of: 1) periodic boundary conditions, and 2) one complete lower compartment and two half upper compartments, which the staff evaluates in Section 4.2.4.2.1.1 of this SER. In addition, the staff notes the applicant provided sensitivity studies in the application that the staff also evaluates in Section 4.2.4.2.1.1 of this SER.

The applicant described in Section A.4.4.2.3, “CFD Model of EOS-37PTH DSC in HSM-MX,” of the UFSAR the CFD model, including the defining materials, the decay heat that is applied as heat generation over the elements representing homogenized fuel assemblies, and porous media modeling. The staff found the CFD modeling to be acceptable for the HSM-MX because it was consistent with the approved CFD modeling in Section 4.4.2.3, “CFD Model of EOS-37PTH DSC in EOS-HSM,” of the UFSAR (ADAMS Accession Number ML18043A206). The applicant described the boundary conditions which are shown in Figure A.4-6 of the UFSAR, “Exterior Boundary Conditions for the Side Wind Load Cases of EOS-37PTH DSC in HSM-MX,” which the staff found acceptable, except for the use of periodic boundary conditions which the staff evaluates in Section 4.2.4.2.1.1 of this SER. The applicant also described the grid convergence index (GCI) calculation for the CFD model of the HSM-MX loaded with the EOS-37PTH DSC that follows the same methodology as discussed in Section 4.9.4.8, “Evaluation of Grid Convergence Index for Wind Impact,” of the UFSAR. Based on the staff review of the statements described above, the staff finds the description of the CFD model of the EOS-37PTH DSC in the HSM-MX to be acceptable, except for the use of: 1) periodic boundary conditions, and 2) one complete lower compartment and two half upper compartments, which the staff evaluates in Section 4.2.4.2.1.1 of this SER.

4.2.4.2.1.1 Sensitivity Studies to CFD Model of EOS-37PTH DSC in HSM-MX

The applicant illustrated the use of periodic boundary conditions in the thermal model shown in Figure A.4-27, “Comparison of Designs and Boundary Conditions used in Periodic and Symmetric Models of the HSM-MX in Section A.4.5.7.1,” of the UFSAR. The applicant also performed a sensitivity study in that section to compare the maximum fuel cladding temperature, maximum concrete temperature, and selected component average temperatures in the thermal model with the use of periodic boundary conditions to the use of symmetric boundary conditions. The applicant concluded, based on its results of the thermal evaluation of the HSM-MX loaded with the EOS-37PTH DSC using the periodic boundary conditions on the repetitive segment of the HSM-MX, that the use of periodic boundary conditions provides comparable temperature results for the HSM-MX loaded with the EOS-37PTH DSC to the use of symmetric boundary conditions. However, the staff finds that the use of symmetric boundary conditions favorable when low-speed wind is considered during normal conditions of storage because the flow and thermal pattern from neighboring HSM-MX compartments is not repetitive in nature. Therefore, the staff concludes it is not appropriate to use periodic boundary conditions for the HSM-MX. However, the staff accepts based on the results of the applicant’s sensitivity study that the calculated maximum temperatures with symmetric boundary conditions are slightly higher than the calculated maximum temperatures with periodic boundary conditions.

While the applicant did not apply insolation to the HSM-MX CFD model, the applicant performed a sensitivity study with the application of insolation on the load case that had the smallest margin to the maximum fuel cladding and concrete temperature limits, and the results of the sensitivity study showed that insolation had an insignificant effect on the thermal performance of the HSM-MX. Based on the staff's review of the applicant's response to observation 4-4 (ADAMS Accession Number ML18178A029), the staff found the results of the sensitivity study to be acceptable. The applicant also provided justification for the simplifications on the outlet ducts in the CFD model of the HSM-MX, in addition to a sensitivity study on the effect of inlet and outlet vent bird screens on the thermal performance of the HSM-MX, both in Section A.4.4.2.3.8, "Justification of the Treatment of Outlet Ducts and Bird Screens in CFD Model," of the UFSAR. Based on the staff's review of Section A.4.4.2.3.8 of the UFSAR, the staff finds the applicant's conclusion that the simplifications will have a small increase on DSC shell temperatures to be acceptable, and therefore have a negligible impact in fuel cladding maximum temperatures for the HSM-MX.

The applicant also performed a sensitivity study, described in Section A.4.5.7.2, "End Unit Model of HSM-MX," of the UFSAR, to compare the maximum fuel cladding temperature, maximum concrete temperature, and selected component average temperatures in the thermal model of the middle unit of the HSM-MX in an infinite array to the end unit of the HSM-MX. The applicant illustrated the thermal model of the end unit in Figure A.4-28, "CFD Model for End Unit HSM-MX with EOS-37PTH DSC Loaded in Lower Compartment." of the UFSAR. In the sensitivity study, the applicant described in Section A.4.5.7.2 of the UFSAR the differences of the configurations between the end unit and middle unit models, as shown in Licensing Drawing No. MX01-50000-SAR, and specifically that the outlet vent of the end lower compartment is closed with a cover plate. The applicant concluded, based on the its results of the thermal evaluation of the end unit, that the thermal performance of the end unit model of the HSM-MX is bounded by the thermal performance of the HSM-MX located in the middle of an infinite array. Based on the staff's review of Section A.4.5.7.2 of the UFSAR, the staff finds the applicant's conclusion to be acceptable when the outlet vent of the end unit lower compartment is closed with a cover plate to mitigate the wind as shown in Licensing Drawing No. MX01-50000-SAR.

The applicant also performed a sensitivity study, described in Section A.4.5.7.3 of the UFSAR, with the associated Figure A.4-28a, "Comparisons of Designs and Boundary Conditions used in Periodic Model (Load Case 1e-S in Section A.4.5.3) and Full Model (Load Case 1e-S-full in Section A.4.5.7.3) of the HSM-MX." In the middle unit thermal model, the applicant included a full model (two full upper compartments and one full lower compartment) to better understand the physics of low-speed wind during normal conditions without using periodic boundary conditions. However, in this middle unit thermal model the applicant closed the windward outlet vent, which is not shown to be closed on the licensing drawings for middle units of the HSM-MX. The staff disagrees with the applicant's description in Section A.4.5.7.3 of the UFSAR that most of the wind will be blocked by upwind vent covers and that the arrangement and design of the outlet vent covers ensure that the vents of the middle compartments never encounter wind.

To address this, the staff modified the applicant's middle unit thermal model that includes two full upper and one full bottom compartment by unblocking the windward outlet vent and running the model until the temperatures converged. The staff found the fuel cladding temperature was reported in Table A.4-33a, "Maximum Fuel Cladding and Concrete Temperatures in HSM-MX Loaded with EOS-37PTH DSC for Periodic and Full Models with Bounding Normal Conditions," of the UFSAR for the load case 1e-S-full with the windward outlet vent blocked, and with the windward outlet vent unblocked, the fuel cladding temperature increased to approximately 682 °F (361 °C) due to the application of low-speed wind. However, these temperature results remain below the applicant’s bounding results provided in Table A.4-33a. Therefore, based on the results of the staff’s modification to the applicant’s analysis which, with an unblocked windward vent that includes the effects of low-speed wind, the staff finds the applicant’s middle unit thermal model described in Section A.4.5.7.3 of the UFSAR accurately models the HSM-MX. Provided a change to the end unit outlet vent cover plate has not been made, the full middle unit thermal model, which includes two full upper and one full bottom compartment with an unblocked windward outlet vent, should be used as the design basis model for future design changes that are compliant with 10 CFR 72.48.

Based on the staff review of the statements described above, and the results of the staff’s modification to the applicant’s analysis, the staff finds the sensitivity studies performed on the CFD model of the EOS-37PTH DSC in the HSM-MX to be acceptable.

4.2.4.2.1.2 Confirmatory Analysis

As part of the staff’s confirmatory analysis of the applicant’s CFD models, the staff reviewed the thermal models used and confirmed that the proper material properties and boundary conditions were used. The staff verified that the applicant’s selected code models and assumptions were adequate for the flow and heat transfer characteristics prevailing in the HSM-MX geometry and analyzed conditions. The staff also consulted engineering drawings to verify that adequate geometry dimensions were translated to the analysis models. The material properties presented in the UFSAR were reviewed to verify that they were appropriately referenced and applied. The staff assured that the applicant performed appropriate sensitivity analysis calculations to obtain mesh-independent results that would provide bounding predictions for all conditions analyzed in the application.

4.2.4.3 EOS-37PTH DSC with Type 4H Basket for HLZC 7 – Storage Evaluation

In Section A.4.4.3.1.1, “Convergence of the CFD Model,” and Figure A.4-7, “Convergence of Maximum Fuel Cladding Temperatures for all Steady-State Load Cases of EOS-37PTH DSC in HSM-MX with HLZC7,” the applicant demonstrated that after a number of iterations for all normal and off-normal cases, the maximum fuel cladding temperature remains constant with relatively small changes. The applicant also described that the flux reports were monitored, and those results also showed that the thermal calculations are computationally convergent. Based on the staff’s review of Figure A.4-7, the staff finds the thermal calculations are computationally converged.

The applicant showed in Table A.4-2, “Maximum Fuel Cladding and Concrete Temperatures for Storage Conditions of EOS-37PTH DSC in HSM-MX with HLZC 7,” that for the normal, off-normal, and accident load cases considered, the fuel cladding and concrete maximum temperatures remain below their allowable temperature limits; therefore, based on the staff’s review of Table A.4-2, the staff finds the results to be acceptable. The applicant calculated the GCI for the fuel cladding and concrete and showed in Table A.4-19, “GCI Calculations Based on LC 1e-S and LC 1f-S for Updated HSM-MX Loaded with EOS-37PTH DSC,” that the maximum fuel cladding and concrete temperatures, including the GCIs, remain below the temperature limit of 752 °F (400 °C) and 300 °F (149 °C), respectively; therefore, based on the staff’s review of Table A.4-19, the staff finds the results to be acceptable. The applicant performed a sensitivity study that included wind during off-normal conditions, as described in the applicant's response to request for additional information (RAI) 4-5 (ADAMS Accession Number ML19058A410) to determine the maximum fuel and concrete temperatures. The applicant's results showed that while the fuel and concrete temperatures increased, the fuel cladding temperature maintains a significant margin from the 1058 °F (570 °C) off-normal temperature limit, and the concrete remains below its allowable limit of 300 °F (149 °C); therefore, the staff finds the sensitivity study to be acceptable. The applicant also provided maximum temperatures of the basket plate, transition rails, DSC shell, and heat shield in both the upper and lower compartments for the bounding normal, off-normal, and accident condition load cases in Table A.4-3, "Maximum Temperatures of Key Components in HSM-MX Loaded with EOS-37PTH DSC with HLZC7." of the UFSAR. The applicant clarified that the heat shield does not have a specific temperature limit that would degrade its heat transfer characteristics; therefore, the staff finds it acceptable that a maximum allowable temperature limit was not provided. The applicant also clarified that for DSC components that have a structural function, such as the DSC shell, transition rails, and basket plates, the temperatures from the various load cases are considered in the structural evaluation as the staff confirmed in UFSAR Section A.3.4.4.1, "Summary of Pressures and Temperatures," which are based on the actual calculated temperatures or a conservative bounding temperature. Based on the staff's review of UFSAR Section A.3.4.4.1, the staff finds it acceptable that maximum allowable temperature limits were not provided for the DSC shell, transition rails, and basket plates.

The staff compared the maximum temperatures in Tables A.4-2 and A.4-3 of the UFSAR to Figures A.4-9 through A.4-11 which show temperature profiles for the fuel cladding, basket plates, transition rails, DSC shell, HSM-MX, and heat shields, and found the maximum temperatures in the tables and on the figures to be consistent, except for the HSM-MX temperatures. The inconsistency in HSM-MX temperatures was justified in Section A.4.4.3.5, "Impact of Design Changes," of the UFSAR, where the applicant summarized based on a sensitivity study of design changes that a fixed temperature increase was added to all thermal models results for the HSM-MX concrete. Based on the staff's review of the applicant's justification, the staff finds it acceptable that the HSM-MX concrete temperatures are higher than the maximum temperatures shown in Figures A.4-9 through A.4-11 of the UFSAR. The applicant also showed in Table A.4-7, "Comparison of Average Gas Temperature in EOS-37PTH DSC Cavity," and the staff finds it to be acceptable, that the average helium temperature for the EOS-37PTH DSC in the HSM-MX with HLZC7 was bounded by the average helium temperature for the EOS-37PTH DSC in the HSM from Table 4-45, "Maximum Internal Pressures in the EOS-37PTH," of the UFSAR for normal, off-normal, and accident conditions.

Based on the staff review of the statements described above, the staff finds the applicant's storage evaluation of the EOS-37PTH DSC with the Type 4H basket for HLZC 7 to be acceptable.

4.2.4.4 EOS-37PTH DSC with Type 4L/5 Basket – Storage in HSM-MX

Section A.4.4.4, "EOS-37PTH DSC with Basket Type 4L/5 – Storage in HSM-MX," of the UFSAR provides the thermal evaluation for the Type 4L/5 basket within the EOS-37PTH DSC that is within the HSM-MX using HLZCs 8 and 9 for normal, off-normal, and accident conditions. The applicant identified that the maximum allowable heat load in the HSM-MX upper compartment is 41.8 kW and in the lower compartment it is 46.4 kW, which the staff verified is consistent with Figure 1H of the TS. The applicant identified based on a sensitivity analysis that the maximum decay heat in the Type 4L/5 basket is bound by the Type 4H basket, and the applicant also identified that the bounding load case for the Type 4H basket would also be used for the Type 4L/5 basket. Based on the staff's review of the statements in Sections A.4.4.4.1, and A.4.5.5.1 both entitled, "EOS-37PTH DSC and Basket Type 4L – Description of Load Cases for Storage," of the UFSAR, and the associated results in Tables A.4-23 through A.4-25 of the UFSAR, the staff finds the bounding load case to be acceptable.

The applicant described in Section A.4.4.4.1.1, "Damaged/Failed Fuel Assemblies," of the UFSAR that HLZC 8 can accommodate either a maximum of 8 damaged fuel assemblies, or 4 failed fuel assemblies, along with intact fuel assemblies, but not both damaged and failed fuel assemblies. The applicant also described that there are no credible accident conditions that could alter the physical configuration of the damaged fuel assemblies, and therefore the applicant concludes, and the staff finds acceptable that the evaluation for intact fuel assemblies with 46.4 kW for HLZC 8 bounds the damaged fuel configuration with 41.8 kW.

The applicant also described in Section A.4.4.4.1.1 of the UFSAR that Table 4.9.6-10, "Maximum Component Temperatures of EOS-37PTH DSC for HLZC 6 with Four Failed FAs," of the UFSAR showed that the maximum fuel cladding temperatures for the intact configuration is bounding when compared to the failed fuel assembly configuration. The applicant described, and the staff finds acceptable that this is due to the placement of the failed FAs and the reduced maximum heat load (44.3 kW for HLZC 6 with 4 failed FAs compared to 50 kW for HLZC 4 with intact FAs). The applicant also described that this similar behavior would occur for HLZC 8 due to the identical location of the failed FAs and the reduced heat load (41.8 kW for HLZC 8 with 4 failed FAs compared to 46.4 kW for HLZC 8 with intact FAs). Based on the staff's review of Section A.4.4.4.1.1 of the UFSAR, the staff agrees that the applicant's thermal evaluation for intact FAs with 46.4 kW for HLZC 8 bounds the failed fuel configuration with 41.8 kW for HLZC 8.

4.2.4.4.1 EOS-37PTH DSC with Type 4L/5 Basket HLZC 8 and 9 – Storage Evaluation

The applicant described in Section A.4.4.4.2, "EOS-37PTH DSC with Basket Type 4L/5 HLZC 8 and 9 – Storage Evaluation," of the UFSAR the modifications made to the thermal model from Section A.4.4.2, "EOS-37PTH DSC with Basket Type 4H – Thermal Model for Storage in HSM-MX," of the UFSAR, specifically the material properties of the basket and the heat generation rates due to the new HLZCs. In Table A.4-26, "Comparison of Maximum Temperature between HLZCs 8 and 9 with HLZC7," of the UFSAR the applicant provided the maximum temperatures for HLZCs 8 and 9 during normal conditions of storage and compared those values to the maximum temperatures for HLZC 7. Based on the staff's review of Table A.4-26, the applicant showed that the results from HLZC 7 with 50 kW were bounding, except for the heat shield in the upper compartment which is slightly higher; however, the heat shield does not have a specific temperature limit. The applicant described that similarly for off-normal and accident conditions, HLZC 7 is also bounding; therefore, the applicant concluded, and the staff accepts that no further evaluation is required.

4.2.4.5 EOS-89BTH DSC with Type 3 Basket – Storage in HSM-MX

The applicant described in Section A.4.4.5, “EOS-89BTH DSC with Basket Type 3 – Storage in HSM-MX,” of the UFSAR that explicit thermal models of the EOS-89BTH DSC in the HSM-MX were not developed. Instead the applicant’s evaluation is based on a comparison of the maximum DSC shell temperatures. The applicant described that only the lowest heat load, 34.44 kW in HLZC 3, is qualified for storage in the HSM-MX, the staff verified this was described in Figure 2, “EOS-89BTH DSC Heat Load Zone Configurations and Fuel Qualification,” of the Technical Specifications. The applicant described in Section A.4.4.5, “EOS-89BTH DSC with Basket Type 3 – Storage in HSM-MX” of the UFSAR that for the EOS-89BTH DSC, the transfer operations are a more bounding condition in terms of thermal performance as compared to storage operations. The applicant described that this is based on the lower decay heat limit for steady state transfer operations (34.44 kW) versus the decay heat allowed for steady state storage operations (43.6 kW). The applicant presented in Table A.4-27, “Comparison of EOS-89BTH DSC Temperatures in Updated HSM-MX and EOS TC125/TC108,” of the UFSAR the maximum and average temperatures of the EOS-89BTH DSC shell during storage in the HSM-MX and showed that with 41.8 kW the temperatures are lower than during transfer operations with 34.44 kW. The applicant concluded, and the staff finds acceptable based on the statements above in Section 4.2.4.5 of this SER that storage of the EOS-89BTH DSC with HLZC 3 (34.44 kW) in the HSM-MX is allowed because of the bounding temperatures of the DSC shell temperature during steady-state transfer operations at 34.44 kW, compared to the DSC shell temperature for the EOS-37PTH DSC in the HSM-MX at 41.8 kW during normal conditions of storage.

4.2.5 Additional Changes Not Associated with the RAIs

The applicant described in Enclosure 4 to E-53166, “Additional Changes Not Associated with RAIs,” (ADAMS Accession Number ML19058A283) that changes were made to facilitate fabrication of the HSM-MX. Changes affecting the thermal analysis included: simplifying the geometry in the front wall of the HSM-MX, extending the concrete door opening interior chamfer, increasing the thickness of the HSM-MX roof, and modifying the side heat shield. The staff confirmed these changes were described in Section A.4.5.1, “Design Changes in Updated HSM-MX,” of the UFSAR, shown in figures in Section A.4, “Thermal Evaluation,” of the UFSAR, and on the Licensing Drawing No. MX01-50000-SAR, and therefore were included in the thermal analysis results in Section A.4.5, “Thermal Evaluation for Storage in Updated HSM-MX.” Based on the staff’s review, the staff finds the additional changes to be acceptable.

4.3 Technical Specification Changes

The staff reviewed TS Figures 1A through 1I, and Figure 2 which describe HLZCs 1 through 9 for the EOS-37PTH DSC, and HLZCs 1 through 3 for the EOS-89BTH DSC and show the maximum decay heat per zone, maximum number of fuel assemblies per zone, and maximum total decay heat per DSC. Based on the staff’s review of these TS figures, the staff finds that they adequately describe the configurations analyzed in Chapter 4 and Appendix A-4, “THERMAL EVALUATION,” of the UFSAR, and are therefore acceptable.

The staff reviewed TS 3.1.3 which describes the time limit for completion of DSC transfer. The staff finds the time limit for the 37PTH DSC with HLZCs 4 through 9 in EOS-TC125 with the maximum decay heat of 50 kW to be consistent with the analysis results provided in Sections 4.9.6.1.4.4 and 4.9.6.2 of the UFSAR and therefore acceptable. The staff finds the other DSC transfer operation and required action completion time limits in TS 3.1.3 to be consistent with the description provided in Section 4.9.6.1.4.4 of the UFSAR, or unchanged from the initial certificate of the NUHOMS EOS storage system (ADAMS Accession Number ML17215A159), and therefore acceptable.

The staff finds the applicant's removal of the maximum decay heat values in Limiting Conditions for Operation (LCO) 3.1.3 to be acceptable because the HLZC number is referenced in LCO 3.1.3; Figure 1A through Figure 2 of the TS include the maximum decay heat and HLZC number and those figures remain applicable to LCO 3.1.3. The staff also finds the applicant's clarification of Surveillance Requirement (SR) 3.1.3 to be acceptable because SR 3.1.3 is only applicable after the initiation of draining of the water in the transfer cask (TC)/DSC.

The staff reviewed TS 5.1.3 which describes the temperature monitoring program for the EOS-HSM and HSM-MX. The TS 5.1.3.1 description of the temperature monitoring program for the EOS-HSM remained essentially unchanged with changes only to separate it from the HSM-MX. The TS 5.1.3.2 description of the temperature monitoring program for the HSM-MX included the daily visual inspection of the inlets and outlets of the HSM-MX, in addition to the daily temperature measurement program of the HSM-MX concrete. The applicant did not specify the upper and lower compartment concrete temperature limits and maximum heat-up rate limits in TS 5.1.3.1.b and 5.1.3.2.b. However, the applicant described that the upper and lower compartment concrete temperature limits and maximum heat-up rate limits shall be established in the individual user's own temperature measurement program. The applicant will assist the user in implementing these limits by providing the user with a specification that documents the upper and lower compartment concrete temperature limits and maximum heat-up rate limits based on the as-built configuration, which will be incorporated into the evaluation performed by the user as required by 10 CFR 72.212, "Conditions of a general license issued under § 72.210." The applicant specified the accident concrete temperature limit and associated time limits in TS 5.1.3.1.b.iv and TS 5.1.3.2.b.iv. The staff finds that TS 5.1.3 prevents conditions that could lead to exceeding the concrete and fuel cladding temperature criteria.

4.4 Findings

F4.1 Structures, systems, and components (SSCs) important to safety are described in sufficient detail in Chapter 4 and Appendix A.4 of the UFSAR to enable an evaluation of their thermal effectiveness. The HSM-MX SSCs important to safety remain within their operating temperature ranges.

F4.2 The HSM-MX is designed with a heat-removal capability having verifiability and reliability consistent with its importance to safety. The HSM-MX is designed to provide adequate heat removal capacity without active cooling systems.

F4.3 The spent fuel cladding is protected against degradation leading to gross ruptures by maintaining the cladding temperature below maximum allowable limits in a helium environment.

Protection of the cladding against degradation is expected to allow ready retrieval of spent fuel for further processing or disposal.

The staff concludes that the thermal design of the HSM-MX is in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria have been satisfied. The evaluation of the thermal design provides reasonable assurance that the HSM-MX will allow safe storage of spent fuel for a certified life of twenty years. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, and accepted engineering practices.

5.0 CONFINEMENT EVALUATION

The staff reviewed the information provided by the applicant and found the five following changes requested in Amendment No. 1 to require confinement evaluation:

1 Change No. 1, add a new basket type (Type 4) with staggered alignment of the steel, aluminum, and poison basket plates to the EOS-37PTH DSC. This change allows for the loading of intact, damaged or failed fuel.
2 Change No. 2, add a new basket type (Type 5) that is comparable in geometry to existing Types 1, 2 and 3 baskets but with the low conductivity poison and low emissivity option of the Type 4 basket with the ability to be stored in either the EOS-HSM or the new NUHOMS® MATRIX design for the EOS-37PTH DSC.
3 Change No. 3, accept fuel assemblies with a minimum cooling time of two years, in selected locations, as contents of the EOS-37PTH DSC.
4 Change No. 4, add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel in an EOS-37PTH or an EOS-89BTH DSC.
5 Change No. 5, revised certain CoC and TS conditions for consistency and clarity, as described further in the application package.

The confinement review ensures that radiological releases from the storage system to the environment will be within the limits established by the regulations and that the spent fuel cladding and fuel assemblies will be sufficiently protected during storage against degradation that might otherwise lead to gross ruptures.

The staff reviewed the information provided in this amendment application and finds that the confinement design and confinement boundary components remain unchanged, and both EOS-37PTH and EOS-89BTH DSCs retain leak tight conditions as addressed in Amendment 0. Therefore, the staff determined that all the changes Nos. 1–5 proposed in the amendment have no negative impact on the confinement performance and that the NUHOMS® EOS System continues to fulfill the confinement acceptance criteria as listed in Section 5.4 of NUREG 1536, Revision 1.

5.1 Findings

F5.1 On the basis of review of the proposed changes Nos. 1–5 and the submitted documents, the staff concludes that the proposed changes have no negative impact on the confinement system and that the NUHOMS® EOS System continues to meet the confinement requirements of 10 CFR Part 72.

6.0 SHIELDING EVALUATION

The staff reviewed the information provided by the applicant and found the five following changes requested in Amendment No. 1 to require shielding evaluation:

1. Change No. 1, add a new basket type (Type 4) with staggered alignment of the steel, aluminum, and poison basket plates to the EOS-37PTH DSC. This change allows for the loading of intact, damaged or failed fuel.
2. Change No. 2, add a new basket type (Type 5) that is comparable in geometry to existing Types 1, 2 and 3 baskets but with the low conductivity poison and low emissivity option of the Type 4 basket with the ability to be stored in either the EOS-HSM or the new NUHOMS® MATRIX design for the EOS-37PTH DSC.
3. Change No. 3, accept fuel assemblies with a minimum cooling time of two years, in selected locations, as contents of the EOS-37PTH DSC.
4. Change No. 4, add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel in an EOS-37PTH or an EOS-89BTH DSC.
5. Change No. 5, revised certain CoC and TS conditions for consistency and clarity, as described further in the application package.

6.1 Review Objective

The objective of this review is to verify that the EOS dry cask spent fuel storage system with these requested changes in design continues to provide adequate protection against direct radiation from the contents. The review seeks to ensure that the shielding design is sufficient and reasonably capable of meeting the operational dose requirements of 10 CFR 72.104 and 72.106 in accordance with 10 CFR 72.236(d).

Among the requested changes identified in Section 6.0 above, the following items affect the shielding design (evaluated in this section of the SER) and the radiation protection plan (evaluated in Section 11) for the system design:

- Reduce the required minimum cooling time to 2.0 years for the fuel to be transferred by the EOS-TC125/135. Note that the minimum cooling time for the EOS-TC108 remains at 3.0 years; the minimum cooling time information was moved to TS Figures 1B and 1C (ADAMS Accession Number ML19176A315).
- Add one new basket, Type 4, to allow for storage of damaged fuel and failed fuel.

- Add a definition of failed fuel in the TS. Failed fuel, either as a failed fuel assembly or bulk material that has already been sealed in a secondary container, must be loaded in the specially designed Failed Fuel Can (FFC). The maximum assembly average burnup for the fuel assembly remains 62 GWd/MTU.
- Allow damaged fuel containing control components to be stored in the designated damaged fuel compartments within the EOS-37PTH dry shield canister. Similarly, failed control component debris may be stored only in the failed fuel compartments.
- Allow new control components as defined in the TS, and additional control components (CC) not explicitly listed herein, but that meet the definition provided above and have similar functional characteristics as those listed above, are also authorized within the DSC.
- Add the fuel qualification tables (FQTs) to the TS.

The applicant also added a new fuel basket, the Type 5 basket in the EOS-37PTH canister. However, the Type 5 basket is identical to the previously approved basket types 1, 2, and 3 except that it has a lower emissivity coating and a low thermal conductivity poison plate. Because these changes have no impact on the shielding features of the basket in comparison with previously approved basket types 1/2/3, the staff did not perform a specific shielding evaluation for this new basket type.

The staff notes that the applicant added the source term definition for reconstituted boiling water reactor (BWR) fuel with the same burnup, enrichment and cooling time (BECT) combination as amendment 0 of the CoC. Since reconstituted BWR fuel is already an authorized content at the same fuel BECTs, the staff expects that this new information would not impact the shielding analyses as presented in amendment 0. The staff finds the change acceptable because the information added does not represent any design change.

6.2 General Description of the NUHOMS® EOS Dry Cask Storage System

The NUHOMS® EOS system with the MATRIX HSM is a staggered (i.e., a two-level module) dry cask spent fuel storage system for use at a facility possessing a general license under 10 CFR Part 50 in accordance with the regulations specified by 10 CFR 72.210. The EOS system was initially designed to store intact pressurized water reactor (PWR) and BWR fuel assemblies (FAs) within the EOS-37PTH DSC and EOS-89BTH DSC, respectively. EOS-TC108 and EOS-TC125/135 are designed to facilitate the loading and transfer of the EOS-DSC to the EOS horizontal storage module (EOS-HSM) or HSM-MX. All of those canister and transfer cask designs have been approved by the NRC in Amendment No. 0.

The new canisters, namely basket Types 4 and 5 of EOS-37PTH, are designed for storage of PWR spent fuel only. However, the new Basket Type 4 allows for storage of damaged and failed fuel provided that the damaged fuel is placed with end caps and the failed fuel is put in an FFC. Failed fuel is defined as ruptured fuel rods, severed fuel rods, loose fuel pellets, fuel fragments, or fuel assemblies that may not maintain the configuration for normal or off-normal conditions per the definition in Section 1.1 of TS.

Basket Type 4 incorporates a plate configuration that offsets the aluminum plates by a small length to allow for damaged/failed fuel storage in the EOS-37PTH DSC. The Type 4 basket has two options: Type 4H and Type 4L. The Type 4H basket is fabricated from a coated steel plate for higher emissivity and incorporates higher thermal conductivity poison plates. The Type 4L basket has a low emissivity coated steel plate and low thermal conductivity poison plates. These requirements are further specified in detail in the material and design limits discussed in Section 4.2 and Section 10.1 of the UFSAR.

6.3 Shielding Design Features

The EOS System consists of a spent fuel DSC and a concrete overpack structure EOS-HSM or HSM-MX in a horizontal configuration. The HSM-MX is a two-tiered staggered, high-density horizontal storage module (HSM), which contains compartments to accommodate DSCs with various lengths. The reinforced concrete overpack houses the DSC that is loaded with the spent fuel. The DSCs are made of cylindrical stainless-steel shell welded onto a bottom plate. A top plate is welded to the canister after the fuel is loaded. The internal cavity of the canister is partitioned into square cells to hold the fuel assemblies, damaged fuel or failed fuel with end caps and in an FFC respectively, and non-fuel hardware (NFHW) if the latter is to be loaded with the PWR fuel.

The HSM base has two alternatives, a single piece (EOS-HSM) or a split base (EOS-HSMS). EOS-HSM and EOS-HSMS modules are arranged in arrays to minimize required space and maximize self-shielding. The DSCs are longitudinally restrained to prevent movement during seismic events. The HSM arrays are fully expandable to permit modular expansion in support of operating power plants.

The EOS-HSM/EOS-HSMS can be arranged in either a single-row or a back-to-back configuration. The EOS-HSM or EOS-HSMS provides the bulk of the radiation shielding for the DSCs. Thick concrete supplemental shield walls are used at either end of an EOS-HSM and EOS-HSMS array and along the back wall of single-row arrays to minimize radiation dose rates both onsite and offsite. Two or more empty modules can be substituted for the end walls until the array is fully built.

The new Type 4 canister has no significant structural changes that impact the shielding features of the EOS-37PTH DSC. The overpack (including storage module closure door) and the DSC wall provide shielding sufficient for the dry cask spent fuel storage system to meet the regulatory requirements of 10 CFR 72.236(d). The DSC shells are welded stainless or duplex steel pressure vessels that include thick shield plugs at both ends to ensure external radiation levels are As Low As is Reasonably Achievable (ALARA).

As mentioned earlier, failed fuel is loaded in the FFC and the damaged fuel is loaded with end caps to prevent the fuel from moving outside of the fuel cell envelope.

The system design also includes three transfer cask designs, TC108, TC125, and TC135, to accommodate the needs for transferring the two DSCs to or from the ISFSI. The EOS-TC108 is designed with a removable neutron shield for use at nuclear plant sites that cannot use one of the other EOS-TCs because of space limitations and/or crane capacity. A cask spacer is required in the bottom of the EOS-TC to provide the correct interface at the top of the EOS-TC during loading, drying, and sealing operations for DSCs that are shorter than the cavity length of the EOS-TC. The TCs will provide the primary shielding during loading and transferring the DSCs to the HSM.

6.4 Specification of Authorized Contents

The system is designed to hold two different DSCs, an EOS-37PTH DSC or an EOS-89BTH DSC, which are designed to hold 37 PWR fuel assemblies and 89 BWR fuel assemblies respectively. However, this amendment affects only the EOS-37PTH PWR fuel DSC design. Tables 2-2 and 2-4 of the UFSAR for the EOS system provides the design parameters for the fuel assemblies to be stored in the system. In addition, the EOS-37PTH DSC is authorized to load certain non-fuel hardware that can fit into the profile of the authorized PWR fuel assemblies. The applicant provides detailed specifications in pages 2-7 to 2-9 of the UFSAR for the control components that may be loaded in the EOS-37PTH.

To accommodate the need of storing fuel with various lengths, the Type 4 DSC is fabricated with three different lengths: 165.5, 185.5, and 205.5 inches for EOS-Short, EOS-Medium, and EOS-Long, respectively. The EOS-HSM and EOS-HSMS are similarly built with three different lengths to accommodate the various DSCs.

The proposed changes with respect to shielding design include adding a new dry canister design type (Type 4) to allow storage of damaged or failed fuel to be stored in the EOS system. The damaged fuel and failed fuel can be loaded only in the designated locations of the DSC as specified in the TS. The maximum uranium loading per FFC is the mass of one fuel assembly as defined in Table 2 of the TS.

A major change in this amendment request is to use a new approach to specify the authorized PWR fuel contents in the TS of the system. Based on the regulatory requirement of 10 CFR 72.236(a), specification must be given for the authorized contents of the storage system because it is imperative to ensure that the shielding design is adequate for the contents to be stored. The applicant developed a new scheme for specification of the authorized spent fuel contents to replace the voluminous FQTs in a typical TS. Specifically, the new scheme for specifying the authorized contents consists of the following four components:

1. A table that defines the allowable minimum enrichment for a given range of burnup as shown in TS Table 7A.

2. One simple FQT table as shown in TS Table 7B applicable to every PWR fuel assembly to be loaded in the EOS-37PTH DSC.

3. One special FQT table, as shown in TS Table 7C, for fuel to be loaded in zone 3 of HLZC 4 and HLZC 7.

4. A specific instruction for assemblies whose enrichment does not meet the requirements in TS Table 7A (these are termed “outliers”) to determine if the assembly can still be loaded into the cask with additional restrictions.

It is important to note that the burnup in the FQT is based on a per fuel assembly unit. The general licensees (the users) will need to determine whether a fuel assembly is qualified to be stored in the cask by multiplying the uranium weight of the fuel assembly and the fuel burnup, which is expressed in unit of GWd/MTU, and comparing it to the required cooling time in the FQT for the enrichment of the assembly.

The applicant developed this fuel qualification method using the following steps as discussed in Sections 6.2.8 and 6.5.1 of the UFSAR:

1. First, the applicant developed a step function to correlate the minimum allowable enrichment range for a given range of burnup. This step function is developed based on the spent fuel characteristics and population distribution data that are collected by the US Energy Information Agency (EIA) and published in the spent fuel database GC-859 (EIA, 2015). The applicant chose the minimum allowable enrichment for a given burnup is determined in such a way that it bounds 99.5% of the fuel assemblies collected in the database. The step function is captured in Table 7A of the TS for the EOS-37PTH DSC.
2. The step function developed in step 1 divides the spent fuel assemblies into two groups: group 1 encompasses 99.5% of the discharged fuel assemblies and the group 2 covers the rest of fuel assemblies in the database and identified as the outliers with respect to the majority of the spent fuel population. The outliers all have enrichment lower than the minimum required value determined by step 1.
3. The applicant developed the source terms based on the search through a wide range of BECTs combinations to identify the one that produces the highest total dose rate (both neutron and gamma) as the design basis BECT for the shielding analyses for the transfer cask and storage configuration for each HLZC to demonstrate that the system is capable of meeting the regulatory requirements of 10 CFR 72.104 and 72.106 under normal/off-normal and design basis accident conditions of operations, respectively. This approach assures that the design basis source terms will bound 99.5% of the BECTs for each fuel category.
4. The applicant developed one bounding FQT as presented in Table 7B of the TS for every PWR fuel assembly to be loaded in the EOS-37PTH DSC. An additional FQT, as shown in 7C of the TS, is developed for fuel located in zone 3 of HLZC 4 and HLZC 7. For example, a separate FQT is developed for zone 3 of HLZC 4 and HLZC 7 because zone 3 includes the peripheral locations that have a lower decay heat limit but with a dominating contribution to the dose rate outside the canister. The applicant provided FQT in Table 7C of the TS for the peripheral zone (zone 3) of HLZC 4 and HLZC 7. Table 7B and Table 7C of the TS provide the BECTs for 99.5% of the fuel population to be loaded in the EOS system.
5. In addition, the applicant developed a procedure to provide explicit instructions to the general licensees for handling the outliers that have enrichment lower than the minimum value as specified in Table 7B and Table 7C of the TS. Specifically, these instructions include: (1) limiting the peripheral region to at most 4 outliers (see TS Section 2.1), and (2) applying a cooling time penalty by extrapolating into the gray-shaded region of TS

Table 7B and 7C. The footnotes to these tables provides guidance for acceptability and extrapolation (ADAMS Accession Number ML19176A315).

The staff reviewed the new method and finds it to be acceptable. First, the new approach provides a reasonable assurance that 99.5% of the spent fuel assemblies, as compiled in the GC-859 database, are bounded in terms of burnup and enrichment ranges. Thus, only five out of 1000 fuel assemblies are outliers. As such, the staff does not expect that these outlier fuel assemblies will all be loaded into the same cask or the same ISFSI. To further assure correct loading of the outliers, the applicant has provided specific instructions to limit the number of outliers that can be loaded into a cask at the peripheral locations as defined in Figure 3 in the TS. The combination of these two restrictions makes it highly unlikely to have a single cask loaded with all outliers such that a storage facility would exceed the regulatory dose limits of 10 CFR 72.104 and 72.106. The staff obtained the GC-859 database and confirmed that the minimum enrichment for the range of the burnup as presented in Table 7A, 7B and 7C of the TS envelop all the fuel assemblies collected in the database.

In addition, the new approach for specifying the authorized contents provides a means for dealing with some of the fuel assemblies that are not covered by the FQTs with the burnup and enrichment ranges provided in Table 7A of the TS. Therefore, this approach is more comprehensive and consistent with the risk-informed regulatory philosophy because the decision is based on a comprehensive analysis of the known spent fuel population.

Furthermore, the applicant analyzed the contributions of the fuel assemblies in the inner and peripheral zones to the dose rate outside the cask. The results show that the fuel assemblies in the peripheral zone contribute 80% of the dose rate for the transfer cask and 95% of the maximum dose rate for the storage configuration. Similarly, shielding analyses performed by the applicant as discussed in Section 6.2.2 of the UFSAR demonstrate that the lower heat load loading patterns are bounded by the high decay heat cask. Therefore, these analyses demonstrate that the risk of exceeding the regulatory dose limits of 10 CFR 72.104 and 72.106 is minimal even with loading some of the fuel assemblies that are outside the burnup and enrichment ranges. As such, there would be no expected significant adverse impact on the public beyond the controlled area boundary if the general licensee loads the cask following the new approach as specified in the TS.

In summary, the proposed approach for specifying the authorized contents in the TS has significantly reduced the complexity and size of the TS while still capturing the most important information necessary to assure that the allowable contents are within the capacity of the shielding design. It also provides much-desired flexibility for dealing with otherwise unqualified fuel. On these bases, the staff found that the new method developed by the applicant to replace the FQTs for specification of the allowed contents is acceptable because it provides the same level of assurance for protecting the public and occupational workers as required by 10 CFR 72.236(d).

6.5 Source Terms Calculations

The applicant calculated the design basis source terms (both neutron and gamma) using the FQTs as discussed in Section 6.4, “Specification of Authorized Contents,” of this SER. The applicant selected the design basis FA primarily based upon the fuel weight because the source strength from the active fuel region is proportional to the weight of the fuel per assembly. The applicant calculated the gamma and neutron source terms of the PWR spent fuel (both intact and failed fuel) in this amendment using the ORIGEN-ARP module of the SCALE 6.0 code (SCALE, 2009). The applicant generated the ORIGEN-ARP data libraries using the two-dimensional depletion analysis code TRITON (SCALE, 2009) and the FA design data in Chapter 2 of the UFSAR. The cross sections used in the source term calculations are the 238-group cross section library that is generated from ENDF/B-VII (Brookhaven National Laboratory [BNL], 2011). The applicant provided its design basis neutron and gamma source terms and their associated spectra for each decay heat loading in Tables 6-10 through 6-19d of the UFSAR.

The applicant included the neutrons produced by subcritical multiplication of neutrons in the fuel with the equation $S^* = S/(1 - k_{eff})$, where S is the neutron source generated by the spent fuel, k_{eff} is the neutron multiplication factor of the system under dry storage conditions, and S* is the neutron source used in the shielding calculations.

The staff reviewed the information provided by the applicant for its source term calculations in Section 6.2.1 of the UFSAR and finds that the computer code and data the applicant used are appropriate. The TRITON code is a transport-theory-based spent fuel depletion analysis code that provides the most advanced and reliable source term calculation method for spent fuel because neutron transport theory is the most accurate representation of the nuclear particle transport phenomenon. The TRITON code also is one of the recommended computer codes of NUREG-1536, Revision 1, for source term calculations of spent fuel. Also, the staff finds that the ENDF/B-VII (BNL, 2011) cross section library used in the source calculation is the most advanced one for nuclear reactor applications and therefore is appropriate for this application.

The staff performed confirmatory analyses of the source terms (neutron and gamma) based on a few selected BECT combinations for the design based spent fuel without natural uranium blankets. In its confirmatory analyses, the staff used the ORIGEN-ARP module of the SCALE 6.1 code (SCALE, 2011) with the spent fuel characteristic database distributed with the code. The results of the staff's analyses confirm the design basis source terms presented in the UFSAR. On this basis, the staff determined that the design basis source terms presented in the UFSAR are bounding and acceptable.

The applicant states that some of the fuel may contain axial natural uranium blankets at the ends of the FA. In Section 6.2 of the UFSAR, the applicant asserts that for axial blankets that are up to 10% of the active fuel length (5% each end), the effect on the source term is negligible, and the presence of axial blankets would have little effect on the overall dose assessment. Therefore, the applicant did not consider the axial natural uranium blankets in the source term and shielding calculations. The staff reviewed the applicant's justification for not considering the effect of the natural enrichment uranium blankets on the source terms and their axial distributions.

The staff does not agree with the applicant's assertion because the natural uranium blankets on a fuel assembly will cause the burnup in the middle section of fuel to peak significantly for three reasons:

(1) The fuel assemblies containing natural uranium blankets will substantially tilt the neutron flux to the center of the reactor because neutrons produced by fissions in the natural uranium blankets are minimal.

(2) As a result, the burnup of the fuel assembly will peak up in the center region of the fuel because the natural uranium blankets do not produce much energy. The middle part of the fuel must take the extra share of the total fuel burnup; the fuel burnup is given based on the total uranium load in the FA.

(3) The combined effects of items 1 and 2 will lead the neutron and gamma sources in the middle part of the fuel assembly to peak even more because, based on the research published in NUREG/CR-6802 “Recommendations for Shielding Evaluations for Transport and Storage Packages”, the neutron source of a fuel assembly is proportional to the 4.12 power of burnup, i.e., $BU^{4.12}$, where BU is the local burnup.

For these reasons, not accounting the natural uranium blankets in the source terms will produce a greater than 20% underestimate of the neutron source, contrary to the applicant’s determination that the underestimates are insignificant (ADAMS Accession Number ML19176A315).

Also, the applicant assumed 500 parts per million (PPM) of Co-59 impurity in the fuel hardware (e.g., spring in the plenum, end fitting) in the calculation of the gamma source of the activated metal. Because this assumption is inconsistent with the measured value of Co-60 impurity in Inconel-718 based on the measurements published in PNL-6909 (Luksic, 1989), which states that the typical value of the Co-60 impurity is at 0.1 weight percent (1000 PPM) of the fuel hardware, the staff requested the applicant to provide documentation to support its assumption. In its response to the staff’s question (ADAMS Accession Numbers ML19176A315 and ML19204A228]), the applicant states that modern FAs have significantly less cobalt impurity in the stainless steel and Inconel structural materials. To reflect modern fuel designs, the cobalt impurity for these materials has been set to 500 ppm. Older FAs (more than 20 years old) with potentially higher cobalt impurity will have experienced several half-lives of Co-60 decay. The applicant further states that the industry reduced the Co-59 impurity in fuel assembly hardware between the late 1980s and the early 1990s and its discussions with a specific fuel vendor indicate that 500 ppm Co-59 impurity bounds the impurity of metals in a fuel assembly. However, the applicant did not provide any documentation that demonstrates that the 500 PPM Co-59 impurity has been adopted as a mandatory industry standard. As such, the staff does not find this justification to be acceptable because any other vendor can still make fuel assemblies with hardware at different levels of Co-59 impurity. However, the staff finds the dose rate limits set in the TS for the storage cask conservative because they are calculated based on a lower Co-59 impurity in the fuel hardware. As a result, to meet this TS, users will be prohibited from loading fuel into the cask with higher Co-60 levels unless it is loaded with fuel that has a lower overall source term..

6.6 Shielding Analyses

The applicant calculated the dose rates around the transfer cask, the dose rates around the storage cask and the front door, and the annual dose at the control area boundary with a hypothetical array of modules.

6.6.1 Shielding Models

As discussed in Section 6.4 of the UFSAR, the applicant performed shielding analyses using the MCNP5 v1.40 (X-5 Monte Carlo Team, 2008) computer code. MCNP5 is a nuclear particle transport theory-based Monte Carlo solution method computer code for simulation of nuclear particle transport phenomenon. It allows full three-dimensional modeling of the EOS-TC and EOS-HSM/HSM-MX. It is one of the recommended codes of NUREG-1536, Revision 1.

To capture the secondary gammas produced by the (n, gamma) reactions in the system, the applicant turned on the MODE n, p card and added the tally for the gamma particles in the MCNP models. The staff finds that that applicant correctly set up the neutron transport model because this is the only means for capturing the secondary gammas in the neutron transport (dose rate) calculation in the MCNP model. On this basis, the staff finds the applicant's modeling of neutron transport to be acceptable.

For intact fuel, the applicant assumed that the fuel assembly will retain its geometric dimensions and the corresponding source distribution under normal, off-normal, and design basis accident conditions. For damaged and failed fuel, the applicant considered the potential source relocation as a result of fuel movement during normal, off-normal, and accident conditions with credible scenarios. The staff reviewed the applicant's analyses of potential source relocation scenarios and finds the applicant's assumptions and approximations to be acceptable because these scenarios are consistent with potential physical movement of the fuel debris and segments in the FFC.

The applicant modeled the transfer cask and the storage cask with the geometry shown in the engineering drawings as provided in UFSAR Chapter 1 and UFSAR Appendix A.1. However, in the HSM models, the applicant used nominal dimensions for the concrete components. The staff requested a justification for why the minimal dimension (nominal dimension minus the manufacturing tolerance) was not used. The applicant responded that it assumed a lower density concrete that is sufficient to compensate for the non-conservative assumption (i.e., using the nominal instead of the minimum thickness of the concrete). However, the applicant did not provide a sensitivity analysis to demonstrate its assertion.

The staff reviewed the structural dimensions of the HSM and the allowable manufacturing tolerances and finds that the allowable tolerance is about 4% of the nominal thickness of thick concrete shielding components. Since the manufacturing tolerance in the shielding model is only a small fraction of the total thickness of the concrete components, modeling the HSM at nominal dimensions will not significantly underestimate calculated dose rates. On these bases, the staff determined that the results of the calculated dose rates around the TC, HSM, and the controlled area boundary are acceptable.

In addition, the applicant states that it did not take credit for the rebar that is in the concrete. The staff notes that including the rebar in the concrete may produce a slightly higher dose rate because the (n, γ) reactions between thermalized neutrons and Fe-56 will produce secondary gammas with energy from 5.92 MeV to 7.65 MeV (Kim et al., 2006), and the cross section is about 100 barns at 0.01 eV (from the ENDF/B-VII.1 cross section library [BNL, 2011]). Plus, there is very little gamma shielding material after the rebar. However, the staff views the risk of producing a significant number of secondary gamma radiation as low because the volume fraction of the rebar in the concrete is small and the rebar is sparsely arranged in the concrete. The staff's determination that there is reasonable assurance that the dry cask storage system design meets the regulatory requirements is based on evaluation of this specific design.

6.6.2 Material Properties

The applicant provided a bill of materials for the various components of the EOS system. The spent fuel is assumed to be unirradiated, i.e., fresh UO_2. The applicant also provided several sample input and output files for the TC and HSM shielding models. The staff reviewed the material properties and finds that they are consistent with the bill of materials. Although there is a slightly higher secondary gamma and neutron source if the fuel is modeled with the actual spent fuel composition, the difference is insignificant in terms of the dose rate. On this basis and risk-informed considerations, the staff finds that the specifications of the materials in the shielding models are acceptable.

6.6.3 Shielding Analyses

The applicant provided shielding analyses for the previously approved basket designs for intact fuel with reduced cooling time (2 years) as well as the new canister design containing intact fuel, intact fuel with a maximum of 8 damaged fuel assemblies, or intact fuel assemblies with a maximum of 4 failed fuel assembly worth of fuel in the locations as specified in the TS.

The applicant performed shielding analyses to demonstrate that the EOS system as amended continues to meet the regulatory requirements of 10 CFR 72.236(d). The applicant provided estimated dose rates around the transfer cask, the storage module, and the dose rate as a function of distance from a hypothetical 2x10 array of storage module for distances of 6.1 m (20 ft) to 600 m from the ISFSI pad. The applicant also provided an estimated annual dose received by a real individual at the controlled area boundary for an array of EOS under normal, off-normal, and accident conditions. The results are documented in Chapter 11, “Radiation Protection,” of the UFSAR based on the near-field dose rates of a design basis EOS ISFSI as presented in Chapter 6 of the UFSAR.

In the shielding models, the applicant divided the FA into four axial regions: top nozzle, plenum, active fuel, and bottom nozzle. For the top nozzle, plenum, and bottom nozzle, the only isotope that contributes appreciably to the dose rate is Co-60, which arises primarily from cobalt-59 activation of the stainless steel and Inconel in the FA structural materials. The top nozzle, plenum, and bottom nozzle regions are outside of the active fuel region and experience a reduced neutron flux compared to the active fuel region. The applicant used a flux scaling factor for each region to estimate the reduction in the neutron flux compared to the active fuel region based on PNL-6906 (Luksic, 2003). Flux scaling factors are provided in Table 6-4 of the UFSAR.

The staff reviewed the applicant's calculation of the source term from the fuel hardware and finds it to be consistent with the acceptance criterion of NUREG-1536, Revision 1. On this basis, the staff finds that this estimation method for the source in the plenum and end fittings of the fuel assembly is acceptable.

The applicant states that fabrication/installation gaps may exist between the base module and the rear, end, and corner shield walls. The applicant modeled the width, including the Z-gap between the end shield wall segments, to capture additional streaming path for gamma radiations. The staff reviewed the engineering drawings and finds this assumption to be conservative and acceptable.

The applicant also calculated the contribution to the dose rates from the activated metal of the control components (CCs) to be stored within a PWR FA. Several CC types are authorized to be stored in the EOS-37PTH DSC as described in the TS. Examples include burnable poison rod assemblies (BPRAs) and thimble plug assemblies. Control components typically have a Co-60 source because of its light element activation, which contributes substantially to the dose rates. The limit for the maximum radioactivity and the corresponding gamma source strength for each CC in each zone is provided in Table 6-37 of the UFSAR.

The staff reviewed the data presented in Table 6-37 of the UFSAR and the gamma sources used in the shielding models and finds that the models used the correct data. The staff finds that the sources used by the applicant for shielding analyses of the EOS-37PTH DSCs containing CCs are the same as the design limits on the radioactivity of the CCs. On this basis, the staff determined that the shielding analyses for EOS-37PTH DSCs containing authorized CCs are appropriate and acceptable.

The applicant calculated the annual dose at the controlled area boundary based on the average fluxes and dose rates on the faces of the EOS-HSM with a generic 2x10 back-to-back array and two front-to-front arrays of the EOS-HSM and presents the results in Chapter 11 of the UFSAR. These average fluxes and dose rates are computed on the surface of a box that envelops the EOS-HSM model, including the vent covers, door, and fabrication gaps. The average end shield wall dose rates are computed with the 2x1 EOS-HSM “single reflection.” To capture the contribution from side-by-side or back-to-back EOS-HSMs, the applicant developed additional “double reflection” and “triple reflection” models. “Reflection” means the model assumes that the radiation from the EOS-HSM is reflected back. This is a common practice to simulate repeated radiation sources, i.e., another identical source is at the adjacent location of the current source in shielding calculations.

In the “double reflection” model, the end shield wall and corner shield wall are ignored, and a reflective boundary is added on the right side. The double reflection model simulates an EOS-HSM with an adjacent EOS-HSM on each side. Gaps between the modules are included. This model is only used to compute the average fluxes and dose rates on the rear shield wall used as input to the site dose calculations.

In the “triple reflection” model, all shield walls are removed and replaced with reflective boundaries. This model is illustrated in Figure 6-14 of the UFSAR. The triple reflection model simulates an EOS-HSM with an adjacent EOS-HSM on each side and back-to-back.
The triple reflection model is used to compute the average dose rates on the front and roof used as input to the site dose calculation. The triple reflection model is also used to compute vent and gap dose rates.

Under the storage condition, the applicant calculated the dose rates around the storage modules and added the calculated dose rates in the Administrative Controls program of the TS. Specially, the dose rate limits are set as:

For EOS-HSM:

i. 25 mrem/hr average over the front face;
ii. 10 mrem/hr at the door centerline; and
iii. 5 mrem/hr average at the end shield wall exterior.

For HSM-MX:

i. 50 mrem/hr average over the front face;
ii. 10 mrem/hr at the door centerline; and
iii. 5 mrem/hr average at the exterior side wall of the HSM-MX monolith.

The staff reviewed the shielding calculation package, which includes the input and output files for the storage models and finds that the models are consistent with the design of the system and assumptions and approximations as stated in the UFSAR. The staff also finds from the output files that all shielding calculations have properly converged, since these calculations passed all 10 of the MCNP convergence indices.

The staff finds from the UFSAR that the maximum annual dose for a real individual at the controlled area boundary is 1.38 mrem based on the dose rate versus distance as shown in Table 11-8 of the UFSAR. Because the applicant made non-conservative assumptions in the source term and shielding calculations, such as not considering the impact of natural uranium blankets in source term calculations and use of the nominal dimensions for the concrete components in the EOS-HSM and HSM-MX models, the actual dose at the controlled area boundary can potentially be 20% larger than the calculated (i.e., the actual dose could be 1.65 mrem per year). However, the annual dose at the controlled area boundary is still within the regulatory limit of 25 mrem per year. Because it is unlikely that the cask will be loaded to the design basis limits on source terms, the potential of exceeding the regulatory dose limits set forth in 10 CFR 72.104 is low. On this basis, the staff finds that the shielding design of the NUHOMS® EOS is acceptable.

The applicant performed shielding analyses for the EOS-TC calculations for three general configurations that represent the various operational evolutions associated with loading and transfer operations: 1) loading/decontamination; 2) welding/drying; and 3) upending/transfer. These dose rates are computed without any supplementary shielding. The applicant provides summaries of the limiting normal condition surface dose rates for these configurations in Table 6-52 and Table 6-53 for the EOS-TC108 and EOS-TC125/135, respectively. When the EOS-TC is fully prepared for the transfer operation, the maximum dose rate occurs at the side of the EOS-TC. The EOS-TC108 has larger dose rates than the EOS-TC125/135 because it is a lighter cask and provides less shielding.

Because HLZC 6 and 8 are the only configurations of the EOS-37PTH DSC that allow for damaged or failed fuel, the applicant calculated the dose rates of the EOS-TC125/135 loaded with damaged or failed fuel using the source terms for HLZC 6 or 8 of the EOS-37PTH DSC. The applicant assumed that under normal conditions failed fuel could be in the form of a fuel assembly, or as individual fuel rods/fragments that can be placed in a secondary container, before being loaded in an FFC. In the model, the applicant did not take into account the FFC. Therefore, MCNP models are developed only for a failed fuel assembly, which bounds failed fuel in an FFC. The applicant considered three possible configurations in its analyses for failed fuel.

Configuration N1:

Damaged and failed fuels are modeled as intact fuel assemblies.

Configuration N2:

Damaged fuel is modeled as intact and failed fuel is modeled in accordance with the result of fuel reconfiguration analyses of EOS-TC at a horizontal position. This configuration is consistent with normal and off-normal conditions and represents failed fuel shifting to one side when the EOS-TC is moved from vertical to horizontal.

Configuration N3:

In the EOS-TC125/135 shielding analyses, damaged fuel is modeled as intact and failed fuel is modeled in accordance with the result of fuel reconfiguration analyses of EOS-TC at a horizontal position. This configuration is consistent with normal and off-normal conditions.

The staff reviewed the applicant’s modeling of the EOS-37PTH DSC containing failed or damaged fuel and finds scenarios N2 and N3 are consistent with the TS. Scenario N1 does not represent any plausible configuration under normal, off-normal, and accident conditions of operations because the canister is loaded in a vertical position and then lowered to horizontal position for transfer operation. During these operations, the failed and damaged fuel will relocate and so do the sources. As such, scenario N1 does not represent any actual source configuration and therefore the staff did not perform any detailed review of scenario N1.

The applicant presented the expected maximum dose rates in the UFSAR for various stages of the loading operations of canisters containing entirely intact fuel or mixed intact fuel with damaged/failed fuel. The estimated dose rates are documented in Chapter 6 of the UFSAR. The users of this cask design should review this information in developing a radiation protection plan and radiation work permit (RWP) in accordance with the regulatory requirement of 10 CFR 72.104(b), which states that “[o]perational restrictions must be established to meet [ALARA] objectives for radioactive materials in effluents and direct radiation levels associated with ISFSI or MRS operations.”

The applicant also evaluated the shielding design of the system under design basis accident conditions. Through its structural analyses, the applicant determined that the only credible accident scenario that could impact the shielding capability of the system is loss of neutron shield of the TC. The applicant developed an MCNP model for the EOS-TC in which the neutron shield is assumed to be lost. The EOS-TC accident dose rates at 100 m are reported in Table 6-54. Assuming that it would take 8 hours to recover from the accident, the estimated dose to an individual at the site boundary (i.e., a "real individual") would be 35 mrem. This is significantly below the 10 CFR 72.106 dose limit of 5 rem. The applicant asserts that the loss of TC neutron shield is the only plausible accident scenario. The staff found this assertion acceptable as the structural analyses demonstrated that the storage models will withstand the impacts of design basis accidents. In addition, the staff finds that it is conservative to assume that the "real individual" is 100 meters from the accident in calculating the dose received because the minimal distance for a 2x10 ISFSI is around 400 meters from the ISFSI pad based on Table 11-8 of the UFSAR.

The staff reviewed the applicant's shielding analyses and the results of the staff's structural safety evaluation and determined that the applicant has appropriately considered accident conditions. The staff finds the conclusion that the sole credible accident scenario that could impact shielding is loss of the TC neutron shield to be acceptable. The staff finds that the applicant's evaluation of the dose for a "real individual" at the controlled area boundary is in accordance with Spent Fuel Project Office, Interim Staff Guidance – 13, Real Individual, and that the results demonstrate that the dose at the controlled area boundary is below the regulatory limit. On these bases, the staff finds that the applicant has demonstrated that the EOS dry cask spent fuel storage system, as amended, continues to meet the regulatory requirements of 10 CFR 72.104 and 72.106.

6.5.4 Computer Codes and Cross Section Library

The applicant used the same computer code, MCNP5 v1.40, and the associated cross section in the shielding analysis as it used in the previously approved EOS design. For this reason, the staff finds this acceptable and did not perform a review of the applicability of the code and the associated cross section library.

6.5.5 Flux-to-Dose Rate Conversion

The applicant used the ANSI/ANS-6.1.1-1977 flux-to-dose rate conversion factors for neutron and gamma dose rates. The staff finds it acceptable because it meets the acceptance criteria of NUREG-1536, Revision 1, for flux-to-dose rate conversion factors.

6.6 Evaluation Findings

The staff reviewed the application for an amendment to the EOS spent fuel dry storage system design. Based on its review, the staff determined:

F6.1 Sections 1.1 and 6.1 of the UFSAR describe(s) shielding structures, systems, and components (SSCs) important to safety in sufficient detail to allow evaluation of their effectiveness. Licensing drawings EOS01-1010-SAR, sheets 1 to 11 provide the structural configuration and dimensions of the EOS-37PTH DSC. Licensing drawings EOS01-1010-SAR, sheets 12 to 15 provide the structural configuration and dimensions of the end cap and FFC.

F6.2 Sections 6.1 through 6.4 of the UFSAR provide reasonable assurance that the radiation shielding features are sufficient to meet the radiation protection requirements of 10 CFR Part 20, 10 CFR 72.104 and 10 CFR 72.106.

F6.3 Operational restrictions to meet dose and ALARA requirements in 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106 are the responsibility of the site licensee. The shielding features of the EOS spent fuel dry storage system are designed to assist in meeting these requirements.

Based upon its review, the staff has reasonable assurance that the design of the shielding system of the EOS system is in compliance with the regulatory requirements of 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the shielding system design provides reasonable assurance that the system will allow safe storage of spent fuel and control components as specified in the TS in accordance with 10 CFR 72.236(d). This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, accepted engineering practices, the statements and representations in the application, and risk-informed regulation philosophy.

6.7 References

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SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluations, ORNL/TM-2005/39, Version 6, Vols. I–III, January 2009. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-750.

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X-5 Monte Carlo Team, “MCNP – A General N-Particle Transport Code, Version 5,” LA-UR-03-1987, Los Alamos National Laboratory, February 1, 2008.

7.0 CRITICALITY EVALUATION

The staff reviewed the information provided by the applicant and found the five following changes requested in Amendment No. 1 to require criticality evaluation:

1. Change No. 1, add a new basket type (Type 4) with staggered alignment of the steel, aluminum, and poison basket plates to the EOS-37PTH DSC. This change allows for the loading of intact, damaged or failed fuel.
2. Change No. 2, add a new basket type (Type 5) that is comparable in geometry to existing Types 1, 2 and 3 baskets but with the low conductivity poison and low emissivity option of the Type 4 basket with the ability to be stored in either the EOS-HSM or the new NUHOMS® MATRIX design for the EOS-37PTH DSC.
3. Change No. 3, accept fuel assemblies with a minimum cooling time of two years, in selected locations, as contents of the EOS-37PTH DSC.
4. Change No. 4, add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel in an EOS-37PTH or an EOS-89BTH DSC.
5. Change No. 5, revised certain CoC and TS conditions for consistency and clarity, as described further in the application package.

7.1 Change No. 1: Addition of the Type 4 Basket

For the EOS-37PTH, the applicant proposes to add a new basket type (Type 4) that allows the loading of intact, damaged or failed fuel. This basket type includes two options. The option that may include damaged fuel includes low emissivity for the steel plates and a low conductivity poison option and is identified as Type 4L. The option that includes the standard basket plates and poison is identified as Type 4H. The Type 4H basket may be stored in either the EOS-HSM or the new NUHOMS® MATRIX design and, based on Table 1-2 of the UFSAR, may be transferred onsite using either the EOS-TC125 or the EOS-TC135.

The staff reviewed the changes to drawing EOS01-1010-SAR (Revision 2C) in Section 1.3 of the UFSAR and confirmed that the dimensions of the basket that are important for criticality safety, including the basket cells and the thickness of the basket walls and poison plates, are identical to that of the previously approved baskets (Type 1, 2, and 3). The only difference is that in the damaged/failed fuel basket (Type 4), the aluminum is offset vertically. This does not have any adverse effect on the criticality safety of the basket as it does not change the geometry of the basket where the fuel is located. The staff's review with respect to the criticality safety due to the inclusion of the Type 4 basket (Change No. 1) is focused on the criticality safety analyses of the system when including damaged/failed fuel in the Type 4L basket.

The applicant proposes to allow a maximum of 8 damaged fuel assemblies or a maximum of 4 failed fuel assemblies. The damaged/failed fuel assemblies must be placed in specific locations as designated by Figure 1F and 1H of the TS. These figures also state that damaged and failed fuel are not allowed in the same basket. Section 1.1 of the proposed TS states that failed fuel must be located in a failed fuel canister (FFC). Section 2.1 of the proposed TS states that the basket cells that store the damaged fuel assemblies must have top and bottom end caps. The amount of uranium allowed within a FFC is restricted for each assembly class by Table 2 of the proposed TS.

The applicant used the KENO V.a module of the CSAS5 sequence of SCALE 6.0 to perform the criticality safety evaluation. This is the same code used to perform the criticality safety calculations in support of the original issuance of this CoC and therefore the staff found it acceptable to use to model the EOS system to support the modeling of the damaged/failed fuel and fuel debris.

The applicant used the transfer cask for its criticality safety model of the EOS system as this is the most reactive configuration as the storage configuration will be dry when inserted into the EOS-HSM or HSM-MX (i.e. no water in-leakage). Damaged fuel is only allowed in EOS-TC125 and EOS-TC135, which is the transfer cask used in the criticality safety model. The staff found this acceptable.

Section 7.4.1.3 and 7.4.2.D of the UFSAR lists the considerations made by the applicant within its analysis for determining the most reactive configuration for damaged/failed fuel. The applicant performed analyses to consider the effects of fuel pitch variation to account for the possibility of fuel rods crushed inward or bowed outward. The applicant performed analyses to consider the effects of missing fuel rods and replacing guide and instrument tubes with fuel rods and the effects of removing cladding for rods that may have cladding missing. The applicant also considered single and double shear scenarios where a row of rods is displaced or severed. The staff found that accounting for these possible effects is consistent with the definition of damaged and failed fuel per the definitions in Section 1.1 of the proposed TS as recommended in Section 7.5.2.2 of NUREG-1536, Revision 1.

The applicant found that the most reactive configuration is with optimum pitch and full fuel lattice with guide tubes replaced by fuel rods. This is based on the analysis results in Appendix P.6 of the Standardized NUHOMS® CoC No. 1004 UFSAR Revision 16 (ADAMS Accession Number ML19058A287). Although this is a different system than the EOS, the staff found that the reactivity trend would be similar due to the basket geometry, fuel assemblies and soluble boron concentrations and boron loadings of the basket being similar, which mostly controls the reactivity, with external cask materials and the variation in dimensions only having lesser effects on reactivity. The differences between the EOS and Standardized NUHOMS® may show different magnitudes in the reactivity effects but the staff found that the overall trend would be the same. In determining the applicability of the Standardized NUHOMS® assumptions to the EOS, the staff also considered that the damaged fuel model is conservative with respect to a realistic damaged fuel assembly and includes other conservative assumptions such as not taking credit for burnup. Therefore, the staff finds the applicant's assumptions for modeling the damaged/failed fuel acceptable.

The applicant did not take credit for the presence of the FFC, the staff found this assumption acceptable as the presence of FFC will restrict the pitch and also displace moderator, and both effects would cause reactivity to decrease and not including it within the model is conservative. The applicant modeled both damaged and failed fuel the same way; they were both modeled as failed fuel and assumed there were 12 failed fuel assemblies instead of 8 damaged or 4 failed fuel assemblies. This is conservative as damaged and failed fuel are not allowed to be stored together (Figure 1F and 1H of the TS). Because damaged fuel is more reactive than intact fuel, modeling additional damaged/failed fuel assemblies is conservative.

To investigate the reactivity effects of removing the cladding the applicant performed evaluations without the cladding in the EOS system using the most reactive fuel type of each class. The applicant documented the results in Table 7-49 of the UFSAR which shows that the most reactive condition is with cladding removed, and therefore performed all damaged fuel evaluations without cladding. This is consistent with the staff's experience and is due to the increase in moderator when the fuel cladding is replaced with moderator.

To find the most reactive pitch the applicant performed evaluations modifying the pitch within the EOS system using the limiting intact fuel assembly parameters from the intact fuel evaluations. The applicant also varied the number of missing fuel rods to determine the most reactive configuration. The results of the applicant's analyses show that reactivity decreases as fuel rods are removed. The applicant also determined the most reactive internal moderator density for each configuration. The results of the applicant's evaluations are documented in Table 7-50 of the UFSAR. The staff reviewed this information and found that the applicant determined the most reactive pitch, number of missing rods and internal moderator density for the most reactive assembly within each fuel assembly class.

Since the EOS is also allowed to store fuel debris, Section 7.4.1.3 and 7.4.2.F of the UFSAR also described the applicant's assumptions for failed fuel assembly debris, which is allowed based on the definition of failed fuel in Section 1.1 of the proposed TS.

The fuel debris analysis is more reactive (produces a higher k-eff) than the failed fuel analysis. The applicant assumed 4 failed fuel assemblies which is consistent with the amount allowed within the proposed TS. The assumptions are similar to those of the damaged/failed fuel except that instead of using the fuel diameter from the limiting intact fuel assembly the applicant varies the diameter and array size in addition to the pitch and the internal moderator density. The applicant considered a range of pellet diameters and array sizes as listed in Table 7-80 until peak reactivity is identified. The applicant also shows the range of fuel mass loadings used with the variation in array size and fuel pellet diameter in Table 7-81 of the UFSAR. The staff found the range of analyzed fuel mass loadings to be within limits of the allowable uranium mass from Table 2-4b of the TS. Results of the applicant's analyses of the most reactive fuel debris configuration are listed in Table 7-80 of the UFSAR. The staff reviewed this information and found that the applicant determined the most reactive configuration for fuel debris.

The applicant used the most reactive damaged/failed fuel model to determine the allowable enrichment of the damaged/failed fuel. The applicant demonstrated that for the most reactive fuel class that the fuel debris model is bounded by the damaged/failed fuel model and therefore the applicant did not determine separate enrichment limits for the fuel debris. The staff verified this by comparing the results from Table 7-80 of the UFSAR for fuel debris to that of the same fuel assembly class in 7-62 (without control components) and found that the damaged/failed fuel model is slightly higher than that of the fuel debris model. The differences are close enough that it is difficult to conclude that the damaged/failed fuel model will always be limiting for all conditions specified in the proposed TS, however the staff has reasonable assurance that the fuel debris model is represented by the damaged/failed fuel model. In making this judgment, the staff took into consideration the conservatisms within the model such as the fresh fuel assumption (i.e. no credit for burnup).

The applicant calculated the k-eff for all conditions specified within Table 4 of the TS including both basket types (A and B) that have the 2 different boron loadings, and all allowable soluble boron concentrations and configurations with and without control components. The results of these calculations are shown in Tables 7-52 through 7-79 of the UFSAR. The staff reviewed these tables and confirmed that the k-eff for these conditions are all below the upper subcritical limit and that the conditions are appropriately reflected in the proposed TS within Table 4 for each fuel class.

The applicant has updated Table 4 of the proposed TS and Table 7-51 of the UFSAR to reflect that the maximum enrichment limits for the various soluble boron concentration limits are applicable to all of the basket types for intact fuel and the A4L and B4L for the damaged fuel. The staff finds that the applicant has adequately defined the limits for the damaged fuel within the proposed TS and that adding the damaged/failed fuel for Basket Type 4L meets the criticality safety regulations in 10 CFR 72.124 and 72.236(c).

7.2 Change No. 2: Addition of the Type 5 Basket

For the EOS-37PTH, the applicant proposes to add a new basket type (Type 5) that is comparable in geometry to currently approved Types 1, 2 and 3 but with the low emissivity for the steel plates and a low conductivity poison. The Type 5 basket may be stored in either the EOS-HSM or the new NUHOMS® MATRIX design and may be transferred onsite using either the EOS-TC125 or the EOS-TC135.

The EOS-37PTH basket Type 5 poison (B-10) loading requirements for the MMC are in Table 5 of the TS (Appendix B to the CoC) and are the same as those used with basket Types 1, 2, and 3. The staff verified that this has not changed since the last amendment as the amount of absorber used within the criticality analysis in Table 7.1 of the UFSAR bounds (is lower than) that of the requirement in Table 5 of the proposed TS and therefore the staff found the Type 5 basket acceptable for all spent fuel contents previously approved for the EOS-37PTH, which includes all intact fuel assemblies described in Table 1 of the proposed TS including enrichment and soluble boron restrictions in Table 4 of the proposed TS. As a result, the staff finds that adding the new basket type (Type 5) meets the criticality safety regulations in 10 CFR 72.124 and 72.236(c).

7.3 Change No. 3: Reduce the Cooling Time to Two Years

For the EOS-37PTH, the applicant proposes to revise the allowable contents to include fuel assemblies that have a minimum cooling time of two years. This change does not affect the criticality safety of the EOS system as the criticality safety analysis assumes a fresh fuel composition and the staff found that the system will still meet the criticality safety regulations in 10 CFR 72.124 and 72.236(c) with this change.

7.4 Change No. 4: Addition of the HSM-MX Design

The applicant proposes to add a new NUHOMS®-MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel canistered in an EOS-37PTH or an EOS-89BTH DSC. The applicant has discussed this change in Appendix A of the UFSAR. Appendix A of the UFSAR does not include an updated Section A.7 on criticality. The staff reviewed the previous UFSAR (ADAMS Accession Number ML18043A204) to determine if the criticality safety analysis performed for the EOS-HSM bounds that of the HSM-MX.

The addition of the HSM-MX allows the fuel DSCs to be stored in a 2-tiered staggered structure versus the single tier of the currently approved EOS-HSM. The HSM-MX would increase neutron interaction for each of the DSC canisters, however this increase will be small as compared to the reactivity of the TC when flooded with moderator (water).

The criticality safety analysis documented in Chapter 7 of NUREG/CR-7203, “Quantitative Impact Assessment of Hypothetical Spent Fuel Reconfiguration in Spent Fuel Storage Casks and Transportation Packages”, states that the reactivity of the canister in the TC bounds that within the storage module because the canister in the storage module is dry and without moderator. The staff agrees with this statement because nuclear fuel is undermoderated (i.e. adding moderator, water, increases reactivity) and the applicant does not take credit for burnup. Therefore, the staff finds that the design of the dry storage module does not affect the EOS system’s ability to maintain subcriticality and therefore meets criticality safety regulations in 10 CFR 72.124 and 72.236(c).

7.5 Change No. 5: CoC and TS Modifications for Consistency and Clarity

The applicant has proposed to modify certain CoC and TS items for consistency and clarity. The staff reviewed these additional changes and did not find that they adversely affect the criticality safety of the system and therefore meets regulations in 10 CFR 72.124 and 72.236(c).

7.6 Evaluation Findings

The staff has reviewed the 10 CFR Part 72 acceptance criteria and as a result of the proposed changes in this amendment the staff has made the following findings:

F7.1 Structures, systems, and components important to criticality safety are described in sufficient detail in Chapters 1, 2 and 7 of the UFSAR to enable an evaluation of their effectiveness.

F7.2 The cask and its spent fuel transfer systems are designed to be subcritical under all credible conditions.

F7.3 The criticality design continues to be based on favorable geometry, fixed neutron poisons, and soluble poisons of the spent fuel pool. An appraisal of the fixed neutron poisons has shown that they will remain effective for the term requested in the CoC application and there is no credible way for the fixed neutron poisons to significantly degrade during the requested term in the CoC application; therefore, there is no need to provide a positive means to verify their continued efficacy as required by 10 CFR 72.124(b).

F7.4 The analysis and evaluation of the criticality design and performance have demonstrated that the cask will enable the storage of spent fuel for the term requested in the CoC application.

The staff concludes that the criticality design features for the EOS Amendment No. 1 are in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the criticality design provides reasonable assurance that the EOS Amendment No. 1 will allow safe storage of spent fuel. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

8.0 MATERIALS EVALUATION

The staff reviewed the information provided by the applicant and found the five following changes requested in Amendment No. 1 to require materials evaluation:

1. Change No. 1, add a new basket type (Type 4) with staggered alignment of the steel, aluminum, and poison basket plates to the EOS-37PTH DSC. This change allows for the loading of intact, damaged or failed fuel.
2. Change No. 2, add a new basket type (Type 5) that is comparable in geometry to existing Types 1, 2 and 3 baskets but with the low conductivity poison and low emissivity option of the Type 4 basket with the ability to be stored in either the EOS-HSM or the new NUHOMS® MATRIX design for the EOS-37PTH DSC.
3. Change No. 3, accept fuel assemblies with a minimum cooling time of two years, in selected locations, as contents of the EOS-37PTH DSC.
4. Change No. 4, add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel in an EOS-37PTH or an EOS-89BTH DSC.
5. Change No. 5, revised certain CoC and TS conditions for consistency and clarity, as described further in the application package.

The staff reviewed and evaluated the application using the guidance in Chapter 8 of NUREG-1536, Revision 1, to reach reasonable assurance of adequate materials performance under normal, off-normal, and accident-level conditions. Staff review of the application identified a limited number of changes associated with the materials evaluation areas listed in NUREG-1536, Revision, 1 Section 8.2.

8.1 General Design and Materials

The staff reviewed the applicant's changes in CoC No. 1042 Amendment No. 1 pertaining to cask design and materials, environmental conditions and the engineered drawings. The staff review of the applicant's changes in this section included:

- Change No. 1 EOS-37PTH DSC, new type 4 basket with staggered plates and allow the loading of damaged and failed fuel in the EOS-37PTH DSC including the failed fuel cans
- Change No. 2: For the EOS-37PTH DSC, add a new type 5 basket
- Change No. 4 Add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel canistered in an EOS-37PTH or an EOS-89BTH DSC.

8.1.1 Storage System Design and Materials

The applicant provided a description of the proposed changes. As described in UFSAR Section 8.2.1, the overall design of the storage system and materials used in the EOS storage system is comparable to the original approved CoC. The applicant made no changes to the canister pressure boundary materials or designs, basket materials, or shielding materials.

In UFSAR Section 1.1, the applicant described the new type 4 basket with staggered plates and a low conductivity neutron absorber material and optional low emissivity coating included in Change No. 1. The applicant clarified that the type 4 basket does not use new materials compared to previously approved basket designs. The applicant stated that the staggered plate basket design eliminates small gaps in the basket plates that could potentially allow material in one basket cell to be transported to an adjoining basket cell. The applicant stated that the purpose of this design change is to prevent a particle from a damaged or failed fuel assembly from being transported from one basket cell to another.

In UFSAR Section 2.2.1, the applicant stated that the new type 4 basket in the EOS-37PTH DSC may be used to store damaged fuel using the damaged fuel basket end caps. The applicant stated that the damaged fuel end caps are designed to keep the contents of the damaged fuel in the basket cell where the damaged fuel is loaded. The applicant also stated that the damaged fuel basket end caps allow the damaged fuel to be unloaded if necessary. The applicant showed that the damaged fuel end caps have a screen on both the top and bottom end caps that allow the damaged fuel to be dried and inerted while retaining fuel particles that may be released from the damaged assembly.

The applicant stated that the new type 4 basket in the EOS-37PTH DSC may be used to store failed fuel using failed fuel cans. The applicant stated that the failed fuel cans are designed to keep the contents of the failed fuel in the basket cell where the failed fuel is loaded. The applicant also stated that the failed fuel cans allow the failed fuel to be unloaded if necessary. The applicant showed that the failed fuel cans have a screen on both the top and bottom that allow the failed fuel to be dried and inerted while retaining fuel particles that may be released from the failed fuel.

The applicant added fuel spacers that may be used in the EOS-37PTH DSC to accommodate variable sized contents as described in UFSAR Section 9.1.1. The applicant clarified that the fuel spacers are not a 10 CFR Part 72 requirement and the fuel spacers are only relevant to transportation of the EOS-37PTH DSC under the requirements of 10 CFR Part 71. The applicant added information on the materials of construction of the fuel spacers in UFSAR Table 8-1 which identifies that the spacers will be constructed from stainless steel or an aluminum alloy.

The applicant included a new horizontal storage module design called the NUHOMS® MATRIX (HSM-MX) that allows for higher density storage of DSCs using a tiered HSM design described in UFSAR Appendix A. The applicant stated that the HSM-MX construction used similar materials as the EOS-HSM design that was approved in the original EOS CoC. Specifically, the HSM-MX is a steel reinforced concrete design with structural steel materials used to support the DSCs. The staff review of the applicable codes and material properties for the HSM-MX design is in SER Section 8.2.

The staff reviewed the general design and materials in the application and determined that the applicant has described the design and construction of the components included in the application. The staff determined that that the design and materials in the amendment application are similar to the design and construction of the previously approved components and systems in the original EOS CoC (1042). Therefore, the staff determined that the general design and materials for the components used in the amendment application are acceptable.

The staff determined that the materials of construction for the damaged fuel end caps and the FFCs are adequate because (1) the design includes screens at the bottom and top to contain fuel debris and allow filling/drainage and (2) these components are constructed in accordance with the ASME Code Section III subsection NF for FFCs and NG for end caps and using ASME code approved materials consistent with the original EOS CoC.

8.1.2 Environmental Conditions

The applicant did not provide an analysis of the potential degradation due to irradiation of the stainless-steel DSC, carbon steel components of the NUHOMS® EOS System, or aluminum components of the DSC. A previous assessment of neutron fluence has been conducted for dry storage systems. For dry storage systems, a neutron flux of 10^4–10^6 n/cm^2-s [6.5×10^4–6.5×10^6 n/in^2-s] is typical (Sindelar et al., 2011). At these flux levels, the accumulated neutron fluence after 60 years is about 10^{13}–10^{15} n/cm^2 [6.5×10^{13}–6.5×10^{15} n/in^2].

NUREG-2214, “Managing Aging Processes in Storage (MAPS) Report” includes an assessment of the effects of neutron radiation on stainless steels, carbon steels and aluminum alloy materials. To verify the conservatism of the previous estimate of accumulated neutron fluence by Sindelar et al. (2011), the NRC staff performed an independent calculation of the maximum potential accumulated neutron fluence on the dry storage system components (NUREG-2214). This worst-case estimate is greater than that calculated using the flux levels reported in Sindelar et al. (2011), however, the NRC determined the fluence level is still three orders of magnitude below the levels reported to degrade the fracture resistance of carbon and alloy steels, stainless steels, and aluminum alloys (NUREG-2214). Therefore, the staff concluded that the changes proposed in the application are acceptable because the neutron fluence is insufficient to result in a degradation of material properties of the storage system components.

The staff reviewed the general design and materials in the application and determined that the environmental conditions of the components included in the application are similar to the environmental conditions of the components in the original EOS CoC and that radiation levels that are below those that would be expected to degrade material properties. Therefore, the staff determined that the environmental conditions for the components used in the amendment application are acceptable.

8.1.3 Engineering Drawings

The applicant provided engineering drawings for the new type 4 and type 5 baskets included in Change Nos. 1 and 2 in UFSAR Section 1.3. The applicant also provided engineering drawings for the damaged fuel basket end caps and the failed fuel can for the type 4 basket of the EOS-37PTH DSC. The applicant stated that the design and materials of construction for the damaged fuel end caps and the FFCs are similar to previously approved end caps and FFCs used in other CoC No. 1004 DSCs. The applicant provided engineering drawings for the HSM-MX design showing the materials of construction and the safety classifications of the components in UFSAR Section A.1.3.

The staff reviewed the proposed design changes, design drawings, material specifications, and safety classifications of the components in accordance with the guidance in NUREG/CR-5502, “Engineering Drawings for 10 CFR Part 71 Package Approvals,” and NUREG/CR-6407, “Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety.” The staff determined that the drawings contained the necessary information including the safety classification of the components, bill of materials with material specifications, dimensions and dimensional tolerances.

8.2 Materials Selection

The staff reviewed the applicant’s changes in CoC No. 1042 Amendment No. 1 pertaining to materials selection. The staff review of the applicant’s changes included in this section included:

- Change No. 1: For the EOS-37PTH DSC, add a new type 4 basket with staggered plates, a low emissivity option for the basket steel plates, and low conductivity for the basket poison plates. This change allows for the loading of intact, damaged or failed fuel with up to eight damaged fuel assemblies, or four compartments containing failed fuel rods, with the remaining locations containing intact fuel assemblies.
- Change No. 2: EOS-37PTH DSC New type 5 basket with optional low conductivity neutron absorber
- Change No. 4: Add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel canistered in an EOS-37PTH or an EOS-89BTH DSC

8.2.1 Applicable Codes and Standards and Alternatives to the Code

The applicant provided engineered drawings with the quality category and bill of materials for the damaged fuel basket end caps and the failed fuel cans in UFSAR Section 1.3. The applicant indicated that the major components of the damaged fuel basket end caps are category “A” components and are designed and constructed in accordance with ASME Section III Subsection NG using ASME SA-240 Type 304 stainless steel. The applicant indicated that the major components of the failed fuel cans are category “A” components and are designed and constructed in accordance with ASME Section III Subsection NF using ASME SA-240 Type 304 stainless steel.

The staff reviewed the intended functions of the damaged fuel basket end caps and the failed fuel cans along with the operating procedures for these components. The staff also reviewed the specifications for the materials of construction, quality category, design code for the damaged fuel basket end caps and the failed fuel cans. The staff determined that the materials, quality category and design and construction of the damaged fuel basket end caps is acceptable because they are designed and constructed in accordance with ASME Section III Division 1 Subsection NG - Core Support Structures. The staff determined that the materials, quality category and design and construction of the failed fuel cans in accordance with ASME Section III Subsection NF is acceptable for this component.

The applicant indicated in UFSAR Section A.2.1.2 that the new reinforced concrete HSM-MX is designed in accordance with American Concrete Institute (ACI) 349-06 (ACI, 2007) and constructed to ACI 318-08 (ACI, 2008). The applicant stated that the concrete temperature limit criteria in NUREG-1536, Revision 1, Section 8.4.14.2 is used for normal and off-normal conditions. The applicant included an alternate to the ACI 349-06 code in the TS. The applicant cited ACI 349-13, Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, Section RE.4, and stated that the specified 28-day compressive strength may be increased to 7,000 psi for HSM fabrication so that any losses in properties (e.g., compressive strength) resulting from long-term thermal exposure will not affect the safety margins based on the specified 5,000 psi compressive strength used in the design calculations. In addition, the applicant stated that short, randomly oriented steel fibers may be used to provide increased ductility, dynamic strength, toughness, tensile strength, and improved resistance to spalling per ACI 349-13 Section RE.4.

The staff reviewed the design and construction code for the HSM-MX including the alternate identified as ACI 349-13 Section RE.4. The NRC staff have previously determined that ACI 349-06 and ACI 318-08 are acceptable for the design and construction of concrete structures. The staff reviewed the specified exception using increased concrete strength so that any losses in compressive strength resulting from long-term thermal exposure will not affect the safety margins based on the specified 5,000 psi compressive strength used in the design calculations. The staff determined that the exception is acceptable because the increased strength will prevent concrete spalling and that any losses in compressive strength will be offset by the higher initial compressive strength of the concrete.

8.2.2 Material Properties

The applicant stated in UFSAR Section 10.1.7 that the high-strength low-alloy (HSLA) steel used in the basket may be manufactured from ASME Code edition 2010 with 2011 addenda, SA-517 Gr A, B, E, F, or P. The applicant stated that this material is qualified by the material properties at elevated temperature in ASME Section II, Part D, which exceed the values of yield and ultimate strength in UFSAR Table 8-10.

The staff reviewed the applicant’s required specifications for the basket material as well as the requirements for ASME SA-517 Gr A, B, E, F, and P. The staff confirmed that the material properties specified by the applicant are consistent with ASME SA-517 Gr A, B, E, F, and P. The staff determined that the applicant has adequately specified the mechanical properties of the ASME SA-517 grades because the specified properties are consistent with the requirements of the ASME SA-517 grades identified in the application.

The applicant stated that for the EOS-37PTH DSC, the proposed changes include the loading of 2-year cooled fuel (TS Section 2.1). The applicant revised the material to be stored in the EOS-37PTH DSC to allow for the storage of damaged or failed fuel in the EOS-37PTH DSC. The applicant proposed new heat load zone configuration (HLZC) for these DSCs to accommodate fuel that had been cooled for a minimum of 2 years and increased the maximum allowable per assembly decay heat. However, the applicant did not increase the maximum heat load for any DSC. The applicant provided analyses of the component temperatures to support the new HLZC for the EOS-37PTH DSC, and the storage of damaged and failed fuel in the EOS-37PTH DSC.

The staff reviewed the calculated component temperatures including the DSC shell, basket and the neutron absorber for each of the new HLZCs for the EOS-37PTH DSC and EOS-89BTH DSCs. The staff determined that the changes in the DSC component temperatures resulting from the new or revised HLZC in the application are minimal. The staff determined that the proposed new and revised HLZC are acceptable because the temperatures of the DSC components remain below their respective temperature limits for normal, off normal and accident conditions.

The staff reviewed the calculated component temperatures including the DSC shell, basket and the neutron absorber for the storage of damaged and failed fuel in the EOS-37PTH DSC. The staff determined that the storage of damaged and failed fuel in the EOS-37PTH DSC is acceptable because temperatures of the DSC components remain below their respective temperature limits for normal, off normal and accident conditions.

The staff reviewed the calculated temperatures for the aluminum alloy basket transition rails for each of the new HLZCs for EOS-37PTH DSC. The staff also reviewed the calculated temperatures for the aluminum alloy basket transition rails for the storage of damaged and failed fuel in the EOS 37PTH DSC. The staff reviewed the potential for changes to mechanical properties and creep of the aluminum alloy basket transition rails. The staff used the guidance included in the MAPS Report (NUREG-2214) to assess the effect of temperature on thermal aging of the aluminum alloy basket transition rails (MAPS Report Section 3.2.3.7) and creep (MAPS Report Section 3.2.3.5). The staff determined that the changes in the temperatures for the aluminum alloy basket transition rails resulting from the new or revised HLZC in the application are minimal. However, the staff determined that the temperatures of the aluminum alloy basket transition rails are sufficiently high to result in over-aging of the alloy resulting in a loss of strength over time. The staff note that the applicant assumed properties of annealed material for the material properties of the aluminum alloy basket transition rails to account for the reduced strength associated with over-aging. The staff determined that use of the annealed properties is consistent with the stipulation in ASME Section II part D to use time dependent mechanical properties when a heat-treated aluminum alloy is used at temperatures where the mechanical properties can be altered. The staff determined that the proposed new and revised HLZC are acceptable because the mechanical properties of the aluminum alloy basket transition rails are assumed to be equivalent to the fully annealed material to account for the effects of temperature.

8.2.3 Alternative or Substitute Materials for Important to Safety Components

The applicant indicated that the new EOS-37PTH DSC type 4 basket included in Change No. 1 and the new type 5 basket included in Change No. 2 are classified as quality category A components but are manufactured from non-code materials (UFSAR Section 1.3). The EOS DSCs included in the original EOS CoC had a basket structural material constructed with ASTM A829 grade (Gr) 4130 high-strength low-alloy (HSLA) steel. The applicant expanded the range of permissible basket materials for both the EOS-37PTH DSC and the EOS-89BTH DSC in the CoC Amendment No. 1 application. The structural material of the basket in the CoC Amendment No. 1 application is specified as a HSLA steel. The applicant specified that the HSLA steel for the basket in UFSAR Section 10.1.7 and TS Section 4.3.2 includes the following materials:

- ASTM A829 Gr 4130 or AMS 6345 SAE 4130, quenched and tempered at not less than 1050°F, 103.6 ksi minimum yield, and 123.1 ksi minimum ultimate stress.
- ASME Code edition 2010 with 2011 addenda, SA-517 Gr A, B, E, F, or P.
- Other HSLA steel meeting the criteria described in UFSAR Section 10.1.7.C and TS Section 4.3.2.C which include heat treatment requirements, minimum strength, minimum fracture toughness and qualification and production testing requirements and acceptance criteria.

The staff reviewed the allowable material for the basket and determined that the applicant has specified appropriate materials and required mechanical properties as a function of temperature. The staff reviewed the applicant’s requirements for minimum fracture toughness and determined that the specified fracture toughness requirements are consistent with staff guidance in NUREG/CR-1815, “Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick,” for category 1 structures where a large margin of safety is required. The staff determined that the applicant’s provisions for qualification before use and production acceptance criteria are sufficient to ensure the material properties meet the TS.

The applicant stated that the DSC support structure for the HSM-MX uses several high strength low alloy (HSLA) steels identified in UFSAR Tables A.8-2, A.8-3 and A.8-4 which apply to ASTM A572 Grade 50, ASTM A992 Grade 50, and ASTM A588 steels respectively. The applicant provided mechanical properties of these materials including tensile strength, yield strength and modulus of elasticity up to temperatures of 500 °F [260 °C]. The applicant referenced data obtained for structural steel showing changes in yield strength and tensile strength up to temperatures of 1400°F [760°C] and changes to elastic modulus up to temperatures of 1000°F [538°C] (Fintel, 1985). In response to a request for additional information, the applicant provided a comparison of the mechanical properties for the HSLA steels identified in UFSAR Tables A.8-2, A.8-3 and A.8-4 (ASTM A572 Grade 50, ASTM A992 Grade 50, and ASTM A588 steels respectively) to results of elevated temperature testing of HSLA steels reported by Sief et al, (2016) and Aziz and Kodur (2016). The applicant showed that the mechanical property values used in the UFSAR were conservative with respect to the values reported in the literature for temperatures below 250°F. The applicant clarified that 250°F [121°C] is the bounding temperature considered in the structural evaluations of the HSM-MX components made of the three steels.

The staff reviewed the applicant's estimationed mechanical properties of the ASTM A572 Grade 50, ASTM A992 Grade 50, and ASTM A588 HSLA steels. The staff also reviewed data published by the National Institute of Standards and Technology (NIST) (Sief et al. 2016) as well as elevated temperature mechanical property data for A572, A588, and A992 steels (Aziz and Kodur, 2016; Garlock, et al., 2014; Lee, 2012). Based on the available test data for structural steels, the staff determined that limited reductions in yield and tensile strength occur at temperatures below 392°F [200°C]. The staff reviewed the methodology used by the applicant to determine the mechanical properties at elevated temperatures and the available test data for these specific materials. The staff determined that the mechanical properties of the A572, A588 and A992 steels provided by the applicant conservatively account for the changes in mechanical properties at elevated temperatures.

8.2.4 Copper Bearing or Other Weathering Steels or Other Corrosion Control Measures for Coastal ISFSI Locations

The applicant stated in UFSAR Section A.8.2.1 that at coastal sites with operational experience of corrosion due to atmospheric chlorides, the front and rear DSC supports steel and weld filler metal have a minimum of 0.20% copper content or are stainless steel for the HSM-MX. The applicant stated that for carbon steels, weld material with 1% or more nickel is acceptable in lieu of 0.20% copper content. The applicant stated that the copper content is equivalent to weathering steel, and nickel-bearing weld materials show equivalent corrosion resistance.

The staff reviewed the materials of construction, the design of the DSC support structure, and the operating environment. The staff also reviewed the performance of the optional 0.20% copper and 1% nickel steels for added corrosion resistance in environments containing chlorides. The staff reviewed the applicant's allowed substitution of copper containing steels and found it to be consistent with the guidance in NUREG 1536, Revision 1, Section 8.4.6.

The staff noted that the results of long-term corrosion testing in a variety of environments show that the 0.20% copper steels and 1 percent nickel weld metals have increased corrosion resistance beneficial for structural steels in corrosive atmospheres (McCuen and Albrecht, 1994; ASM International, 1987). The staff finds the use of the DSC support structure steels to be acceptable because of the limited exposure to moisture, the applicant's assumption of reduced wall thickness in its structural analyses, and the use of copper and nickel-bearing steels that are capable of providing additional corrosion protection in environments with atmospheric chlorides.

8.2.5 Coatings

The applicant stated that the proprietary high emissivity coating of the fuel basket is important to safety since it is relied on for heat transfer (UFSAR Section 1.3). The applicant provided a description of the proprietary process and minimum acceptable emissivity values for the basket with a high emissivity value. The applicant described testing and acceptance criteria for alternate high emissivity coatings including minimum acceptable emissivity values and temperature tolerance.

The applicant also described the low emissivity coating for the basket in UFSAR Section 8.2. The applicant stated that the low emissivity coating is a standardized coating that has been previously used in the nuclear industry. The applicant provided the minimum emissivity value of the low conductivity coating in the application.

The staff reviewed the emissivity values and standard references of emissivity values of materials and coatings. For the high emissivity coating, the applicant classified the coating as important to safety with minimum specified emissivity value and specified requirements for alternate coatings that assure the important to safety coating will perform as required. The staff determined that the applicant's approach is acceptable because (1) the emissivity value for the coating provided by the applicant was determined by the staff in an independent review to be appropriate and (2) the applicant's specified acceptance testing and inspection of the high emissivity coating is sufficient for heat transfer. For the low emissivity coating, the staff confirmed through an independent review of information pertaining to the coating systems that the minimum emissivity value specified by the applicant was valid. The staff determined that the coatings specifications provided by the applicant were acceptable.

8.2.6 Neutron Absorber Materials for Criticality Control

The applicant described the low conductivity neutron absorber as either a Boral^{TM} or a metal matrix composite (MMC) in UFSAR Section 10.1.5. The applicant specified minimum conductivity values and B-10 concentrations for the Boral and the MMC neutron absorber materials.

The staff reviewed the proposed design changes, design drawings, material specifications, and safety classifications of the neutron absorber materials. The staff determined that the neutron absorber plates are quality category A components that are a non-code material. The staff determined that the neutron absorber plates are enriched borated aluminum alloy or MMC, similar to those that were previously evaluated and approved for use in the EOS 37PTH DSC as well as other dry storage systems. The staff determined that the changes proposed in the application are acceptable because the low conductivity neutron absorber materials use either Boral™ or a MMC with specified B-10 concentrations and these types of materials have previously been evaluated and approved as neutron absorber materials in dry storage systems.

8.2.7 Low Temperature Ductility of Ferritic Steels

The staff review of the information provided by the applicant is included in Section 8.2.3.

8.3 Corrosion and Galvanic/Chemical/Radiolytic Reactions of Fuel with Canister Internals

The staff reviewed the applicant's changes in CoC No. 1042 Amendment No. 1 pertaining to materials selection. The staff review of the applicant's changes in this section included:

- Change No. 5: Certain CoC and TS items are revised for consistency and clarity.

The applicant revised the definition of control components authorized for storage in the TS Section 1.1 and included a detailed description of the control components in UFSAR Section 2.2.1. The description provided by the applicant includes 4 types of control components including Burnable Poison Rod Assemblies, Thimble Plug Assemblies, Control Element Assemblies and Neutron Sources. The applicant also stated that the control components not explicitly listed in USFAR Section 2.2.1 but that meet the definition provided above and have similar functional characteristics as those listed above, are also authorized within the DSC. The applicant clarified that control component materials exposed to the pool water are limited to zirconium alloys, nickel alloys, and stainless steels.

The staff reviewed the applicant's definition of control components in TS Section 1.1 and the detailed description of the specifically listed control components in UFSAR Section 2.2.1. The staff reviewed the information provided by the applicant on the materials of construction for these components. The staff determined that the materials in the specifically listed control components are consistent with the description in NUREG 1536, Revision 1, Section 8.4.8 "Galvanic/Corrosive Reactions" to assess the potential for galvanic, chemical and/or radiolytic reactions of the fuel or contents with canister internals. The staff's review noted the previous assessment of these materials in NUREG-1536, Revision 1, Section 8.4.8.2, which states:

> *The staff has found the following materials to be acceptable for storage when the canister is constructed of stainless steel with stainless steel and aluminum basket components: Neutron source materials composed of stainless steel or zirconium alloy cladding containing: antimony-beryllium, americium-beryllium, plutonium-beryllium, polonium-beryllium, and californium. Exposure of these various contents to the wet loading and dry storage environment was assessed and found to be satisfactory. Control elements composed of zircaloy or stainless-steel cladding containing: boron carbide, borosilicate glass, silver-indium-cadmium alloy, or thorium oxide. Exposure of these various contents to the wet loading and dry storage environment was assessed and found to be satisfactory.*

Because these materials have previously been evaluated for potential galvanic, chemical and/or radiolytic reactions of the fuel or contents with canister internals, the staff determined that the materials included in the application are acceptable.

8.4 Cladding Integrity/Fuel

The staff reviewed the applicant's changes in CoC No. 1042 Amendment No. 1 pertaining to cladding integrity/fuel, cladding temperature limits and damaged fuel definition. The staff review of the applicant's changes included in this section included:

- Change No. 1 and 2 for the use of the EOS-TC125 and EOS-TC135 transfer casks with the EOS 37PTH type 4 and type 5 basket;

- Change No. 3 EOS-37PTH DSC, some locations within the basket are now able to accept fuel assemblies with a minimum cooling time of two years.

8.4.1 Cladding Mechanical Properties

The applicant provided a proprietary structural analysis for damaged fuel cladding in Chapter 3 of the UFSAR that demonstrates that the cladding does not undergo additional degradation under normal and off-normal conditions of storage. The analysis was based on the mechanical properties and fracture resistance of the cladding materials. The applicant used available information on the mechanical properties of cladding alloys to support this analysis of the performance of Zircaloy-2, Zircaloy-4, ZIRLO™, and M5™ cladding alloys (EPRI, 2001; Martin-Rengel at al., 2013, Fourgeaud et al., 2009, Cazalis et al., 2005). In response to a RAI, the applicant also provided an additional analysis to show that hydride reorientation would be unlikely to occur with the cladding alloys during drying and storage. The applicant supported its analysis with the available data on cladding hoop stress evaluations that considered the type of fuel, operational history, and fuel cladding temperature limits (Bratton et al., 2015; Richmond and Geelhood, 2018). Although the applicant's independent calculation of maximum cladding hoop stress for PWR fuel rods were slightly more than 90 MPa (megapscal), the applicant stated this result is driven by conservatisms of the thermal model. The applicant concluded that based on hoop stresses calculated within a bounding population of spent fuel rods, all hoop stresses are expected to remain below the threshold value of 90 MPa for hydride reorientation during dry storage operations.

The staff reviewed the applicant's analyses as well as available information on cladding mechanical properties and fracture resistance. The staff determined that the mechanical properties used in the assessment of cladding integrity are adequate because they are supported by tests of the cladding materials using test methods that are appropriate to obtain the required properties. The staff determined that the analysis provided by the applicant is consistent with the analysis of the performance of fuel cladding included in NUREG-1536, Revision 1, Section 8.8.2. Therefore, the staff determined that the applicant has adequately addressed the mechanical properties of the cladding for the fuel to be stored.

8.4.2 Cladding Temperature Limits

The applicant described new EOS-37PTH DSC basket types in Change No. 1 and 2. These changes included a new type 4 basket with a low emissivity option for the basket steel plates and low conductivity basket poison plates and a new type 5 basket (Change No. 2) that is comparable in geometry to existing types 1, 2 and 3 baskets, but with the low conductivity poison and low emissivity option of the type 4 basket described in Change No. 1. The applicant showed that for the new type 4 and type 5 baskets proposed in the application (CoC No. 1042 Amendment No. 1), the maximum cladding temperatures remained below the 400°C (752 °F) limit for normal and off normal conditions and below 570 °C (1058°F) for accident conditions.

Similarly, the applicant showed that adding the EOS-TC125 and the EOS-TC135 transfer casks as allowable systems for the transfer of the EOS-37PTH DSC with the Type 4 and Type 5 basket did not result in changes to the allowable maximum temperatures for normal, off normal or accident temperatures for either the cladding or the EOS-37PTH DSC materials.

The applicant stated that the changes were evaluated for structural, thermal, shielding, confinement and criticality adequacy, as applicable, and has concluded that these changes to the NUHOMS® EOS System have no significant effect on safety.

The staff reviewed the proposed changes included in the application along with the guidance on cladding temperature limits included in NUREG-1536, Revision 1, Section 8.4.17.1. As noted in NUREG-1536, Revision 1, there are three considerations for cladding temperature limits:

- For high burn-up fuel, defined as any fuel with a burn-up greater than 45Gwd/MTU, the maximum allowable cladding temperature limit is 400°C (752 °F);
- During loading operations, repeated thermal cycling (repeated heat up/cooldown cycles) may occur but should be limited to less than 10 cycles, where cladding temperature variations are not more than 65°C (117°F) each; and
- For off-normal and accident conditions, the maximum cladding temperature should not exceed 570°C (1058°F).

The staff confirmed that the maximum fuel cladding temperature limit of 400°C (752°F) is applicable to normal conditions of storage and all short-term operations from the spent fuel pool to ISFSI pad, including vacuum drying and helium backfilling for the EOS-37PTH DSC. The staff confirmed that the operational specifications do not permit thermal cycling of the fuel cladding with temperature differences greater than 65°C (117°F) during DSC drying, backfilling and transfer operations. The staff confirmed that for off-normal and accident conditions, the maximum cladding temperature does not exceed 570°C (1058°F). The staff determined that the proposed changes in the application are acceptable with respect to fuel cladding because the proposed changes in the application result in cladding temperatures and temperature cycles that follow the guidance in NUREG-1536, Revision 1, Section 8.4.17.1 for normal, off-normal and accident conditions.

8.4.3 Damaged Fuel Definition

The applicant stated that Change No. 1 was introduced for the EOS-37PTH DSC to allow for the loading of (1) damaged fuel assemblies confined within top and bottom end caps to ensure retrievability and (2) failed fuel assemblies loaded within individual failed fuel canisters. The applicant defined damaged and failed fuel as follows:

- Damaged assemblies are assemblies containing missing or partial fuel rods, fuel rods with known or suspected cladding defects greater than hairline cracks or pinhole leaks. The extent of damage in the fuel assembly, including noncladding damage, is to be limited such that a fuel assembly maintains its configuration under normal and off-normal conditions.

- Failed fuel is defined as ruptured fuel rods, severed fuel rods, loose fuel pellets, or fuel assemblies that may not maintain its configuration under normal or off-normal conditions. Fuel assemblies may contain breached rods, grossly breached rods, and other defects such as missing or partial rods, missing grid spacers, or damaged spacers to the extent that the assembly may not maintain its configuration under normal or off-normal conditions. Fuel debris and fuel rods that have been removed from a fuel assembly and placed in a rod storage basket are also considered failed fuel. Loose fuel debris, not contained in a rod storage basket must be placed in a failed fuel can for storage, provided the size of the debris is larger than the failed fuel can screen mesh opening.

The applicant also stated in UFSAR Section 2.2.1 that the fuel compartment and the top and bottom end caps together form the “acceptable alternative, per NUREG-1536, Revision 1” for confinement of damaged fuel assemblies. The applicant stated that the top and bottom end caps provide for the confinement of gross fuel particles to a known volume in the event that any fuel particles smaller than a pellet are released from the damaged assembly. The applicant stated that the bottom end cap is designed to be removable and contains a socket for the use of a handling tool which allows gross fuel particles to be retrieved.

The staff reviewed the application and the guidance included in NUREG-1536, Revision 1, Section 8.4.17.2 for fuel classification. The applicant has limited the storage of damaged fuel with the use of basket end caps to fuel assemblies that can be handled by normal means after normal and off normal events. The applicant’s approach, which included the use of end caps to contain debris for damaged fuel and the use of individual failed fuel canisters, provided the size of the debris is larger than the failed fuel can screen mesh opening, is consistent with the guidance in NUREG-1536, Revision 1, and previously approved damaged and failed fuel storage in the DSCs included in the CoC No. 1004. The staff determined that the application was acceptable because the content of the application with respect to fuel classification was consistent with the guidance in NUREG-1536, Revision 1, Sections 8.4.17.2 and 8.6.

The staff determined that for damaged fuel in the EOS-37PTH DSC using damaged fuel end caps, the functions the applicant has imposed on the damaged fuel assemblies and the damaged fuel end caps by fuel specific and system-related functions meet a regulatory requirement for storage. Specifically, the staff determined that the applicant’s specifications for damaged fuel and the functions of the damaged fuel end caps meet the regulatory requirements of 10 CFR 72.236(h) and (m) and allow the system users to meet the regulatory requirements of 10 CFR 72.122(h)(1) and (h)(5). The thermal, shielding and criticality evaluations of the EOS-37PTH DSC for the storage of damaged fuel is included in Sections 4, 6 and 7 of this SER respectively.

8.5 Findings

F8.1. The applicant has met the requirements in 10 CFR 72.236(b). The applicant described the materials design criteria for SSCs important to safety in sufficient detail to support a safety finding.

F8.2. The applicant has met the requirements in 10 CFR 72.124(b). Neutron absorbing materials are demonstrated to effectively control criticality without significant degradation over the storage life.

F8.3. The applicant has met the requirements in 10 CFR 72.236(g). The properties of the materials in the storage system design have been demonstrated to support the safe storage of SNF.

F8.4. The applicant has met the requirements in 10 CFR 72.236(h). The materials of the SNF storage container are compatible with their operating environment such that there are no adverse degradation or significant chemical or other reactions.

F8.5. The applicant has met the requirements in 10 CFR 72.236(a) and 10 CFR 72.236(m). SNF specifications have been provided and adequate consideration has been given to compatibility with retrieval of stored fuel for ultimate disposal.

The staff concludes the material properties of the structures, systems, and components For the EOS Amendment No. 1 are in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria have been satisfied. The evaluation of the material properties provides reasonable assurance that the EOS Amendment No. 1 will allow safe storage of SNF. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

8.6 References

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9.0 OPERATING PROCEDURES EVALUATION

The staff reviewed the information provided by the applicant and found the two following changes requested in Amendment No. 1 to require an operating procedures evaluation:

1. Change No. 1, add a new basket type (Type 4) with staggered alignment of the steel, aluminum, and poison basket plates to the EOS-37PTH DSC. This change allows for the loading of intact, damaged or failed fuel.
2. Change No. 4, add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel in an EOS-37PTH or an EOS-89BTH DSC.

The applicant included revised operating procedures in UFSAR Section 9.1 for loading the DSC and transfer to the EOS-HSM and UFSAR Section 9.2 which includes the procedures for unloading the DSC. These changes include specific steps for the TC and DSC preparation, the loading of damaged and failed fuel and the use of fuel spacers. For the loading of damaged fuel, the applicant's revised procedures included the installation of top and bottom end caps into the basket locations where damaged fuel are also loaded. For failed fuel, the applicant's procedures ensure that the failed fuel can lids are installed. For fuel spacers, the applicant's revised procedures include steps to verify that fuel spacers, if required, are present. The applicant's procedures include controls to ensure that damaged and failed fuel are placed within known basket cell locations. Procedures for unloading the EOS-DSCs with damaged and failed fuel are also included.

The applicant added operating procedures for the NUHOMS® MATRIX HSM in UFSAR Chapter A.9. The applicant identified that the operating procedures for the preparation of the DSC and transfer casks for fuel loading were identical to the procedures already included in UFSAR Chapter 9. The applicant included specific operating procedures for the transfer of loaded DSCs into and removal of the DSCs from the HSM-MX. In addition, the applicant included specific HSM-MX monitoring procedures after placement of the DSC. The applicant stated the procedures are included for monitoring the HSM-MX vents for blockage in order to meet the TS for the HSM-MX thermal monitoring program (TS Section 5.1.3.2).

The staff reviewed the revised operating procedures for the loading and unloading of damaged and failed fuel for the EOS-DSCs and the use of fuel spacers. The staff determined that the procedures are complete and appropriately reference the TS for loading of damaged and failed fuel. The staff determined that the revised operating procedures for loading were acceptable because they include (1) the use of a failed fuel can and a failed fuel can lid for failed fuel, and (2) the use of top and bottom basket end caps to confine any fuel debris for the storage of damaged fuel. In addition, the staff determined that the applicant's unloading procedures are acceptable because the procedures are complete and ensure that the damaged and failed fuel, including fuel debris, can be unloaded from the EOS-DSCs.

The staff also reviewed the operating procedures for the NUHOMS® MATRIX HSM included in UFSAR Chapter A.9. The staff note that the DSC and transfer cask loading procedures for the HSM-MX do not vary from the procedures for the EOS-HSM included in UFSAR Chapter 9. The staff determined that the DSC transfer procedures into the HSM-MX were conceptually similar to the transfer procedures for DSC transfer into and removal from the EOS-HSM. The staff determined that the procedures for the HSM-MX include appropriate steps to position and align the DSC for transfer and prepare the HSM-MX to receive the DSC. The staff determined that the DSC removal procedures include appropriate steps to align the transfer cask and prepare the transfer cask and the HSM-MX for removal operations. The staff reviewed the monitoring procedures after DSC transfer into the HSM-MX and determined that the procedures include appropriate steps for monitoring the HSM-MX vents for blockage in order to meet the TS for the HSM-MX thermal monitoring program (TS Section 5.1.3.2). The staff concludes that the proposed changes to operating procedures for NUHOMS® EOS System Amendment No. 1 meet the requirements of 10 CFR Part 72.

10.0 ACCEPTANCE TESTS AND MAINTANANCE PROGRAM EVALUATION

The staff reviewed the information provided by the applicant and found the two following changes requested in Amendment No. 1 to require an acceptance tests and maintenance program evaluation:

1. Change No. 1, add a new basket type (Type 4) with staggered alignment of the steel, aluminum, and poison basket plates to the EOS-37PTH DSC. This change allows for the loading of intact, damaged or failed fuel.
2. Change No. 4, add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel in an EOS-37PTH or an EOS-89BTH DSC.

The applicant included revised acceptance testing for the thermal conductivity of the neutron absorber for the EOS-DSC basket materials. The applicant's change includes specific conductivity acceptance criteria and specific testing methods in accordance with ASTM Standards or an equivalent method.

The applicant also included material requirements and testing methods and acceptance criteria for the HSLA basket structure as evaluated in SER Section 8.2.3. The applicant identified material property testing and sampling requirements for materials to be tested in accordance with ASTM Standards, and the applicant also identified requirements for evaluating the integrity of processes for the HSLA basket materials that are used to control emissivity values. The applicant included both testing requirements and acceptance criteria to determine compliance with the material specifications.

The applicant added acceptance tests and a maintenance program for the NUHOMS® MATRIX HSM in UFSAR Chapter A.10. The applicant identified that the acceptance tests for the DSC and transfer casks components were identical to the acceptance tests for these components already included in UFSAR Chapter 10. The applicant included specific acceptance tests for the HSM-MX pertaining to the specifications and testing of concrete, reinforcing steel, DSC support structures, welder qualification and welding procedures for the HSM-MX. The applicant identified that the maintenance program for the HSM-MX is identical to the maintenance program for the EOS-HSM already included in UFSAR Chapter 10.

The staff reviewed the applicant's changes to the acceptance tests and maintenance program. The staff determined that the applicant's changes are acceptable because the applicant has included acceptance tests that address the technical changes to the important to safety SSCs in for NUHOMS® EOS System Amendment No. 1. The staff determined that the applicant included specific testing requirements that are based on appropriate ASTM standards, ACI standards, ASME Code, and American Welding Society (AWS) Code. The staff determined that the acceptance criteria and maintenance program are adequate to verify the specifications for these SSCs. The staff concludes that the proposed changes to the acceptance tests and maintenance program for NUHOMS® EOS System Amendment No. 1 meet the requirements of 10 CFR Part 72.

11.0 RADIATION PROTECTION EVALUATION

The objectives of the radiation protection evaluation are to determine whether the design features and proposed operations meet the following criteria:

1. the proposed DSC radiation protection features meet the NRC design criteria for protecting the general public and occupational workers from direct radiation;

2. the applicant has proposed engineering features and operating procedures for the DSC that will ensure occupational exposures will remain ALARA; and

3. the radiation doses to the general public will meet regulatory standards during both normal conditions and anticipated occurrences of accidents.

The applicant provided an updated dose rate versus distance curve for the new contents of the EOS-37PTH DSC loaded with intact fuel, damaged fuel, and failed fuel at a reduced cooling time. The applicant also provided an update of the estimated dose that is expected to be received by the operators when completing the operations of loading the ISFSI.

The applicant revised the radiation protection analyses to account for the dose rate changes around the transfer cask and the HSM models of the ISFSI resulting from the new contents, i.e., same intact fuel with shorter cooling time, damaged fuel, and failed fuel.

The staff reviewed the updated radiation protection plan for the EOS dry cask spent fuel storage system with these requested changes. The staff finds that the applicant has provided an adequate estimate of the doses in Table 11-4 of the UFSAR for the system operations and finds them to be appropriate. The radiation protection plan outlined in the UFSAR includes cautions and reminders of the use of optional supplemental shielding when practical to further reduce the operator’s exposure to radiation. On these bases, the staff determined that the amended EOS dry cask spent fuel storage system design continues to meet the regulatory requirements of 10 CFR 72.104 and the ALARA principle as required by 10 CFR Part 20.

12.0 ACCIDENT ANALYSIS EVALUATION

The applicant did not request changes to the principal design criteria related to the SSCs important to safety. For this reason, the staff finds the applicant complied with the relevant general criteria established in 10 CFR Part 72 and does not require an accident analysis evaluation of the principal design criteria. Internal pressure changes were investigated as part of the thermal evaluation and found to be either bounding, or non-safety significant for all cases, therefore no further confinement evaluation was necessary for accident conditions.

13.0 TECHNICAL SPECIFICATIONS

The staff reviewed the proposed amendment to determine that applicable changes made to the conditions in the CoC and to the TS for CoC No. 1042, Amendment No. 1 would be in accordance with the requirements of 10 CFR Part 72. The staff reviewed the proposed changes to confirm that the changes were properly evaluated and supported in the applicant's revised UFSAR. These modifications were found acceptable based on the staff's findings for the Structural, Thermal, Confinement, Shielding, Criticality, Materials, Operating Procedures, Acceptance Test and Maintenance Program, and Radiation Protection sections of this SER.

The staff finds that the proposed changes to the TS for the NUHOMS® EOS System conform to the changes requested in the amendment application and do not affect the ability of the cask system to meet the requirements of 10 CFR Part 72. The proposed changes provide reasonable assurance that the NUHOMS® EOS System will continue to allow safe storage of spent nuclear fuel.

14.0 QUALITY ASSURANCE EVALUATION

There were no changes to the applicant's quality assurance program requested in the amendment application.

15.0 CONCLUSIONS

The staff has performed a comprehensive review of the amendment application, during which the following requested changes to the NUHOMS® EOS System were considered:

Change No. 1:
For the EOS-37PTH DSC, add a new basket type (Type 4) with staggered alignment of the steel, aluminum, and poison basket plates. This change allows for the loading of intact, damaged or failed fuel – with up to eight damaged fuel assemblies, or four compartments containing failed fuel rods, with the remaining locations containing intact fuel assemblies. An option is also introduced for the Type 4 basket crediting a low emissivity option for the basket steel plates, and low conductivity for the basket poison plates. When equipped with the low emissivity coating and low conductivity poison, this basket type is identified as "4L." When equipped with the standard poison and coating identical to that of Type 1, 2 and 3 baskets, this basket type is identified as "4H." The Type 4 basket may be stored in either the EOS-HSM or the new NUHOMS® MATRIX design (described in Change No. 4 below). The Type 4 basket may be transferred onsite in either the EOS-TC125 or the EOS-TC135.

Change No. 2:
For the EOS-37PTH DSC, add a new basket type (Type 5) that is comparable in geometry to existing Types 1, 2 and 3 baskets, but with the low conductivity poison and low emissivity option of the Type 4 basket with the ability to be stored in either the EOS-HSM or the new NUHOMS® MATRIX design (described in Change No. 4 below). The Type 5 basket may be transferred onsite in either the EOS-TC125, or the EOS-TC135.

Change No. 3:
For the EOS-37PTH DSC, some locations within the basket are now able to accept fuel assemblies with a minimum cooling time of two years.

Change No. 4:
Add a new NUHOMS® MATRIX (HSM-MX) design as an alternative to the EOS-HSM design for the storage of spent fuel canistered in an EOS-37PTH or an EOS-89BTH DSC. The HSM-MX provides a staggered two-tiered self-contained modular structure for storage of these spent fuel DSCs. The HSM-MX is designed to store the DSCs that are authorized for storage in the EOS-HSM Short and EOS-HSM Medium HSMs.

Change No. 5:
Certain CoC and TS items are revised for consistency and clarity.

Based on the statements and representations provided by the applicant in its amendment application, as supplemented, the staff concludes that the changes described above to the NUHOMS® EOS System do not affect the ability of the cask system to meet the requirements of 10 CFR Part 72. Amendment No. 1 for the Standardized NUHOMS® System should be approved.

Issued with Certificate of Compliance No. 1042, Amendment No. 1
on May 19, 2020.