PRELIMINARY
SAFETY EVALUATION REPORT

TN AMERICAS LLC
NUHOMS® EOS
DRY SPENT FUEL STORAGE SYSTEM

DOCKET NO. 72-1042
MODEL NO. NUHOMS® EOS
CERTIFICATE OF COMPLIANCE NO. 1042

CONTENTS

ABBREVIATIONS

3D	three-dimensional
ACI	American Concrete Institute
ADAMS	Agencywide Documents Access and Management System
AISC	American Institute of Steel Construction
ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
B	boron
B&PV	boiler and pressure vessel
B&W	Babcock and Wilcox
B_2O_3	boric acid
BLEU	blended low-enriched uranium
BPRA	burnable poison rod assembly
BWR	boiling-water reactor
C	Celsius
CC	control component
CE	Combustion Engineering
CFD	computational fluid dynamics
CFR	*Code of Federal Regulations*
CISCC	chloride-induced stress-corrosion cracking
Co	cobalt
CoC	certificate of compliance
DOE	U.S. Department of Energy
DSC	dry shielded canister
F	Fahrenheit
fps	feet per second
g	gravity
g/cm^3	grams per cubic centimeter
GCI	grid convergence index
GWd	gigawatt days
HLZC	heat load zone configuration
hr	hour
HSM	horizontal storage module
IBCP	inner bottom cover plate
ISFSI	independent spent fuel storage installation
ISG	interim staff guidance
ITCP	inner top cover plate

k_{eff}	multiplication factor k effective
kW	kilowatt
lb	pound(s)
LCO	limiting condition for operation
MCNP	Monte Carlo N-Particle
MMC	metal matrix composite
mph	miles per hour
mrem	millirem
MTU	metric tons of uranium
NEA	Nuclear Energy Agency
NRC	U.S. Nuclear Regulatory Commission
OBCP	outer bottom cover plate
ORNL	Oak Ridge National Laboratory
OTCP	outer top cover plate
PCT	peak cladding temperature
psf	pounds per square foot
psi	pounds per square inch
psig	pounds per square inch gauge
PWR	pressurized-water reactor
QA	quality assurance
QAPD	Quality Assurance Program Description
Ra	Raleigh number
RAI	request for additional information
Re	Reynolds number
SAR	safety analysis report
SER	safety evaluation report
SFA	spent fuel assembly
SNF	spent nuclear fuel
SR	surveillance requirement
SSC	structure, system, and component
TC	transfer cask
TPA	thimble plug assembly
TS	technical specification(s)
UFSAR	updated final safety analysis report
UO_2	uranium dioxide
USL	upper subcritical limit
WE	Westinghouse

1.0 SUMMARY

By letter dated June 16, 2015 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15173A379), as supplemented on July 30, 2015 (ADAMS Accession No. ML15223A204), December 18, 2015 (ADAMS Accession No. ML15364A399), April 7, 2016 (ADAMS Accession No. ML16111A670), June 13, 2016 (ADAMS Accession No. ML16169A044), and July 28, 2016 (ADAMS Accession No. ML16215A015), AREVA Inc. (the applicant), now TN Americas LLC, submitted an application to the U.S. Nuclear Regulatory Commission (NRC) to obtain a certificate of compliance (CoC) for the NUHOMS® EOS System. The NUHOMS® EOS System consists of the following major components:

- EOS horizontal storage module (HSM), EOS-HSM
- pressurized water reactor (PWR) dry shielded canisters (DSC), EOS-37PTH DSC
- boiling water reactor (BWR) DSC, EOS-89BTH DSC
- EOS transfer cask (TC), EOS-TC

This safety evaluation report (SER) documents the review and evaluation of the application, NUHOMS® EOS System Safety Analysis Report (SAR), Revision 7, and Revision 7 to Technical Specifications (TS). The SER uses the same section-level format provided in NUREG-1536, Revision 1, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," issued July 2010 (ADAMS Accession No. ML101040620).

The NRC staff's assessment is based on whether the applicant meets the applicable requirements of
Title 10 of the Code of Federal Regulations (10 CFR) Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High Level Radioactive Waste, and Reactor Related Greater Than Class C Waste," for the independent storage of spent fuel.

1.1 General Description

The NRC staff's objective in reviewing the general description of the NUHOMS® EOS System is to ensure that the applicant has provided a nonproprietary description that is adequate to familiarize reviewers and other interested parties with the pertinent features of the system.

1.2 General Description and Operations Features

The NUHOMS® EOS System is an improved version of the NUHOMS® HD System described in CoC No. 1030. The NRC has found the NUHOMS® HD System acceptable and documented its approval in the SER (ADAMS Accession No. ML070160089, NRC, 2010). The applicant designed NUHOMS® EOS system for high thermal loads, limited space, and superior radiation shielding performance. Chapters 4, 6, and 11 of SER evaluate these operations features.

The EOS System can store either PWR or BWR spent fuel assemblies (SFAs) in the EOS-37PTH DSC or EOS-89BTH DSC, respectively. The DSC is identified by the type of SFA and the maximum number of SFAs it can contain in the fuel basket.

The EOS-37PTH and the EOS-89BTH DSCs will be transferred during loading operations using the EOS-TC. The EOS-TC consists of a 135-ton cask (EOS-TC135), a 125-ton cask (EOS-TC125), and a 108-ton cask (EOS-TC108). It has a top cover plate that allows air circulation through the TC/DSC annulus during transfer operations at certain heat loads when time limits for transfer operations cannot be satisfied.

The EOS-37PTH and the EOS-89BTH DSCs will be stored in the EOS-HSM that may be fabricated in three lengths in order to accommodate the range of DSC lengths. It has special design features for enhanced shielding and heat rejection capabilities. The EOS-HSM is designated as either the EOS-HSM or the EOS-HSMS; they are essentially identical except the base for EOS-HSMS is split into upper and lower sections, which are tied together via shear keys and six grouted tie rods. The SAR and this SER use EOS-HSM for both the EOS-HSM and the EOS-HSMS.

1.2.1 Dry Shielded Canister

The EOS-37PTH DSC is designed to accommodate up to 37 intact PWR SFAs with uranium dioxide (UO_2) fuel and zirconium-alloy cladding, with or without control components (CCs). The EOS-37PTH DSC is designed for a maximum heat load of 50 kilowatts (kW) when transferred in the EOS-TC125/135, and a maximum heat load of 41.8 kW when transferred in the EOS-TC108. It can be transferred in any EOS-TC with a maximum heat load of 36.35 kW without air circulation available.

The EOS-89BTH DSC is designed to accommodate up to 89 intact BWR SFAs with UO_2 fuel and zirconium-alloy cladding, with or without fuel channels. The EOS-89BTH DSC is designed for a maximum heat load of 43.6 kW when transferred in the EOS-TC125/135, and a maximum heat load of 41.6 kW when transferred in the EOS-TC108. It can be transferred in any EOS-TC with a maximum heat load of 34.44 kW without air circulation available.

The primary confinement for both DSC models consists of the cylindrical shell, the top and bottom inner cover plates, the drain port cover plate, the vent plug, and the associated welds. The outer top cover plate (OTCP) and the test port plug provide the redundant confinement boundary. The top and bottom shield plugs provide shielding for the EOS-37PTH and EOS-89BTH DSCs to minimized occupational doses during drying, sealing, handling, and transfer operations. The drain port cover plate and vent plug welds are made after drying operations are completed.

The DSC basket structure consists of interlocking slotted plates to form an egg-crate-type structure, which forms a grid of 37 fuel compartments housing the PWR SFAs for EOS-37PTH or a grid of 89 fuel compartments housing the BWR SFAs for EOS-89BTH. The egg-crate structure is composed of one or more of the following: a steel plate, an aluminum plate, and a neutron-absorber plate. The steel plates are fabricated from high-strength low-alloy steels meeting the requirements of American Society for Testing and Materials (ASTM) A829 Grade 4130 (American Iron and Steel Institute 4130) for steel. The steel plates are hot rolled, heat-treated, and tempered to provide structural support for the SFAs. The staff's review and acceptance of these steels is documented in Section 8.5.2. The poison plates are made of borated metal matrix composites (MMCs) and provide the necessary criticality control. The aluminum plates, together with the poison plates, provide a heat conduction path from the SFAs to the DSC rails and shell.

1.2.2 Horizontal Storage Module

Each EOS-HSM provides a self-contained modular structure for the storage of spent fuel canisterized in an EOS-37PTH or EOS-89BTH DSC. The EOS-HSM is constructed from reinforced concrete and structural steel. The thick concrete roof and walls provide substantial neutron and gamma shielding. The EOS-HSMs are installed on a load-bearing foundation, which consists of a reinforced concrete basemat on a subgrade suitable to support the loads. The EOS-HSMs are not tied to the basemat. Table 1-1 of the SAR lists the key design parameters of the EOS-HSM.

The EOS-HSM provides a means of removing spent fuel decay heat by a combination of radiation, conduction, and convection. Ambient air enters the EOS-HSM through ventilation inlet openings on both sides of its lower front wall and circulates around the DSC and the heat shields. Air exits through air outlet openings on each side of the top of the EOS-HSM. Decay heat is rejected from the DSC to the EOS-HSM air space by convection and then removed from the EOS-HSM by natural circulation air flow. Heat is also radiated from the DSC surface to the heat shields and EOS-HSM walls and roof, where the natural convection air flow and conduction through the walls and roof aid in removing the decay heat. The passive cooling system for the EOS-HSM is designed to preserve fuel cladding integrity by maintaining SFA peak cladding temperatures below acceptable limits during long-term storage. Wind deflectors are installed on the EOS-HSM at heat loads greater than 41.8 kW for the EOS-37PTH and greater than 41.6 kW for the EOS-89BTH to mitigate the effect of sustained winds for high heat load DSCs.

1.2.3 Transfer Equipment and Transfer Cask

The NUHOMS® EOS System uses transfer equipment to move the DSCs between the plant's fuel or reactor building and independent spent fuel storage installation (ISFSI). The transfer equipment consists of a TC, a lifting yoke, a ram system, a prime mover, a transfer trailer, a cask support skid, and a skid positioning system. The lifting yoke is used for handling the TC within the fuel/reactor building and is used by licensees regulated under 10 CFR Part 50, “Domestic licensing of production and utilization facilities.” The hydraulic or mechanical ram system consists of a hydraulic cylinder or mechanical frame with a capacity and a reach sufficient for DSC insertion into and retrieval from the EOS-HSM.

The EOS-TC provides the principal biological shielding and heat rejection mechanism for the EOS-DSC and SFAs during handling in the fuel or reactor building, EOS-DSC closure operations, transfer to the ISFSI, and placement in the EOS-HSM. Table 1-1 of the SAR lists the key design parameters of the TC. The primary function of the EOS-TC is to provide onsite transport of loaded DSCs between the plant’s spent fuel pool and the plant’s onsite ISFSI. The TC’s design has sufficient shielding to provide reasonable assurance that dose rates are as low as reasonably achievable (ALARA). Two top-lifting trunnions are provided for handling the TC using a lifting yoke and overhead crane. Lower pocket trunnions are provided for rotating the cask from and to the vertical and horizontal positions onto the support skid and transport trailer. The EOS-TC108 is designed with a removable neutron shield for use at nuclear plant sites with space limitations, crane capacity limits, or both.

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. All EOS-TCs use a bottom cover incorporating wedges and a top cover assembly allowing for air circulation. This mechanism enables cooling air to travel through the annular space between the EOS-DSC and the TC inner diameter through the entire cask length and to exit through the vent passages in the modified top cover assembly of the cask.

As identified in SAR Table 2-1, only TC and lifting yoke (regulated under 10 CFR Part 50) are important to safety. Other transfer equipment components are not important to safety. Therefore, the transfer equipment is not evaluated in this SER. Chapters 3, 4, and 8 of this SER evaluates TC.

1.3 Drawings

Chapter 1 of the SAR contains both public and proprietary drawings for the NUHOMS® EOS System, including drawings of the structures, systems, and components (SSCs) important to safety. The NRC staff determined that the drawings contain sufficient detail on dimensions, materials, and specifications to allow for a thorough evaluation of the NUHOMS® EOS System. Chapters 3 through 12 of this SER evaluates specific SSCs.

1.4 Dry Shielded Canister Contents

The EOS-37PTH DSC is designed to store up to 37 intact PWR SFAs, with or without CCs. It is qualified for storage of Babcock and Wilcox (B&W) 15x15 class, Combustion Engineering (CE) 14x14 class, CE 15x15 class, CE 16x16 class, Westinghouse (WE) 14x14 class, WE 15x15 class, and WE 17x17 class PWR SFA designs, as described in Chapter 2 of the SAR.

The EOS-89BTH DSC is designed to store up to 89 intact BWR SFAs, with or without channels. It is qualified for storage of 7x7, 8x8, 9x9, and 10x10 class BWR SFAs of initial design or equivalent reload SFAs, as described in Chapter 2 of the SAR.

Reconstituted assemblies containing up to five replacement irradiated stainless steel rods per assembly or an unlimited number of low enriched or natural uranium fuel rods or nonfuel rods are acceptable for storage in both DSCs as intact SFAs. Both DSCs can store SFAs containing blended low enriched uranium (BLEU) fuel material. The maximum allowable planar average initial enrichment of the fuel to be stored is 5.00 weight percent uranium (U)-235 for EOS-37PTH and 4.80 weight percent U-235 for EOS-89BTH, and the maximum assembly average burnup is 62,000 megawatt days (MWd) per metric ton of uranium (MTU). Chapters 2 and 6 of the SAR discuss additional fuel characteristics.

1.5 Technical Qualifications of Applicant

Section 1.5 of the SAR defines agents and contractors. TN Americas LLC is the prime contractor for design and procurement of the NUHOMS® EOS System components. TN Americas LLC will subcontract the fabrication, testing, onsite construction, and quality assurance (QA) services, as necessary, to qualified firms on a project specific basis, in accordance with the requirements of the TN Americas LLC's QA program.

1.6 Quality Assurance Program

Section 1.6 of the SAR describes the QA program, and SAR Chapter 14 further discusses the program in detail. The QA program applies to the design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of the NUHOMS® EOS System and components identified as "important to safety" and "safety-related." Chapter 2 of the SAR defines these components and systems.

The NRC staff evaluates the TN Americas LLC's QA program in Chapter 14 of the SER.

1.7 Evaluation Findings

F1.1 A general description of the NUHOMS® EOS System is presented in Chapter 1 of the SAR, including design and operating characteristics, unusual or novel design features, and principal safety considerations.

F1.2 Drawings for SSCs important to safety are presented in Chapter 1 of the SAR. Chapters 3 through 14 of this SER evaluate specific SSCs.

F1.3 SAR Chapters 1, 2, and 5 state the specifications for the spent fuel to be stored in the NUHOMS® EOS System.

F1.4 Section 1.5 of the SAR identifies the technical qualifications of the applicant to engage in the proposed activities.

F1.5 Chapter 14 of the SAR discusses the QA program and implementing procedures.

The staff concludes that the information presented in Chapter 1 of the SAR satisfies the requirements for the general description of the proposed system under 10 CFR Part 72. This finding is reached on the basis of a review that considered the regulation itself, Regulatory Guide 3.61, "Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Cask," issued February 1989; and accepted practices.

1.8 References

Title 10, *Code of Federal Regulations*, Part 50, "Domestic Licensing of Production and Utilization Facilities."

Title 10, *Code of Federal Regulations*, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste."

U.S. Nuclear Regulatory Commission, "Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Cask," Regulatory Guide 3.61, February 1989.

U.S. Nuclear Regulatory Commission, "Standard Review Plan for Spent Fuel Dry Cask Storage Systems at a General License Facility," NUREG-1536, Revision 1, July 2010 (ADAMS Accession No. ML101040620).

U.S. Nuclear Regulatory Commission, Safety Evaluation Report, Docket No. 72-1030, Transnuclear, Inc. NUHOMS® HD Horizontal Modular Storage System for Irradiated Nuclear Fuel, 2010, ADAMS Accession No. ML070160089.

2.0 PRINCIPAL DESIGN CRITERIA

The NRC staff's objective in reviewing the principal design criteria related to the SSCs important to safety is to ensure that they comply with the relevant general criteria established in 10 CFR Part 72.

2.1 Structures, Systems, and Components Important to Safety

Table 2-1 of the SAR provides safety classification of major system components as either important to safety or not important to safety. The SSCs identified as important to safety include the EOS-37PTH DSC, EOS-89BTH DSC, EOS-HSM, EOS HSMS, and EOS-TC (TC135/TC125/TC108).

The safety classifications are based on the guidance in NUREG/CR-6407, INEL-95/0551, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety," issued February 1996.

2.2 Spent Fuel To Be Stored

The NUHOMS® EOS System has two DSC designs: EOS-37PTH DSC and EOS-89BTH DSC. Both DSCs store intact SFAs that meet the design characteristics specified in SAR Tables 2-2, 2-3, and 2-4 and other limits acceptable for storage in the NUHOMS® EOS System. The cavity length of the DSC is determined for a specific site to match the SFA length used at that site, including CCs, as applicable. The EOS-37PTH DSC and EOS-89BTH DSC payloads also include dummy and reconstituted SFAs. The SAR states that intact SFAs for storage in an EOS-37PTH DSC and EOS-89BTH DSC include reconstituted assemblies that contain (1) up to five replacement irradiated stainless steel rods per assembly, or (2) an unlimited number of BLEU or natural uranium fuel rods or non-fuel rods. The applicant also considers SFAs that contain fixed integral nonfuel rods as intact SFAs. Chapters 3, 4, 6, and 7 evaluate SFAs to be stored.

2.3 Design Criteria for Environmental Conditions and Natural Phenomena

Section 2.3 of the SAR describes the design criteria for meeting the requirements in 10 CFR Part 72.122 (b) for protection against environmental conditions and natural phenomena, including the following:

- tornado wind and tornado missiles
- flooding
- seismic events
- snow and ice loading
- tsunami
- lighting

The staff has determined that the descriptions provide a sufficient overview of the environmental conditions and natural phenomena for its evaluation. Chapters 3 through 12 of this SER provide further evaluation of these and other normal, off-normal, and accident conditions.

2.4 Safety Protection Systems

Section 2.4 of the SAR summarizes the design criteria for the NUHOMS® EOS System as discussed below.

2.4.1 General

The NUHOMS® EOS System provides safe and long-term dry storage of SFAs. Chapters 3 through 12 of the SAR discuss in detail the key elements and operation design considerations, including shielding and operations to minimize occupational dose and contamination, maintaining SFAs in subcritical configuration, providing effective heat removal, and keeping the temperature at appropriate levels.

2.4.2 Structural

Chapter 3 of the SAR presents the structural analysis for the EOS-37PTH DSC, EOS-89BTH DSC, EOS-HSM, and EOS-TC. It also describes the ability of these components to perform their design functions during normal and off-normal operating conditions, as well as under postulated accident conditions and extreme natural phenomena. Sections 3.6 and 3.7 of the SAR discuss the load combinations considered for combining normal operating, off-normal, and accident loads for the EOS-37PTH DSC, EOS-89BTH DSC, EOS-HSM, and EOS-TC. Chapter 3 of the SER documents the staff’s evaluation.

2.4.3 Thermal

Chapter 4 of the SAR presents the thermal analysis. The NUHOMS® EOS System is designed to passively remove decay heat. The DSC design ensures fuel cladding integrity by limiting fuel cladding temperature and maintaining a nonoxidizing environment inside the canister. Chapter 4 of this SER documents the staff’s evaluation.

2.4.4 Shielding/Confinement/Radiation Protection

SAR Chapters 5, 6, and 11 discuss the shielding analysis, confinement analysis, and radiological protection capabilities of the NUHOMS® EOS System, respectively. The DSC’s confinement is obtained with redundant welded closures and is verified through non-destructive examinations at the completion of welding. Radiation exposure is minimized through the shielding capabilities of the EOS-TC and the HSM. Chapters 5, 6, and 11 of this SER document the staff’s evaluation.

2.4.5 Criticality

Chapter 7 of the SAR presents the criticality analysis. The design criteria for criticality safety is the effective neutron multiplication factor upper subcritical limit of 0.95 minus statistical uncertainties and bias, which is limiting for all postulated arrangements of fuel within the canister. The control method used to prevent criticality is incorporation of poison material in the DSC and credit for soluble boron in the spent fuel pool. Chapter 7 of this SER documents the staff’s evaluation.

2.4.6 Materials Evaluation

Chapter 8 of the SAR presents the materials analysis. It describes the technical basis for the materials of construction of the storage system, considering their exposure to mechanical loading, radiation, heat, and moisture and potential contaminants in the environment. It also discusses the performance of the fuel cladding, the potential for hydrogen gas generation within the canister, and closure weld testing. Chapter 8 of this SER documents the staff's evaluation.

2.4.7 Operating Procedures

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Chapter 9 of the SAR describes generic operating procedures. It outlines the loading, unloading, and recovery operations and provides the basis and general guidance for more detailed, site-specific procedures. Chapter 9 of this SER documents the staff's evaluation.

2.4.8 Acceptance Tests and Maintenance

Chapter 10 of the SAR describes the acceptance test and maintenance program for the NUHOMS® EOS System, including the commitments, industry standards, and regulatory requirements used to establish the acceptance, maintenance, and periodic surveillance tests. Chapter 10 of this SER documents the staff's evaluation.

2.4.9 Decommissioning Considerations

The purpose of the staff's review is to assess the applicant's conceptual decommissioning plan to determine whether the cask system provides adequate provisions to facilitate decommissioning of the ISFSI once the spent fuel has been transferred to another location for storage or reprocessing. The applicable 10 CFR Part 72 requirements for decommissioning are in 10 CFR 72.130, "Criteria for decommission," and 72.236(l). The specific decommissioning plan for the ISFSI will depend on U.S. Department of Energy's (DOE's) fuel transportation system capability and requirements for a specific plant.

Section 2.4.9 of the SAR discusses two potential options for the removal of spent fuel from the ISFSI for storage/disposal at another NRC-approved location. The first option assumes that the NUHOMS® EOS DSC will be used with DOE's transportation system for offsite shipment. The DSC design features result minimal surface contamination and prevent the external surfaces of the DSC from contact with the fuel pool. Using the first option for facility decommissioning would result in very little DSC-related decontamination at the ISFSI.

The second option permits the removal of spent fuel from the NUHOMS® EOS DSC and shipment to a disposal facility in an NRC-approved transportation package. This option will likely result in contamination of the internal parts of a DSC and will require decontamination before disposal. Decommissioning the ISFSI will involve the steps identified in the first option, as well as decontamination and disposal of the empty DSCs.

2.5 Evaluation Findings

F2.1 The SAR and docketed materials adequately identify and characterize the spent nuclear fuel (SNF) to be stored in the NUHOMS® EOS DSC in conformance with the requirements given in 10 CFR 72.236, "Specific requirements for spent fuel storage cask approval and fabrication."

F2.2 The SAR and the docketed materials relating to the design bases and criteria meet the general requirements as given in 10 CFR 72.122(a), (b), (c), (f), (h)(1), (h)(4), (i), and (l).

F2.3 The SAR and docketed materials relating to the design bases and criteria for structures categorized as important to safety meet the requirements given in 10 CFR 72.122(a), (b)(1), (b)(2), (b)(3), (c), (f), (h)(1), (h)(4), and (i); and 10 CFR 72.236.

F2.4 The SAR and docketed materials meet the regulatory requirements for design bases and criteria for thermal consideration as given in 10 CFR 72.122 (a), (b)(1), (b)(2), (b)(3), (c), (f), (h)(1), (h)(4), and (i).

F2.5 The SAR and docketed materials relating to the design bases and criteria for shielding, confinement, radiation protection, and ALARA considerations meet the regulatory requirements as given in 10 CFR 72.104(a) and (b); 10 CFR 72.106(b); 10 CFR 72.122(a), (b), (c), (f), (h)(1), (h)(4), and (i); and 10 CFR 72.126(a).

F2.6 The SAR and docketed materials relating to the design bases and criteria for criticality safety meet the regulatory requirements as given in 10 CFR 72.124(a) and (b).

F2.7 The SAR and docketed materials relating to the design bases and criteria for materials meet the regulatory requirements as given in 10 CFR 72.104(a); 10 CFR 72.106 (b); 10 CFR 72.122 (a), (b), (c), (h)(1), (i), and (l); 10 CFR 72.124; and 10 CFR 72.236 (g), (h), (i), and (m).

F2.8 The SAR and docketed materials relating to the design bases and criteria for retrievability meet the regulatory requirements as given in 10 CFR 72.122(a), (b)(1), (b)(2), (b)(3), (c), (f), (h)(1), (h)(4), and (l).

F2.9 The SAR and docketed materials relating to the design bases and criteria for other SSCs not important to safety, but which are subject to NRC approval, meet the general regulatory requirements in 10 CFR Part 72: Subpart E, "Siting Evaluation Factors," 10 CFR 72.104, "Criteria For Radioactive Materials In Effluents And Direct Radiation From And ISFSI or MRS," and 10 CFR 72.106, "Controlled Area of an ISFSI or MRS"; Subpart F, "General Design Criteria," 10 CFR 72.122, "Overall Requirements," 10 CFR 72.124, and 10 CFR 72.126, "Criteria for Radiological Protection"; and Subpart L, "Approval of Spent Fuel Storage Casks."

The staff concludes that the principal design criteria for the NUHOMS® EOS System are acceptable and meet the regulatory requirements of 10 CFR Part 72. 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. Chapters 3 through 14 of this SER provide a more detailed evaluation of design criteria and an assessment of compliance with those criteria.

2.6 References

Title 10, *Code of Federal Regulations*, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste."

U.S. Nuclear Regulatory Commission, “Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety,” NUREG/CR-6407, INEL-95/0551, February 1996.

3.0 STRUCTURAL EVALUATION

This chapter presents the results of the NRC staff's review for the structural evaluation of the NUHOMS® EOS System. The applicant stated that the NUHOMS® EOS System consists of the following important-to-safety components:

- two DSCs, the EOS-37PTH DSC and the EOS-89BTH DSC, that provide confinement in an inert environment, structural support, and criticality control for the SFAs
- two DSC basket designs
- an HSM design, designated as either the EOS-HSM or the EOS-HSMS (split base), equipped with design features for shielding and heat rejection capabilities
- an EOS-TC system with a top cover plate that allows air circulation through the TC/DSC annulus during transfer operations

The EOS-HSM and EOS-HSMS are arranged in arrays (single row or back-to-back) to facilitate self-shielding. Shield walls are placed at both ends and at the back of a single row to reduce radiation dose rates. Two or more empty modules can be substituted for the end walls to accommodate expansion until the array is fully built.

The EOS-TC system is configured with three lengths for a 135-ton cask (EOS-TC135), a 125-ton cask (EOS-TC125), and a 108-ton cask (EOS-TC108).

According to the Chapter 1.1 of the SAR, the EOS-37PTH DSC is designed for a maximum heat load of 50 kW when transferred in the EOS-TC125/135, and a maximum heat load of 41.8 kW when transferred in the EOS-TC108. The EOS-89BTH DSC is designed for a maximum heat load of 43.6 kW when transferred in the EOS-TC125/135, and a maximum heat load of 41.6 kW when transferred in the EOS-TC108. The EOS-37PTH DSC can be transferred in any EOS-TC with a maximum heat load of 36.35 kW without air circulation available and, similarly, the EOS-89BTH with a maximum heat load of 34.4 kW.

Chapter 3 of the SAR provides a complete structural evaluation of the EOS-37PTH DSC and the EOS-89BTH DSC shell assembly and basket components, the EOS-HSM and EOS-HSMS, as well as the EOS-TC135, EOS-TC125, and EOS-TC108. The staff reviewed the applicant's structural evaluation, in accordance with NUREG-1536 and the applicable regulations. The staff concludes that the applicant demonstrates the NUHOMS® EOS System design is compatible with the requirements of 10 CFR 72.236, which require maintaining the spent fuel in a subcritical condition, providing adequate radiation shielding and confinement, having adequate heat removal capability, and providing a redundant sealing of the confinement system. The staff evaluated the structural performance of the NUHOMS® EOS System by considering primarily the system components of (1) DSC, (2) fuel basket assembly, (3) fuel rod, (4) HSM, and (5) TC for normal, off-normal, and accident conditions. The bases for the staff's findings are discussed in further detail in this chapter.

3.1 Structural Design of the NUHOMS® EOS System

The staff reviewed the applicant's description and information of the SSCs important to safety in SAR Chapters 1 and 3 to ensure the information is consistent and supplementary.

3.1.1 EOS-37PTH-EOS89BTH Dry Shielded Canister

The applicant stated that the DSC consists of a fuel basket and a shell assembly. The confinement/pressure boundary includes the DSC shell, the inner bottom cover plate (IBCP), the inner top cover plate (ITCP), the vent port plug, the drain port cover plate, and the associated welds. The IBCP is welded to the shell using a full penetration weld, while the ITCP is attached to the shell using a partial penetration weld. The vent port plug and the drain port cover plate are both welded to the ITCP using a partial penetration weld. Non-pressure boundary shield plugs are included at each end of the assembly. The inner bottom shield is confined between the IBCP and outer bottom cover plate (OBCP). The top shield plug is confined by the ITCP and four lifting lugs, which are welded to the inside of the DSC shell. The grapple ring support is welded to the OBCP using a full penetration weld. Grapple ring assembly connections are all made using full penetration welds. As depicted in SAR Drawings EOS01-1001-SAR and EOS01-1006-SAR, the design of the DSC includes five design options: EOS-37PTH (short, medium, and long) and EOS-89BTH (short and medium). The applicant considers and the staff also concludes the EOS-37PTH (long) DSC, which uses the TC135 for transfer operations, is the bounding configuration because it is the longest and the heaviest of the five options.

The DSC shell assembly geometry and the materials used for its analysis and fabrication are shown on Drawings EOS01-1000-SAR, EOS01-1001-SAR, EOS01-1005-SAR, and EOS01-1006-SAR included in Chapter 1 of the SAR. According to the SAR, the DSC shell thickness is 0.50 inch, and the top and bottom closure assemblies are 10.0 inches and 8.0 inches, respectively. The DSC shell is constructed entirely from stainless steel or duplex steel. The draining and venting systems are covered by the port plugs. The OTCP and the ITCP are welded to the cylindrical shell with multilayer welds. The DSC cavity is pressurized above atmospheric pressure with helium.

3.1.2 Fuel Basket Assembly

The applicant stated that the basket locates and confines the SFAs inside the DSC. The basket is made of interlocking, slotted plates to form an egg-crate type structure. The egg-crate structure forms either 37 compartments that house the PWR SFAs or 89 compartments that house the BWR SFAs. As depicted in SAR Drawings EOS01-1010-SAR and EOS01-1020-SAR, typical stackup of grid plates is composed of a structural steel plate, an aluminum plate for heat transfer, and a neutron absorber plate for criticality control.

According to the SAR, the basket structure is open at each end; therefore, when the EOS-TC is orientated in the vertical position, the SFA loads are applied directly to the cover plates of the DSC and not to the basket. When the EOS-TC is oriented in the horizontal position, the longitudinal SFA loads from handling may be partially applied to the basket due to friction. The SFAs are laterally supported in the fuel compartments of the basket, which, in turn, is laterally supported by the basket transition rail and the DSC inner shell.

3.1.3 Fuel Rod

The applicant stated that the NUHOMS® EOS System is designed to accommodate PWR (14x14, 15x15, 16x16, and 17x17 array designs) and BWR (7x7, 8x8, 9x9, and 10x10 array designs) fuel types and reload assemblies that are available for storage. The EOS-37PTH DSC is designed to accommodate up to 37 intact PWR SFAs with UO_2 fuel and zirconium-alloy cladding, and with or without control components. The EOS-89BTH DSC is designed to accommodate up to 89 intact BWR SFAs with UO_2 fuel and zirconium-alloy cladding, and with or without fuel channels. Tables 2-3 and 2-4 of the SAR contain the PWR SFA design characteristics and the BWR SFA design characteristics, respectively.

3.1.4 EOS-HSMS/EOS-HSM

The applicant described the EOS-HSM as a freestanding, reinforced concrete structure, designed to provide environmental protection and radiological shielding for the EOS-37PTH DSC or EOS-89BTH DSC. According to the applicant, the EOS-HSM consists of a base unit and a roof unit (the EOS-HSMS consists of two segments of the base unit and a roof unit and may be used in lieu of the EOS-HSM). The applicant stated that the EOS-HSMs may be arranged either in a single-row array or a back-to-back array. To provide the necessary shielding, end shield walls are placed at each end of an array and, for a single-row array, rear shield walls are placed in the back of the HSMs. The applicant explained that the DSC is supported inside the EOS-HSM by a DSC support structure that spans between the front and rear walls of the HSM and is comprised of two main support beams, two extension plates, and two Nitronic sliding rails. The web of each main support beam has openings to allow the air flow around the DSC. Drawing EOS01-3000-SAR of the SAR contains details on the construction of the EOS-HSM.

3.1.5 EOS-TC135/EOS-TC125/EOS-TC108

The applicant stated that the EOS TCs provide shielding and protection from potential hazards during DSC loading and closure operations as well as during transfer to the EOS-HSM. According to the applicant, the TCs are non-pressure retaining cylindrical vessels with welded bottom assemblies and a bolted top cover plate. The TCs are constructed of SA-516 Grade 70 carbon steel and include an aluminum neutron shield tank, lead gamma shielding, and A182 steel trunnions. The applicant stated that the EOS-TCs use a bottom cover incorporating wedges that lifts the canister off the bottom of the TC, and a top cover assembly that allows air circulation for cooling. This modified top cover assembly allows cooling air to enter the annular space between the EOS-DSC and the TC inner diameter. The cooling air passes through the entire cask length and exits through the vent passages in the modified top cover assembly of the cask. The applicant further stated that the neutron shield tanks on the TCs are designed to retain pressure and the EOS-TC108 is designed with removable neutron shield panels. The EOS-TC geometry and the materials used for its analysis and fabrication are shown on Drawings EOS01-2000-SAR, EOS01-2001-SAR, EOS01-2002-SAR, EOS01-2010-SAR, EOS01-2011-SAR, and EOS01-2012-SAR included in Chapter 1 of the proprietary SAR.

The staff reviewed the descriptions and drawings of the SSCs important to safety, specifically, the DSCs, the fuel basket assemblies, the SFAs, the HSMs, and the TCs. The staff concludes that the descriptions of the structural components are complete and adequate because they are consistent with the guidance of NUREG-1536.

3.2 Design Criteria

The staff evaluated the applicant’s design criteria for the various SSCs important to safety. In most cases, the applicant used consensus codes or standards that are generally accepted by the staff. In the cases where the applicant deviated from an acceptable code, or in situations where there is no code or standard that is applicable, the staff evaluated the design criteria using generally accepted engineering principles to determine the design criteria adequately protect public health and safety.

3.2.1 EOS-37PTH/EOS89BTH Dry Shielded Canister

Section 3.1.1.1.1 of the SAR states that the EOS-37PTH DSC and the EOS-89BTH DSC are designed using the 2011 edition of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, Division 1, Subsection NB (ASME B&PV, 2011) and the ASME Code alternatives as described in Section 4.4.4 of the TS. The applicant applied the stress acceptance criteria of ASME B&PV Code, Section III, Division 1, Level A and B Service Limits to the normal and off-normal loading conditions, respectively. For accident conditions, the applicant applied the Service Level D stress limits in ASME B&PV Code, Section III, Division 1, Appendix F. The applicant used elastic and plastic analyses for the calculation of component stresses for all normal, off-normal, and accident conditions respectively.

Table 3-1 of the SAR summarizes the stress limits for Service Level A, B, and D loading conditions for the DSC shell components. For the stress limits associated with the ITCP and OTCP-to-shell partial penetration welds, the applicant invoked the local primary stress provisions of paragraph F-1341, in ASME B&PV Code, Appendix F, with increased stress limits to 150 percent of those with the general primary stresses. As summarized in Table 3.9.1-4 of the SAR, the applicant also applied a stress reduction factor of 0.8 on the stress intensity limits in accordance with NUREG-1536, Section 8.4.7.3. To complement the technical basis for the increased stress limits, the applicant performed a plastic analysis of ASME B&PV Code, Section III, Division 1, Subsection NB-3228, along with the strain criteria provisions from ASME B&PV Code, Section III, Appendix FF, in a sensitivity study to demonstrate the safety margins of the partial penetration welds. The staff concludes that the applicants' sensitivity analysis is acceptable and provides the detailed evaluation of this analysis in Section 3.4.1 of this SER.

3.2.2 Fuel Basket Assembly

Section 3.1.1.1.1 of the SAR states that the EOS-37PTH basket and the EOS-89BTH basket are designed using the 2011 edition of the ASME B&PV Code, Section III, Division 1, Subsection NG. The applicant applied the stress acceptance criteria of Subsection NG-3200 Level A, B and D Service Limits to the normal, off-normal, and accident loading conditions, respectively. Where applicable, the applicant applied the stress limits of Subsection NG-3200 and Appendix F Level D Service Limits to the accident loading conditions. Additionally, to qualify the steel basket plates, the applicant used the equivalent plastic strain criteria in Section 3.1.1.1.1 of the SAR for the Service Level D loading conditions. Table 3-2 of the SAR summarizes the stress limits for Service Level A, B, and D service loading conditions for the DSC basket assemblies. SAR Table 3.9.2-5 summarizes the additional strain limits for Service Level D loading conditions.

3.2.3 Fuel Rod

Section 3.9.6.3.3 of the SAR states that the combination of the maximum calculated bending stress due to the inertia load and axial stress due to rod internal pressure must be less than the yield strength of the fuel cladding material to ensure the fuel cladding does not fracture for the side drop analysis. In section 3.9.6.4.3 of the SAR for the corner drop, the applicant stated that the maximum principal strain must be less than the yield strain of 0.926 percent for Zircaloy cladding at 750 ˚F which is the bounding temperature for Zircaloy cladding. Section 3.5.1.2 of NUREG-1536 states that cladding should be protected against rupture. The staff finds that when the strain of the Zircaloy cladding is maintained below the maximum yield strain, there is reasonable assurance that the cladding will not rupture. Therefore, the staff concludes that the applicant's design criteria for the fuel cladding material protects against fracture and is an acceptable.

3.2.4 EOS-HSMS/EOS-HSM

The applicant stated in Section 3.1.1.2 of the SAR that the EOS-HSM and EOS-HSMS were designed to the provisions of American Concrete Institute (ACI) 349-06, "Code Requirements for the Nuclear Safety-Related Concrete Structures and Commentary," supplemented with ACI 318-08, "Building Code Requirements for Structural Concrete and Commentary"; the alternate provisions to the ASME B&PV Code as described in Section 4.4.4 of the TS; and the American Institute of Steel Construction (AISC) Steel Construction Manual, 13th Edition.

3.2.5 EOS-TC135/EOS-TC125/EOS-TC108

Section 3.1.1.3 of SAR states that the EOS-TC135, EOS-TC125, and the EOS-TC108 are designed using the 2011 edition of the ASME B&PV Code, Section III, Division 1, Subsection NF. The applicant applied the elastic stress acceptance criteria of ASME B&PV Code, Section III, Division 1, Level A and B Service Limits to the normal and off-normal conditions, respectively. For accident conditions, the applicant applied the Service Level D stress limits of ASME B&PV Code, Section III, Division 1, Appendix F. Table 3-3 of the SAR summarizes the stress limits for Service Level A, B, C, and D loading conditions for the TC structural shell. Table 3-4 of the SAR summarizes the stress limits for Service Level A, B, C, and D Service loading conditions for the TC bolts. The applicant stated that the neutron shields were designed using the 2011 edition of the ASME B&PV Code, Section III, Division 1, Subsection ND, and summarized the stress limits for the neutron shields in Table 3-5 of the SAR. The applicant designed the upper lifting trunnions and associated welds in accordance with American National Standards Institute (ANSI) N14.6, "Radioactive Materials—Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4,500 kg) or More," issued 1993, for a nonredundant lifting device. The applicant stated that the trunnions will be tested to 300 percent of the design load during fabrication.

The staff reviewed the design criteria established by the applicant for the SSCs important to safety, which includes the DSCs, the fuel basket assembly, the SFAs, the HSMs, and the TCs. The staff concludes the design criteria are acceptable because the criteria are consistent with NUREG-1536 or because the criteria are consistent with generally accepted engineering principles.

3.3 Loads

The staff evaluated the structural loads that the applicant applied in the analysis of the SSCs important to safety under normal, off-normal, and accident conditions and determined that they are appropriate and consistent with NUREG-1536.

3.3.1 EOS-37PTH/EOS89BTH Dry Shielded Canister

Dead Load

The applicant considered three configurations to determine the dead load on the DSC shell:

(1) DSC vertical in the EOS-TC135: The payload of 105 kips is applied as a uniform pressure acting on the IBCP.
(2) DSC horizontal in the EOS-TC135: The end components and the basket assembly bear against the DSC shell which is supported by the TC.
(3) DSC horizontal in the EOS-HSM: The end components and the basket assembly bear against the DSC shell which is supported by the EOS-HSM support rails.

Internal Pressure

Section 3.9.1.2.7 of the SAR states that the design pressure is 15 pounds per square inch gauge (psig), the off-normal pressure is 20 psig, and the accident pressure is 130 psig. For conservatism, the applicant used the off-normal pressure for all normal and off-normal load combinations including blowdown and pressure test operations.

EOS-HSM Loading and Unloading

For loading the DSC into the EOS-HSM, the applicant applied a 135-kip ram push on the grapple ring for normal, off-normal, and accident conditions. For unloading, the applicant applied an 80-kip ram pull on the grapple ring for normal and off-normal conditions and a 135-kip pull for accident conditions.

Transfer/Handling Load

To simulate handling operations while in the TC, the applicant applied an additional 1g vertical, 1g transverse, and 1g axial loads individually to the DSC. The applicant also simultaneously applied a ±0.5g axial, ±0.5g transverse, and ±0.5g vertical load to the DSC.

Seismic

The applicant applied a 1g vertical, 2g transverse, and 1.25g axial loads as the seismic load on the DSC while it is in the EOS-HSM.

Cask Drop

The applicant considered a 65-inch side drop of the TC and a 65-inch corner drop at an angle of 30 degrees to the horizontal onto a 36-inch thick reinforced concrete pad underlain by a 470-inch deep soil subgrade. The applicant calculated a maximum TC deceleration of 53.4g for the side drop and 16.0g axial deceleration for the corner drop. To envelop the calculated decelerations, the applicant used 75g for three drop scenarios: the bottom end drop, the top end drop, and the side drop.

Thermal Loads

The applicant considered thermal loads as a result of ambient temperatures ranging from -40 °F to 117 °F. For normal hot conditions, the applicant used 100 °F; for normal cold conditions, the applicant uses -20 °F. For both of these conditions, the applicant determined a bounding shell temperature of 422 °F as stated in Table 4-6 of the SAR. For off-normal cold at -40 °F, off-normal hot at 117 °F, and accident (blocked vent) conditions, the applicant produced shell temperatures of 285 °F, 435 °F, and 604 °F, respectively.

3.3.2 Fuel Basket Assembly

Dead Load

The applicant applied the weight of the SFAs as a uniform pressure within the fuel compartment of the basket when the DSC is in the horizontal position.

Handling Loads

The applicant applied an additional 1g vertical, 1g transverse, and 1g axial to the SFAs within the basket to simulate handling operations, which the applicant considered as a normal load.

Thermal Load

The applicant considered the basket temperature profiles as presented in Chapter 4 of the SAR for the thermal stress analysis, in addition to their use to establish at-temperature stress limits of the basket structural components.

Cask Drop

The applicant calculated a maximum TC deceleration of 53.4g for the side drop and 16.0g axial deceleration for the corner drop. To bound the loading condition, the applicant considered 60g and 75g inertial forces for side drop and end drop analysis, respectively.

3.3.3 Fuel Rod

Dead Load

The applicant used both the weight of the fuel and the cladding for modeling inertia forces, and took no credit for the stiffness of the fuel.

Internal Pressure

The applicant considered 2,235 pounds per square inch (psi) as the internal pressure of the fuel to compute the axial stress in the fuel cladding for the side drop and considered 1,400 psi for the corner drop.

Drop Load

The applicant calculated a maximum TC deceleration of 53.4g for the side drop and 16.0g axial deceleration for the corner drop. As a conservative approach, the applicant used a higher deceleration value for the side drop evaluation. For the fuel rod buckling associated with the TC axial deceleration response time history in the corner drop event, the drop load is considered in an explicit dynamic analysis, which recognized the fuel rod terminal velocity of 224 in/sec corresponding to a drop height of 65 inches and the TC axial deceleration response.

3.3.4 EOS-HSMS/EOS-HSM

Dead Load

The applicant used the heaviest design weight of the HSM as the dead load by applying a 1g vertical acceleration (386.4 in/sec^2) to the model.

Live Load

Section 3.9.4.7.2 of the SAR considered a 200 pound-per-square-foot (psf) pressure on the roof of the HSM, which included a 110 psf snow and ice load, as well as the weight of the DSC on the rails as the live load.

Handling Loads

For normal handling, the applicant applied an axial force of 70 kips in each direction to each DSC support rail for a total of 140 kips of loading, which enveloped the insertion and extraction forces. In addition to the axial force, the applicant also distributed the weight of the DSC to both DSC support beams of the HSM.

The applicant considered that off-normal ram loads will occur due to misalignment resulting in binding of the DSC on the rails made of carbon steel beams, which are anchored to the front and rear HSM walls. For the DSC support structure, the applicant defined the off-normal handling load as 135 kips on one DSC support beam plus a vertical load of one half the DSC weight on both beams at the most critical location.

EOS-HSM Thermal Load

The HSM temperature profiles as determined in Chapter 4 of the SAR for normal, off-normal, and accident blocked vent conditions are considered for the thermal stress analysis, in addition to their use to establish at-temperature stress limits of the HSM structural components.

EOS-HSM Design Basis Wind Load

The applicant stated that the forces and moments on the concrete structure generated by tornado force winds provide an upper limit bounding for wind load. By reviewing the SAR calculations, the staff confirmed the assessment made by the applicant. For this reason, the staff finds it acceptable that the applicant did not conduct a separate analysis for normal wind loads.

Tornado Wind Loads

The applicant used the Region I tornado intensities from Regulatory Guide 1.76, Revision 1, “Design Basis Tornado and Tornado Missiles for Nuclear Power Plants,” issued March 2007, in performing the stress analysis and stability analysis. For Region I, the maximum wind speed is 230 miles per hour (mph) due to a rotational speed of 184 mph and a translational speed of 46 mph.

Tornado Missile Loads

The applicant used three tornado missiles that it states envelopes the spectrum given in Section 3.5.1.4, Revision 3, “Missiles Generated by Tornadoes and Extreme Winds,” issued March 2007, of NUREG 0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition”:

- 4,000 pound (lb) automobile traveling at 195 feet per second (fps) at 25 feet above the ground
- 15-foot schedule 40 steel pipe, 12-inch diameter, weighing 750 lb., traveling at 154 fps
- 1-inch diameter solid steel sphere, weighing 0.147 lb., traveling at 26 fps

The applicant stated that evaluation for the effects of the small diameter solid spherical missile is not required, because there is no opening in the EOS-HSM leading directly to the DSC through which such a missile could pass. The staff reviewed Drawing EOS01-3000-SAR for the general arrangement of the HSM and confirms that no inlet/outlet openings exist that will provide a direct path to the DSC for a small diameter solid sphere missile.

Seismic Load

The applicant considered the spectra in Regulatory Guide 1.60, Revision 1, “Design Response Spectra for Seismic Design of Nuclear Power Plants,” issued December 1973, with an enhanced frequency content around 9 Hz to specify the HSM base motion input at the top of the storage pad. The spectra are anchored at 0.45g and 0.30g peak accelerations in the horizontal and vertical directions, respectively. The applicant calculated amplified acceleration in the longitudinal and transverse directions of the HSM based on the predominant frequency of 32.7 Hz and 18.7 Hz of the structure in the respective directions. The result was an inertial seismic load of 0.936g, 0.628g, and 0.333g in the transverse, longitudinal, and vertical directions, respectively.

Flood Load

The applicant considered a flood height of 50 feet and a water velocity of 15 fps to calculate a drag pressure of 436 psf on the leading face of the HSM and applied it in three cases—front to back, back to front, and right side to left side.

3.3.5 EOS-TC135/EOS-TC125/EOS-TC108

Dead and Live Loads

The applicant used the loaded weight of the EOS-TC plus the EOS-37PTH DSC of 270 kips (unloaded TC is 136 kips, and loaded DSC is 134 kips). For handling loads, the applicant included a dynamic load factor of 1.15.

Thermal Loads

The TC temperature profiles presented in Chapter 4 of the SAR are considered in the thermal stress analysis. Additionally, the temperature profiles are used to establish at-temperature stress limits of the TC structural components.

Transfer Handling Loads

In order to simulate handling operations while the DSC is in the TC, the applicant applied an additional 1g vertical, 1g transverse, and 1g axial load individually to the TC. The applicant simultaneously applied a ±0.5g axial, ±0.5g transverse, and ±0.5g vertical load to the TC.

Cask Drop

In Appendix 3.9.3 of the SAR, the applicant simulated a 65-inch side drop of a loaded TC from the transfer trailer onto an unyielding surface and calculated this drop would produce a 53.4g downward acceleration on the DSC and TC. The applicant also evaluated a corner drop of a loaded TC and calculated a 16.0g downward acceleration. The applicant used an acceleration of 65g as the inertial load, which is bounding for both drop scenarios.

Tornado Wind Load

The applicant used the Region I tornado intensities from Regulatory Guide 1.76, Revision 1 in their stress analysis and stability analysis, which are described in Section 3.3.4 of this SER.

Tornado Missile Load

The applicant used the tornado missiles specified in NUREG-0800, Section 3.5.1.4, Revision 3, which are described in Section 3.3.4 of this SER.

Horizontal Transfer and Seismic Loads on Neutron Shield Tanks

The applicant combined the horizontal transfer and seismic loads by applying to the EOS-TC108 a 20 psig internal pressure to the neutron shield tank and combined accelerations of 1g dead weight, 1g vertical, 1g lateral, and 1g axial. Additionally, the applicant added a uniform internal pressure of 7.5 psig that was equal to the maximum hydrostatic pressure, which resulted in an internal pressure of 27.5 psig.

In the same manner, the applicant applied to the EOS-TC124 and EOS-TC135 a total internal pressure of 40 psig along with combined accelerations of 2g vertical, 2g lateral, and 2g axial.

The staff reviewed the normal, off-normal, and accident loads that the applicant used to analyze the structural performance of the SSCs important to safety, specifically the DSCs, the fuel basket assemblies, the SFAs, the HSMs, and the TCs. The staff concludes that the analyzed loads are consistent with the loads in Table 3-2 of NUREG-1536. The staff also finds the SSCs important to safety will perform adequately under the analyzed loads.

3.4 Analysis Methodology

The staff reviewed the analytical approach used by the applicant to evaluate the structural performance of the SSCs important to safety. The staff confirmed that hand calculations were properly computed with generally accepted engineering equations. The staff confirmed that all aspect of the applicant's computer-based models (i.e. finite element models) were consistent with standard practices described in NUREG-1536. The applicant used the commercially available finite element software package ANSYS, Release 14.0, for the computer-based analysis of the SSCs important to safety, which the staff finds is appropriate.

3.4.1 EOS-37PTH/EOS89BTH Dry Shielded Canister

The applicant applied 11 different load combinations to the DSC using the loads described in Section 3.3.1, specifically identifying effects on the DSC during loading, handling, and storage for normal, off-normal, and accident conditions. Table 2-5 of the SAR lists the11 load combinations that the applicant used in its analysis.

The applicant stated that the EOS DSC shell assembly is analyzed for the postulated conditions with a three-dimensional (3D), 180-degree half-symmetric finite element model using the nominal dimensions of the long cavity DSC. The applicant modeled each of the DSC shell assembly components using the ANSYS SOLID185 solid element within the ANSYS computer modeling software. Because these elements have only translational degrees of freedom at each of the eight corner nodes, the applicant used multiple layers of elements through the thickness of the DSC components to accurately simulate the component bending behavior. The applicant modeled the interfaces between the OTCP, ITCP, and top shield plug surfaces using the ANSYS CONTA178 node-to-node contact element, which allows the transfer of compressive bearing forces when two elements come into contact. As discussed in Section 3.5.1 and 3.6.1 of this SER, structural adequacy of the DSC is demonstrated if it meets the stress provisions of Section III, Division 1, Subsection NB of the ASME B&PV Code. Specifically, the stress categorization at specific DSC locations must satisfy the stress intensity limits specified in ASME B&PV Code.

In Section 3.9.1.2.6 of the SAR, the applicant conducted a sensitivity analysis on the safety margin of partial penetration welds using limit analysis and strain acceptance criteria on the internal pressure load combinations and the side drop load combinations. The sensitivity analysis supplemented the commonly used stress categorization-based acceptance criteria. The limit analysis is consistent with the design provisions of ASME B&PV Code, Section III, Division 1, Subsection NB-3228 and the strain acceptance criteria are consistent with the criteria in Appendix FF of the ASME B&PV Code.

For the limit analysis on the pressure load combinations, the applicant modeled the material as elastic-perfectly plastic with a yield stress based on $1.5S_m$. The applicant performed an ANSYS quasi-static analysis by applying either an internal pressure of 20 psig or a 1g acceleration and linearly increased the pressure and acceleration for each case, respectively, until the solution no longer converged. The applicant reported the results in Figures 3.9.1-24 and 3.9.1-25 of the SAR. Both figures indicate a continuing increase in the closure lid displacement well past the design basis pressure of 30 psig and an acceleration of 83.25g until the solution failed to converge at 270 psig and an acceleration of 217g, respectively.

The limit analyses revealed that the weld would undergo unbounded deformation after the material yield strength is reached. To recognize the potential material rupture associated with large weld deformation and, hence, high plastic strain concentration, the applicant performed an elastic-plastic analysis to aid in the determination of the weld performance margins for the DSC subject to a side drop accident. For the strain-based sensitivity study in accordance with ASME B&PV Code, Section III, Division 1, Appendix FF, the applicant used the material properties described in the SAR as a baseline analysis case. The applicant performed two additional analyses with increased yield strength to account for strain rate effects specified in Section FF-1145 of the ASME B&PV Code. Table 3.9.1-15 of the SAR summarizes the maximum strains in the partial penetration weld of the DSC undergoing the 75g side drop. The calculated maximum equivalent plastic strain has a factor of safety of 2.6, considering the uniform strain limit.

The staff reviewed the sensitivity studies in SAR and the appropriate sections of the ASME B&PV Code. The staff notes that the weld material is not one of the design attributes included in ASME B&PV Code, Appendix FF, for which the strain-based acceptance criteria can be used. However, the staff finds the results acceptable because the large calculated strain margin against weld material rupture indicate the structural adequacy of the weld for maintaining its confinement function. For these reasons, the staff concludes that the primary local stress categorization, as discussed in Table 3.9.1-4 of the SAR, is acceptable for evaluating stress performance margins for the partial penetration welds in the DSC.

To evaluate the stress performance of the DSC assembly components, the applicant applied an enveloping method to determine limiting stresses in the components. The applicant stated that for some load combinations, it combined various individual loads in a single analysis in order to reduce the number of computer runs, but still produce conservative results. In evaluating other load combinations, the applicant calculated the stress intensities for each individual load (e.g., dead load, pressure load) within the load combination. These individual stress intensities were added to determine the total stress in the component for each combination. By reviewing the sample, representative calculations in the SAR, the staff concludes that the enveloping method is conservative and acceptable.

3.4.2 Fuel Basket Assembly

For the basket assembly analysis, the applicant applied four load combinations that use the loads described in Section 3.3.3 of this SER and encompass the various conditions of the DSC basket during normal, off-normal, and accident conditions. Table 2-6 of the SAR lists the load combinations the applicant used in its analysis.

The applicant used both hand calculations and the finite element analysis software program ANSYS to perform the stress analysis. The applicant modeled a 6-inch slice of the basket assembly that is one half the width of a basket plate. The egg-crate design of the basket is mirrored in the 6-inch-long model such that one end of the model lies at the symmetry plane of the horizontal plates and is at the free edge of the vertical plates. The opposite configuration occurs at the other end of the 6-inch long model. The applicant modeled the steel grid plates, the DSC shell, and the R45 transition rails using ANSYS SHELL181 elements and the aluminum transition rails using ANSYS SOLID185 elements. The applicant stated that no structural strength was taken for the poison plates or for the aluminum plate and therefore did not include them in the model, but captured the mass of these components by increasing the density of the adjacent steel grid plates. The applicant modeled the contact between the grid plates at the slots, between the grid plates and the aluminum transaction rails, and between the basket and the DSC shell using ANSYS CONTA178 elements. The applicant modeled the bolts that connect the transition rails to the grid plates and the tie rods for the R90 transition rail assemblies using ANSYS BEAM4 elements.

3.4.3 Fuel Rod

SAR Sections 3.9.6.3 and 3.9.6.4 describe the finite element model used for the side drop and corner drop analyses of the PWR fuel, respectively. The applicant based the model on the geometry data summarized in SAR Tables 3.9.6-1 and 3.9.6-2. The applicant stated that this method was used for the side drop analysis of the PWR SFAs in Appendix Z to the UFSAR for

CoC No. 1004 (AREVA, 2014), and the corner drop analysis for the NUHOMS® 32P at Calvert Cliffs (Exelon Generation, 2015). Appendix Z to the UFSAR for CoC No. 1104 is proprietary.

SAR Sections 3.9.6.5 and 3.9.6.6 describe the finite element model used for the side drop and corner drop analyses of the BWR fuel, respectively. The applicant based the model on the geometry data from Table 3.9.6-8 of the SAR. The applicant stated that this method was used for the side drop analysis of the BWR SFAs in Appendix Y of the UFSAR for CoC No. 1004 (AREVA, 2014), and the corner drop analysis for the NUHOMS® 32P at Calvert Cliffs (Exelon Generation, 2015). Appendix Y to the UFSAR for CoC No. 1104 is proprietary.

3.4.4 EOS-HSMS/EOS-HSM

The applicant applied seven load combinations for the concrete structure (Table 3.9.4-5 of the SAR) and eight allowable stress design combinations for the steel structures (Table 3.9.4-16 of the SAR) based on the loads described in Section 3.3.4 of this SER that encompass the various conditions of the HSM during loading and storage for normal, off-normal, and accident conditions.

The applicant developed a 3D ANSYS finite element model of the EOS-HSM that includes all the concrete components and used the eight-node SOLID185 brick element to model the structure. The applicant modeled the DSC using BEAM4 beam elements. The mass of the DSC, which accounts for the inertial load exerted on the HSM, is lumped at 11 discrete nodes using the MASS21 lumped mass element. The DSC main support beam, W12x36, and the brace, C3x5, are also modeled using BEAM4 beam elements with the appropriate section properties. The applicant incorporated the DSC support structure into the lower base segment part of the EOS-HSM model to transfer the loads from the support structure to the concrete components. The applicant used the node coupling option of ANSYS to represent the connection between the base and the roof of the EOS-HSM model. For the EOS-HSMS optional design with segmented base, the applicant used CONTA178 contact elements across the interface between the upper and lower segments to transfer the load from the roof and upper segment. Additionally, the applicant constrained the nodes at the bottom of the EOS-HSM model in all three translational degrees of freedom to maximize the design forces and moments for design evaluation. The applicant post-processed the results of the ANSYS analysis for the various load combinations to determine the maximum shear, axial, and bending moment forces in the concrete components.

The applicant performed the thermal stress analysis of the EOS-HSM on the reinforced concrete components only because the connections of the door and the support structure are designed to permit full thermal growth. For the thermal evaluation, the applicant restrained the bottom of the EOS-HSM model at one set of edge nodes (axial and lateral) and one node in the front wall and two in the back wall in the vertical direction, then applied friction forces at the bottom of the EOS-HSM model base in the axial and lateral directions.

The applicant developed a 3D finite element model of the DSC main support beam with stiffener plates and rail extension plates using BEAM189 elements in ANSYS to form the diagonal web elements that result from the triangular opening in the web. The model recognized that the beam is aligned in the plane, which is inclined by 30 degrees from vertical, and is completely restrained at the bottom end of the rail extension baseplate. The ends of the beam are restrained for vertical displacement and rotation about the longitudinal axis to simulate the simple support conditions. The beam is also restrained laterally at the locations of lateral braces.

The applicant modeled the heat shields in ANSYS using SHELL63 elements and BEAM4 elements to represent the studs. The applicant used the ANSYS model to determine the seismic load on the studs and panel by considering the natural frequency and damping of the system. The applicant used the spectral accelerations and corresponding modal forces to calculate the stress incurred in the HSM components. This structural analysis approach follows the common mode superposition dynamic analysis practice; therefore, the staff finds this analytical approach acceptable.

3.4.5 EOS-TC135/EOS-TC125/EOS-TC108

The applicant used a geometric and load bounding representation, which enveloped the three EOS-TCs, and referred to it as the EOS-TCMAX. The applicant considered the geometric dimensions of the ANSYS model to yield the most bounding stresses and deformations. The trunnions and associated welds were evaluated using hand calculations while the local shell evaluation around the trunnion was evaluated using the ANSYS model.

For the accident side and end drop scenarios, the applicant used a 3D half symmetric model with SOLID185 elements to model the EOS-TC components, and COMBIN39 spring elements to model the top cover bolts and node couples in all three directions to model welds. For the EOS-TC108 neutron shield, the applicant modeled a 120-degree segment SHELL181 3D element. The applicant also implemented surface to surface contact elements using CONTA173 to model interactions among TC components in the ANSYS analysis. The applicant used material properties at 300 °F.

3.4.6 Cask Drop

For the EOS System components that are subjected to inertial loads due to impact as a result of a 65-inch cask drop, the applicant used an LS-DYNA finite element analysis to determine the acceleration values that were used in the quasi-static impact analysis. The applicant used available solid elements for the LS-DYNA model of the transfer cask components, and modeled the fuel to reduce the structural credit for the fuel assemblies. The applicant chose the EOS-TC108 loaded with an EOS-37PTH DSC as the bounding configuration because this is the lightest weight combination and will produce the highest accelerations.

The applicant constructed a half symmetry finite element analysis model consisting of the EOS-TC108, the EOS-37PTH DSC, a dummy fuel representation, a concrete pad, and the underlying soil. The applicant used a 36-inch thick reinforced concrete pad underlain by 470 inches of soil, with material properties taken from NUREG/CR-6608, “Summary and Evaluation of Low Velocity Impact Tests of Solid Steel Billet onto Concrete Pads,” issued February 1998.

Figures 3.9.3-9 and 3.9.3-10 of the SAR present the resulting acceleration time histories for the side drop and corner drop, respectively. On the basis of the response time histories, the applicant reported maximum accelerations for the side drop and the corner drop, which were considered for the quasi-static analysis of the EOS System components.

The staff reviewed the applicant’s analytical approach to evaluating the SSCs important to safety in the NUHOMS® EOS system under normal, off-normal, and accident conditions. Specifically, the staff reviewed the ANSYS models, including the quasi-static analysis, which was used to calculate the stresses and strains in the component material as a response to the applied structural loads. The staff concludes that the analytical approach used by the applicant for the various SSCs important to safety is acceptable because it is consistent with state of the practice engineering principles. Furthermore, the staff finds that the ANSYS finite element models used to determine the structural performance of the SSCs important to safety are appropriate because they are consistent with the computational modeling software technical review guidance of NUREG-1536.

3.5 Normal and Off-Normal Conditions

The staff reviewed the results of the applicant's evaluation of the SSCs important to safety that comprise the NUHOMS® EOS system under normal and off-normal conditions. This review included the various load combinations that the applicant applied to the structural components to characterize each condition of loading.

The goal of a structural evaluation is to illustrate, through analysis, that the calculated stresses or strains in a component are less than those allowed by the code or standard on which the design is based. To make this comparison, it is a standard engineering practice to determine a margin of safety or factor of safety as shown below:

$$Margin\ of\ Safety = \frac{Allowed\ Stress}{Calculated\ Stress} - 1 \geq 0$$

$$Factor\ of\ Safety = \frac{Calculated\ Stress}{Allowed\ Stress} \leq 1$$

Both equations present the same engineering principle in that the calculated stress must be less than the allowed stress for the structural design to be adequate. In the SAR, the applicant substituted the term "stress ratio" for the term "factor of safety." The concept is the same in that in order to achieve a stress ratio (factor of safety) less than or equal to one, the calculated stress in the component must be less than the code allowed stress in the component.

In evaluating reinforced concrete design, and in some cases steel design, the structural member's capacity to resist axial, shear, and bending moment forces are compared to the applied forces, instead of comparing calculated and code allowed stresses. This practice is referred to as strength design. In this case, the applicant used the term demand-to-capacity ratio, as shown below, to equate the calculated forces or loads applied to the structural member (demand) to the maximum force or load that the member can support (capacity).

$$Demand\ to\ capacity\ ratio = \frac{Demand}{Capacity}$$

In strength design, the design loads are also multiplied by factors based on the type of load (dead load, live load, wind load, etc.) and are applied in combinations (e.g., dead load in combination with live load). These combinations of factored loads are the code-specified strength limit states that establish the required strength to be provided in the structural component being designed. In some cases, such as tip-over and sliding analysis, a demand-to-capacity ratio is set to a value larger than 1.0 in order to provide an additional margin to the limit state. Table 3-3 of NUREG-1536 lists the minimum load combinations that the NRC accepts for steel and reinforced concrete, non-confinement structures.

The applicant used these terms throughout the normal, off-normal, and accident conditions analysis to demonstrate the structural performance of the components that comprise the NUHOMS® EOS system. The staff bases the structural performance findings of the NUHOMS® EOS system on these terms.

3.5.1 EOS-37PTH/EOS-89BTH Dry Shielded Canister

The applicant presented the results of the normal and off-normal conditions of loading in Tables 3.9.1-7 through 3.9.1-12 of the SAR for the DSC body and associated welds. The tables list; 1) the calculated stress in the shell for each stress category, 2) the stress allowables (based on the material properties of the shell material at 500 °F and SAR Table 3-1), and 3) the calculated stress ratio (actual stress/stress allowable). The normal and off-normal condition load cases from Table 2-5 of the SAR are LC1 through LC5 and LC9. The applicant considered the following components: the confinement and non-confinement portions of the DSC, the ITCP, the outer top cover plant, the ITCP, the ITCP-to-shell weld, and the OTCP-to-shell weld.

For LC1 (normal condition), the applicant evaluated the DSC in the vertical position in the TC, with the inner top cover installed. The loads applied include the dead weight of the basket assembly and off-normal pressure (20 psig).

For LC2 and LC3 (normal conditions), the applicant evaluated the DSC in the TC in the horizontal position on the trailer, supported at the trunnions and saddle locations. The loads applied include the dead weight of the basket assembly, off-normal pressure, and handling loads (1g vertical, transverse, and axial).

For LC4 (normal/off-normal condition), the applicant evaluated the DSC in the TC in the horizontally position on the trailer, supported by the trunnions and saddle locations. The DSC is being transferred into the HSM with the hydraulic ram. The applied loads include the dead weight of the basket assembly, with and without off-normal pressure, and ram pushing load (135 kips).

The load conditions for LC5 are similar to LC4 except that the ram pushing force of 135 kips is replaced with a ram pull force of 80 kips representing retrieval of the DSC from the HSM to the TC.

The applicant also evaluated LC9, a normal/off-normal condition, where the DSC is in the horizontal position on the rails of the HSM. The applied loads include the dead weight of the basket assembly, and off-normal pressure.

The stress ratios reported in Tables 3.9.1-7 through 3.9.1-12 of the SAR for the DSC shell, ITCP, OTCP, and IBCP were all very small. The most critically stressed component in all cases is the ITCP-to-shell weld. SER Table 3-1 summarizes the maximum stress ratio for the ITCP-to-shell weld under normal and off-normal load conditions.

The staff reviewed the applicant's analyses for normal and off-normal conditions and concludes that the design of the DSC and associated components is structurally adequate for normal and off-normal loading conditions because all stress ratios are less than 1.0. These stress ratios indicate that the stresses on the components important to safety caused by the applied loads are less than the stress limits specified in the ASME B&PV Code.

3.5.1.1 Dry Shielded Canister Fatigue Analysis

In Section 3.9.1.4 of the SAR, the applicant evaluated the fatigue effects on the DSC using the criteria of ASME B&PV Code, Section III, Division 1, Subsection NB-3222.4. The applicant evaluated the DSC against the six criteria specified in the ASME Code and determined the DSC will perform adequately against fatigue. The staff finds that fatigue of the DSC will not need to be reevaluated during the licensing period.

The staff reviewed the criteria contained in ASME B&PV Code, Section III, Division 1, Subsetion NB-3222.4 and the applicant's analysis. The staff finds that the applicant satisfies the stated criteria within the code, and concludes that fatigue will not be a factor during the licensing period. For this reason, the staff finds it was not necessary for the applicant to evaluate the DSC for fatigue during the requested licensing period.

Table 3-1 Stress Ratios for the Limiting Component for Normal and Off-Normal Load Conditions

Load Case	Limiting Component	Stress Category	Stress Intensity (ksi)	Stress Intensity Limit (ksi)	Stress Ratio
1	ITCP-to-Shell Weld	$P_L + P_b + Q + P_e$	34.48	46.32	0.74
2	ITCP-to-Shell Weld	$P_L + P_b + Q + P_e$	27.93	46.30	0.60
3	ITCP-to-Shell Weld	$P_L + P_b + Q + P_e$	27.93	46.30	0.60
4	ITCP-to-Shell Weld	$P_L + P_b + Q + P_e$	29.44	46.30	0.64
5	ITCP-to-Shell Weld	$P_L + P_b + Q + P_e$	29.11	46.30	0.63
9	ITCP-to-Shell Weld	$P_L + P_b + Q + P_e$	31.18	46.30	0.67

3.5.2 Fuel Basket Assembly

For the normal and off-normal conditions, the applicant determined that the horizontal orientation was the governing or bounding position because greater stress is produced on the basket assembly in the horizontal position than in the vertical position. For this reason, the applicant did not evaluate the basket assembly in the vertical position. The staff reviewed the SAR description and determines that the IBCP of the DSC support the weight of the fuel rods when the DSC is in the vertical position. When the DSC is in the horizontal position, the basket assembly supports the weight of the fuel rods; therefore, the staff concludes that the applicant's assessment is acceptable.

The applicant considered the following load combinations:

- Dead weight of the fuel and basket plus 1.0g in the vertical direction.
- Dead weight of the fuel and basket plus 0.5g in the vertical direction and 0.5g in the transverse direction.
- Dead weight of the fuel and basket plus 1.0g in the transverse direction.

The applicant reported the results for these load combinations for maximum stress, stress allowable, and stress ratio in SAR Tables 3.9.2-3 and 3.9.2-4 for the EOS-37PTH and EOS-89BTH, respectively. For the EOS-37PTH, the stress ratio for the grid plates, angle plates, transition rails, bolts, and tie rods are below 1.0. The SAR Table 3.9.2-3 shows the highest stress ratio is 0.883 and occurs in the transition rails, due to primary, bending, and secondary stresses. For the EOS-89BTH, all but one stress ratio for the grid plates, angle plates, transition rails, bolts, and tie rods are less than 1.0. The highest stress ratio is 0.921, which occurs in the transition rails due to primary membrane-plus-bending. In Table 3.9.2-4 of the SAR, the applicant reported a stress ratio of 1.214 in the transition rails due to primary, bending, and secondary stresses, which indicates that this component is overstressed. In note 4 to SAR Table 3.9.2-4, the applicant stated that this is a peak stress ratio, which will occur only near the bolts and is primarily due to the thermal stress. The overstress condition only occurs during heat-up after initial loading of the spent fuel into the canister. The thermal stress is self-limiting in nature because after the initial heat-up at fuel loading, thermal stresses are reduced. The staff has reasonable assurance to conclude that the thermal stress performance of the fuel basket is adequate.

With the exception of the isolated thermal stress case, all the stress ratios associated with the fuel basket assemblies are less than 1.0, indicating that the resultant stress in the material is less than the stress limits allowed by ASME B&PV Code. For this reason, the staff finds that the structural performance of the fuel basket assembly is acceptable.

3.5.3 Fuel Rod

The applicant did not analyze the fuel rod under normal and off-normal loading conditions because these loading conditions are bounded by the fuel rod accident drop conditions. The staff reviewed the loading conditions on the fuel rods during normal, off-normal, and accident conditions and concludes that the accident conditions bound the normal and off-normal conditions; therefore, the applicant's assessment is acceptable. In the SER at Section 3.6.3, the staff finds that the fuel rods perform adequately under accident conditions; therefore, the absence of this fuel rod analysis is acceptable.

3.5.4 EOS-HSMS/EOS-HSM

The applicant presented the results of the normal and off-normal conditions of loading in Tables 3.9.4-13 and 3.9.4-14 of the SAR. In these tables, the applicant reported the largest computed shear, axial force, and bending moment demands in the concrete components as a result of the load combination. The tables also list the cross-sectional capacities of the concrete base and wall components and the demand-to-capacity ratios. The normal and off-normal load conditions from Table 2-7 of the SAR are C1 through C3. The component cross sections that the applicant considered are the 32-inch rear wall bottom, the 12-inch rear wall top, the 54-inch front wall bottom, the 42-inch front wall top, the 24-inch side wall bottom, the 14-inch side wall bottom, the 12-inch side wall top, and the 44-inch roof.

For load case C1 (normal condition), the loads evaluated include the weight of the concrete components and the normal handling loads.

For load case C2 (off-normal condition), the loads evaluated include combining the wind load, the weight of the concrete components, the live load, and the normal thermal load.

For load case C3 (off-normal condition), the loads evaluated include the weight of the concrete components, the live load, the thermal load, and the off-normal handling load.

For all of the normal and off-normal load combinations, the applicant reported demand-to-capacity ratios for shear, axial force, and bending moment for individual components. The staff reviewed the results of the normal and off-normal load conditions and finds that the design of the concrete components of the EOS-HSM is adequate for normal and off-normal loading conditions based on the low force ratios reported by the applicant. The computed forces in most of the concrete components are well below 50 percent of the capacity, with the highest demand-to-capacity ratio at 98 percent, due to combined shear and bending in the 12-inch top side wall.

The applicant reported the highest combined shear force/moment in Table 3.9.4-13 and the highest axial force/moment in Table 3.9.4-14 of the SAR. The applicant combined the results for load combinations C1 through C6 (normal, off-normal, and accident), and separately identified the results of load case C7 (accident—thermal). As a result, the maximum strength design demand-to-capacity ratios reported by the applicant for load combinations C1 through C6 were evaluated under normal, off-normal, or accident conditions. The nature of the load combinations for load and resistance factor design or strength design allows for the comparison of the results of normal, off-normal, and accidents. The staff finds the reported results acceptable because under all load combinations and for all conditions, the demand-to-capacity remains less than 1.0. These demand-to-capacity ratios indicate the load carrying capacity of the structural members of the EOS-HSMS/EOS-HSM is greater than maximum load combinations. The staff concludes that the structural performance of the concrete EOS-HSM is adequate for normal and off-normal load conditions.

For the support structure, the applicant considered three normal and off-normal load combinations (N1 through N3) described in Tables 3.9.4-15 and 3.9.4-16 of the SAR. The applicant evaluated the DSC main support beams, stiffener plates, extension baseplates, DSC stop plates, and brace members.

For load case N1 (normal), the loads include the self-weight of the support structure, the weight of the DSC, and the normal handling loads.

Load case N2 (normal) is the insertion/extraction combination and includes the self-weight of the support structure, the weight of the DSC, and the normal handling loads.

For load case N3 (off-normal), the applicant considered the self-weight of the support structure, the weight of the DSC, the off-normal handling loads, and the normal thermal load.

The applicant reported the analysis results in Tables 3.9.4-17 through 3.9.4-20 of the SAR. The following are the largest demand-to-capacity ratios for the various components:

- entire beam cross section due to weak axis bending: 0.19
- axial compression of the flange: 0.39
- axial compression of the web elements: 0.75
- weak axis bending of the stiffener elements: 0.71

Because the demand-to-capacity ratios for all of the steel support structure components are less than 1.0, the staff concludes that the performance of the DSC steel support structure under normal and off-normal conditions is adequate.

3.5.5 EOS-TC135/EOS-TC125/EOS-TC108

For the normal and off-normal load conditions, the applicant considered the vertical lifting and down ending of the loaded TC as well as the ram loading of the DSC into the HSM. The applicant summarized the loading combinations in Table 2-8 of the SAR.

For the vertical configuration, the applicant stated that the total dead weight bears on the two upper trunnions and the weight of the loaded DSC bears on the bottom end plate of the EOS-TCMAX. The applicant used a dynamic load factor of 1.15. Table 3.9.5-4 of the SAR presents the results of the trunnion analysis (trunnion, weld, and base metal) with the stress margin of safety, which is defined as material strength-to-demand minus 1.0. The lowest margin of safety for the 6-g and 10-g cases was 0.12 which occurred in the weld material used to attach the trunnion to the top ring.

Because the margins of safety with respect to the yield strength (6-g case) and ultimate strength (10-g case) are all positive, the staff concludes that the trunnions meet the provisions of ANSI N14.6 and NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants: Resolution of Generic Technical Activity A-36," issued July 1980. Therefore the staff finds that the structural strength of the trunnions is adequate to provides reasonable assurance that the transfer cask will not be dropped due to trunnion failure under normal and off-normal lifting conditions.

The applicant modeled the TC body components, including the top and bottom ring, the inner and outer shell, the lead shielding, the bottom end plate, the ram access penetration ring and the top lid, using ANSYS SOLID185 elements to evaluate the stress in the shell during lift and loading operations. To account for the weight of the components that were not included in the model, the applicant increased the densities of the modeled components so that the total weight of the model was equal to the actual cask. The applicant reported the results of the shell evaluation in Table 3.9.5-4 of the SAR.

For the vertical configuration, the applicant reported the lowest margin of safety of 0.60 which occurs in the top ring due to primary membrane-plus-bending-plus-secondary stress. For the down ending configuration where the TC is still in the vertical position, the applicant reported the lowest margin of safety of 0.26 in the bottom ring due to primary membrane-plus-bending-plus secondary stress.

For the horizontal configuration in which the DSC is being loaded or unloaded into the HSM, the applicant used an inertial force of 1g for loading and -1g for unloading. The applicant reported the results of the horizontal analysis in SAR Table 3.9.5-4 which indicates the lowest margin of safety of 0.14 occurring in the bottom ring as a result of primary membrane-plus-bending-plus secondary stress for the loading case. For the unloading case, the lowest margin of safety was 0.33 and also occurred in the bottom ring and also due to primary membrane-plus-bending-plus secondary stress.

Because the margins of safety for the TC components are greater than zero for all configurations, indicating that the stress in the TC components resulting from the applied load is less than the code allowed stress, the staff concludes that the structural performance of the TC is acceptable for normal and off-normal conditions.

The applicant reported the results of the neutron shield structural evaluation with regard to normal and off-normal load combinations in Table 3.9.5-6 of the SAR. The highest stress ratio (calculated/allowable) is 0.97, which occurs in the EOS-TC108 I-beam during horizontal loading and unloading. The applicant also considered the welds in the neutron shield and reported the results in Table 3.9.5-7 of the SAR which indicates that the highest stress ratio is 0.72 in the weld that connects the neutron shield panel with the I-beam of the TC-135 due to horizontal operations and seismic loads.

Because the calculated stress ratios in the neutron shield are less than 1.0, the staff concludes that the structural performance is adequate for normal and off-normal loading conditions.

The staff reviewed the applicant's analysis of the DSCs, the fuel assembly baskets, the SFAs, the HMS, and the TCs that comprise the NUHOMS® EOS System. The staff finds that all SSCs important to safety have the structural capacity to withstand normal and off-normal conditions of use and maintain their ability to perform their designated safety function.

3.6 Accident Conditions

The staff reviewed the results of the applicant's evaluation of the SSCs important to safety that comprise the NUHOMS® EOS system. This review included the various load combinations that the applicant applied to the structural components to characterize accident conditions of use.

As with normal and off-norm conditions, the applicant used margin of safety, factor of safety, and stress ratio, described in Section 3.5 of this SER, in evaluating the structural performance of the SSCs important to safety under accident load conditions. The staff bases the structural performance findings of the NUHOMS® EOS system on these terms.

3.6.1 EOS-37PTH/EOS89BTH Dry Shielded Canister

The applicant presented the results of the accident conditions of loading in Tables 3.9.1-7 through 3.9.1-12 of the SAR. As with the normal and off-normal conditions, the applicant reported, for each stress category, the stress in the shell assembly, including inner and OTCP-to-shell welds, the stress allowable in Table 3.1 of the SAR; and the stress ratio (calculated stress/stress allowable). LC6 through LC8 and LC10 represent the accident condition load cases from Table 2-5 of the SAR.

For LC6, the applicant evaluated two scenarios. One with the DSC in the horizontal position resting on the rails of the HSM, and the other with the DSC transiting out of the HSM to the TC under a pull force. The loads include the dead weight of the basket assembly, off-normal pressure, and a ram pulling load of 135 kips.

For LC7A, the applicant subjected the DSC to a 65-inch drop while in the horizontal position in the TC. The loads evaluated include the dead weight of the basket assembly on the shell wall, off-normal pressure of 20 psig, and a 75g deceleration.

For LC7B, the applicant subjected the DSC to a 65-inch drop while in the vertical position in the TC. The loads evaluated include the dead weight of the basket assembly on the IBCP, off-normal pressure of 20 psig, and a 75g deceleration.

For LC8, the applicant analyzed the DSC in the horizontal position in the TC. The TC is supported at the trunnions and saddle locations while in the horizontal position. The loads evaluated include the dead weight of the basket assembly on the wall of the DSC and an internal pressure of 130 psig. The applicant reported 130 psig as the bounding pressure for the DSC in the HSM with a blocked vent accident and in the TC under accident fire conditions.

For LC10, the applicant considered the DSC in the horizontal position on the rails of the HSM. The loads evaluated include the dead weight of the basket assembly on the shell of the DSC; the off-normal pressure; and the seismic load, which includes inertial forces of 1.25g in the axial direction, 2g in the transverse direction, and 1g in the vertical direction.

SER Table 3-2 summarizes the maximum stress ratios, from the applicant's analysis, for the limiting components that comprise the confinement boundary for each of the accident load combinations.

The staff reviewed the applicant's analysis of the DSC under all accident conditions and concludes that the structural performance of the DSC and its associated components is adequate because all stress ratios are less than 1.0, indicating that the resultant stress is less than the code allowed stress. The greatest stress ratio occurs in the ITCP-to-shell weld when the DSC in the TC experiences a side drop. Even under this extreme loading condition, the stress of a side drop on the confinement weld does not exceed 76 percent of the code allowed stress.

Table 3-2 Stress Ratios for Limiting Components for Accident Load Conditions

Load Case	Limiting Component	Stress Category	Stress Intensity (ksi)	Stress Allowable (ksi)	Stress Ratio
6	ITCP-to-Shell Weld	P_L	6.74	46.90	0.14
7A	ITCP-to-Shell Weld	P_L	35.77	46.90	0.76
7B	DSC Shell (Confinement Boundary)	$P_m + P_b$	33.49	57.06	0.59
8	ITCP	$P_m + P_b$	25.82	57.06	0.45
10	DSC Shell (Confinement Boundary)	$P_m + P_b$	28.98	57.06	0.51

3.6.1.1 Dry Shielded Canister Shell Buckling Evaluation

The applicant conducted a buckling evaluation in Section 3.9.1.3 of the SAR to determine whether buckling of the DSC shell is a credible mode of failure. The applicant used the same model to evaluate buckling as was used for the drop evaluation. The applicant determined that the DSC can support a 130g load applied to the IBCP without buckling. The ASME B&PV Code, Section III, Division 1, Subsection F-1331.5 stipulates that in order to preclude the possibility of canister buckling under a compressive load, the maximum compressive load should be limited to two-thirds of the calculated buckling load.

The applicant reported the maximum compressive load on a DSC shell that is subjected to a top end drop is 75 g. This maximum expected load is less than the ASME code limits and is significantly less than the 130g load that can be withstood by the IBCP without buckling. For these reasons, the staff concludes that there is reasonable assurance that DSC shell will not buckle under the maximum expected compressive load.

3.6.2 Fuel Basket Assembly

In Section 3.9.2.3.7.2 of the SAR, the applicant calculated the stress on the EOS-37PTH and EOS-89BTH basket assemblies due to an onsite 75g axial end drop. The results of these calculations showed the stress from an end drop was not controlling. For this reason, the applicant only analyzed the side drop. The applicant used the same ANSYS model for the accident load analysis that was used for the normal and off-normal load analysis. The applicant considered three azimuthal orientations for the side drop:

- 180-degree side drop on rails—Due to symmetry, this also includes a drop at zero degree on the rails.
- 270-degree side drop away from rails—Due to symmetry, this also includes a drop at 90 degree on the rails.
- 225-degree side drop on rails—Due to symmetry, this also includes the various other orientations that lie at 45-degree angles between the 180-degree and 270-degree increments.

The applicant determined the strain of a 60g design basis drop on the basket in the three orientations described above. The results are reported in the SAR in Table 3.9.2-6 for the EOS-37PTH basket and in Table 3.9.2-10 for the EOS-89BTH basket. The maximum strain on both baskets occurs, due to bending, from a 180-degree side drop. The maximum strain measured for the EOS-37PTH basket is 0.00834 and for the EOS-89BTH is 0.00611. The maximum allowable strain for fuel basket assemblies is 0.03. The strain ratio is 0.278 for the EOS-37PTH and 0.204 for the EOS-89BTH. Because the strain ratios are less than 1.0, indicating that the actual strain in the basket is less than the code allowed strain, the staff concludes that the performance of both baskets under the 60g side drop accident is acceptable.

3.6.3 Fuel Rod

The stress on PWR SFA cladding following a 75g side drop are reported by the applicant the in Table 3.9.6-3 of the SAR. The greatest stress reported by the applicant occurs in the 14x14 PWR SFA. Because the calculated stress is less than the yield stress of the cladding (stress ratio of 0.92), the staff concludes that the performance of the PWR SFA cladding under a 75g side drop scenario is acceptable.

Table 3.9.6-7 of the SAR reports the strain on the PWR SFA cladding following a 65-inch corner drop. According to the applicant, the maximum principal strain in the PWR fuel cladding occurs in the 14x14 PWR SFA. Because the maximum strain is less than the allowable strain (strain ratio of 0.21), the staff concludes that the performance of the PWR SFA cladding under the 65-inch corner drop scenario is acceptable.

Table 3.9.6-10 of the SAR reports the stress in the BWR fuel assembly cladding for the 75g side drop. The largest stress reported by the applicant occurs in the 10x10 BWR SFA. Because this is less than the yield stress (stress ratio of 0.81), the staff concludes that the performance of the BWR SFA cladding under a 75g side drop scenario is acceptable.

Table 3.9.6-15 of the SAR reports the strain on the BWR SFA cladding for the 65-inch corner drop. According to the applicant, the maximum principal strain in the BWR fuel cladding occurs in the 7x7 and 8x8 BWR SFA. Because the maximum strain is less than the allowable strain (strain ratio of 0.28), the staff concludes that the performance of the BWR SFA cladding under the 65-inch corner drop scenario is acceptable.

3.6.4 EOS-HSMS/EOS-HSM

The applicant presented the results of the accident conditions of loading in Tables 3.9.4-13 and 3.9.4-14 of the SAR. These tables show the largest computed shear, axial force, and bending moment demands in the concrete components as a result of the load combination, along with the demand-to-capacity ratios. The accident load conditions from Table 2-7 of the SAR are C4 through C7. The concrete components that the applicant considered are the 32-inch rear wall bottom, the 12-inch rear wall top, the 54-inch front wall bottom, the 42-inch front wall top, the 24-inch side wall bottom, the 14-inch side wall bottom, the 12-inch side wall top, and the 44-inch roof.

For load case C4 (accident—earthquake), the loads evaluated include the weight of the concrete components, the live loads (includes the weight of the DSC, snow, and ice), the normal thermal loads, and the seismic load.

Load case C5 (accident—tornado) is similar to load case 4, except the seismic loads are replaced with tornado effect loads.

Load case C6 (accident—flood) is similar to load case 4, except the seismic loads are replaced with flood loads.

For load case C7 (accident—thermal), the loads evaluated include the weight of the concrete components, the live loads (includes the weight of the DSC, snow, and ice), and the accident thermal loads due to a blocked vent.

For all of the accident load combinations, the applicant reported demand-to-capacity ratios well below 1.0 for shear, axial force, and bending moment.

In Tables 3.9.4-13 and 3.9.4-14 of the SAR, the applicant reported the highest combined shear force/moment and axial force/moment, respectively, and combined the results for load combinations C1 through C6 (normal, off-normal and accident), and only identified the results of load case C7 (accident—thermal) separately. As a result, the maximum demand-to-capacity ratios for load combinations C1 through C6 could be due to normal, off-normal, or accident conditions. The nature of the load combinations for load and resistance factor design or strength design allows for the comparison of the results of normal, off-normal, and accidents.

As was the case in Section 3.5.4 of this SER, the staff finds the reporting of the results acceptable. In addition, the staff finds the design of the concrete components of the EOS-HSM is adequate for accident loading conditions. The force ratios are less than 1.0, which indicates that the load carrying capacity of the concrete components is greater than the maximum applied load. Overall, the computed forces in the concrete components fall well below 50 percent of the load capacity. The highest demand-to-capacity ratio is 0.98 in the 12-inch top side wall due to combined shear and bending.

For the steel support structure, the applicant considered four accident load combinations (A5S, A5V, A8S, and A8V) described in Tables 3.9.4-15 and 3.9.4-16 of the SAR. The applicant evaluated the DSC main support beams, stiffener plates, extension baseplates, DSC stop plates, and brace members.

For load case A5S (accident—earthquake), the loads include the self-weight of the support structure, the weight of the DSC, normal thermal loads, and the earthquake loads. These loads must be less than the strength capacity by a factor of 1.6.

Load case A5V (accident—earthquake) is similar to load case A5S, except that the loads must be less than the shear strength by a factor of 1.4.

For load case A8S (accident—thermal), the loads include the self-weight of the support structure, the weight of the DSC, and the accident thermal loads due to a blocked vent. These loads must be less than the strength capacity by a factor of 1.7.

Load case A8V (accident—thermal) is similar to load case A8S, except that the loads must be less than the shear strength by a factor of 1.4.

The applicant reported the results of the analysis in Tables 3.9.4-17 through 3.9.4-20 of the SAR. The following are the largest stress demand-to-capacity ratios for the various components:

- entire beam cross section resulting from weak axis bending: 0.73
- axial compression of the flange: 0.27
- axial compression of the web elements: 0.76
- weak axis bending of the stiffener elements: 0.81

SAR Table 3.9.4-21 reports the stress ratio for the stop plate, DSC seismic impact plate, extension baseplate, and lateral braces. The highest stress ratio in these components is 0.86, which occurs in the extension baseplate. SAR Table 3.9.4-22 reports the stress ratio in the welds between the stop plate and rail, extension baseplate and rail, stiffener and lateral brace, and stiffener and rail. The largest stress ratio is 0.67, which occurs in the weld between the stiffener plate and rail.

Because the stress ratios for all of the steel support structure components and welds are less than 1.0, the staff concludes the performance of the DSC steel support structure under accident loading conditions is adequate.

In Sections 3.9.4.10.3 and 3.9.4.10.6 of the SAR, the applicant evaluated the EOS-HSM and shield door for local damage due to tornado generated missile impact. The applicant used the modified National Defense Research Committee formula to calculate the effects of a non-deforming projectile penetrating a massive concrete target. The applicant determined the maximum penetration depth, minimum thickness to prevent perforation, and minimum thickness necessary to prevent scabbing of each of the tornado generated missiles which the staff evaluated in Section 3.3.4 of this SER. According to the applicant, the maximum penetration depth of 7.6 inches occurred as a result of the 12-inch diameter, schedule 40 pipe striking the HSM. The minimum thickness necessary to prevent perforation of the pipe is 18.5 inches. The minimum thickness required to prevent scabbing from an armor piercing shell is27.7 inches. These thicknesses are calculated using the estimates plus 20% from ACI 349-06. The thicknesses of all the concrete components of the EOS-HSM and shield door exceed 30.5 inches; therefore, the staff concludes that the structural performance of the EOS-HSM against local damage due to tornado generated missiles is adequate.

In Section 3.9.4.10.6.2, of the SAR, the applicant analyzed the global response of the EOS-HSM 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 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 determined 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 that are modeled as rectangular plates. The ductility ratios calculated for all of the concrete components are less than 10.0, meaning the ductility provided is greater than the ductility demand. The staff determines that the applicant's method of calculating the ductility ratio is acceptable because it is consistent with that of ACI 349-06. Furthermore, because the ductility ratios are less than 10.0, the staff concludes that the structural performance of the EOS-HSM is adequate with respect to the global response of the components as a result of the impulsive loads caused by tornado generated missiles.

In Section 3.9.4.10.4 of the SAR, the applicant evaluated the heat shields and attachment bolts. The applicant determined that the stress interaction ratios for the bolts was less than 1.0, and the maximum calculated bending moment in the panels was less than the moment capacity of the panels. Based on the results of the applicant's analysis, the staff finds that the structural performance of the heat shields and attachment bolts is adequate.

3.6.5 EOS-TC135/EOS-TC125/EOS-TC108

The applicant evaluated the side and end drops, as well as tornado missile impact, for the TCs. Based on the results of the LS-DYNA analysis described in Section 3.9.3 of the SAR, the applicant applied an inertial force of 65g to the TC ANSYS model for the side drop and end drop scenarios. The applicant reported the results for the TC components in Tables 3.9.5-1 through 3.9.5-3 of the SAR. The stress ratios were all less than 1.0, with the maximum stress ratio of 0.96 occurring in the bottom end plate due to primary membrane stress caused by the side drop. Because all stress ratios are less than 1.0, indicating that the resultant stresses are less than the code allowed stresses, the staff finds that the performance of the TC due to a side or end drop is adequate.

The applicant analyzed the TC shell and top cover plate for tornado wind and missile loads in Section 3.9.7.2.6.1.2 of the SAR. The applicant determined the stress in the shell and the top cover plate due to the combined effect of tornado wind forces and a massive missile impact through superposition. Table 3.9.7-8 of the SAR presents the total stress in the shell and top cover. All stresses resulting from tornado loads were less than the ASME code allowed stresses. Additionally, the applicant determined that the maximum missile penetration was due to a 15-foot long, 6.625-inch diameter, schedule 40 pipe weighing 287 lb., and traveling at 135 fps impacting the TC. The applicant determined the maximum penetration depth to be 0.526 inches, which is less than the shell thickness of 1 inch. The staff conducted a confirmatory calculation using the Ballistic Research Laboratory formula (determined to be bounding by the applicant) using an 8-inch diameter armor piercing shell weighing 276 lb. and traveling at 185 fps. The penetration depth for this missile hazard is 0.647 inches which is greater than that determined by the applicant but less than the thickness of the TC shell. The staff finds that the TC performance against missile penetration to be acceptable and that there is reasonable assurance that a tornado generated missile will not penetrate the TC shell and impact the DSC canister.

The applicant evaluated the lead slump (deformation) in the TC following side and end drops. The amount of slump affects the shielding performance of the TC. The applicant applied an inertial load of 65g on the ANSYS model. The applicant reported a maximum lead slump of 2.2 inches in the axial direction after an end drop. The staff concludes that the applicant's determination of the lead slump is accurate. The staff presents the findings from its shielding evaluation in Chapter 6 of the SER.

3.6.6 EOS-TC135/EOS-TC125/EOS-TC108 Neutron Shields

In evaluating accident conditions, the applicant only considered seismic (earthquake) loads because it assumes a seismic load would result in a complete loss of the neutron shield, and thus a drop accident would be less severe. The applicant applied the dead weight, a 20 psig internal pressure, and accelerations of 1g in all three orthogonal directions to the ANSYS model. The applicant reported the stress results on the neutron shield panels and welds resulting from earthquake forces in Tables 3.9.5-6 and 3.9.5-7, respectively, in the SAR. All stress ratios were less than 1.0, with the highest ratio of 0.97 occurring in the I-Beam.

Because the stress ratios for the neutron shield components and welds are less than 1.0, indicating that the resulting stress is less than the code allowed stress, the staff finds the structural performance of the neutron shield under accident conditions to be acceptable and that the neutron shield will continue to perform its shielding function following an earthquake.

The staff reviewed the applicant's analysis of the SSCs important to safety for the NUHOMS® EOS storage system and finds that all components have the structural capacity to withstand accident conditions of loading and maintain their ability to perform their designated safety function.

3.7 Stability Analysis

The staff reviewed the results of the applicant's stability evaluation for SSCs important to safety of the NUHOMS® EOS system that are susceptible to overturning and sliding in accident conditions. To assess whether a component adequately resists overturning, the applicant compared the overturning moment (the rotational force causing the component to tip over) to the resisting moment (the rotational force resisting the tip over). In order to determine the adequacy of a component to resist sliding, the applicant compared the sliding force to the resisting force. Table 3-3 of NUREG-1536 provides the formula for calculating safety factor with 10% increased margin. The safety factor against overturning and sliding is:

$$\frac{resisting\ moment\ or\ force}{overturning\ moment\ or\ sliding\ force} \geq 1.1$$

The staff used this factor of safety as the basis to evaluate the stability performance of the NUHOLMS® EOS.

3.7.1 HSM

The applicant evaluated the HSM for sliding and overturning due to design basis wind, flood, seismic, and massive missile impact loads using hand calculations. In addition to the loads reported in Section 3.3.4 of this SER, the applicant also assumed a static coefficient friction of 0.6 between the concrete HSM and the concrete storage pad.

In Section 3.9.7.1.8.1.1 of the SAR, the applicant conducted a static analysis for tornado wind of a HSM loaded with a DSC. The HSM is also accompanied by a rear shield wall, two end shield walls, and two corner blocks. The applicant calculated tornado wind forces of 218 psf windward pressure, 154 psf leeward suction, and 326 psf suction on the roof to determine an overturning moment. The applicant calculated the stabilizing moment using gravity loads and compared it to the overturning moment resulting in the minimum safety factor (M_{ot}/M_{st}) from tornado wind of 1.59. Because the safety factor is greater than 1.1, consistent with the provisions of NUREG-1536, the staff finds that the EOS-HSM will not overturn as a result of tornado winds.

In Section 3.9.7.1.8.1.2 of the SAR, the applicant 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 determined that the EOS-HSM will rotate a maximum of 0.7 degrees based on the principle of the conservation of energy and a maximum of 3.12 degrees based on the time-dependent analysis. Both values are less than 21.7 degrees, which is the angle at which the center of gravity is directly above the point of rotation. These values are less than the minimum angle needed to overturn a module. The angle of rotation needed to overturn an EOS-HSM exceeds the maximum angle of rotation calculated by the applicant by a factor of almost 7. For this reason, the staff finds that the EOS-HSM will not overturn as a result of the most severe combined tornado wind effects.

The applicant performed 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 determined that a single module will slide 1.62 inches. Based on the time-dependent analysis, the applicant determined that the maximum distance a single module will slide is 1.30 inches. NUREG 1536 recommends that the factor of safety for sliding should exceed 1.1. The applicant's sliding analyses assume a single loaded module. However, the applicant indicated that additional storage modules will be added to the EOS-HSM array. The weight of additional storage modules will significantly increase the resistance to sliding of modules on the ISFSI pad. For this reason, the staff finds that there is reasonable assurance that the EOS-HSM array will not experience excessive sliding as a result of combined tornado effects.

The applicant conducted a static overturning analysis against flood loads by summing the moments about the bottom outside corner of a single loaded module. For the most limiting module length, the applicant determined the minimum factor of safety against overturning to be 1.12. Because this is greater than 1.1, consistent with the provisions of NUREG 1536, the staff finds that the EOS-HSM will not overturn as a result of the design basis flood.

For the sliding analysis for flood loads, the applicant adjusted the effective weight of the HSM and the DSC to account for the buoyancy force of the water in the static analysis. For the most limiting module length, the applicant calculated a minimum safety factor against sliding to be 1.09. Although this is less than the 1.1 ratio stipulated by NUREG 1536, the addition of other modules in the array will significantly increase the resisting force by adding more weight to the array, and ultimately increase the factor of safety. For this reason, the staff concludes that the safety factor will increase with the addition of more module and that the EOS-HSM array will not slide as a result of the design basis flood.

In Section 3.9.7.1.8.3.1 of the SAR, the applicant conducted a static seismic analysis on one HSM loaded with a DSC and one end shield wall. The applicant did not consider the effects of the other end shield wall, the rear shield wall, and corner blocks which provide more resistance to overturning. Using a seismic acceleration of 0.45g in the horizontal direction and 0.30g in the vertical direction, the applicant determined an overturning moment and compared it to the stabilizing moment resulting from gravity loads. The applicant determined a minimum safety factor resulting from the seismic inertial load to be 1.13. Because the safety factor is greater than 1.1, consistent with the provisions of NUREG-1536, the staff finds that the EOS-HSM will not overturn as a result of the design basis earthquake.

The applicant performed a static sliding analysis for the seismic inertial load in Section 3.9.7.1.8.3.2 of the SAR. Using the same seismic acceleration as for the overturning analysis, the applicant determined the force applied to the EOS-HSM due to the seismic accelerations and compared it with the force necessary to slide the loaded EOS-HSM. The applicant determined that the minimum safety factor against sliding due to the seismic inertial load to be 1.18. Because the safety factor is greater than 1.1, consistent with the provisions of NUREG-1536, the staff finds that the EOS-HSM will not slide as a result of the design basis earthquake.

3.7.2 Transfer Cask

The applicant evaluated the TC for overturning due to design basis wind, seismic, and massive missile impact loads using hand calculations.

In Section 3.9.7.2.6.1.1 of the SAR, the applicant evaluated the stability of the loaded TC on the trailer under the design basis tornado wind load. The applicant estimated the weight of the TC, DSC, and trailer to be 170 kips, which is less than the lightest configuration presented in Table 3.9.7-6 of the SAR. The applicant calculated the overturning moment resulting from the force of the wind on the projected area of the TC and trailer. The applicant calculated the stabilizing moment resulting from the weight of the TC and trailer and compared it to the overturning moment. The applicant incorporated a load factor of 1.1 into its analysis and determined the factor of safety against overturning to be 3.92.

The staff reviewed the calculations and found the applicant incorrectly applied the load factor in its analysis. Table 3-3 of NUREG-1536 indicates that the factor of safety against overturning should be greater than 1.1. The applicant multiplied the resisting moment, rather than the overturning moment by 1.1, which inflated the factor of safety. When properly calculated, the actual factor of safety is 3.56. The revised factor of safety, 3.56, remains greater than 1.1; therefore, staff finds that the TC and trailer will not overturn due to the design basis tornado winds.

The applicant conducted two dynamic overturning analyses of a loaded TC on a trailer: one using conservation of momentum (Sections 3.9.7.2.6.5.1 of the SAR), and the other using a time-dependent analysis (Section 3.9.7.2.6.5.2 of the SAR). The applicant analyzed the tornado wind concurrently with a massive missile impact load. The applicant analyzed an automobile to be the bounding impact load because it delivers the highest amount of energy to the TC. The applicant determined that the TC and trailer will rotate 1.91 degrees based on the conservation of momentum analysis and 7.55 degrees based on the time-dependent analysis. The applicant compared these angles with the angle of rotation of 32.51 degrees, which is the angle at which the TC and its trailer will tip over.

The applicant calculated a bounding factor of safety of 4.3 against overturning. Because this bounding factor of safety is greater than 1.1, consistent with NUREG-1536, the staff finds that a trailer containing a TC loaded with a DSC will not tip over as a result of combined tornado effects.

The applicant conducted a static analysis to determine the stability of the EOS-TC on the trailer as part of the design basis seismic load calculation in Section 3.9.7.2.6.4 of the SAR. As was done for the EOS-HSM, the applicant determined the factor of safety by dividing the stabilizing moment by the overturning moment. The applicant determined the factor of safety against overturning to be 1.21. Because the factor of safety is greater than 1.1, consistent with NUREG-1536, the staff finds that the TC and trailer will not tip over due to the design basis seismic load.

The staff reviewed the applicant’s analysis of the SSCs important to safety, specifically the EOS HSM and the TC, for the NUHOMS® EOS storage system that are susceptible to overturning. Based on the factors of safety against overturning and sliding reported by the applicant, the staff finds that all applicable SSCs important to safety have the capacity to withstand accident conditions of loading without sliding or overturning.

3.8 Evaluation Findings

F3.1 The SAR adequately describes all SSCs that are important to safety, providing drawings and text in sufficient detail to allow evaluation of their structural effectiveness.

F3.2 The applicant has met the requirements of 10 CFR 72.236(b). The SSCs important to safety are 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.

F3.3 The applicant has met the requirements of 10 CFR Part 72.236(c) for maintaining subcritical conditions. The structural design and fabrication of the dry storage system includes structural margins of safety for those SSCs important to nuclear criticality safety. The applicant has demonstrated adequate structural safety for the handling, packaging, transfer, and storage under normal, off-normal, and accident conditions.

F3.4 The applicant has met the requirements of 10 CFR 72.236(l) for spent fuel storage cask approval. The design analysis and submitted bases for evaluation acceptably demonstrate that the cask and other systems important to safety will reasonably maintain confinement of radioactive material under normal, off-normal, and credible accident conditions.

F3.5 The applicant has met the requirements of 10 CFR 72.236 with regard to inclusion of the following provisions in the structural design:

- design, fabrication, erection, and testing to acceptable quality standards
- adequate structural protection against environmental conditions and natural phenomena, fires, and explosions
- appropriate inspection, maintenance, and testing
- adequate accessibility in emergencies
- a confinement barrier that acceptably protects the cladding during storage
- structures that are compatible with appropriate monitoring systems
- structural designs that are compatible with retrievability of SNF

F3.6 The applicant has met the specific requirements of 10 CFR 72.236(g) and (h) as they apply to the structural design for spent fuel storage cask approval. The cask system structural design acceptably provides for the following required provisions:

- storage of the spent fuel for a minimum required years
- compatibility with wet or dry loading and unloading facilities

The staff concludes that the structural performance of the SSCs important to safety that comprise the NUHOMS® EOS dry storage system are in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria in Section 3.2 of NUREG-1536 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.

3.9 References

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ANSYS Computer Code and User's Manual.

AREVA Inc., "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 14, USNRC Docket No. 72-1004, September 2014.

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Exelon Generation, Updated Safety Analysis Report, Revision 23, Calvert Cliffs Nuclear Power Plant Independent Spent Fuel Storage Installation, License No. SNM-2505, 2015.

Title 10, Code of Federal Regulations, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste."

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U.S. Nuclear Regulatory Commission, "Design Response Spectra for Seismic Design of Nuclear Power Plants," U.S. Atomic Energy Commission, Regulatory Guide 1.60, Revision 1, December 1973.

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U.S. Nuclear Regulatory Commission, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," NUREG-1536, Revision 1, July 2010.

U.S. Nuclear Regulatory Commission, "Summary and Evaluation of Low-Velocity Impact Tests of Solid Steel Billet onto Concrete Pads," NUREG/CR-6608, February 1998.

4.0 THERMAL EVALUATION

The NUHOMS® EOS System provides horizontal storage of high-burnup spent PWR and BWR SFAs in DSCs that are placed in an EOS horizontal storage module (EOS-HSM/HSMS) using an EOS TC (EOS-TC108/125/135). The new PWR and BWR DSCs are the EOS-37PTH DSC and the EOS-89BTH DSC, respectively.

The applicant performed thermal evaluations to demonstrate that the NUHOMS® EOS-HSM/HSMS, EOS-TC108/125/135, EOS-37PTH DSC, and EOS-89BTH DSC meet the thermal design criteria defined by 10 CFR Part 72.

The staff conducted the thermal review and documented the evaluations below. The staff determines that the applicant's thermal evaluation is acceptable because the thermal design of the NUHOMS® EOS system meets the thermal requirements to maintain the fuel cladding and cask component temperatures below the required limits under normal, off-normal, short-term operation, and accident storage conditions, and the applicable design and acceptance criteria have been satisfied, in compliance with 10 CFR Part 72

4.1 Decay Heat Removal System

The staff reviewed the applicant's description and information of the SSCs important to safety in SAR Chapter 1 as supplemented by the additional information in SAR Chapter 4 to ensure the information is consistent and supplementary and the information contains sufficient details to support an in-depth staff evaluation.

4.1.1 Horizontal Storage Module (EOS-HSM or EOS-HSMS)

Chapter 1 of the SAR states that the EOS-HSM is an improved version of the NUHOMS® HD System which enhances the heat rejection capabilities up to heat loads of 50 kW and 43.6 kW for the EOS-37PTH DSC and EOS-89BTH DSC, respectively. The applicant noted that the EOS-HSM improves air flow in the HSM internal cavity by redesigning (1) the inlet and outlet vents, (2) the heat shields, and (3) the DSC support structure for increased air flow and capacity. The cooling air enters the EOS-HSM from the inlet vent, absorbs the heat from the EOS DSCs, and leaves the EOS-HSM through the outlet vent with higher temperatures.

The staff reviewed the inlet configuration of NUHOMS® EOS-HSM, as shown in Figure 1-5 of SAR section 1.1 and Figure 4-9 of SAR 4.4.2.3.5. The staff compared the design and configuration of the NUHOMS® EOS-HSM and the NUHOMS® HSM-H, which was approved as part of the NUHOMS® HD System (ADAMS Accession No. ML070160089). The staff verified that the designs of the inlet vent, the support beam, and the outlet vent are modified in the EOS-HSM. The staff also confirms the modifications reduce the airflow resistance at the inlet vent. The modifications promote airflow circulation beneath the DSC, increase the airflow area at the outlet vent, and will enhance the heat removal capability from the DSC to the ambient and therefore decrease the fuel cladding temperatures. The staff concludes that Chapter 4 of the SAR appropriately describes the configuration of the EOS-HSM.

4.1.2 Transfer Cask (EOS-TC108/125/135)

EOS-TCs

SAR Section 4.5 states that the EOS-TC designs are based on modifications to the current OS200FC TC design, which the staff approved in CoC No. 1004 SER (ADAMS Accession No. ML13273A327). The applicant stated that, compared to the OS200FC TC, the EOS-TCs have a larger inside diameter which reduces the cooling flow resistance and increased cavity lengths to increase heat removal area for EOS-TC108/125/135. The NUHOMS® EOS-TC (EOS-TC108/125/135) is made of a carbon steel structural shell and maintains an air circulation feature. The EOS-TC125 and the EOS-TC135 have an attached liquid neutron shield, and the EOS-TC108 has a removable liquid neutron shield.

The staff reviewed SAR Sections 4.5 and 4.6 for thermal evaluation of the EOS-37PTH DSC and EOS-89BTH DSC during normal, off-normal, and hypothetical accident transfer operations in the EOS-TC125/135/108. The staff evaluated the information using the guidance in Chapter 4 of NUREG-1536. The staff finds reasonable assurance that thermal performance under normal, off-normal, and hypothetical accident transfer operations is adequate.

EOS-TC125/135

The applicant stated in SAR Section 4.5 that the EOS-TC135 is a longer variant of the EOS-TC125 with identical heat load limits of 50.0 kW for loading the EOS-37PTH DSC and 43.6 kW for loading the EOS-89BTH DSC. The temperatures of the EOS-TC135 remain bounded by those of the EOS-TC125 because the heat load is the same but the heat dissipation area and the thermal mass are larger for the EOS-TC135 because of its longer cavity length and increased surface area.

The staff reviewed the descriptions for both the EOS-TC125 and the EOS-TC135 and accepted that the thermal evaluations for the EOS-37PTH and EOS-89BTH DSCs loaded in the EOS-TC125 remain bounding for the EOS-37PTH and EOS-89BTH DSCs loaded in the EOS-TC135 due to its greater heat dissipation rate.

As described in SAR Section 4.5, the EOS-TC125 and EOS-TC135 contain design provisions for the use of an air circulation system (equal to or greater than 850 cubic feet per minute) to improve thermal performance for heat loads greater than 36.35 kW and 34.44 kW for EOS-37PTH and EOS-89BTH DSC, respectively. The air circulation system consists of redundant, industrial-grade pressure blowers and power systems, ducting, and other components. The air circulation system is not needed for heat loads less than 36.35 kW in the EOS-37PTH DSC and less than 34.44 kW in the EOS-89BTH DSC.

The staff reviewed the descriptions of the air circulation system presented in SAR Section 4.5. The air circulation system consists of redundant, industrial grade pressure blowers and power system to generate a flow rate of 850 cubic feet per minute (cfm) or greater. The staff confirmed that augmented air circulation system in the EOS-TC125/135 improves thermal performance, and therefore provides adequate assurance for heat removal.

EOS-TC108

SAR Section 4.6 states that the EOS-TC-108 has a lower weight and a lower thermal mass than the EOS-TC125/135. The applicant noted that the maximum heat loads of the EOS-TC108 are limited to 41.8 kW and 41.6 kW for the EOS-37PTH DSC and the EOS-89BTH DSC, respectively, because of the lower thermal mass in EOS-TC108. As described in SAR Section 4.6, the EOS-TC108 contains design provisions for the use of an air circulation system to improve its thermal performance for heat loads greater than 36.35 kW and 34.44 kW for EOS-37PTH and EOS-89BTH DSCs, respectively. The air circulation system is not needed with heat loads less than 36.35 kW for the EOS-37PTH DSC and less than 34.44 kW for the EOS-89BTH DSC.

The staff reviewed SAR Section 4.6 and confirmed that the conditions for using air circulation for the EOS-TC108 are acceptable and are described in sufficient detail in SAR Section 4.6.

4.2 Material and Design Limits

The applicant summarized several thermal design criteria in SAR Section 4.2 for the NUHOMS® EOS system:

(1) The temperature limit of the fuel cladding is 752 ˚F for normal conditions of storage and short-term storage operations, consistent with the provisions of Interim Staff Guidance (ISG) SFST-ISG-11, Revision 3, “Cladding Considerations for the Transportation and Storage of Spent Fuel,” issued 2003.

(2) The temperature limit of the fuel cladding is 1,058 ˚F for off-normal storage and accident conditions, consistent with the provisions of SFST-ISG-11.

(3) The maximum temperature limits are 620 ˚F and 262 ˚F for lead and neutron shielding, respectively.

(4) The maximum DSC internal pressures are 20 psig for structural evaluations under normal and off-normal conditions and 130 psig for accident conditions.

(5) The fuel rod rupture rates are assumed to be 1 percent, 10 percent, and 100 percent of the fuel rods under normal, off-normal, and accident conditions, respectively.

The staff finds that these thermal design criteria are acceptable because they are consistent with the provisions of SFST-ISG-11, NUREG-1536, the materials handbook, or design criteria that were approved by the NRC in previous applications for the NUHOMS® system (Standardized NUHOMS® System, CoC No. 1004 (NRC, 2014)).

The applicant summarized the effective thermal properties of the EOS-37PTH DSC and EOS-89BTH DSC components in SAR Section 4.2, Tables 1 through 10. SAR Section 4.2, Tables 11 and 12, summarize the effective gamma shielding thermal properties of the EOS-TC108/125 and the effective neutron shielding properties of the EOS-TC125, respectively. The applicant listed the material properties of helium and air in SAR Tables 8-27 and 8-28, respectively. The helium is backfilled into the DSC after drying operations and is used to provide an inert environment for the spent fuel. Helium also enhances the heat removal capability because of its higher heat conduction than air. Table 8-35 of the SAR provides information on the emissivity of the basket steel plate, that is, the efficiency of the basket steel plate surface to emit thermal energy.

The staff reviewed the material thermal properties of (1) storage with the EOS-37PTH DSC or the EOS-89BTH DSC stored within the EOS-HSM and (2) onsite transport with the EOS-37PTH DSC or EOS-89BTH DSC loaded in the EOS-TC108/125/135. The staff finds the thermal properties of the components and the related polynomial functions used in the thermal analyses are consistent with those used in the CoC No. 1004 NUHOMS® system previously approved by the NRC and documented in SER (NRC, 2014).

4.3 Thermal Loads and Environmental Conditions

The applicant described the heat load zone configurations (HLZCs) of the EOS-37PTH DSC in TS Figure 1 and EOS-89BTH DSC in TS Figure 2. As shown in TS Figure 1, the EOS-37PTH DSC allows maximum heat loads of 50 kW (HLZC #1) when loaded in the EOS-TC125/135, 41.8 kW (HLZC #2) loaded in the EOS-TC108/125/135, and 36.35 kW (HLZC #3) loaded in the EOS-TC108/125/135. TS Figure 2 shows that the EOS-89BTH DSC has maximum heat loads of 43.6 kW (HLZC #1) loaded in the EOS-TC125 only, 41.6 kW (HLZC #2) loaded in the EOS-TC108/125, and 34.44 kW (HLZC #3) loaded in the EOS-TC108/125. For the EOS-37PTH and EOS-89BTH DSCs, HLZCs #1, #2, and #3 have identical zoning with different allowable heat loads. HLZC #1 bounds HLZCs #2 and #3 for both the EOS-37PTH and EOS-89BTH DSCs because HLZC #1 of both the EOS-37PTH and EOS-89BTH DSCs allows the maximum total heat load and the maximum heat load per SFA in each zone, as summarized in SER Table 4-1.

SAR Chapter 4 summarizes the thermal performance of the NUHOMS® EOS System. The summary describes the HLZC in DSC, maximum heat load, TC (EOS-TC108/125/135), and storage module (EOS-HSM and EOS-HSMS) used for thermal evaluations, as summarized in SER Table 4.1.

The staff reviewed the EOS-37PTH DSC and EOS-89BTH DSC configurations described in SAR Chapter 4 and TS Figures 1 and 2. As noted in SER Table 4-1, the staff confirmed that HLZC #1, provides the bounding configurations for both the EOS-37PTH and EOS 89BTH DSCs.

The maximum heat loads are 50 kW for EOS-37PTH DSC and 43.6 kW for EOS-89BTH DSC for HLZC #1. Therefore, with the DSC structural configuration for all HLZCs and the maximum design heat load in HLZC #1 is unchanged, the staff accepted that HLZC #1 is the bounding HLZC among all of the HLZCs, and no thermal evaluation needs to be performed for HLZCs #2 and #3 for all storage conditions.

Table 4-1 EOS-37PTH and EOS-89BTH DSCs HLZCs

<table>
<tr><th>DSC Type</th><th>Heat Load Zone Configuration</th><th>Max. Heat Load (kW)</th><th>Transfer Cask</th><th>Storage Module</th></tr>
<tr><td rowspan="3">EOS-37PTH</td><td>1</td><td>50.00</td><td>EOS-TC125/EOS-TC135</td><td rowspan="6">EOS-HSM/ EOS-HSMS</td></tr>
<tr><td>2</td><td>41.80</td><td rowspan="2">EOS-TC125/EOS-TC135/ EOS-TC108</td></tr>
<tr><td>3</td><td>36.35</td></tr>
<tr><td rowspan="3">EOS-89BTH</td><td>1</td><td>43.60</td><td>EOS-TC125</td></tr>
<tr><td>2</td><td>41.60</td><td rowspan="2">EOS-TC125/EOS-TC108</td></tr>
<tr><td>3</td><td>34.44</td></tr>
</table>

The applicant stated in SAR Section 4.2 that the maximum ambient temperature for normal storage conditions varies with the heat load during storage operations. This maximum ambient temperature has the following five parameters:

(1) The maximum yearly average temperature is 70 °F for normal storage conditions, with a heat loads greater than 41.8 kW for the EOS-37PTH DSC and greater than 41.6 kW for the EOS-89BTH DSC.
(2) The daily average ambient temperature is 90 °F for normal storage conditions, with a heat load up to 41.8 kW for the EOS-37PTH DSC and up to 41.6 kW for the EOS-89BTH DSC.
(3) The ambient temperature has a range of -40 °F without solar insolation to 117 °F with full solar insolation for off-normal storage operations, corresponding to a 24-hour calculated average temperature of 103 °F.
(4) The ambient temperature has a range of 0 °F to 100 °F for normal transfer operations and from 0 °F to 117 °F for off-normal transfer operations.
(5) The maximum DSC internal pressures of 15, 20, and 130 psig are acceptable for normal, off-normal, and accident conditions, respectively.

TS 4.5.3, “Site Specific Parameters and Analyses,” requires that the system users verify the parameters and analyses mentioned in items (1)–(4) above for applicability at their specific site.

The staff reviewed SAR Section 4.2 and confirmed that the ambient temperature ranges noted above for thermal evaluations of normal storage, off-normal storage, and off-normal transfer conditions are adequate to assure that the fuel cladding and cask component temperatures will remain below the required limits. Therefore, the staff confirmed that the system users shall verify the ambient temperature specifications in TS 4.5.3, items #3 and #4, and the related thermal analyses for applicability at their specific site. In Chapter 3 of the SER, the staff confirmed that the maximum DSC internal pressures must be less than 15, 20, and 130 psig for normal, off-normal, and accident conditions. The staff’s findings here are consistent with the bases for staff’s approval of CoC No. 1004 (NRC, 2014).

4.4 Analytical Methods, Models, and Calculations

4.4.1 Computer Model

SAR Section 4.4 states that the applicant used ANSYS FLUENT computational fluid dynamics (CFD) models to demonstrate that the maximum temperatures of key components (i.e. fuel cladding, concrete, and heat shield) are below the maximum temperature limits. The applicant's analysis provides the average temperature of the cavity gas for pressure calculation and the average temperatures of the basket plates and the DSC shells for thermal expansion calculations.

The applicant described the decay heat removal system in SAR Section 4.1. The decay heat load was applied as heat generation over the elements representing homogenized SFAs. The thermal model includes (1) heat transfer within the fuel region occurring only by conduction and radiation and neglecting any convection heat transfer, (2) convection within the EOS-HSM cavity, (3) radiation among the DSC shell, heat shields, support structure, and HSM, (4) solar insolation through the HSM front wall and roof, and (5) heat dissipation from the HSM and the vent outlet by convection and radiation to the ambient environment.

The staff reviewed the description of the thermal model specified in SAR Section 4.1 and determined that the applicant's thermal model is acceptable because the assumptions, material thermal properties, heat transfer mechanisms, and numerical methodology used in the thermal model provide an acceptable basis for evaluating the thermal phenomena existing in the cask designs.

Porous Media Model

The applicant presented the porous media model in SAR Appendix 4.9.2.3 and used the porous media model to evaluate the flow through the support structure with the inertial resistance and viscous resistance factors. The applicant described the porous media parameters for the Nitronic rail and finned side heat shield in SAR Appendices 4.9.2.3.4.1 and 4.9.2.3.4.2, respectively. SAR Section 4.4.2.3.3 show the inertial resistance factors for the porous zones along the support beam and for the inlet and outlet of the dose-reduction hardware. The low Reynolds k-ε turbulence model with full buoyancy effects was used to simulate the airflow within the cavity of the EOS-HSM.

The staff reviewed the porous media model described in SAR Appendix 4.9.2.3.4 and calculations of both the inertial resistance factor and the viscous resistance factor of the flow through the slotted Nitronic rail, the support beam, and the inlet and outlet of the dose-reduction hardware that the applicant provided in a response to the staff's request for additional information (RAI) (AREVA, 2015). The staff determined that the porous media model and the calculated factors of inertial resistance and viscous resistance are appropriate and acceptable because the model, assumptions, and calculations are consistent with the flow phenomena used in the thermal models of the previously approved NUHOMS® systems (NRC, 2014) and in accordance with the flow engineering justification of the flow characteristics provided in the engineering handbooks.

Wind Effects

As described in SAR Appendix 4.9.4, the applicant evaluated the impact of the wind speed and its direction on the thermal performance of the EOS-HSM loaded with the EOS-37PTH DSC and

EOS-89BTH DSC, separately. The applicant evaluated the wind speeds for three different directions (frontal, backward, and side) to assess the wind impact on heat removal capability. The applicant selected the EOS-37PTH DSC, loaded within the EOS-HSM with 50 kW (HLZC #1) under the normal hot storage condition, as the representative bounding storage condition for both the EOS-37PTH and EOS-89BTH DSCs because it has the smallest margin of safety when compared to the allowable normal temperature limit for peak cladding temperature (PCT) of 752 °F. SAR Table 4.9.4-1 lists the design load cases for the wind effects study of the EOS-HSM loaded with the EOS-37PTH DSC under the normal hot condition.

The applicant stated in SAR Appendix 4.9.4 that both frontal and back winds enhance the thermal performance of the EOS-HSM loaded with the EOS-37PTH DSC, and the predicted DSC shell and maximum fuel cladding temperatures decrease as the wind speed increases. The applicant noted in SAR Appendix 4.9.4.6 that the side wind could have potential impact to the flow field near the EOS-HSM outlet vent. As such, the wind deflectors were designed to be installed on the top of the EOS-HSM and next to the outlet vent to help protect the flow field from wind disturbance.

The applicant summarized the fuel cladding and DSC shell temperatures of the EOS-37PTH DSC for all load cases in Tables 4.9.4-1 and 4.9.4-2 of the SAR. The applicant included an administrative control in TS 5.1.3(a)(ii) and 5.1.3(b)(iii) to perform the visual inspection of the wind deflectors. The applicant also included administrative control in TS 5.5 to specify the requirements for the use of wind deflectors.

To reduce uncertainty in the analysis, the applicant performed two analyses for the bounding case (50 kW, HLZC #1) with a side wind. The applicant predicted PCTs of 735 °F by the extrapolation method and 729 °F from the thermal model. Both calculated PCTs are below the required limit of 752 °F, consistent with SFST-ISG-11.

In an RAI, the applicant was asked to explain the impact of wind on the thermal performance of the EOS-HSM storage system and state whether wind deflectors enhance heat removal capability. In response, the applicant evaluated two scenarios. First, the applicant evaluated an EOS-HSM loaded with an EOS-37PTH DSC in the HLZC #2 and a maximum heat load of 41.8 kW. Second, the applicant evaluated an EOS-HSM under the same conditions, but without the wind deflector described in SAR Section 4.9.4.7 (AREVA, 2016b). These evaluations used the modified side wind thermal model, which considered basket assembly components and SFAs, as described in the SAR at Appendix 4.9.4.6.1. The applicant calculated a PCT of 688 °F, which is below the bounding limit of 752 °F by a margin of 64 °F. The applicant reported a PCT below 752 ˚F for an EOS-89BTH DSC in the HLZC #2 with a maximum heat load of 41.6 kW. The staff finds these results provide adequate assurance that the thermal performance of the EOS-HSM storage system will fall within the bounding limits of 752 ˚F.

The applicant revised TS 5.5 for the wind deflector requirements as follows.

- If the heat load of an EOS-37PTH DSC during storage operations is greater than 41.8 kW, wind deflectors shall be installed on the EOS-HSM.

- If the heat load of an EOS-89BTH DSC during storage operations is greater than 41.6 kW, wind deflectors shall be installed on the EOS-HSM.

To account for the ambient temperatures at ISFSIs when evaluating the effect of wind on the thermal performance of storage modules (EOS-HSM), the applicant revised SAR Sections 4.2 and 4.3 and Appendix 4.9.4. Under normal storage conditions, thermal calculations assume a maximum yearly average temperature of 70 °F for an EOS-37PTH DSC with heat loads greater than 41.8 kW and for an EOS-89BTH DSC with a heat load greater than 41.6 kW. Under normal storage conditions, when the heat load for an EOS-37PTH DSC is up to 41.8 kW and for the EOS-89BTH DSC is up to 41.6 kW, a general licensee will assume a daily average ambient temperature of 90 °F at an ISFSI. The TS 4.5.3 at items 3a and 3b present site-specific parameters and analyses.

The staff reviewed the applicant's thermal evaluations and the results provided in SAR Appendix 4.9.4. The staff concludes that (1) the wind deflectors are needed to ensure that the thermal performance of the EOS-HSM remains within its allowable limits for the maximum heat loads of greater than 41.8 kW for the EOS-37PTH DSC and greater than 41.6 kW for the EOS-89BTH DSC, as described in TS 5.5, and (2) the wind deflectors are not required for the maximum heat load configurations of HLZC #2 and HLZC #3 for both the EOS-37PTH DSC and EOS-89BTH DSC because of a sufficient safety margin when compared to the limit of 752 °F, consistent with SFST-ISG-11. The staff also confirmed that the site-specific parameters listed in TS 4.5.3, which shall be verified by the system users for applicability at their specific site.

Hot Gap Between the Basket Assembly and DSC Shell

The applicant described in SAR Section 4.4.3 that a nominal diametrical cold gap of 0.4 inch is considered between the basket assembly and the DSC shell for the EOS-37PTH DSC. The applicant used the average temperatures for the basket plates, transition rails, and DSC shell at the hottest cross-section for the normal hot condition to calculate the thermal expansion at thermal equilibrium. The applicant listed these temperatures in SAR Table 4-7.

The applicant stated in SAR Section 4.4.3 that the thermal model considers a uniform diametrical hot gap of 0.3 inch between the EOS-37PTH DSC shell and basket assembly. The computed hot gap of 0.307 inch, as shown in SAR Table 4-10, is higher than the gap of 0.3 inch considered in the thermal model and only results in a temperature difference of 1.5 °F higher across the gap.

The staff reviewed the descriptions in SAR Section 4.4.3 and determined that using the uniform diametrical hot gap of 0.3 inch in the applicant's thermal model is acceptable based on the calculated temperature margin and engineering justification. The staff finds that a margin of 28 °F between the calculated PCT of 724 °F and the temperature limit of 752 ˚F for the normal hot storage condition provides a reasonable assurance on the safety margin, as shown in SAR Table 4-5.

Airflow in the Annulus of a TC or DSC

The applicant calculated a Raleigh number (Ra) and the Reynolds number (Re) within the flow regime within the TC/DSC annulus, as shown in SAR Section 4.5.3.3.1. Based on the calculations, the applicant stated that (1) the effect of natural convection is negligible and forced convection dominates the heat transfer in the TC/DSC annulus, and (2) the air flow in the TC/DSC annulus with the blower operating is in the turbulent flow regime.

The staff reviewed the calculations of Ra number and Re number presented in SAR Section 4.5.3.3.1 and determined that the flow in the TC/DSC annulus can be characterized as a turbulent flow in which the forced convection dominates the heat transfer within the TC/DSC annulus. This is because (1) the calculated Re is greater than the critical Re of 2280 defined for the turbulent flow; and (2) the ratio (Ra/Re^2) is much less than 0.1 which indicates that the natural convection is negligible and the forced convection dominates the heat transfer as a type of turbulent flow in the TC/DSC annulus.

4.4.2 EOS-37PTH and EOS-89BTH Dry Shielded Canisters in EOS-HSM (Storage Conditions)

SAR Section 4.4 describes the thermal evaluation of EOS-HSM storage system. The applicant performed the thermal analyses of the EOS-HSM loaded with the EOS-37PTH DSC with a maximum heat load of 50 kW and the EOS-89BTH DSC with a maximum heat load of 43.6 kW for normal, off-normal, and hypothetical accident conditions. As shown in SER Table 4-2 (or SAR Table 4-1), the load cases used for the EOS-37PTH and EOS-89BTH DSCs are identical under normal storage, off-normal storage, and accident conditions. The EOS-37PTH DSC has a bounding configuration of HLZC #1 with heat load of 50 kW, and the EOS-89BTH DSC has a bounding configuration of HLZC #1 with heat load of 43.6 kW. Therefore, the applicant used HLZC #1 to perform the thermal evaluations for both the EOS-37PTH and EOS-89BTH DSCs. The applicant did not perform any thermal evaluations for HLZC #2 and HLZC #3 for all storage conditions.

The staff reviewed the thermal loads provided in SAR Section 4.3 and verified that HLZC #1 is the bounding configuration for the thermal evaluation of the storage conditions because of the maximum heat loads being used in both EOS-37PTH DSC and EOS-89BTH DSC.

The applicant described the load cases in SAR Section 4.4.1, as shown in SER Table 4-2 for both the EOS-37PTH DSC and EOS-89BTH DSC. The staff reviewed all the load cases in SER Table 4-2 and verified that (1) load case 3 (ambient temperature 117 ˚F, insolation, and HLZC #1) bounds all other cases in normal storage and off-normal storage, (2) load case 4 (ambient temperature -40 ˚F and no insolation) is the bounding case for the extreme cold conditions, and (3) load case 5 (ambient temperature 117 ˚F, solar heat, and 40-hour blockage) bounds all other cases in storage accidents for both the EOS-37PTH DSC and EOS-89BTH DSC loaded within EOS-HSM.

Table 4-2 EOS-37PTH DSC and EOS-89BTH DSC in EOS-HSM, Design Load Cases for Storage Conditions

Load Case No.	Operation Condition	Ambient Temperature (°F)	Insolation	HLZC
1	Normal Hot	100	Yes	1
2	Normal Cold	-20	No	1
3	Off-Normal Hot	117	Yes	1
4	Off-Normal Cold	-40	No	1
5	Accident—Blocked Vents for 40 Hours	117	Yes	1

The applicant summarized the maximum and average temperatures of key components for the EOS-HSM loaded with the EOS-37PTH DSC under normal, off-normal, and accident conditions in SAR Tables 4-6 and 4-7, respectively. The applicant provided the maximum and average temperatures of key components for the EOS-HSM loaded with the EOS-89BTH DSC under normal, off-normal, and accident conditions in SAR Tables 4-18 and 4-19, respectively.

The applicant compared the maximum component temperatures between the EOS-37PTH DSC (50.0 kW) and EOS-89BTH DSC (43.6 kW) for load cases 3 (off-normal hot) and 5 (40-hour blocked vent accident) and then stated that for all EOS-HSM load cases, the maximum temperatures for the EOS-37PTH DSC at 50.0 kW will bound the maximum temperatures for the EOS-89BTH DSC at 43.6 kW. SER Table 4-3 (a combination of SAR Tables 4-5 and 4-17) summarizes the comparison.

The staff reviewed the calculated temperatures shown in SER Table 4-3, SAR Tables 4-5, 4-6, 4-7, 4-17, 4-18, and 4-19 and confirmed the following:

- The PCTs of the EOS-37PTH DSC and the EOS-89BTH DSC loaded within the EOS-HSM are below their corresponding limits of 752 °F under normal conditions and 1,058 °F under off-normal and accident conditions.
- The maximum concrete temperatures of the EOS-37PTH DSC and the EOS-89BTH DSC loaded within the EOS-HSM are below their corresponding limits of 300 °F, as indicated by NUREG-1536, under normal and off-normal conditions, and 500 °F, given in ACI 349-06, under accident conditions.
- The temperatures of the EOS-89BTH DSC loaded within the EOS-HSM remain bounded by the temperatures of EOS-37PTH DSC loaded within the EOS-HSM under normal, off-normal, and accident conditions. The bounding remains effective mainly because the EOS-37PTH DSC has a heat load of 50 kW greater than the heat load of 43.6 kW in the EOS-89BTH DSC.

Table 4-3 EOS-37PTH DSC (50 kW) and EOS-89BTH DSC (43.6 kW) in EOS-HSM, Design Load Cases for Normal, Off-Normal, and Accident Conditions

<table>
<tr><th rowspan="3">Load Case</th><th colspan="3">Fuel Cladding Temperatures (°F)</th><th colspan="3">Concrete Temperature (°F)</th></tr>
<tr><th colspan="2">Maximum</th><th rowspan="2">Limit</th><th colspan="2">Maximum</th><th rowspan="2">Limit</th></tr>
<tr><th>EOS-37PTH</th><th>EOS-89BTH</th><th>EOS-37PTH</th><th>EOS-89BTH</th></tr>
<tr><td>1</td><td>724</td><td>695</td><td rowspan="2">752</td><td>258</td><td>242</td><td rowspan="4">300</td></tr>
<tr><td>2</td><td>< 724</td><td>< 695</td><td>< 258</td><td>< 242</td></tr>
<tr><td>3</td><td>734</td><td>< 734</td><td rowspan="3">1,058</td><td>272</td><td>< 272</td></tr>
<tr><td>4</td><td>621</td><td>< 695</td><td>116</td><td>< 242</td></tr>
<tr><td>5</td><td>865</td><td>< 865</td><td>464</td><td>< 464</td><td>500</td></tr>
</table>

Air Temperature Rise in the EOS-HSM

The applicant stated in TS 5.1.3b that the difference in air temperature between the inlet vent and the outlet vent of the EOS-HSM is measured at the site during normal operations. The applicant presented the inlet and outlet temperature differences for different load cases, performed for the EOS-37PTH DSC under normal operations, in SAR Table 4-9 and in its response to an RAI (AREVA, 2016) (see SER Table 4-4). Based on the calculated temperature differences, the applicant identified that the bounding case for the EOS-37PTH DSC is the storage condition with side wind, heat load of 41.8 kW, and without wind deflectors (load case 2, defined in SAR Appendix 4.9.4-1) in terms of maximum inlet and outlet air temperature differences under the condition without the wind deflectors.

The applicant noted in its RAI response (AREVA, 2016a) that at the end of the 40-hour blocked vent accident, the PCT is 865 °F with a 193 °F margin below the accident limit of 1,058 °F, consistent with SFST-ISG-11 and with an air temperature rise of 149 °F between inlet and outlet vents. The applicant used the air temperature difference of 138 ˚F under normal conditions because it is lower than that for the 40-hour blocked vent accident condition. The applicant noted in a followup discussion on its RAI response (AREVA, 2016b), about the inlet and exit air temperatures for Option 3, that the air temperature rise is expected to be very similar between 41.8 kW (a limit for the EOS-37PTH DSC without the wind deflectors) and 41.6 kW (a limit for the EOS-89BTH DSC without the wind deflectors) because of a small difference in the heat load. Therefore, the staff determined that a limit of 138 ˚F in TS 5.1.3b is appropriate for both the EOS-37PTH DSC and the EOS-89BTH DSC.

The staff reviewed the calculated temperature differences for different load cases as shown in SER Table 4.4 and determined that the air temperature difference of 138 ˚F from load case 2 (41.8 kW, side wind, and with no wind deflectors) from SAR Appendix 4.9.4 can be used as the limit of the air temperature rise between inlet and outlet vents for the EOS-HSM thermal monitor program to detect the blocked vent accident. This is because (1) a lower temperature rise of 138 ˚F is more conservative than that (149 ˚F) predicted for the 40-hour blocked event (50 kW, with no wind deflectors), and (2) the temperature of 138 ˚F was calculated for a heat load of 41.8 kW, greater than a heat load of 41.6 kW at which the wind deflectors are required to be in place for the EOS-89BTH DSC.

The staff confirmed that the temperature difference of 138 ˚F between inlet and outlet vents (1) is lower than that for the EOS-37PTH DSC with 50 kW and 40-hour blocked vents and (2) bounds the temperature rise for the EOS-89BTH DSC with a heat load greater than 41.6 kW and with wind deflectors. Therefore, the staff determined that a maximum temperature rise of 138 ˚F is acceptable as the limit in TS 5.1.3b.

Table 4-4 Summary of Air Temperature Rise between Inlet Vent and Outlet Vent (EOS-37PTH DSC in EOS-HSM)

Load Case No.	Description	Air Temperature Difference (°F) (T_{outlet}–T_{inlet})
1a (SAR Table 4-9)	Normal hot, 50 kW (HLZC #1), steady state, 100 °F ambient with insolation	97
3 (SAR Table 4-9)	Off-normal hot, 50 kW (HLZC #1), steady state, 117 °F ambient with insolation	99
4 (SAR Table 4-9)	Off-normal cold, 50 kW (HLZC #1), steady state, -40 °F ambient without insolation	75
5 (SAR Table 4-1)	40-hour blocked vents, 50 kW (HLZC #1), 117 °F ambient, with insolation	149
#2 (SAR Appendix Table 4.9.4-1)	41.8 kW (HLZC #2), 90 °F ambient, without wind deflectors, side wind	138
#S-2 (SAR Appendix Table 4.9.4-1)	50 kW (HLZC #1), 70 °F ambient, with wind deflectors, side wind	98

4.4.3 Loading Conditions (Vacuum Drying)

The applicant described the thermal evaluation for loading/unloading condition in SAR Section 4.5.11 and provided the results in SAR Table 4-32. The applicant performed the steady-state thermal analyses with the TS/DSC annulus filled with water to maintain the maximum DSC shell temperature below the boiling temperature of water (223 °F) in the open atmosphere. The applicant calculated the PCTs of 648 °F at 50.0 kW for the EOS-37PTH DSC and 637 °F at 43.6 kW for the EOS-89BTH DSC in vacuum drying operations.

Consistent with SFST-ISG-11, the staff reviewed the conditions in the TC/DSC annulus (boiling temperature of water at 223 °F), the results in SAR Table 4-32, and the margins between PCTs and the 752 °F limit under short-term operation. The staff confirmed that there are significant safety margins of 104 °F and 115 °F for the EOS-37PTH DSC and the EOS-89BTH DSC, respectively, because of the presence of helium during blowdown and vacuum drying operations and the cooling provided by water in the TC/DSC annulus.

4.4.4 EOS-37PTH and EOS-89BTH Dry Shielded Canisters in Transfer Operation

4.4.4.1 EOS-37PTH DSC in EOS-TC125 and EOS-TC135

The applicant described the EOS-37PTH DSC loaded in the EOS-TC125 in SAR Section 4.5 for normal and off-normal conditions and in SAR Section 4.5.5 for hypothetical accident conditions. SAR Table 4-23 shows the design load cases for the EOS-TC125. SAR Section 4.5.1 states that load case 3 (off-normal conditions) bounds load case 2 (normal conditions) and load case 4 (off-normal conditions) because of higher ambient temperatures. The air circulation is

850 cubic feet per minute for load case 6. In load case 7, the initial temperatures are taken from the steady-state results of load case 6a, and the air circulation is assumed to be turned off or lost at time zero and the system begins to heat up. Load case 10 bounds load case 9 because of higher ambient temperatures.

The staff reviewed the descriptions in SAR Section 4.5.1 and SAR Table 4-23 and confirmed the bounding correlations among load cases 2, 3, and 4, as well as between load cases 9 and 10, based on the ambient temperatures and loading conditions described in SAR Table 4-23 and the engineering justification.

The applicant performed the thermal analyses and listed the maximum temperatures and transfer time limits of load cases 1 and 3 in SAR Table 4-24 (50 kW, without air circulation), load cases 8 and 10 in SAR Table 4-25 (36.35 kW, without air circulation), load cases 6a and 6b in SAR Table 4-26 (50 kW, with air circulation), and load case 7 in SAR Table 4-27 (50 kW, with air circulation turned off during the transfer operation) for the EOS-37PTH DSC in the EOS-TC125. SAR Tables 4-29 and 4-30 show the maximum and average temperatures, respectively, of key components, such as the fuel cladding, DSC shell, lead, and neutron shield, in the EOS-TC125 loaded with the EOS-37PTH DSC.

Based on the thermal analyses, the applicant stated in SAR Section 4.5.4 and Table 4-24 that the PCTs at 12 and 14 hours after the start of the transfer operations are 724 °F and 736 °F, respectively, for load case 1, and are 723 °F and 734 °F, respectively, for load case 3. SAR Section 4.5.4 states that there is no time limit for the EOS-TC125 loaded with the EOS-37PTH DSC for heat loads less than or equal to 36.35 kW (HLZC #3). There is a time limit of 10 hours for all transfer operations for heat loads greater than 36.35 kW (HLZC #3) and less than or equal to 50 kW (HLZC #1) to provide an additional margin and to ensure sufficient time for the initiation of recovery actions.

The staff reviewed the temperature results described in SAR Section 4.5.4 and Table 4-24 and concluded that the time limit of 10 hours for transfer operations for the EOS-TC125 loaded with the EOS-37PTH DSC at a heat load range of 36.35 kW to 50 kW is acceptable because of the following:

- The applicant’s thermal model is appropriate and acceptable.
- The PCTs of 736 ˚F and 734 ˚F for load case 1 (no air circulation) and load case 3 (no air circulation), respectively, are below the limit of 752 °F at the end of 14 hours under transient conditions.
- The DSC component temperatures for load cases 1 and 3 are below the allowable design limits at the end of 14 hours under transfer conditions.

Therefore, the staff concludes that a time limit of 10 hours is acceptable for all transfer operations for heat loads greater than 36.35 kW (HLZC #3) and less than or equal to 50 kW (HLZC #1) because both the PCT and maximum DSC component temperatures are below the corresponding limits with sufficient safety margins at the end of 10 hours of transfer operations.

The staff reviewed the temperature results shown in SAR Table 4-25 and concluded that the time limit is not required for the EOS-TC125 loaded with the EOS-37PTH DSC at a heat load of less than 36.35 kW because of the following:

- The applicant's thermal model is appropriate and acceptable.
- The fuel cladding temperatures of 732 ˚F and 714 ˚F for load case 8 (no air circulation) and load case 10 (no air circulation), respectively, are below the limit of 752 °F, consistent with the provisions of SFST-ISG-11, at steady-state conditions.
- The DSC component temperatures for load cases 8 and 10 are below the allowable design limits at steady-state conditions.

Therefore, the staff concluded that a time limit to complete the transfer operation is not required for the EOS-TC125 loaded with the EOS-37PTH DSC for heat loads less than or equal to 36.35 kW.

The applicant performed thermal analysis of load case 6a (off-normal, 50 kW, hot ambient 117 ˚F, horizontal, with insolation, air circulation on, and transient) and predicted a PCT of 732 ˚F at 8 hours after the initiation of air circulation. The results, presented in SAR Table 4-26, illustrate that the PCT of 732 ˚F is below the limit of 752 ˚F, consistent with the provisions of SFST-ISG-11, and the key component temperatures are below the allowable design limits. The applicant stated in TS 3.1.3 that if transfer operations cannot be completed within the time limit of 10 hours and the TC/DSC is in a horizontal orientation, one of the recovery actions is to initiate air circulation within 1 hour. If air circulation is initiated as a recovery option, it must be operated for a minimum duration of 8 hours to allow sufficient time for TC/DSC components to cool down.

The staff reviewed the applicant's thermal analysis described in SAR Section 4.5.4 and the temperature results in SAR Table 4-26 and concluded that TS 3.1.3 is acceptable because the PCT is below the limit of 752 °F, consistent with SFST-ISG-11, and the TC/DSC component temperatures are below the allowable design limits at 8 hours after the initiation of air circulation.

SAR Section 4.5.4 indicates that after 8-hour air circulation, the blowers in operation can be turned off to complete the DSC transfer. The applicant performed the thermal analysis of load case 7 (off-normal, 50 kW, hot ambient 117 ˚F, horizontal, no air circulation) and predicted PCTs of 733 ˚F and 737 ˚F at 4 hours and 6 hours, respectively, which are both below the limit of 752 ˚F, as specified in SFST-ISG-11. The predicted results in SAR Table 4-27 show that the fuel cladding and TC/DSC component temperatures are below the allowable design limits of the fuel cladding (400 ˚C or 752 ˚F) as specified in SFST-ISG-11, Revision 3, and the cask components as indicated in SAR Table 4-27. The applicant chose a time limit of 4 hours to complete the DSC transfer operations to increase the safety margin.

The staff reviewed the description in SAR Section 4.5.4 and the temperature results in Table 4-27 and confirmed that after 8 hours of air circulation, the blowers can be turned off, and the DSC transfer needs to be completed within 4 hours of turning off the blowers. The staff determined that there is reasonable assurance that the PCT and the maximum TC/DSC component temperatures are below the corresponding limits, based on the thermal model used for the thermal analysis and the maximum temperatures presented in SAR Table 4-27.

The applicant noted in SAR Section 4.5.4 that if air circulation cannot be initiated within 1 hour of exceeding the 10-hour time limit specified in SAR Table 4-31, the TC/DSC has to be returned to the cask handling area to be positioned in vertical orientation and then the TC/DSC annulus will be filled with clean water. The applicant specified in TS Limiting Condition for Operation (LCO) 3.1.3 that a total of 5 hours is available to complete Actions A.2 and A.3, and the total time from the beginning of transfer operations is 15 hours. The applicant performed analysis and calculated a PCT of 742 ˚F at the end of 15 hours, which is below the allowable limit of 752 ˚F and consistent with the provisions of SFST-ISG-11.

The staff reviewed the calculations in SAR Section 4.5.4 and confirmed that the PCT of 742 ˚F at the end of 15 hours after the beginning of the transfer operation remains below the specified limit of 752 ˚F, consistent with SFST-ISG-11. The staff confirmed that other TC/DSC component temperatures are below the corresponding limits with large margins at the end of 14 hours, as shown in SAR Table 4-24.

SAR Section 4.5.5 states that the accident condition with loss of neutron shield and loss of air circulation (load case 5: 50 kW, HLZC #1, and ambient 117 ˚F) is the bounding case for accident conditions, including fire. The applicant calculated a PCT of 935 ˚F which is far below the limit of 1,058 ˚F for accident conditions, consistent with the provisions of SFST-ISG-11.

The staff reviewed the conditions of load case 5 in SAR Section 4.5.5 and determined that there is no significant safety issue for the EOS-TC125 loaded with the EOS-37PTH DSC under the bounding accident condition (load case 5) because both the PCT and maximum TC/DSC component temperatures still remain below the allowable limits.

The staff determined that the time limits of transfer operations for the EOS-TC125 loaded with EOS-37PTH DSC are applicable to the EOS-TC135 loaded with the EOS-37PTH DSC because the EOS-TC135 has the same heat load, but larger heat dissipation area and thermal mass. As a result, the PCT of the EOS-TC135 remains bounded by the PCT of the EOS-TC125 in each load case and is below the allowable limit of 752 °F within the proposed time limits for transfer operations (SAR Table 4-31). This is consistent with SFST-ISG-11.

Based on the thermal evaluations and the predicted safety margins, the staff determined that the time limits for the completion of EOS-37PTH DSC transfer, as described in TS 3.1.3 (SER Table 4-5), are acceptable because the PCT is below the limit of 752 °F, in accordance with the provisions of SFST-ISG-11, and the maximum cask component temperatures are below the corresponding design limits allowed for DSC/TC transfer operations. The time limit is 10 hours for any heat load in loading pattern HLZC #1 or HLZC #2, and there is no time limit for loading pattern HLZC #3 (heat load less than 36.35 kW).

Table 4-5 Time Limit for Completion of DSC Transfer in EOS-TC125/135

DSC Model	Operating Conditions	Maximum Heat Load (kW/DSC)	Time Limits (Hours)
EOS-37PTH	Normal/Off-normal Transfer	> 36.35 and ≤ 50.0 (HLZC #1)	10
EOS-37PTH	Normal/Off-normal Transfer	≤ 36.35 (HLZC #3)	No limit
EOS-37PTH	Insertion into EOS-HSM or restart of air circulation after inactivation	> 36.35 and ≤ 50.0 (HLZC #1)	4
EOS-37PTH	Loss of neutron shield with loss of air circulation	> 36.35 and ≤ 50.0 (HLZC #1)	No limit
EOS-89BTH	Normal/Off-normal Transfer	> 34.44 and ≤ 43.6 (HLZC #1)	10
EOS-89BTH	Normal/Off-normal Transfer	≤ 34.44 (HLZC #3)	No limit
EOS-89BTH	Insertion into EOS-HSM or restart of air circulation after inactivation	> 34.44 and ≤ 43.6 (HLZC #1)	4
EOS-89BTH	Loss of neutron shield with loss of air circulation	> 34.44 and ≤ 43.6 (HLZC #1)	No limit

4.4.4.2 EOS-89BTH DSC in EOS-TC125

SAR Section 4.5.6 states that the design load cases for transfer of the EOS-89BTH DSC are identical to those for the EOS-37PTH DSC (SAR Table 4-23). The maximum heat loads and HLZCs for the EOS-89BTH DSC are different from those for the EOS-37PTH DSC. TS Figure 2 shows the maximum heat loads of the EOS-89BTH DSC and its HLZC #1 (43.6 kW) in the EOS-TC125, HLZC #2 (41.6 kW) in the EOS-TC108/125, and HLZC #3 (34.44 kW) in the EOS-TC108/125.

SAR Table 4-34 shows the maximum temperatures of EOS-TC125 key components (fuel cladding, DSC shell, lead, and neutron shield) loaded with the EOS-89BTH DSC (load cases 1–10). Based on the analytical results for the EOS-37PTH DSC and the EOS-89BTH DSC, SAR Section 4.5.6.2 states that the maximum temperatures of the EOS-37PTH DSC bound the maximum temperatures of the EOS-89BTH DSC during transfer operations.

The staff reviewed the maximum decay heat loads of 50.0 kW for the EOS-37PTH DSC and 43.6 kW for the EOS-89BTH DSC, as well as the analytical results shown in SAR Tables 4.32 to 4.34. The staff confirmed that the maximum temperatures for the EOS-37PTH DSC bound the maximum temperatures for the EOS-89BTH DSC during transfer operations because of a lower heat load within the EOS-89BTH DSC. The staff determined that the time limits for transfer operations for the EOS-TC125 loaded with the EOS-37PTH DSC are applicable for the

EOS-TC125 loaded with the EOS-89PTH DSC because the EOS-37PTH DSC has a larger heat load than the EOS-89BTH DSC.

The staff concluded that both the PCT and maximum DSC component temperatures of the EOS-TC125 loaded with the EOS-89BTH DSC remain bounded by those of the EOS-TC125 loaded with the EOS-37PTH DSC. Therefore, they are below the allowable limits, which are consistent with SFST-ISG-11. SAR Tables 4-32, 4-33, and 4-34 list the PCT and the maximum DSC component temperatures of the EOS-TC125 loaded with the EOS-89BTH DSC.

Based on the thermal evaluations and the predicted safety margins, the staff determined that the time limits for the completion of EOS-89BTH DSC transfer by EOS-TCs, as described in TS 3.1.3 (or SER Table 4-5), are acceptable because the PCT is below the limit of 752 °F, consistent with SFST-ISG-11, and the maximum cask component temperatures are below the corresponding design limits allowed for DSC/TC transfer operations. The time limit is 10 hours for the heat load patterns of HLZC #1 and HLZC #2, and there is no time limit for the loading pattern HLZC #3 with heat load less than 34.44 kW.

4.4.4.3 EOS-37PTH DSC or EOS-89BTH DSC in EOS-TC108

The applicant stated in SAR Section 4.6 that the EOS-TC108 has a lower mass than the EOS-TC125 and EOS-TC135. With a lower mass in the EOS-TC108, the maximum heat loads allowed in the EOS-TC108 are limited to 41.8 kW for the EOS-37PTH DSC and 41.6 kW for the EOS-89BTH DSC. SAR Section 4.6 states that, similar to the EOS-TC125, the EOS-TC108 contains design provisions for using air circulation to improve its thermal performance for heat loads greater than 36.35 kW and 34.44 kW for the EOS-37PTH DSC and the EOS-89BTH DSC, respectively. The air circulation system is not needed for heat loads less than or equal to 36.35 kW for the EOS-37PTH DSC and less than or equal to 34.44 kW for the EOS-89BTH DSC.

The applicant showed the design load cases for the EOS-TC108 in SAR Table 4-36 (load cases 1–10). SAR Table 4-40 shows the maximum component temperatures of the EOS-TC108 loaded with the EOS-37PTH DSC, and SAR Table 4-41 shows the proposed time limits for transfer operations. SAR Table 4-43 shows the maximum component temperatures of the EOS-TC108 loaded with the EOS-89BTH DSC, and SAR Table 4-44 shows the proposed time limits for transfer operations.

The staff reviewed SAR Section 4.6 and the maximum component temperatures of the EOS-TC108 loaded with the EOS-37PTH DSC (SAR Tables 4-37, 4-39, and 4-40) and with the EOS-89BTH DSC (SAR Tables 4-38, 4-42, and 4-43) for load cases 1–10. The staff finds the results to be acceptable because the EOS-TC108 loaded with the EOS-37PTH DSC or the EOS-89BTH DSC has lower heat loads (of 41.8 kW and 41.6 kW, respectively) when compared to the EOS-TC125 loaded with the EOS-37PTH DSC (50.0 kW). Therefore, it is bounded by the EOS-TC125 loaded with the EOS-37PTH DSC with a heat load of 50.0 kW.

The staff accepted the proposed transfer time limits for the EOS-TC108 loaded with the EOS-37PTH DSC and loaded with the EOS-89BTH DSC, as shown in SER Table 4-6, and specified in SAR Tables 4-41 and 4-44, respectively. The staff based its acceptance on the fact that (1) the EOS-TC108 is bounded by the EOS-TC125 in thermal heat load, and (2) the cladding and TC/DSC component temperatures of the EOS-TC108 are below the corresponding temperature limits, as shown in SAR Table 4-40 for the EOS-37PTH DSC and Table 4-43 for the EOS-89BTH DSC.

Based on the thermal analyses, SAR Section 4.6.3 states that there is no time limit for the EOS-TC108 loaded with the EOS-37PTH DSC with heat loads less than 36.35 kW (HLZC #3), as well as for the EOS-TC108 loaded with the EOS-89BTH DSC with heat loads less than 34.44 kW (HLZC #3). SAR Section 4.6.3 states that there is a time limit of 10 hours for all transfer operations for the EOS-TC108 loaded with (1) the EOS-37PTH DSC with heat loads greater than 36.35 kW and less than 41.8 kW (HLZC #2), and (2) the EOS-89BTH DSC with heat loads greater than 34.44 kW and less than 41.6 kW (HLZC #2). HLZC #1 is not applicable to the EOS-TC108 loaded with the EOS-37PTH DSC and the EOS-89BTH DSC.

The staff reviewed SAR Section 4.6 and SAR Tables 4-36 to 4-44 and determined that the time limit for the completion of DSC transfer, as specified in SER Table 4-5, is also applicable to the EOS-TC108 loaded with the EOS-37PTH DSC (SAR Table 4-41) or the EOS-89BTH DSC (SAR Table 4-44). This is because (1) the maximum allowable heat loads of the EOS-TC108 loaded with the EOS-37PTH DSC and the EOS-89BTH DSC are lower than the heat loads allowed for the EOS-TC125 and the EOS-TC135; and (2) the PCT and the cask component temperatures are below the corresponding limits for transfer operations, consistent with SFST-ISG-11.

Table 4-6 Time Limit for Completion of DSC Transfer in EOS-TC108

DSC Model	Operating Conditions	Maximum Heat Load (kW/DSC)	Time Limits (Hours)
EOS-37PTH	Normal/Off-normal Transfer	> 36.35 and ≤ 41.8 (HLZC #2)	10
EOS-37PTH	Normal/Off-normal Transfer	≤ 36.35 (HLZC #3)	No limit
EOS-37PTH	Insertion into EOS-HSM or restart of air circulation after inactivation	> 36.35 and ≤ 41.8 (HLZC #2)	4
EOS-37PTH	Loss of neutron shield with loss of air circulation	> 36.35 and ≤ 41.8 (HLZC #2)	No limit
EOS-89BTH	Normal/Off-normal Transfer	> 34.44 and ≤ 41.6 (HLZC #2)	10
EOS-89BTH	Normal/Off-normal Transfer	≤ 34.44 (HLZC #3)	No limit
EOS-89BTH	Insertion into EOS-HSM or restart of air circulation after inactivation	> 34.44 and ≤ 41.6 (HLZC #2)	4
EOS-89BTH	Loss of neutron shield with loss of air circulation	> 34.44 and ≤ 41.6 (HLZC #2)	No limit

4.4.4.4 Operation of Air Circulation System for DSC/TC Transfer

SAR Section 4.5.4 states that the air circulation system features redundant blower and power systems, and the entire air circulation system is assembled and verified to operate within 7 days before beginning transfer operations as indicated in TS 3.1.3 and SAR Section 9.1.5. With an additional power source provided by the licensee at the ISFSI site and because of the redundant nature of the air circulation system, it is very unlikely that air circulation cannot be initiated. TS 3.1.3 states that if the DSC and HLZC combination result in a time limit for the completion of DSC transfer, the air circulation system shall be assembled and verified to be operable within 7 days before beginning the transfer operations of the loaded DSC.

The staff reviewed SAR Sections 4.5.4 and 9.1.5 and the applicant's response to a related RAI (AREVA, 2015). The staff confirmed that two blowers form a redundant system (each blower is independently coupled to each respective motor, power generator, and flexible power cord). The staff has determined that the air circulation system specified in TS 3.1.3 is acceptable if the required time limit for the completion of a DSC transfer was not met.

4.4.5 Maximum Internal Pressure

SAR Section 4.7 describes the calculations of the maximum internal pressures for the EOS-37PTH and the EOS-89BTH DSCs. The applicant calculated the internal DSC pressures using the ideal gas equation. The applicant incorporated the following assumptions:

- That 1 percent, 10 percent, and 100 percent of the fuel rods are ruptured when evaluating normal, off-normal, and accident conditions, respectively.

- The DSC is backfilled with helium at a pressure of 3.5 psig after vacuum drying.

- With helium in the DSC cavity and water at a temperature of 223 ˚F in the TC/DSC annulus, the applicant used the bounding average helium temperatures of 303 ˚F and 299 ˚F for the calculation of the initial amount of helium within the EOS-37PTH DSC and EOS-89BTH DSC cavities, respectively.

- The initial temperature of fill gas in the fuel rod plenum is room temperature (i.e., 70 °F).

The staff reviewed SAR Section 4.7 and confirmed that the applicant's pressure calculation, incorporated the assumptions, principles, and formula used which the staff approved in the safety evaluation for CoC No. 1004 (NRC, 2014). The staff finds the use of the ideal gas equation, which is employed in all types of engineering assessments, is appropriate for assessing the NUHOMS® EOS System in this SER.

SAR Table 4-45 reports the calculated maximum internal pressures of 10.5, 19.0 and 120.3 psig, respectively, for normal, off-normal, and accident conditions for the EOS-37PTH DSC. SAR Table 4-46 reports the calculated maximum internal pressures of 10.8, 17.8 and 101.1 psig, respectively, for normal, off-normal, and accident conditions for the EOS-89BTH DSC.

The staff reviewed the assumptions, methodology, and calculations presented in SAR Section 4.7 and the calculated maximum internal pressures reported in SAR Table 4-45 for the EOS-37PTH DSC and Table 4-46 for the EOS-89BTH DSC. The staff verified that the calculated maximum internal pressures of both the EOS-37PTH (as shown in SAR Table 4-45) and EOS-89BTH DSC (as shown in SAR Table 4-46) remain below the corresponding limits of 15, 20, and 130 psig required for normal, off-normal, and accident conditions. Based on the calculated maximum internal pressures, the staff concludes that the applicant's pressure calculations provide reasonable assurance that both EOS-37PTH and EOS-89BTH DSCs will not be over pressurized under normal, off-normal, and accident conditions.

4.4.6 Study of Grid Convergence Index

The applicant performed a grid convergence index (GCI) study of the ANSYS FLUENT CFD model for the EOS-HSM loaded with the EOS-37PTH DSC, as described in SAR Appendix 4.9.3.1, to determine the discretization error of the solution. The applicant stated in SAR Appendix 4.9.3.1 that based on the GCI study, the grid number used to evaluate the thermal performance of the EOS-HSM loaded with the EOS-37PTH DSC is acceptable because the PCT exhibits the monotonic-convergence feature and stays about the same with a slight increase of around 1.2 °F when increasing the grid number by a factor of 2.

The applicant also performed a GCI study for the EOS-TC125 loaded with the EOS-37PTH DSC, as described in SAR Appendix 4.9.3.2. The applicant stated that based on the GCI study, the grid number used to evaluate the thermal performance of the EOS-TC125 loaded with the EOS-37PTH DSC is acceptable because the computed PCT is close to the asymptotic value and stays about the same, with a very small GCI value of 1 percent.

SAR Appendix 4.9.3 states that the discretization error, as determined from the thermal model of the EOS-HSM (and EOS-TC) loaded with the EOS-37PTH DSC, is also applicable for the thermal model of the EOS-HSM (and EOS-TC) loaded with the EOS-89BTH DSC. Because the EOS-37PTH DSC and the EOS-89BTH DSC designs are similar, a similar behavior is expected for the thermal models of both DSCs loaded within the EOS-HSM and the EOS-TC.

The staff reviewed the mesh-sensitivity methodology and calculations presented in SAR Appendix 4.9.3. The staff determined that the methodology for determining the GCI is appropriate in accordance with the guidance in NUREG-2152, "Computational Fluid Dynamics Best Practice Guidelines for Dry Cask Applications: Final Report," issued March 2013, and that the calculated GCIs for the EOS-HSM and EOS-TC loaded with the EOS-37PTH DSC or EOS-89BTH DSC are acceptable in accordance with the justification in GCI value and change of PCT between two different numbers of meshing.

4.5 Conclusion

The staff determined that the designs of the EOS-37PTH and EOS-89BTH DSCs loaded within the EOS-HSM are acceptable and meet the thermal requirements of storage under normal, off-normal, and accident conditions, in compliance with 10 CFR Part 72.

The staff determined that the designs of the EOS-37PTH and EOS-89BTH DSCs loaded in the EOS-TC/108/125/135 are acceptable and meet the thermal requirements of short-term operations and transfer operations under normal, off-normal, and accidental conditions, in compliance with 10 CFR Part 72.

4.6 Evaluation Findings

F4.1 Chapter 4 of the SAR describes SSCs important to safety in sufficient detail to enable an evaluation of their thermal effectiveness. The EOS-HSM SSCs important to safety remain within their operating temperature ranges.

F4.2 The staff has reasonable assurance that the EOS-HSM storage system provides adequate heat removal capacity without active cooling systems for all permitted loading configurations of the EOS-37PTH and EOS-89BTH DSCs.

F4.3 The staff has reasonable assurance that the EOS-TC108/125/135 system provides adequate heat removal capacity without active cooling systems for the EOS-37PTH DSCs that are designated for transfer in the EOS-TC108/125/135 system.

F4.4 The staff has reasonable assurance that the EOS-TC108/125 system provides adequate heat removal capacity without active cooling systems for the EOS-89BTH DSCs that are designated for transfer in the EOS-TC108/125 system.

F4.5 The staff has reasonable assurance that spent fuel cladding will be protected against degradation that leads to gross ruptures by maintaining the clad temperature below maximum allowable limits and by providing an inert environment in the EOS-HSM cask cavity under normal, off-normal, and accidental storage conditions for the EOS-37PTH DSC and EOS-89BTH DSC reviewed for this application.

F4.6 The staff finds the following LCOs and Surveillance Requirements (SRs) to be acceptable:

(1) LCO 3.1.1 and SR 3.1.1 proposed for fuel integrity during drying
(2) LCO 3.1.2 and SR 3.1.2 for DSC helium backfill pressure
(3) LCO 3.1.3 and SR 3.1.3 proposed for the time limit for the completion of DSC transfer

F4.7 The staff finds that the site ambient temperatures proposed in items (3) and (4) of TS 4.5.3 are appropriate for thermal evaluations and shall be verified by the system user for applicability at a specific site.

F4.8 The staff determines that (1) the EOS-HSM thermal monitor program of TS 5.1.3 for air inlet/outlet vents and wind deflectors is appropriate and acceptable, and (2) the requirements of TS 5.5 for the installation of the wind deflectors are acceptable.

The staff finds that the thermal design of the EOS-37PTH DSC and EOS-89BTH DSC are 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 system will allow for the safe storage of spent fuel for a certified life. 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.

4.7 References

American Concrete Institute, "Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary," ACI 349-06, November 2006.

ANSYS Inc., ANSYS FLUENT Theory Guide, Version 14.00, and Users Guide, Version 14.0.

AREVA Inc., letter E-43624, “Revision 4 to Application for Approval of the Spent Fuel Cask Design for the NUHOMS® EOS System, Response to Request for Additional Information (Docket No. 72-1042, TAC No. L25028),” December 18, 2015, ADAMS Accession No. ML15364A505.

AREVA Inc., letter E-44592, “Revision 5 to Application for Approval of the Spent Fuel Cask Design for the NUHOMS® EOS System, Response to Second Request for Additional Information (Docket No. 72-1042, TAC No. L25028),” April 7, 2016a, ADAMS Accession No. ML16111A648.

AREVA Inc., letter E-45191, “Revision 6 to Application for Approval of the Spent Fuel Cask Design for the NUHOMS® EOS System, Revised Response to Questions 3-2 and 4-1 from the Second Request for Additional Information (Docket No. 72-1042, TAC No. L25028),” June 13, 2016b, ADAMS Accession No. ML16169A039.

AREVA, Inc., “Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel,” Revision 14, Docket No. 72-1004, September 2014.

Title 10, *Code of Federal Regulations*, Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste.”

U.S. Nuclear Regulatory Commission, Safety Evaluation Report, Docket No. 72-1030, Transnuclear, Inc. NUHOMS® HD Horizontal Modular Storage System for Irradiated Nuclear Fuel, 2010, ADAMS Accession No. ML070160089.

U.S. Nuclear Regulatory Commission, “Cladding Considerations for the Transportation and Storage of Spent Fuel,” SFST-ISG-11, Revision 3, 2003.

U.S. Nuclear Regulatory Commission, “Computational Fluid Dynamics Best Practice Guidelines for Dry Cask Applications: Final Report,” NUREG-2152, March 2013.

U.S. Nuclear Regulatory Commission, Safety Evaluation Report, Docket No. 72-1004, Transnuclear, Inc. Standardized NUHOMS® Horizontal Modular Storage System For Irradiated Nuclear Fuel, Amendment No. 13, 2014, ADAMS Accession No. ML13273A327.

U.S. Nuclear Regulatory Commission, “Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility,” NUREG-1536, Revision 1, July 2010.

5.0 CONFINEMENT EVALUATION

The staff reviewed the NUHOMS® EOS-37PTH and EOS-89BTH DSC Systems confinement features and capabilities to ensure that (1) that any radiological releases to the environment will be within the limits established in 10 CFR Part 72, and (2) the spent fuel cladding will be protected against degradation that might lead to gross ruptures during storage, as required in 10 CFR 72.122(h)(1). The staff also reviewed this application to determine whether the NUHOMS® EOS-37PTH and EOS-89BTH DSC Systems fulfill the acceptance criteria listed in NUREG-1536 and applicable ISGs.

The staff determined that the applicant's confinement evaluation is acceptable because the confinement design of the NUHOMS® EOS system met the regulatory requirements of 10 CFR Part 72. This included maintaining the fuel cladding integrity and preventing the release of radiological material below the required limits under normal, off-normal, and accident storage conditions.

5.1 Confinement Design Characteristics

<u>Boundary and Design Features</u>

The confinement boundary of the NUHOMS® EOS-37PTH and EOS-89BTH includes the cylindrical shell, the top inner cover plate, drain port cover, vent plug, the bottom inner cover plate, and the associated welds. An outer top cover plate, which rests atop the top inner cover plate and is welded to the cylindrical shell, and an outer bottom cover plate, which is also welded to the cylindrical shell, provide a redundant confinement boundary as required by 10 CFR 72.236(e).

The applicant identified that the cylindrical shell to inner bottom cover plate weld is made during fabrication of the DSCs and stated this weld is made in accordance with ASME B&PV Code, Section III, Subsection NB. The applicant stated that the welds between the cylindrical shell and inner top cover, which include the drain port cover and vent plug welds were placed after fuel loading. In addition, these welds were designed, fabricated, inspected, and tested using alternatives to the ASME B&PV Code specified in TS Section 4.4.4. The staff determined the alternatives to the ASME B&PV Code are acceptable and the staff's evaluation of the alternatives is presented in Section 8.19 of the SER.

The applicant reported that the cylindrical shell and inner bottom cover are pressure tested in accordance with ASME B&PV Code, Section III, NB-6300.

Finally, the applicant reported that a leak test of the shell assembly, including the inner bottom cover, will be performed in accordance with ANSI N14.5 1997, "Radioactive Materials—Leakage Tests on Packages for Shipment," and ASME B&PV Code, Section V, Article 10. The applicant identified that the acceptance criterion for the test is "leaktight," as defined in ANSI N14.5 1997.

Figure 5-1 of the SAR depicts the confinement boundaries and welds. Chapters 9 and 10 of the SAR discuss the confinement boundary pressure tests, welds, and the leak testing performed to verify their integrity.

Confinement Penetrations

All confinement penetrations are welded closed before storage.

Seals and Welds

The fabrication welds of the DSC that are part of the confinement boundary include the multiple layer weld applied to the shell bottom and the full-penetration welds applied to the cylindrical shell. These welds are inspected via radiographic or ultrasonic means, in accordance with ASME B&PV Code, Section III, Subsection NB. The remaining welds are applied using a multilayer technique during DSC closure operations in accordance with NRC staff guidance and the ASME B&PV Code, as confirmed by the materials review in SER Chapter 8. All confinement welds are leak tested to demonstrate that no credible leakage less than or equal to 1×10-7 ref·cm3/s is detected, which meets the leaktight criteria in ANSI N14.5 1997.

Closure

There are no mechanical closure devices used in the DSCs

5.2 Confinement Monitoring Capability

Periodic surveillance of the storage module for blockage of inlet and outlet vents, as well as the licensee's use of radiation monitors, are adequate to ensure the continued effectiveness of the confinement boundary. Because the DSC is welded shut, the NRC staff finds that the periodic surveillance adequately enables the licensee to detect any closure degradation and to take appropriate corrective actions to maintain safe storage conditions. This position is consistent with the guidance in NUREG-1536 (Section 5.4.2, Confinement Monitoring), which indicates that no confinement monitoring capability is necessary for welded closures.

5.3 Nuclides with Potential Release

The SSCs are fully welded and leak tested in accordance with ANSI N14.5 1997 to demonstrate that the DSCs are leaktight. Additionally, the analyses presented in SAR Chapter 3 (structural), Chapter 4 (thermal), and Chapter 8 (materials) demonstrate that the confinement boundary is not compromised during normal, off-normal, and accident conditions. Consequently, there is no credible contribution to the radiological consequences as a result of a potential release of canister contents.

5.4 Confinement Analysis

5.4.1 Normal Conditions

Release of Radioactive Material

As discussed in Section 5.3 of this SER, the release of radioactive material is not a credible event for normal conditions.

Pressurization of Confinement Vessel

The NRC staff confirmed from the thermal evaluation that the calculated maximum normal pressure in the vessel is below design limits (15 psig). This calculated pressure is based upon the applicant's estimates of the moles of gas in the canister (assuming 1 percent cladding failure), free volume within the canister, and the applicant's calculated bulk average gas temperature. SAR Tables 4-45 and 4-46 report the calculated values. Inspection of the reported maximum pressure confirmed that they were below the associated design pressures; therefore, the staff determines the confinement boundary will remain intact.

5.4.2 Off Normal Conditions

Pressurization of Confinement Vessel

A similar review to that of normal events was performed for off-normal events reported by the applicant (10 percent rod failure, 20 psig design limit) and the maximum pressures are reported in SAR Tables 4-45 and 4-46. Inspection of the reported maximum pressure confirmed that they were below the associated design pressures; therefore, the staff determines the confinement boundary will not be challenged by internal pressures and will remain intact.

Release of Radioactive Material

As discussed in Section 5.3 of SER, the release of radioactive material is not a credible event for off-normal conditions.

5.4.3 Accident Conditions

Pressurization of Confinement Vessel

A similar review to that of normal events was performed for accident events reported by the applicant (100 percent rod failure, 130 psig design limit) and the maximum pressures are reported in SAR Tables 4-45 and 4-46. Inspection of the reported maximum pressure confirmed that they were below the associated design pressures; therefore, the staff determines the confinement will not be challenged by internal pressures and will remain intact.

Release of Radioactive Material

As discussed in Section 5.3 of this SER, the release of radioactive material is not a credible event for accident conditions.

Fission Gas Products

Because no credible leakage is expected and the confinement integrity was demonstrated to remain intact under accident conditions, the staff determined that cataloging the estimated fission gas products is not necessary in accordance with the guidance of NUREG-1536.

5.5 Evaluation Findings

F5.1 Chapters 1, 2, and 5 of the SAR describe confinement SSCs important to safety in sufficient detail to permit the evaluation of their effectiveness.

F5.2 The design of the DSC adequately protects the spent fuel cladding against degradation that might otherwise lead to gross ruptures. Chapter 4 of the SER discusses the relevant temperature considerations.

F5.3 The design of the DSC provides redundant sealing of the confinement system closure joints using multiple welds. An outer top cover plate, which rests atop the top shield plug top inner cover plate and is welded to the cylindrical shell, and an outer bottom cover plate, which is also welded to the cylindrical shell, provide a redundant confinement boundary.

F5.4 The DSCs have no bolted closures or mechanical seals. The confinement boundary contains no external penetrations for pressure monitoring or overpressure protection. No instrumentation is required to remain operational under accident conditions. Because the DSC uses an entirely welded, redundant closure system, no direct monitoring of the closure is required.

F5.5 The confinement system will reasonably maintain confinement of radioactive material. Chapter 11 of the SER shows that the direct dose from the DSC satisfies the regulatory requirements of 10 CFR 72.104(a) and 10 CFR 72.106(b).

The staff concludes that the design of the DSC confinement system is in compliance with the requirements in 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the confinement system design provides reasonable assurance that the DSCs will allow for the safe storage of spent fuel. This conclusion is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, the applicant’s evaluation, and accepted engineering practices.

5.6 References

American National Standards Institute, Institute for Nuclear Materials Management, “Radioactive Materials—Leakage Tests on Packages for Shipment,” ANSI N14.5, 1997.

American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, 2010 Edition through 2011 Addenda.

Title 10, *Code of Federal Regulations*, Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C waste.”

U.S. Nuclear Regulatory Commission, “Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility,” NUREG-1536, Revision 1, July 2010.

6.0 SHIELDING EVALUATION

The staff reviewed the capability of the NUHOMS® EOS System shielding features to ensure adequate protection against direct radiation from its contents. The regulatory requirements for providing adequate radiation protection to licensee personnel and members of the public include 10 CFR Part 20, “Standards for Protection against Radiation,” 10 CFR 72.104(a), 10 CFR 72.106(b), 10 CFR 72.212(b), and 10 CFR 72.236(d). Because the dose requirements in 10 CFR Part 72 for members of the public include direct radiation, effluent releases, and radiation from other uranium fuel cycle operations, the NRC staff documents its overall assessment of compliance with these regulatory limits in Chapter 11 of this SER on radiation protection of the SER.

The shielding review focuses on the calculation of the dose rates from both direct gamma and neutron radiation at locations near the EOS-HSMs and EOS-TC and at assumed distances away from the EOS-HSMs. Chapter 11 of the SAR presents estimated occupational exposures and offsite dose rates that are based on the dose rates calculated in Chapter 6 of the SAR. Chapter 6 of the SER evaluates near-field dose rates for normal and off-normal conditions for the EOS-TC and EOS-HSM.

The applicant performed the calculations using a loss of neutron shield accident for a single EOS-TC to demonstrate compliance with 10 CFR 72.106. SAR Chapter 11 documents site dose calculations for an array of EOS-HSMs under normal, off-normal, and accident conditions, based on the near-field EOS-HSM results evaluated in SAR Chapter 6. Compliance with 10 CFR 72.104 and 10 CFR 72.106 for an array of EOS-HSMs can only be demonstrated using a site-specific calculation given the large number and arrangement of EOS-HSMs and the distance to the site boundary.

The staff finds the applicant’s methodology, source terms, and dose rates presented in SAR Chapter 6 to be reasonably bounding for general licensee to implement the EOS System. The general licensee may use these results in lieu of near-field calculations, although each site should evaluate the inputs for applicability. The general licensee may perform site-specific EOS-TC and EOS-HSM near-field calculations to modify key input parameters.

6.1 Shielding Design Description

The staff reviewed the applicant’s criteria for protection against direct radiation and the method for reducing direct radiation dose rates to ensure compliance with requirements in 10 CFR 72.104 and 10 CFR 72.106. The staff also ensures the applicant considered ALARA principle in its shielding design.

6.1.1 Design Criteria

Sections 2.4.4 and 6.1 of the SAR specify design criteria for the surface dose rates on the concrete EOS-HSM and EOS-TC designs. The applicant prepared calculations for a 2x10 ISFSI accident configuration using the same method as described for the normal condition models. At distances of 200 meters and 370 meters from the ISFSI, the accident dose rate is approximately 1.1 millirem (mrem) per hour (hr) and 0.1 mrem/hr, respectively. The recovery time for this accident is assumed to be 5 days (120 hours). Based on the 5-day recovery time, the total exposure to an individual at distances of 200 meters and 370 meters is 132 mrem and 12 mrem, respectively. This is significantly less than the limit in 10 CFR 72.106 of 5 rem. In an accident during transfer operations, the EOS-TC may be damaged, which would result in an offsite dose. For accident conditions, the applicant calculated the dose assuming the absence of the neutron shield, including the steel or aluminum shell. SAR Section 6.4.3 documents the EOS-TC accident calculations, and SAR Table 6-54 presents the results.

The maximum dose rate is 2.15 mrem/hr at a distance of 100 meters from the EOS-TC. Assuming an 8-hour recovery time, the dose to an individual at the site boundary is 17 mrem, which is significantly below the limit in 10 CFR 72.106 of 5 rem. This dose is also conservatively large because it is calculated at a distance of 100 meters from the EOS-TC.

The staff evaluated the EOS system shielding design criteria and found them acceptable. The SAR analysis provides reasonable assurance that the shielding design criteria meet the regulatory requirements of 10 CFR Part 20, 10 CFR 72.104(a), and 10 CFR 72.106(b). The TS include surface dose rate limits for the EOS-HSM and EOS-TCs. The staff evaluates the overall radiological protection design features and design criteria for the EOS in Chapter 11 of the SER.

6.1.2 Design Features

The SAR indicates that the EOS-37PTH DSC and EOS-89BTH DSC shells are welded stainless or duplex steel pressure vessels that include thick shield plugs at both ends to maintain occupational exposures ALARA. The top end of the DSC has nominally 10 inches of steel shielding and the bottom 8 inches of steel shielding. The confinement boundary is designed, fabricated, and tested to ensure that it is leaktight. Section 2.4.2.1 of the SAR summarizes the DSC features that ensure confinement of the contents. The EOS-HSM provides the bulk of the radiation shielding for the DSCs. The EOS-HSM’s design can be arranged in either a single-row or a back-to-back arrangement. The applicant explained that thick concrete supplemental shield walls are used at either end of an EOS-HSM array and along the back wall of single-row arrays to minimize radiation dose rates both on and off site. Also, the nominal thickness of the EOS-HSM roof is 44 inches for biological shielding. Separate shield walls at the end of a module row, in conjunction with the module wall, provide a minimum thickness of 4 feet for shielding. Similarly, an additional shield wall is used at the rear of the module if the ISFSI is configured as single module array. Thick concrete side walls between EOS-HSMs in an array provide sufficient shielding to minimize doses in adjacent EOS-HSMs during loading and retrieval operations. Section 11.3 of the SAR summarizes the offsite dose calculations for representative arrays of design-basis EOS-HSMs to provide assurance that the limits in 10 CFR 72.104 and 10 CFR 72.106(b) are not exceeded.

The EOS-TCs are designed to provide sufficient shielding to ensure that dose rates are ALARA. The EOS-TCs are constructed of steel and lead gamma shielding with high-density polyethylene neutron shielding at the bottom and water neutron shielding jackets and tanks. Chapter 6 of the SAR provides the dose rates on and around the EOS-TCs, and Section 11.2 of the SAR provides the occupational exposures associated with a loading campaign. SAR Chapters 6 and 11 give off-normal and accident doses and dose rates. According to the applicant, there is no radioactive release of effluents during normal and off-normal storage operations. Also, there is no credible accident that causes significant releases of radioactive effluents from the DSC. Therefore, no off-gas or monitoring system is required for the EOS-HSM. An off-gas system is required only during DSC drying operations. Based on the analyses presented in SAR Chapter 3 (structural), Chapter 4 (thermal), and Chapter 8 (materials), the applicant demonstrated that the confinement boundary is not compromised during normal, off-normal, and accident conditions. Consequently, there is no credible contribution to the radiological consequences as a result of a potential release of canister contents. Therefore, the staff determines it acceptable.

6.2 Source Specification

Section 6.2 of the SAR presents the source specification. All gamma and neutron source term calculations were generated using the ORIGEN-ARP module of SCALE 6.0. ORIGEN-ARP is a control module for the ORIGEN-S computer program. ORIGEN-ARP allows a simplified input description that can rapidly compute source terms and decay heat compared to a full two-dimensional SCALE 6.0/TRITON calculation.

The applicant explained in the SAR that ORIGEN-ARP used interpolated cross-section libraries to generate source terms that are essentially equivalent to the detailed TRITON runs. TRITON has been benchmarked against experimentally measured isotopes and results in excellent agreement with the measured data in Oak Ridge National Laboratory (ORNL)/TM-2010/44, “Predictions of PWR Spent Nuclear Fuel Isotopic Compositions,” SCALE 5.1, March 2010. As part of the code validation, the TRITON benchmark cases from SCALE 5.1 were rerun using the ENDF/B-VII 238-group cross-section library. The isotopes important for shielding for which benchmark data are available include cesium-137/barium-137m, cesium-134, europium-154, cerium-144/praseodymium-144, ruthenium-106/rhodium-106, strontium-90/ytrrium-90, and curium-244. The average ratio of the measured to calculated concentration for these nuclides is close to unity, indicating that TRITON/ORIGEN-ARP is an acceptable program for source term generation. SAR Chapter 6 derives the design-basis PWR and BWR source terms. Non-SFA hardware (including CCs and fuel channels), BLEU, and reconstituted rods are also allowed. Sections 6.2.4, 6.2.5, and 6.2.6 of the SAR, respectively, discuss the source terms for these items. The design-basis SFAs selected for source term analysis are SFAs with maximum amount of uranium in MTU for both PWR and BWR.

The EOS-DSC baskets are zoned by heat load. According to the applicant, heat load zoning allows hotter SFAs, which generally have larger neutron and gamma source terms, to be placed in the inner zones and shielded by SFAs in the outer zone. Figure 6-1 and Figure 6-2 of the SAR show the HLZCs that are conservative for the shielding analysis for the EOS-37PTH and EOS-89BTH DSCs. The EOS-TC108 and EOS-TC125/135 have different HLZCs because the EOS-TC125/135 is more heavily shielded than the EOS-TC108 and can therefore be loaded with stronger sources. The SFAs are zoned by heat load, and the applicant developed source terms for each zone. Candidate sources were developed for high burnup (62 gigawatt days (GWd)/MTU), medium burnup (50 GWd/MTU), and lower burnup (40 GWd/MTU) fuel. The cooling time was selected so that the decay heat meets or exceeds the heat load limit for each zone.

Based on the EOS-TC and EOS-HSM dose rates (for the active fuel) and cobalt (Co)-60 activity (for the end hardware), the applicant determined reasonably bounding combinations of burnup, enrichment, and cooling time. For these combinations, the applicant computed the sources in the bottom nozzle, active fuel, plenum, and top nozzle using the appropriate light elements from SAR Table 6-5 and Table 6-6.

The applicant postulated that, during an EOS-TC accident, the water in the neutron shield is lost. In this scenario, there is no hydrogenous neutron shield and the neutron dose rate dominates the primary gamma dose rate. The highest allowed burnup (62 GWd/MTU) was used in accident calculations with no neutron shield because the neutron source is maximized for high-burnup fuel.

CCs may also be included with the PWR SFAs. For BWR fuel, the BWR source presented in Section 6.2.2 of the SAR includes the fuel channel and associated attachment hardware. CCs may be grouped into two categories—(1) those that extend into the top, plenum, and active fuel regions of the SFA and (2) those that essentially extend only into the top and plenum regions of the SFA. The burnable poison rod assembly (BPRA) is used as a representative CC for category (1) and the thimble plug assembly (TPA) is used as a representative CC for category (2). The objective is to use these representative CC types to develop Co-60 activity limits for CCs.

The applicant conservatively assumed the reconstituted rods to be solid, which maximizes the mass of the cobalt impurity. Removing five rods removes both the UO_2 fuel pellets and any associated cladding, end caps, and plenum springs. The fuel rod is then replaced with a solid stainless steel rod with the same length and diameter of the fuel rod being replaced. Table 6-38 and Table 6-39 of the SAR provide the masses of a reconstituted SFA for PWR and BWR fuel, respectively. These masses are used to determine the light element masses.

The staff evaluated the basis and methodology for determining design-basis fuel types and found it acceptable. Each design-basis fuel type has the highest uranium loading among other fuels in its category and has burnup and cooling times that bound the burnup and cooling time parameters requested for storage in the EOS. The staff's conclusions for design-basis fuel types are presented in greater detail in Section 6.2.7.

6.2.1 Initial Enrichment

The maximum allowable planar average initial enrichment of the fuel to be stored is 5.00 weight percent U-235 for the EOS-37PTH, and the maximum assembly average burnup is 62,000 MWd/MTU. The SFAs (with or without CCs) must be cooled to meet the decay heat limits specified in TS Figure 1 before storage. The maximum allowable lattice average initial enrichment of the fuel to be stored is 4.80 weight percent U-235 for the EOS-89BTH, and the maximum assembly average burnup is 62,000 MWd/MTU. The SFAs (with or without channels) must be cooled to meet the decay heat limits specified in TS Figure 2 before storage.

In terms of shielding, the source term is a complex function of burnup, enrichment, and cooling time, and it has both gamma and neutron components. Source terms, particularly the neutron component, are maximized when using lower enrichments for a given burnup. Based on data for thousands of SFAs discharged to date in the United States, SAR Table 6-7 provides empirical relationships between burnup and minimum enrichment. These empirical relations encompass the vast majority of used fuel that will be stored in the EOS system. For the BPRA, the host SFA is burned to 50 GWd/MTU in two cycles. The minimum enrichment is 3.1 percent based on Table 6-7 of the SAR. The SFA loading is 0.492 MTU. The assembly power is 19.68 megawatts, the irradiation time per cycle is 625 days, and the down time between cycles is 30 days. Decay heat, Co-60 activity, and the gamma source term are requested for a decay time of 10 years.

In addition, the source term inputs used to rank the burnup, enrichment, and cooling time combinations were based on the total light element masses provided in Table 6-5 and Table 6-6 of the SAR for PWR and BWR fuel, respectively, and, therefore, includes the entire SFA source.

6.2.2 Computer Codes

Section 6.4.1 of the SAR describes the computer code, Monte Carlo N-Particle (MCNP)5, version 1.40, that was used in the shielding analysis. MCNP5 is a Monte Carlo transport program that allows full 3D modeling of the EOS-TC and EOS-HSM. The applicant stated that it was not necessary to develop geometrical approximations when developing the shielding models.

6.2.3 Gamma Source

Tables 6-10 through 6-29 of the SAR list the gamma source terms for each design-basis fuel. The SAR presents a dose rate analysis to evaluate the effect of each gamma energy group on calculated surface dose rates, including the EOS-TC108, EOS-TC125/135, and EOS-HSM inlet and outlet vent dose rates. The analysis demonstrates that fuel gammas with energies from 0.45 to 3.0 MeV account for more than 99 percent of the external gamma dose. Therefore, only the fuel gamma energy range was examined in the gamma shielding evaluation. The staff performed confirmatory analysis and verified the percent of the external gamma dose.

The gamma source term includes Co-60 gamma radiation from activated assembly hardware listed in Table 6-37 of the SAR. The activated hardware source terms are calculated assuming the hardware masses listed in SAR Table 6-35 and reactor flux scaling factors listed in SAR Table 6-4. The source term and decay heat for the decay times of interest are dominated by Co-60. Co-60 primarily arises through activation of the Co-59 impurity present in the metal. Therefore, the BPRA and TPA hardware that has the largest Co-59 mass in each region is used to prepare the light element inputs. For the BPRA, the B&W 15x15 array is used for the top and the WE 17x17 Pyrex is used for the plenum and active fuel regions. For the TPA, the WE 17x17 array is used for all regions.

Table 6-36 of the SAR summarizes the results for Co-60 activity and decay heat for both the BPRA and TPA for a cooling time of 10 years. It is observed that the BPRA source may be used in the active fuel region, as the TPA does not extend into this region.

6.2.4 Neutron Source

The applicant examined several different burnup and enrichment combinations for the neutron source and bounding source terms to maximize the dose rates on the side of the EOS-TC or outlet vent of the EOS-HSM. Tables 6-10 through 6-29 of the SAR provide source terms for both normal and accident conditions. EOS-TC accident source terms maximize the neutron source because the only EOS-TC accident that results in a loss of shielding effectiveness is a loss of neutron shield accident. No off-normal events impact the shielding effectiveness of the EOS-TC and EOS-HSM. The applicant identified two accident events—(1) loss of neutron shielding for the EOS-TCs and (2) loss of EOS-HSM outlet vent covers as a result of a tornado or missile event.

6.2.5 Other Parameters Affecting the Source

The applicant’s calculated average value of the neutron source distribution was 1.215, as shown in Table 6-30 of the SAR. This value has a physical meaning, as it is the ratio of the total neutron source from an SFA with the given axial burnup profile to an assembly with a flat burnup profile. The neutron source term as computed by ORIGEN-ARP is for a flat burnup profile (average assembly burnup). Therefore, the “raw” PWR neutron source computed by

ORIGEN-ARP is scaled by the factor of 1.215 to account for the burnup profile. For the BWR neutron source, the average value of the source distribution was calculated as 1.232, and the "raw" neutron sources computed by ORIGEN-ARP are increased by this factor to account for the burnup profile.

As indicated in Section 6.2 of the SAR, CC may also affect the source. Section 6.2.5 of the SAR describes the BLEU fuel. BLEU fuel is fabricated from highly enriched uranium that has been downblended with depleted uranium. BLEU fuel may have slightly different uranium isotopes compared to standard fuel; however, the source term for the BLEU fuel is negligible.

6.2.6 Confirmatory Analysis

The staff performed confirmatory analyses for selected fuel types and burnup conditions. The staff used the ORIGEN-ARP module of SCALE 6.1 using the ENDF/B-VII 238-group cross-section library. The staff examined the proposed contents listed in Tables 2-2, 2-3, and 2-4 of the SAR and has reasonable assurance that the design-basis gamma and neutron source terms for the EOS-37PTH DSC and EOS-89BTH DSC configurations are acceptable for the shielding analysis.

The staff finds the flux scaling factors to be bounding and appropriate for determination of hardware source terms. All EOS-37PTH DSC calculations conservatively include both the SFA and CC sources. BWR fuel does not include CC, other than the fuel channel, which is included in the source term. As discussed in SAR 6.3.2, the applicant performed the EOS-TC calculations for three configurations representing the three operational stages during loading and transfer: loading/decontamination, welding/drying, and downending/transfer. The applicant conservatively computed these dose rates without any supplementary shielding that would typically be used to maintain ALARA. The source term and decay heat for the decay times of interest are dominated by Co-60. It is important to note that the source term and dose rate are driven by Co-60, which arises primarily from activation of a Co-59 impurity in the metal and to a much lesser extent from nickel-60 activation through an (n,p) reaction. Therefore, the BPRA and TPA hardware that has the largest Co-59 mass in each region is used to prepare the light element inputs. For the BPRA, the B&W 15x15 array is used for the top and the WE 17x17 Pyrex is used for the plenum and active fuel regions. For the TPA, the WE 17x17 array is used for all regions. Table 6-3 of the SAR provides elemental compositions for Zircaloy-4, Inconel-718, Inconel X-750, and 304 stainless steel. Table 6-36 of the SAR summarizes the results for Co-60 activity and decay heat for both the BPRA and TPA for a cooling time of 10 years. It is observed that the BPRA source may be used in the active fuel region, as the TPA does not extend into this region. The cobalt impurity assumption in Zircaloy and Inconel are acceptable for the EOS shielding analysis.

The staff has reasonable assurance that the gamma source terms used in the shielding analysis are bounding or appropriate for the NUHOMS® EOS system based on historical statements and dose rate comparisons presented in the SAR. The staff considered the following factors in this determination:

- Co-60 has a 5.27-year half-life, and high-energy gamma fission products significantly decay within the same time frame.
- The design-basis burnup and initial uranium loading used in the SAR shielding analysis are significantly higher than the maximum burnup and uranium loading allowed in the CoC.
- The maximum exterior dose rates are limited in the CoC.

- Each general licensee will perform site-specific dose evaluations to demonstrate compliance with 10 CFR Part 72 radiological requirements, operate the NUHOMS® EOS system under a 10 CFR Part 20 radiological program, and monitor dose rates during ISFSI operations.

The staff also accepts that the lower-than-average initial enrichment values used to determine neutron source terms are adequate for each burnup level examined in the NUHOMS® EOS system shielding analysis. The values bound a significant portion of discharged fuel and the design-basis source terms are calculated for burnups significantly higher than those allowed in the CoC. The CoC has some limits which provide adequate control of the total source term and exterior dose rates; for example, maximum burnup, minimum cooling time, maximum initial uranium loading, and maximum dose rates. Therefore, license conditions for minimum enrichment are not required for the NUHOMS® EOS system. Each general licensee should use minimum fuel enrichments when performing radiological evaluations under 10 CFR 72.212, "Conditions of General License Issued under § 72.210."

6.3 Shielding Model Specifications

Section 6.3 of the SAR presents the EOS shielding and source configuration. The applicant performed the shielding analysis of the EOS using MCNP5 and developed separate primary gamma and neutron models. The EOS-TC and EOS-HSM neutron models were run in coupled neutron-photon mode so that the secondary gamma dose rate from (n,γ) reactions could be computed. The secondary gamma dose rate from the EOS-TC arises primarily from neutron absorption in the water neutron shield. Secondary gammas from the EOS-HSM are negligible but are computed for completeness.

The shielding model for normal and accident conditions consist of detailed 3D near-field dose rate calculations for the EOS-TC and EOS-DSC, including all shielding materials, the SNF source, gamma shield cross plates, and internal air passage streaming pathways based on the design drawings in Section 1.3 of the SAR. Section 1.3 of the SAR presents radial and axial views of the EOS-DSC and EOS-TC shielding models.

The EOS-37PTH DSC and EOS-89BTH DSC were modeled explicitly, including the steel basket structure, aluminum plates, MMC (conservatively modeled without boron), transition rails, and shield plugs. Table 6-47 of the SAR summarizes key dimensions used to develop the DSC models, and SAR Figures 6-3 through 6-6 illustrate the basic MCNP model. These figures only illustrate the EOS-TC108 with the EOS-89BTH DSC, and the other EOS-TC and EOS-DSC combinations are similar. The applicant used three model configurations to simulate the EOS System during the various stages from loading to transfer. These configurations, described in SAR Section 6.3.2, are based on loading/decontamination, welding/drying, and downending/transfer.

The applicant stated that the source terms used in the EOS-37PTH DSC models were the combined fuel and CC source terms. The CC source term from Table 6-37 of the SAR was simply added to the fuel source term from Tables 6-10 through 6-16 of the SAR. The CC source was added to every SFA in the EOS-37PTH DSC. Tables 6-20 through 6-26 of the SAR provide the EOS-89BTH DSC source terms. The applicant did not model temporary shielding, which would be used in practice to shield penetrations or localized areas of high dose rate. Therefore, the computed dose rates are larger than the dose rates that would be observed in actual practice.

For each TC/DSC combination, the applicant calculated dose rates on the surface and 30 centimeters (cm) and 100 cm from the surfaces of the EOS-TC. Dose rates were also computed at 300 cm from the side surface. All side dose rates were computed in 18 axial bins. Figure 6-7 of the SAR shows the general tally locations. In addition, for the final transfer configuration, dose rates were computed on the bottom and top surface in six radial segments, and on the side surface in 18 radial segments and 24 angular segments.

For accident models, the applicant developed the four transfer configurations discussed above. In the accident models, the water neutron shield, neutron shield panel, and borated polyethylene bottom neutron shield are replaced with void, and the accident source terms are used. The dose rate was calculated at a distance of 100 meters from the EOS-TC. Ground is modeled to account for ground scatter at large distances.

The staff evaluated the applicant’s configuration of shielding and source, accident shielding models, and shielding material properties, and finds them acceptable.

6.3.1 Source Configuration

As noted in Section 6.2 of the SAR, the shielding source in the EOS-DSC baskets was zoned by heat load, and source terms were developed for each zone. Cooling time was selected so that the decay heat meets or exceeds the heat load limit for each zone. The cooling time required at these burnups is generally much larger than the minimum allowed cooling time for each zone. The applicant also determined the burnup that results in a cooling time that matches the minimum cooling time for each zone. From these four candidate burnup and cooling time combinations, the applicant selected a bounding source for each zone. The source DSC region was also modeled with a number of simplifications and bounding assumptions that effectively reduce the amount of actual shielding and result in higher calculated dose rates.

Each design-basis fuel type has the highest uranium loading among other fuels in its category and has burnup and cooling times that bound the burnup and cooling time parameters requested for storage in the EOS. The staff evaluated the basis and methodology for determining the HLZC based on the design-basis fuel types and found them acceptable.

6.3.2 Material Properties

In general terms, basic materials used in the models, such as 304 stainless steel, carbon steel, and concrete, are obtained from PNNL-15870, “Compendium of Material Composition Data for Radiation Transport Modeling,” Revision 1, issued March 2011, and are summarized in Table 6-41 of the SAR. According to the applicant, not all materials were used in every model. The density of concrete has been conservatively reduced to 2.243 grams per cubic centimeter (g/cm^3). SAR Table 6-41 does not list simple materials consisting of one element. Such materials include lead, which was modeled with a reduced density of 11.18 g/cm^3. Aluminum was used in the basket plates, with a density of 2.7 g/cm^3. The MMC poison was modeled as pure aluminum (no boron), with a reduced density of 2.56 g/cm^3. Borated polyethylene was used at the bottom of the EOS-TC for neutron shielding. Approximately 16 percent boric acid by weight (B_2O_3) is added to the polyethylene so that the material is 5 percent boron by weight. The atom density of hydrogen was conservatively reduced by 15 percent to account for potential hydrogen loss due to aging. Table 6-42 of the SAR provides the borated polyethylene composition used in the EOS-TC models. The SFAs were homogenized for simplicity. SFAs were modeled as fresh fuel with 3 weight percent of U-235 enrichment.

6.3.3 Streaming Paths and Regional Densities

Dose rates are dominated by streaming from the vents because little radiation penetrates the thick concrete shield walls, and repairing the EOS-HSM with grout in localized areas will have no effect on worker exposure or site dose rates. The applicant stated that the primary gammas dominated the total dose rate, while the dose rate from neutrons and secondary gammas was considered negligible. The bulk shielding of the EOS-HSM is very effective in the absence of streaming. The average dose rates on the rear and end (side) shield walls are 0.115 mrem/hr and 0.544 mrem/hr, respectively. The average dose rate on the front face of the module (excluding the inlet vents) is 4.23 mrem/hr. The average roof dose rate between the vent covers is 496 mrem/hr, but this dose rate is primarily due to streaming from the outlet vents and not radiation penetrating the roof block.

The maximum dose rate of 1,900 mrem/hr occurs at the roof outlet vent. The inlet vent dose rate is 712 mrem/hr. The 1.5-inch gap dose rate is 302 mrem/hr on the front and 69.9 mrem/hr on the rear shield wall. This gap is along the entire length of the EOS-HSM between adjacent modules. On the roof, the outlet vent cover blocks much of this gap. Therefore, the dose rate from this roof gap is reported in two parts: (1) the roof gap from the vent cover to the front face (in front of the vent cover) and (2) the roof gap from the vent cover to the rear (behind the vent cover). These dose rates are 777 and 1,000 mrem/hr, respectively.

Two empty EOS-HSM base modules may be used side by side. Each EOS-HSM base module has a 1-foot-thick concrete block on each side, which means that two empty EOS-HSM base modules, side by side, create 4 feet of concrete shielding, which exceeds the standard 3-foot-thick shielding of an end shield wall. If the end of a row of EOS-HSMs is shielded in this manner, the inlet vent on the side of outermost base module must be blocked to prevent radiation streaming.

The use of dose reduction hardware is optional and is not required in the applicant's modeling. While dose reduction hardware may significantly reduce the gamma dose rate, it has little effect on the neutron dose rate. The neutron dose rate is typically small compared with the gamma dose rate.

The staff evaluated the SAR shielding model and found it acceptable. The composition and density of materials in the shielding analysis are appropriate or bounding or both. The model dimensions and material specifications provide reasonable assurance that the shielding analysis adequately modeled the NUHOMS® EOS System. Chapter 8 of SER evaluates the material integrity of the shielding materials.

6.4 Shielding Analyses

This section describes the computer codes, version, computational models, data, and assumptions with their bases used in evaluating shielding effectiveness and estimating dose rates for areas of concern.

6.4.1 Computer Codes

The applicant performed shielding analyses using MCNP5 version 1.40 to calculate the dose rate for the EOS-TCs and EOS-HSMs. All relevant details of the EOS-37PTH DSC, EOS-89BTH DSC, EOS-TC108, EOS-TC125/135, and EOS-HSM were modeled explicitly. Section 6.4 of the SAR presents the MCNP5 calculations. The individual cross-section libraries used for each nuclide are based on ENDF/B-V cross-section data. The SAR provides references for MCNP photon and neutron benchmarking problems against experimental data.

6.4.2 Flux-to-Dose Rate Conversion

The applicant used MCNP5 to compute the neutron or gamma flux at the location of interest, and the flux was converted to a dose rate using the conversion factors in SAR Table 6-51.

6.4.3 Dose Rates

6.4.3.1 Normal Conditions

SAR Section 6.3.2 describes the MCNP model geometry. The applicant developed MCNP models for the EOS-TC108 and EOS-TC125/135 with both the EOS-37PTH DSC and EOS-89BTH DSC. Dose rates were computed for three configurations and at the surface, and 30 cm, 100 cm, and 300 cm from the surface. Figures 6-7 to 6-10 of the SAR show calculations for normal condition design-basis dose rates at the different locations.
Tables 6-55 through 6-58 of the SAR list the calculated dose rates for design-basis fuel loaded into the EOS-HSM.

The gamma dose component dominates the calculated total dose rates for the air inlets, air outlets, and side of the EOS-HSM, and the neutron dose component dominates the top dose rate. This is expected because the EOS-HSM design consists of a base module that includes the door and 1-foot-thick shield walls on the sides and rear. A 3-foot-8-inch-thick roof block that matches the length and width of the base rests on the base module. The calculated dose rates are below the dose rate design criteria specified in the SAR.

The SAR also presents calculations for normal condition dose rates surrounding the EOS-TC108 and EOS-TC125/135 TC locations shown in SAR Figures 6-7 to 6-10 on the surface and at 1 meter. As shown in Tables 6.52 to 6.53 of the SAR, the maximum dose rates calculated for the side, top, and bottom of the EOS-TC108 configuration are approximately 2,640 mrem/hr, 259 mrem/hr, and 146 mrem/hr, respectively. For the EOS-TC125/135 configuration, the maximum dose rates are 1,140 mrem/hr, 94.1 mrem/hr, and 148 mrem/hr, respectively. The EOS-TC108 and EOS-TC125/135 feature reduced lead thickness next to the top nozzle region of the SFA. For this reason, the maximum dose rate at the side of the EOS-TC occurs next to the top nozzle rather than the active fuel.

Section 6.3 of the SAR indicates that the EOS-TC108 has a removable neutron shield. The shield is formed of three panels that are connected with hinges on two joints and latches on the third joint. The interface joint between the three panels features 1.5 inches of aluminum, which allows limited neutron streaming through these three joints along the length of the EOS-TC108. The EOS--TC108 does not include this streaming path because the neutron shield was modeled as continuous around the circumference.

The staff found that the applicant explicitly modeled the neutron shield joints in a supplementary model, and the dose rates in the vicinity of the joints do not exceed the reported peak dose rates. In addition, the dose rates used in the dose assessment are essentially unchanged when the neutron shield joints are modeled. The staff found the approach acceptable to model the EOS-TC108 neutron shield as continuous around the circumference of the transfer cask.

6.4.3.2 Accident Conditions

The SAR indicates that accident models were also developed for the four transfer configurations. In the accident models, the water neutron shield, neutron shield panel, and borated polyethylene bottom neutron shield are replaced with void, and the accident source terms are used. The dose rate was calculated at a distance of 100 m from the EOS-TC. Ground is modeled to account for ground scatter at large distances and does not identify an accident that significantly degrades the shielding capability of the concrete. Table 6-54 of the SAR provides the accident results. The maximum dose rate 100 meters from an EOS-TC during an accident is 2.15 mrem/hr. If an 8-hour recovery time is assumed, the dose to an individual at the site boundary is 17 mrem, which is significantly below the dose limit in 10 CFR 72.106 of 5 rem. The staff finds these model acceptable based on the dose rates calculation and the limit of 5 rem will not be exceeded.

6.4.4 Occupational Exposures

The SAR states that occupational exposures to ISFSI personnel during EOS-DSC retrieval are similar to those exposures calculated for EOS-DSC insertion. However, dose rates for retrieval operations will be lower than those for insertion operations because of radioactive decay of the spent fuel inside the EOS-HSM. Therefore, the dose rates for EOS-DSC retrieval are bounded by the dose rates calculated for insertion. Chapter 11 of the SAR presents the estimated occupational exposures that are based on dose rate calculations in Chapter 6 of the SAR.

6.4.5 Offsite Dose Calculations

In Chapter 11 of the SAR, the applicant estimated the offsite dose rates from two configurations of EOS-HSMs. At longer distances, the annual exposure from the 2x10 back-to-back array is similar to the two 1x10 front-to-front array configurations. In accordance with 10 CFR 72.104, the annual whole-body dose to an individual at the site boundary is limited to 25 mrem. The data in Table 11-6 of the SAR demonstrate that the dose rate drops below 25 mrem at a distance of approximately 370 meters from the ISFSI. Therefore, 370 meters is the minimum distance with design-basis fuel to the site boundary for a 20-cask array for the EOS; however, a shorter distance may be demonstrated in a site-specific calculation.

6.4.6 Confirmatory Calculations

The staff performed a confirmatory analysis of selected EOS-HSM dose rates with EOS-37PTH and EOS-89BTH DSCs. The confirmatory evaluation of the EOS-HSM was based on the design features and model specifications discussed in SAR Sections 6.1, 6.2, and 6.3, coupled with an analysis of the applicant’s calculations. The staff’s calculated dose rates were in close agreement with the SAR values.

The staff found that the calculated surface dose rates and estimated dose rates beyond the controlled area boundary are acceptable for the EOS-HSM. The staff determined through confirmatory calculations that offsite dose rates increase as the assumed air density decreases. Site-specific dose analysis should therefore account for appropriate atmospheric conditions.

The staff also performed independent calculations with SCALE 6.1 and statistically demonstrated that the two-stage MCNP modeling technique is acceptable for determining offsite dose rates. In addition, the staff performed confirmatory calculations of the design-basis SFAs to calculate the quantities of Co-60 and demonstrate that the dose rates on the side of the

EOS-TCs will not increase compared to dose rates computed using design-basis sources. The staff evaluated the offsite dose estimations and found that the SAR adequately demonstrated that the EOS was designed to meet the offsite dose criteria of 10 CFR 72.104(a) for a minimum controlled area distance of 370 meters, as stated in 10 CFR 72.106(b).

The staff performed a confirmatory analysis of selected dose rates around the EOS-TCs with SCALE 6.1 based on the design features and model specifications discussed in Sections 6.1 and 6.3 of the SER. The staff found that the calculated surface dose rates and 1-meter dose rates are acceptable. All dose rates remain below the applicable dose rate limits of the SAR. The CoC includes as conditions the fuel characteristics in SAR Table 1-1 and the burnup, cooling time, and initial uranium loading parameters listed in TS Section 2.2, as well as the calculated EOS-HSM and EOS-TC dose rates, as discussed above.

Chapter 11 of this SER evaluates the overall offsite dose rates from the EOS. The staff has reasonable assurance that each general licensee can achieve compliance with 10 CFR 72.104(a). The general licensee using the EOS must perform a site-specific evaluation, as required by 10 CFR 72.212(b), to demonstrate compliance with 10 CFR 72.104(a). The actual doses to individuals beyond the controlled area boundary depend on several site-specific conditions, such as fuel characteristics, cask-array configuration, topography, demographics, atmospheric conditions, and use of engineered features. In addition, the dose limits in 10 CFR 72.104(a) include doses from other fuel cycle activities, such as reactor operations. Consequently, each applicant for a site license is responsible for the final determination of compliance with 10 CFR 72.104(a).

The general licensee will also have an established radiation protection program as required by 10 CFR Part 20, Subpart B, “Radiation Protection Programs,” and will demonstrate compliance with dose limits to individual members of the public, as required by 10 CFR Part 20, Subpart D, “Radiation Dose Limits for Individual Members of the Public,” by evaluations and measurements.

The NRC has included a license condition for engineered features used for radiological protection. The license condition states that engineering features (e.g., berms, shield walls) used to ensure compliance with 10 CFR 72.104(a) are to be considered important to safety and must be evaluated to determine the applicable QA category.

6.5 Evaluation Findings

F6.1 The SAR sufficiently describes shielding design features and design criteria for the SSCs important to safety in sufficient detail to allow evaluation of their effectiveness.

F6.2 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 The site licensee is responsible for establishing operational restrictions to meet dose and ALARA requirements in 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106. The NUHOMS® EOS System’s shielding features are designed to assist in meeting these requirements.

The staff concludes that the design of the shielding system for the NUHOMS® EOS System is in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the shielding system provides reasonable assurance that the

NUHOMS® EOS System will provide for the safe storage of spent fuel. This finding is based on a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

6.6 References

Oak Ridge National Laboratory, "MCNP/MCNPX—Monte Carlo N-Particle Transport Code System Including MCNP5 1.40 and MCNPX 2.5.0 and Data Libraries," CCC-730, Radiation Safety Information Computational Center Computer Code Collection, January 2006.

Oak Ridge National Laboratory, "A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation," ORNL/TM-2005/39, Version 6, SCALE, January 2009.

Oak Ridge National Laboratory, "Standard- and Extended-Burnup PWR and BWR Reactor Models for the ORIGEN2 Code," ORNL/TM-11018, December 1989.

Pacific Northwest National Laboratory, "Compendium of Material Composition Data for Radiation Transport Modeling," PNNL-15870, Revision 1, March 2011.

Title 10, *Code of Federal Regulations*, Part 20, "Standards for Protection against Radiation."

Title 10, *Code of Federal Regulations*, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

7.0 CRITICALITY EVALUATION

The staff's objective in reviewing the applicant's criticality evaluation of the NUHOMS® EOS system design is to verify that the spent fuel contents remain subcritical under the normal, off-normal, and accident conditions of handling, packaging, transfer, and storage. The applicable regulatory requirements are in 10 CFR 72.124, 10 CFR 72.236(a), 10 CFR 72.236(c), and 10 CFR 72.236(g).

The staff reviewed the information provided in the NUHOMS® EOS SAR to determine whether the NUHOMS® EOS system will fulfill the acceptance criteria listed in Chapter 7 of NUREG-1536:

- The multiplication factor (k_{eff}), including all biases and uncertainties at a 95 percent confidence level, should not exceed 0.95 under all credible normal, off-normal, and accident conditions.
- At least two unlikely, independent, and concurrent or sequential changes to the conditions essential to criticality safety under normal, off-normal, and accident conditions should occur before an accidental criticality is deemed to be possible.
- When practicable, criticality safety of the design should be established on the basis of favorable geometry, permanent, fixed, neutron-absorbing materials (poisons), or both. Where solid neutron-absorbing materials are used, the design should provide for a positive means to verify their continued efficacy during the storage period.
- Criticality safety of the cask system should not rely on the use of the following credits:
  - burnup of the fuel
  - fuel-related burnable neutron absorbers
  - more than 75 percent for fixed neutron absorbers when subject to standard acceptance tests

7.1 Criticality Design Criteria and Features

The staff reviewed the applicant's principal criticality design criteria in SAR Chapters 1 and 2 as well as related information provided in SAR Chapter 7 to verify the information is consistent and the information contains sufficient details to support an in-depth staff evaluation.

The design criteria for criticality safety of the cask system require that the calculated value of the effective neutron multiplication factor, k_{eff}, including biases and uncertainties, shall not exceed 0.95 under normal, off-normal, and accident conditions. The major components of the NUHOMS® EOS system are a DSC, a concrete overpack, and a lead-shielded TC. Criticality safety of the NUHOMS® EOS system depends on the geometry of the fuel baskets; the use of fixed neutron absorbers, either integral to the basket material or as fixed panels; the presence of soluble boron in the spent fuel pool water; and fissile mass limitations. The NUHOMS® EOS includes two DSCs designs. The EOS-37PTH DSC is designed to store the PWR SFAs listed in Table 2-2 of the SAR. The EOS-89BTH DSC is designed to store the BWR SFA types listed in Table 2-3 of the SAR.

Each DSC has multiple basket types. The EOS-37PTH DSC has two basket types, A and B, that both use an MMC poison material. Tables 7-1 and 7-3 of the SAR show the fixed poison loading and required minimum soluble boron concentration for each fuel type authorized for storage with EOS-37PTH DSC baskets A and B, respectively. The EOS-89BTH DSC has three basket types—M1-A, M1-B, and M2-A. The M1-A and M1-B may use either BORAL® or an MMC as a fixed absorber, while the M2-A is fabricated only with BORAL®. Table 7-2 of the SAR shows the fixed poison loading, and Table 7-4 of the SAR shows the maximum lattice average initial enrichment for each EOS-89BTH basket type.

TS 3.2.1 includes surveillance requirements to verify the soluble boron concentration for the EOS-37PTH DSC.

The staff reviewed Chapters 1, 2, and 7 of the SAR and verified that they clearly identify and adequately describe the design criteria and features important to criticality safety. The staff also verified that the SAR contains engineering drawings, figures, and tables that are sufficiently detailed to support an in-depth staff evaluation.

Additionally, the staff verified that the design-basis off-normal and postulated accident events will not have an adverse effect on the design features important to criticality safety. The applicant showed in Chapter 3 of the SAR that the basket will remain intact during all normal, off-normal, and accident conditions. Based on the information provided in the SAR, the staff concludes that the NUHOMS® EOS system design with the EOS-37PTH and EOS-89BTH DSC meets the requirements of 10 CFR 72.236.

7.2 Fuel Specification

The staff reviewed the specifications for the range or type of SFAs to be stored in the proposed casks. Staff, through review and independent analysis, confirmed the specifications in SAR Chapters 1, 2, and 7 are conservative. The staff also confirmed specifications important to criticality safety are appropriately captured in the TS.

The NUHOMS® EOS System is designed to store 37 PWR or 89 BWR assemblies in each DSC. The applicant limited the assembly types allowed to the FAs with characteristics described in Tables 2-2 through 2-4 of the SAR and TS 2.1 and 2.2. SFAs with integral burnable absorbers and control components may also be stored. The applicant described the specifications for the CCs in Section 2.2.1 of the SAR. The fuel specifications that are most important to criticality safety are maximum initial enrichment, number of fuel rods, clad outer diameter, minimum clad thickness, fuel rod pitch, and number of guide tubes. These parametric values, when specified, represent the limiting or bounding parameters for the FAs.

The loading of any basket will depend on the basket material, the fixed absorbers, and the minimum soluble boron concentration in the flooded canister during loading. The applicant gave the maximum enrichment for loading intact fuel in TS 2.1 and 2.2 for the EOS-37PTH and EOS-89BTH, respectively, and for different basket types and minimum soluble boron concentrations.

PWR assemblies loaded in the EOS-37PTH may contain CCs, which are limited by the thermal and radiological characteristics listed in TS Table 3 and Figure 1. Section 2.2.1 of the SAR lists some examples of CCs. BWR assemblies loaded in the EOS-89BTH may include channels, with or without channel fasteners.

The SAR and TS also include specifications of the conditions of the fuel. Neither the EOS-37PTH nor the EOS-89BTH are designed to accommodate damaged SFAs. Reconstituted SFAs, where fuel pins have been replaced by stainless steel or Zircaloy pins that displace the same amount of borated water, are bounded by the intact fuel, for criticality purposes, and may be stored as undamaged assemblies.

In Chapter 3 of the SAR, the applicant demonstrated that undamaged fuel cladding will not fail during normal, off-normal, or accident conditions.

The staff verified that TS 2.1 and 2.2 include all SFA parameters important to criticality safety. The staff reviewed the fuel specifications considered in the applicant's criticality analysis and verified that they are consistent with the specifications given in Chapters 1, 2, and 12 of the SAR and applicable TS. Staff finds the applicant's fuel specifications are sufficiently conservative and provide reasonable assurance that typical fuel loadings will remain subcritical.

7.3 Model Specification

The staff reviewed the applicant's model for evaluating criticality to verify that the applicant used the most reactive combination of tolerances for the range of the acceptable values, the dimensions and materials are consistent with the engineering drawings, and the compositions and densities are provided for all materials used in the calculational model.

The applicant used the following key modelling assumptions which are recommended by NUREG-1536 and have been determined to be acceptable by prior staff review:

- fresh, undamaged, and unburned fuel (i.e., no burnup credit is taken)
- pellet density 97.5 percent of theoretical
- homogeneous, peak-planar average enrichment in BWR fuel
- the presence of non-fuel hardware, such as BPRAs (PWR) or fuel channels (BWR)
- no integral burnable poisons
- limited credit for boron (B)-10 content in the borated absorber plates (see SER Section 7.3.2)

The applicant provided sample input files for criticality calculations with DSCs loaded with PWR and BWR assemblies. The applicant analyzed conditions in both the concrete overpack and the TC. The NRC staff reviewed these input files and verified the applicant's modeling assumptions were applied appropriately. Staff further reviewed the applicant's evaluation of the most reactive fuel characteristics and basket configuration, which is described in Sections 7.3.1 and 7.5.

7.3.1 Configuration

The applicant modeled a dry, loaded DSC within a TC, with the DSC/TC annulus and surrounding volume filled with unborated water. The applicant did not consider the water neutron shield and explicitly modeled gaps between egg-crate basket plates. The applicant modeled FAs as arrays of fuel pins and instrument/guide tubes or water rods. The applicant did not include grid plates, spacers, and assembly hardware in the model. In all models, the applicant shifted the FAs to a position within the basket cell that was closest to the center of the DSC to conservatively increase calculated system reactivity.

The applicant selected the configuration with the DSC inside of a TC rather than within an HSM. In cases with zero internal moderator, the applicant stated that the reactivity of the canister under storage conditions is bounded by the TC analysis due to the close, fast neutron reflection of the steel and lead. In the HSM, the more distant concrete overpack reflects thermal neutrons, which are shielded from the fuel by the DSC.

7.3.1.1 EOS-37PTH

The applicant modeled an EOS-37PTH basket section equivalent to the active fuel height with periodic axial and reflective radial boundary conditions. The axial boundary conditions effectively make the applicant's model infinitely tall, which conservatively reduces neutron leakage from the model. This configuration cannot account for axial blankets; however, the axially infinite model is bounding. The applicant's use of reflective radial boundary conditions effectively models an infinite array of TCs.

Basket criticality controls are conservatively modeled. Steel in the basket structure absorbs neutrons and displaces moderator when flooded. The applicant conservatively modeled any simplifications and approximations in such a way so as to minimize these neutron absorbing materials.

The space between the DSC shell and the basket contains aluminum rails with hollow portions. The applicant included hollow space to evaluate the presence of water that may fill any void between the DSC shell and basket.

To determine the most reactive configuration, the applicant made a series of parametric evaluations, with each bounding case becoming the base case for the next evaluation. The applicant modeled the effects of potential variations in geometry and material properties by evaluating the effect of (in no particular order): moderating materials amongst an array of TCs; TC shell tolerances; gaps between egg-crate sections of the basket; poison plate thickness; dimensions of TC rails; basket cell width; basket plate thickness; different TC models; gaps at intersecting egg-crate plates; and positions of FAs within basket cells.

The applicant presented the results of all of these calculations in Tables 7-13 through 7-15 of the SAR. In some cases, the applicant varied moderator density in conjunction with another parameter. In all cases, the applicant either found that the changes had little significant effect on system reactivity, or the applicant chose the most reactive parameter and included it in the final determination of the most reactive configuration. At no point did the applicant take credit for more than the minimum amount of neutron absorber verified by the acceptance criteria in SAR Section 10.1.5.

To determine the most reactive SFA, the applicant used the above assumptions with a Type B basket having a B-10 loading as specified in Table 7-1 of the SAR (31.5 milligrams per square centimeter) and internal moderator borated to 2,000 parts per million. The applicant's base case is a WE 17x17 class assembly with an initial enrichment of 5.0 weight percent U-235. The applicant assumed the pellet-clad gap is filled with water. In cases where non-fuel hardware that extends into the active fuel regions is present, the applicant modeled the component with an equal volume of non-poison material (see SER Section 7.3.2). The applicant determined the most reactive SFA for each class listed in Chapter 2 of the SAR and presented the results in Table 7-16 of the SAR.

Following the determination of the most reactive SFA and configuration, the applicant determined the maximum initial enrichment for each assembly class for each basket type in the most reactive configuration. The applicant minimized B-10 content, ignored the neutron shield, and assumed that the interstitial space between the EOS-TCs was filled with water. The applicant presented these results in Tables 7-17 through 7-38 of the SAR.

In Chapter 3, staff's structural evaluation finds reasonable assurance that the basket will be geometrically stable, and the fuel will maintain its integrity and not deform. As a result, the staff finds the applicant's modeling configuration and assumptions for the EOS-37PTH DSC appropriate and consistent with the design described in Chapters 1 and 2 of the SAR.

7.3.1.2 EOS-89BTH

The applicant modeled an EOS-89BTH basket section with an effective height of one basket assembly plate (12 inches). With the construction of the basket, this effectively modeled plates aligned in one direction as whole, while the lower and upper halves of the intersecting plates above and below, respectively, are split. The applicant used periodic axial and reflective radial boundary conditions to model an infinite array of infinitely tall packages.

The applicant used the GE12 10x10 SFA with an enrichment of 4.20 weight percent U-235 and a 0.12-inch-thick fuel channel in the base model. The applicant assumed that the gap between the cladding and fuel pin is filled with water and ignored all burnable absorbers. The applicant modeled the poison plate in this case with a B-10 areal density of 29 milligrams per square centimeter. The applicant used these parameters to compare all of the BWR FAs listed in Chapter 2 of the SAR to determine the most reactive SFA. The applicant determined a bounding 10x10 fuel design to establish enrichment limits for all BWR fuel designs except the ABB-10-C fuel designs. The applicant noted in Table 8 of the TS that an appropriate reduction in maximum enrichment shall be required for this SFA design. The applicant also determined a 9x9 fuel design to be comparably reactive. The applicant considered all three designs to determine enrichment limits specified in the TS.

The applicant modeled the space between the basket and the DSC as a mixture of aluminum and water.

For its initial configuration, the applicant conservatively minimized steel that serves as a neutron absorber and displaces moderator. The applicant demonstrated that other changes from the actual design were either conservative or resulted in no change to system reactivity. Figures 7-14 and 7-15 in the SAR show the cross-section views of the base model. The applicant listed the dimensional tolerances in Table 7-41 of the SAR.

The applicant's most reactive configuration evaluations included changes to the basket model that differ from the actual design described above. To determine the most reactive configuration, the applicant evaluated the effects of potential variations in geometry and material properties by determining the effects of (in no particular order): gaps at intersecting egg-crate plates; poison plate thickness; presence of moderator and structural materials in the space between the basket and DSC; cladding diameter; positions of FAs within basket cells; basket plate material thickness; variations in basket plate length; flooding of the DSC/TC annulus; internal flooding; and interstitial moderation in space amongst an array of TCs.

The applicant showed the results of all of these evaluations in Table 7-42 of the SAR. In all cases, the applicant either found that the changes had little significant effect on system reactivity, or the applicant chose the most reactive parameter and included it in the final determination of the most reactive configuration.

Using the most reactive configuration determined from the evaluations listed above, the applicant performed separate evaluations for each allowable fixed poison loading, depending on the basket type, for the three SFA types discussed above. The applicant presented the results of the criticality analyses in Table 7-43 of the SAR.

In Chapter 3, staff's structural evaluation finds reasonable assurance that the basket will be geometrically stable, and the fuel will maintain its integrity and not deform. As a result, the staff finds the applicant's modeling configuration and assumptions for the EOS-89BTH DSC appropriate and consistent with the design described in Chapters 1 and 2 of the SAR.

7.3.2 Material Properties

The applicant modeled all steel and aluminum alloys of the basket structure as SS304 and aluminum, respectively.

The applicant modeled all zirconium alloys in the fuel as Zircaloy-4 for PWRs and Zircaloy-2 for BWRs.

The applicant applied 90 percent credit for the minimum B-10 content in the borated aluminum MMC materials and took 75 percent credit for the minimum B-10 content in BORAL® panels. The applicant listed the B-10 content modeled in its analysis in Tables 7-1 and 7-2 of the SAR.

Since the payload of the EOS-37PTH may include CCs, the applicant evaluated the displacement of borated water within the assembly models. The applicant conservatively took no credit for neutron poisons within these components and assumed the CC material to exhibit the neutronic properties of $^{11}B_4C$. This accurately modeled the physical presence of these components while conservatively minimizing the neutron absorption cross-section.

The staff reviewed SAR Table 7-3, which gives the specifications for the maximum assembly average initial enrichment during wet loading and unloading of the PWR basket as a function of assembly class, soluble boron concentration, and basket type. The staff finds these acceptable.

7.4 Criticality Analysis

The staff reviewed the applicant's computer code to determine that the code is appropriate for the particular application and the applicant has used the code correctly.

In general, the applicant's analysis demonstrated that combinations of changes to certain individual system or SFA parameters affected the system k_{eff}. The applicant captured these effects by using the most reactive combination of parameter changes with the most reactive SFA in the final analysis. Staff confirmed the applicant conservatively selected the fuel parameters that maximize calculated k_{eff}. Since typical cask loadings will consist of less reactive SFAs than the applicant assumed in its analysis, the staff finds reasonable assurance that the system will remain subcritical.

7.4.1 Computer Programs

The applicant performed the criticality analysis for the NUHOMS® EOS System using the CSAS5 control module of the SCALE 6.0 package with the 44-group ENDF/B-V cross-section library. CSAS5 implements the BONAMI and NITAWL modules for cross-section processing. KENO V.a is a 3D Monte Carlo multigroup neutron transport code used to calculate k_{eff}.

CSAS5 is a standard code used in the nuclear industry for performing criticality analyses. The applicant's use of CSAS5 is acceptable to the staff.

7.4.2 Multiplication Factor

The applicant performed calculations showing that the NUHOMS® EOS System will meet the design criterion of k_{eff} + 2 sigma ≤ upper subcritical limit (USL). The staff finds reasonable assurance that k_{eff} for the NUHOMS® EOS System for all fuel loadings and conditions specified in the SAR and proposed TS will not exceed the USL. SAR Chapter 7 gives the results of the applicant's criticality calculations for all assembly, basket, and fuel types with boron loadings.

7.4.3 Benchmark Comparisons

The applicant selected 92 benchmark experiments from the Nuclear Energy Agency's "International Handbook of Evaluated Criticality Safety Benchmark Experiments," issued September 2009. All of the selected benchmark experiments are applicable to systems that use soluble boron (EOS-37PTH), and 51 experiments are available that use unborated water (EOS-89BTH). The applicant tested the benchmark data for parametric trends with respect to the energy of average lethargy of fission, average energy group causing fission, soluble boron, assembly separation, and moderator-to-fuel-volume ratio.

The applicant demonstrated that there is no close correlation between the parameters and k_{eff} and the data are normally distributed. The applicant chose to use the single-sided tolerance limit methodology described in NUREG/CR-6698, "Guide for Validation of Nuclear Criticality Safety Calculational Methodology," issued January 2001, to obtain the USL values for both the EOS-37PTH and the EOS-89BTH DSCs.

Based upon its review, the staff finds that the analysis and the resulting USL are acceptable for the criticality design of the NUHOMS® EOS System as proposed in the SAR. This finding is based upon the applicant's selection of SCALE modules (BONAMI, NITAWL, and KENO V.a) and a cross-section library (ENDF/B-V 44-group) that has been shown to have a small bias when used to evaluate thermal systems with fresh, uranium fuel.

7.5 Confirmatory Calculations

The staff used the CSAS/KENO-VI codes in the SCALE 6.1 suite of analytical codes to perform confirmatory analyses. The staff's calculations used the continuous energy ENDF/B-VII cross-section library. The staff evaluated the applicant's choice of basic DSC within a TC configuration for investigation into the most reactive configuration. The staff confirmed that close reflection from the TC materials bounds that of more distant thermal reflection caused by the HSM when there is zero internal moderation. The staff evaluated both PWR and BWR baskets, the bounding fuel types selected by the applicant, and several boron concentration and enrichment combinations. The results of the staff's confirmatory calculations largely confirmed the conclusions from the applicant's analysis reviewed by staff in SER Sections 7.3.1.1 and 7.3.1.2. In evaluating the applicant's conclusion concerning the EOS 89BTH gap fraction analysis, that staff could not confirm the conclusion. However, the staff performed a set of confirmatory calculations and found the discrepancy in the gap fraction analysis for the EOS 89BTH had no significant effect to system reactivity or safety.

7.6 Evaluation Findings

Based on the information provided in the SAR and verified by the staff's own confirmatory analyses, the staff concludes that the NUHOMS® EOS system meets the acceptance criteria specified in NUREG-1536. In addition, the staff finds the following:

F7.1 Chapters 1, 2, and 7 of the SAR describe SSCs important to criticality safety in sufficient detail to enable an evaluation of their effectiveness.

F7.2 The NUHOMS® EOS system is designed to be subcritical under all credible conditions.

F7.3 The criticality design is based on favorable geometry and fixed neutron poisons. An appraisal of the fixed neutron poisons has shown that they will remain effective for the licensed storage period. In addition, there is no credible way for the EOS-37PTH and EOS 89BTH baskets to lose the fixed neutron poisons. Therefore, it is not required that the applicant verify the continued efficacy of the fixed neutron poisons during the storage period.

F7.4 The applicant's analysis and evaluation of the criticality design and performance demonstrated that the the storage of spent fuel for the licensed period provides an adequate margin of safety. The staff independently verified and confirmed that the NUHOMS® EOS system will provide an adequate margin of safety for the storage of spent fuel for the licensed period.

The staff concludes that the criticality design features for the NUHOMS® EOS system 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 NUHOMS® EOS system will allow for the safe storage of spent fuel. In reaching this conclusion, the staff has considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

7.7 References

Dean, J.C., Tayloe Jr., R.W., "Guide for Validation of Nuclear Criticality Safety Calculational Methodology", NUREG/CR-6698, prepared by Science Applications International Corporation for the U.S. Nuclear Regulatory Commission, January 2001.

Nuclear Energy Agency (NEA) Nuclear Science Committee, International Criticality Safety Benchmark Evaluation Project, "International Handbook of Evaluated Criticality Safety Benchmark Experiments," NEA/NSC/DOC(95)03, September 2009.

Oak Ridge National Laboratory, "SCALE 6: Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers," Radiation Shielding Information Center Code Package CCC-750, February 2009.

Title 10, *Code of Federal Regulations*, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

U.S. Nuclear Regulatory Commission, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," NUREG-1536, Revision 1, July 2010.

8.0 MATERIALS EVALUATION

The applicant provided the results of its materials evaluation in Chapter 8 of the SAR for the NUHOMS® EOS System. The staff evaluated this information using the guidance in Chapter 8 of NUREG-1536 to reach reasonable assurance of adequate materials performance under normal, off-normal, and accident-level conditions.

8.1 Applicable Codes and Standards

As described in Section 8.2.1 of the SAR, the principal codes and standards applied to the NUHOMS® EOS components are the ASME B&PV Code, the ASTM standards, the ACI codes, and the ANSI standards. Materials meeting the requirements of these codes and standards conform to acceptable chemical and physical properties and are produced using controlled processes and procedures.

The DSC confinement boundary and associated weld filler materials are procured in accordance with the ASME B&PV Code, Section III, Subsection NB requirements (ASME, 2011a), except as listed in the alternatives to codes and standards in TS Section 4.4.4. The applicant stated that alternatives to ASME SA-240 Types 304 and 316 austenitic stainless steels may be used for the DSC shell materials. The applicant stated that these alternatives, Type 2205 and UNS S31803 duplex stainless steels, provide enhanced resistance to chloride-induced stress-corrosion cracking (CISCC). These duplex stainless steels are not included in ASME B&PV Code, Section II, Part D, Subpart 1, Tables 2A and 2B, for design stress intensity. However, the applicant stated that UNS S31803 has been accepted for Class 1 components by ASME B&PV Code Case N-635-1 (ASME, 2003), which is endorsed by NRC Regulatory Guide 1.84, “Design, Fabrication, and Materials Code Case Acceptability, ASME Section III,” Revision 34, issued October 2007. The applicant also stated that Type 2205 falls within the chemical and mechanical requirements of UNS S31803.

The staff reviewed the composition requirements for the duplex stainless steels and confirmed that UNS S31803 is an accepted ASME B&PV Code alternative, and that Type 2205 falls within the chemical and mechanical requirements of UNS S31803. The staff reviewed supplier information on Type 2205 and UNS S31803 duplex stainless steels and confirmed that dual-certified material (i.e., materials that are certified to meet the chemical and physical properties of both Type 2205 and UNS S31803 duplex stainless steels) is produced and available.

The staff finds that the codes and standards specified for the EOS components are acceptable because they sufficiently control the chemical and physical properties of the materials and they conform to U.S. industry consensus codes and standards, as recommended in NUREG-1536.

8.2 Environment

In Section 8.1.2 of the SAR, the applicant described the environmental conditions under which the EOS system will be used. The staff reviewed the environmental description to verify its accuracy, such that the material evaluations throughout Chapter 8 of the SAR account for the effects of the ambient conditions.

The applicant stated that the EOS-37PTH and the EOS-89BTH DSCs are exposed to the ambient weather conditions at the licensee’s site for the duration of the licensing period. The ambient environment may contain chloride aerosols, varying humidity levels, and freezing temperatures. The applicant also stated that the DSC exterior surfaces are sheltered from the direct effects of weather, though moisture and aerosols present in the air pass through the HSM interior by natural convention. The applicant provided a tabulation of temperatures in SAR Chapter 4 that includes the average and maximum temperatures of the DSC shell under normal, off-normal, and accident conditions.

For the DSC, the applicant stated in TS Section 4.4.4 that normal and off-normal temperatures remain below the 600 °F operating limit for duplex stainless steels (ASME B&PV Code Case N-635-1 for duplex stainless steels provides allowable stress values only up to this temperature limit). As discussed in detail below, duplex stainless steels can be susceptible to embrittlement under certain thermal exposures. The applicant showed in SAR Figure 4-16 that, under accident conditions, the shell temperatures for the EOS-37PTH DSC may exceed the 600 °F limit. However, TS Section 4.4.4 states that accident conditions would only exceed the limit for durations too short to cause embrittlement.

The staff reviewed the thermal stability of duplex stainless steels at temperatures consistent with the reported hypothetical accidents involving blocked vents to ensure that the duplex stainless steels would not be susceptible to embrittlement. Results of testing reported by Chen et al. (2002) and time-temperature-transformation information published by Outokumpu (2014) indicate that the formation of the embrittling sigma phase in duplex stainless steels occurs rapidly at temperatures of 1,652 °F. Weng et al. (2003) showed that exposure temperatures of 752 °F for 16 hours resulted in decreases in the measured Charpy V-notch impact energy of Type 2205 duplex stainless steels. Alteration of mechanical properties, including increased hardness and decreased impact strength, as a result of spinodal decomposition of the ferrite phase (often termed “885 °F embrittlement”) can occur at lower temperatures. However, the time required for meaningful changes to material toughness or corrosion resistance at a temperature of 662 °F is more than 500 hours (Taveres et al., 2005; Della Rovere et al., 2013). The staff noted that TS Section 5.1.3 requires either daily visual inspections of HSM inlets and outlets or daily HSM temperature measurements to ensure that such prolonged periods of elevated temperatures do not occur. Therefore, the staff concludes that embrittlement of the S32203 or Type 2205 duplex stainless steel DSC shell will not occur under the hypothesized accident conditions because the period of time the DSC shell temperatures are above the material’s operating limit of 600 °F is short when compared with the time necessary for metallurgical changes to result in embrittlement of the alloy.

The applicant stated that, during storage, the interior of the DSC is exposed to an inert helium environment. The DSC is vacuum dried and backfilled with helium after loading the fuel and welding the inner top cover plate. The staff reviewed the NUHOMS® EOS operating procedures described in SAR Section 9.1.3 and TS Sections 3.1.1 and 3.1.2 and verified that operating procedures require the EOS-37PTH and the EOS-89BTH DSCs to be vacuum dried and backfilled with helium before placement inside the HSM.

The applicant stated that, during loading and unloading, the DSC is placed in the fuel pool while inside the TC. The annulus between the TC and DSC is filled with demineralized water and an inflatable seal is used to cover the annulus between the DSC and the cask. Thus, the exterior of the DSC is not exposed to pool water. The interior of the DSC and the exterior of the TC are exposed to either demineralized water (BWR) or diluted boric acid (PWR). The TC and DSC are kept in the spent fuel pool only for a short period of time, typically less than 24 hours. The staff reviewed the operating procedures in SAR Section 9.1.2 and TS Section 3.2.1 and confirmed that the exposure conditions for the DSC and the TC during fuel loading are accurately described.

The applicant stated that the outer surfaces of the roof, front wall, door, and shield walls of the HSM concrete are directly exposed to the weather. The HSM side and rear walls, interior, and the DSC exterior surfaces are sheltered from direct effects of weather, though moisture and aerosols present in the air pass through the HSM interior by natural convention. The applicant provided a tabulation of temperatures in SAR Chapter 4 that includes the average and maximum temperatures of the HSM under normal, off-normal, and accident conditions.

The applicant stated that the radial neutron shield of the TC is filled with potable water. The removable neutron shield of the TC108 is not immersed in the fuel pool. It is installed onto the TC after the cask is removed from the pool. The staff reviewed the NUHOMS® EOS operating procedures described in SAR Section 9.1.3 and verified that the operating procedures do not require the removable neutron shield of the TC108 to be immersed in the spent fuel pool.

The staff reviewed the applicant's description of the operating environments for the DSCs, TCs, and HSMs. The staff also reviewed the applicant's descriptions of the operating procedures described in Chapter 9 of the SAR. Based on the staff's verification of the information provided by the applicant, the staff determined that the applicant's description of the operating environments is accurate and acceptable. In addition, based on the review of technical literature on the embrittlement of duplex stainless steels documented above, the staff finds the compatibility of these steels with the DSC operating environment to be acceptable. The staff finds that the descriptions of the operating environments use of consensus codes and standards and the materials evaluation are consistent with the recommendations in NUREG-1536.

8.3 Drawings

Section 1.3 of the SAR provides drawings for the EOS-37PTH and EOS-89BTH DSCs, the EOS-TC108 and EOS-TC125/135 TCs, and the EOS-HSM. The parts list for each component gives the material specifications, governing codes, and quality categories. The staff reviewed the drawings for the DSCs, TCs, and HSM and finds the drawings to be acceptable because all materials and subcomponents of the SSCs are identified, including the material specifications, quality category, and code criteria.

8.4 Material Selection (Structural)

The applicant provided a general description of the materials of construction in SAR Sections 1.1, 1.2, 1.3, 2.1, 2.4, 3.1, 5.1, and 8.2. SAR Section 10.1 gives additional information on the materials, fabrication details, and testing programs. The staff reviewed the information contained in these sections and the information presented in the SAR drawings to determine whether the selected materials are acceptable for their structural applications. Chapter 8 of the SER documents the staff's evaluations of each of the major component areas.

8.4.1 Dry Shielded Canister Confinement

The DSC is the primary confinement barrier for the stored SNF. Structural components of the DSC confinement boundary (cylindrical shell, inner top cover plate, outer top cover plate, outer bottom cover plate, and port covers) are fabricated from either austenitic stainless steel meeting the requirements of ASME SA-240, Type 304 or 316, with a maximum carbon content of 0.03 weight percent or duplex stainless steel meeting the requirements of UNS S31803 and

Type 2205 (when enhanced resistance to CISCC is required). The applicant selected these types of steels because of their strength, ductility, resistance to corrosion, and metallurgical stability. As described in TS Section 4.4.4, the optional duplex stainless steels and their welds are evaluated for susceptibility to brittle fracture by Charpy V-notch fracture toughness testing in accordance with ASME B&PV Code, Section III, NB-2300.

The staff reviewed the design and construction of the DSC subcomponents and determined that the use of austenitic stainless steel grades Type 304 and 316 are adequate for the DSC confinement boundary. The staff noted that, because there is no ductile-to-brittle transition in the range of temperatures expected to be encountered for the Type 304 and 316 austenitic stainless steels, the susceptibility of these materials to brittle fracture is negligible. The staff also noted that maintaining carbon content less than 0.03 weight percent avoids material sensitization in weld heat-affected zones that could lead to local corrosion or stress-corrosion cracking. The staff noted that these materials are approved materials for Class 1 components in ASME B&PV Code, Section III (ASME, 2011a). The staff also determined that the duplex stainless steels UNS S31803 and Type 2205 are adequate for the construction of the DSC shell and lids; these materials are approved materials for Class 1 components in accordance with ASME B&PV Code Case N-635-1 (ASME, 2003), which is approved by the NRC in Regulatory Guide 1.84. The staff further determined that the use of Charpy V-notch testing as specified in ASME B&PV Code, Section III, NB-2300, is adequate to ensure that the duplex stainless steel DSC confinement boundary retains adequate fracture toughness to avoid brittle fracture by the formation of sigma phase at elevated temperatures or as a result of spinodal decomposition of the ferrite phase. Therefore, based on the materials' conformance to the ASME B&PV Code and the fracture toughness testing that will be performed on the duplex stainless steels, the staff finds the selection of the DSC confinement materials to be acceptable.

8.4.2 Dry Shielded Canister Basket Assembly

The DSC basket is a mechanical assembly of steel fuel compartment boxes that are designed to accommodate either PWR or BWR SFAs. The boxes are lined with an aluminum alloy for heat conduction and an MMC or BORAL® neutron absorbers. The primary basket structural material is a high-strength, low-alloy steel such as ASTM A829 Grade 4130. Also, ASTM B221 aluminum alloy 6061, ASTM A516 Grade 70 steel, and ASTM A193 Grade B7 alloy steel are used for the transition rail components. The steels used in the fuel basket assembly, including the fasteners, are selected based on strength. The aluminum alloy in the basket transition rails is selected based on thermal conductivity, and no credit is taken for the aluminum's strength.

The staff reviewed the technical literature for the steel basket material to determine whether it is acceptable for use. The staff reviewed technical information on the modulus of elasticity, yield strength, tensile strength and ductility of ASTM A829 Grade 4130 high-strength, low-alloy steel over a temperature range of 75 °F to 1,200 °F after tempering at 800 °F and 1,050 °F (Gerberich et al., 1962) and determined that the required mechanical properties for the DSC application are consistent with documented properties of high-strength, low-alloy steels such as ASTM A829 Grade 4130. Therefore, based on the staff's confirmation that the mechanical properties of the proposed basket materials are consistent with those required by the applicant's structural analyses, the staff finds the selection of the basket assembly materials to be acceptable.

8.4.3 Transfer Cask

The TC is primarily a shielding cask used to handle the DSC during its transfer from the spent fuel pool to the HSM. Structural materials for the NUHOMS® EOS TC are ASME carbon and low-alloy steel grades. The TC structural components for the inner and outer shells are fabricated from ASME SA-516 Grade 70 carbon steel. The top ring and bottom ring located at each end of the TC are constructed from ASME SA-350 Grade LF3 low-alloy steel. The top cover plate may be constructed of carbon steel or aluminum. The trunnions are fabricated from ASTM A182 Grade F6NM martensitic stainless steel.

The staff reviewed the description of the TC and the specifications for the materials of construction to determine whether the materials are acceptable for use. The staff reviewed the material properties, fabrication, welding, and heat-treatment requirements for the selected materials and confirmed that the materials' mechanical properties are appropriate for the application and consistent with those used in the applicant's structural analyses. Based on this verification of material properties, the staff finds the selection of the basket assembly materials to be acceptable.

8.4.4 Horizontal Storage Module

The reinforced concrete HSM is designed to provide environmental protection and radiological shielding for the DSC. The main structural components of the HSM are fabricated with reinforced concrete. Structural materials for the HSM include concrete designed in accordance with ACI 349-06 and constructed in accordance with ACI 318-08. The EOS-HSM concrete subcomponents are designed and constructed using a specified 28-day compressive strength of 5,000 psi, normal weight concrete. The cement is Type II or Type III Portland cement meeting the requirements of ASTM C150. The concrete aggregate meets the specifications of ASTM C33. The reinforcing steel is ASTM A615 or A706 Grade 60. For HSM applications where the general or local area temperature exceeds 200 °F but does not exceed 300 °F, the concrete will be constructed using aggregates that have a coefficient of thermal expansion no greater than $6x10^{-6}$ in./in./°F, or are either limestone, dolomite, marble, basalt, granite, gabbro, or rhyolite. Alternatively, in accordance with ACI 349-13, the specified 28-day compressive strength can be increased to 7,000 psi for HSM fabrication, in lieu of the above aggregate types or coefficient of thermal expansion requirements.

Based on the information provided in the SAR, the staff finds the selection of HSM materials to be acceptable because the design and fabrication of the concrete structures are in accordance with the ACI codes, which ensures that the materials are suitable for structural support and protection of the DSC from environmental conditions.

8.4.5 Dry Shielded Canister Support Structure

The applicant stated that the structural materials of the EOS DSC support structure conform to ASTM specifications and are constructed in accordance with the AISC Steel Construction Manual (AISC, 2005). The DSC support structure is fabricated from ASTM A913 Grade 70 steel that is coated with an inorganic zinc-rich primer and a high-build epoxy enamel finish. Welding procedures are in accordance with ASME B&PV Code, Section IX (ASME, 2011c), or American Welding Society (AWS) D1.1, "Structural Welding Code—Steel" (AWS, 2010).

The staff reviewed the materials of construction, the design of the DSC support structure, and the operating environment. The staff noted that ASTM A913 Grade 70 steel is a high-strength, low-alloy steel commonly used to produce shapes for structural applications similar to those of the DSC support structure. Based on the common use of the applicant's proposed materials and the conformance to the construction guidance of AISC, ASME, and AWS, the staff concludes that the selection of materials for the DSC support structure is acceptable.

8.5 Fracture Toughness

8.5.1 Austenitic Stainless Steels

In Section 8.2.1.1 of the SAR, the applicant stated that the DSC structural material may be constructed from either ASME SA-240 Type 304 or 316 austenitic stainless steel with less than 0.03 weight percent carbon. The staff noted that, in accordance with ASME B&PV Code, Section III, Subsection NB, Article NB-2311 (ASME, 2011a), these austenitic stainless steel materials do not require testing for fracture toughness.

8.5.2 Duplex Stainless Steels

In TS Section 4.4.4, the applicant stated that DSC shell materials constructed from Type 2205 and UNS S31803 duplex stainless steels will be evaluated using Charpy V-notch fracture toughness testing in accordance with ASME B&PV Code, Section III, NB-2300 (ASME, 2011a). The applicant clarified that, in accordance with ASME B&PV Code, Section III, NB-2300, impact testing is not required for the siphon port cover or the vent port plug because these components are less than 5/8 inch thick and are exempt from fracture toughness testing (AREVA, 2015).

The staff reviewed the fracture toughness requirement in ASME B&PV Code, Section III, NB-2300 (ASME, 2011a), and finds that the proposed Charpy V-notch impact testing is an acceptable means to assess the fracture toughness of the duplex stainless steels used for the DSC shell and lids. The staff confirmed that, in accordance with ASME B&PV Code, Section III, NB-2311(a)(1), the siphon and vent port cover plugs do not require impact testing. The staff reviewed the available information on fracture toughness testing of duplex stainless steel welds (Sieurin and Sandstrom, 2006) and determined that Charpy V-notch impact testing is adequate to evaluate the effects of welding processes on the fracture toughness of duplex stainless steel alloys.

8.5.3 Ferritic Steels

In Sections 8.2.13 and 10.1.7 of the SAR, the applicant summarized its analyses and testing for the ductility and fracture toughness of ferritic steels used in the DSC baskets and TCs.

For the low-alloy steel basket plates, the applicant stated that tensile and dynamic tear testing will be performed on each heat treatment lot of material, with the dynamic tear testing based on the recommendations in NRC Regulatory Guide 7.11, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)," issued June 1991. Regulatory Guide 7.11 references ASTM E604, "Standard Test Method for Dynamic Tear Testing of Metallic Materials," which establishes a minimum 80 percent or greater shear fracture appearance at the lowest service temperature.

The TC is constructed using ASME SA-350 Grade LF3 steel top and bottom rings, ASME SA-516 Grade 70 steel inner and outer structural shells and bottom plate, and ASTM A182 Grade F6NM martensitic stainless steel trunnions. The applicant stated that ASME SA-350 Grade LF3 steel is a cryogenic steel that has been used on AREVA Inc. metal casks and has consistently demonstrated nil ductility transition temperatures below -80 °F, and, therefore, this material need not be impact tested for the TC application. The staff noted that the ASME SA-350 Grade LF3 standard includes a minimum impact toughness at -150 °F, significantly below the TC's minimum service temperature of 0 °F. The applicant also stated that the ASME SA-516 Grade 70 material and the procedures for all welds in the load path are subject to Charpy impact testing at 0 °F in accordance with ASTM B&PV Code, Section III, Article NF-2300, for Class 1 supports. The applicant stated that the trunnion materials are martensitic stainless steel and are subject to drop weight testing at -40 °F in accordance with ANSI N14.6 or to Charpy impact testing at 0 °F in accordance with ASME B&PV Code, Section III, Article NF-2300, for Class 1 supports. More recent editions of the ASTM test specifications than those invoked by ANSI N14.6 may be used.

The staff reviewed the applicant's use of ferritic steels to confirm that appropriate testing is in place to ensure adequate fracture toughness. The staff finds the applicant's selection and testing of ferritic steels acceptable because the proposed Charpy impact testing and drop weight testing at or below the materials' service temperature are capable of ensuring that the DSC basket and TC components can perform their intended function in normal and accident conditions. The staff reviewed the dynamic tear testing specifications for the basket plates and determined that the acceptance criteria are consistent with the criteria recommended for Category I containments (Regulatory Guide 7.11) that require a very large margin of safety and sufficient fracture toughness to arrest large cracks under dynamic loading (Holman and Langland, 1981).

8.6 Material Properties

SAR Tables 8-4 through 8-29, 8-33, and 8-35 provide mechanical and physical property data for the major structural materials, including stainless steels, carbon steel, bolting materials, concrete, neutron poison plates, and shielding material. Most of the values in the tables were obtained from ASME B&PV Code, Section II, Part D; however, some of the values were obtained from other acceptable references such as the ACI codes, material property and engineering handbooks, and technical reports. The staff independently verified the temperature-dependent values for the stress allowable, modulus of elasticity, Poisson's ratio, weight density, and coefficient of thermal expansion.

SAR Tables 8-25 and 8-26 provide the mechanical properties of the Zircaloy-2 and Zircaloy-4 cladding. The properties of the fuel cladding were derived from Geelhood et al. (2008), who modeled the mechanical properties of Zircaloy cladding based on a large collection of data from uniaxial tension tests, biaxial burst tests, and ring stretch tests. The applicant reduced the calculated yield strength data by the model uncertainty (9.7 ksi) for conservatism. The staff used technical references to verify the calculated material properties, particularly considering the potential effects of high levels of burnup and hydrogen concentration.

The staff finds the material properties used in the applicant's structural analyses to be acceptable and appropriate for the expected load conditions (e.g., hot or cold temperature, wet or dry conditions) because the staff independently verified that the properties are based on consensus codes and standards or other technical references commonly used and accepted in the materials industry.

8.7 Weld Design and Specification

The applicant summarized the design and inspection of welds in Section 8.2.4 of the SAR. The DSC materials of construction consist of either austenitic stainless steel (Type 304 or 316) or duplex stainless steel (UNS S31803 or Type 2205). The staff noted that both the austenitic stainless steels and duplex stainless steels are readily weldable using a range of commonly available welding techniques. The DSC shell assembly is designed, fabricated, examined, and tested in accordance with the requirements of the ASME B&PV Code, Section III, Subsection NB. The DSC shell is constructed from rolled and welded plate, and the weld seams are multilayer full-penetration welds. These confinement boundary shell welds are subjected to surface and volumetric non-destructive examination in accordance with the requirements of ASME B&PV Code, Section III, Subsection NB. Non-confinement boundary welds are subjected to either surface, or a combination of surface and volumetric, non-destructive examination. Welds for the DSC closure lids are inspected using progressive penetrant testing. The staff noted that progressive penetrant testing examination of the closure welds is an NRC-accepted alternative to the ASME B&PV Code. The staff determined that the DSC welds are well characterized on the license drawings, and standard welding symbols and notations are in accordance with AWS A2.4, “Standard Symbols for Welding, Brazing, and Nondestructive Examination.”

The TC materials of construction are primarily low-alloy steel (ASME SA-350 Grade LF3) and carbon steels (ASME SA-516 Grade 70). The staff noted that both of these materials are readily weldable using a range of commonly available welding techniques. The TC shell assembly is designed, fabricated, examined, and tested in accordance with the requirements of ASME B&PV Code, Section III, Subsection NF. The TC top ring and bottom ring are constructed from ASME SA-350 Grade LF3 low-alloy steel that is welded to the ASME SA-516 Grade 70 carbon steel. Structural welds that connect the TC top and bottom rings to the inner and outer shell are examined with magnetic-particle testing. The TC125 and the TC135 designs have an attached tank surrounding the TCs that is constructed from welded ASTM A36 and ASME SA-516 Grade 70 carbon steel that is filled with water for neutron shielding. The TC108 design has a removable neutron shielding tank constructed from welded aluminum alloy 6061-T6. The staff determined that the TC welds are well characterized on the license drawings, and standard welding symbols and notations are in accordance with AWS A2.4.

The welds of the DSC support structure are designed in accordance with the AISC Steel Construction Manual and visually inspected in accordance with AWS D1.1 (AWS, 2010). The staff determined that the TC welds are well characterized on the license drawings, and standard welding symbols and notations are in accordance with AWS A2.4.

The staff finds the design and inspection of the welded joints of the DSC, DSC support structure, and TC to be acceptable because they meet the requirements of the ASME B&PV Code, AWS codes, AISC Steel Construction Manual, and the guidance contained in NUREG-1536. In addition, the staff finds the alternatives to the ASME B&PV Code acceptable for the closure lid-to-shell weld inspection using liquid penetrant techniques performed in accordance with ASME B&PV Code, Section V, Article 6.

8.8 Corrosion Reactions

The applicant analyzed potential corrosion reactions in Section 8.2.5 of the SAR. This section of the SER describes the staff’s review of each of the potential reactions.

8.8.1 Aluminum-Based Neutron Absorbers in Deionized Water and Boric Acid

The applicant stated that the aluminum-based neutron-absorber materials, which include MMC and BORAL®, have high resistance to corrosion as a result of a protective oxide film on the metal surface that is stable over a pH range of 4.5 to 8.5. The applicant also stated that there are no chemical, galvanic, or other reactions that could reduce the areal density of boron in the neutron poison plates with either of the poison plate materials. The applicant stated that the pores in the core material exposed at the edges of BORAL® can retain water, which can cause delamination of the skin from the core during drying or storage (i.e., blister formation). The applicant stated that blister formation was evaluated previously and determined to have no effect on the criticality control function of Boral (NUREG-0933, "Resolution of Generic Safety Issues," Issue 196, "Boral Degradation," dated October 23, 2012). The applicant noted that MMCs are tested to verify that they will not be subject to this phenomenon.

The staff reviewed the materials of construction for the neutron-absorber materials for their potential to degrade in the water and boric acid environments. The staff noted that there is widespread industry experience with both MMCs and BORAL® in spent fuel pool and dry cask storage system applications. The staff also noted that the period of immersion in the pool is insufficient to cause significant localized corrosion, such as pitting or crevice corrosion in the aluminum. The staff finds the use of the aluminum-based neutron-absorber materials acceptable because the water chemistry and pH of spent fuel pools is tightly controlled to prevent corrosion reactions, and thus the protective oxide films on aluminum and its alloys will remain intact during their brief immersion into the spent fuel pools (ASM International, 1987a). In addition, although the applicant did not explicitly address the corrosion of the other aluminum components in the DSC basket (e.g., transition rails), the staff notes that these aluminum components would also be expected to retain their protective oxide films during the brief pool exposures (ASM International, 1987a).

8.8.2 Austenitic Stainless Steel in Deionized Water and Boric Acid

The applicant stated that the DSC shell and cover plates are made from austenitic or duplex stainless steels that do not exhibit general corrosion when immersed in deionized water. The applicant also cited results of corrosion testing of Type 304 austenitic stainless steel in saturated boric acid solutions, which found corrosion to be either very low or immeasurable. The applicant stated that, because of the relatively low boric acid concentration in PWR spent fuel pool water and the relatively short time of immersion, Type 304 stainless steel would be expected to have no measurable corrosion in the DSC application when immersed in PWR spent fuel pools. The applicant also stated that, while stress-corrosion cracking has occurred in stagnant, high-concentration boric acid solutions, the conditions experienced by the DSC in the spent fuel pool are insufficient to cause this phenomenon. The applicant further stated that galvanic attack can occur between the aluminum transition rails in contact with the stainless steel DSC shell in the spent fuel pool water. However, the attack is mitigated by the passivity of the aluminum and the stainless steel in the short time the pool water is in the DSC. Also, the low conductivity of the pool water tends to minimize galvanic reactions.

The staff reviewed the stainless steel materials of construction for the DSC with respect to their susceptibility to corrosion reactions during fuel loading in the spent fuel pool. The staff noted that there is widespread experience with the same or similar materials in spent fuel pools (e.g., stainless steel spent fuel pool storage racks) and other licensed dry cask storage systems. The stainless steel will be in the passive condition before immersion. Corrosion and galvanic corrosion reactions will be limited by the low conductivity and the lack of aggressive species, such as chlorides, that can break down the passive oxide films on the stainless steels. As a result, based on the presence of protective passive films and the low corrosivity of the spent fuel pool water, the staff finds the use of the stainless steels acceptable.

8.8.3 High-Strength, Low-Alloy Steel in Deionized Water and Boric Acid

The applicant stated that the high-strength, low-alloy steel basket material, such as ASTM A829 Grade 4130, receives a proprietary treatment process to provide short-term protection in deionized water. The applicant indicated that a small amount of rust may form, but the amount will be insufficient to affect performance. The applicant evaluated the potential loss of material from corrosion using data published by the Electric Power Research Institute (EPRI) for steels exposed to boric acid concentrations that bound the range of concentrations used in PWR primary water (EPRI, 2001).

The staff reviewed the materials and environment for the DSC, the applicant's proprietary treatment process, and the EPRI corrosion data cited by the applicant. The staff determined that the proprietary treatment is adequate to protect the basket structure from significant degradation during the short-term fuel loading operation. The staff also confirmed that, regardless of the use of the treatment, the applicant adequately analyzed the potential loss of material as a result of the steel's exposure to the spent fuel pool water to show that the effects of corrosion would be insignificant. Based on the staff's independent verification that loss of material will not affect the structural performance of the basket, the staff finds the use of the high-strength, low-alloy steel in the pool water environment to be acceptable.

8.8.4 Lubricants and Cleaning Agents

The applicant stated that the DSC is cleaned in accordance with approved procedures to remove cleaning residues before shipment to the storage site. The basket is also cleaned before installation in the DSC. Decontamination agents may be applied on the TC surfaces at each use. A graphite-based dry lubricant is applied to the surface of the Nitronic 60 sliding surfaces in the TC and on the HSM's DSC support structure. Lubricants also may be used on the TC cover bolts and on the trunnion and lower rotating socket bearing surfaces. The applicant stated that the cleaning agents have no adverse effect on the DSC materials and their design functions.

The applicant stated that the graphite lubricant that is used on the DSC support rails is noble relative to stainless steel. Therefore, galvanic corrosion of the stainless steel DSC or the stainless steel (Nitronic 60) DSC support rail is possible under conditions in which an electrolyte is present. The applicant cited data on the absence of observed metal loss from galvanic corrosion testing on graphite composites and stainless steel in a 3.5 weight percent sodium chloride solution (Miller, 1975). The applicant stated that normal conditions inside the HSM are dry, and the formation of an electrolyte that could support corrosion reactions is unlikely after initial loading and is limited to intermittent water from high wind and rain. The applicant also stated that the formation of an electrolyte by deliquescence of deposited salts is possible after sufficient time for the DSC to cool, but the surface area of the DSC is large compared to the surface area of the graphite, and the favorable anode to cathode ratio will limit the loss of material from galvanic corrosion.

The staff reviewed the applicant's analysis and the cited work of Miller (1975) to evaluate the potential for galvanic corrosion of the DSC due to the presence of graphite. The staff also reviewed the work of Kain (1998) that showed galvanic corrosion of stainless steel is possible when a graphite or carbon fiber containing gaskets was present in a simulated pipe flange that was exposed to seawater. The staff noted that the normal condition inside the HSM is dry and that the presence of an aqueous electrolyte to support galvanic corrosion would be limited. The staff reviewed the previous NUHOMS® designs and operating procedures and confirmed that graphite is specified as a lubricant for the standardized NUHOMS® storage system used by general licensees under NRC CoC No. 1004 (AREVA, 2014). The staff noted that no qualified inspections of the standardized NUHOMS® DSCs have been performed to verify the absence of galvanic corrosion; however, such inspections are anticipated when these systems enter their renewed operating period (from 20 to 60 years of storage).

The staff also reviewed the potential for galvanic corrosion on the TC canister rails. The staff noted that, although these surfaces are periodically wetted during fuel loading, the period of immersion is brief. The staff also noted that the interior bearing surfaces of the TC are periodically inspected during normal maintenance, as described in Section 10.2.1.1 of the SAR, and these visual inspections will be capable of identifying degradation of the canister rails as a result of galvanic corrosion.

Based on the limited potential to form an aqueous electrolyte (DSC support) or the brief time of aqueous exposure (TC rails), and the fact that the inspection data on NUHOMS® TCs and DSCs will become available to initiate corrective actions if necessary, the staff finds the use of the graphite lubricants to be acceptable.

8.8.5 Canister Shell during Storage

The applicant stated that the DSC external surfaces are protected from direct exposure to precipitation and are exposed only to the humidity and aerosols in the cooling air that flows through the HSM. The applicant also stated that the stainless steel outer surfaces and the rail surfaces upon which the DSC rests are not subject to general corrosion. The applicant indicated that sites near the coast or other sources of chloride aerosols could experience pitting, stress-corrosion cracking, or crevice corrosion (NRC Information Notice 2012-20, “Potential Chloride-Induced Stress Corrosion Cracking of Austenitic Stainless Steel and Maintenance of Dry Cask Storage System Canisters,” dated November 14, 2012). The applicant stated that the time necessary for the accumulation of significant chloride-containing salts and the time for the DSC to cool to allow elevated relative humidity values sufficient for the deliquescence of deposited chloride salts will be greater than the initial 20-year licensing period.

In a response to an NRC RAI, the applicant provided a proprietary analysis of the chloride accumulation and temperature as a function of time for the proposed NUHOMS® EOS system. Using conservative values for initial heat load, airborne salt concentrations, salt accumulation rates, and DSC surface temperatures, the applicant showed that the conditions for CISCC are unlikely to occur during the initial 20-year licensing period.

The applicant stated that, for sites near chloride aerosol sources, the NUHOMS® EOS System provides options for canisters made of duplex stainless steel, which, due to its partially ferritic grain structure, is very resistant to stress-corrosion cracking. The applicant also indicated that an option for an inspection port on the front of the HSM provides for improved aging management beyond the 20-year initial license period.

The staff reviewed the information provided by the applicant and determined that the analysis of the period of time necessary to accumulate significant chloride salts is conservative. In addition, the staff determined that, even with the conservative assumptions on chloride salt accumulation, the temperature of the DSC surface will prevent the formation of relative humidity values inside the HSM that are sufficient for the deliquescence of any deposited chloride containing salts. The staff determined that the applicant's analysis is consistent with the results of previous NRC testing to characterize the conditions in which CISCC of austenitic stainless steels can occur (He et al., 2014).

The staff also reviewed the available information on the CISCC resistance of duplex stainless steels (Tseng et al., 2003; Cottis and Newman, 1993). The staff determined that UNS S31803 duplex stainless steels are more resistant to CISCC compared to austenitic stainless steels; however, CISCC has been reported in offshore applications when welding practices were used that altered the microstructure of the alloy (Leonard, 2003). The staff reviewed studies conducted by Liou et al. (2002), which showed that increased nitrogen content in Type 2205 stainless steels was beneficial for maintaining a favorable ratio of ferrite to austenite phases that is necessary for CISCC resistance. The staff also found that cooling rates have a significant effect on the resulting microstructure of duplex stainless steels. Cooling rates above 0.41 °F/s are necessary to avoid embrittlement from the formation of sigma phase, but cooling rates above 90 °F/s result in an unfavorable ratio of ferrite to austenite and diminish CISCC resistance (Sieurin and Sandstrom, 2007). In Section 8.2.3 of the SAR, the applicant stated that the fabrication specification of the duplex stainless steels will use the latest edition of the API standard for the welding of duplex stainless steels (API Technical Report 938-C, "Use of Duplex Stainless Steels in the Oil Refining Industry," issued April 2011) to avoid the embrittlement (API, 2011).

Based on the staff's verification of the applicant's analysis that shows that the conditions within the HSM will not support deliquescence of any deposited chloride containing salts (a precursor to CISCC), and the fact that the susceptibility of duplex stainless steels to CISCC will be mitigated by the use of industry standard welding practices for these materials, the staff finds the use of the austenitic and duplex stainless steels for the DSC shell to be acceptable.

8.8.6 Dry Shielded Canister Support Structure

The applicant stated that the DSC support structure is protected from direct exposure to precipitation, and it is exposed only to the humidity and aerosols in the cooling air that flows through the HSM. The applicant also stated that the epoxy enamel coating system for the DSC support structure is more than adequate for the 20-year initially licensed storage period. The applicant cited inspections for license extension that have found only minor local rusting (Duke Energy Carolinas, LLC, 2009; Calvert Cliffs Nuclear Power Plant, 2012). The applicant indicated that, although the epoxy coating is used and has shown to be effective in previous applications (Duke Energy Carolinas, LLC, 2009; CENG, Calvert Cliffs Nuclear Power Plant, 2012), the applicant used a stress analysis that included a reduction of 1/16 inch of thickness from all surfaces to account for potential metal loss from corrosion. The applicant stated that, at ISFSIs with operational experience of corrosion with atmospheric chlorides, additional protection is provided by specifying a minimum 0.2 percent copper content for the structural steel and weld filler metal, which results in an adherent self-protecting oxide layer equivalent to weathering steel. The applicant stated that weld filler metal with 1 percent or more nickel is acceptable in lieu of 0.20 percent copper content because the nickel-bearing weld materials show equivalent corrosion resistance (Larrabee and Coburn, 1962).

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 percent copper and 1 percent nickel steels for added corrosion resistance in environments containing chlorides. The staff noted that the results of long-term corrosion testing in a variety of environments show that the 0.2 percent 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, 1987b). 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.

8.8.7 Transfer Cask

The applicant stated that the use of a protective coating and the performance of periodic inspection and maintenance will mitigate the effects of TC corrosion. Section 8.2.8 of the SAR lists the TC coatings. The exposed carbon steel surfaces of the TC are coated with enamels that the applicant stated are suitable for exposures in the spent fuel pool and long-term exposure to the elevated temperatures of the TC. The applicant stated that the coatings are not important to safety. The applicant indicated that the inspection, maintenance, and repair of the protective coatings will be performed as specified by Sections 10.2.1 and 10.3.1 of the SAR to prevent corrosion of the TC from affecting design functions. The applicant also stated that inspections of the TC, including inspections for coating degradation and corrosion, will be performed before each loading campaign. The applicant stated that paint damage will be repaired using the originally specified paint system.

The staff reviewed the information provided by the applicant, including the data sheets for the coatings specified for the TC in SAR Section 8.2.8 and the inspection, maintenance, and repair procedures in Sections 10.2.1 and 10.3.1 of the SAR. The staff determined that the polyurethane coating specified for the external surfaces of the TC has been adequately evaluated for the service conditions specified. The staff also determined that the epoxy coatings specified for the internal carbon steel surfaces of the TC have adequate temperature and chemical resistance for the expected service conditions that will be encountered during spent fuel loading. The staff reviewed the inspection, maintenance, and repair actions specified in the SAR and determined that the coating inspection and repair activities identified in the SAR are adequate to prevent corrosion of the TC. As a result, based on the capability of the coatings to protect the TC surfaces and the maintenance practices that ensure that coating degradation and corrosion will be adequately managed, the staff finds the compatibility of the TC materials with their environment to be acceptable.

8.9 Creep Behavior of Aluminum Components

The applicant provided the results of its creep analysis for aluminum DSC basket components in Section 8.2.6 of the SAR. These components include the aluminum transition rails, neutron-absorber plates, and the aluminum plates that form the basket grid structure.

The applicant provided a creep analysis for the transition rails and aluminum plates that established the allowable stresses to limit creep strain to 1 percent over 550,000 hours (63 years), which is a more conservative strain rate than that specified in the ASME B&PV Code, Section II, Part D, Appendix 1 (5.5 percent strain over 550,000 hours). The applicant demonstrated that the actual stresses on the aluminum plates and transition rails under normal and off-normal conditions are significantly less than these allowable stresses.
Sections 3.9.2.1.6.3 and 3.9.2.2.6.3 of the SAR describe the details of the analysis for the EOS-37PTH and EOS-89BTH baskets, respectively. The applicant stated that its structural

analyses do not credit the neutron-absorber plates to demonstrate mechanical integrity. As a result, the applicant did not provide a creep analysis for these components.

The staff reviewed the applicant's creep analysis to confirm that the effects of aluminum creep on the design basis of the DSCs have been adequately addressed. Based on its review of the DSC basket design temperatures and stresses provided in SAR Section 3.9.2 and the aluminum creep analysis provided in SAR Section 8.2.6, the staff confirmed that the extent of creep is within the bounds provided by the ASME B&PV Code. Therefore, the staff finds the applicant's consideration of the effects of creep on the function of the aluminum basket components to be acceptable.

In addition, the staff noted that Table 8-3 of the SAR states that the TC designs include an aluminum top cover plate and an aluminum neutron shield tank. The applicant did not specifically address the creep behavior of these components. However, the staff noted that the maximum design temperatures of the aluminum TC components are significantly lower than those evaluated for the DSC basket components, and the TC is exposed to the elevated temperatures only during the relatively short time when the DSC is being loaded and transported to the HSM. Therefore, the staff finds that there is reasonable assurance that creep will not challenge the function of the aluminum top cover plate.

8.10 Bolt Applications

The applicant addressed the use of bolting that performs important-to-safety functions in Section 8.2.7 of the SAR. The HSM design uses zinc-coated SA-193 Grade B7 alloy steel bolting in the DSC support structure, heat shields, and roof, door, and wall assemblies. The design of the top cover and bottom ram access ports of the TC uses SA-540 Grade B23 alloy steel bolting, which may be plated or coated for corrosion protection.

The staff evaluated the bolting corrosion resistance, brittle fracture resistance, and compatibility (thermal expansion matching) with the materials being joined. First, regarding corrosion resistance, the staff noted that the HSM bolting is within a sheltered environment that is protected from direct precipitation, and the zinc coating on this bolting is capable of mitigating corrosion. While the bolting associated with the TC may not be coated, these bolts will be regularly inspected and maintained as described in SAR Section 10.2.1, which states that all threaded parts of the TC will be inspected before each loading campaign. Next, regarding brittle fracture resistance, the staff noted that the SA-193 Grade B7 and SA-540 Grade B23 grades denote high-strength steels that are quench and tempered in accordance with the ASME specifications to ensure a minimum ductility. Finally, regarding thermal expansion, the staff confirmed that the high-strength steel bolting has appropriate compatibility with the thermal expansion of the materials being joined. These materials include steel and stainless steel HSM and TC components, which have thermal expansion coefficients similar to that of the steel bolts. However, an optional aluminum top cover plate for the TC has a significantly different thermal expansion coefficient relative to the steel bolts that fasten it. In its evaluation of this case, the staff reviewed the applicant's response to an RAI (AREVA, 2015), which showed that thermal expansion stresses created by the heating of the cover plate remain well below the allowable stresses on the closure bolts.

The staff finds the applicant's selection of bolting materials to be acceptable, based on the staff's review of the applicant's bolting materials described above, which included the confirmation of adequate corrosion resistance, material ductility, and thermal expansion compatibility.

8.11 Protective Coatings

As described in Section 8.2.8 of the SAR, the NUHOMS® EOS system uses a range of coating systems. The DSC confinement boundary is an all-welded austenitic or duplex stainless steel and has no coatings on any external surface. Some interior components of the DSC that are exposed to air, spent fuel pool water, and helium are coated with electroless nickel or receive a proprietary treatment for corrosion protection.

8.11.1 Electroless Nickel

Electroless nickel is identified as a coating for the DSC top shield plug. The electroless nickel coating is used to protect the shield plug from corrosion during storage before installation. The applicant stated that the electroless nickel coating is not important to safety and did not provide a specification for the electroless nickel.

8.11.2 Other Coating Systems

As discussed earlier in Section 8.8.7 of this SER, the exterior and interior carbon steel surfaces of the EOS-TC are coated with a painting system suitable for spent fuel pool immersion and for withstanding long-term exposure to the elevated temperatures of the TC. The exterior of the removable aluminum alloy neutron shield for the NUHOMS® EOS TC108 is also coated.

The applicant has identified the following coatings for the TC:

- PPG Amerishield™ enamel or Carboline Carboguard® 890 is used for the EOS-TC exterior surfaces.
- PPG Amerishield™, color white, is used for coating the exterior of the removable EOS-TC108 neutron shield. This neutron shield is not immersed.
- Carboline Thermaline® 450 or Amercoat® 91 is used for coating the EOS-TC interior surfaces, which are exposed to higher service temperatures.

The applicant stated that the DSC support structure in the HSM is coated with an inorganic zinc-rich primer and a high build epoxy enamel finish. Embedments and fasteners are galvanized. The applicant stated that the coatings are not important to safety.

The staff documents its evaluation of the use of coatings in the DSC support structure and TCs in Sections 8.8.6 and 8.8.7 of this SER, respectively.

8.12 Neutron Shielding

The applicant described the neutron shielding materials in Sections 6.3.1, 8.2.2.4, and 8.2.9 of the SAR. During storage, the concrete of the HSM provides for the neutron shielding. As described in SAR Section 1.2.1.3, the HSM walls and roof are 4 feet thick to provide neutron shielding. During transfer of the DSC to the HSM in the TC, shielding in the TC is provided by water in the radial direction and borated high-density polyethylene (Quadrant Borotron®, or similar, 5-percent boron by weight) in the axial direction.

The staff reviewed the use of the borated polyethylene neutron shielding, as the staff had not yet reviewed this material for other spent fuel dry storage systems. The staff verified that the SAR sufficiently describes the mechanical properties, thermal properties, and chemical composition data for this material. The staff also reviewed (1) the tests that demonstrate the neutron-absorbing ability of the material and (2) the ability of the material to withstand the maximum normal operating temperature of 228 °F as defined in Table 4-29 of the SAR. To ensure the minimum neutron shielding properties of the borated polyethylene, the applicant relied on the manufacturer's materials certification of 5-percent boron by weight, but it reduced that boron concentration by 15 percent in the shielding models to add conservatism. To demonstrate that the material can withstand the maximum normal operating temperature, the applicant provided additional information in a response to an RAI (AREVA, 2015). In that response, the applicant justified the exceedance of the material's 180 °F long-term service temperature (defined in the Borotron® Material Safety Data Sheet) by stating that any oxidative degradation of the material is limited by the small amount of available oxygen in the welded enclosure in which the shielding material resides.

The staff finds the use of the borated polyethylene neutron shielding material in the TC acceptable because the manufacturer's chemical certification of the minimum boron content, which is decreased by 15 percent in the shielding models, provides a sufficiently conservative basis for ensuring minimum shielding properties. In addition, although the material's continuous service temperature may be exceeded in normal operations, the exposure time is limited to the short durations of transfer operations, and the degradation of the material by oxidative reactions is mitigated by the limited available oxygen in the material's metal enclosure.

8.13 Criticality Control

The applicant described the neutron-absorbing materials for criticality control in Sections 8.2.2.5 and 8.2.10 of the SAR. The EOS-37PTH canister basket uses a boron carbide/aluminum MMC material, and the EOS-89BTH canister basket uses either the MMC material or BORAL®, which is constructed of a core of mixed aluminum and boron carbide particles that is clad with aluminum. SAR Table 8-33 describes the material property data of the absorber materials.

Table 8-32 of the SAR defines the minimum B-10 areal densities of the MMC and BORAL® panels. The applicant's criticality calculations take credit for 90 percent of the specified B-10 density for the MMC and 75 percent of the specified B-10 density for BORAL® to take into account uncertainties in neutron attenuation. The staff noted that NUREG-1536 recommends the reduced 75 percent credit for products that use coarse particles of boron carbide that may allow neutron channeling. This is consistent with Section 10.1.5.2 of the SAR, which states that the BORAL® is distinguished by its larger boron carbide powder size. Section 10.1.5 of the SAR describes BORAL® as having 80 percent of particles (by weight) smaller than 200 microns, while the MMC material has 90 percent of particles smaller than 100 microns.

Section 10.1.5 of the SAR describes the required qualification of the fabrication process for the MMC material and acceptance testing for both the MMC and BORAL® materials. The qualification testing of the MMC material includes mechanical testing and testing for uniform B-10 distribution. Acceptance testing for both the MMC and BORAL® materials includes B-10 testing, dimensional inspections, thermal conductivity measurements, and visual inspections for any imperfections in the panels. The staff noted that the acceptance testing for the B-10 areal density of BORAL® may be performed with chemical analysis, but no specific provision exists to benchmark the chemistry testing with neutron transmission testing, as recommended in NUREG-1536. The applicant stated that qualification of the fabrication process of the BORAL® materials is not required because of the long experience with the use of this material and the fact that the criticality calculations take credit for only 75 percent of the minimum specific B-10 density.

The staff reviewed the applicant's use of neutron-absorber materials against the guidance in NUREG-1536, including the percent credit taken for the areal density, qualification of the fabrication process, and acceptance testing of samples of the material that will be installed in the DSC baskets. The staff noted that the aluminum MMC and BORAL® neutron-absorber materials are commonly used in storage applications; the staff has approved their use in the NUHOMS® HD system (ADAMS Accession No. ML070160089). In support of the earlier applications of BORAL®, its manufacturers performed qualification testing to demonstrate the material's suitability for use in spent fuel storage, including testing for exposure to radiation, spent fuel pool water (for corrosion), and elevated temperatures (EPRI, 2009). The staff also noted that, in regards to the potential use of chemical analysis only to determine the acceptability of the B-10 density of BORAL®, uncertainties in the measured density are considered to be adequately addressed by the fact that the criticality calculations take credit for only 75 percent of the minimum specific B-10 density and other conservatisms in the calculations described in Section 7.3 of this SER, including the assumption of fresh fuel (i.e., no burnup credit).

The staff reviewed the operating experience and laboratory testing regarding the blistering of BORAL®, a known condition where the outer cladding separates and deforms outward from the core. The staff's evaluation of blistering in storage applications was previously summarized in the final rule for the NUHOMS® HD system, in which blistering was concluded to not affect the B-10 density, and thus neutron attenuation, of BORAL®, based on a review of testing of blistered coupons (*Federal Register*, 2006).

The staff finds the applicant's use of neutron shield materials acceptable based on the common use of these materials, the applicant's crediting of a reduced percentage of B-10 areal density in a manner consistent with the guidance in NUREG-1536, other conservatisms used in the criticality calculations (e.g., no burnup credit taken), and the qualification and acceptance testing that is capable of ensuring that neutron absorption properties are met.

8.14 Concrete and Reinforcing Steel

In Section 8.2.1.3 of the SAR, the applicant stated that the design and construction of the reinforced concrete horizontal storage module is in accordance with ACI 349-06 and ACI 318-08. Table 8-2 and the HSM drawings in the SAR describe the materials of construction for the HSM. NUREG-1536 recommends the review of the use of embedment materials to ensure that no degradation of the concrete will occur and to confirm that the applicant has appropriately evaluated the effects of high temperatures on concrete properties.

The staff reviewed the embedment materials to ensure that they are compatible with the concrete. NUREG-1536 recommends that embedments in concrete satisfy the concrete design code and that aluminum and zinc-coated material not be used for any objects that might be exposed to wet concrete as this may cause a damaging chemical reaction. The staff notes that Section 26.8 of ACI 318-08 states that aluminum embedments shall be coated to prevent reaction with the concrete; however, the cited ACI code does not prohibit the use of zinc coatings. Based on the staff's review of the SAR's description of the embedment materials, which indicate that no zinc coatings or aluminum materials are used that could cause adverse chemical reactions, the staff finds the applicant's use of embedment materials acceptable and consistent with the ACI codes.

The staff also reviewed the applicant's consideration of elevated concrete temperatures in the design of the HSM. The staff noted that ACI 349-06, Section E.4, and NUREG-1536 include temperature limitations on concrete; however, ACI Code allows temperatures above those limits if tests are provided to evaluate the potential reduction in strength and evidence is provided to verify that the increased temperatures do not cause deterioration of the concrete.

Section 8.2.2.3 of the SAR states that the HSM design uses temperature-dependent values taken from the scientific literature for the strength of the concrete. Table 8-23 of the SAR reports these values. Also, TS Section 5.3 states that the HSM concrete shall be tested during the fabrication process for elevated temperatures to verify that there are no significant changes in properties or signs of deterioration. Based on the applicant's use of temperature-dependent HSM material properties in accordance with ACI 349 Code, and the concrete testing for elevated temperatures required in the TS, the staff finds the applicant's consideration of elevated HSM temperatures to be acceptable.

8.15 Seals

The applicant discussed the seals in Section 8.2.12 of the SAR and stated that the only mechanical seal in the storage system is an elastomer O-ring in the TC bottom ram access penetration plate. During fuel loading, the O-ring and cover plate isolate the spent fuel pool water from the uncontaminated water in the annulus between the storage canister and TC. Table 8-3 of the SAR shows that this seal is constructed of ethylene propylene. This seal is leak tested annually (SAR Section 10.2.1.1), and it is replaced, as needed, as part of the TC maintenance activities (SAR Section 10.3.1).

The staff reviewed the elastomeric O-ring in the TC to determine whether it may adversely react with the environment to become brittle or lose elasticity. Based on the staff's review of the applicant's maintenance activities, which include annual testing of the O-ring seal and replacement, if needed, the staff finds the applicant's activities to maintain the seal's function to be acceptable.

8.16 Cladding

8.16.1 Cladding Temperature Limits

The applicant provided its thermal analysis of fuel cladding in Chapter 4 and Section 8.3 of the SAR. Specifically, SAR Tables 4-5 and 4-17 provide the calculated cladding temperatures for the EOS-37PTH and EOS-89BTH DSCs, respectively, for normal, off-normal, and accident conditions.

The staff reviewed the applicant's calculated cladding temperatures to confirm that there is reasonable assurance that creep will not cause gross rupture of the cladding and that hydride reorientation will not degrade the mechanical properties of the cladding. The guidance in NUREG-1536 establishes a maximum fuel cladding temperature limit of 400 °C for normal storage conditions and short-term loading operations and 570 °C for off-normal and accident conditions. In its review of the applicant's thermal analyses, the staff noted that the applicant's calculated temperatures are below these maximum temperature limits.

In addition, in a proprietary analysis within the SAR, the applicant stated that its structural analyses for design-basis accidents used a fuel cladding thickness that was reduced to account for oxidation that occurs during the fuel's residence in the reactor.

The staff evaluated the applicant's determination of the degree of cladding oxidation to ensure that it is appropriately justified. NUREG-1536 recommends that structural calculations use a cladding thickness that is reduced by a degree of oxidation that is justified with oxide thickness measurements, computer codes based on experimental data, or other means. The staff reviewed the data from the literature upon which the applicant based its oxidation analysis, which originated from measurements of high burnup reactor fuel with Zircaloy-4 cladding, and confirmed that the applicant used a reduced cladding thickness that was conservative.

Finally, in Sections 4.5.11 and 8.3.2 of the SAR, the applicant addressed the recommendation in NUREG-1536 to avoid hydride reorientation by limiting thermal cycling in loading operations to less than 10 cycles, where cladding temperature variations are more than 65 °C. The applicant stated that its use of helium to force the water out of the canister before vacuum drying, in combination with the cooling provided by the water in the annulus between the DSC and TC, eliminates the thermal cycling of the fuel cladding. The staff noted that it had previously reviewed an AREVA calculation (AREVA, 2009) that showed that, at the pressures to which the canister is dried, there is sufficient thermal conductivity in the helium to maintain the thermal cycling below the limit of 65 °C (NRC, 2010).

The staff evaluated the applicant's thermal cycling analysis to ensure that the loading operation will not result in conditions that could promote creep or hydride reorientation. The staff finds the applicant's loading operations acceptable because the staff confirmed that (1) the calculated cladding temperatures do not exceed the limits recommended in NUREG-1536, (2) the structural analyses appropriately considered the effects of cladding oxidation, and (3) the use of helium and the presence of the annulus water during the canister draining operation will effectively mitigate thermal cycling that could lead to embrittlement from hydride reorientation.

8.16.2 Fuel Classification

The staff reviewed the manner in which the applicant defined its fuel to ensure that it adequately defined the SNF. TS 2.1 and 2.2 define the acceptable fuel contents, which include intact fuel with or without control components and fuel channels. Also, the TS define "intact" fuel as assemblies with no known or suspected defects in excess of pinhole leaks or hairline cracks, and with no missing rods.

The staff evaluated the applicant's methodology for classifying the fuel and finds it acceptable because it provides a clear description of the characteristics of the fuel that will be allowed to be stored in the dry storage system. Also, the allowable fuel characteristics are consistent with the acceptance criteria recommended in NUREG-1536, which notes that pinhole leaks and hairline cracks present a minimal ALARA concern.

8.16.3 Reflood Analysis

In a proprietary portion of the SAR, the applicant provided its analysis of fuel cladding stresses caused by reflooding of the DSC. The staff evaluated the applicant's analysis to verify that the applicant appropriately considered the effects of thermal gradients on cladding stresses during a reflooding event. The staff finds the applicant's analysis acceptable because the applicant demonstrated that the total stress on the cladding would be maintained below the material's yield strength and thus would not challenge the integrity of the fuel rods.

8.17 Prevention of Oxidation Damage During Loading of Fuel

In Section 8.4 of the SAR, the applicant stated that oxidation of the fuel cladding is prevented by using helium to force the water out of the canister after fuel loading and subsequently alternating vacuum evacuation and helium backfill. Section 9.1.3 of the SAR describes this operation. TS Sections 3.1.1 and 3.1.2 detail the requirements for canister drying and helium backfill.

The staff reviewed the applicant's drying operations against the criteria in NUREG-1536. NUREG-1536 states that maintaining the fuel rods in an inert environment is one method to demonstrate that the fuel cladding will be protected against splitting due to oxidation. Based on the applicant's use of a helium cover gas during all aspects of the drying operation, the staff finds that the applicant will take adequate steps to prevent the oxidation of the fuel cladding.

8.18 Flammable Gas Generation

The applicant addressed the potential for hydrogen gas generation during wet loading and unloading operations in Section 8.5 of the SAR. The applicant stated that hydrogen generation from aluminum will be limited to the time in which the surface oxide layer is formed in the water environment. In addition, the applicant stated that operating experience has not shown any problems with aluminum oxidation due to galvanic coupling with steels. Nevertheless, as shown in TS Section 5.4, the applicant will monitor for the presence of hydrogen in the space under the inner top cover plug in the DSC cavity during loading and unloading operations. If hydrogen concentration exceeds 4 percent, the cavity will be purged with helium to reduce the hydrogen concentration before welding or cutting resumes.

The staff evaluated the applicant's approach against Section 8.4.19 of NUREG-1536, which states that operating procedures should contain guidance for detecting the presence of hydrogen and preventing its ignition. Based on the applicant's inclusion of activities in the TS Section 5.4 to prevent flammable gas generation and ignition, the staff finds the applicant's approach acceptable.

8.19 Canister Closure Welds Testing

The applicant described the testing of the DSC closure welds in Sections 8.6 and 10.1.1.1 of the SAR and TS Section 4.4.4 (on code alternatives). The applicant stated that the confinement boundary weld between the inner top cover plate and canister shell is pneumatically pressure tested in accordance with ASME B&PV Code, Section III, Division 1, Article NB-6300. After this pressure test, the siphon and vent port covers are welded, and a helium leak test is performed to ensure leak tightness of all the confinement welds (welds between the inner top cover, canister shell, and siphon and vent port covers). The root and final passes of these confinement welds are also examined by dye penetrant testing. In addition, the applicant stated that the multilayer structural weld between the outer top cover plate and the canister shell is examined by progressive dye penetrant testing.

The staff evaluated the applicant's closure weld testing activities to reach reasonable assurance that the welds will have adequate structural integrity and that the confinement boundary will maintain an inert helium environment within the canister to prevent oxidation and maintain adequate heat transfer properties.

In its review of the confinement boundary weld testing, the staff noted that the testing for the welds between the inner top cover, canister shell, and siphon and vent port covers is in accordance with the ASME B&PV Code and the guidance in NUREG-1536. For the leak testing required in paragraph NB-6320 of the ASME B&PV Code, the TS include an optional alternative to allow a reduced test pressure if helium is used as a leak test medium. The applicant justified this by stating that the use of helium in the leak test provides for significantly greater sensitivity than if other media were used (the ASME B&PV Code does not specify the gas used in the leak test). The staff finds the applicant's procedures for testing of the confinement boundary welds associated with the inner cover plate to be acceptable because the welds will be constructed and tested in accordance with the guidance in NUREG-1536 and the ASME B&PV Code (with alternatives), which provides reasonable assurance of the welds' structural strength and confinement capability.

In its review of the testing of the structural weld between the outer top cover plate and the canister shell, the staff noted that NUREG-1536 recommends progressive dye penetrant examination of this multipass weld, provided that the weld is executed in accordance with the welding and inspection guidance in Section 8.4.20 of NUREG-1536. The staff noted that TS Section 4.4.4 states that the outer top cover plate weld will be a multilayer weld and will receive multilayer dye penetrant examinations in accordance with the guidance in NUREG-1536. The staff finds the applicant's procedures for the outer top cover plate weld to be acceptable because the multilayer weld will be constructed and tested in accordance with the staff guidance, which provides reasonable assurance of the weld's structural strength or confinement capability.

8.20 Periodic Inspections

The applicant described its periodic inspection activities in Sections 8.6.1 and 10.2 of the SAR. The thermal performance of the HSM is required to be verified by daily temperature measurements or daily visual surveillance of the HSM inlet and outlets vents in accordance with TS 5.1.3. In addition, TC inspections will be performed annually or before each loading campaign, depending on the inspection scope, to identify material degradation or loss of component function (e.g., leak tightness of a ram penetration seal).

The staff reviewed the applicant's inspection activities to determine if the SAR adequately describes periodic inspection programs for monitoring material conditions or performance. The staff finds the applicant's periodic inspection activities acceptable because (1) daily temperature monitoring or visual inspections of HSM vents provide for timely identification of degradation of the thermal performance of the HSM and (2) the visual inspections and leak testing of TC components are capable of identifying degradation that could challenge the TC's intended functions.

In addition to inspections, TS 5.1.2 requires a monitoring program to ensure that radiation doses to individuals outside the controlled area are in accordance with regulatory limits in 10 CFR 72.104. The staff finds this radiation monitoring activity acceptable because it is capable of ensuring compliance with the regulatory limits and is in agreement with Section 6.5.4.3 of NUREG-1535, which recommends that compliance with the regulatory dose limits should be verified through a monitoring program for direct radiation or effluent measurements.

8.21 Evaluation Findings

F.8.1 The SAR adequately describes the materials that are used for SSCs important to safety and the suitability of those materials for their intended functions in sufficient detail to evaluate their effectiveness.

F8.2 The applicant has met the requirements of 10 CFR 72.122(a). The material properties of SSCs important to safety conform to quality standards commensurate with their safety function.

F8.3 The applicant has met the requirements of 10 CFR 72.104(a), 10 CFR 72.106(b), and 10 CFR 72.124. Materials used for criticality control and shielding are adequately designed and specified to perform their intended function.

F8.4 The applicant has met the requirements of 10 CFR 72.122(h)(1) and 10 CFR 72.236(h). The design of the DSC and the selection of materials adequately protect the SNF cladding against degradation that might otherwise lead to damaged fuel.

F8.5 The applicant has met the requirements of 10 CFR 72.236(h) and 10 CFR 72.236(m). The material properties of SSCs important to safety will be maintained during normal, off-normal, and accident conditions of operation so that the SNF can be readily retrieved without posing operational safety problems.

F8.6 The applicant has met the requirements of 10 CFR 72.236(g). The material properties of SSCs important to safety will be maintained during all conditions of operation so that the SNF can be safely stored for the minimum required years and maintenance can be conducted as required.

F8.7 The applicant has met the requirements of 10 CFR 72.236(h). The NUHOMS® EOS system employs materials that are compatible with wet and dry SNF loading and unloading operations and facilities. These materials should not degrade over time or react with one another during any conditions of storage.

The staff concludes that the material properties of the SSCs of the NUHOMS® EOS system 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 NUHOMS® EOS system will allow for the safe storage of SNF for a licensed (certified) life of 20 years. 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.

8.22 References

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9.0 OPERATING PROCEDURES EVALUATION

The applicant provided the operating procedures for the NUHOMS® EOS System in Chapter 9 of the SAR. The staff evaluated the information using the guidance in NUREG-1536 to ensure that the applicant's SAR presents acceptable operating sequences, guidance, and generic procedures for key operations, such as cask loading, cask handling and storage operations, and cask unloading. This review also ensures that the SAR incorporates and is compatible with the applicable operating control limits in the TS.

9.1 Procedures for Loading the Dry Shielded Canister and Transfer to the Horizontal Storage Module

The loading procedures described in the SAR include preparation and inspection provisions to be accomplished before cask loading. These include cleaning and decontaminating the TC and other equipment as necessary and inspecting the DSCs for any physical damage and to confirm their cleanliness.

Chapter 9 of the SAR provides that (1) the boron content of the water in the DSC is verified to meet the TS and (2) the fuel identification for the SFAs that are loaded into the DSC basket compartment is verified and documented. The procedures also discuss verification by plant record or other means that the candidate SFAs meet the physical, thermal, and radiological criteria specified in the TS.

Chapter 9 of the SAR discusses the practice of draining water from the NUHOMS® EOS-37PTH and EOS-89BTH DSCs before welding the inner top cover and shield plug. Helium will be used to assist in draining water from the NUHOMS® EOS-37PTH and EOS-89BTH DSCs. It should be noted that if the gaseous atmosphere is oxidizing, oxidation of fuel pellets or fuel fragments can occur if a cladding breach (such as a pinhole) already exists. Oxidation may occur very rapidly and cause significant swelling of fuel pellets and fragments, which could result in gross fuel cladding breaches. Section 8.4.18 of NUREG-1536 recommends the use of an inert gas when assisting in the removal of water as one means to prevent loss of retrievability or an inadequately analyzed configuration from a shielding and criticality perspective.

SAR Chapter 9 states that the licensee needs to (1) monitor the TC/DSC annulus water level and replenish if necessary; and (2) drain a minimum of 60 gallons of water from the DSC back into the fuel pool or other suitable location using the vacuum drying system or an optional liquid pump, prior to the start of welding operations.

The SAR Chapter 9 also noted that the licensee should monitor hydrogen concentration in the DSC cavity during the inner top cover plate cutting and welding operations, and ensure the measured hydrogen concentration below a limit of 2.4 percent (60 percent of flammability limit of 4.0 percent). If the limit is exceeded, the licensee needs to stop all welding operations and purge the DSC cavity with approximately 2–3 psig helium to reduce the hydrogen concentration below the 2.4 percent limit.

All handling and transportation events applicable to moving the NUHOMS® EOS-37PTH and EOS-89BTH DSCs to the storage location are similar to those approved by the staff in the SER for NUHOMS® HD System (ADAMS Accession No. ML070160089) and are bounded by the analyses in Chapter 12 of the SAR.

Monitoring operations include daily surveillances of the HSM air inlets and outlets in accordance with TS requirements.

The loading procedures incorporate general ALARA principles and practices, which include periodic monitoring of dose rates, the use of annulus sealing equipment to reduce occupational exposure and limit DSC contamination, the use of temporary shielding, the use of special tools to reduce occupational exposure, and warnings and notes that identify potential radiological hazards. The procedures incorporate TS LCO 3.3.1, which specifies limits for surface dose rates and radionuclide contamination. Each cask user will need to develop detailed loading procedures that incorporate the ALARA objectives of the site-specific radiation protection program.

The NRC staff also reviewed the procedures for criticality control, particularly the proper loading of authorized assemblies. The applicant specified administrative controls to fuel loading in Section 9.1.2 of the SAR. Since the applicant is not seeking to apply burnup credit to the NUHOMS® EOS System (NRC, 2010) at this time and has built other conservative assumptions into its analyses, the staff finds that there is significant margin to criticality and these administrative controls are acceptable in this case.

The staff reviewed the operation procedures described in the SAR and finds that the steps described are appropriate for the loading operations. The general licensees will develop its site-specific operation procedures following these general procedures and guidance.

9.2 Procedures for Unloading the Dry Shielded Canister

Chapter 9 of the SAR details unloading procedures similar to those that the staff previously approved for use with the NUHOMS® HD System (ADAMS Accession No. ML070160089). Chapter 9 of the SAR includes steps to obtain a sample of the DSC atmosphere and to check for the presence of fission gas indicative of degraded fuel. If degraded fuel is suspected, the user of the cask is to plan, review, and implement additional measures appropriate for the specific conditions to minimize exposures to workers and radiological releases to the environment.

Specifically, the applicant stated in the SAR that the licensee should do the following to ensure operations safety:

- Monitor the applicable time limits for the unloading operations until the TC/DSC annulus is filled with water. The forced cooling will be initiated if the time limits for unloading cannot be met.
- Verify that the measured hydrogen concentration is below the limit of 2.4 percent during unloading operations. If the limit is exceeded, the licensee needs to stop all welding operations and purge the DSC cavity with approximately 2–3 psig helium to reduce the hydrogen concentration below the 2.4 percent limit.

The staff reviewed the operation procedures described in the SAR and finds that the steps described are appropriate for the unloading operations. The general licensees will develop its site-specific operation procedures following these general procedures and guidance.

9.3 Evaluation Findings

F9.1 The NUHOMS® EOS System is compatible with wet loading and unloading. Chapter 9 of the SAR summarizes the general procedures for these operations. Detailed procedures will need to be developed and evaluated on a site-specific basis.

F9.2 The welded cover plates of the EOS-37PTH and EOS-89BTH DSCs allow for the ready retrieval of the spent fuel for further processing or disposal, as required.

F9.3 The NUHOMS® EOS-37PTH and EOS-89BTH DSCs' geometry and general operating procedures facilitate decontamination. Only routine decontamination will be necessary after the cask is removed from the spent fuel pool.

F9.4 No significant radioactive waste is generated during operations associated with the ISFSI. Contaminated water from the spent fuel pool will be governed by the 10 CFR Part 50 license conditions.

F9.5 No significant radioactive effluents are produced during storage. Any radioactive effluents generated during the cask loading will be governed by the 10 CFR Part 50 license conditions.

F9.6 The technical bases for the general operating procedures described in the SAR are adequate to protect health and minimize danger to life and property. Detailed procedures will need to be developed and evaluated on a site-specific basis.

F9.7 Chapter 10 of the SER assesses the operational restrictions to meet the limits of 10 CFR Part 20. The site licensee may also establish additional site-specific restrictions.

The staff concludes that the generic procedures and guidance for the operation of the NUHOMS® EOS System are in compliance with 10 CFR Part 72 and that the applicable acceptance criteria have been satisfied. The evaluation of the operating procedure descriptions provided in the SAR offers reasonable assurance that the cask will enable the safe storage of spent fuel. This finding is based on a review that considered the regulations, appropriate regulatory guides, applicable codes and standards, and accepted practices.

9.4 References

Title 10, *Code of Federal Regulations*, Part 20, "Standards for Protection against Radiation."

Title 10, *Code of Federal Regulations*, Part 50, "Domestic Licensing of Production and Utilization Facilities."

Title 10, *Code of Federal Regulations*, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

U.S. Nuclear Regulatory Commission, Safety Evaluation Report, Docket No. 72-1030, Transnuclear, Inc. NUHOMS® HD Horizontal Modular Storage System for Irradiated Nuclear Fuel, 2010, ADAMS Accession No. ML070160089.

U.S. Nuclear Regulatory Commission, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," NUREG-1536, Revision 1, July 2010.

10.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAMS

10.1 Acceptance Tests

The applicant described the acceptance tests and maintenance program for the NUHOMS® EOS System in Chapter 10 of the SAR. The staff evaluated the information using the guidance in NUREG-1536 to ensure that all materials and components will be procured with certification and supporting documentation to assure compliance with procurement specifications and inspection upon receipt for visual and dimensional traceability. The staff finds that the acceptance tests and maintenance program for the NUHOMS® EOS DSC are in compliance with 10 CFR Part 72 and that the applicable acceptance criteria and industry standards have been satisfied.

10.1.1 Structural and Pressure Tests

Dry Shielded Canister

The applicant stated in Section 10.1.1.1 of the SAR that the DSC confinement boundary is fabricated, inspected, and tested in accordance with the ASME B&PV Code, Section III, Division 1, Subsection NB, with alternatives as specified in TS Section 4.4.4. The applicant stated that this is accomplished through a pneumatic pressure test of 1.1 times the DSC design pressure of 15 psig. The shell and inner bottom cover plate assembly are tested during fabrication, and the inner bottom cover plate and the closure weld are tested after final confinement boundary closure in the field.

The staff reviewed the test pressure for the DSC and finds that it in compliance with ASME B&PV Code, Section III, Division 1, Subsection NB-6000. Therefore, it is acceptable.

Horizontal Storage Module

The applicant stated that concrete mix design, placement, and testing are performed in accordance with ACI 318-08 and the minimum 28-day compressive strength is 5,000 psi, if controls are placed on the aggregate type or coefficient of thermal expansion. As an alternative to the controls on the aggregate type, the minimum specified 28-day compressive strength may be increased to 7,000 psi to account for the loss in strength resulting from the elevated temperature. The applicant stated that the compressive tests are conducted after heating the test cylinders to 500 °F in accordance with ACI 349-06.

Because the 28-day compressive tests meet the provisions of ACI 318-08 and ACI 349-06, the staff finds the concrete test acceptable.

Transfer Cask

The applicant stated that the TC assembly welds are performed in accordance with ASME B&PV Code, Section IX, and examined by magnetic particle examination to the acceptance standards of ASME B&PV Code, Section III, Division 1, Subsection NF-5340. The applicant stated that the upper trunnions of the TC are tested at fabrication to three times the design load, for use in the critical load non-redundant lifting, and inspected afterwards in accordance with ANSI N14.6. Additionally, the applicant stated that the liquid neutron shield tank is hydrostatically tested to 1.25 times the pressure relief valve setting shown on drawings EOS01-2003-SAR and EOS01-2010-SAR.

The staff reviewed the consensus codes and standards cited by the applicant and finds that the weld examinations, loads tests, and pressure tests are in accordance with the applicable codes and are therefore acceptable. The staff noted that the test pressure listed in the table in Section 10.1.1.3 for the TC108 (35 psig) is much greater than 1.25 times the relief valve pressure setting listed in note 8 of Drawing EOS01-2003-SAR (20 psig). However, because the test pressure is greater than that required by the code, the staff concludes that this is acceptable.

10.1.2 Leak Tests

The NUHOMS® EOS DSCs are designed to be leaktight and follow the measurements defined in ANSI N14.5-1997. The NUHOMS® EOS DSCs were tested during fabrication and demonstrated a leakage rate less than or equal to the leaktight criterion of $1{\times}10^{-7}$ ref·cm^3/s in ANSI N14.5-1997. The DSC inner top cover plate, port covers, and their welds are leak tested in the field to the same acceptance criterion after the SFAs are loaded. Leak testing procedures follow ASME B&PV Code, Section V, Article 10, Appendix IX; ASTM E1603-2014 "Standard Practice for Leakage Measurement Using the Mass Spectrometer Leak Detector or Residual Gas Analyzer in the Hood Mode"; or equivalent standard that provides the sensitivity required by ANSI N14.5. The staff finds this leaktight testing and the TS commitment to perform this testing acceptable.

10.1.3 Visual and Nondestructive Examination Inspections

In Section 10.1.3 of the SAR, the applicant described the inspection criteria for the fabrication of the storage system components. The applicant stated that, for components designed to a code or standard, the inspections are dictated by that code or standard. Some examples of the inspection criteria include the following:

- The DSC welds are examined in accordance with Class 1 nuclear facility components described in ASME B&PV Code, Section III, Division I, Subsection NB, and the alternatives to the ASME B&PV Code listed in Section 4.4.4 of the TS. For example, confinement boundary shell welds are subject to surface and volumetric non-destructive examination.

- The HSM concrete is visually inspected in accordance with ACI 311.4R, "Guide for Concrete Inspection," and the reinforcing steel placement is inspected in accordance with ACI 117, "Specification for Tolerances for Concrete Construction and Materials."

- The TC structural welds are inspected with magnetic particle testing, using acceptance criteria defined in ASME B&PV Code, Section III, Division I, Subarticle NF-5340.

The staff reviewed the applicant's proposed examinations to verify that they are consistent with the requirements of the applicable codes and standards. This review included verification that the fabrication standards (and thus the associated examination requirements) are characterized on the component drawings in Chapter 1 of the SAR. As documented in the staff's materials evaluation in Section 8.19 of this SER, this review also included confirmation that the applicant's proposed alternatives to the ASME B&PV Code examinations of the DSC field closure welds are consistent with the guidance in NUREG-1536. The staff finds the applicant's proposed examinations acceptable because they conform to the requirements of the fabrication codes and standards, as appropriate; they follow the recommendations in NUREG-1536 when alternatives to the ASME B&PV Code are used; and they are adequately described in the design drawings.

10.1.4 Shielding Tests

The applicant described fabrication and testing controls for each shielding material in Sections 10.1.4 and 9.1.5.1 of the SAR. The concrete used in the construction of the EOS-HSM shall be mixed, poured, and tested in accordance with procedures in SAR Appendix 1.D and dimensions in the design drawings. The HSM concrete is tested in accordance with ASTM C138-2014, "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete," in order to verify a minimum density of 140 lb per cubic foot. The EOS-TCs' lead shielding is installed as lead sheet or interlocking lead bricks, rather than being cast in place. The neutron shield material in the lid and bottom end is also installed as solid sheets of borated high-density polyethylene. Shielding performance is verified by material certification and dimensional inspection.

The neutron shield shell is filled with water during operations which provides the radial neutron shielding. The DSC's shielding performance has to be verified from the top and bottom shield plugs and cover plates. Material certifications and dimensional inspections need to be verified.

The staff reviewed the shielding fabrication testing and controls and effectiveness tests and found them acceptable. Each cask user will need to develop site-specific, detailed tests that incorporate the shielding effectiveness tests described in this section.

10.1.5 Neutron Absorber Tests

The staff reviewed the acceptance tests that are important to maintaining criticality safety. The NUHOMS® EOS relies heavily on fixed neutron absorbers in the DSC basket. The applicant specifies the required acceptance test to the fixed neutron absorbers in Section 10.1.5 of the SAR. For MMC, the applicant requires the material to be manufactured in accordance with ASTM C1671-2014, "Standard Practice for Qualification and Acceptance of Boron Based Metallic Neutron Absorbers for Nuclear Criticality Control for Dry Cask Storage Systems and Transportation Packaging," with B-10 areal density testing in accordance with ASTM E2971-2014, "Standard Test Method for Determination of Effective Boron-10 Areal Density in Aluminum Neutron Absorbers using Neutron Attenuation Measurements," or in accordance with ASTM D3171-2014, "Standard Test Methods for Constituent Content of Composite Materials," and ASTM C791-2014, "Standard Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Boron Carbide." For Boral, the applicant required that B-10 areal density testing be verified by chemical analysis and certification of the B-10 fraction for the boron carbide powder, or by neutron transmission testing. The tests are to be performed on a coupon taken from the sheet produced from each ingot, with all material produced from the ingot rejected if the sample should fail to meet the test criteria. These tests are consistent with the acceptance tests that have been approved for other spent fuel storage systems, and the staff finds them to be acceptable.

10.1.6 Thermal Acceptance

The applicant stated in SAR Section 10.1.6 that the thermal acceptance test is not required to verify the performance of each storage unit. SAR Section 10.3.3 states that in lieu of visual inspection for vent blockage, the licensee has the option to monitor the temperature by thermocouples or resistor detectors inserted into wells embedded in the HSM roof. The licensee is responsible for maintenance and calibration of this temperature monitoring instrumentation and data collection.

The staff finds that the acceptance tests and maintenance program described in SAR Chapter 10 are appropriate for the EOS-HSM storage system because the HSM thermal monitoring program, proposed by the applicant, will prevent conditions that could lead to exceeding the concrete and fuel clad temperature criteria.

10.1.7 Low Alloy, High-Strength Steel for Basket Structure

In Section 10.1.7 of the SAR, the applicant summarized the required testing for the ductility and fracture toughness of ferritic steels used in the DSC baskets. The staff finds these tests acceptable as documented in Section 8.5.3 of this SER.

10.2 Maintenance Programs

The applicant provided no maintenance requirements for the DSC, which contains the SSCs important to criticality. The applicant's analysis included cases in which fresh water flooded the TC, and a failure of the TC would have no impact on criticality safety. Thus, it is acceptable without maintenance requirements for the DSC.

10.2.1 Inspection

The applicant identified inspections to be performed on the exterior of a TC before each loading campaign for cracks, dents, gouges, tears, or damaged bearing surfaces. The applicant also provided inspections of the HSM for blockage of the inlet vents by either direct visual inspection or by temperature monitoring as specified in TS Section 5.1.3.

10.2.2 Tests

No tests are required for the TC or the HSM after the completion of fabrication during the initial license period.

10.3 Repair, Replacement, and Maintenance

The applicant described typical repair, replacement, and maintenance activities in Chapter 10 of the SAR. It noted that cracking or damages observed during visual inspection are generally entered into the licensee's corrective action program for repair or maintenance actions. The licensee is responsible for maintenance and calibration of monitoring instrumentation.

10.4 Evaluation Findings

F10.1 Chapter 10 of the SAR describes the applicant's proposed program for pre-operational testing, initial operations, and maintenance of the NUHOMS® EOS System.

F10.2 SSCs important to safety will be designed, fabricated, erected, tested, and maintained to quality standards commensurate with the importance to safety of the function they are intended to perform. Table 2-1 of the SAR identifies the safety importance of SSCs, and Chapter 3 of the SAR presents the applicable standards for their design, fabrication, and testing.

F10.3 The applicant will examine or test the DSC, or both, to ensure that it does not exhibit any defects that could significantly reduce its confinement effectiveness. Chapter 10 of the SAR describes this inspection and testing.

F10.4 Each DSC will be marked with a data plate indicating its model number, unique serial number, and empty weight.

The staff concludes that the acceptance tests and maintenance program for the NUHOMS® EOS DSC are in compliance with 10 CFR Part 72 and that the applicable acceptance criteria have been satisfied. The evaluation of the acceptance tests and maintenance program provides reasonable assurance that the cask will allow for the safe storage of spent fuel throughout its licensed or certified term. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted practices.

10.5 References

American Concrete Institute, “Building Code Requirements for Structural Concrete and Commentary,” ACI 318-08.

American Concrete Institute, “Code Requirements for Nuclear Safety Related Structures,” ACI 349-06.

American Concrete Institute, “Guide for Concrete Inspection,” ACI 311.4R.

American Concrete Institute, “Specification for Tolerances for Concrete Construction and Materials,” ACI 117.

American National Standards Institute, “Leakage Tests on Packages for Shipment of Radioactive Materials,” ANSI N14.5, 1997.

American National Standards Institute, “Radioactive Materials—Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4,500 kg) or More,” ANSI N14.6, 1993.

American Society of Mechanical Engineers, “ASME Boiler and Pressure Vessel Code,” 2010 Edition through 2011 Addenda.

ASTM International, “Standard Practice for Leakage Measurement Using the Mass Spectrometer Leak Detector or Residual Gas Analyzer in the Hood Mode,” ASTM E1603/E1603M, 2014.

ASTM International, “Standard Practice for Qualification and Acceptance of Boron Based Metallic Neutron Absorbers for Nuclear Criticality Control for Dry Cask Storage Systems and Transportation Packaging,” ASTM C1671, 2014.

ASTM International, “Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete,” ASTM C138/C138M, 2014.

ASTM International, “Standard Test Method for Determination of Effective Boron-10 Areal Density in Aluminum Neutron Absorbers using Neutron Attenuation Measurements,” ASTM E2971, 2014.

ASTM International, “Standard Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Boron Carbide,” ASTM C791, 2014.

ASTM International, “Standard Test Methods for Constituent Content of Composite Materials,” ASTM D3171, 2014.

Title 10, *Code of Federal Regulations*, Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste.”

U.S. Nuclear Regulatory Commission, “Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility,” NUREG-1536, Revision 1, July 2010.

11.0 RADIATION PROTECTION EVALUATION

This chapter evaluates the capability of the radiation protection design features, design criteria, and operating procedures of the NUHOMS® EOS System to meet regulatory dose requirements. The regulatory requirements for providing adequate radiation protection to site licensee personnel and members of the public include 10 CFR Part 20, 10 CFR 72.104(a), 10 CFR 72.106(b), 10 CFR 72.212(b), and 10 CFR 72.236(d).

Occupational exposures from the NUHOMS® EOS system are based on the direct radiation dose rates calculated in Chapter 6 of the SAR and the operating procedures discussed in Chapter 9 of the SAR. Doses to individuals beyond the controlled area boundary (members of the public) are determined from the direct radiation (including skyshine) dose rates calculated in Chapter 6 of the SAR and the dose rates from design-basis atmospheric releases calculated in Chapter 11 of the SAR.

Chapters 5, 6, and 9 discuss the NRC staff evaluations of the confinement features, shielding features, and operating procedures, respectively. This chapter discusses staff evaluations of the capability of shielding and confinement features during off-normal and accident conditions.

11.1 Radiation Protection Design Criteria and Features

11.1.1 Design Criteria

Section 11.4.1 of the SAR identifies the radiological protection design criteria as the limits and requirements in 10 CFR Part 20, 10 CFR 72.104, 10 CFR 72.106(b) and the following guidance:

- Regulatory Guide 1.8, “Qualification and Training of Personnel for Nuclear Power Plants,” Revision 2, issued April1987
- Regulatory Guide 8.8, “Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Is Reasonably Achievable,” Revision 3, issued June 1978
- Regulatory Guide 8.10, “Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As Is Reasonably Achievable,” Revision 1-R, issued May 1977

As required by 10 CFR Part 20 and 10 CFR 72.212, each general licensee is responsible for demonstrating site-specific compliance with these requirements. The TS establish surface dose limits on the EOS-HSM and the EOS-TCs that are based on calculated dose rate values used to determine occupational and offsite exposures. The TS also establish exterior contamination limits for the HSM and accessible portions of the DSC. This is consistent with NRC guidance, and the staff finds it acceptable.

11.1.2 Design Features

Section 11.4.2 of the SAR presents radiological protection design features that protect operational personnel and members of the public from radiation. These radiation protection design features include the following:

- The EOS-DSCs are loaded and sealed before transfer to the ISFSI. Seals are stainless steel welds with at least two layers.

- The fuel will not be unloaded, nor will the EOS-DSCs be opened, at the ISFSI unless the ISFSI is specifically licensed for these purposes.
- The fuel is stored in a dry, inert environment inside the EOS-DSCs so that no radioactive liquid is available for leakage.
- The EOS-DSCs are sealed with a helium atmosphere to prevent oxidation of the fuel. Chapter 8 of the SAR describes the leaktight design features.
- The EOS-DSCs are heavily shielded on both ends to reduce external dose rates. Chapter 6 of the SAR discusses the shielding design features.
- No radioactive material will be discharged during storage because the EOS-DSC is designed, fabricated, and tested to be leaktight.
- The outside surface of the EOS-DSC is free from contamination because of the use of clean water sealed in the annulus between the EOS-TC and EOS-DSC during loading operations.
- EOS-HSMs provide thick concrete shielding, while placement of modules immediately adjacent to one another enhances the effectiveness of this shielding.

Section 11.2.1 of the SAR also discusses design features that address the EOS-DSC loading, transfer, and storage operations, as well as the process of instrumentation and controls, control of airborne contaminants, decontamination, radiation monitoring, and others. In addition, Section 11.2.5 of the SAR addresses operational considerations and describes doses during ISFSI array expansion.

The NRC staff evaluated the radiation protection design features and design criteria for the EOS system and found them acceptable. The SAR analysis provides reasonable assurance that use of the NUHOMS® EOS System can meet the regulatory requirements in 10 CFR Part 20, 10 CFR 72.104(a), and 10 CFR 72.106(b).

11.2 Occupational Exposures

Section 11.2 of the SAR describes the occupational dose assessment. Section 11.2.1 explains that the calculations for the near-field dose rates were computed for the EOS-TC108 and EOS-TC125/135 in Chapter 6 of the SAR. As illustrated in Figure 11-1 of the SAR, dose rates were computed at the surface (R8), 30 cm (R9), 100 cm (R10), and 300 cm (R11) at various axial locations. EOS-TC dose rates were computed for three generalized operational configurations—loading/decontamination, welding/drying, and downending/transfer.

The total exposure results are as follows:

- EOS-TC108 with EOS-37PTH DSC: 3,361 person-mrem (~3.4 person-rem)
- EOS-TC108 with EOS-89BTH DSC: 3,270 person-mrem (~3.3 person-rem)
- EOS-TC125/135 with EOS-37PTH DSC: 2,081 person-mrem (~2.1 person-rem)
- EOS-TC125/135 with EOS-89BTH DSC: 1,680 person-mrem (~1.7 person-rem)

The applicant stated that the exposures provided above are bounding estimates. Measured exposures from typical NUHOMS® System loading campaigns have been 600 mrem or lower per canister for normal operations, and exposures for the NUHOMS® EOS System were expected to be similar. Also, Regulatory Guide 8.34, “Monitoring Criteria and Methods to Calculate Occupational Radiation Doses,” issued July 1992, is to be used to define the onsite occupational dose and monitoring requirements.

In Section 11.2.2, the applicant stated that the occupational exposures to ISFSI personnel during EOS-DSC retrieval are similar to those exposures calculated for EOS-DSC insertion. Also, dose rates for retrieval operations will be lower than those for insertion operations due to radioactive decay of the spent fuel inside the EOS-HSM. The dose rates for EOS-DSC retrieval are bounded by the dose rates calculated for insertion.

The NRC staff reviewed the overall occupational dose estimates and found them acceptable. The occupational exposure dose estimates provide reasonable assurance that occupational limits in 10 CFR Part 20, Subpart C, "Occupational Dose Limits," can be achieved. The staff expects that actual operating times and personnel exposure rates will vary for each cask depending on site-specific operating conditions, including detailed procedures and special measures taken to maintain exposures ALARA, and evolving experience with the EOS. Each licensee will have an established radiation protection program, as required in 10 CFR Part 20, Subpart B. In addition, each licensee will demonstrate compliance with occupational dose limits in 10 CFR Part 20, Subpart C, and other site specific 10 CFR Part 50 license requirements with evaluations and measurements. Chapter 9 of this SER presents the NRC staff's evaluation of the operating procedures.

11.3 ALARA

Section 11.4 of the SAR presents evidence that the NUHOMS® EOS System's radiation protection design features and design criteria address ALARA requirements, consistent with 10 CFR Part 20 and Regulatory Guides 8.8 and 8.10. The SAR states that each site licensee will apply its existing site-specific ALARA policies, procedures, and practices for cask operations to ensure that personnel exposure requirements in 10 CFR Part 20 are met. Because the EOS-TC108 is a lighter cask and provides less shielding, it results in larger exposures than the EOS-TC125/135. The EOS-TC108 results in a total computed exposure of approximately 3.4 person-rem; the exposure resulting from an EOS-TC108 crane hangup off-normal event is also considered. As stated in Chapter 2 of the SAR, the ALARA considerations dictate that the general licensee should use the EOS-TC108, provided the licensee is capable of using it.

The NRC staff evaluated the ALARA for the EOS-TC108 and EOS-TC125/135 and found the EOS system acceptable. Chapter 9 of the SER presents the staff's evaluation of how the operating procedures implement ALARA principles and practices. An ISFSI licensee is required by 10 CFR Part 20 to establish and implement ALARA policies, procedures, and practices during site operations. In addition, conditions in the TS establish limits for the surface dose rates and surface contamination on the EOS system, which are binding on ISFSI licensees.

11.4 Public Exposures from Normal and Off-Normal Conditions

Section 11.3 of the SAR summarizes the calculated dose rates to individuals beyond the controlled area (members of the public), as presented in Chapter 6 of the SAR. Two generic ISFSI designs were considered, a 2x10 back-to-back array and a two 1x10 front-to-front array. In the 2x10 back-to-back array, the rear and corner shield walls are absent because the rears of the EOS-HSMs are in contact. In the two 1x10 front-to-front arrays, the EOS-HSMs are aligned with the rear shield walls facing outward and the front of the EOS-HSMs facing inward, separated by approximately 35 ft. The staff found this configuration acceptable because it has the advantage of minimizing the dose rate near the ISFSI. The inlet vents are directed inward in an area that would not normally be occupied. Tables 11-8 and 11-9 of the SAR summarize the MCNP results for the 2x10 back-to-back and two 1x10 front-to-front configurations, respectively.

The SAR indicates that the total annual exposure for each ISFSI layout as a function of distance from each face is provided in Table 11-6 and plotted in Figure 11-2. The total annual exposure estimates are based on 100 percent occupancy for 365 days. At longer distances, the annual exposure from the 2x10 back-to-back array is similar to the two 1x10 front-to-front array configuration.

As discussed in Chapter 6 of the SER, in accordance with 10 CFR 72.104, the applicant concluded that 370 meters is the minimum distance with design-basis fuel to the site boundary for a 20-cask array with the EOS. However, a shorter distance may be demonstrated in a site-specific calculation. These calculations were performed without dose reduction hardware in the inlet and outlet vents, which would reduce the offsite dose rates by 30 to 60 percent.

Section 11.3.2 of the SAR presents calculated dose rates for accident conditions. MCNP inputs for a 2x10 ISFSI accident configuration are prepared using the same method as described for the normal condition models. At distances of 200 meters and 370 meters from the ISFSI, the accident dose rate is approximately 1.1 mrem/hr and 0.1 mrem/hr, respectively. The applicant assumed that the recovery time for this accident is 5 days (120 hours). Therefore, the total exposures to an individual at distances of 200 meters and 370 meters are 132 mrem and 12 mrem, respectively. This is significantly less than the limit of 5 rem stated in 10 CFR 72.106.

In a design basis accident during cask transfer operations, resulting in damage to the EOS-TC, an offsite dose is projected. In its analysis of accident conditions, the applicant assumed the absence of a neutron shield, including the steel or aluminum shell. The applicant documented the EOS-TC accident calculations in Section 6.4.3 of the SAR and presented the results in Table 6-54 of the SAR. The maximum dose rate is 2.15 mrem/hr at a distance of 100 meters from the EOS-TC. Assuming an 8-hour recovery time, the dose to an individual at the site boundary is 17 mrem, a dose that is significantly below the 10 CFR 72.106 limit of 5 rem for the controlled area of the site. This estimated site boundary dose is conservative because it was calculated at a distance of 100 meters from the EOS-TC.

The staff evaluated the public dose estimates from direct radiation and the assumed atmospheric release from normal and off-normal (anticipated) conditions and found them acceptable. Chapters 5 and 6 of this SER present the staff's evaluation and confirmatory analysis of the shielding and confinement dose calculations. The staff concludes that the calculated dose rates from design-basis confinement releases are insignificant compared to the dose rates from direct radiation. Therefore, direct radiation (including skyshine) is the primary dose pathway to individuals beyond the controlled area during normal and off-normal conditions.

The staff has reasonable assurance that each general licensee can achieve compliance with 10 CFR 72.104(a). The general licensee using the NUHOMS® EOS System must perform a site-specific evaluation, as required by 10 CFR 72.212(b), to demonstrate compliance with 10 CFR 72.104(a). The actual doses to individuals beyond the controlled area boundary depend on several site-specific conditions, such as fuel characteristics, cask-array configuration, topography, demographics, atmospheric conditions, and use of engineered features (e.g., berms). In addition, the dose limits in 10 CFR 72.104(a) include doses from other fuel cycle activities, such as reactor operations. Consequently, each applicant for a site license is responsible for the final determination of compliance with 10 CFR 72.104(a).

The general licensee will also have an established radiation protection program as required by 10 CFR Part 20, Subpart B, and will demonstrate compliance with dose limits to individual members of the public, as required by 10 CFR Part 20, Subpart D, by evaluations and measurements.

With regard to engineered features used for radiological protection, TS 4.5.3 states that engineering features (e.g., berms and shield walls) used to ensure compliance with 10 CFR 72.104(a) are to be considered important to safety and must be evaluated to determine the applicable QA category.

11.5 Evaluation Findings

F11.1 The SAR sufficiently describes the radiation protection design bases and design criteria for the SSC important to safety.

F11.2 Radiation shielding and confinement features of the NUHOMS® EOS System are sufficient to meet the radiation protection requirements of 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106.

F11.3 The NUHOMS® EOS System is designed to provide redundant sealing of confinement systems.

F11.4 The NUHOMS® EOS System is designed to facilitate decontamination to the extent practicable.

F11.5 The SAR adequately evaluates the NUHOMS® EOS System and its systems important to safety to demonstrate that they will reasonably maintain confinement of radioactive material under normal, off-normal, and accident conditions.

F11.6 The SAR sufficiently describes the means for controlling and limiting occupational exposures within the dose and ALARA requirements of 10 CFR Part 20.

F11.7 The site licensee is responsible for imposing the operational restrictions necessary to meet dose and ALARA requirements in 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.06. The applicant is designed to assist in meeting these requirements.

The staff concludes that the design of the radiation protection system for the NUHOMS® EOS System is in compliance with 10 CFR Part 72, and the applicable design and acceptance criteria have been satisfied. The evaluation of the radiation protection system's design provides reasonable assurance that the EOS system will provide for the safe storage of spent fuel. This finding is based on a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

11.6 References

Title 10, *Code of Federal Regulations*, Part 20, "Standards for Protection against Radiation."

Title 10, *Code of Federal Regulations*, Part 50, "Domestic Licensing of Production and Utilization Facilities."

Title 10, *Code of Federal Regulations*, Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste.”

U.S. Nuclear Regulatory Commission, “Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Is Reasonably Achievable,” Regulatory Guide 8.8, Revision 3, June 1978.

U.S. Nuclear Regulatory Commission, “Monitoring Criteria and Methods to Calculate Occupational Radiation Doses,” Regulatory Guide 8.34, July 1992.

U.S. Nuclear Regulatory Commission, “Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As Is Reasonably Achievable,” Regulatory Guide 8.10, Revision 1-R, May 1977.

U.S. Nuclear Regulatory Commission, “Qualification and Training of Personnel for Nuclear Power Plants,” Regulatory Guide 1.8, Revision 2, April 1987.

U.S. Nuclear Regulatory Commission, “Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility,” NUREG-1536, Revision 1, July 2010.

12.0 ACCIDENT ANALYSIS EVALUATION

The purpose of the staff's review of the accident analyses is to evaluate the applicant's identification of hazards and the summary analyses of the NUHOMS® EOS system's response to off-normal and accident or design-basis events. This review ensures that the applicant has conducted a thorough accident analysis in accordance with applicable regulatory requirements. Chapter 12 of the SAR presents the applicant's accident analyses.

12.1 Off-Normal Conditions

Off-normal events are those designated as Design Event II, as defined by ANSI/American Nuclear Society (ANS) 57.9-1984. These events are described as infrequent, but can be expected to occur on the order of once per year. The applicant described the NUHOMS® EOS system off-normal events and provided analyses to demonstrate the adequacy of the system design to accommodate these conditions in Section 12.2 of the SAR. The off-normal events addressed by the applicant include the following conditions.

12.1.1 Off-Normal Transfer Load

The applicant postulated that if the EOS-TC is not accurately aligned with respect to the EOS-HSM, the result could be a DSC that binds or jams during transfer operations. The applicant stated that the design features of the DSC and the EOS-HSM support rails decrease the likelihood of binding. The applicant also stated that an increase in the ram pressure would indicate binding of the DSC. Administrative controls limit the applied ram pressure during loading and unloading operations. These controls will ensure that an insertion force of 135 kips and retrieval force of 80 kips is not exceeded. The applicant analyzed the DSC for these forces under off-normal conditions of loading in Section 3.9.4 of the SAR and demonstrated that no breaching of the containment boundary or permanent deformation of the DSC will occur. In the event of binding of the DSC, the applicant stated that the operation would be halted, the movement reversed, alignment rechecked, and the EOS-TC would be repositioned as necessary before attempts to resume transfer. The staff finds the actions proposed by the applicant to limit the force placed on the DSC during loading and unloading are acceptable. Additionally, in SER Section 3.5.1, the staff concludes that the normal and off-normal conditions of loading will not cause breaching of the containment boundary.

12.1.2 Extreme Ambient Temperatures

The applicant stated in SAR Section 12.2.2 that the NUHOMS® EOS System is designed for use at an ambient temperature range of -40 °F – 117 °F. Licensees should verify that this range of ambient temperatures bounds the design basis ambient temperatures for their specific ISFSI site. The applicant noted in SAR Section 4.3 and TS 4.5.3 that a daily average ambient temperature of 103 °F is used in the evaluations, corresponding to a daily maximum temperature of 117 °F for the off-normal hot storage conditions.

The staff reviewed the load cases of extreme ambient temperatures for storage (SAR Table 4-5) and on-site transfer conditions (SAR Table 4-23) in SAR thermal section. The conditions evaluated include (1) the load case #3—the bounding off-normal hot storage condition as shown in SAR Table 4-5 and (2) the load case #3—the bounding off-normal transfer condition as shown in SAR Table 4-23.

Under off-normal storage conditions for the EOS-37PTH DSC in EOS-HSM, the staff finds the PCTs and the maximum DSC component temperatures of the storage load case #3, reported by the applicant in SAR Tables 4-5 and 4-6, fall below the allowable temperature limits under off-normal storage conditions. Under off-normal on-site transfer conditions for the EOS-37PTH DSC in EOS-HSM, the staff also finds the PCTs and the maximum DSC component temperatures of the transfer load case #3, reported by the applicant in SAR Tables 4-24 and 4-29, fall below the allowable temperature limits under off-normal transfer conditions.

Under off-normal storage conditions for the EOS-89BTH DSC in EOS-HSM, the staff finds the maximum fuel cladding and key component temperatures for load case #3 fall below the allowable temperature limits (see SAR Table 4-17). Under off-normal on-site transfer conditions for the EOS-89BTH DSC loaded in EOS-TC125, the maximum fuel cladding and key component temperatures for load case #3 fall below the allowable temperature limits (SAR Table 4-34). Both the off-normal storage and off-normal transfer conditions are calculated considering extreme ambient temperature of 117°F. The thermal analysis of EOS-89BTH DSC (with a maximum heat load of 43.6 kW) is bounded by the thermal analysis of the EOS-37PTH DSC (with a maximum heat load of 50 kW) because of the small heat load in EOS-89BTH DSC. Therefore, fuel cladding and key components of EOS-89BTH DSC, when loaded in EOS-HSM or EOS-TC125, will remain below the maximum allowable temperatures. See the corresponding limits in SAR Table 4-17 for storage conditions and in SAR Table 4-34 for transfer conditions.

Therefore, the staff confirmed that the NUHOMS® EOS system is capable of heat removal with fuel cladding, and DSC component temperatures for both EOS-37PTH DSC and EOS-89BTH DSC are below the allowable limits at ambient temperature up to 117 °F and therefore are in compliance with the thermal requirements in 10 CFR Part 72.

12.2 Accident Events and Natural Phenomena

Accident events and conditions are those designated as Design Events III and IV, as defined by ANSI/ANS 57.9-1984, “Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type).” These are very low-probability events that may occur once during the lifetime of the ISFSI or are hypothetical events considered because their consequences could result in the maximum potential impact on the surrounding environment. These postulated events include human-induced, low-probability events and natural phenomena. The applicant provided analyses to demonstrate the adequacy of the NUHOMS® EOS System design to withstand the postulated accidents described in Section 12.3 of the SAR. The events addressed by the applicant include the postulated accident conditions described below.

12.2.1 EOS-TC Drop

The applicant considered a 65-inch side or corner drop of the EOS-TC from the transfer skid or trailer to be the only credible drop accident because lifts of the EOS-TC are made within the existing heavy loads requirements and procedures of the licensed nuclear power plants. In Appendix 3.9.3 to the SAR, the applicant demonstrated that the confinement barriers of the EOS-37PTH DSC nor the EOS-89BTH DSC will not be breached as a result of the postulated 65-inch drops. Although the applicant’s analysis indicate that the neutron shield could be damaged, it also indicates the resulting dose rates will be kept below the 10 CFR 72.106 limits during the recovery period, as confirmed in Chapters 6 and 11. Section 3.6.1 of this SER presents the staff’s evaluation of the applicant’s analysis and concludes that the stresses in the DSC confinement boundaries are less than those required for material failure; therefore, the confinement boundary will not be breached and that there will be no radiological consequences from this event.

12.2.2 Earthquake

The applicant considered a design seismic event that produces a horizontal acceleration of 0.45 g and a vertical acceleration of 0.30 g at the top of the storage pad. The applicant analyzed a postulated seismic event in Appendices 3.9.1, 3.9.2, 3.9.4, and 3.9.5 of the SAR for the EOS-DSC shell, the EOS basket, the EOS-HSM, and the EOS-TC, respectively. The staff concludes that the NUHOMS® EOS System performance under seismic loading conditions is acceptable in that all components will maintain their structural capacity, continue to perform their designated safety function, and that there will be no breaches in the DSC and no radiological consequences from this event.

The applicant also evaluated the EOS-HSM, the EOS-DSC, and EOS-TC for stability (the ability to resist tipover and sliding) in the event of an earthquake. The staff concludes that the EOS-HSM and the EOS-TC are stable against overturning and that the EOS-DSC will remain on the support rails for the design earthquake defined by a maximum acceleration at the top of the pad of 0.45 g in the horizontal direction and 0.30 g in the vertical direction.

Because the applicant designed the NUHOMS® EOS System's components to withstand the design-basis earthquake accident, the staff concludes that no radiation will be released and no increased dose to the public will occur as a result of a design-basis event.

12.2.3 Tornado Wind and Tornado Missiles Effects on the EOS-HSM

The applicant stated that the EOS-HSM is designed to withstand tornado wind loads, including those from tornado-generated missiles. The applicant designed the NUHOMS® EOS System to the criteria specified in NUREG-0800 and NRC Regulatory Guide 1.76, Revision 1. The applicant's analyses assume a maximum tornado wind velocity of 230 mph and a spectrum of tornado-driven missiles, including a 4,000-lb automobile with a 20-square-foot frontal area moving at 113 fps, 15-foot diameter, schedule 40 pipe traveling at 135 fps, and a 1-inch-diameter steel sphere traveling at 26 fps.

The staff concludes that a tornado wind speed of 230 mph will not tip over the EOS-HSM or exceed the allowable stresses in the concrete components. The staff also concludes that the concrete components have sufficient capacity to withstand the effects of the full spectrum of tornado missiles analyzed. Therefore, the DSC confinement boundary will remain intact for all postulated tornado events. The applicant determined that damage to the concrete HSM from tornado-induced missiles could reduce the effectiveness of its shielding. However, the staff concludes that any resulting increase in radiation exposure to an individual at the controlled area boundary is expected to be well below the 5 rem limit for accidents required by 10 CFR 72.106(b). For this reason, the staff has reasonable assurance that the public health and safety will be protected.

12.2.4 Tornado Wind and Tornado Missiles Effects on the EOS-TC

The applicant analyzed the EOS-TC for the effects of a postulated tornado, including those from tornado-generated missiles, and used stability, penetration, and stress as the evaluation criteria. The applicant designed the EOS-TC to the criteria specified in NUREG-0800 and NRC Regulatory Guide 1.76, Revision 1. The applicant's analyses assume a maximum tornado wind velocity of 230 mph and the same spectrum of tornado-driven missiles as was used for the EOS-HSM.

The staff concludes that a tornado wind speed of 230 mph will not tip over the EOS-TC or exceed the allowable stresses in the TC. The staff also concludes that the EOS-TC has sufficient capacity to withstand the effects of the full spectrum of tornado missiles analyzed. Therefore, the DSC confinement boundary will remain intact for all postulated tornado events. For this reason, the staff has reasonable assurance that the public health and safety will be protected.

12.2.5 Flood

The applicant considered the effects of flood loads on the HSM concrete components in the accident combined loads. Additionally, the applicant considered the potential for HSM tipover and sliding under conditions of a maximum water depth of 50 feet and a maximum velocity of 15 fps acting on the HSM.

The staff concludes that a flooding event will not tip over the HSM and that allowable stresses on the concrete components will not be exceeded when accounting for the additional flood loading. Therefore, the staff has reasonable assurance that the radiological impacts as a result of the EOS-HSM flooding event will be negligible because the DSC will remain intact and the confinement boundary will not breached.

12.2.6 Blockage of EOS-HSM Air Inlet and Outlet Openings

The applicant stated that there is a remote probability that debris from events such as floods and tornadoes could block the ventilation air inlet and outlet openings. Based on the thermal analysis in Sections 4.4.5 and 4.4.11 of the SAR, the applicant demonstrated in the structural analysis that the EOS-HSM component stresses remain below the allowable values. The staff concludes that there are no adverse effects or significant offsite dose consequences resulting from this accident scenario because confinement and shielding are unaffected. The staff finds the applicant’s analysis of this event acceptable.

12.2.6.1 Blockage of EOS-HSM Air Inlet and Outlet Vents (Postulated Accident)

SAR Section 12.3.6 states that the NUHOMS® EOS System design features, such as perimeter security fence and the redundant protected location of the air inlet and outlet vents, reduce the probability of occurrence of such an accident.

The applicant performed thermal evaluations of an accident condition, with 100-percent blockage at inlet and outlet vents for 40 hours (load case 5 as described in SER Table 4-4). SAR Tables 4-5 through 4-7 and Tables 4-17 through 4-19 present the temperature results of this event for the EOS-37PTH DSC and EOS-89BTH DSC, respectively, loaded in an EOS-HSM.

The staff reviewed SAR Sections 4.4.5 and 4.4.11 and the maximum temperatures of fuel cladding and DSC components, as shown in SAR Tables 4-5 through 4-7 and Tables 4-17 through 4-19, for the bounding accident condition (load case 5). The staff confirmed that both fuel cladding and key component temperatures of EOS-37PTH DSC and EOS-89BTH DSC, when loaded within the EOS-HSM with 100 percent blockage at inlet and outlet vents, are below the corresponding limits, in compliance with 10 CFR Part 72. The staff finds that the

NUHOMS® EOS cask is able to provide adequate assurance for heat removal capability without active cooling under the HSM thermal monitoring program specified in TS 5.1.3.

12.2.6.2 Loss/Damage of Wind Deflector (Postulated Accident)

SAR Section 12.3.3 states that the wind deflectors could also become lost or damaged by extreme winds, tornadoes, or similar accidents. Based on the analytical results in SAR Appendix 4.9.4, the applicant stated that the analysis performed for the EOS-37PTH DSC bounds the values for the EOS-89BTH DSC, and the condition caused by a lost or damaged wind deflector is bounded by the blocked vent accident condition for both the EOS-37PTH DSC and EOS-89BTH DSC.

The staff compared the maximum temperatures of the fuel cladding and DSC components under 40-hour blocked vent accident conditions (SAR Sections 4.4.5 and 4.4.11) with those from a loss of the wind deflector (SAR Appendix 4.9.4). The staff finds that the temperatures in accident conditions caused by a damaged or lost wind deflector are bounded by those in the accident condition of air vent blockage. Therefore, the duration of a damaged or lost wind deflector will not exceed periods longer than 40 hours as assumed in the SAR analysis for vent blockage. The staff confirmed that the maximum cladding and component temperatures are below the corresponding limits in a period of 24 hours. Therefore, the staff finds that performance of a daily visual inspection of wind deflectors, as required by TS 5.1.3, is appropriate and acceptable to ensure the fuel cladding temperatures remain below the required limit of 400 ˚C (752 ˚F) with loss or damage of the wind deflectors.

12.2.7 Lightning

The applicant stated that lightning striking the EOS-HSM and causing an off-normal condition is not a credible event and that lightning protection system requirements are site specific and depend on the frequency of occurrence. The applicant asserted that if lightning strikes in the vicinity of the EOS-HSM, the current discharged by the lightning will follow the low-impedance path offered by the surrounding structures. Therefore, the EOS-HSM will not be damaged by the heat or mechanical forces generated by the current passing through the high-impedance concrete. The staff finds that the applicant’s reasoning is consistent with accepted engineering principles and concludes that lightning will not have an adverse effect on the NUHOMS® EOS System.

12.2.8 Fire/Explosion

SAR Section 12.3.8 states that, because combustible materials are not normally stored at an ISFSI, a credible fire will be small and of short duration and any fire within the ISFSI boundary while the DSC is in the EOS-HSM would be bounded by the fire during EOS-TC movement.

The staff reviewed SAR Section 4.5.5 on the hypothetical fire accident, Section 12.3.8 on fire and explosion, and the maximum temperatures of the EOS-TC125 loaded with the EOS-37PTH DSC at 50 kW, loss of neutron shield, and loss of air circulation. The staff finds that the direct engulfment of the EOS-HSM is highly unlikely during storage or onsite transfer because (1) the EOS-HSM concrete acts as a significant insulating fire wall to protect the DSC from the high temperature of the fire, and (2) the short period of fire accident is bounded by the loss of neutron shield and the loss of air circulation accident (load case 5 in SAR Section 4.5.5 and Table 4-28) in which the PCT and maximum DSC component temperatures are below the allowable limits.

The staff finds that the applicant's analysis of the explosion event is acceptable. No offsite radiological impacts are expected to result from fire or explosion events. Some additional dose to workers may be incurred in responding to or recovering from such events, but such doses are not expected to be substantial.

12.3 Evaluation Findings

F12.1 The SSCs of the NUHOMS® EOS System are adequate to prevent accidents and to mitigate the consequences of accidents and natural phenomena events that do occur.

F12.2 The applicant has evaluated the NUHOMS® EOS System to demonstrate that it will reasonably maintain confinement of radioactive material under credible accident conditions.

F12.3 An accident or natural phenomena event will not preclude the ready retrieval of spent fuel for further processing or disposal.

F12.4 The spent fuel will be maintained in a subcritical condition under accident conditions. Neither off-normal nor accident conditions will result in a dose to an individual outside the controlled area that exceeds the limits of 10 CFR 72.104(a) or 10 CFR 72.106(b), respectively.

The staff concludes that the accident design criteria for the NUHOMS® EOS System are in compliance with 10 CFR Part 72 and the accident design and acceptance criteria have been met. The applicant's accident evaluation of the cask adequately demonstrates that it will provide for the safe storage of spent fuel during credible accident situations. This finding is reached based on independent confirmatory calculations, compliance with the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

12.4 References

American National Standards Institute, American Nuclear Society, "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type)," ANSI/ANS 57.9, 1984.

Title 10, *Code of Federal Regulations*, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

U.S. Nuclear Regulatory Commission, "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants," Regulatory Guide 1.76, Revision 1, March 2007.

U.S. Nuclear Regulatory Commission, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," NUREG-0800, Revision 3, March 2007.

13.0 CONDITIONS FOR CASK USE—TECHNICAL SPECIFICATIONS

In this section of the SER, the NRC staff evaluates the operating controls and limits and the TS, including the bases and justification that the applicant established as conditions of use for the NUHOMS® EOS System.

For simplicity in defining the acceptance criteria and review procedures, the term “TS” may be considered synonymous with operating controls and limits. The conditions for use and TS define the conditions that are deemed necessary for safe operation of the NUHOMS® EOS System. Specifically, they define operating limits and controls, monitoring instruments and control settings, surveillance requirements, design features, and administrative controls that ensure safe operation of the NUHOMS® EOS System. As such, the CoC includes these conditions for use and TS.

13.1 Conditions for Use

The NRC staff developed the conditions for use of the NUHOMS® EOS System in accordance with the guidance provided in NUREG 1745, “Standard Format and Content for Technical Specifications for 10 CFR Part 72 Cask Certificates of Compliance,” issued June 2001. The staff derived the conditions from analysis and evaluations provided in the SAR for the NUHOMS® EOS System. These conditions pertain to the design, construction, and operation of the system.

13.2 Technical Specifications

Chapter 13 of the SAR describes the TS required to ensure that the NUHOMS® EOS System is operated safely. The TS were established so that a general licensee can implement requirements for the design, construction, and operation of the NUHOMS® EOS System in accordance with 10 CFR Part 72. An appendix to the CoC for the NUHOMS® EOS System contains the TS, as approved by the staff, which address the following areas:

- use and application
- functional and operating limits
- applicability of LCOs and surveillance requirements
- design features
- administrative controls

Table 13-1 of this SER lists the TS to be implemented for the NUHOMS® EOS System.

Table 13-1 NUHOMS® EOS System TS

1.0 Use and Applications
- 1.1 Definitions
- 1.2 Logical Connectors
- 1.3 Completion Times
- 1.4 Frequency

2.0 Functional and Operating Limits
- 2.1 Fuel To Be Stored in the EOS-37PTH DSC
- 2.2 Fuel To Be Stored in the EOS-89BTH DSC
- 2.3 Functional and Operating Limits Violations

3.0 Limiting Condition for Operation and Surveillance Requirement Applicability
- 3.1 Dry Shielded Canister Fuel Integrity
- 3.2 Cask Criticality Control
- 3.3 Radiation Protection

4.0 Design Features
- 4.1 Site
- 4.2 Storage System Features
- 4.3 Canister Criticality Control
- 4.4 Codes and Standards
- 4.5 Storage Location Design Features

5.0 Administrative Controls
- 5.1 Programs
- 5.2 Lifting Controls
- 5.3 Concrete Testing
- 5.4 Hydrogen Gas Monitoring
- 5.5 EOS-HSM Wind Deflectors

13.3 Evaluation Findings

F13.1 Table 13-1 of the SER lists the TS for the use of the NUHOMS® EOS System. These technical specifications are contained as part of the Certificate of Compliance.

The staff concludes that the conditions for using the NUHOMS® EOS System identify the TS necessary to satisfy the requirements of 10 CFR Part 72 and the staff finds the applicable acceptance criteria have been satisfied. The TS provide reasonable assurance that the cask will provide 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 practices.

13.4 References

Title 10, *Code of Federal Regulations*, Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste.”

U.S. Nuclear Regulatory Commission, “Standard Format and Content for Technical Specifications for 10 CFR Part 72 Cask Certificates of Compliance,” NUREG-1745, Revision 0, June 2001.

14.0 QUALITY ASSURANCE

14.1 Review Objective

The purpose of the NRC staff's review is to determine whether the applicant for approval of the NUHOMS® EOS System has a QA program that complies with the requirements of 10 CFR Part 72, Subpart G, "Quality Assurance." The staff bases its determination on a thorough review and evaluation of the QA program described in the application. The staff review assesses whether the QA program satisfies the conditions of approval in 10 CFR 72.234(b). This chapter documents the results of the staff's review and evaluation.

The staff recognizes that the NUHOMS® EOS System is an improved version of the NUHOMS® HD System described in CoC No. 1030, which the staff approved in 2007. The NRC staff reviewed the application and supplements to the application using guidance in NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," Revision 1, July 2010. Based on the statements and representations in the application, as supplemented, and the conditions specified in the CoC (ADAMS Accession No. ML14288A473) and TS (ADAMS Accession No. ML14288A500), the staff concluded that the requested changes met the requirements of 10 CFR Part 72. The EOS-TC and EOS-HSM proposed in the current application are similar to the TC and HSM-H approved by CoC No. 1030.

14.2 Areas of Review

The complete description and specific commitments of the QA program are contained in the TN Americas LLC, QA Program Description Manual (QAPD Manual). NRC inspectors verify the proper implementation of the QA program by conducting performance inspections. The applicant developed the QAPD Manual to enhance compliance with 10 CFR Part 71, Subpart H, and 10 CFR Part 72, Subpart G, "Quality Assurance." The QAPD Manual describes the QA requirements that apply to the design, licensing, procurement, fabrication, handling, shipping, cleaning, assembly, inspection, modification, testing, operation, repair, maintenance, and lease of storage and transport systems for spent fuel and radioactive materials that are classified as important-to-safety and subject to the requirements of 10 CFR Part 71 and 10 CFR Part 72.

14.3 Evaluation Findings

F14.1 The QA program continues to meet the acceptance requirements. TN Americas LLC's QAPD Manual describes requirements, procedures, and controls that, when properly implemented, comply with the requirements of 10 CFR Part 72, Subpart G.

F14.2 The QAPD Manual covers activities affecting SSCs important to safety as identified in the SAR. Organizations and persons performing QA functions have the independence and authority to perform their functions without undue influence from those directly responsible for costs and schedules;

F14.3 The licensee's description of the QA program describes organizations and persons performing QA functions and indicates that sufficient independence and authority should exist to perform their functions without undue influence from those directly responsible for costs and schedules.

F14.4 The description of the QA program is in compliance with applicable NRC regulations and industry standards, and the QA program can be implemented for the design, fabrication and construction, and operation phases of the installation's life cycle.

14.4 References

TN Americas LLC, "TN Americas LLC Quality Assurance Program Description Manual for 10 CFR Part 71, Subpart H and 10 CFR Part 72, Subpart G," current revision.

Title 10, *Code of Federal Regulations*, Part 71, "Packaging and Transportation of Radioactive Material."

Title 10, *Code of Federal Regulations*, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

U.S. Nuclear Regulatory Commission, "Standard Review Plan for Spent Fuel Dry Cask Storage Systems at a General License Facility," NUREG-1536, Revision 1, July 2010.

15.0 CONCLUSIONS

15.1 Overall Conclusion

The staff performed a detailed safety evaluation of the application for a 10 CFR Part 72 CoC for the NUHOMS® EOS System. The staff performed the review in accordance with the guidance in NUREG-1536. Based on the statements and representations contained in the SAR and the conditions in the CoC, the staff concludes that the NUHOMS® EOS System meets the requirements of 10 CFR Part 72.

15.2 References

Title 10, *Code of Federal Regulations*, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

U.S. Nuclear Regulatory Commission, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," NUREG-1536, Revision 1, July 2010.