APPENDIX A

APPENDIX A.1
GENERAL INFORMATION

Table of Contents

List of Tables

List of Figures

A.1 GENERAL INFORMATION

Appendix A to the NUHOMS® EOS Updated Final Safety Analysis Report (UFSAR) addresses the Important to Safety aspects of adding the NUHOMS® MATRIX (HSM-MX) to the NUHOMS® EOS System described in the UFSAR. The HSM-MX is added to the UFSAR as an alternative to the EOS horizontal storage module (EOS-HSM). The primary reason for adding HSM-MX is to reduce the footprint of the current EOS-HSM, which will allow for greater storage capability on an independent spent fuel storage installation (ISFSI) pad than that currently available.

The HSM-MX is a two-tiered staggered, high-density horizontal storage module (HSM), which contains compartments to accommodate dry shielded canisters (DSCs) with various diameters and lengths (See Figure A.1-7 and Figure A.1-8). The HSM-MX provides an independent, passive system with heat removal capacity sufficient to ensure that peak cladding temperatures during long-term storage of spent fuel assemblies remain below acceptable limits to ensure fuel cladding integrity.

The format of this appendix has been prepared in compliance with the information and methods defined in Revision 1 to U.S. Nuclear Regulatory Commission (NRC) NUREG-1536 [A.1-2]. The analyses presented in this appendix demonstrate that the HSM-MX System meets all the requirements of 10 CFR Part 72 [A.1-1].

Note: References to sections or chapters within this appendix are identified with a prefix A (e.g., Section A.2.3, Appendix A.2.3, Chapter A.2, or Appendix A.2). References to sections or chapters of the UFSAR outside of this Appendix (i.e., main body of the UFSAR) are identified with the applicable UFSAR section or chapter number (e.g., Section 2.3 or Chapter 2).

Where the term "HSM" is used without distinction, this term shall *apply* to both the EOS-HSM and HSM-MX. 72.48

A.1.1 Introduction

This appendix adds the HSM-MX to the NUHOMS® EOS System. Only those features that are being revised or added to the NUHOMS® EOS System are addressed and evaluated in this appendix. Sections of this appendix that are not affected by the addition of the HSM-MX are indicated in this appendix with "No Change." The various DSCs and transfer cask (TC) in the NUHOMS® EOS System remain generally unchanged.

The HSM-MX is a staggered, two-tiered reinforced monolithic structure, consisting of massive reinforced concrete compartments that increase resistance to earthquakes and offer significant self-shielding. The HSM-MX is capable of withstanding all normal/*off-normal* condition loads, as well as the *accident* condition loads created by earthquakes, tornadoes, flooding, and other natural phenomena hazards. The DSCs are axially restrained to prevent movement during seismic events. 72.48

The system is equipped with special design features for enhanced shielding and heat rejection capabilities.

The HSM-MXs are arranged in arrays and fully expandable to permit modular expansion in support of operating power plants. The HSM-MX can be arranged in either a single-row or back-to-back arrangement. The thick concrete monolith of the HSM-MX provides substantial neutron and gamma shielding.

A.1.2 General Description and Operational Features of the NUHOMS® MATRIX

A.1.2.1 NUHOMS® MATRIX CHARACTERISTICS

The NUHOMS® MATRIX provides a staggered two-tiered self-contained modular structure for storage of spent fuel canistered in an EOS-37PTH or EOS-89BTH DSC. The HSM-MX is constructed from reinforced concrete and structural steel. Contact doses for the HSM-MX are designed to be as low as reasonably achievable (ALARA). The key design parameters of the HSM-MX are listed in Table A.1-1.

In lieu of a separate roof and separate shield walls, those features are integral to the monolith in the HSM-MX.

The HSM-MXs provide an independent, passive system with substantial structural capacity to ensure the safe dry storage of spent fuel assemblies (SFAs). To this end, the HSM-MXs are designed to ensure that normal transfer operations and postulated accidents or natural phenomena do not impair the DSC or pose a hazard to the public or plant personnel. Postulated accidents and natural phenomena affecting the HSM-MX are described in detail in Chapter A.12.

The HSM-MX provides a means of removing spent fuel decay heat by a combination of radiation, conduction, and convection. Ambient air enters the HSM-MX through ventilation inlet openings located on the lower tier of the HSM-MX, circulates around the DSC and the heat shields, then exits through the outlets of the HSM-MX. The HSM-MX is designed to remove up to 50.0 kW of decay heat from the bounding EOS-37PTH DSC, when loaded in an HSM-MX lower compartment.

Decay heat is rejected from the DSC to the HSM-MX air space by convection and then removed from the HSM-MX by natural circulation airflow. Heat is also radiated from the DSC surface to the heat shields and HSM-MX walls and roof, where the natural convection airflow and conduction through the walls and roof aid in the removal of the decay heat. The passive cooling system for the HSM-MX is designed to preserve fuel cladding integrity by maintaining SFA peak cladding temperatures below acceptable limits during long-term storage. The outlet vent covers installed on the top of the HSM-MX are designed to mitigate the effect of sustained winds.

Configurations of systems to be stored in the HSM-MX are determined based on heat load, basket type, etc. These configurations are detailed in Table 1-2.

The HSM-MXs are installed on a load-bearing foundation, which consists of a reinforced concrete basemat on a subgrade suitable to support the loads. The HSM-MXs are not tied to the basemat.

Dimensions of the HSM-MX components described in the text and provided in figures and tables of this UFSAR are, in general, nominal dimensions for general system description purposes. Actual design dimensions are contained in the drawings in Section A.1.3.

A.1.2.2 TRANSFER EQUIPMENT

Transfer Trailer:

The EOS DSC will be transferred to the HSM-MX using the same transfer trailer and ram as the transfer equipment transferring the EOS DSC to the EOS-HSM. Thus, there is no change from Section 1.2.2.

Cask Support Skid:

A universal support skid will be used for the transfer of the NUHOMS® EOS DSC to the HSM-MX and is shown in Figure A.1-9. The key design features from the EOS cask support skid are the same as those described in Section 1.2.2; however, in addition, the universal support skid also allows for a NUHOMS® MATRIX loading crane (MX-LC) to capture the skid with a grappling mechanism to raise and lower the TC/DSC for insertion into the HSM-MX.

Ram:

The EOS DSC will be transferred to the HSM-MX using the same ram as the transfer equipment transferring the EOS DSC to the EOS-HSM. Thus, there is no change from Section 1.2.2.

NUHOMS® MATRIX Loading Crane:

The MX-LC is the device used as part of the NUHOMS® transfer equipment, designed and built to assist in loading the DSC into the HSM-MX. The MX-LC is a Part 72 [A.1-1] important-to-safety (ITS) piece of transfer equipment. The MX-LC is designed, fabricated, installed, tested, inspected, and qualified in accordance with *the applicable portions of* ASME NOG-1 [A.1-4], as a Type 1 gantry crane. In addition, the MX-LC is engineered to be "single-failure-proof" per NUREG-0612 [A.1-5]. The MX-LC is considered ITS as it supports the loaded TC/DSC during the DSC's insertion and extraction both into and out of the HSM-MX, respectively, thus providing both a structural and retrieval function. 72.48

NUHOMS® MATRIX Retractable Roller Tray:

The NUHOMS® MATRIX retractable roller tray (MX-RRT) is part of the NUHOMS® transfer equipment and is a device used to support the DSC during transfer operations. There are two MX-RRT beams inserted into opposing channels below the DSC opening on the HSM-MX. Each of the MX-RRT beams are removed upon completion of the loading operation.

The MX-RRT is designed in accordance with ASME B30.1 [A.1-6] as a combination power-operated jack with industrial rollers. Structural acceptance criteria of the MX-RRT are in accordance with ASME NOG-1 [A.1-4]. In addition, the MX-RRT is engineered as "single-failure-proof" per NUREG-0612 [A.1-5]. The MX-RRT function is twofold, first to accept the DSC during its insertion, and second, to lower the DSC onto its permanent pillow blocks within the HSM-MX. The MX-RRT is a Part 72 ITS piece of transfer equipment. The MX-RRT is considered ITS since it supports the DSC during its insertion and extraction both into and out of the HSM-MX, respectively, thus providing both a structural and retrieval function. 72.48

MX-RRT Handling Device

The MX-RRT handling device (RHD) is part of the NUHOMS® Transfer Equipment and is a device used to allow insertion and extraction of the MX-RRT and the HSM-MX shield door shielding blocks. This is a NITS piece of equipment since it does not provide a safety function feature for the HSM-MX.

A.1.2.3 OPERATIONAL FEATURES

This section provides a discussion of the sequence of operations involving the HSM-MX components.

A.1.2.3.1 Spent Fuel Assembly Loading Operations

For the HSM-MX, there is no change from the primary operations listed in Steps 1 to 16 in Section 1.2.3.1. After those steps, the following operations occur, which replace Steps 17 to 20 in Section 1.2.3.1:

17. Move loaded TC to ISFSI
18. Position and align TC/HSM-MX
19. Insert DSC into HSM-MX
20. Close HSM-MX

These operations from Steps 17 to 20 are described in the following paragraphs. The descriptions are intended to be generic and are described in greater detail in Chapter A.9. Plant-specific requirements may affect these operations and are to be addressed by the licensee.

Move Loaded Transfer Cask to ISFSI:

The transfer trailer is moved to the ISFSI along a predetermined route on a prepared road surface. Upon entering the ISFSI, the cask is positioned in front of the HSM-MX loading crane.

Position and align TC/HSM-MX:

The trailer is moved inside the HSM-MX loading crane, and the crane grappling mechanism captures the TC along with the skid.

The HSM-MX loading crane travels laterally and vertically to position the TC in front of its storage compartment in the open HSM-MX with MX-RRTs installed.

Insert DSC into HSM-MX:

After final alignment of the TC, HSM-MX, and ram, the DSC is slid onto the MX-RRT beams inside the HSM-MX by the ram. The DSC is then lowered into place onto the front and rear DSC supports.

Close HSM-MX:

Install HSM-MX door.

A.1.3 Drawings

MX01-5000-SAR NUHOMS® HSM-MX HORIZONTAL STORAGE MODULE – MATRIX Main Assembly 72.48

8 7 6 5 4 3 2 1

H G F E D C B A

Proprietary and Security Related Information for Drawing MX01-5000-SAR, Rev. 1 Withheld Pursuant to 10 CFR 2.390

A.1.4 NUHOMS® EOS System Contents

No change to Section 1.4.

A.1.5 Qualification of TN Americas, LLC (Applicant)

The prime contractor for design and procurement of the NUHOMS® MATRIX is TN Americas, LLC (TN). TN 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 TN's QA Program requirements.

The design activities for the SAR were performed by TN and subcontractors, in accordance with TN QA Program requirements. TN is responsible for the design and analysis of the HSM-MX and the associated transfer equipment.

A.1.6 Quality Assurance

TN Americas LLC's QA Program has been established in accordance with the requirements of 10 CFR Part 72, Subpart G [A.1-1]. The QA Program applies to the design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of the NUHOMS® MATRIX and components identified as ITS and "safety-related." These components and systems are defined in Chapter A.2.

The complete description and specific commitments of the TN Americas LLC QA program are contained in the TN Americas LLC QA Program Description Manual [A.1-3]. This manual has been approved by the NRC for performing 10 CFR Part 72-related activities.

A.1.7 References

A.1-1 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."

A.1-2 NUREG-1536, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," Revision 1, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, July 2010.

A.1-3 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.

A.1-4 ASME NOG-1-2015, "Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge Multiple Girder)," The American Society of Mechanical Engineers, New York, New York, 2015.

A.1-5 NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," U.S. Nuclear Regulatory Commission, July 1980.

A.1-6 ASME B30.1-2015, "Jacks, Industrial Rollers, Air Casters, and Hydraulic Gantries," The American Society of Mechanical Engineers, New York, New York, 2015.

A.1.8 Supplemental Data

A.1.8.1 GENERIC STORAGE ARRAYS

The DSC containing the SFAs is transferred to, and stored in, compartments of the HSM-MX. Multiple compartments are grouped together to form a staggered, two-tiered monolithic structure known as the HSM-MX. Multiple compartments are grouped together to form arrays whose size is determined to meet plant-specific needs. The HSM-MX is arranged within the ISFSI site on a concrete basemat(s) with the entire area enclosed by a security fence. Modules may be placed in a single-row array or in a back-to-back array for site dose and footprint optimization. Like the EOS-HSM, the decay heat within the HSM-MX DSC compartment is primarily removed by internal natural circulation flow though the inlet/outlet vents and conduction through the HSM-MX walls.

Figure A.1-1 and Figure A.1-2 show typical HSM-MX expansion layouts at ISFSIs that are capable of modular expansion to any capacity.

The expansion option shown in Figure A.1-1 allows the array to be expanded with a construction joint splitting the upper compartment at the end of the array. A minimum of five compartments are required in a monolith. End shield walls shall be installed at this location in the interim period between expansions; the shield walls will be removed to allow for expansion of the array. Two empty compartments (one upper and one lower), in addition to the partial empty compartment, are required at the end of an array during the interim period before expansion. At the end of the array, the end wall will be the same thickness as the wall at the beginning of the first array, and all compartments may be filled.

Figure A.1-2 shows the expansion joint used at ~100 feet into the array. This joint addresses the thermal growth due to cyclic temperatures in ambient conditions. When an array is expanded at the expansion joint, two empty compartments (one top and one bottom) are required at the end of the interim array prior to expansion. When the expansion joint is used, and construction continues past the expansion joint, the construction joint configuration can be used to further expand the array, or the array can terminate with an end wall the same thickness as the wall at the beginning of the first array. If using the construction joint configuration, the same requirements described above for the construction joint apply.

These are typical layouts only and do not represent limitations in number of modules, number of rows, and orientation of modules in rows. Back-to-back module configurations require expansion in sets of pairs. Expansion can be accomplished, as necessary, by the licensee, provided the criteria of 10 CFR 72.104, 10 CFR 72.106 and Chapter 14 are met. The parameters of interest in planning the installation layout are the configuration of the HSM-MX array and an area in front of each HSM-MX to provide adequate space for loading operations. Illustrations of typical HSM-MX ISFSI layouts are provided in Figure A.1-4 through Figure A.1-6.

Table A.1-1
Key Design Parameters of the NUHOMS® MATRIX Components

Horizontal Storage Module (HSM-MX):	
Overall length	23’-1” single array
	41’-4” back-to-back array
Overall width	36’-6”
Overall height (two-tiers without vent covers)	27’-1 3/8”
Total weight not including DSC (kips) (max. concrete density of 160 pcf.)	2,450 (single array)
	4,125 (double array)
Materials of construction	Reinforced concrete and structural steel
Heat removal	Conduction, convection, and radiation

Note: Dimensions are based on a single monolith of five compartments (see Figure A.1-2).

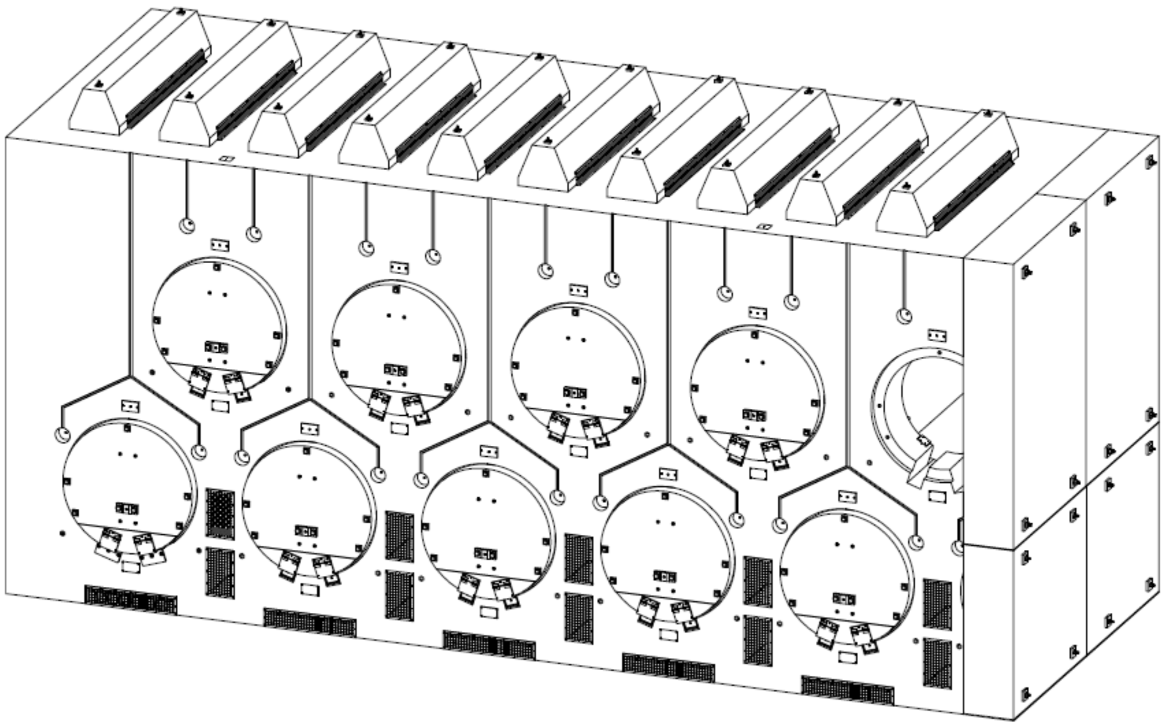


Figure A.1-1
NUHOMS® MATRIX Construction Joint Expansion

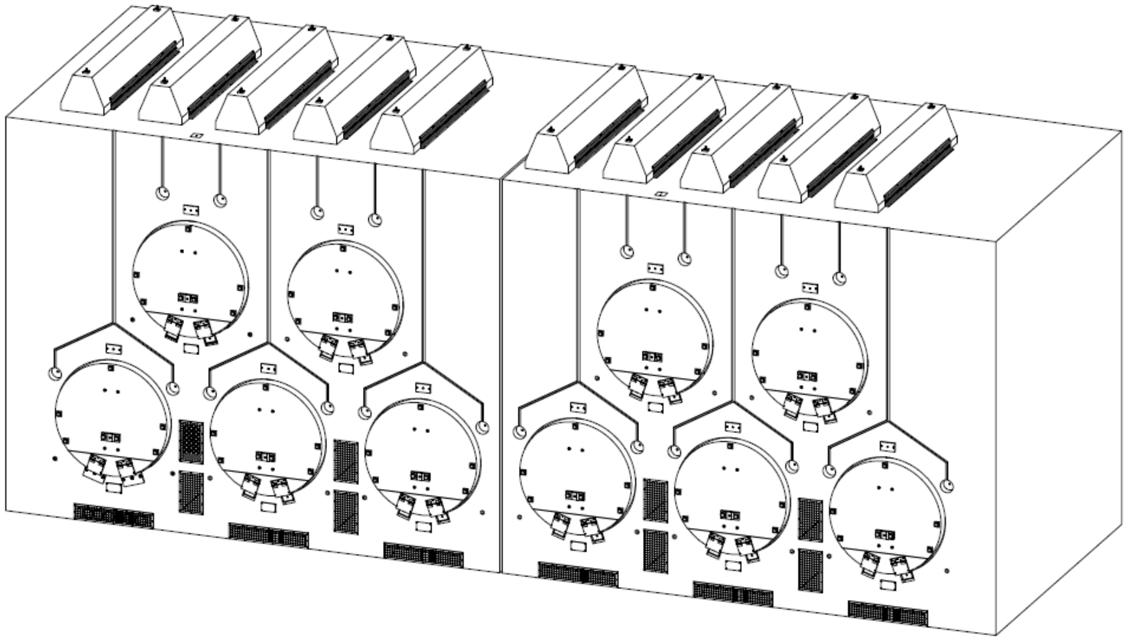


Figure A.1-2
NUHOMS® MATRIX Expansion Joint

Figure A.1-3
Not Used

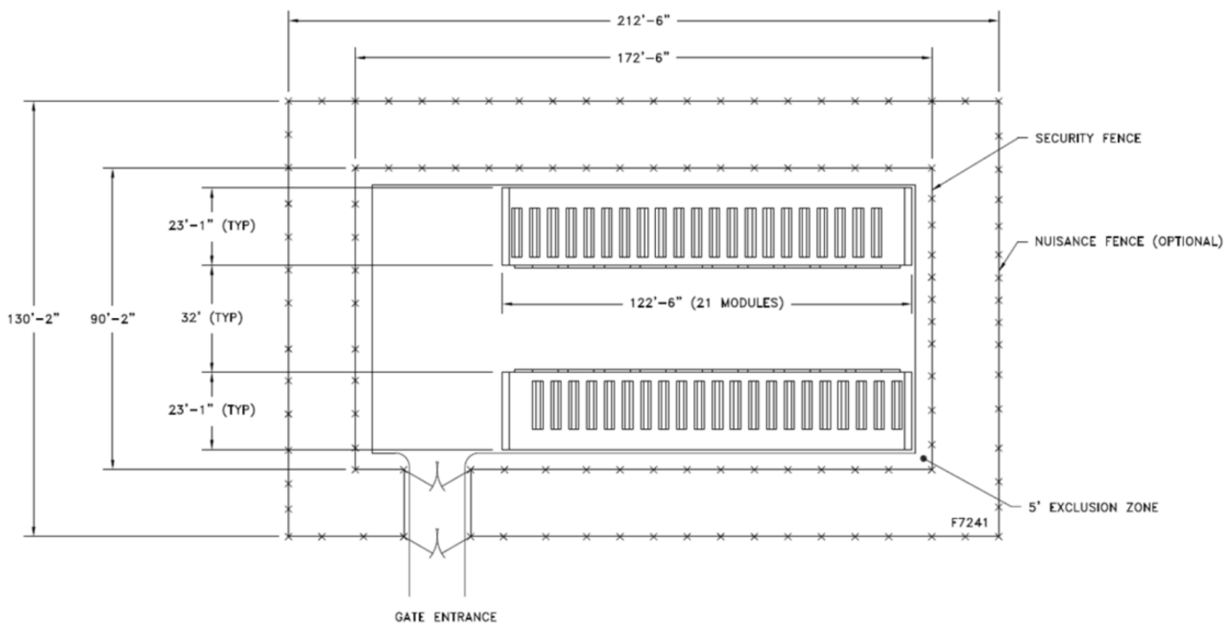


Figure A.1-4
ISFSI Layout Drawing for Single Array

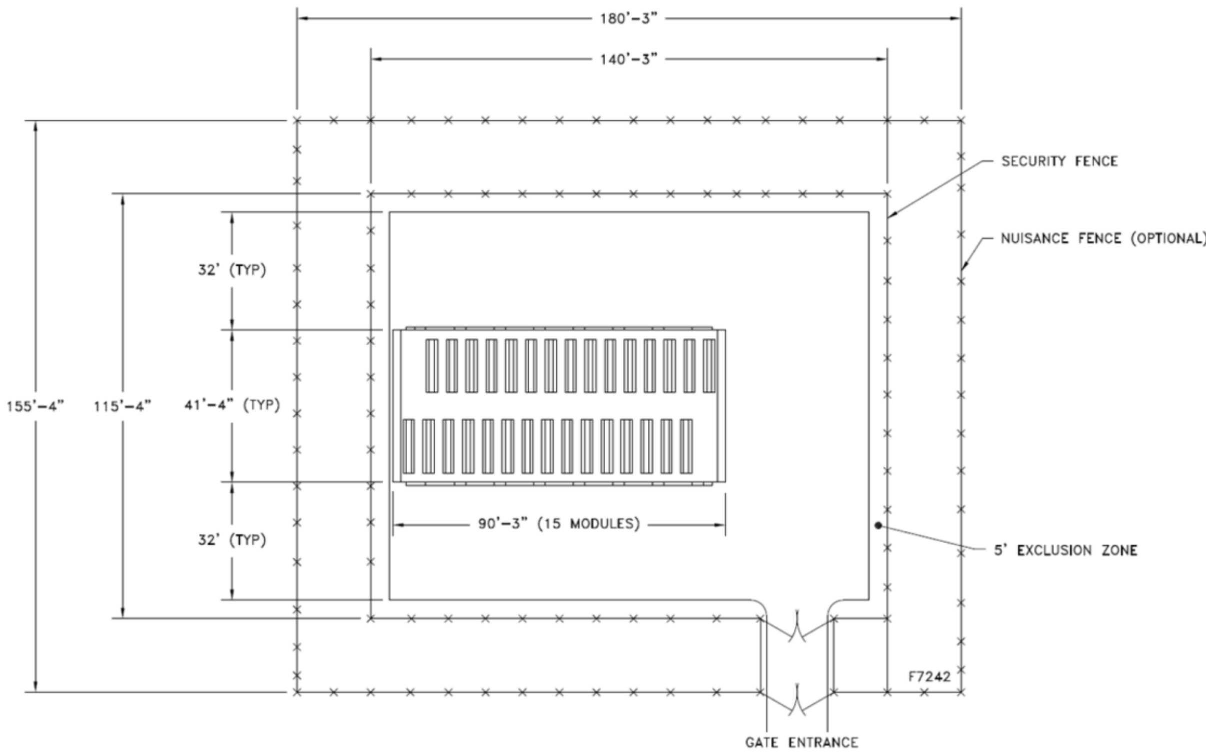


Figure A.1-5
ISFSI Layout Drawing for a Double Array

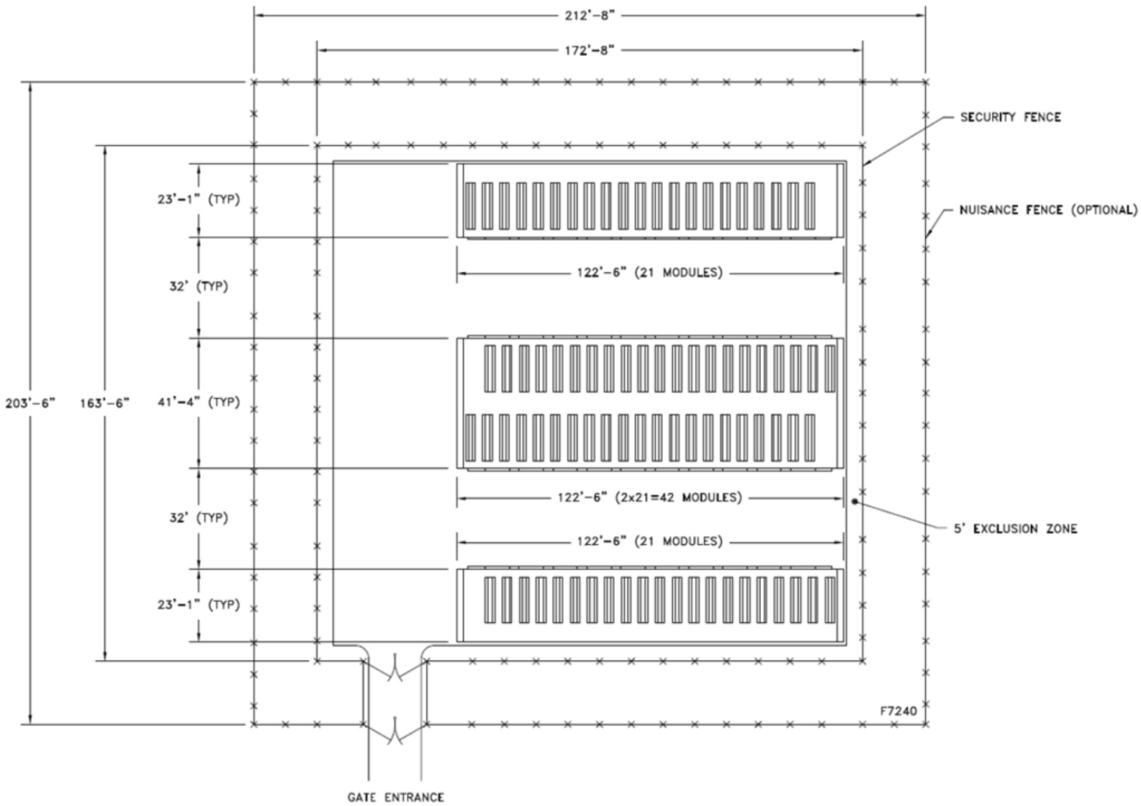


Figure A.1-6
ISFSI Layout Drawing for a Combined Single and Double Array

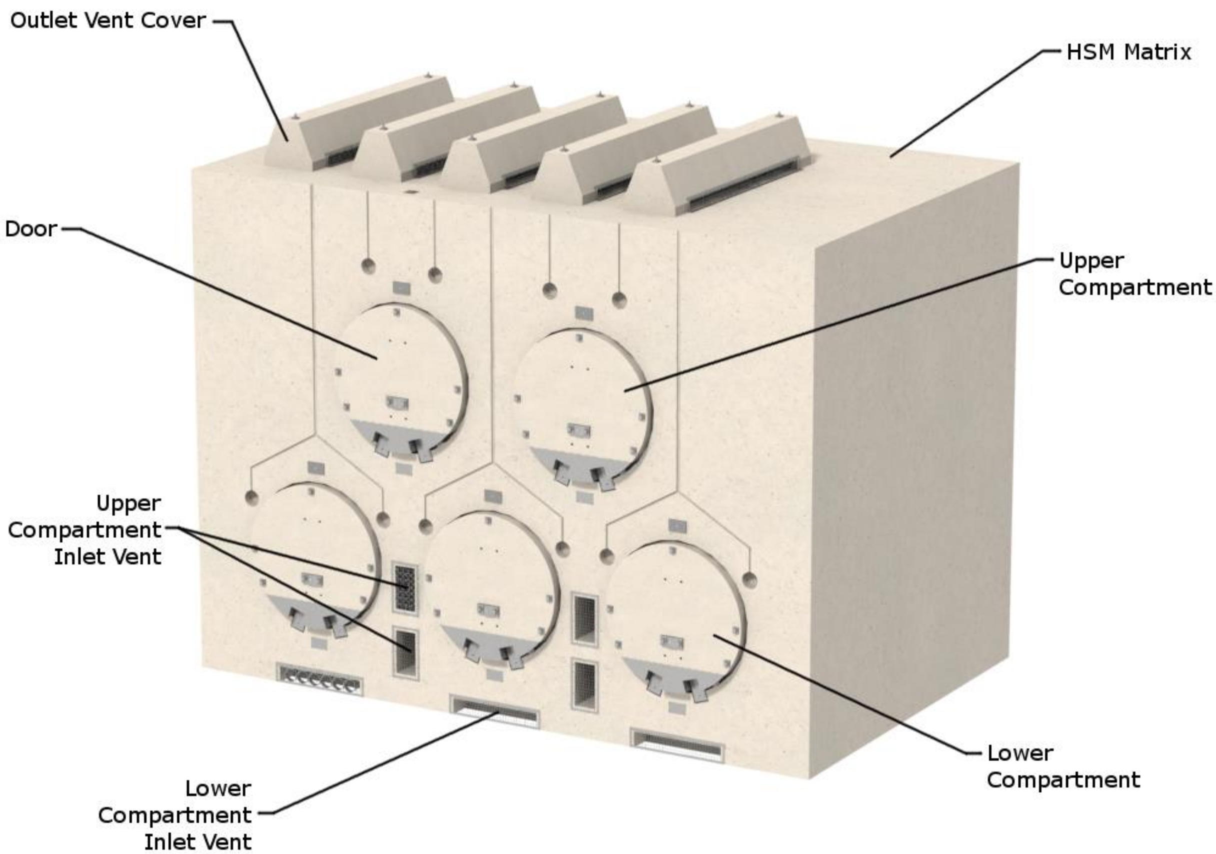


Figure A.1-7
NUHOMS® MATRIX System Components and Structures

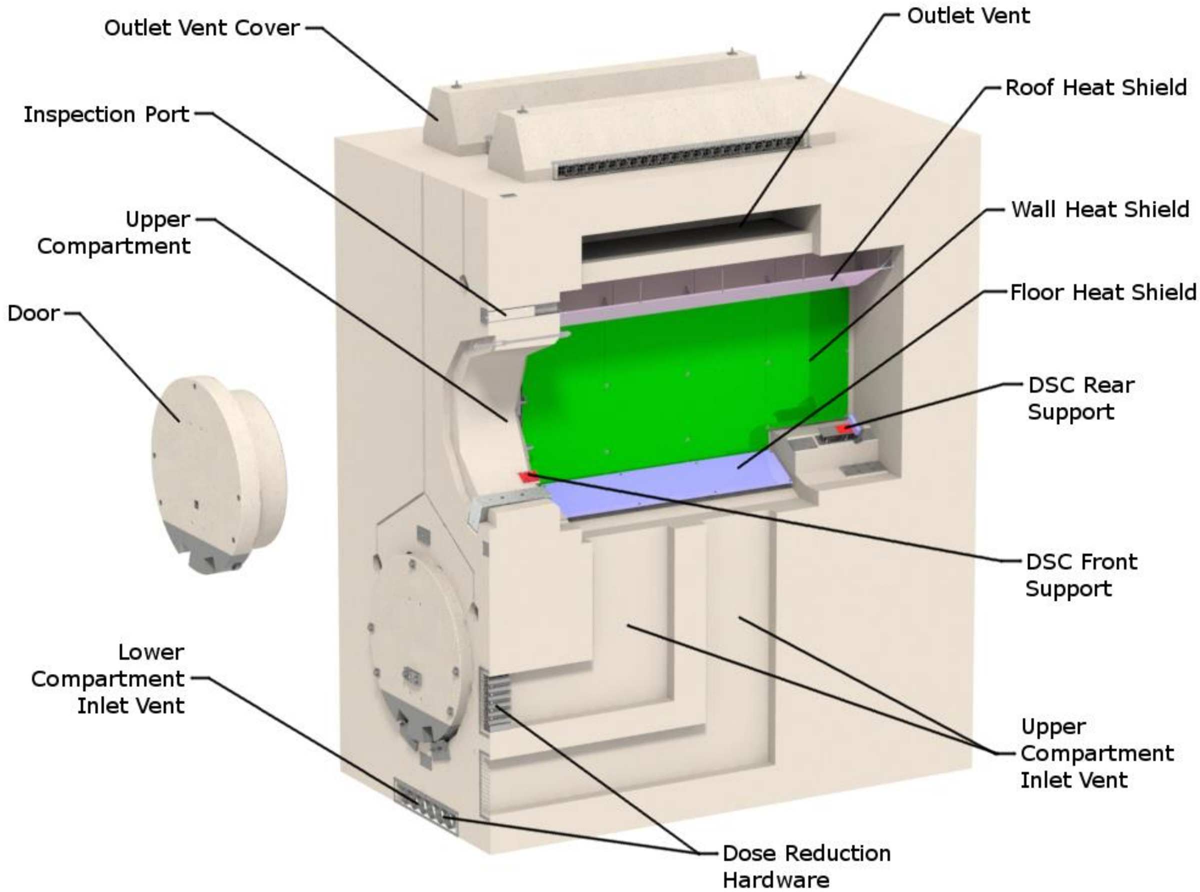


Figure A.1-8
NUHOMS® MATRIX System Components and Structures

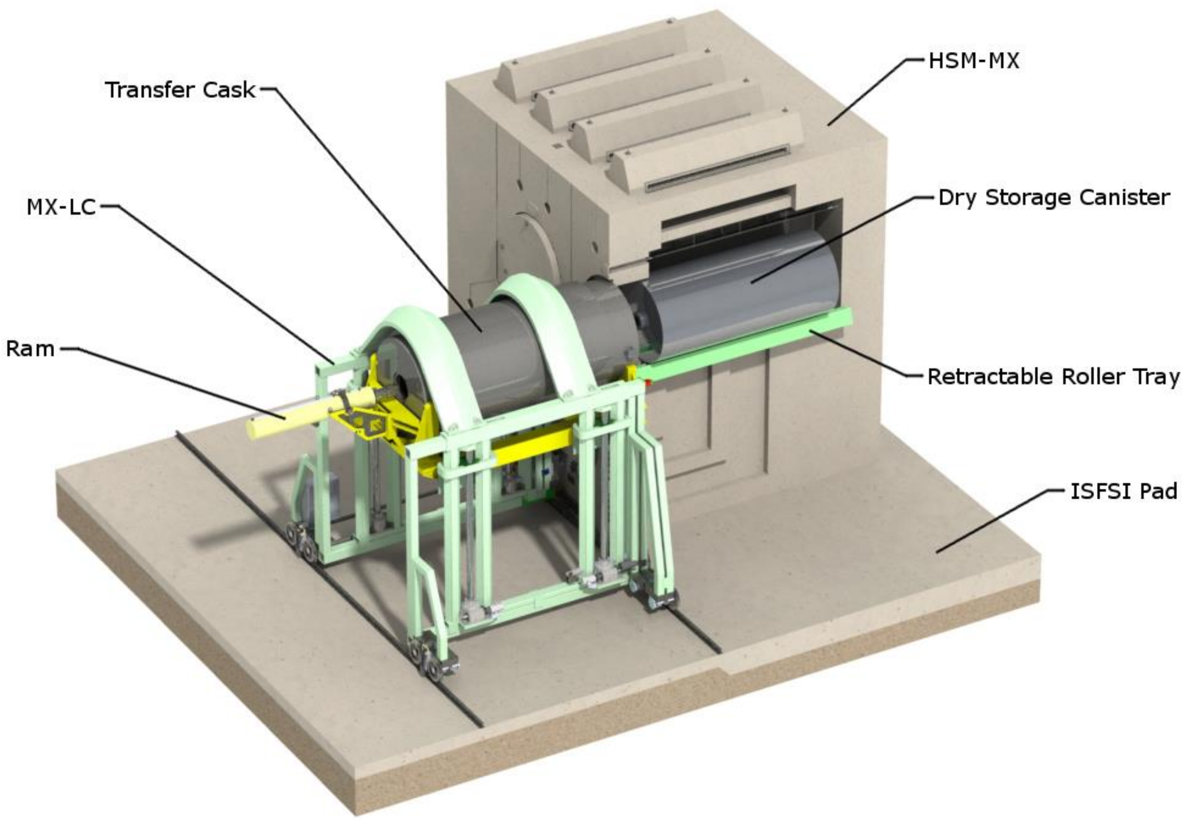


Figure A.1-9
NUHOMS® MATRIX System Components, Structures, and Transfer Equipment

APPENDIX A.2
PRINCIPAL DESIGN CRITERIA

Table of Contents

List of Tables

List of Figures

A.2 PRINCIPAL DESIGN CRITERIA

This section provides the principal design criteria for the NUHOMS® MATRIX (HSM-MX) described in Chapter A.1. Section A.2.1 identifies the structures, systems, and components (SSCs) important-to-safety (ITS) for the HSM-MX design. Section A.2.2 presents a general description of the spent fuel to be stored. Section A.2.3 provides the design criteria for environmental conditions and natural phenomena. Section A.2.4 discusses safety protection systems.

A.2.1 SSCs Important to Safety

Table 2-1 provides a list of major NUHOMS® EOS System independent spent fuel storage installation (ISFSI) components and their classification. In addition, Table A.2-1 provides a list of the major NUHOMS® MATRIX (HSM-MX) components and their classification. Components are classified in accordance with the criteria of 10 CFR Part 72. Structures, systems, and components (SSCs) classified as important-to-safety (ITS) are defined in 10 CFR 72.3 as the features of the ISFSI whose function is:

- To maintain the conditions required to store spent fuel safely.
- To prevent damage to the spent fuel container during handling and storage.
- To provide reasonable assurance that spent fuel can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public.

These criteria are applied to the HSM-MX components in determining their classification in the paragraphs that follow.

A.2.1.1 Dry Shielded Canisters

No Change to Section 2.1.1

A.2.1.2 HSM-MX

The HSM-MX is considered ITS since it provides physical protection and shielding for the dry shielded canister (DSC) during storage. The reinforced concrete HSM-MX is designed in accordance with American Concrete Institute (ACI) 349-06 [A.2-3] and constructed to ACI-318-08 [A.2-4]. The level of testing, inspection, and documentation provided during construction and maintenance is in accordance with the quality assurance requirements as defined in 10 CFR Part 72 [A.2-6], Subpart G and as described in Chapter 14. Thermal instrumentation for monitoring HSM-MX concrete temperatures is considered “not important-to-safety” (NITS).

A.2.1.3 ISFSI Basemat and Approach Slabs

The independent spent fuel storage installation (ISFSI) basemat and approach slabs and buildings for indoor storage are considered NITS and are designed, constructed, maintained, and tested as commercial-grade items.

Licensees are required to perform an assessment to confirm that the license seismic criteria described in Section A.2.3.4 are met.

A.2.1.4 Transfer Equipment

A.2.1.4.1 Transfer Cask and Yoke

No change to Section 2.1.4.1.

A.2.1.4.2 Other Transfer Equipment

The NUHOMS® EOS HSM-MX transfer equipment (i.e., ram, skid, transfer trailer, MATRIX loading crane (MX-LC), MATRIX retractable rolling tray (MX-RRT) and MX-RRT handling device (RHD)) are necessary for the successful loading of the DSCs into the HSM-MX.

MX-LC

The NUHOMS® MX-LC is the device used as part of the NUHOMS® transfer equipment, designed and built to assist in loading the DSC into the HSM-MX. The MX-LC is a Part 72 [A.2-6] ITS piece of transfer equipment. The MX-LC is designed, fabricated, installed, tested, inspected, and qualified in accordance with *the applicable portions of* ASME NOG-1 [A.2-7], as a Type I gantry crane. In addition, the MX-LC is engineered as "single-failure-proof" per NUREG-0612 [A.2-9]. The MX-LC is considered ITS since it supports the loaded TC/DSC during the DSC's insertion and extraction both into and out of the HSM-MX, respectively, thus providing both a structural and retrieval function. 72.48

MX-RRT

The MX-RRT is part of the NUHOMS® transfer equipment and is a device used to support the DSC, during transfer operations. There are two MX-RRT beams inserted into opposing channels below the DSC opening on the HSM-MX. Each of the MX-RRT beams are removed upon completion of the loading operation and replaced with the HSM-MX shield door shielding blocks. The MX-RRT is designed in accordance with ASME B30.1 [A.2-15] as a combination power-operated jack with industrial rollers. Structural acceptance criteria of the MX-RRT is in accordance with ASME NOG-1 [A.2-7]. In addition, the MX-RRT is engineered as "single-failure-proof" per NUREG-0612 [A.2-9]. The MX-RRT function is twofold, one to accept the DSC during its insertion and second, to lower the DSC onto its permanent pillow blocks within the HSM-MX. The MX-RRT is a Part 72 ITS piece of transfer equipment. The MX-RRT is considered ITS as it supports the DSC during its insertion and extraction both into and out of the HSM-MX, respectively, thus providing both a structural and retrieval function. 72.48

MX-RRT Handling Device

The MX-RRT handling device is part of the NUHOMS® Transfer Equipment and is a device used to allow insertion and extraction of the MX-RRT and the HSM-MX shield door shielding blocks. This is a NITS piece of equipment since it does not provide a safety function feature for the HSM-MX.

A.2.1.5 Auxiliary Equipment

No change to Section 2.1.5.

A.2.2 Spent Fuel To Be Stored

Spent fuel that is allowed for storage in the HSM-MX is described in Section 2.2.

A.2.3 Design Criteria for Environmental Conditions and Natural Phenomena

The HSM-MX ITS SSCs described in Section A.2.1 are designed consistent with the 10 CFR Part 72 [A.2-6] §122(b) requirement for protection against environmental conditions and natural phenomena. The criterion used in the design of the NUHOMS® EOS System ensures that exposure to credible site hazards does not impair their safety functions.

A.2.3.1 Tornado Wind and Tornado Missiles for HSM-MX

The HSM-MX and MX-LC are designed to safely withstand 10 CFR 72.122 (b)(2) tornado missiles. The tornado characteristics, as specified in NRC Regulatory Guide (RG) 1.76, Revision 1 [A.2-8], are used to qualify the HSM-MX and MX-LC. The missiles spectrum of NUREG-0800, Revision 3, Section 3.5.1.4 [A.2-10] with missile velocity for Region I is used to qualify the HSM-MX and MX-LC.

Extreme wind effects are much less severe than the specified design basis tornado (DBT) wind forces. The design basis extreme wind for the HSM-MX is calculated per [A.2-10].

However, since the MX-LC is specified per ASME NOG-1 [A.2-7] loading conditions, the design basis wind for the MX-LC is calculated per Region IV of [A.2-12]. Nonetheless, congruent with the HSM-MX, the design basis extreme wind (i.e., tornado wind) for the MX-LC is calculated per Region I of [A.2-10].

A.2.3.1.1 Tornado Wind Design Parameters

No change to Section 2.3.1.1.

A.2.3.1.2 Determination of Forces on Structures

No change to Section 2.3.1.2.

A.2.3.1.3 Tornado Missiles

No change to Section 2.3.1.3.

A.2.3.2 Tornado Wind and Tornado Missiles for EOS-TC

No change to Section 2.3.2.

A.2.3.2.1 Tornado Wind Design Parameters

No change to Section 2.3.2.1.

A.2.3.2.2 Tornado Missiles

No change to Section 2.3.2.2.

A.2.3.3 Water Level (Flood) Design

HSM-MX inlet vents are blocked when the depth of flooding is greater than 0.25 m (10 in.) for the lower compartment, and 2.29 m (7 ft-6 in.), for the upper compartments, above the level of the ISFSI basemat. The DSC in the lower and upper compartments are wetted when flooding exceeds a depth of 1.3 m (4 ft-2 in.), and 4.4 m (14 ft-5 in.), respectively, above ISFSI basemat. Greater flood heights result in submersion of the DSC and blockage of the HSM-MX outlet vents.

The DSC and HSM-MX are conservatively designed for an enveloping design basis flood. The flood is postulated to result from natural phenomena such as tsunamis and seiches, as specified by 10 CFR 72.122(b) [A.2-6]. A bounding assumption of a 15-meter (50-foot) flood height and water velocity of 4.6 m/sec (15 fps) is used for the flood evaluation. The HSM-MX is evaluated for the effects of the 4.6 m/sec (15 fps) water current impinging upon the side of the submerged HSM-MX. The DSC is subjected to an external pressure equivalent to a 15-meter (50-foot) head of water. These evaluations are presented in Section A.12.3.5. The effects of water reflection on DSC criticality safety are addressed in Chapter 7. Due to its short-term, infrequent use, the onsite EOS transfer cask (EOS-TC) is not explicitly evaluated for flood effects. Independent spent fuel storage installation procedures should ensure that the EOS-TC is not used for DSC transfer during flood conditions.

The plant-specific design basis flood (if the possibility for flooding exists at a particular ISFSI site) should be evaluated by the licensee and shown to be enveloped by the flooding conditions used for this generic evaluation of the HSM-MX.

A.2.3.4 Seismic Design

The seismic design criteria for the HSM-MX are based on the NRC RG 1.60 [A.2-13] response spectra anchored at a zero period acceleration (ZPA) of 0.85g in the horizontal direction and 0.80g in the vertical direction and enhanced frequency content above 9 Hz. The horizontal and vertical components of the design response spectra corresponding to a maximum horizontal ground acceleration of 1.0g are shown in Figure A.2-1. The seismic structural evaluations consider both stability evaluation and stress qualification of the HSM-MX. The stability criteria for seismic loading are based on the stability response of a five-compartment construction joint option of the HSM-MX module without the side shield walls attached.

The HSM-MX has no anchorage to the concrete basemat. The stability analyses consider the effects of sliding and rocking motions, and determine the maximum possible sliding of the HSM-MX. The HSM-MX will neither slide nor overturn at design ZPA of 0.48g in the horizontal direction and 0.32g in the vertical direction.

The licensee shall determine if, based on ISFSI-specific site investigations, a soil-structure interaction (SSI) analyses ought to be performed to assess potential site-specific amplifications. The SSI evaluations are based on ISFSI site-specific parameters (free-field accelerations, strain-dependent soil properties, HSM-MX array configurations, etc.). The SSI response spectra at the base of the HSM-MXs are to be bounded by the HSM-MX design basis seismic criteria response spectra, i.e., the RG 1.60 response spectra shape, with enhanced spectral accelerations above 9 Hz, and anchored at 0.85g horizontal and 0.80g vertical directions. The licensee shall reconcile spectral accelerations from the SSI analysis response spectra that exceed the seismic criteria spectra (if any); 5% damped response spectra may be used in making these determinations.

Since the DSC can be considered to act as a large diameter pipe for the purpose of evaluating seismic effects, the "Equipment and Large Diameter Piping System" category in NRC RG 1.61 [A.2-16], Table 1 is applicable. Therefore, a damping value of 3% of critical damping for the design bases safe shutdown earthquake is used. Similarly, from the same RG table, a damping value of 7% of critical damping is used for the reinforced concrete structural components of the HSM-MX.

The seismic criteria for the MX-LC are based on Figures 1 and 2 of NRC Regulatory Guide 1.60 [A.2-13], with enhanced spectral accelerations above 9 Hz, and anchored at 0.85g zero period acceleration (ZPA) in the horizontal direction and 0.80g ZPA in the vertical direction. The seismic structural calculations consider both a stability evaluation and stress qualification of the MX-LC for seismic loading criteria. The stability evaluations address the MX-LC rails and use of any shims under the MX-LC rails due to unevenness in the basemat and approach slab foundation. *The MX-LC component is currently limited to low seismic design criteria with a ZPA of 0.30g in all three directions. Therefore, the use of the MX-LC is limited to those sites which are bounded by the low seismic design criteria.* 72.48

The seismic criteria for the MX-RRTs is based on Figures 1 and 2 of NRC Regulatory Guide 1.60 [A.2-13], with enhanced spectral accelerations above 9 Hz, and anchored at 0.85g ZPA in the horizontal direction and 0.80g ZPA in the vertical direction. As required, the seismic structural calculations shall consider both a stability evaluation and stress qualification for the seismic loading criteria. *The MX-RRT component is currently limited to low seismic design criteria with a ZPA of 0.30g in all three directions. Therefore, the use of the MX-RRT is limited to those sites which are bounded by the low seismic design criteria.* 72.48

A.2.3.5 Snow and Ice Loading

No change to Section 2.3.5.

A.2.3.6 Tsunami

No change to Section 2.3.6.

A.2.3.7 Lightning

A lightning strike will not cause a significant thermal effect on the HSM-MX, MX-LC, MX-RRT, or stored DSC. The effects on the HSM-MX resulting from a lightning strike are discussed in Section 12.3.7.

A.2.4 Safety Protection Systems

A.2.4.1 General

No change to Section 2.4.1.

A.2.4.2 Structural

A.2.4.2.1 EOS-DSC Design Criteria

No change to Section 2.4.2.1.

A.2.4.2.2 HSM-MX Design Criteria

The principal design criteria for the HSM-MX, both the concrete and steel structures, are presented in Table 2-7.

The reinforced concrete HSM-MX is designed to meet the requirements of ACI 349-06 [A.2-3]. The ultimate strength method of analysis is utilized with the appropriate strength reduction factors as described in Appendix A.3.9.4. The load combinations specified in Section 6.17.3.1 of American National Standards Institute (ANSI) 57.9-1984 [A.2-20] are used for combining normal operating, off-normal, and accident loads for the HSM-MX. All seven load combinations specified are considered and the governing combinations are selected for detailed design and analysis. The resulting HSM-MX load combinations and the appropriate load factors are presented in Appendix A.3.9.4. The effects of duty cycle on the HSM-MX are considered and found to have negligible effect on the design.

A.2.4.2.3 EOS-TC Design Criteria

No change to Section 2.4.2.3.

A.2.4.2.4 MX-LC Design Criteria

The MX-LC is designed in accordance with the applicable portions of ASME NOG-1 [A.2-7], as a Type 1 gantry style crane. The MX-LC is engineered to provide *H*igh *I*ntegrity *H*andling (HIH) of the load, defined as a lifting/handling operation, wherein the risk of an uncontrolled lowering of the heavy load is considered non-credible. Demonstration of HIH of the MX-LC occurs when designed for "single-failure-proof" lifting operations per NUREG-0612 [A.2-9], maintaining the supported loads in a safe configuration during design basis events (e.g., seismic). Therefore, design requirements from ASME NOG-1 for Type 1 loading equipment are specified with an additional single failure proof handling capability. MX-LC single-failure-proof handling capability is achieved by ensuring that the applicable design factor is 200% of that required by ASME NOG-1 (i.e., NUREG-0612 application). Alternatively, other load carrying members may be designed with redundant devices to meet the single failure proof handling capability. Therefore, MX-LC HIH may be achieved by having either MX-LC subcomponent SSCs that comply with ASME NOG-1 stress limits plus the 200% NUREG-0612 design factor or with other MX-LC subcomponent SSCs having redundant safety basis protection features. 72.48

The MX-LC in the configuration loaded with the TC and Transfer Skid, and with the TC lid installed is demonstrated to be stable for overturning under tornado wind and missile loading. 72.48

A.2.4.2.5 MX-RRT Design Criteria

Congruent with the MX-LC, the MX-RRT is engineered to provide HIH of the load. Demonstration of HIH of the MX-RRT occurs when designed for "single-failure-proof" lifting operations per NUREG-0612 [A.2-9], maintaining the supported loads in a safe configuration during design basis events (e.g., seismic). Therefore, applicable design acceptance criteria are provided by ASME NOG-1 [A.2-7], plus an additional single-failure-proof handling capability. MX-RRT single failure proof handling capability is achieved by ensuring that the design factor is 200% of that from ASME NOG-1 (i.e., NUREG-0612 application). In lieu of the 200% requirement, it is acceptable to have other load carrying members designed with redundant devices to meet the single failure proof handling. Therefore, MX-RRT HIH may be achieved by having either MX-RRT subcomponent SSCs that comply with ASME NOG-1 stress limits plus the 200% NUREG-0612 design factor or with other MX-RRT subcomponent SSCs having redundant safety-basis protection features.

A.2.4.3 Thermal

The NUHOMS® MATRIX relies on natural convection through the air space in the HSM-MX to cool the DSC. This passive convective ventilation system is driven by the pressure difference due to the stack effect (ΔP_s) provided by the height difference between the bottom of the DSC and the HSM-MX air outlet. This pressure difference is greater than the flow pressure drop (ΔP_f) at the design air inlet and outlet temperatures. The details of the ventilation system design are provided in Chapter A.4.

Thermal analysis is based on fuel assemblies with decay heat up to 50.0 kW per DSC for the EOS-37PTH and up to 34.4 kW per DSC for the EOS-89BTH. Zoning is used to accommodate high per assembly heat loads. The heat load zoning configurations for the DSCs are shown in Figure 1A through Figure *1K* and Figure 2 of the Technical Specifications [A.2-18] for 37PTH and 89BTH DSC, respectively. Among the various HLZCs presented in Figure 1 for EOS-37PTH DSC, only HLZC # 7 through 9 *and 11* presented in Figure 1G through Figure 1I *and Figure 1K* are applicable for storage in *the* HSM-MX. Similarly for the EOS-89BTH, among the various HLZCs presented in Figure 2 for EOS-89BTH DSC, only HLZC # 3 is permitted for storage in the HSM-MX. 72.48

The thermal analyses for storage are performed for the environmental conditions listed in Table A.2-2. The remainder of the environment conditions are provided in Table 2-9.

Peak clad temperature of the fuel at the beginning of the long-term storage does not exceed 400 °C for normal conditions of storage, and for short-term operations, including DSC drying and backfilling. Fuel cladding temperature shall be maintained below 570 °C (1058 °F) for accident conditions involving fire or off-normal storage conditions.

For onsite transfer in the EOS-TC, air circulation may be used, as a recovery action, to facilitate transfer operations in the EOS-37PTH DSC as described in the Technical Specifications [A.2-18].

A.2.4.4 Shielding/Confinement/Radiation Protection

The HSM-MX provides the bulk of the radiation shielding for the DSCs. The HSM-MX designs can be arranged in either a single-row or a back-to-back arrangement. The nominal thickness of the HSM-MX roof is 50 inches for biological shielding. Additionally, the front wall has a minimum thickness of 39 inches. Sufficient shielding is provided by thick concrete side walls between HSM-MXs in an array to minimize doses in adjacent HSM-MXs during loading and retrieval operations. Section A.11.3 provides a summary of the offsite dose calculations for representative arrays of design basis HSM-MXs providing assurance that the limits in 10 CFR 72.104 and 10 CFR 72.106(b) are not exceeded.

There are no radioactive releases of effluents during normal and off-normal storage operations. Also, there are no credible accidents that cause significant releases of radioactive effluents from the DSC. Therefore, there are no off-gas or monitoring systems required for the HSM-MX.

A.2.4.5 Criticality

No change to Section 2.4.5.

A.2.4.6 Material Selection

No change to Section 2.4.6.

A.2.4.7 Operating Procedures

The sequence of operations are outlined for the HSM-MX in Chapter A.9 for loading of fuel, closure of the DSC, transfer to the ISFSI using the TC, insertion into the HSM-MX, monitoring operations, and retrieval and unloading. Throughout Chapter A.9, CAUTION statements are provided at the step where special notice is needed to maintain as low as reasonably achievable (ALARA), protect the contents of the DSC, protect the public and/or ITS components of the HSM-MX.

A.2.4.8 Acceptance Tests and Maintenance

Chapter A.10 specifies the acceptance testing and maintenance program for ITS components of the HSM-MX.

A.2.4.9 Decommissioning

The exact decommissioning plan for the ISFSI will be dependent on the U.S. Department of Energy's fuel transportation system capability and requirements for a specific plant. Because of the minimal contamination of the outer surface of the DSC, no contamination is expected on the internal passages of the HSM-MX. It is anticipated that the prefabricated HSM-MXs can be dismantled and disposed of using commercial demolition and disposal techniques.

A.2.5 References

A.2-1 Title 10, Code of Federal Regulations, Part 100, "Reactor Site Criteria."

A.2-2 American Society of Mechanical Engineers, "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Subsections NB, NF, ND and NCA, 2010 Edition with 2011 Addenda.

A.2-3 ACI 349-06, "Code Requirements for Nuclear Safety Related Concrete Structures," American Concrete Institute.

A.2-4 ACI 318-08, "Building Code Requirements for Structural Concrete and Commentary," American Concrete Institute.

A.2-5 Title 10, Code of Federal Regulations, Part 50, "Domestic Licensing of Production and Utilization Facilities."

A.2-6 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."

A.2-7 ASME NOG-1-2015, "Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge Multiple Girder)," The American Society of Mechanical Engineers, New York, New York, 2015.

A.2-8 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.76, "Design Basis Tornado and Tornado Missiles for Nuclear Power Plants," Revision 1, March 2007.

A.2-9 NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," U.S. Nuclear Regulatory Commission, July 1980.

A.2-10 NUREG-0800, Standard Review Plan, Section 3.3.1 "Wind Loading," Section 3.3.2 "Tornado Loads", and Section 3.5.1.4 "Missiles Generated by Tornado and Extreme Winds," Revision 3, March 2007.

A.2-11 NUREG-0800, Standard Review Plan, Section 3.5.3 "Barrier Design Procedures," Revision 3, March 2007.

A.2-12 American Society of Civil Engineers, ASCE 7-10, "Minimum Design Loads for Buildings and Other Structures," (formerly ANSI A58.1).

A.2-13 NRC Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants" Revision 1, December 1973.

A.2-14 ANSI N14.6, "American National Standard for Special Lifting Device for Shipping Containers Weighing 10,000 lbs. or More for Nuclear Materials," American National Standards Institute, Inc., 1993.

A.2-15 ASME B30.1-2015, "Jacks, Industrial Rollers, Air Casters, and Hydraulic Gantries," The American Society of Mechanical Engineers, New York, New York, 2015.

A.2-16 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," Revision 1, March 2007.

A.2-17 NOT USED

A.2-18 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *2*.

A.2-19 NOT USED

A.2-20 ANSI 57.9-1984, Design Criteria for an Independent Spent Fuel Storage Installation (Dry Type).

Table A.2-1
HSM-MX System Major Components and Safety Classification

Component	10 CFR Part 72 Classification[1]
Horizontal Storage Module (HSM-MX)	
Reinforced Concrete	ITS
Thermal Instrumentation (if used)	NITS
Transfer Equipment	
MX-LC	ITS
MX-RRT	ITS
Universal Support Skid	ITS

Notes:

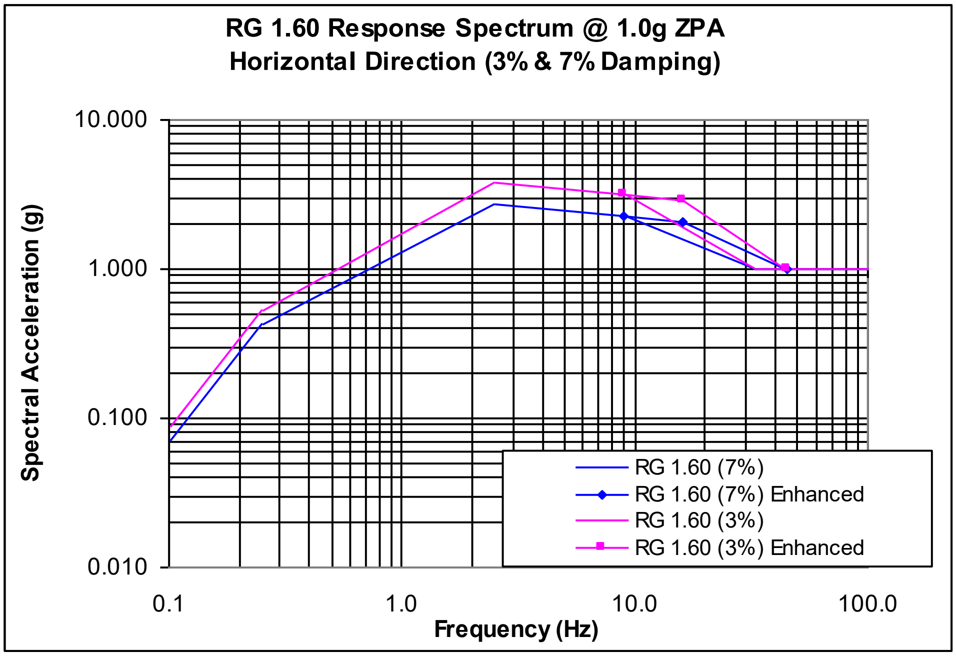
1. SSCs ITS are defined in 10 CFR 72.3 as those features of the ISFSI whose function is (1) to maintain the conditions required to store spent fuel safely, (2) to prevent damage to the spent fuel container during handling and storage, or (3) to provide reasonable assurance that spent fuel can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public.

Table A.2-2
Thermal Conditions for HSM-MX System Analyses

Operating Conditions	EOS-37PTH/EOS-89BTH DSC Location	Minimum Ambient Temperature	Maximum Ambient Temperature
Normal	HSM-MX	-20 °F	100 °F
Off-Normal	HSM-MX	-40 °F	117 °F
Accident	HSM-MX(1)	n/a	117 °F

Notes:

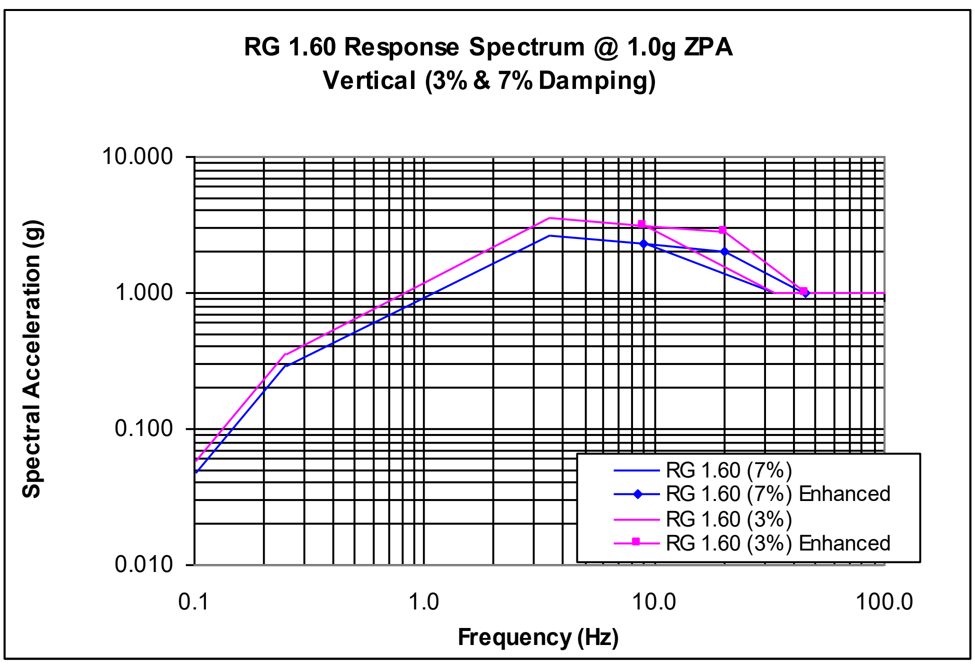
1. 10% rod rupture is considered for this blocked vent accident condition for DSC internal pressure calculation.



HORIZONTAL

RG 1.60 (3%, Horiz. Enhanced)	
Freq (Hz)	**Acc. (g)**
0.10	0.085
0.25	0.529
2.5	3.755
9.0	3.130
16.0	2.885
45.0	1.000
100.0	1.000

RG 1.60 (7%, Horiz. Enhanced)	
Freq (Hz)	**Acc. (g)**
0.10	0.069
0.25	0.432
2.5	2.720
9.0	2.270
16.0	2.093
45.0	1.000
100.0	1.000



VERTICAL

RG 1.60 (3%, Vert. Enhanced)	
Freq (Hz)	**Acc. (g)**
0.10	0.056
0.25	0.353
3.5	3.577
9.0	3.130
20.0	2.797
45.0	1.000
100.0	1.000

RG 1.60 (7%, Vert. Enhanced)	
Freq (Hz)	**Acc. (g)**
0.10	0.046
0.25	0.287
3.5	2.590
9.0	2.270
20.0	2.030
45.0	1.000
100.0	1.000

Figure A.2-1
RG 1.60 Response Spectra with Enhancement in Frequencies above 9.0 Hz

APPENDIX A.3
STRUCTURAL EVALUATION

Table of Contents

List of Tables

A.3 STRUCTURAL EVALUATION

This chapter and its appendices describe the structural evaluation for the NUHOMS® MATRIX (HSM-MX), described in Appendix A.1, under normal and off-normal conditions, accident conditions, and natural phenomena events. Structural evaluations are provided for the important-to-safety components (ITS), which are the EOS-37PTH DSC, the EOS-89BTH DSC, and the HSM-MX monolith. The analyses in Chapter 3 of the EOS-TCs envelop the HSM-MX system and are therefore not provided in this chapter.

A.3.1 Structural Design

The HSM-MX is a staggered horizontal storage version of the NUHOMS® EOS System, which provides environmental protection and radiological shielding for the DSCs. The HSM-MX is designed to accommodate EOS-37PTH DSC and 89BTH DSC configurations. The HSM-MX provides heat rejection from the spent fuel decay heat. Sections in this section of the Appendix that do not have an effect on the evaluations presented in Chapter 3 of the Updated Final Safety Analysis Report (UFSAR) include a statement that there is no change. In addition, a complete evaluation of the HSM-MX has been performed and is summarized in this section and appendices, which are ITS in accordance with 10 CFR Part72 [A.3-1].

A.3.1.1 Design Criteria

A.3.1.1.1 EOS-37PTH DSC/EOS-89BTH DSC Design Criteria

No change to Section 3.1.1.1.

A.3.1.1.1.1 Stress Criteria

No change to Section 3.1.1.1.1.

A.3.1.1.1.2 Stability Criteria

No change to Section 3.1.1.1.2.

A.3.1.1.2 HSM-MX Design Criteria

The HSM-MX concrete and steel components are designed to the requirements of American Concrete Institute (ACI) 349-06 [A.3-2] and the American Institute of Steel Construction (AISC) Manual of Steel Construction [A.3-3], respectively, meeting the load combinations in accordance with the requirements of ANSI 57.9 [A.3-4]. The load combination and design criteria for concrete components are described in Appendix A.3.9.4.

A.3.1.1.3 EOS-TC Design Criteria

No change to Section 3.1.1.3.

A.3.2 Weight and Centers of Gravity

Table A.3-1 summarizes the weights of the HSM-MX. The dead weights of the components are determined based on the nominal dimensions.

A.3.3 Mechanical Properties of Materials

A.3.3.1 EOS-37PTH DSC/EOS-89BTH DSC

No change to Section 3.3.1.

A.3.3.2 HSM-MX

The material properties for the HSM-MX are summarized in Chapter A.8.

A.3.3.3 EOS-TC

No change to Section 3.3.3.

A.3.4 General Standards for NUHOMS® MATRIX System

A.3.4.1 Chemical and Galvanic Reaction

No change to Section 3.4.1 for the EOS System. Chemical and galvanic reactions for the HSM-MX System are presented in Chapter A.8.

A.3.4.2 Positive Closure

No change to Section 3.4.2.

A.3.4.3 Lifting Devices

No change to Section 3.4.3.

A.3.4.4 Heat

A.3.4.4.1 Summary of Pressures and Temperatures

Temperatures and pressures for the HSM-MX are described in Chapter A.4. The thermal evaluations for storage and transfer conditions are performed in Chapter A.4 for normal, off-normal, and accident conditions. The internal pressure evaluation is performed in Chapter A.4, Section A.4.5.

Maximum temperatures for the various components of the HSM-MX, loaded with an EOS-37PTH DSC or an EOS-89BTH DSC under normal, off-normal and accident conditions are summarized in Chapter A.4, Section A.4.5 for all the applicable heat zone loading configurations provided in Appendix A, Technical Specification [A.3-5].

These temperatures are used for the structural evaluations documented in Appendices A.3.9.1 and A.3.9.4. Stress allowables for the components are a function of component temperature. The temperatures used to perform the structural analyses are based on actual calculated temperatures or conservatively selected higher temperatures.

A.3.4.4.2 Differential Thermal Expansion

No change to Section 3.4.4.2.

A.3.4.4.2.1 Minimum Gaps within the Interlocking Slots

No change to Section 3.4.4.2.1.

A.3.4.4.2.2 Axial Gaps between the Basket Assembly Plates

No change to Section 3.4.4.2.2.

A.3.4.4.2.3 Radial Gap between the Basket Assembly and the DSC Shell

No change to Section 3.4.4.2.3.

A.3.4.4.2.4 Axial Gaps between Fuel Assemblies and the DSC Cavity

No change to Section 3.4.4.2.4.

A.3.4.4.2.5 Axial Gap between the Basket Assembly and the DSC Cavity

No change to Section 3.4.4.2.5.

A.3.4.4.2.6 Axial Gap between the Transition Rails and the DSC Cavity

No change to Section 3.4.4.2.6.

A.3.4.4.2.7 Axial Gap between the TC125/TC135 Cavity and the DSC Shell

No change to Section 3.4.4.2.7.

A.3.4.4.2.8 Axial Gap between the Rear DSC support, Axial Retainer and the HSM-MX cavity

A gap of 0.5 inch is provided between the rear DSC Support and the HSM-MX to accommodate any thermal growth. This section verifies that there is no interference when the rear DSC support increases from room temperature to accident temperature.

The maximum temperature of the rear DSC support is assumed to be 350°F. A mean thermal expansion coefficient of 7.0×10^{-6} in/in/°F for 350°F is used. The thermal growth of the rear DSC support is determined as:

$$\Delta L_{rs} = L_{cold} \times \alpha \times \Delta T$$

$$\Delta L_{rs} = 21.5 \times 7.0 \times 10^{-6} \times (350 - 70) = 0.042\ in.$$

The maximum thermal growth between the rear DSC Support and the HSM-MX is 0.042 inch and is less than the initial 0.5-inch gap.

Therefore, there is sufficient clearance for free thermal expansion between the rear DSC supports and HSM-MX.

A gap is provided between the axial retainer and DSC to accommodate any thermal growth. Shims are used to adjust the gap to be *3/16* inch *minimum* initially. The bounding thermal expansion temperature ranges from the normal operating temperature to the blocked vent accident temperature. The largest average temperature difference for the DSC is 396 °F - 293 °F = 103 °F. The axial retainer is conservatively assumed to experience the same temperature difference. The average HSM concrete temperature difference is 207 °F - 152 °F = 55 °F. Conservatively, a higher temperature difference of 105 °F is applied to the DSC and axial retainer, and a lower temperature difference of 50 °F is applied to the HSM concrete. Thermal expansion coefficients of 7.5 x 10-6 in/in/°F and 10.1 x 10-6 in/in/°F for 350 °F are used for the Axial Retainer and the DSC, respectively. The instantaneous coefficients of thermal expansion are used here as the initial temperatures are above 70 °F. A thermal expansion coefficient of 5.5 x 10-6 in/in/°F is used for the HSM concrete. The growth of the HSM is subtracted from the growth of the DSC and axial retainer as it increases the gap. 72.48

$$\Delta L = L_{DSC} \times \alpha_{DSC} \times \Delta T_{DSC} + L_{AR} \times \alpha_{AR} \times \Delta T_{AR} - L_{HSM} \times \alpha_{HSM} \times \Delta T_{HSM}$$

$$\Delta L = 199.5 \times 10.1 \times 10^{-6} \times (105) + 36.5 \times 7.5 \times 10^{-6} \times (105) - (199.5 + 36.5) \times 5.5 \times 10^{-6} \times (50) = 0.175 \text{ in}$$

The maximum thermal growth between the axial retainer and DSC is 0.175 inch and is less than a *3/16* inch gap. 72.48

A.3.4.5 <u>Cold</u>

No change to Section 3.4.5.

A.3.5 Fuel Rods General Standards for NUHOMS® MATRIX System

No change to Section 3.5.

A.3.6 Normal Conditions of Storage and Transfer

This section presents the structural analysis of the EOS-37PTH DSC/ EOS-89BTH DSCs, the HSM-MX and the EOS-TC subjected to normal conditions of storage and transfer. The analyses performed evaluate the components for the design criteria described in Section A.3.1.1.

Numerical analyses have been performed for the normal and accident conditions. In general, numerical analyses have been performed for the regulatory events. The analyses are summarized in this section.

The detailed structural analyses of the HSM-MX are included in Appendices A.3.9.1 through A.3.9.7.

A.3.6.1 EOS-37PTH DSC/89BTH DSC

Details of the structural analysis of the DSC shell assemblies are provided in Appendix A.3.9.1, while the structural analysis for basket assemblies are provided in Appendix 3.9.2. There are no changes to the analysis described for the DSC shell except that the DSC shell is analyzed for dead weight and seismic load combinations, which are affected when the DSC is loaded into the HSM-MX and are provided in Appendix A.3.9.1. The design or loading conditions for the basket remain the same when loaded into the DSC shell and, therefore, results for the basket from Appendix 3.9.2 remain the same and are applicable.

A.3.6.2 HSM-MX

The HSM-MX design is able to accommodate different DSC lengths. For the structural evaluation, the HSM-MX with the longest DSC bounds all sizes. The following table shows how the bounding loads are used for structural evaluation of the HSM-MX.

Component	Weight (kips)	Thermal Heat Load
EOS-37PTH DSC (Loaded Weight)	134	50 kW
EOS-89BTH DSC (Loaded Weight)	120	43.6 kW
Bounding HSM-MX (Double Array)	4,125 [(2)]	50 kW for lower compartment and 41.8 kW for upper compartment [(1)]

Notes:

1. The thermal loading condition of the HSM-MX is based on the most conservative thermal loading configuration.
2. For stability evaluation, several different combinations of DSC and HSM bounding weights are considered.

Detailed geometry descriptions, material properties, loadings, and structural evaluation for the HSM-MX are presented in Appendix A.3.9.4.

A.3.6.3 EOS-TC

No change to Section 3.6.3.

A.3.7 Off–Normal and Hypothetical Accident Conditions of Storage and Transfer

This section presents the structural analyses of the EOS-37PTH DSC, EOS-89BTH DSC and the HSM-MX subjected to off-normal and hypothetical accident conditions. These analyses are summarized in this section, and described in detail in Appendices A.3.9.1 through A.3.9.7.

A.3.7.1 EOS-37PTH DSC/89BTH DSC

Detailed geometry descriptions, material properties, loadings, and structural evaluation for the affected loads combinations of the DSC are presented in Appendix A.3.9.1. The design and loading conditions for the basket remain the same when loaded into the DSC shell and, therefore, results for the basket from Appendix 3.9.2 remain the same and are applicable.

A.3.7.2 HSM-MX

Detailed geometry descriptions, material properties, loadings, and structural evaluation for the HSM-MX are presented in Appendix A.3.9.4.

A.3.7.3 EOS-TC

No change to Section 3.7.3.

A.3.8 References

A.3-1 Title 10, Code of Federal Regulations, Part 72, "Licensing Requirements for the Storage of Spent Fuel in the Independent Spent Fuel Storage Installation," U.S. Nuclear Regulatory Commission.

A.3-2 ACI 349-06, "Code Requirements for Nuclear Safety Related Concrete Structures," American Concrete Institute, November 2006.

A.3-3 American Institute of Steel Construction, "AISC Manual of Steel Construction," 13th Edition or 14th Edition.

A.3-4 ANSI/ANS 57.9-1984, "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type)," American National Standards Institute.

A.3-5 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *2*.

Table A.3-1
Summary of HSM-MX Weight and Center of Gravity

Component	Description	
Empty HSM-MX	Total Weight (kips)	
	Single Array	2,448
	Double Array	4,125
	Center of Gravity from Bottom in Vertical Direction (inches)	
	Single Array	176.42
	Double Array	178.79
HSM-MX Loaded with EOS-37PTH DSC	Maximum Weight (kips)	
	Single Array	3,048
	Double Array	5,325
	Center of Gravity from Bottom in Vertical Direction (inches)	
	Single Array	168.68
	Double Array	169.39
HSM-MX Loaded with EOS-89BTH DSC	Maximum Weight (kips)	
	Single Array	3,053
	Double Array	5,335
	Center of Gravity from Bottom in Vertical Direction (inches)	
	Single Array	168.63
	Double Array	169.33

Notes:

1. The weight and center of gravity values listed in the table are corresponding to the maximum concrete density of 160 pcf.
2. The weight values are for the HSM-MX having three lower compartments and two upper compartments.

APPENDIX A.3.9.1
DSC SHELL STRUCTURAL ANALYSIS

Table of Contents

List of Tables

List of Figures

A.3.9.1 DSC SHELL STRUCTURAL ANALYSIS

The purpose of this appendix is to present the structural evaluation of the shell assembly of the EOS-37PTH dry shielded canister (DSC) and the EOS-89BTH DSC under all applicable normal, off-normal and accident loading conditions during storage in the NUHOMS® MATRIX (HSM-MX).

The DSC shell is evaluated in Chapter 3.9.1 for all loads and load combinations. Only dead weight, and seismic load combinations affect the DSC when stored in the HSM-MX. Therefore, results from Chapter 3.9.1 are applicable to this chapter except for dead weight and seismic load combinations.

A.3.9.1.1 General Description

No change to Section 3.9.1.1.

A.3.9.1.2 DSC Shell Assembly Stress Analysis

No change to Section 3.9.1.2.

A.3.9.1.2.1 Material Properties

No change to Section 3.9.1.2.1.

A.3.9.1.2.2 DSC Shell Stress Criteria

No change to Section 3.9.1.2.2.

A.3.9.1.2.3 Finite Element Model Description

No change to Section 3.9.1.2.3 except that ANSYS version 17.1 [A.3.9.1-1] is used for the analysis in this appendix.

A.3.9.1.2.4 Mesh Sensitivity

No change to Section 3.9.1.2.4.

A.3.9.1.2.5 Post-Processing

No change to Section 3.9.1.2.5.

A.3.9.1.2.6 Stress Categorization Sensitivity Studies

No change to Section 3.9.1.2.6.

A.3.9.1.2.7 Load Cases for DSC Shell Stress Analysis

No change to Section 3.9.1.2.7, except the dead weight load as described in A.3.9.1.2.7.1 and the seismic loads as described in A.3.9.1.2.7.6.

The load case considered for the option with the Alternate 1-Bottom Forging is the seismic load with seismic axial forces toward the HSM-MX door. 72.48

A.3.9.1.2.7.1 Dead Weight

The dead weight is analyzed for the following basic configurations:

- When the DSC is vertical in the EOS-TC135 (No change to Section 3.9.1.2.7.1),
- When the DSC is horizontal in the EOS-TC135 (No change to Section 3.9.1.2.7.1),
- When the DSC is horizontal in the HSM-MX.

The model for the HSM-MX differs from EOS-HSM in boundary conditions representing the DSC supports. The DSC supports and axial retainers are shown in Figure A.3.9.1-1.

<u>Horizontal Position in HSM-MX</u>

When stored in the HSM-MX, the DSC shell is supported by the front and rear DSC supports. The inertial loads of the DSC internals are accounted for by applying an equivalent pressure onto the inner surface of the DSC shell. The magnitude of the pressure is determined based on the payload of 105 kips.

The interfaces between the DSC and the HSM-MX DSC supports, axial retainer and rear stop plate are modeled through node-to-node contact elements (CONTA178). The nodes representing the HSM-MX supports are constrained in all Degrees of Freedom (DOF). Similarly, the stop plate and axial retainer are also constrained in all degrees of freedom.

Figure A.3.9.1-2 and Figure A.3.9.1-3 show the pressure load and boundary conditions applied to the Finite Element Model (FEM).

Gaps for the contact elements are set to zero, placing the DSC and the HSM-MX DSC supports in initial contact.

A.3.9.1.2.7.2 Fabrication Pressure and Leak Testing

No change to Section 3.9.1.2.7.2.

A.3.9.1.2.7.3 Internal and External Pressure

No change to Section 3.9.1.2.7.3.

A.3.9.1.2.7.4 HSM-MX Loading/Unloading

No change to Section 3.9.1.2.7.4 except that the loads applied by the ram are balanced by the friction between the DSC shell and the EOS-TC and or MX-RRT support.

A.3.9.1.2.7.5 Transfer/Handling Load

No change to Section 3.9.1.2.7.5.

A.3.9.1.2.7.6 Seismic Load during Storage

The model described in Section A.3.9.1.2.7.1 for dead weight in HSM-MX is used and updated to reflect the effect of the vertical 0.8g load, transverse 1.7g load, axial (longitudinal) 1.7g load, and the internal pressure load of 20 psig.

Two elastic-plastic runs are performed for this load:

1. 0.8g vertical + 1.7g transverse + 1.7g axial with the weight of DSC internals modeled by equivalent pressure application on TSP with addition of internal pressure of 20 psig.
2. 0.8g vertical + 1.7g transverse + 1.7g axial with the weight of DSC internals modeled by equivalent pressure application on IBCP with addition of internal pressure of 20 psig.

The compound effect of dead weight, 0.8g vertical and 1.7g transverse, is modeled by multiplying the pressure from the dead weight case by a conservative factor of 4.

Seismic axial forces away from the HSM-MX door (load case 1 above) are resisted by the rear plates located at the ends of the DSC rear supports. The OTCP is recessed from the edge of the DSC shell, thus, the rear plate bears against the bottom edge of the DSC shell. The nodes of the top end of DSC shell, which come into contact with the rear stop plate, are restrained in the axial direction.

Seismic axial forces toward the HSM-MX door (load case 2 above) are resisted by the front axial retainers. The retainer is a steel bar located horizontally through the HSM-MX door. The retainer bears against the OBCP *or the Alternate 1-Bottom Forging when used*. The nodes of the OBCP *or the Alternate 1-Bottom Forging when used*, which bear against the area of the axial retainer bar, are restrained in the axial direction. Figure A.3.9.1-4 shows the pressure load applied to the DSC while supported by the HSM-MX DSC supports. 72.48

The DSC shell*, OBCP, and Alternate 1-Bottom Forging* experience compressive bearing stress in the vicinity of the axial retainer and rear plate. The bearing stresses experienced by the DSC shell*, OBCP, and Alternate 1-Bottom Forging* need not be evaluated for Service Level D loads. 72.48

A.3.9.1.2.7.7 Cask Drop

No change to Section 3.9.1.2.7.7.

A.3.9.1.2.7.8 Thermal Loads

Thermal analysis is performed to support the new HLZCs 4, 5, 6, 7, 8 and 9 as discussed in Technical Specification [A.3.9.1-2] (See Figure 1D through Figure 1I). For thermal stress analysis, temperature profiles and maximum component temperatures are based on thermal analysis of the EOS-37PTH DSC for transfer conditions. For transfer operations, HLZC 4 bounds HLZC 5, 6, 7, 8 and 9. The new HLZC 4 DSC maximum temperature is 480 °F (Chapter 4, Figure 4.9.6-4) which is below the temperatures of 484 °F (Chapter 4, Figure 4-32) for transfer operation. Therefore, new HZLC temperatures are bounded by the original thermal stress analysis. Therefore, no change to Section 3.9.1.2.7.8.

A.3.9.1.2.8 Load Combinations

No change to Section 3.9.1.2.8, except the dead weight and seismic load combinations described in Section A.3.9.1.2.7. Table A.3.9.1-1 provides the load combinations described in Section 3.9.1.2.8, in this chapter for information purpose. Only load combinations 9 and 10 affecting the DSC stored in HSM-MX on the front and rear DSC supports are analyzed.

A.3.9.1.3 DSC Shell Buckling Evaluation

No change to Section 3.9.1.3.

A.3.9.1.4 DSC Fatigue Analysis

No change to Section 3.9.1.4.

A.3.9.1.5 DSC Weld Flaw Size Evaluation

No change to Section 3.9.1.5.

A.3.9.1.6 Conclusions

The EOS DSC shell assembly has been analyzed for normal, off-normal, and accident load conditions using three dimensional finite element analyses. The load combinations provided in Section A.3.9.1.2.8 are used in the analysis of the EOS DSC. Analyses are performed only for the dead weight and seismic load combinations (9 and 10), which affect the DSC when stored in the HSM-MX. Stress intensities in different components of the DSC shell assembly, compared with ASME code stress intensity allowables and the resulting stress ratios, are summarized in Table A.3.9.1-2. The stress ratio is calculated by dividing the maximum stress intensity by the stress intensity allowable value, with the stress ratio required to be less than 1.

For the option with the Alternate 1-Bottom Forging, stress intensities in the Alternate 1-Bottom Forging are compared with ASME code allowables and the resulting stress ratios are summarized in Table A.3.9.1-2a. The maximum stress ratio is 0.28. Stress intensities for the DSC without the Alternate 1-Bottom Forging are bounding for the other components. 72.48

The DSC weld stresses are summarized in Table A.3.9.1-3. The maximum weld stress ratio is 0.87 and occurs at the DSC shell to ITCP weld for Load Combination 9. The maximum radial weld stress is summarized in Table A.3.9.1-4. The maximum radial stress between the DSC and OTCP is 4.22 ksi. Therefore, the flaw size evaluation from Section 3.9.1.5 still remains valid.

Table A.3.9.1-5 summarizes the stress results for the controlling load combination. The maximum component stress ratio remains the same as in the original analysis and is equal to 0.92 in the grapple ring support. The second maximum component stress ratio is equal to 0.87 and occurs in the confinement boundary area of the DSC shell during load combination 9 (storage condition in the HSM-MX, dead weight normal conditions).

The structural integrity of the DSC shell, including closure welds, is maintained since the maximum stress ratio is less than 1. Therefore, it is concluded that the EOS DSC is structurally adequate under all anticipated load conditions for service during the transfer and storage in the HSM-MX.

A.3.9.1.7 <u>References</u>

A.3.9.1-1 ANSYS Computer Code and User's Manual, Release 14.0, Release 14.0.3 and Release 17.1

A.3.9.1-2 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *2*.

Table A.3.9.1-1
EOS-37PTH/EOS-89BTH DSC Shell Assembly Loads and Load Combinations
(2 Sheets)

Loading Type	DSC Orientation	Load for Analysis	Load Combination	Service Level	Load Combination No.	
Dead weight (DW)	Vertical(1)	1g down (axial)	DW+ Normal Pressure+ Normal Thermal(2)	A	1	
Normal Pressure		20 psig internal pressure				72.48
Thermal		Normal vertical orientation thermal				
Dead weight (DW)	Horizontal(3)	1g down	DW + H + Pressure+ Thermal (117 °F) DW + H + Pressure+ Thermal (-40 °F)	A	2 3	
Thermal-Off Normal Hot		Off-Normal –Hot (117 °F)				
Thermal–Off Normal Cold		Off-Normal Cold (-40 °F)				
Internal Pressure-Off Normal		20 psig				
Handling in transfer cask (H)(15)		H=± 1g axial± 1 g trans.±1 g vertical				
Dead weight (DW)	Horizontal(3)	1g down	DW+ Ram (135 kips insertion)+ Pressure +Thermal DW + Ram (80 kips, retrieval) + Pressure + Thermal	A/B(7)	4 5	
Ram Loads (push/pull)		135 kips (push)(5), 80 kips (pull)(6)				
Internal pressure-Off-Normal		20 psig(9)				
Thermal—Off Normal		Thermal –Off Normal(8)				
Dead weight (DW)	Horizontal(3)	1g down	DW + Ram (135 kips retrieval) + Pressure	D	6	
Ram Loads (pull)		135 kips(6)				
Internal pressure-Off-Normal		20 psig(9)				

Table A.3.9.1-1
EOS-37PTH/EOS-89BTH DSC Shell Assembly Loads and Load Combinations
(2 Sheets)

Loading Type	DSC Orientation	Load for Analysis	Load Combination	Service Level	Load Combination No.
Dead Weight (DW)	Horizontal(3) Vertical(3)	1g down	DW + Pressure+ 65 inch Accident Drop	D	7A
Internal pressure-Off-Normal		20 psig(9)			
Accident Side/corner drop(17)		65 inch drop			7B
Dead Weight (DW)	Horizontal	1g down	DW + Accident Pressure	D	8
Internal pressure-Accident		130 psig(3)(9)(10)			
Dead Weight (DW)	Horizontal (11)	1g down	DW + Pressure+ Thermal	A	9
Internal Pressure-Off-Normal		20 psig			
Thermal-Off Normal		Thermal-Off Normal			
Dead Weight (DW)	Horizontal (11)	1g down	DW + Pressure+ Seismic (S)	D	10
Internal Pressure-Off-Normal		20 psig			
Seismic (S)		S=±1.7g(axial) ±1.7g(transverse ±0.8g(vertical)(16)			
Test Pressure at fabricator—23 psig(12)	Vertical	23 psig internal pressure	23 psig (15x1.5=23 psig) internal pressure	Test	11
External pressure	Horizontal	See Note (14)		D	12

Notes

1. DSC in Transfer cask in vertical orientation. Only inner top cover is installed.
2. Use bounding thermal case for normal operations of transfer cask in vertical orientation.
3. DSC in Transfer Cask; Transfer Cask is in horizontal orientation. In case of End drop, the orientation is vertical supported by IBS in case of Bottom End drop and TSP in case of Top End drop.
4. Not used.
5. The push loads are applied at the canister bottom surface within the grapple ring support.
6. The pull loads are applied at the inner surface of the grapple ring.

7. Level B evaluations may take credit for 10% increase in allowable per NB-3223(a). Level B is used for the case with internal pressure. Level A is used for the case without internal pressure.
8. Use controlling thermal off-normal case.
9. Load combination results to bound cases with and without internal pressure. Use bounding pressure of HSM blocked vent accident or transfer cask accident fire conditions.
10. Use bounding pressure of HSM blocked vent accident or transfer cask accident fire conditions.
11. DSC in HSM supported on the DSC supports.
12. Conservatively use 23 psig as the test pressure; test configuration is circular shell and inner bottom welded to shell; a top end lid with a155 kips clamping force may be used to seal the test assembly.
13. Not Used.
14. The maximum accident condition external pressure *allowed by calculation for stability when the DSC is in the horizontal position.* 72.48
15. These handling loads in conjunction with Level A limits bounds case of transfer cask in fuel building under seismic loads (Level D accident condition).
16. Unless lower g loads can be justified based on frequency analysis of HSM loaded with bounding DSC.
17. The top end drop and bottom end drop are not credible events under 10 CFR Part 72, therefore these drop analyzes are not required. However, consideration of end drops (for 10 CFR Part 71 conditions) and the 65" side drop to conservatively envelope the effects of a corner drop.

Table A.3.9.1-2
DSC Results - Load Combinations
(2 Sheets)

Load Combination Number	Service Level	Loads	Components		Stress Category [ksi]				
					P_m	P_m+P_b	P_L	P_m(or P_L)+P_b+Q	P_m(or P_L)+P_b+Q+P_e
9	A	DW+IP (20psi)	DSC Shell (Confinement)	Stress Intensity	6.77	12.11	18.07	27.90	45.44
				Allowable Stress	17.50	26.25	26.25	52.50	52.50
				Stress Ratio	0.39	0.46	0.69	0.53	0.87
			DSC Shell (Non-Confinement)	Stress Intensity	4.99	6.87	7.46	11.61	31.00
				Allowable Stress	17.50	26.25	26.25	52.50	52.50
				Stress Ratio	0.29	0.26	0.28	0.22	0.59
			OTCP	Stress Intensity	1.81	7.01	2.99	8.46	15.08
				Allowable Stress	17.50	26.25	26.25	52.50	52.50
				Stress Ratio	0.10	0.27	0.11	0.16	0.29
			ITCP	Stress Intensity	1.96	7.12	3.62	10.96	17.30
				Allowable Stress	17.50	26.25	26.25	52.50	52.50
				Stress Ratio	0.11	0.27	0.14	0.21	0.33
			OBCP	Stress Intensity	1.10	2.71	1.91	5.61	20.15
				Allowable Stress	17.50	26.25	26.25	52.50	52.50
				Stress Ratio	0.06	0.10	0.07	0.11	0.38
			IBCP	Stress Intensity	2.87	4.72	5.23	8.20	24.42
				Allowable Stress	17.50	26.25	26.25	52.50	52.50
				Stress Ratio	0.16	0.18	0.20	0.16	0.47

Table A.3.9.1-2
DSC Results - Load Combinations
(2 Sheets)

Load Combination Number	Service Level	Loads	Components		Stress Category[ksi]		
					P_m	P_m+P_b	P_L
10	D	DW+ Seismic+ IP(20psi)	DSC Shell (Confinement)	Stress Intensity	22.10	29.10	34.00
				Allowable Stress	44.38	57.06	57.06
				Stress Ratio	0.50	0.51	0.60
			DSC Shell (Non-Confinement)	Stress Intensity	20.10	22.60	20.30
				Allowable Stress	44.38	57.06	57.06
				Stress Ratio	0.45	0.40	0.36
			OTCP	Stress Intensity	7.13	13.00	14.30
				Allowable Stress	44.38	57.06	57.06
				Stress Ratio	0.16	0.23	0.25
			ITCP	Stress Intensity	5.53	11.20	9.27
				Allowable Stress	44.38	57.06	57.06
				Stress Ratio	0.12	0.20	0.16
			OBCP	Stress Intensity	19.80	26.70	5.60
				Allowable Stress	44.38	57.06	57.06
				Stress Ratio	0.45	0.47	0.10
			IBCP	Stress Intensity	11.10	16.10	18.60
				Allowable Stress	44.38	57.06	57.06
				Stress Ratio	0.25	0.28	0.33

72.48

Table A.3.9.1-2a
DSC Results (Alternate-1 Bottom Forging) - Load Combinations

Load Combination Number	Service Level	Loads	Components		Stress Category [ksi]		
					P_m	P_m+P_b	P_L
10	*D*	*DW+ Seismic+ IP(20psi)*	*Alternate -1 Bottom Forging*	*Stress Intensity*	*9.71*	*16.07*	*7.66*
				Allowable Stress	*44.38*	*57.06*	*57.06*
				Stress Ratio	*0.22*	*0.28*	*0.13*

Table A.3.9.1-3
DSC Weld Stress Results- Load Combinations

Load Combination Number	Service Level	Loads	Weld Components	Stress Category	Stress Intensity [ksi]	Allowable Stress [ksi]	Stress Ratio
9	A	DW+IP (20psi)	DSC-ITCP	P_L	16.50	23.2	0.71
				$P_L+P_b+Q+P_e$	40.19	46.3	0.87
			DSC-OTCP	P_L	11.57	23.2	0.50
				$P_L+P_b+Q+P_e$	30.24	46.3	0.65
			DSC-OBCP	P_L	5.46	23.2	0.24
				$P_L+P_b+Q+P_e$	25.77	46.3	0.56
10	D	DW+ Seismic + IP (20psi)	DSC-ITCP	P_L	25.0	46.9	0.53
			DSC-OTCP	P_L	38.8	46.9	0.83
			DSC-OBCP	P_L	17.30	46.9	0.37

Table A.3.9.1-4
DSC-OTCP Maximum Radial Weld Stress (S_x) Results- Load Combinations

Load Combination Number	Service Level	Loads	Maximum Radial Stress [ksi]
9	A	DW+IP (20psi)	0.14
10	D	DW+Seismic +IP(20psi)	4.22

Table A.3.9.1-5
Controlling DSC Load Combination Results Summary

Components / Welds	Controlling Load Combination (1)		Service Level	Max. Stress Ratio
	Number	Description		
DSC Shell Containment	9	DW + IP + Thermal	A	0.87
DSC Shell Non Containment	5	DW + Ram Retrieval+ IP + Thermal	A/B	0.85
OTCP	8	DW + Accident P	D	0.45
ITCP	8	DW + Accident P	D	0.45
OBCP	5	DW + Ram Retrieval + IP + Thermal	A/B	0.78
IBCP	4	DW + Ram Insert + IP + Thermal	A/B	0.47
Grapple Support	5	DW + Ram Retrieval + IP + Thermal	A/B	0.92
Grapple Ring	5	DW + Ram Retrieval + IP + Thermal	A/B	0.81
OTCP-DSC Shell Weld	10	DW + IP + max (HS_TOP, HS_BOT)	D	0.83
ITCP-DSC Shell Weld	9	DW + IP	A	0.87
OBCP-DSC Shell Weld	5	DW + Ram Retrieval + IP + Thermal	A/B	0.75

Note: (1) See Table A.3.9.1-1 for the load combination description.

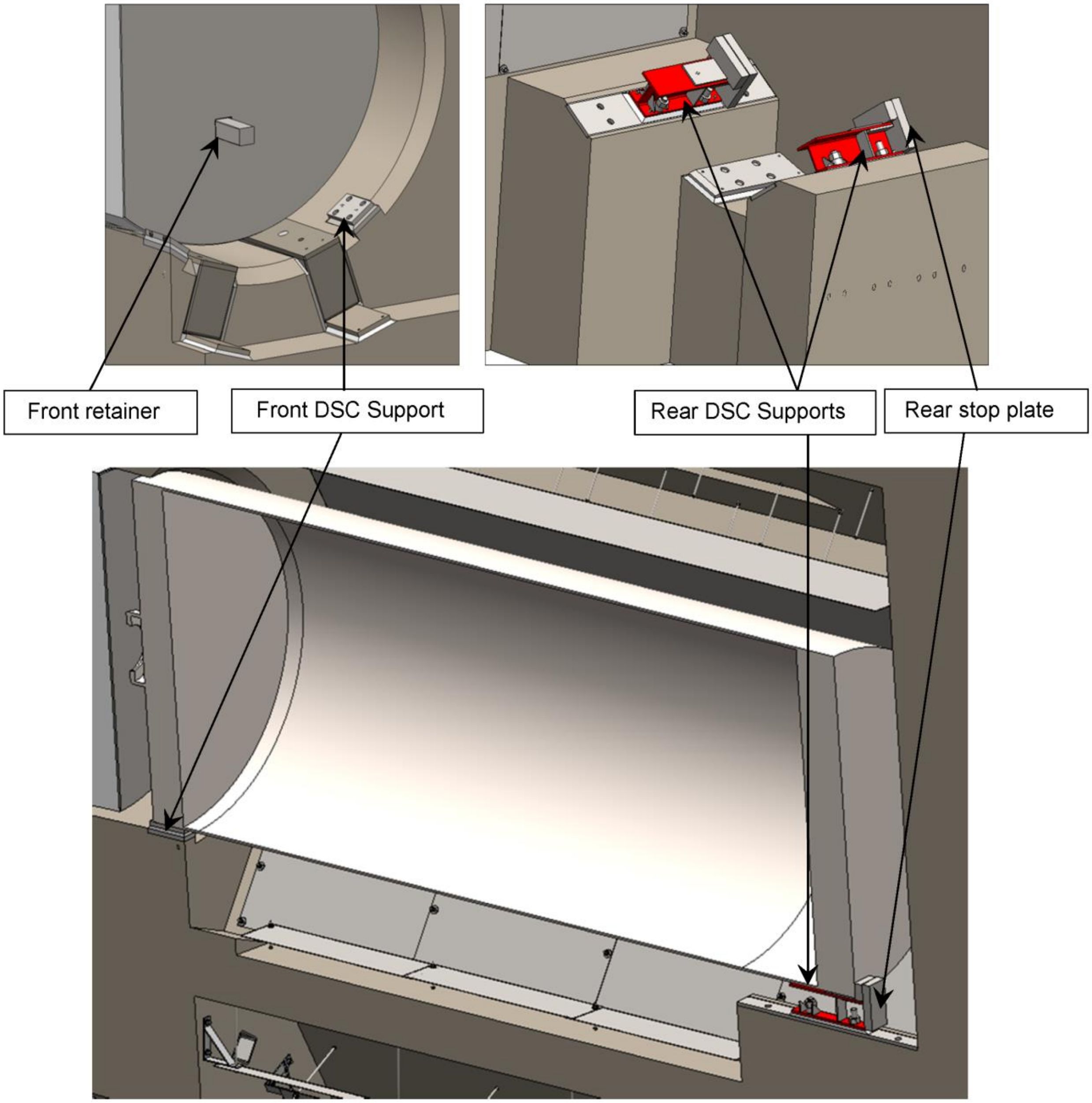


Figure A.3.9.1-1
DSC Supports and Axial Retainers

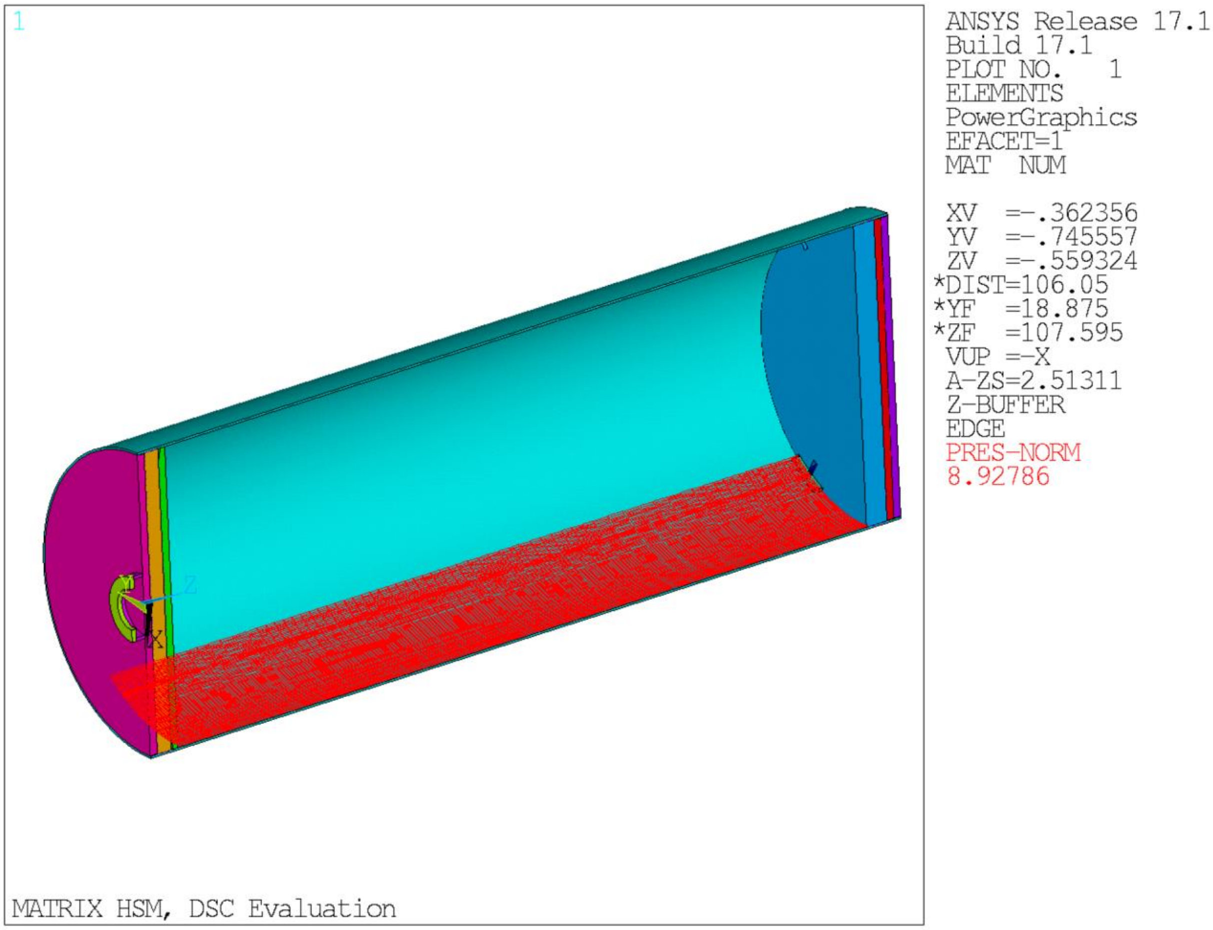


Figure A.3.9.1-2
DSC Dead Weight Equivalent Pressure

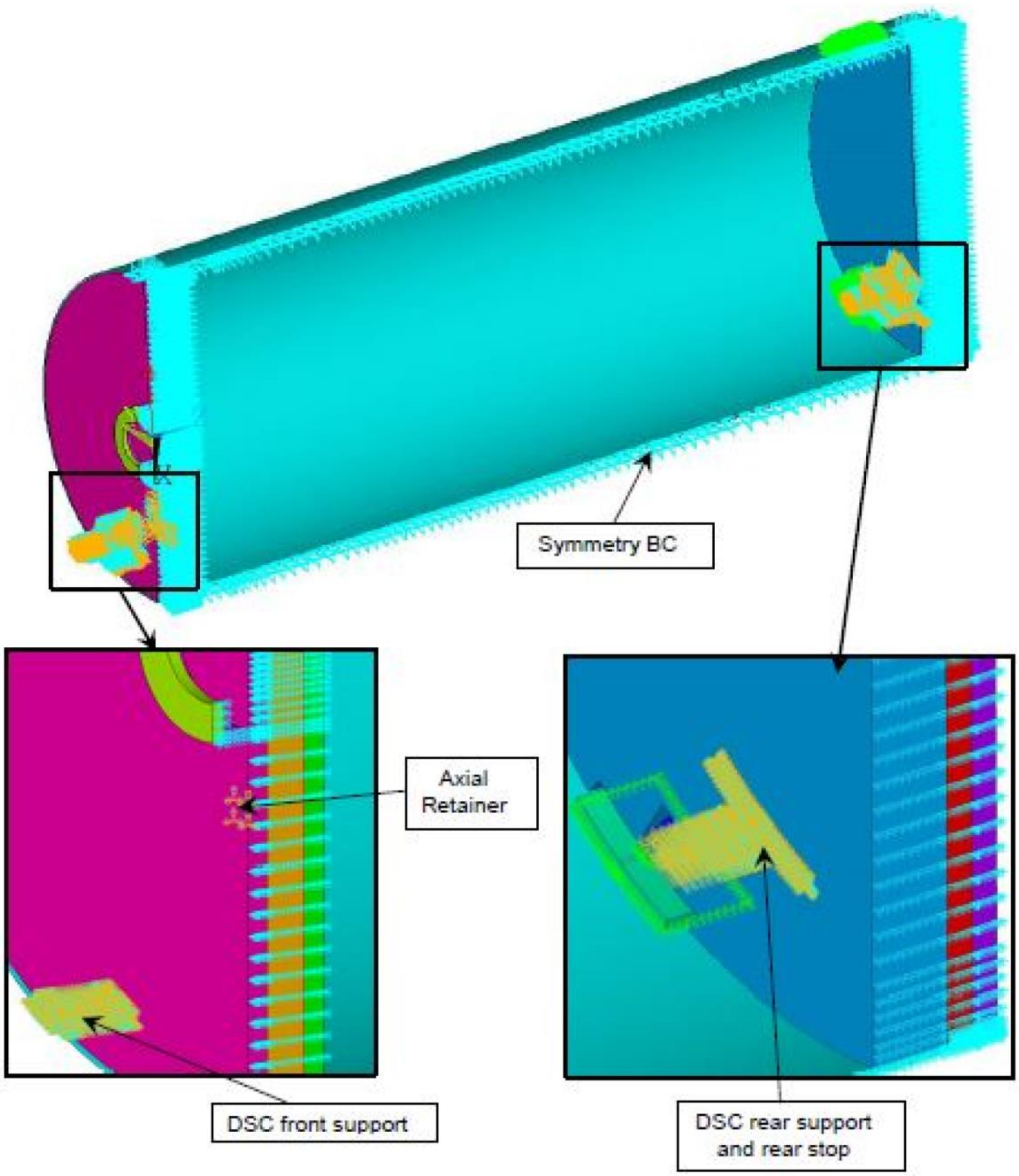


Figure A.3.9.1-3
DSC Boundary Conditions in HSM-MX

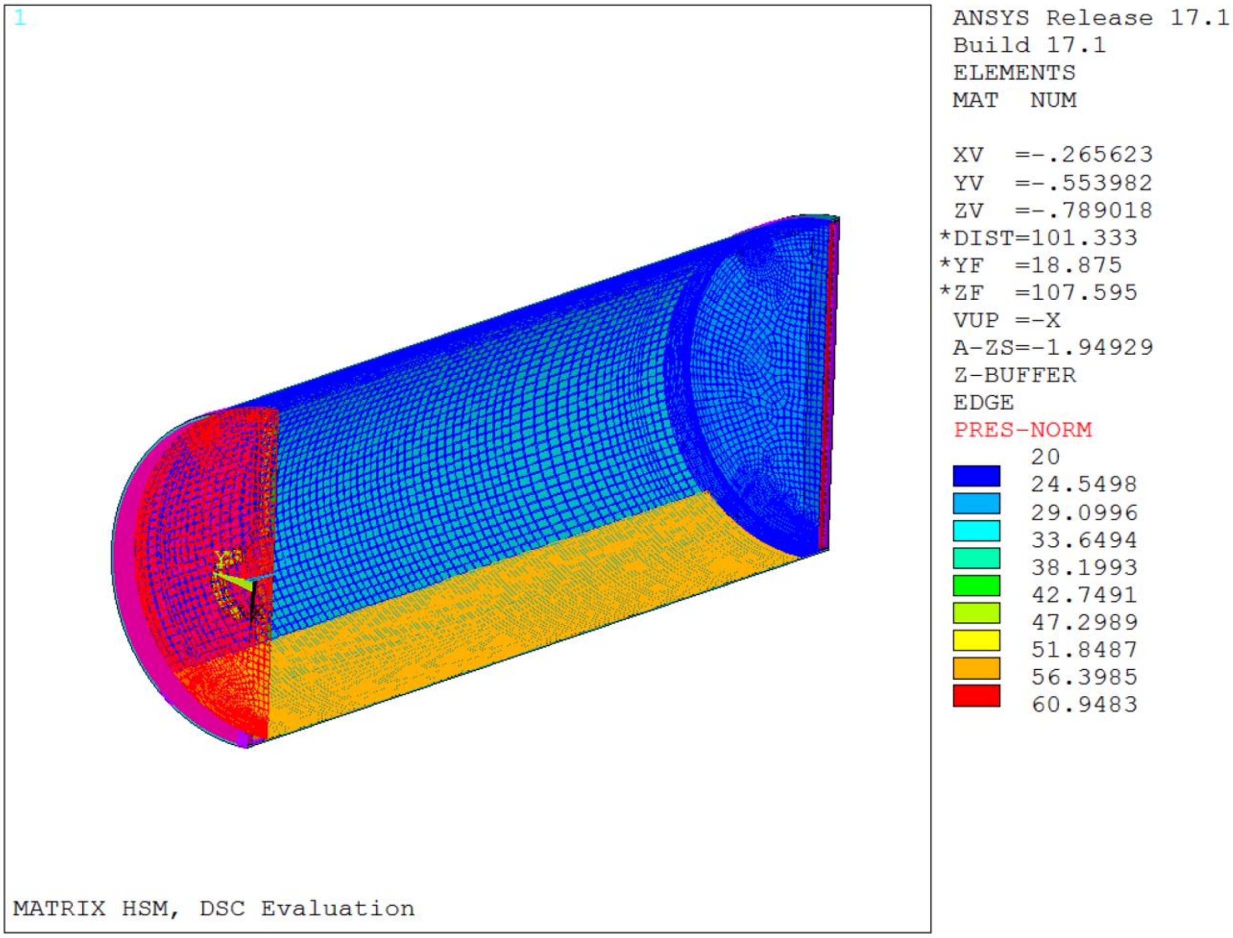


Figure A.3.9.1-4
Internals Seismic Equivalent Pressures with Internal Pressure, Load Case 2

A.3.9.2 EOS-37PTH AND EOS-89BTH BASKET STRUCTURAL ANALYSIS

There is no change to the EOS-37PTH and EOS-89BTH Basket Structural evaluation documented in Sections 3.9.2 due to the addition of the NUHOMS® MATRIX.

A.3.9.3 NUHOMS® EOS SYSTEM ACCIDENT DROP EVALUATION

There is no change to the EOS-37PTH DSC and EOS-89BTH DSC within the EOS-TC108 for drop evaluation documented in Sections 3.9.3 due to the addition of the NUHOMS® MATRIX.

APPENDIX A.3.9.4
HSM-MX STRUCTURAL ANALYSIS

Table of Contents

List of Tables

List of Figures

A.3.9.4 HSM-MX STRUCTURAL ANALYSIS

The purpose of this appendix is to present the structural evaluation of the NUHOMS® MATRIX (HSM-MX) due to all applied loads during storage and transfer operations.

A.3.9.4.1 General Description

General description and operational features for the HSM-MX is provided in Appendix A.1. The HSM-MX is a freestanding, staggered reinforced concrete structure, designed to provide environmental protection and radiological shielding for the EOS-37PTH/EOS-89BTH DSC. The drawings of the HSM-MX, showing different components and overall dimensions, are provided in Appendix A.1.3

The HSM-MX is one of the three main components of the NUHOMS® MATRIX System. The system consists of the dual purpose (Transportation/Storage) EOS-37PTH/EOS-89BTH DSC, the HSM-MX, and the onsite transfer cask (EOS-TC) with associated ancillary equipment.

The HSM-MX overpack system comprises the MATRIX Horizontal Storage Modules, the MATRIX retractable roller tray (MX-RRT), the MATRIX loading crane (MX-LC) and associated trailer interface for storing dry shielded canisters (DSCs).

The HSM-MX is a staggered, two-tiered, high density, high-heat rejection, storage overpack that provides a self-contained modular structure for storage of DSCs. The HSM-MX is constructed from reinforced concrete and structural steel. The thick concrete roof and walls of the HSM-MX provide substantial neutron and gamma shielding. The monolithic structure increases resistance to earthquakes and offers significant self-shielding. The MX-RRT delivers the DSC from the transfer cask to the HSM-MX and places it on the front and rear DSC supports.

The HSM-MX can be arranged in both single-row or back-to-back row arrays.

For thermal protection of the HSM-MX concrete, stainless steel heat shields are installed inside the HSM-MX. The primary function of the heat shields is to limit the temperature of the surrounding concrete walls. The heat shields guide the cooling airflow through the HSM-MX.

A.3.9.4.2 Material Properties

The material properties used in the analysis and design of the HSM-MX and its components are discussed in detail in Chapter 8 and Appendix A.8.

A.3.9.4.3 Design Criteria

No change to Section 3.9.4.3.

A.3.9.4.4 Load Cases

A summary of the design loads for HSM-MX concrete component evaluation is similar to Table 3.9.4-4 except the definition of normal handling (R_o) and off-normal handling (R_a) loads, and is provided in Table A.3.9.4-4 for information only. This table also presents the applicable codes and standards for specific load.

A.3.9.4.5 Load Combination

The load combinations used in the structural analysis of the HSM-MX structure comply with the requirements of 10 CFR 72.122 [A.3.9.4-1] and ANSI 57.9-84 [A.3.9.4-8] and are provided in Table A.3.9.4-5.

A.3.9.4.6 Finite Element Models

The structural analysis of HSM-MX storage modules arranged in a back-to-back row array provides a conservative estimate of the response of the HSM-MX under the postulated static and dynamic loads for any HSM-MX array configurations. The frame and shear wall action of the HSM-MX concrete components are considered to be the primary load carrying mechanism of the structural system. The analytical model is evaluated for normal operating, off-normal, and postulated accident loads acting on the HSM-MX.

A single Finite Element Model (FEM) is developed for the HSM-MX storage arranged in a back-to-back row array, where each row consists of three lower compartments and two upper compartments. This is a configuration with the minimum number of storage modules that an HSM-MX array can have. A back-to-back row array, instead of a single row array, is considered because the back wall shared by two rows is only 30 inch whereas, for a single row array, the thickness of the rear shield wall at the modules back end is 44 inch. Moreover, an array with additional storage modules would have a greater natural frequency in the transverse direction (that is, the direction of array expansion), resulting in a lower seismic loads. Therefore, the model based on a back-to-back row array with each row consisting of three lower compartments and two upper compartments provides a conservative estimate of the response of the HSM-MX structural elements under various static and dynamic loads.

The analysis results from ANSYS are post-processed using CivilFEM® [A.3.9.4-18] software. CivilFEM® defines the shell elements at the mid-planes of the walls and slabs that are represented by the 3D solid elements in the ANSYS model. Forces and moments on the shell elements that are equivalent to the displacement results on solid elements are computed by CivilFEM®. Then the results of the shell forces and moments are utilized to determine reinforcement areas.

A.3.9.4.6.1 Finite Element Model to Evaluate HSM-MX Concrete Components for Mechanical Loads

A three-dimensional (3D) finite element model (FEM) of the HSM-MX, including all the concrete components, is developed in the computer program ANSYS [A.3.9.4-14]. The eight-node brick element (ANSYS element type SOLID185) is used to model the concrete structure. Each node of the eight-node brick element has three translational degrees of freedom. A global element dimension of 4-inch is used in the model. As demonstrated in A.3.9.4.6, the model can accurately simulate the frame and shear wall action of the HSM-MX concrete components, which are the primary load-resisting mechanisms. The mass of the DSC is evenly distributed over the four supports using lumped mass elements (ANSYS element type MASS21). The mass of the door is included as lumped mass elements placed around the recessed door opening at the five embedment locations of the door. The mass of the vent cover is also included as lumped mass elements at the vent cover support locations on the roof. A plot of the CAD model and ANSYS FEM of the HSM-MX back-to-back array are shown in Figure A.3.9.4-1 and Figure A.3.9.4-2, respectively. The coordinate system for the model is shown in Figure A.3.9.4-2, where the origin is located at the bottom left corner on the front.

The model is assumed to neither uplift due to dead weight nor slide due to friction with the ISFSI pad. Therefore, the model is restrained vertically at all nodes on the bottom of the model, and also restrained laterally and axially at all nodes on the bottom of the model to prevent rigid body movement.

A.3.9.4.6.2 Finite Element Model of the HSM-MX Concrete Structure for Thermal Stress Analysis

Thermal stress analyses of the HSM-MX were performed using a 3D FEM, which includes only the concrete components developed in Section A.3.9.4.6.1. The connections of the door to the HSM-MX concrete structure are designed so that free thermal growth is permitted in these members when the HSM-MX is subjected to thermal loads. Because of their free thermal growth, the doors do not induce thermal stresses in the concrete components of the HSM-MX. Therefore, the analytical model of the HSM-MX for thermal stress analysis of the concrete components does not include doors. The ANSYS models with temperature profile, which are used to perform thermal stress analysis of the concrete components for normal thermal hot and blocked vent accident thermal conditions, are shown in Figure A.3.9.4-3 and Figure A.3.9.4-4, respectively.

For thermal stress analysis, the FEM has Z-degrees of freedom restrained along the bottom front edge of the module (Z=0 and Y=0 in the ANSYS model), X-degrees of freedom restrained along the bottom left side edge of the module (X=0 and Y = 0 in the ANSYS model), and Y-degrees of freedom restrained at the base of the module (Y=0 in the ANSYS model).

A.3.9.4.6.3 Finite Element Model for Structural Analysis of Heat Shield Panels and supporting brackets for the heat shields

The primary function of the heat shields is to limit the temperature of the surrounding concrete walls to acceptable values. The stainless steel heat shields are evaluated for their ability to sustain structural integrity after being subjected to two loads: a combination of 1g dead load due to its own weight, and a seismic load that is dependent upon its natural frequency as well as the in-structure response spectra (ISRS) at the supports.

The FEMs of the HSM-MX (single and back-to-back double) arrays developed in Section A.3.9.4.6.1 are used for the modal time-history analysis using ANSYS. In order to determine the appropriate seismic loading for the heat shields, ISRS are determined for the locations of the various heat shield attachments. The ISRS are determined by performing modal time history analysis of the entire HSM-MX structures. ANSYS is used to determine the natural vibration frequencies of the coupled panel-stud system. Shell elements (ANSYS element type SHELL63) are used to model the heat shield panels and support brackets and beam elements (ANSYS element type BEAM4) are used for the studs. The analytical models of the coupled lower side heat shield (LSHS) and Studs, and coupled lower top heat shield (LTHS) and studs are shown in Figure A.3.9.4-6. Similar models were used for the upper bottom heat shields (UBHS), upper side heat shield (USHS), and upper top heat shield (UTHS).

A.3.9.4.7 Normal Operation Structural Analysis

This section describes the design basis normal operation events for the HSM-MX components and presents analyses that demonstrate the adequacy of the design safety features of the HSM-MX. The normal operating loads for which the HSM-MX components are designed include dead load, live load, normal handling loads, normal thermal loads, and wind load. The ANSYS FEM described in Section A.3.9.4.6.1 is used to evaluate concrete forces and moments due to these normal loads. The methodology used to evaluate the effects of these normal loads is addressed in the following paragraphs.

A.3.9.4.7.1 HSM-MX Dead Load (DL) Analysis

Dead loads are applied to the analytical model by application of 1g acceleration in the vertical direction where g is the gravitational acceleration (386.4 in/sec^2). The 5% variation of dead load as indicated in ANSI/ANS 57.9 is not used because the heaviest design weight is used for analysis.

A.3.9.4.7.2 HSM-MX Live load (LL) Analysis

Live load analysis is performed by applying 200 psf pressure on the roof. The DSC weight is also applied on the DSC supports as a live load.

A.3.9.4.7.3 HSM-MX Normal Operational Handling Load (R_o) Analysis

Normal operation assumes the canister is sliding over the MX-RRT due to a hydraulic ram force of up to 135,000 lbs (insertion) and 80,000 lbs (extraction) applied at the grapple ring and resisted by an axial load of 70,000 lb (insertion) and 40,000 lb (extraction) developing at each side of the MX-RRT supports. Here the total resisting axial load of 140,000 lbs is greater than the hydraulic ram force of 135,000 lbs. Only the insertion load is applied in the ANSYS FEM, since the extraction load is bounded by the insertion load. In addition, the DSC weight is applied to the MX-RRT support locations on both sides (4 points).

A.3.9.4.7.4 HSM-MX Normal Operating Thermal (T_o) Stress Analysis

The normal operating thermal (T_o) loads on the HSM-MX include the effect of design basis heat load of up to 50 kW generated by the DSC, plus the effect of normal ambient temperature. To evaluate the effects of normal thermal loads on the HSM-MX, heat transfer analyses for a range of normal ambient temperatures (-20 °F and 100 °F) are performed with a DSC heat load of 50 kW. The normal thermal cold condition (-20 °F) is bounded by the off-normal thermal cold condition (-40 °F). Therefore, the off-normal thermal cold condition is used in place of the normal thermal cold condition. The ambient condition that causes the maximum temperature and maximum gradients in the concrete components is used in the analysis. The normal thermal hot condition is the governing case for this load case. The HSM-MX thermal stress analysis was performed using thermal profiles and maximum temperatures that bound those reported in Section A.4.5. The ANSYS FEM described in Section A.3.9.4.6.2 is used for the normal thermal load analysis.

A.3.9.4.7.5 HSM-MX Design Basis Wind Load (W) Analysis

The DSCs inside the HSM-MX are not affected by wind load. The concrete structure forces and moments due to the design basis wind load (W) are bounded by the result of tornado generated wind load discussed in Section A.3.9.4.9.1. Therefore, no separate analysis is performed for this case.

A.3.9.4.8 Off-Normal Operation Structural Analysis

This section describes the design basis off-normal events for the HSM-MX components and presents analyses that demonstrate the adequacy of the design safety features of the HSM-MX.

The off-normal operating loads for which the HSM-MX components are designed include off-normal handling load and off-normal thermal load.

For an operating NUHOMS® MATRIX System, off-normal events could occur during fuel loading, TC handling, canister transfer, trailer towing, and other operational events. Two credible off-normal events bound the range of off-normal conditions for the HSM-MX. The limiting off-normal events as defined above are defined as a jammed DSC during loading or unloading from the HSM-MX and the extreme ambient temperatures of -40 °F (winter) and +117 °F (summer). These events bound the range of expected off-normal structural loads and off-normal temperatures acting on the HSM-MX. The ANSYS FEM described in Section A.3.9.4.6.1 is used to evaluate concrete forces and moments due to these loads.

A.3.9.4.8.1 HSM-MX Off-Normal Handling Loads (R_a) Analysis

This load case assumes that the EOS-TC is not accurately aligned with respect to the HSM-MX resulting in binding of the DSC during a transfer operation causing the hydraulic pressure in the ram to increase. The ram force is limited to a maximum load of 135,000 lbs during insertion, as well as during retrieval. Therefore, for the DSC, the off-normal jammed canister load (R_a) is defined as an axial load of 135,000 lbs on one side of MX-RRT supports. In addition, the DSC weight is applied to MX-RRT support locations of the loaded MX-RRT rail (2 points).

A.3.9.4.8.2 HSM-MX Off-Normal Thermal Loads Analysis

This load case is the same as the normal thermal load, but with an ambient temperature range from -40 °F to 117 °F. The temperature distributions for the extreme ambient conditions are considered for the concrete component evaluation. The concrete forces and moments due to this load case are bounded by the results of the accident blocked vent condition discussed in Section A.3.9.4.9.4. Therefore, no separate analysis is performed for this case.

A.3.9.4.9 Accident Condition Structural Analysis

The design basis accident events specified by ANSI/ANS 57.9-1984, and other credible accidents postulated to affect the normal safe operation of the HSM-MX are addressed in this section.

Each accident condition is analyzed to demonstrate that the requirements of 10 CFR 72.122 are met and that adequate safety margins exist for the HSM-MX design. The resulting accident condition stresses, forces and moments in the HSM-MX components are evaluated and compared with the applicable code limits. The postulated accident conditions addressed in this section include:

- Tornado winds and tornado generated missiles (W_t, W_m)
- Design basis earthquake (E)
- Design basis flood (FL)
- Blocked Vent Accident Thermal (T_a)

The ANSYS FEM described in Section A.3.9.4.6.1 is used to evaluate concrete forces and moments due to these loads.

A.3.9.4.9.1 Tornado Winds/Tornado Missile Load (W_t, W_m) Analysis

The most severe tornado generated wind and missile loads selected for analysis are specified by U.S. NRC (NRC) Regulatory Guide 1.76 [A.3.9.4-4] and NUREG-0800 [A.3.9.4-5]. The extreme design basis wind loads are less severe than tornado generated wind loads and, therefore, do not need to be addressed.

The tornado wind intensities used for the HSM-MX analysis are obtained from NRC Regulatory Guide 1.76, Rev. 0 [A.3.9.4-4], which bound the design basis requirements. Region I intensities are utilized since they result in the most severe loading parameters. For this region, the maximum wind speed is 360 mph, the rotational speed is 290 mph, and the maximum translational speed is 70 mph. The radius of the maximum rotational speed is 150 ft, the pressure drop across the tornado is 3 psi and the rate of pressure drop is 2 psi per second [A.3.9.4-4].

The maximum wind speed used of 360 mph provides substantial conservatism relative to the maximum wind speed of 230 mph prescribed in current regulatory guidance in NRC Regulatory Guide 1.76 Revision 1 [A.3.9.4-17]. For the purposes of the structural evaluation as described in Appendix A.3, as well as the accident evaluation as described in Appendix A.12 the design basis tornado (DBT) refers to the bounding criteria from Regulatory Guide 1.76, Rev. 0 used in the analysis.

Tornado loads are generated for three separate loading phenomena:

- Pressure or suction forces created by drag as air impinges and flows past the HSM-MX. These pressure or suction forces are due to tornado-generated wind with maximum wind speed of 360 mph.
- Pressure or suction forces created by drag due to tornado-generated pressure drop or differential pressure load of 3 psi.
- Impact, penetration and spalling forces created by tornado-generated missiles impinging on the HSM-MX.

The determination of impact forces created by tornado missiles for the HSM-MX is consistent with that presented in Section 2.3.1.2. The four types of missiles listed below envelope the missile spectrum of NUREG-0800, Revision 2, Section 3.5.1.4 [A.3.9.4-5]. These missiles also bound the design basis missile spectrum of NRC Regulatory Guide 1.76, Revision 1 [A.3.9.4-17] and NUREG 0800, Revision 3, Section 3.5.1.4 [A.3.9.4-6]. Evaluation of the effects of small diameter spherical missiles (artillery) is not required because there are no openings in the HSM-MX leading directly to the DSC through which such missiles could pass.

1. Utility wooden pole, 13.5″ diameter, 35′ long, Weight = 1124 lbs, Impact velocity = 180 fps.
2. Armor piercing artillery shell 8″ diameter, Weight = 276 lbs, Impact velocity = 185 fps.
3. Steel pipe, 12.75″ diameter, Schedule 40, 15 ft long, Weight = 750 lbs, Impact velocity = 154 fps.

4. Automobile traveling through the air not more than 25 ft above the ground and having contact area of 20 sq. ft, Weight = 4000 lbs, Impact Horizontal Velocity = 195 fps.

Stability and stress analyses are performed to determine the response of the HSM-MX to tornado wind pressure loads. The stability analyses are discussed in detail in Appendix A.3.9.7. The stress analyses are performed using the ANSYS FEM of the HSM-MX to determine design forces and moments. These conservative analyses envelope the effects of wind pressures on the HSM-MX in other array configurations. Thus, the requirements of 10 CFR 72.122 are met.

The HSM-MX is qualified for maximum design basis tornado (DBT) generated design wind loads of 238 psf and 167 psf on the windward and leeward HSM-MX walls (See Table A.3.9.4-1 and Table A.3.9.4-2), respectively, and a pressure drop of 3 psi.

An HSM-MX array is protected by end side walls, shield walls, or an adjacent module. For an HSM-MX array, the module on the windward end of the array has either an end side wall or an end shield wall to protect the module from tornado missile impacts. The end walls are also subjected to the 238 psf windward pressure load. The 167 psf suction load is applicable to the end side wall on the opposite end module in the array. A suction of 355 psf is also applied to the roof of each HSM-MX in the array.

For the stress analyses, the DBT wind pressures are applied to the HSM-MX as uniformly distributed loads. The bending moments and shear forces at critical locations in the HSM-MX concrete components are calculated by performing an analysis using the ANSYS analytical model of the HSM-MX as described in Section A.3.9.4.6. The wind and tornado loads are identified as load combination C2 and C5 as provided in Table A.3.9.4-5. The demand to capacity ratios in terms of reinforcement areas for the bounding load combinations are presented in Table A.3.9.4-6 for each of the HSM-MX components.

Conservatively, the design basis extreme wind pressure loads are assumed to be equal to those calculated for the DBT (based on 360 mph wind speed) in the formulation of HSM-MX load combination results.

In addition, the adequacy of the HSM-MX to resist tornado missile loads is checked using the modified National Defense Research Committee (NDRC) empirical formulae [A.3.9.4-10] for local damage evaluation, and response chart solution method [A.3.9.4-13] for global response. These evaluations are described in Section A.3.9.4.10.5.

A.3.9.4.9.2 Earthquake (Seismic) Load (E) Analysis

The design basis seismic load used for analysis of the HSM-MX components is as discussed in Section A.2.3.4. Based on NRC Regulatory Guide 1.61 [A.3.9.4-3], a damping value of 4% is used for seismic analysis of steel structural components and a damping value of 7% is used for seismic analysis of concrete components of the HSM-MX. An evaluation of the frequency content of the loaded HSM-MX is performed to determine the amplified accelerations associated with the design basis seismic response spectra for the HSM-MX. The results of the frequency analysis of the HSM-MX structure (which includes a simplified model of the DSC) yield a lowest frequency of 23.94 Hz in the transverse direction and 24.08 Hz in the longitudinal direction. The lowest vertical frequency exceeds 45 Hz; therefore, the spectral acceleration is not amplified in the vertical direction. Thus, based on the enhanced Regulatory Guide 1.60 response spectra amplifications, the corresponding seismic accelerations used for the design of the HSM-MX are 1.33g and 1.33g in the transverse and longitudinal directions, respectively, and 0.800g in the vertical direction. The resulting amplified accelerations are given in Table A.3.9.4-3.

An equivalent static analysis of the HSM-MX is performed using the ANSYS FEM described in Section A.3.9.4.6.1 by applying the amplified seismic accelerations load. The dominant frequencies are lower for the double row array in the X and Y directions, whereas the single row array has a lower frequency in the Z direction. Therefore, the spectral accelerations to be used in seismic analysis are taken from the double row array model for the X and Y directions, and from the single row array model for the Z direction.

The responses for each orthogonal direction are combined using the square root of the sum of the squares (SRSS) method. The resulting moments and forces due to the combined seismic load are included in the HSM-MX load combination results.

For sites having a higher zero period acceleration than analyzed, the reinforcement requirement may need to be reviewed, and additional rebar may be added for such sites.

The stability evaluation of the HSM-MX due to seismic load is discussed in Appendix A.3.9.7.

Seismic analysis of the HSM-MX heat shields consists of a modal time-history analysis of the HSM-MX using the seismic acceleration load corresponding to the ISRS with ±15% peak-broadening and the frequency response of each type of heat shield. The ground motion time histories used in the modal time-history analysis of the HSM-MX are based on four earthquakes,

- Hector Mine,
- Chi-Chi,
- Denali,
- Mianzhuqingping.

The time histories are compatible with the enhanced NRC Regulatory Guide 1.60 [A.3.9.4-2] response spectra. The acceleration, velocity, and displacement time histories and corresponding spectra in the two horizontal and vertical directions, all with 1.0g zero period acceleration (ZPA), are shown for the ground motion based on the Hector Mine earthquake in Figure A.3.9.4-7 through Figure A.3.9.4-12 for information only. The time histories are scaled down in the modal time-history analyses because their response spectra are anchored at 1.0g ZPA whereas the seismic criteria for the HSM-MX are based on 0.85g ZPA in the horizontal directions and 0.80g ZPA in the vertical direction. The envelops of the ISRS of heat shield support nodes due to the four ground motions are shown in Figure A.3.9.4-13 through Figure A.3.9.4-15 for lower top heat shield (LTHS) only.

A.3.9.4.9.3 Flood Load (FL) Analysis

Since the source of flooding is site specific, the exact source, or quantity of flood water, should be established by the licensee. However, for this generic evaluation of the HSM-MX, bounding flooding conditions are specified that envelope those that are postulated for most plant sites. As described in Section 2.3.3, the design basis flooding load is specified as a 50-foot static head of water and a maximum flow velocity of 15 feet per second. Each licensee should confirm that this represents a bounding design basis for their specific ISFSI site.

Since the HSM-MX is open to the atmosphere, static differential pressure due to flooding is not a design load.

The maximum drag pressure, D, acting on the HSM-MX due to a 15 fps flood water velocity is calculated as follows:

$$D = \frac{C_D \, \rho_w \, V^2}{2\,g} \qquad [A.3.9.4\text{-}15]$$

Where:

V = 15 fps, Flood water velocity

C_D = 2.0, Drag coefficient for flat plate

ρ_w = 62.4 lb/ft^3, Flood water density

g = 32.2 ft/sec^2, Acceleration due to gravity

D = Drag pressure (psf)

The resulting flood induced drag pressure is: D = 436 psf.

The following flood load cases are considered to account for different flow direction:

- Case 1: Flood water flowing longitudinally from the front row to the back row of the module or vice versa.

- Case 2: Flood water flowing transversely from the right side wall to the left side wall of the module or vice versa.

The ANSYS FEM described in Section A.3.9.4.6.1 is used for the structural evaluation. The results for the flood load case are obtained by enveloping results from the above load cases.

The stability evaluation of the HSM-MX due to flood load is discussed in Appendix A.3.9.7.

A.3.9.4.9.4 Accident Blocked Vent Thermal (T_a) Stress Analysis

The postulated accident thermal event occurs due to blockage of the air inlet and outlet vents under off-normal ambient temperatures range from -40 °F to 117 °F. The HSM-MX thermal stress analysis was performed using the thermal profiles and maximum temperatures reported in Section A.4.5.

The ANSYS FEM described in Section A.3.9.4.6.2 is used for the structural analysis for the accident blocked vent condition.

A.3.9.4.10 Structural Evaluation

The load categories associated with normal operating conditions, off-normal conditions and postulated accident conditions are described previously. The load combination results and design strengths of HSM-MX components are presented in this section.

A.3.9.4.10.1 HSM-MX Concrete Components

To determine the required strength (internal axial forces, shear forces, and bending moments) for each HSM-MX concrete component, linear elastic finite element analyses are performed for the normal, off-normal, and accident loads using the analytical models described in Sections A.3.9.4.6.1 and A.3.9.4.6.2 for mechanical and thermal loads, respectively.

The concrete design loads are multiplied by load factors and combined to simulate the most adverse load conditions. The load combinations listed in Table A.3.9.4-5 are used to evaluate the concrete components. The demand to capacity ratios (in terms of reinforcement areas) for the bounding load combinations are presented in Table A.3.9.4-6 for each HSM-MX component. The reinforcement directions are shown in Figure A.3.9.4-5. The thermal stresses of HSM-MX concrete components used in the load combination results are based on thermal results that bound those reported in Section A.4.5.

The required longitudinal reinforcement areas for the critical sections of concrete are calculated in accordance with the requirements of ANSI 57.9 [A.3.9.4-8] and ACI 349-06 [A.3.9.4-9], including the strength reduction factors defined in ACI 349-06, Section 9.3. The longitudinal reinforcement areas provided for the HSM-MX concrete components exceed the required reinforcement areas as shown in Table A.3.9.4-6.

A.3.9.4.10.2 HSM-MX Shield Door

The shield door is free to grow in the radial direction when subjected to thermal loads. Therefore, there are no stresses in the door due to thermal growth. The dead weight, differential pressure, flood and seismic loads cause insignificant stresses in the door compared to stresses due to missile impact load. Therefore, the door is evaluated only for the missile impact load.

The minimum thickness of a concrete component to prevent perforation and scabbing are 18.5 inches and 27.7 inches, respectively. Thus, the 28-inch thick door is adequate to protect from local damage due to missile impact. The computed maximum ductility ratio for the door is less than 2, which satisfies the ductility requirement if compared against the allowable ductility ratio of 10 as per ACI 349-06 [A.3.9.4-9]. Therefore, the concrete door meets the ductility requirement and is adequate to protect from the global effect of missile impact.

A.3.9.4.10.3 HSM-MX Heat Shield

The heat shield panels are connected by bolts and threaded studs to the support brackets and surrounding concrete walls. The HSM-MX heat shield consists of different variations such as lower cavity side heat shield (LSHS), lower cavity top heat shield (LTHS), upper cavity bottom heat shield (UBHS), upper cavity side heat shield (USHS) and upper cavity top heat shield (UTHS).

The heat shield panels consists of 12 gauge 0.1054-inch thick stainless steel.

The maximum interaction ratio for the combined axial and bending stress for all bolts is 0.98, which is less than 1.0, in the UBHS and maximum bending stress in the panel is 30.0 ksi, which is less than the allowable stress of 32.2 ksi.

The maximum temperature used in the stress analysis of the heat shields bounds the maximum temperatures reported in Section A.4.5. Expansion due to off-normal and accident condition for all heat shields will not be restrained by the supporting elements.

A.3.9.4.10.4 HSM-MX DSC Axial Retainer

The DSC axial retainer consists of a 3.5 in x 3.5 in solid steel square rod. The axial retainer slides horizontally through the HSM-MX door and stops the forward motion of the DSC towards the door. The anchor plate of the axial retainer (2 ½ in. thick, in the middle and 2 in. thick near the edge 6 in. x 15 in. plate), which is bolted to the door, supports the axial motion of the retainer and transfers the DSC seismic load to the door. The motion towards the back wall is controlled by the rear stop plate.

The calculated compressive strength of the axial retainer rod is 280.3 kips which is greater than the equivalent force of 270.5 kips, due to seismic load. The maximum seismically induced shear load in the anchor plate is 135.3 kips. The allowable shear strength of the anchor plate is 498.6 kips. The bounding seismically induced moment in the anchor plate is 507.2 in-kips. The allowable flexural strength of the anchor plate at that location is 714.0 in-kips. Hence, the DSC axial retainer design is adequate to perform its intended function.

A.3.9.4.10.5 Evaluation of Concrete Components for Missile Loading

Missile impact effects are assessed in terms of local damage and overall structural response. Local damage that occurs in the immediate vicinity of the impact area is assessed in terms of penetration, perforation, spalling and scabbing. Evaluation of local effects is essential to ensure that protected items (the DSC and fuel) would not be damaged by a missile perforating a protective barrier, or by secondary missiles such as scabbing particles. Evaluation of overall structural response is essential to ensure that protected items are not damaged or functionally impaired by deformation or collapse of the impacted structure.

The tornado-generated missiles are conservatively assumed to strike normal to the surface with the long axis of the missile parallel to the line of flight to maximize the local effects. Plastic deformation to absorb the energy input by the tornado-generated missile load is desirable and acceptable, provided that the overall integrity of the structure is not impaired. Due to complex physical process associated with missile impact effects, the HSM-MX structure is primarily evaluated conservatively by application of empirical formulae.

A.3.9.4.10.5.1 Local Damage Evaluation

Local missile impact effects consist of (a) missile penetration into the target, (b) missile perforation through the target, and (c) spalling and scabbing of the target. This also includes punching shear in the region of the target. Per F.7.2.3 of ACI 349-06 [A.3.9.4-9], if the concrete thickness is at least 20% greater than that required to prevent perforation, the punching shear requirement of the code need not be checked.

The following enveloping missiles are considered for local damage:

- Utility wooden pole
- Armor piercing artillery shell

- 12-inch diameter schedule 40 steel pipe

Large deformable missiles such as automobiles are incapable of producing significant local damage. Concrete thickness satisfying the global structural response requirements including punching shear is considered to preclude unacceptable local damage. Therefore, the local effects from an automobile are evaluated using punching shear criteria of ACI 349-06 [A.3.9.4-9]

The following empirical formulae are used to determine the local damage effects on reinforced concrete target:

A. Modified NDRC formulas for penetration depth [A.3.9.4-10]:

$$x = \sqrt{4KNWd\left(\frac{v_o}{1000\ d}\right)^{1.8}} \text{, for x/d} \leq 2.0$$

$$x = \left[KNW\left(\frac{v_o}{1000\ d}\right)^{1.8}\right] + d \text{ , for x/d} > 2.0$$

Where,

x = Missile penetration depth, inches

K= concrete penetrability factor = $\frac{180}{\sqrt{f_c'}}$

N = projectile shape factor
= 0.72 flat nosed
= 0.84 blunt nosed
= 1.0 bullet nosed (spherical end)
= 1.14 very sharp nose

W = weight of missile, lb

ν_o = striking velocity of missile, fps

d = effective projectile diameter, inches.
for a solid cylinder, d = diameter of projectile and
for a non-solid cylinder, d = $(4A_c/\pi)^{1/2}$

A_c = projectile impact area, in^2

B. Modified NDRC formula for perforation thickness [A.3.9.4-10]:

$$\frac{e}{d} = 3.19\left(\frac{x}{d}\right) - 0.718\left(\frac{x}{d}\right)^2 \text{ , for x/d} \leq 1.35$$

$$\frac{e}{d} = 1.32 + 1.24\left(\frac{x}{d}\right) \text{ , for } 1.35 \leq \text{x/d} \leq 13.5$$

Where,

e = perforation thickness, in.

In order to provide an adequate margin of safety the design thickness $t_d = 1.2e$ [A.3.9.4-9]

C. Modified NDRC formula for scabbing thickness [A.3.9.4-10]:

$$\frac{s}{d} = 7.91\left(\frac{x}{d}\right) - 5.06\left(\frac{x}{d}\right)^2 \text{, for } x/d \leq 0.65$$

$$\frac{s}{d} = 2.12 + 1.36\left(\frac{x}{d}\right) \text{, for } 0.65 \leq x/d \leq 11.75$$

Where,

s = scabbing thickness, in.

In order to provide an adequate margin of safety the design thickness $t_d = 1.2s$ [A.3.9.4-9]

The concrete targets of the HSM-MX that may be subjected to local damage due to missile impact are:

- 24-inch thick roof panel
- 44-inch thick roof side wall
- 39-inch thick (minimum) front wall
- 36-inch thick end shield wall
- 36-inch thick end shield wall with 11-inch thick (minimum) side wall (upper compartment)
- 44-inch thick end wall (lower compartment)
- 82-inch thick end wall (upper compartment)
- 44-inch thick rear wall (for the case of single row array)

The minimum thickness of concrete target components listed above is 36 inches and 24 inches for horizontal and vertical missiles impacts, respectively. So, the required perforation thickness and required scabbing thickness are compared against 36 inches and 24 inches for horizontal and vertical missiles impacts, respectively, to ensure the adequacy of design.

Local Impact Effects of Utility Wooden Pole Missile

Per section 6.4.1.2.5 of [A.3.9.4-10], utility wooden pole missiles do not have sufficient strength to penetrate a concrete target and that the scabbing thickness required for wood missiles is substantially less than that required for a steel missile with the same mass and velocity. Practically, wooden pole missiles do not appear to be capable of causing local damage to the 12-inch or thicker walls (also see Section 2.1.1 of [A.3.9.4-13]). Since none of the concrete targets are less than 12 inches thick, the postulated wood missiles do not cause any local damage to the HSM-MX concrete component.

Local Impact Effects of Armor Piercing Artillery Shell Missile

The penetration depth for this missile is calculated using the NDRC Formula as given in Section A.3.9.4.10.5.1 (a) and the parameters used in the formula are as listed below:

$d = 8.0$ in. effective diameter of missile

$W = 276$ lb weight of missile

$v_o = 185$ fps striking velocity of missile

$f'_c = 5000$ psi concrete compressive strength

$K = 180/\sqrt{5000} = 2.55$ concrete penetrability factor

$N = 0.84$ projectile shape factor (blunt nosed)

Penetration depth, $x = 4.6$ in. for x/d (= 0.58) ≤ 2.0

Perforation thickness, $e = 12.9$ in. for x/d (= 0.58) ≤ 1.35

Required perforation thickness = 1.2*12.9 = 15.5 in. < 36 in.

Scabbing thickness, $s = 23.1$ in. for x/d (= 0.58) ≤ 0.65

Required scabbing thickness = 1.2*23.1 = 27.7 in. < 36 in.

Similarly, for vertical impact:

Required perforation thickness = 11.2 in. < 24 in

Required scabbing thickness = 22.7 in. < 24 in

Therefore, penetration and perforation of the concrete components of the HSM-MX do not occur due to this missile impact.

Local Impact Effects of 12-Inch Diameter Schedule 40 Steel Pipe Missile

The penetration depth for this missile is calculated using the NDRC Formula as given in Section A.3.9.4.10.5.1 and the parameters used in the formula are as listed below:

$\phi = 12.75$ in. outer diameter of 12-inch dia. schedule 40 steel pipe.

$A_c = 15.74$ in^2 missile impact area (cross sectional area of steel)

$d = (4*15.74/\pi)^{1/2} = 4.5$ in. effective diameter of missile

W = 750 lb weight of missile

v_o = 154 fps striking velocity of missile

f'_c = 5000 psi concrete compressive strength

$K = 180/\sqrt{5000} = 2.55$ concrete penetrability factor

N = 0.72 projectile shape factor (flat nosed)

Penetration depth, x = 7.6 in. for x/d (= 1.69) ≤ 2.0

Perforation thickness, e = 15.4 in. for 1.35 ≤ x/d (= 1.69) ≤ 13.5

Required perforation thickness = 1.2*15.4 = 18.5 in. < 36 in.

Scabbing thickness, s = 19.9 in. for 0.65 ≤ x/d (= 1.69) ≤ 11.75

Required scabbing thickness = 1 .2*19.9 = 23.9 in. < 36 in.

Similarly, for vertical impact:

Required perforation thickness = 14.8 in. < 24 in

Required scabbing thickness = 20 in. < 24 in

Therefore, penetration and perforation of the concrete components of the HSM-MX do not occur due to this missile impact.

A.3.9.4.10.5.2 Global Structural Response

When a missile strikes a structure, large forces develop at the missile-structure interface, which decelerate the missile and accelerate the structure. The response of the structure depends on the dynamic properties of the structure and the time dependent nature of the applied loading (interface force-time function). The force-time function is, in turn, dependent on the type of impact (elastic or plastic) and the nature and extent of local damage.

In an elastic impact, the missile and the structure deform elastically, remain in contact for a short period of time (duration of impact), and subsequently disengage due to the action of elastic interface restoring forces.

In a plastic impact, the missile or the structure (or both) may sustain permanent deformation or damage (local damage). Elastic restoring forces are small, and the missile and the structure tend to remain in contact after impact. Plastic impact is much more common than elastic impact, which is rarely encountered. Test data have indicated that the impact from all postulated tornado-generated missiles can be characterized as a plastic impact.

If the interface forcing function can be defined or conservatively idealized, the structure can be modeled mathematically, and conventional analytical or numerical techniques can be used to predict structural response. If the interface forcing function cannot be defined, the same mathematical model of the structure can be used to determine structural response by application of conservation of momentum and energy balance techniques with due consideration for type of impact (elastic or plastic).

In either case, in lieu of a more rigorous analysis, a conservative estimate of structural response can be obtained by first determining the response of the impacted structural element, and then applying its reaction forces to the structure. The predicted structural response enables assessment of structural design adequacy in terms of strain energy capacity, deformation limits, stability and structural integrity.

The overall structural response of each component as a whole (global response) is determined by single degree of freedom analysis using response charts solution method of [A.3.9.4-13].

The following enveloping missiles are considered for global structural response:

- Utility wooden pole
- Armor piercing artillery shell
- 12-inch diameter schedule 40 steel pipe
- Automobile missile

The peak interface force and impact duration for each missile are calculated as follows:

A. Utility Wooden Pole Missile

For wooden missile, the interface forcing function is a rectangular pulse having a force magnitude of F and duration t_i, per Section 2.3.1 of [A.3.9.4-13]

$F = PA$

$t_i = M_m \nu_c / F$

Where,

F = interface force (lb)

P = interface pressure (psi) = 2500 psi for wood missiles [A.3.9.4-13]

A = cross sectional area of the missile (in^2) = $\pi * 13.5^2/4 = 143.1$ in^2

t_i = impact duration (sec)

W_m = weight of missile (lb) = 1124 lb

M_m = missile mass ($lb\text{-}sec^2/ft$) = W_m/g = 1124 lb /32.2 ft/sec^2 = 34.9 $lb\text{-}sec^2/ft$

ν_c = change in velocity during impact (conservatively = ν_s) (fps) = 180 fps

Therefore,

$F = 358$ kip and $t_i = 0.0175$ sec

For the missile with vertical velocity, F is the same and t_i =0.0117 sec

B. Armor Piercing Artillery Shell

For solid steel missile, the concrete is a soft target per section 6.4.2 of [A.3.9.4-10] with a penetration depth of 4.6 in. The interface forcing function is a rectangular pulse per Section 6.4.2.1.1 of [A.3.9.4-10].

$F = W_m V_0^2/2gX$

$t_i = 2X/V_0$

Where,

F = interface force (lb)

t_i = impact duration (sec)

W_m = missile weight (lb) = 276 lb

V_0 = initial velocity of the missile (fps) = 185 fps

X = penetration depth = 4.6 in.

Therefore,

$F = 383$ kip and $t_i = 0.00414$ sec

For the missile with vertical velocity,

F =170 kip and t_i =0.00622 sec

C. 12-Inch Diameter Schedule 40 Steel Pipe

For steel pipe missile, the interface forcing function is a triangular pulse per Section 2.3.2 of [A.3.9.4-13].

$t_i = 400M_m /PA$

$F = (2M_m v_s)/t_i$

Where,

F = peak interface force (lb)

P = collapse stress of pipe (psi) = 60000 psi

A = cross sectional metal area of the missile (in^2) = 15.74 in^2

t_i = impact duration (sec)

W_m = weight of missile (lb) = 750 lb

M_m = missile mass (lb-sec^2/ft) = W_m/g = 750 lb /32.2 ft/sec^2 = 23.29 lb-sec^2/ft

ν_s = striking velocity of missile = 154 fps

Therefore,

F = 728 kip and t_i = 0.00986 sec

For the missile with vertical velocity F_{peak} = 485 kip

D. Automobile Missile

For automobile missile, the interface forcing function per 2.3.3 of [A.3.9.4-13] is as follows:

$F_t = 0.625\ \nu_c\ W \sin(20t)$ $\quad 0 < t \leq 0.0785$ sec

$F_t = 0$ $\quad t > 0.0785$ sec

Where,

F_t = force as a function of time (lb)

W = weight of automobile (lb) = 4000 lb

ν_c = change in velocity during impact (conservatively = ν_s) (fps) = 195 fps

Therefore,

F = 488 kip and t_i = 0.0785 sec

For the missile with vertical velocity, F_{peak} =325 kip

The lower compartment module left sidewall, top left sidewall, right shield wall, front wall, rear wall, roof and roof sidewall of the HSM-MX are evaluated for global response, since these components may interface with missile loading. The lower compartment module left side wall, upper compartment module left side wall and rear wall are idealized as a simply supported plate. The roof is idealized as a plate clamped to three sides and free at the other side adjacent to vent opening. The roof sidewall is idealized as a plate clamped to three sides and free at the other side facing the top. The yield resistance and fundamental period of vibration of concrete components are then determined based on the assumed idealized boundary condition using the equations given in Section 4.4 of [A.3.9.4-13]. For the right shield wall and front wall, ANSYS finite element models are used to determine the yield resistance and fundamental period of vibration. The calculated value of yield resistance, R_y, and fundamental period of vibration, T_n, for different concrete components are tabulated below.

Component	R_y (kip)	T_n (sec)
Lower Compartment Module Left Side Wall	*1323*	0.0048
Upper Compartment Module Left Side Wall	*2889*	0.0025
Right Shield Wall	*789.2*	0.016
Front Wall	*893.0*	0.0079
Rear Wall	*886.3*	*0.0032*
Roof	*432.3*	0.0040
Roof Side Wall	*1323*	0.0015

72.48

In the response chart solution method, the structural response is determined by entering the chart with calculated values of C_T and C_R to determine the ductility ratio, μ, which is compared against the allowable ductility ratio as given in Appendix F of ACI 349-06 [A.3.9.4-9]. The dimensionless ratios, C_T and C_R, are defined as follows:

$$C_R = \frac{R_y}{F} \qquad\qquad C_T = \frac{t_i}{T_n}$$

The maximum value of ductility ratio of all seven components is found to be less than the allowable ductility ratio per ACI 349-06 [A.3.9.4-9], which is 10 if flexure controls the design and 1.3 if shear controls the design. Hence, the global response of HSM-MX is within deformation limit meeting the ductility requirement.

Each component is also evaluated for punching shear capacity with interfacing utility wooden pole missile and automobile missile. All the components have punching shear capacity greater than the peak missile interface force.

A.3.9.4.11 Conclusions

The load categories associated with normal operating conditions, off-normal conditions and postulated accident conditions are described and analyzed in previous sections. The load combination results for HSM-MX components important-to-safety are also presented. Comparison of the results with the corresponding design capacity shows that the design strength of the HSM-MX is greater than the strength required for the most critical load combination.

A.3.9.4.12 References

A.3.9.4-1 Code of Federal Regulation Title 10, Part 72 (10CFR Part 72), "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

A.3.9.4-2 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Revision 1, 1973.

A.3.9.4-3 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," Revision 1, March 2007.

A.3.9.4-4 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants," Revision 0, April 1974.

A.3.9.4-5 NUREG-0800, Standard Review Plan, Section 3.5.1.4, "Missiles Generated by Natural Phenomena," Revision 2, July 1981.

A.3.9.4-6 NUREG-0800, Standard Review Plan, Section 3.3.1, "Wind Loading," Section 3.3.2 "Tornado Loads," and Section 3.5.1.4 "Missiles Generated by Tornado and Extreme Winds," Revision 3, March 2007.

A.3.9.4-7 Not used.

A.3.9.4-8 ANSI/ANS 57.9-1984, "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type)," American National Standards Institute, American Nuclear Society.

A.3.9.4-9 ACI 349-06, "Code Requirements for Nuclear Safety Related Concrete Structures," American Concrete Institute.

A.3.9.4-10 American Society of Civil Engineers, "Structural Analysis and Design of Nuclear Plant Facilities," ASCE Publication No. 58.

A.3.9.4-11 Not used.

A.3.9.4-12 American Society of Civil Engineers, "Minimum Design Loads for Buildings and Other Structures," ASCE 7-10 (formerly ANSI A58.1).

A.3.9.4-13 Bechtel Corporation, "Design Guide Number C-2.45 for Design of Structures for Tornado Missile Impact," Rev. 0, April 1982.

A.3.9.4-14 "ANSYS Computer Code and User's Manual", Release 17.1

A.3.9.4-15 Binder, Raymond C., "Fluid Mechanics," 3rd Edition, Prentice-Hall, Inc, 1973.

A.3.9.4-16 AREVA Inc., "Updated Final Safety Analysis Report For The Standardized Advanced NUHOMS® Horizontal Modular Storage System For Irradiated Nuclear Fuel," Revision 6, US NRC Docket Number 72-1029, August 2014.

A.3.9.4-17 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants," Revision 1, March 2007.

A.3.9.4-18 "CivilFEM® Documentation", Release 17.1, SP1.

Table A.3.9.4-1
Design Pressures for Tornado Wind Flowing from Front Wall to Rear Wall and Vice Versa

Component	Velocity Pressure, q_v (psf)	External Pressure Coefficient, C_p	Internal Pressure Coefficient, (GC_{pi})	Max. Design Pressure, $q_v*(G*C_p-GC_{pi})$ (psf)
Windward (Front Row Front Wall)	276	0.80	±0.18	238
Leeward (Back Row Front Wall)		-0.47(1)		-160
Side (Right Side Wall)		-0.70		-214
Side (Left Side Wall)		-0.70		-214
Roof		-1.30		-355

Notes:

1. The C_p value is taken for L/B = 496”/438” ≈ 1.13.
2. The gust effect factor, G=0.85 considering the HSM-MX as rigid.

Table A.3.9.4-2
Design Pressures for Tornado Wind Flowing from Right Side to Left Side Wall and Vice Versa

Component	Velocity Pressure, q_v (psf)	External Pressure Coefficient, C_p	Internal Pressure Coefficient, (GC_{pi})	Max. Design Pressure, $q_v*(G*C_p-GC_{pi})$ (psf)
Side (Front Row Front Wall)	276	-0.70	±0.18	-214
Side (Back Row Front Wall)		-0.70		-214
Windward (Right Side Wall)		0.80		238
Leeward (Left Side Wall)		-0.50(1)		-167
Roof		-1.30		-355

Notes:

1. The C_p value is taken for L/B = 431”/438” ≈ 0.88
2. The gust effect factor, G=0.85 considering the HSM-MX as rigid.

Table A.3.9.4-3
Spectral Acceleration Applicable to Different Components of HSM-MX for Seismic Analysis

Direction	Frequency (Hz)	Spectral Acceleration Corresponding to Design ZPA (Design ZPA = 0.85g horizontal & 0.80g vertical)		
		at 3% Damping (for DSC)	at 4% Damping (for steel structure)	at 7% Damping (for concrete components)
X (Transverse)	23.94	1.62g	1.53g	1.33g
Y (Vertical)	49.02	0.80g	0.80g	0.80g
Z (Longitudinal)	24.08	1.61g	1.52g	1.33g

Table A.3.9.4-4
Load Cases for HSM-MX Concrete Components Evaluation

Design Load Type	Load Notation	Design Parameters	Applicable Codes / References
Normal			
Dead	DL	Includes self-weight with 160 pcf density for concrete.	ANSI/ANS 57.9-1984 [A.3.9.4-8]
Live	LL	Design live load of 200 psf on roof which includes snow and ice load and DSC weight of 135 kip applied on DSC supports.	ANSI/ANS 57.9-1984 [A.3.9.4-8] & ASCE 7-10 [A.3.9.4-12]
Normal Handling	R_O	140 kip of DSC insertion load is distributed to both sides of the MX-RRT supports. The DSC weight is also applied at both sides of the MX-RRT support locations (4 points).	
Normal Thermal	T_O	DSC with spent fuel rejecting up to 50.0 kW of decay heat. Extreme ambient air temp. -20 °F and 100 °F. Reference temperature = 70 °F.	
Off-Normal/Accidental			
Off-Normal Handling	R_a	135 kip of DSC insertion and retrieval load is applied to one side of the MX-RRT supports. The DSC weight is also applied at one side of the MX-RRT support locations (two points).	
Accidental Thermal	T_a	Enveloped of Off-Normal and Accidental Thermal (vent blocked) condition. Extreme ambient temperatures -40 °F and 117 °F. Reference temperature = 70 °F	
Earthquake	E	ZPA of 0.85g in horizontal and 0.80g in vertical direction with enhancement in frequency above 9 Hz and 7% damping.	NRC Reg. Guide 1.60 [A.3.9.4-2] & Reg. Guide 1.61 [A.3.9.4-3]
Flood	FL	Maximum flood height of 50 ft and max. velocity of water 15 ft/sec	10 CFR Part 72 [A.3.9.4-1]
Wind/ Tornado Wind	W/W_t	Maximum wind speed of 360 mph, and a pressure drop of 3 psi	ASCE 7-10 [A.3.9.4-12] & NRC Reg Guide 1.76 [A.3.9.4-4]
Tornado Generated Missile	W_m	Four types of tornado-generated missiles	NUREG-0800 Section 3.5.1.4 [A.3.9.4-5]

Table A.3.9.4-5
Load Combination for HSM-MX Concrete Components Evaluation

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

Note: See Table A.3.9.4-4 for notation.

Table A.3.9.4-6
Demand to Capacity Ratios for HSM-MX Longitudinal Reinforcement Areas

Component Name	*Thickness (in)*	*Reinforcement*	*$A_{s,provided}$ (in^2/in)*	*A_{sx}*			*A_{sy}*			*A_{sip}*		
				$A_{sx,reqd}$ (in^2/in)	*D/C_{asx}*	*Governing Load Combination*	*$A_{sy,reqd}$ (in^2/in)*	*D/C_{asy}*	*Governing Load Combination*	*$A_{sip,reqd}$ (in^2/in)*	*D/C_{asip}*	*Governing Load Combination(1)*
Bottom Unit Front Wall Bottom	*51*	*#8@6"*	*0.1317*	*0.1140*	*0.87*	*C4*	*0.0593*	*0.45*	*C4*	*0.1287*	*0.49*	*C1*
Top Unit Front Wall Bottom	*51*	*#8@7"*	*0.1129*	*0.0780*	*0.69*	*C7*	*0.0671*	*0.59*	*C4*	*0.1280*	*0.57*	*C1*
Front Wall Top	*39*	*#8@7"*	*0.1129*	*0.0943*	*0.84*	*C4*	*0.0927*	*0.82*	*C4*	*0.1556*	*0.69*	*C4*
Bottom Unit Vent Wall	*11.5*	*#5@12"*	*0.0258*	*0.0188*	*0.73*	*C4*	*0.0122*	*0.47*	*C4*	*0.0285*	*0.55*	*C1*
Top Unit Side Vent Wall	*11*	*#5@12"*	*0.0258*	*0.0110*	*0.43*	*C4*	*0.0122*	*0.47*	*C4*	*0.0276*	*0.53*	*C1*
Bottom Unit Side Wall	*37*	*#6@8"*	*0.0550*	*0.0298*	*0.54*	*C4*	*0.0256*	*0.47*	*C4*	*0.0925*	*0.84*	*C1*
Bottom Unit End Side Wall	*44*	*#8@8"*	*0.0988*	*0.0830*	*0.84*	*C4*	*0.0576*	*0.58*	*C7*	*0.1102*	*0.56*	*C1*
Top Unit End Side Wall	*82*	*#8@7"*	*0.1129*	*0.0372*	*0.33*	*C4*	*0.0476*	*0.42*	*C4*	*0.2047*	*0.91*	*C1*
Bottom Unit Rear Wall Bottom	*78*	*#6@4"*	*0.1100*	*0.0650*	*0.59*	*C4*	*0.0194*	*0.18*	*C4*	*0.1949*	*0.89*	*C1*
Rear Wall	*30*	*#8@12"*	*0.0658*	*0.0124*	*0.19*	*C4*	*0.0062*	*0.09*	*C4*	*0.1030*	*0.78*	*C4*
Roof Top Panel	*24*	*#6@7"*	*0.0629*	*0.0278*	*0.44*	*C2*	*0.0515*	*0.82*	*C5*	*0.0600*	*0.48*	*C1*
Roof Bottom Panel	*10*	*#5@12"*	*0.0258*	*0.0116*	*0.45*	*C5*	*0.0072*	*0.28*	*C4*	*0.0246*	*0.48*	*C1*
Roof Side Panel	*11*	*#5@9"*	*0.0344*	*0.0057*	*0.17*	*C5*	*0.0057*	*0.16*	*C5*	*0.0276*	*0.40*	*C1*
Roof Side Panel	*10.5*	*#5@9"*	*0.0344*	*0.0050*	*0.15*	*C5*	*0.0126*	*0.37*	*C7*	*0.0503*	*0.73*	*C5*
Roof Side Wall	*44*	*#8@8"*	*0.0988*	*0.0264*	*0.27*	*C5*	*0.0667*	*0.68*	*C2*	*0.1102*	*0.56*	*C1*
Roof	*50*	*#8@7"*	*0.1129*	*0.0910*	*0.81*	*C2*	*0.0716*	*0.63*	*C5*	*0.1250*	*0.55*	*C1*
Inclined Slab	*11.5*	*#5@12"*	*0.0258*	*0.0110*	*0.42*	*C4*	*0.0129*	*0.50*	*C4*	*0.0285*	*0.55*	*C1*
Pedestal	*23.89*	*#7@12"*	*0.0500*	*0.0270*	*0.54*	*C4*	*0.0393*	*0.79*	*C4*	*0.0600*	*0.60*	*C1*

72.48

Note 1:

$A_{sip,required}$ is governed by minimum in-plane shear reinforcement requirement for most components. C1 is shown for such components.

Figure A.3.9.4-1
HSM-MX (Back-to-Back) CAD Model

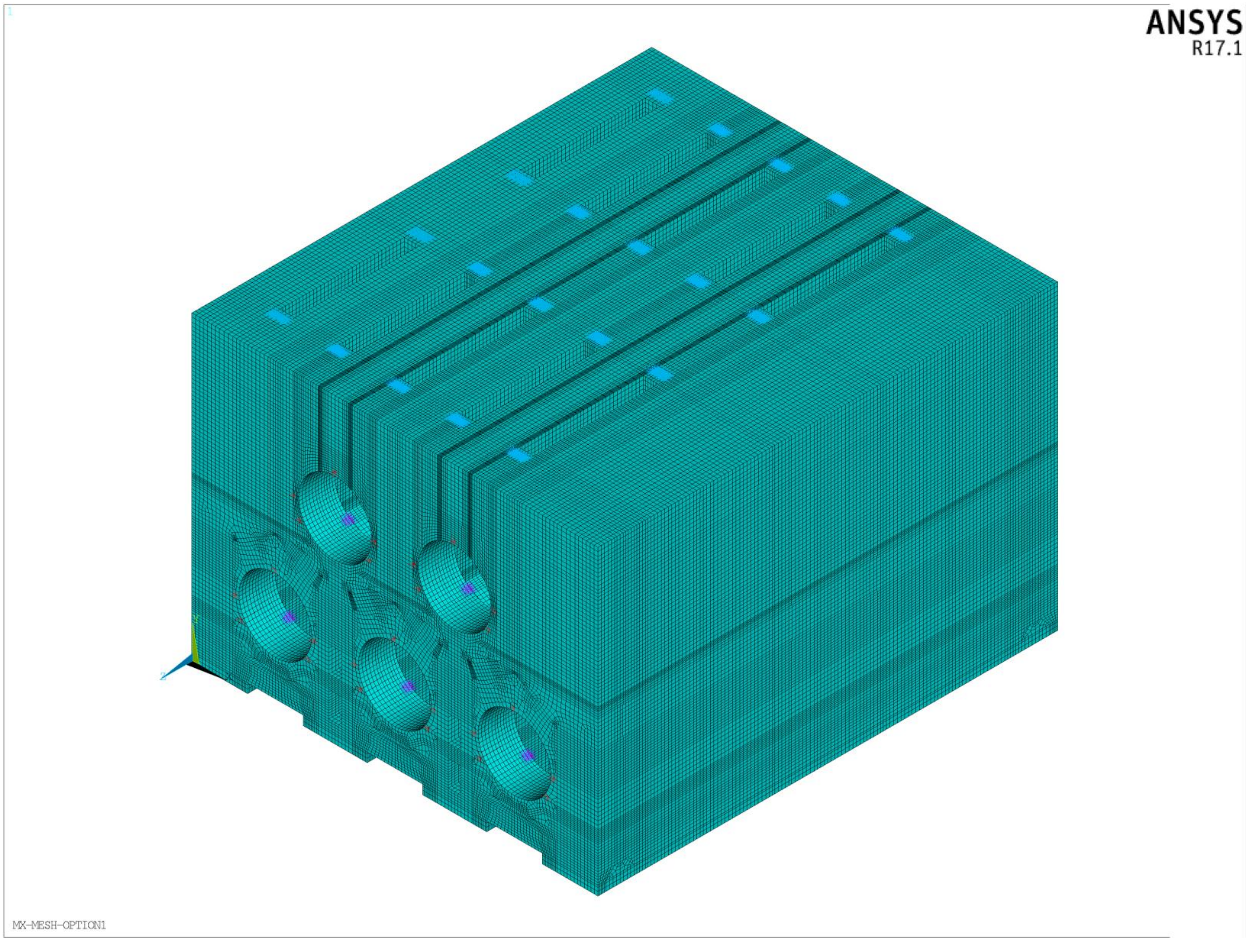
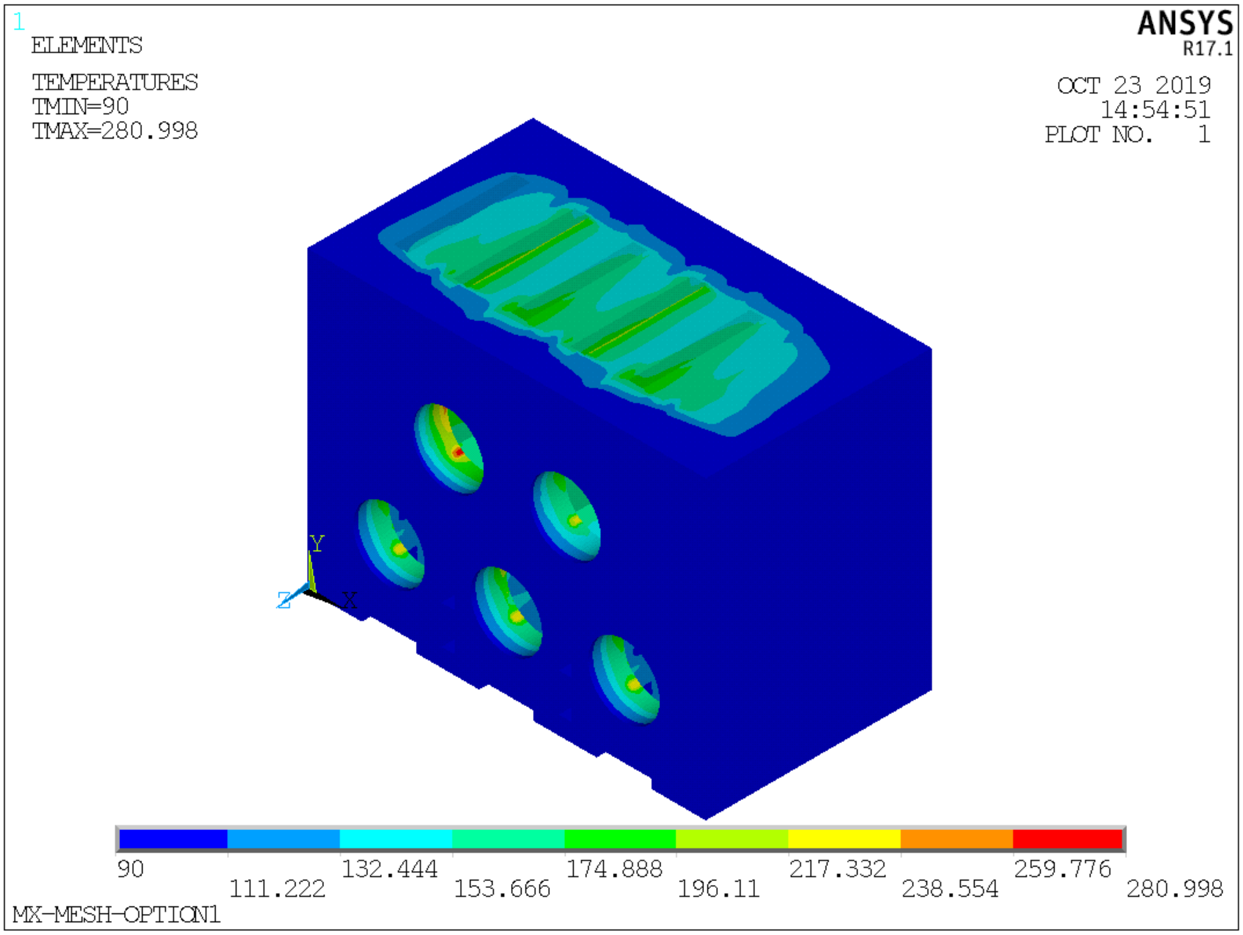


Figure A.3.9.4-2
HSM-MX (Back-to-Back) Meshed Model



72.48

Figure A.3.9.4-3
Temperature Distribution of HSM-MX for Normal Thermal Hot Condition

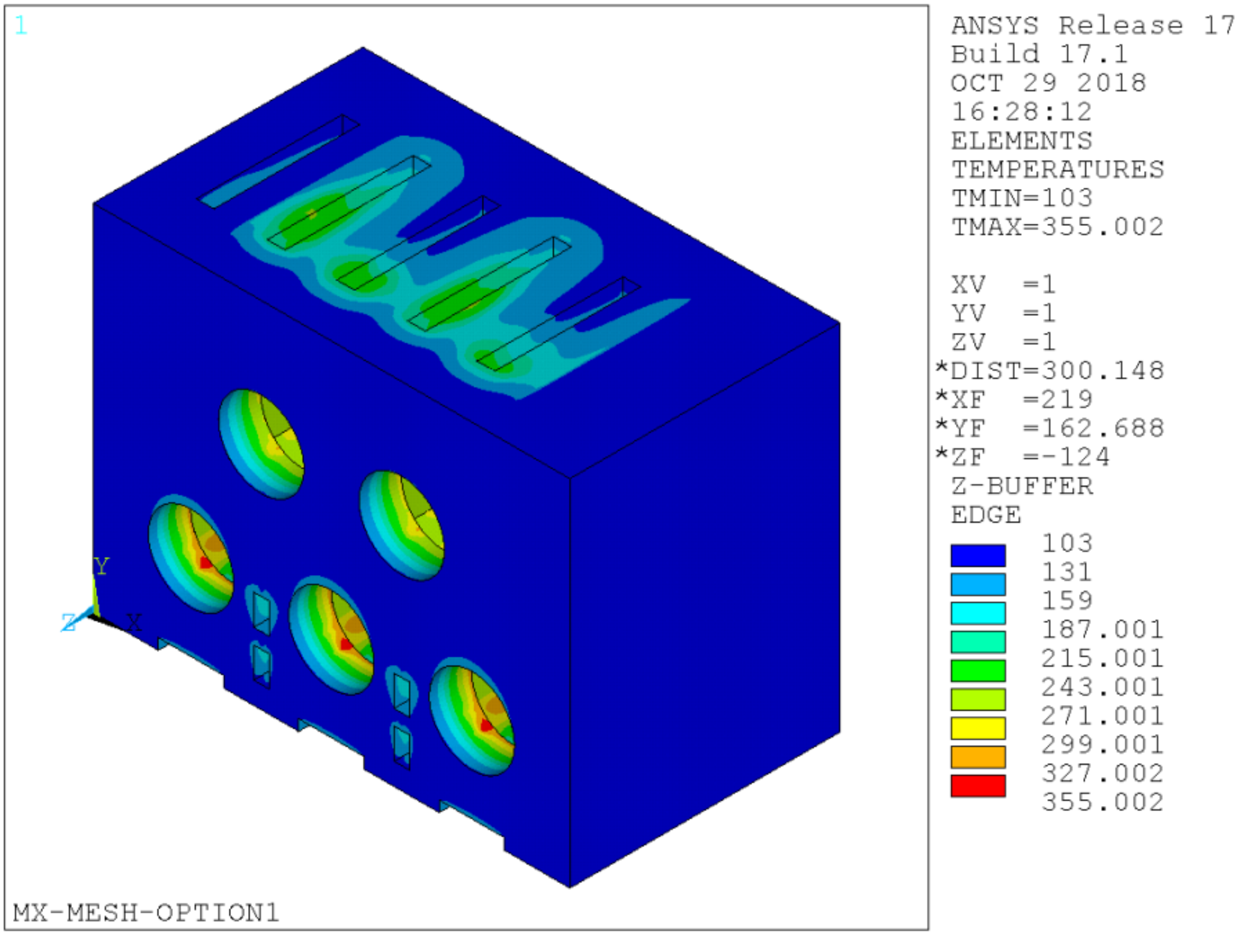


Figure A.3.9.4-4
Temperature Distribution of HSM-MXS for Blocked Vent Accident Thermal Condition

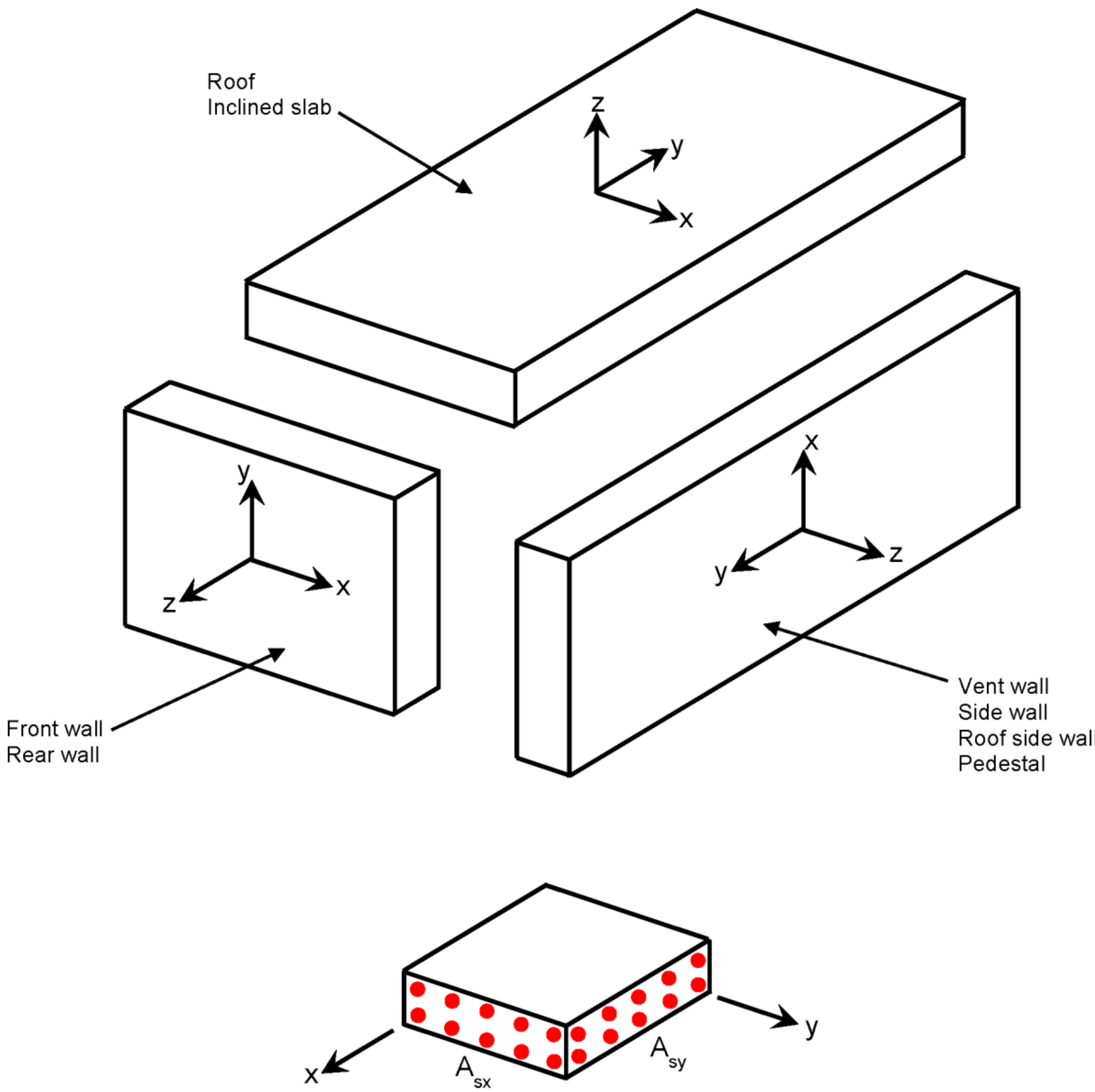
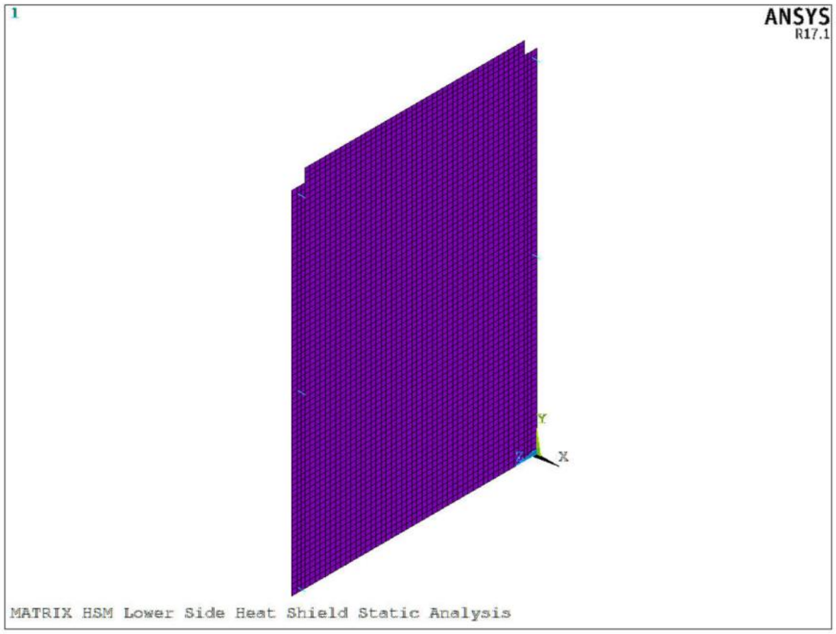
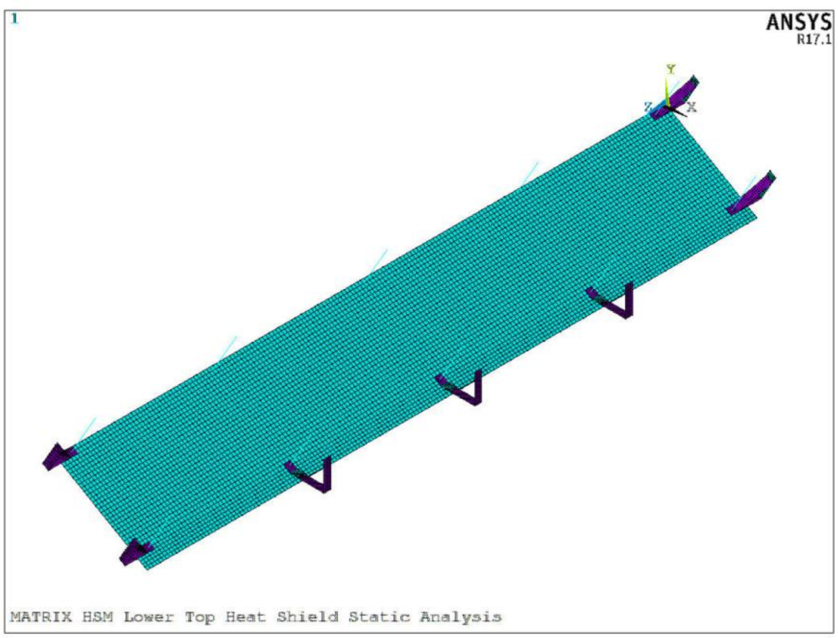


Figure A.3.9.4-5
HSM-MX Concrete Reinforcement Directions



(a)



(b)

Figure A.3.9.4-6
Analytical Model of Heat Shield
(a) Coupled Lower Side Heat Shield and Studs (b) Coupled Lower Top Heat Shield and Studs

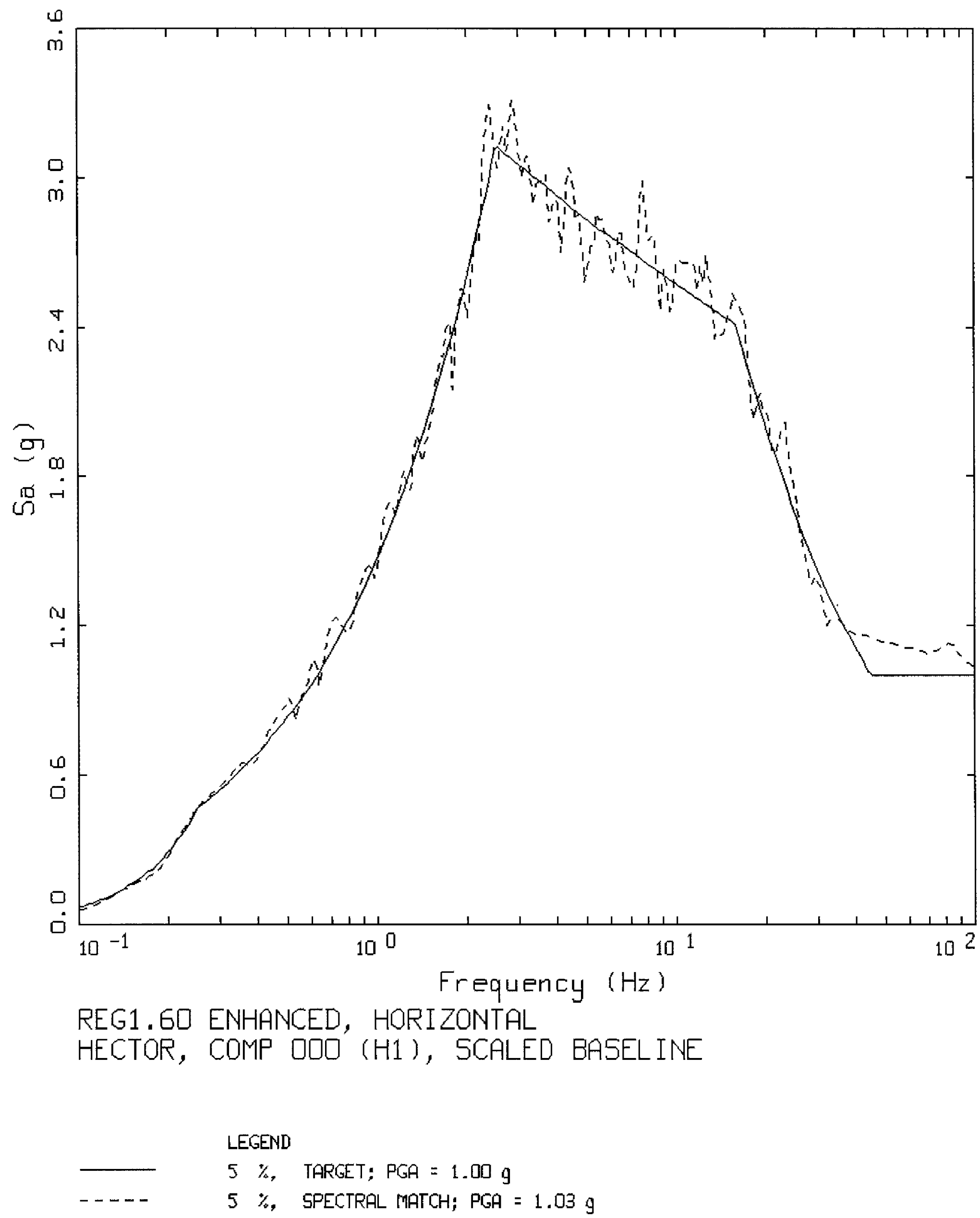


Figure A.3.9.4-7
Horizontal Target and 5% Spectral Match (Horizontal 1, Hector Mine Earthquake)

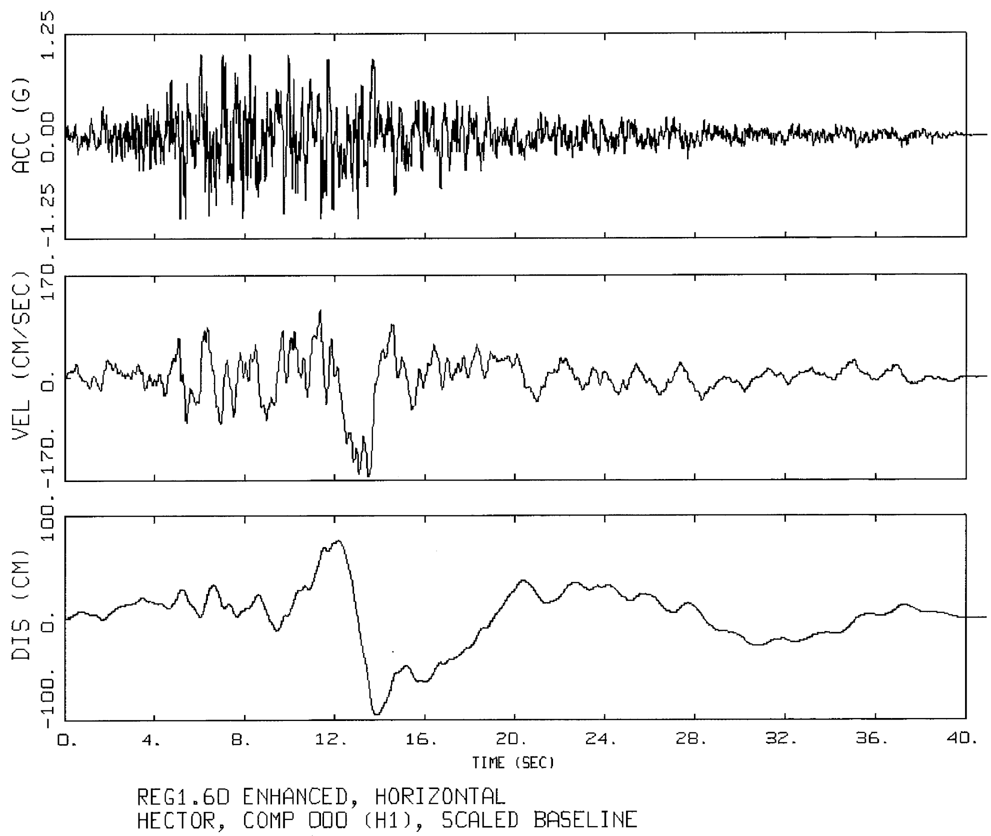


Figure A.3.9.4-8
Baseline Corrected Acceleration, Velocity and Displacement Time Histories
(Horizontal 1, Hector Mine Earthquake)

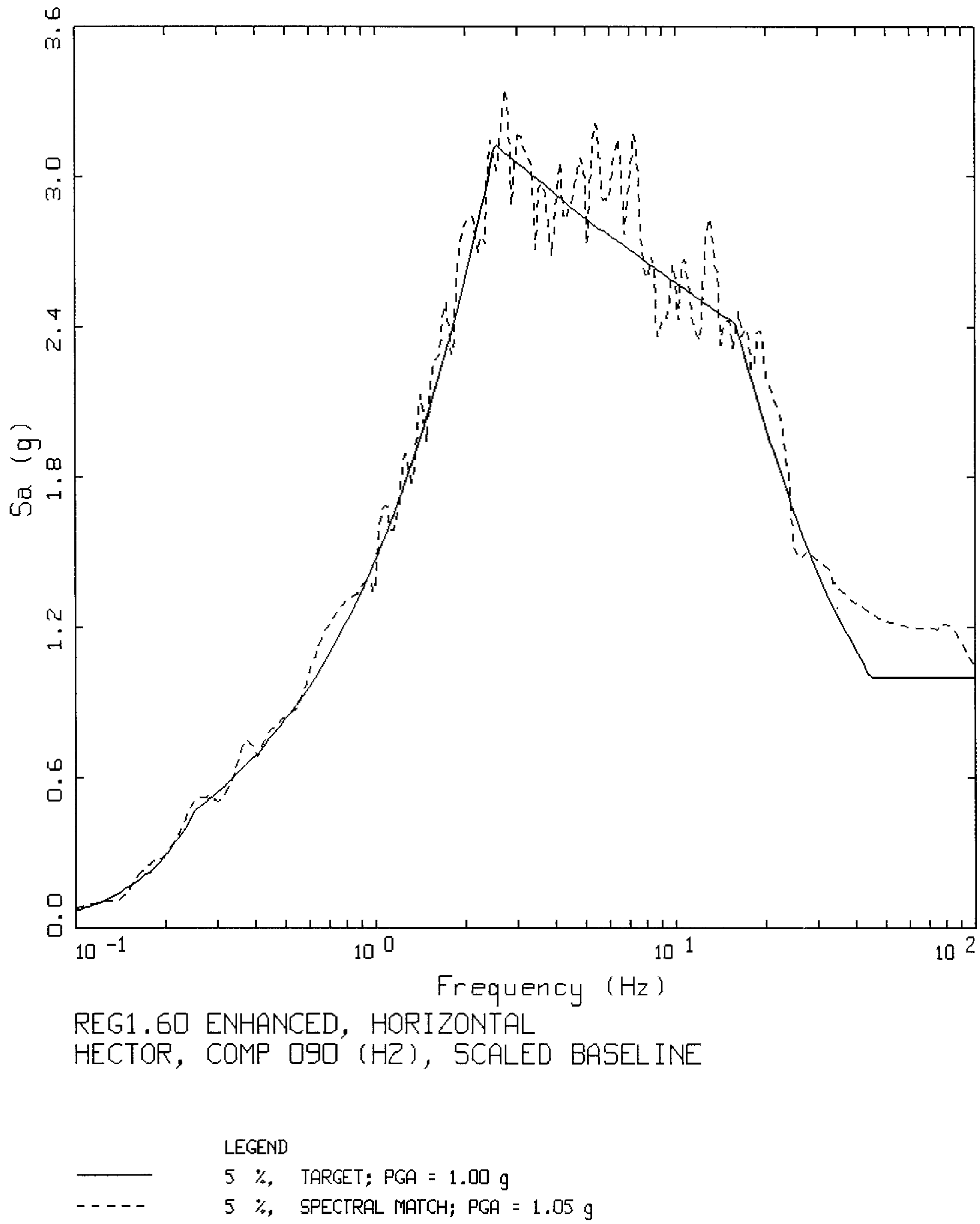


Figure A.3.9.4-9
Horizontal Target and 5% Spectral Match (Horizontal 2, Hector Mine Earthquake)

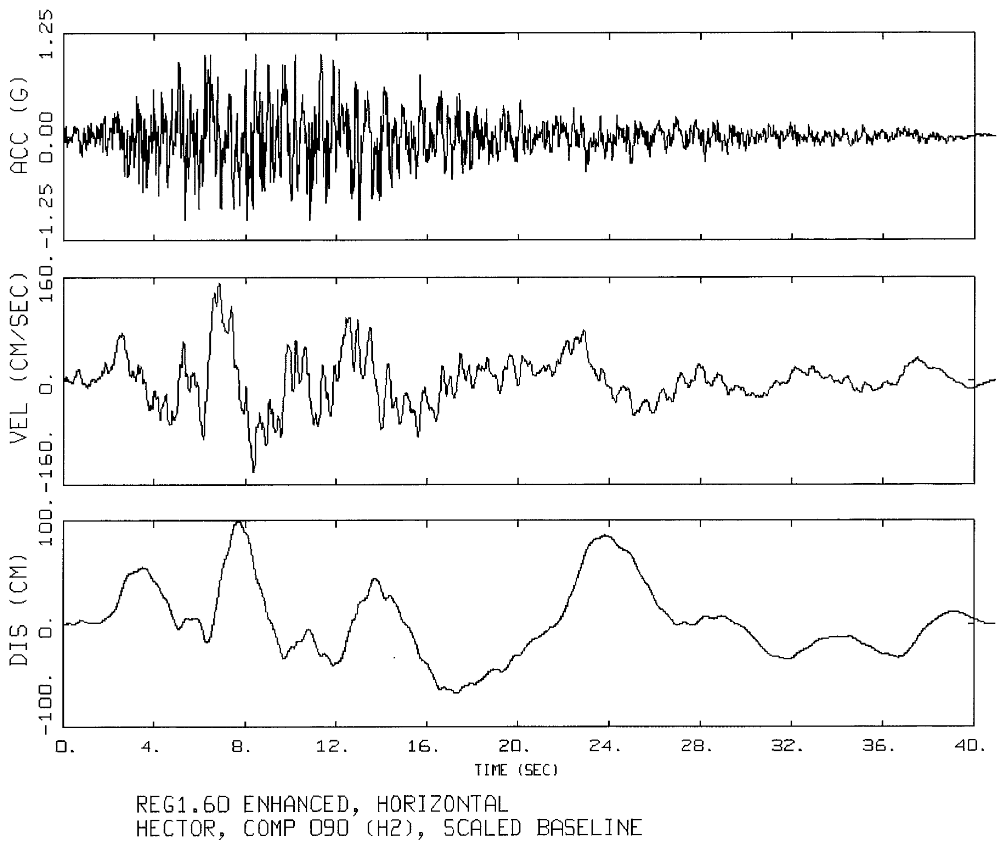


Figure A.3.9.4-10
Baseline Corrected Acceleration, Velocity and Displacement Time Histories
(Horizontal 2, Hector Mine Earthquake)

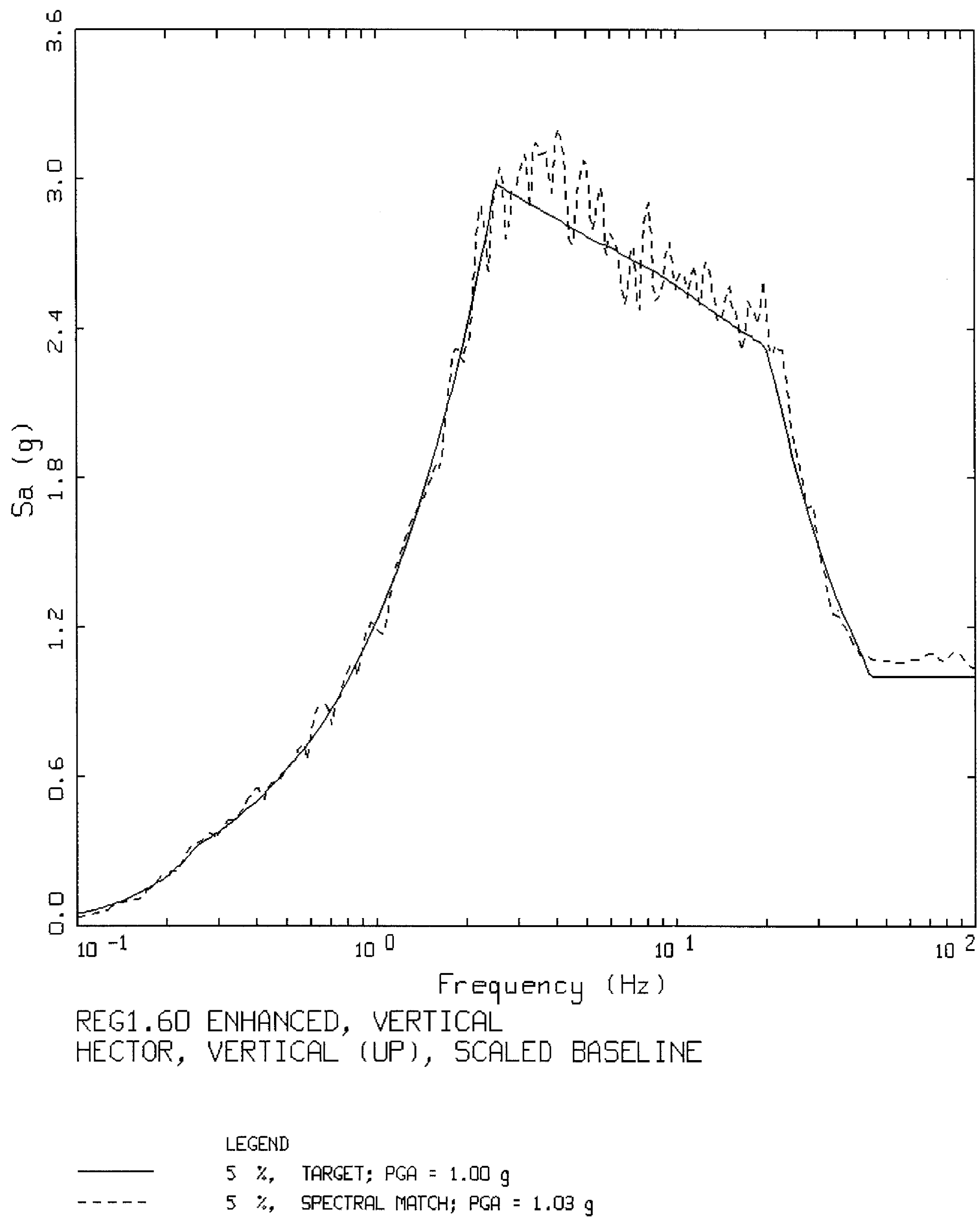


Figure A.3.9.4-11
Vertical Target and 5% Spectral Match (Vertical Up, Hector Mine Earthquake)

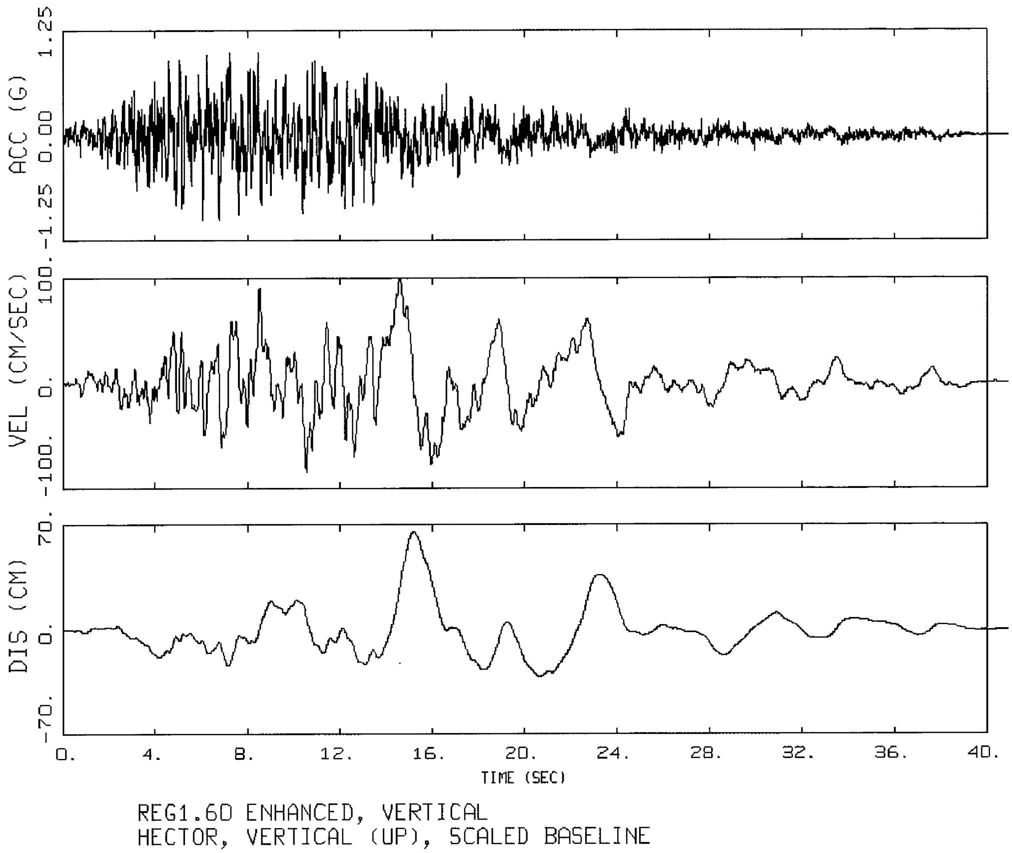


Figure A.3.9.4-12
Baseline Corrected Acceleration, Velocity and Displacement Time Histories
(Vertical Up, Hector Mine Earthquake)

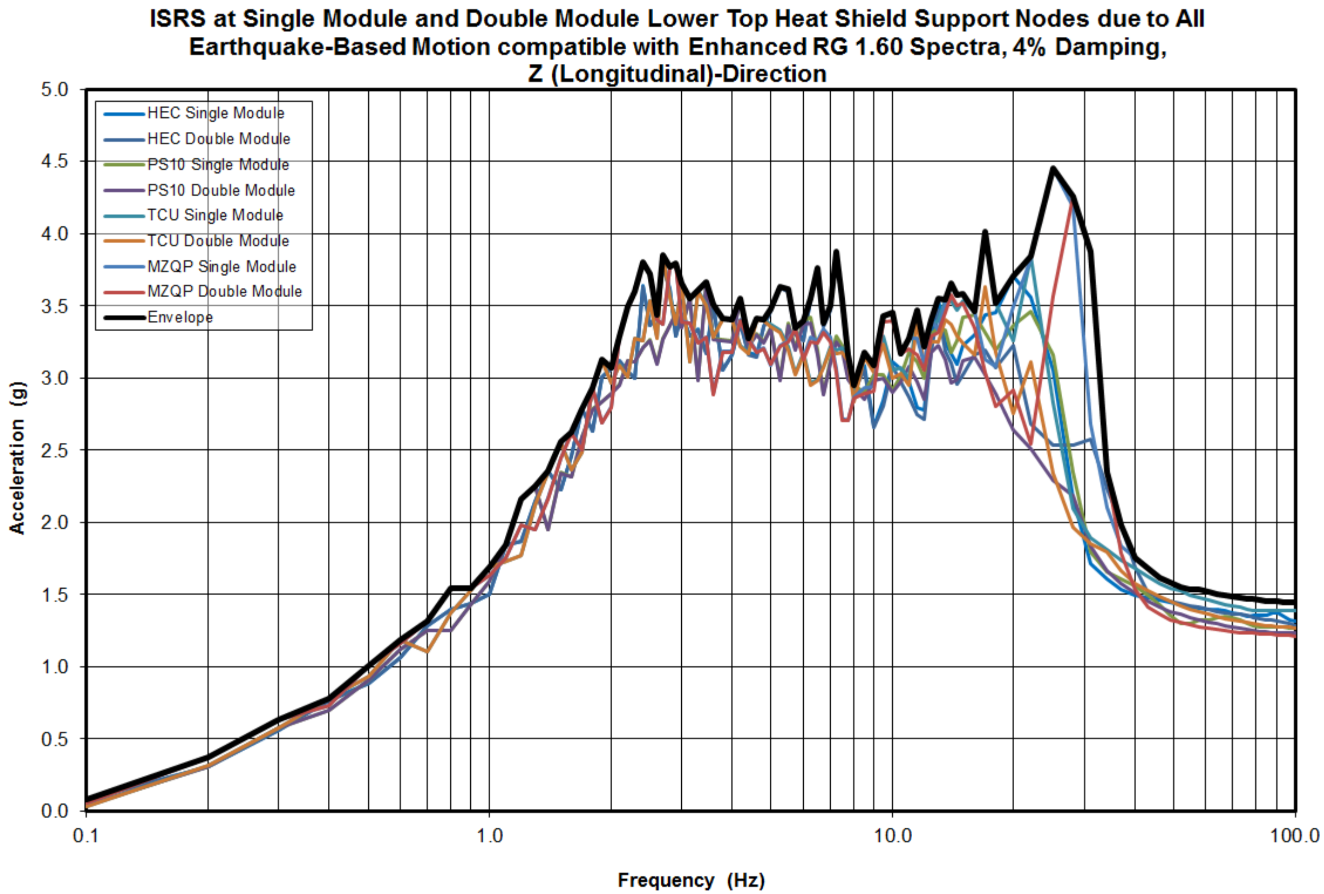


Figure A.3.9.4-13
Lower Top Heat Shield Support Node ISRS due to Envelope of Four Earthquake-Based Motions Compatible with Enhanced RG1.60 Spectra, 4% Damping, X-Direction

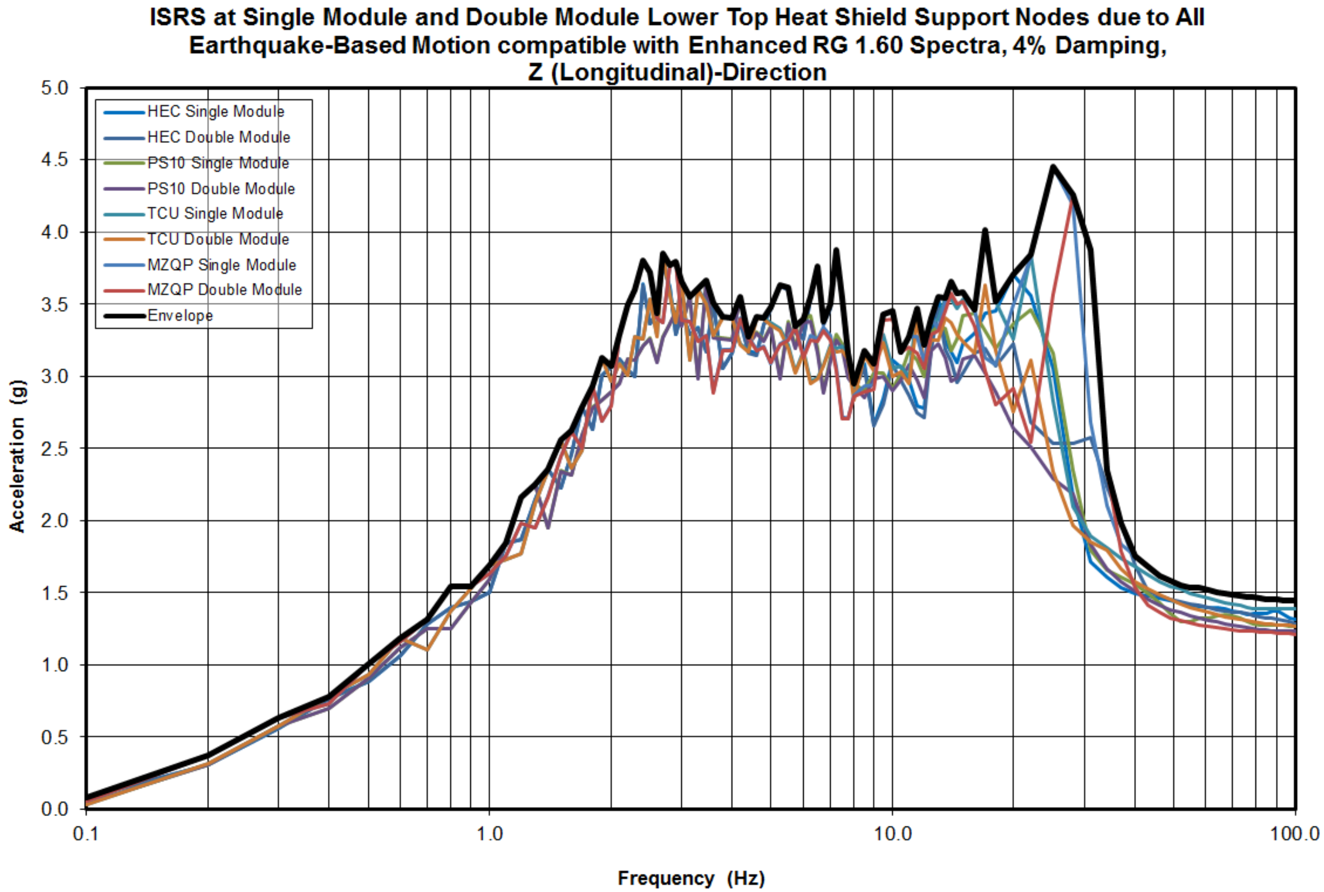


Figure A.3.9.4-14
Lower Top Heat Shield Support Node ISRS due to Envelope of Four Earthquake-Based Motions Compatible with Enhanced RG1.60 Spectra, 4% Damping, Y-Direction

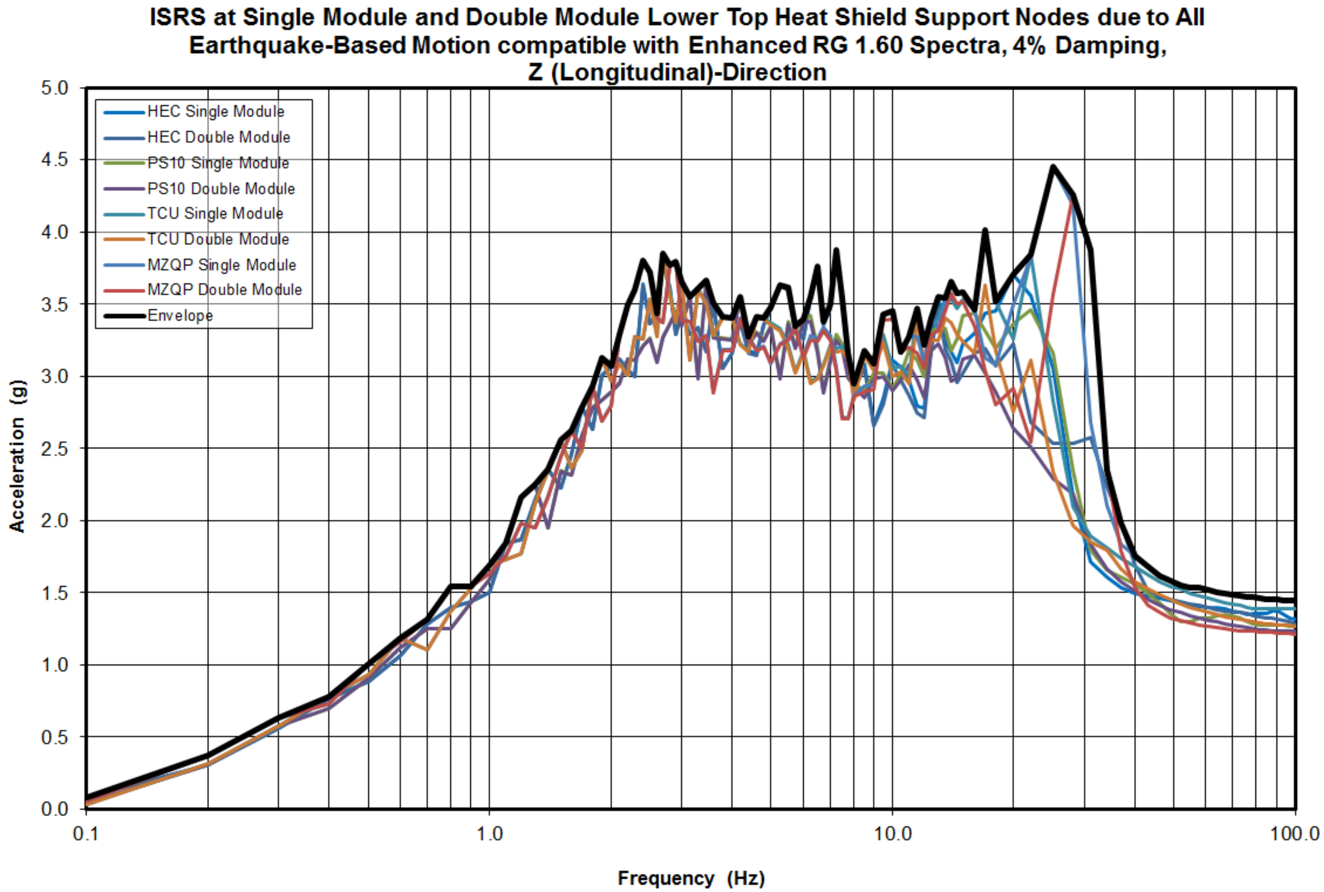


Figure A.3.9.4-15
Lower Top Heat Shield Support Node ISRS due to Envelope of Four Earthquake-Based Motions Compatible with Enhanced RG1.60 Spectra, 4% Damping, Z-Direction

A.3.9.5 NUHOMS® EOS-TC BODY STRUCTURAL ANALYSIS

There is no change to the evaluation of the NUHOMS® EOS-TC Body Structural Analysis documented in Sections 3.9.5 due to the addition of the NUHOMS® MATRIX.

A.3.9.6 NUHOMS® EOS FUEL CLADDING EVALUATION

There is no change to the evaluation of the NUHOMS® EOS fuel Cladding evaluation documented in Sections 3.9.6 due to the addition of the NUHOMS® MATRIX.

APPENDIX A.3.9.7
NUHOMS® MATRIX STABILITY ANALYSIS

Table of Contents

List of Tables

List of Figures

A.3.9.7 NUHOMS® MATRIX STABILITY ANALYSIS

A.3.9.7.1 General Description

The system consists of the dual-purpose (transportation/storage) EOS-37PTH and EOS-89BTH DSCs, the HSM-MX and the onsite transfer cask (EOS-TC) with associated ancillary equipment. Each NUHOMS® MATRIX (HSM-MX) is designed to store DSCs containing up to either 37 pressurized water reactor (PWR) or 89 boiling water reactor (BWR) spent fuel assemblies (SFAs).

The HSM-MX is a staggered, two-tiered compartment, high density, high-heat rejection, storage overpack that provides a self-contained modular structure for storage of DSCs. The HSM-MX is constructed from reinforced concrete and structural steel. The thick concrete roof and walls of the HSM-MX provide substantial neutron and gamma shielding. The monolithic structure increases resistance to earthquakes and offers significant self-shielding. The NUHOMS® MATRIX retractable roller tray (MX-RRT) delivers the DSC from the transfer cask to the HSM-MX and places it on the DSC supports.

The HSM-MX storage modules can be arranged in both single row or back-to-back row arrays. The HSM-MX assembly considered for the stability evaulaution is in a single row array, having three lower compartments and two upper compartments.

A.3.9.7.1.1 HSM-MX Stability Evaluation

The sliding and overturning stability analyses due to design basis wind, flood, and massive missile impact loads are performed using hand calculations. A non-linear dynamic seismic stability analysis is performed using LS-DYNA [A.3.9.7-7].

A.3.9.7.1.2 Material Properties

The HSM-MX assembly is constructed of reinforced concrete and steel. The analyses consider rigid body motions. Therefore, the mechanical properties of the materials are not used as design inputs in the evaluations. The non-linear dynamic evaluation performed using LS-DYNA for the seismic loads, consists of simplified models of the HSM-MX and DSCs representative of their global masses and inertia properties.

A.3.9.7.1.3 Mass Properties

The mass properties of the HSM-MX are listed in Table A.3.9.7-1. Bounding values of concrete density (140 pcf) are considered for static analyses. Nominal concrete density of 150 pcf is considered for the non-linear dynamic seismic evaluation.

A.3.9.7.1.4 Friction Coefficients

The static analyses are performed using a concrete-to-concrete friction coefficient of 0.6. The non-linear dynamic analysis for the seismic loads are performed for a range of friction coefficients for concrete against concrete, varying from 0.8 as the upper bound, 0.6 as the nominal coefficient of friction for concrete poured directly on the independent spent fuel storage installation (ISFSI) pad and 0.4 as the lower bound.

A.3.9.7.1.5 Methodology

The stability of the HSM-MX unit is evaluated for four load cases that may cause overturning and sliding of a freestanding module. These four load cases are:

- Tornado-generated wind loads
- Massive missile impact loads
- Flood loads
- Seismic loads

A.3.9.7.1.6 Assumptions

1. The analyses assume that the dynamic coefficient of friction is equal to the static coefficient. This assumption maximizes the rocking uplift displacements of the HSM-MX (particularly for the high friction coefficient analysis cases).
2. For the non-linear dynamic seismic analysis, coefficients of friction between the HSM-MX and the concrete ISFSI pad are varied between a lower limit of 0.4 and an upper limit of 0.8, with a single intermediate value of 0.6. The coefficients of friction for all other contact surfaces are taken as 0.25.
3. The differential pressure load caused by the tornado pressure drop does not affect the overall stability of the HSM-MX and is ignored. The structure is vented, and so any differential pressure is negligible, as the internal and external pressures equilibrate.
4. This stability evaluation is applicable to both single and double array HSM-MX design.
5. For the non-linear dynamic time history analyses, impact damping coefficients are included in all contact definitions (concrete-to-concrete and steel-to-steel) to obtain a coefficient of restitution (COR) of at least 0.8.

A.3.9.7.1.7 Loads and Boundary Conditions

A.3.9.7.1.7.1 Earthquake Input

The earthquake input motions are in the form of acceleration time histories whose response spectra match the Regulatory Guide 1.60 [A.3.9.7-8] response spectra for 5% damping anchored at 0.85g zero period acceleration (ZPA) in both horizontal directions and 0.80g in the vertical direction and enhanced for frequencies above 9 Hz.

The LS-DYNA [A.3.9.7-7] non-linear dynamic analyses are performed using seven sets of earthquake acceleration time histories. Each set consists of three orthogonal components (2 horizontal and 1 vertical), developed to match the Regulatory Guide 1.60 [A.3.9.7-8] response spectra (enhanced for frequencies above 9 Hz) and have a total approximate duration of 40 seconds. The starting seed for each set consists of actual strong motion recordings whose Fourier spectra are altered to match the target Regulatory Guide 1.60 [A.3.9.7-8] spectra (enhanced for frequencies above 9 Hz) but retains the phase spectra of the actual strong motion record. The horizontal time histories are scaled to 0.85g and the vertical time histories are scaled to 0.80g. The description of each set is as follow:

1. Time History Set number 1 (HEC) is developed based on the Magnitude 7.1 Hector Mine, 1999 earthquake (digitized at 0.01 seconds).
2. Time History Set number 2 (LCN) is based on the Magnitude 7.3 Landers/Lucern earthquake of 1992 (digitized at 0.005 seconds).
3. Time History Set number 3 (PS10) is based on the Magnitude 7.9 Denali earthquake site PS-10 of 2002 (digitized at 0.005 seconds).
4. Time History Set number 4 (TAB) is based on the Magnitude 7.4 Tabas earthquake of 1978 (digitized at 0.02 seconds).
5. Time History Set number 5 (TCU) is based on the Magnitude 7.6 Taiwan, 1999 earthquake (digitized at 0.005 seconds).
6. Time History Set number 6 (SHIF) is based on the Magnitude 7.9 Wenchuan China, 2008 earthquake, Shifangbajiao site (digitized at 0.005 seconds).
7. Time History Set number 7 (MIAN) is based on the Magnitude 7.9 Wenchuan China, 2008 earthquake, Mianzhuqingping site (digitized at 0.005 seconds).

Each component in each of the seven time history sets meets the spectral matching requirements of NUREG/CR-6728 [A.3.9.7-5].

A.3.9.7.1.7.2 Wind and Tornado Input

The HSM-MX is evaluated for overturning and sliding due to the design basis tornado (DBT) specified in Appendix A.2. The DBT is based on the NRC Regulatory Guide 1.76 [*A.3.9.7-9*] Region I Intensities. The maximum wind speed is 360 mph. The tornado loads are generated for three separate loading phenomena, as follows, which are combined in accordance with Section 3.3.2 of NUREG-0800 [A.3.9.7-1] (i.e. tornado wind load is concurrent with (additive to) tornado missile loads). 72.48

1. Pressure or suction forces created by drag as air impinges and flows past the HSM-MX with a maximum tornado wind speed of 360 mph.
2. Suction forces due to a tornado generated pressure drop or differential pressure load of 3 psi.
3. Impact forces created by tornado-generated missiles impinging on the HSM-MX.

Per NUREG-0800, the total tornado load on a structure is combined as follows:

$W_t = W_p$

$W_t = W_w + 0.5W_p + W_m$

Where,

W_t = Total tornado load
W_w = Load from tornado wind effect
W_p = Load from tornado atmospheric pressure change effect
W_m = Load from tornado missile impact effect

Note that W_p is not applicable to the stability analysis as discussed in Section A.3.9.7.1.6. Thus, the load combination for tornado loading for this analysis is simplified to:

$$W_t = W_w + W_m$$

In addition, a 1.1 factor is added to Dead weight + Tornado load. (Table 3-3 of NUREG-1536 [A.3.9.7-3])

The envelope of a range of missiles from Chapter 2 is used for the missile impact load.

As shown in Table A.3.9.7-2, the automobile impact on to the HSM-MX has the maximum momentum and is considered as bounding evaluation.

A.3.9.7.1.7.3 Flood Input

The HSM-MX is evaluated for a flood height of 50 feet with a water velocity of 15 fps.

In addition, a 1.1 factor is added to Dead weight + Flood load (Table 3-3 of NUREG-1536 [A.3.9.7-3]).

A.3.9.7.2 HSM-MX Stability Analyses

The load categories associated with the HSM-MX stability analysis are described in the previous section. The analysis steps and results for each load category are presented in this section.

A.3.9.7.2.1 Design Basis Tornado Wind and Missile Loads

The HSM-MX is evaluated for forces created by drag as air impinges and flows past the HSM-MX with a maximum tornado wind speed of 360 mph.

For sliding and overturning analysis, it is assumed that the module is subjected to the load due to 238 psf windward pressure load acting on the front wall. The leeward side of the same module is subjected to a wind suction load of 167 psf. A suction of 355 psf is applied to the roof. These loads are shown in Table A.3.9.7-3.

In addition, missiles loads are combined with the tornado wind load per NUREG-800 [A.3.9.7-1] and NUREG-1536 [A.3.9.7-3].

Static Overturning Analysis due to Tornado Wind

The empty HSM-MX will rotate about B, shown in Figure A.3.9.7-1.

In the overturning analysis of the HSM-MX, the effects of tornado wind forces are first determined. An overturning moment is then calculated and is compared with a stabilizing moment. The safety factor against overturning computed for the HSM-MX due to tornado wind is 3.28, which includes a factor of 1.1

Dynamic Overturning Analysis of Tornado Wind Concurrent with Massive Missile Impact Loading

A dynamic analysis based on the conservation of energy is conducted for the combined effects of wind and concurrent massive missile impact loading. The effects of the concurrent massive missile impact loads are used in determining the initial angular momentum from the conservation of angular momentum equation using the wind loads from the previous section. Then the angle of rotation is determined from the conservation of energy of the concurrent loading.

The wind loads are calculated conservatively for HSM-MX single array:

Horizontal $F_{hw} = (P_{windward} + P_{leeward})(L_{base})(h_{HSM})$

Vertical: $F_{vw} = (P_{roof})(L_{base})(w_{HSM})$

The concurrent wind loading is accounted for by reducing the inertia that resists motion in the denominator of the equation.

$$\omega_B = \frac{m_m \cdot d_m \cdot v_i}{m_m \cdot d_m^2 + I_{tot} - \left(\frac{F_{hw}}{g}\right)\left(\frac{h}{2}\right)^2 - \left(\frac{F_{vw}}{g}\right)\left(\frac{w}{2}\right)^2}$$

Where,

F_{hw} = Horizontal tornado wind load
F_{vw} = Vertical tornado wind load
ω_B = Angle of rotation
m_m = Mass of the missile
d_m = Distance from missile impact to floor
v_i = Initial missile velocity
I_{tot} = Total moment of inertia of HSM-MX
h = Height of HSM-MX
w = Width of HSM-MX

The conservation of energy is used for overturning.

Rotational Kinetic Energy = Change in Potential Energy – Work Done by Horizontal Wind force

$$\frac{I_{tot}\omega_B^2}{2} = (W - F_{vw}) \cdot r \cdot [\sin(\beta + \theta) - sin\beta] - F_{hw} \cdot r \cdot [\cos(\beta + \theta) - cos\beta]$$

Where,

θ = Angle of tipping
β = Angle from the horizontal to center of gravity (CG) of HSM-MX (52.1°)
r = Diagonal distance from CG to point B
I_{tot} = Total moment of Inertia of HSM-MX
W = Weight of the empty HSM-MX

The HSM-MX is stable against overturning as tip-over does not occur until the CG rotates past the edge (point B, Figure A.3.9.7-1) of the HSM-MX to an angle of more than 90°- 52.1° = 37.9°. The HSM-MX rotates a maximum of 0.000029 degrees, which includes a factor of 1.1 and is less than the 37.9 degrees required to overturn the module.

<u>Time-Dependent Overturning Analysis of Tornado Wind Concurrent with Massive Missile Impact Loading</u>

In addition to the dynamic overturning analysis, a time dependent analysis is used to ensure the absence of any overturning.

An approximate relationship for the deceleration of an automobile impacting a rigid wall is given by:

$$-\ddot{x} = 12.5g \cdot x \text{ Eq. D-1 of [A. 3.9.7 4]}$$

where,

$-\ddot{x}$ = Deceleration (ft/sec^2)
x = Distance automobile crushes into target (ft)

A force time history is obtained:

$$F = 0.625 V_s W_m sin20t \qquad Eq.D - 6 \text{ of } [A. 3.9.7 - 4]$$

The overturning moment is:

$$M_{ot} = F \cdot d_m + \frac{F_{hw} h}{2}$$

Where,

d_m = Distance from missile impact to floor
h = Vertical height to the top of HSM-MX and is a function of rotation

The stabilizing moment is:

$$M_{st} = (W_{HSM} - F_{vw}) \cdot r\cos(\beta + \theta)$$

Where,

W_{HSM} = Weight of the loaded HSM-MX
r = Diagonal distance from CG to point B
θ = Angle of rotation

The moment causing acceleration is:

$$M_{acc} = M_{ot} - M_{st}$$

The angular velocity is:

$$\omega_i = \left[\frac{M_{acc,i} + M_{acc,i-1}}{2} \cdot (t_i - t_{i-1})\right] / I_{tot} + \omega_{i-1}$$

Where,

i = Index for current time step
i-1 = Index for previous time step
I_{tot} = Total moment of Inertia of HSM-MX

The angle of rotation is:

$$\theta_i = \left[\frac{\omega_i + \omega_{i-1}}{2} \cdot (t_i - t_{i-1})\right] + \theta_{i-1}$$

The angle of rotation is zero as the overturning moment due to missile impact and wind loading is less than the resisting moment.

Sliding Analysis for Tornado Wind Concurrent with Massive Missile Impact loading

The combined wind + missile impact case is considered for HSM-MX sliding analysis based on the conservation of energy.

First, the conservation of momentum is used for the sliding analysis.

$$V = \frac{m \cdot v_i}{M + m - F_{hw}/386.4}$$

Where,

V = Initial linear velocity of module after impact
v_i = Initial velocity of missile
m = Mass of the missile
M = Mass of the HSM-MX

Then using the conservation of energy:

$$Friction\ Energy = Initial\ Kinetic\ Energy\ of\ System + Work\ done\ by\ Wind$$

$$\mu \cdot (gM - F_{vw})d = \frac{(M+m)\cdot V^2}{2} + F_{hw}d$$

Where,

72.48

- μ = 0.6 *(*coefficient of friction for concrete-to-concrete surfaces*)*
- F_{vw} = Uplift force generated by DBT wind pressure on the roof
- d = Sliding distance of HSM-MX
- F_{hw} = Sliding force generated by DBT wind pressure

The sliding distance of the HSM-MX module is calculated to be 0.15 inches, which includes a factor of 1.1.

Time-Dependent Sliding Analysis for Tornado Wind Concurrent with Massive Impact Loading

In addition to the dynamic sliding analysis, a time dependent analysis is used to provide a bounding sliding displacement.

The total force causing sliding is:

$$F_{slide} = F + F_{hw}$$

The resisting force from friction is:

$$F_{resis} = \mu(W - F_{vw})$$

Therefore the force causing acceleration is:

$$F_{acc} = F_{slide} - F_{resis}$$

The velocity is:

$$v_i = \left[\frac{F_{acc,i} + F_{acc,i-1}}{2} \cdot (t_i - t_{i-1})\right] / m_{tot} + v_{i-1}$$

Where,

- i = Index for current time step
- i-1 = Index for previous time step
- m_{tot} = Total mass of empty HSM-MX

The sliding displacement is:

$$x_i = \left[\frac{v_i + v_{i-1}}{2} \cdot (t_i - t_{i-1})\right] + x_{i-1}$$

The sliding displacement is zero as the sliding force due to missile impact and wind loading is less than the resisting force.

A.3.9.7.2.2 Flood Loads

The HSM-MX is designed for a flood height of 50 feet and water velocity of 15 fps. The module is evaluated for the effects of a water current of 15 fps impinging on the side of a submerged HSM-MX. Under 50 feet of water, the inside of the module is rapidly filled with water. Therefore, the HSM-MX components are not evaluated for the 50 feet static head of water.

Calculation of the drag pressure due to design flood is shown in Appendix A.3.9.4.9.3.

Overturning Analysis

The factor of safety against overturning of an empty HSM-MX, for the postulated flooding conditions, is calculated by summing moments about the bottom outside corner of a single array HSM-MX. The factor of safety against overturning of the HSM-MX due to the postulated design basis flood water velocity is 1.98 inches, which includes a factor of 1.1.

Sliding Analysis

The factor of safety against sliding of a freestanding single array HSM-MX due to the maximum postulated flood water velocity of 15 fps is calculated using methods similar to those described above. The effective weight of the HSM-MX acting vertically downward, less the effects of buoyancy acting vertically upward is calculated. The factor of safety against sliding for a single array HSM-MX due to the postulated design basis flood water velocity is 1.42 inches, which includes a factor of 1.1.

A.3.9.7.2.3 Seismic Loads

The static sliding and overturning analysis for the seismic loads are performed to determine the maximum seismic accelerations before HSM-MX starts sliding or overturning. Non-linear dynamic analysis is performed using LS-DYNA for the earthquake inputs discussed in A.3.9.7.1.7.1 to determine the maximum sliding and overturning distances.

A.3.9.7.2.3.1 Low Seismic Load

HSM-MX static overturning analysis

The stabilizing moment due to the components dead weight and the overturning moment due to the seismic forces are calculated and compared. The 1.1 coefficient of the load combination (Table 3-3 of NUREG-1536 [A.3.9.7-3]) is conservatively applied to the overturning moment only. Both the maximum HSM-MX concrete density (160 pcf) with maximum DSC weight (to maximize the overturning moment) and minimum HSM-MX concrete density (140 pcf) with minimum DSC weight (to minimize the stabilizing moment) are considered. The overturning analysis is done considering the smallest distance from the HSM-MX center of gravity to HSM-MX corner point B (Figure A.3.9.7-1).

Table A.3.9.7-5 shows the results. The safety factor $M_{st}/1.1M_{ot}$ is less than 1, meaning the HSM-MX can have some lifting under the seismic loads. The non-linear dynamic analyses (Section A.3.9.7.2.3.2) estimate the amount of lifting for high seismic loads.

The maximum acceptable accelerations before any lifting occurs are $a_v = 0.40$g and $a_h = 0.60$g (assuming $a_v = \frac{2}{3}a_h$)

HSM-MX static sliding analysis

The resisting friction force and horizontal seismic force are calculated and compared. The 1.1 coefficient of the load combination (Table 3-3 of NUREG-1536 [A.3.9.7-3]) is conservatively applied to the horizontal seismic force only.

Resisting friction force: $F_{fr} = \mu W(1 - 0.4a_v)$ $\mu: Coefficient\ of\ friction$

Horizontal seismic force: $F_{hs} = a_h W$

Safety factor: $SF = F_{fr}/1.1F_{hs} = \mu(1 - 0.4a_v)/(1.1a_h)$

For static sliding analysis of the HSM-MX, the safety factor is independent of the weight considered. It only depends on the coefficient of friction and accelerations.

Table A.3.9.7-5 shows the results for a nominal coefficient of friction of 0.6 and gives a safety factor of 0.44. The HSM-MX will slide under 0.85g horizontal and 0.80g vertical loads. The non-linear dynamic analyses (Section A.3.9.7.2.3.2) estimate the amount of sliding for high seismic loads.

The maximum acceptable accelerations before any sliding occurs are $a_v = 0.32$g and a_h =0.48g (assuming $a_v = \frac{2}{3}a_h$)

<u>Seismic Stability of the DSC on DSC Supports inside the HSM-MX</u>

This evaluation is performed for the DSC resting on the supports inside the HSM-MX, which includes the stability of the DSC against lifting off from one of the support during a seismic event and potential sliding off of the DSC from the supports. The horizontal equivalent static acceleration of 0.85g is applied laterally to the center of gravity of the DSC. The point of rigid body rotation of the DSC is assumed to be the center of the support, point of contact with the DSC (as shown in Figure A.3.9.7-5). The applied moment acting on the DSC is calculated by summing the overturning moments.

The stabilizing moment, acting to oppose the overturning moment, is calculated by subtracting the effects of the upward vertical seismic acceleration of 0.80g from the total weight of the DSC and summing moments at the point of rigid body rotation.

Figure A.3.9.7-5 shows a DSC on its front and rear DSC supports and define the geometric parameters and loads used below.

Stabilizing moment:

$$M_{st} = (W - 1.1F_v)X \qquad \text{with} \qquad F_v = 0.4W a_v \quad X = R\sin\theta$$

Overturning moment:

$$M_{ot} = 1.1F_h Y \qquad \text{with} \qquad F_h = W a_h \qquad Y = R\cos\theta$$

Safety coefficient:

$$SF = \frac{M_{st}}{M_{ot}} = \frac{1 - 0.44a_v}{1.1a_h}\tan\theta$$

For DSC overturning analysis, the safety factor is independent of the DSC weight or radius considered. It only depends on the support angle and the accelerations. The minimum support angle θ to avoid DSC overturning (Figure A.3.9.7-5) is 55.3°.

Assuming $a_v = {}^2/_3\, a_h$, the maximum seismic accelerations are 0.54g horizontal and 0.36g vertical before DSC overturning occurs

A.3.9.7.2.3.2 High Seismic Load

Non-Linear Dynamic Time-History Analyses of HSM-MX for High Seismic Loads

LS-DYNA Finite Element Model *of the* HSM-MX 72.48

A finite element model (FEM) of the HSM-MX monolithic expansion single array design loaded with five DSCs was created for use with LS-DYNA [A.3.9.7-7]. The HSM-MX unit and DSC are constructed with solid 4-node tetrahedral elements for meshing simplicity, whereas the IFSFI pad includes 8-node solids elements. All components are modeled with rigid materials for the stability analysis. The FEM includes the DSC axial retainers modeled with 0.5 inch gap to the DSC, the front and rear DSC supports with stop plates and five front doors and top vent covers.

The model does not include the metallic components (heat shields, etc.) which are not structurally important for the stability analysis. Their weight is accounted for in the total weight of the HSM-MX.

The HSM-MX rests on top of the ISFSI concrete pad and is free to slide or rock when subjected to the forces resulting from the prescribed pad seismic accelerations. In the FEM, contacts are defined between the HSM-MX and the ISFSI pad as well as between the DSCs with their front and rear DSC supports and parts of the HSM-MX concrete that could be in contact with the DSCs if they lift from their supports. Contact definitions are included between all interfacing parts using contacts algorithm in LS-DYNA.

Contacts are defined for the following interfaces:

- HSM-MX to basemat, no initial gap
- DSC to for supports, no initial gap
- DSC to rear stop plate, no initial gap
- DSC to HSM-MX front circular opening, initial 1.5” gap between DSC Ø75.5” and the door opening Ø78.5”
- DSC to front axial retainer, initial gap of 0.5”

Coefficient of Restitution

The coefficient of restitution is defined as the ratio of the velocity of a body immediately after impact to its velocity immediately prior to impact. A coefficient of restitution equal to 0 means a perfectly plastic impact in which the impacting body “sticks” to the impacted body. A coefficient of restitution equal to 1 means a perfectly elastic impact in which the impacting body bounces off the impacted body with no energy loss. For the case of concrete impacting against concrete, a reasonable coefficient of restitution is in the order of 0.1 since a concrete body does not “bounce” upon impacting on a concrete surface. For the LS-DYNA analyses, a coefficient of restitution of at least 0.8 is used as a conservative value. The coefficient of restitution is inputted into LS-DYNA analyses as the parameter viscous damping coefficient ((VDC) in percent of critical) of the surface-to-surface contact.

Non-Linear Dynamic Analyses

The seismic analyses inputs as described in Section A.3.9.7.1.7.1 consist of three components of acceleration in the form of earthquake time histories applied to the ISFSI pad. Thus, all nodal points of the pad move as prescribed by these input motions. Examples of the input motion displacement, velocity and acceleration histories used in LS-DYNA analysis are shown in Figure A.3.9.7-13, Figure A.3.9.7-14 and Figure A.3.9.7-15 in the global X, Y, and Z directions, respectively, for the motion derived from the Hector Mine (HEC) earthquake. The three components of the acceleration time histories are applied simultaneously in each of the three orthogonal directions. Each of the seven time history sets are analyzed with three different coefficients of friction (0.4, 0.6, and 0.8) for a total of 21 computer runs.

In order to obtain the sliding displacement of the HSM-MX relative to the pad, the change in X-lengths and change in Z-lengths (Figure A.3.9.7-4) between the four HSM-MX corner nodes and one ISFSI pad node are plotted over time.

Two uplift values are reported, one each for rotation about the global X and Z axes. For rocking about the X-axis, the change in the vertical (global Y) distance between the +Z and –Z node pairs is plotted and tabulated. For rocking about the Z axis, the change in the vertical distance between the +X and –X node pairs is plotted and tabulated.

The gaps between the DSCs and front axial retainers are verified against the DSC sliding on the support. Also, the loads on the DSC supports are verified against the uplift.

The maximum values over time for sliding and rocking movements from the seven time histories are used to get the "computed" response as the median value plus 1 standard deviation (shown in Table A.3.9.7-6). This methodology is in accordance with NUREG/CR-6865 [A.3.9.7-6]

A.3.9.7.2.4 Results

Table A.3.9.7-4 through Table A.3.9.7-6 show a summary of the results from the analyses performed in Section A.3.9.7.2.

For flood, wind, and missile impact, it is determined that the uplift and sliding values are small for the HSM-MX. Therefore, the DSC remains stable on the front and rear DSC supports inside the HSM-MX.

The maximum seismic acceleration before HSM-MX sliding or overturning occurs are 0.48g horizontal and 0.32g vertical for a coefficient friction of 0.6 between the HSM-MX and the ISFSI pad. The non-linear dynamic analysis shows a maximum resultant sliding of 12.5 inches and a maximum uplift of 0.13 inches for the set of seismic earthquake inputs.

Figure A.3.9.7-7 and Figure A.3.9.7-8 show the maximum sliding results in both horizontal directions, and Figure A.3.9.7-9 shows the maximum rocking for the input earthquake loads. On each sliding plots (Figure A.3.9.7-7 and Figure A.3.9.7-8), the four curves represent the displacement of each bottom corner of the HSM-MX relative to the ISFSI pad. For the rocking plot (Figure A.3.9.7-9), the two curves represents the relative vertical displacement between 2 HSM-MX bottom corners.

Figure A.3.9.7-10 shows the sliding of five DSCs on the front and rear DSC supports. Figure A.3.9.7-11 shows total load on four support for all five DSCs. The sliding fluctuates in the range of 0 to 0.5 inches, which is the initial gap in front axial retainer.

Figure A.3.9.7-12 shows the load between the DSC shell and circular opening on the front door. There is no contact between the DSC and the HSM-MX. Therefore, DSCs do not lift from their supports during a seismic event.

A.3.9.7.3 EOS Transfer Cask Missile Stability and Stress Evaluation

There is no change to the EOS transfer cask missile stability and stress evaluation documented in Sections 3.9.7.2 due to the addition of the HSM-MX.

A.3.9.7.4 References

A.3.9.7-1 NUREG-0800, Standard Review Plan, "Missiles Generated by Natural Phenomena," Revision 2, U.S. Nuclear Regulatory Commission, July 1981.

A.3.9.7-2 American Society of Civil Engineers, ASCE 7-10, "Minimum Design Loads for Buildings and Other Structures."

A.3.9.7-3 NUREG-1536 Revision 1, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," July 2010, U.S. Nuclear Regulatory Commission.

A.3.9.7-4 Bechtel Report BC-TOP-9A Rev. 2, "Topical Report – Design of Structures for Missile Impact," September 1974.

A.3.9.7-5 NUREG/CR-6728, "Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-consistent Ground Motion Spectra Guidelines," October 2001, Prepared by Risk Engineering, Inc. for U.S. Nuclear Regulatory Commission.

A.3.9.7-6 NUREG/CR-6865, "Parametric Evaluation of Seismic Behavior of Freestanding Spent Fuel Dry Cask Storage Systems," February 2005, U.S. Nuclear Regulatory Commission. 72.48

A.3.9.7-7 LS-DYNA Version 7.0.0, Rev. 79055, Livermore Software Technology Corporation (LSTC).

A.3.9.7-8 NRC Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Rev. 1, December 1973.

A.3.9.7-9 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.76, "Design Basis Tornado and Tornado Missiles for Nuclear Power Plants," Rev. 1, March 2007.

Table A.3.9.7-1
Sizes and Weight for Various HSM-MX Models

HSM-MX Module	Total Length of HSM-MX (in.)	Nominal Weight of Empty HSM-MX (kips)(1)
HSM-MX Single Array	277	2.355
HSM-MX Double Array	496	3,945

Notes:

(1) The nominal weights for the HSM-MX are based on concrete density of 150 pcf.

Table A.3.9.7-2
Missile Load Data for HSM-MX Stability Analysis

Missile	Mass (lbs.)	Dimensions	Velocity (fps)	Momentum (lbs-fps)
Utility Wooden Pole	1,124	13.5” Diameter 35’ Long	180	202,320
Armor Piercing Artillery Shell	276	8” Diameter	185	51,060
Steel Pipe	750	12” Sch. 40 15’ Long	154	115,500
Automobile	4,000	20 ft^2 Contact Area	195	780,000

Table A.3.9.7-3
Design Pressures for Tornado Wind Loading of HSM-MX

Wall Orientation(1)	Velocity Pressure (psf)	Ext. Pressure Coefficient (2)	Int. Pressure Coefficient (3)	Max/Min Design Pressure (psf) (4)
Front	276.4	0.680	± 0.18	237.7
Left	276.4	-0.595		-214.2
Rear(5)	276.4	-0.425		-167.2
Right	276.4	-0.595		-214.2
Top	276.4	-1.105		-355.2

Notes:

(1) Wind direction assumed to be from front. Wind loads from other directions may be found by rotating above table values to desired wind direction.

(2) These values are calculated using the external pressure coefficients from Figure 27.4-1 of [A.3.9.7-2] times the gust effect factor (0.85) from Section 26.9 of [A.3.9.7-2]

(3) Internal pressure coefficient taken from Table 26.11-1 of [A.3.9.7-2]

(4) These values are computed based on Equation 27.4-1 of [A.3.9.7-2]

(5) The bounding C_p of -0.5 from an L/B ratio of 0-1 is used for wind in all directions from Figure 27.4-1 of [A.3.9.7-2]

Table A.3.9.7-4
Summary of HSM-MX Sliding and Stability Results

Loading	Tornado Wind + Missile(1)		Flood	
Result	Maximum Sliding Distance (in)	Maximum Rocking Uplift (°)	Safety Factor against Sliding	Safety Factor against Tipping
HSM-MX Single Array	0.15	0.000029	1.42	1.98

Notes:

(1) 1.1 Factor Included.

Table A.3.9.7-5
Static analysis, Overturning and Sliding of the HSM-MX

	Concrete Density [pcf]		140	160
Overturning	Overturning Moment [in.kips]		463,757	523,739
	Stabilizing Moment [in.kips]		344,115	383,056
	Safety Factor(1)		0.67	0.66
	Max accelerations before overturning	$a_v = {}^2/_3\, a_h$	0.41	0.40
		a_h	0.61	0.60
Sliding	Horizontal Seismic Force [kips]		2126	2408
	Resisting Friction Force(3) [kips]		1021	1156
	Safety Factor(2)		0.44	
	Max accelerations before sliding	$a_v = {}^2/_3\, a_h$	0.32	
		a_h	0.48	

Notes:

(1) $SF = M_{st}/1.1M_{ot}$

(2) $SF = F_{fr}/1.1F_{hs}$

(3) Nominal Coefficient of friction 0.6

Table A.3.9.7-6
Summary of Displacement of HSM-MX relative to the ISFSI pad for nominal concrete density (150 pcf)

Earthquake	Coefficient of Friction	X-Displ. [in](2)	Z-Displ. [in](2)	Resultant [in](1)	X-Rocking [in]	Z-Rocking [in]
1. HEC	0.4	7.29	3.53	7.61	0.00	0.00
	0.6	2.45	2.08	2.55	0.00	0.02
	0.8	1.59	1.11	1.65	0.01	0.06
2. LCN	0.4	6.79	7.99	9.11	0.00	0.00
	0.6	3.83	5.52	6.65	0.00	0.02
	0.8	2.66	3.12	3.94	0.02	0.13
3. PS10	0.4	9.32	6.76	10.75	0.00	0.00
	0.6	5.13	3.36	6.12	0.00	0.07
	0.8	2.69	1.12	2.91	0.01	0.14
4. TAB	0.4	9.84	7.00	11.51	0.00	0.00
	0.6	5.39	3.78	6.48	0.00	0.02
	0.8	1.98	1.13	2.22	0.01	0.05
5. TCU	0.4	9.14	4.22	9.52	0.00	0.00
	0.6	3.73	1.40	3.77	0.00	0.02
	0.8	1.51	0.51	1.53	0.01	0.07
6. SHIF	0.4	8.49	9.57	12.77	0.00	0.00
	0.6	3.69	7.74	8.57	0.00	0.02
	0.8	2.35	4.63	5.19	0.01	0.10
7. MIAN	0.4	5.13	11.47	11.51	0.00	0.00
	0.6	3.19	7.69	8.11	0.00	0.02
	0.8	1.91	4.54	4.84	0.02	0.11
Maximum	0.4	9.84	11.47	12.77	0.00	0.00
	0.6	5.39	7.74	8.57	0.00	0.07
	0.8	2.69	4.63	5.19	0.02	0.14
Average	0.4	8.00	7.22	10.40	0.00	0.00
	0.6	3.92	4.51	6.04	0.00	0.03
	0.8	2.10	2.31	3.18	0.01	0.09
Median	0.4	8.49	7.00	10.75	0.00	0.00
	0.6	3.73	3.78	6.48	0.00	0.02
	0.8	1.98	1.13	2.91	0.01	0.10
Median + σ	0.4	10.16	9.80	12.50	0.00	0.00
	0.6	4.77	6.33	8.66	0.00	0.04
	0.8	2.46	2.88	4.41	0.01	0.13

(1) The resultant displacement is the square root of the sum of the squares of the X- and Z-displacements over time. This is not the resultant of the maximum X- and Z-Displacements

(2) Absolute values are reported = max(abs(u(t)))

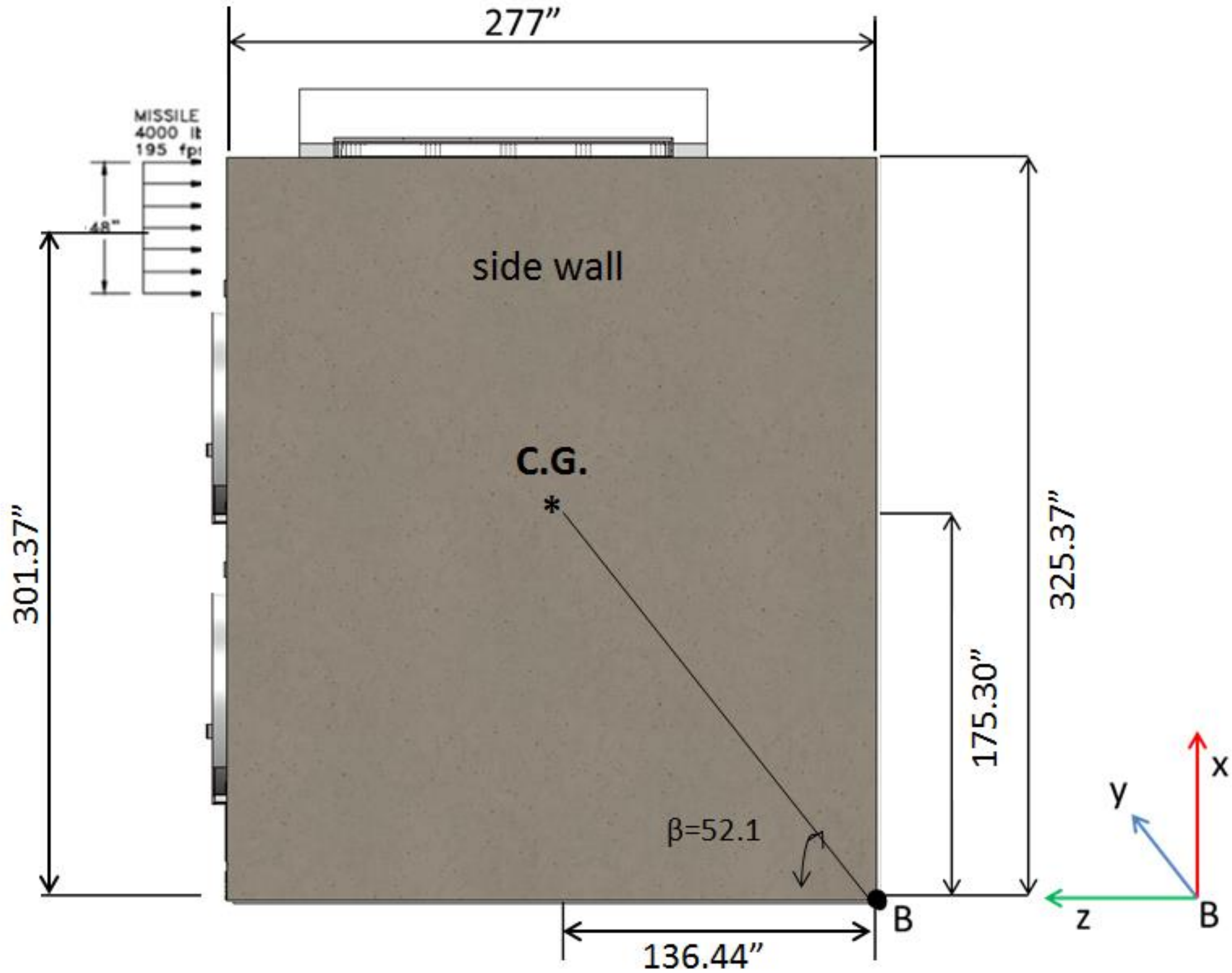


Figure A.3.9.7-1
HSM-MX Dimensions for Stability Analysis (Static)

Figure A.3.9.7-2
Not Used

Figure A.3.9.7-3
Not Used

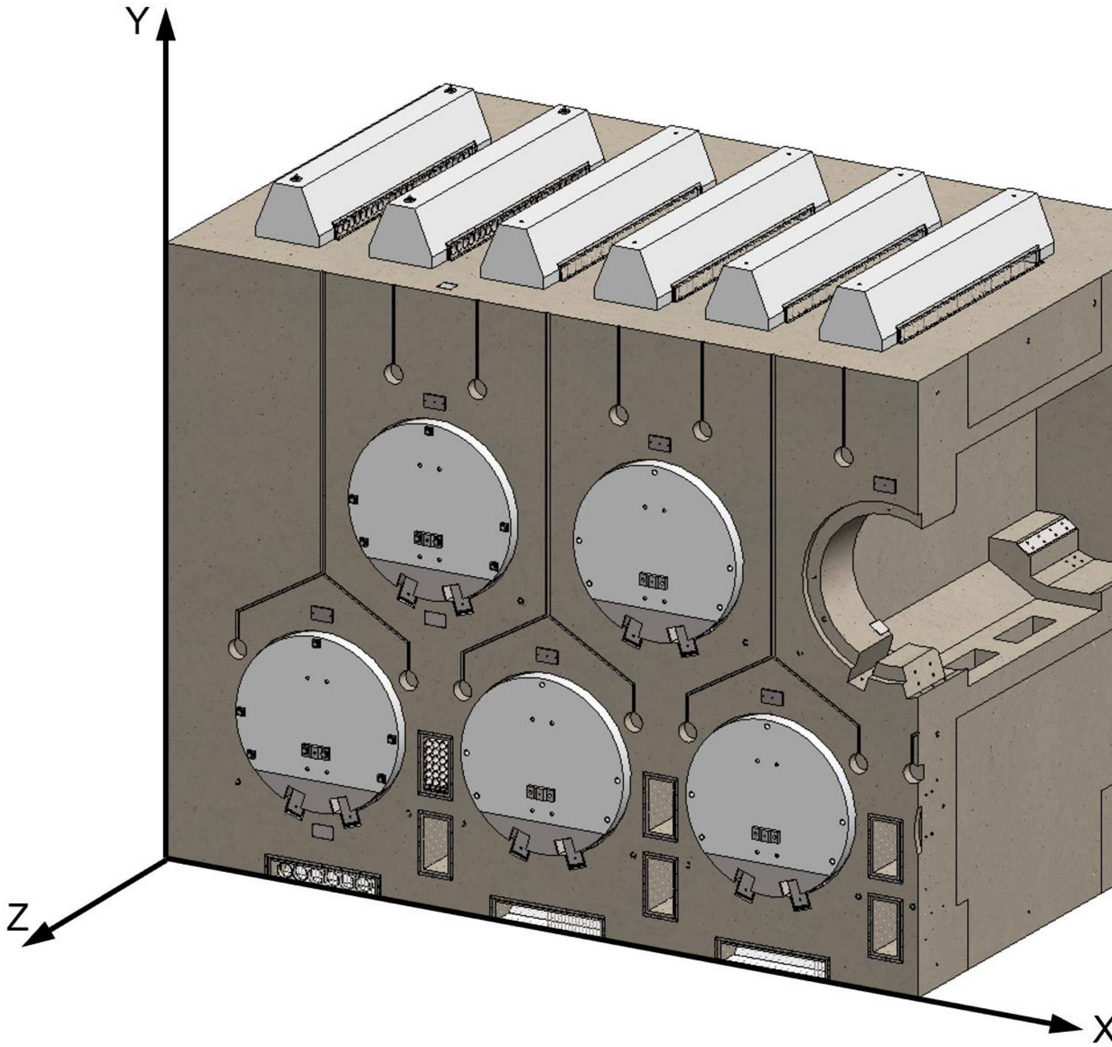


Figure A.3.9.7-4
HSM-MX Single Array Design with Five DSCs

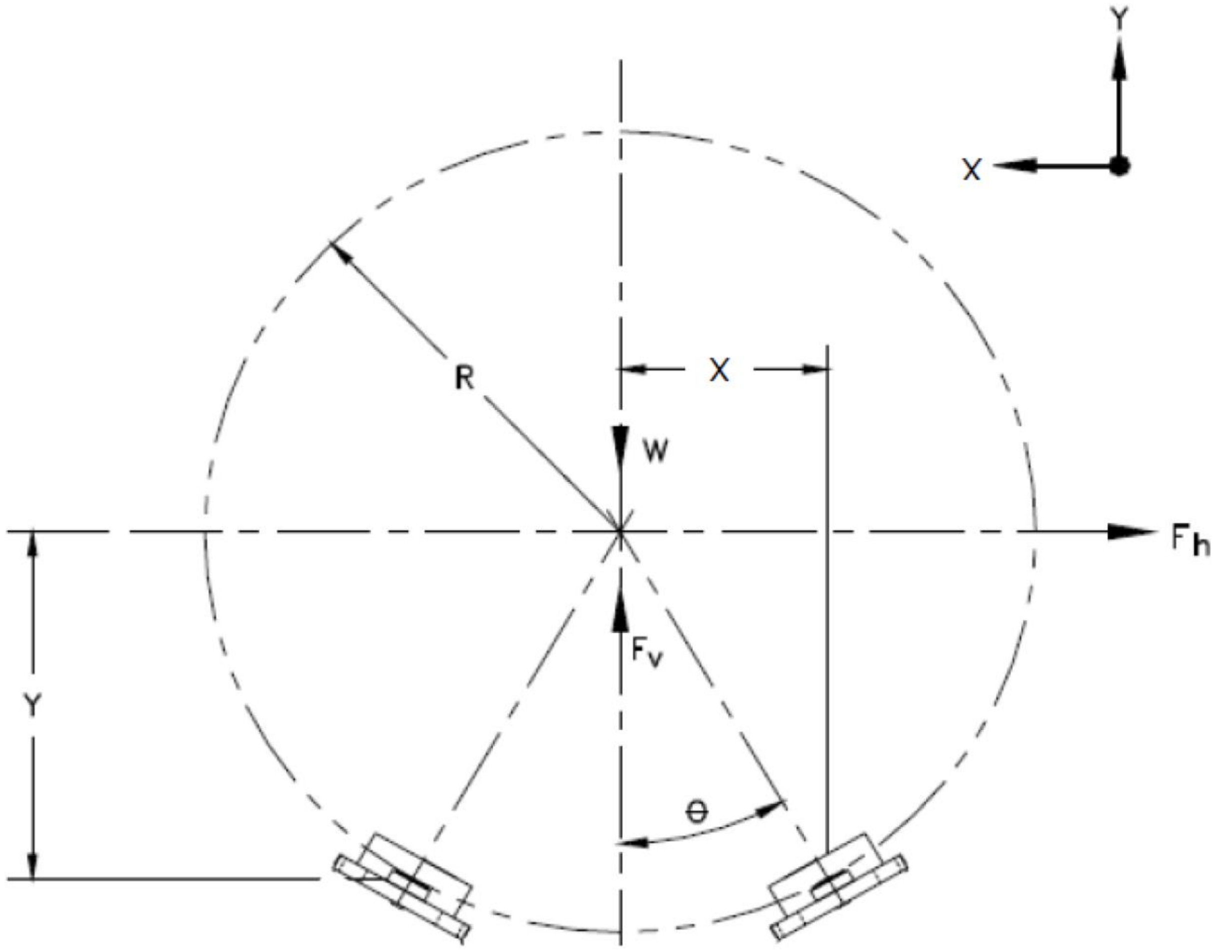


Figure A.3.9.7-5
Seismic Stability of DSC on HSM-MX

Figure A.3.9.7-6
Not Used

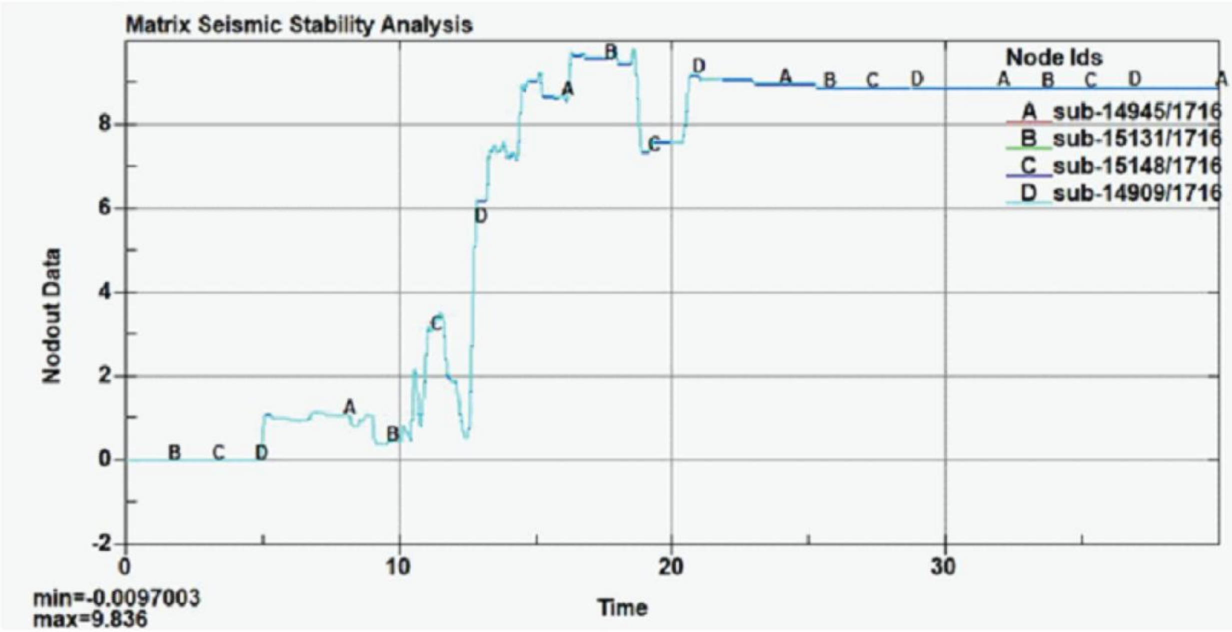


Figure A.3.9.7-7
HSM-MX Maximum X-Direction Sliding TAB, μ=0.4

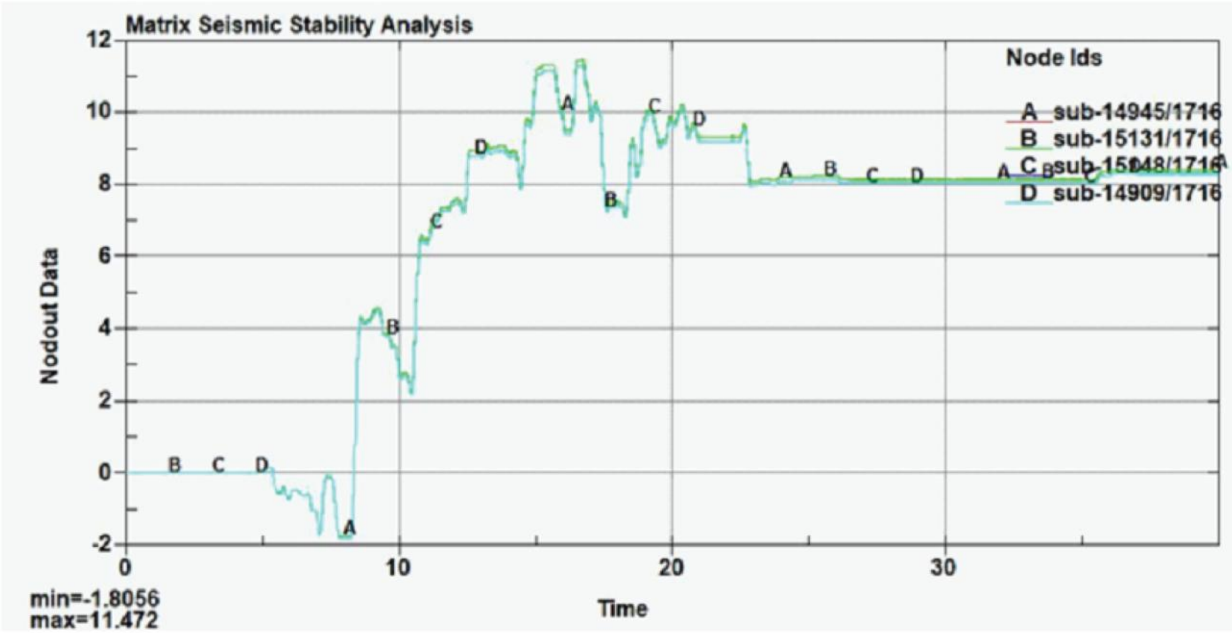


Figure A.3.9.7-8
HSM-MX Maximum Z-Direction Sliding MIAN, μ=0.4

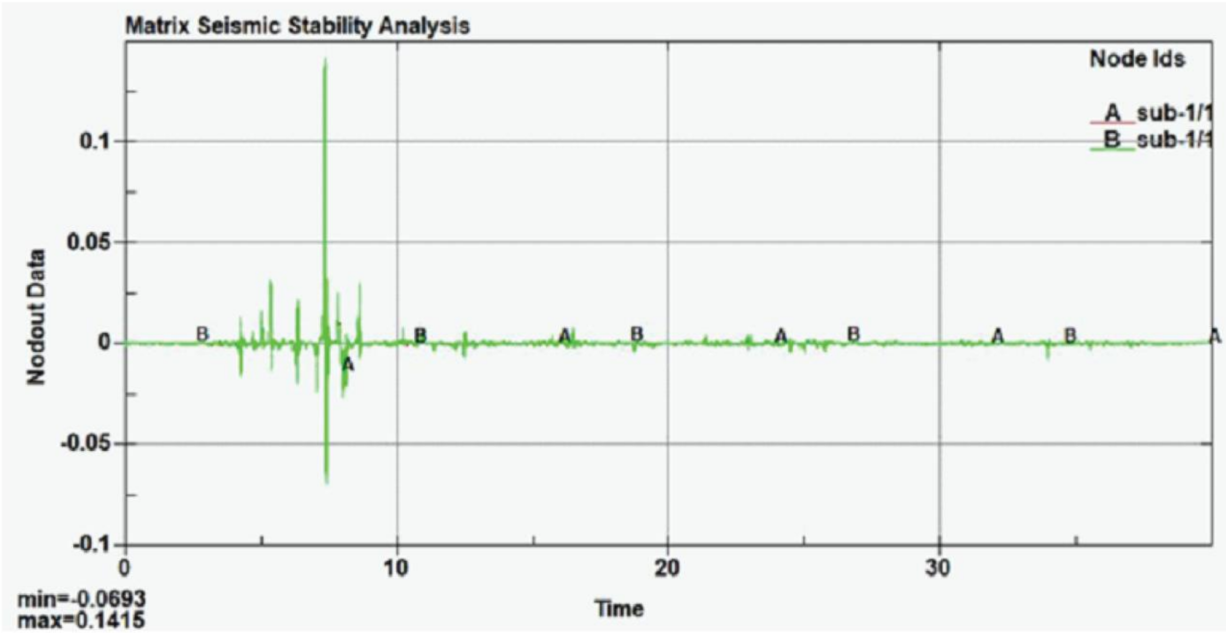


Figure A.3.9.7-9
HSM-MX Maximum Rocking PS10, μ=0.8

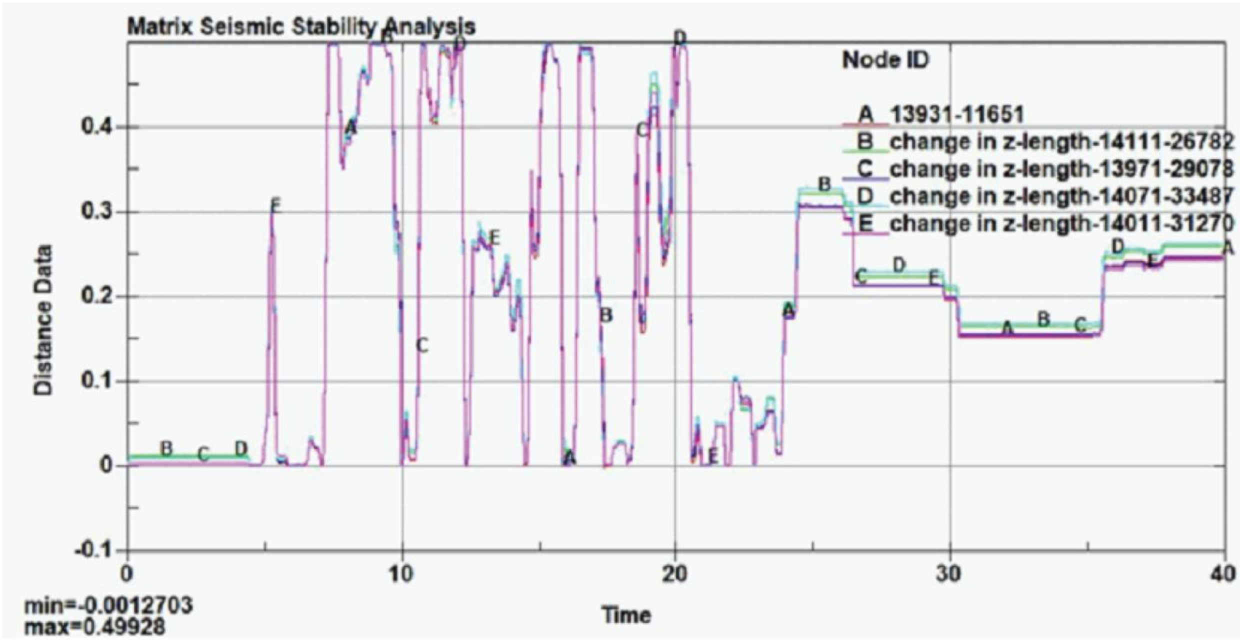


Figure A.3.9.7-10
DSC Sliding on Supports during Max. HSM-MX Z-direction Sliding Case: MIAN, μ=0.4

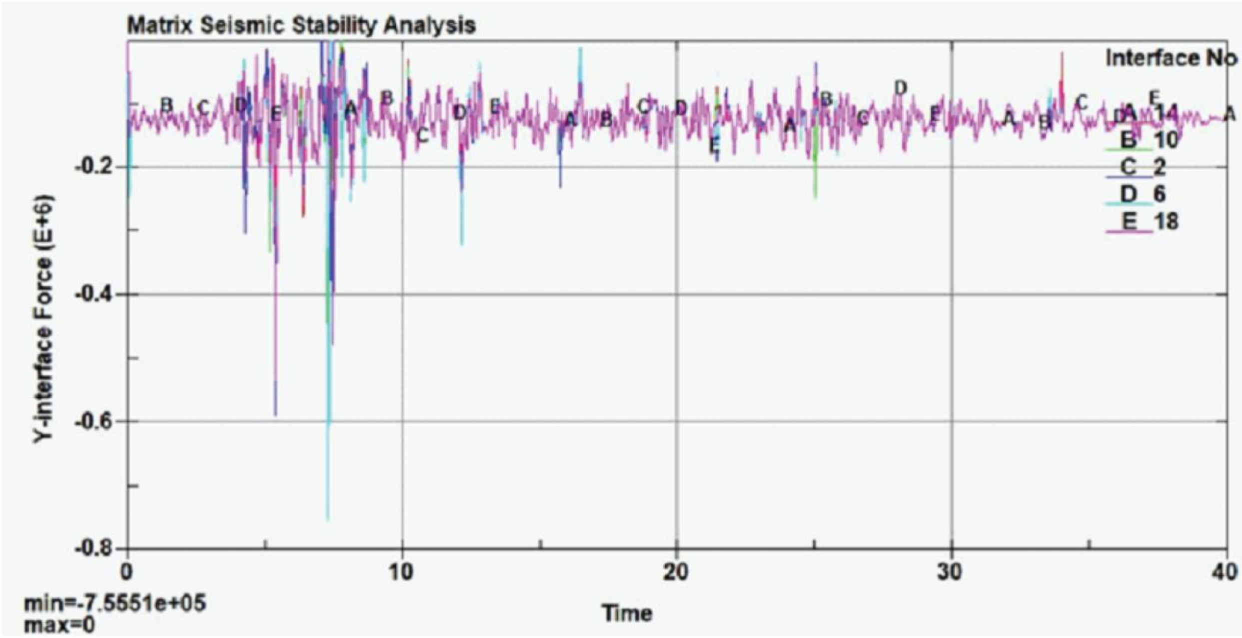


Figure A.3.9.7-11
DSC Load on Supports during Max. HSM-MX Z-Direction Rocking Case:
PS10, μ=0.8

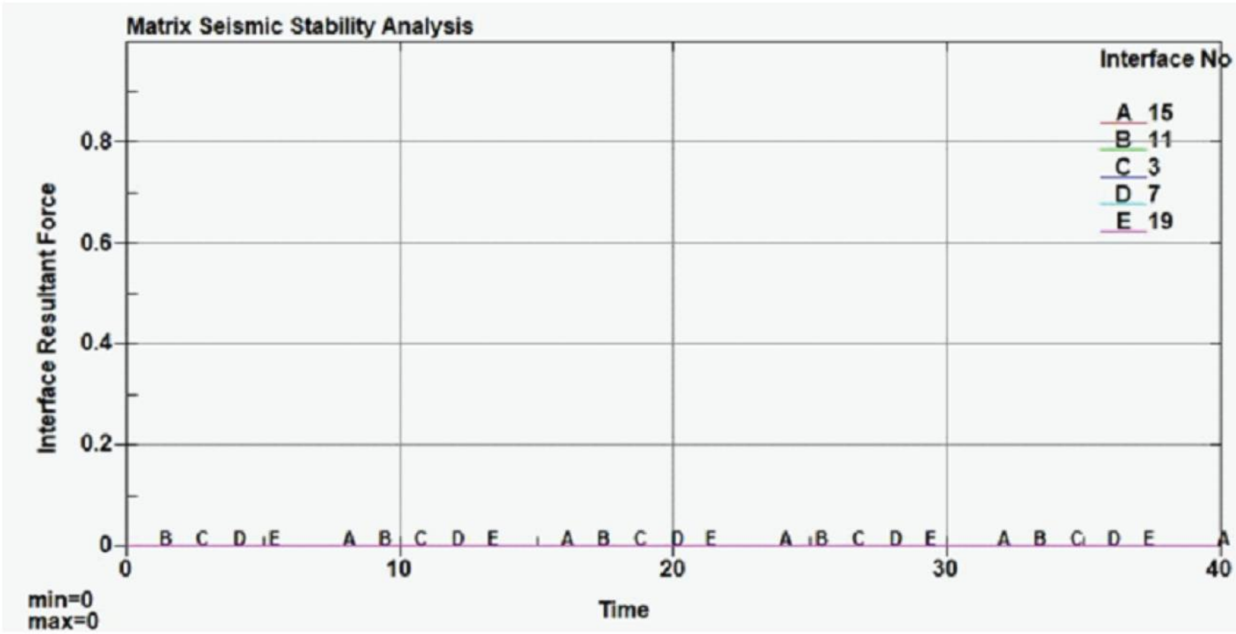


Figure A.3.9.7-12
DSC Load on Door Opening During Max. HSM-MX Z-Direction Rocking
Case: PS10, μ=0.8

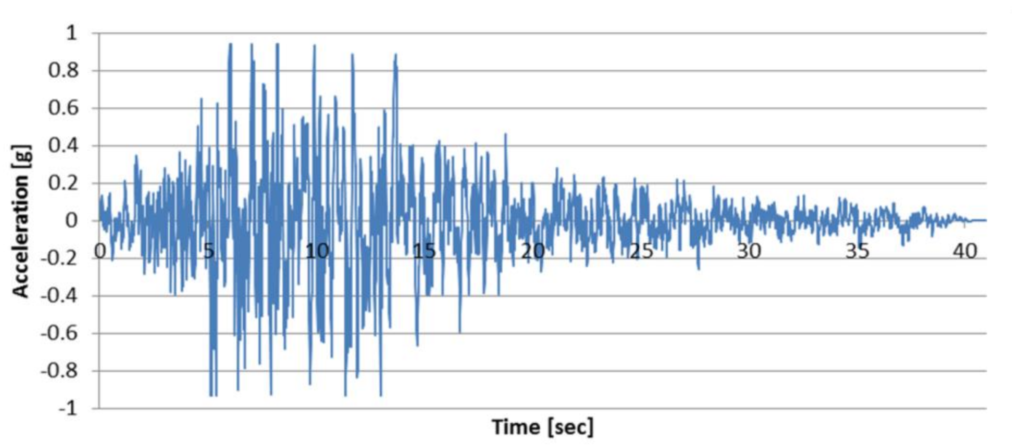
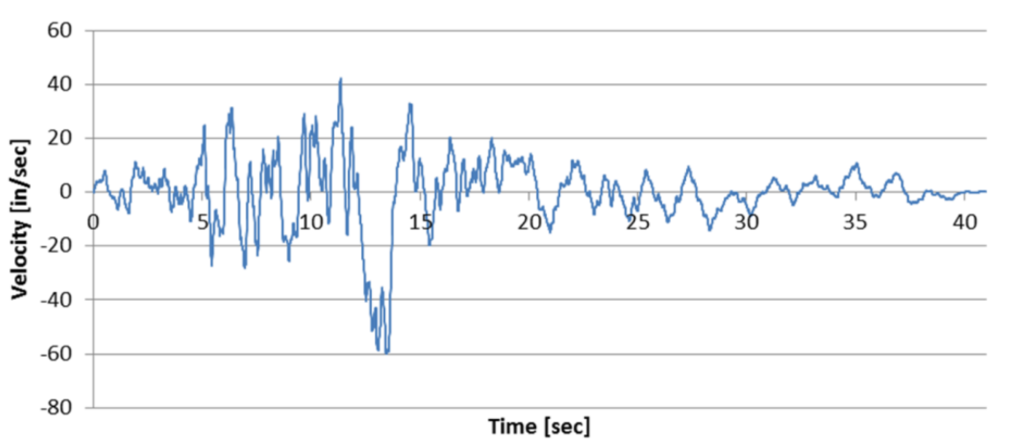
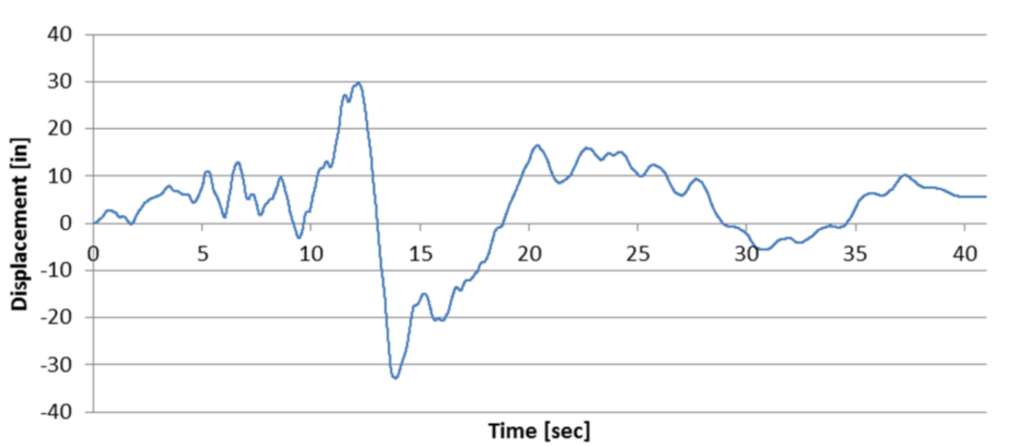
	Horizontal Acceleration Time History, H1
	Horizontal Velocity Time History, H1
	Horizontal Displacement Time History, H1

Figure A.3.9.7-13
Horizontal Time History Set 1, HEC – Global X Direction

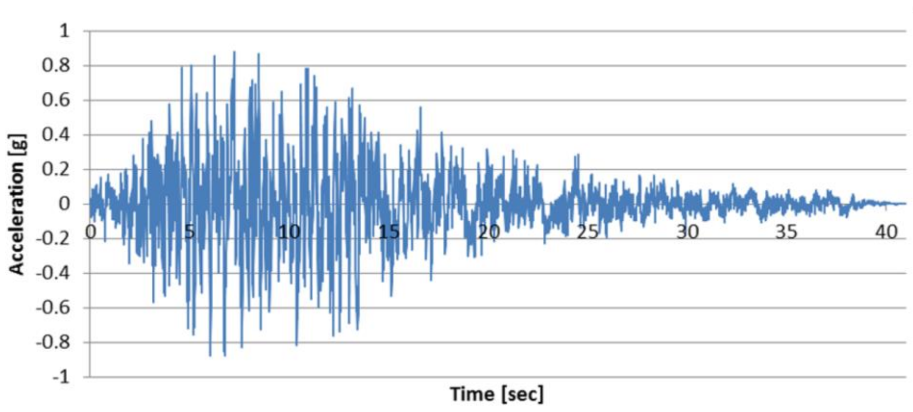
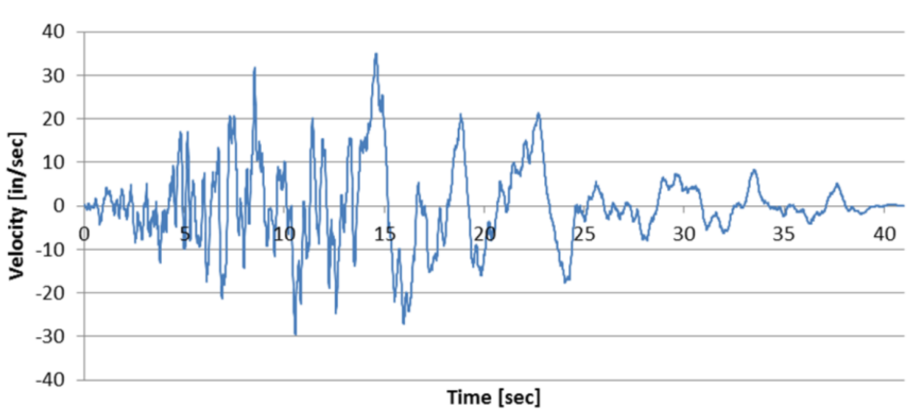
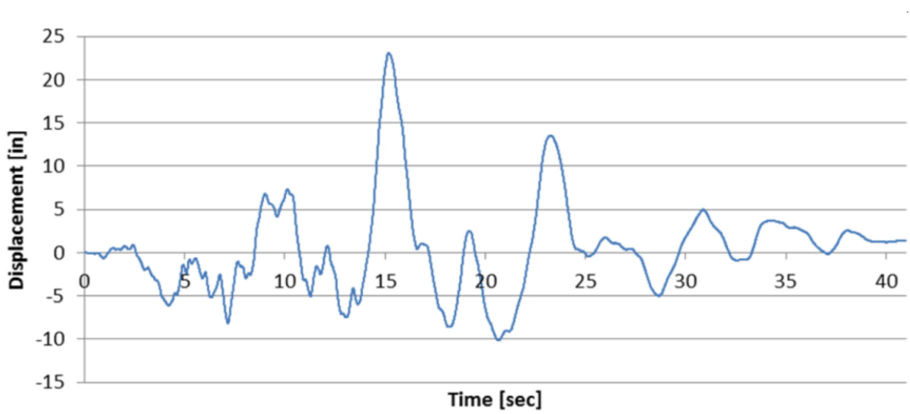
	Vertical Acceleration Time History, V
	Vertical Velocity Time History, V
	Vertical Displacement Time History, V

Figure A.3.9.7-14
Vertical Time History Set 1, HEC – Global Y Direction

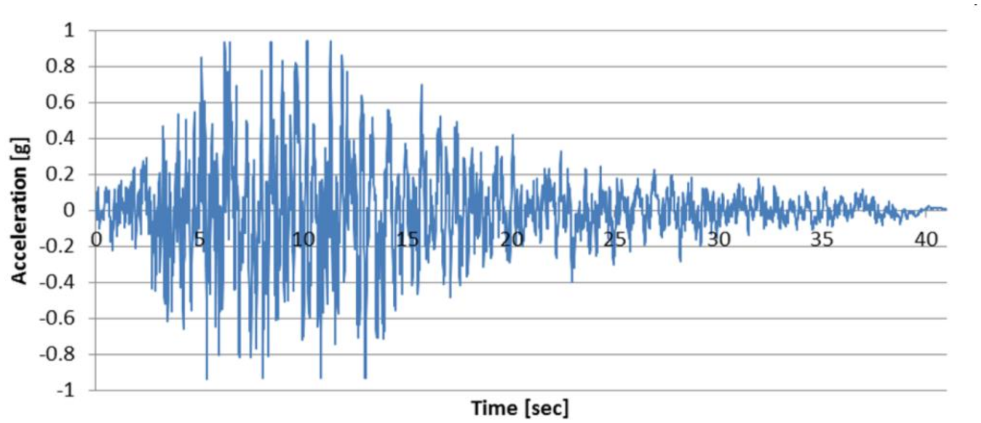
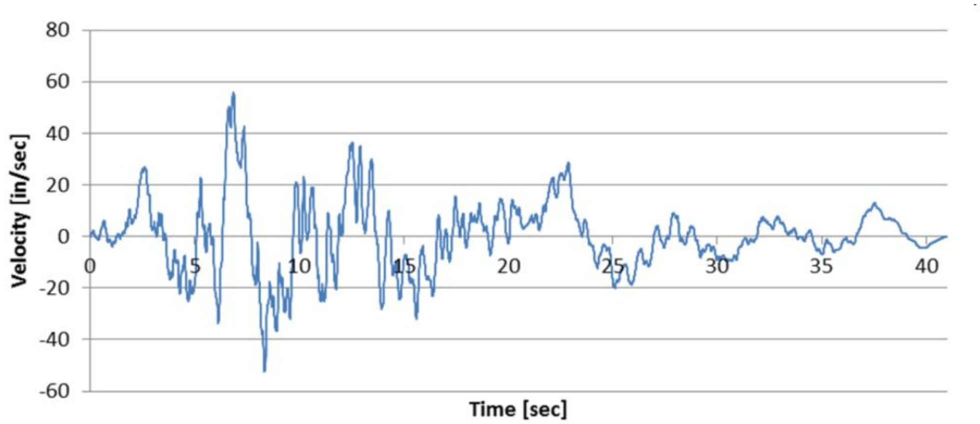
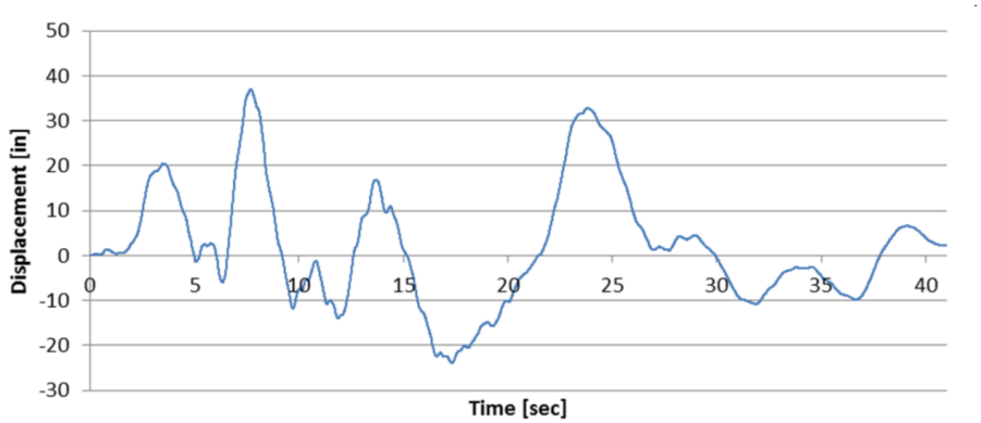
	Horizontal Acceleration Time History, H2
	Horizontal Velocity Time History, H2
	Horizontal Displacement Time History, H2

Figure A.3.9.7-15
Horizontal Time History Set 1, HEC – Global Z Direction

APPENDIX A.4
THERMAL EVALUATION

Table of Contents

List of Tables

List of Figures

A.4 THERMAL EVALUATION

The thermal evaluation described in this chapter is applicable to the NUHOMS® EOS System that includes EOS-37PTH or EOS-89BTH dry shielded canisters (DSCs) loaded inside the NUHOMS® MATRIX (HSM-MX).

A summary of the EOS-37PTH and EOS-89BTH DSC configurations analyzed in this chapter for storage operations in HSM-MX is shown below:

DSC Type	Basket Assembly Type	HLZC	Max. Heat Load (kW)	Transfer Cask	Storage Module
EOS-37PTH	4H	7	50.00	EOS-TC125/ EOS-TC135 *and EOS-TC108(3)*	HSM-MX
	4H/4L/5	8(1)	46.40(2)		
	4H/4L/5	9	37.80		
	4H	*11*	*44.50*	*EOS-TC125/EOS-TC135*	
EOS-89BTH	3	3	34.44	EOS-TC125/ EOS-TC108	

Note:

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

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

(3) Transfer operations in EOS-TC108 are permitted for HLZCs 4 through 9 in EOS-37PTH DSC only with Basket Type 4H.

The various basket types within the EOS-37PTH DSC and EOS-89BTH DSC are described in Chapter 1, Section 1.1 and Appendix 4.9.6, Section 4.9.6.1.1.

Descriptions of the detailed analyses performed for normal, off-normal, and hypothetical accident conditions are provided in Section A.4.4 for storage operations. Transfer operations for the EOS-37PTH DSC with HLZCs 7 through 9 are presented in Section 4.9.6.2. Transfer operations for the EOS-89BTH DSC with HLZC 3 are presented in Section 4.5.6.

In order to accommodate lessons learned from the mockup development, the original HSM-MX design has been slightly revised for improved fabricability. Section A.4.5 evaluates the thermal performance of the updated HSM-MX with the EOS-37PTH and EOS-89BTH DSCs under the bounding normal, off-normal, and accident storage conditions.

Storage Evaluation for EOS-37PTH DSC with Basket Type 4H for HLZC 11 in HSM-MX is presented in Section A.4.6.

A.4.1 Discussion of Decay Heat Removal System

Chapter 4, Section 4.1 provides a detailed description of the decay heat removal system within the EOS-37PTH and EOS-89BTH DSCs during storage operations in the EOS-HSM. The decay heat removal system described for storage operations in theEOS-HSM is also applicable for storage operations in the HSM-MX.

Similar to the EOS-HSM described in Chapter 4, Section 4.1, no instrumentation is required to monitor the thermal performance if daily visual inspections of the air inlet and outlet vents are performed. However, in lieu of the daily visual inspections, a direct measurement of the HSM-MX temperature or any other means that would provide an indication of the thermal performance may be used for monitoring in accordance with requirements in Technical Specifications [A.4-13].

A.4.2 Material and Design Limits

To establish the heat removal capability, several thermal design criteria are established for the NUHOMS® EOS System.

- Design criteria for the EOS-37PTH and EOS-89BTH DSCs are identical to those described in Chapter 4, Section 4.2.
- For normal and off-normal conditions, the maximum concrete temperature limit is 300 °F, as noted in Section 3.5.1.2 of [A.4-1]. For the accident conditions, if the concrete temperature exceeds the short-term limit of 350 °F noted in Appendix E.4 of ACI 349-06 [A.4-4], concrete testing will be performed, as described in Chapter A.8, Section A.8.2.1.3.

A.4.2.1 Summary of Thermal Properties of Materials

The thermal properties of the materials used in the thermal evaluation for Type 4H baskets are the same as those specified in Chapter 4, Section 4.2.1. The basket material properties for Type 4L/5 baskets are discussed in Appendix 4.9.6, Section 4.9.6.1.1.

A.4.3 Thermal Loads and Environmental Conditions

For storage operations in the HSM-MX, the maximum temperature is 100 °F for normal storage conditions. A daily average ambient temperature of 90 °F is used in the evaluations, corresponding to a daily maximum temperature of 100 °F for the normal hot storage conditions as discussed in Chapter 4, Section 4.3.

Off-normal ambient temperature is considered in the range of - 40 °F to 117 °F. 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 and hypothetical accident storage conditions, as discussed in Chapter 4, Section 4.3. Ambient temperatures of -20 °F and -40 °F are considered for the normal and off-normal cold storage conditions, respectively.

The HSM-MX is located outdoors and is exposed to the environment. Wind is a normal environment variable that varies frequently both in direction and magnitude. For the HSM-MX, low speed wind in the range of 0 to 15 mph is considered for normal storage conditions based on the discussion in Section 2.5 of NUREG-2174 [A.4-2].

A.4.4 Thermal Evaluation for Storage

This section provides an evaluation of the thermal performance of the HSM-MX loaded with the EOS-37PTH DSC for normal, off-normal, and hypothetical accident conditions.

Sections A.4.4.1 through A.4.4.3 present the evaluation for EOS-37PTH DSC with Basket Type 4H and a maximum heat load of 50 kW per HLZC 7 in the HSM-MX. A detailed description of Basket Type 4H is presented in Chapter 1, Section 1.1, Chapter 4, and Appendix 4.9.6, Section 4.9.6.1.1.

Within the HSM-MX, the maximum allowable heat loads differ between the upper and the lower compartments for the same DSC. For an EOS-37PTH DSC with Basket Type 4H, the maximum allowable heat loads in the upper and lower compartments are 41.8 kW and 50 kW, respectively.

Section A.4.4.1 and Section A.4.4.2 present a description of the loading cases and the computational fluid dynamics (CFD) model used for the thermal evaluation of the EOS-37PTH during storage in the HSM-MX, respectively.

Section A.4.4.3 presents the results of the thermal evaluation for the EOS-37PTH DSC with Basket Type 4H during storage operations in the HSM-MX per HLZC 7. Sections A.4.4.3.1, A.4.4.3.2, and A.4.4.3.3 discuss the normal, off-normal, and hypothetical accident conditions of storage, respectively.

Section A.4.4.4 presents the thermal evaluation of the EOS-37PTH DSC with Basket Type 4L/5 during storage operations in the HSM-MX per HLZCs 8 and 9. A description of Basket Type 4L/5 for the EOS-37PTH DSC is presented in Chapter 1, Section 1.1, Chapter 4, and Appendix 4.9.6, Section 4.9.6.1.1.

EOS-37PTH DSC with Basket Type 4L/5 has a maximum heat load of 46.4 and 41.8 kW, respectively, while loaded in the lower and upper compartments of the HSM-MX.

Since Type 4H baskets have higher emissivity steel plates and higher conductivity poison plates, they are more efficient in heat transfer than Type 4L/5 baskets. Therefore, all the thermal evaluations for EOS-37PTH Type 4L/5 baskets for storage and transfer conditions in Sections A.4.4.4 and A.4.5.5 are also applicable for EOS-37PTH Type 4H baskets.

Section A.4.4.5 presents the qualification of the EOS-89BTH DSC with a maximum heat load of 34.44 kW in the HSM-MX.

Proprietary Information on Pages A.4-6 through A.4-17
Withheld Pursuant to 10 CFR 2.390

A.4.4.3.1.2 Temperature Calculations

The maximum temperatures of fuel cladding and concrete of the HSM-MX loaded with the EOS-37PTH DSC for normal storage conditions (LCs 1a through 1e) are summarized in Table A.4-2.

The maximum temperatures of various components of the HSM-MX loaded with the EOS-37PTH DSC for the bounding normal storage condition (LC 1e) are summarized in Table A.4-3. The average temperatures of key components of the HSM-MX loaded with the EOS-37PTH DSC for the bounding normal storage condition (LC 1e) are summarized in Table A.4-4.

Typical temperature plots for the key components in the HSM-MX loaded with the EOS-37PTH DSC are shown in Figure A.4-9 for the bounding normal hot condition.

A.4.4.3.1.3 Airflow Calculations

The streamlines for the airflow inside the HSM-MX loaded with the EOS-37PTH DSC under normal hot storage condition are shown in Figure A.4-13. Cool air enters into the HSM-MX from the inlet, absorbs the heat from the EOS-37PTH DSC, and leaves the HSM-MX through the outlet with higher temperatures. Table A.4-6 summarizes the air temperatures and mass flow rates at the inlet and outlet for the quiescent normal condition of storage.

A.4.4.3.1.4 GCI Calculation

A.4.4.3.2 Off-Normal Conditions of Storage

A.4.4.3.2.1 Temperature Calculations

The maximum temperatures of fuel cladding and concrete of the HSM-MX loaded with the EOS-37PTH DSC for off-normal storage conditions (LC 2) are summarized in Table A.4-2.

The maximum temperatures of various components of the HSM-MX loaded with the EOS-37PTH DSC for off-normal storage conditions (LC 2) are summarized in Table A.4-3. The average temperatures of key components of the HSM-MX loaded with the EOS-37PTH DSC for off-normal storage condition (LC 2) are summarized in Table A.4-4.

Typical temperature plots for the key components in the HSM-MX loaded with the EOS-37PTH DSC are shown in Figure A.4-10 for off-normal hot conditions.

The minimum temperatures for fuel cladding and basket assembly components assuming no credit for decay heat for off-normal cold storage condition is -40 °F. All materials can be subjected to a minimum environment temperature of -40 °F without any adverse effects.

A.4.4.3.2.2 Airflow Calculations

Table A.4-6 summarizes the air temperatures and mass flow rates at the inlet and outlet for LC 2 for off-normal condition of storage.

A.4.4.3.3 Hypothetical Accident Conditions of Storage

A.4.4.3.3.1 Temperature Calculations

The maximum temperatures of fuel cladding and concrete of the HSM-MX loaded with the EOS-37PTH DSC for hypothetical accident condition of storage (LC 3) are summarized in Table A.4-2.

The maximum temperatures of various components of the HSM-MX loaded with the EOS-37PTH DSC for hypothetical accident condition of storage (LC 3) are summarized in Table A.4-3. The average temperatures of key components of the HSM-MX loaded with the EOS-37PTH DSC for hypothetical accident condition of storage (LC 3) are summarized in Table A.4-4. The values listed in Table A.4-3 and Table A.4-4 for LC 3 are based on transient simulation results at 32 hours.

Typical temperature plots for the key components in the HSM-MX loaded with the EOS-37PTH DSC are shown in Figure A.4-11 for hypothetical accident conditions.

For the accident blocked vent condition, the time histories of the maximum and average temperatures for the key components are shown in Figure A.4-12. All the temperatures increase steadily during the 32 hours of the blocked vent event.

A.4.4.3.4 Internal Pressure

Chapter 4, Section 4.7.1 calculates the maximum internal pressure of the EOS-37PTH DSC during storage in the EOS-HSM and transfer in EOS-TC125/135/108. For the EOS-37PTH DSC during storage in HSM-MX, the average gas temperature in the DSC cavity is computed using the same approach presented in Chapter 4, Section 4.7.1.2 and listed in Table A.4-7. As shown in Table A.4-7, the average helium temperatures determined for the EOS-37PTH DSC in HSM-MX with HLZC 7 are lower than the temperatures determined for HLZCs 1 through 3. Therefore, the maximum internal pressures in Chapter 4, Table 4-45 remain bounding for HLZC 7 under normal, off-normal, and accident storage conditions, respectively.

A.4.4.3.5 Impact of Design Changes

The original HSM-MX design has been slightly revised for improved fabricability as described in Section A.4.5.1. Detailed thermal evaluations for the storage in the updated HSM-MX are presented in Section A.4.5. This section evaluates the discrepancy of the original HSM-MX and the thermal model in Section A.4.4.2.2. The evaluation in this section is obsolete and no longer applicable.

[ ]

Proprietary Information on This Page
Withheld Pursuant to 10 CFR 2.390

A.4.4.4 EOS-37PTH DSC with Basket Type 4L/5 - Storage in HSM-MX

This section presents the thermal evaluation of the EOS-37PTH DSC with Basket Type 4L/5 during storage operations in the HSM-MX. A description of Basket Type 4L/5 for the EOS-37PTH DSC is presented in Chapter 1, Section 1.1 and Appendix 4.9.6, Section 4.9.6.1.1.

This evaluation considers HLZC 8 with a maximum heat load of 46.4 kW and HLZC 9 with a maximum heat load of 37.8 kW. HLZC 8 and HLZC 9 are shown in Figure 1H and Figure 1I of the Technical Specifications [A.4-13], respectively.

HLZC 8 can accommodate either damaged or failed FAs along with intact FAs but not both. In addition, when damaged or failed FAs are loaded per HLZC 8, the maximum heat load is limited to 41.8 kW per DSC. As discussed in Chapter 1, Section 1.1, damaged/failed FAs shall only be loaded in the EOS-37PTH DSC with Basket Type 4L.

EOS-37PTH DSC with Basket Type 4L/5 has a maximum heat load of 46.4 kW while loaded in the lower compartment of the HSM-MX. The maximum heat load for the EOS-37PTH DSC with Basket Type 4L/5 while loaded in the upper compartment of the HSM-MX is 41.8 kW.

Utilizing these new HLZCs, this section evaluates the thermal performance of the HSM-MX loaded with the EOS-37PTH DSC for normal, off-normal, and accident conditions.

Proprietary Information on Pages A.4-23 and A.4-24
Withheld Pursuant to 10 CFR 2.390

A.4.4.4.2 EOS-37PTH DSC with Basket Type 4L/5 - Thermal Model for Storage in HSM-MX

To evaluate the thermal performance of the EOS-37PTH DSC with Basket Type 4L/5 based on HLZCs 8 and 9 during storage operations in HSM-MX, the thermal model from Section A.4.4.2 is modified to simulate LCs described in Section A.4.4.4.1. The modifications in the LCs described in Section A.4.4.4.1 are limited to the changes in material properties of the basket components as described in Appendix 4.9.6, Section 4.9.6.1.1, and heat generation rates based on the new HLZCs, but no changes are considered to the mesh.

A.4.4.4.3 EOS-37PTH DSC with Basket Type 4L/5 for HLZC 8 and 9 –Storage Evaluation

Table A.4-9 and Table A.4-10 present the maximum temperatures of fuel cladding and key components of the EOS-37PTH DSC with Basket Type 4L/5 loaded in the HSM-MX based on HLZCs 8 and 9 during storage operations.

Table A.4-11 presents the average temperatures of fuel cladding and key components of the EOS-37PTH DSC with Basket Type 4L/5 loaded in the HSM-MX based on HLZCs 8 and 9 during storage operations.

Figure A.4-14 and Figure A.4-15 present the temperature profiles of key components in the HSM-MX loaded with the EOS-37PTH DSC for HLZCs 8 and 9, respectively.

Comparison with HLZC 7

Table A.4-12 presents a comparison of the maximum temperatures for HLZCs 8 and 9 with the bounding design basis values from HLZC 7. As shown in the comparison, the maximum temperatures determined for HLZC 7 with 50 kW, remain bounding for HLZCs 8 and 9.

Similar to the normal condition, the maximum temperatures during off-normal and accident storage conditions for HLZCs 8 or 9 will also remain bounded by HLZC 7. Therefore, no further evaluation is required for off-normal and accident storage condition with HLZCs 8 and 9.

Based on this discussion, all design criteria are satisfied for storage of the EOS-37PTH DSC with HLZCs 8 or 9 in the HSM-MX.

Proprietary Information on Pages A.4-26 through A.4-28
Withheld Pursuant to 10 CFR 2.390

A.4.5.4 EOS-37PTH DSC with Basket Type 4H – Storage in Updated HSM-MX

A.4.5.4.1 Convergence of the CFD Model

A.4.5.4.2 Temperature Calculations

The maximum temperatures of fuel cladding and concrete of the updated HSM-MX loaded with the EOS-37PTH DSC for the bounding normal, off-normal, and accident storage conditions are summarized in Table A.4-16.

The maximum temperatures of various components of the HSM-MX loaded with the EOS-37PTH DSC for the bounding normal, off-normal, and accident storage conditions are summarized in Table A.4-17. The average temperatures of key components of the HSM-MX loaded with the EOS-37PTH DSC for the bounding normal, off-normal, and accident storage conditions are summarized in Table A.4-18.

Typical temperature plots for the key components in the HSM-MX loaded with the EOS-37PTH DSC are shown inFigure A.4-21, Figure A.4-22, andFigure A.4-23, respectively, for the bounding normal hot, off-normal hot, and accident conditions.

A.4.5.4.3 Airflow Calculations

The streamlines for the airflow inside the updated HSM-MX loaded with the EOS-37PTH DSC under normal hot storage condition are shown in Figure A.4-24. Cool air enters into the HSM-MX from the inlet, absorbs the heat from the EOS-37PTH DSC, and leaves the HSM-MX through the outlet with higher temperatures. Table A.4-20 summarizes the air temperatures and mass flow rates at the inlet and outlet for the normal and off-normal hot conditions of storage.

A.4.5.4.4 GCI Calculation

A.4.5.4.5 Internal Pressure

Chapter 4, Section 4.7.1 calculates the maximum internal pressure of the EOS-37PTH DSC during storage in the EOS-HSM and transfer in EOS-TC125/135/108. For the EOS-37PTH DSC during storage in the updated HSM-MX, the average gas temperature in the DSC cavity is computed using the same approach presented in Chapter 4, Section 4.7.1.2 and listed in Table A.4-21. As shown in Table A.4-21, the average helium temperatures determined for the EOS-37PTH DSC in the updated HSM-MX with HLZC 7 are lower than the temperatures determined for HLZCs 1 through 3. Therefore, the maximum internal pressures in Chapter 4, Table 4-45 remain bounding for HLZC 7 under normal, off-normal, and accident storage conditions, respectively.

A.4.5.5 EOS-37PTH DSC with Basket Type 4L/5 – Storage in Updated HSM-MX

This section presents the thermal evaluation of the EOS-37PTH DSC with Basket Type 4L/5 during storage operations in the updated HSM-MX. This section follows the same methodology as discussed in Section A.4.4.4. The only difference is the design changes that made to HSM-MX as discussed in Section A.4.5.1.

Same as Section A.4.4.4, this evaluation considers HLZC 8 with a maximum heat load of 46.4 kW and HLZC 9 with a maximum heat load of 37.8 kW. HLZCs 8 and 9 are discussed in Section A.4.4.4.

A.4.5.5.1 EOS-37PTH DSC and Basket Type 4L - Description of Load Cases for Storage

[ ]

A.4.5.5.2 EOS-37PTH DSC with Basket Type 4L/5 - Thermal Model for Storage in HSM-MX

To evaluate the thermal performance of the EOS-37PTH DSC with Basket Type 4L/5 based on HLZCs 8 and 9 during storage operations in the updated HSM-MX, the thermal model from Section A.4.5.3 is modified to simulate LCs described in Section A.4.5.5.1. The modifications in the LCs described in Section A.4.5.5.1 are limited to the changes in material properties of the basket components as described in Appendix 4.9.6, Section 4.9.6.1.1, and heat generation rates based on the new HLZCs, but no changes are considered to the mesh.

A.4.5.5.3 EOS-37PTH DSC with Basket Type 4L/5 for HLZCs 8 and 9 –Storage Evaluation

72.48

Figure A.4-23 and Figure A.4-24 present the maximum temperatures of fuel cladding and key components of the EOS-37PTH DSC with Basket Type 4L/5 loaded in the updated HSM-MX based on HLZCs 8 and 9 during storage operations.

Figure A.4-25 presents the average temperatures of fuel cladding and key components of the EOS-37PTH DSC with Basket Type 4L/5 loaded in the updated HSM-MX based on HLZCs 8 and 9 during storage operations.

Figure A.4-25 and Figure A.4-26 present the temperature profiles of key components in the HSM-MX loaded with the EOS-37PTH DSC for HLZCs 8 and 9, respectively.

Comparison with HLZC 7

Table A.4-26 presents a comparison of the maximum temperatures for HLZCs 8 and 9 with the bounding design basis values from HLZC 7. As shown in the comparison, the majority of the maximum component temperatures determined for HLZC 7 with 50 kW remain bounding for HLZCs 8 and 9. The maximum temperature of the heat shield in the upper compartment for HLZC 8 is slightly higher (2 °F) than that for HLZC 7.

Similar to the normal condition, the maximum temperatures during off-normal and accident storage conditions for HLZCs 8 or 9 will also remain bounded by HLZC 7. Therefore, no further evaluation is required for off-normal and accident storage condition with HLZCs 8 and 9.

Based on this discussion, all design criteria are satisfied for storage of the EOS-37PTH DSC with HLZCs 8 or 9 in the updated HSM-MX.

A.4.5.6 EOS-89BTH DSC with Basket Type 3 - Storage in Updated HSM-MX

Proprietary Information on Pages A.4-33 through A.4-39
Withheld Pursuant to 10 CFR 2.390

A.4.6 EOS-37PTH DSC with Basket Type 4H for HLZC 11 – Storage Evaluation

This section presents the thermal evaluation of the EOS-37PTH DSC with Basket Type 4H during storage operations in the HSM-MX per HLZC 11 with intact, damaged, and failed fuel assemblies (FAs).

A.4.6.1 Description of HLZC 11

HLZC 11 is shown in Figure 1K of Technical Specifications [A.4-13]. As seen from Figure 1K of Technical Specifications [A.4-13], HLZC 11 has a maximum heat load of 44.5 kW per DSC, and a maximum heat load of 3.5 kW per FA.

Proprietary Information on This Page
Withheld Pursuant to 10 CFR 2.390

A.4.6.5 Temperature Calculations

The maximum temperatures of fuel cladding and concrete of the HSM-MX loaded with the EOS-37PTH DSC with HLZC 11 are summarized in Table A.4-36. The maximum fuel cladding and concrete temperatures are 699 °F and 280 °F, within the temperature limits of 752 °F and 300 °F, respectively.

The maximum and average temperatures of key components of the HSM-MX loaded with the EOS-37PTH DSC for the storage conditions are summarized in Table A.4-37 and Table A.4-38, respectively. Average temperatures are calculated based on the volume average temperatures of the elements representing the whole component.

A.4.6.7 Internal Pressure Calculation

A.4.7 References

A.4-1 NUREG-1536, "Standard Review Plan for Spent Fuel Dry Cask Storage Systems at a General License Facility," Revision 1, U.S. Nuclear Regulatory Commission, July 2010.

A.4-2 NUREG-2174, "Impact of Variation in Environmental Conditions on the Thermal Performance of Dry Storage Casks - Final Report," U.S. Nuclear Regulatory Commission, March 2016.

A.4-3 J.M. Cuta, U.P. Jenquin, and M.A. McKinnon, "Evaluation of Effect of Fuel Assembly Loading Patterns on Thermal and Shielding Performance of a Spent Fuel Storage/Transportation Cask," , PNNL-13583, Pacific Northwest National Laboratory, November 2001.

A.4-4 ACI 349-06, "Code Requirements for Nuclear Safety Related Concrete Structures" American Concrete Institute.

A.4-5 ANSYS FLUENT, ANSYS FLUENT Users Guide, Version 17.1, ANSYS, Inc.

A.4-6 ANSYS ICEM CFD, Version 17.1, ANSYS, Inc.

A.4-7 NUREG-2152, "Computational Fluid Dynamics Best Practice Guidelines for Dry Cask Applications," U.S. Nuclear Regulatory Commission, March 2013.

A.4-8 American Society of Mechanical Engineers, "Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer," ASME V&V 20-2009, November 30th, 2009.

A.4-9 I. E. Idelchik, "Handbook of Hydraulic Resistance," 3rd Edition, Begell House, Inc., 1996.

A.4-10 A Zigh, J Solis, "Computational Fluid Dynamics Best Practice Guidelines in Analysis of Dry Storage Cask," WM2008 Conference, Phoenix, AZ, February 24-28, 2008.

A.4-11 ASHRAE Handbook, Fundamentals, SI Edition, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1997.

A.4-12 P. J. Roache, "Quantification of Uncertainty in Computational Fluid Dynamics," Annual Review of Fluid Mechanics, Vol. 29, 123-160, 1997.

A.4-13 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *2*.

Table A.4-1
EOS-37PTH DSC in HSM-MX, Design Load Cases for Storage Conditions with HLZC 7

Load Case	Operating Condition	Description	Mesh	Ambient Temperature (°F)
1a	Normal		Base	100 (1)
1b				
1c				
1d				
1e				
1f			Fine	
2	Off-Normal		Base	117 (1)
3 (2)	Accident		Base	117 (1)

Notes:

(1) Daily average temperatures are used as noted in Section A.4.3.

(2) Initial temperatures are taken from steady-state results of Load Case 2.

Table A.4-2
Maximum Fuel Cladding and Concrete Temperatures for Storage Conditions of EOS-37PTH DSC in HSM-MX with HLZC 7

Load Case (1)	Description	Max Fuel Cladding Temperature (°F)			Concrete Temperature (°F)	
		Upper Compartment	Lower Compartment	Limit	Maximum(4)	Limit
1a		641	686	752(2)	246	300(2)
1b		651	684		245	
1c		660	690		250	
1d		671	699		260	
1e		676	708		273	
1f		676	707		273	
2		653	696	1058(2)	263	
3		724	777		371	500(3)

Notes:

(1) See Table A.4-1 for the description of the LCs.

(2) The temperature limits are from NUREG-1536 [A.4-1].

(3) The temperature limit for concrete at accident condition is 500 °F. The maximum concrete temperature for accident conditions is above the 350 °F limit given in ACI 349-06 [A.4-4]. Testing will be performed, as described in Chapter A.8, Section A.8.2.1.3.

(4) According to the sensitivity study in Section A.4.4.3.5, the maximum concrete temperatures are added by 9 °F for conservatism.

Proprietary Information on Pages A.4-47 through A.4-52
Withheld Pursuant to 10 CFR 2.390

Table A.4-9
Maximum Fuel Cladding and Concrete Temperatures for Storage Conditions of EOS-37PTH DSC in HSM-MX with HLZCs 8 and 9

Load Case (1)	Max Fuel Cladding Temperature (°F)			Concrete Temperature (°F)	
	Upper Compartment	Lower Compartment	Limit	Maximum(4)	Limit
LC1e for HLZC 8	679	698	752(2)	262	300(2)
LC1e for HLZC 9(3)	675	698		262	

Notes:

(1) See Table A.4-8 for the description of the LCs.

(2) The temperature limits are from NUREG-1536 [A.4-1].

(3) DSC in the upper compartment is modeled per HLZC 9, whereas DSC in the lower compartment is modeled per HLZC 8 as discussed in Section A.4.4.4.1.

(4) According to the sensitivity study in Section A.4.4.3.5, the maximum concrete temperatures are added by 9 °F for conservatism.

Proprietary Information on Pages A.4-54 through A.4-57
Withheld Pursuant to 10 CFR 2.390

Table A.4-14
EOS-37PTH DSC in Updated HSM-MX, Design Load Cases for Storage Conditions with HLZC 7

Load Case	Operating Condition	Description	Mesh	Ambient Temperature (°F)
1e-S	Normal		Base	100 (1)
1f-S			Fine	
2-S	Off-Normal		Base	117 (1)
3-S (2)	Accident		Base	117 (1)

Notes:

(1) Daily average temperatures are used as noted in Section A.4.3.

(2) Initial temperatures are taken from steady-state results of Load Case 2-S.

Proprietary Information on This Page
Withheld Pursuant to 10 CFR 2.390

Table A.4-16
Maximum Fuel Cladding and Concrete Temperatures for Storage Conditions of EOS-37PTH DSC in Updated HSM-MX with HLZC 7

72.48

Load Case (1)	Description	Max Fuel Cladding Temperature (°F) *(4)*			Concrete Temperature (°F) *(4)*	
		Upper Compartment	Lower Compartment	Limit	Maximum	Limit
1e		676	708	752(2)	264	300(2)
1e-S		680	704		261	
		4	-4		-3	
2		653	696	1058(2)	254	
2-S		648	685		245	
		-5	-11		-9	
3		724	777		362	
3-S		699	770		*358*	500(3)
		-25	-7		*-4*	

72.48

Notes:

(1) See Table A.4-1 and Table A.4-14 for the description of the LCs.

(2) The temperature limits are from NUREG-1536 [A.4-1].

(3) The temperature limit for concrete at accident condition is 500 °F. The maximum concrete temperature for accident conditions is above the 350 °F limit given in ACI 349-06 [A.4-4]. Testing will be performed, as described in Chapter A.8, Section A.8.2.1.3.

(4) The temperatures reported in the above table do not consider the impact of the lower inlet shield block (lower compartment). This impact is evaluated in Section A.4.5.7.4. Therefore, the temperature increases reported in Section A.4.5.7.4 should be considered in addition to the temperatures listed above. 72.48

Proprietary Information on Pages A.4-61 through A.4-65
Withheld Pursuant to 10 CFR 2.390

Table A.4-23
Maximum Fuel Cladding and Concrete Temperatures for Storage Conditions of EOS-37PTH DSC in Updated HSM-MX with HLZCs 8 and 9

72.48

Load Case (1)	Max Fuel Cladding Temperature (°F) (4)			Concrete Temperature (°F) (4)	
	Upper Compartment	Lower Compartment	Limit	Maximum	Limit
LC 1e-S for HLZC 8	682	694	752(2)	256	300(2)
LC 1e-S for HLZC 9(3)	677	694		252	

Notes:

(1) See Table A.4-22 for the description of the LCs.

(2) The temperature limits are from NUREG-1536 [A.4-1].

(3) DSC in the upper compartment is modeled per HLZC 9, whereas DSC in the lower compartment is modeled per HLZC 8 as discussed in Section A.4.4.4.1.

(4) The temperatures reported in the above table do not consider the impact of the lower inlet shield block (lower compartment). This impact is evaluated in Section A.4.5.7.4. Therefore, the temperature increases reported in Section A.4.5.7.4 should be considered in addition to the temperatures listed above. 72.48

Proprietary Information on Pages A.4-67 through A.4-74
Withheld Pursuant to 10 CFR 2.390

Table A.4-33b
Maximum Temperatures of Key Components in HSM-MX Loaded with EOS-37PTH DSC for Periodic and Full Models with Bounding Normal Condition

72.48

Load Case	Upper Compartment (2)				Lower Compartment (2)			
	Basket Plate (°F)	Transition Rails (°F)	DSC Shell (°F)	Heat Shield (°F)	Basket Plate (°F)	Transition Rails (°F)	DSC Shell (°F)	Heat Shield (°F)
1e-S (1)	630	492	409	260	657	528	431	256
1e-S-full-O	*651*	*513*	*432*	*292*	*625*	*501*	*403*	*226*
$\Delta_{(1e\text{-}S\text{-}full\text{-}O\ -\ 1e\text{-}S)}$	*21*	*21*	*23*	*32*	*-32*	*-27*	*-28*	*-30*

72.48

Note:

(1) Results of LC 1e-S are from Table A.4-17.

(2) The temperatures reported in the above table do not consider the impact of the lower inlet shield block (lower compartment). This impact is evaluated in Section A.4.5.7.4. Therefore, the temperature increases reported in Section A.4.5.7.4 should be considered in addition to the temperatures listed above. 72.48

Proprietary Information on This Page
Withheld Pursuant to 10 CFR 2.390

Table A.4-34
EOS-37PTH DSC in HSM-MX, Design Load Case for Storage Conditions with HLZC 11

Load Case No.	Description	Ambient Temperature (°F)	HLZC
1e-S-full-O for HLZC 11	[,]	100	11

Table A.4-35
Summary of Convergence for CFD Model of EOS-37PTH DSC in HSM-MX with HLZC 11 for Storage Conditions

[ ]

Table A.4-36
Maximum Fuel Cladding and Concrete Temperatures for EOS-37PTH DSC in HSM-MX with HLZC 11 for Storage Conditions

Load Case(1)	***Description***	***Max Fuel Cladding Temperature (°F)***			***Concrete Temperature (°F)***	
		Upper Fuel	***Lower Fuel***	***Limit***(2)	***Maximum***	***Limit***(2)
1e-S-full-O for HLZC 7(3)	[ ]	*700*	*679*	*752*	*281*	*300*
1e-S-full-O for HLZC 11	[ ]	*699*	*674*		*280*	
ΔLC 1e-S-full-O for HLZC 11 - LC 1e-S-full-O for HLZC 7		*-1*	*-5*		*-1*	

Notes:

(1) See Table A.4-33a and Table A.4-34 for the description of the load cases.

(2) The temperature limits are from NUREG-1536 [A.4-1].

(3) The results for the bounding load case LC 1e-S-full-O for HLZC 7 are obtained from Table A.4-33a.

Proprietary Information on Pages A.4-79 through A.4-139
Withheld Pursuant to 10 CFR 2.390

APPENDIX A.5
CONFINEMENT

There is no change to the confinement assessment documented in Chapter 5 due to the addition of the NUHOMS® MATRIX.

APPENDIX A.6
SHIELDING EVALUATION

Table of Contents

List of Tables

List of Figures

A.6 SHIELDING EVALUATION

The radiation shielding evaluation for the NUHOMS® EOS System for transfer of an EOS dry shielded canister (EOS-DSC) and storage in an EOS horizontal storage module (EOS-HSM) is documented in Chapter 6. The following radiation shielding evaluation addresses the storage of an EOS-DSC in a NUHOMS® MATRIX (HSM-MX). Detailed three-dimensional (3D) dose rate evaluations are performed to determine the dose rate fields around an HSM-MX. These near-field dose rates are used as input to the dose assessment documented in Chapter A.11.

The methodology, source terms, and dose rates presented in this chapter are developed to be reasonably bounding for general licensee implementation of the EOS System. These results may be used in lieu of near-field evaluations by the general licensee, although the inputs utilized in this chapter should be evaluated for applicability by each site. Site-specific HSM-MX near-field evaluations may be performed by the general licensee to modify key input parameters.

Site dose evaluations for the HSM-MX under normal, off-normal, and accident conditions are documented in Chapter A.11, based on the near-field HSM-MX results presented in this chapter. Because the arrangement and the distance to the site boundary is site-specific, compliance with 10 CFR 72.104 and 10 CFR 72.106 for the HSM-MX can only be demonstrated using a site-specific evaluation. Inputs for the site dose evaluations developed in the current chapter may be directly used as input to a site-specific dose evaluation by the general licensee.

A.6.1 Discussions and Results

The following is a summary of the methodology and results of the shielding analysis of HSM-MX. More detailed information is presented in the body of the chapter.

Source Terms

For the HSM-MX, the DSC in the lower compartment is limited to 50.0 kW, while the DSC in the upper compartment is limited to 41.8 kW. PWR heat load *zone* configurations (HLZC) 7, 8, *9, and 11* are used with the HSM-MX, as well as boiling water reactor (BWR) HLZC 3. The HLZCs are defined in the Technical Specifications, Figure 1G through Figure 2 [A.6-2].

Dose rate evaluations are performed for the HSM-MX filled with either the EOS-89BTH or EOS-37PTH DSC. EOS-89BTH DSC source terms are developed for the EOS-HSM analysis in Section 6.2 for HLZC 1. These source terms are used without modification in the HSM-MX analysis in both the lower and upper compartments. BWR HLZC 1, which has a heat load of 43.6 kW, is conservatively modeled in the upper HSM-MX compartment, although the upper compartment is limited to a lower decay heat. Note that BWR HLZC 1 is not an allowed content for the HSM-MX, as the only BWR HLZC authorized for storage in the HSM-MX is HLZC 3. Utilizing HLZC 1 sources in the HSM-MX adds a large degree of conservatism in the dose rate results, because HLZC 1 accepts stronger sources compared to HLZC 3.

EOS-37PTH DSC HLZC 4 and 10 source terms are developed for the EOS-HSM analysis in Section 6.2, and it is demonstrated that HLZC 10 bounds HLZC 4. Therefore, HLZC 10 sources are used in HSM-MX analysis in both the upper and lower compartments. HLZC 10 is not authorized for use in the HSM-MX but results in bounding source terms and dose rates compared to HLZC 11. In addition, the same control component (CC) source is used in each basket location, as defined in Table 6-37.

Dose Rates

The EOS-37PTH and EOS-89BTH DSCs are transferred to the HSM-MX using the EOS-TC. The EOS-TC dose rates provided in Chapter 6 are applicable to transfer to the HSM-MX. Therefore, the dose rates reported in this appendix are limited to the HSM-MX.

The Monte Carlo transport code, MCNP5 [A.6-1], is used to compute dose fields around the HSM-MX using detailed 3D models. [

] *Summaries* of the limiting HSM-MX dose rates *are* provided in Table A.6-2 *and Table A.6-2a for the EOS-89BTH and EOS-37PTH DSC, respectively. Dose rates are higher for the EOS-37PTH DSC with the exception of the door centerline*. The dose rate excluding the contribution from the inlet and outlet vents is small, as the dose rates are due primarily to streaming from the vents. The maximum dose rates at the inlet and outlet vents are *1,570* mrem/hr and *1,370* mrem/hr, respectively. The average dose rate on the front face of the module is *51.1* mrem/hr, and the average dose rate on the roof above the vent covers is *206* mrem/hr. The dose rate at the door centerline is 1.97 mrem/hr. The fluxes and dose rates on the surface of the HSM-MX are used as input to a generic site dose evaluation documented in Chapter A.11.

The shielding effectiveness of the HSM-MX is not affected by any off-normal events. The following geometry changes may occur in an accident:

- Loss of outlet vent covers
- Loss of dose reduction hardware
- Damage to interior walls due to missile impact when the HSM-MX is in the construction joint expansion configuration with the removable end shield wall absent

10 CFR 72.106 limits the dose to an individual at the site boundary to be less than 5 rem due to an accident. Monte Carlo N-Particle (MCNP) cases are developed for the HSM-MX, in which all vent covers and dose reduction hardware are absent, which is not credible. An MCNP case is also developed for a missile impact when the HSM-MX is in the construction joint expansion configuration with the removable end shield wall absent. In this configuration, it is conservatively assumed that two interior walls are penetrated. The HSM-MX accident *for the EOS-37PTH DSC* increases the average dose rate on the front, roof, and end of the module to *100* mrem/hr, *6,070* mrem/hr, and *537* mrem/hr, respectively*, which are higher than the HSM-MX accident dose rates for the EOS-89BTH DSC*. The fluxes and dose rates on the surface of the HSM-MX in an accident condition are used as input to an accident site dose evaluation documented in Chapter A.11.

A.6.2 Source Specification

Source term information in Section 6.2 is applicable to the HSM-MX evaluation.

A.6.2.1 Computer Programs

No change to Section 6.2.1.

A.6.2.2 PWR and BWR Source Terms

Dose rate evaluations are performed for the HSM-MX filled with either the EOS-89BTH or EOS-37PTH DSC. EOS-89BTH DSC source terms are developed for the EOS-HSM analysis in Section 6.2 for HLZC 1. These source terms are provided in Table 6-27 through Table 6-29 and maximize the dose rates at the vents. These source terms are used without modification in the HSM-MX analysis in both the lower and upper compartments. BWR HLZC 1, which has a heat load of 43.6 kW, is conservatively modeled in the upper HSM-MX compartment, although the upper compartment is limited to 41.8 kW. Note that BWR HLZC 1 is not an allowed content for the HSM-MX, because the only BWR HLZC authorized for storage in the HSM-MX is HLZC 3. Utilizing HLZC 1 sources in the HSM-MX adds a large degree of conservatism in the dose rate results, because HLZC 1 accepts stronger sources compared to HLZC 3.

EOS-37PTH DSC HLZC 4 and 10 source terms are developed for the EOS-HSM analysis in Section 6.2, and it is demonstrated that HLZC 10 bounds HLZC 4. Therefore, HLZC 10 sources are used in HSM-MX analysis in both the upper and lower compartments. HLZC 10 sources are defined in Table 6-19a through Table 6-19c. HLZC 10 is not authorized for use in the HSM-MX but results in bounding source terms and dose rates compared to HLZC 11. HLZC 10 allows eight 3.5 kW FAs, while HLZC 11 allows only four 3.5 kW FAs and four 3.2 kW FAs in the lower compartment and allows only eight 3.0 kW FAs in the upper compartment. In addition, the same control component (CC) source is used in each basket location, as defined in Table 6-37.

A.6.2.3 Axial Source Distributions and Subcritical Neutron Multiplication

No change to Section 6.2.3.

A.6.2.4 Control Components

No change to Section 6.2.4.

A.6.2.5 Blended Low Enriched Uranium Fuel

No change to Section 6.2.5.

A.6.2.6 Reconstituted Fuel

No change to Section 6.2.6.

A.6.2.7 Irradiation Gases

No change to Section 6.2.7.

A.6.2.8 Justification for the Reasonably Bounding Source Term Methodology

No change to Section 6.2.8.

A.6.3 Model Specification

MCNP5 is used to perform detailed 3D near-field dose rate evaluations for the HSM-MX. All relevant details of the EOS-89BTH DSC*, EOS-37PTH DSC,* and HSM-MX are modeled explicitly.

Separate primary gamma and neutron models are developed. The HSM-MX neutron models are run in coupled neutron-photon mode so that the secondary gamma dose rate from (n,γ) reactions may be computed. The secondary gamma dose rates from the HSM-MX are negligible but are computed for completeness.

The treatment of subcritical neutron multiplication is suppressed in MCNP by using the NONU card. This is done because the fuel assemblies are modeled as fresh fuel and homogenized for simplicity, which would cause inaccurate treatment of subcritical neutron multiplication by MCNP. Subcritical neutron multiplication is accounted for in the neutron source magnitude.

A.6.3.1 Material Properties

The HSM-MX models use the same material properties documented in Section 6.3.1 with the exception of the concrete density. Concrete used in the HSM-MX is modeled without steel rebar at a conservatively low density of 138 pcf (2.22 g/cm^3) compared to 140 pcf (2.24 g/cm^3) for the EOS-HSM.

A.6.3.2 MCNP Model Geometry for the EOS-TC

The EOS-TC models documented in Section 6.3.2 are applicable for transfer to the HSM-MX.

A.6.3.3 MCNP Model Geometry for the HSM-MX

A complete analysis is performed separately for the EOS-89BTH and EOS-37PTH DSCs. Detailed HSM-MX MCNP models are developed for *the same EOS-DSC* in the upper and lower compartments. The *EOS-DSC* models developed in Section A.6.3.2 are used without modification in the HSM-MX models. *Source* terms are as described in Section A.6.2.2.

The HSM-MXs are modeled explicitly, including the inlet (front) and outlet (roof) vents. The lower compartment features a single horizontal inlet vent at ground level directly under the DSC, while the upper compartment features two vertical inlet vents that are located between the lower compartments. Key dimensions used to develop the HSM-MX models are summarized in Table A.6-1, and figures illustrating the MCNP models with key features labeled are provided in Figure A.6-1 through Figure A.6-6.

The HSM-MX is a monolithic design of two tiers of DSCs. The length of the monolith is arbitrary and determined by the customer. The roof is integral to the HSM-MX, as well as the end shield walls and the rear shield wall. The monolith may be either a single row or a double row (i.e., back-to-back arrangement).

The minimum thickness of the roof is 4 feet 2 inches. The minimum thickness of the integral end shield wall is 3 feet 8 inches. The minimum thickness of the optional removable end shield wall is 3 feet. In the single-row design, the thickness of the integral rear shield wall is 3 feet 8 inches. In the back-to-back design, the wall thickness between rows is 2 feet 6 inches.

Air inlet vents are located on the front and air outlet vents are located on the roof. Because little radiation directly penetrates the thick concrete shielding, essentially all of the dose rate is due to gamma radiation streaming from the vents. Radiation streaming through the outlet vents is mitigated by the use of vent covers, see Figure A.6-1. Under normal and off-normal conditions the vent covers are always in place.

The baseline MCNP configuration features an HSM-MX with a rear shield wall. On the left side (-x direction) an end shield wall is modeled, while on the right side (+x direction) a mirror boundary is modeled at the centerline of the DSC in the upper compartment, see Figure A.6-1 through Figure A.6-4. The length of the DSC is in the z-direction. This configuration is used to compute dose rates and fluxes on the end shield wall.

A second MCNP configuration features mirror boundaries on both the left and right sides of the model through the centerline of the DSCs in the lower compartments, although the rear shield wall is modeled explicitly, see Figure A.6-5. This configuration is used to simulate the interior region of a single row and is used to compute dose rates and fluxes on the rear shield wall.

A third MCNP configuration features mirror boundaries on the left, right, and rear of the model, see Figure A.6-6. This configuration is used to simulate the interior region of a double row (i.e., back-to-back arrangement) and is used to compute front and roof vent dose rates, as well as average front and roof dose rates and fluxes.

[

]

When an HSM-MX is to be expanded in the future, construction may be terminated at a construction joint and a 3 feet thick removable end shield wall is attached. The two complete compartments (one upper and one lower) nearest the end must remain empty when the HSM-MX is loaded, as indicated in Figure A.6-8. This configuration is explicitly modeled to determine the end dose rate when the removable end shield wall is absent. If an array to be expanded terminates at an expansion joint rather than a construction joint, the two compartments (one upper and one lower) nearest the end wall must remain empty. End dose rates for this configuration are bounded by the construction joint option with the end shield wall removed.

ADVANTG [A.6-3] is used to develop weight windows to accelerate problem convergence for all models.

The average fluxes on the faces of the HSM-MX are used as input to a generic site dose evaluation that is documented in Chapter A.11. These average fluxes are computed on the surface of a box that envelops the HSM-MX model, including the vent covers and door.

[

]

A.6.4 Shielding Analysis

A.6.4.1 Computer Codes

MCNP5 v1.40 *[A.6-1] and v1.60 [A.6-4] are* used in the shielding analysis. MCNP5 is a Monte Carlo transport program that allows full 3D modeling of the HSM-MX. Therefore, no geometrical approximations are necessary when developing the shielding models. 72.48

A.6.4.2 Flux-to-Dose Rate Conversion

No change to Section 6.4.2.

A.6.4.3 EOS-TC Dose Rates

No change to Section 6.4.3.

A.6.4.4 HSM-MX Dose Rates

[ ]

[

]

The maximum dose rate at the roof outlet vent is *1,370* mrem/hr. The maximum dose rate at the lower compartment inlet vent is *1,570* mrem/hr, while the maximum dose rate at the upper compartment inlet vent is *1,480* mrem/hr.

The total dose rate is dominated by primary gammas, while the dose rate from neutrons and secondary gammas is negligible. The bulk shielding of the HSM-MX is very effective in the absence of streaming. The average dose rate on the rear and end (side) shield walls is *0.680* mrem/hr and *1.07* mrem/hr, respectively. The dose rate at the door centerline is 1.97 mrem/hr. These surfaces do not contain streaming paths, although the average rear and end dose rates are computed to the top of the vent covers and include contribution from the roof vents. The average dose rate on the front face of the module is *51.1* mrem/hr, and the average dose rate on the roof above the vent covers is *206* mrem/hr.

Input for Site Dose Evaluation

The average dose rate and flux on the surface of the HSM-MX is of interest for use in the generic site dose evaluations. The site dose evaluations are documented in Chapter A.11, although the inputs to the site dose evaluation are obtained from the HSM-MX evaluations described in the current chapter.

[

]

Average fluxes and dose rates on the end, rear, front, and roof of the HSM-MX with the EOS-89BTH DSC are reported in Table A.6-3, Table A.6-4, and Table A.6-5, for primary gamma, secondary gamma, and neutron radiation, respectively. These dose rates and fluxes are applicable to normal and off-normal conditions. *Similar fluxes and dose rates for the EOS-37PTH DSC are reported in Table A.6-9 through Table A.6-11.*

[

]

Expansion Considerations

As shown in Figure A.6-8, when an array is in the construction joint expansion configuration, the two complete compartments (one upper and one lower) at the end of the module must remain empty. A removable end shield wall is attached. These empty compartments are required to maintain low dose rates when the removable end shield wall is absent during subsequent construction activities. If an array to be expanded terminates at an expansion joint rather than a construction joint, the two compartments (one upper and one lower) nearest the end wall must remain empty. End dose rates for this configuration are bounded by the construction joint option with the end shield wall removed.

Use of Low-Density Grout for HSM-MX Repair

[

.]

A.6.5 Supplemental Information

A.6.5.1 PWR Fuel Qualification

The discussion on PWR fuel qualification in Section 6.5.1 is also applicable to the HSM-MX. The same PWR fuel qualification table (FQT) is used for the EOS-HSM and HSM-MX.

A.6.5.2 References

A.6-1 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, RSICC Computer Code Collection, January 2006.

A.6-2 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *2*.

A.6-3 ADVANTG – An Automated Variance Reduction Parameter Generator, Oak Ridge National Laboratory, August 2015.

A.6-4 Oak Ridge National Laboratory, "MCNP6.1/MCNP5/MCNPX Monte Carlo N-Particle Transport Code System Including MCNP6.1, MCNP5-1.60, MCNPX-2.7.0 and Data Libraries," CCC-810, RSICC Computer Code Collection, August 2013. 72.48

Proprietary Information on Pages A.6-12 through A.6-45
Withheld Pursuant to 10 CFR 2.390

APPENDIX A.7
CRITICALITY EVALUATION

There is no change to the criticality evaluation documented in Chapter 7 due to the addition of the NUHOMS® MATRIX.

APPENDIX A.8
MATERIALS EVALUATION

Table of Contents

List of Tables

A.8 MATERIALS EVALUATION

This chapter only provides the material evaluation for the NUHOMS® MATRIX (HSM-MX) in accordance with the guidance outlined in NUREG-1536, Revision 1 [A.8-1]. There are no changes to the materials evaluation of other components in the NUHOMS® EOS System in Chapter 8.

A.8.1 General Information

A.8.1.1 HSM-MX Materials

Steel materials employed in the various components of the HSM-MX, particularly those that are relied on for structural integrity, are based on American Society for Testing and Materials (ASTM) and American Society of Mechanical Engineers (ASME) specifications. Horizontal storage module (HSM) concrete is based on American Concrete Institute (ACI) specifications.

A.8.1.2 Environmental Conditions

The dry shielded canister (DSC) and NUHOMS® MATRIX (HSM-MX) are exposed to the ambient weather conditions at the licensee site for the duration of the licensing period. Depending on the licensee local conditions, the environment may include chloride aerosols, precipitation, and freezing temperatures. The monolith roof, front wall, door, sides, rear (for single row arrays) and shield walls (if applicable) of the HSM-MX concrete are directly exposed to the weather. The HSM-MX 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-MX interior via natural convection. Material temperatures of the storage system components are presented in Chapter A.4.

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 DSC and TC are unchanged from the NUHOMS® EOS System; therefore, there are no changes to the environmental conditions relative to the DSC and TC discussed in Section 8.1.2 *and Appendix B, Section B.8.1.2.* 72.48

A.8.1.3 Engineering Drawings

The drawings for HSM-MX are provided in Chapter A.1, Section A.1.3. The material specification, governing code, and quality category are specified in the parts list for each component.

There are no changes to the EOS-37PTH, EOS-89BTH and *EOS*-TC drawings provided in Chapter 1, Section 1.3. 72.48

A.8.2 Materials Selection

This section discusses the materials used in the HSM-MX components. Table A.8-1 summarizes the materials selected for HSM-MX. Materials utilized in the HSM-MX are largely the same as those used in the EOS-HSM, and the materials for the EOS-DSCs and EOS-TCs have not changed. Therefore, the tables described in Section 8.2 also applicable to HSM-MX. Temperature-dependent mechanical and thermal properties for the materials listed in Table A.8-1 are presented in Table A.8-2 through Table A.8-4.

A.8.2.1 Applicable Codes and Standards and Alternatives

A.8.2.1.1 EOS-37PTH and EOS-89BTH DSC

No change from Section 8.2.1.1.

A.8.2.1.2 EOS-TC Transfer Cask

No change from Section 8.2.1.2.

A.8.2.1.3 HSM-MX Horizontal Storage Module

The applicable codes for the HSM-MX are:

- Concrete construction per ACI-318-08 [A.8-4].
- Concrete Design per ACI-349-06 [A.8-5].
- DSC Support design per AISC Manual of Steel Construction [A.8-7].

Cement, aggregate, reinforcing steel, and steel structures conform to ASTM specifications.

The HSM-MX 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 Gr. 60 deformed bars placed vertically and horizontally at each face of the walls, roof and slabs.

The concrete surface temperature limits criteria are based on the provisions in Section 3.5.1.2 of NUREG-1536, as follows:

- If concrete temperatures in general or local areas are at or below 200 °F for normal/off-normal conditions/occurrences, no tests to prove capability at elevated temperatures or reduction of concrete strength are required.
- If concrete temperatures, in general, or local areas exceed 200 °F, but do not exceed 300 °F, no tests to prove capability at elevated temperatures or reduction of concrete strength are required if the aggregates have a coefficient of thermal expansion (CTE) no greater than $6x10^{-6}$ in/in/°F, or are one of the following materials: limestone, dolomite, marble, basalt, granite, gabbro, or rhyolite.

The above criteria in lieu of the ACI 349-06 requirements do not extend above 300 °F for normal/off-normal conditions and do not modify the ACI 349-06 requirements for accident conditions. Per E.4.2 of ACI 349-06 [A.8-5], the accident conditions or short-term period (i.e., blocked vent accident transient) concrete temperatures are limited to 350 °F. Higher temperatures are allowed per E.4.3 if tests are provided to evaluate the reduction in strength and this reduction is applied to design allowables. HSM-MX concrete compressive tests are performed on specimens heated to or above that maximum accident temperature for no less than 40 hours. HSM-MX concrete temperature testing is performed whenever there is a significant change in the cement, aggregate, or water-cement ratio of the concrete mix design. See Section 5.3 of the Technical Specifications [A.8-17].

Alternatively, per the ACI 349-13 [A.8-10] commentary Section RE.4, 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, so that any losses in properties (e.g., compressive strength, modulus of elasticity) resulting from long-term thermal exposure will not affect the safety margins based on the specified 5,000 psi compressive strength used in the design evaluations. Additionally, also as indicated in Section RE.4, short, randomly oriented steel fibers may be used to provide increased ductility, dynamic strength, toughness, tensile strength, and improved resistance to spalling. See Section 4.4.4 of the Technical Specifications [A.8-17].

The rear DSC supports consists of a W6 x 25 structural beam of ASTM A992 Gr.50 material or equivalent built-up I-Beam of ASTM A572 Gr. 50 material coated with an inorganic zinc-rich primer and a high-build epoxy enamel finish. The DSC rests on an ASTM A240 Type 304 support plate welded to the beam. A corrosion allowance of 1/16 inch is used in the design calculations. Welding procedures are in accordance with ASME Code Section IX or AWS D1.1 [A.8-11].

At coastal sites with operational experience of corrosion due to atmospheric chlorides, the front and rear DSC supports steel and weld filler metal have a minimum of 0.20% copper content or are stainless steel. For carbon steels, weld material with 1% or more nickel is acceptable in lieu of 0.20% copper content. The copper content is equivalent to weathering steel [A.8-12], and nickel-bearing weld materials show equivalent corrosion resistance [A.8-13].

A.8.2.2 Material Properties

The material properties used in the HSM-MX design analyses are listed in Table 8-4 through Table 8-6, Table 8-13, Table 8-23, and Table 8-24. Additionally, new materials used in the HSM-MX are provided in Table A.8-2 through Table A.8-4. Each table cites the source for the properties. Table A.8-1 ties these materials to the individual components.

A.8.2.2.1 EOS-37PTH and EOS-89BTH DSC

No change from Section 8.2.2.1.

A.8.2.2.2 EOS TC Transfer Cask

No change from Section 8.2.2.2.

A.8.2.2.3 HSM-MX Horizontal Storage Module

In accordance with ACI 349-06, Section E.4.3, the strength properties of the concrete and reinforcing steel used in the HSM-MX structural analysis are taken at the maximum calculated temperature. Temperature-dependent mechanical properties of concrete and reinforcing steel are taken from [A.8-3] and presented in Table 8-23, and Table 8-24.

The material properties of the ASTM A992 Gr 50 steel used for the rear DSC support are listed in Table A.8-3, and the material properties for the ASTM A572 Gr. 50 front and rear stop plate and optional built-up I-beam are listed in Table A.8-2. The material properties used for the Type 304 stainless steel used for the front DSC supports and heat shields are provided in Table 8-5. The material properties used for the Type 316 stainless steel used as an option for the front DSC supports and heat shields are listed in Table 8-5.

The properties ASTM A588 for the axial retainer is provided in Table A.8-4.

A.8.2.2.4 Materials Employed in the Shielding Analysis 72.48

Shielding properties of steel and concrete are obtained from [A.8-6] and are summarized in Table 8-30. Concrete used in the HSM-MX is modeled without steel rebar at a density of 138 pcf (2.211 g/cm^3).

A.8.2.2.5 Materials Employed in the Criticality Analysis 72.48

No change to Section 8.2.2.5.

A.8.2.3 Materials for ISFSI Sites with Experience of Atmospheric Chloride Corrosion

Front and rear DSC supports at sites with operational experience of corrosion caused by atmospheric chlorides are fabricated from steels equivalent to weathering steel or stainless steel.

A.8.2.4 Weld Design and Inspection

There are no changes to the weld design and inspection for the DSC and *EOS*-TC described in Section 8.2.4. 72.48

The rear DSC supports are bolted inside the HSM. The welds of the rear DSC supports are designed in accordance with the Manual of Steel Construction [8-7], and visually inspected in accordance with AWS D1.1 with acceptance criteria for statically loaded, non-tubular structures.

A.8.2.5 Galvanic and Corrosive Reactions

A.8.2.5.1 Behavior of Aluminum and Neutron Absorbers in Water and Boric Acid

No change to Section 8.2.5.1.

A.8.2.5.2 Behavior of Stainless Steel in Deionized Water and Weak Boric Acid

No change to Section 8.2.5.2.

A.8.2.5.3 Behavior of Low-Alloy Steel in Deionized Water and Weak Boric Acid

No change to Section 8.2.5.3.

A.8.2.5.4 Lubricants and Cleaning Agents

No change to Section 8.2.5.4.

A.8.2.5.5 Corrosion of Canister Shell During Storage

No change to Section 8.2.5.5. 72.48

A.8.2.5.6 Corrosion of DSC Front and Rear Supports

The DSC front and rear supports 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-MX. Exposed surfaces are coated with an inorganic zinc-rich rimer and high build epoxy enamel finish or galvanized, except for the stainless steel contact plates. The front DSC support is a stainless steel contact plate that sits atop a galvanized steel plate. Epoxy enamels such as Carboguard® 890 are suitable for continuous service to 300 °F, while inorganic zinc primers such as Carbozinc 11 have much higher temperature resistance. The maximum temperature on the rear DSC supports is about 270 °F. The top coat is expected to experience chalking and other effects of radiation over 10^6 rad, but the inorganic primer coat is insensitive to radiation. Inspections for license extension [A.8-15, A.8-16] have found only minor local rusting. Nonetheless, the stress analysis removes 1/16 inch from all surfaces to account for corrosion. At independent spent fuel storage installations (ISFSIs) with operational experience of corrosion with atmospheric chlorides, additional protection is provided by specifying a minimum 0.2% copper content, which results in an adherent self-protecting oxide layer equivalent to weathering steel [A.8-12].

A.8.2.5.7 Corrosion of Transfer Cask

No change to Section 8.2.5.7.

A.8.2.6 Creep Behavior of Aluminum

No change to Section 8.2.6.

A.8.2.7 Bolt Applications

No change to Section 8.2.7.

A.8.2.8 Protective Coatings and Surface Treatments

No change to Section 8.2.8.

A.8.2.9 Neutron Shielding Materials

No change to Section 8.2.9.

A.8.2.10 Materials for Criticality Control

No change to Section 8.2.10.

A.8.2.11 Concrete and Reinforcing Steel

No change to Section 8.2.11.

A.8.2.12 Seals

No change to Section 8.2.12.

A.8.2.13 Low Temperature Ductility of Ferritic Steels

No change to Section 8.2.13.

A.8.3 Fuel Cladding

No change to Section 8.3.

A.8.4 Prevention of Oxidation Damage During Loading of Fuel

No change to Section 8.4.

A.8.5 Flammable Gas Generation

No change to Section 8.5.

A.8.6 DSC Closure Weld Testing

No change to Section 8.6.

A.8.7 References

A.8-1 NUREG-1536, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General license Facility," Revision 1, U.S. Nuclear Regulatory Commission, July 2010.

A.8-2 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, 2010 Edition with 2011 Addenda.

A.8-3 Mark Fintel, "Handbook of Concrete Engineering," September 1974.

A.8-4 ACI-318-08, "Building Code Requirement for Structural Concrete and Commentary," American Concrete Institute.

A.8-5 American Concrete Institute, "Code Requirements for Nuclear Safety Related Concrete Structures", ACI-349-06.

A.8-6 PNNL-15870, Re. 1, "Compendium of Material Composition Data for Radiation Transport Modeling," Pacific Northwest National Laboratory, March 2011.

A.8-7 American Institute of Steel Construction, Manual of Steel Construction, 13th Edition or 14th Edition.

A.8-8 Mark Fintel, "Handbook of Concrete Engineering, Second Edition," September 1985.

A.8-9 ASTM A572/A572M, "Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel," Latest Edition.

A.8-10 ACI-349-13, "Code Requirements for Nuclear Safety Related Concrete Structures and Commentary," American Concrete Institute.

A.8-11 American Welding Society, AWS D1.1, March 2010, Structural Welding Code-Steel.

A.8-12 [ ]

A.8-13 C. P. Larrabee, S. K. Coburn, "The Atmospheric Corrosion of Steels as Influenced by Changes in Chemical Composition," First International Congress on Metallic Corrosion, 1962

A.8-14 ASTM A992, "Standard Specification for Structural Steel Shapes."

A.8-15 Duke Energy Carolinas, LLC, Oconee Nuclear Station, Docket No. 72-4, License No. SNM-2503, License Renewal Application for the Site-Specific Independent Spent Fuel Storage Installation (ISFSI) - Response to Requests for Additional Information, License Amendment Request No. 2007-06, ADAMS ML090370066, January 30, 2009 (Response to Question A-4).

A.8-16 Calvert Cliffs Nuclear Power Plant, Independent Spent Fuel Storage Installation, Material License No. SNM-2505, Docket No. 72-8, Response to Request for Supplemental Information, RE: Calvert Cliffs Independent Spent Fuel Storage Installation License Renewal Application (TAC No. L24475), ADAMS ML12212A216, July 27, 2012.

A.8-17 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *2*.

A.8-18 ASTM A588/A588M, "Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance."

Table A.8-1
HSM-MX Materials

HSM Subcomponents	Material
HSM-MX walls, roof, floor, end shield walls	Reinforced concrete with ASTM A615 or A706 Gr 60 reinforcing steel
DSC Support Pedestal DSC Support Pedestal Stop Plate DSC Support Pedestal Support Plate	ASTM A992 Gr. 50 or ASTM A572 Gr. 50 ASTM A572 Gr. 50 ASTM A240 Type 304 or 316
HSM-MX Door Door Steel Liner Assembly Threaded Inserts Inspection Penetration Sleeve Door	Reinforced concrete Steel Steel Steel
Axial Retainer Rod Axial Retainer miscellaneous plate (fastener plate, spacer plate)	ASTM A588 Steel
HSM-MX Heat Shields	Stainless steel ASTM A240 Type 304 or 316
HSM-MX Outlet Vent Cover HSM-MX Outlet Vent Liners HSM Inlet Vent Screen Assembly	Reinforced concrete Carbon Steel Carbon Steel
Bird Screens and Dose Reduction Hardware	Stainless steel or Carbon Steel
Fasteners: Bolts Washers Nuts	 ASTM A193 Gr B7/ A325/A563/A490/A108 ASTM A36/F436/F844/ Stainless Steel ASTM A194/A563/A194/ Carbon Steel
Threaded Embedments: Stud Bolt Sleeve Nut Nut	 ASTM A193-Gr. B7, ASTM A193-B8 CL 2 or ASTM A193-B8M CL 2 ASTM A194 Gr 2H or A563 Gr A ASTM A194 Gr 8M or A563 Gr A

Table A.8-2
Material Properties, ASTM A572 Grade 50 Steel

Temp (°F)	E [(2)] (10^3 ksi)	S_y[(3)] (ksi)	S_u[(4)] (ksi)	α_{AVG} [(5)] (10^{-6} °F^{-1})	ρ (lb/in^3) [(6)]
-20					0.280
70	29.0[(7)]	50.0[(1)]	65.0[(1)]		
100	29.0	48.5	65.0	6.3	
150					
200	28.4	46.0	63.7	6.5	
250					
300	27.8	44.0	65.0	6.7	
350					
400	27.3	42.5	65.0	6.9	
450					
500	26.7	41.5	65.0	7.1	
550					
600	26.1	41.0	62.4	7.2	
650					
700	25.5	40.0	53.3	7.4	

Notes

1. Reference [A.8-9].
2. Based on lowest rate of reduction provided in [A.8-8] Figure 7.5.
3. Based on lowest rate of reduction provided in [A.8-8] Figure 7.3.
4. Based on lowest rate of reduction provided in [A.8-8] Figure 7.4.
5. Based on lowest rate of reduction provided in [A.8-8] Figure 7.6.
6. ASME Section II Part D [A.8-2].
7. Based on AISC, Table B4.1 [A.8-7].

Table A.8-3
Material Properties, ASTM A992 Grade 50

Temp (°F)	E [(2)] (10^3 ksi)	Yield Strength[(3)] (ksi)	Tensile Strength[(4)] (ksi)	ρ [(5)] (lb/in^3)
-20				0.280
70	29.0[(6)]	50.0 [(1)]	65.0 [(1)]	
100	29.0	48.5	65.0	
150				
200	28.4	46.0	63.7	
250				
300	27.8	44.0	65.0	
350				
400	27.3	42.5	65.0	
450				
500	26.7	41.5	65.0	

Notes

1. Reference [A.8-14].
2. Based on lowest rate of reduction provided in [A.8-8] Figure 7.5.
3. Based on lowest rate of reduction provided in [A.8-8] Figure 7.3.
4. Based on lowest rate of reduction provided in [A.8-8] Figure 7.4.
5. ASME Section II Part D, Table PRD [A.8-2].
6. Based on AISC, Table B4.1 [A.8-7]

Table A.8-4
Material Properties, ASTM A588

Temp (°F)	E [(2)] (10^3 ksi)	Yield Strength[(3)] (ksi)	Tensile Strength[(4)] (ksi)	Density[(5)] (lb/in^3)
-20				0.280
70	29.0 [(6)]	50.0 [(1)]	70.0 [(1)]	
100	29.0	48.5	70.0	
150				
200	28.4	46.0	68.6	
250				
300	27.8	44.0	70.0	
350				
400	27.3	42.5	70.0	
450				
500	26.7	41.5	70.0	

Notes

1. Reference [A.8-18].
2. Based on lowest rate of reduction provided in [A.8-8] Figure 7.5.
3. Based on lowest rate of reduction provided in [A.8-8] Figure 7.3.
4. Based on lowest rate of reduction provided in [A.8-8] Figure 7.4.
5. ASME Section II Part D, Table PRD [A.8-2].
6. Based on AISC, Table B4.1 [A.8-7]

APPENDIX A.9
OPERATING PROCEDURES

Table of Contents

List of Figures

A.9 OPERATING PROCEDURES

This chapter presents the operating procedures for the NUHOMS® MATRIX (HSM-MX) described in previous chapters and shown on the drawings in Chapter A.1, Section A.1.3. The procedures include preparation of the NUHOMS® EOS system dry shielded canister (DSC) and fuel loading, closure of the DSC, transfer to the independent spent fuel storage installation (ISFSI) using the transfer cask (TC), DSC transfer into HSM-MX, monitoring operations, and DSC retrieval from the HSM-MX. The NUHOMS® EOS transfer equipment, MATRIX loading crane (MX-LC), MATRIX retractable roller tray (MX-RRT), and the existing plant systems and equipment are used to accomplish these operations.

The generic NUHOMS® HSM-MX procedures described in this chapter have been developed to minimize the amount of time required to complete the subject operations, to minimize personnel exposure, and to assure that all operations required for DSC loading, closure, transfer, and storage are performed safely. Plant-specific ISFSI procedures are to be developed by each licensee in accordance with the requirements of 10 CFR 72.212(b) and the guidance of Regulatory Guide 3.61 [A.9-4]. These generic procedures are provided as a guide for the preparation of plant-specific procedures and serve to explain how the HSM-MX system operations are to be accomplished. They are not intended to be limiting in that the licensee may judge that alternate acceptable means are available to accomplish the same operational objective.

Pictograms of the HSM-MX System operations are presented in Figure A.9-1. The location of the various operations may vary with individual plant requirements. Chapter A.9 provides a description as to how these operations are to be performed for the HSM-MX system.

See Chapter 1 for description of components.

The generic terms used throughout this section are as follows.

- TC, or transfer cask is used for the *EOS*-TC125 transfer cask.
- DSC is used for the EOS-37PTH DSC or EOS-89BTH DSC.
- HSM-MX is used for the storage module.
- MX-RRT is used to insert/retrieve DSC into/from HSM-MX module.
- MX-LC is used to lift and position *TC* with HSM-MX. 72.48

Note: If applicable to the planned DSC heat *load* zone configuration per Figure *1G, 1H, or 1I* of the Technical Specifications [A.9-5], the *air circulation* system *shall* be *assembled and* verified operational *within 7 days* prior to initiating transfer operations *per Technical Specification LCO 3.1.3 [A.9-5]*.

A.9.1 Procedures for Loading the DSC and Transfer to the HSM-MX

The following steps describe the recommended operating procedures for HSM-MX system. A pictorial representation of key phases of this process is provided in Figure A.9-1.

A.9.1.1 TC and DSC Preparation

No change. See Section 9.1.1.

A.9.1.2 DSC Fuel Loading

No change. See Section 9.1.2.

A.9.1.3 DSC Drying and Backfilling

No change. See Section 9.1.3.

A.9.1.4 DSC Sealing Operations

No change. See Section 9.1.4.

A.9.1.5 TC Downending and Transfer to ISFSI

No change. See Section 9.1.5.

A.9.1.6 DSC Transfer to the HSM-MX

CAUTION: The insides of empty compartments have the potential for high dose rates due to adjacent loaded compartments. Proper as low as reasonably achievable (ALARA) practices should be followed for operations inside these compartments and in the areas outside these compartments whenever the door from the empty compartment has been removed.

1. MX-LC Rails are installed, aligned and verified on the pad for the loading campaign. Alignment is verified to the specifically designated features on the face of HSM-MX.

CAUTION: Prior to using the MX-LC to lift the loaded TC above the 65 inch lift height restriction of Technical Specification (TS) 5.2.1 [A.9-5], verify using available meteorological data that no impending tornado conditions exist or forecasted winds expect to exceed gusts to 44 mph. If, during operations with the MX-LC, either of these conditions is forecasted, place the MX-LC in a secured position with the TC at a height not to exceed the 65 inch lift height restriction of TS 5.2.1 [A.9-5] 72.48

2. Prior to transporting the TC to the ISFSI, remove the HSM-MX door, inspect the compartment of the HSM-MX, removing any debris and ready the HSM-MX to receive a DSC. The doors on adjacent compartments should remain in place.

3. Inspect the DSC, and MX-RRT support pads inside HSM-MX compartment.

4. For ALARA purposes, reinstall the HSM-MX door.

5. Inspect the HSM-MX air inlet and outlets to ensure that they are clear of debris. Inspect the screens on the air inlet and outlets for damage.

CAUTION: The insides of empty compartments have the potential for high dose rates due to adjacent loaded compartments. Proper ALARA practices should be followed for operations inside these compartments and in the areas outside these compartments whenever the MX-RRT operations are being performed.

6. Remove the MX-RRT cover plates and shield plugs.

7. Insert and install MX-RRT into HSM-MX. Extend the MX-RRT rollers, secure and verify that the rollers are extended.

8. Transport the TC from the plant's fuel/reactor building to the ISFSI along the designated transfer route.

9. Once at the ISFSI, move the transfer trailer inside the MX-LC at "home" position between the skid and the MX-LC grappling mechanism.

10. Use the MX-LC grappling mechanism to capture the skid along with TC, disengage the skid positioning system, move the skid up in the vertical direction to clear it from the transfer trailer, and then the transfer trailer is moved from MX-LC.

11. Remove the FC system, and install the ram cylinder assembly.

11a. If the HSM-MX upper compartment is to be loaded, install the MX-LC brackets to the embedments on each adjacent HSM-MX module. 72.48

12. Remove the HSM-MX door.

13. Unbolt and remove the TC top cover plate.

14. Move MX-LC along the rail in front of HSM-MX until the TC is completely against the face of HSM-MX.

15. The skid is moved until the target compartment is reached. If necessary, adjust the MX-LC position until the MX-LC is properly aligned with the targeted compartment.

16. Secure the MX-LC/skid/cask to the front wall embedments of the HSM-MX using the restraints.

17. The hydraulic power unit is connected to the ram cylinder. The grapple is moved until it engages with grapple ring of the canister. Using the ram cylinder, fully insert the DSC into the HSM-MX compartment.

18. Disengage the ram grapple mechanism so that the grapple is retracted away from the DSC grapple ring.

19. Retract the MX-RRT rollers; the DSC is lowered onto the HSM-MX front and rear DSC supports.

    Note: The time limit for transfer operations, if any, starts with the initiation of the TC/DSC annulus water draining described in Step 9 of Section 9.1.4 and ends when the DSC is fully seated onto the front and rear DSC supports.

CAUTION: Verify that the applicable time limits for transfer operations of Section 3.1.3 of the Technical Specifications [A.9-5] are met.

20. Remove the wall embedments from the HSM-MX.

21. Retract the skid with TC from docking position and lower it.

22. Place the HSM-MX door. Verify that the HSM dose rates are compliant with the limits specified in Section 5.1.2 of the Technical Specifications [A.9-5].

23. Move MX-LC to its "home" position, and the transfer trailer is moved into accepting position.

24. Lower the Skid along with TC onto the transfer trailer. Reconnect the skid positioning system. Remove the ram cylinder assembly.

25. Bolt the TC cover plate into place, tightening the bolts to the required torque in a star pattern.

CAUTION: The insides of *loaded* compartments have the potential for high dose rates. Proper ALARA practices should be followed for operations in the areas outside these compartments whenever the MX-RRT operations are being performed.

26. Remove the MX-RRT from the HSM-MX. 72.48

27. Place MX-RRT shield plugs and cover plates for the MX-RRT accesses.

27a. If previously installed, remove the MX-LC brackets from the HSM-MXs.

28. Move the transfer trailer from MX-LC to the designated equipment storage area. Return the remaining transfer equipment to the storage area.

29. Close and lock the ISFSI access gate and activate the ISFSI security measures.

A.9.1.7 Monitoring Operations

1. Perform routine security surveillance in accordance with the licensee's ISFSI security plan.

2. Perform a daily visual surveillance of the HSM-MX air inlets and outlets (bird screens) to verify that no debris is obstructing the HSM-MX vents in accordance with Section 5.1.3.2(a) of the Technical Specification [A.9-5] requirements, or, perform a temperature measurement for each *HSM-MX* in accordance with Section 5.1.3.2(b) of the Technical Specification [A.9-5] requirements. 72.48

A.9.2 Procedures for Unloading the DSC

The following section outlines the procedures for retrieving the DSC from the HSM-MX. The procedures for removing the FAs from the DSC are the same as described in Section 9.2.

A.9.2.1 DSC Retrieval from the HSM-MX

1. Ready the TC, transfer trailer, loading crane, and skid for service. Fill the TC liquid neutron shield and remove the top cover plate from the TC. Transport the trailer into the ISFSI.

CAUTION: Confirm a functional test of the air circulation system, including the blowers, generators, and power cords, etc. was satisfactorily performed within 7 days prior to commencing Transfer Operations, if required per Section 3.1.3 of the Technical Specifications [A.9-5]. 72.48

Note: Verify that a TC spacer of appropriate height is placed inside the TC to provide the correct airflow and interface at the top of the TC during cutting and unloading operations for DSCs that are shorter than the TC cavity length.

2. MATRIX MX-LC rails are installed, aligned and verified on the pad for the unloading campaign. Alignment is verified to the specifically designated features on the face of HSM-MX.

CAUTION: Prior to using the MX-LC to unload the upper compartment of the HSM-MX, verify using available meteorological data that no impending tornado conditions exist or forecasted winds expect to exceed gusts to 44 mph. If, during operations with the MX-LC, either of these conditions is forecasted, place the MX-LC in a secured position with the TC at a height not to exceed the 65 inch lift height restriction of Technical Specification 5.2.1 [A.9-5]. 72.48

3. Move the transfer trailer inside the MX-LC "home" position between the skid and the MX-LC grappling mechanism.

4. Use the MX-LC grappling mechanism to capture the skid along with TC, disengage the skid positioning system, move the skid up vertically to clear it from the transfer trailer, then move the transfer trailer from the MX-LC.

5. Install the ram cylinder assembly.

CAUTION: The insides of *loaded* compartments have the potential for high dose rates. Proper ALARA practices should be followed for operations in the areas outside these compartments whenever the MX-RRT operations are being performed. 72.48

6. Remove the MX-RRT shield blocks plugs and cover plates.

7. Insert and install MX-RRT into HSM-MX. Extend the MX-RRT rollers, secure and verify that the rollers are extended.

CAUTION: *High dose rates are expected in the HSM-MX compartment after removal of the HSM-MX door.* Proper ALARA practices should be followed.

72.48

7a. If the HSM-MX upper compartment is to be unloaded, install the MX-LC brackets to the embedments on each adjacent HSM-MX module.

8. Remove the HSM-MX door.
9. Unbolt and remove the TC top cover plate.
10. Move MX-LC along the rail in front of HSM-MX until the TC is completely against the face of HSM-MX.
11. Move MX-LC along the face of the HSM-MX to the target HSM-MX compartment.
12. The skid is moved in to the target compartment. If necessary, adjust the MX-LC position until the MX-LC is properly aligned with the targeted cavity.
13. Secure the MX-LC/skid/cask to the front wall embedments of the HSM-MX using the restraints.
14. The hydraulic power unit is connected to the ram cylinder. *Remove the bottom ram access cover plate. Extend the ram through the TC into the HSM-MX* until it engages with the grapple ring of the canister. 72.48
15. Operate the ram grapple and engage the grapple arms with the DSC grapple ring.
16. Recheck all alignment marks and ready all systems for DSC transfer.

CAUTION: The time limits for the unloading of the DSC should be determined using the heat loads at the time of the unloading operation and the methodology presented in Sections 4.5 and 4.6 before pulling the DSC out of the HSM-MX.

17. Activate the ram to pull the DSC into the TC.
18. Disengage the ram grapple mechanism so that the grapple is retracted away from the DSC grapple ring.
19. Retract and disengage the ram system from the TC and move it clear of the TC. Remove the TC embedments from the HSM-MX.
20. Retract the skid with TC from docking position and lower it.
21. Move MX-LC to its “home” position, and move the transfer trailer to accepting position.

22. Lower the skid along with TC onto the transfer trailer. Reconnect the skid positioning system, remove the ram cylinder assembly, and install the *air circulation system if a time limit to complete transfer operations applies*. 72.48

23. Bolt the TC cover plate into place, tightening the bolts to the required torque in a star pattern.

CAUTION: The insides of empty compartments have the potential for high dose rates due to adjacent loaded compartments. Proper ALARA practices should be followed for operations inside these compartments and in the areas outside these compartments whenever the MX-RRT operations are being performed.

24. Disconnect MX-RRT operating mechanism and retract MX-RRT to MX-RRT handling device.

25. Place MX-RRT shield plugs and cover plates for the MX-RRT accesses.

26. Move the transfer trailer from MX-LC and ready the trailer for transfer.

27. Replace the HSM-MX door.

27a. If previously installed, remove the MX-LC brackets from the HSM-MXs. 72.48

A.9.2.2 Removal of Fuel from the DSC

No change, see Section 9.2.2.

A.9.3 References

A.9-1 U.S. Nuclear Regulatory Commission, Office of the Nuclear Material Safety and Safeguards, "Safety Evaluation of VECTRA Technologies' Response to Nuclear Regulatory Commission Bulletin 96-04 For the NUHOMS®-24P and NUHOMS®–7P.

A.9-2 U.S. Nuclear Regulatory Commission Bulletin 96-04, "Chemical, Galvanic or Other Reactions in Spent Fuel Storage and Transportation Casks," July 5, 1996.

A.9-3 SNT-TC-1A, "American Society for Nondestructive Testing, Personnel Qualification and Certification in Nondestructive Testing," 2006.

A.9-4 U.S. Nuclear Regulatory Commission, Regulatory Guide 3.61 "Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Container," February 1989.

A.9-5 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *2*.

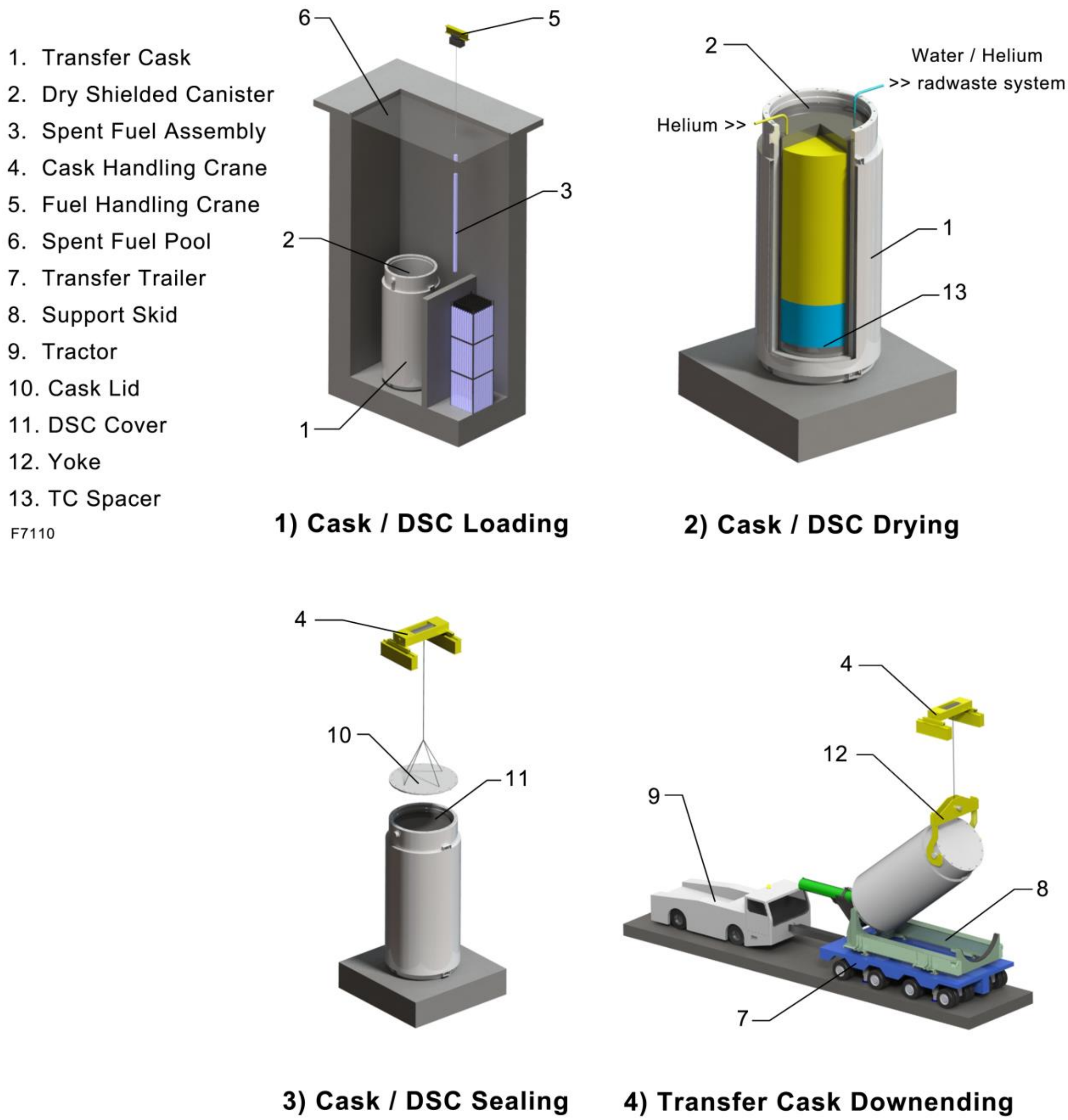
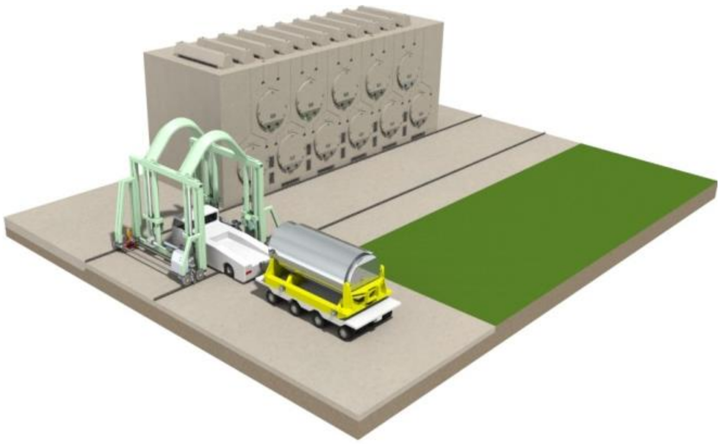
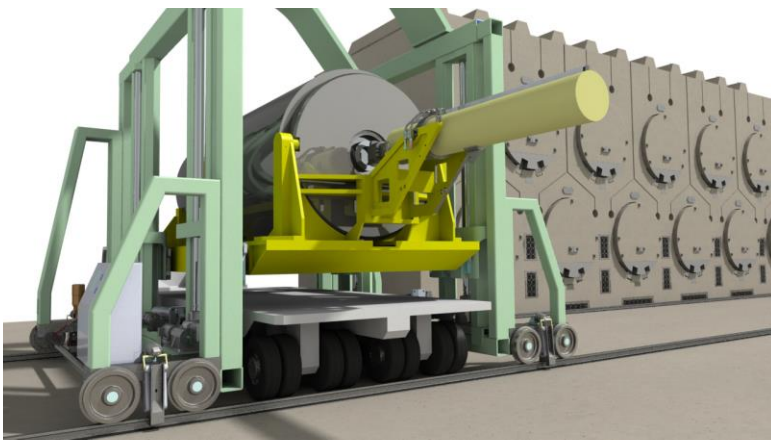


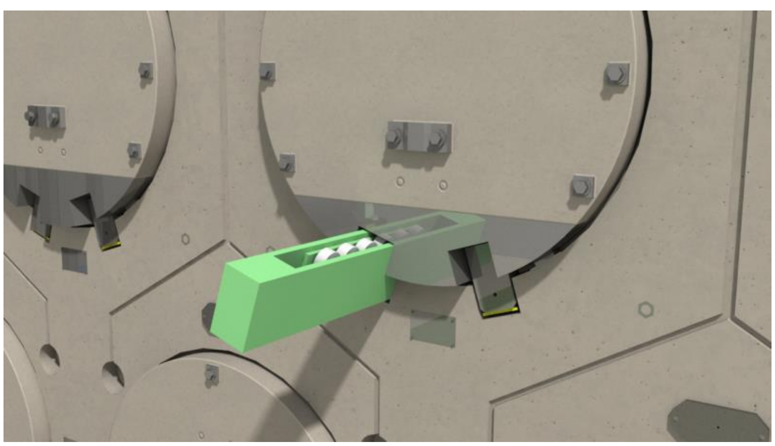
Figure A.9-1
NUHOMS® MATRIX Loading Operations
4 Pages



5) **Tow Trailer to Loading Crane at ISFSI**

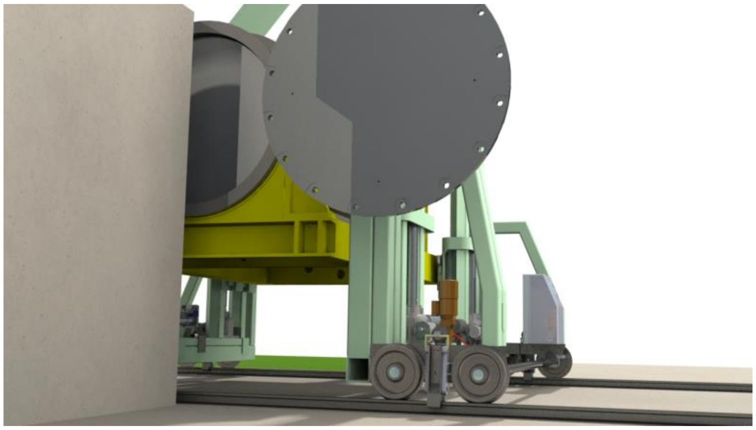


6) **Transfer TC from Trailer to Loading Crane**



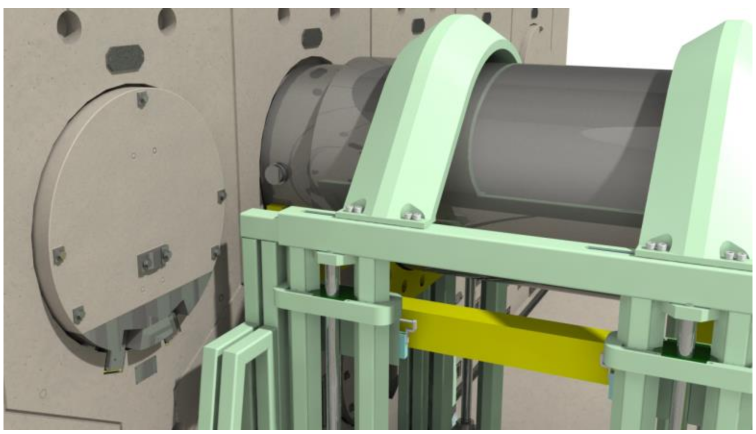
7) **Insert and Install Retrievable Roller Tray (MX-RRT)**

Figure A.9-1
NUHOMS® MATRIX Loading Operations
4 Pages



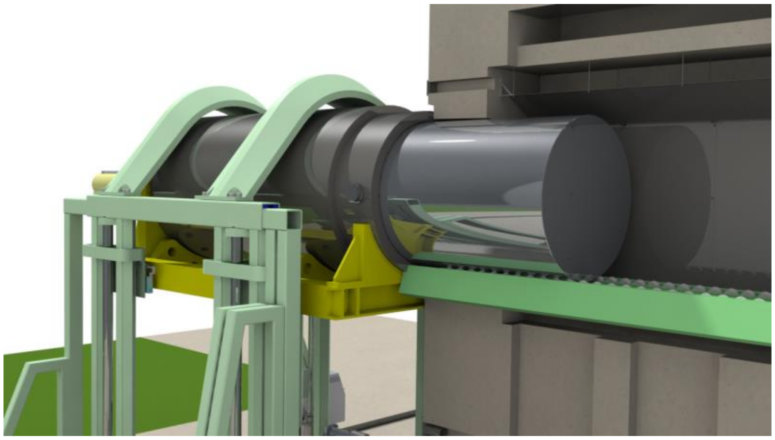
8) Remove the Transfer Cask Cover.

9) Align Transfer Cask at X-Plane Direction, Engage Ram Grapple with Canister, HSM Door Is Removed.

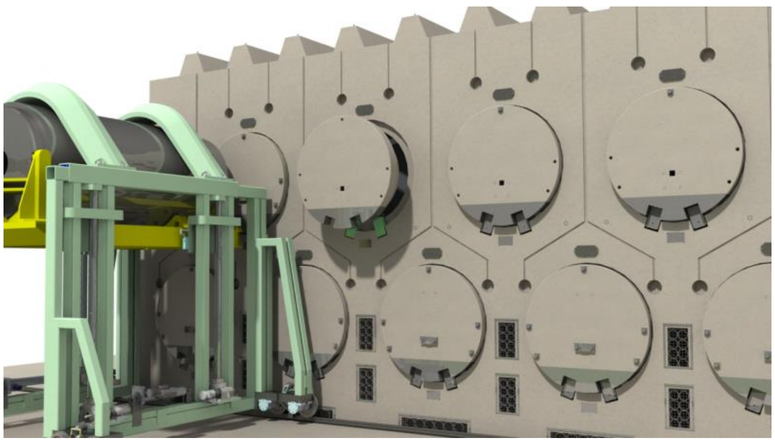


10) Align Transfer Cask at Z-Direction.

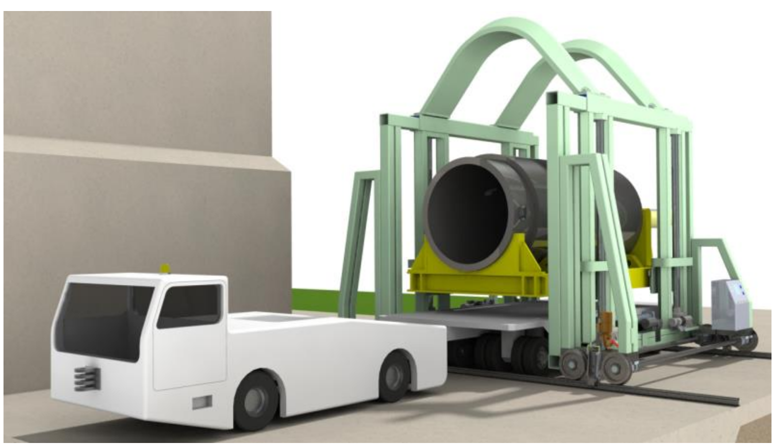
Figure A.9-1
NUHOMS® MATRIX Loading Operations
4 Pages



11) Transfer Canister to HSM-MX



12) Remove Cask and Install HSM-MX Door



13) Transfer Cask from Loading Crane to Trailer

Figure A.9-1
NUHOMS® MATRIX Loading Operations
4 Pages

APPENDIX A.10
ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Table of Contents

A.10 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This chapter specifies the acceptance testing and maintenance program for important-to-safety (ITS) components of the NUHOMS® MATRIX (HSM-MX).

A.10.1 Acceptance Tests

The addition of the HSM-MX to the standardized NUHOMS® EOS system does not result in any change to the pre-operational tests described in Section 10.1, since the EOS-DSCs and EOS-TCs involved are not changed.

A.10.1.1.1 DSC

No change to Section 10.1.1.1.

A.10.1.1.2 HSM-MX

Concrete mix design, placement, and testing are performed in accordance with ACI-318 [A.10-1]. The minimum 28-day compressive strength is 5000 psi if controls are placed on the aggregate type or coefficient of thermal expansion as described in Section 8.2.1.3. If the alternative described in that section is used, the minimum is 7000 psi. In accordance with American Concrete Institute (ACI) 349 Appendix E, paragraph E.4.3 [A.10-2], compressive testing of the concrete mix design for the monolith, and doors is conducted after heating the test cylinders prior to testing. For the HSM-MX, the testing of the specimens are performed at a temperature of 500 °F per Table 4-17. See Sections 4.4.4 and 5.3 of the Technical Specifications [A.10-4].

The reinforcing steel, ITS fasteners, and steel for the door and the front and rear DSC supports are tested for mechanical properties in accordance with the governing specifications called out on the drawings in Chapter A.1.

Weld procedures and welders for the front and rear DSC supports are qualified in accordance with ASME Code Section IX or American Welding Society (AWS) D1.1 [A.10-3].

A.10.1.1.3 Transfer Cask

No change to Section 10.1.1.3.

A.10.1.2 Leak Tests

No change to Section 10.1.2.

A.10.1.3 Visual Inspection and Non-Destructive Examinations

No change to Section 10.1.3.

A.10.1.4 Shielding Tests

No change to Section 10.1.4.

A.10.1.5 Neutron Absorber Tests

No change to Section 10.1.5.

A.10.1.6 Thermal Acceptance Tests

No change to Section 10.1.6.

A.10.1.7 Low Alloy High Strength Steel for Basket Structure

No change to Section 10.1.7.

A.10.1.8 Cask Identification

No change to Section 10.1.8.

A.10.2 Maintenance Program

No change to Section 10.2 associated with the addition of the HSM-MX. HSM inspections from Section 10.2.1.2 are applicable to the HSM-MX.

A.10.3 Repair, Replacement, and Maintenance

No change to Section 10.3 associated with the addition of the HSM-MX. Requirements of Section 10.3.2 for the HSM are applicable to the HSM-MX.

A.10.4 References

A.10-1 ACI 318-08, “Building Code Requirements for Structural Concrete and Commentary,” American Concrete Institute, Detroit, MI.

A.10-2 ACI 349-06, “Code Requirements for Nuclear Safety Related Structures,” American Concrete Institute, Detroit, MI.

A.10-3 American Welding Society, AWS D1.1/D1.1M, “Structural Welding Code – Steel.”

A.10-4 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *2*.

APPENDIX A.11
RADIATION PROTECTION

Table of Contents

List of Tables

List of Figures

A.11 RADIATION PROTECTION

This chapter describes the design features of the NUHOMS® MATRIX (HSM-MX)*, EOS-TC, and EOS-DSC* that maintain radiation exposure to site personnel as low as reasonably achievable (ALARA), as well as minimize exposure to the public. An occupational dose assessment for operation of the HSM-MX is provided. Radiation exposures to offsite individuals are also computed for both normal and accident conditions of an independent spent fuel storage installation (ISFSI). This chapter provides an example of how to demonstrate compliance with the relevant radiological requirements of 10 CFR Part 20 [A.11-1], 10 CFR Part 72 [A.11-2], and 40 CFR Part 190 [A.11-3]. Each user must perform site-specific calculations to account for the actual layout of the HSM-MXs and fuel source.

A.11.1 Radiation Protection Design Features

The HSM-MX has design features that ensure a high degree of integrity for the confinement of radioactive materials and reduction of direct radiation exposures during storage. These features are described in Section A.11.4.2.

A.11.2 Occupational Dose Assessment

This section provides estimates of occupational dose for typical EOS transfer cask (EOS-TC) and ISFSI loading operations. Assumed annual occupancy times, including the anticipated maximum total hours per year for any individual, and total person-hours per year for all personnel for each radiation area during normal operation and anticipated operational occurrences, will be evaluated by the licensee in a 10 CFR 72.212 evaluation to address the site-specific ISFSI layout, inspection, and maintenance requirements. In addition, the estimated annual collective doses associated with loading operations will be addressed by the licensee in a 10 CFR 72.212 evaluation.

A.11.2.1 EOS-DSC Loading, Transfer, and Storage Operations

The dose rates used in the occupational dose assessment are summarized in Table A.11-1. The EOS-TC loading and transfer dose rates are unchanged from the values presented in Chapter 11. The HSM-MX dose rate reported in Table A.11-1 is the average dose rate on the front surface of an HSM-MX and is obtained from Chapter A.6.

The estimated occupational exposures to ISFSI personnel during loading, transfer, and storage operations using the EOS-TC108 (time and number of workers may vary depending on individual ISFSI practices) are provided in *Table A.11-1a and* Table A.11-2 for the *EOS-37PTH DSC and* EOS-89BTH DSC*, respectively*. Similar operations for the EOS-TC125/135 are provided in Table A.11-3 and Table A.11-4. The task times, number of personnel required, and total doses are listed in these tables. The total exposure results are as follows:

- *EOS-TC108 with EOS-37PTH DSC: 8,690 person-mrem (~8.7 person-rem)*
- EOS-TC108 with EOS-89BTH DSC: 4,535 person-mrem (~4.5 person-rem)
- EOS-TC125/135 with EOS-37PTH DSC: *4,231* person-mrem (*~4.2* person-rem)
- EOS-TC125 with EOS-89BTH DSC: 2,523 person-mrem (~2.5 person-rem)

Use of a minimum 74.0 inch diameter shield plug for the EOS-37PTH DSC results in a negligible increase in occupational exposure (<5%). 72.48

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 HSM-MX are expected to be similar.

Regulatory Guide 8.34 [A.11-4] is to be used to define the onsite occupational dose and monitoring requirements.

A.11.2.2 EOS-DSC Retrieval Operations

Occupational exposures to ISFSI personnel during EOS-DSC retrieval are similar to those exposures calculated for EOS-DSC insertion. Dose rates for retrieval operations will be lower than those for insertion operations due to radioactive decay of the spent fuel inside the HSM-MX. Therefore, the dose rates for EOS-DSC retrieval are bounded by the dose rates calculated for insertion.

A.11.2.3 Fuel Unloading Operations

No change to Section 11.2.3.

A.11.2.4 Maintenance Operations

The dose rates for surveillance activities are shown in Table A.11-7 and Table A.11-8 for doses rates 6.1 m from the front of an HSM-MX. The 6.1-meter dose rate is a conservative estimate for surveillance activities. The HSM-MX surface dose rates provided in Chapter A.6 can be used for temperature sensor maintenance activities, including calibration and repair.

The general licensee will evaluate the additional dose to personnel from ISFSI operations, based on the particular storage configuration and site personnel requirements.

A.11.2.5 Doses during ISFSI Expansion

During the ISFSI expansion using the construction joint option, the removable end shield wall is absent, and the two complete compartments (one upper and one lower) at the end of the module are empty. The maximum dose rate at the end of the module for the array expansion configuration is *6.22* mrem/hr, which is low (see Section A.6.4.4). If the array terminates at an expansion joint, two empty compartments (one upper and one lower) are also required at the end of the array, and dose rates are bounded by the construction joint option. The maximum dose rate on the surface of the integral shield wall is *7.89* mrem/hr (see *Table A.6-2a*). Therefore, the end dose rate during array expansion activities is approximately the same as the end dose rate with an integral end shield wall, and elevated dose rates during array expansion activities are not anticipated.

A.11.3 Offsite Dose Calculations

Calculated dose rates in the immediate vicinity of the HSM-MX are presented in Chapter A.6, which provides a detailed description of source term configuration, analysis models, and bounding dose rates. The *bounding* HSM-MX dose rates reported in Chapter A.6 are conservatively based on the EOS-*37PTH* DSC HLZC *10*, which is not authorized for storage in the HSM-MX. Offsite dose rates and annual exposures are presented in this section. Neutron and gamma-ray offsite dose rates are computed, including skyshine, in the vicinity of the two generic ISFSI layouts containing design-basis contents.

A.11.3.1 Normal Conditions (10 CFR 72.104)

Offsite dose rates are a result of direct radiation from the ISFSI. The operation of loading an HSM-MX occurs over a very short time period and contributes negligibly to the offsite dose rates. Therefore, normal condition offsite dose rate calculations are computed only for a loaded ISFSI. No off-normal conditions have been identified that affect offsite dose rates.

Two generic ISFSI configurations are considered that each store 22 EOS-DSCs. In the first configuration, the 22 DSCs are stored in a single HSM-MX with the DSCs in a 2x11 back-to-back configuration. In the 2x11 back-to-back configuration, the front of the modules face outward and the rows are separated by a wall of concrete. In the second configuration, the 22 DSCs are stored in two HSM-MX systems that each contain 11 DSCs in a 1x11 configuration. In the two 1x11 front-to-front configuration, the modules are aligned with the rear shield walls facing outward and the front of the modules facing inward, separated by 32 ft. This configuration has the advantage of minimizing the dose rate near the ISFSI because the inlet vents are directed inward in an area that would not normally be occupied.

It is noted in Chapter A.6 that HSM-MX *vent* dose rates are larger for the EOS-*37PTH* DSC compared to the EOS-*89BTH* DSC. Therefore, offsite dose rates are computed only for the bounding EOS-DSC. This evaluation provides results for distances ranging from 6.1 to 600 m from each face for the two configurations.

The Monte Carlo computer code Monte Carlo N-Particle Version 5 (MCNP5) [A.11-5] is used to calculate the dose rates at the specified locations around the HSM-MX. The results of this evaluation provide an example of how to demonstrate compliance with the relevant radiological requirements of 10 CFR 20, 10 CFR 72, and 40 CFR 190 for a specific site. Each user must perform site-specific calculations to account for the actual layout of the HSM-MXs and fuel source.

The total annual exposure for each ISFSI layout as a function of distance from each face is given in Table A.11-5 and plotted in Figure A.11-1. The total annual exposure estimates are based on 100% occupancy for 365 days. At large distances, the annual exposure from the 2x11 back-to-back configuration is similar to the two 1x11 front-to-front configuration. Per 10 CFR 72.104, the annual whole-body dose to an individual at the site boundary is limited to 25 mrem. Based on the data shown in Table A.11-5, the offsite dose rate drops below 25 mrem at a distance of approximately *370* m from the ISFSI. Therefore, *370* m is the minimum distance with design basis fuel to the site boundary for the HSM-MX system with 22-DSCs; however, a shorter distance can be demonstrated in a site-specific calculation.

The methodology, inputs, and assumptions for the MCNP analyses are summarized in the following paragraphs.

- The 2x11 back-to-back configuration is modeled as a box enveloping the HSM-MX, including the 44 inch thick shield walls on the two ends. Source particles are started on the surfaces of the box. A sketch of this geometry is shown in Figure A.11-2. The interiors of the HSM-MX and shield walls are modeled as air. Most particles that enter the interiors of the HSM-MX and shield walls will, therefore, pass through unhindered.
- The HSM-MXs in the two 1x11 front-to-front configuration are modeled as two boxes that envelop each 1x11 row, including the 44-inch thick shield walls on the two ends and 44 inch thick rear shield wall in each row. Source particles are started on the surfaces of one of the modules, which is modeled as air. The opposite module is modeled as solid concrete. A sketch of this geometry is shown in Figure A.11-3. The dose field is then created for a source in both modules by accounting for model symmetry, as indicated in Figure A.11-3.
- The ISFSI approach slab is modeled as concrete. Because the ground composition has, at best, only a secondary impact on the dose rates at the detectors, any differences between this assumed layout and the actual layout would not have a significant effect on the site dose rates.
- The "universe" is a sphere surrounding the ISFSI. To account for skyshine, the radius of this sphere (r=500,000 cm) is more than 10 mean free paths for neutrons and 50 mean free paths for gammas in air, thus ensuring that the model is of a sufficient size to include all interactions, including skyshine, affecting the dose rate at the detectors.
- The 2x11 and two 1x11 surface sources are input to reproduce the average dose rate and spectrum on the surface of the HSM-MX, as computed in Chapter A.6. The surface average fluxes on the front, roof, side, and rear of the HSM-MXs *with the EOS-37PTH DSC* are explicitly computed and are provided in *Table A.6-9* through *Table A.6-11. The surface average fluxes for the EOS-89BTH DSC provided in Table A.6-3 through Table A.6-5 are not used in the bounding EOS-37PTH DSC offsite dose rate analysis but could be used for an EOS-89BTH DSC offsite dose rate analysis.* The primary and secondary gamma fluxes are simply summed in the gamma input file. These surface spectra are directly input to MCNP for each face.

- Source particles on the ISFSI surface are specified with a cosine distribution. For a cosine distribution, the outward particle current is equal to half of the flux. The MCNP source description requires the number of source particles per second emitted on each face (particle current). Because the current is half of the flux for a cosine distribution, and the flux at each face is known, the input current for each face (particles/s) is computed as A*F/2, where A is the area of the face (cm^2) and F is the total flux on each face (particles/cm^2-s). The surface source evaluations are summarized in Table A.11-6.
- ANSI/ANS 6.1.1-1977 flux-to-dose rate factors are utilized [A.11-6]. These factors are provided in Table 6-51.
- For the 2x11 back-to-back configuration with end shield walls, the "box" dimensions are 1260 cm wide, 2096 cm long, and 903 cm high. For the two 1x11 front-to-front configuration with end and back shield walls, the "box" dimensions are 704 cm wide, 2096 cm long, and 903 cm high. The two 1x11 rows are 975 cm (32 ft) apart.
- Dose rates are calculated for distances of 6.1 m (20 ft) to 600 m from the edges of the two ISFSI configurations. Point detectors are placed at the following locations, as measured from each face of the "box": 6.095 m (20 ft), 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 70 m, 80 m, 90 m, 100 m, 200 m, 300 m, 400 m, 500 m, and 600 m. Each point detector is placed 91 cm (~3 ft) above the ground.

The MCNP results for the 2x11 back-to-back and two 1x11 front-to-front configurations are summarized in Table A.11-7 and Table A.11-8, respectively. At near distances, the 2x11 configuration results in larger front dose rates than the outward rear of the two 1x11 configuration. For example, the 6.1 m front dose rate is *18.1* mrem/hr for the 2x11 configuration compared to *1.42* mrem/hr for the two 1x11 configuration. However, at near distances, the two 1x11 configuration results in nominally larger side dose rates than the 2x11 configuration.

At large distances, the dose rates are approximately the same, regardless of configuration or direction from the ISFSI, as the dose rate at large distances is dominated by skyshine from the radiation streaming from the roof outlet vents. Also, note that the neutron dose rate is negligible compared to the gamma dose rate at all dose rate locations.

The total Monte Carlo uncertainty is < 5% for all dose rate locations. The annual exposures reported in Table A.11-5 are simply the computed dose rates multiplied by 8760 hours (1 year).

The preceding analyses and results are intended to provide high estimates of dose rates for generic ISFSI layouts. The written evaluations performed by a general licensee for the actual ISFSI must consider the type and number of storage units, layout, characteristics of the irradiated fuel to be stored, site characteristics (e.g., berms, distance to the controlled area boundary, etc.), and reactor operations at the site in order to demonstrate compliance with 10 CFR 72.104.

A.11.3.2 Accident Conditions (10 CFR 72.106)

Per 10 CFR 72.106, the exposure to an individual at the site boundary due to an accident is limited to 5 rem. In an accident, the HSM-MX outlet vent covers and all dose reduction hardware may be lost. In addition, it is assumed that the HSM-MX is in an expansion configuration with the removable end shield wall absent and that a missile strike has damaged two interior walls. This accident scenario results in elevated dose rates on the front, roof, and side of the ISFSI. The average HSM-MX roof, front, and side dose rates and fluxes *for the EOS-37PTH DSC* in an accident are provided in Chapter A.6, *Table A.6-12* through *Table A.6-14*. *The surface average accident fluxes for the EOS-89BTH DSC provided in Tables A.6-6 through Table A.6-8 are not used in the bounding EOS-37PTH DSC accident offsite dose rate analysis but could be used for an EOS-89BTH DSC accident offsite dose rate analysis.*

Table A.11-9 shows the bounding dose rate as a function of distance from a 2x11 back-to-back configuration of HSM-MXs for the accident configuration described above. These dose rates are calculated assuming damage to every module in the array. This is a highly conservative scenario that is not credible, as an accident is not expected to damage every module.

MCNP inputs for a 2x11 ISFSI accident configuration are prepared using the same method as described for the normal condition models. At a distance of 200 m from the ISFSI, *which is significantly closer than the minimum estimated site boundary distance of 370 m,* the accident dose rate is approximately *0.550* mrem/hr. It is assumed that the recovery time for this accident is five days (120 hours). Therefore, the total exposure to an individual at a distance of 200 m is approximately *66* mrem. This is significantly less than the 10 CFR 72.106 limit of 5 rem.

The EOS-TC may also be damaged in an accident during transfer operations, which would result in an offsite dose, see the discussion in Section 11.3.2.

A.11.4 Ensuring that Occupational Radiation Exposures Are ALARA

A.11.4.1 Policy Considerations

No change to Section 11.4.1.

A.11.4.2 Design Considerations

No change to the EOS-DSC and EOS-TC, see Section 11.4.2.

The HSM-MX storage modules include no active components that require periodic maintenance, thereby minimizing potential personnel dose due to maintenance activities.

The HSM-MXs provide thick concrete shielding, and the shielding design features of the storage modules minimize occupational exposure for any activities on or near the ISFSI.

Regulatory Position 2 of Regulatory Guide 8.8 is incorporated into the design considerations, see Section 11.4.2.

A.11.4.3 Operational Considerations

The areas of highest operational dose of HSM-MX are the front of a loaded HSM-MX at the air inlet vent. Operating procedures, temporary shielding, and personnel training are put into practice to minimize personnel exposure in this area.

The HSM-MX is designed to be essentially maintenance free. It is a passive system with no moving parts. The only anticipated maintenance procedures are the visual inspection of the bird screens on the HSM-MX ventilation inlet and outlet openings, and periodic maintenance of the temperature sensors.

A.11.5 References

A.11-1 Title 10, Code of Federal Regulations, Part 20, "Standards for Protection Against Radiation."

A.11-2 Title 10, Code of Federal Regulations Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste, and Reactor-Related greater than Class C Waste."

A.11-3 Title 40, Code of Federal Regulations, Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations."

A.11-4 U.S. Nuclear Regulatory Commission, Regulatory Guide 8.34, "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses," July 1992.

A.11-5 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, RSICC Computer Code Collection, January 2006.

A.11-6 ANSI/ANS-6.1.1-1977, "Neutron and Gamma-Ray Fluence-to-Dose Factors, American Nuclear Society, LaGrange Park, Illinois, March 1977.

Table A.11-1
Occupational Dose Rates

			Dose Rate (mrem/hr)			
			EOS-TC108		EOS-TC125/135	
Dose Rate Location	**Averaged Segments**	**Config.**	***EOS-37PTH DSC***	**EOS-89BTH DSC**	**EOS-37PTH DSC**	**EOS-89BTH DSC**
DRL1 through DRL10	(1)	(1)	*(1)*	(1)	(1)	(1)
HSM-MX (HMX)	Front face surface average	-	*60*	50	*60*	50

Note 1: Information pertaining to dose rate locations DRL1 through DRL10 is provided in Table 11-1.

Table A.11-1a
Occupational Exposure, EOS-TC108 with EOS-37PTH DSC
(2 Pages)

No. (2)	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person-mrem)	% of Total Dose
1	Place an empty EOS-DSC into an EOS-TC and prepare the EOS-TC for placement into the spent fuel pool.	N/A	N/A	6	4.00	0	0	0%
2	Move the EOS-TC containing an EOS-DSC without fuel into the spent fuel pool.	N/A	N/A	6	1.50	0	0	0%
3	Remove the loaded EOS-TC from the fuel pool and place in the decontamination area.	Decon.	DRL1	2	0.25	496	248	2.9%
4	Install neutron shield. Fill neutron shield with water.	Decon.	DRL4	3	0.33	2467	2442	28.1%
5	Prep and weld inner top cover plate.	Welding	DRL3	2	0.75	384	576	6.6%
6	Vacuum dry and backfill with helium.	Welding	DRL3	2	0.50	384	384	4.4%
7	Weld outer top cover plate and port covers, perform non-destructive examination.	Welding	DRL3	2	0.50	384	384	4.4%
8	Drain annulus. Install EOS-TC aluminum top cover. Ready the support skid and transfer trailer.	Transfer	DRL5	1	0.50	1162	581	6.7%
9	Place the EOS-TC onto the skid and trailer. Secure the EOS-TC to the skid.	Transfer	DRL2	2	0.33	1534	1012	11.6%
10	Install retractable roller tray (RRT).	Transfer	HMX	2	2.00	60	240	2.8%
11	Remove aluminum top cover and replace with steel top cover.	Transfer	DRL3	2	0.33	358	236	2.7%

Table A.11-1a
Occupational Exposure, EOS-TC108 with EOS-37PTH DSC
(2 Pages)

No. (2)	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person-mrem)	% of Total Dose
12	Transfer the EOS-TC to ISFSI.	N/A	N/A	6	1.83	0	0	0%
13	Position the EOS-TC inside the loading crane (MX-LC).	Transfer	HMX+DRL2	2	0.50	1594	1594	18.3%
14	Remove forced cooling system (if used) and install the ram cylinder assembly.	Transfer	DRL9	2	0.50	69	69	0.8%
15	Remove HSM-MX door.	Transfer	HMX	2	0.50	60	60	0.7%
16	Remove the EOS-TC top cover.	Transfer	HMX+DRL6	2	0.67	243	326	3.7%
17	Align and dock the EOS-TC with the HSM-MX. Secure the EOS-TC to the HSM-MX.	Transfer	HMX+DRL7	2	0.25	421	211	2.4%
18	Transfer the EOS-DSC from the EOS-TC to the HSM-MX using the ram cylinder.	N/A	N/A	3	0.50	0	0	0%
19	Disengage the ram and un-dock the EOS-TC from the HSM-MX.	Transfer	HMX+DRL10	2	0.08	173	28	0.3%
20	Install HSM-MX access door. Move EOS-TC to the transfer skid for removal.	Transfer	HMX	2	0.50	60	60	0.7%
21	Uninstall RRT.	Transfer	HMX	2	2.00	60	240	2.8%
						Total(1)	8690	

Notes:

*(1) A building crane hang-up off-normal event adds 1983 person-mrem (DRL1/Decon. * 4 workers * 1 hour).*

(2) Occupational exposures for steps 1 through 9 are consistent with Chapter 11, Table 11-2.

Table A.11-2
Occupational Exposure, EOS-TC108 with EOS-89BTH DSC
(2 Pages)

No. (2)	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person -mrem)	% of Total Dose
1	Place an empty EOS-DSC into an EOS-TC and prepare the EOS-TC for placement into the spent fuel pool.	N/A	N/A	6	4.00	0	0	0%
2	Move the EOS-TC containing an EOS-DSC without fuel into the spent fuel pool.	N/A	N/A	6	1.50	0	0	0%
3	Remove the loaded EOS-TC from the fuel pool and place in the decontamination area.	Decon.	DRL1	2	0.25	194	97	2.1%
4	Install neutron shield. Fill neutron shield with water.	Decon.	DRL4	3	0.33	1050	1040	22.9%
5	Prep and weld inner top cover plate.	Welding	DRL3	2	0.75	198	297	6.5%
6	Vacuum dry and backfill with helium.	Welding	DRL3	2	0.50	198	198	4.4%
7	Weld outer top cover plate and port covers, perform non-destructive examination.	Welding	DRL3	2	0.50	198	198	4.4%
8	Drain annulus. Install EOS-TC aluminum top cover. Ready the support skid and transfer trailer.	Transfer	DRL5	1	0.50	586	293	6.5%
9	Place the EOS-TC onto the skid and trailer. Secure the EOS-TC to the skid.	Transfer	DRL2	2	0.33	747	498	11.0%
10	Install retractable roller tray (RRT).	Transfer	HMX	2	2.00	50	200	4.4%
11	Remove aluminum top cover and replace with steel top cover.	Transfer	DRL3	2	0.33	199	133	2.9%
12	Transfer the EOS-TC to ISFSI.	N/A	N/A	6	1.83	0	0	0%

Table A.11-2
Occupational Exposure, EOS-TC108 with EOS-89BTH DSC
(2 Pages)

No. (2)	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person -mrem)	% of Total Dose
13	Position the EOS-TC inside the loading crane (MX-LC).	Transfer	HMX+DRL2	2	0.50	797	797	17.6%
14	Remove forced cooling system (if used) and install the ram cylinder assembly.	Transfer	DRL9	2	0.50	137	137	3.0%
15	Remove HSM-MX door.	Transfer	HMX	2	0.50	50	50	1.1%
16	Remove the EOS-TC top cover.	Transfer	HMX+DRL6	2	0.67	150	200	4.4%
17	Align and dock the EOS-TC with the HSM-MX. Secure the EOS-TC to the HSM-MX.	Transfer	HMX+DRL7	2	0.25	239	120	2.6%
18	Transfer the EOS-DSC from the EOS-TC to the HSM-MX using the ram cylinder.	N/A	N/A	3	0.50	0	0	0%
19	Disengage the ram and un-dock the EOS-TC from the HSM-MX.	Transfer	HMX+DRL10	2	0.08	171	29	0.6%
20	Install HSM-MX access door. Move EOS-TC to the transfer skid for removal.	Transfer	HMX	2	0.50	50	50	1.1%
21	Uninstall RRT.	Transfer	HMX	2	2.00	50	200	4.4%
						Total(1)	4535	

Note:

(1) A building crane hang-up off-normal event adds 776 person-mrem (DRL1/decon * 4 workers * 1 hour).

(2) Occupational exposures for steps 1 through 9 are consistent with Chapter 11, Table 11-3.

Table A.11-3
Occupational Exposure, EOS-TC125/135 with EOS-37PTH DSC
(2 Pages)

No. (2)	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person -mrem)	% of Total Dose
1	Drain neutron shield if necessary. Place an empty EOS-DSC into an EOS-TC and prepare the EOS-TC for placement into the spent fuel pool.	N/A	N/A	6	4.00	0	0	0%
2	Move the EOS-TC containing an EOS-DSC without fuel into the spent fuel pool.	N/A	N/A	6	1.50	0	0	0%
3	Remove a loaded EOS-TC from the fuel pool and place in the decontamination area. Refill neutron shield tank if necessary.	Decon.	DRL1	2	0.25	*142*	*71*	*1.7%*
4	Decontaminate the EOS-TC and prepare welds.	Decon.	DRL2	2	1.75	*431*	*1508*	*35.6%*
		Decon.	DRL3	2	0.50	*339*	*339*	*8.0%*
5	Weld inner top cover plate.	Welding	DRL3	2	0.75	*179*	*269*	*6.3%*
6	Vacuum dry and backfill with helium.	Welding	DRL3	2	0.50	*179*	*179*	*4.2%*
7	Weld outer top cover plate and port covers, perform non-destructive examination.	Welding	DRL3	2	0.50	*179*	*179*	*4.2%*
8	Drain annulus. Install EOS-TC top cover. Ready the support skid and transfer trailer.	Transfer	DRL5	1	0.50	*267*	*134*	*3.2%*
9	Place the EOS-TC onto the skid and trailer. Secure the EOS-TC to the skid.	Transfer	DRL2	2	0.33	*342*	*226*	*5.3%*
10	Install RRT.	Transfer	HMX	2	2.00	*60*	*240*	*5.7%*

Table A.11-3
Occupational Exposure, EOS-TC125/135 with EOS-37PTH DSC
(2 Pages)

No. (2)	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person -mrem)	% of Total Dose
11	Transfer the EOS-TC to ISFSI.	N/A	N/A	6	1.83	0	0	0%
12	Position the EOS-TC inside the loading crane (MX-LC).	Transfer	HMX+DRL2	2	0.50	*402*	*402*	*9.5%*
13	Remove forced cooling system (if used) and install the ram cylinder assembly.	Transfer	DRL9	2	0.50	*46*	*46*	*1.1%*
14	Remove HSM-MX door.	Transfer	HMX	2	0.50	*60*	*60*	*1.4%*
15	Remove the EOS-TC top cover.	Transfer	HMX+DRL6	2	0.67	*126*	*169*	*4.0%*
16	Align and dock the EOS-TC with the HSM-MX. Secure the EOS-TC to the HSM-MX.	Transfer	HMX+DRL7	2	0.25	*191*	*96*	2.3%
17	Transfer the EOS-DSC from the EOS-TC to the HSM-MX using the ram cylinder.	N/A	N/A	3	0.50	0	0	0%
18	Disengage the ram and un-dock the EOS-TC from the HSM-MX.	Transfer	HMX+DRL10	2	0.08	*91*	*15*	*0.3%*
19	Install HSM-MX access door. Move EOS-TC to the transfer skid for removal.	Transfer	HMX	2	0.50	*60*	*60*	*1.4%*
20	Uninstall RRT.	Transfer	HMX	2	2.00	*60*	*240*	*5.7%*
						Total(1)	*4231*	

Note:

(1) Use of aluminum cask lid increases total occupational dose by approximately *4%*.

(2) Occupational exposures for steps 1 through 9 are consistent with Chapter 11, Table 11-4.

Table A.11-4
Occupational Exposure, EOS-TC125 with EOS-89BTH DSC
(2 Pages)

No.[(1)]	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person -mrem)	% of Total Dose
1	Drain neutron shield if necessary. Place an empty EOS-DSC into an EOS-TC and prepare the EOS-TC for placement into the spent fuel pool.	N/A	N/A	6	4.00	0	0	0%
2	Move the EOS-TC containing an EOS-DSC without fuel into the spent fuel pool.	N/A	N/A	6	1.50	0	0	0%
3	Remove a loaded EOS-TC from the fuel pool and place in the decontamination area. Refill neutron shield tank if necessary.	Decon.	DRL1	2	0.25	62	31	1.2%
4	Decontaminate the EOS-TC and prepare welds.	Decon.	DRL2	2	1.75	181	634	25.1%
		Decon.	DRL3	2	0.50	98	98	3.9%
5	Weld inner top cover plate.	Welding	DRL3	2	0.75	113	170	6.7%
6	Vacuum dry and backfill with helium.	Welding	DRL3	2	0.50	113	113	4.5%
7	Weld outer top cover plate and port covers, perform non-destructive examination.	Welding	DRL3	2	0.50	113	113	4.5%
8	Drain annulus. Install EOS-TC top cover. Ready the support skid and transfer trailer.	Transfer	DRL5	1	0.50	191	96	3.8%
9	Place the EOS-TC onto the skid and trailer. Secure the EOS-TC to the skid.	Transfer	DRL2	2	0.33	239	158	6.3%
10	Install RRT.	Transfer	HMX	2	2.00	50	200	7.9%
11	Transfer the EOS-TC to ISFSI.	N/A	N/A	6	1.83	0	0	0%

Table A.11-4
Occupational Exposure, EOS-TC125 with EOS-89BTH DSC
(2 Pages)

No.[1]	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person -mrem)	% of Total Dose
12	Position the EOS-TC inside the loading crane (MX-LC).	Transfer	HMX+DRL2	2	0.50	289	289	11.5%
13	Remove forced cooling system (if used) and install the ram cylinder assembly.	Transfer	DRL9	2	0.50	114	114	4.5%
14	Remove HSM-MX door.	Transfer	HMX	2	0.50	50	50	2.0%
15	Remove the EOS-TC top cover.	Transfer	HMX+DRL6	2	0.67	93	125	4.9%
16	Align and dock the EOS-TC with the HSM-MX. Secure the EOS-TC to the HSM-MX.	Transfer	HMX+DRL7	2	0.25	141	71	2.8%
17	Transfer the EOS-DSC from the EOS-TC to the HSM-MX using the ram cylinder.	N/A	N/A	3	0.50	0	0	0%
18	Disengage the ram and un-dock the EOS-TC from the HSM-MX.	Transfer	HMX+DRL10	2	0.08	88	14	0.6%
19	Install HSM-MX access door. Move EOS-TC to the transfer skid for removal.	Transfer	HMX	2	0.50	50	50	2.0%
20	Uninstall RRT.	Transfer	HMX	2	2.00	50	200	7.9%
						Total[2]	2523	

Note:

(1) Occupational exposures for steps 1 through 9 are consistent with Chapter 11, Table 11-5.

(2) Use of an aluminum cask lid increases the total occupational exposure by approximately 70 person-mrem.

Table A.11-5
Total Annual Exposure from ISFSI

Distance (m)	2x11		Two 1x11	
	Front Total Dose (mrem)	Side Total Dose (mrem)	Back Total Dose (mrem)	Side Total Dose (mrem)
6.1	*158403*	*15336*	*12475*	*64705*
10	*97434*	*11970*	*10212*	*35113*
20	*36484*	*7386*	*6750*	*13024*
30	*18112*	*5082*	*4821*	*7194*
40	*10642*	*3736*	*3586*	*4712*
50	*6921*	*2794*	*2750*	*3352*
60	*4820*	*2177*	*2153*	*2516*
70	*3505*	*1705*	*1720*	*1941*
80	*2627*	*1379*	*1385*	*1530*
90	*2023*	*1117*	*1132*	*1229*
100	*1584*	*923*	*931*	*999*
200	*239*	*169*	*177*	*182*
300	*55*	*41*	*44*	*45*
400	*16*	*12*	*13*	*13*
500	*5*	*4*	*4*	*4*
600	*2*	*1*	*1*	*1*

Table A.11-6
ISFSI Surface Sources

2x11 Back-to-Back Configuration			
Source	**Area (cm²)**	**Neutron Source (n/s)**	**Gamma Source (γ/s)**
Roof	2.640E+06	*2.364E+08*	*3.295E+11*
Front 1	1.892E+06	*8.021E+07*	*1.024E+11*
Front 2	1.892E+06	*8.021E+07*	*1.024E+11*
Side 1	1.137E+06	*8.649E+05*	*6.068E+08*
Side 2	1.137E+06	*8.649E+05*	*6.068E+08*
Total	8.697E+06	*3.985E+08*	*5.355E+11*
Two 1x11 Front-to-Front Arrays (source for one of the two rows)			
Source	**Area (cm²)**	**Neutron Source (n/s)**	**Gamma Source (γ/s)**
Roof	1.474E+06	*1.320E+08*	*1.840E+11*
Front	1.892E+06	*8.021E+07*	*1.024E+11*
Back	1.892E+06	*1.469E+06*	*1.237E+09*
Side 1	6.351E+05	*4.830E+05*	*3.389E+08*
Side 2	6.351E+05	*4.830E+05*	*3.389E+08*
Total	6.528E+06	*2.147E+08*	*2.883E+11*

Table A.11-7
2x11 Back-to-Back Dose Rates
(2 Pages)

In Front of ISFSI				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	*1.78E+01*	*2.79E-01*	*1.81E+01*	*0.03%*
10	*1.09E+01*	*1.75E-01*	*1.11E+01*	*0.03%*
20	*4.10E+00*	*6.81E-02*	*4.16E+00*	*0.05%*
30	*2.03E+00*	*3.45E-02*	*2.07E+00*	*0.1%*
40	*1.19E+00*	*2.04E-02*	*1.21E+00*	*0.1%*
50	*7.77E-01*	*1.31E-02*	*7.90E-01*	*0.1%*
60	*5.41E-01*	*9.06E-03*	*5.50E-01*	*0.1%*
70	*3.94E-01*	*6.33E-03*	*4.00E-01*	*0.1%*
80	*2.95E-01*	*4.67E-03*	*3.00E-01*	*0.2%*
90	*2.27E-01*	*3.57E-03*	*2.31E-01*	*0.2%*
100	*1.78E-01*	*2.79E-03*	*1.81E-01*	*0.2%*
200	*2.68E-02*	*4.35E-04*	*2.73E-02*	*0.4%*
300	*6.09E-03*	*1.28E-04*	*6.22E-03*	*0.6%*
400	*1.72E-03*	*5.07E-05*	*1.77E-03*	*1.1%*
500	*5.36E-04*	*2.06E-05*	*5.57E-04*	*1.6%*
600	*1.89E-04*	*8.49E-06*	*1.97E-04*	*2.5%*

Table A.11-7
2x11 Back-to-Back Dose Rates
(2 Pages)

At Side of ISFSI				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	*1.69E+00*	*6.20E-02*	*1.75E+00*	*0.1%*
10	*1.32E+00*	*4.82E-02*	*1.37E+00*	*0.1%*
20	*8.16E-01*	*2.75E-02*	*8.43E-01*	*0.1%*
30	*5.63E-01*	*1.72E-02*	*5.80E-01*	*0.1%*
40	*4.15E-01*	*1.15E-02*	*4.27E-01*	*1.0%*
50	*3.11E-01*	*7.96E-03*	*3.19E-01*	*0.2%*
60	*2.43E-01*	*5.68E-03*	*2.49E-01*	*0.7%*
70	*1.90E-01*	*4.30E-03*	*1.95E-01*	*0.2%*
80	*1.54E-01*	*3.26E-03*	*1.57E-01*	*0.3%*
90	*1.25E-01*	*2.57E-03*	*1.28E-01*	*0.5%*
100	*1.03E-01*	*2.04E-03*	*1.05E-01*	*0.7%*
200	*1.89E-02*	*3.59E-04*	*1.93E-02*	*0.5%*
300	*4.59E-03*	*1.17E-04*	*4.71E-03*	*0.7%*
400	*1.34E-03*	*4.11E-05*	*1.38E-03*	*1.1%*
500	*4.15E-04*	*1.93E-05*	*4.34E-04*	*1.6%*
600	*1.51E-04*	*7.85E-06*	*1.59E-04*	*1.9%*

Table A.11-8
Two 1x11 Front-to-Front Dose Rates
(2 Pages)

In Back of ISFSI				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	*1.37E+00*	*5.33E-02*	*1.42E+00*	*0.1%*
10	*1.12E+00*	*4.26E-02*	*1.17E+00*	*0.1%*
20	*7.45E-01*	*2.56E-02*	*7.71E-01*	*0.1%*
30	*5.34E-01*	*1.65E-02*	*5.50E-01*	*0.1%*
40	*3.98E-01*	*1.10E-02*	*4.09E-01*	*0.1%*
50	*3.06E-01*	*7.72E-03*	*3.14E-01*	*0.1%*
60	*2.40E-01*	*5.66E-03*	*2.46E-01*	*0.1%*
70	*1.92E-01*	*4.23E-03*	*1.96E-01*	*0.2%*
80	*1.55E-01*	*3.25E-03*	*1.58E-01*	*0.2%*
90	*1.27E-01*	*2.51E-03*	*1.29E-01*	*0.2%*
100	*1.04E-01*	*2.00E-03*	*1.06E-01*	*0.2%*
200	*1.99E-02*	*3.77E-04*	*2.03E-02*	*0.4%*
300	*4.95E-03*	*1.18E-04*	*5.07E-03*	*0.7%*
400	*1.44E-03*	*4.76E-05*	*1.49E-03*	*0.9%*
500	*4.76E-04*	*1.58E-05*	*4.92E-04*	*1.8%*
600	*1.62E-04*	*8.42E-06*	*1.70E-04*	*1.5%*

Table A.11-8
Two 1x11 Front-to-Front Dose Rates
(2 Pages)

At Side of ISFSI				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	*7.25E+00*	*1.38E-01*	*7.39E+00*	*0.02%*
10	*3.93E+00*	*8.30E-02*	*4.01E+00*	*0.03%*
20	*1.45E+00*	*3.54E-02*	*1.49E+00*	*0.1%*
30	*8.01E-01*	*2.02E-02*	*8.21E-01*	*0.1%*
40	*5.25E-01*	*1.28E-02*	*5.38E-01*	*0.1%*
50	*3.74E-01*	*8.64E-03*	*3.83E-01*	*0.1%*
60	*2.81E-01*	*6.11E-03*	*2.87E-01*	*0.1%*
70	*2.17E-01*	*4.54E-03*	*2.22E-01*	*0.1%*
80	*1.71E-01*	*3.35E-03*	*1.75E-01*	*0.1%*
90	*1.38E-01*	*2.68E-03*	*1.40E-01*	*0.1%*
100	*1.12E-01*	*2.14E-03*	*1.14E-01*	*0.2%*
200	*2.04E-02*	*3.61E-04*	*2.08E-02*	*0.5%*
300	*5.03E-03*	*1.10E-04*	*5.14E-03*	*0.5%*
400	*1.44E-03*	*4.00E-05*	*1.48E-03*	*0.6%*
500	*4.70E-04*	*1.61E-05*	*4.86E-04*	*0.9%*
600	*1.63E-04*	*6.49E-06*	*1.70E-04*	*0.8%*

Table A.11-9
2x11 Back-to-Back Accident Dose Rates
(2 Pages)

In Front of ISFSI				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	*6.59E+01*	*6.63E-01*	*6.65E+01*	*0.1%*
10	*4.78E+01*	*4.75E-01*	*4.83E+01*	*0.1%*
20	*2.59E+01*	*2.42E-01*	*2.61E+01*	*0.1%*
30	*1.67E+01*	*1.45E-01*	*1.69E+01*	*0.1%*
40	*1.19E+01*	*9.51E-02*	*1.19E+01*	*0.1%*
50	*8.83E+00*	*6.62E-02*	*8.90E+00*	*0.2%*
60	*6.78E+00*	*4.86E-02*	*6.83E+00*	*0.2%*
70	*5.34E+00*	*3.66E-02*	*5.38E+00*	*0.2%*
80	*4.27E+00*	*2.86E-02*	*4.30E+00*	*0.3%*
90	*3.45E+00*	*2.18E-02*	*3.47E+00*	*0.2%*
100	*2.82E+00*	*1.78E-02*	*2.84E+00*	*0.2%*
200	*5.30E-01*	*3.54E-03*	*5.34E-01*	*0.7%*
300	*1.30E-01*	*1.09E-03*	*1.31E-01*	*0.8%*
400	*3.79E-02*	*4.00E-04*	*3.83E-02*	*1.3%*
500	*1.19E-02*	*1.48E-04*	*1.20E-02*	*1.5%*
600	*4.13E-03*	*6.80E-05*	*4.20E-03*	*3.3%*

Table A.11-9
2x11 Back-to-Back Accident Dose Rates
(2 Pages)

At Side of ISFSI				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	*1.67E+02*	*8.25E-01*	*1.68E+02*	*0.04%*
10	*9.96E+01*	*5.31E-01*	*1.00E+02*	*0.1%*
20	*4.01E+01*	*2.40E-01*	*4.03E+01*	*0.1%*
30	*2.25E+01*	*1.40E-01*	*2.26E+01*	*0.5%*
40	*1.46E+01*	*9.16E-02*	*1.47E+01*	*0.1%*
50	*1.04E+01*	*6.33E-02*	*1.04E+01*	*0.1%*
60	*7.72E+00*	*4.66E-02*	*7.76E+00*	*0.2%*
70	*5.92E+00*	*3.48E-02*	*5.95E+00*	*0.1%*
80	*4.67E+00*	*2.69E-02*	*4.70E+00*	*0.2%*
90	*3.73E+00*	*2.16E-02*	*3.75E+00*	*0.2%*
100	*3.03E+00*	*1.73E-02*	*3.05E+00*	*0.3%*
200	*5.47E-01*	*3.41E-03*	*5.50E-01*	*0.4%*
300	*1.36E-01*	*9.78E-04*	*1.37E-01*	*0.9%*
400	*3.95E-02*	*3.78E-04*	*3.98E-02*	*2.2%*
500	*1.27E-02*	*1.73E-04*	*1.29E-02*	*1.6%*
600	*4.46E-03*	*8.27E-05*	*4.54E-03*	*2.5%*

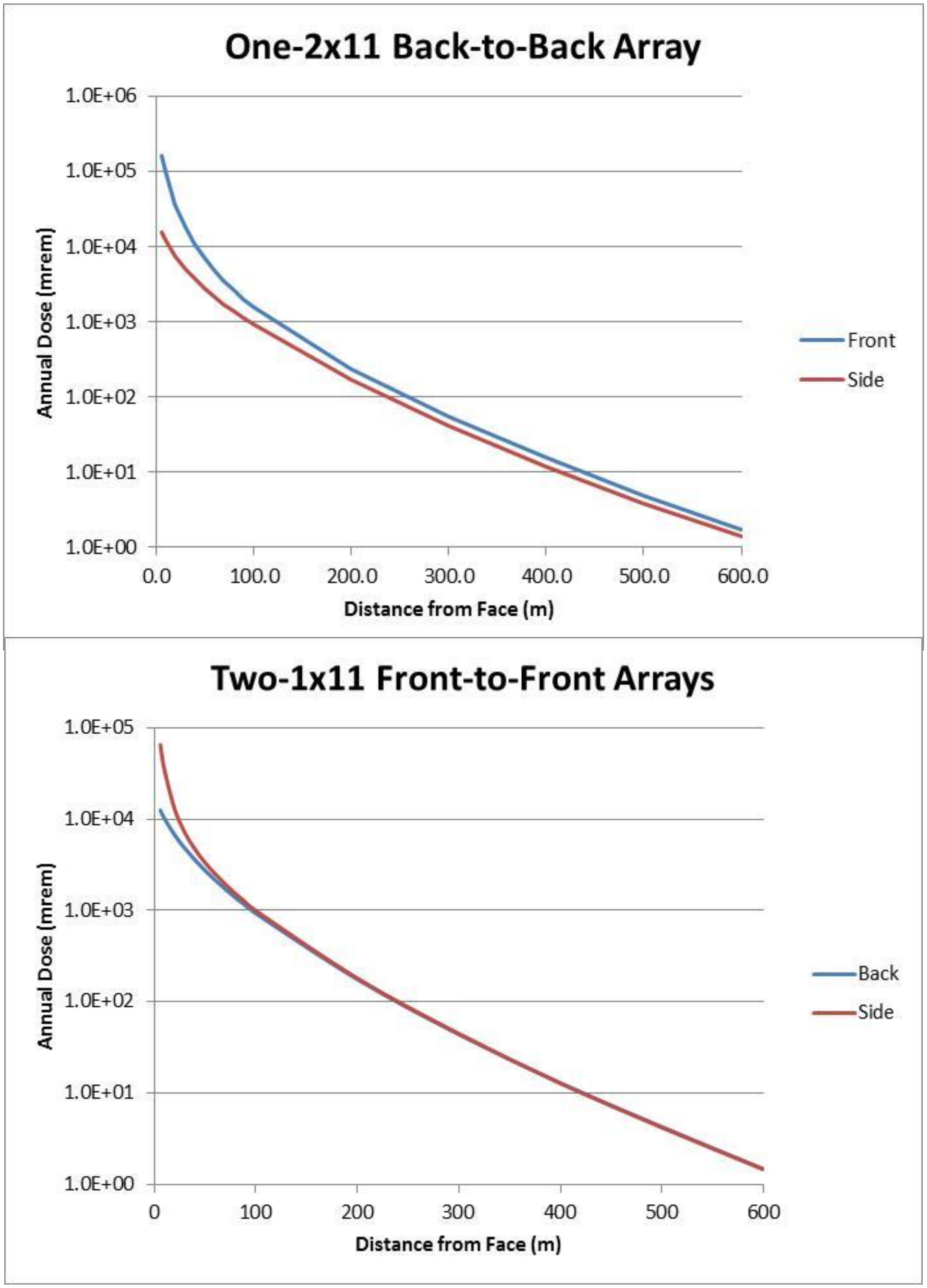


Figure A.11-1
Total Annual Exposure from the ISFSI

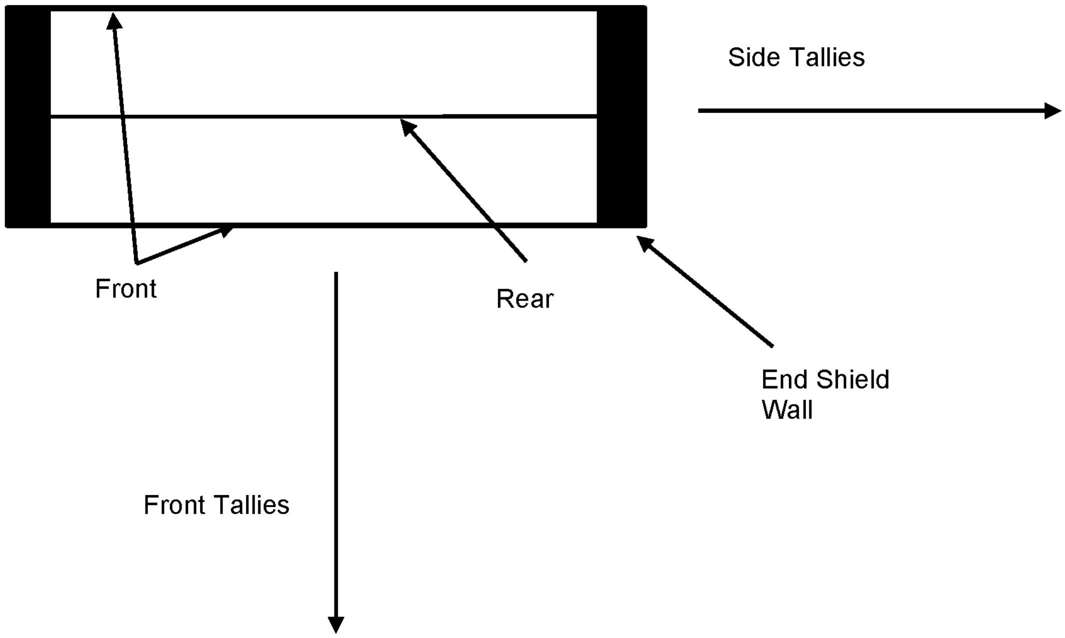
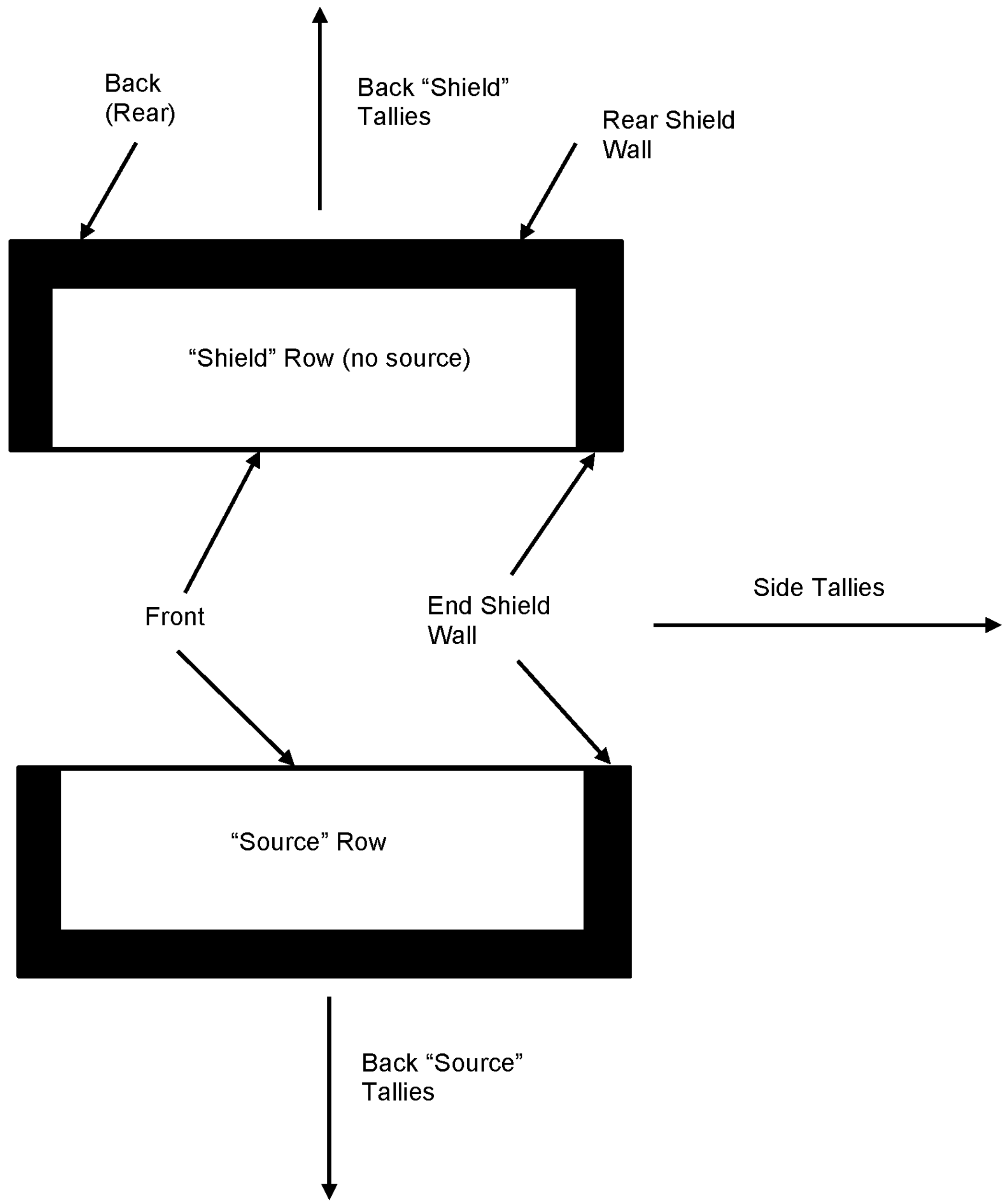


Figure A.11-2
2x11 ISFSI MCNP Geometry



Note: Back “Source” Tallies and Back “Shield” Tallies are summed to create the total back dose rates. Side Tallies are multiplied by two to create the total side dose rates.

Figure A.11-3
Two 1x11 ISFSI MCNP Geometry

APPENDIX A.12
ACCIDENT ANALYSES

Table of Contents

A.12 ACCIDENT ANALYSES

A.12.1 Introduction

No change to Section 12.1, except that this appendix is updated to include the NUHOMS® MATRIX (HSM-MX) *with an EOS-DSC (DSC hereafter)*.

A.12.2 Off-Normal Events

Off-normal events are design events of the second type (Design Event II) as defined in ANSI/ANS 57.9 [A.12-2]. Design Event II conditions consist of a set of events that do not occur regularly, but can be expected to occur with a moderate frequency, or about once during a calendar year of independent spent fuel storage installation (ISFSI) operation.

For the HSM-MX, off-normal events could occur during trailer movement, EOS-37PTH dry shielded canister (DSC) or EOS-89BTH DSC transfer and other operational events. The two off-normal events, which bound the range of off-normal conditions, are:

- A “jammed” DSC during loading or unloading from the HSM-MX
- The extreme ambient temperatures of -40 °F (winter) and +117 °F (summer)

These two events envelop the range of expected off-normal structural loads and temperatures acting on the HSM-MX.

A.12.2.1 Off-Normal Transfer Load

Although unlikely, the postulated off-normal handling event assumes that the leading edge of the DSC becomes jammed against some element of the support structure during transfer between the EOS transfer cask (EOS-TC) and the HSM-MX.

Cause of Event

It is postulated that if the EOS-TC is not accurately aligned with respect to the HSM-MX, may bind or jam the DSC during transfer operations.

The interiors of the EOS-TC and the HSM-MX are inspected prior to transfer operations to ensure there are no obstacles. Also, the DSC has beveled lead-ins on each end, designed to avoid binding or sticking on small (less than 0.25-inch) obstacles. The EOS-TC and the MATRIX retractable roller tray (MX-RRT) supports are designed to minimize binding or obstruction during DSC transfer. The postulated off-normal handling load event considers that the leading edge of the DSC becomes jammed against some element of the MX-RRT because of an unlikely gross misalignment of the EOS-TC.

The interfacing dimensions of the top end of the EOS-TC and the HSM-MX access opening sleeve are specified so that docking the EOS-TC with the HSM-MX is not possible should gross misalignments between the EOS-TC and HSM-MX exist.

Detection of Event

The normal load to push/pull the DSC in and out of the EOS-TC/HSM-MX is 135 kips and 80 kips, respectively, applied at the grapple ring and resisted by an axial load of 70 kips push and 40 kips pull on each of the MX-RRT. This movement is performed at a very low speed. System operating procedures and technical specification limits defining the safeguards to be provided ensure that the system design margins are not compromised. If the DSC were to jam or bind during transfer, the pressure increases. The off-normal load set for the “jammed DSC” for both insertion and retrieval are 135 kips and 80 kips, respectively. This load is administratively controlled to ensure that during the transfer operation this load is not exceeded.

During the transfer operation, the force exerted on the DSC by the ram is that required to first overcome the static frictional resisting force between the EOS-TC rails and the MX-RRT rollers. Once the DSC begins to slide on the rollers, the resisting force is a function of sliding friction between the DSC and the EOS-TC rails or between the DSC and the MX-RRT. If motion is prevented, the pressure increases, thereby increasing the force on the DSC until the ram system pressure limit is reached. This limit is controlled so that adequate force is available but is sufficiently low to ensure that component damage does not occur.

Analysis of Effects and Consequences

The DSC and the HSM-MX are designed and analyzed for off-normal transfer loads of 135 kips for insertion and 80 kips for retrieval during insertion and retrieval (unloading) operations. These analyses are discussed in Appendix A.3.9.1 for DSC and A.3.9.4 for HSM-MX. For either loading or unloading of the DSC under off-normal conditions, the stresses on the shell assembly components are demonstrated to be within the ASME allowable stress limits. Therefore, permanent deformation of the DSC shell components does not occur. The internal basket assembly components are unaffected by these loads based on clearances provided between the basket and DSC internal cavity.

There is no breach of the confinement pressure boundary and, therefore, no potential for release of radioactive material exists.

Corrective Actions

No changes to corrective actions described in Section 12.2.1.

A.12.2.2 Extreme Temperatures

The HSM-MX is designed for use at ambient temperatures of -40 °F (winter) and 117 °F (summer). Even though these extreme temperatures are likely to occur for a short period of time, it is conservatively assumed that these temperatures occur for a sufficient duration to produce steady state temperature distributions in HSM-MX. Each licensee should verify that this range of ambient temperatures envelopes the design basis ambient temperatures for the ISFSI site. The components affected by the postulated extreme ambient temperatures are the EOS-TC and DSC during their transfer from the plant's fuel/reactor building to the ISFSI site, and the HSM-MX during storage of a DSC.

Cause of Event

Off-normal ambient temperatures are natural phenomena.

Detection of Event

Off-normal ambient temperature conditions are confirmed by the licensee to be bounding for their site.

Analysis of Effects and Consequences

The thermal evaluation of the HSM-MX for extreme ambient conditions is presented in Chapter A.4. The effects of extreme ambient temperatures on the NUHOMS® MATRIX System are analyzed in sections as follows:

Components	**UFSAR Sections**
EOS-37PTH DSC and EOS-89BTH DSC Shell	Appendix 3.9.1 and A.3.9.1
EOS-37PTH Basket and EOS-89BTH Basket	Appendix 3.9.2
HSM-MX	Appendix A.3.9.4 & A.3.9.7
EOS-TC	Appendix 3.9.5

Corrective Actions

None

A.12.3 Postulated Accidents

The design basis accident events specified by ANSI/ANS 57.9-1984 [A.12-2] and other postulated accidents that may affect the normal safe operation of the HSM-MX are addressed in this section.

The following sections provide descriptions of the analyses performed for each accident condition. The analyses demonstrate that the requirements of 10 CFR 72.122 [A.12-1] are met and that adequate safety margins exist for the HSM-MX System design. The resulting accident condition stresses in the HSM-MX components are evaluated and compared with the applicable code limits set forth in Chapter A.2.

Radiological calculations are performed to confirm that on-site and off-site dose rates are within acceptable limits. Similarly seismic calculations are performed to confirm that seismic stresses are within acceptable stress limits.

The postulated accident conditions addressed in this section include:

- EOS-TC drop
- Earthquake
- Tornado wind pressure and tornado-generated missiles
- Flood
- Blockage of HSM-MX air inlet openings
- Lightning
- Fire/Explosion

A.12.3.1 EOS-TC Drop

Cause of Accident

As described in Chapter A.9, handling operations involving hoisting and movement of EOS-TC loaded with the EOS-37PTH or EOS-89BTH DSC is typically performed inside the plant's fuel handling building. These include utilizing the crane for placement of the empty DSC into the EOS-TC cavity, lifting the EOS-TC/DSC onto the transfer skid/trailer. An analysis of the plant's lifting devices used for these operations, including the crane and lifting yoke, is needed to address a postulated drop accident for the EOS-TC and its contents. The postulated drop accident scenarios addressed in the plant's 10 CFR Part 50 [A.12-3] licensing basis are plant-specific and should be addressed by the licensee.

Once the EOS-TC is loaded onto the transfer skid/trailer and secured, it is pulled to the HSM-MX site by a tractor vehicle. A predetermined route is chosen to minimize the potential hazards that could occur during transfer. This movement is performed at very low speeds. System operating procedures and technical specification limits defining the safeguards to be provided ensure that the system design margins are not compromised. As a result, it is highly unlikely that any plausible incidents leading to an EOS-TC drop accident could occur. At the ISFSI site, the transfer skid/trailer is used in conjunction with the MATRIX loading crane (MX-LC). The MX-LC is used to assist in loading the DSC into the HSM. The MX-LC is designed, fabricated, installed, tested, inspected and qualified in accordance with *the applicable portions of* ASME NOG-1*[A.12-9]*, as a Type I gantry type of crane, as per the guidance provided in NUREG-0612 [A.12-4]. The transfer skid/trailer is backed up to, and aligned with, the HSM-MX using transfer equipment. The EOS-TC/MX-LC is docked with, and secured to, the HSM-MX access opening. The MX-RRT rollers are extended into HSM-MX through front wall slots for the MX-RRT and secured. The loaded DSC is transferred to or from the HSM-MX using a transfer equipment. The MX-RRT is then lowered to place the DSC on the front and rear DSC supports in the HSM-MX. As a result, for a loaded EOS-TC drop accident to occur during these operations is considered non credible. 72.48

Lifts of the EOS-TC loaded with the dry storage canister are made within the existing heavy loads requirements and procedures of the licensed nuclear power plant. The EOS-TC design meets requirements of NUREG-0612 [A.12-4] and American National Standards Institute (ANSI) N14.6 [A.12-4].

The EOS-TC is transferred to the ISFSI in a horizontal configuration. Therefore, the only drop accident evaluated during storage or transfer operations is a side drop or a corner drop.

The EOS-TC and DSC are evaluated for a postulated side and corner drops to demonstrate structural integrity during transfer and plant handling.

Accident Analysis

No change to accident analysis in Section 12.3.1.

Accident Dose Calculation

No change to the accident dose calculation described in Section 12.3.1.

Corrective Actions

No change to corrective actions described in Section 12.3.1.

A.12.3.2 Earthquake

Cause of Accident

The explicitly evaluated seismic response spectra for the NUHOMS® HSM-MX consist of the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.60 (Reg. Guide 1.60) [A.12-6] with enhanced spectral accelerations above 9 Hz, and anchored to a maximum ground acceleration of 0.85g horizontal and 0.80g for the vertical peak accelerations. The results of the frequency analysis of the HSM-MX structure (which includes a simplified model of the DSC) yield a lowest frequency of 23.94 Hz in the transverse direction and 24.08 Hz in the longitudinal direction. The lowest vertical frequency is 49.02 Hz. Thus, based on the Reg. Guide 1.60 response spectra amplifications, the corresponding seismic accelerations used for the design of the HSM-MX are 1.33g and 1.33g in the transverse and longitudinal directions, respectively, and 0.80g in the vertical direction. The corresponding accelerations applicable to the DSC are 1.62g and 1.61g in the transverse and longitudinal directions, respectively, and 0.80g in the vertical direction.

Accident Analysis

The seismic analyses of the components that are important to safety are analyzed as follow:

Components	**UFSAR Sections**
EOS-37PTH DSC and EOS-89BTH DSC Shell	Appendix 3.9.1 and A.3.9.1
EOS-37PTH Basket and EOS-89BTH Basket	Appendix 3.9.2
HSM-MX	Appendices A.3.9.4 & A.3.9.7
EOS-TC	Appendix 3.9.5

The results of these analyses show that seismic stresses are well below the applicable stress limits.

Accident Dose Calculations

The dose rate increase is bounded by Section A.12.3.3.

Corrective Actions

No change to corrective actions described in Section 12.3.2.

A.12.3.3 Tornado Wind and Tornado Missiles Effect on HSM-MX

Cause of Accident

No change to the cause of accident described in Section 12.3.3.

Accident Analysis

Stability and stress analyses are performed to determine the response of the HSM-MX to flood, massive missile impact and tornado wind pressure loads.

The stress analyses are performed using the ANSYS [A.12-7]. HSM-MX storage modules arranged in a back-to-back row array provides a conservative estimate of the response of the HSM-MX under postulated static and dynamic loads for any HSM-MX array configurations. These analyses are described in Appendix A.3.9.4.

The sliding and overturning stability analyses due to wind, flood and massive impact loads are performed using closed-form calculation methods to determine the sliding and overturning response of the HSM-MX. A non-linear seismic stability analysis is performed using LS-DYNA [A.12-8]. These analyses are described in Appendix A.3.9.7, Section A.3.9.7.1.

Thus, the requirements of 10 CFR 72.122 are met.

Accident Dose Calculation

As discussed in the evaluations, the tornado wind and tornado missiles do not breach the HSM-MX to the extent that the DSC confinement boundary is compromised. Localized scabbing of the end shield wall of a HSM-MX array may be possible. When the array is in the expansion configuration with the removable end shield wall absent, two inner walls may be damaged as a result of a missile impact.

The HSM-MX outlet vent covers and all dose reduction hardware (DRH) may be lost due to a tornado or tornado missile event. The assumed accident damage increases the dose rates on the front, roof, and end (side) of the HSM-MX. The effect on the average rear dose rate is negligible because the rear surface does not contain vents and sustains little damage in an accident. The HSM-MX accident increases the average dose rate on the front, roof, and end of the module to *100* mrem/hr, *6,070* mrem/hr, and *537* mrem/hr, respectively (see Section A.6.1).

In the evaluation for the impact on public exposure, a 2x11 ISFSI configuration and a distance to the site boundary of *370* m is used. As documented in Chapter A.11, Section A.11.3.2, for a 2x11 ISFSI configuration, the accident dose rate is approximately *0.550* mrem/hour at a distance of 200 m from the ISFSI*, which is significantly closer than the minimum estimated site boundary distance of 370 m.* It is assumed that the recovery time for this accident is five days (120 hours). Therefore, the total exposure to an individual at a distance of 200 m is *66* mrem. This is significantly less than the 10 CFR 72.106 limit of 5 rem. Note that the dose is bounded by the EOS-HSM accident dose documented in Section 12.3.3.

Corrective Action

No change to corrective actions described in Section 12.3.3.

A.12.3.4 Tornado Wind and Tornado Missiles Effect on EOS-TC

Cause of Accident

No change to cause of accident described in Section 12.3.4.

Accident Analysis

No change to accident analysis described in Section 12.3.4.

Accident Dose Calculation

No change to accident dose calculation described in Section 12.3.4.

Corrective Actions

No change to corrective actions described in Section 12.3.4.

A.12.3.5 Flood

Cause of Accident

This event is described in Section 12.3.5.

Accident Analysis

The HSM-MX is evaluated for flooding in Appendix A.3.9.4. Based on the evaluation presented in that section, the HSM-MX can withstand the design basis flood.

Accident Dose Calculation

No change to accident dose calculation described in Section 12.3.5.

Corrective Actions

No change to corrective actions described in Section 12.3.5.

A.12.3.6 Blockage of HSM-MX Air Inlet Openings

This accident conservatively postulates the complete blockage of the air inlet openings of the HSM-MX.

Cause of Accident

Since the HSM-MX is located outdoors, there is a remote probability that the air inlet or outlet openings could become blocked by debris from such unlikely events as floods and tornadoes. There are no credible scenarios that could block both the inlet and outlet vents at the same time due to the significant height difference between the inlet and out vent locations. Therefore, only blockage of the inlet vents is considered in the UFSAR. The HSM-MX design features, such as the perimeter security fence and the redundant protected location of the air inlet and outlet openings, reduce the probability of occurrence of such an accident. Nevertheless, for this conservative generic analysis, such an accident is postulated to occur and is analyzed.

Accident Analysis

The thermal evaluation of this event is presented in Chapter A.4, Section A.4.5 for the EOS-37PTH DSC stored inside an HSM-MX. The analysis performed for the EOS-37PTH DSC bounds the values for the EOS-89BTH DSC. Therefore, the temperatures determined for Load Case #3-S in Section A.4.5 are used in the HSM-MX structural evaluation of this event. The HSM-MX structural analysis, presented in Appendix A.3.9.4, demonstrates that the HSM-MX component stresses remain below allowable values.

Accident Dose Calculation

There are no offsite dose consequences as a result of this accident.

Corrective Actions

No change to corrective actions described in Section 12.3.6.

A.12.3.7 Lightning

Cause of Accident

No change to cause of accident described in Section 12.3.7.

Accident Analysis

No change to accident analysis described in Section 12.3.7.

Corrective Actions

No change to corrective actions described in Section 12.3.7.

A.12.3.8 Fire/Explosion

Cause of Accident

No change to cause of accident described in Section 12.3.8.

Accident Analysis

No change to accident analysis described in Section 12.3.8.

Accident Dose Calculation

No change to the accident dose calculation described in Section 12.3.8.

Corrective Actions

No change to corrective actions described in Section 12.3.8.

A.12.4 References

A.12-1 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."

A.12-2 ANSI/ANS-57.9-1984, "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type)," American National Standards Institute, American Nuclear Society.

A.12-3 Title 10, Code of Federal Regulations, Part 50, "Domestic Licensing of Production and Utilization Facilities."

A.12-4 NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," U.S. Nuclear Regulatory Commission, July 1980.

A.12-5 ANSI N14.6-1993, "American National Standards for Special Lifting Device for Shipping Containers Weighing 10,000 lbs. or More for Nuclear Materials," American National Standards Institute.

A.12-6 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," U.S. Atomic Energy Commission, Revision 1, December 1973.

A.12-7 ANSYS Computer Code and User's Manual, Release 14.0 and 17.1.

A.12-8 LS-DYNA Version 7.0.0, Rev. 79055, Livermore Software Technology Corporation (LSTC)

A.12-9 ASME NOG-1-2015, "Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)," The American Society of Mechanical Engineers, New York, New York, 2015. 72.48

APPENDIX A.13
OPERATING CONTROLS AND LIMITS

The operating controls and limits, including those for the NUHOMS® MATRIX are described in Chapter 13.

APPENDIX A.14
QUALITY ASSURANCE

The addition of the NUHOMS® MATRIX to the NUHOMS® EOS system does not require any changes to the quality assurance requirements stipulated in Chapter 14. Chapter 14 provides the Quality Assurance Program applied 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.”

APPENDIX B

Appendix B is newly added in Revision 4 by Amendment 2.

Appendix B is newly added in Revision 4 by Amendment 2.

APPENDIX B.1
GENERAL INFORMATION

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

List of Figures

B.1 GENERAL INFORMATION

Appendix B to the NUHOMS® EOS Updated Final Safety Analysis Report (UFSAR) addresses the important-to-safety aspects of adding the NUHOMS® 61BTH Type 2 Dry Shielded Canister (DSC) licensed under Revision 18 of the UFSAR of CoC 1004 [B.1-4] to the HSM-MX as part of the NUHOMS® MATRIX System.

The NUHOMS® 61BTH DSC licensed under Revision 18 of the UFSAR of CoC 1004 [B.1-4] is a dual purpose (storage/transportation) DSC with two alternate configurations designated as NUHOMS® 61BTH Type 1 DSC or Type 2 DSC. Only the NUHOMS® 61BTH Type 2 DSC is added to the HSM-MX in this appendix.

The NUHOMS® 61BTH Type 2 DSC is added to the NUHOMS® EOS UFSAR as an alternative to the EOS-89BTH DSC in the HSM-MX for horizontal storage of spent boiling water reactor (BWR) fuel assemblies (FAs). The NUHOMS® 61BTH Type 2 DSC is to be stored in the HSM-MX and transferred from a plant's fuel/reactor building in the NUHOMS® OS197/OS197H/OS197FC-B/OS197HFC-B transfer cask (TC) depending on the DSC heat load. All these TCs are licensed under Revision 18 of the UFSAR of CoC 1004 [B.1-4]. This new system is referred as the NUHOMS® MATRIX-61BTH System in this appendix.

Approval of the NUHOMS® MATRIX-61BTH System components is sought under the provisions of 10 CFR Part 72, Subpart L for use under the provisison of a general license in accordance with 10 CFR Part 72, Subpart K. The TN QA *P*rogram applicable to this system satisfies the requirements of 10 CFR Part 72, Subpart G [B.1-1]. 72.48

The format of this appendix has been prepared in compliance with the information and methods defined in Revision 1 to U.S. Nuclear Regulatory Commission (NRC) NUREG-1536 [B.1-2]. Evaluation addressed in this appendix is limited to those areas where existing analysis in Revision 18 of the UFSAR of CoC 1004 [B.1-4] is not bounding to demonstrate that the NUHOMS® MATRIX-61BTH System meets all the requirements of 10 CFR Part 72 [B.1-1]. Sections of this appendix that are not affected by the addition of the NUHOMS® 61BTH Type 2 DSC in the HSM-MX are indicated with "No Change."

Note: References to sections or chapters within this appendix are identified with a prefix B (e.g., Section B.2.3 or Appendix B.2 or Chapter B.2). References to sections or chapters of the UFSAR outside of this appendix (i.e., main body or other appendices of the UFSAR) are identified with the applicable UFSAR section or chapter number (e.g., Section 2.3 or Chapter 2), or appendix (e.g., Appendix A). References to sections of Revision 18 of the UFSAR of CoC 1004 are identified with the applicable UFSAR section or chapter number (e.g., Section 2.3 of reference [B.1-4] or Chapter 2 of reference [B.1-4]) or appendix (e.g., Appendix T of reference [B.1-4]).

When used without distinction, the term OS197FC-B refers to both the OS197HFC-B and OS197FC-B. When used without distinction, the term OS197 refers to the OS197/OS197H/OS197HFC-B, and OS197FC-B.

B.1.1 Introduction

This appendix adds the NUHOMS® 61BTH Type 2 Dry Shielded Canister (DSC) licensed under Revision 18 of the UFSAR of CoC 1004 [B.1-4] in Appendix T to the NUHOMS® MATRIX (HSM-MX) as described and evaluated in Appendix A.

The NUHOMS® 61BTH Type 2 DSC is designed to accommodate up to 61 intact (including reconstituted) or up to 16 damaged (with up to four failed fuel cans (FFCs) loaded with failed fuel) with the remainder intact BWR fuel assemblies with or without fuel channels. Alternatively, 61 damaged BWR fuel assemblies can also be stored. Figure 5 of the Technical Specifications [B.1-5] provides the requirements for location of the intact, damaged, and failed fuels.

The NUHOMS® MATRIX-61BTH System provides structural integrity, confinement, shielding, criticality control, and passive heat removal independent of any other facility structures or components.

The NUHOMS® MATRIX-61BTH System consists of the following components:

- A NUHOMS® 61BTH Type 2 DSC, described in detail in Section B.1.2.1.1. It provides confinement, an inert environment, structural support, heat rejection, and criticality control for the 61 BWR fuel assemblies.
- An HSM-MX matrix module, as described in Section B.1.2.1.2, provides for environmental protection, shielding, and heat rejection during storage,
- An OS197 TC, as described in Section B.1.2.1.3, provides for onsite transfer of the NUHOMS® 61BTH Type 2 DSC.

The alternate NUHOMS® MATRIX-61BTH System configurations are summarized below:

<table>
<tr><th>System Configuration</th><th>Neutron Absorber Plate Type</th><th>Max. Heat Load (kW) per DSC</th><th>Transfer Cask</th><th>Storage Module</th></tr>
<tr><td>1</td><td rowspan="2">Borated Aluminum or MMC or BORAL®</td><td>22.0</td><td>OS197 or OS197H or OS197FC-B</td><td rowspan="3">HSM-MX</td></tr>
<tr><td>2</td><td>27.4</td><td rowspan="2">OS197FC-B</td></tr>
<tr><td>3</td><td>Borated Aluminum or MMC</td><td>31.2</td></tr>
</table>

The NUHOMS® MATRIX-61BTH System requires the use of non-safety related auxiliary transfer equipment described in Section B.1.2.2 and Appendix P of reference [B.1-4] for the NUHOMS® OS197FC TC, but there is no change to any of these items when used with an NUHOMS® OS197/OS197H/OS197FC-B TC.

B.1.2 General Description and Operational Features of the NUHOMS® MATRIX-61BTH System

B.1.2.1 NUHOMS® MATRIX-61BTH System Characteristics

B.1.2.1.1 NUHOMS® 61BTH Type 2 DSC

Each NUHOMS® 61BTH Type 2 DSC (61BTH Type 2 DSC) consists of a DSC shell assembly (cylindrical shell, canister bottom and top cover plates, and shield plugs or shield plug assemblies) and a basket assembly. A sketch of the NUHOMS® 61BTH DSC components is shown in Figure T.1-1 of reference [B.1-4]. The NUHOMS® 61BTH Type 2 DSC incorporates a top grid assembly as shown in Figure T.1-2 of reference [B.1-4] in lieu of the top hold down ring shown in Figure T.1-1 of reference [B.1-4].

The 61BTH Type 2 DSC may be configured in two alternate NUHOMS® MATRIX-61BTH System configurations depending on the DSC heat load, as described in Section B.1.1.

The 61BTH Type 2 DSC and associated configurations allow flexibility to accommodate the payload fuel types described in Section B.2.2, and are compatible with the lifting capacity of most fuel handling cranes. The key design parameters and estimated weights of the 61BTH Type 2 DSC are listed in Table T.1-1 of reference [B.1-4].

The 61BTH Type 2 DSC is shown on drawings NUH61BTH-2000-SAR through drawing NUH61BTH-2003-SAR, included in Section B.1.3.

The primary confinement boundary for the 61BTH Type 2 DSC consists of the DSC shell, the top and bottom inner cover plates, the siphon and vent block, the siphon and vent port cover plates, and the associated welds. Figure T.3.1-1 of reference [B.1-4] provides a pictorial representation of the confinement boundary for the 61BTH Type 2 DSC. The outer top cover plate and associated welds form the redundant confinement boundary.

The cylindrical shell and the inner bottom cover plate boundary welds are fully compliant to Subsection NB of the ASME Code [B.1-6] and are made during fabrication. The top closure confinement welds are multi-layer welds applied after fuel loading and comply with the guidance of ISG-15 [B.1-8]. The outer top cover plate is welded to the shell subsequent to leak testing of the confinement boundary to the leak-tight criteria of ANSI N14.5-1997 [B.1-7].

The 61BTH Type 2 DSC basket structure (refer Figure T.1-3 of reference [B.1-4] for a cross-sectional view) consists of 2 × 2 and 3 × 3 stainless steel fuel compartment assemblies held in place by basket rails in combination with a top grid assembly provided at the top of the basket (Figure T.1-2 of reference [B.1-4]). The four 2 × 2 and five 3 × 3 compartment assemblies are held together by welded stainless steel boxes wrapped around the fuel compartments, which also retain the neutron poison plates placed between the compartment assemblies. The poison plates provide the necessary criticality control and provide a heat conduction path from the fuel assemblies to the canister shell. This method of construction forms a very strong structure of compartment assemblies which provide for storage of 61 fuel assemblies. The clearance dimension between each compartment and fuel assembly is sized to accommodate the limiting fuel assembly size. The details of a 61BTH Type 2 DSC basket assembly are shown in NUH61BTH-2002-SAR, included in Section B.1.3.

The 61BTH Type 2 DSC is designed to use three types of poison materials in the basket: borated aluminum alloy, boron carbide/aluminum metal matrix composite (MMC) or BORAL®. For each poison material, the 61BTH Type 2 DSC basket is analyzed for six alternate basket configurations, depending on the boron loadings analyzed, to accommodate the various fuel enrichment levels (designated as “A” for the lowest B-10 loading to “F” for the highest B-10 loading). The maximum lattice average enrichment of the fuel assemblies allowed for the 61BTH Type 2 DSC basket as a function of the minimum B-10 areal density for various poison materials is shown in Table 9 to Table 12 of the Technical Specifications [B.1-5].

Three alternate designs of the top grid assembly have been provided to provide additional flexibility in fuel assembly loading operations and accommodate alternate hoist grapple designs used at some plants. Alternates 1 and 2 are shown in drawing NUH61BTH-2002-SAR. Alternate 3 is shown in drawing NUH61BTH-2006-SAR and is for intact fuel loadings only. The Top Grid Assembly Alternates 1, 2, and 3 are also interchangably referred to as Hold Down Rings (HDRs).

The transition rails support the fuel assemblies and transfer mechanical loads to the DSC shell. They also provide the thermal conduction path from the basket assembly to the canister shell wall, making the basket assembly efficient in rejecting heat from its payload. The details of the transitional rails are shown on drawing NUH61BTH-2003-SAR.

A top and bottom end cap is installed on each of the fuel compartments that receive a damaged fuel assembly as shown in drawings NUH61BTH-2004-SAR.

The failed fuel assemblies are to be placed in individual failed fuel cans (FFCs). Each FFC is constructed of sheet metal and is provided with a welded bottom closure and a removable top closure, which allows lifting of the FFC with the enclosed damaged assembly/debris. The FFC is provided with screens at the bottom and top to contain fuel debris and allow fill/drainage of water from the FFC during loading operations. The FFC is protected by the fuel compartment tubes, and its only function is to confine the failed fuel.

The FFC geometry and the materials used for its fabrication are shown on drawing NUH61BTH-72-1105.

During dry storage of the spent fuel in the NUHOMS® MATRIX-61BTH system, no active systems are required for the removal and dissipation of the decay heat from the fuel. The 61BTH Type 2 DSC is designed to transfer the decay heat from the fuel to the canister body via the basket and ultimately to the ambient via either the HSM-MX in storage mode or the TC in the transfer mode.

Each canister is identified by a Mark Number, **V-61BTH-W-X-Y-Z**, where:

V refers to user specific designations;

W refers to the DSC Type as described previously (2);

X refers to the basket type (A or B or C or D or E or F);

Y refers to the poison material type (1 = Borated Aluminum, 2 or 2L = MMC for low heat load DSC, 2H = MMC for high heat load DSC, or 3 = BORAL®); and

Z is a number corresponding to a specific canister.

B.1.2.1.2 NUHOMS® MATRIX

There is no change to the design as presented in Appendix A.1.2.1, except that the front DSC support thickness is increased and rear spacer blocks are added between the rear DSC support and the grout in the NUHOMS® MATRIX cavity to align the centerline of the 61BTH Type 2 DSC with that of the HSM-MX door opening. These radial spacer blocks are shown in drawing MX01-5001-SAR. Since the 61BTH Type 2 length is not variable, the rear DSC support spacer blocks are fixed at a 3.18 inch length.

B.1.2.1.3 OS197 Transfer Cask

Depending on the DSC heat load, the NUHOMS® OS197, OS197H, OS197FC-B, or OS197HFC-B transfer casks (TCs) can be used to transfer the NUHOMS® 61BTH Type 2 DSC from a plant's fuel/reactor building to the HSM-MX.

The NUHOMS® OS197/OS197H TCs are described in Revision 18 of the UFSAR of CoC 1004 [B.1-4] and in the drawings included in Appendix E of this UFSAR. The heat load is limited to a maximum of 22.0 kW for these TCs.

The NUHOMS® OS197FC-B/OS197HFC-B TCs consists of the NUHOMS® OS197/OS197H TCs with a modified top lid and TC bottom plate. The modifications necessary to convert NUHOMS® OS197/OS197H TCs into NUHOMS® OS197FC-B/OS197HFC-B TCs are shown on drawings NUH-03-8000-SAR and NUH-03-8007-SAR and are described below.

The top lid of the NUHOMS® OS197FC-B/OS197HFC-B TCs are scalloped out at sixteen locations on the lid underside (refer Figure T.1-4 of reference [B.1-4]) to provide slots that provide an exit path for air circulation through the TC/DSC annulus. This external air circulation feature is needed during the transfer mode if decay heat in a NUHOMS® 61BTH Type 2 DSC is greater than 22.0 kW and specific time limits to complete transfer operations are not met.

To provide distribution of the fan airflow to the TC/DSC annulus region, ten wedge shaped one-half inch steel plates are attached to the inside bottom plate of the TC to form radial channels emanating from the ram access opening to the TC/DSC annulus. The air circulation system is sized to provide a minimum capacity of 450 cfm. The addition of wedges increases the length of the NUHOMS® OS197FC-B TC to 207.72 inches while maintaining the same TC cavity length as OS197/OS197H TC.

B.1.2.2 Transfer Equipment for the NUHOMS® MATRIX-61BTH System

Transfer Trailer

The same transfer trailer loading the EOS-DSCs in EOS-TCs to the HSM-MX will be used for loading the 61BTH Type 2 DSC in the OS197 to the HSM-MX. Therefore, there is no change to Section 1.2.2.

Cask Support Skid

A universal support skid will be used for the transfer of the 61BTH Type 2 DSC in the OS197 to the HSM-MX and is shown in Figure A.1-9. The key design features from the OS197 cask support skid are the same as those described in Section 1.2.2; however, the universal support skid also allows for a NUHOMS® MATRIX loading crane to capture the skid with a grappling mechanism to raise and lower the TC/DSC for insertion into the HSM-MX.

Ram

The same ram loading the EOS-DSCs in EOS-TCs to the HSM-MX will be used for loading the 61BTH Type 2 DSC in the OS197 to the HSM-MX. Therefore, there is no change to Section 1.2.2.

NUHOMS® MATRIX Loading Crane

The same NUHOMS® MATRIX loading crane (MX-LC) loading the EOS-DSCs in EOS-TCs to the HSM-MX will be used for loading the 61BTH Type 2 DSC in the OS197 to the HSM-MX. Therefore, there is no change to Section A.1.2.2.

NUHOMS® MATRIX Retractable Roller Tray

The same NUHOMS® MATRIX retractable roller tray (MX-RRT) loading the EOS-DSCs in EOS-TCs to the HSM-MX will be used for loading the 61BTH Type 2 DSC to the HSM-MX. Therefore, there is no change to Section A.1.2.2.

MX-RRT Handling Device

The same MX-RRT handling device loading the EOS-DSCs in EOS-TCs to the HSM-MX will be used for loading the 61BTH Type 2 in the OS197 to the HSM-MX. Therefore, there is no change to Section A.1.2.2.

HSM-MX Transfer Cask Adapter

To account for the difference between the OS197 top flange diameter and the EOS-TC diameter, an HSM-MX transfer cask (TC) adapter may be mounted to the door recess of the HSM-MX, see Figure B.1-1. The adapter interface is designed mainly to aid in TC/HSM alignment as well as protect workers from radiation shielding between the OS197 and the HSM-MX door opening during transfer operations. Dose rates and occupational exposure in Chapter B.6 and Chapter B.11 are reported without the HSM-MX TC adapter; therefore, the use of this item is mainly for alignment and ALARA purposes.

B.1.2.3 Operational Features for the NUHOMS® MATRIX-61BTH System

B.1.2.3.1 Spent Fuel Assembly Loading Operations

The primary operations for loading fuels into the NUHOMS® 61BTH Type 2 DSC, moving the loaded OS197 TC to ISFSI, and transferring the NUHOMS® 61BTH Type 2 DSC to the HSM-MX is same as described in Section A.1.2.3.1.

B.1.3 Drawings

NUH61BTH-2000-SAR	NUHOMS® 61BTH DSC Type 2 Main Assembly
NUH61BTH-2001-SAR	NUHOMS® 61BTH DSC Type 2 Shell Assembly
NUH61BTH-2002-SAR	NUHOMS® 61BTH DSC Type 2 Basket Assembly
NUH61BTH-2003-SAR	NUHOMS® 61BTH DSC Type 2 Transition Rails
NUH61BTH-2004-SAR	NUHOMS® 61BTH DSC Type 2 Damaged Fuel End Caps
NUH61BTH-2006-SAR	NUHOMS® 61BTH DSC Type 2, Top Grid Assembly Alternate 3
NUH61BTH-72-1105	NUHOMS® 61BTHF Type 2 Transportable Canister for BWR Fuel, Failed Fuel Can
MX01-5001-SAR	NUHOMS® HSM-MX Horizontal Storage Module – MATRIX 61BTH Front and Rear Spacers

Drawings from Section T.1.5 of Reference [B.1-4]:

NUH-03-8000-SAR	General License NUHOMS® ISFSI Onsite Transfer Cask Overview
NUH-03-8007-SAR	General License NUHOMS® ISFSI OS197FC-B Onsite Transfer Cask Main Assembly

Drawing from Section A.1.3:

MX01-5000-SAR	NUHOMS® HSM-MX Horizontal Storage Module – MATRIX Main Assembly

8 7 6 5 4 3 2 1

H G F E D C B A

Proprietary and Security Related Information for Drawing NUH61BTH-2000-SAR NP Withheld Pursuant to 10 CFR 2.390

8 7 6 5 4 3 2 1

H G F E D C B A

Proprietary and Security Related Information for Drawing NUH61BTH-2001-SAR Withheld Pursuant to 10 CFR 2.390

8 7 6 5 4 3 2 1

H G F E D C B A

8 7 6 5 4 3 2 1

H G F E D C B A

Proprietary and Security Related Information for Drawing NUH61BTH-2002-SAR Withheld Pursuant to 10 CFR 2.390

8 7 6 5 4 3 2 1

H G F E D C B A

8 7 6 5 4 3 2 1

H G F E D C B A

Proprietary and Security Related Information
for Drawing NUH61BTH-2003-SAR
Withheld Pursuant to 10 CFR 2.390

8 7 6 5 4 3 2 1

H G F E D C B A

8 7 6 5 4 3 2 1

H G F E D C B A

Proprietary and Security Related Information
for Drawing NUH61BTH-2004-SAR
Withheld Pursuant to 10 CFR 2.390

8 7 6 5 4 3 2 1

8 7 6 5 4 3 2 1

H G F E D C B A

Proprietary and Security Related Information for Drawing NUH61BTH-2006-SAR Withheld Pursuant to 10 CFR 2.390

8 7 6 5 4 3 2 1

H G F E D C B A

Proprietary and Security Related Information
for Drawing NUH61BTH-72-1105-SAR
Withheld Pursuant to 10 CFR 2.390

8 7 6 5 4 3 2 1

H G F E D C B A

Proprietary and Security Related Information for Drawing MX01-5001-SAR Withheld Pursuant to 10 CFR 2.390

H G F E D C B A

8 7 6 5 4 3 2 1

B.1.4 NUHOMS® 61BTH Type 2 DSC Contents

The NUHOMS® 61BTH Type 2 DSC is designed to store intact (including reconstituted) and/or damaged BWR fuel assemblies with or without fuel channels, as described in Section B.2.2. The fuel to be stored is limited to a maximum initial lattice average initial enrichment of 5.0 wt. % and the maximum allowable fuel assembly average burnup is limited to 62 GWd/MTU.

The NUHOMS® 61BTH Type 2 DSC is also authorized to store fuel assemblies containing blended low enriched uranium (BLEU) fuel material.

Reconstituted fuel assemblies containing replacement irradiated stainless steel rods or lower enrichment UO_2 rods instead of Zircaloy clad enriched UO_2 rods are acceptable for storage in the NUHOMS® 61BTH Type 2 DSC as intact fuel assemblies.

The NUHOMS® 61BTH Type 2 DSC can also accommodate up to a maximum of 61 damaged fuel assemblies placed in the fuel compartments located in accordance with Figure 5 of the Technical Specifications [B.1-5]. The DSC basket cells that store damaged fuel assemblies are provided with top and bottom end caps to ensure retrievability.

The NUHOMS® 61BTH Type 2 DSC, when used with the top grid assembly (Alternate 1) design, is also able to accommodate up to a maximum of four failed fuel assemblies encapsulated in individual failed fuel canisters (FFC) and placed in cells located at the outer edge of the DSC as shown Figure 5 of the Technical Specifications [B.1-5].

The contents of the NUHOMS® 61BTH Type 2 DSC is stored with an inert atmosphere of helium.

Further details about the contents authorized in the NUHOMS® 61BTH Type 2 DSC are provided in Chapter B.2, and definitions of damaged fuels, failed fuels, BLEU fuels, and reconstituted fuels are provided in Section 1.1 of the Technical Specifications [B.1-5].

Chapter B.3 provides the structural analysis. Chapter B.4 includes the thermal analysis. Chapter B.5 covers the confinment analysis. Chapter B.6 provides the shielding analysis. Chapter B.7 covers the criticality safety of the NUHOMS® 61BTH Type 2 DSC system and its contents, listing material densities, moderator ratios, and geometric configurations.

The criticality control features of the NUHOMS® 61BTH Type 2 DSC are designed to maintain the neutron multiplication factor k-effective less than the upper subcritical limit equal to 0.95 minus benchmarking bias and modeling bias under all conditions.

B.1.5 Qualification of TN Americas, LLC (Applicant)

The prime contractor for design and procurement of the NUHOMS® MATRIX-61BTH System components is TN Americas, LLC (TN). TN 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 TN's QA Program requirements.

The design activities for the NUHOMS® MATRIX-61BTH System UFSAR were performed by TN and subcontractors, in accordance with TN QA Program requirements. TN is responsible for the design and analysis of the NUHOMS® 61BTH Type 2 DSC, NUHOMS® MATRIX (HSM-MX), OS197 TC, and associated transfer equipment.

Closure activities associated with welding the top cover plates on the DSCs following fuel loading are typically performed by the licensee under the licensee's NRC approved QA Program.

B.1.6 Quality Assurance

The TN Americas, LLC (TN) Quality Assurance (QA) Program has been established in accordance with the requirements of 10 CFR Part 72, Subpart G [B.1-1]. The QA Program applies to the design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of the NUHOMS® MATRIX-61BTH System and components identified as "important-to-safety" and "safety-related." These components and systems are defined in Chapter B.2.

The complete description and specific commitments of the TN QA Program are contained in the TN QA Program Description Manual [B.1-3]. This manual has been approved by the NRC for performing 10 CFR Part 72-related activities.

B.1.7 References

B.1-1 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."

B.1-2 NUREG-1536, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," Revision 1, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, July 2010.

B.1-3 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.

B.1-4 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

B.1-5 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 2.

B.1-6 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsections NB, NG, and NF, 1998 edition including 2000 Addenda.

B.1-7 ANSI N14.5-1997, "Leakage Tests on Packages for Shipment."

B.1-8 U.S. Nuclear Regulatory Commission, Interim Staff Guidance 15, "Materials Evaluation," January 10, 2001.

B.1.8 Supplemental Data

B.1.8.1 Generic Storage Arrays

Information provided in Section A.1.8.1 for the HSM-MX generic storage arrays is applicable to the 61BTH for storage in the HSM-MX. Additionally, 61BTH DSCs and EOS-DSCs may be stored adjacent to each other within the same module because such a configuration is already bounded by the current EOS-DSC analysis or explicitly analyzed. The heat load of the 61BTH is sufficiently low such that the thermal analysis provided in Section A.4 for EOS-DSCs stored in the HSM-MX is bounding of a 61BTH adjacent to an EOS-DSC, and a structural reconciliation of the 61BTH DSC adjacent to an EOS-DSC is provided in Section B.3.9.7.2.3.2. Dose rates for the 61BTH are sufficiently lower than the EOS-DSCs, therefore the evaluation in Chapter A.6 for an HSM-MX fully loaded with EOS-DSCs is bounding of the mixed loading.

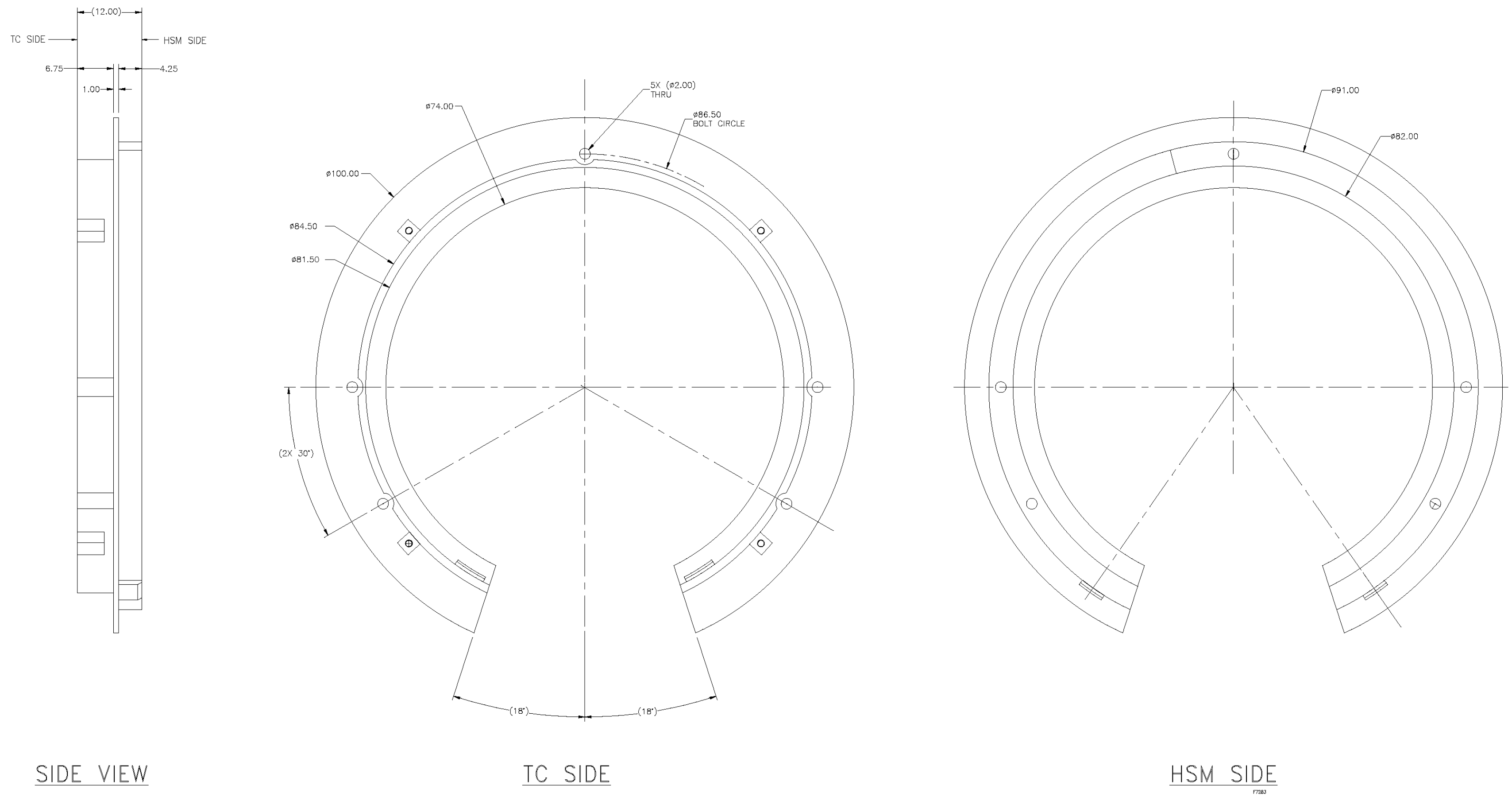


Figure B.1-1
Optional Adapter Ring to Dock the OS197 TC loaded with the 61BTH Type 2 DSC with the HSM-MX

APPENDIX B.2
PRINCIPAL DESIGN CRITERIA

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

List of Tables

B.2 PRINCIPAL DESIGN CRITERIA

This section provides the principal design criteria for the NUHOMS® 61BTH Type 2 DSC described in Appendix B.1. The documentation herein references Revision 18 of the UFSAR of CoC 1004 [B.2-7] to include the 61BTH Type 2 DSC as an authorized storage DSC in the HSM-MX. Evaluation of this DSC in HSM-MX is limited to those areas where existing analysis in CoC 1004 is not bounding.

Section B.2.1 identifies structures, systems, and components (SSCs) important-to-safety (ITS) for the 61BTH System design. Section B.2.2 presents a general description of the spent fuel to be stored. Section B.2.3 provides the design criteria for environmental conditions and naturally occurring phenomena. Section B.2.4 provides a description of the systems that have been designated as important to safety. Section B.2.5 discusses decommissioning considerations. Section B.2.6 summarizes the NUHOMS® 61BTH DSC, HSM-MX, and OS197/OS197H/OS197HFC-B and OS197FC-B TCs design criteria.

TN Americas has considered the requirements in 10CFR 72.236(m) [B.2-3] for compatibility with removal of stored spent nuclear fuel from a reactor site, transportation, and ultimate disposition by the Department of Energy. TN Americas is planning to address these in future transport applications under the requirements of 10 CFR Part 71 for 61BTH Type 2 DSCs.

B.2.1 SSCs Important to Safety

Table B.2-1 provides a list of the major NUHOMS® 61BTH Type 2 DSC components and their classification. Components are classified in accordance with the criteria of 10 CFR Part 72. Structures, systems, and components (SSCs) classified as important-to-safety (ITS) are defined in 10 CFR 72.3 as the features of the ISFSI whose function is:

- To maintain the conditions required to store spent fuel safely.
- To prevent damage to the spent fuel container during handling and storage.
- To provide reasonable assurance that spent fuel can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public.

B.2.1.1 Dry Shielded Canisters

The 61BTH Type 2 DSC provides the fuel assembly support required to maintain the fuel geometry for criticality control. Accidental criticality inside a DSC could lead to offsite doses comparable with the limits in 10 CFR Part 100 [B.2-1], which must be prevented. The DSC also provides the confinement boundary for radioactive materials. Therefore, the DSC is designed to maintain structural integrity under all accident conditions identified in Chapter B.12 without losing its function to provide confinement of the spent fuel assemblies. The DSC is designed, constructed, and tested in accordance with a quality assurance (QA) program incorporating a graded quality approach for ITS requirements as defined by 10 CFR Part 72, Subpart G, paragraph 72.140(B) and described in Chapter B.14.

B.2.1.2 HSM-MX

No change to Section A.2.1.2.

B.2.1.3 ISFSI Basemat and Approach Slabs

No change to Section A.2.1.3.

B.2.1.4 Transfer Equipment

B.2.1.4.1 Transfer Cask and Yoke

No change to Section 3.4.4.1 of reference [B.2-7].

B.2.1.4.2 Other Transfer Equipment

No change to Section A.2.1.4.2.

B.2.1.5 Auxiliary Equipment

No change to Section A.2.1.5.

B.2.2 Spent Fuel to Be Stored

The NUHOMS® 61BTH Type 2 DSC is designed to store intact (including reconstituted), damaged, and failed BWR fuel assemblies as specified in Section 2.3 of the Technical Specifications (TS) [B.2-10]. The fuel to be stored is limited to a maximum lattice average initial enrichment of 5.0 wt. % U-235. The maximum allowable fuel assembly average burnup is limited to 62 GWd/MTU.

The NUHOMS® 61BTH Type 2 DSC is also authorized to store fuel assemblies containing blended low enriched uranium (BLEU) fuel material. Fuel pellets containing BLEU fuel material are no different than commercial grade UO_2 fuel pellets except for elevated concentrations of U-232, U-234, and U-236. It is established in Section 6.2.5 that BLEU fuel has negligible effect on source terms and estimated dose rates compared to commercial grade uranium.

Reconstituted fuel assemblies containing replacement irradiated stainless steel rods or lower enrichment UO_2 rods instead of Zircaloy clad enriched UO_2 rods are acceptable for storage in 61BTH Type 2 DSCs as intact fuel assemblies. The effect on dose rates from irradiated stainless steel rods is negligible when the reconstituted fuel assemblies are loaded in the inner basket locations as discussed in Section B.6.2.6.

The NUHOMS® 61BTH Type 2 DSCs can also accommodate up to a maximum of 61 damaged fuel assemblies placed in the fuel compartments located in accordance with TS Figure 5 [B.2-10]. Damaged BWR fuel assemblies are fuel assemblies containing fuel rods with known or suspected cladding defects greater than hairline cracks or pinhole leaks. The extent of damage in the fuel assembly, including non-cladding damage, is to be limited such that a fuel assembly maintains its configuration for normal and off-normal conditions. The extent of cladding damage is also limited such that no release of pellet material is observed during inspection and handling operations in the pool prior to loading operations. Damaged fuel assemblies shall also contain top and bottom end fittings. Damaged fuel assemblies may also contain missing or partial fuel rods.

The NUHOMS® 61BTH Type 2 DSC, when used with the top grid assembly (Alternate 1) design, is also able to accommodate up to a maximum of four failed fuel assemblies encapsulated in individual failed fuel canisters (FFC) and placed in cells located at the outer edge of the DSC as shown in TS Figure 5 [B.2-10]. Failed fuel is defined as ruptured fuel rods, severed fuel rods, loose fuel pellets, fuel fragments, or the fuel assemblies that may not maintain configuration for normal and off-normal conditions. Failed fuel assemblies may also contain breached rods, grossly breached rods, and other defects such as missing or partial rods, missing grid spacers, or damaged spacers to the extent that the fuel assembly may not maintain configuration for normal or off-normal conditions. Failed fuel shall be stored in a failed fuel canister (FFC). The DSC may contain both failed and damaged fuel when loaded per TS Figure 5 [B.2-10].

Fuel debris and damaged fuel rods that have been removed from a damaged fuel assembly and placed in a secondary container are also considered as failed fuel. Loose fuel debris not contained in a secondary container may also be placed in an FFC for storage, provided the size of the debris is larger than the FFC screen mesh opening and it is located at least 10 inches above the top of the bottom shield plug of the DSC.

Fuel debris may be associated with any type of UO_2 fuel provided that the maximum uranium content and initial enrichment limits are met. The total weight of each FFC plus all its contents shall be less than 705 lbs. The maximum uranium content for the FFC is defined in TS Table 13 [B.2-10].

As limited by their definition, damaged FAs maintain their geometric configuration for normal and off-normal conditions and are confined to their respective compartments by means of top and bottom end caps. Damaged FAs do not contain missing major sub-components like top and bottom nozzles that impact their ability to maintain their geometric configuration for normal and off-normal conditions during loading.

From the standpoint of NUREG-1536 Revision 1, the damaged FAs for the EOS System are more similar to the undamaged FAs, where their geometry is still in the form of intact bundles. For completeness, failed fuel for the EOS System is more similar to the damaged FAs per NUREG-1536 Revision 1 and will require FFCs.

The fuel compartment and the top and bottom end cap together form the “acceptable alternative,” per NUREG-1536 Revision 1 for confinement of damaged fuel. If fuel particles are released from the damaged assembly, the top and bottom end caps provide for the confinement of gross fuel particles to a known volume. Similarly, the FFC provides confinement of the FFC contents to a known volume, and has lifting features to allow the ability to unload the FFC. Additionally, consistent with ISG-2, Revision 2, ready retrieval of the damaged and failed fuel is based on the ability to remove a canister from the HSM.

The structural analysis for damaged fuel cladding described in Chapter B.3 demonstrates that the cladding does not undergo additional degradation under normal and off-normal conditions of storage. The structural analyses performed for FFCs are provided in Section T.3.6.3.4 of reference [B.2-7]. The criticality analysis described in Chapter B.7 is based on damaged and failed fuel in the most limiting credible geometry and material reconfigurations under normal, off-normal, and accident conditions. The maximum enrichment values for damaged or failed fuel are reduced to account for fuel reconfiguration. The thermal analysis described in Chapter B.4 evaluates the effect on the surrounding intact fuel assemblies of reconfiguration of damaged fuel assemblies into rubble under accident conditions. The shielding analysis described in Chapter B.6 states that damaged or failed fuel reconfiguration has a negligible effect on dose rates compared to intact fuel.

A 61BTH Type 2 DSC containing less than 61 fuel assemblies may contain dummy fuel assemblies in the empty slots. The dummy assemblies are unirradiated, stainless steel encased structures that approximate the weight and center of gravity of a fuel assembly. The 61BTH Type 2 DSCs may store up to 61 BWR fuel assemblies arranged in any of the ten alternate heat load zone configurations shown in TS Figure 4A through Figure 4J [B.2-10] with a maximum decay heat of 1.2 kW per assembly and a maximum heat load of 31.2 kW per canister. TS Figure 5 [B.2-10] provides location of damaged and failed fuel assemblies inside the 61BTH Type 2 DSC.

The 61BTH Type 2 DSC is designed with six alternate basket configurations based on the boron content in the poison plates as listed in TS Table 9 through Table 12 [B.2-10] (designated as "A" for the poison plates with the lowest B-10 loading to "F" for the highest B-10 loading). Three alternate poison materials are allowed: (a) borated aluminum alloy, (b) a boron carbide/aluminum metal matrix composite (MMC), or (c) BORAL®. For criticality analysis, 90% of the B-10 content present in the borated aluminum alloy and MMC is credited, while only 75% of the B-10 content in BORAL® is credited.

A summary of the minimum B-10 loadings required in the poison plates as a function of the maximum lattice average enrichment level of the fuel assembly to be stored in the 61BTH Type 2 basket is presented in TS Table 9 for intact fuel, TS Table 10 for up to 16 damaged fuel assemblies, TS Table 11 for failed and damaged fuel, and TS Table 12 for greater than 16 damaged fuel assemblies [B.2-10].

B.2.3 Design Criteria for Environmental Conditions and Natural Phenomena

Table B.2-5 summarizes the design criteria for the 61BTH Type 2 DSC. This table also summarizes the applicable codes and standards utilized for design. Design criteria for the HSM-MX remain the same as shown in Appendix A. The design criteria for the OS197/OS197H/OS197HFC-B/OS197 FC-B TC remain the same as described in Chapter 3, Section 3.2.5 of reference [B.2-7].

B.2.3.1 Tornado Wind and Tornado Missiles

No change to section A.2.3.1.

The evaluation of tornado-generated missile loads on the transfer cask summarized in Chapter 8, Section 8.2 of reference [B.2-7] remains unchanged.

B.2.3.2 Water Level (Flood) Design

No change to Section A.2.3.3.

B.2.3.3 Seismic Design

No change to Section A.2.3.4.

B.2.3.4 Snow and Ice Loading

No change to Section A.2.3.5.

B.2.3.5 Combined Load Criteria

No change to Appendix T, Section T.2.2.5 of reference [B.2-7].

The criteria applicable to the 61BTH Type 2 DSC and HSM-MX are discussed in the following subsections.

B.2.3.5.1 61BTH Type 2 DSC Structural Design Criteria

No change to Appendix T, Section T.2.2.5.1 of reference [B.2-7].

B.2.3.5.1.1 61BTH Type 2 DSC Shell Stress Criteria

No change to Appendix T, Section T.2.2.5.1.1 of reference [B.2-7].

B.2.3.5.1.2 61BTH Type 2 DSC Shell Assembly Stability Criteria

No change to Appendix T, Section T.2.2.5.1.2 of reference [B.2-7].

B.2.3.5.1.3 61BTH Type 2 DSC Basket Stress Criteria

No change to Appendix T, Section T.2.2.5.1.3 of reference [B.2-7].

B.2.3.5.1.4 61BTH Type 2 DSC Basket Stability

No change to Appendix T, Section T.2.2.5.1.4 of reference [B.2-7].

B.2.3.5.2 HSM-MX Design Criteria

No change to Section A.2.4.2.2.

B.2.3.5.3 NUHOMS® OS197/OS197H/OS197HFC-B and OS 197FC-B TC Structural Design Criteria

No change to Appendix T, Section T.2.2.5.3 of reference [B.2-7].

B.2.4 Safety Protection Systems

B.2.4.1 General

No change to Appendix T, Section T.2.3.1 of reference [B.2-7].

B.2.4.2 Protection by Multiple Confinement Barriers and Systems

No change to Appendix T, Section T.2.3.2 of reference [B.2-7].

B.2.4.3 Protection by Equipment and Instrumentation Selection

No change to Appendix T, Section T.2.3.3 of reference [B.2-7].

B.2.4.4 Nuclear Criticality Safety

B.2.4.4.1 Control Methods for Prevention of Criticality

No change to Appendix T, Section T.2.3.4.1 of reference [B.2-7].

B.2.4.4.2 Error Contingency Criteria

No change to Appendix T, Section T.2.3.4.2 of reference [B.2-7].

B.2.4.4.3 Verification Analysis-Benchmarking

No change to Appendix T, Section T.2.3.4.3 of reference [B.2-7].

B.2.4.5 Radiological Protection

No change to Appendix T, Section T.2.3.5 of reference [B.2-7].

B.2.4.6 Fire and Explosion Protection

No change to Appendix T, Section T.2.3.6 of reference [B.2-7].

B.2.5 Decommissioning Considerations

No change to Appendix T, Section T.2.4 of reference [B.2-7].

B.2.6 Summary of NUHOMS® 61BTH System Design Criteria

B.2.6.1 61BTH Type 2 DSC Design Criteria

The NUHOMS® 61BTH Type 2 DSC is designed to store intact, damaged, and failed BWR fuel assemblies with assembly average burnup, lattice average initial enrichment, and cooling time as described in Table 2.3 of TS [B.2-10]. The BWR fuel assembly design characteristics are provided in Table 13 of TS [B.2-10]. The maximum total heat generation rate of the stored fuel is limited to 1.2 kW per fuel assembly. The maximum heat load per canister is limited to 31.2 kW in order to keep the maximum fuel cladding temperature below the limit [B.2-8] necessary to ensure cladding integrity. The fuel cladding integrity is assured by the NUHOMS® 61BTH Type 2 DSC and basket design, which limits fuel cladding temperature and maintains a non-oxidizing environment in the DSC cavity as described in Chapters T.4 and T.7 of reference [B.2-7].

The NUHOMS® 61BTH Type 2 DSC is designed to maintain a subcritical configuration during loading, handling, storage, and accident conditions using a combination of fixed neutron absorbers and favorable geometry. The fixed neutron absorbers are in the form of plates made from either borated aluminum alloy or MMC or BORAL®.

The NUHOMS® 61BTH Type 2 DSC (shell and closure) is designed and fabricated as a Class 1 component in accordance with the rules of the ASME BPV Code, Section III, Subsection NB [B.2-9] and the alternative provisions to the ASME Code as described in Section 4.4.4 of the TS [B.2-10].

The basket is designed and fabricated in accordance with the rules of the ASME BPV Code, Section III, Subsection NG, Article NG-3200 [B.2-9] and the alternative provisions to the ASME Code as described in Section 4.4.4 of the TS [B.2-10].

The principal design loadings for the NUHOMS® 61BTH Type 2 DSC are provided in Table B.2-5. The applicable load combinations for the NUHOMS® 61BTH Type 2 DSC are presented in Table B.2-2 and the corresponding stress criteria are presented in Table B.2-3 and Table B.2-4.

The NUHOMS® 61BTH system is designed to withstand the effects of severe environmental conditions and natural phenomena such as earthquakes, tornadoes, lightning and floods. Chapter B.12 describes the NUHOMS® 61BTH Type 2 DSC behavior under these accident conditions.

The NUHOMS® 61BTH Type 2 DSC design, fabrication, and testing are covered by *TN's* Quality Assurance Program, which conforms to the criteria in Subpart G of 10 CFR Part 72. 72.48

B.2.6.2 HSM-MX Design Criteria

No change to section A.2.4.2.2.

B.2.6.3 OS197/OS197H/OS197FC-B/OS197HFC-B TCs Design Criteria

No change to Appendix T, Section T.2.5.3 of reference [B.2-7].

B.2.7 References

B.2-1 Title 10, Code of Federal Regulations, Part 100, "Reactor Site Criteria."

B.2-2 NUREG-1536, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," July 2010, U.S. Nuclear Regulatory Commission.

B.2-3 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."

B.2-4 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Revision 1, December 1973.

B.2-5 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," Revision 1, March 2007.

B.2-6 ANSI 57.9-1984, "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Type)," American National Standards Institute, New York, NY.

B.2-7 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

B.2-8 NRC Interim Staff Guidance 11, "Cladding Considerations for the Transportation and Storage of Spent Fuel," Revision 3, November 17, 2003.

B.2-9 American Society of Mechanical Engineers, ASME Boiler And Pressure Vessel Code, Section III, Division 1, Subsections NB, NG, and NF, 1998 edition with 2000 Addenda.

B.2-10 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 2.

Table B.2-1
Classification of NUHOMS® 61BTH Type 2 DSC Components

Important To Safety		Not Important To Safety
Canister Assembly (1)	**Basket Assembly (1)**	
• Cylindrical shell • Bottom shield plug • Inner bottom cover/forging • Outer bottom cover/forging • Grapple ring and support • Top shield plug • Inner top cover plate • Outer top cover plate • Siphon/vent port cover plate • Siphon vent block • Support ring • Test port plug • Weld filler metal • Key	• Fuel compartment tube • Fuel compartment wrap • Poison (neutron absorbing) plate • Basket plate • Basket Stud, washers, hex nut • Basket plate insert • R45 & R90 Basket rails, including R90 stiffener plate • Basket holddown ring plate • Spacer pad • Top grid plate, including shield plug grid plate aluminum plate • Holddown ring alignment leg • Weld filler metal • Top Cap, including tool socket and tool socket closure plate • Bottom cap • Failed Fuel Can	• Siphon tube • Quick connect coupling • Male connector • Alignment key • Canister lifting lug and reinforcing plate • Electroless nickel coating • Bottom cap tool socket and stand off pad • Top grid angle, bolts, washers • Basket lockwashers

Note

1. Detailed quality category designation is also provided on the drawings in Appendix T.1, Section T.1.5 of reference [B.2-7].

Table B.2-2
Summary of 61BTH Type 2 DSC Load Combinations
(4 sheets)

Load Case	Horizontal DW		Vertical DW		Internal Pressure [9]	External Pressure	Thermal Condition	Lifting Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
Non-Operational Load Cases										
NO-1 Fab. Leak Testing	—	—	—	—	—	14.7 psig	70°F	—	155 kip axial	Test
NO-2 Fab. Leak Testing	—	—	—	—	15/23 psig [13]	—	70°F	—	155 kip axial	Test
NO-3 DSC Uprighting	x	—	—	—	—	—	70°F	x	—	A
NO-4 DSC Vertical Lift	—	—	x	—	—	—	70°F	x	—	A
Fuel Loading Load Cases										
FL-1 DSC/Cask Filling	—	—	Cask	—	—	Hydrostatic	120°F Cask	x	x	A
FL-2 DSC/Cask Filling	—	—	Cask	—	Hydrostatic	Hydrostatic	120°F Cask	x	x	A
FL-3 DSC/Cask Xfer	—	—	Cask	—	Hydrostatic	Hydrostatic	120°F Cask	—	—	A
FL-4 Fuel Loading	—	—	Cask	x	Hydrostatic	Hydrostatic	120°F Cask	—	—	A
FL-5 Xfer to Decon	—	—	Cask	x	Hydrostatic	Hydrostatic	120°F Cask	—	—	A
FL-6 Inner Cover plate Welding	—	—	Cask	x	Hydrostatic	Hydrostatic	120°F Cask	—	—	A
FL-7 Fuel Deck Seismic Loading	—	—	Cask	x	Hydrostatic	Hydrostatic	120°F Cask	—	Note 10	C
Draining/Drying Load Cases										
DD-1 DSC Blowdown	—	—	Cask	x	Hydrostatic + 15 psig	Hydrostatic	120°F Cask	—	—	A
DD-2 Vacuum Drying	—	—	Cask	x	0 psia	Hydrostatic + 14 psig	120°F Cask	—	—	A
DD-3 Helium Backfill	—	—	Cask	x	12 psig	Hydrostatic	120°F Cask	—	—	A
DD-4 Final Helium Backfill	—	—	Cask	x	3.5 psig	Hydrostatic	120°F Cask	—	—	A
DD-5 Outer Cover Plate Weld	—	—	Cask	x	3.5 psig	Hydrostatic	120°F Cask	—	—	A
Transfer Trailer Loading										
TL-1 Vertical Xfer to Trailer	—	—	Cask	x	15 psig	—	0°F Cask	—	—	A
TL-2 Vertical Xfer to Trailer	—	—	Cask	x	15 psig	—	120°F Cask	—	—	A
TL-3 Laydown	Cask	X	—	—	15 psig	—	0°F Cask	—	—	A
TL-4 Laydown	Cask	X	—	—	15 psig	—	120°F Cask	—	—	A

Appendix B is newly added in Revision 4 by Amendment 2.

Table B.2-2
Summary of 61BTH Type 2 DSC Load Combinations
(4 sheets)

Load Case	Horizontal DW		Vertical DW		Internal Pressure[9]	External Pressure	Thermal Condition	Lifting Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
Transfer To/From ISFSI										
TR-1 Axial Load - Cold	Cask	X	—	—	15 psig	—	0°F	1g Axial	—	A
TR-2 Transverse Load - Cold	Cask	X	—	—	15 psig	—	0°F	1g Transverse	—	A
TR-3 Vertical Load - Cold	Cask	X	—	—	15 psig	—	0°F	1g Vertical	—	A
TR-4 Oblique Load - Cold	Cask	X	—	—	15 psig	—	0°F	½ g Axial + ½ g Trans + ½ g Vert.	—	A
TR-5 Axial Load - Hot	Cask	X	—	—	15 psig	—	100°F	1g Axial	—	A
TR-6 Transverse Load - Hot	Cask	X	—	—	15 psig	—	100°F	1g Trans.	—	A
TR-7 Vertical Load - Hot	Cask	X	—	—	15 psig	—	100°F	1g Vertical	—	A
TR-8 Oblique Load - Hot	Cask	X	—	—	15 psig	—	100°F	½ g Axial + ½ g Trans + ½ g Vert.	—	A
TR-9 25g Corner Drop [12]	Note 1, 14		Note 1, 14		20 psig	—	100°F [2]	—	25g Corner Drop	D
TR-10 75g Side Drop [12]	Note 1		—	—	20 psig	—	—		75g Side Drop	D
TR-11 Top or Bottom End Drops [12]			Note 1, 12		20 psig	—	—		60g End Drop	D

Table B.2-2
Summary of 61BTH Type 2 DSC Load Combinations
(4 sheets)

HSM LOADING	Horizontal DW		Vertical DW		Internal Pressure(9)	External Pressure(9)	Thermal Condition	Handling Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
LD-1 Normal Loading - Cold	Cask	X	—	—	15 psig	—	0°F Cask	+80 Kip	—	A
LD-2 Normal Loading - Hot	Cask	X	—	—	15 psig	—	100° F Cask	+80 Kip	—	A
LD-3	Cask	X	—	—	15 psig	—	117° F w/shade (5)	+80 Kip	—	A
LD-4 Off-Normal Loading - Cold	Cask	X	—	—	20 psig	—	0° F Cask	+80 Kip	FF	B
LD-5 Off-Normal Loading - Hot	Cask	X	—	—	20 psig	—	100° F Cask (5)	+80 Kip	FF	B
LD-6	Cask	X	—	—	20 psig	—	117° F w/shade (5)	+80 Kip	FF	B
LD-7 Accident Loading	Cask	X	—	—	20 psig	—	117° F w/shade (5)	+80 Kip	FF	C/D

HSM STORAGE	Horizontal DW		Vertical DW		Internal Pressure(9)	External Pressure(9)	Thermal Condition	Handling Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
HSM-1 Off-Normal	HSM	X	—	—	15 psig	—	-40° F HSM	—	—	B
HSM-2 Normal Storage	HSM	X	—	—	15 psig	—	0° F HSM	—	—	A
HSM-3 Off-Normal	HSM	X	—	—	15 psig	—	117° F HSM	—	—	B
HSM-4 Off-Normal Temp. + Failed Fuel	HSM	X	—	—	20 psig	—	117° F HSM	—	FF	C
HSM-5 Blocked Vent Storage	HSM	X	—	—	120 psig	—	117°F HSM/BV (2)(4)	—	—	D
HSM-6 B.V. + Failed Fuel Storage	HSM	X	—	—	120 psig	—	117°F HSM/BV (2)(4)	—	FF	D
HSM-7 Earthquake Loading - Cold	HSM	X	—	—	15 psig	—	0° F HSM	—	EQ	C/D (15)
HSM-8 Earthquake Loading - Hot	HSM	X	—	—	15 psig	—	100°F HSM	—	EQ	C/D (15)
HSM-9 Flood Load (50’ H_2O) - Cold	HSM	X	—	—	15 psig	22 psig	0° F HSM	—	Flood (3)	C
HSM-10 Flood Load (50’ H_2O) - Hot	HSM	X	—	—	15 psig	22 psig	100°F HSM	—	Flood (3)	C

Appendix B is newly added in Revision 4 by Amendment 2.

Table B.2-2
Summary of 61BTH Type 2 DSC Load Combinations
(4 sheets)

HSM UNLOADING	Horizontal DW		Vertical DW		Internal Pressure(9)	External Pressure(9)	Thermal Condition	Handling Loads	Other Loads	Service Level
	DSC	Fuel	DSC	Fuel						
UL-1 Normal Unloading - Cold	HSM	X	—	—	15 psig	—	0°F HSM	+60 Kip	—	A
UL-2 Normal Unloading - Hot	HSM	X	—	—	15 psig	—	100° F HSM	+60 Kip	—	A
UL-3	HSM	X	—	—	15 psig	—	117° F w/shade	+60 Kip	—	A
UL-4 Off-Normal Unloading - Cold	HSM	X	—	—	20 psig	—	0° F HSM	+60 Kip	FF	B
UL-5 Off-Normal Unloading - Hot	HSM	X	—	—	20 psig	—	100° F HSM	+60 Kip	FF	B
UL-6	HSM	X	—	—	20 psig	—	117° F w/shade	+60 Kip	FF	B
UL-7 Off-Normal Unloading - FF/Hot (6)(11)	HSM	X	—	—	20 psig	—	100° F HSM	+80 Kip	FF	C
UL-8 Accident Unloading - FF/Hot (7)(11)	HSM	X	—	—	120 (7) psig	—	100° F HSM	+80 Kip	FF	D
RF-1 DSC Reflood	—	—	Cask	X	20 psig (max)	Hydrostatic	120° F Cask	—	—	D

Summary of 61BTH Type 2 DSC Load Combinations Notes:

1. 25g and 75g drop acceleration includes gravity effects. Therefore, it is not necessary to add an additional 1.0g load.
2. For Level D events, only maximum temperature case is considered (thermal stresses are not limited for level D events and maximum temperatures give minimum allowables).
3. Flood load is an external pressure equivalent to 50 feet of water.
4. BV = HSM vents are blocked.
5. At temperature, over 100 °F a sunshade is required over the Transfer Cask. Temperatures for these cases are enveloped by the 100 °F (without sunshade) case.
6. As described in Section T.4 of reference [B.2-7], this pressure assumes release of the fuel cover gas and 30% of the fission gas. Since unloading requires the HSM door to be removed, the pressure and temperatures are based on the normal (unblocked vent) condition. Pressure is applied to the confinement boundary.
7. As described in Section T.4 of reference [B.2-7], this pressure assumes release of the fuel cover gas and 30% of the fission gas. Although unloading requires the HSM door to be removed, the pressure and temperatures are based on the blocked vent condition. Pressure is applied to the shell, inner bottom, and inner top cover plates.
8. Not used.
9. Unless noted otherwise, pressure is applied to the confinement boundary.

10. Fuel deck seismic loads are assumed enveloped by handling loads.
11. Load Cases UL-7 and UL-8 envelop loading cases where the stresses due to insertion loading of 80 kips are added to stresses due to internal pressure (in reality, the insertion force is opposed by internal pressure).
12. The 60g top end drop and bottom end drop are not credible events, therefore these drop analyses are not required. However, consideration of 60g end drop and 75g side drop conservatively envelops the effect of 25g corner drop.
13. Conservatively based on normal operating pressure times 1.5 to cover future 10 CFR Part 71 requirements.
14. A 25g corner drop analysis (30° from horizontal) of 61BTH Type 2 DSC without support from the TC is to be documented.
15. Service Level C is for the standard seismic event and Service Level D is for the high seismic event.

Table B.2-3
Summary of Stress Criteria for Subsection NB Pressure Boundary Components

No change to Table T.2-12 of reference [B.2-7].

Table B.2-4
Summary of Stress Criteria for Subsection NG Components

No change to Table T.2-13 of reference [B.2-7].

Table B.2-5
Summary of NUHOMS® 61BTH Type 2 DSC Design Loadings (1)(2)

Component	Design Load Type	Section Reference	Design Parameters	Applicable Codes
61BTH Type 2 DSC	—	—	—	ASME Code, 1998 Edition with 2000 Addenda, Section III, Subsection NB and Appendix F (Shell) and Subsections NG, NF and Appendix F (Basket/Top Grid) with alternatives noted in Section 4.4.4 of TS [B.2-10]
	Flood	T.2.2.2 of reference [B.2-7]	Maximum water height: 50 ft and water velocity of 15 ft/sec	10CFR72.122(b) [B.2-3]
	Seismic	B.3.9.1.2.5.5	S = ± 2.0g (axial) ± 2.0g (transverse) ± 0.8g (vertical)	NRC Reg. Guides 1.60 and 1.61 [B.2-4] and [B.2-5]
	Dead Load	T.3.6.1.2 T.3.6.1.3 of reference [B.2-7] B.3.9.1.2.5.5	Maximum enveloping weight of loaded 61BTH DSC: 94,000 lb	ANSI 57.9-1984 [B.2-6]
	Normal and Off-Normal Pressure	T.3.6.1. T.3.6.2 of reference [B.2-7]	Normal: Enveloping internal pressure of ≤ 15 psig. Off-Normal: ≤ 20 psig	10CFR72.122(h) [B.2-3]
	Test Pressure	T.3.6.1.2 of reference [B.2-7]	Enveloping internal pressure of 23 psig applied w/o DSC outer top cover plate	10CFR72.122(h) [B.2-3]
	Normal and Off-Normal Operating Temperature	T.3.6.1.2 T.3.6.1.3 T.3.6.2 of reference [B.2-7]	Normal: Ambient air temperature 0 °F to 100 °F Off Normal: Ambient air temperature -40 °F to 117 °F	ANSI 57.9-1984 [B.2-6]
	Normal Handling Loads	T.3.6.1.2 T.3.6.1.3 of reference [B.2-7]	1. Hydraulic ram load of: 80,000 lb (DSC HSM insertion) 60,000 lb (DSC HSM extraction) 2. Transfer (to/from ISFSI) Loads of: 2a. ± 1.0g axial 2b. ± 1.0g transverse 2c. ± 1.0g vertical 2d. ± 0.5g axial ± 0.5g transverse ± 0.5g vertical	ANSI 57.9-1984 [B.2-6]
	Off-Normal Handling Loads	T.3.6.1.2 of reference [B.2-7]	Hydraulic ram load of: 80,000 lb (DSC HSM insertion) 60,000 lb (DSC HSM extraction)	ANSI-57.9-1984 [B.2-6]
	Accident Handling Loads	T.3.7 of reference [B.2-7]	Hydraulic ram load of: 80,000 lb DSC HSM insertion) 80,000 lb (DSC HSM extraction)	
	Accidental Cask Drop Loads	T.3.7.5 of reference [B.2-7]	Equivalent static deceleration of 75g for horizontal side drops, and 25g oblique corner drop	10CFR72.122(b) [B.2-3]
	Accident Internal Pressure	T.4 of reference [B.2-7]	Enveloping internal pressure of ≤ 120 psig based on 100% fuel cladding rupture and fill gas release, 30% fission gas release, and ambient air temperature of 117 °F	10CFR72.122(h) [B.2-3]

Note:

1. The design loadings for the OS197/OS197H/OS197FC-B TC remain unchanged from Chapter 3, Table 3.2-1 of reference [B.2-7].
2. The design loadings for the HSM-MX remain unchanged from Section A.2.3 and Section A.2.4.2.2.

APPENDIX B.3
STRUCTURAL EVALUATION

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

B.3 STRUCTURAL EVALUATION

This chapter and its appendices describe the structural evaluation for the NUHOMS® 61BTH Type 2 DSC and OS197 on-site Transfer Cask (TC) to be used in the NUHOMS® MATRIX (HSM-MX) system, described in Appendix B.1, under normal and off-normal conditions, accident conditions, and natural phenomena events. Structural evaluations are provided for the important-to-safety components (ITS), which are the 61BTH Type 2 DSC and the HSM-MX. The analyses in Appendix T.3 of the CoC 1004 UFSAR [B.3-3] of the OS197 TC envelop the transfer operations of the 61BTH Type 2 DSC for the HSM-MX system and are, therefore, not provided in this chapter.

B.3.1 Structural Design

The HSM-MX is a staggered horizontal storage version of the NUHOMS® EOS System, which provides environmental protection and radiological shielding for the DSCs. The HSM-MX provides heat rejection from the spent fuel decay heat. Sections in this Appendix that do not have an effect on the evaluations presented in Appendix T of the CoC 1004 UFSAR [B.3-3] for the 61BTH Type 2 DSC and OS197 TC or Appendix A.3 for the HSM-MX include a statement that there is no change. A complete evaluation of the 61BTH Type 2 DSC and HSM-MX, which are ITS in accordance with 10 CFR Part 72 [B.3-1], has been performed and is summarized in Appendices B.3 and A.3, respectively.

B.3.1.1 Design Criteria

B.3.1.1.1 61BTH Type 2 DSC Design Criteria

No change to Section T.2 of the CoC 1004 UFSAR [B.3-3].

B.3.1.1.1.1 Stress Criteria

No change to Section T.2.2.5.1.1 of the CoC 1004 UFSAR [B.3-3].

B.3.1.1.1.2 Stability Criteria

No change to Section T.2.2.5.1.2 of the CoC 1004 UFSAR [B.3-3].

B.3.1.1.2 HSM-MX Design Criteria

No change to Appendix A.3.1.1.2.

B.3.1.1.3 OS197 TC Design Criteria

No change to Section T.2.2.5.3 of the CoC 1004 UFSAR [B.3-3].

B.3.2 Weight and Centers of Gravity

No change to Section T.3.2, Table T.3.2-1 of the CoC 1004 UFSAR [B.3-3] for the 61BTH Type 2 DSC and OS197 TC system, and Appendix A.3.2, Table A.3-1 for the HSM-MX.

B.3.3 Mechanical Properties of Materials

B.3.3.1 61BTH Type 2 DSC

No change to Section T.3.3 of the CoC 1004 UFSAR [B.3-3].

B.3.3.2 OS197 TC

The material properties for OS197TC are summarized in Section B.8.2.2.

B.3.3.3 HSM-MX

The material properties for the HSM-MX are summarized in Chapter A.8.

B.3.4 General Standards for NUHOMS® MATRIX System

B.3.4.1 Chemical and Galvanic Reaction

No change to Section T.3.4.1 of the CoC 1004 UFSAR [B.3-3] for the 61BTH Type 2 DSC and OS197 TC. Chemical and galvanic reactions for the HSM-MX system are presented in Chapter A.8.

B.3.4.2 Positive Closure

No change to Section T.3.4.2 of the CoC 1004 UFSAR [B.3-3].

B.3.4.3 Lifting Devices

No change to Section T.3.4.3 of the CoC 1004 UFSAR [B.3-3].

B.3.4.4 Heat

B.3.4.4.1 Summary of Pressures and Temperatures

No change to Section T.3.4.4.1 of the CoC 1004 UFSAR [B.3-3]. Temperatures and pressures for the HSM-MX are described in Chapter B.4. The temperatures are used for the structural evaluations of the 61BTH Type 2 DSC documented in Appendix B.3.9.1.

Maximum temperatures for the various components of the HSM-MX loaded with the 61BTH Type 2 DSC under normal, off-normal, and accident conditions are summarized in Chapter B.4 for all the applicable heat zone loading configurations provided in Appendix A, Technical Specification [B.3-2].

B.3.4.4.2 Differential Thermal Expansion

No change to Section 3.4.4.2.

B.3.4.4.2.1 Axial Gaps between Fuel Assemblies and the DSC Cavity

No change to Section T.3.4.4.2.1 of the CoC 1004 UFSAR [B.3-3].

B.3.4.4.2.2 Radial Gap between the Basket Assembly and the DSC Shell

No change to Section T.3.4.4.2.2 of the CoC 1004 UFSAR [B.3-3].

B.3.4.4.2.3 Axial Gap between the Basket Assembly and the DSC Cavity

No change to Section T.3.4.4.2.3 of the CoC 1004 UFSAR [B.3-3].

B.3.4.4.2.4 Axial Gaps between the Neutron Absorber and Basket Plate Inserts

No change to Section T.3.4.4.2.4 of the CoC 1004 UFSAR [B.3-3].

B.3.4.4.2.5 Axial Gap between the Aluminum Rails and the End Components

No change to Section T.3.4.4.2.5 of the CoC 1004 UFSAR [B.3-3].

B.3.4.4.2.6 Axial Gap between the Rear DSC support, Axial Retainer, and the HSM-MX Cavity

EOS 37PTH DSC length of 199.5 inches is greater than the 61BTH Type 2 DSC length of 196.04 inches. No change to Section A.3.4.4.2.8 for the axial gap between the rear DSC support and the HSM-MX cavity. The *minimum* gap between the DSC and axial retainer remains the same for the 61BTH Type 2 DSC and EOS DSC. 72.48

B.3.4.5 Cold

No change to Section 3.4.5.

B.3.5 Fuel Rods General Standards for 61BTH Type 2 System

No change to Section T.3.5 of the CoC 1004 UFSAR [B.3-3].

B.3.6 Normal Conditions of Storage and Transfer

This section presents the structural analysis of the 61BTH Type 2 DSC, the HSM-MX, and the OS197 TC subjected to normal conditions of storage and transfer. The analyses performed evaluate the components for the design criteria described in Section B.3.1.1.

Numerical analyses have been performed for the normal and accident conditions. The analyses are summarized in this section and described in detail in Appendix B.3.9.1 for the 61BTH Type 2 DSC, Section T.3.6 of the CoC 1004 UFSAR [B.3-3] for the OS197 TC, and Appendices B.3.9.4 and B.3.9.7 for the HSM-MX.

B.3.6.1 61BTH Type 2 DSC

Details of the structural analysis of the DSC shell assemblies are provided in Appendix B.3.9.1, while the structural analysis for the 61BTH Type 2 basket assemblies are provided in Section T.3.6 of the CoC 1004 UFSAR [B.3-3]. There are no changes to the analysis described for the DSC shell except that the DSC shell is analyzed for dead weight, pressure, and seismic load combinations, which are affected when the DSC is loaded into HSM-MX and are provided in Appendix B.3.9.1. The design or loading conditions for the basket remain the same when loaded into the DSC shell and, therefore, results for the basket from Section T.3.6 of the CoC 1004 UFSAR [B.3-3] remain the same and are applicable.

B.3.6.2 HSM-MX

No change to Section A.3.6.2 except the structural evaluations for the HSM-MX when loaded with the 61BTH Type 2 DSC are presented in Appendix B.3.9.4.

B.3.6.3 OS197 TC

No change to Section T.3.6 of the CoC 1004 UFSAR [B.3-3].

B.3.7 Off–Normal and Hypothetical Accident Conditions of Storage and Transfer

This section presents the structural analyses of the 61BTH Type 2 DSC, the OS197 TC, and the HSM-MX subjected to off-normal and hypothetical accident conditions. These analyses are summarized in this section and described in detail in Appendix B.3.9.1 for the 61BTH Type 2 DSC, Section T.3.7 of the CoC 1004 UFSAR [B.3-3] for the OS197 TC, and Appendices B.3.9.1 through B.3.9.7 for the HSM-MX.

B.3.7.1 61BTH Type 2 DSC

Detailed geometry descriptions, material properties, loadings, and structural evaluation for the affected load combinations of the DSC are presented in Appendix B.3.9.1. The design and loading conditions for the basket remain the same when loaded into the DSC shell and, therefore, results for the basket from Section T.3.7 of the CoC 1004 UFSAR [B.3-3] remain the same and are applicable.

B.3.7.2 HSM-MX

Structural evaluations for the HSM-MX considering the use of the 61BTH Type 2 DSC for storage/transfer operations are presented in Appendix B.3.9.4.

B.3.7.3 OS197 TC

No change to Section T.3.7 of the CoC 1004 UFSAR [B.3-3] for the OS197 TC accident analysis.

B.3.8 References

B.3-1 Title 10, Code of Federal Regulations, Part 72, "Licensing Requirements for the Storage of Spent Fuel in the Independent Spent Fuel Storage Installation," U.S. Nuclear Regulatory Commission.

B.3-2 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 2.

B.3-3 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

APPENDIX B.3.9.1
DSC SHELL STRUCTURAL ANALYSIS

Table of Contents

List of Tables

Appendix B is newly added in Revision 4 by Amendment 2.

List of Figures

B.3.9.1 61BTH TYPE 2 DSC SHELL STRUCTURAL ANALYSIS

The purpose of this appendix is to present the structural evaluation of the shell assembly of the 61BTH Type 2 dry shielded canister (DSC) under all applicable normal, off-normal, and accident loading conditions using the OS197 transfer cask (TC) for transfer operations and stored in the NUHOMS® MATRIX (HSM-MX).

The DSC shell is evaluated in CoC 1004 for all loads and load combinations. Only the storage condition loads for the 61BTH Type 2 DSC stored in HSM-MX is evaluated in this section. Therefore, results from Chapter T.3.6 and T.3.7 from CoC 1004 [B.3.9.1-6] are applicable to this chapter.

B.3.9.1.1 General Description

No Change to the general description of 61BTH Type 2 DSC presented in Chapter T.3.1.1 of CoC 1004 [B.3.9.1-6].

B.3.9.1.2 61BTH Type 2 DSC Shell Assembly Stress Analysis

No Change to the DSC shell stress analysis for the 61BTH Type 2 DSC presented in Chapter T.3.6.1 and Section T.3.7.4 of CoC 1004 [B.3.9.1-6] except for storage condition loads. The storage condition loads are evaluated in this section.

B.3.9.1.2.1 Material Properties

For elastic analysis, temperature dependent material properties used for each component of the DSC shell assembly are obtained from the American Society of Mechanical Engineers (ASME) code [B.3.9.1-3]. The allowable stresses are taken at 400 °F.

For plastic analyses, a bilinear stress-strain curve with a 5% tangent modulus is used for steel components.

B.3.9.1.2.2 61BTH Type 2 DSC Shell Stress Criteria

No Change to the stress criteria of 61BTH Type 2 DSC presented in Chapter T.2.2.5.1.1 of CoC 1004 [B.3.9.1-6].

B.3.9.1.2.3 61BTH Type 2 Finite Element Model Description

The 61BTH Type 2 DSC shell assembly is analyzed for the storage load conditions using a three-dimensional (3D) 180° half- symmetric finite element model (FEM). Enveloping dimensions were used as an input parameter for developing a finite element model to envelop the 61BTH Type 2 DSC. The finite element model description is the same as described in Section 3.9.1.2.3. ANSYS version 17.1 [B.3.9.1-1] is used for the analysis in this appendix.

Figure B.3.9.1-1 depicts the components of the HSM-MX DSC support and axial retainer. Table B.3.9.1-1 lists the dimensional inputs used for the 61BTH Type 2 DSC model. Table B.3.9.1-2 lists the material designations of each modeled DSC component. The details of the top and bottom welds are shown in Figure B.3.9.1-5. A description of the FEM for the DSC components are shown below.

B.3.9.1.2.4 Post-Processing

No change to Section 3.9.1.2.5.

B.3.9.1.2.5 Load Cases for 61BTH Type 2 DSC Shell Stress Analysis

No change to Section T.3.6.1 as provided in CoC 1004 [B.3.9.1-6], except storage condition loads such as dead weight, pressure, and seismic loads.

B.3.9.1.2.5.1 Dead Weight

The dead weight is analyzed for the following three basic configurations:

- When the DSC is vertical in the OS197/OS197H/OS197FC/OS197FC-B TC,
- When the DSC is horizontal in the OS197/OS197H/OS197FC/OS197FC-B TC,
- When the DSC is horizontal in the HSM-MX.

When the DSC is vertical in the OS197/OS197H/OS197FC/OS197FC-B TC

No change to the dead weight (vertical) analysis of 61BTH Type 2 DSC presented in Chapter T.3.6.1.2 of CoC 1004 [B.3.9.1-6].

When the DSC is horizontal in the OS197/OS197H/OS197FC/OS197FC-B TC

No change to the dead weight (horizontal in TC) analysis of 61BTH Type 2 DSC presented in Chapter T.3.6.1.2 of CoC 1004 [B.3.9.1-6].

When the DSC is horizontal in the HSM-MX

When stored in the HSM-MX, the DSC shell is supported by the front and rear DSC supports. The inertial loads of the DSC internals are accounted for by applying an equivalent pressure onto the inner surface of the DSC shell. The magnitude of the pressure is determined based on the payload of 100 kips.

The interfaces between the DSC and the HSM-MX supports, axial retainer, and rear stop plates are modeled through surface-to-surface contact elements (ANSYS CONTA173 and TARGE170). The supports, stop plate, and axial retainer are constrained in all degrees of freedom.

Figure B.3.9.1-2 and Figure B.3.9.1-3 show the pressure load and boundary conditions applied to the Finite Element Model (FEM).

B.3.9.1.2.5.2 Internal and External Pressure

The DSC pressure boundary is defined by the DSC shell, the IBCP, the ITCP, and the associated welds. Since there are no gaps between the top end plate components, the ITCP bears against the OTCP. Since the ITCP meets the leaktight requirements of ANSI N14.5 [B.3.9.1-7], no leakage is feasible and, therefore, the pressure load is shared by the two plates according to their relative stiffness. Similarly, the absence of gaps between the bottom end components allows the IBCP to bear against the IBS, which, in turn, bears against the OBCP.

Normal (Level A)	15 psig (Elastic)
Off-Normal (Level B)	20 psig (Elastic)
Accident (Level D)	120 psig (Elastic-plastic)

The design pressure of the DSC is 15 psig. A bounding pressure of 20 psig was used in structural evaluations for normal and off-normal conditions. Two load cases were analyzed: one with an internal pressure of 20 psig (normal) and the second with an internal pressure of 120 psig (accident) in addition to the load applied for the dead weight load case.

All of the nodes of the inner surface of DSC shell confined by ITCP and IBCP are selected for application of internal pressure. Figure B.3.9.1-4 shows the internal pressure applied onto the inside of the DSC cavity.

In addition to the internal pressure loads listed above, the DSC will be subjected to hydrostatic, blowdown, vacuum, and test pressures during the fuel loading and draining/drying processes. Prior to loading fuel and without the top end components in place, the TC/DSC annulus is filled with water resulting in a hydrostatic external load on the DSC shell. The hydrostatic load is then balanced by filling the DSC with water.

After the fuel is loaded, the TSP and ITCP are installed and an internal blowdown pressure of 15 psig is applied to evacuate the DSC of water. The DSC internals are then dried under vacuum conditions. The DSC is backfilled with helium at 20 psig.

Equivalent external pressure of 22 psig corresponding to the flood load is applied at all external nodes of the DSC.

B.3.9.1.2.5.3 HSM-MX Loading/Unloading

No Change to the HSM-MX loading/unloading evaluation of 61BTH Type 2 DSC presented in Chapter T.3.6 of CoC 1004 [B.3.9.1-6].

B.3.9.1.2.5.4 Transfer/Handling Load

No Change to the HSM-MX transfer/handling evaluation of 61BTH Type 2 DSC presented in Chapter T.3.6 of CoC 1004 [B.3.9.1-6].

B.3.9.1.2.5.5 Seismic Load during Storage

The model described in Section B.3.9.1.2.5.1 for dead weight in the HSM-MX is used and updated to reflect the effect of the vertical 0.8g load, transverse 2.0g load, axial (longitudinal) 2.0g load, and the internal pressure load of 20 psig.

Two elastic-plastic runs are performed for this load:

1. 0.8g vertical + 2.0g transverse + 2.0g axial with the weight of DSC internals modeled by equivalent pressure application on ITCP with addition of internal pressure of 20 psig.
2. 0.8g vertical + 2.0g transverse + 2.0g axial with the weight of DSC internals modeled by equivalent pressure application on IBCP with addition of internal pressure of 20 psig.

The dead weight, 0.8g vertical and 2.0g transverse effect is modeled by multiplying the pressure from the dead weight case by a conservative factor of 4.5.

Seismic axial forces toward the HSM-MX door are resisted by the axial retainer. The retainer is a 3.5” by 3.5” steel bar located horizontally through the HSM-MX door. The retainer bears against the OBCP. The OBCP experiences compressive bearing stresses in the vicinity of the axial retainer. The bearing stresses experienced by the OBCP need not be evaluated for Service Level D loads.

Seismic axial forces away from the HSM-MX door are resisted by the DSC stop plates located at the ends of the supports. The stop plates are 10 inches wide. Because the OTCP is recessed from the edge of the DSC shell, the stop plates bear against the bottom edge of the DSC shell only.

B.3.9.1.2.5.6 Cask Drop

No change to the cask drop evaluations of 61BTH Type 2 DSC presented in Chapter T.3.7.4 of CoC 1004 [B.3.9.1-6].

B.3.9.1.2.5.7 Thermal Loads

The heat load for the 61BTH Type 2 DSC is 31.2 kW provided Section T.1 of CoC 1004 [B.3.9.1-6] is lower compared to the heat load of 50.0 kW for the EOS 37PTH DSC [B.3.9.1-2]. Section B.3.9.4.11 concludes that the EOS-37PTH DSC bounds the 61BTH Type 2 DSC when stored in the HSM-MX. The maximum shell temperature of the 61BTH Type 2 DSC when stored in HSM-H or HSM-HS provided in CoC 1004 [B.3.9.1-6] is less compared to the EOS 37PTH-DSC when stored in the HSM-MX. Therefore, the evaluation for the NUHOMS® 61BTH Type 2 DSC is performed using temperature gradient taken from EOS 37PTH DSC.

B.3.9.1.2.5.8 61BTH Type 2 Load Combinations

No change to the load combinations for the evaluation of 61BTH Type 2 DSC presented in Table T.2-11 of CoC 1004 [B.3.9.1-6], except for storage load combinations. Table B.3.9.1-4 provides the HSM-MX storage load combinations described in this section.

Stresses generated by applied loads described in Section B.3.9.1.2.5 are combined in a manner that bounds all load conditions under consideration. The methodologies for combining the load cases into their corresponding load combinations are described in the following sections.

Load Combination 1

Load Combination 1 (LC1) addresses the DSC when it is in the horizontal position. LC1 is developed by post processing the stresses from an FEM that includes the dead weight and an internal pressure of 20 psig within the DSC and subsequently added with the stress intensities from the thermal load case. This load combination is the same as HSM-1/2/3/4 provided in Table T.2-11 of CoC 1004 [B.3.9.1-6].

Load Combination 2

Load Combination 2 (LC2) addresses the DSC when it is in the horizontal position. LC2 is developed by post processing the stresses from an FEM that includes the dead weight and an internal pressure of 120 psig within the DSC. This load combination is the same as HSM-5/6 provided in Table T.2.11 of CoC 1004 [B.3.9.1-6].

Load Combination 3

Load Combination 3 (LC3) addresses the DSC when it is in the horizontal position. LC3 is developed by post processing the stresses from an FEM that includes the dead weight, an internal pressure of 20 psig, and the seismic loads. This load combination is the same as HSM-7/8 provided in Table T.2.11 of CoC 1004 [B.3.9.1-6].

Load Combination 4

Load Combination 4 (LC4) addresses the DSC when it is in the horizontal position. LC4 is developed by post processing the stresses from an FEM that includes the dead weight and an external pressure of 22 psig within the DSC. This load combination is the same as HSM-9/10 provided in Table T.2.11 of CoC 1004 [B.3.9.1-6].

B.3.9.1.3 61BTH Type 2 DSC Shell Buckling Evaluation

No Change to the DSC shell buckling evaluation of 61BTH Type 2 DSC presented in Chapter T.3.7.4.2.4 of CoC 1004 [B.3.9.1-6].

B.3.9.1.4 61BTH Type 2 DSC Fatigue Analysis

Fatigue effects on the NUHOMS® 61BTH Type 2 DSC are addressed using NB-3222.4 criteria of [B.3.9.1-4]. Fatigue effects need not be specifically evaluated provided the criteria in NB-3222.4(d) are met. The six criteria and their application to the DSC are presented below:

A. The first criterion states that the DSC is adequate for fatigue effects provided that the total number of atmospheric-to-operating pressure cycles during normal operation (including startup and shutdown) does not exceed the number of cycles on the applicable fatigue curve corresponding to an S_a value of three times the S_m value of the material at operating temperatures. This condition is satisfied for the DSC since the pressure is not cycled during its design life. The pressure established at the time that the DSC is sealed following fuel loading and DSC closure operations is maintained during normal storage in the HSM-MX.

B. The second criterion states that DSC is adequate for fatigue effects provided that the specified full range of pressure fluctuations during normal operation does not exceed the quantity (1/3) × design pressure × (S_a/S_m), where S_a is the value obtained from the applicable fatigue curve for the total specified number of significant pressure fluctuations, and S_m is the allowable stress intensity for the material at operating temperatures.

   Significant pressure fluctuations are those for which the total excursion exceeds (1/3) × design pressure × (S/S_m), where S equals the value of S_a for 10^6 cycles. Using a design pressure of 20.0 psig, an S_m value of 18,700 psi, and an S value of 28,200 psi, the total range for a significant pressure fluctuation is 10.1 psig. This pressure fluctuation is not expected to occur during normal storage as a result of seasonal ambient temperature changes.

   Ambient temperature cycles significant enough to cause a measurable pressure fluctuation are assumed to occur five times per year for 80 years. The number of fluctuations with this pressure range is expected to be 400 for the DSC. The value of S_a associated with this number of cycles is 159 ksi. Hence, the value of (1/3) × design pressure × (S_a/S_m) is equal to 56.68 psig. Clearly, this value will not be exceeded during the pressure fluctuation of the DSC. Therefore, the second criterion is satisfied for the DSC.

C. The third criterion states that the DSC is adequate for fatigue effects provided that the temperature differences between any two adjacent points on the DSC during normal operation do not exceed $S_a/2E\alpha$, where S_a is the value obtained from the applicable fatigue curve for the specified number of startup-shutdown cycles, α is the instantaneous coefficient of thermal expansion at the mean value of the temperatures at the two points, and E is the modulus of elasticity at the mean value of the temperatures at the two points.

For an operational cycle of the DSC, thermal gradients occur during fuel loading, DSC closure, and transfer of the DSC to the HSM-MX. This half-cycle is approximately reversed for DSC unloading operations. However, this normal operational cycle occurs only once in the 50-year design service life of a DSC. Since there is only one startup-shutdown cycle associated with the DSC, the value of S_a is very large (>700 ksi). Therefore, the value of $S_a/2E\alpha$ is very large (>1390 °F). This is far greater than the temperature difference between any two adjacent points on the DSC. Thus, the third criterion is satisfied for the DSC.

D. The fourth criterion states that the DSC is adequate for fatigue effects provided that the temperature difference between any two adjacent points on the DSC does not change during normal operation by more than the quantity $S_a/2E\alpha$, where S_a is the value obtained from the applicable fatigue curve for the total specified number of significant temperature-difference fluctuations.

A temperature-difference fluctuation is considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$ where S is the value of S_a (28,200 psi) obtained from the applicable fatigue curve for 10^6 cycles if the number of cycles is 10^6 or less.

Small fluctuations in the DSC thermal gradients during normal storage in the HSM-MX occur as a result of seasonal ambient temperature changes. Ambient temperature cycles significant enough to cause a measurable thermal gradient fluctuation are assumed to occur five times per year for 80 years. The temperature gradient fluctuation is 400 cycles. Since this is less than 10^6 cycles, therefore, the value of $S/2E\alpha$ at 10^6 cycles is 56 °F.

The most significant fluctuation in normal operating temperature occurs during a change in ambient temperature from -20 to 100 °F. A review of thermal evaluation of HSM-MX loaded with NUHOMS® 61BTH Type 2 DSC storage load cases in Chapter 4 concluded that the temperature difference between adjacent points in the DSC does not exceed the quantity 56 °F; therefore, the fourth condition is satisfied for the DSC.

E. The fifth criterion states that for components fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, the total algebraic range of temperature fluctuation experienced by the component during normal operation must not exceed the magnitude $S_a/2(E_1\alpha_1 - E_2\alpha_2)$, where S_a is the value obtained from the applicable fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion at the mean temperature value involved for the two materials of construction.

A temperature fluctuation is considered to be significant if its total excursion exceeds the quantity $S/2(E_1\alpha_1 - E_2\alpha_2)$, where S is the value of S_a obtained from the applicable fatigue curve for 10^6 cycles. If the two materials have different applicable design fatigue curves, the lower value of S_a shall be used. Since the structural material used to construct the DSC shell is SA240 Type 304 and the shield plug is A-36, therefore taking the values of $E_1 = 26.5 \times 10^6$ psi, $E_2 = 27.7 \times 10^6$, $\alpha_1 = 9.5 \times 10^{-6}$, and $\alpha_2 = 7.1 \times 10^{-6}$, the quantity $S/2(E_1\alpha_1 - E_2\alpha_2) =$ 255.9 °F.

Since the DSC experiences temperature fluctuation from -20 to 100 °F, the range of temperature fluctuation is 120 °F, which is less than 255.9 °F. Therefore, the fifth criterion is satisfied for the 61 BTH Type 2 DSC.

F. The sixth criterion states that the DSC is adequate for fatigue effects provided that the specified full range of mechanical loads does not result in a stress range which exceeds the S_a value obtained from the applicable fatigue curve for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds 10^6, the S_a value at $N = 10^6$ may be used.

A load fluctuation is considered to be significant if the total excursion of stresses exceeds the value of S_a obtained from the applicable fatigue curve for 10^6 cycles. The only mechanical loads that affect the DSC are those associated with handling loads and a seismic event. One handling load cycle and a major seismic event are postulated during the design life of the DSC. The DSC stresses resulting from these mechanical load fluctuations are small since the structural capacity of the DSC is designed for extreme accident loads such as a postulated cask drop.

The number of significant cycles associated with mechanical load fluctuations is conservatively assumed to be 1,000. The value of S_a associated with this number of cycles is 119 ksi. Since the maximum stress range intensity permitted by the code is 3.0 S_m, or 56.1 ksi for SA-240 Type 304 stainless steel at 400 °F, this sixth condition is satisfied for the DSC.

The evaluation presented in the preceding paragraphs demonstrates that the six criteria contained in NB-3222.4(d) are satisfied for all components of the NUHOMS® 61BTH Type 2 DSC.

B.3.9.1.5 61BTH Type 2 DSC Weld Flaw Size Evaluation

B.3.9.1.5.1 Methodology

It is stipulated that the critical flaw configuration is a circumferential weld flaw exposed to the tensile component radial stress. The determination of the allowable surface and subsurface flaw depth is accomplished by means of the methodology outlined below.

- Determine the tensile radial membrane stress in the weld. Evaluate membrane radial stresses occurring at the weld between the OTCP and the DSC shell for all individual loads.
- Determine limiting membrane radial stresses in the OTCP weld for all load combinations, for all applicable service levels (A and D).
- Multiply limiting stresses with safety factors SF_m for the corresponding service levels.
- Since OTCP weld is gas tungsten arc welding (GTAW) (non-flux weld), according to ASME Code Section XI, Division 1, Figure C-4210-1 [B.3.9.1-5], maximum allowable flaw depth is estimated using limit load.

The allowable membrane stress, S_t, in the flawed section for each service level is determined from Article C-5322, Appendix C [B.3.9.1-5], where the relation between the applied membrane stress and flaw depth at incipient stress is given.

B.3.9.1.5.2 Flaw Size Calculation

For 3D, half-symmetric model, as described in Section B.3.9.1.2.3, the tensile radial membrane stresses in the weld are evaluated by the stress linearization method explained in Section B.3.9.1.2.4.

Radial stresses for controlling load combination are calculated by adding individual load cases. Bounding radial tensile stresses in OTCP weld for all load combinations for Service Levels A and D are assessed. The allowable flaw depths, calculated by means of the methodology described in the previous section, are shown in Table B.3.9.1-10.

Based on the evaluation, requirements for welding and weld inspections should be based on limiting the weld critical depth for surface and subsurface flaws to the following values:

- Surface Crack: 0.38 inch
- Subsurface Crack: 0.38 inch

B.3.9.1.6 Conclusions

The 61BTH Type 2 DSC shell assembly has been analyzed for normal, off-normal, and accident load conditions using three dimensional finite element analyses in Appendix T, Chapters T.3.6 and T.3.7 from CoC 1004 [B.3.9.1-6], except for storage loads. The storage load combinations provided in B.3.9.1.2.5.8 are used for the analysis of the 61BTH Type 2 DSC. Stress intensities in different components of the DSC shell assembly compared with ASME code stress intensity allowables and the resulting stress ratios are summarized in Table B.3.9.1-5. The stress ratio is calculated by dividing the maximum stress intensity by the stress intensity allowable value, with the stress ratio required to be less than 1.

The DSC weld stresses are summarized in Table B.3.9.1-6 and Table B.3.9.1-7. The maximum weld stress ratio is 0.96 and occurs at the DSC shell to ITCP weld for Load Combination 1. The maximum radial weld stress is summarized in Table B.3.9.1-8.

Table B.3.9.1-9 summarizes the stress results for the controlling load combination. The maximum component stress ratio is equal to 0.73 in the DSC shell confinement for LC1 (storage condition in the HSM-MX, dead weight normal conditions). The second maximum component stress ratio is equal to 0.61 and occurs in the outer bottom cover plate during the seismic load (LC3).

The structural integrity of the DSC shell, including closure welds, is maintained since the maximum stress ratio is less than 1. Therefore, it is concluded that the NUHOMS® 61BTH Type 2 DSC is structurally adequate under all anticipated load conditions for service during the transfer and storage in the HSM-MX.

B.3.9.1.7 References

B.3.9.1-1 ANSYS Computer Code and User's Manual, Release 17.1.

B.3.9.1-2 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 2.

B.3.9.1-3 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition through 2000 Addenda.

B.3.9.1-4 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, 1998 Edition through 2000 Addenda.

B.3.9.1-5 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section XI, Division 1, Appendix C, 1998 Edition Addenda through 2000 Addenda.

B.3.9.1-6 TN Americas LLC, "Updated Final Safety Analysis Report for the NUHOMS® Horizontal Modular Storage System for Irridiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

B.3.9.1-7 ANSI N14.5, "Leakage Tests on Packages for Shipment of Radioactive Materials," 1997.

Table B.3.9.1-1
61BTH Type 2 DSC Input Dimensions for Finite Element Model

DSC Type	Length (in)	Cavity (in)	OD (in)	Shell (in)	OTCP (in)	ITCP (in)	TSP (in)	OBCP (in)	IBCP (in)	BSP (in)
61BTH Type 2	198.50	186.05	67.19	0.50	1.25	0.75	5.75	1.70	0.75	2.25

Table B.3.9.1-2
Material of the 61BTH Type 2 DSC Components (Analysis)

DSC Shell	ASME SA-240 Type 304
OTCP	ASME SA-240 Type 304
ITCP	ASME SA-240 Type 304
TSP	ASTM A36
OBCP	ASME SA-240 Type 304
IBCP	ASME SA-240 Type 304
BSP	ASTM A36
Grapple Ring Support	ASME SA-240 Type 304
Grapple Ring	ASME SA-240 Type 304
Support Ring	ASME SA-240 Type 304

Table B.3.9.1-3
Elastic Plastic Material Properties

Material Property	SA-240 Type 304 @ 400 °F	SA-36 @ 400 °F
Elastic Modulus (psi)	26.5×10^6	27.7×10^6
Yield Strength (psi)	20.7	30.8
Tangent Modulus, E_t (psi)	5% of E = 1.325×10^6	5% of E = 1.385×10^6

Table B.3.9.1-4
NUHOMS® 61BTH DSC Shell Assembly Loads and Load Combinations

Loading Type	DSC Orientation	Loads for Analysis	Load Combination	Service Level	Load Combination No.
Dead Weight (DW)	Horizontal (HSM – 1/2/3/4)	1g Down	DW + Pressure + Thermal	A	1
Internal Pressure – Off Normal		20 psig			
Thermal – Off Normal		Thermal Off Normal			
Dead Weight (DW)	Horizontal (HSM – 5/6)	1g Down	DW + Accident Pressure	D	2
Internal Pressure – Accident		120 psig			
Dead Weight (DW)	Horizontal HSM – 7/8	1g Down	DW + Pressure + Seismic	D	3
Internal Pressure – Off Normal		20 psig			
Seismic (S)		S = ± 1.61 (axial) ± 1.62 (transverse) ± 0.80 (vertical)			
External Pressure	Horizontal HSM – 9/10	22 psig	DW + EP	D	4

Table B.3.9.1-5
NUHOMS® 61BTH DSC Results Load Combinations
(4 sheets)

LC No.	Service	Loads	Components		Stress Category [ksi]				
					P_m	$P_m + P_b$	P_L	P_m (or P_L) + P_b + Q	P_m (or P_L) + P_b + Q + P_e
1	A	DWh + PI(20)	DSC Shell (Confinement)	Stress Intensity	5.85	10.23	18.64	23.46	41
				Allowable Stress	18.7	28.05	28.05	56.1	56.1
				Stress Ratio	0.31	0.36	0.66	0.42	0.73
			DSC Shell (Non-Confinement)	Stress Intensity	5.88	6.82	7.13	9.05	28.44
				Allowable Stress	18.7	28.05	28.05	56.1	56.1
				Stress Ratio	0.31	0.24	0.25	0.16	0.51
			OTCP	Stress Intensity	5.88	10.21	8.1	17.99	24.61
				Allowable Stress	18.7	28.05	28.05	56.1	56.1
				Stress Ratio	0.31	0.36	0.29	0.32	0.44
			ITCP	Stress Intensity	3.14	8.41	7.38	18.86	29.04
				Allowable Stress	18.7	28.05	28.05	56.1	56.1
				Stress Ratio	0.17	0.3	0.26	0.34	0.52
			OBCP	Stress Intensity	2.47	6.48	3.68	6.2	21.02
				Allowable Stress	18.7	28.05	28.05	56.1	56.1
				Stress Ratio	0.13	0.23	0.13	0.11	0.37
			IBCP	Stress Intensity	2.87	4.11	5.86	8.61	24.83
				Allowable Stress	18.7	28.05	28.05	56.1	56.1
				Stress Ratio	0.15	0.15	0.21	0.15	0.44

Table B.3.9.1-5
NUHOMS® 61BTH DSC Results Load Combinations
(4 sheets)

LC No.	Service	Loads	Components		Stress Category [ksi]				
					P_m	$P_m + P_b$	P_L	P_m (or P_L) + P_b + Q	P_m (or P_L) + P_b + Q + P_e
2	D	DWh + PI(120)	DSC Shell (Confinement)	Stress Intensity	12.36	22.22	22.81	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.28	0.39	0.4	NA	—
			DSC Shell (Non-Confinement)	Stress Intensity	4.57	9.28	4.99	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.1	0.16	0.09	NA	—
			OTCP	Stress Intensity	17.63	32.31	17.24	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.39	0.56	0.3	NA	—
			ITCP	Stress Intensity	17.88	29.92	17.48	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.4	0.52	0.3	NA	—
			OBCP	Stress Intensity	16.74	32.52	2.14	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.37	0.56	0.04	NA	—
			IBCP	Stress Intensity	2.79	18.94	5.37	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—

Table B.3.9.1-5
NUHOMS® 61BTH DSC Results Load Combinations
(4 sheets)

LC No.	Service	Loads	Components		Stress Category [ksi]				
					P_m	$P_m + P_b$	P_L	P_m (or P_L) + P_b + Q	P_m (or P_L) + P_b + Q + P_e
3	D	DWh + max. (HS_TOP, HS_BOT) + IP(20)	DSC Shell (Confinement)	Stress Intensity	21.76	32.5	25.28	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.49	0.56	0.44	NA	—
			DSC Shell (Non-Confinement)	Stress Intensity	18.78	29.34	21.58	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.42	0.51	0.37	NA	—
			OTCP	Stress Intensity	17.36	22.61	21.36	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.39	0.39	0.37	NA	—
			ITCP	Stress Intensity	12.48	18.17	21.88	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.28	0.32	0.38	NA	—
			OBCP	Stress Intensity	14.71	35.06	16.53	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.33	0.61	0.29	NA	—
			IBCP	Stress Intensity	12.57	26.37	21.58	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.28	0.46	0.37	NA	—

Table B.3.9.1-5
NUHOMS® 61BTH DSC Results Load Combinations
(4 sheets)

LC No.	Service	Loads	Components		Stress Category [ksi]				
					P_m	$P_m + P_b$	P_L	P_m (or P_L) + P_b + Q	P_m (or P_L) + P_b + Q + P_e
4	D	External Pressure	DSC Shell (Confinement)	Stress Intensity	8.26	17.01	14.47	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.18	0.3	0.25	NA	—
			DSC Shell (Non-Confinement)	Stress Intensity	8.09	11.68	10.74	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.18	0.2	0.19	NA	—
			OTCP	Stress Intensity	2.33	2.87	6.27	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.05	0.05	0.11	NA	—
			ITCP	Stress Intensity	2.84	3.6	7.91	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.06	0.06	0.14	NA	—
			OBCP	Stress Intensity	2.05	5.06	4.49	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.05	0.09	0.08	NA	—
			IBCP	Stress Intensity	3.45	5.42	6.84	NA	—
				Allowable Stress	44.8	57.6	57.6	NA	—
				Stress Ratio	0.08	0.09	0.12	NA	—

Table B.3.9.1-6
DSC Weld Stress Results – Load Combinations (Outer Top Cover Plate (OTCP) to DSC Shell Weld Stress Results)

Load Combination Number	Service Level	Stress Category	Loads	Stress Intensity [ksi]	Allowable Stress (ksi)	Stress Ratio
1	A	P_m	DW_h+PI_{20}	17.18	22.44	0.77
		$P_m + P_b$	DW_h+PI_{20}	19.96	44.88	0.44
		P_L	DW_h+PI_{20}	NA	NA	NA
		P_m (or P_L) + P_b + Q	DW_h+PI_{20}	NA	NA	NA
		P_m (or P_L) + P_b + Q + P_e	DW_h+PI_{20}	32.30	44.88	0.72
2	D	P_m	DW_h+PI_{120}	30.23	46.08	0.66
		$P_m + P_b$	DW_h+PI_{120}	40.99	46.08	0.89
		P_L	DW_h+PI_{120}	NA	NA	NA
		P_m (or P_L) + P_b + Q	DW_h+PI_{120}	NA	NA	NA
3	D	P_m	DW_h + max. (HS_TOP, HS_BOT) + PI_{20}	23.63	46.08	0.51
		$P_m + P_b$	DW_h + max. (HS_TOP, HS_BOT) + PI_{20}	26.19	46.08	0.57
		P_L	DW_h + max. (HS_TOP, HS_BOT) + PI_{20}	NA	NA	NA
		P_m (or P_L) + P_b + Q	DW_h + max. (HS_TOP, HS_BOT) + PI_{20}	NA	NA	NA
4	D	P_m	External Pressure	7.20	51.20	0.14
		$P_m + P_b$	External Pressure	7.53	51.20	0.15
		P_L	External Pressure	NA	NA	NA
		P_m (or P_L) + P_b + Q	External Pressure	NA	NA	NA

Table B.3.9.1-7
DSC Weld Stress Results – Load Combinations (Inner Top Cover Plate (ITCP) to DSC Shell Weld Stress Results)

Load Combination Number	Service Level	Stress Category	Loads	Stress Intensity [ksi]	Allowable Stress (ksi)	Stress Ratio
1	A	P_m	DW_h+PI_{20}	18.82	22.44	0.84
		$P_m + P_b$	DW_h+PI_{20}	27.40	44.88	0.61
		P_L	DW_h+PI_{20}	NA	NA	NA
		P_m (or P_L) + P_b + Q	DW_h+PI_{20}	NA	NA	NA
		P_m (or P_L) + P_b + Q + P_e	DW_h+PI_{20}	43.17	44.88	0.96
2	D	P_m	DW_h+PI_{120}	26.85	46.08	0.58
		$P_m + P_b$	DW_h+PI_{120}	42.63	46.08	0.93
		P_L	DW_h+PI_{120}	NA	NA	NA
		P_m (or P_L) + P_b + Q	DW_h+PI_{120}	NA	NA	NA
3	D	P_m	DW_h + max. (HS_TOP, HS_BOT) + PI_{20}	24.80	46.08	0.54
		$P_m + P_b$	DW_h + max. (HS_TOP, HS_BOT) + PI_{20}	27.97	46.08	0.61
		P_L	DW_h + max. (HS_TOP, HS_BOT) + PI_{20}	NA	NA	NA
		P_m (or P_L) + P_b + Q	DW_h + max. (HS_TOP, HS_BOT) + PI_{20}	NA	NA	NA
4	D	P_m	External Pressure	7.70	51.20	0.15
		$P_m + P_b$	External Pressure	9.02	51.20	0.18
		P_L	External Pressure	NA	NA	NA
		P_m (or P_L) + P_b + Q	External Pressure	NA	NA	NA

Table B.3.9.1-8
DSC-OTCP Maximum Radial Weld Stress (S_x) Results – Load Combinations

Load #	Service Level	S_x
DW_h+PI_{20}	A	0.00
DW_h+PI_{120}	D	0.00
DW_h + max.(HS_TOP, HS_BOT) + $PI_{(20)}$	D	0.58
DW_h + External Pressure	D	0.11

Table B.3.9.1-9
Controlling DSC Load Combination Results Summary

Components/Welds	Controlling Load Combination (1)		Service Level	Max. Stress Ratio
	Number	Description		
DSC Shell Containment	1	$DWh + PI_{(20)}$	A	0.73
DSC Shell Non Containment	4	$DWh + max.(HS\_TOP, HS\_BOT) + IP_{(20)}$	D	0.51
OTCP	2	$DWh + PI_{(120)}$	D	0.56
ITCP	2	$DWh + PI_{(120)}$	D	0.52
OBCP	4	$DWh + max.(HS\_TOP, HS\_BOT) + IP_{(20)}$	D	0.61
IBCP	4	$DWh + max.(HS\_TOP, HS\_BOT) + IP_{(20)}$	D	0.46
Grapple Support Plate	4	$DWh + max.(HS\_TOP, HS\_BOT) + IP_{(20)}$	D	0.22
Grapple Ring	2	$DWh + PI_{(120)}$	D	0.21
Support Ring	1	$DWh + PI_{(20)}$	A	0.49
OTCP-DSC Shell Weld	2	$DWh + PI_{(120)}$	D	0.89
ITCP-DSC Shell Weld	1	$DWh + PI_{(20)}$	A	0.96
OBCP-DSC Shell Weld	4	$DWh + max.(HS\_TOP, HS\_BOT) + IP_{(20)}$	D	0.54

Note:

(1) See Table A.3.9.1-1 for the load combination description.

Table B.3.9.1-10
Weld Flaw Size for Controlling Load Combinations

Load #	Service Level	S_x	Safety Factor	$SF*S_x$	Allowable a/t	Subsurface Flaws		Surface Flaws	
						Weld Thickness (2t)	Flaw Depth (2a)	Weld Thickness (t)	Flaw Depth (a)
DWh + $PI_{(20)}$	A	Note (1)	2.7	0	(1.00) 0.75	0.5	0.38	0.5	0.38
DWh + max. (HS_TOP, HS_BOT) + $PI_{(20)}$	D	0.58	1.3	0.75	(0.98) 0.75	0.5	0.38	0.5	0.38

Note 1: The radial stress for the DWh +PI (20) load case is very low.

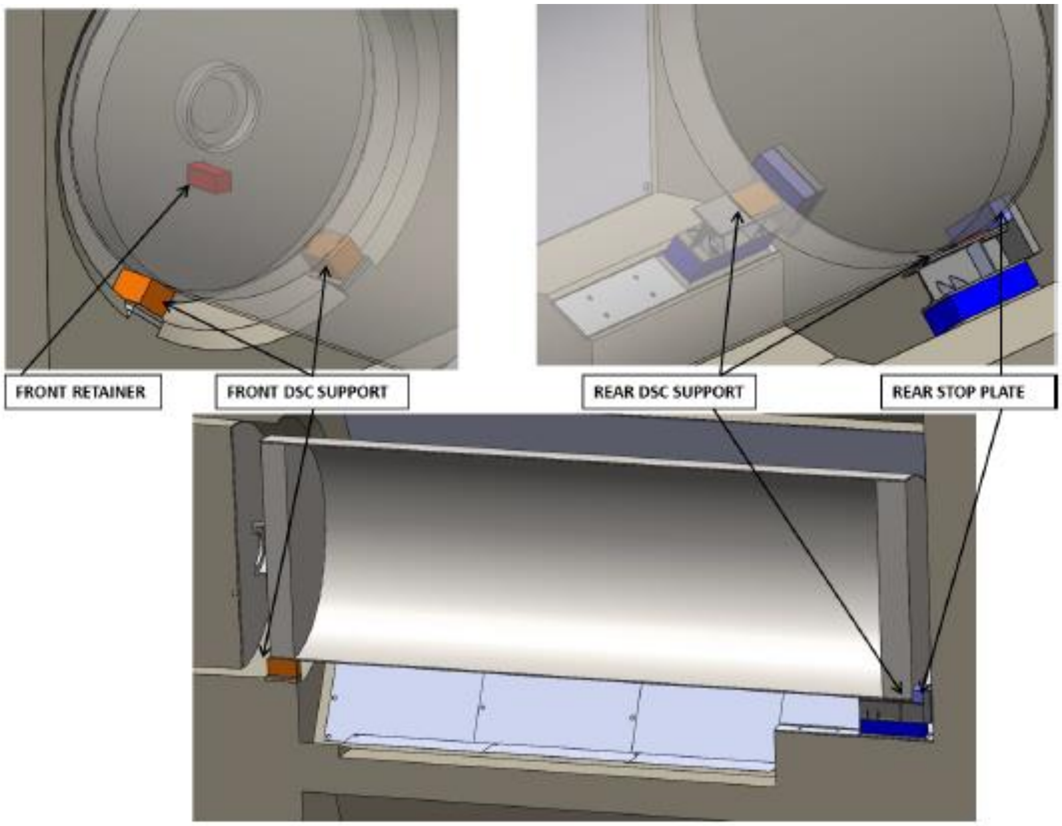


Figure B.3.9.1-1
HSM-MX-DSC Supports and Axial Retainers

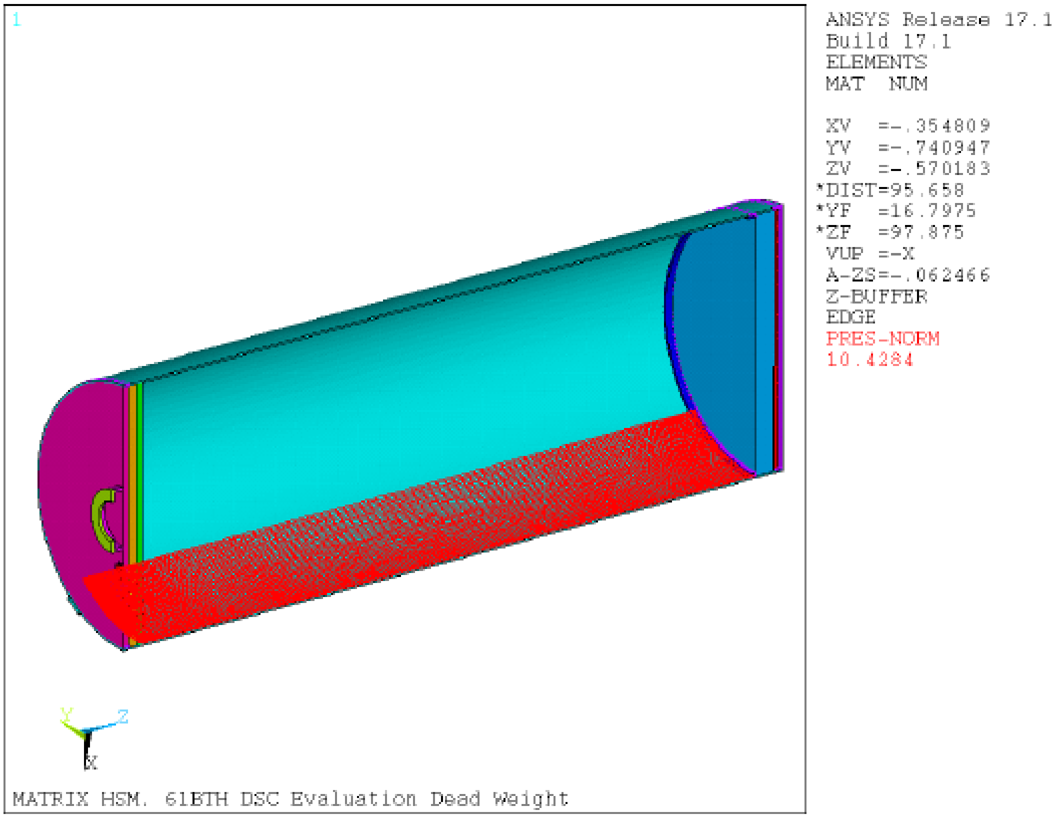


Figure B.3.9.1-2
61BTH Type 2 DSC Dead Weight Equivalent Pressure

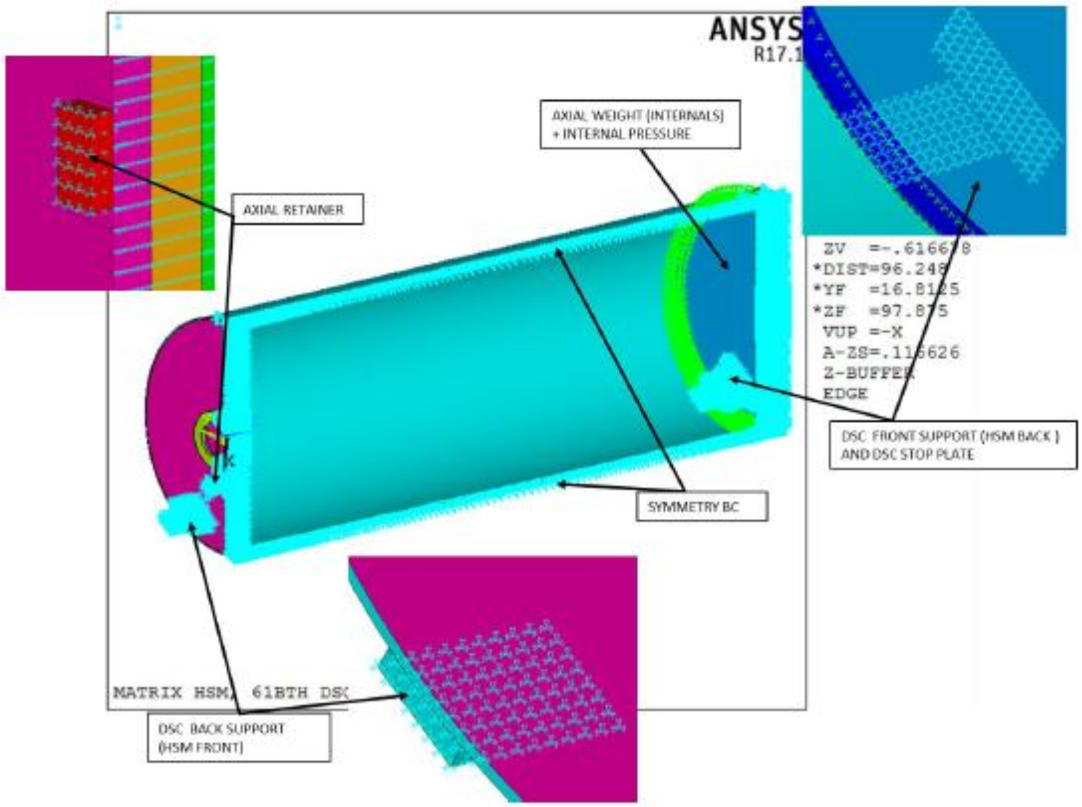


Figure B.3.9.1-3
61BTH Type 2 DSC Boundary Conditions in HSM-MX

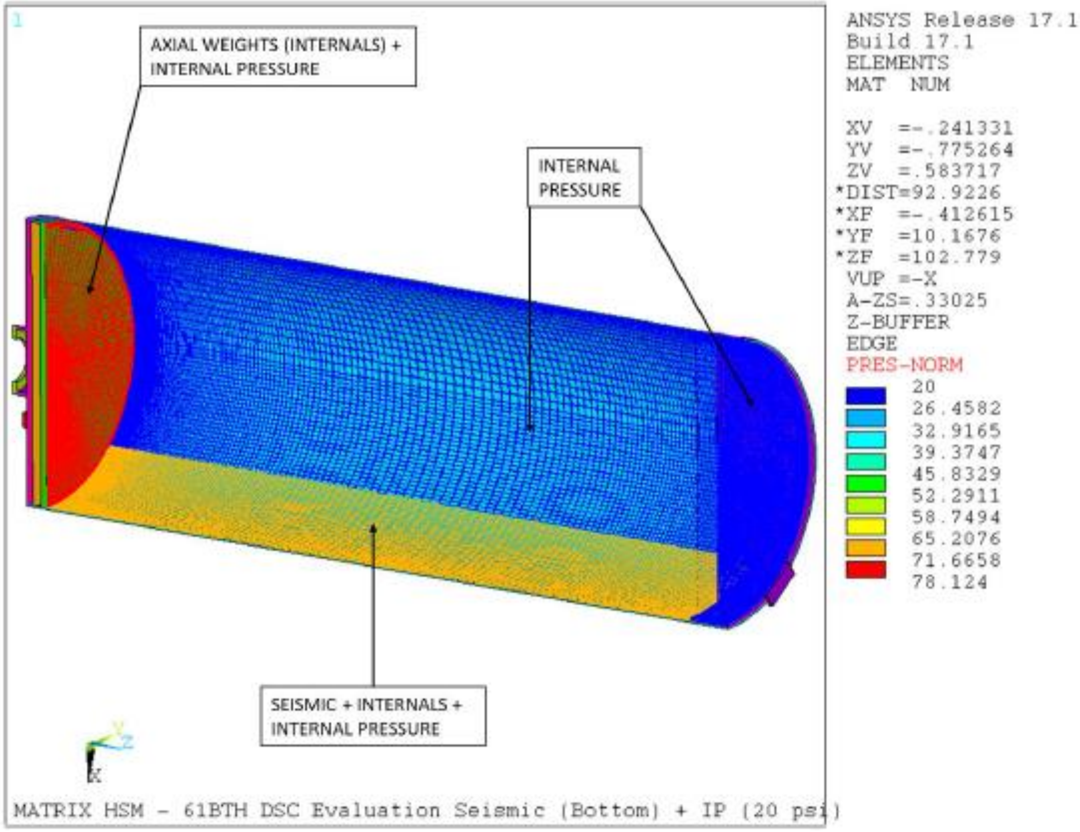


Figure B.3.9.1-4
61BTH Type 2- Internals Seismic Equivalent Pressures with Internal Pressure

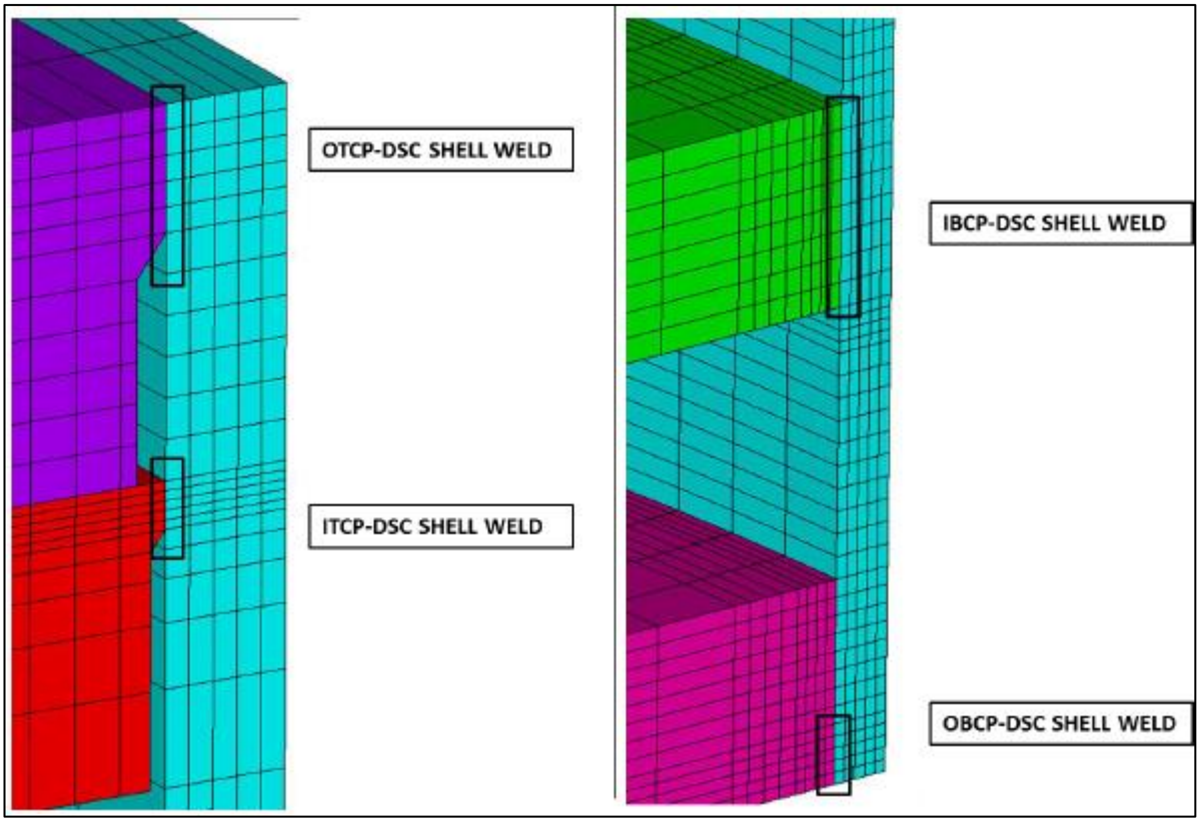


Figure B.3.9.1-5
61BTH Type 2 DSC Finite Element Model Welds

B.3.9.2 NUHOMS® 61BTH TYPE 2 BASKET STRUCTURAL ANALYSIS

There is no change to the structural evaluation of the NUHOMS® 61BTH Type 2 basket documented in Section T.3.6.1.3 for normal conditions and Section T.3.7.4.3 for off-normal and accident conditions described in the CoC 1004 [B.3.9.2-1] when used for the HSM-MX system.

72.48

B.3.9.2.1 References

B.3.9.2-1 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

B.3.9.3 NUHOMS® 61BTH TYPE 2 SYSTEM ACCIDENT DROP EVALUATION

There is no change to the accident drop evaluation of the NUHOMS® 61BTH Type 2 system within the OS197 transfer cask (TC) documented in Section T.3.7.4.3.1 of the CoC 1004 [B.3.9.3-1] when used for the HSM-MX system.

B.3.9.3.1 References

B.3.9.3-1 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

APPENDIX B.3.9.4
HSM-MX STRUCTURAL ANALYSIS

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

B.3.9.4 HSM-MX STRUCTURAL ANALYSIS

The purpose of this appendix is to present the structural evaluation of the NUHOMS® MATRIX (HSM-MX) loaded with the 61BTH Type 2 DSC due to all applied loads during storage and transfer operations.

B.3.9.4.1 General Description

General description and operational features for the HSM-MX is provided in Appendix A.1. The drawings of the HSM-MX, showing different components and overall dimensions, are provided in Appendix A.1.3.

Due to the smaller diameter of the 61BTH Type 2 DSC, the front and rear DSC supports in the HSM-MX are modified with spacers in order to elevate the 61BTH Type 2 DSC. The centerline of the 61BTH Type 2 DSC when stored in the HSM-MX will be at the same elevation as the EOS37-PTH/EOS-89BTH DSC. The drawings of the spacers are provided in Appendix B.1.3.

Comparison between the 61BTH Type 2 DSC and the EOS-37PTH/EOS-89BTH DSC that can be stored in the HSM-MX is given below.

Parameter	61BTH Type 2 DSC	EOS-37PTH/EOS-89BTH DSC
Diameter	67.25 in	75.50 in
Length (max)	196 in	197.5 in
Heat Load (max)	31.2 kW	50.0 kW
Weight (DSC only)	93 kips	120 kips
Weight (empty Single Array HSM-MX)	2,450 kips	

B.3.9.4.2 Material Properties

No change to Section A.3.9.4.2.

B.3.9.4.3 Design Criteria

No change to Section A.3.9.4.3.

B.3.9.4.4 Load Cases

The percentage change in the total system weight compared to Appendix A.3.9.4 is less than 2%. This will have minimal impact on the load cases described in Section A.3.9.4.4. The load cases described in Section A.3.9.4.4 are bounding due to the lighter weight and lower heat load of the 61BTH Type 2 DSC. The seismic load will be decreased due to the lighter weight of the 61BTH Type 2 DSC, which will increase the HSM-MX natural frequencies.

B.3.9.4.5 Load Combination

No change to Section A.3.9.4.5.

B.3.9.4.6 Finite Element Models

No change to Section A.3.9.4.6.

B.3.9.4.7 Normal Operation Structural Analysis

No change to Section A.3.9.4.7.

B.3.9.4.7.1 HSM-MX Dead Load (DL) Analysis

No change to Section A.3.9.4.7.1.

B.3.9.4.7.2 HSM-MX Live load (LL) Analysis

No change to Section A.3.9.4.7.2. The weight of the 61BTH Type 2 DSC is bound by the DSC weight used in Section A.3.9.4.7.2.

B.3.9.4.7.3 HSM-MX Normal Operational Handling Load (R_o) Analysis

No change to Section A.3.9.4.7.3. The weight of the 61BTH Type 2 DSC and associated handling loads are bound by those used in Section A.3.9.4.7.3.

B.3.9.4.7.4 HSM-MX Normal Operating Thermal (T_o) Stress Analysis

No change to Section A.3.9.4.7.4. The normal thermal load due to the 61BTH Type 2 DSC is bound by the thermal load used in Section A.3.9.4.7.4.

B.3.9.4.7.5 HSM-MX Design Basis Wind Load (W) Analysis

No change to Section A.3.9.4.7.5.

B.3.9.4.8 Off-Normal Operation Structural Analysis

No change to Section A.3.9.4.8.

B.3.9.4.8.1 HSM-MX Off-Normal Handling Loads (R_a) Analysis

No change to Section A.3.9.4.8.1. The weight of the 61BTH Type 2 DSC and associated handling loads are bound by those used in Section A.3.9.4.8.1.

B.3.9.4.8.2 HSM-MX Off-Normal Thermal Loads Analysis

No change to Section A.3.9.4.8.2.

B.3.9.4.9 Accident Condition Structural Analysis

No change to Section A.3.9.4.9.

B.3.9.4.9.1 Tornado Winds/Tornado Missile Load (W_t, W_m) Analysis

No change to Section A.3.9.4.9.1.

B.3.9.4.9.2 Earthquake (Seismic) Load (E) Analysis

No change to Section A.3.9.4.9.2. The seismic load resulting from the storage of the 61BTH Type 2 DSC is bound by the load used in Section A.3.9.4.9.2.

B.3.9.4.9.3 Flood Load (FL) Analysis

No change to Section A.3.9.4.9.3.

B.3.9.4.9.4 Accident Blocked Vent Thermal (T_a) Stress Analysis

No change to Section A.3.9.4.9.4. The accident thermal load due to the 61BTH Type 2 DSC is bound by the thermal load used in Section A.3.9.4.9.4.

B.3.9.4.10 Structural Evaluation

No change to Section A.3.9.4.10.

B.3.9.4.10.1 HSM-MX Concrete Components

No change to Section A.3.9.4.10.1.

B.3.9.4.10.2 HSM-MX Shield Door

No change to Section A.3.9.4.10.2.

B.3.9.4.10.3 HSM-MX Heat Shield

No change to Section A.3.9.4.10.3. The seismic load resulting from the storage of the 61BTH Type 2 DSC is bound by the load used in Section A.3.9.4.10.3.

B.3.9.4.10.4 HSM-MX DSC Axial Retainer

No change to Section A.3.9.4.10.4. The seismic load resulting from the storage of the 61BTH Type 2 DSC is bound by the load used in Section A.3.9.4.10.4.

B.3.9.4.10.5 Evaluation of Concrete Components for Missile Loading

No change to Section A.3.9.4.10.5.

B.3.9.4.10.5.1 Local Damage Evaluation

No change to Section A.3.9.4.10.5.1.

B.3.9.4.10.5.2 Global Structural Response

No change to Section A.3.9.4.10.5.2.

B.3.9.4.11 Conclusions

The load categories, results, and design capacities associated with normal operating conditions, off-normal conditions, and postulated accident conditions that are described and analyzed in Section A.3.9.4 remain applicable for the HSM-MX loaded with the 61BTH Type 2 DSC. There is no adverse impact on the HSM-MX when loaded with the 61BTH Type 2 DSC compared to the results presented in Section A.3.9.4. Comparison of the results with the corresponding design capacity shows that the design strength of the HSM-MX is greater than the strength required for the most critical load combination.

B.3.9.5 NUHOMS® OS197-TC BODY STRUCTURAL ANALYSIS

There is no change to the evaluation of the OS197 TC body structural analysis documented in Sections T.3.6.1.9 for normal and off-normal operations and Section T.3.7 for accident conditions under the CoC 1004 [B.3.9.5-1] when used for the HSM-MX system.

B.3.9.5.1 References

B.3.9.5-1 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

B.3.9.6 FUEL CLADDING EVALUATION

There is no change to the evaluation of the fuel cladding evaluation documented in Section T.3.5 of CoC 1004 UFSAR [B.3.9.6-1] due to the implementation of the 61BTH Type 2 DSC for storage/transfer operations for the NUHOMS® MATRIX.

B.3.9.6.1 References

B.3.9.6-1 TN Americas, LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

APPENDIX B.3.9.7
NUHOMS® MATRIX STABILITY ANALYSIS

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

List of Tables

B.3.9.7 NUHOMS® MATRIX STABILITY ANALYSIS

B.3.9.7.1 General Description

No change to Section A.3.9.7.1, except that the system consists of the 61BTH Type 2 DSC, the HSM-MX, and OS197 TC with associated ancillary equipment. The 61BTH Type 2 DSC contains up to 69 boiling water reactor (BWR) spent fuel assemblies (SFAs).

B.3.9.7.1.1 HSM-MX Stability Evaluation

No change to Section A.3.9.7.1.1.

B.3.9.7.1.2 Material Properties

No change to Section A.3.9.7.1.2.

B.3.9.7.1.3 Mass Properties

No change to Section A.3.9.7.1.3.

B.3.9.7.1.4 Friction Coefficients

No change to Section A.3.9.7.1.4.

B.3.9.7.1.5 Methodology

No change to Section A.3.9.7.1.5.

B.3.9.7.1.6 Assumptions

No change to Section A.3.9.7.1.6.

B.3.9.7.1.7 Loads and Boundary Conditions

B.3.9.7.1.7.1 Earthquake Input

No change to Section A.3.9.7.1.7.1.

B.3.9.7.1.7.2 Wind and Tornado Input

No change to Section A.3.9.7.1.7.2.

B.3.9.7.1.7.3 Flood Input

No change to Section A.3.9.7.1.7.3.

B.3.9.7.2 HSM-MX Stability Analyses

No change to Section A.3.9.7.2.

B.3.9.7.2.1 Design Basis Tornado Wind and Missile Loads

No change to Section A.3.9.7.2.1.

B.3.9.7.2.2 Flood Loads

No change to Section A.3.9.7.2.2.

B.3.9.7.2.3 Seismic Loads

No change to Section A.3.9.7.2.3.

B.3.9.7.2.3.1 Low Seismic Load

No change to Section A.3.9.7.2.3.1, except that, for the HSM-MX static overturning analysis with minimum HSM-MX concrete density (140 pcf), the 61BTH Type 2 DSC weight (to minimize the stabilizing moment) is considered. Table B.3.9.7-1 shows the results where the overturning safety factor is less than 1, meaning the HSM-MX can have some lifting under the seismic loads. The non-linear dynamic analyses (Section B.3.9.7.2.3.2) estimate the amount of lifting for high seismic loads. The maximum acceptable accelerations before any lifting occurs are a_v = 0.40g and a_h = 0.60g (assuming a_v = 2/3 a_h).

B.3.9.7.2.3.2 High Seismic Load

The non-linear dynamic stability analysis model described in Section A.3.9.7.2.3.2 conservatively uses the minimum weight of 113 kip for the EOS-37PTH/EOS-89BTH DSC weight. A sensitivity analysis based on a model with three (out of five) cavities loaded with the DSCs demonstrates that the resulting DSC weight difference of 2 × 113 kips = 226 kips has a negligible effect on the maximum sliding and uplift displacements. Since the largest weight difference between the EOS-37PTH/EOS-89BTH DSCs and 61BTH Type 2 DSC is 120 kips – 93.2 kips = 26.8 kips, the reduced weight of five 61BTH DSCs, with the maximum weight difference of 26.8 kips × 5 = 134 kips, will also have a negligible effect on sliding and rocking behavior. Therefore, the analysis in Section A.3.9.7.2.3.2 bounds the storage of the 61BTH Type 2 DSCs as well as mixed loading of the 61BTH and EOS-89BTH DSCs.

B.3.9.7.2.4 Results

The stability analyses presented in Section A.3.9.7.2 consist of an empty HSM-MX for all load cases except for the seismic load. Hence, there is no change to the HSM-MX stability evaluation for non-seismic loads documented in Section A.3.9.7.2 due to the addition of the 61BTH Type 2 DSC.

There is no change to the HSM-MX stability evaluation for the seismic load documented in Section A.3.9.7.2 due to the addition of the 61BTH Type 2 DSC, except for the static overturning analysis, the results for which are shown in Table B.3.9.7-1.

B.3.9.7.3 OS197 Transfer Cask Missile Stability and Stress Evaluation

The transfer operations are performed using the OS197 TC as described in Section 1.3.2.1 of CoC 1004 [B.3.9.7-1]. There are no changes to the missile stability and stress evaluation of the OS197 TC performed in Appendix C.5 of CoC 1004 [B.3.9.7-1].

B.3.9.7.4 References

B.3.9.7-1 TN Americas LLC, "Update Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

Table B.3.9.7-1
Static Analysis, Overturning, and Sliding of the HSM-MX

	Concrete Density [pcf]		140
Overturning	Overturning Moment [in.kips]		447,262
	Stabilizing Moment [in.kips]		328,646
	Safety Factor(1)		0.67
	Max accelerations before overturning	$a_v = {}^2/_3\, a_h$	0.40
		a_h	0.60
Sliding	Horizontal Seismic Force [kips]		2,042
	Resisting Friction Force(3) [kips]		980
	Safety Factor(2)		0.44
	Max accelerations before sliding	$a_v = {}^2/_3\, a_h$	0.32
		a_h	0.48

Notes:

(1) SF = M_{st}/1.1 M_{ot}.

(2) SF = F_{fr}/1.1 F_{hs}.

(3) Nominal Coefficient of friction 0.6.

APPENDIX B.4
THERMAL EVALUATION

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

List of Tables

List of Figures

Appendix B is newly added in Revision 4 by Amendment 2.

B.4 THERMAL EVALUATION

The thermal evaluation described in this chapter is to demonstrate that a 61BTH Type 2 Dry Shielded Canister (DSC) can be loaded inside the OS197 transfer cask (TC) and the NUHOMS® MATRIX (HSM-MX) for normal, off-normal, and accident conditions while maintaining temperatures and pressures within the specified regulatory limits per NUREG-1536 [B.4-1].

A summary of the 61BTH Type 2 DSC configuration analyzed in this chapter is shown below:

DSC Type	**Basket Assembly Type or Heat Load Zone Configuration (HLZC)**	**Max. Heat Load (kW)**	**Neutron Absorber Material**	**Transfer Cask**	**Time Limit for Transfer Operation**	**Storage Module**
61BTH Type 2	1, 2, 9	22.0	Borated Aluminum or BORAL® or MMC	OS197 or OS197H or OS197FC-B	No	NUHOMS® MATRIX (HSM-MX)
	3, 4	19.4				
	8	27.4		OS197FC-B	Yes	
	5, 6, 7, 10	31.2	Borated Aluminum or MMC			

NOTE: The 61BTH Type 2 DSC and the OS197 TCs (OS197, OS197H, or OS197FC-B) are licensed under Revision 18 of the UFSAR of CoC 1004 in Appendix T [B.4-2] and no changes are considered.

As shown in the above table, the 61BTH Type 2 DSC will be transferred in an OS197 TC and stored in an HSM-MX. Since the combination of the 61BTH Type 2 DSC and the OS197 TC for transfer operations is approved for use in the CoC 1004 and there are no changes to the components, the thermal analyses performed for transfer operations presented in Appendix T.4 of the CoC 1004 UFSAR for the NUHOMS® general license [B.4-2] are applicable. In addition to these evaluations, Section B.4.5.6 presents new evaluations to determine the duration required to run the air circulation and the duration available to complete the transfer operations once the air circulation is turned off. For storage operations of the 61BTH Type 2 DSC in the HSM-MX, new analyses are presented in Section B.4.4 since this combination was not previously analyzed.

The 61BTH Type 2 DSC is analyzed based on a maximum heat load of 31.2 kW from 61 boiling water reactor (BWR) fuel assemblies (FAs) with a maximum heat load of 1.2 kW per assembly. A total of ten HLZCs shown in Figures 4A through 4J of the Technical Specification [B.4-3] are authorized in the 61BTH Type 2 DSC. The location of damaged and failed FAs inside the 61BTH Type 2 DSC is also provided in Figure 5 of the Technical Specification [B.4-3]. HLZCs considered for the 61BTH Type 2 DSC including the placement of damaged/failed fuel assemblies are identical to those previously evaluated in Appendix T, Section T.4 of [B.4-2].

Descriptions of the detailed analyses performed for normal, off-normal, and hypothetical accident conditions are provided in Section B.4.4 for storage operations, and Section B.4.5 for transfer operations. The thermal analyses performed for the loading and unloading conditions are described in Section B.4.5.5. DSC internal pressures are discussed in Section B.4.6.

B.4.1 Discussion of Decay Heat Removal System

The 61BTH Type 2 DSC is designed to passively reject decay heat during storage and transfer for normal, off-normal, and hypothetical accident conditions while maintaining temperatures and pressures within specified limits. Objectives of the thermal analyses performed for this evaluation include:

- Determination of maximum and minimum temperatures with respect to material limits to ensure components perform their intended safety functions,
- Determination of temperature distributions to support the calculation of thermal stresses,
- Determination of maximum DSC internal pressures for normal, off-normal, and hypothetical accident conditions, and
- Determination of the maximum fuel cladding temperature, and to confirm that this temperature will remain sufficiently low to prevent unacceptable degradation of the fuel during storage.

Fuel assemblies (FAs) are considered as homogenized materials in the fuel compartments. The effective thermal conductivity of the FAs used in the thermal analysis is based on the conservative assumption that heat transfer within the fuel region occurs only by conduction and radiation where any convection heat transfer is neglected. The lowest effective properties among the applicable FAs are selected to perform the thermal analysis. Evaluations of heat transfer from the FAs to the basket assembly credits conduction through the basket assembly materials (steel/neutron absorber material/aluminum) and helium fill gas within the DSC. Convection and radiation heat transfer within the basket assembly is conservatively ignored.

During loading and transfer operations, evaluations of the heat transfer from the DSC shell assembly through the TC credit conduction and radiation through the TC/DSC annulus gap, conduction through the various shells of the TC, and convection through the liquid neutron shield, along with the impact of the TC being vertical or horizontal. For heat loads above 22 kW in the 61BTH Type 2 DSC, there is a time limit to transfer. If this time limit cannot be met, then either the TC/DSC annulus gap must be refilled with water or forced cooling (air circulation) must be implemented.

During DSC storage in the HSM-MX, the evaluation of the heat transfer from the DSC shells through the HSM-MX credits conduction, convection, and radiation in the following manners:

- Conduction through the DSC shell assembly and into the DSC supports in the HSM-HX,
- Convection through the air flowing from the front vents around the DSC and out of the roof vents, and
- Radiation from the DSC outer surface to the concrete and heat shields in the HSM-HX.

As discussed in Chapter A.4, Section A.4.4, the heat load per DSC is limited to 50 kW when loaded in the lower compartment, and 41.8 kW when loaded in the upper compartment of HSM-MX. Since the maximum allowable heat load of the 61BTH Type 2 DSC is 31.2 kW and less than 41.8 kW, there are no restrictions on storage of a 61BTH Type 2 DSC in either the upper or lower compartments.

There is no instrumentation required to monitor TC thermal performance. For the HSM-MX, no instrumentation is required to monitor the thermal performance if daily visual inspections of the air inlet and outlet vents are performed. However, in lieu of the daily visual inspections, a direct measurement of the HSM-MX temperature or any other means that would provide an indication of the thermal performance may be used for monitoring in accordance with requirements in Technical Specifications [B.4-3].

B.4.2 Material and Design Limits

To establish the heat removal capability, several thermal design criteria are established for the HSM-MX System. Thermal design criteria for the 61BTH Type 2 DSC is identical to that described in Appendix T, Section T.4.1 of [B.4-2]. These are:

- Maximum temperatures of the containment structural components must not adversely affect the containment function.
- For intact fuel assemblies, a maximum fuel cladding temperature limit of 400 °C (752 °F) has been established for normal conditions of storage and for short-term transfer operations such as transfer, vacuum drying, and helium backfill [B.4-1]. During off-normal storage and accident conditions, the maximum fuel cladding temperature limit is 570 °C (1058 °F) [B.4-1].
- A maximum temperature limit of 327 °C (620 °F) is considered for the lead in the TC, corresponding to the melting point [B.4-4].
- The temperature limit for the bottom neutron shield (NS-3) in the TC is limited by the loss of the water content within the NS-3. The long-term bulk average temperature of the NS-3 material is set to 250°F or less , the short-term limits for normal operations are 300°F [B.4-5], and the short-term limit for accident conditions are 1300°F [B.4-6].
- The temperature of the water in the neutron shield is limited by the rating of the pressure relief valves (30 psig) on the neutron shield. The temperature of the water cannot rise above the equivalent steam saturation temperature at this pressure (i.e., approximately 274 ºF) without risk of activating the relief valves and losing some of the water in the neutron shield.
- All materials can be subjected to a minimum environment temperature of -40 °F (-40 °C) without adverse effects.
- The maximum DSC internal pressure during normal and off-normal and accident conditions are 15 psig, 20 psig, and 120 psig, respectively. The evaluations of the maximum DSC internal pressure during normal, off-normal, and hypothetical accident conditions assume the rupture of 1%, 10 %, and 100% of the fuel rods, respectively.
- For normal and off-normal conditions, the maximum concrete temperature limit is 300 °F, as noted in Section 3.5.1.2 of [B.4-1]. For the accident conditions, if the concrete temperature exceeds the short-term limit of 350 °F noted in Appendix E.4 of ACI 349-06 [B.4-7], concrete testing will be performed as described in Chapter A.8, Section A.8.2.1.3.

B.4.2.1 Summary of Thermal Properties of Materials

Thermal properties for the 61BTH Type 2 DSC and OS197 TC are provided in Appendix T, Section T.4.2 of [B.4-2].

Thermal properties for the HSM-MX used in the ANSYS FLUENT [B.4-14] model are the same as discussed in Appendix A.4.2.

[

]

The following nomenclature is used in the tables of material properties.

T = temperature
k = thermal conductivity
C_p = specific heat
ρ = density

For ease of modeling, the thermal property inputs for ANSYS FLUENT models are all in SI units.

Proprietary Information on Pages B.4-7 through B.4-12
Withheld Pursuant to 10 CFR 2.390

B.4.2.2 Neutron Absorber Plate Conductivity Requirements

The 61BTH Type 2 DSC design for use of various neutron absorber materials, which include borated aluminum, Boral® Composite Panel, and MMC. The neutron absorber material can be made from a single piece, or can be paired with aluminum sheet with a thickness not less than nominal 0.063 inches. The nominal thickness of the single or paired neutron absorber plate with aluminum sheet considered in the base model is 0.31 inches.

The specified thickness of the neutron absorber may vary in the fabrication. The thermal conductivity acceptance criteria for the neutron absorber is based on the nominal thickness specified above and provided in Appendix T, Section T.4.3 of [B.4-2].

To maintain the thermal performance of the basket, the minimum thermal conductivity shall be such that the total thermal conductance (sum of conductivity × thickness) of the neutron absorber and the aluminum 1100 plate shall equal the conductance assumed in the analysis for the base model. Samples of the acceptance criteria for various neutron absorber thicknesses for 61BTH Type 2 DSC are also presented in Appendix T, Section T.4.3 of [B.4-2]. For plate thickness not shown in the samples, interpolation/extrapolation can be used to determine the minimum required conductivity of a neutron absorber plate paired with an aluminum plate thicker than 0.063 inches.

B.4.3 Thermal Loads and Environmental Conditions

For storage operations in the HSM-MX, the normal ambient temperature is considered in the range of -20 °F to 100 °F. A daily average ambient temperature of 90 °F is used in the evaluations, corresponding to a daily maximum temperature of 100 °F for the normal hot storage conditions as discussed in Chapter A.4, Section A.4.3.

Off-normal ambient temperature is considered in the range of - 40 °F to 117 °F. 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 as discussed in Chapter A.4, Section A.4.3.

Ambient temperatures of -20 °F and -40 °F are considered for the normal and off-normal cold storage conditions, respectively.

The HSM-MX is located outdoors and is exposed to the environment. Wind is a normal environment variable that varies frequently both in direction and magnitude. For the HSM-MX, low speed wind in the range of 0 to 15 mph is considered for normal storage conditions based on the discussion in Section 2.5 of NUREG-2174 [B.4-8].

Summary of OS197FC-B load cases for the 61BTH Type 2 DSC are provided in Appendix T, Table T.4-4, and Table T.4-5 of [B.4-2] and Section B.4.5.6.1. The ambient temperature ranges are 0 to 100 °F (-17.8 to 37.8 °C) for normal transfer and 0 to 117 °F (-17.8 to 47.2 °C) for off-normal transfer operations. The indoor ambient temperature of 120 °F is considered for fuel loading operations in the fuel building.

B.4.4 Thermal Evaluation for Storage

This section provides an evaluation of the thermal performance of the HSM-MX loaded with the 61BTH Type 2 DSC with a maximum heat load of 31.2 kW for normal, off-normal, and hypothetical accident conditions.

Section B.4.4.1 and Section B.4.4.2 present a description of the loading cases and the CFD model used for the thermal evaluation of the 61BTH Type 2 DSC during storage in the HSM-MX, respectively. Section B.4.4.3 presents the results of the thermal evaluation for normal, off-normal, and hypothetical accident conditions of storage for the 61BTH Type 2 DSC.

B.4.4.1 61BTH Type 2 DSC - Description of Loading Cases for Storage

Proprietary Information on Pages B.4-16 through B.4-18
Withheld Pursuant to 10 CFR 2.390

B.4.4.2.4 CFD Model of 61BTH Type 2 DSC in HSM-MX

B.4.4.2.5 CFD Model of 61BTH Type 2 DSC in HSM-MX with Two Full Upper and One Full Bottom Compartments

B.4.4.3 61BTH Type 2 DSC – Storage Conditions

Temperature Calculations

The maximum temperatures of fuel cladding and concrete of HSM-MX loaded with 61BTH Type 2 DSC for the bounding normal, off-normal, and accident storage conditions are summarized in Table B.4-5.

The maximum temperatures of various components of the HSM-MX loaded with the 61BTH Type 2 DSC for the bounding normal, off-normal, and accident storage conditions are summarized in Table B.4-6. The average temperatures of key components of the HSM-MX loaded with the 61BTH Type 2 DSC for the bounding normal, off-normal, and accident storage conditions are summarized in Table B.4-7.

Typical temperature plots for the key components in the HSM-MX loaded with the 61BTH Type 2 DSC are shown in Figure B.4-6, Figure B.4-7, and Figure B.4-8, respectively, for bounding normal hot, off-normal hot, and accident conditions.

GCI Calculation

Average Helium Temperature

Section T.4.6.6.4 of [B.4-2] calculates the maximum internal pressure of the 61BTH DSC during storage in the HSM-H and transfer in the OS197FC-B. Since the same type of 61BTH DSC is stored in the HSM-MX, Section B.4.6 presents the internal pressure calculation based on the same methodology and computation as discussed in Section T.4.6.6.4 of [B.4-2].

The average helium temperatures calculated for the 61BTH Type 2 DSC stored in the HSM-MX are much lower than those in HSM-H for normal, off-normal, and accident conditions. Therefore, the maximum internal pressures discussed in Section T.4.6.6.4 of [B.4-2] remain bounding for the 61BTH Type 2 DSC stored in the HSM-MX.

B.4.5 Thermal Evaluation for Transfer Casks with 61BTH Type 2 DSC

The OS197 TCs (OS197H, OS197FC, and OS197FC-B) are used to transfer the loaded 61BTH Type 2 DSC between the fuel building and the ISFSI. Thermal evaluation of the 61BTH Type 2 DSCs in the OS197 TCs is presented in Appendix T, Chapter T.4 of [B.4-2]. These evaluations are applicable for transfer operations due to the following reasons:

1. 61BTH Type 2 DSC and OS197 TC are identical to the design previously evaluated in Appendix T of CoC 1004 [B.4-2] as discussed in Chapter B.1, Section B.1.1.
2. The combination of DSC/TC for transfer operations remains unchanged from those evaluated in Appendix T, Chapter T.4 of [B.4-2].
3. HLZCs considered for the 61BTH Type 2 DSC including the placement of damaged/failed fuel assemblies are identical to those previously evaluated in Appendix T, Chapter T.4 of [B.4-2].
4. Ambient conditions for transfer operations presented in Section B.4.3 for transfer operations remain identical to the ambient conditions considered in Appendix T, Section T.4.5.2 of [B.4-2].
5. Various load cases evaluated for transfer operations in Appendix T, Section T.4.5.2 of [B.4-2] remain applicable without any changes.
6. Time limits for transfer operations if necessary before initiation of a recovery action such as air circulation are evaluated in Appendix T, Section T.4.5.4 of [B.4-2].

If air circulation is chosen as a recovery option, additional time limits that specify the minimum duration required to run the air circulation and also the maximum duration available to complete transfer operations once the air circulation is turned off are determined in Section B.4.5.6.

Background of Transfer Evaluation in CoC 1004

Thermal evaluation for transfer operations for the 61BTH Type 2 DSCs in the OS197 TCs in Appendix T, Chapter T.4 of [B.4-2] are performed using a two-step approach. The two steps are:

1. Thermal evaluation of the OS197TCs with the 61BTH DSC is performed to determine the DSC shell temperature profile and the maximum component temperatures of the OS197 TC components.

   In this step, the fuel basket and the hold down ring within the 61BTH Type 2 DSC are modeled as homogenous solids. Since the fuel basket is modeled as homogenous solids, this step only considers the total heat load per DSC and does not depend on the individual HLZCs. Based on a review of the various HLZCs, two sets of evaluations are performed. The first set is for transfer operations with heat loads ≤ 22.0 kW and the second set is for transfer operations with heat loads > 22.0 kW and ≤ 31.2 kW.

This evaluation is summarized in Section B.4.5.1.

2. Thermal evaluation of the 61BTH Type 2 DSC to determine the maximum fuel cladding temperature and basket component temperatures for intact, damaged and failed fuel.

   In this step, a detailed model of the 61BTH Type 2 DSC including the fuel basket is developed and temperatures profiles for the DSC shell from Step 1 are retrieved and applied as boundary condition. Since each individual fuel assembly is modeled, this step evaluates the performance of various HLZCs considered and determines the maximum fuel cladding temperature and other DSC component temperatures.

   This evaluation is summarized in Section B.4.5.2.

B.4.5.1 Thermal Evaluation of OS197 TCs with 61BTH DSC

Based on the discussion in Appendix T, Section T.4.5 of [B.4-2], OS197 and OS197H TCs are only allowed to transfer a 61BTH Type 2 DSC when the heat load is less than or equal to 22.0 kW and OS197FC-B TC with air circulation is used if the heat load is greater than 22.0 kW and less than or equal to 31.2 kW.

The 61BTH Type 2 DSC loaded in the OS197 TC is evaluated for following decay heat loads:

1. The OS197FC-B TCs are designed and analyzed for transferring 61BTH Type 2 DSCs with a maximum decay heat load of 31.2 kW (HLZC 5 through HLZC 8 and HLZC 10 of Appendix T.4 of [B.4-2]),
2. The OS197/OS197H TCs are designed and analyzed for transferring 61BTH DSCs with a maximum decay heat load of 22.0 kW (HLZC 1 through HLZC 4 and HLZC 9 of Appendix T.4 of [B.4-2]).

This section also establishes the maximum time limits for transfer operations during normal and off-normal conditions, and recommends the applicable corrective actions if the transfer operations cannot be completed within the time limits. The time limits are necessary to satisfy the criteria described in Section B.4.2 for the fuel cladding and for the various components of the TCs. There are no time limits for any postulated accident conditions considered during transfer operations.

The OS197FC-B TC contains design provisions for the use of air circulation system to improve its thermal performance for heat loads greater than 22.0 kW for 61BTH Type 2 DSC. The air circulation system consists of redundant, industrial grade pressure blowers and power systems, ducting, etc. When operating, the fan system is expected to generate a flow rate of 400 cfm or greater, which will be ducted to the location of the ram access cover at the bottom of the TC. The air circulation system is not needed for heat loads ≤22.0 kW. Section B.4.5.6 establishes the minimum duration required to operate the air circulation. It also evaluates the duration available once the air circulation is turned off to transfer the DSC to the storage module. This evaluation is based on 61BTH Type 2 DSC with maximum allowable heat load of 31.2 kW. If the maximum heat load of a DSC is less than 31.2 kW, new time limits may be determined to provide additional time for these transfer operations.

Section B.4.5.1.1 presents a discussion on the various load cases considered in the thermal evaluation of the 61BTH Type 2 DSC during transfer operations in the OS197 TCs.

Section B.4.5.1.2 presents a description of the model used for the thermal evaluation of the 61BTH Type 2 DSC during the transfer in the OS197 TCs.

Section B.4.5.1.3 presents the results of the thermal evaluation for normal, off-normal, and hypothetical accident conditions of transfer for the OS197 TCs with heat loads >22.0 kW and ≤ 31.2 kW in the 61BTH Type 2 DSC.

B.4.5.1.1 61BTH Type 2 DSC - Description of Load Cases for Transfer

Various load cases are considered to determine the thermal performance of the OS197 TCs with the 61BTH Type 2 DSC described in Appendix T, Section T.4.5.2 of [B.4-2]. The load cases are further listed in the following tables:

1. Table T.4-4 of [B.4-2] for a maximum decay heat load of 22.0 kW,
2. Table T.4-5 of [B.4-2] for a maximum decay heat load of 31.2 kW.

The load cases considered for transfer of the 61BTH Type 2 DSC include the vertical loading condition inside of the fuel handling facility, normal and off-normal horizontal transfer conditions with and without air circulation outside the fuel handling facility, and hypothetical accident scenarios.

It should be noted that the thermal evaluations in Appendix T, Chapter T.4 of [B.4-2] for heat loads ≤ 22.0 kW are based on the 61BTH Type 1 DSC. The 61BTH Type 2 DSC uses aluminum R90 rail in place of the steel plate rail in the 61BTH Type 1 DSC and is thermally more efficient than the 61BTH Type 1 DSC. Therefore, the thermal evaluation for the OS197 TCs with the 61BTH Type 1 DSC reported in Appendix T, Section T.4.5 of [B.4-2] represents the bounding thermal evaluation for the OS197 TCs with heat loads ≤ 22.0 kW in the 61BTH Type 2 DSC.

For the five HLZCs (HLZC 1 through HLZC 4 and HLZC 9) with heat loads ≤ 22.0 kW allowed for the 61BTH Type 2 DSCs as shown in Figure 4A through Figure 4D and Figure 4I of the Technical Specifications [B.4-3], steady-state transfer operations are permitted.

For the five HLZCs (HLZC 5 through HLZC 8 and HLZC 10) with heat loads >22.0 kW and ≤31.2 kW allowed for the 61BTH Type 2 DSCs as shown in Figure 4E through Figure 4H and Figure 4J of the Technical Specifications [B.4-3], time limits are established to complete the normal and off-normal transfer operations to ensure that the temperature limits for the various components described in Section B.4.2 are not exceeded. There are no time limits associated with accident conditions that are evaluated at steady-state.

If the transfer operations for the five HLZCs (HLZC 5 through HLZC 8 and HLZC 10) cannot be completed within the time limits established in Technical Specifications [B.4-3], one of the recovery options is to initiate the air circulation. Section B.4.5.6.1 presents additional load cases that are evaluated if air circulation is initiated. Table B.4-9 presents the load cases for these evaluations.

For all the normal, off-normal hot conditions, and accident design load cases considered in Tables T.4-4 and T.4-5 of [B.4-2], insolation is considered per 10 CFR 71.71 [B.4-9].

B.4.5.1.2 Thermal Model of OS197FC-B TC

There is no change to the thermal model of the OS197FC-B TC with the 61BTH Type 2 DSC described in Appendix T, Section T.4.5.1 of [B.4-2].

The SINDA/FLUINT™ [B.4-10] and Thermal Desktop® [B.4-11] computer codes described in Appendix T, Section T.4.5.1.1 of [B.4-2] are used to model the OS197FC-B TC (or OS197/OS197H TC) with the 61BTH DSCs to determine the temperature distribution in the TC and the DSC shell.

If air circulation is initiated as one of the recovery options, the thermal model described in Section B.4.5.6.2 is used to evaluate the thermal performance.

B.4.5.1.3 OS197 TC Thermal Model Results

The maximum temperature results for the 61BTH DSC shell assemblies and TC components during transfer are discussed in Appendix T.4, Section T.4.5.3 and presented in Table T.4-7 through Table T.4-9 of Appendix T.4 of [B.4-2]. These results are for 31.2 kW and 22.0 kW heat loads, respectively. The DSC shell temperatures are used as boundary conditions in the 61BTH DSC thermal analysis presented in Section B.4.5.2 to calculate the basket and fuel cladding temperatures.

B.4.5.1.3.1 Normal and Off-Normal Transfer without Forced Air Circulation (FC)

There is no change to the normal and off-normal transfer evaluations described in Appendix T.4, Section T.4.5.3.1 of [B.4-2] without FC.

Steady-State analyses are performed to determine the maximum temperature results listed in Table T.4-7 of Appendix T.4 of [B.4-2] for the 61BTH DSC shell assemblies and TC components for DSC transfer under normal and off-normal operations with a decay heat load ≤ 22.0 kW.

Transient analyses are performed to determine the time limit for DSC transfer operations for 61BTH Type 2 DSCs with a decay heat load higher than 22.0 kW up to 31.2 kW. The transient maximum temperature results of the 61BTH DSC shell assemblies and TC components for DSC transfer without FC under normal and off-normal operations with a decay heat load above 22.0 kW are listed in Appendix T.4, Table T.4-8 of [B.4-2].

Based on targeted DSC shell temperatures of approximately 405 °F (for HLZCs 7 and 10) and 445 ºF (for HLZCs 5, 6, and 8) to avoid excessive fuel cladding temperatures, the transient analysis indicates that time limits approximately 15 and 28 hours, respectively, are available to transfer the DSC into the HSM-MX or take some other corrective actions. The anticipated corrective actions are described in Appendix T.4, Section T.4.5.3.1 of [B.4-2].

The results from Section B.4.5.2 documented in Tables T.4-12 and T.4-17 of [B.4-2] show that, even with these shell temperatures for normal and off-normal transfer conditions, there is considerable margin in the bounding cladding temperatures (734 ºF and 722 ºF calculated for normal and off-normal cases, respectively, vs. a 752 ºF limit).

B.4.5.1.3.2 Normal and Off-Normal Transfer with Forced Air Circulation

The normal and off-normal transfer evaluations described in Appendix T.4, Section T.4.5.3.2 of [B.4-2] are applicable under steady-state conditions when air circulation is enabled.

For the transfer time periods exceeding the specific time limits above 22.0 kW, one of the corrective actions available to limit the temperature increase is to initiate air circulation in the TC/DSC annulus.

Table T.4-9 of Appendix T.4 of [B.4-2] presents the maximum component temperatures achieved under bounding normal and off-normal ambient operating conditions for the OS197FC-B TC with a 61BTH DSC with 31.2 kW of decay heat and a flow rate of 400 cfm of air circulation. As seen, all component temperatures are below their limits.

Section B.4.5.6 presents additional analyses that determine the minimum duration required to run the air circulation and also the maximum duration available to complete transfer operations once air circulation is turned off. Table B.4-10 presents the results for these evaluations.

B.4.5.1.3.3 Accident Transfer

There is no change to the accident transfer thermal results presented in Appendix T.4, Section T.4.5.3.3 of [B.4-2].

Based on the discussion in Appendix T.4, Section T.4.5.3.3 of [B.4-2], loss of neutron shield is the bounding accident condition. Table T.4-10 of [B.4-2] presents the peak component temperatures achieved under this accident at steady-state conditions.

B.4.5.1.4 Evaluation of OS197FC-B TC Performance

There is no change to the evaluation presented in Appendix T, Section T.4.5.4 of [B.4-2] on the thermal performance of the OS197FC-B TC for normal, off-normal, and accident conditions of operation when heat loads are less than or equal to 22 kW. For heat loads > 22kW and ≤ 31.2 kW, the transfer time limits of 26 hours and 13 hours specified in Appendix T.4.5.4 of [B.4-2] are based on a 2 hour recovery time. However, to be consistent with the EOS-37PTH and EOS-89BTH DSCs the recovery time to complete the various action statements in LCO 3.1.3 of the Technical Specifications [B.4-3] is increased by 3 hours to a total of 5 hours with corresponding reduction in the transfer time limits. Therefore, the time limits for EOS-61BTH DSC are reduced to 23 hours and 10 hours based on the HLZC.

Based on the discussion in Section 4.5.4, if air circulation cannot be initiated within 1 hour after exceeding the transfer time limit, 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. As discussed in Section 4.5.4, a total of 5 hours is available to complete Action A.2 and Action A.3 of the LCO 3.1.3 of the Technical Specifications [B.4-3] with a maximum duration of 1 hour for Action A.2.

The allowable duration for the transfer operations (defined as from the time when the water in the TC-DSC annulus is drained to when the DSC is loaded into the storage module) will vary depending only on the DSC type and the heat load configuration. For simplicity of operations, a single time limit is used for all ambient conditions and TC orientations (i.e., longer times are available for the non-controlling conditions). The following table summarizes the permissible operational conditions:

DSC Heat Load Zoning Configuration	Transfer Time Limit (1), (2) (4)
HLZCs 1, 2,3, 4 and 9 (5) (≤ 22 kW)	No time limit
HLZCs 5, 6 (≤ 31.2 kW)	23.0 Hours (3)
HLZCs 7, 10 (5) (≤ 31.2 kW)	10.0 Hours (3)
HLZC 8 (≤ 27.4 kW)	23.0 Hours (3)

Notes:
(1) Transfer time is defined as from the time when the TC/DSC annulus water is drained to when the DSC is loaded into the storage module.
(2) The listed allowable transfer times are valid for all ambient conditions and TC orientations.
(3) Initiate recovery operations such as air circulation if the operation time exceeds the limit per LCO 3.1.3 of Technical Specifications [B.4-3].
(4) The transfer operation time limit is reset only if the transfer cask annulus is refilled with water.
(5) Thermal evaluation of 61BTH DSC for HLZCs 9 and 10 is presented in Section T.4.6.10 of [B.4-2].

B.4.5.2 61BTH DSC Thermal Analysis

Thermal analysis of the 61BTH DSC for transfer operations is described in Appendix T, Section T.4.6 of [B.4-2]. In addition to these evaluations, Section B.4.5.6 presents additional evaluations to determine the maximum fuel cladding temperatures and basket component temperatures if air circulation is initiated.

B.4.5.2.1 Heat Load Zoning Configurations

There is no change to the HLZCs allowed within the 61BTH Type 2 DSC. A total of 10 HLZCs are allowed for the 61BTH DSCs as shown in Figure 4A through Figure 4J of the Technical Specification [B.4-3]. Thermal evaluation of the 61BTH Type 2 DSC with HLZCs 1 through 8 are presented in Appendix T, Section T.4.6.1 through Section T.4.6.9 of [B.4-2].

Thermal evaluation of the 61BTH Type 2 DSC for HLZCs 9 and 10 is presented in Appendix T, Section T.4.6.10 of [B.4-2].

It should be noted that the thermal evaluations in Appendix T.4 of [B.4-2] for heat loads ≤ 22.0 kW are based on the 61BTH Type 1 DSC. The 61BTH Type 2 DSC uses aluminum R90 rail in place of the steel plate rail in the 61BTH Type 1 DSC and is thermally more efficient than the 61BTH Type 1 DSC. Therefore, the thermal evaluation for the OS197 TCs with the 61BTH Type 1 DSC reported in Appendix T, Section T.4.5 of [B.4-2] represents the bounding thermal evaluation for the OS197 TCs with heat loads ≤ 22.0 kW in the 61BTH Type 2 DSC.

B.4.5.2.2 61BTH DSC Thermal Model

There is no change to the 61BTH Type 2 DSC thermal model described in Appendix T, Section T.4.6.2, T.4.6.3, T.4.6.4 and T.4.6.5 of [B.4-2].

If air circulation is initiated as one of the recovery options, the thermal model described in Section B.4.5.6.2 is used to evaluate the thermal performance.

B.4.5.2.3 61BTH Type 2 DSC Thermal Evaluation (HLZCs 1 through 8, Intact Fuel)

There is no change to the thermal evaluation of 61BTH Type 2 DSC transfer in the OS197 TCs described in Appendix T.4, Sections T.4.6.6, T.4.6.7 and T.4.6.8 of [B.4-2] for normal, off-normal and accident conditions, respectively.

Section B.4.5.6 presents additional analyses that determine the minimum duration required to run the air circulation and also the maximum duration available to complete transfer operations once air circulation is turned off. Table B.4-10 presents the results for these evaluations.

Normal Transfer Evaluation

The bounding maximum fuel cladding temperatures during normal transfer conditions are listed in Table T.4-12 of [B.4-2]. The maximum fuel cladding temperatures are well below the allowable fuel cladding temperature limit of 752 °F (400 °C) [B.4-1] for short-term transfer operations.

The maximum temperatures of the basket assembly components for normal transfer conditions for the bounding HLZCs are listed in Tables T.4-13 and T.4-14 of [B.4-2] for maximum heat loads per DSC up to 22.0 kW and 31.2 kW, respectively.

The DSC temperature distributions for normal transfer operations are shown in Figures T.4-29 and T.4-30 of [B.4-2] for 22.0 kW heat load and Figures T.4-33 and T.4-34 of [B.4-2] for 31.2 kW heat load, respectively.

Off-Normal Transfer Evaluation

The bounding maximum fuel cladding temperatures during normal transfer conditions are listed in Table T.4-17 of [B.4-2]. The maximum fuel cladding temperatures are well below the allowable fuel cladding temperature limit of 752 °F (400 °C) [B.4-1] for short-term transfer operations.

The maximum temperatures of the basket assembly components for off-normal transfer conditions for the bounding HLZCs are listed in Tables T.4-18 and T.4-19 of [B.4-2] for maximum heat loads per DSC up to 22.0 kW and 31.2 kW, respectively.

The DSC temperature distributions for off-normal transfer operations are shown in Figures T.4-29 and T.4-30 of [B.4-2] for 22.0 kW heat load and Figures T.4-33 and T.4-34 of [B.4-2] for 31.2 kW heat load, respectively.

Accident Transfer Evaluation

The maximum fuel cladding temperatures during accident transfer conditions are evaluated for all decay HLZCs as listed in Table T.4-21 of [B.4-2]. The maximum fuel cladding temperatures are well below the allowable fuel temperature limit of 1058 °F (570 °C) [B.4-1] for accident transfer operations.

The maximum temperatures of the basket assembly components for normal transfer conditions for the bounding HLZCs are listed in Tables T.4-22 and T.4-23 of [B.4-2] for maximum heat load per DSC up to 22.0 kW and 31.2 kW heat load, respectively.

Figure T.4-31 of [B.4-2] shows the DSC temperature distributions for accident transfer operations with 22.0 kW heat load.

B.4.5.3 Thermal Evaluation of 61BTH Type 2 DSC with HLZCs 9 and 10

There is no change to the thermal evaluation of the 61BTH Type 2 DSC with HLZCs 9 and 10 presented in Appendix T, Sections T.4.6.10.1 and T.4.6.10.2 of [B.4-2], respectively. These evaluations are performed using the DSC thermal model described in Section B.4.5.2. The only change considered to this thermal model is the updated HLZC.

Based on thermal evaluations in Sections T.4.6.10.1 and T.4.6.10.2 of [B.4-2], the 61BTH Type 2 DSC with HLZCs 9 and 10 meet all design criteria described in Section B.4.2 for normal, off-normal and accident transfer operations. The time limits for transfer operations determined for the 61BTH Type 2 DSC with HLZC 7 in Section B.4.5.1.4 are applicable to the 61BTH Type 2 DSC with HLZC 10.

B.4.5.3.1 61BTH Type 2 DSC Thermal Evaluation (Failed Fuel)

There is no change to the thermal evaluation of the failed FAs along with damaged and intact FAs presented in Appendix T.4, Section T.4.6.9 of [B.4-2].

The maximum fuel cladding and basket component temperatures for the 61BTHF Type 2 DSC for bounding accident transfer condition are reported in Appendix T, Section T.4.6.9.4 of [B.4-2] and compared to the maximum fuel cladding and basket component temperatures from Tables T.4-21 and T.4-23 of [B.4-2] for the 61BTH Type 2 DSC with intact FAs.

The results show that storing up to 16 damaged/failed FAs within the FFCs in specified locations in the basket and the remaining compartments with intact FAs has no negative impact on peak fuel cladding and DSC component temperatures when compared with the 61BTH DSC loaded with all intact FAs. Further, none of the material temperature limits is exceeded.

The maximum fuel cladding temperature for the 61BTHF DSC with maximum heat load of 31.2 kW for the bounding accident condition is 814 °F and that is well below the allowable limit of 1058 °F for the 61BTH Type 2 DSC established in Section B.4.2.

B.4.5.4 Thermal Analysis of 61BTH DSC with up to 61 Damaged FAs

There is no change to the thermal evaluation of 61BTH Type 2 DSC with up to 61 damaged FAs presented in Appendix T, Section T.4.6.11 of [B.4-2].

Figure 5 of the Technical Specification [B.4-3] shows that the 61BTH DSC allows for the storage of up to 61 damaged fuel assemblies. For the worst case with 60 damaged FAs and one intact FA, the maximum fuel cladding temperature for intact FA is 955 °F. However, for all evaluations with intact FAs, the maximum fuel cladding temperatures are well below the limit of 1058 °F. For the case with 61 damaged fuel assemblies, since all damaged fuel assemblies are considered as rubble, there are no thermal limits associated with this scenario. Therefore, there is no impact on loading damaged fuel along with intact fuel within the 61BTH Type 2 DSC.

B.4.5.5 Thermal Evaluation for Loading/Unloading Conditions

There is no change to the thermal evaluation for loading and unloading conditions presented in Appendix T, Section T.4.7 of [B.4-2] .

B.4.5.5.1 Maximum Fuel Cladding Temperature during Vacuum Drying

There is no change to the thermal evaluation during vacuum drying operations presented in Appendix T, Section T.4.7.1 of [B.4-2].

Tables T.4-25 and T.4-27 of [B.4-2] provide the maximum calculated temperatures for the fuel cladding and the basket components for the 61BTH Type 2 DSC during vacuum drying.

The maximum cladding temperatures for vacuum drying using helium are 598 °F for the 61BTH Type 2 DSC. This maximum cladding temperature is well below the limit of 752 °F [B.4-2].

B.4.5.5.2 Evaluation of Thermal Cycling of Fuel Cladding during Vacuum Drying, Helium Backfilling and Transfer

There is no change to the discussion on thermal cycling of fuel cladding during vacuum drying operations presented in Section T.4.7.2 of [B.4-2].

B.4.5.5.3 Reflooding Evaluation

There is no change to the discussion on unloading operations presented in Section T.4.7.3 of [B.4-2].

B.4.5.6 Minimum Duration to Operate Forced Air Circulation (FC)

Section B.4.5.1.4 summarizes the transfer time limits for OS197FC-B TC loaded with 61BTH Type 2 DSC with heat loads > 22.0 kW and ≤ 31.2 kW. If the transfer time limit cannot be satisfied, one of the recovery actions is to initiate Forced Air Circulation (FC). This section provides a thermal evaluation to establish the minimum duration for FC once initiated, and the subsequent transfer time limit once the air circulation is turned off to complete the transfer of the DSC into the storage module or return the DSC to the fuel handling building and refill the TC/DSC annulus with water.

Section B.4.5.6.1 presents a discussion on the various load cases considered in the thermal evaluations to determine the FC operation time. Section B.4.5.6.2 presents a description of the thermal CFD model used in this evaluation, Section B.4.5.6.3 discusses the results, and Section B.4.5.6.4 presents the applicable time limits for transfer.

B.4.5.6.1 Description of Load Cases

Based on the discussion in Section B.4.5.1, air circulation is used if the total heat load is > 22.0 kW and ≤ 31.2 kW for the OS197 TC. HLZCs 5, 6, 7, 8 and 10 can be loaded with maximum decay heat loads > 22.0 kW based on LCO 3.1.3 of Technical Specifications [B.4-3]. As discussed in Section B.4.4.1, HLZC 7 is the bounding HLZC among the five HLZCs (5, 6, 7, 8 and 10) and is thus used in this evaluation.

The load cases considered to establish the operational time limit of the FC include the initial steady-state evaluations with the OS197FC-B TC in vertical orientation loaded with 61BTH Type 2 DSC inside the fuel handling building, followed by three stage horizontal transient transfer evaluation for 27 hours with and without air circulation outside the building. The air circulation generates a flow rate of 400 cfm or greater and is described in Section B.4.5.1. A GCI study is also performed using a finer mesh to evaluate the mesh sensitivity. The Load Cases (LC) are discussed below and listed in Table B.4-9.

LC 1 is the initial steady state evaluation for the OS197FC-B TC in vertical orientation inside the fuel handling building during loading of the 61BTH Type 2 DSC with the TC/DSC annulus filled with water at 223°F and indoor ambient temperature of 120°F. Similar to Section T.4.5 of [B.4-2], a TC thermal model in horizontal orientation is assumed for the steady state evaluation of the TC vertically placed inside the fuel handling building.

LC 1-1 is the 15 hour horizontal transient transfer analysis outside the fuel handling building with outdoor ambient temperature of 100°F and without any air circulation. The clock starts (t=0) when the TC is in the vertical orientation inside the fuel handling building and the TC/DSC annulus water is drained. During this LC, the TC is placed on the transfer skid in the horizontal orientation and moved outdoors. The results from LC 1 are used as initial condition for LC 1-1.

LC 1-2 is the 8 hour horizontal transient transfer analysis outside the fuel handling building with outdoor ambient temperature of 100°F and forced air circulation. The results from LC 1-1 are used as initial condition for LC 1-2. LC 1-2 will establish that 8 hours is the minimum duration for which the FC should be kept in operation.

LC 1-3 is the 4 hour horizontal transient transfer analysis outside the fuel handling building with outdoor ambient temperature of 100°F without any air circulation. The results from LC 1-2 are used as initial condition for LC 1-3. If air circulation is initiated as a recovery operation during transfer, it needs to be turned off before transferring the DSC to the storage module. LC 1-3 establishes the time available to complete the transfer operation once the FC is turned off.

Number of Elements in the Coarse and Fine Meshes of OS197FC-B TC with 61BTH DSC

Mesh Set	Number of Hexahedra Elements in the Combined model
Coarse Mesh	36,258,466
Fine Mesh	56,692,153

Proprietary Information on Pages B.4-33 and B.4-34
Withheld Pursuant to 10 CFR 2.390

B.4.5.6.3 Results

Temperature Calculations

The maximum temperatures of the key components of the OS197FC-B TC loaded with 61BTH Type 2 DSC with HLZC 7 for the various load cases described in Table B.4-9 are reported in Table B.4-10.

Figure B.4-10 shows the temperature history of the fuel cladding during the transient transfer operations for LCs 1-1, 1-2 and 1-3. As seen from Figure B.4-10, during LC 1-2 the air circulation slows down the heat up rate of the TC loaded with the DSC. Temperatures reported in Table B.4-10 show that the temperatures of all key components remain below allowable limits at the end of FC. Based on LC 1-2 analysis, the air circulation must be operated for at least 8 hours to cool down the TC/DSC system once initiated.

Based on LC 1-3, a maximum of 4 hours is allowed to complete the transfer of the 61BTH Type 2 DSC to the storage module or to re-establish the air circulation. Table B.4-10 shows that the temperatures for all LCs remain below the maximum allowable temperature limits discussed in Section B.4.2.

Figure B.4-11 through Figure B.4-13 show the temperature contours for LCs 1-1 through 1-3.

GCI Calculation

Following the methodology discussed in Section A.4.4.2.3.7, GCI is calculated in Table B.4-11 based on the fine (LC 2-1) and coarse (LC 1-1) meshes. As shown in Table B.4-11, the GCI based on the coarse mesh is 7.2 ºF. The maximum fuel cladding temperature including the GCI for the coarse mesh is 677.6 ºF, remaining below the temperature limit of 752 ºF.

B.4.5.6.4 Discussion of Applicable Time Limits

The transfer time limit for the OS197FC-B TC loaded with HLZC 7 with maximum heat load of 31.2 kW is 13 hours and an additional 2 hours is considered to initiate FC as a recovery option if the operation time exceeds the transfer time limit of 13 hours as reported in Appendix T.4.5.4 of [B.4-2]. Based on the results of LC 1-1 in Section B.4.5.6.3, at the end of the 15 hours transient transfer operation, the maximum fuel cladding temperature reaches 670ºF with sufficient margin to the fuel cladding temperature limit of 752ºF. However, a time limit of 13 hours reported in Appendix T.4.5.4 of [B.4-2] is further reduced by 3 hours in this application for a transfer time limit of 10 hours to provide an additional margin to the temperature limit for both the vertical transfer operations within the fuel building and horizontal transfer operations that occur outside the building and to maintain consistency among operations with the EOS-37PTH/EOS-89BTH DSCs. The maximum fuel cladding temperature at 10 hours after the start of operations is 643°F for LC 1-1. Further, this reduction in the time limit will ensure that sufficient time is provided to initiate the recovery actions.

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 operation, it must be maintained for a minimum duration of 8 hours before it is turned off. Once the air circulation is terminated, the DSC transfer to the storage module must be completed within the next 4 hours. The maximum fuel cladding temperature at 4 hours after the air circulation is turned off is 692°F with sufficient margin to the temperature limit of 752°F.

The minimum duration of 8 hours to run the blower and the time limit of 4 hours after the blower is turned off for completion of the transfer operations are determined based on the 61BTH Type 2 DSC in the OS197FC-B TC with the maximum allowable heat load of 31.2 kW. These time limits to initiate the recovery actions also apply to other HLZCs with heat loads > 22.0 kW and ≤ 31.2 kW. However, if the maximum heat load of the DSC is less than 31.2 kW, new time limits can be determined to provide additional time for these transfer operations.

B.4.6 Maximum Internal Pressure

There is no change to the maximum internal pressure evaluation presented in Appendix T, Chapter T.4 of [B.4-2] for the 61BTH Type 2 DSC.

The methodology to calculate the maximum internal pressures for the 61BTH Type 2 DSC for normal, off-normal, and accident conditions is described in Section T.4.6.6.4 of [B.4-2]. The methodology accounts for the free DSC cavity volume, the quantities of DSC backfill gas, fuel rod fill gas, irradiation gases, and the average gas temperature in the DSC cavity and the DSC internal pressures are then calculated using ideal gas law.

Based on this methodology, the maximum internal pressures for normal, off-normal, and accident conditions are evaluated in Sections T.4.6.6.4, T.4.6.7.6, and T.4.6.8.5 of [B.4-2], respectively.

As shown in Tables T.4-16, T.4-20, and T.4-24 of [B.4-2], the maximum internal pressures for the 61BTH Type 2 DSC at normal, off-normal, and accident conditions are 7.6 psig, 12.1 psig and 68.7 psig remaining below the design basis pressures of 15 psig, 20 psig, and 120 psig considered in the structural evaluation for normal, off-normal, and accident conditions.

Therefore, it is concluded that the 61BTH Type 2 DSC maintains confinement for normal, off-normal, and accident conditions of storage and transfer operations.

B.4.7 References

B.4-1 NUREG-1536, "Standard Review Plan for Spent Fuel Dry Cask Storage Systems at a General License Facility," Revision 1, U.S. Nuclear Regulatory Commission, July 2010.

B.4-2 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket No. 72-1004.

B.4-3 CoC 1042, Appendix A, "NUHOMS® EOS System Generic Technical Specifications," Amendment 2.

B.4-4 Perry, R. H., Chilton, C. H., "Chemical Engineers' Handbook," 5th Edition, 1973.

B.4-5 GESC NS-3, NAC International, Atlanta Corporate Headquarters (Test Report NS-3-001, NAC International (while BISCO Products, Inc.), Norcross, GA.

B.4-6 GESC, NAC International, Atlanta Corporate Headquarters, 655 Engineering Drive, Norcross, Georgia, (Engineering Report #NS3-020, "Effects of 1300 °F on Unfilled NS-3," NAC International (while Bisco Products, Inc.), Norcross, GA, 11/November 1984)

B.4-7 ACI 349 06, "Code Requirements for Nuclear Safety Related Concrete Structures" American Concrete Institute.

B.4-8 NUREG-2174, "Impact of Variation in Environmental Conditions on the Thermal Performance of Dry Storage Casks - Final Report," U.S. Nuclear Regulatory Commission, March 2016.

B.4-9 Title 10, Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material," 2003.

B.4-10 SINDA/FLUINT™, "Systems Improved Numerical Differencing Analyzer and Fluid Integrator," Version 4.7, Cullimore & Ring Technologies, Inc., Littleton, CO, 2004.

B.4-11 Thermal Desktop™, Version 4.7, Cullimore & Ring Technologies, Inc., Littleton, CO, 2004.

B.4-12 SOLIDWORKS 2016 x64 Edition SP05.

B.4-13 ANSYS ICEM CFD, Version 17.1, ANSYS, Inc.

B.4-14 ANSYS FLUENT Users Guide, Version 17.1, ANSYS, Inc.

B.4-15 ANSYS Design Modeler, Version 17.1, ANSYS, Inc.

Proprietary Information on Pages B.4-39 through B.4-42
Withheld Pursuant to 10 CFR 2.390

Table B.4-5
61BTH Type 2 DSC in HSM-MX, Maximum Fuel Cladding and Concrete Temperatures for Storage Conditions

Load Case (1)	Description	Max Fuel Cladding Temperature (°F)			Concrete Temperature (°F)	
		Upper Compartment	Lower Compartment	Limit	Maximum	Limit
1a		679	671	752(2)	223	300(2)
1b		679	670		223	
1c		682	642		232	
2		651	654	1058(2)	204	
3		698	711		281	500(2)

Notes:

(1) See Table B.4-1 for the description of the load cases.

(2) The temperature limits are from NUREG-1536 [B.4-1].

Proprietary Information on Pages B.4-44 through B.4-71
Withheld Pursuant to 10 CFR 2.390

B.5 CONFINEMENT

There is no change to the 61BTH Type 2 DSC confinement assessment documented in Chapter T.7 of the Standardized NUHOMS® UFSAR [B.5-1].

B.5.1 References

B.5-1 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

APPENDIX B.6
SHIELDING EVALUATION

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

List of Tables

List of Figures

B.6 SHIELDING EVALUATION

The following radiation shielding evaluation addresses the storage of a 61BTH Type 2 DSC (61BTH DSC) in a NUHOMS® MATRIX (HSM-MX). It is demonstrated that the vent dose rates for storage of the 61BTH DSC are bounded by the vent dose rates for storage of either the EOS-37PTH or EOS-89BTH DSC documented in Chapter A.6. Therefore, the site dose evaluation documented in Chapter A.11 for an EOS-DSC bounds the 61BTH DSC.

It is also demonstrated that dose rates for transfer of the 61BTH DSC within the OS197 transfer cask (TC) are similar to dose rates for transfer of the EOS-89BTH DSC within the EOS-TC125 documented in Chapter 6. Therefore, the exposure estimate for transfer of the 61BTH DSC to the HSM-MX documented in Chapter B.11 is similar to the exposure estimate for transfer of the EOS-89BTH DSC to the HSM-MX documented in Chapter A.11.

The 61BTH DSC may store up to 120 irradiated stainless steel rods contained within reconstituted fuel assemblies.

The 61BTH DSC may store up to 4 failed fuel canisters (FFCs) containing failed fuel, up to 61 damaged fuel assemblies, or up to 61 intact fuel assemblies. Failed and damaged fuel shall not be present within the same DSC.

The methodology, source terms, and dose rates presented in this chapter are developed to be reasonably bounding for general licensee implementation of the EOS System. The term “reasonably bounding” is quantified in Section 6.2.8. These results may be used in lieu of near-field evaluations by the general licensee, although the inputs utilized in this chapter should be evaluated for applicability by each site. Site-specific HSM-MX near-field evaluations may be performed by the general licensee to modify key input parameters.

Site dose evaluations for the HSM-MX under normal, off-normal, and accident conditions are documented in Chapter B.11. Because the arrangement and the distance to the site boundary is site-specific, compliance with 10 CFR 72.104 and 10 CFR 72.106 for the HSM-MX can only be demonstrated using a site-specific evaluation.

B.6.1 Discussions and Results

The following is a summary of the methodology and results of the shielding analysis of HSM-MX. More detailed information is presented in the body of the chapter.

Source Terms

For the HSM-MX, the DSC in the lower compartment is limited to 50.0 kW, while the DSC in the upper compartment is limited to 41.8 kW. Because the 61BTH DSC is limited to 31.2 kW, it may be placed in either the upper or lower compartment. Ten heat load zone configurations (HLZCs) are available for the 61BTH DSC. The HLZCs are defined in the Technical Specifications, Figure 4A through Figure 4J [B.6-6].

To simplify the analysis, a hybrid HLZC is developed by selecting the hottest fuel allowed in each basket location. A basket could not be loaded in this manner because the thermal limits would be exceeded, although this method results in conservative source terms and dose rates. Source terms are developed for each zone of the hybrid HLZC for use in the OS197 TC and HSM-MX evaluations.

Dose Rates

The 61BTH DSC is transferred to the HSM-MX using the OS197 TC. Dose rates are computed at the surface of the OS197 TC using the Monte Carlo transport code MCNP5 [B.6-1]. Dose rates for transfer of the 61BTH DSC in the OS197 TC are shown to be similar to dose rates for transfer of the EOS-89BTH DSC within the EOS-TC125. This dose rate comparison is provided in Table B.6-14.

MCNP5 is also used to compute dose fields around the HSM-MX using detailed 3D models. [ ] Dose rates at the HSM-MX inlet and outlet vents, which are the primary source of radiation in the site dose analysis, are compared with the EOS-DSC in Table B.6-17. The dose rate excluding the contribution from the inlet and outlet vents is small, as the dose rates are due primarily to streaming from the vents. Therefore, the site dose analysis performed for the EOS-DSC in Chapter A.11 bounds the 61BTH DSC.

B.6.2 Source Specification

General BWR source term information in Section 6.2 is applicable to the OS197 and HSM-MX evaluation. Supplemental information is provided in this section.

B.6.2.1 Computer Programs

Source terms are generated using the ORIGEN-ARP module of SCALE6.0 [B.6-5]. The default ge7x7-0 library is used for enrichments ≥ 1.5 wt.% U-235. Because enrichments below 1.5 wt.% U-235 are not available in the default library, library ge7x7-0-lowe is utilized for enrichments below 1.5 % U-235. This low-enrichment library is generated using the same TRITON models used by Oak Ridge National Laboratory to develop the default library, although with the enrichments reduced.

B.6.2.2 PWR and BWR Source Terms

[

]

Reasonably bounding BWR source terms are developed for the 61BTH Type 2 DSC within the OS197 TC and HSM-MX. The term “reasonably bounding” is quantified in Section 6.2.8. Ten HLZCs are available for the 61BTH DSC. The HLZCs are defined in the Technical Specifications, Figure 4A through Figure 4J [B.6-6].

To simplify the analysis, a hybrid HLZC is developed by selecting the hottest fuel allowed in each basket location for the ten HLZCs. The hybrid HLZC features four radial zones, as illustrated in Figure B.6-1. The total decay heat of this configuration is 42.9 kW, although the 61BTH DSC is limited to 31.2 kW. A 61BTH DSC could not be loaded in this manner because the thermal limits are exceeded, although the hybrid HLZC results in conservative source terms and dose rates. Source terms are developed for each zone of the hybrid HLZC for use in the OS197 TC and HSM-MX evaluations.

The methodology used to develop the source terms are the same as documented in Section 6.2.2. ORIGEN-ARP light element mass inputs are obtained from Table 6-6. Burnup, enrichment, and cooling time combinations are developed to target decay heats of 0.48 kW/FA, 0.7 kW/FA, 1.2 kW/FA, and 0.54 kW/FA. These decay heats per FA correspond to the hybrid HLZC provided in Figure B.6-1. The minimum cooling time is 2 years. A constant specific power of 25 MW/MTU (4.95 MW/FA) is utilized in all source term calculations, which is a typical value for BWR fuel (see Section 3.4.6.2 of NUREG/CR-7194 [B.6-3]). The effect of specific power on source terms is discussed in Section B.6.2.9. Candidate source terms for each decay heat are summarized in Table B.6-1.

In general, the bounding source terms for the OS197 TC and HSM-MX analyses are different. For the OS197 TC, the dose rate due to neutrons and secondary gammas may exceed the dose rate due to primary gammas. However, dose rates for the HSM-MX are dominated by primary gammas streaming through the inlet and outlet vents. Therefore, separate source terms are developed for each system to maximize dose rates.

MCNP models are developed for the OS197 TC and HSM-MX. These models are used to compute the dose rate at the side of the OS197 TC and outlet vent of the HSM-MX for each candidate source. These dose rates are used only to rank the relative source strength of each source and are provided in Table B.6-1. The OS197 TC ranking dose rates are computed with the candidate source in the applicable zone, as indicated in Figure B.6-1. The HSM-MX ranking dose rates are generated for each candidate source in all 61 basket locations. HSM-MX dose rates are also elevated because the vent covers are not included in the source term ranking models to accelerate model convergence.

The following burnup, enrichment, and cooling time combinations result in reasonably bounding source terms for OS197 TC analysis:

- 0.48 kW/FA: 62 GWd/MTU, 3.8% U-235, 9.730 years
- 0.54 kW/FA: 62 GWd/MTU, 3.8% U-235, 7.528 years
- 0.70 kW/FA, 62 GWd/MTU, 3.8% U-235, 4.915 years
- 1.20 kW/FA, 62 GWd/MTU, 3.8% U-235, 2.563 years

The following burnup, enrichment, and cooling time combinations result in reasonably bounding source terms for HSM-MX analysis:

- 0.48 kW/FA: 40 GWd/MTU, 2.5% U-235, 4.358 years
- 0.54 kW/FA: 40 GWd/MTU, 2.5% U-235, 3.862 years
- 0.70 kW/FA, 50 GWd/MTU, 3.1% U-235, 3.711 years
- 1.20 kW/FA, 62 GWd/MTU, 3.8% U-235, 2.563 years

Based on the limiting burnup, enrichment, and cooling time combinations provided above, source terms are developed for each of the four fuel assembly regions (bottom nozzle, active fuel, plenum, and top nozzle) using the light elements for each region defined in Table 6-6. OS197 TC source terms are provided in Table B.6-2 through Table B.6-5, while HSM-MX source terms are provided in Table B.6-6 through Table B.6-9.

B.6.2.3 Axial Source Distributions and Subcritical Neutron Multiplication

No change to Section 6.2.3. As indicated in Table B.6-2 through Table B.6-9, the neutron source computed in ORIGEN-ARP is scaled by a factor of 1.232 to account for the increase in the neutron source magnitude for the axial source distribution utilized. Subcritical neutron multiplication is accounted for utilizing $k = 0.4$.

B.6.2.4 Control Components

No change to Section 6.2.4 (BWR fuel does not contain control components).

B.6.2.5 Blended Low Enriched Uranium Fuel

No change to Section 6.2.5.

B.6.2.6 Reconstituted Fuel

B.6.2.7 Irradiation Gases

The quantity of gas generated by irradiation is 20.2 g-moles per fuel assembly, see Section T.4.6.6.4 of [B.6-4].

B.6.2.8 Justification for Reasonably Bounding Source Term Methodology

No change to Section 6.2.8.

B.6.2.9 Sensitivity Study on Specific Power

Due to the manner in which the design basis sources are developed, increasing the specific power has essentially no effect on OS197 TC or HSM-MX dose rates. The design basis source terms are developed to target the maximum allowed decay heat, see Table B.6-1. If the specific power is increased 20% to 30 MW/MTU, the cooling times must increase to maintain the same decay heat. The net effect is no increase in dose rate.

A source term sensitivity study is developed for 30 MW/MTU using the same decay heat targets over the range of burnups and enrichments shown in the Technical Specification (TS) fuel qualification tables (FQTs) (TS Tables 19 and 20) [B.6-6]. The methodology described in Section B.6.2.2 is used to rank the relative strength of the 25 MW/MTU and 30 MW/MTU source terms. The results are reported in Table B.6-27 and Table B.6-28 for the OS197 TC and HSM-MX, respectively. It is observed that the dose rate perturbation is ±1%, which is negligible.

The effect of specific power on the source term is addressed in Section 3.4.2.4 of NUREG/CR-6716 [B.6-7]. It is stated in this NUREG that specific power has little effect on neutron dose rates but may increase gamma dose rates. In the NUREG analysis, PWR source terms are developed for a burnup of 40 GWd/MTU, enrichment of 3.5%, cooling time of 5 years, and specific powers of 20 MW/MTU and 40 MW/MTU. It is stated in the NUREG that the gamma dose rate due to the 40 MW/MTU source is approximately 30% higher than the 20 MW/MTU source.

The NUREG analysis is replicated with BWR fuel in the periphery of the OS197 TC. The conclusion is consistent with the NUREG, with an increase in gamma dose rate of 32%. This study is summarized in Table B.6-29. However, because the cooling time is treated as a fixed quantity (5 years), these two sources have different decay heats. The decay heat of the 40 MW/MTU source is 13% higher than the 20 MW/MTU source. In the EOS methodology used to develop the design basis source terms in Section B.6.2.2, all candidate source terms in each zone have the same decay heat. If the cooling time of the 40 MW/MTU case in the NUREG study is extended to 5.75 years so that the decay heat matches the 20 MW/MTU case, the difference in dose rate between the 20 MW/MTU and 40 MW/MTU sources is within ±1%, consistent with Table B.6-27 and Table B.6-28. This is demonstrated in the last column of Table B.6-29. Therefore, the source terms used in the UFSAR analysis have an additional decay heat constraint absent in the NUREG analysis.

Specific power would affect the dose rates only if the specific power is increased while the cooling times provided in TS Tables 19 and 20 [B.6-6] remain fixed. In this scenario, the fuel assemblies would exceed 1.2 kW/FA and 0.54 kW/FA. Dose rates would increase, but the fuel assemblies would also exceed the thermal limits, and fuel assemblies with these sources could not be stored.

The increase in FQT cooling times due to a specific power of 30 MW/MTU is small, ranging from 0 years for low burnups to approximately 0.2 years for high burnups. If the peripheral zone sources are generated for 30 MW/MTU but with FQT cooling times defined by TS Table 20 [B.6-6], the design basis OS197 TC and HSM-MX sources increase to 0.549 kW/FA and 0.566 kW/FA, respectively, see Table B.6-30. Both decay heats exceed the peripheral zone decay heat limit of 0.54 kW/FA. Using these sources, OS197 TC dose rates increase < 2% and HSM-MX dose rates increase < 5%. These dose rate perturbations are small and generally understood to be well-within the uncertainty of dose rate calculations and measurements.

It is not recommended to apply dose rate scaling factors to account for a specific power of 30 MW/MTU because (1) the sensitivity analysis results in Table B.6-27 and Table B.6-28 show no effect on dose rate for higher specific power if the EOS source term development methodology is applied, and (2) if 30 MW/MTU is utilized in source term development with the existing FQT cooling times and decay heat is allowed to exceed the limits, the dose rate effect is small (< 2% for OS197 TC and < 5% for HSM-MX). In the latter scenario, fuel assemblies associated with these sources could not be stored because thermal limits are exceeded.

B.6.3 Model Specification

MCNP5 is used to perform detailed 3D near-field dose rate evaluations for the OS197 TC and HSM-MX. All relevant details of the 61BTH Type 2 DSC, OS197 TC, and HSM-MX are modeled explicitly.

Separate primary gamma and neutron models are developed. The neutron models are run in coupled neutron-photon mode so that the secondary gamma dose rate from (n,γ) reactions may be computed.

The treatment of subcritical neutron multiplication is suppressed in MCNP by using the NONU card. Subcritical neutron multiplication is treated in this manner because the fuel assemblies are modeled as fresh fuel and homogenized for simplicity, which would cause inaccurate treatment of subcritical neutron multiplication by MCNP. Subcritical neutron multiplication is accounted for in the neutron source magnitude.

B.6.3.1 Material Properties

MCNP material compositions for carbon steel, stainless steel, air, water, concrete, and soil are defined in Table 6-41 and are used in the 61BTH DSC models for the OS197 TC and HSM-MX. Aluminum and poison in the 61BTH DSC are modeled as aluminum at a density of 2.7 g/cm^3. The lead in the OS197 TC is modeled at a density of 11.34 g/cm^3. The NS-3 composition used in the OS197 TC models is provided in Table B.6-10.

The HSM-MX models use the same material properties documented in Table 6-41 with the exception of the concrete density. Concrete used in the HSM-MX is modeled at a conservatively low density of 138 pcf (2.22 g/cm^3) compared to 140 pcf (2.24 g/cm^3) for the EOS-HSM.

Because the fuel type is the same as used in the EOS-89BTH DSC analysis, the BWR dry fuel compositions from Table 6-45 are used for the fuel.

B.6.3.2 MCNP Model Geometry for the OS197 TC

Normal Condition Model

A detailed MCNP model is developed for normal condition transfer of the 61BTH Type 2 DSC inside of the OS197 TC. The MCNP model is illustrated in Figure B.6-2 and Figure B.6-3.

Key dimensions for the 61BTH Type 2 DSC are provided in Table B.6-11. The basket is constructed of separate 2x2 and 3x3 compartments wrapped with 0.105 inch thick steel sheet. The 2x2 compartments have a steel thickness of 0.120 inches, and the 3x3 compartments have a steel thickness of 0.135 inches. The effective steel thickness for the entire basket, including the wrapper, is 0.171 inches. To simplify the model geometry, each compartment is modeled with an effective steel thickness of 0.170 inches. The basket aluminum and poison are conservatively modeled at 0.3 inches rather than the nominal value of 0.31 inches.

The complex steel and aluminum geometry in the transition rails are modeled as simple annuli to capture the effective thickness of steel and aluminum in this region.

Key dimensions for the as-modeled OS197 TC geometry are provided in Table B.6-12.

All fuel assemblies are modeled as intact. Under normal conditions, damaged fuel has the same geometry as intact fuel. Four out of 61 compartments may contain FFCs with failed fuel. Reconfiguration of fuel in the four FFCs will have a negligible effect on OS197 TC dose rates. Explicit analysis of four reconfigured fuel assemblies in the EOS-37PTH DSC showed little effect on EOS-TC125/135 dose rates, see Section 6.4.3. Also, due to the hybrid HLZC assumption (Figure B.6-1), the OS197 FC dose rates are computed for a highly conservative HLZC compared to an as-loaded 61BTH DSC, resulting in significant conservatisms in the source terms.

Accident Condition Model

Under accident conditions, the neutron shield and neutron shield shell are assumed to be lost, and the dose rate is computed at 100 m. Lead slump of 2.2 inches is assumed at the top of the lead. Ground and atmospheric air are modeled to account for ground scatter and skyshine at large distances. Because the neutron shielding is lost, the dose rate is neutron dominated. The normal condition sources are high-burnup with maximized neutron sources and are also used in the transfer cask accident models.

Under accident conditions, all damaged fuel assemblies may reconfigure, and the 61BTH DSC may contain up to 61 damaged fuel assemblies. However, at 100 m, fuel reconfiguration has little effect on accident dose rates. Explicit EOS-37PTH DSC accident calculations performed with damaged fuel at 75% and 50% of the nominal fuel assembly length show virtually no difference in dose rate (see Section 6.4.3). Also, accident conditions with reconfigured fuel in the OS197 TC is addressed in Section T.5.4.8 of the Standardized NUHOMS® UFSAR [B.6-4], where it is concluded that it is conservative to model the fuel as intact when computing dose rates at 100 m. Therefore, the fuel is modeled as intact in the accident cases.

B.6.3.3 MCNP Model Geometry for the HSM-MX

The HSM-MX model geometry is developed in detail in Section A.6.3.3. The triple-reflection MCNP model is utilized with the 61BTH DSC. The triple-reflection model features reflective boundary conditions on the right and left sides, as well as the rear. Because of the reflective boundaries, dose rates are maximized at the inlet and outlet vents. The HSM-MX with the 61BTH DSC is illustrated in Figure B.6-4. Only the triple-reflection model is developed for the 61BTH DSC because this is sufficient to demonstrate that EOS-DSC dose rates are bounding.

ADVANTG [B.6-2] is used to develop weight windows to accelerate problem convergence for all models.

All fuel assemblies are modeled as intact. Under normal conditions, damaged fuel has the same geometry as intact fuel. Four out of 61 compartments may contain FFCs with failed fuel. Reconfiguration of four out of 61 fuel assemblies will have a negligible effect on HSM-MX dose rates. Also, due to the hybrid HLZC assumption (Figure B.6-1), the HSM-MX dose rates are computed for a highly conservative HLZC compared to an as-loaded 61BTH DSC, resulting in significant conservatisms in the source terms.

B.6.4 Shielding Analysis

B.6.4.1 Computer Codes

MCNP5 v1.40 is used in the shielding analysis [B.6-1]. MCNP5 is a Monte Carlo transport program that allows full 3D modeling of the HSM-MX. Therefore, no geometrical approximations are necessary when developing the shielding models.

B.6.4.2 Flux-to-Dose Rate Conversion

No change to Section 6.4.2.

B.6.4.3 OS197 TC Dose Rates

Normal Conditions

OS197 TC dose rates are computed with and without reconstituted FAs. The source terms for standard FAs are provided in Table B.6-2 through Table B.6-5. The reconstituted fuel assembly source term to be applied on the periphery for reconstituted FAs containing 5 irradiated stainless steel rods per FA (120 rods per DSC) is provided in Table B.6-21.

Dose rates are computed using mesh tallies similar to the mesh tallies utilized in the EOS-TC125 models to facilitate dose rate comparisons. To simplify the presentation, only maximum total dose rates are reported at or near the surface of the OS197 TC in Table B.6-13. This table provides dose rates for "transfer" and "transfer peak." "Transfer" dose rates correspond to the tally structure shown in Figure 6-7. Using this tally structure, the bottom and top tallies correspond to the entire bottom or top surface, and the side tallies are circumferential averages around the entire cask. The "transfer peak" dose rates are computed using a more refined tally structure, as indicated in Figure 6-8 through Figure 6-10. In the refined tallies, the top and bottom tallies have six annular regions, and the side tallies have 24 angular regions. While Figure 6-7 through Figure 6-10 depict the EOS-89BTH DSC within the EOS-TC125, the tally locations are similar for the OS197 TC.

Dose rates with and without reconstituted fuel assemblies are reported in Table B.6-13. Reconstituted fuel does not have a large effect on OS197 TC dose rates because the bounding source is neutron-dominated, and an increase in Co-60 activity due to irradiated stainless steel rods is largely offset by a reduction in the neutron source due to the loss of uranium-oxide rods.

The OS197 TC dose rates reported in Table B.6-13 are highly conservative due to the hybrid HLZC assumption (see Figure B.6-1). Due to the large neutron sources in each zone, approximately 40% of the dose rate at the side of the OS197 is due to fuel assemblies in the inner zones. If HLZC 1 through 10 were modeled explicitly, the dose rates would decrease compared to the hybrid HLZC.

The maximum OS197 TC and EOS-TC125(89BTH) dose rates are compared in Table B.6-14. The dose rates computed for the OS197 TC (61BTH) are bounded by the EOS-TC125(89BTH) dose rates on the side, where the majority of operations occur. Dose rates are similar at the top of both TCs, where their magnitudes are considerably lower. Dose rates are larger for the OS197 TC on the bottom of the cask, although the cask bottom is inaccessible during decontamination and welding operations.

Occupational exposure for transfer of the EOS-89BTH DSC to the HSM-MX is provided in Table A.11-4. In the OS197 TC occupational dose assessment provided in Section B.11.2.1, EOS-TC125(89BTH) dose rates are conservatively applied for decontamination and welding operations, and OS197 TC dose rates are applied for transfer operations.

[ ]

Accident Conditions

The 100 m dose rate under accident conditions with only standard fuel is provided in Table B.6-15 and is 1.28 mrem/hr. When 24 reconstituted FAs are loaded into the peripheral storage locations containing 5 irradiated stainless steel rods each, the dose rate decreases slightly to 1.27 mrem/hr. These values are bounded by the maximum EOS-TC dose rate from Table 6-54.

Proprietary Information on This Page
Withheld Pursuant to 10 CFR 2.390

B.6.5 Supplemental Information

B.6.5.1 61BTH DSC Fuel Qualification

Chapter B.6 presents the shielding analysis for design basis fuel. A highly conservative approach is employed in which a hybrid HLZC is developed using the maximum heat loads from HLZC 1 through 10. The hybrid HLZC is illustrated in Figure B.6-1. A 61BTH DSC could not be loaded in this manner due to thermal limitations. For instance, if 1.2 kW fuel is loaded, the peripheral region is limited to 0.393 kW/FA (see Figure 4J in the TS [B.6-6]).

Although a highly conservative approach is employed to compute HSM-MX dose rates using the 61BTH DSC, the dose rates are below the dose rates computed for the EOS-DSCs (EOS-37PTH and EOS-89BTH), see Table B.6-16 and Table B.6-17. The TS dose rate limits in TS Section 5.1.2(c) are based upon EOS-DSC dose rates. Nevertheless, to provide additional assurance that TS dose rate limits will be met, a relationship between decay heat, burnup, enrichment, cooling time, and bounding source terms is developed and provided as fuel qualification tables (FQTs). The methodology to develop these FQTs is the same as used to develop the design basis source terms.

A heat load of 0.54 kW/FA is modeled on the periphery, while the maximum heat load of 1.2 kW/FA is modeled within interior locations, see Figure B.6-1. Following the methodology developed for the EOS-37PTH DSC (see Section 6.5.1), FQTs are developed for both the maximum heat load (1.2 kW/FA) and maximum peripheral heat load (0.54 kW/FA).

The purpose of the FQTs is solely to provide an additional dose rate constraint. Decay heat for each fuel assembly to be loaded is determined using NRC Regulatory Guide 3.54, ORIGEN-ARP, or other acceptable method.

The FQT developed based on 1.2 kW is a global constraint and is applied to every fuel assembly to be loaded in the 61BTH DSC. This FQT is provided as TS Table 19. The 0.54 kW FQT is applicable only to fuel located in peripheral locations of HLZC 2, 4, 5, 6, 7, and 8 and is provided as TS Table 20. The peripheral locations are defined in TS Figure 6. TS Table 20 does not apply to HLZC 1, 3, 9, or 10, or to the interior locations of any HLZC.

The burnup in the FQTs is expressed in units of GWd/FA rather than GWd/MTU. The burnup in GWd/FA is the burnup in GWd/MTU multiplied by the MTU of the fuel assembly. The minimum cooling times are obtained from these tables using linear interpolation.

As documented in Section 6.2.8, a small percentage (<0.5%) of fuel assemblies are low-enrichment outlier fuel (LEOF). Based on Table 6-60, LEOF BWR fuel is rare, as only ~30 have been generated over the past 40 years. To determine if a fuel assembly is LEOF, the enrichment is compared against the minimum value specified in TS Table 18. LEOF would not affect storage dose rates, which are gamma dominated, but could have a small effect (generally < 5%) on transfer cask dose rates. Based on these considerations, up to 4 LEOFs are allowed in the peripheral region. A minimum of five non-LEOFs shall circumferentially separate LEOFs within the peripheral region. There are no limitations on the number and location of LEOF stored in the inner region.

Because LEOF, by definition, is below the minimum enrichments provided in the FQTs, minimum cooling times for LEOF are obtained by extrapolating the FQT cooling times using an appropriate method. Because minimum cooling times increase with lower enrichments, this extrapolation provides an additional cooling time penalty.

The overall method for application of these FQTs and qualification of LEOF is provided below.

1. Determine the decay heat of all fuel to be loaded in an 61BTH DSC using NRC Regulatory Guide 3.54, ORIGEN-ARP, or another acceptable method. Confirm the decay heat limit is met for each basket location.
2. Determine if LEOF is present in the fuel to be loaded by application of TS Table 18.
   a) Up to 4 LEOF are allowed in the peripheral region. A minimum of five non-LEOFs shall circumferentially separate LEOFs within the peripheral region.
   b) There are no limitations on the number and location of LEOF stored in the inner region.
3. Verify all fuel to be loaded meets the minimum cooling time of TS Table 19. Fuel that does not meet the cooling time limitations of this table cannot be loaded.
4. For fuel in the peripheral locations of HLZC 2, 4, 5, 6, 7, and 8, verify all fuel to be loaded meets the minimum cooling time of TS Table 20. This table does not apply to HLZC 1, 3, 9, or 10, or to the interior locations of any HLZC.

Interpolation and/or extrapolation of the FQT cooling times is acceptable, as needed. These FQTs provide an additional constraint to ensure compliance with the dose rate limitations in TS 5.1.2(c).

B.6.5.2 References

B.6-1 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, RSICC Computer Code Collection, January 2006.

B.6-2 ADVANTG – An Automated Variance Reduction Parameter Generator, Oak Ridge National Laboratory, August 2015.

B.6-3 NUREG/CR-7194, "Technical Basis for Peak Reactivity Burnup Credit for BWR Spent Nuclear Fuel in Storage and Transportation Systems," US Nuclear Regulatory Commission.

B.6-4 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

B.6-5 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.

B.6-6 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 2.

B.6-7 NUREG/CR-6176, "Recommendations on Fuel Parameters for Standard Technical Specifications for Spent Fuel Storage Casks," US Nuclear Regulatory Commission.

Proprietary Information on This Page
Withheld Pursuant to 10 CFR 2.390

Table B.6-2
OS197 TC Source Term for 0.48 kW/FA, 61BTH DSC (Normal and Accident)

Burnup (GWd/MTU)			62	62	62	62
Enrichment (wt. % U-235)			3.8	3.8	3.8	3.8
Cooling Time (years)			9.730	9.730	9.730	9.730
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	2.506E+10	5.042E+14	2.178E+10	1.044E+10
5.00E-02	to	1.00E-01	4.380E+09	1.355E+14	1.488E+09	1.651E+09
1.00E-01	to	2.00E-01	1.369E+09	9.990E+13	1.934E+09	6.038E+08
2.00E-01	to	3.00E-01	7.443E+07	2.919E+13	1.301E+08	3.447E+07
3.00E-01	to	4.00E-01	1.411E+08	1.883E+13	3.972E+08	7.428E+07
4.00E-01	to	6.00E-01	1.639E+09	9.768E+13	8.456E+09	1.091E+09
6.00E-01	to	8.00E-01	8.635E+08	9.951E+14	4.411E+09	6.214E+08
8.00E-01	to	1.00E+00	7.308E+08	5.085E+13	2.189E+08	2.771E+08
1.00E+00	to	1.33E+00	1.268E+12	3.124E+13	4.036E+11	4.766E+11
1.33E+00	to	1.66E+00	3.581E+11	5.907E+12	1.140E+11	1.346E+11
1.66E+00	to	2.00E+00	8.386E+00	6.457E+10	4.340E+01	5.592E+00
2.00E+00	to	2.50E+00	8.569E+06	2.105E+10	2.727E+06	3.220E+06
2.50E+00	to	3.00E+00	7.321E+03	1.629E+09	2.330E+03	2.751E+03
3.00E+00	to	4.00E+00	3.492E-07	1.763E+08	3.579E-08	1.967E-06
4.00E+00	to	5.00E+00	7.681E-29	1.364E+07	3.977E-28	5.124E-29
5.00E+00	to	6.50E+00	2.213E-29	5.472E+06	1.146E-28	1.476E-29
6.50E+00	to	8.00E+00	2.815E-30	1.074E+06	1.458E-29	1.878E-30
8.00E+00	to	1.00E+01	3.757E-31	2.279E+05	1.945E-30	2.506E-31
Total Gamma, g/(sec*FA)			1.660E+12	1.969E+15	5.564E+11	6.260E+11
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						3.926E+08
Treated with peaking factor 1.232 and k-eff=0.4 (dry)						8.061E+08

Table B.6-3
OS197 TC Source Term for 0.54 kW/FA, 61BTH DSC (Normal and Accident)

Burnup (GWd/MTU)			62	62	62	62
Enrichment (wt. % U-235)			3.8	3.8	3.8	3.8
Cooling Time (years)			7.528	7.528	7.528	7.528
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	3.469E+10	5.635E+14	3.583E+10	1.473E+10
5.00E-02	to	1.00E-01	5.865E+09	1.512E+14	2.031E+09	2.213E+09
1.00E-01	to	2.00E-01	1.961E+09	1.144E+14	3.245E+09	8.931E+08
2.00E-01	to	3.00E-01	1.085E+08	3.305E+13	2.207E+08	5.203E+07
3.00E-01	to	4.00E-01	2.184E+08	2.142E+13	6.857E+08	1.191E+08
4.00E-01	to	6.00E-01	2.864E+09	1.918E+14	1.479E+10	1.908E+09
6.00E-01	to	8.00E-01	1.503E+09	1.140E+15	7.716E+09	1.047E+09
8.00E-01	to	1.00E+00	4.054E+09	9.365E+13	1.222E+09	1.304E+09
1.00E+00	to	1.33E+00	1.694E+12	4.070E+13	5.392E+11	6.367E+11
1.33E+00	to	1.66E+00	4.784E+11	9.576E+12	1.523E+11	1.798E+11
1.66E+00	to	2.00E+00	8.873E+00	1.288E+11	4.585E+01	5.918E+00
2.00E+00	to	2.50E+00	1.145E+07	1.057E+11	3.644E+06	4.302E+06
2.50E+00	to	3.00E+00	9.781E+03	6.699E+09	3.113E+03	3.676E+03
3.00E+00	to	4.00E+00	3.658E-07	6.537E+08	3.749E-08	2.061E-06
4.00E+00	to	5.00E+00	7.681E-29	1.483E+07	3.977E-28	5.124E-29
5.00E+00	to	6.50E+00	2.213E-29	5.951E+06	1.146E-28	1.476E-29
6.50E+00	to	8.00E+00	2.815E-30	1.167E+06	1.458E-29	1.878E-30
8.00E+00	to	1.00E+01	3.757E-31	2.479E+05	1.945E-30	2.506E-31
Total Gamma, g/(sec*FA)			2.224E+12	2.360E+15	7.573E+11	8.388E+11
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						4.269E+08
Treated with peaking factor 1.232 and k-eff=0.4 (dry)						8.766E+08

Table B.6-4
OS197 TC Source Term for 0.70 kW/FA, 61BTH DSC (Normal and Accident)

Burnup (GWd/MTU)			62	62	62	62
Enrichment (wt. % U-235)			3.8	3.8	3.8	3.8
Cooling Time (years)			4.915	4.915	4.915	4.915
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	5.295E+10	7.584E+14	7.179E+10	2.340E+10
5.00E-02	to	1.00E-01	8.303E+09	2.109E+14	2.965E+09	3.137E+09
1.00E-01	to	2.00E-01	3.064E+09	1.690E+14	6.063E+09	1.454E+09
2.00E-01	to	3.00E-01	1.734E+08	4.824E+13	4.168E+08	8.692E+07
3.00E-01	to	4.00E-01	3.760E+08	3.289E+13	1.319E+09	2.133E+08
4.00E-01	to	6.00E-01	5.557E+09	4.640E+14	2.872E+10	3.703E+09
6.00E-01	to	8.00E-01	2.907E+09	1.472E+15	1.498E+10	1.984E+09
8.00E-01	to	1.00E+00	3.316E+10	2.076E+14	1.001E+10	1.029E+10
1.00E+00	to	1.33E+00	2.389E+12	6.129E+13	7.604E+11	8.979E+11
1.33E+00	to	1.66E+00	6.747E+11	1.919E+13	2.147E+11	2.536E+11
1.66E+00	to	2.00E+00	1.663E+02	5.380E+11	9.625E+01	1.212E+02
2.00E+00	to	2.50E+00	1.614E+07	8.430E+11	5.138E+06	6.067E+06
2.50E+00	to	3.00E+00	1.379E+04	3.912E+10	4.390E+03	5.184E+03
3.00E+00	to	4.00E+00	3.865E-07	3.669E+09	3.962E-08	2.177E-06
4.00E+00	to	5.00E+00	7.681E-29	1.639E+07	3.977E-28	5.124E-29
5.00E+00	to	6.50E+00	2.213E-29	6.580E+06	1.146E-28	1.476E-29
6.50E+00	to	8.00E+00	2.815E-30	1.291E+06	1.458E-29	1.878E-30
8.00E+00	to	1.00E+01	3.757E-31	2.741E+05	1.945E-30	2.506E-31
Total Gamma, g/(sec*FA)			3.170E+12	3.445E+15	1.111E+12	1.196E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						4.722E+08
Treated with peaking factor 1.232 and k-eff=0.4 (dry)						9.696E+08

Table B.6-5
OS197 TC Source Term for 1.20 kW/FA, 61BTH DSC (Normal and Accident)

Burnup (GWd/MTU)			62	62	62	62
Enrichment (wt. % U-235)			3.8	3.8	3.8	3.8
Cooling Time (years)			2.563	2.563	2.563	2.563
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	8.763E+10	1.591E+15	1.781E+11	4.215E+10
5.00E-02	to	1.00E-01	1.138E+10	4.874E+14	4.269E+09	4.312E+09
1.00E-01	to	2.00E-01	4.676E+09	4.315E+14	1.076E+10	2.309E+09
2.00E-01	to	3.00E-01	2.752E+08	1.200E+14	7.669E+08	1.443E+08
3.00E-01	to	4.00E-01	7.429E+08	8.947E+13	2.990E+09	4.444E+08
4.00E-01	to	6.00E-01	1.014E+10	1.130E+15	5.219E+10	6.760E+09
6.00E-01	to	8.00E-01	5.450E+09	2.147E+15	2.814E+10	3.679E+09
8.00E-01	to	1.00E+00	2.230E+11	4.504E+14	6.729E+10	6.894E+10
1.00E+00	to	1.33E+00	3.255E+12	1.080E+14	1.036E+12	1.223E+12
1.33E+00	to	1.66E+00	9.193E+11	4.247E+13	2.926E+11	3.455E+11
1.66E+00	to	2.00E+00	7.075E+05	2.600E+12	2.710E+05	5.177E+05
2.00E+00	to	2.50E+00	2.200E+07	5.882E+12	7.011E+06	8.268E+06
2.50E+00	to	3.00E+00	1.880E+04	1.954E+11	5.990E+03	7.064E+03
3.00E+00	to	4.00E+00	4.061E-07	1.804E+10	4.163E-08	2.288E-06
4.00E+00	to	5.00E+00	7.681E-29	1.804E+07	3.977E-28	5.124E-29
5.00E+00	to	6.50E+00	2.213E-29	7.241E+06	1.146E-28	1.476E-29
6.50E+00	to	8.00E+00	2.815E-30	1.420E+06	1.458E-29	1.878E-30
8.00E+00	to	1.00E+01	3.757E-31	3.016E+05	1.945E-30	2.506E-31
Total Gamma, g/(sec*FA)			4.518E+12	6.606E+15	1.673E+12	1.698E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						5.201E+08
Treated with peaking factor 1.232 and k-eff=0.4 (dry)						1.068E+09

Table B.6-6
HSM-MX Source Term for 0.48 kW/FA, 61BTH DSC

Burnup (GWd/MTU)			40	40	40	40
Enrichment (wt. % U-235)			2.5	2.5	2.5	2.5
Cooling Time (years)			4.358	4.358	4.358	4.358
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	4.981E+10	6.231E+14	7.212E+10	2.206E+10
5.00E-02	to	1.00E-01	7.636E+09	1.804E+14	2.742E+09	2.848E+09
1.00E-01	to	2.00E-01	2.843E+09	1.493E+14	5.690E+09	1.343E+09
2.00E-01	to	3.00E-01	1.610E+08	4.234E+13	3.916E+08	8.051E+07
3.00E-01	to	4.00E-01	3.522E+08	3.027E+13	1.248E+09	1.999E+08
4.00E-01	to	6.00E-01	5.224E+09	3.608E+14	2.700E+10	3.481E+09
6.00E-01	to	8.00E-01	2.731E+09	1.024E+15	1.408E+10	1.853E+09
8.00E-01	to	1.00E+00	4.717E+10	1.492E+14	1.424E+10	1.460E+10
1.00E+00	to	1.33E+00	2.195E+12	4.671E+13	7.001E+11	8.139E+11
1.33E+00	to	1.66E+00	6.197E+11	1.500E+13	1.977E+11	2.298E+11
1.66E+00	to	2.00E+00	1.077E+03	6.731E+11	3.454E+02	7.893E+02
2.00E+00	to	2.50E+00	1.483E+07	1.275E+12	4.731E+06	5.500E+06
2.50E+00	to	3.00E+00	1.267E+04	5.027E+10	4.042E+03	4.699E+03
3.00E+00	to	4.00E+00	2.442E-07	4.666E+09	2.504E-08	1.376E-06
4.00E+00	to	5.00E+00	6.911E-30	6.040E+06	3.579E-29	4.611E-30
5.00E+00	to	6.50E+00	1.991E-30	2.424E+06	1.031E-29	1.329E-30
6.50E+00	to	8.00E+00	2.533E-31	4.756E+05	1.312E-30	1.690E-31
8.00E+00	to	1.00E+01	3.380E-32	1.010E+05	1.750E-31	2.255E-32
Total Gamma, g/(sec*FA)			2.930E+12	2.623E+15	1.035E+12	1.090E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.732E+08
Treated with peaking factor 1.232 and k-eff=0.4 (dry)						3.556E+08

Table B.6-7
HSM-MX Source Term for 0.54 kW/FA, 61BTH DSC

Burnup (GWd/MTU)			40	40	40	40
Enrichment (wt. % U-235)			2.5	2.5	2.5	2.5
Cooling Time (years)			3.862	3.862	3.862	3.862
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	5.498E+10	7.307E+14	8.640E+10	2.475E+10
5.00E-02	to	1.00E-01	8.159E+09	2.160E+14	2.953E+09	3.044E+09
1.00E-01	to	2.00E-01	3.103E+09	1.832E+14	6.415E+09	1.479E+09
2.00E-01	to	3.00E-01	1.767E+08	5.162E+13	4.430E+08	8.916E+07
3.00E-01	to	4.00E-01	3.957E+08	3.760E+13	1.434E+09	2.266E+08
4.00E-01	to	6.00E-01	5.925E+09	4.373E+14	3.062E+10	3.948E+09
6.00E-01	to	8.00E-01	3.097E+09	1.101E+15	1.598E+10	2.097E+09
8.00E-01	to	1.00E+00	7.049E+10	1.756E+14	2.128E+10	2.180E+10
1.00E+00	to	1.33E+00	2.342E+12	5.259E+13	7.473E+11	8.688E+11
1.33E+00	to	1.66E+00	6.615E+11	1.767E+13	2.110E+11	2.453E+11
1.66E+00	to	2.00E+00	6.320E+03	9.408E+11	1.970E+03	4.630E+03
2.00E+00	to	2.50E+00	1.583E+07	1.923E+12	5.050E+06	5.870E+06
2.50E+00	to	3.00E+00	1.352E+04	7.060E+10	4.314E+03	5.016E+03
3.00E+00	to	4.00E+00	2.468E-07	6.537E+09	2.530E-08	1.391E-06
4.00E+00	to	5.00E+00	6.911E-30	6.159E+06	3.579E-29	4.611E-30
5.00E+00	to	6.50E+00	1.991E-30	2.472E+06	1.031E-29	1.329E-30
6.50E+00	to	8.00E+00	2.533E-31	4.849E+05	1.312E-30	1.690E-31
8.00E+00	to	1.00E+01	3.380E-32	1.030E+05	1.750E-31	2.255E-32
Total Gamma, g/(sec*FA)			3.150E+12	3.006E+15	1.124E+12	1.172E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.766E+08
Treated with peaking factor 1.232 and k-eff=0.4 (dry)						3.626E+08

Table B.6-8
HSM-MX Source Term for 0.70 kW/FA, 61BTH DSC

Burnup (GWd/MTU)			50	50	50	50
Enrichment (wt. % U-235)			3.1	3.1	3.1	3.1
Cooling Time (years)			3.711	3.711	3.711	3.711
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	6.168E+10	8.895E+14	1.000E+11	2.806E+10
5.00E-02	to	1.00E-01	9.028E+09	2.618E+14	3.284E+09	3.389E+09
1.00E-01	to	2.00E-01	3.488E+09	2.217E+14	7.387E+09	1.678E+09
2.00E-01	to	3.00E-01	1.995E+08	6.251E+13	5.111E+08	1.016E+08
3.00E-01	to	4.00E-01	4.530E+08	4.519E+13	1.665E+09	2.611E+08
4.00E-01	to	6.00E-01	6.852E+09	5.832E+14	3.541E+10	4.566E+09
6.00E-01	to	8.00E-01	3.583E+09	1.413E+15	1.848E+10	2.427E+09
8.00E-01	to	1.00E+00	8.372E+10	2.405E+14	2.527E+10	2.589E+10
1.00E+00	to	1.33E+00	2.591E+12	6.621E+13	8.259E+11	9.667E+11
1.33E+00	to	1.66E+00	7.318E+11	2.299E+13	2.332E+11	2.730E+11
1.66E+00	to	2.00E+00	1.123E+04	1.115E+12	3.613E+03	8.227E+03
2.00E+00	to	2.50E+00	1.751E+07	2.233E+12	5.580E+06	6.532E+06
2.50E+00	to	3.00E+00	1.496E+04	8.380E+10	4.768E+03	5.581E+03
3.00E+00	to	4.00E+00	3.141E-07	7.771E+09	3.220E-08	1.770E-06
4.00E+00	to	5.00E+00	2.333E-29	1.049E+07	1.208E-28	1.556E-29
5.00E+00	to	6.50E+00	6.721E-30	4.209E+06	3.480E-29	4.484E-30
6.50E+00	to	8.00E+00	8.549E-31	8.257E+05	4.427E-30	5.703E-31
8.00E+00	to	1.00E+01	1.141E-31	1.753E+05	5.908E-31	7.611E-32
Total Gamma, g/(sec*FA)			3.492E+12	3.810E+15	1.251E+12	1.306E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						3.011E+08
Treated with peaking factor 1.232 and k-eff=0.4 (dry)						6.183E+08

Table B.6-9
HSM-MX Source Term for 1.20 kW/FA, 61BTH DSC

Burnup (GWd/MTU)			62	62	62	62
Enrichment (wt. % U-235)			3.8	3.8	3.8	3.8
Cooling Time (years)			2.563	2.563	2.563	2.563
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	8.763E+10	1.591E+15	1.781E+11	4.215E+10
5.00E-02	to	1.00E-01	1.138E+10	4.874E+14	4.269E+09	4.312E+09
1.00E-01	to	2.00E-01	4.676E+09	4.315E+14	1.076E+10	2.309E+09
2.00E-01	to	3.00E-01	2.752E+08	1.200E+14	7.669E+08	1.443E+08
3.00E-01	to	4.00E-01	7.429E+08	8.947E+13	2.990E+09	4.444E+08
4.00E-01	to	6.00E-01	1.014E+10	1.130E+15	5.219E+10	6.760E+09
6.00E-01	to	8.00E-01	5.450E+09	2.147E+15	2.814E+10	3.679E+09
8.00E-01	to	1.00E+00	2.230E+11	4.504E+14	6.729E+10	6.894E+10
1.00E+00	to	1.33E+00	3.255E+12	1.080E+14	1.036E+12	1.223E+12
1.33E+00	to	1.66E+00	9.193E+11	4.247E+13	2.926E+11	3.455E+11
1.66E+00	to	2.00E+00	7.075E+05	2.600E+12	2.710E+05	5.177E+05
2.00E+00	to	2.50E+00	2.200E+07	5.882E+12	7.011E+06	8.268E+06
2.50E+00	to	3.00E+00	1.880E+04	1.954E+11	5.990E+03	7.064E+03
3.00E+00	to	4.00E+00	4.061E-07	1.804E+10	4.163E-08	2.288E-06
4.00E+00	to	5.00E+00	7.681E-29	1.804E+07	3.977E-28	5.124E-29
5.00E+00	to	6.50E+00	2.213E-29	7.241E+06	1.146E-28	1.476E-29
6.50E+00	to	8.00E+00	2.815E-30	1.420E+06	1.458E-29	1.878E-30
8.00E+00	to	1.00E+01	3.757E-31	3.016E+05	1.945E-30	2.506E-31
Total Gamma, g/(sec*FA)			4.518E+12	6.606E+15	1.673E+12	1.698E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						5.201E+08
Treated with peaking factor 1.232 and k-eff=0.4 (dry)						1.068E+09

Table B.6-10
NS-3 Composition

Element	NS-3 (atom/b-cm)
H	4.498E-02
B-10	6.077E-05
B-11	2.446E-04
C	9.595E-03
O	3.704E-02
Al	6.887E-03
Si	1.243E-03
Ca	1.454E-03
Fe	1.042E-04
Total	1.016E-01

Table B.6-11
61BTH Type 2 DSC Key As-Modeled Dimensions

Parameter	As-Modeled Dimension (in)
Stainless steel shell thickness	0.5
Stainless steel shell outer diameter	67.25
Stainless steel rail thickness (total)	0.4375
Aluminum rail thickness (total)	1.25
Overall height	196.000
Cavity height	179.500
Total bottom steel shielding thickness (sum of stainless steel inner plate, carbon steel shield plug, and stainless steel outer plate)	7.5
Total top steel shielding thickness (sum of carbon steel shield plug, stainless steel inner top cover plate, and stainless steel outer top cover plate)	9.0
Basket height	164
Stainless steel basket member thickness	0.170
Aluminum and poison basket member thickness	0.3
Compartment inner dimension	6.0

Table B.6-12
OS197 TC Key As-Modeled Dimensions

Parameter	As-Modeled Dimension (in)
Lid inner stainless steel thickness	3.0
Lid NS-3 thickness	2.0
Lid outer stainless steel thickness	0.25
Inner stainless steel shell thickness	0.5
Lead thickness	3.56
Outer stainless steel shell thickness, upper and lower regions	2.0 (46.5 inch length near upper trunnion) 1.5 (remaining)
Water neutron shield thickness, upper and lower regions	2.5 (46.5 inch length near upper trunnion) 3.0 (remaining)
Outer stainless steel shell thickness	0.188
Bottom inner stainless steel plate thickness	1.92
Bottom NS-3 thickness	2.25
Bottom outer stainless steel plate thickness	0.75
Diameter of ram hole	22.0
Thickness of stainless steel ram cover plate	1.0

Proprietary Information on Pages B.6-30 through B.6-42
Withheld Pursuant to 10 CFR 2.390

Table B.6-27
OS197 TC Side Dose Rate Sensitivity Results

		Side Dose Rate (mrem/hr)(1)		
Zone	Heat (kW/FA)	SP = 25 MW/MTU	SP = 30 MW/MTU	Change in Dose Rate (%)
1	0.48	27.53	27.51	-0.1%
2	0.70	104.93	104.90	0.0%
3	1.20	176.25	176.26	0.0%
4	0.54	448.24	447.82	-0.1%
Total	-	756.95	756.49	-0.1%

(1) Using the methodology outlined in Section B.6.2.2, each "ranking" dose rate represents the OS197 TC side dose rate contribution from that zone.

Table B.6-28
HSM-MX Roof Vent Dose Rate (No Vent Cover) Sensitivity Results

		Roof Vent Dose Rate (mrem/hr)(1)		
Zone	Heat (kW/FA)	SP = 25 MW/MTU	SP = 30 MW/MTU	Change in Dose Rate (%)
1	0.48	1.76E+04	1.76E+04	0.0%
2	0.70	2.56E+04	2.57E+04	0.1%
3	1.20	4.35E+04	4.37E+04	0.4%
4	0.54	1.98E+04	1.98E+04	-0.2%

(1) Using the methodology outlined in Section B.6.2.2, each "ranking" dose rate represents each fuel assembly in all 61 basket locations. In the actual configuration, the inner locations (zones 1, 2, and 3) contribute much less than the peripheral zone (zone 4) to the vent dose rates.

Table B.6-29
BWR Sensitivity Study Similar to NUREG/CR-6716, OS197 TC

SP	SP = 20 MW/MTU	SP = 40 MW/MTU	SP = 40 MW/MTU
BECT	BU = 40 GWd/MTU E = 3.5% CT =5.0 years	BU = 40 GWd/MTU E = 3.5% CT =5.0 years	BU = 40 GWd/MTU E = 3.5% CT =5.75 years
Heat (kW/FA)	0.390	0.442	0.389
E_{max} (MeV)	Gamma Source (g/s)	Gamma Source (g/s)	Gamma Source (g/s)
5.00E-02	5.136E+14	6.046E+14	5.164E+14
1.00E-01	1.466E+14	1.756E+14	1.470E+14
2.00E-01	1.157E+14	1.430E+14	1.155E+14
3.00E-01	3.320E+13	4.055E+13	3.318E+13
4.00E-01	2.294E+13	2.868E+13	2.292E+13
6.00E-01	2.351E+14	3.061E+14	2.331E+14
8.00E-01	8.928E+14	9.809E+14	9.004E+14
1.00E+00	1.034E+14	1.299E+14	1.025E+14
1.33E+00	3.778E+13	4.385E+13	3.798E+13
1.66E+00	1.091E+13	1.360E+13	1.096E+13
2.00E+00	3.360E+11	5.218E+11	3.232E+11
2.50E+00	6.193E+11	1.114E+12	5.981E+11
3.00E+00	2.330E+10	3.700E+10	2.219E+10
4.00E+00	2.158E+09	3.415E+09	2.056E+09
5.00E+00	3.241E+06	3.344E+06	3.251E+06
6.50E+00	1.301E+06	1.342E+06	1.305E+06
8.00E+00	2.552E+05	2.633E+05	2.559E+05
1.00E+01	5.418E+04	5.590E+04	5.433E+04
Total	2.113E+15	2.469E+15	2.121E+15
Gamma Dose Rate (mrem/hr)	103.2	136.5	102.7
Change in Dose Rate (%)	-	32%	-0.4%

Table B.6-30
Dose Rate Increase for 30 MW/MTU Irradiation and FQT Cooling Times

System	OS197 TC	HSM-MX
BECT	BU = 62 GWd/MTU E = 3.8% CT =7.54 years	BU = 40 GWd/MTU E = 2.5% CT = 3.86 years
Heat (kW/FA)	0.549	0.566
E_{max} (MeV)	Gamma Source (g/s)	Gamma Source (g/s)
5.00E-02	5.761E+14	7.829E+14
1.00E-01	1.546E+14	2.331E+14
2.00E-01	1.172E+14	1.996E+14
3.00E-01	3.385E+13	5.604E+13
4.00E-01	2.201E+13	4.113E+13
6.00E-01	2.052E+14	4.656E+14
8.00E-01	1.166E+15	1.131E+15
1.00E+00	9.933E+13	1.844E+14
1.33E+00	4.496E+13	5.912E+13
1.66E+00	1.097E+13	1.986E+13
2.00E+00	1.409E+11	1.064E+12
2.50E+00	1.228E+11	2.245E+12
3.00E+00	7.622E+09	7.975E+10
4.00E+00	7.409E+08	7.376E+09
5.00E+00	1.493E+07	6.190E+06
6.50E+00	5.992E+06	2.484E+06
8.00E+00	1.176E+06	4.873E+05
1.00E+01	2.496E+05	1.035E+05
Dose Rate (mrem/hr)	456	2.07E+04
25 MW/MTU Dose Rate (mrem/hr)	448	1.98E+04
Change in Dose Rate (%)	1.7%	4.5%

			0.54	0.54	0.54			
	0.54	0.54	1.2	1.2	1.2	0.54	0.54	
	0.54	0.7	0.7	0.7	0.7	0.7	0.54	
0.54	1.2	0.7	0.48	0.48	0.48	0.7	1.2	0.54
0.54	1.2	0.7	0.48	0.48	0.48	0.7	1.2	0.54
0.54	1.2	0.7	0.48	0.48	0.48	0.7	1.2	0.54
	0.54	0.7	0.7	0.7	0.7	0.7	0.54	
	0.54	0.54	1.2	1.2	1.2	0.54	0.54	
			0.54	0.54	0.54			

Units are kW/FA

Figure B.6-1
61BTH DSC Hybrid HLZC

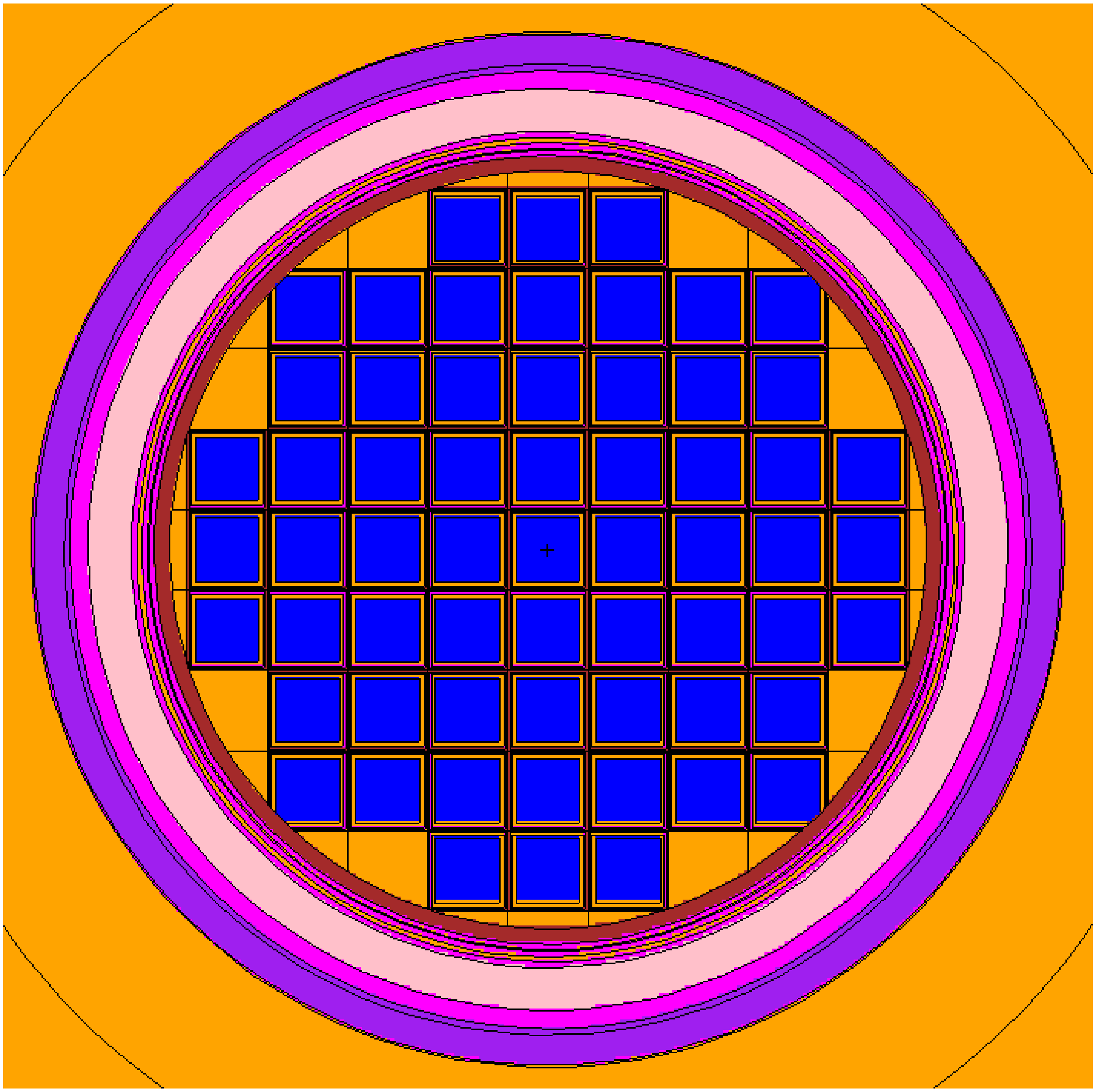


Figure B.6-2
OS197 TC MCNP Model, 61BTH DSC (x-y view)

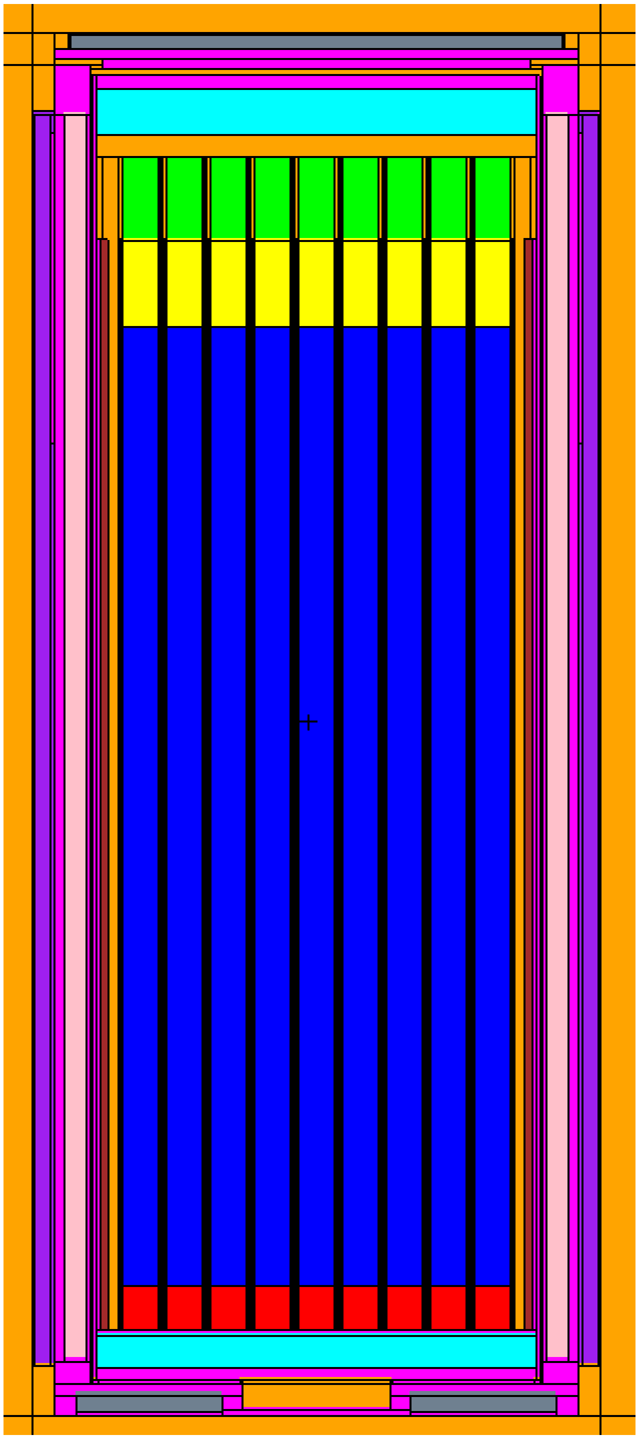
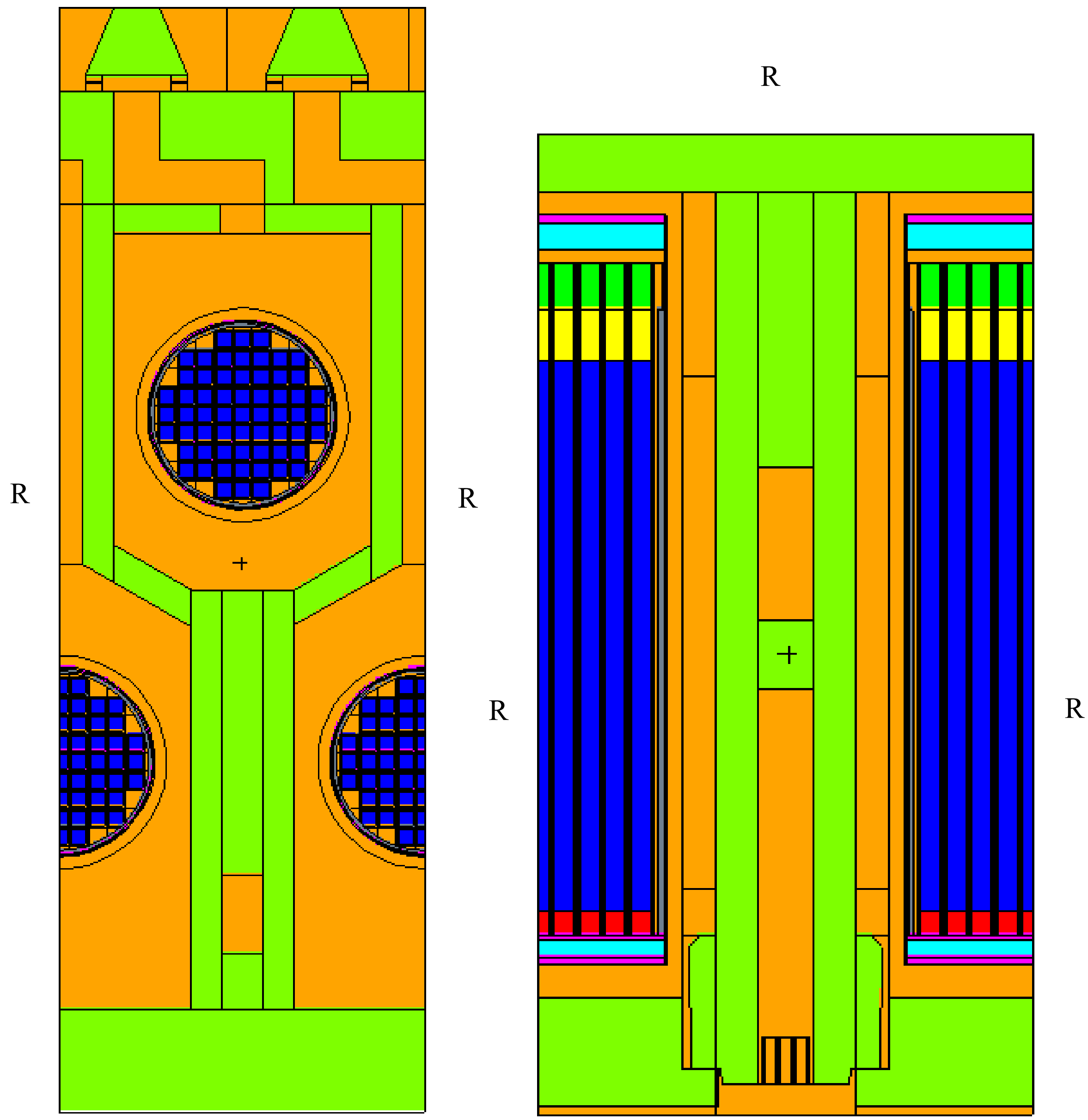


Figure B.6-3
OS197 TC MCNP Model, 61BTH DSC (x-z view)



X-Y View X-Z View

Reflective surfaces are denoted with an "R".

Figure B.6-4
HSM-MX MCNP Triple-Reflection Model, 61BTH DSC

APPENDIX B.7
CRITICALITY EVALUATION

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

B.7 CRITICALITY EVALUATION

NOTE: The criticality evaluation for the NUHOMS®-61BTH Type 2 Dry Shielded Canister (DSC) (including 61BTHF) and OS197/OS197H/OS197FC-B is documented in Chapter T.6 of the Standardized NUHOMS® UFSAR [B.7-1]. The documentation herein references Revision 18 of the Updated Final Safety Analysis Report (UFSAR) of CoC 1004 to include the 61BTH Type 2 DSC as an authorized storage DSC in the HSM-MX.

The criticality evaluation is performed under normal, off-normal, and accident conditions as defined in both 10CFR Part 72 and 10CFR Part 71, independent of the storage HSM. As a result, the criticality results remain unchanged under storage conditions in the HSM-MX.

The authorized content for the 61BTH Type 2 DSC in the HSM-MX that does not change from Appendix T.6 of CoC 1004 [B.7-1] are listed in Table 13 of the Technical Specifications (TS) [B.7-2]. Therefore, there is no change to the criticality evaluation documented in Chapter T.6 of the Standardized NUHOMS® UFSAR [B.7-1].

The criticality results for the NUHOMS®-61BTH Type 2 DSC (including 61BTHF) are presented in Appendix T.6 of CoC 1004 [B.7-1]. The minimum B10 poison loading required as a function of assembly initial lattice average enrichment is provided in Table 9 through Table 12 of the TS [B.7-2].

B.7.1 References

B.7-1 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

B.7-2 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 2.

APPENDIX B.8
MATERIALS EVALUATION

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

B.8 MATERIALS EVALUATION

This chapter describes the materials evaluation for the NUHOMS®-61BTH Type 2 DSC and OSC197 TC to be used in the NUHOMS® MATRIX (HSM-MX) system, described in Appendix B in accordance with the guidance outlined in NUREG-1536, Revision 1. There are no changes to the materials evaluation of other components in the NUHOMS® EOS System in Chapter 8.

B.8.1 General Information

B.8.1.1 NUHOMS® 61BTH Type 2 *and OS197 TC* System Materials 72.48

No change to Appendix T, Section T.3.3.2 of CoC 1004 [B.8-2].

For the HSM-MX, no change to Chapter A.8, Section A.8.1.1.

The OS197 TC shell, inner liner, top cover plate, and bottom cover plate use ASME material SA-240, Type 304, while the top flange and bottom support rings use ASME SA-182, F304N. No change to the material properties are provided in Table P.3.3-1 in Appendix P of CoC 1004. [B.8-2]. 72.48

B.8.1.2 Environmental Conditions

No change to Appendix T, Section T.2.2 of reference [B.8-2] for the 61BTH Type 2.

No change to Chapter A.8, Section A.8.1.2 for the HSM-MX. 72.48

B.8.1.3 Engineering Drawings

The drawings for 61BTH Type 2 system DSC and *OS197* TC are provided in Chapter B.1, Section B.1.3. The material specification, governing code, and quality category are specified in the parts list for each component. 72.48

The drawings for HSM-MX are provided in Chapter A.1, Section A.1.3. The material specification, governing code, and quality category are specified in the parts list for each component.

B.8.2 Materials Selection

This section discusses the materials used in the components of the NUHOMS®-61BTH Type 2 DSC and OS197 TC to be used in the NUHOMS® MATRIX (HSM-MX) system. No change to section A.8.2 for the HSM-MX.

B.8.2.1 Applicable Codes and Standards and Alternatives

No change to Appendix T, Section T.3.1.2.1 and T.3.1.2.2. ASME Code Alternatives for the 61BTH Type 2 DSC are provided in Section 4.4.4 of the Technical Specifications.

No change to Chapter A.8, Section A.8.2.1.3 for the HSM-MX.

No change to Chapter 3, Section 3.2.5.3 or Chapter 4, Section 4.9 and Table 4.9-1 of CoC 1004 [B.8-2] for the OS197 TC.

B.8.2.2 Material Properties

No change to Appendix T, Section T.3.3 of CoC 1004 [B.8-2] for the 61BTH Type 2 DSC and OS197 TC.

Material properties of the OS197 TC are provided in Table 8.1-3 of CoC 1004 UFSAR [B.8-2]. In cases where multiple material options are allowed, the material properties used for analysis are provided. There are no changes to the material properties as provided in Table 8.1-3. The shell, inner liner, top cover plate, and bottom cover plate use ASME material SA-240 Type 304 (row 1); alternatively, the shell and top cover plates may be SA-516 Gr. 70 (row 4). The top flange and bottom support ring/bottom flange use ASME SA-182 F304N (row 9). The lower trunnions are constructed from ASME SA-479, Type 304. The lower trunnion sleeve may be fabricated from ASME SA-516 Gr. 70 (row 4) or SA-508 Cl. 1A. The upper trunnion is fabricated from ASME SA-533 Gr. B, Cl. 2 or SA-508, Cl. 3A (row 8). Additionally, one option for the upper trunnion uses ASME SA-182 Type FXM-19 (row 2). The lead gamma shielding is provided by ASTM B29 Chemical Copper Lead (row 15), and the transfer cask top cover plate bolts are SA-193 B7 (row 14).

No change to Chapter A.8, Section A.8.2.2 for HSM-MX.

B.8.2.3 Materials for ISFSI Sites with Experience of Atmospheric Chloride Corrosion

The DSC materials of construction for the 61BTH Type 2 are addressed in Section T.3.4.1 of the CoC 1004 UFSAR. There is no change to the HSM materials of construction as described in Chapter A.8, Section A.8.2.3. 72.48

B.8.2.4 Weld Design and Inspection

No change to Appendix T, Section T.3.1.2.1 of CoC 1004 [B.8-2] for 61BTH Type 2 DSC.

No change to Section 3.2.5.3 of CoC 1004 [B.8-2] for the OS197 TC. 72.48

No change to Chapter A.8, Section A.8.2.4 for HSM-MX.

B.8.2.5 Galvanic and Corrosive Reactions

No change to Appendix T, Section T.3.4 of CoC 1004 [B.8-2] for 61 BTH Type 2 DSC.

No change to Chapter A.8, Section A.8.2.5 for HSM-MX.

B.8.2.6 Poison or Borated Aluminum Accetance

No change to Appendix T, Section T.9.1.7 of CoC 1004 [B.8-2].

B.8.2.7 Bolt Applications

61BTH Type 2 has no bolted closure as it relates to confinement penetration or closure. Appendix T, Table 2-15 of CoC 1004 [B.8-2] lists the bolts as not important to safety. The HSM-MX uses no rails, and thus there will be no bolted rails for storage of 61BTH Type 2 DSC.

The specifications for the bolts are provided in Section B.1.3. Cleaning agents used for final cleaning of the 61BTH Type 2 DSC should be selected for compatibility with spent fuel pool water and DSC materials. The lubricant should be selected for its ability to maintain lubricity under long term storage conditions as provided in Section T.3.4.1 of CoC 1004 [B.8-2].

B.8.2.8 Protective Coatings and Surface Treatments

No change to Appendix T, Section T.3.4.1 of CoC 1004 [B.8-2] for 61 BTH Type 2 DSC.

No change to Chapter 8, Section 8.2.8 for HSM-MX.

B.8.2.9 Neutron Shielding Materials

The 61BTH DSC does not contain hydrogenous neutron shielding material. During transfer of the 61BTH DSC from the pool to the HSM-MX, neutron shielding is provided by water in a radial neutron shield jacket of the OS197 TC. The bottom end and lid of the OS197 TC also include a layer of solid NS-3 neutron shielding material. The NS-3 composition utilized in the MCNP shielding models is provided in Table B.6-10. The hydrogen content in the NS-3 material is conservatively reduced approximately 10% in the shielding analysis. Because of the short duration of the transfer operations, the NS-3 material is not subjected to significant thermal or radiation-induced degradation.

B.8.2.10 Materials for Criticality Control

Criticality is controlled by geometry and by utilizing fixed neutron poison material in the fuel basket.

As described in Appendix T, Section T.1.2.1.1 of CoC 1004 [B.8-2], the 61BTH DSC is designed to use three types of poison materials in the basket: Borated Aluminum alloy, Boron Carbide/Aluminum Metal Matrix Composite (MMC), or BORAL®. For each poison material, the 61BTH DSC basket is analyzed for six alternate basket configurations, depending on the boron loadings analyzed, to accommodate the various fuel enrichment levels (designated as "A" for the lowest B-10 loading to "F" for the highest B-10 loading).

B.8.2.11 Concrete and Reinforcing Steel

No change to Section *A*.8.2.2. 72.48

B.8.2.12 Seals

The space between the top of the DSC and inside of the transfer cask is sealed to prevent contamination. For BWR plants, the pool water is deionized. This affects the interior surfaces of the DSC, lid, and the basket. The transfer cask and DSC are only kept in the spent fuel pool for a short period of time, typically about 6 hours to load or unload fuel, and 2 hours to lift the loaded transfer cask/DSC out of the spent fuel pool.

During storage, the interior of the DSC is exposed to an inert helium environment. The helium environment does not support the occurrence of chemical or galvanic reactions because both moisture and oxygen must be present for a reaction to occur. The DSC is thoroughly dried before storage by a vacuum drying process. It is then backfilled with helium, thus stopping corrosion. Since the DSC is vacuum dried, galvanic corrosion is also precluded as there is no water present at the point of contact between dissimilar metals.

B.8.3 Fuel Cladding

B.8.3.1 Fuel Burnup

As described in Appendix T, Section T.1.1 of CoC 1004 [B.8-2], the fuel to be stored is limited to a maximum assembly average burnup of 62 GWd/MTU for 61BTH Type 2 DSC.

B.8.3.2 Cladding Temperature Limits

No change to Appendix T, *Section T 4.1 or* Table T.4-17 of CoC 1004 [B.8-2] for the 61BTH Type 2 DSC. 72.48

B.8.4 Prevention of Oxidation Damage During Loading of Fuel

The operations described in Appendix T, Section T.8.1.2 of CoC 1004 [B.8-2] require that the canister is filled with helium as the water is pumped below the top of the fuel rods. Subsequent operations alternate evacuation and helium backfill. The final condition of helium purity for storage is controlled by the acceptance criteria as provided in Appendix T.

B.8.5 Flammable Gas Generation

The hydrogen generation is monitored and controlled prior and during welding operations in accordance with the operations instructions as provided in Appendix T, Section T.9 of CoC 1004 [B.8-2].

B.8.6 DSC Closure Weld Testing

No change to Appendix T, Section T.9.1.2 for 61BTH Type 2 DSC closure weld acceptance testing as provided in CoC 1004 [B.8-2].

B.8.7 References

B.8-1 NUREG-1536, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General license Facility," Revision 1, U.S. Nuclear Regulatory Commission, July 2010.

B.8-2 TN Americas LLC, "Updated Final Safety Analysis Report for the NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 7-1004, January 2019.

APPENDIX B.9
OPERATING PROCEDURES

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

B.9 OPERATING PROCEDURES

This chapter presents the operating procedures for the NUHOMS® MATRIX-61BTH System described in previous chapters and shown on the drawings in Chapter B.1, Section B.1.3. The procedures include preparation of the NUHOMS®-61BTH Type 2 dry shielded canister (DSC) and fuel loading, closure of the DSC, transfer to the independent spent fuel storage installation (ISFSI) using the OS197FC-B transfer cask (TC), DSC transfer into HSM-MX, monitoring operations, and DSC retrieval from the HSM-MX. The NUHOMS® EOS transfer equipment, MATRIX loading crane (MX-LC), MATRIX retractable roller tray (MX-RRT), TC adapter, and the existing plant systems and equipment are used to accomplish these operations.

The following sections outline the typical operating procedures for the NUHOMS® MATRIX-61BTH System. These generic procedures have been developed to minimize the amount of time required to complete the subject operations, to minimize personnel exposure, and to assure that all operations required for DSC loading, closure, transfer, and storage are performed safely. Plant-specific ISFSI procedures are to be developed by each licensee in accordance with the requirements of 10 CFR 72.212(b) and the guidance of Regulatory Guide 3.61 [B.9-1]. These generic procedures are provided as a guide for the preparation of plant-specific procedures and serve to explain how the NUHOMS® MATRIX-61BTH System operations are to be accomplished. They are not intended to be limiting in that the licensee may judge that alternate acceptable means are available to accomplish the same operational objective.

Pictograms of the NUHOMS® MATRIX System operations are presented in Figure A.9-1. The location of the various operations may vary with individual plant requirements. Chapter B.9 provides a description as to how these operations are to be performed for the NUHOMS®-61BTH Type 2 DSC, the OS197FC-B TC, and HSM-MX as part of the NUHOMS® MATRIX System.

See Chapter B.1 for description of components.

The generic terms used throughout this section are as follows:

- TC, or transfer cask, is used for the OS197FC-B transfer cask.
- DSC is used for the NUHOMS®-61BTH Type 2 DSC.
- HSM-MX is used for the storage module.
- MX-RRT is used to insert/retrieve DSC into/from HSM-MX module.
- MX-LC is used to lift and position DSC with HSM-MX.

Note: If applicable to the planned DSC heat zone loading configuration per Figures 4A through 4J and 5 of the Technical Specifications [B.9-2], the forced cooling (FC) system should be verified operational prior to initiating the transfer operations and installed as soon as practical once the cask is on the transfer skid.

B.9.1 Procedures for Loading the DSC and Transfer to the HSM-MX

Pictograms of the generic NUHOMS® MATRIX System operations are presented in Figure A.9-1. The location of the various operations may vary with individual plant requirements. The following steps describe the recommended generic operating procedures for the NUHOMS® MATRIX-61BTH System.

B.9.1.1 Preparation of the Transfer Cask and DSC

1. Prior to placement in dry storage, the candidate intact and damaged fuel assemblies shall be evaluated (by plant records or other means) to verify that they meet the physical, thermal and radiological criteria specified in Technical Specification 2.3.

2. Prior to being placed in service, the transfer cask is to be cleaned or decontaminated as necessary to insure a surface contamination level of less than those specified in Technical Specification 3.3.1.

3. Place the transfer cask in the vertical position in the cask decon area using the cask handling crane and the transfer cask lifting yoke.

4. Place scaffolding around the cask so that the transfer cask top cover plate and surface of the cask are easily accessible to personnel.

5. Remove the transfer cask top cover plate and examine the cask cavity for any physical damage and ready the cask for service.

6. Examine the DSC for any physical damage which might have occurred since the receipt inspection was performed. The DSC is to be cleaned and any loose debris removed. Record the DSC serial number which is located on the grapple ring. Verify the correct DSC type, basket type, and poison material types against the DSC serial number. Verify that the DSC is appropriate for the specific fuel loading campaign per Technical Specification 2.3.

CAUTION: If loading fuel assemblies through the basket hold down ring (HDR) or top grid assembly (TGA), verify that the lifting grapple will be able to release fuel assemblies while inside the HDR/TGA.

7. Using a crane, lower the DSC into the cask cavity by the internal lifting lugs and rotate the DSC to match the cask and DSC alignment marks.

8. If damaged fuel assemblies are to be included in a specific loading campaign, place the required number of bottom end caps provided (up to a maximum of 61) into the bottom of the appropriate 2x2 compartments of the basket, as shown in Figure 5 of Technical Specification. Place and verify that the bottom fuel assembly spacers, if required, are present in the fuel cells. Optionally, this step may be performed at any prior time.

9. If failed fuel is to be loaded in the DSC, place the empty failed fuel cans (refer to drawing NUH61BTH-72-1105) in the appropriate locations in the 61BTH DSC. (Note: If the failed fuel is to be loaded into the failed fuel can prior to loading into the DSC, skip this step.)

10. Fill the TC/DSC annulus with clean, demineralized water. Place the inflatable seal into the upper cask liner recess and seal the TC/DSC annulus by pressurizing the seal with compressed air.

11. Fill the DSC cavity with water from the fuel pool or an equivalent source.

    Note: A TC/DSC annulus pressurization tank filled with demineralized water as described above is connected to the top vent port of the TC via a hose to provide a positive head above the level of water in the TC/DSC annulus. This is an optional arrangement, which provides additional assurance that contaminated water from the fuel pool will not enter the TC/DSC annulus, provided a positive head is maintained at all times.

    Note: In the steps that follow, actions pertaining to the removable hold down ring also apply to the removable type top grid assembly.

12. For DSCs with removable hold down rings, test fit the hold down ring into the canister. Examine the hold down ring to ensure a proper fit. Remove hold down ring. (Note this step may be completed earlier and hold down ring may be left in place while testing the top shield plug fit-up.)

13. Place the top shield plug onto the DSC. Examine the top shield plug to ensure a proper fit. If using the rigging cables under the yoke to install the shield plug, attach the rigging cables to the shield plug and adjust the rigging cables as necessary to obtain even cable tension. Remove top shield plug and hold down ring, if present. (Note this step may be complete earlier.)

14. Position the cask lifting yoke above the transfer cask and engage the cask lifting trunnions.

15. Visually inspect the yoke lifting hooks to insure that they are properly positioned and engaged on the cask lifting trunnions.

16. Provide for later connection to a water draining/pumping device to the siphon port of the DSC and position any connecting hose such that the hose will not interfere with loading (yoke, fuel, shield plug, rigging, etc.). A flowmeter or other suitable means for measuring the amount of water removed must be provided for at a suitable location as part of this connection.

17. Move the scaffolding away from the cask as necessary.

18. Lift the cask just far enough to allow the weight of the cask to be distributed onto the yoke lifting hooks. Re-inspect the lifting hooks to insure that they are properly positioned on the cask trunnions.

19. Optionally, secure a sheet of suitable material to the bottom of the transfer cask to minimize the potential for ground-in contamination. This may also be done prior to initial placement of the cask in the decon area.

20. Fill the TC liquid neutron shield with demineralized water as required by licensee ALARA requirements and crane capacity limits. This step may be completed at any time prior to immersion of the TC/DSC into the pool.

21. Prior to the cask being lowered into the fuel pool, the water level in the pool should be adjusted as necessary to accommodate the TC/DSC volume. If the water placed in the DSC cavity was obtained from the fuel pool, a level adjustment may not be necessary.

B.9.1.2 DSC Fuel Loading

1. Lift the TC/DSC and position it over the cask loading area of the spent fuel pool in accordance with the plant's 10 CFR 50 cask handling procedures.

2. Lower the cask into the fuel pool until the bottom of the cask is at the height of the fuel pool surface. As the cask is lowered into the pool, spray the exterior surface of the cask with demineralized water.

3. Place the cask in the designated location of the fuel pool.

4. Disengage the lifting yoke from the cask lifting trunnions and move the yoke. Spray the lifting yoke with clean water if it is raised out of the fuel pool.

5. The potential for fuel misloading is essentially eliminated through the implementation of procedural and administrative controls. The controls instituted to ensure that damaged and/or intact fuel assemblies are placed into a known cell location within a DSC, will typically consist of the following:
   - A TC/DSC loading plan is developed to verify that the failed, damaged, and/or intact fuel assemblies meet the burnup, enrichment and cooling time parameters of Technical Specification 2.3.
   - The loading plan is independently verified and approved before the fuel load.
   - A fuel movement schedule is then written, verified and approved based upon the loading plan. All fuel movements from any rack location are performed under strict compliance with the fuel movement schedule.
   - If loading damaged fuel assemblies, verify that the required number of bottom end caps are installed in appropriate fuel compartment tube locations before fuel load.

- If failed fuel is to be loaded in the DSC, place the empty failed fuel cans (refer to drawing NUH61BTH-72-1105) in the appropriate locations in the 61BTH DSC. (Note: If the failed fuel is to be loaded into the failed fuel can prior to loading into the DSC, skip this step.)

6. Prior to insertion of a spent fuel assembly into the DSC, the identity of the assembly is to be verified by two individuals using an underwater video camera or other means. Read and record the fuel assembly identification number from the fuel assembly and check this identification number against the DSC loading plan which indicates which fuel assemblies are acceptable for dry storage.

7. Position the fuel assembly for insertion into the selected DSC storage cell and load the fuel assembly. Repeat Steps 6 and 7 for each SFA loaded into the DSC. A maximum of 61 damaged fuel or 4 failed fuel assemblies may be loaded into the appropriate 2x2 compartments of the 61BTH DSC basket per Technical Specification 2.3. If loading failed fuel, ensure that the failed fuel can lids are installed. After the DSC has been fully loaded, check and record the identity and location of each fuel assembly in the DSC. If loading damaged fuel assemblies, place top end caps over each damaged fuel assembly placed into the basket.

8. After all the SFAs have been placed into the DSC and their identities verified, place the hold down ring or optional top grid assembly as applicable. Visually verify that the hold down ring is properly seated. If using the hold down ring or top grid assembly not integral to the basket, they may be placed on the basket before loading the SFAs.

9. Position the lifting yoke and the top shield plug and lower the shield plug into the DSC. Note that separate rigging may be used to install the shield plug prior to engaging the trunnions with the lifting yoke.

CAUTION: Verify that all the lifting height restrictions as a function of temperature specified in Technical Specification 5.2.1 can be met in the following steps which involve lifting of the transfer cask.

10. Visually verify that the top shield plug is properly seated within the DSC.

11. Position the lifting yoke with the cask trunnions and verify that it is properly engaged.

12. Raise the transfer cask to the pool surface. Prior to raising the top of the cask above the water surface, stop vertical movement.

13. Inspect the top shield plug to verify that it is properly seated within the DSC. If not, lower the cask and reposition the top shield plug and/or remove the shield plug and reposition the hold down ring. Repeat Steps 8 through 13 as necessary.

14. Continue to raise the cask from the pool and spray the exposed portion of the cask with water until the top region of the cask is accessible.

15. Drain any excess water from the top of the DSC shield plug back to the fuel pool. Check the radiation levels at the center of top shield plug and around the perimeter of the cask. Disconnect the top shield plug rigging.

16. Drain a minimum of 50 gallons of water. Optionally up to approximately 1100 gallons of water (as indicated on the flow meter) may be drained from the DSC back into the fuel pool or other suitable location to meet the weight limit on the crane. Use 1-3 psig of helium to backfill the DSC with an inert gas per ISG-22 [B.9-5] guidance and Technical Specification 3.1.1 as water is being removed from the DSC.

17. Lift the cask from the fuel pool. As the cask is raised from the pool, continue to spray the cask with water and decon as directed. Provisions shall be made to assure that air will not enter the DSC cavity. One way to achieve this is by replenishing the helium in the DSC cavity during cask movement from the fuel pool to the decon area in case of malfunction of equipment used for cask movement.

18. Move the cask with loaded DSC to the cask decon area.

19. Replace the water removed from the DSC cavity in Step 16 with water from the fuel pool or an equivalent source.

20. Install cask seismic restraints if required (required only on plant specific basis).

B.9.1.3 DSC Drying and Backfilling

CAUTION: During performance of steps listed in Section B.9.1.3, monitor the TC/DSC annulus water level and replenish as necessary to maintain cooling.

1. Check the radiation levels along the perimeter of the cask. The cask exterior surface should be decontaminated as necessary. Temporary shielding may be installed as necessary to minimize personnel exposure.

2. Place scaffolding around the cask so that any point on the surface of the cask is easily accessible to personnel.

3. Disengage the rigging cables from the top shield plug and remove the eyebolts. Disengage the lifting yoke from the trunnions and position it clear of the cask.

4. Decontaminate the exposed surfaces of the DSC shell perimeter and remove the inflatable TC/DSC annulus seal.

5. Verify that the neutron shield (NS) is filled before the draining operation in Step 6 is initiated and continually monitored during the first five minutes of the draining evolution to ensure the NS remains filled.

6. Connect the cask drain line to the cask, open the cask cavity drain port and allow water from the annulus to drain out until the water level is approximately 12 inches below the top edge of the DSC shell. Take swipes around the outer surface of the DSC shell and check for smearable contamination in accordance with the Technical Specification 3.3.1 limits.

CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

7. Verify that the NS is filled before the draining operation in Step 8 is initiated and continually monitored during the first five minutes of the draining evolution to ensure the NS remains filled.

8. Drain approximately 1100 gallons of water or more (as indicated on a flowmeter) from the DSC back into the fuel pool or other suitable location if not drained in B.9.1.2 Step 16. Consistent with ISG-22 [B.9-5] guidance and Technical Specification 3.1.1, helium at 1-3 psig is used to backfill the DSC with an inert gas as water is being removed from the DSC. The minimum volume of water to be drained is to minimize hydrogen generation within the DSC cavity. It is also acceptable to completely drain the water within the DSC instead of draining only minimum volume.

CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

9. Install the welding machine onto the inner top cover plate and place the inner top cover plate with the welding machine onto the DSC. Optionally, the inner top cover plate and the welding machine can be placed separately. Verify proper fit-up of the inner top cover plate with the DSC shell.

72.48

10. Check radiation levels along the surface of the inner top cover plate. Temporary shielding may be installed as necessary to minimize personnel exposure.

11. Insert approximately ¼ inch tubing of sufficient length and adequate temperature resistance through the vent port such that it terminates just below the DSC top shield plug. Connect the tubing to a hydrogen monitor to allow continuous monitoring of the hydrogen atmosphere in the DSC cavity during welding of the inner top cover plate, in compliance with Technical Specification 5.4.

12. Cover the TC/DSC annulus to prevent debris and weld splatter from entering the annulus.

13. Ready the welding machine and tack weld the inner top cover plate to the DSC shell. Install the inner top cover plate weldment and remove the welding machine. 72.48

CAUTION: Continuously monitor the hydrogen concentration in the DSC cavity using the arrangement or other alternate methods described in Step 11 during the inner top cover plate cutting/welding operations. Verify that the measured hydrogen concentration does not exceed a safety limit of 2.4% [B.9-6 and B.9-7] (60.0% of flammability limit of 4.0%). If this limit is exceeded, stop all welding operations and purge the DSC cavity with 2-3 psig helium via the tubing to reduce the hydrogen concentration safely below the 2.4% limit.

14. Perform dye penetrant weld examination of the inner top cover plate weld in accordance with the Technical Specification 4.4.4 requirements.

15. If using a suction pump rather than blowdown to remove water, skip to Step 17; otherwise, place the strongback so that it sits on the inner top cover plate and is oriented such that:

    - The DSC siphon and vent ports are accessible
    - The strongback stud holes line up with the TC lid bolt holes

16. Lubricate the studs and, using a crossing pattern, adjust the strongback studs to snug tight ensuring approximately even pressure on the cover plate.

17. Remove purge lines and connect the VDS to the DSC siphon and vent ports.

18. Install temporary shielding to minimize personnel exposure throughout the subsequent welding operations as required.

19. Verify that the NS is filled before the draining operation in Step 20 is initiated and continually monitored during the first five minutes of the draining evolution to ensure the NS remains filled.

20. Remove water from DSC cavity if not fully drained in Step 8.

    - If using blowdown method to remove water, engage helium supply (up to 15 psig) and open the valve on the vent port and allow helium to force the water from the DSC cavity through the siphon port. Use of helium is required per Technical Specification 3.1.1.
    - Alternatively a suction pump may be used to remove water from DSC.

21. Once the water stops flowing from the DSC, close the DSC siphon port and disengage the gas source or turn off the suction pump, as applicable.

22. Connect the hose from the vent port and the siphon port to the intake of the vacuum pump. Connect a hose from the discharge side of the VDS to the plant's radioactive waste system or spent fuel pool. Connect the VDS to a helium source.

Note: Proceed cautiously when evacuating the DSC to avoid freezing consequences.

CAUTION: During the vacuum drying evolution, personnel should be in the area of loading operations, or in nearby low dose areas in order to take proper action in the event of a malfunction.

23. Open the valve on the suction side of the pump, start the VDS and draw a vacuum on the DSC cavity. The cavity pressure should be reduced in steps of approximately 100 mm Hg, 50 mm Hg, 25 mm Hg, 15 mm Hg, 10 mm Hg, 5 mm Hg, and 3 mm Hg. After pumping down to each level (these levels are optional), the pump is valved off and the cavity pressure monitored. The cavity pressure will rise as water and other volatiles in the cavity evaporate. When the cavity pressure stabilizes, the pump is valved in to complete the vacuum drying process. It may be necessary to repeat some steps, depending on the rate and extent of the pressure increase. Vacuum drying is complete when the pressure stabilizes for a minimum of 30 minutes at 3 mm Hg absolute or less as specified in Technical Specification 3.1.1.

    Note: The user shall ensure that the vacuum pump is isolated from the DSC cavity when demonstrating compliance with Technical Specification 3.1.1 requirements. Simply closing the valve between the DSC and the vacuum pump is not sufficient, as a faulty valve allows the vacuum pump to continue to draw a vacuum on the DSC. Turning off the pump, or opening the suction side of the pump to atmosphere are examples of ways to assure that the pump is not continuing to draw a vacuum on the DSC.

CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel) to minimize personnel exposure.

24. Open the valve to the vent port and allow the helium to flow into the DSC cavity.

25. Pressurize the DSC with helium (0 to 15 psig).

26. Helium leak test the inner top cover plate weld for a leak rate of 1×10^{-4} atm-cm^3/sec. This test is optional.

27. If a leak is found, repair the weld, repressurize the DSC and repeat the helium leak test.

28. Once no leaks are detected, depressurize the DSC cavity by releasing the helium through the VDS to the plant's spent fuel pool or radioactive waste system.

29. Re-evacuate the DSC cavity using the VDS. The cavity pressure should be reduced in steps of approximately 10 mm Hg, 5 mm Hg, and 3 mm Hg. After pumping down to each level, the pump is valved off and the cavity pressure is monitored (these levels are optional). When the cavity pressure stabilizes, the pump is valved in to continue the vacuum drying process. Vacuum drying is complete when the pressure stabilizes for a minimum of 30 minutes at 3 mm Hg absolute or less in accordance with Technical Specification 3.1.1 limits.

    Note: The user shall ensure that the vacuum pump is isolated from the DSC cavity when demonstrating compliance with Technical Specification 3.1.1 requirements. Simply closing the valve between the DSC and the vacuum pump is not sufficient, as a faulty valve allows the vacuum pump to continue to draw a vacuum on the DSC. Turning off the pump, or opening the suction side of the pump to atmosphere are examples of ways to assure that the pump is not continuing to draw a vacuum on the DSC.

30. Open the valve on the vent port and allow helium to flow into the DSC cavity to pressurize the DSC between 18.5 to 20.0 psig for 61BTH Type 2 DSC and hold for 10 minutes. Depressurize the DSC cavity by releasing the helium through the VDS to the plant spent fuel pool or radioactive waste system to about 2.5 psig in accordance with Technical Specification 3.1.2 limits.

CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

31. Close the valves on the helium source.

32. Remove the strongback, if installed in Step 15 or Step 30 above, decontaminate as necessary, and store.

B.9.1.4 DSC Sealing Operations

CAUTION: During performance of steps listed in Section B.9.1.4, monitor the cask/DSC annulus water level and replenish as necessary to maintain cooling.

1. Disconnect the VDS from the DSC. Seal weld the prefabricated plugs over the vent and siphon ports. Inject helium into blind space just prior to completing welding and perform a dye penetrant weld examination in accordance with the Technical Specification 4.4.4 requirements. Use of an optional test head is acceptable to perform the helium leak test of the inner top cover plate and vent/siphon port welds in accordance with Technical Specification 5.1.2.f. If an optional test head is not used, proceed to Step 2.

2. Temporary shielding may be installed as necessary to minimize personnel exposure. Install the welding machine onto the outer top cover plate and place the outer top cover plate with the welding system onto the DSC. Optionally, outer top cover plate may be installed separately from the welding machine. Verify proper fit up of the outer top cover plate with the DSC shell. 72.48

3. Tack weld the outer top cover plate to the DSC shell. Place the outer top cover plate weld root pass.

4. Helium leak test the inner top cover plate and vent/siphon port plate welds using the leak test port in the outer top cover plate in accordance with Technical Specification 5.1.2.f limits. Verify that the personnel performing the leak test are qualified in accordance with SNT-TC-1A [B.9-4]. Alternatively, this can be done with a test head in Step 1 of Section B.9.1.4.

5. If a leak is found, remove the outer cover plate root pass (if not using test head), the vent and siphon port plugs and repair the inner cover plate welds. Then install the strongback (if used) and repeat procedure steps from B.9.1.3 Step 23.

6. Perform dye penetrant examination of the root pass weld. Weld out the outer top cover plate to the DSC shell and perform dye penetrant examination on the weld surface in accordance with the Technical Specification 4.4.4 requirements.

7. Install and seal weld the prefabricated plug, if applicable, over the outer cover plate test port and perform dye penetrant weld examinations in accordance with Technical Specification 4.4.4 requirements.

8. Remove the welding machine from the DSC. 72.48

9. Verify that the NS is filled before the draining operation in Step 10 is initiated and continually monitored during the first five minutes of the draining evolution to ensure the NS remains filled.

10. Open the cask drain port valve and drain the water from the cask/DSC annulus.

11. Rig the cask top cover plate and lower the cover plate onto the transfer cask.

12. Bolt the cask cover plate into place, tightening the bolts to the required torque in a star pattern.

CAUTION: Monitor the applicable time limits of Technical Specification 3.1.3 until the completion of DSC transfer Step 6 of Section B.9.1.6.

B.9.1.5 TC Downending and Transfer to ISFSI

No change to Section T.8.1.5 of reference [B.9-3].

B.9.1.6 DSC Transfer to the HSM-MX

CAUTION: The insides of empty compartments have the potential for high dose rates due to adjacent loaded compartments. Proper as low as reasonably achievable (ALARA) practices should be followed for operations inside these compartments and in the areas outside these compartments whenever the door from the empty compartment has been removed.

1. MX-LC Rails are installed, aligned, and verified on the pad for the loading campaign. Alignment is verified to the specifically designated features on the face of HSM-MX.

2. Prior to transferring the TC to the ISFSI, remove the HSM-MX door, inspect the compartment of the HSM-MX, remove any debris, and ready the HSM-MX to receive a DSC. The doors on adjacent compartments should remain in place.

3. Inspect the DSC and MX-RRT support pads, and add spacer blocks at the front and rear DSC supports inside HSM-MX compartment.

4. For ALARA purposes, reinstall the HSM-MX door.

5. Inspect the HSM-MX air inlet and outlets to ensure that they are clear of debris. Inspect the screens on the air inlet and outlets for damage.

CAUTION: The insides of empty compartments have the potential for high dose rates due to adjacent loaded compartments. Proper ALARA practices should be followed for operations inside these compartments and in the areas outside these compartments whenever the MX-RRT operations are being performed.

6. Remove the MX-RRT cover plates and shield plugs.

7. Insert and install MX-RRT into HSM-MX. Extend the MX-RRT rollers, secure and verify that the rollers are extended.

8. Transfer the TC from the plant's fuel/reactor building to the ISFSI along the designated transfer route.

9. Once at the ISFSI, move the transfer trailer inside the MX-LC at “home” position between the skid and the MX-LC grappling mechanism.

10. Use the MX-LC grappling mechanism to capture the skid along with TC, disengage the skid positioning system, move the skid up in the vertical direction to clear it from the transfer trailer, and then the transfer trailer is moved from MX-LC.

11. Remove the FC system and install the ram cylinder assembly.

12. Remove the HSM-MX door and, if applicable, install the HSM-MX TC adapter.
13. Unbolt and remove the TC top cover plate.
14. Move MX-LC along the rail in front of HSM-MX until the TC is completely against the face of HSM-MX.
15. The skid is moved until the target compartment is reached. If necessary, adjust the MX-LC position until the MX-LC is properly aligned with the targeted compartment.
16. Secure the MX-LC/skid/cask to the front wall embedments of the HSM-MX using the restraints.
17. The hydraulic power unit is connected to the ram cylinder. The grapple is moved until it engages with the grapple ring of the canister. Using the ram cylinder, fully insert the DSC into the HSM-MX compartment.
18. Disengage the ram grapple mechanism so that the grapple is retracted away from the DSC grapple ring.
19. Retract the MX-RRT rollers; the DSC is lowered onto the HSM-MX front and rear DSC supports.

    Note: The time limit for transfer operations, if any, starts with the initiation of the TC/DSC annulus water draining described in Step 9 of Section 9.1.4 and ends when the DSC is fully seated onto the front and rear DSC supports.

CAUTION: Verify that the applicable time limits for transfer operations of Section 3.1.3 of the Technical Specifications [B.9-2] are met.

20. Remove the wall embedments from the HSM-MX.
21. Retract the skid with TC from docking position and lower it.
22. If applicable, remove the HSM-MX TC adapter. Place the HSM-MX door. Verify that the HSM dose rates are compliant with the limits specified in Section 5.1.2 of the Technical Specifications [B.9-2].
23. Move MX-LC to its “home” position, and the transfer trailer is moved into accepting position.
24. Lower the skid along with TC onto the transfer trailer. Reconnect the skid positioning system. Remove the ram cylinder assembly.
25. Bolt the TC cover plate into place, tightening the bolts to the required torque in a star pattern.

CAUTION: The insides of empty compartments have the potential for high dose rates due to adjacent loaded compartments. Proper ALARA practices should be followed for operations inside these compartments and in the areas outside these compartments whenever the MX-RRT operations are being performed.

26. Remove the MX-RRT from the HSM-MX.

27. Place MX-RRT shield plugs and cover plates for the MX-RRT accesses.

28. Move the transfer trailer from MX-LC to the designated equipment storage area. Return the remaining transfer equipment to the storage area.

29. Close and lock the ISFSI access gate and activate the ISFSI security measures.

B.9.1.7 Monitoring Operations

Refer to Section A.9.1.7.

B.9.2 Procedures for Unloading the DSC

The following section outlines the procedures for retrieving the DSC from the HSM-MX. The procedures for removing the FAs from the DSC are the same as described in Section T.8.2.2 of reference [B.9-3].

B.9.2.1 DSC Retrieval from the HSM-MX

1. Ready the TC, transfer trailer, loading crane, and skid for service. Fill the TC liquid neutron shield and remove the top cover plate from the TC. Transfer the trailer into the ISFSI.

   Note: Verify that a TC spacer of appropriate height is placed inside the TC to provide the correct airflow and interface at the top of the TC during cutting and unloading operations for DSCs that are shorter than the TC cavity length.

2. MATRIX MX-LC rails are installed, aligned, and verified on the pad for the unloading campaign. Alignment is verified to the specifically designated features on the face of HSM-MX.

3. Move the transfer trailer inside the MX-LC "home" position between the skid and the MX-LC grappling mechanism.

4. Use the MX-LC grappling mechanism to capture the skid along with TC, disengage the skid positioning system, move the skid up vertically to clear it from the transfer trailer, and then move the transfer trailer from the MX-LC.

5. Install the ram cylinder assembly.

CAUTION: The insides of empty compartments have the potential for high dose rates due to adjacent loaded compartments. Proper ALARA practices should be followed for operations inside these compartments and in the areas outside these compartments whenever the MX-RRT operations are being performed.

6. Remove the MX-RRT shield blocks plugs and cover plates.

7. Insert and install MX-RRT into HSM-MX. Extend the MX-RRT rollers, secure and verify that the rollers are extended.

CAUTION: The insides of empty compartments have the potential for high dose rates due to adjacent loaded compartments. Proper ALARA practices should be followed for operations inside these compartments and in the areas outside these compartments whenever the door from the empty compartment has been removed.

8. Remove the HSM-MX door and, if applicable, install the HSM-MX TC adapter.

9. Unbolt and remove the TC top cover plate.

10. Move MX-LC along the rail in front of HSM-MX until the TC is completely against the face of HSM-MX.

11. Move MX-LC along the face of the HSM-MX to the target HSM-MX compartment.

12. The skid is moved into the target compartment. If necessary, adjust the MX-LC position until the MX-LC is properly aligned with the targeted cavity.

13. Secure the MX-LC/skid/cask to the front wall embedments of the HSM-MX using the restraints.

14. The hydraulic power unit is connected to the ram cylinder. The grapple is moved until it engages with the grapple ring of the canister. Using ram cylinder, fully insert the ram into HSM-MX compartment.

15. Operate the ram grapple and engage the grapple arms with the DSC grapple ring.

16. Recheck all alignment marks and ready all systems for DSC transfer.

CAUTION: The time limits for the unloading of the DSC should be determined using the heat loads at the time of the unloading operation and the methodology presented in Sections 4.5 and 4.6 before pulling the DSC out of the HSM-MX.

17. Activate the ram to pull the DSC into the TC.

18. Disengage the ram grapple mechanism so that the grapple is retracted away from the DSC grapple ring.

19. Retract and disengage the ram system from the TC and move it clear of the TC. Remove the TC embedments from the HSM-MX.

20. Retract the skid with TC from docking position and lower it.

21. Move MX-LC to its "home" position and move the transfer trailer to accepting position.

22. Lower the skid along with TC onto the transfer trailer. Reconnect the skid positioning system, remove the ram cylinder assembly, and reinstall the FC system.

23. Bolt the TC cover plate into place, tightening the bolts to the required torque in a star pattern.

CAUTION: The insides of empty compartments have the potential for high dose rates due to adjacent loaded compartments. Proper ALARA practices should be followed for operations inside these compartments and in the areas outside these compartments whenever the MX-RRT operations are being performed.

24. Disconnect MX-RRT operating mechanism and retract MX-RRT to MX-RRT handling device.
25. Place MX-RRT shield plugs and cover plates for the MX-RRT accesses.
26. Move the transfer trailer from MX-LC and ready the trailer for transfer.
27. If applicable, remove the HSM-MX TC adapter. Replace the HSM-MX door.

B.9.2.2 Removal of Fuel from the DSC

Refer to Section T.8.2.2 of reference [B.9-3].

B.9.3 References

B.9-1 U.S. Nuclear Regulatory Commission, Regulatory Guide 3.61 "Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Container," February 1989.

B.9-2 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 2.

B.9-3 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

B.9-4 SNT-TC-1A, "American Society for Nondestructive Testing, Personnel Qualification and Certification in Nondestructive Testing," 1992.

B.9-5 U.S. Nuclear Regulatory Commission, Interim Staff Guidance (ISG)-22, "Potential Rod Splitting Due to Exposures to an Oxidizing Atmosphere during Short-term Cask Loading Operations in LWR or Other Uranium Oxide Based Fuel."

B.9-6 U.S. Nuclear Regulatory Commission, Office of the Nuclear Material Safety and Safeguards, "Safety Evaluation of VECTRA Technologies' Response to Nuclear Regulatory Commission Bulletin 96-04 for the NUHOMS®-24P and NUHOMS®-7P."

B.9-7 U.S. Nuclear Regulatory Commission Bulletin 96-04, "Chemical, Galvanic or Other Reactions in Spent Fuel Storage and Transportation Casks," July 5, 1996.

APPENDIX B.10
ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

B.10 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This chapter specifies the acceptance testing and maintenance program for important-to-safety (ITS) components of the 61BTH Type 2 DSC transferred in the OS197 and stored in the NUHOMS® MATRIX (HSM-MX).

Appendix B is newly added in Revision 4 by Amendment 2.

B.10.1 Acceptance Tests

This chapter specifies the acceptance testing and maintenance program for important-to-safety (ITS) components of the 61 BTH Type 2 dry shielded canister (DSC) and OS197 transfer cask (OS197) from CoC 1004, Revision 18, and the Matrix HSM (HSM-MX) as presented in Appendix A. The testing and maintenance of the OS197 lift yoke are governed by 10 CFR Part 50 heavy load regulations and are not covered in this license.

B.10.1.1 Structural and Pressure Tests

B.10.1.1.1 DSC

The structural tests of the 61BTH Type 2 DSC are presented in Section T.9.1.2 of CoC 1004 and the pressure tests are presented in Section T.9.1.3 [B.10-5].

B.10.1.1.2 HSM-MX

See Section A.10.1.1.2 of Appendix A for applicable testing for the HSM-MX. Testing for the spacer blocks to accommodate the smaller 61BTH Type 2 DSC diameter are tested for mechanical properties in accordance with the governing specifications provided in drawing MX01-5000-SAR.

B.10.1.1.3 Transfer Cask

Refer to section 4.2.3.3 of CoC 1004 [B.10-5] for structural and pressure tests pertaining to the OS197. Sections pertaining to the OS200 or OS197L are not included within this scope.

B.10.1.2 Leak Tests

Refer to section T.9.1.3 of CoC 1004 [B.10-5] for leak testing requirements for the 61BTH Type 2 DSC.

B.10.1.3 Visual Inspection and Non-Destructive Examinations

Visual inspections are performed at the fabricator's facility to ensure that the DSC, the HSM, and the TC conform to the drawings and specifications. The visual inspections include weld, dimensional, surface finish, and cleanliness inspections. Visual inspections specified by codes applicable to a component are performed in accordance with the requirements and acceptance criteria of those codes. Requirements specific to each component follow.

B.10.1.3.1 DSC

Visual inspections are performed at the fabricator's facility to ensure that the DSC, the Transfer Cask and the HSM-MX conform to the drawings and specifications. The visual inspections include weld, dimensional, surface finish, and cleanliness inspections. Visual inspections specified by codes applicable to a component are performed in accordance with the requirements and acceptance criteria of those codes.

All weld inspection is performed using qualified processes and qualified personnel according to the applicable code requirements, e.g., ASME or AWS. Non-destructive examination (NDE) requirements for welds are specified on the drawings provided in Chapter B.1; acceptance criteria are as specified by the governing code. NDE personnel are qualified in accordance with SNT-TC-1A [B.10-18].

The confinement welds on the DSC are inspected in accordance with ASME B&PV Code Subsection NB [B.10-19] including alternatives to ASME Code specified in Section 4.4.4 of the Technical Specifications [B.10-4] for the NUHOMS-61BTH DSC confinement boundary and basket.

DSC non-confinement welds are inspected to the NDE acceptance criteria of ASME B&PV Code Subsection NG or NF, based on the applicable code for the components welded.

B.10.1.3.2 HSM-MX

Refer to Section A.10.1.3 of Appendix A.

B.10.1.3.3 Transfer Cask

The trunnions of the OS197 are tested in accordance with the requirements in Section 4.2.3.3 of [B.10-5].

B.10.1.4 Components

The components that require testing are discussed in Section T.9.1.4 of CoC 1004 [B.10-5].

B.10.1.5 Shielding Tests

Refer to Section T.9.1.5 of CoC 1004 [B.10-5].

B.10.1.5.1 DSC

Shielding in the DSC is provided by the top and bottom shield plugs and cover plates. Shielding requirements of the 61BTH Type 2 DSC are provided in Section T.9.1.5 of CoC 1004 [B.10-5].

B.10.1.5.2 HSM

Shielding requirements for the HSM-MX are provided in Section A.10.1.4 of Appendix A.

B.10.1.5.3 Transfer Cask

Section T.9.1.5 of CoC 1004 [B.10-5] provides the shielding requirements for the OS197.

B.10.1.6 Neutron Absorber Tests

The neutron absorber used for criticality control in the 61BTH Type 2 DSC baskets may consist of one of the following materials:

- Borated aluminum
- Boron carbide/aluminum metal matrix composite (MMC)
- BORAL®

The 61BTH Type 2 safety analyses do not rely upon the tensile strength of these materials. The radiation and temperature environment in the cask is not sufficiently severe to damage these metallic/ceramic materials. To assure performance of the neutron absorber's design function, only the presence of B-10 and the uniformity of its distribution need to be verified, with testing requirements specific to each material. The boron content of these three types of materials is given in Tables 9-12 of the Technical Specifications [B.10-4].

B.10.1.6.1 Borated Aluminum

The material is produced by direct chill (DC) or permanent mold casting with boron precipitating primarily as a uniform fine dispersion of discrete AlB_2 or TiB_2 particles in the matrix of aluminum or aluminum alloy (other boron compounds, such as AlB_{12}, can also occur). For extruded products, the TiB_2 form of the alloy shall be used. For rolled products, either the AlB_2, the TiB_2, or a hybrid may be used.

Boron is added to the aluminum in the quantity necessary to provide the specified minimum B-10 areal density in the final product. The amount required to achieve the specified minimum B-10 areal density will depend on whether boron with the natural isotopic distribution of the isotopes B-10 and B-11, or boron enriched in B-10 is used. In no case shall the boron content in the aluminum or aluminum alloy exceed 5% by weight.

The criticality calculations take credit for 90% of the minimum specified B-10 areal density of borated aluminum. The basis for this credit is the B-10 areal density acceptance testing, which shall be as specified in Section B.10.1.6.4. The specified acceptance testing assures that, at any location in the material, the minimum specified areal density of B-10 will be found with 95% probability and 95% confidence.

Visual Inspections of Borated Aluminum

Neutron absorbers shall be 100% visually inspected in accordance with the Certificate Holder's QA procedures. Blisters shall be treated as non-conforming. Material that does not meet these acceptance criteria shall be reworked, repaired, or scrapped.

Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4, "Quality Control, Visual Inspection of Aluminum Mill Products" [B.10-6]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

Thermal Conductivity Testing

Acceptance testing shall conform to ASTM E1225 [B.10-7], ASTM E1461 [B.10-8], or equivalent method performed at room temperature on coupons taken from the rolled or extruded production material. Initial sampling shall be one test per lot, and may be reduced if the first five tests meet the specified minimum thermal conductivity. For cast products, the lot shall be defined by the heat or ingot. For other products, the lot shall be defined as material produced in a single production campaign using the same heat or lots of aluminum and boron carbide feed materials.

If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

After 25 tests of a single type of material with the same aluminum alloy matrix, the same boron content, and the same primary boron phase (e.g., B_4C, TiB_2, or $AlB_{2)}$, if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The measured thermal conductivity values shall satisfy the minimum required conductivities as specified in Section T.4.3 of CoC 1004 [B.10-5].

In cases where the specified thickness of the neutron absorber may vary, the equations introduced in Section T.4.3 of CoC 1004 [B.10-5] shall be used to determine the minimum required effective thermal conductivity.

The thermal conductivity test requirement does not apply to aluminum that is paired with the neutron absorber.

B.10.1.6.2 Boron Carbide/Aluminum Metal Matrix Composites (MMC)

The material is a composite of fine boron carbide particles in an aluminum or aluminum alloy matrix. The material shall be produced by either direct chill casting, permanent mold casting, powder metallurgy, molten metal infiltration, or thermal spray techniques. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding or produced by molten metal infiltration shall not exceed 50% by volume.

The final MMC product shall have density greater than 98% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity. For MMC with an integral cladding, the final density of the core shall be greater than 97% of theoretical density demonstrated by qualification testing, with no more than 0.5 volume % interconnected porosity of the core and cladding as a unit of the final product.

At least 50% by weight of the B_4C particles in MMCs shall be smaller than 40 microns. No more than 10% of the particles shall be over 60 microns.

Prior to use in the 61BTH Type 2 DSC, MMCs shall pass the qualification testing specified in Section B.10.1.6.5, and shall subsequently be subject to the process controls specified in Section B.10.1.6.6.

The criticality calculations take credit for 90% of the minimum specified B-10 areal density of MMCs. The basis for this credit is the B-10 areal density acceptance testing, which is specified in Section B.10.1.6.4. The specified acceptance testing assures that at any location in the final product, the minimum specified areal density of B-10 will be found with 95% probability and 95% confidence.

Visual Inspection of MMCs

Neutron absorbers shall be 100% visually inspected in accordance with the Certificate Holder's QA procedures. Blisters shall be treated as non-conforming. For clad MMCs, visual inspection shall verify that there are no cracks through the cladding, exposed core on the face of the sheet, or solid aluminum at the edge of the sheet. Material that does not meet these acceptance criteria shall be reworked, repaired, or scrapped.

Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4, "Quality Control, Visual Inspection of Aluminum Mill Products" [B.10-6]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

Thermal Conductivity Testing

Acceptance testing shall conform to ASTM E1225 [B.10-7], ASTM E1461 [B.10-8], or equivalent method performed at room temperature on coupons taken from the rolled or extruded production material. Initial sampling shall be one test per lot, and may be reduced if the first five tests meet the specified minimum thermal conductivity. For cast products, the lot shall be defined by the heat or ingot. For other products, the lot shall be defined as material produced in a single production campaign using the same heat or lots of aluminum and boron carbide feed materials.

If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

After 25 tests of a single type of material with the same aluminum alloy matrix, the same boron content, and the same primary boron phase (e.g., B_4C, TiB_2, or AlB_2), if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The measured thermal conductivity values shall satisfy the minimum required conductivities as specified in Section T.4.3 of CoC 1004 [B.10-5].

In cases where the specified thickness of the neutron absorber may vary, the equations introduced in Section T.4.3 of CoC 1004 [B.10-5] shall be used to determine the minimum required effective thermal conductivity.

The thermal conductivity test requirement does not apply to aluminum that is paired with the neutron absorber.

B.10.1.6.3 BORAL Specification and Acceptance Testing

This material consists of a core of aluminum and boron carbide powders between two outer layers of aluminum, mechanically bonded by hot-rolling an "ingot" consisting of an aluminum box filled with blended boron carbide and aluminum powders. The core, which is exposed at the edges of the sheet, is slightly porous. Before rolling, at least 80% by weight of the B_4C particles in BORAL® shall be smaller than 200 microns. The nominal boron carbide content shall be limited to 65% (+ 2% tolerance limit) of the core by weight. The criticality calculations take credit for 75% of the minimum specified B-10 areal density of BORAL®. B-10 areal density will be verified by chemical analysis and by certification of the B-10 isotopic fraction for the boron carbide powder, or by neutron transmission testing. Areal density testing is performed on a coupon taken from the sheet produced from each ingot. If the measured areal density is below that specified, all the material produced from that ingot will be either rejected, or accepted only on the basis of alternate verification of B-10 areal density for each of the final pieces produced from that ingot.

Visual Inspection of BORAL®

Neutron absorbers shall be 100% visually inspected in accordance with the Certificate Holder's QA procedures. Blisters shall be treated as non-conforming. Visual inspection shall verify that there are no cracks through the cladding, exposed core on the face of the sheet, or solid aluminum at the edge of the sheet. Material that does not meet these acceptance criteria shall be reworked, repaired, or scrapped.

Thermal Conductivity Testing

Acceptance testing shall conform to ASTM E1225 [B.10-7], ASTM E1461 [B.10-8], or equivalent method performed at room temperature on coupons taken from the rolled or extruded production material. Initial sampling shall be one test per lot, and may be reduced if the first five tests meet the specified minimum thermal conductivity. For cast products, the lot shall be defined by the heat or ingot. For other products, the lot shall be defined as material produced in a single production campaign using the same heat or lots of aluminum and boron carbide feed materials.

If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

After 25 tests of a single type of material with the same aluminum alloy matrix, the same boron content, and the same primary boron phase (e.g., B_4C, TiB_2, or AlB_2), if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The measured thermal conductivity values shall satisfy the minimum required conductivities as specified in Section T.4.3 of CoC 1004 [B.10-5].

In cases where the specified thickness of the neutron absorber may vary, the equations introduced in Section T.4.3 CoC 1004 [B.10-5] shall be used to determine the minimum required effective thermal conductivity.

The thermal conductivity test requirement does not apply to aluminum that is paired with the neutron absorber.

B.10.1.6.4 Specification for Acceptance Testing of Neutron Absorber Content

Acceptance testing for neutron absorber content shall be performed by either neutron transmission or by B-10 volume density measurement.

B.10.1.6.4.1 Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission

a. Neutron transmission acceptance testing procedures shall be subject to approval by the Certificate Holder. Test coupons shall be removed from the rolled or extruded production material at locations that are systematically or probabilistically distributed throughout the lot. Test coupons shall not exhibit physical defects that would not be acceptable in the finished product, or that would preclude an accurate measurement of the coupon's physical thickness.

   A lot is defined as all of the pieces produced from a single ingot or heat, or from a group of billets from the same heat. If this definition results in lot size too small to provide a meaningful statistical analysis of results, an alternate larger lot definition may be used, as long as it results in accumulating material that is uniform for sampling purposes.

   The sampling rate for neutron transmission measurements shall be such that there is at least one neutron transmission measurement for each 2000 square inches of final product in each lot.

   The B-10 areal density is measured using a collimated thermal neutron beam of up to 1.1 inch diameter.

The neutron transmission through the test coupons is converted to B-10 areal density by comparison with transmission through calibrated standards. These standards are composed of a homogeneous boron compound without other significant neutron absorbers. For example, boron carbide, zirconium diboride, or titanium diboride sheets are acceptable standards. These standards are paired with aluminum shims sized to match the effect of neutron scattering by aluminum in the test coupons. Uniform but non-homogeneous materials such as metal matrix composites may be used for standards, provided that testing shows them to provide neutron attenuation equivalent to a homogeneous standard. Standards will be calibrated, traceable to nationally recognized standards, or by attenuation of a monoenergetic neutron beam correlated to the known cross section of B-10 at that energy.

The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the one-sided tolerance limit for a normal distribution may be used for this purpose. Otherwise, a non-parametric (distribution-free) method of determining the one-sided tolerance limit may be used. Demonstration of the one-sided tolerance limit shall be evaluated for acceptance in accordance with the certificate holder's QA procedures.

b. The following illustrates one acceptable method and is intended to be utilized as an example. Therefore, the following text is not part of the Technical Specifications. The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The B-10 areal densities determined by neutron transmission are converted to volume density (i.e., the B-10 areal density is divided by the thickness at the location of the neutron transmission measurement or the maximum thickness of the coupon). The lower tolerance limit of B-10 volume density is then determined, defined as the mean value of B-10 volume density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor with 95% probability and 95% confidence [B.10-9].

Finally, the minimum specified value of B-10 areal density is divided by the lower tolerance limit of B-10 volume density to arrive at the minimum plate thickness which provides the specified B-10 areal density.

Any plate which is thinner than the statistically derived minimum thickness from B.10.1.6.4.1(a) or the minimum design thickness, whichever is greater, shall be treated as non-conforming, with the following exception. Local depressions are acceptable, as long as they total no more than 0.5% of the area on any given plate, and the thickness at their location is not less than 90% of the minimum design thickness. Edge effects due to manufacturing operations such as shearing, deburring, and chamfering need not be included in this determination.

Non-conforming material shall be evaluated for acceptance in accordance with the certificate holder's QA procedures.

B.10.1.6.4.2 Specification for Acceptance Testing of Neutron Absorbers by B-10 Volume Density Measurement

a. B-10 volume density measurement acceptance testing procedures shall be subject to approval by the certificate holder. Test coupons shall be removed from the rolled or extruded production material at locations that are systematically or probabilistically distributed throughout the lot. Test coupons shall not exhibit physical defects that would not be acceptable in the finished product, or that would preclude an accurate measurement of the coupon's physical thickness.

A lot is defined as all the pieces produced from a single ingot or heat or from a group of billets from the same heat. If this definition results in lot size too small to provide a meaningful statistical analysis of results, an alternate larger lot definition may be used, as long as it results in accumulating material that is uniform for sampling purposes.

The sampling rate for B-10 volume density measurements shall be such that there is at least one density measurement for each 2000 square inches of final product in each lot.

Areal density is determined by measuring the B-10 volume density in test samples and converting the measured values to areal density. The method of measurement of B-10 volume density shall be subject to approval by the certificate holder. The method of measurement of B-10 volume density shall be qualified against neutron transmission testing. Results of the two test methods shall be compared and a penalty shall be derived to account for the performance based results of neutron transmission testing.

The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the one-sided tolerance limit for a normal distribution may be used for this purpose. Otherwise, a non-parametric (distribution-free) method of determining the one-sided tolerance limit may be used. Demonstration of the one-sided tolerance limit shall be evaluated for acceptance in accordance with the certificate holder's QA procedures.

b. The following illustrates one acceptable method and is intended to be utilized as an example. Therefore, the following text is not part of the Technical Specifications. The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The B-10 areal densities are determined by volume density as described above. The lower tolerance limit of B-10 volume density is then determined, defined as the mean value of B-10 volume density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor with 95% probability and 95% confidence [B.10-9]. Finally, the minimum specified value of B-10 areal density is divided by the lower tolerance limit of B-10 volume density to arrive at the minimum plate thickness that provides the specified B-10 areal density.

Any plate that is thinner than the statistically derived minimum thickness from B.10.1.6.4.2(a) or the minimum design thickness, whichever is greater, shall be treated as nonconforming, with the following exception. Local depressions are acceptable, as long as they total no more than 0.5% of the area on any given plate, and the thickness at their location is not less than 90% of the minimum design thickness. Edge effects due to manufacturing operations such as shearing, deburring, and chamfering need not be included in this determination.

Non-conforming material shall be evaluated for acceptance in accordance with the certificate holder's QA procedures.

B.10.1.6.5 Specification for Qualification Testing of MMCs

B.10.1.6.5.1 Applicability and Scope

Metal matrix composites (MMCs) acceptable for use in the 61BTH Type 2 DSC are described in Section B.10.1.6.2.

Prior to initial use in a spent fuel dry storage or transport system, such MMCs shall be subjected to qualification testing that will verify that the product satisfies the design function. Key process controls shall be identified per Section B.10.1.6.6 so that the production material is equivalent to or better than the qualification test material. Changes to key processes shall be subject to qualification before use of such material in a spent fuel dry storage or transport system.

ASTM test methods and practices are referenced below for guidance. Alternative methods may be used with the approval of the certificate holder.

B.10.1.6.5.2 Design Requirements

In order to perform its design functions, the product must have at a minimum sufficient strength and ductility for manufacturing and for the normal and accident conditions of the storage/transport system. This is demonstrated by the tests in Section B.10.1.6.5.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section B.10.1.6.5.5.

B.10.1.6.5.3 Durability

There is no need to include accelerated radiation damage testing in the qualification. Such testing has already been performed on MMCs, and the results confirm what would be expected of materials that fall within the limits of applicability cited above. Metals and ceramics do not experience measurable changes in mechanical properties due to fast neutron fluences typical over the lifetime of spent fuel storage, about 10^{15} neutrons/cm^2.

Thermal damage and corrosion (hydrogen generation) testing shall be performed unless such tests on materials of the same chemical composition have already been performed and found acceptable. The following paragraphs illustrate two cases where such testing is not required.

Thermal damage testing is not required for unclad MMCs consisting only of boron carbide in an aluminum 1100 matrix, because there is no reaction between aluminum and boron carbide below 842°F, well above the basket temperature under normal conditions of storage or transport [B.10-10].

Corrosion testing is not required for MMCs (clad or unclad) consisting only of boron carbide in an aluminum 1100 matrix, because testing on one such material has already been performed by Transnuclear [B.10-11].

B.10.1.6.5.4 Required Qualification Tests and Examinations to Demonstrate Mechanical Integrity

At least three samples, one each from approximately the two ends and middle of the qualification material run, shall be subject to:

a. Room temperature tensile testing (ASTM- B557 [B.10-12]) demonstrating that the material has the following tensile properties:

   – Minimum yield strength, 0.2% offset: 1.5 ksi
   – Minimum ultimate strength: 5 ksi
   – Minimum elongation in 2 inches: 0.5%

   As an alternative to the elongation requirement, ductility may be demonstrated by bend testing per ASTM E290 [B.10-13]. The radius of the pin or mandrel shall be no greater than three times the material thickness, and the material shall be bent at least 90 degrees without complete fracture.

b. Testing to verify more than 98% of theoretical density for non-clad MMCs and 97% for the matrix of clad MMCs. Testing or examination for interconnected porosity on the faces and edges of unclad MMC, and on the edges of clad MMC shall be performed by a means to be approved by the certificate holder. The maximum interconnected porosity is 0.5 volume %.

c. Delamination Testing of Clad MMC

   Clad MMCs shall be subjected to thermal damage testing following water immersion to ensure that delamination does not occur under normal conditions of storage. An example of such a test would be: (1) immerse a specimen at least 6 by 6 inches in water under pressure ≥30 psig for at least 24 hours, (2) place the specimen in a vacuum furnace preheated to at least 300 °F and evacuate the furnace. Acceptance criterion: no blistering or delamination of the cladding.

B.10.1.6.5.5 Test for Uniform B-10 Distribution

Uniformity of the boron distribution shall be verified either by:

a. Neutron radioscopy or radiography (ASTM E94 [B.10-14], E142 [B.10-15], and E545 [B.10-16]) of material from the ends and middle of the test material production run, verifying no more than 10% difference between the minimum and maximum B-10 areal density, or

b. Quantitative testing for the B-10 areal density, B-10 density, the boron carbide weight fraction, or the boron weight fraction on locations distributed over the test material production run, verifying that one standard deviation in the sample is less than 10% of the sample mean. Testing may be performed by a neutron transmission method similar to that specified in Section B.10.1.6.4.1, or by chemical analysis for boron carbide or boron content in the composite.

B.10.1.6.5.6 Qualification Report

Qualification report shall be prepared by, or subject to approval by the certificate holder.

B.10.1.6.6 Specification for Process Controls for MMCs

B.10.1.6.6.1 Applicability and Scope

Key processing changes shall be subject to qualification prior to use of the material produced by the revised process. The certificate holder shall determine whether a complete or partial re-qualification program per Section B.10.1.6.5 is required, depending on the characteristics of the material that could be affected by the process change.

B.10.1.6.6.2 Definition of Key Process Changes

Key process changes are those which could adversely affect the uniform distribution of the boron carbide in the aluminum, reduce density, reduce corrosion resistance, or reduce the mechanical strength or ductility of the MMC.

B.10.1.6.6.3 Identification and Control of Key Process Changes

The manufacturer shall provide the certificate holder with a description of materials and process controls used in producing the MMC. The certificate holder and manufacturer shall identify key process changes as defined in Section B.10.1.6.6.2.

An increase in nominal boron carbide content over that previously qualified shall always be regarded as a key process change. The following are examples of other changes that are established as key process changes, as determined by the certificate holder's review of the specific applications and production processes:

a. Changes in the boron carbide particle size specification that increase the average (d50) particle size by more than 5 microns or that increase the amount of particles larger than 60 microns from the previously qualified material by more than 5% of the total distribution but less than the 10% limit,

b. Change of the billet production process (e.g., from vacuum hot pressing to cold isostatic pressing followed by vacuum sintering),

c. Change in the nominal matrix alloy,

d. Changes in mechanical processing that could result in reduced density of the final product (e.g., for PM or thermal spray MMCs that were qualified with extruded material, a change to direct rolling from the billet),

e. For MMCs using a magnesium-alloyed aluminum matrix, changes in the billet formation process that could increase the likelihood of magnesium reaction with the boron carbide, such as an increase in the maximum temperature or time at maximum temperature,

f. Changes in powder blending or melt stirring processes that could result in less uniform distribution of boron carbide (e.g., change in duration of powder blending), and

g. For MMCs with an integral aluminum cladding, a change greater than 25% in the ratio of the nominal aluminum cladding thickness (sum of two sides of cladding) and the nominal matrix thickness could result in changes in the mechanical properties of the final product.

B.10.1.7 Thermal Acceptance

Refer to the second paragraph of section T.9.1.6 of CoC 1004 [B.10-5] for thermal acceptance criteria for the 61BTH Type 2 DSC.

B.10.1.8 Cask Identification

Each DSC, HSM, and TC is marked with a model number, serial number, and empty weight per 10 CFR 72.236(k).

B.10.2 Maintenance Program

There are no maintenance requirements for the DSC for the initial licensed period of storage. The NUHOMS®-61BTH system is a passive system and therefore will require little, if any, maintenance over the lifetime of the ISFSI.

B.10.2.1 Inspection

B.10.2.1.1 Transfer Cask Inspections

Refer to Section 4.5.1 of CoC 1004 [B.10-5] for routine inspections and Section 4.5.2 of CoC 1004 [B.10-5] for annual inspections of the OS197.

Additionally, appropriate aging management activities such as time limited aging analyses (TLAAs) and aging management programs (AMPs) have been developed for the OS197 TCs that are in the period of extended operation (beyond the initial 20 years of service) in the CoC 1004 Renewal [B.10-17]. Aging management programs (AMPs) credited with managing aging effects during the extended storage period are provided in CoC 1004 UFSAR Table 12.3-5 [B.10-5]. It is the responsibility of the owner of each OS197 TC to perform the required activities to ensure that no identified aging effect results in a loss of intended design function for the term of renewal.

B.10.2.2 HSM Inspections

There is no change to Section 10.2 associated with the HSM-MX. HSM inspections from Section 10.2.1.2 are applicable to the HSM-MX.

B.10.3 Repair, Replacement, and Maintenance

B.10.3.1 Transfer Cask

Refer to Section 4.5 of CoC 1004 [B.10-5] for OS197 repair, replacement, and maintenance requirements.

B.10.3.2 HSM Repair, Replacement, and Maintenance

See A.10.3 for HSM-MX repair, replacement, and maintenance requirements

B.10.4 References

B.10-1 ACI 318-08, "Building Code Requirements for Structural Concrete and Commentary," American Concrete Institute, Detroit, MI.

B.10-2 ACI 349-06, "Code Requirements for Nuclear Safety Related Structures," American Concrete Institute, Detroit, MI.

B.10-3 American Welding Society, AWS D1.1/D1.1M, "Structural Welding Code – Steel."

B.10-4 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 2.

B.10-5 TN Americas, LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

B.10-6 The Aluminum Association, "Aluminum Standards and Data," 2003.

B.10-7 ASTM E1225, "Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique"

B.10-8 ASTM E1461, "Thermal Diffusivity of Solids by the Flash Method."

B.10-9 Natrella, "Experimental Statistics," Dover, 2005.

B.10-10 Sung, C., "Microstructural Observation of Thermally Aged and Irradiated Aluminum/Boron Carbide (B_4C) Metal Matrix Composite by Transmission and Scanning Electron Microscope," 1998.

B.10-11 Boralyn Testing submitted to the NRC under Docket 71-1027, 1998.

B.10-12 ASTM B557, "Standard Test Methods of Tension Testing Wrought and Cast Aluminum and Magnesium-Alloy Products."

B.10-13 ASTM E290, "Standard Methods for Bend Testing of Materials for Ductility."

B.10-14 ASTM E94, "Recommended Practice for Radiographic Testing."

B.10-15 ASTM E142, "Controlling Quality of Radiographic Testing."

B.10-16 ASTM E545, "Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing."

B.10-17 Certificate of Compliance Renewal Application for the Standardized NUHOMS® System Certificate of Compliance No. 1004, Docket No. 72-1004, Revision 3, September 2016.

B.10-18 SNT-TC-1A, "American Society for Nondestructive Testing, Personnel Qualification and Certification in Nondestructive Testing," 1992.

B.10-19 ASME Boiler and Pressure Vessel Code, Section III, 2004 Edition with 2006 Addenda.

APPENDIX B.11
RADIATION PROTECTION

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

List of Tables

B.11 RADIATION PROTECTION

This chapter describes the design features of the NUHOMS® MATRIX (HSM-MX), OS197 TC, and 61BTH Type 2 DSC that maintain radiation exposure to site personnel as low as reasonably achievable (ALARA), as well as minimize exposure to the public. Radiation exposures to offsite individuals computed for both normal and accident conditions of an independent spent fuel storage installation (ISFSI) for the EOS-DSC are conservatively applied to the 61BTH DSC.

This chapter provides an example of how to demonstrate compliance with the relevant radiological requirements of 10 CFR Part 20 [B.11-1], 10 CFR Part 72 [B.11-2], and 40 CFR Part 190 [B.11-3]. Each user must perform site-specific calculations to account for the actual layout of the HSM-MXs and fuel source.

B.11.1 Radiation Protection Design Features

The HSM-MX has design features that ensure a high degree of integrity for the confinement of radioactive materials and reduction of direct radiation exposures during storage. These features are described in Section B.11.4.2.

B.11.2 Occupational Dose Assessment

This section provides estimates of occupational dose for the OS197 TC and ISFSI loading operations. Assumed annual occupancy times, including the anticipated maximum total hours per year for any individual, and total person-hours per year for all personnel for each radiation area during normal operation and anticipated operational occurrences, will be evaluated by the licensee in a 10 CFR 72.212 evaluation to address the site-specific ISFSI layout, inspection, and maintenance requirements. In addition, the estimated annual collective doses associated with loading operations will be addressed by the licensee in a 10 CFR 72.212 evaluation.

B.11.2.1 61BTH DSC Loading, Transfer, and Storage Operations

The dose rates for the 61BTH DSC within the OS197 TC are similar to the dose rates for the EOS-89BTH DSC within the EOS-TC125 on the top and side, see the discussion in Section B.6.4.3. Therefore, the decontamination and welding dose rates for the EOS-89BTH DSC within the EOS-TC125 from Table 11-1 are conservatively applied for the OS197 TC occupational dose assessment. Transfer dose rates for the OS197 TC and HSM-MX front average dose rates are obtained from the analysis documented in Chapter B.6. Dose rates used as input for the occupational dose assessment are provided in Table B.11-1 and include reconstituted FAs containing a total of 120 irradiated stainless steel rods on the periphery. Dose rate locations around the cask are analogous to the EOS-TC125 dose rate locations illustrated in Figure 11-1.

The estimated occupational exposures to ISFSI personnel during loading, transfer, and storage operations (time and number of workers may vary depending on individual ISFSI practices) are provided in Table B.11-2. The total exposure is 2.5 person-rem.

The exposure provided is a bounding estimate. Measured exposures from typical NUHOMS® System loading campaigns have been 600 mrem or lower per canister for normal operations, and exposures for the HSM-MX are expected to be similar.

Regulatory Guide 8.34 [B.11-4] is to be used to define the onsite occupational dose and monitoring requirements.

B.11.2.2 61BTH DSC Retrieval Operations

Occupational exposures to ISFSI personnel during 61BTH DSC retrieval are similar to those exposures calculated for 61BTH DSC insertion. Dose rates for retrieval operations will be lower than those for insertion operations due to radioactive decay of the spent fuel inside the HSM-MX. Therefore, the dose rates for 61BTH DSC retrieval are bounded by the dose rates calculated for insertion.

B.11.2.3 Fuel Unloading Operations

No change to Section 11.2.3.

B.11.2.4 Maintenance Operations

The dose rates for surveillance activities are shown in Table A.11-7 and Table A.11-8 for doses rates 6.1 m from the front of an HSM-MX loaded with an EOS-DSC. It is demonstrated in Section B.6.4.4 that vent dose rates for the EOS-DSC bound the 61BTH DSC. The 6.1-meter dose rate is a conservative estimate for surveillance activities. The HSM-MX surface dose rates for the EOS-89BTH DSC provided in Chapter A.6 may be used for temperature sensor maintenance activities, including calibration and repair.

The general licensee will evaluate the additional dose to personnel from ISFSI operations, based on the particular storage configuration and site personnel requirements.

B.11.2.5 Doses during ISFSI Expansion

No change to Section A.11.2.5, as the 61BTH DSC is bounded by the EOS-DSC within the HSM-MX.

B.11.3 Offsite Dose Calculations

B.11.3.1 Normal Conditions (10 CFR 72.104)

The vent dose rates for an HSM-MX containing an EOS-DSC bound the vent dose rates for the 61BTH DSC, see the discussion in Section B.6.4.4. Therefore, the EOS-DSC site dose analysis documented in Section A.11.3 may be used to bound the 61BTH DSC.

Two generic configurations are considered, 2x11 and two 1x11. The total annual exposure for each configuration is provided in Table A.11-5. Detailed dose rate results as a function of distance are provided in Table A.11-7 and Table A.11-8 for the 2x11 and two 1x11 configurations, respectively.

The analyses and results are intended to provide high estimates of dose rates for generic ISFSI layouts. The written evaluations performed by a general licensee for the actual ISFSI must consider the type and number of storage units, layout, characteristics of the irradiated fuel to be stored, site characteristics (e.g., berms, distance to the controlled area boundary, etc.), and reactor operations at the site in order to demonstrate compliance with 10 CFR 72.104.

B.11.3.2 Accident Conditions (10 CFR 72.106)

HSM-MX 2x11 accident dose rates for the EOS-DSC are provided in Table A.11-9. These dose rates are calculated assuming damage to every module in the array. This is a highly conservative scenario that is not credible, as an accident is not expected to damage every module. As stated in Section A.11.3.2, at a distance of 200 m from the ISFSI, the accident dose is significantly less than the 10 CFR 72.106 limit of 5 rem.

The OS197 TC may also be damaged in an accident during transfer operations, which would also result in an offsite dose. It is demonstrated in Section B.6.4.3 that the 100 m accident dose rate for the 61BTH DSC within the OS197 TC is bounded by the accident dose rate for the EOS-TC. The bounding dose for an EOS-TC accident presented in Section 6.4.3 is significantly less than the 10 CFR 72.106 limit of 5 rem.

B.11.4 Ensuring that Occupational Radiation Exposures Are ALARA

B.11.4.1 Policy Considerations

No change to Section 11.4.1.

B.11.4.2 Design Considerations

The EOS-DSC and EOS-TC design considerations provided in Section 11.4.2 also apply to the 61BTH DSC and OS197 TC. However, the OS197 TC utilizes NS-3 rather than borated polyethylene to provide neutron shielding at the ends of the transfer cask.

The HSM-MX storage modules include no active components that require periodic maintenance, thereby minimizing potential personnel dose due to maintenance activities.

The HSM-MXs provide thick concrete shielding, and the shielding design features of the storage modules minimize occupational exposure for any activities on or near the ISFSI.

Regulatory Position 2 of Regulatory Guide 8.8 is incorporated into the design considerations, see Section 11.4.2.

B.11.4.3 Operational Considerations

No change to Section A.11.4.3.

B.11.5 References

B.11-1 Title 10, Code of Federal Regulations, Part 20, "Standards for Protection Against Radiation."

B.11-2 Title 10, Code of Federal Regulations Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste, and Reactor-Related greater than Class C Waste."

B.11-3 Title 40, Code of Federal Regulations, Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations."

B.11-4 U.S. Nuclear Regulatory Commission, Regulatory Guide 8.34, "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses," July 1992.

Table B.11-1
Occupational Dose Rates, OS197 with 61BTH DSC

Dose Rate Location	Averaged Segments(1)	Config.	Dose Rate (mrem/hr)
DRL1	A1-18, R11	Decon.	62
DRL2	A3-16, R10	Decon.	181
	A3-16, R10	Transfer	208
DRL3	A17, R9	Decon.	98
	A17, R9	Welding	113
	A17, R9	Transfer	-
DRL4	A3-11, R9	Decon.	-
DRL5	A1-18, R10	Transfer	164
DRL6	A17-18, R9	Transfer	14
DRL7	A17-18, R10	Transfer	22
DRL8	A2, R9	Transfer	-
DRL9	A19, R0	Transfer	204
DRL10	A1, R10	Transfer	61
HMX-MX (HMX)	Front face surface average	-	48

(1) Dose rate locations analogous to Figure 11-1.

Table B.11-2
Occupational Exposure, OS197 with 61BTH DSC
(2 Sheets)

No.	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person-mrem)	% of Total Dose
1	Drain neutron shield if necessary. Place an empty 61BTH DSC into an OS197 TC and prepare the OS197 TC for placement into the spent fuel pool.	N/A	N/A	6	4.00	0	0	0%
2	Move the OS197 TC containing a 61BTH DSC without fuel into the spent fuel pool.	N/A	N/A	6	1.50	0	0	0%
3	Remove a loaded OS197 TC from the fuel pool and place in the decontamination area. Refill neutron shield tank if necessary.	Decon.	DRL1	2	0.25	62	31	1.3%
4	Decontaminate the OS197 TC and prepare welds.	Decon.	DRL2	2	1.75	181	634	25.8%
		Decon.	DRL3	2	0.50	98	98	4.0%
5	Weld inner top cover plate.	Welding	DRL3	2	0.75	113	170	6.9%
6	Vacuum dry and backfill with helium.	Welding	DRL3	2	0.50	113	113	4.6%
7	Weld outer top cover plate and port covers, perform non-destructive examination.	Welding	DRL3	2	0.50	113	113	4.6%
8	Drain annulus. Install OS197 TC top cover. Ready the support skid and transfer trailer.	Transfer	DRL5	1	0.50	164	82	3.3%
9	Place the OS197 TC onto the skid and trailer. Secure the OS197 TC to the skid.	Transfer	DRL2	2	0.33	208	137	5.6%
10	Install retractable roller tray (RRT).	Transfer	HMX	2	2.00	48	192	7.8%
11	Transfer the OS197 TC to ISFSI.	N/A	N/A	6	1.83	0	0	0%
12	Position the OS197 TC inside the loading crane (MX-LC).	Transfer	HMX+DRL2	2	0.50	256	256	10.4%
13	Remove forced cooling system (if used) and install the ram cylinder assembly.	Transfer	DRL9	2	0.50	204	204	8.3%
14	Remove HSM-MX door.	Transfer	HMX	2	0.50	48	48	2.0%
15	Remove the OS197 TC top cover.	Transfer	HMX+DRL6	2	0.67	62	83	3.4%
16	Align and dock the OS197 TC with the HSM-MX. Secure the OS197 TC to the HSM-MX.	Transfer	HMX+DRL7	2	0.25	70	35	1.4%
17	Transfer the 61BTH DSC from the OS197 TC to the HSM-MX using the ram cylinder.	N/A	N/A	3	0.50	0	0	0%

Table B.11-2
Occupational Exposure, OS197 with 61BTH DSC
(2 Sheets)

No.	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person-mrem)	% of Total Dose
18	Disengage the ram and un-dock the OS197 TC from the HSM-MX.	Transfer	HMX+DRL10	2	0.08	109	18	0.7%
19	Install HSM-MX access door. Move OS197 TC to the transfer skid for removal.	Transfer	HMX	2	0.50	48	48	2.0%
20	Uninstall RRT.	Transfer	HMX	2	2.00	48	192	7.8%
						Total	2452	

APPENDIX B.12
ACCIDENT ANALYSES

Table of Contents

Appendix B is newly added in Revision 4 by Amendment 2.

B.12 ACCIDENT ANALYSES

B.12.1 Introduction

No change to Section 12.1, except that this appendix is updated to include the NUHOMS® 61BTH Type 2 DSC and OS197 On Site Transfer Cask (TC) when loaded in the NUHOMS® HSM-MX.

B.12.2 Off-Normal Events

Off-normal events are design events of the second type (Design Event II) as defined in ANSI/ANS 57.9 [B.12-2]. Design Event II conditions consist of a set of events that do not occur regularly, but can be expected to occur with a moderate frequency, or about once during a calendar year of independent spent fuel storage installation (ISFSI) operation.

For the HSM-MX, off-normal events could occur during trailer movement, 61BTH Type 2 Dry Shielded Canister (DSC) transfer, and other operational events. The two off-normal events, which bound the range of off-normal conditions, are:

- A “jammed” DSC during loading or unloading from the HSM-MX
- The extreme ambient temperatures of -40 °F (winter) and +117 °F (summer)

These two events envelop the range of expected off-normal structural loads and temperatures acting on the HSM-MX.

B.12.2.1 Off-Normal Transfer Load

Although unlikely, the postulated off-normal handling event assumes that the leading edge of the 61BTH Type 2 DSC becomes jammed against some element of the support structure during transfer between the OS197 transfer cask and the HSM-MX.

Cause of Event

It is postulated that if the OS197 transfer cask is not accurately aligned with respect to the HSM-MX, it may bind or jam the 61BTH Type 2 DSC during transfer operations. The interiors of the OS197 transfer cask and the HSM-MX are inspected prior to transfer operations to ensure there are no obstacles. The OS197 transfer cask and the MATRIX retractable roller tray (MX-RRT) supports are designed to minimize binding or obstruction during 61BTH Type 2 DSC transfer. The postulated off-normal handling load event considers that the leading edge of the 61BTH Type 2 DSC becomes jammed against some element of the MX-RRT because of an unlikely gross misalignment of the OS197 transfer cask.

The interfacing dimensions of the top end of the OS197 transfer cask and the HSM-MX access opening sleeve are specified so that docking the OS197 transfer cask with the HSM-MX is not possible should gross misalignments between the OS197 transfer cask and HSM-MX exist.

Detection of Event

The normal load to push/pull the 61BTH Type 2 DSC in and out of the OS197 transfer cask/HSM-MX is 135 kips and 80 kips, respectively, applied at the grapple ring and resisted by an axial load of 70 kips push and 40 kips pull on each of the MX-RRT. This movement is performed at a very low speed. System operating procedures and technical specification limits defining the safeguards to be provided ensure that the system design margins are not compromised. If the 61BTH Type 2 DSC were to jam or bind during transfer, the pressure would increase. The off-normal load set for the "jammed DSC" for both insertion and retrieval are 135 kips and 80 kips, respectively. This load is administratively controlled to ensure that, during the transfer operation, this load is not exceeded.

During the transfer operation, the force exerted on the 61BTH Type 2 DSC by the ram is that required to first overcome the static frictional resisting force between the OS197 transfer cask rails and the MX-RRT rollers. Once the 61BTH Type 2 DSC begins to slide on the rollers, the resisting force is a function of sliding friction between the 61BTH Type 2 DSC and the OS197 transfer cask rails or between the 61BTH Type 2 DSC and the MX-RRT. If motion is prevented, the pressure increases, thereby increasing the force on the 61BTH Type 2 DSC until the ram system pressure limit is reached. This limit is controlled so that adequate force is available but is sufficiently low to ensure that component damage does not occur.

Analysis of Effects and Consequences

The analysis of effects and consequences for off-normal loads for insertion and retrieval of the DSC are bounded by those found in Section B.12.2.1. The analyses are discussed in Appendix B.3.9.1 for the 61BTH Type 2 DSC and Appendix B.3.9.4 for the HSM-MX. For either loading or unloading of the DSC under off-normal conditions, the stresses on the shell assembly components are demonstrated to be within the ASME allowable stress limits. Therefore, permanent deformation of the DSC shell components does not occur. The internal basket assembly components are unaffected by these loads based on clearances provided between the basket and DSC internal cavity.

There is no breach of the confinement pressure boundary and, therefore, no potential for release of radioactive material exists.

Corrective Actions

No changes to corrective action as described in Section 12.2.1.

B.12.2.2 Extreme Temperatures

The HSM-MX is designed for use at ambient temperatures of -40 °F (winter) and 117 °F (summer). Even though these extreme temperatures are likely to occur for a short period of time, it is conservatively assumed that these temperatures occur for a sufficient duration to produce steady state temperature distributions in HSM-MX. Each licensee should verify that this range of ambient temperatures envelopes the design basis ambient temperatures for the ISFSI site. The components affected by the postulated extreme ambient temperatures are the OS197-TC and 61BTH Type 2 DSC during their transfer from the plant's fuel/reactor building to the ISFSI site, and the HSM-MX during storage of a 61BTH Type 2 DSC.

Cause of Event

Off-normal ambient temperatures are natural phenomena.

Detection of Event

Off-normal ambient temperature conditions are confirmed by the licensee to be bounding for their site.

Analysis of Effects and Consequences

The thermal evaluation of the HSM-MX for extreme ambient conditions is presented in Chapter B.4. The effects of extreme ambient temperatures on the NUHOMS@ MATRIX System are analyzed in sections as follows:

Components	**UFSAR Sections**
NUHOMS® 61BTH Type 2 DSC Shell	Appendix B.3.9.1
NUHOMS® 61BTH Type 2 Basket	Appendix B.3.9.2
HSM-MX	Appendices B.3.9.4 and B.3.9.7
OS197 Transfer Cask	Appendix B.3.9.5

Corrective Actions

Restrictions for onsite handling of the transfer cask with a loaded DSC under extreme temperature conditions are presented in Technical Specifications 5.2.1 and Section 5.1.1, g. There is no change to this requirement as a result of addition of the NUHOMS®-61BTH Type 2 DSC.

B.12.3 Postulated Accidents

The design basis accident events specified by ANSI/ANS 57.9-1984 [B.12-2] and other postulated accidents that may affect the normal safe operation of the HSM-MX are addressed in this section.

The following sections provide descriptions of the analyses performed for each accident condition. The analyses demonstrate that the requirements of 10 CFR 72.122 [B.12-1] are met and that adequate safety margins exist for the HSM-MX System design. The resulting accident condition stresses in the HSM-MX components are evaluated and compared with the applicable code limits set forth in Chapter B.2.

The postulated accident conditions addressed in this section include:

- OS197 Transfer Cask drop
- Earthquake
- Tornado wind pressure and tornado-generated missiles
- Flood
- Blockage of HSM-MX air inlet openings
- Lightning
- Fire/Explosion

B.12.3.1 OS197 Transfer Cask (TC) Drop

Cause of Accident

As described in Chapter B.9, handling operations involving hoisting and movement of an OS197 Transfer Cask loaded with the 61BTH Type 2 DSC is typically performed inside the plant's fuel handling building.

This event is described in Section 8.2.5 of [B.12-3]. These include utilizing the crane for placement of the empty DSC into the OS197-TC cavity, and lifting the OS197-TC/DSC onto the transfer skid/trailer. An analysis of the plant's lifting devices used for these operations, including the crane and lifting yoke, is needed to address a postulated drop accident for the OS197-TC and its contents. The postulated drop accident scenarios addressed in the plant's 10 CFR Part 50 [B.12-4] licensing basis are plant-specific and should be addressed by the licensee.

Once the OS197-TC is loaded onto the transfer skid/trailer and secured, it is pulled to the HSM-MX site by a tractor vehicle. A predetermined route is chosen to minimize the potential hazards that could occur during transfer. This movement is performed at very low speeds. System operating procedures and technical specification limits defining the safeguards to be provided ensure that the system design margins are not compromised. As a result, it is highly unlikely that any plausible incidents leading to an OS197-TC drop accident could occur.

At the ISFSI site, the transfer skid/trailer is used in conjunction with the MATRIX loading crane (MX-LC). The MX-LC is used to assist in loading the DSC into the HSM. The MX-LC is designed, fabricated, installed, tested, inspected, and qualified in accordance with ASME NOG-1, as a Type I gantry type of crane, per the guidance provided in NUREG-0612 [B.12-5]. The transfer skid/trailer is backed up to, and aligned with, the HSM-MX using transfer equipment. The OS197-TC/MX-LC is docked with, and secured to, the HSM-MX access opening. The MX-RRT rollers are extended into HSM-MX through front wall slots for the MX-RRT and secured. The loaded DSC is transferred to or from the HSM-MX using transfer equipment. The MX-RRT is then lowered to place the DSC on the front and rear DSC supports in the HSM-MX. As a result, for a loaded OS197-TC drop accident to occur during these operations is considered non credible.

Lifts of the OS197-TC loaded with the dry storage canister are made within the existing heavy load requirements and procedures of the licensed nuclear power plant. The OS197-TC design meets requirements of NUREG-0612 [B.12-5] and American National Standards Institute (ANSI) N14.6 [B.12-6].

The OS197-TC is transferred to the ISFSI in a horizontal configuration. Therefore, the only drop accident evaluated during storage or transfer operations is a side drop or a corner drop.

The OS197-TC and DSC are evaluated for postulated side and corner drops to demonstrate structural integrity during transfer and plant handling.

Accident Analysis

No change to accident analysis as described in Sections T.11.2.5.2 of [B.12-3].

Accident Dose Calculation

The accident dose of 46 mrem at 100 m from the EOS-TC documented in Section 12.3.1 bounds the accident dose for the 61BTH DSC within the OS197-TC. This dose is significantly below the 10 CFR 72.106 limit of 5 rem. Accident dose rates for the OS197-TC are provided in Section B.6.4.3.

Corrective Actions

No change to corrective actions as described in Sections T.11.2.5.4 of [B.12-3].

B.12.3.2 Earthquake

Cause of Accident

No change to cause of accident as described in Section A.12.3.2.

Accident Analysis

The seismic analyses of the components that are important to safety are analyzed as follows:

Components	**UFSAR Sections**
NUHOMS® 61BTH Type 2 DSC Shell	Appendix B.3.9.1
NUHOMS® 61BTH Type 2 Basket	Appendix B.3.9.2
HSM-MX	Appendices B.3.9.4 and B.3.9.7
OS197-TC	Appendix B.3.9.5

72.48

The results of these analyses show that seismic stresses are well below the applicable stress limits.

Accident Dose Calculations

The dose rate increase is bounded by Section A.12.3.3.

Corrective Actions

No change to corrective actions described in Section 12.3.2.

B.12.3.3 Tornado Wind and Tornado Missiles Effect on HSM-MX

Cause of Accident

No change to cause of accident as described in Section 12.3.3.

Accident Analysis

No change to accident analysis as described in Section A.12.3.3.

Accident Dose Calculations

The dose rate increase is bounded by Section A.12.3.3.

Corrective Action

No change to corrective action as described in Section 12.3.3.

B.12.3.4 Tornado Wind and Tornado Missiles Effect on OS197 Transfer Cask

This event is described in Section 8.2.2 of [B.12-3].

Cause of Accident

No change to cause of accident for the OS197-TC as described in Section 8.2.2.1 of [B.12-3].

72.48

Accident Analysis

No change to accident analysis of OS197-TC as described in Section 8.2.2.*2*, B of [B.12-3].

Accident Dose Calculations

The accident dose for the EOS-TC described in Section 12.3.4 bounds the OS197-TC.

Corrective Actions

Corrective actions for the OS197-TC are the same as described in Section 12.3.4 for EOS-TC.

B.12.3.5 Flood

Cause of Accident

No change to cause of accident as described in Section 12.3.5.

Accident Analysis

No change to accident analysis as described in Section A.12.3.5.

Accident Dose Calculations

No change to accident dose as described in Section 12.3.5.

Corrective Actions

No change to corrective actions as described in Section 12.3.5.

B.12.3.6 Blockage of HSM-MX Air Inlet Openings

This accident conservatively postulates the complete blockage of the air inlet openings of the HSM-MX.

Cause of Accident

No change to cause of accident as described in Section A.12.3.6.

Accident Analysis

The thermal evaluation of this event is presented in Chapter B.4, Section B.4.4 for the 61BTH Type 2 DSC stored inside an HSM-MX. The analysis performed for the EOS-37PTH DSC bounds the values for the 61BTH Type 2 DSC. Therefore, the temperatures determined for Load Case #3-S in Section A.4.5.4 are used in the HSM-MX structural evaluation of this event. The HSM-MX structural analysis, presented in Appendix B.3.9.4, demonstrates that the HSM-MX component stresses remain below allowable values.

Accident Dose Calculation

There are no offsite dose consequences as a result of this accident.

Corrective Actions

No change to corrective actions as described in Section 12.3.6.

B.12.3.7 Lightning

Cause of Accident

No change to cause of accident as described in Section 12.3.7.

Accident Analysis

No change to accident analysis as described in Section 12.3.7.

Corrective Actions

No change to corrective actions as described in Section 12.3.7.

B.12.3.8 Fire/Explosion

Cause of Accident

Combustible materials are not normally stored at an ISFSI. Therefore, a credible fire is very small and of short duration, caused potentially by fire or explosion from a vehicle or portable crane.

Direct engulfment of the HSM-MX is highly unlikely. Any fire within the ISFSI boundary while the 61BTH Type 2 DSC is in the HSM-MX is bounded by the fire during OS197-TC movement. The HSM-MX concrete acts as a significant insulating fire wall to protect the 61BTH Type 2 DSC from the high temperatures of the fire.

Accident Analysis

The evaluation of the hypothetical fire event is presented in Appendix B.4, Section B.4.5.1.3.3. The thermal evaluation of the fire event is bounded by the loss of neutron shield and loss of air circulation accident. The maximum temperatures for the bounding loss of neutron shield and loss of air circulation steady-state accident condition are presented in Appendix T.4, Table T.4-10, Table T.4-21, and Table T.4-23 of [B.12-3], which demonstrates that the maximum component temperatures are below the allowable limits.

OS197-TC structural analysis information is provided in Appendix B.3.9.5.

Accident Dose Calculation

The DSC confinement boundary is not breached as a result of the postulated fire/explosion scenario. Accordingly, no DSC damage or release of radioactivity is postulated. Because no radioactivity is released, no resultant dose increase is associated with this event.

The fire scenario may result in the loss of OS197-TC neutron shielding should the fire occur while the DSC is in the OS197-TC. The effect of the loss of neutron shielding due to a fire is bounded by that resulting from an OS197-TC drop scenario. It is demonstrated in Section B.12.3.1 that the bounding EOS-TC accident dose rates bound the OS197-TC accident dose rates.

Corrective Actions

No change to corrective actions described in Section 12.3.8.

B.12.4 References

B.12-1 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."

B.12-2 ANSI/ANS-57.9-1984, "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type)," American National Standards Institute, American Nuclear Society.

B.12-3 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 18, USNRC Docket Number 72-1004, January 2019.

B.12-4 Title 10, Code of Federal Regulations, Part 50, "Domestic Licensing of Production and Utilization Facilities."

B.12-5 NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," U.S. Nuclear Regulatory Commission, July 1980.

B.12-6 ANSI N14.6-1993, "American National Standards for Special Lifting Device for Shipping Containers Weighing 10,000 lbs. or More for Nuclear Materials," American National Standards Institute.

B.13
OPERATING CONTROLS AND LIMITS

The operating controls and limits for the addition of the 61BTH Type 2 DSC to the NUHOMS® EOS System are described in the CoC 1042 Amendment 2 Technical Specifications.

B.14
QUALITY ASSURANCE

The addition of the NUHOMS®-61BTH Type 2 DSC and the OS197FC-B TC to the NUHOMS® EOS system does not require any changes to the quality assurance requirements stipulated in Chapter 14. Chapter 14 provides the Quality Assurance Program applied to the design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of the NUHOMS® MATRIX System and components identified as "important-to-safety" and "safety-related."