SAFETY EVALUATION REPORT

DOCKET NO. 72-1014

HOLTEC INTERNATIONAL

HI-STORM 100 CASK SYSTEM

CERTIFICATE OF COMPLIANCE NO. 1014

AMENDMENT NO. 7

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SAFETY EVALUATION REPORT

DOCKET NO. 72-1014
HI-STORM 100 CASK SYSTEM
HOLTEC INTERNATIONAL, INC.
CERTIFICATE OF COMPLIANCE NO. 1014
AMENDMENT NO. 7

SUMMARY

By letter dated April 27, 2007, as supplemented June 12, July 14, December 19, 2008, January 16, February 6, and April 6, 11, 22, and May 13, 2009, Holtec International, Inc. (Holtec) submitted an amendment request to the U. S. Nuclear Regulatory Commission (NRC) for the HI-STORM 100 Cask System Certificate of Compliance (CoC) - No. 1014 requesting the following changes:

- ➢ Addition of the HI-STORM 100U underground Vertical, Ventilated Module (VVM) and associated systems (HI-STORM 100U System). The HI-STORM 100U System provides an alternative underground storage design to be used with Holtec multi-purpose canisters (MPC) and the HI-TRAC transfer cask. The HI-STORM 100U System also includes the following major structures and components:
    - MPC Storage Cavity ,
    - Top Independent Spent Fuel Storage Installation (ISFSI) Pad,
    - Support Foundation,

- ➢ Upgrading all thermal simulations (steady state and transient) to utilize a 3-D model of the VVM, along with previously approved 3-D models of the MPC,

- ➢ Incorporating a mandatory radiation protection perimeter around loaded cavities,

- ➢ Reinstating the decay heat limits for damaged fuel and fuel debris in the above ground system from previously approved CoC 1014 Amendment 3 in Technical Specifications (TS) Appendix B, Section 2.4. Due to an administrative oversight, these had been inadvertently deleted from CoC 1014, Amendments 5 and 6,

- ➢ Incorporating the previously approved provisions of CoC 1014, Amendment 6 that add instrument tube tie rods (ITTRs) to the approved contents of MPC-24 and MPC-32 models,

- ➢ Incorporating separate TS Appendices A and B for the above ground system and for the HI-STORM 100U System, and

- ➢ Incorporate editorial corrections.

Additionally, the NRC Staff (Staff) recommended the following editorial change to CoC 1014:

- ➢ Revise CoC Appendix B and B-100U, TS 3.4.5 to be consistent with the intent of Holtec's original submittal and the staff's original evaluation.

This Safety Evaluation Report (SER) documents the review and evaluation of the proposed amendment. The SER uses the same Section-level format provided in NUREG-1536, “Standard Review Plan for Dry Cask Storage Systems,” with some differences implemented for clarity and consistency.

The staff's assessment is based on whether Holtec meets the applicable requirements of 10 CFR Part 72 for independent storage of spent fuel and of 10 CFR Part 20 for radiation protection. The staff’s assessment focused only on modifications requested in the amendment as supported by the submitted Updated Final Safety Analysis Report (UFSAR) and did not reassess previously approved portions of the UFSAR) or CoCs through amendment 6.

1.0 GENERAL DESCRIPTION

The objective of the review of the general description of the design changes made to the HI-STORM 100 Cask System is to ensure that Holtec has provided a description that is adequate to familiarize reviewers and other interested parties with the pertinent features of the system, including the changes.

1.1 HI-STORM 100U System General Description and Operational Features

The HI-STORM 100U System is an underground dry cask storage system for spent light water reactor fuel. The system comprises seven discrete components: the MPC, the HI-TRAC transfer cask, the HI-STORM 100 VVM, the MPC storage cavity, VVM interface pad, top surface pad, and the support foundation.

1.1.1 HI-STORM 100U Vertical Ventilated Module

The VVM provides for storage of MPCs in a vertical configuration inside a subterranean cylindrical cavity entirely below the top-of-the-grade (TOG) of the top surface pad. The MPC storage cavity is defined by the cavity enclosure container (CEC), consisting of the container shell integrally welded to the bottom plate. The top of the container shell is stiffened by the container flange (a ring shaped flange), that is also integrally welded. All of the constituent parts of the CEC are made of thick low carbon steel plate. In its installed configuration, the CEC is interfaced with the surrounding subgrade for most of its height except for the top region where it is girdled by the top ISFSI pad.

1.1.2 Top ISFSI Pad

The top ISFSI pad serves several purposes in the HI-STORM 100U System, such as:

- It provides an essentially impervious barrier of reinforced concrete against seepage of water from rain/snow into the subgrade.
- It provides the interface surface for the CEC flange.
- It helps maintain a clean, debris-free region around the VVMs.
- It provides the necessary riding surface for the cask transporter.

The ISFSI pad is composed of two distinct regions separated by suitably engineered expansion joints. These are referred to as:

i. the VVM interface pad (VIP) and
ii. the top surface pad (TSP).

As its name implies, the VIP is in close contact with the container flange and the upper part of the container shell for sealing and shielding purposes. The balance of the ISFSI pad, lower in elevation than the VIP, is the TSP.

1.1.3 Support Foundation

The support foundation is a continuous reinforced concrete pad that supports the weight of a VVM array in an underground storage facility.

1.2 Alternative Materials for Important-to-Safety (ITS) Structural Components

In the bill of materials, Holtec specified certain American Society of Testing Materials (ASTM)/ American Society of Mechanical Engineers (ASME) material grades “or equivalents” for the VVM and CEC shell components that are classified as ITS. The equivalent materials are not delineated as specific ASTM/ASME material grades. Instead, to allow flexibility, Holtec specified the terms "equivalent" and "critical characteristics" to define the requirements for a substitute material. These terms are explained in the UFSAR and included in the terms and definitions section. The adopted definitions along with UFSAR Table 2.I.9 established the requirements for “equivalent” materials. The UFSAR Table 2.I.9 lists four material properties (“critical characteristics”) that must equal or exceed the originally specified material properties in order for a material to be acceptable as an equivalent. Those four properties are yield strength, ultimate strength, elongation, and Charpy impact strength. With the definitions and UFSAR table 2.I.9 as controls, Holtec may employ alternatives to the normally specified materials of construction. This strategy allows flexibility during fabrication should the originally specified material not be available.

In the event that one or more of the critical characteristics of the replacement material is slightly lower than the original material specification, then the use of the 10 CFR 72.48 process is necessary to ensure that regulatory and technical requirements for the material substitution are fully satisfied.

ITS components will be fabricated only from ASME or ASTM materials. Foreign material specifications will not be used.

The staff finds this approach to alternative structural materials is acceptable.

2.0 PRINCIPAL DESIGN CRITERIA EVALUATION

The objective of evaluating the principal design criteria related to the structures, systems, and components (SSCs) important to safety is to ensure that they comply with the relevant general criteria established in 10 CFR Part 72.

2.1 Structures, Systems and Components Important to Safety

HI-STORM 100U System SSCs important to safety are identified in Chapter 2 of the UFSAR. The safety classifications are based on the guidance in U.S. Nuclear Regulatory Commission, “Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety,” NUREG/CR-6407, INEL-95/0551, February 1996.

2.2 Design Bases for Structures, Systems and Components Important to Safety

The HI-STORM 100 Cask System design criteria summary includes the allowed range of spent fuel configurations and characteristics, the enveloping conditions of use, and the bounding site characteristics.

2.2.1 Spent Fuel Specifications

The HI-STORM 100 Cask System is designed to store either 24 or 32 PWR fuel assemblies and up to 68 BWR fuel assemblies. Detailed specifications for the approved fuel assemblies, as modified by this amendment, are given in UFSAR Section 2.1. These include the maximum enrichment, maximum decay heat, maximum average burnup, minimum cooling time, maximum initial uranium mass, and detailed physical fuel assembly parameters. The limiting fuel specifications are based on the fuel parameters considered in the structural, thermal, shielding, criticality, and confinement analyses.

2.2.2 External Conditions

UFSAR Section 2.2 identifies the bounding site environmental conditions and natural phenomena for which the HI-STORM 100 Cask System is analyzed.

2.3 Design Criteria for Safety Protection Systems

The principal design criteria HI-STORM 100 Cask System are summarized in FSAR Tables 2.0.1, 2.0.2, and 2.0.3. The codes and standards of the design and construction of the system and changes to the design criteria are specified in UFSAR Section 2.2. The cask transfer facility (CTF) does not fall under the requirements of 10 CFR Parts 50 or 72. It will be designed, developed and operated by the cask system user at the site location, dependant upon site-specific needs and capabilities. Three major types are described in the UFSAR. The stand-alone, above ground facility, an underground facility, combined with a mobile lifting device, or an underground facility, combined with a cask transporter/crawler. The confinement barrier and systems of the storage system shall not be compromised by the equipment used in the transfer operations that are identified as ancillary equipment, including the CTF. In meeting the general specifications for the CTF as identified in UFSAR Section 2.3.3, the cask system user will verify that use of one of the underground CTF options will not change the potential environmental and loading conditions to create unanalyzed conditions on the cask system during the transfer operations.

2.3.1 General

Chapter 2 of the UFSAR was revised to include the addition of the HI-STORM 100U System.

2.3.2 Decommissioning

The decommissioning features of the HI-STORM 100 Cask System did not change with this amendment and were not reevaluated by the staff.

2.4 Evaluation Findings

Based on the NRC staff's review of information provided in the HI-STORM 100 Cask System amendment request, the staff finds the following:

F2.1 The staff concludes that the principal design criteria for the HI-STORM 100 Cask System are acceptable with regard to demonstrating compliance with the regulatory requirements of 10 CFR Part 72. This finding is based on a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices. More detailed evaluations of design criteria and assessments of compliance with those criteria are presented in SER Sections 3 through 14.

3.0 STRUCTURAL EVALUATION

The objectives of the structural review were to assess the safety analysis of the structural design features, the structural design criteria, and the structural analysis and evaluation criteria used to confirm the structural performance of the HI-STORM 100U System design under normal operations, off-normal operations, accident conditions and natural phenomena events for those ITS SSCs.

The review was conducted utilizing appropriate regulations in 10 CFR 72.236 that identify the specific requirements for spent fuel storage cask approval and fabrication. The unique characteristics of the spent fuel to be stored are identified, as required by 10 CFR 72.236(a), so that the design basis and design criteria that must be provided for the ITS SSCs can be assessed to be compliance with 10 CFR 72.236(b). The application was also evaluated to determine whether the HI-STORM 100U System fulfils the acceptance criteria listed in Section 3 of NUREG -1536.

The application of materials and the design of the HI-STORM 100U System establish a new concept for the storage of commercial spent nuclear fuel. The proposed system is different from the aboveground HI-STORM 100 System as defined in ANSI/ANS 57.9. The standard HI-STORM 100 Cask System is an above-ground cask/silo system while the proposed HI-STORM 100U System is a below-ground drywell/caisson type system, as defined in ANSI/ANS 57.9.

The following structural reviews and evaluations were performed by the staff. The MPC and the HI-TRAC transfer cask for the HI-STORM 100U System (below-ground) are identical to the MPC and HI-TRAC transfer cask for the HI-STORM 100 (above-ground). The only additional review or evaluations for these components were for specific conditions and loading cases for the MPC behavior inside the CEC under seismic loading conditions. This is due to the MPC guides of the HI-STORM 100U VVM divider shell imposing different conditions than the channel supports of the HI-STORM 100 overpack on the MPC. Therefore, it is necessary for the seismic analyses of the HI-STORM 100U System to consider the effects of these guides on the MPC containment boundary.

3.1 Structural Design of the HI-STORM 100U System

3.1.1 Structures, Systems, and Components Important to Safety

ITS SSCs are identified in Table 2.2.6 of the UFSAR for the HI-STORM 100 Cask System. Common SSCs for the HI-STORM 100U System are also identified in Table 2.2.6. SSCs unique to the HI-STORM 100U System have the assigned safety classification defined in Table 2.I.8 of the UFSAR. The safety classifications provided are based on the guidance in NRC, “Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety,” NUREG/CR-6407, INEL-95/0551, February 1996.

UFSAR Tables 2.2.6, 2.I.1, and 2.I.8 also identify the function and the governing code for the components. The governing code for the structural design of the MPC, the HI-TRAC transfer cask, and metal components of the VVM is the ASME Code. The governing ASME Code paragraphs for the VVM primary load bearing parts are identified in UFSAR, Table 2.I.3.

Section 1.I.5 of the UFSAR contains the drawings for the HI-STORM 100U System which include drawings of the ITS SSCs. The staff submitted a request for additional information (RAI) on June 6, 2006 and subsequently documented in the staff's evaluation of the HI-STORM 100U System issued on January 24, 2007, that a Bill of Material or equivalent information be included in the UFSAR. While a Bill of Material was not provided, equivalent information necessary to characterize each component has been provided in Drawing 4501 Revision 6 and UFSAR Tables 2.I.7 and 8. The staff finds this acceptable.

3.1.2 Design Basis for Structures, Systems, and Components Important to Safety

The above ground HI-STORM 100 Cask System design criteria summary includes the allowed range of spent fuel configurations and characteristics, the enveloping conditions of use, and the bounding site characteristics. The HI-STORM 100U System design summary includes the same design basis elements as the above ground HI-STORM 100 Cask System. However, Holtec did not provide bounding site characteristics and did not provide analyses and evaluations of the design for all applicable loads for bounding site parameters. The staff found this unacceptable. Therefore, the staff has restricted the HI-STORM 100U System to applications where the support foundation is built directly on bedrock. This is described in greater detail in SER Section 3.1.7.

3.1.3 Design Criteria for Structures, Systems, and Components Important to Safety

The principal design criteria for the MPC, the above-ground HI-STORM 100 overpack, and the HI-TRAC transfer cask designs are summarized in FSAR Tables 2.0.1, 2.0.2, and 2.0.3, respectively. This application requested changes to FSAR Tables 2.0.1, 2.0.2, and 2.0.3 to be consistent with those changes described in greater detail elsewhere in the FSAR. The codes and standards for the design and construction of the HI-STORM 100 Cask System and the changes to the design criteria are specified in UFSAR Section 2.2. The principal design criteria for the HI-STORM 100U VVM are described in UFSAR Supplement 2.I. UFSAR Tables 2.I.1, 2.I.3, 2.I.5, 2.I.6, and 2.I.8 summarize and identify the specific design criteria unique to the HI-STORM 100U System. UFSAR Section 2.I.0 provides an overview of the principal design criteria within the various technical disciplines.

The staff identified that no design criteria had been specified for reinforced concrete in UFSAR Table 2.I.1, and that no design criteria had been specified to evaluate the maximum stresses in the MPC shell due to impact with the guide ribs during a seismic event. In response to staff's RAI issued on December 4, 2008, Holtec provided reinforced concrete design criteria for ITS components and maximum strain limits for the MPC for accident events during storage. The staff finds this acceptable.

The structural design criteria for the HI-STORM 100U System are based on the ASME Code, Section III, 1995 Edition with the 1997 Amendments. Plain (unreinforced) encapsulated concrete used in the closure lid is based on American Concrete Institute (ACI) 318-05, reinforced concrete design criteria are based on ACI 318-05, and the optional non-structural concrete for the encasement of the CEC will be reinforced with either fiber reinforcement or corrosion resistant/coated steel wire reinforcement per ACI 318, ACI 544.2R: "Measurement of Properties for Fiber Reinforced Concrete," ACI 544.3R-93 or latest: "Guide for Specifying, Proportioning, Mixing, Placing and Finishing Steel and Fiber Reinforced Concrete," and ASTM C-1116-03 or latest: "Standard Specification for Fiber-Reinforced Concrete and Shotcrete" for the criteria. Holtec has stated that concrete encasement is used only to create an advantageous chemical environment around the CEC steel shell. The staff finds this acceptable.

3.1.4 Concrete Encasement

The CEC concrete encasement shall provide a minimum of five inches of cover to provide a pH buffering effect for additional corrosion mitigation. This concrete thickness has been selected to provide a 100-year service life based upon data provided in literature cited in the UFSAR. A claim of 100-year service life provides some degree of uncertainty. However, the concrete thickness is conservative. The thickness specified for the concrete is greater than that specified by several recognized codes or references that are based upon a 20-year minimum design life. Thus, a working life of significantly greater than 20 years is assured. Additionally, an inspection of the interior surface of the CEC, along with a thickness survey of the CEC wall, will be performed once every 20 years to verify the continued efficacy of the corrosion protection measures. The staff finds this acceptable.

It is recognized that shrinkage cracks occur in concrete. Such cracks may create a path for water to intrude to the steel portions of the CEC that are being protected from corrosion by the concrete. To control the inevitable shrinkage cracks that form in concrete, Holtec has specified the addition of wire or fiber reinforcement to the concrete. The reinforcement materials will be corrosion and radiation resistant.

The staff notes that the use of reinforcement is a departure from normal practice by this applicant. Normally, reinforcement is avoided in structures whose primary purpose is radiation shielding. This is because the presence of rebar can create unintended voids in the concrete leading to a deficient radiation shield. However, in the case of the CEC, the primary shielding will be accomplished by the earthen backfill. The purpose of the HI-STORM 100U System concrete encasement is to mitigate any corrosive effects from the soil, and not to provide for radiation shielding. Thus, use of reinforcement will enhance the corrosion prevention performance of the concrete in maintaining tight cracks while the concrete creates a chemically less corrosive environment for the steel CEC. The staff finds this acceptable.

3.1.5 Material Properties

UFSAR Tables 2.I.4, 2.I.7, 2.I.8, 3.I.3, and 3.I.4 provide the information on the materials used in the proposed VVM.

3.1.6 Weights and Centers of Gravity

Weights are presented as bounding weights and are provided in UFSAR Table 3.I.1 with the centers of gravity of the various components and assembled components provided in UFSAR Table 3.I.2.

3.1.7 Evaluation of the HI-STORM 100U System Structural Design

The HI-STORM 100U System has three major components: the MPC, the HI-TRAC transfer cask, and the HI-STORM 100U VVM. The MPC and the HI-TRAC components used in the HI-STORM 100U System are identical to those used in the HI-STORM 100 (above-ground). The structural sub-components of the HI-STORM 100U VVM include the following items: the steel and concrete closure lid, the steel CEC shell, bottom plate and flange, and the steel divider shell and attachments. The CEC is not anchored to the support foundation, however lateral support is provided at the base by recessing the CEC several inches into the support foundation concrete. All of these components have been classified as ITS in UFSAR Table 2.I.8.

In the initial submittal, Holtec did not consider the “interfacing SSCs” that surround and support the VVM part of the HI-STORM 100U System. Consequently, for events and associated loading conditions that are unique to a site, such as seismic loads and long-term settlement with the VVM embedded in the specific site soil stratum, the design and the resulting physical dimensions, etc., of the proposed VVM could not be demonstrated to be a bounding design based on characteristics used to identify the acceptability of a certified spent fuel storage system at a specific site.

The structural elements originally defined by Holtec as interfacing SSCs included:

- the reinforced concrete support foundation,
- the optional (based on surrounding subgrade materials corrosion potential) concrete encasement of the CEC,
- the subgrade material laterally surrounding the CEC or the concrete encased CEC, and
- the reinforced concrete VIP.

Surrounding the VIP pad is the TSP that transmits the load from the transporter to the surrounding subgrade material. The TSP was originally categorized by Holtec as a “proximate structure.” These interfacing and proximate structures had not been designated as ITS in the originally submitted UFSAR. In response to staff’s RAI issued on December 4, 2008, Holtec revised the UFSAR to designate these components ITS.

As ITS components, they must have a design basis. Therefore, the staff submitted an RAI on December 4, 2008, for Holtec to provide the minimum steel reinforcement requirements for the support foundation based on the seismic analyses that have been performed, and the structural criteria to minimize long-term settlement. The RAI also requested Holtec provide the minimum steel reinforcement requirements for the VIP and TSP necessary to safely carry the loaded transporter. Additionally, the staff submitted an RAI for Holtec to provide specific values or ranges of values for all the parameters involved in the seismic evaluations completed for an isolated HI-STORM 100U VVM that can be utilized by a general licensee of the HI-STORM 100U System to evaluate whether their proposed site characteristics are bounded by these values.

The applicable regulations in 10 CFR Part 72 are provided below.

- 10 CFR 72.3 defines design basis as “that information that identifies the specific functions to be performed by a structure, system, or component of a facility, or a spent fuel cask, and the specific values or ranges of values chosen for controlling parameters as reference bounds for design.”

- 10 CFR 72.212, “(b) The general licensee shall:…. (3) Review the FSAR and related SER,…. to determine whether or not the reactor site parameters,…. are enveloped by the cask design basis….”

- 10 CFR 72.24 states that “The minimum information to be included in the FSAR must consist of the following:…. (d) An analysis and evaluation of the design and performance of structures, systems, and components important to safety….”

The regulations in 10 CFR Parts 72.3, 72.24(d) and 72.212(b)(3) require Holtec to analyze and evaluate a design and determine the specific controlling parameters for that design, so that the general licensee can determine whether the site specific parameters are enveloped by the design parameters. These basic requirements must be contained in Holtec's FSAR; however, the staff found the application did not adequately provide these requirements. Specifically, Holtec did not analyze and evaluate some of the ITS components within the design to determine all of the controlling parameters for the design, without which, the general licensee will be unable to determine if the site parameters are bounded by the controlling parameters for the design.

The analysis and evaluation of all ITS components of the design is the minimum information that must be included in the FSAR (10 CFR 72.24(d)). In its response, dated January 16, 2009, to staff RAIs issued December 4, 2008, Holtec provided a design for the TSP and the support foundation. However, no information was provided to demonstrate that the design was analyzed and evaluated for the combination of loads that the HI-STORM 100U System will be subjected. These loads include:

- dead load,
- live load,
- seismic load,
- and long-term settlement.

Instead, Holtec shifted the responsibility for the analysis and evaluation of this design to the general licensee as described in proposed TS Sections 3.4-8 and 12 in their January 16, 2009, response. Neither the regulations, nor the licensing/rulemaking process, allow the general licensee to assume the obligations of the CoC holder.

In the absence of an analysis and evaluation of the design of all ITS components for specific or bounding site parameters that include site soil characteristics, the staff is required to restrict the design of the support foundation to locations where the support foundation rests directly on bedrock or on substrate material having a shear wave velocity equal to or greater than 3500 fps. For these controlling parameters, the internal forces in the support foundation due to dead load, live load, seismic load and long-term settlement are minimal and, as such, the design of the support foundation as described in TS Table 3-3 of the January 16, 2009, response is acceptable. However, any deviation from the support foundation being directly supported on bedrock will require Holtec to submit an amendment request to CoC-1014 for staff evaluation.

The TSP that supports the weight of the transporter during loading operations rests on the substrate material between the TSP and the support foundation. An analysis and evaluation of the TSP for all applicable loads for the selected bounding parameters of this substrate material must be performed by Holtec and incorporated into the application prior to approval and beginning the rulemaking process to codify the design in 10 CFR 72.214. This analysis and evaluation has been provided by Holtec, as discussed in detail in a subsequent section. The staff finds this acceptable.

Individual loads for the three design conditions of normal, off-normal and accident conditions, including natural phenomena, have been addressed in UFSAR Sections 2.I.4, 2.I.5, and 2.I.6. It is correctly noted that the seismic analyses will utilize a detailed model of the MPC, the fuel basket, and the spent fuel in the determination of the response to seismic loads.

The loading combinations are identified in the UFSAR Section 2.I.5.
The allowable stresses under various service levels and temperatures are provided in UFSAR Tables 3.I.3 (a) through (c) for the steel materials and in UFSAR Table 3.I.4 for concrete and

soil substrate. The staff has reviewed these and finds them acceptable.

3.2 Structural Analysis of the HI-STORM 100U System

The structural analysis for the HI-STORM 100U System is presented in the UFSAR Chapter 3. For the portions of the system that are different from the above ground HI-STORM 100, the structural analyses are presented in UFSAR Chapter 3.I. The HI-STORM 100U System components are designed to protect the cask contents from significant structural degradation, preserve retrievability, provide adequate shielding, and maintain subcriticality and confinement under the design basis normal, off-normal, and accident loads. The design basis normal, off-normal, and accident conditions for the HI-STORM 100 Cask System and those components of the HI-STORM 100U System that are identical are defined in UFSAR Section 2.2. UFSAR Section 2.I.3 states that, “Applicable loads for an MPC contained in a VVM or for a HI-TRAC that services a VVM are identical to those already identified in the main body of Chapter 2 ...” The staff notes that loads and the load path are different for an MPC used in the HI-STORM 100 Cask System and the HI-STORM 100U System. For the design basis conditions as applied to those components that are unique to the HI-STORM 100U System, UFSAR Sections 2.I.3 through 2.I.6 provide the relevant information. Changes made to the structural design criteria and the structural analysis with respect to the application for the HI-STORM 100U System are described in the following sections of the staff’s evaluation.

3.2.1 Analysis and Evaluation of the Top Surface Pad

The TSP is classified as ITS. The function of the TSP is to provide haul paths for the transporter to deliver a loaded HI-TRAC to an empty VVM. The TSP is isolated from the VVM by appropriately located expansion joints to isolate the CEC from any unbalanced loads imparted by the transporter. The minimum characteristics of the TSP (pad thickness and strength, and reinforcing bar layout and strength) are provided in UFSAR Table 2.I.7. The TSP is supported by the lateral subgrade, and the loaded transporter imparts a localized loading to the TSP. A structural evaluation is performed to demonstrate that the gross moment and shear capacities set forth in ACI 318-05 are not exceeded under a load of 450,000 lb, which bounds the weight of a typical transporter carrying a loaded HI-TRAC. A 3x3 array of VVMs is modeled using ANSYS®, with the loaded transporter positioned directly over the central VVM cavity, or centered between two adjacent VVM cavities. The substrate (with properties characteristic of an 800 ft/sec shear wave velocity) is extended beyond the TSP apron a distance equal to the depth of the subgrade below the TSP. The base of the substrate, grounded on the support foundation is assumed fixed, and the displacement normal to the four lateral free surfaces of the substrate is also zeroed. The VIPs that are enclosed by the TSP are ignored since they are separated from the TSP by expansion joints. The transporter is not modeled; instead, a vertical pressure is applied to the top surface of the TSP to simulate the loaded interface. Consideration of these two configurations is expected to provide bounding safety factors for both bending moments and shear forces. To ensure conservative results, a transporter with the smallest span that can be moved over a VVM is chosen. The configuration forms a gridwork of concrete beams with wide beams parallel to the transporter path (transporter path beams) and narrower cross-beams perpendicular to the transporter path crossbeams.

For each configuration the first load case consists of an equal pressure of approximately 47 psi applied to each of 2 load patches straddling the VVM. This represents the weight of a loaded transporter divided over two tracks. In addition to the applied pressure, the weight of the TSP and the substrate is included using the maximum weight densities ascribed to these components in UFSAR Tables 2.I.2 and 2.I.4. All loads are considered live loads when computing final safety factors.

The second load case in each configuration consists of the live load pressure cited above plus an additional vertical pressure increment on each load patch to balance the additional vertical force and overturning moment from the vertical and horizontal components of the design basis seismic acceleration (UFSAR Table 2.I.4). For this analysis, the design basis accelerations are imposed at the TSP. The net seismic horizontal acceleration (in the most limiting direction) and the vertical acceleration are combined using the 100%-40%-40% rule (RG 1.92, Revision 2). To maximize the load on the TSP and bound all possible seismic load orientations, the vertical pressures on each load patch are calculated twice. First, the pressures are calculated assuming that 100% of the net horizontal acceleration acts in the direction perpendicular to the transporter (i.e., parallel to the TSP cross-beams) combined with 40% of the vertical acceleration. Then the load patch pressures are recalculated assuming 100% of the vertical acceleration and 40% of the net horizontal acceleration oriented the direction perpendicular to the transporter (i.e., parallel to the TSP cross-beams). The bounding load patch pressures on each side of the VVM cavity are approximately 83 psi and 24 psi. These values are used as input to the ANSYS finite element solution for this second load case in each configuration.

UFSAR Table 3.I.11 summarizes the important results for both load configurations and includes minimum safety factors in bending and shear. Details of the calculations, including the complete set of ANSYS® results, are found in the calculation package supporting this application [UFSAR Reference 3.I.27].

The staff notes that for the second load case (seismic case) no amplification due to TSP flexibility has been assumed in applying the net horizontal acceleration at the top of the TSP to the center of gravity of the loaded transporter. Studies have shown that for casks stored on 2 foot thick continuous ISFSI pads the amplification from the top of the pad to the center of gravity of the cask can be significant (References Bjorkman and Moore), and since the TSP is a gridwork of beams it is expected to have a higher amplification than a continuous pad of the same thickness. Therefore, the bounding seismic parameters for net horizontal acceleration at a specific site must account for this amplification by either reducing the unamplified pad net horizontal acceleration by the amplification factor that would occur for a Soil Structure Interaction (SSI) analysis had the loaded transporter been present in the analysis, or revising the design to incorporate the effect of the amplification.

3.2.2 Seismic Analysis of HI-STORM 100U System

The proposed HI-STORM 100U System consists of a site-specific array of underground VVMs resting on a subsurface flexible concrete pad embedded in soil (e.g., a 2 x 5 array is shown in UFSAR Figure 1.I.3). The UFSAR, as originally submitted, allowed that each VVM could be placed on a separate foundation pad since Holtec stated "each VVM may have its own suitably sized Support Foundation." In an RAI issued December 4, 2008, the staff requested Holtec to provide justification for allowing each VVM to potentially rest on its own Support Foundation "Padlet" rather than on a continuous reinforced concrete mat supporting all VVMs in an array. To support this request the staff cited a statement in the UFSAR that "The Support Foundation… must be designed… to minimize long-term settlement…" Using individual padlets, each supporting a single VVM, works against this design requirement. Because VVMs may be either loaded or unloaded for long periods of time, the use of individual VVM padlets may lead to unacceptable differential settlement between adjacent VVMs. Such differential settlement can be completely avoided by using a continuous reinforced concrete support foundation. In addition, a continuous support foundation can span over potentially softer soil and provides added assurance against instability during construction activities associated with future ISFSI array construction. In Holtec's January 16, 2009, the padlet concept was replaced with a single reinforced concrete support foundation.

To determine the seismic adequacy of the design, Holtec submitted an LS-DYNA® soil-structure interaction (SSI) analysis of a single VVM and extended foundation pad anchored to bedrock and surrounded laterally by soft soil. This model was subjected to an acceleration time history defined by R.G. 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," with a net horizontal peak ground acceleration (PGA) of 0.5g. Based on the results of this analysis, Holtec performed a stress evaluation of ITS VVM components, including the MPC confinement boundary. The staff determined the stress evaluation of the MPC confinement boundary to be inconclusive with respect to the calculation of the ASME Code stress intensities.

The staff noted that additional justification for the following was necessary:
(1) a single VVM bounds the results for multiple VVMs,
(2) a rigid concrete pad (i.e., bedrock) results in a conservative structural response when compared to a flexible concrete pad, and
(3) a VVM model supported directly on bedrock provides reasonably accurate results when compared to a more realistic SSI model where soil exists on all sides and beneath the flexible concrete pad.

Holtec provided an SSI analysis of a single VVM and extended foundation pad anchored directly to bedrock and surrounded laterally by soft soil as an analysis representative of a methodology that would be applied on a site-specific basis by licensees. The staff determined that this approach is not acceptable, as it does not demonstrate that such an analysis methodology could reasonably represent the critical response characteristics of an ISFSI site that could be developed within the scope of the defined characteristics.

To resolve these issues Holtec constructed a 5x5 VVM array as shown in UFSAR Figures 3.I.4 and 3.I.5. A single monolithic continuous foundation pad was used to support all 25 VVMs on soil. To assess the effect of partial loading 6 different cases were analyzed using the SSI computer code SASSI®. These loading cases correspond to different states of the ISFSI that would likely occur in actual practice. To limit the size of the numerical problem, all cases involve VVMs loaded about one axis of symmetry.

The cases considered an assessment of the effect of the number of filled cavities, and the location of filled cavities on the system response. Applicable material properties and dimensions for steel, substrate, and concrete portions of the model are given in UFSAR Tables 2.I.4 and 3.I.4. Because SASSI® is a linear program the substrate is attached to the container shell at common nodes. The SASSI® solution considers the array subject to each directional seismic input separately, with an square root sum the squares combination of results from three directional inputs providing the final solution. For the case where a horizontal seismic input is considered, the mass of the contained MPC is conservatively "smeared" on the container shell to maximize the potential of the container shell to ovalize during the seismic event. For the case with vertical seismic input, the mass of the contained MPC is attached to the baseplate. The top concrete pads at grade are not modeled, but their mass is attached to the top lid of each CEC. Details of the SASSI® model and the simulations are presented in a calculation package [UFSAR Reference 3.I.14]. The important results are the seismically induced ovalization of the cavities and the beam-like membrane stress in the CEC of the loaded cavities. The results from the SASSI® analyses are summarized in UFSAR Table 3.I.5.

Holtec's major conclusions from the linear SSI analyses are:
(1) the loaded VVM at the boundary of the array produces maximum response,
(2) in all cases the response of the VVM structure is a fraction of the allowable response, and
(3) the stress level in the support foundation is too small to cause initial cracking of the concrete on the tension side.

Based on independent hand calculations using the SASSI® output, the staff disagreed with Holtec's third conclusion, concluding that it is likely that concrete cracking does occur on the tension side of the support foundation. An assessment of concrete cracking is important since it can change the bending stiffness of the foundation pad, and, in turn, alter the response. In addition, the staff was concerned that an assessment of the uncertainty in soil properties was not part of the SSI methodology proposed by Holtec. To clarify the issues of concrete cracking and uncertainty in soil properties the staff provided in an RAI issued February 28, 2008, that Holtec revise UFSAR Section 3.I.4.7.1, Design Basis Seismic Model, to incorporate the guidance provided in ASCE Standard 4-98, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary," Section 3.3, "Soil-Structure Interaction Modeling and Analysis", and ASCE/SEI Standard 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities." Holtec submitted revised UFSAR sections in its June 12, 2008, response, and the staff finds this acceptable.

To assess the staff's conclusion regarding concrete cracking, Holtec, in the June 12, 2008, response to staff RAIs, performed a cracking evaluation based on the SASSI® support foundation nodal displacements, and concluded that concrete cracking did not occur during the seismic event. While the staff disagrees with Holtec's assumption for the sine wave length used in the calculation (the staff position is that it should be half the length assumed by Holtec), this was compensated by Holtec's very conservative cracking strain in the evaluation. Therefore, the staff finds Holtec's assumption that seismic loads alone are not likely to cause cracking acceptable. However, when the bending moments in the support foundation due to seismic loads are added to the bending moments due to dead load, live load and long-term settlement, concrete cracking most likely does occur during a seismic event. To address this issue and comply with the ASCE Standards Holtec an SASSI® analysis with cracked concrete properties, and showed that the change in response was not significant. The staff finds this acceptable.

UFSAR Table 3.I.6 provides a comparison of the results between the "padlet" non-linear solution and the linear (SASSI®) solution. The results show that the non-linear (LS-DYNA®) solution provides a uniformly stronger response. The tabular results from the LS-DYNA® output are documented in the calculation package [UFSAR Reference 3.I.27].

In additional investigations Holtec studied the effects of support pad size and the variation in reinforced concrete stiffness properties using the non-linear (LS-DYNA®) model and a singly loaded VVM located at the edge of the foundation on the symmetry axis. Specifically, the following three additional scenarios (the padlet solution discussed above is labeled as Case 1), were analyzed:

Case 1:
Support Foundation Padlet with Inelastic Concrete Behavior (Reference "Padlet Solution")
Case 2:
Support Foundation Padlet with Elastic Concrete Behavior – 50% reduced modulus per ASCE 4-98 (Reduced modulus padlet solution)
Case 3:

Support Foundation 5x5 Pad with Elastic Concrete Behavior – 50% concrete modulus
(flexible pad/ reduced modulus solution)
Case 4:
Support Foundation 5x5 Pad with Elastic Concrete Behavior – 100% concrete modulus
(flexible pad solution)

The geometry for the simulations applicable to Cases 3 and 4 is shown in UFSAR Figure 3.I.6. UFSAR Table 3.I.7 provides a comparison of the response parameters from the “padlet” non-linear solution (Case 1) with the three other cases. From this table it can be seen that Cases 3 and 4 dominate all of the critical response parameters. Therefore, the padlet model should not be used as the Design Basis Seismic Model in the SSI methodology set forth in UFSAR Section 3.I.4.7.1.

UFSAR Table 3.I.8 provides additional results for the four cases: These additional results pertain to the peak interface load on the support foundation and its state of flexural stress. The calculation package [UFSAR Reference 3.I.27] contains the detailed LS-DYNA® output, from which the results in Tables 3.I.7 and 3.I.8 are extracted. Based on these results, Holtec concluded that:

i. Cases 3 and 4 provide the largest response parameters.
ii. The interface loads and the magnitude of the support pad stress are either the maximum or close to the maximum for Case 3.
iii. the “flexible pad” – single VVM model merits being designated as the Design Basis Seismic Model (DBSM).

The staff agrees that the “flexible pad” (cases 3 and 4) shall be designated as the Design Basis Seismic model.

3.2.2.1 SSI Design Basis Seismic Model

The dynamic simulation of the structural response of the buried VVM was performed using the commercial finite element code, LS-DYNA®. The seismic input for the transient FE SSI analysis is a 20-second duration acceleration-time history set developed using R.G.1.60 response spectra set with 5% damping. The acceleration time histories meet the spectra bounding, power spectral density bounding and statistical independence requirements of Standard Review Plan 3.7.1. The HI-STORM 100U System SSI analysis was performed for an earthquake with a net peak horizontal zero period acceleration (ZPA) of 0.5 g’s and a vertical ZPA of 0.33g’s per UFSAR Table 2.I.4. As noted in the UFSAR, however, each site is required to impose the site-specific seismic event in the evaluation.

The LS-DYNA® model of the buried VVM is developed based on the dimensions specified in the HI-STORM 100U System licensing drawing. UFSAR Figures 3.I.3 and 3.I.6 show the extent of the padlet and 5x5 array models, which consist of

- the CEC components that includes the lid conservatively modeled as a rigid body as its only structural function during a seismic event is to act as a shim to transfer lateral load from the top of the divider shell to the CEC top flange,.
- a fully loaded MPC with explicitly modeled fuel basket and fuel assemblies,
- the layered substrate, the concrete Top Pad (made up of the VVM Interface Pad and
- the TSP surrounding the VVM and the concrete Support Foundation.

To investigate the effects of the VVM support pad size, the SSI analyses consider two extreme pad sizes: (1) a "padlet" that supports a single VVM and (2) a large pad consisting of a 5x5 VVM array, that is consistent with the linear SASSI® analysis that has been discussed in UFSAR Section 3.I.4.7.2. It is noted that the "padlet" case maximizes the rigid body rocking of the VVM while the large pad case maximizes the interaction between the VVM and the surrounding soil. The LS-DYNA® model for the "padlet" case spans laterally a total of 150' in diameter and extends down approximately 51' to the bedrock elevation. While maintaining the same dimensions in the vertical direction, the LS-DYNA® model developed for the large pad case consists of a 196.33'×96.67' rectangular lateral boundary.

To maximize the contact load applied to the CEC container shell, the lateral dimensions of the 2' thick top pad are conservatively assumed to be 16'×16', which exceed the design pitch (12'×12') for HI-STORM 100U System. Non-reflective boundary conditions are imposed on the lateral boundary surfaces of the substrate. Since the horizontal seismic time history is imposed along the x-direction, only a half model is developed due to the symmetric configuration. Symmetric boundary conditions are specified for the nodes on the x-z plane of the model. The lateral and vertical seismic acceleration time histories, which are baseline corrected, are specified for the substrate bottom nodes (i.e., bedrock elevation) using the LS-DYNA® command for prescribed motion. The gravity is specified separately as a 1-g body load to the entire model. Both SSI models described above were developed using brick elements except for the MPC shell, fuel basket and its lateral supports, which were modeled using thin shell elements.

The density of the top concrete pad was increased to include the weight of a typical cask transporter. The VVM support pad used an elastic material model with an appropriate Young's Modulus to facilitate the study of the effects of potential cracking in the VVM supporting pad. The two-layer substrate is modeled as linear-elastic material except for the region immediately surrounding the VVM, where the soil may plastically deform in an earthquake event, and therefore, is considered to behave as bilinear elastic-plastic material. The bilinear elastic-plastic is used as a simple material model to characterize the substrate adjacent to the VVM and the CEC steel members. The yield stress for the bi-linear substrate material is set at 25 psi which is the bounding soil pressure that is expected to act on the CEC shell based on a solution for quasi-static seismic analysis of retaining walls under the earthquake condition with a horizontal ZPA of over 1.0g.

LS-DYNA® automatic contacts are defined for all potential contact interfaces of the buried VVM model. A friction coefficient of 0.5 is assumed for all contact interfaces except for the concrete/soil contact interface where the friction coefficient is set to 0.8. Gaps between the VVM lid and divider/container shells, between fuel assemblies and the fuel basket, between the fuel basket and the MPC, and between the MPC and the CEC components are included in the model. Therefore, this SSI model considers the impact interaction of all HI-STORM 100U contents in a seismic event

3.2.2.2 MPC Confinement Boundary Integrity during a Seismic Event

In a seismic event, the loaded MPC in the HI-STORM 100U could experience certain impact loading from the top MPC guide attached to the divider shell of the cask. The primary stress intensity of the MPC shell (away from the impact location) resulting from the impact under seismic conditions was calculated by Holtec in the LS-DYNA® time history SSI analysis (Calculation 7 in Holtec's April 27, 2007, application) and compared to the corresponding Level D stress limit of the material specified in the ASME B&PV Code, Section III, Division 1, Subsection NB. However, for this evaluation, Holtec estimated an average maximum primary stress intensity resulting from the MPC shell acting in a beam-like fashion from a stress contour plot and compared it to the Level D allowable value. In an RAI provided on December 4, 2008, the staff asked that this calculation to be expanded to include an evaluation of the maximum stress intensity acting anywhere on the containment boundary since an evaluation of primary stress alone (as defined by the ASME code) does not ensure structural integrity during an impact event. In addition, the local region near the impact location required evaluation even though Level D (ASME Code Appendix F) does not require an evaluation in this region, since the ASME Code was not developed to cover this situation. The ASME Code was developed to ensure structural integrity and safety margins for load-controlled events (i.e., internal pressure) and not energy-limited events such as drop impact, puncture or missile impact.

To evaluate the structural integrity of the MPC enclosure in the impact region where the maximum stress/strain occurs and where a potential breach would be most likely to originate, Holtec modified the element mesh of the MPC model used in the existing SSI analysis to incorporate a finer mesh in the region of interest and performed a bounding MPC-to-guide impact analysis (Calculation 11 in Holtec's April 27, 2007, application). The MPC-to-guide model consisted of the modified mesh MPC and fixed guide rib. The MPC was given an initial impact velocity into the fixed guide rib that bounds the maximum approach velocity between the MPC and guide rib obtained from the global SSI analysis. Additionally, the impact model assumed that the MPC contents moved toward the MPC guide in the same manner as the MPC shell to maximize the impact loading. However the guide rib is fixed.

To evaluate the maximum strains in the MPC shell, Holtec adopted a maximum strain acceptance criterion of 0.10 in/in or 10% strain. The staff finds Holtec's strain-based acceptance criterion acceptable for the following reasons:

1. The impact can be classified as a "non-moderated impact." By non-moderated impact the staff means an impact in which virtually all of the kinetic energy is absorbed by the containment boundary and its integral components, and no energy is absorbed by non-integral or temporary components such as impact limiters, which moderate the impact.
2. The minimum true strain at failure (rupture) of Type 308 stainless steel weld metal at the 98% exceedence probability level is approximately 40% strain. This value includes the effects of temperature and strain rate and is conservative for Type 304 and 316 base metal, since weld metal is slightly less ductile than base metal.
3. The strain evaluated by Holtec is the maximum surface strain which is greater than the average strain through the thickness of the MPC shell.
4. While Holtec has not considered the effects of stress triaxiality in establishing the 10% strain criterion, it is nonetheless acceptable since the maximum triaxiality factor for this case (biaxial tension) will not be greater than 2.0, which would reduce the 98% exceedence probability failure strain from 40% to 20%, thus providing a minimum safety margin for the acceptance criterion of 2.0.
5. Holtec's modified MPC finite element mesh size in Calculation 11 together with the convergence study performed in Calculation 11 provides confidence in the interpreted finite element results.

3.2.2.3 Convergence Study as Applied to Applicants Maximum Plastic Strain Results

The staff found that the SSI analysis performed to predict the global response of the HI-STORM 100U System did not provide sufficient mesh refinement and compatible integration order for the finite elements comprising the MPC confinement boundary in the vicinity of the impact of the

MPC shell with the guide ribs to adequately predict the maximum plastic strains in the shell. Therefore, no adequate measure of confinement boundary structural integrity margins could be established.

Specifically, the MPC shell elements use reduced (single point) integration in the plane of the element with three integration points through the thickness. This is the lowest order of integration in the plane of the element, and as such, the element can only develop a constant moment along its length. In addition the shell mesh in the vicinity of the guide ribs is very coarse. The coarseness of the mesh combined with reduced (single point) integration may lead to a significant underestimate of maximum stresses. Accuracy of the results from a finite element model is essential to demonstrating the structural integrity of the confinement boundary during an accident event. In an RAI provided on December 4, 2008, the staff requested Holtec to provide a convergence study to demonstrate that the maximum stresses in the MPC shell elements in the vicinity of the impact with the MPC guide ribs are reasonably accurate.

To address this issue Holtec modified the element mesh of the MPC model used in the existing SSI analysis to incorporate a finer mesh in the region of interest and performed a bounding MPC-to-guide impact analysis (Calculation 11 in Holtec's April 27, 2007, application). In the global response model the MPC shell elements in the region of impact were 3.5" long and used reduced integration. In the modified MPC shell model the elements were fully integrated and had a size of 1.1" and produced a maximum plastic strain of 3.1%.

As mentioned above, in the modified MPC model Holtec chose an element size of 1.1" with full integration. This choice of element size, however, appeared to have no firm basis upon which the staff could make a determination as to the accuracy of the plastic strain results derived from it. Therefore, the staff requested Holtec provide an appropriate convergence study to demonstrate that the mesh size used (1.1") provided reasonable accuracy.

The results of the convergence study showed that if the guide rib were considered a hard discontinuity (i.e., knife edge) the converged maximum plastic strain on the element surface would be 4.68%. The convergence study also showed that for the original 3.5" element with reduced integration the maximum plastic strain in the element was 0.37% and for the 1.1" element in the modified model the maximum plastic strain in the element was 2.72%, which is 72% less than the converged result. Thus the maximum plastic strain in the MPC shell for the 1.1" elements in the modified model must be increased by 72% from 3.1% strain to 5.3% strain. Recognizing that the actual impact of the MPC shell into the guide rib is not a "knife edge" impact, the 5.3% strain must be considered a conservative estimate of maximum plastic strain, which is well below the acceptance criterion of 10% strain.

The staff also noted that in the LS-DYNA® MPC models the full penetration weld between the shell and base plate and the lid closure weld were modeled as pinned connections instead of moment connections. While the staff finds this model unacceptable, it recognizes that the stresses at these locations will be small due to a seismic event, and that Holtec plans to correct this situation in site-specific analyses. In UFSAR Section 3.I.4.7.1 (b) it is stated "The MPC Shell, baseplate and top lid shall be modeled using sufficient element discretization to simulate the presence of welds at gross structural discontinuities… with accuracy."

The staff finds this acceptable.

3.2.3 Seismic Event During ISFSI Excavation

The UFSAR for the HI-STORM 100 Cask System states that

> "The excavation of land in the vicinity of an ISFSI with loaded MPCs is permitted if such excavation is carried out outside the perimeter of the radiation protection space set forth in the licensing drawing. Such a construction activity shall be treated as one of potential safety consequence to the operating ISFSI and unless the facility's probabilistic risk assessment analysis identities an earthquake to be non-credible in the period that the proximate land cavity is present, a soil-structure interaction analysis shall be performed to support the §72.212 evaluation. The seismic analysis will be carried out in accordance with the provisions of Subsection 3.I.7.1 with an explicit inclusion of the site modification due to construction in the model."

The HI-STORM-100 Cask System has structurally integral and secure shielding that remains integral with the system during all operational movements and under all accident conditions including any ISFSI site construction activities. Unlike the HI-STORM 100 Cask System, the HI-STORM 100U System has non-integral shielding (soil) that is susceptible to being stripped from the system as a result of human error, or a seismic event occurring during construction activities involving excavation near the installed ISFSI.

To add an additionally ISFSI site adjacent to an existing VVM array, the submitted UFSAR described excavating the soil beneath the new support foundation down to bedrock, and replacing the removed soil with engineered fill. For the VVM example array discussed in the UFSAR, this required excavating 30 feet below the bottom of the support foundation, resulting in a total excavation depth of 50 feet, at a horizontal distance from the edge of the array that could be as little as the radiation protection space distance. This constitutes a potentially large open pit excavation adjacent to an existing ISFSI site, where the consequences of soil instability and the resulting loss of shielding are significantly greater than they would be for an above ground ISFSI. The staff found this unacceptable.

This issue is not required to be addressed by a general licensee in a 10 CFR 72.212 evaluation, but by the CoC owner. Holtec is required to provide clear and specific guidance and evaluation criteria for such construction activities. The staff provided an RAI on December 4, 2008, requesting Holtec clarify the UFSAR and TS by requiring site - specific seismic analyses for construction activities involving excavation near an installed ISFSI that could jeopardize the stability of the support foundation, the ISFSI Pad or the soil within the radiation protection space.

Additionally, the accident evaluations in the submitted UFSAR did not address accidents at an ISFSI where addition of the ISFSI site requires excavation of soil adjacent to an existing array of VVMs and further construction activities to install additional modules. These activities next to an array of already installed (and loaded) VVMs results in additional conditions that must be considered in the accident evaluations for the HI-STORM 100U System due to its unique design. Therefore, the staff provided an RAI on December 4, 2008, for Holtec to provide analyses for scenarios for storage conditions (including seismic) occurring with construction and excavation activities adjacent to an array of loaded VVMs and provide the necessary modifications to the technical analyses and evaluations (e.g., structural, shielding, etc.) that support, or are impacted by, the accident evaluations.

In its response dated January 16, 2009, Holtec revised the TS and UFSAR to require a site-specific seismic analysis for all construction and excavation activities adjacent to an existing array of VVMs. However, Holtec deferred the seismic analysis and accident evaluation to the general licensee's 10 CFR 72.212 evaluation. This is an incorrect utilization of 10 CFR 72.212 as this evaluation is performed to show that the site parameters are "enveloped by the cask design bases considered" in the certificate holder's FSAR referenced by the CoC. The staff found this unacceptable.

Specifically, the revised TS provided in Holtec's January 16, 2009, response states that the "Radiation Protection Space (RPS)… is intended to ensure that substrate material… remains essentially intact under all service conditions including during an excavation activity adjacent to the RPS. A retaining wall at the edge of the RPS shall be constructed to prevent possible loss of shielding within the RPS during excavation under any credible event such as human error or an earthquake. If possible, the RPS retaining wall(s) shall be keyed to the reinforced concrete pads at the bottom and top of the VVM. The retaining walls shall be important-to-safety and shall be designed to comply with a national consensus standard (such as ACI 318 (2005))."

The addition of the retaining wall(s), as described in the TS, constituted a modification to the design that can significantly alter the structural response of the system due to the application of the design loads. This is particularly true of the seismic response where the addition of the retaining wall(s) alters the relationship between an array's center of mass and its center of resistance, introducing additional rotational components to the response that have not been considered. Such a modified design had not been analyzed and evaluated by Holtec. In addition, no accident evaluation was performed for construction and excavation activities taking place next to an array of loaded VVMs. The staff finds this unacceptable.

Therefore, to ensure the stability and integrity of the soil within the RPS, the staff requires that no excavation activities associated with the construction of new VVMs shall take place within a distance from the RPS equal to ten times the depth of the planned excavation. The staff has added appropriate language to the CoC and TS to capture this requirement.

3.3 Special Topics

The single most challenging event to the integrity of the MPC confinement boundary is dropping the canister while it is lowered from the HI-TRAC transfer cask into the underground VVM. This event is credible since the probability of occurrence of such an event is greater than $1x10^{-6}$. Additionally, this transfer will take place in the open environment outside of the nuclear power plant's secondary containment isolation system. Holtec did not perform an evaluation of this event to demonstrate confinement boundary integrity. Therefore, it must be demonstrated that all systems and components within the load path of the transfer operation meet the single failure proof guidelines of Section 5.1.6 of NUREG-0612. In Holtec's June 12, 2008, response to the February 28, 2008 RAI Holtec incorporated the requirement to use the single failure proof guidelines of Section 5.1.6 of NUREG-0612. Additionally, Holtec also committed to TS requirements to ensure that the MPC can be stopped and held during a Design Basis Earthquake event.

The special lifting devices associated with the VVM involve the lifting location devices for the outer shell of the CEC and the divider shell, neither of which is moved with a loaded MPC present so they do not have to meet the design requirements of ANSI N14.6. The closure lid of the VVM must meet the ANSI N14.6 criteria since it will be lifted with a loaded MPC below the opening.

Differential thermal expansion has been addressed in the design considerations of the VVM, as discussed in UFSAR Section 3.I.4.4.

The staff finds this acceptable.

3.4 Corrosion Mitigation for the Cavity Enclosure Container

The VVM is an ITS in-ground structure configured like a covered silo. As an in-ground structure, it is susceptible to more challenging corrosion conditions than a comparable above-ground steel structure. In order to provide reasonable assurance that the VVM will meet its intended design life of 40 years and perform its intended safety functions, the potentially degrading effects of soil corrosion must be mitigated.

Although the CEC portion of the VVM is not part of the MPC containment boundary, it should not corrode to the extent where localized in-leakage of groundwater occurs or where gross general corrosion prevents the CEC from performing its primary safety function. In addition, the foundation anchor housings (which are the only parts which cannot be inspected after installation) shall be protected from degradation over time.

Corrosion mitigation of the exterior of the CEC warrants special consideration for the following reasons:
(i) inaccessibility of the exterior coated surface after installation,
(ii) potential for a highly aggressive (i.e. corrosive) soil environment at certain sites, and
(iii) potential for a high radiation field. Since the buried configuration will not allow for the inspection and re-application of surface preservative, corrosion mitigation measures shall be determined after careful evaluation of the soil's corrosivity at the user's ISFSI site.

To evaluate soil corrosivity, a "10 point" soil-test evaluation procedure, in accordance with the guidelines of Appendix A of American National Standard (ANSI) for Polyethylene Encasement for Ductile-Iron Pipe Systems", ANSI/AWWA C105/A21, will be utilized. The classical soil evaluation criteria in this standard focuses on parameters such as: 1) resistivity, 2) pH, 3) redox (oxidation-reduction) potential, 4) sulfides, 5) moisture content, 6) potential stray current, and 7) experience with existing installations in the area. Using a procedure outlined in the aforementioned standard, the ISFSI soil environment corrosivity is categorized as either "mild" for a soil test evaluation resulting in 9 points or less or "aggressive" for a soil test evaluation resulting in 10 points or greater. The specific mitigation measures that shall be implemented based upon soil environment corrosivity shall be (as specified in the TS):

- For mild corrosivity: exterior coating with either concrete encasement or cathodic protection or both
- For aggressive corrosivity: exterior coating with cathodic protection, concrete encasement optional.

These measures are further detailed in the following subsections.

3.4.1 Coatings

In addition to a corrosion allowance for the CEC structural steel itself, the CEC shall be coated with a radiation resistant surface preservative designed for below-grade and/or immersion service. Inorganic and/or metallic coatings are sufficiently radiation resistant for this application; therefore radiation testing is not required for inorganic or metallic coatings. Organic coatings such as epoxy, however, must have proven radiation resistance or must be tested without failure to at least 10^7 Rads. Radiation resistance to lower radiation levels is acceptable on a site-specific basis.

Radiation testing shall be performed in accordance with ASTM D 4082, "Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light Water Nuclear Power Plants", or equivalent. The coating should be conservatively treated as a service Level II coating as described in USNRC R.G. 1.54. As such, the coating shall be subjected to appropriate quality assurance in accordance with the applicable guidance provided by ASTM D 3843-00, "Standard Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities".

The coating should preferably be shop applied in accordance with manufacturers instructions and, if appropriate, applicable guidance from ANSI C 210-03, "Standard Practice for Liquid-Epoxy Coating Systems for the Interior and Exterior of Steel Water Pipelines." A Keeler & Long polyamide-epoxy coating, according to the manufacturer's product data sheet, is pre-tested to radiation levels up to $1\text{x}10^9$ Rads without failure.

Alternative coatings may be selected by Holtec on the basis of pre-established criteria which are described in the UFSAR chapter 3. These criteria include consideration of various environmental conditions along with a ranking of their relative importance. The specified Keeler & Long epoxy meets all the criteria and is the standard coating for this application.

The staff finds this acceptable.

3.4.2 Concrete Encasement

The CEC concrete encasement shall provide a minimum of five inches of cover to provide a pH buffering effect for additional corrosion mitigation. This concrete thickness has been selected to provide a 100-year service life based upon data provided in literature cited in the UFSAR. A designed 100-year service life provides a degree of uncertainty. However, the concrete thickness is conservative. The thickness specified for the concrete is greater than that specified by several recognized codes or references that are based upon a 20-year minimum design life. Thus, a working life of significantly greater than 20 years is reasonably assured. Additionally, an inspection of the interior surface of the CEC, along with a thickness survey of the CEC wall, will be performed once every 20 years to verify the continued efficacy of the corrosion protection measures.

Shrinkage cracks occur in concrete. Such cracks may create a path for water to intrude to the steel portions of the CEC that are being protected from corrosion by the concrete. To control the inevitable shrinkage cracks that form in concrete, Holtec has specified the addition of wire or fiber reinforcement to the concrete. The reinforcement materials will be corrosion and radiation resistant.

The staff notes that the use of reinforcement is a departure from normal practice by this vendor. Normally, reinforcement is avoided in structures where the primary purpose is radiation shielding. This is because the presence of rebar can create unintended voids in the concrete, leading to a deficient radiation shield. However, in the case of the CEC, the primary shielding will be accomplished by the earthen backfill. The purpose of the HI- STORM 100-U System concrete encasement is to mitigate any corrosive effects from the soil, not provide for radiation shielding. Thus, use of reinforcement will enhance the corrosion prevention performance of the concrete and not affect the shielding.

The staff finds this acceptable.

3.4.3 Impressed Current Cathodic Protection System

When required by soil conditions, an ICCPS will be employed. The initial start-up of the ICCPS must occur within one year after installation of the VVM to ensure timely corrosion mitigation. In addition, the ICCPS should be maintained operable at all times after initial start-up except for system shutdowns due to power outages, repair or preventive maintenance and testing, or system modifications. Because there are a multitude of ISFSI variables that affect the design of the ICCPS for a particular site, the essential criteria for its performance and operational characteristics are established in Holtec's UFSAR, which each ISFSI site must follow as required by 10 CFR 72.212(b)(2)(ii)(3).

Records of system operating data necessary to adequately track the operable status of the ICCPS shall be maintained in accordance with the user's QA program.

Finally, the surface preservative used to coat the CEC must meet the requirements described in the UFSAR for resistance to environmental conditions and also be compatible with cathodic protection and resistant to the alkaline conditions created by cathodic protection and/or concrete encasement. Organic coatings, such as the Keeler & Long epoxy coating previously specified are inherently compatible with these conditions.

The staff finds this acceptable.

3.4.4 Conclusion-Corrosion Mitigation

The corrosion mitigation methods described in the UFSAR have a support role to an important-to-safety system (the CEC portion of the VVM) and are required as a result of the unique design features and corrosion environment associated with underground structures. Since the ITS portions of the CEC are normally not accessible for routine inspection, certain parameters of the cathodic protection system are incorporated into the TS. This ensures through operational monitoring that the ICCPS is performing as designed and thus no degradation of the CEC is occurring. Operational history becomes the alternative to direct inspection, hence the requirement for TS requirements placed on a non-safety-related system. In the event of unforeseen questions about the operability of the ICCPS (or other component of the corrosion mitigation measures) the CEC structure may be examined by means of ultrasonic inspection (UT) from the inside of a CEC cell where there is no fuel canister yet installed, by remote means in a cell where a spent fuel canister is installed, or a cell from which the canister has been removed to allow inspection.

The staff finds that Holtec has specified in sufficient detail the design and operational parameters for an effective corrosion mitigation program for a range of potential environments. Additionally, operation and control of the ICCPS by TS ensures reliable operation of this system in the place of a routine inspection of the protected important-to-safety components of the CEC.

The staff finds this acceptable.

3.5 Evaluation Findings

Based on review of information provided by Holtec, the staff finds the following:

(1) Holtec has specified in sufficient detail the design and operational parameters for an effective corrosion mitigation program for a range of potential environments. TS operation and control of the ICCPS, in lieu of routine inspections of the protected ITS components of the CEC ensures reliable operation of this system.

(2) The analysis and evaluation of all ITS components of the design is the minimum information that must be included in the FSAR (10 CFR 72.24(d)). In the January 16, 2009, response to the December 4, 2008, RAI Holtec provided a design for the TSP and the support foundation. However, no information was provided to demonstrate that the design was analyzed and evaluated for the combination of loads to which the HI-STORM 100U System will be subjected. These loads include dead load, live load, seismic load and long-term settlement. Instead, Holtec shifted the responsibility for the analysis and evaluation of the design to the general licensee, as described in the proposed TSs Section 3.4-8 and 12 submitted with their response. Neither the regulation, nor the licensing/rulemaking process, allows the general licensee to assume the obligations of the CoC holder, and the staff found this unacceptable.

In the absence of an analysis and evaluation of all ITS components of the design for specific or bounding site parameters, which include site soil characteristics, the staff is required to restrict the present design of the support foundation to sites where the support foundation rests directly on bedrock or on substrate material having a shear wave velocity equal to or greater than 3500 fps. For these controlling parameters, the internal forces in the support foundation due to dead load, live load, seismic load and long-term settlement are minimal and, as such, the design in TS Table 3-3 is acceptable. However, any deviation from the support foundation being directly supported on bedrock will require Holtec to submit an amendment to the CoC.

(3) In its response dated January 16, 2009, Holtec revised the UFSAR and TS to require a site-specific seismic analysis for all construction and excavation activities adjacent to an existing array of VVMs. However, Holtec deferred the seismic analysis and accident evaluation to the general licensee's 10 CFR 72.212 evaluation. This is an incorrect utilization of the 10 CFR 72.212 evaluation as the evaluation is used to show that the site parameters are "enveloped by the cask design bases considered" in the certificate holder's FSAR referenced by the CoC.

Specifically, the TS states (See Holtec's January 16, 2009 ,response) that the "Radiation Protection Space (RPS)… is intended to ensure that substrate material… remains essentially intact under all service conditions including during an excavation activity adjacent to the RPS. A retaining wall at the edge of the RPS shall be constructed to prevent possible loss of shielding within the RPS during excavation under any credible event such as human error or an earthquake. If possible, the RPS retaining wall(s) shall be keyed to the reinforced concrete pads at the bottom and top of the VVM. The retaining walls shall be important-to-safety and shall be designed to comply with a national consensus standard (such as ACI 318 (2005))."

The addition of the retaining wall(s), as described in the TS, constitutes a modification to the design that can significantly alter the structural response of the system due to the application of the design loads. This is particularly true of the seismic response, where the addition of the retaining wall(s) will alter the relationship between an array's center of mass and its center of resistance, introducing additional rotational components to the response that have not been considered. Such a modified design has not been analyzed and evaluated by Holtec. Additionally, no accident evaluation has been performed for construction and excavation activities taking place next to an array of loaded VVMs. The staff finds this unacceptable.

Therefore, to ensure the stability and integrity of the soil within the RPS, the staff requires that no excavation activities associated with the construction of new VVMs shall take place within a distance from the RPS equal to ten times the depth of the planned excavation. The staff has added appropriate language to the CoC and TS to capture this requirement.

(4) In the seismic analysis and evaluation of the TSP for the case of a loaded transporter on the pad (second load case) Holtec assumed no amplification due to the out-of-plane flexibility of the TSP in applying the net horizontal acceleration at the top of the TSP to the center of gravity of the loaded transporter. Studies have shown that for casks stored on two foot thick continuous ISFSI pads the amplification from the top of the pad to the center of gravity of the cask can be significant, and since the TSP is a gridwork of beams it is expected to have a higher amplification than a continuous pad of the same thickness. Therefore, the bounding seismic parameters for net horizontal acceleration at a specific site must account for this amplification by reducing the unamplified pad net horizontal acceleration by the amplification factor that would occur for an SSI analysis with the loaded transporter present in the analysis. This requirement has been included in the TS.

4.0 HI- STORM 100U SYSTEM THERMAL EVALUATION

The thermal review ensures that the cask components and fuel material temperatures of the HI-STORM 100U System will remain within the allowable values or criteria for normal, off-normal, and accident conditions. These objectives include confirmation that the fuel cladding temperature will be maintained below specified limits throughout the storage period to protect the cladding against degradation that could lead to gross ruptures. This review also confirms that the cask thermal design has been evaluated using acceptable analytical techniques and/or testing methods. The review was conducted against the appropriate regulations as described in 10 CFR 72.236 that identify the specific requirements for spent fuel storage cask approval and fabrication. The unique characteristics of the spent fuel to be stored are identified, as required by 10 CFR 72.236(a), so that the design basis and the design criteria that must be provided for the structures, systems, and components important to safety can be assessed under the requirements of 10 CFR 72.236(b). The application was also reviewed to determine whether the HI-STORM 100U System design fulfills the acceptance criteria listed in Sections 2, 4 and 11 of NUREG-1536 as well as associated ISG documents.

The following significant item relevant to the staff's review, affect the thermal performance of the HI-STORM 100U System.

4.1 Spent Fuel Cladding

Holtec adopted certain guidelines of NRC, "Standard Review Plan for Dry Cask Storage

Systems," NUREG-1536, January 1997, and NRC, ISG-11, Revision 3, "Cladding Considerations for the Transportation and Storage of Spent Fuel," November 17, 2003, to demonstrate the safe storage of the material content described in Chapter 2 of the UFSAR and the CoC for those aspects relevant to the HI-STORM 100U System design. Holtec's application intends to demonstrate the HI-STORM 100U System complies with all of the following eight criteria:

1. The fuel cladding temperature for long-term storage shall be limited to 752°F (400°C).

2. The fuel cladding temperature for short-term operations shall be limited to 752°F (400°C) for high burnup fuel and 1058°F (570°C) for moderate burnup fuel.

3. The fuel cladding temperature should be maintained below 1058°F (570°C) for accident and off-normal event conditions.

4. The maximum internal pressure of the MPC should remain within its design pressures for normal, off-normal, and accident conditions.

5. The cask system materials should be maintained within their minimum and maximum temperature criteria for normal, off-normal, and accident conditions.

6. For fuel assemblies proposed for storage, the cask system should ensure a very low probability of cladding breach during long-term storage.

7. The HI-STORM 100U System should be passively cooled.

8. The thermal performance of the cask system shall be in compliance with the design criteria specified in UFSAR Chapters 1 and 2 for normal, off-normal, and accident conditions.

4.2 Thermal Properties of Materials

Material property tables for the HI-STORM 100U System components are included in the UFSAR Section 4.2. The functional performance of insulation applied on the cylindrical surface of the divider shell is ensured by specifying a minimum thermal resistance. UFSAR Table 4.I.1 provides the material properties of thermal insulation and soil surrounding the HI-STORM 100U VVM. The temperature range for the material properties covers the range of temperatures encountered during the thermal analysis with exceptions that were justified by Holtec. The staff finds the material properties used by Holtec in the thermal analyses of HI-STORM 100U System acceptable.

4.3 Specifications for Components

The evaluation of HI-STORM 100U System thermal performance, material temperature limits for long term normal, short-term operations, and off-normal and accident conditions are provided in UFSAR Table 4.3.1. Fuel cladding temperature limits included in UFSAR Table 4.3.1 are adopted from ISG-11. These limits are applicable to all fuel types, burnup levels, and cladding materials approved by the NRC for power generation. Temperature limits for the insulation material used in the HI-STORM 100U System are specified in UFSAR Table 2.I.8.

4.4 HI-STORM 100U System

4.4.1 General Description

The HI-STORM 100U System utilizes an underground VVM designed to accept all MPC models for storage at an ISFSI. The VVM provides for storage of MPCs in a vertical configuration inside a subterranean cylindrical cavity entirely below TOG of the ISFSI. The MPC storage cavity is defined by the CEC, consisting of the container shell integrally welded to the bottom plate. The top of the container shell is stiffened by the container flange (a ring shaped flange), that is also integrally welded. All of the constituent parts of the CEC are made of thick low carbon steel plate. The cylindrical surface of the divider shell is equipped with insulation to ensure that the heated air streaming up around the MPC in the inner coolant air space causes minimal preheating of the air streaming down the intake plenum. As discussed in UFSAR Supplement 3.I.4 the insulation material is selected to be water and radiation resistant and non-degradable under accidental wetting. The staff finds the description of the cask system design acceptable.

4.4.2 Design Criteria

UFSAR Table 2.I.1 provides the principal design criteria applicable to the VVM. To minimize the heating of the downward flowing inlet air and the upward column of heated air, the divider shell is insulated on its outside surface. The critical characteristic of the insulation is specified in UFSAR Table 2.I.1. Per this table, the divider shell thermal insulation must have a heat transfer resistance ≥ 4 h-ft^2-°F/Btu and it must be stable at temperatures < 800°F. The thermal insulation material is required to meet the temperature and humidity service conditions for the design life of the VVM. Because the thermal performance of the HI-STORM 100U System relies on buoyancy-driven convection of air, and because of the relative proximity of the inlet and outlet vents to each other, the effect of wind on its thermal performance is also considered. The allowable long-term and short term section-average temperature limits for concrete (used in the closure lid) are established in Appendix 1.D of the UFSAR. Section-average temperature limits for structural steel in the VVM are provided in UFSAR Table 2.I.8. The VVM is designed for extreme cold conditions, as discussed in UFSAR Subsection 2.2.2.2. The safety of structural steel material used for the VVM from brittle fracture is discussed in UFSAR Subsection 3.1.2.3. The staff finds the description of the cask system thermal design acceptable.

4.4.3 Design Features

The VVM is engineered for outdoor below-grade storage for the duration of its design life, and it is designed to withstand normal, off-normal, and extreme environmental phenomena as well as accident conditions of storage with appropriate margins of safety. As discussed in UFSAR Supplement 1.I, the principal components of the VVM are the MPC CEC, and the closure lid. The CEC is comprised of the following subcomponents:

1. Container Shell (a cylindrical enclosure shell)
2. Bottom Plate
3. Container Flange (a top ring flange)
4. Divider Shell
5. MPC bearing pads
6. Foundation Anchor Housings

The Closure Lid is comprised of the following subcomponents:

1. The integral steel weldment (filled with shielding concrete), and
2. The removable vent screen assemblies (inlet and outlet).

The staff finds the description of the HI-STORM 100U System design acceptable.

4.5 HI-STORM 100U System Thermal Model

The thermal performance of the HI-STORM 100U System is modeled with the FLUENT® Computational Fluid Dynamics program. The thermal analysis model developed by Holtec has the following key attributes:

1. The airflow through the cooling passages of the VVM is modeled as turbulent, using the k-omega model with transitional option.

2. The MPC is modeled as a three-dimensional (3-D) array of square shaped cells inside a cylindrical shell with bottom and top closures. The fuel basket bottom and top mouseholes are explicitly modeled as rectangular openings. The helium flow within the MPC is modeled as laminar.

3. The fuel assembly enclosed in a square envelope (fuel channel for BWR fuel or fuel storage cell for PWR fuel) is replaced by porous media with equivalent flow resistance.

4. The porous media hydraulic resistance of the fuel assemblies stored within the MPC is obtained using 3-D CFD models of design-basis assemblies specified in UFSAR Chapter 2. Details of the hydraulic resistance calculations are provided in UFSAR Section 4.4.1.2.

5. The vertical surfaces between adjacent modules are assumed insulated.

6. The underside of the VVM foundation pad as shown in Figure 1.I.1 of the UFSAR is assumed supported on a subgrade at 77°F. This is the same boundary condition applied to the bottom of the ISFSI pad for the above-ground cask modeling as described in UFSAR Section 4.4.

Holtec constructed a 3-D model of the HI-STORM 100U VVM to perform the thermal analysis of the underground casks. The VVM lid with its inlet and outlet vents and internal flow passages, the inner and outer annulus, the U-turn and the gas plenum above the MPC are explicitly modeled. Holtec stated that access to ambient air is artificially restricted in the model by erecting a vertical cylinder above the VVM. The cylinder is open at the top to allow air ingress and exit. In this manner lateral access to air is blocked and the potential for hot air mixing above the VVM is maximized. In order to verify this assumption, the staff performed a confirmatory analysis and found that the Holtec model did not capture accurately the effect of surrounding casks. The staff found that by including other casks, the air inlet temperature was elevated by about 13°F to about 93°F as compared to Holtec's assumed value of 80°F. This information was provided to Holtec, and Holtec used this value as the air inlet temperature to perform the thermal evaluation of an array of casks using only a single VVM model as explained above. Since the staff's confirmatory analysis was based on a configuration using periodic boundary conditions, it was reasonable to increase the inlet temperature for a single VVM to include the intermixing effect, and at the same time simplify the calculations. If Holtec decides to continue using this approach (modeling a single VVM to represent an array of casks) during later amendment requests, the higher temperature must be used. Otherwise, the thermal model of a single VVM will be unacceptable. As an acceptable approach, Holtec may develop an array of VVMs to properly obtain the operating conditions at the inlet vents.

4.6 Thermal Evaluation for Normal Conditions of Storage

Holtec performed the thermal evaluation of HI-STORM 100U System by considering two different scenarios: quiescent and non-quiescent ambient conditions. For the quiescent ambient conditions case Holtec assumed a bounding ambient temperature of 80°F. The results of the analysis for the bounding PWR and BWR canisters (MPC-32 and MPC-68) are provided in UFSAR Table 4.I.2 and Table 4.I.3. The UFSAR results are below the temperature and pressure limits for normal storage assuming quiescent conditions and no intermixing effects. The MPC calculated pressure is 99.5 psig, just 0.5 psig below the permissible limit per UFSAR Tables 2.2.3, 2.I.8, and 2.2.1.

Holtec also evaluated a case for non-quiescent ambient conditions defined as a horizontal wind on an isolated HI-STORM 100U System module. This case is evaluated using a 3-D half-symmetric model of the VVM. Holtec used this model to compute fuel cladding temperatures at several wind speeds. The results are presented in UFSAR Table 4.I.7 for the case of X=3 where X is defined as the ratio of maximum permissible assembly decay heat generation rates in the inner and outer regions. X = 3 corresponds to a total MPC heat load of 30.17 kW. Based on these calculations, Holtec determined that ambient conditions at five mph wind speed will result in the maximum peak cladding temperature for this configuration. Holtec performed these calculations to determine a bounding wind speed only. Therefore, these results do not represent the bounding configuration in terms of maximum heat load (X=0.5). For the non-quiescent conditions case, Holtec's thermal analysis is based on the following assumptions:

1) A five mph horizontal wind (constant speed and direction) is blowing

2) The inlet air is at 92.6°F to factor the limited mixing of the feed air

3) The VVM contains a loaded MPC-32 based on a regionalized loading configuration of X=0.5

4) For the aboveground system the total and specific heat loads in Regions 1 (inner region) and 2 (outer region) are computed as follows:

Q_d = 36.9 kW
q_1 = 0.709 kW
q_2 = 1.419 kW

Based on the above assumptions, Holtec performed two calculations at two different heat loads (36.9 and 35.05 kW) to determine the "trend" in the peak cladding temperature. Based on this trend, Holtec determined a maximum heat load of 33 kW for the X=0.5 case. Holtec determined a maximum peak cladding temperature of approximately 734°F (390°C) considering the trend in temperature change. This approach to determine the maximum peak cladding temperature is unacceptable to the staff since it involves approximations and does not include uncertainties in the analysis. Holtec determined the following heat loads for the HI-STORM 100U System design:

X	Total MPC Heat Load for the HI-STORM 100USystem Design (kW)
0.5	33.0
1	30.4
2	28.1
3	27.0

As stated in SER Section 4.8, based on a confirmatory calculation the staff determined a maximum peak cladding temperature which was below ISG-11 allowable limit for the maximum requested heat load of 33 kW.

The two scenarios described above assumed the HI-STORM 100U System is located at sea level. However, if an ISFSI is located at an elevation greater than sea level, the effect of altitude on the peak cladding temperature shall be quantified as part of the 10 CFR 72.212 evaluation for the site using the site ambient conditions (ambient temperature, air density at the inlet vents, wind speed, etc.).

Based on the confirmatory analyses described in SER Section 4.8 the staff finds Holtec's thermal evaluation for normal conditions of storage acceptable.

4.7 OFF-NORMAL AND ACCIDENT EVENTS

4.7.1 Off-Normal Events

Holtec considered two off-normal conditions: elevated ambient temperature and partial blockage of air inlets. These two off-normal conditions were evaluated assuming quiescent conditions and no intermixing. Results for these off-normal events are provided in UFSAR Tables 4.I.5 and 4.I.6. The results are well below the permissible short-term temperature limits for fuel cladding, concrete, and structural steels. Holtec did not update these calculations for non-quiescent conditions and intermixing effect, but the staff concluded that evaluating non-quiescent conditions and intermixing would result in temperatures higher than the results provided in the UFSAR but would still be below the short-term allowable limits. However, the calculated average gas cavity pressure was based on quiescent conditions using a lowered averaged gas temperature. Per UFSAR Tables 4.I.6, there is a 7.6 psig margin from the allowable limit.

4.7.2 Accident Events

Holtec considered five accident events: fire, flood, burial under debris, 100% blockage of air ducts, and extreme environmental temperature. Holtec did not update these calculations for non-quiescent conditions and intermixing effect but the staff concluded that evaluating for non-quiescent conditions and intermixing would result in temperatures higher than the results provided in the UFSAR but would still be below the short-term allowable limits.

Fire

Holtec stated that the fire described in the FSAR, revision 6, Section 4.6 bounds the HI-STORM 100U System fire event because heat input to the VVM is much lower because of the much lower exposed area to the fire. Downward flow of combustion gases into the module cavity is not credible because heated gases rise up.

Flood

The worst flood condition would prevent air flow with no MPC cooling. This event is bounded by the 100% inlet ducts blocked accident.

Burial Under Debris

The FSAR, revision 6, Section 4.6 burial under debris-event bounds the HI-STORM 100U System burial under debris-event because of the greater HI-STORM 100U System thermal inertia as compared to the aboveground overpacks.

100% Blockage of Air Inlet Ducts

Analysis results for this accident after 24 hours of blockage are provided in UFSAR Table 4.I.9. The results demonstrate that fuel cladding and component temperatures remain below their respective short-term limits provided the inlet ducts are cleared from any blockage within 24 hours.

Extreme Environmental Temperature

This condition is defined as an ambient temperature of 125°F and is evaluated by adding 45°F to the calculated normal condition of 80°F for quiescent conditions. The results for this event are provided in UFSAR Table 4.I.8 and are less than accident temperature limits.

The staff finds the description, assumptions, and analysis results of off-normal and accident events acceptable.

4.8 Confirmatory Analyses

The staff reviewed Holtec's models and calculation options to determine the adequacy of the HI-STORM 100U System thermal design. Additionally, the staff performed selected confirmatory analyses using the FLUENT© finite volume CFD code as an independent evaluation of the thermal analysis and modeling options presented in Holtec's UFSAR.

Specifically the staff performed sensitivity analysis using the 3-D model developed by Holtec. The staff investigated the extent of the domain (location of pressure boundary), energy balance, and effect of wind on the calculated peak cladding temperature. Also, since Holtec built a single module to represent an array of VVMs, the staff built an array of VVMs to verify Holtec's claim that a single VVM with a vertical cylinder on top of it would restrict the flow of lateral air which would increase the cladding temperature.

The staff developed a periodic boundary condition model to represent the worse scenario since this model assumes an infinite array of VVMs. The periodic model developed by the staff included four one-quarter symmetry VVMs. The model included the volume of air above the TOG with the pressure boundary located far enough so it does not affect the results. To simplify the model and expedite the calculations, the MPC internals were not modeled. The heat load was applied as uniform heat flux on the MPC inner wall. The staff used this model to perform additional calculations to investigate the intermixing effect. The staff determined that once the steady state calculation had converged, the air inlet temperature increased by approximately 13°F with respect to the ambient temperature to about 93°F as compared to Holtec's assumed value of 80°F. Holtec used this higher inlet temperature in their thermal analysis using the single VVM thermal model.

While reviewing Holtec's CFD model the staff found that the location of the pressure boundary was too close to the air inlet vent and as such it may have some effect on the analysis results because the flow would be still developing. In Holtec's CFD model the location of the lateral cylindrical pressure boundary is approximately 0.5 m from the inlet vent. The staff modified Holtec's model by extending the location of the lateral pressure boundary. Based on these calculations, the staff concluded that the modeled lateral pressure boundary should be located at least 1 m away from the inlet vent to allow for a properly developed flow.

According to Holtec peak cladding temperature increases for low wind speed as compared to quiescent conditions (as is it shown in UFSAR Table 4.I.7) for the HI-STORM 100U System design, and the staff performed additional 3-D analyses to confirm this. Holtec evaluated the effect of low wind speed by performing three CFD analyses at 5, 10, and 15 mph as shown in UFSAR Table 4.I.7. From this table the cladding temperature reaches its maximum at approximately five mph. The staff performed additional analysis at 1, 2, 4, and 6 mph wind speed and verified that the maximum temperature occurs at about 5 mph. Initially, Holtec considered wind as an off-normal event, and therefore short-term temperature limits were used. When short-term limits were used, Holtec's results show a large margin to allowable limits. The staff questioned Holtec's position that wind was an off-normal event, and therefore, short-term temperature limits could be used. The staff used Holtec's FSAR to support its decision of treating wind as part of the normal conditions. In HI-STORM 100 FSAR, revision 1, Holtec defined off-normal operation in accordance with ANSI/ANS-57.9. Per ANSI/ANS-57.9, off-normal operations are those conditions which, although not occurring regularly, are expected to occur no more than once a year. However, it appears that low wind speeds (e.g. 5 mph wind) would occur much more frequently and therefore, should be treated as a normal condition. Treating low speed wind as a normal occurrence requires the use of the long term storage allowable temperature limit (752°F or 400°C.)

The MPC design is unchanged by the addition of the HI-STORM 100U System. UFSAR Section 7.1.6 demonstrates that the MPC meets the criteria of ISG-18 for the lid-to-shell and port welds, and is valid for the HI-STORM 100U System. In addition, Holtec supplemented the USAR to specify leak testing of the other confinement boundary welds after fabrication to a leaktight sensitivity. The analyses for normal, off-normal, and accident conditions for the HI-STORM 100U system demonstrates that the MPC confinement boundary will maintain its integrity. Therefore, leakage from the MPC confinement boundary is not considered credible and no additional confinement analysis is required.

In summary, the staff found, based on additional extensive confirmatory analyses, that the boundary location, air intermixing, and low speed wind all have an impact on the calculated peak cladding temperature. The pressure boundary must be located far enough from the VVM so it does not affect the flow. The intermixing effect is taken in account by using a single model of a VVM and increasing the air inlet temperature by a factor obtained from an analysis of a cask array. Low wind speed has a major impact on the calculated temperature, and its occurrence should be treated as a normal condition. As a result of the staff's confirmatory analyses, Holtec lowered the maximum cask heat load so the calculated peak cladding temperature would be below acceptable limits as explained in SER Section 4.6.

4.9 Conclusion

Holtec adequately described and justified the proposed changes to the CoC in the License

Amendment Request. These changes considerably affect previous thermal results but the staff finds these changes acceptable. Holtec's compliance with ISG-11, Rev. 3, allowable temperature limits during normal onsite transport in a vertical orientation requires the use of a supplemental cooling system. The addition and type of supplemental cooling system is left to the end user of the storage system. Holtec stated in the UFSAR that the end user shall perform a thermal analysis, including the SCS, based on the thermal methodology described in the UFSAR.

4.10 Evaluation Findings

F4.1 UFSAR Chapter 2 describes SSCs important to safety to enable an evaluation of their thermal effectiveness. Cask SSCs important to safety remain within their operating temperature ranges.

F4.2 The HI-STORM 100U System is designed with a heat-removal capability having verifiability and reliability consistent with its importance to safety. Except during short-term operations, the cask is designed to provide adequate heat removal capacity without active cooling systems.

F4.3 The spent fuel cladding is protected against degradation leading to gross ruptures under long-term storage by maintaining cladding temperatures below 752°F (400°C). Protection of the cladding against degradation is expected to allow ready retrieval of spent fuel for further processing or disposal.

F4.4 The spent fuel cladding is protected against degradation leading to gross ruptures under off-normal and accident conditions by maintaining cladding temperatures below 1058°F (570°C). Protection of the cladding against degradation is expected to allow ready retrieval of spent fuel for further processing or disposal.

F4.5 The staff finds that the thermal design of the HI-STORM 100U System is in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria have been satisfied. The evaluation of the thermal design provides reasonable assurance that the cask will allow safe storage of spent fuel. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

5.0 SHIELDING EVALUATION

The objective of the shielding review is to ensure that there is adequate protection to the public and workers against direct radiation from the cask contents. The review intends to ensure that the proposed shielding features and contents provide adequate protection against direct radiation to the operating staff and members of the public, and that direct radiation exposures can satisfy regulatory requirements during normal operating, off-normal, and design-basis accident conditions. The objective includes review of the shielding design description, radiation source definition, shielding model specification and shielding analyses for the proposed HI-STORM 100U System addition.

The regulatory requirements for providing adequate radiation protection to licensee personnel and members of the public include 10 CFR Part 20, 10 CFR 72.104, 10 CFR 72.106(b), 10 CFR 72.212, and 10 CFR 72.236(d). Because 10 CFR Part 72 dose requirements for members of the public include direct radiation, effluent releases, and radiation from other uranium fuel-cycle operations, an overall assessment of compliance with these regulatory limits is provided in SER Section 10.

Due to its configuration, the HI-STORM 100 VVM results in significantly lower dose rates at the site boundary than the aboveground HI-STORM 100 Cask System overpack designs. The HI-STORM 100U System uses the same MPCs and transfer casks as the HI-STORM 100 aboveground overpacks. The proposed contents are the same as those that are currently approved for the HI-STORM 100 Cask System of casks except for the prohibition of damaged fuel and fuel debris in the HI-STORM 100U System. Therefore, this review focuses on the VVM and any modifications to operations arising from the addition of the HI-STORM 100U System to the HI-STORM 100 Cask System. Based upon the analysis and dose rates for the HI-STORM 100U System, the staff modified the radiation protection program in CoC Appendix A-100U TS 5.7 to incorporate appropriate dose rate limits for the VVM.

5.1 Shielding Design Features and Design Criteria

5.1.1 Shielding Design Features

The shielding design of the VVM utilizes the concrete and steel of the module for gamma shielding, with neutron shielding provided by the module concrete. However, since a MPC placed in the VVM is below the surface of the surrounding soil, shielding is also provided by the soil. Due to this design feature, the dose rates at the site boundary using a VVM are less than, and bounded by, the dose rates from the aboveground HI-STORM 100 overpacks. Holtec performed the shielding analysis for the HI-STORM 100U System containing an MPC-32 loaded with intact design-basis fuel and determined dose rates for the positions shown in UFSAR Figure 5.I.1.

The staff evaluated the shielding design features of and the analysis results relevant to the VVM, as presented in the UFSAR. The shielding design features associated with the VVM include the steel and concrete closure lid, the steel CEC, the aboveground concrete pad surrounding the module, and the surrounding soil, since the VVM provides for subterranean spent fuel storage. The shielding design features may also include an optional concrete encasement surrounding the below-grade portion of the module, used for corrosion protection purposes as determined by site soil conditions). However, this optional feature was not utilized in the shielding evaluation.

Due to the unique configuration of the HI-STORM 100U System, expansion of an operating ISFSI can impact the shielding design, since the required soil removal will also remove shielding. Holtec proposed technical specification CoC Appendix A-100U TS 5.7.9 to minimize any potential radiological effects from such excavation activities. Holtec then proposed additional CoC Appendix B-100U TS 3.4.9 and 3.4.7 and expanded upon TS 5.7.9 of Appendix A-100U of the CoC to provide for protection of the shielding soil with excavation next to an operating ISFSI. It is recognized that the soil shielding between the loaded HI-STORM 100U System and the excavation area is vulnerable to accidents and natural phenomena events during excavation activities. The staff identified that the design should address accidents and natural phenomena events during excavation. The proposed TS required a wall to be constructed to industry standards (such as ACI-318 for a concrete wall) and seismic qualification to verify stability of the ISFSI and that the wall strength is not exceeded in the most vulnerable configuration with adjacent excavation activities. The staff found that if the wall is constructed along with the ISFSI array, the general licensee will have to exercise foresight to ensure compliance with the conditions of TS 5.7.9 of Appendix A-100U to the CoC at the time of future excavation next to the operating ISFSI array. The staff found this unacceptable. In addition to the RPS established in CoC Appendix A-100U, TS 5.7.9, CoC 1014 Appendix B-100U, TS 3.4.7 was added to prohibit excavation next to an operating HI-STORM 100U System ISFSI within a distance equal to ten times the excavation depth beyond the RPS. Additionally, the use of a retaining wall was not allowed. Though Holtec did not provide an accident evaluation during excavation for all credible accident and natural phenomena events considered during non-excavation conditions, the staff finds the prescribed distance between an operating ISFSI and any excavation to be sufficient to ensure that an adequate amount of soil and, therefore shielding, will remain in place during accidents with ongoing excavation near the ISFSI.

The staff finds the revised shielding design features along with the staff supplied CoC Appendix B-100U, TS 3.4.7 to be acceptable. Based on information provided by Holtec, and the conditions provided in the CoC, and appendices A and B TS, the staff finds that the shielding design features of the HI-STORM 100U Cask System meets the radiological requirements of 10 CFR Part 20 and 10 CFR Part 72.

5.1.2 Shielding and Source Term Design Criteria

The overall radiological protection design requirements are provided in 10 CFR Part 20 and 10 CFR 72.104, 72.106(b), 72.212, and 72.236(d). Holtec analyzed the HI-STORM 100U System loaded with spent fuel and hardware having the characteristics described in UFSAR Section 2.1.9. Although there were no numerical limits in the regulations for surface dose rates, the dose rates on the surface of the cask system serve as design criteria to ensure there is sufficient shielding to meet radiological limits in accordance with 72.236(d). UFSAR Section 5.1.1 describes the maximum surface dose rate criteria for the HI-STORM 100 Cask System overpacks. These criteria are based on the source terms of the contents. Due to the underground configuration of the HI-STORM 100U System, the UFSAR applicable criteria are those for the storage VVM top and air vent openings which are 60 mrem/hr and 175 mrem/hr, respectively. Based on these design criteria Holtec calculated bounding dose rates at the exterior of the HI-STORM 100U System. Holtec calculated bounding dose rates that are less than the proposed design criteria (see SER Section 5.4). The staff reviewed the design criteria and found them acceptable. The staff found that no additional criteria were necessary for other areas of the HI-STORM 100U System due to their additional functions and due to the TS requirements that ensure adequate performance of those functions as well as the low dose rates at the surface of these areas. The shielding and source term design criteria defined in the UFSAR provide reasonable assurance that the HI-STORM 100U System can meet the radiological requirements of 10 CFR Part 20 and 10 CFR Part 72. General licensees will be required to protect personnel and minimize dose in accordance with As Low as Reasonably Achievable (ALARA) principles and the regulations of 10 CFR Part 20. A radiation protection program is defined in CoC Appendix A-100U TS 5.7 to ensure compliance with these requirements for the HI-STORM 100U System. A dose rate limit based on the bounding shielding analysis is incorporated into the proposed CoC Appendix A-100U TS 5.7 for the top of the HI-STORM 100U System (see SER Section 10.4 for staff’s evaluation of the proposed TS limit). Limits related to maximum decay heat, maximum burnup, minimum cooling time, maximum uranium loading, and the burnup equation coefficients for the system contents are incorporated into CoC Appendix B-100U.

5.1.3 Preferential Loading Criteria

Similarly with the HI-STORM 100 Cask System, the HI-STORM 100U System is designed to store fuel in either a uniform loading pattern or regional loading pattern (preferential) as discussed in UFSAR Section 2.1.9.1. Both loading patterns are limited by maximum allowable decay heat limits for individual fuel assemblies, as specified in CoC Appendix B-100U Sections 2.4.1 and 2.4.2. Similarly for the aboveground overpacks, the analysis for the HI-STORM 100U System uses a uniform loading pattern to determine bounding dose rates. The application indicates that the analyzed uniform loading pattern (an MPC-32 containing design-basis assemblies with 69,000 MWd/MTU burnup and 5 years cooling) results in maximum dose rates for the cask lid.

The staff reviewed the source term calculations provided in Section 5.2 of the FSAR and the contributions to the dose rates from neutrons and gammas. The staff identified that fuel with a 45,000 MWd/MTU burnup and cooled for 3 years had greater gamma source strength than fuel burned to 69,000 MWd/MTU and cooled for 5 years. Also, while the neutron dose rate was a significant portion of the total dose rate, the gamma contribution was still dominant for dose rates near the cask and at the controlled area boundary (i.e. at 100 meters). Thus, Holtec provided additional analysis using this lower burnup and cooling time combination and showed that the originally selected combination resulted in maximum dose rates at the calculated locations on the VVM lid. The lower burnup and cooling time resulted in maximum dose rates and was used in additional dose rate calculations for other HI-STORM 100U System features away from the lid. This additional analysis was also applied to a uniform loading pattern. However, Holtec previously demonstrated that the uniform loadings selected and analyzed in the shielding evaluation bound the possible regionalized loadings from a dose perspective (Refer to Holtec's response, dated February 18, 2006, to RAI question 5-4 for Amendment 5 to the HI-STORM 100 Cask System). Based on the statements and analysis provided by Holtec, as well as its own independent evaluation, the staff has reasonable assurance that the analyzed uniform loading pattern results in bounding dose rates over the preferential loading pattern for various combinations of fuel parameters. The staff notes that each general licensee must perform an analysis under 10 CFR 72.212 to verify dose limits and will have to consider the specific loading pattern that will be used within each cask.

5.2 Source Specification

The design-basis source specifications for bounding calculations are presented in UFSAR Section 5.2. There are no proposed changes to the allowable contents affecting the design-basis source specifications used in the shielding evaluation in this amendment. Holtec used the design-basis source terms determined for previously approved amendments. Based on the burnup equation method, the PWR and BWR fuel may have combinations of burnups up to 68.2 GWd/MTU and 65 GWd/MTU, respectively, and cooling times as low as 3 years. The exact combinations of these parameters are limited by the allowable maximum decay heats specified in CoC Appendix B-100U, Sections 2.4.1 and 2.4.2 for uniform and regionalized loading. The burnup and cooling time combinations used in the current amendment analyses and their associated decay heats conservatively bound the allowable decay heats defined in the amended CoC Appendix B-100U, Sections 2.4.1 and 2.4.2. The staff's review of the source term analyses and the burnup equation method is documented in the SERs for previous amendments (e.g., refer to the SERs for Amendments 2 and 5). Limits on the allowable contents specifications, including those already stated, are incorporated into Appendix B-100U of the proposed CoC. Additionally, dose rate limits based on the shielding analysis are incorporated into criteria for the proposed CoC Appendix A-100U,TS 5.7.

5.3 Shielding Model Specifications

The HI-STORM 100U System shielding and source configuration is described in UFSAR Sections, 5.I.3, 5.3 and 5.4. Holtec performed the analysis with MCNP-4A® using shielding model specifications and methods similar to those for previously approved amendments for the HI-STORM 100 to calculate bounding doses for near-field and off-site dose rates. Configuration and model features unique to the VVM are described in UFSAR, Section 5.I.3.

5.3.1 Shielding and Source Configuration

Holtec used a shielding and source configuration similar to the configuration used in previously approved amendments for the HI-STORM 100 Cask System, accounting for differences in the modeled VVM and the analyzed MPC basket. The analysis for the HI-STORM 100U System used the MPC-32 filled with intact design-basis assemblies. In previous amendment 5, Holtec indicated the source configuration of damaged fuel in the MPC-32 configuration would behave similar to damaged fuel configurations already analyzed and approved for the MPC-24 and MPC-68, as documented in HI-STORM 100 FSAR, revision 6. Therefore, Holtec concluded the shielding performance of the MPC-32 would not be significantly affected by the damaged fuel. Thus, Holtec only performed analyses for intact fuel in the proposed amendment. The staff also notes that the application was modified during the review to limit the proposed HI-STORM 100U System contents to intact fuel only. Holtec modeled the MPC at the highest allowable elevation in the VVM which is 30.5“ below the inlet vents.

The staff questioned the use of the MPC-32 when previous analyses indicated that the MPC-24 provided bounding dose rates. In response, Holtec noted the level of conservatism included in the analyzed contents for the MPC-32. The staff also questioned the level of conservatism in the analyzed contents for the MPC-24 as well as the relatively small differences in dose rates between the two MPCs in an aboveground overpack. The conservatisms included those described in the previously referenced RAI response for Amendment 5 (see SER Section 5.1.3) where maximum burnups for regionalized loading were determined using the burnup equation coefficients for the 14x14A assembly class (this assembly class has the highest allowable burnup for a given cooling time) and for the design basis Babcock &Wilcox 15x15 assembly (assembly with highest uranium mass loading) with an enrichment of 5.0 wt. % (since higher enrichments result in higher allowable burnups). There is additional conservatism due to the reduction of the allowable contents’ decay heats for storage in the VVM versus the aboveground overpacks. While applicable for MPCs loaded under the TS contents limits, the MPC-32 may not result in the highest dose rates. The staff has reasonable assurance that the dose rates calculated for the MPC-32 with the analyzed source term will bound the dose rates from any MPC placed in the VVM. Based upon these considerations, the staff finds that, while the bases and assumptions should be applied consistently throughout the shielding analysis, and the analysis should have used the source term and configuration determined to result in bounding dose rates, the use of the MPC-32, with its design-basis source term, is acceptable for analyzing dose rates from the HI-STORM 100U System for this amendment.

Due to the unique configuration of the HI-STORM 100U System, additional analysis was performed to determine dose rates for personnel involved with any construction activities near an existing array of VVMs. This construction activity includes any excavation activities near the array of VVMs. The analysis relied upon a minimum of 6.5 feet of soil between the nearest loaded VVM and the excavation activity. For these activities, Holtec determined the dose rates at the minimum soil thickness. A new technical specification, CoC Appendix A-100U TS 5.7.9 was included based upon this shielding configuration and the soil material properties specified in UFSAR Table 5.I.3 to ensure that actual excavation activities met the conditions analyzed in the shielding evaluation. Holtec also performed dose rate calculations to evaluate the degree of potential streaming from a test station for the ICCPS as well as the exposed cavity of a neighboring empty VVM.

5.3.2 Material Properties

Holtec used the same material properties as previously approved for the HI-STORM 100 Cask System. For the soil, Holtec used the composition and density specified in UFSAR Table 5.I.3. The staff notes that this density is less than the minimum density specified in proposed CoC Appendix B-100U, TS 3.4.6.d for the concerns addressed by that TS paragraph. As in Amendment 5, the shielding calculations used a minimum allowable concrete density of 140 lb/ft^3 to determine dose rates; however, UFSAR Section 5.3.2 notes that the concrete density can be increased up to 200 lb/ft^3 at the request of the user to improve the shielding characteristics of the system and address potential ALARA considerations.

5.3.3 Staff Evaluation

The staff evaluated Holtec's shielding models and found them to be acceptable. The shielding model, shielding and source configuration, and material properties are similar to those previously approved by NRC for the HI-STORM 100 Cask System. For the excavation dose rate analysis, the staff found the soil properties and configuration distance to be acceptable. Based on the statements and calculations presented by Holtec, the staff finds the model is valid for the HI-STORM 100U System.

5.4 Shielding Analyses

Holtec submitted dose rates for the HI-STORM 100U System for normal and accident conditions in UFSAR Sections 5.I.4 and 11.I. Holtec indicated it used the same shielding analysis techniques as previously approved for the HI-STORM 100 Cask System. Though not affected by the VVM, dose rates for the transfer casks were also discussed in this review, as appropriate, in evaluating the use of HI-STORM 100 transfer casks with the HI-STORM 100U System and its proposed contents.

5.4.1 Normal Conditions

Holtec presented bounding dose rates for various locations surrounding the above-ground portion of the VVM loaded with an MPC-32. The maximum surface dose rates on the lid and the air vents are approximately 28 mrem/hr and 69 mrem/hr, respectively. While dose rates for the transfer cask are unaffected by the storage VVM design, the changes in the location of activities, such as during transfer of the MPC between the transfer cask and the VVM may impact personnel dose with areas of higher dose rates now at locations more easily accessible to more personnel. Therefore, as discussed in UFSAR Section 10, appropriate ALARA practices, such as controlling actual locations of personnel and using temporary shielding during loading and unloading operations, should be used to mitigate exposures from peak dose rate areas.

5.4.2 Occupational Exposures

Holtec calculated occupational exposures for the HI-STORM 100U System using the HI-STORM 100 Cask System loaded with design-basis contents. Holtec provided justification for using the estimates for the aboveground overpack system that were provided in FSAR Revision 6, Chapter 10 to represent or bound the estimates for the HI-STORM 100U System.

The staff reviewed the justification and found use of the occupational exposures estimated for the aboveground overpack system as estimates for the HI-STORM 100U System to be acceptable (see SER Section 10).

5.4.3 Off-site Dose Calculations

Holtec estimated offsite dose rates at the site boundary for a single VVM. The results listed in UFSAR Table 5.I.2 indicated that a single VVM, assumed design-basis fuel and full occupancy, did not exceed the annual dose limit requirement of 25 mrem at 100 meters. Thus, the doses from the HI-STORM 100U System were significantly less than the doses from a single HI-STORM 100 Cask System that required a minimum distance of 350 meters to meet the annual dose limit for design-basis fuel. While Holtec did not estimate dose rates from an array of VVMs, the comparison between a single VVM and a single aboveground overpack indicated that the dose rates for an array of VVMs were bounded by the dose rates from an equivalent array of aboveground overpacks. This analysis determined that indicated that the minimum distance necessary to satisfy the annual dose limit is 550 meters (for a 2x5 array). Off-site dose calculations for both direct radiation and releases are discussed further in SER Section 10.4.

5.4.4 Accident Conditions

UFSAR Section 11.I did not identify an accident that significantly degraded the shielding of the VVM when there is no nearby excavation (e.g., for expanding the ISFSI). The estimated accident dose rates were the same as those estimated for normal conditions. In the January 16, 2009, RAI response, Holtec provided an accident analysis for the HI-STORM 100U System with nearby excavation occurring. This analysis was initially limited to consideration of tornado missile impacts on the exposed soil. Though the RPS size was expanded to address the most penetrating tornado missile, the shielding analysis used the soil thickness from the original RPS size (i.e., 6.5 feet versus the 10.5 feet proposed as a result of the tornado missile evaluation) and modeled an 8" diameter penetration to the VVM surface at the fuel mid-height. The result was a 1.4 rem dose at 100 meters over 30 days. As a result of staff's continued concerns regarding accident and natural phenomena during excavation, Holtec proposed that a retaining wall be built at the RPS boundary to prevent loss of RPS soil. Holtec then proposed a revised TS 3.4.7 to accommodate this retaining wall. This wall was neglected in the shielding analysis. As described in SER Section 5.1.1, staff still had concerns regarding accident evaluations for excavation next to an operating ISFSI. Therefore, the staff modified the CoC Appendix A-100U and B TS to further increase the distance between an operating 100U ISFSI and excavation activities, and removed the Holtec proposed retaining wall. Based on the final requirement for separation of excavation from an operating ISFSI and the foregoing analyses, loss of water in the transfer cask water jacket remains the bounding accident for direct radiation.

5.4.5 Staff Evaluation

SER Section 10 examines the overall dose (i.e., direct radiation and hypothetical radionuclide release) from the HI-STORM 100U System. The staff reviewed the dose calculations for normal operations and found them acceptable. Dose rates were calculated for the HI-STORM 100U System loaded with design-basis contents.

The staff finds that compliance with 10 CFR Part 20 and 10 CFR 72.104(a) from direct radiation can be achieved by general licensees. The actual doses to individuals beyond the controlled area boundary depend on several site specific conditions such as fuel characteristics, cask-array configurations, topography, demographics, and distances. In addition, 10 CFR 72.104(a) includes doses from other fuel cycle activities, such as reactor operations. Each general licensee is responsible to verify compliance with 10 CFR 72.104(a) in accordance with 10 CFR 72.212. In addition, a general licensee will also have an established radiation protection program as required by 10 CFR Part 20, Subpart B and will demonstrate compliance with dose limits to individual members of the public and workers (including for excavation activities), as required, by evaluation and measurements. The staff notes that the system contents result in relatively significant direct radiation dose rates, which is a concern primarily for operations involving the transfer cask (i.e., loading, unloading, and transport) for the HI-STORM 100U System. Thus, each user may be required to take additional ALARA precautions to minimize doses to personnel and to make additional use of realistic fuel characteristics and distances to demonstrate compliance with public dose limits in 10 CFR Part 20 and 10 CFR Part 72.

The staff reviewed the accident evaluation and finds it acceptable for the design changes requested in the application. The staff has reasonable assurance that the does from the HI-STORM 100U System satisfies 10 CFR 72.106(b) at or beyond a controlled boundary of 100 meters for the design-basis accidents. The staff notes that the bounding accident condition is the loss of water in the transfer cask's water jacket. For this condition, the estimated dose to members of the public at 100 meters and at further distances for a conservative exposure time of 30 days is approximately 50% below the 5 rem accident limit in 10 CFR 72.106(b). The staff also notes that while the estimated off-site accident dose may be less accurate because precise exposure times cannot be predicted, the 30-day exposure is conservative based upon realistic considerations, and because the radiation from these events can be mitigated within a reasonable time.

As discussed in SER Section 10.4, the general criteria for a radiation protection program that are tailored to the dose rates from the VVM are provided in the CoC Appendix A-100UTS 5.7 (See Section 10.4 of this SER). The decay heat limits are specified in CoC Appendix B-100U. The burnup equation and associated limits for burnup, cooling time, enrichment, and fuel assembly characteristics are also incorporated into CoC Appendix B-100U.

5.5 Evaluation Findings

Based on the NRC staff's review of information provided for the amendment request, the staff finds the following:

F5.1 The UFSAR sufficiently describes shielding design features and design criteria for the structures, systems, and components important to safety.

F5.2 Radiation shielding features of the HI-STORM 100U System are sufficient to meet the radiation protection requirements of 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106.

F5.3 Operational restrictions to meet dose and ALARA requirements in 10 CFR Part 20, 10 CFR 72.104 and 72.106 are the responsibility of each general licensee. The HI-STORM 100U System shielding features are designed to satisfy these requirements.

F5.4 The staff finds the design addresses construction activities involving excavation (for ISFSI expansion) adjacent to the (operating) HI-STORM 100U System sufficient to ensure that the shielding features will continue to be sufficient to meet the radiation protection requirements of 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106.

F5.5 The staff concludes that the design of the radiation protection system of the HI-STORM 100U can be operated in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the radiation protection system design provides reasonable assurance that the HI-STORM 100U System will provide safe storage of spent fuel. This finding is based on a review that considered the regulation itself, the appropriate regulatory guides, applicable codes and standards, Holtec's analyses, the staff's confirmatory analyses, and acceptable engineering practices.

6.0 CRITICALITY EVALUATION

The purpose of the criticality review is to ensure that all credible normal, off-normal, and accident conditions have been identified and their potential consequences on criticality considered for the proposed HI-STORM 100U System such that the cask system will meet the criticality requirements of 10 CFR Part 72. These requirements include: 10 CFR 72.124(a), 72.124(b), 72.236(c), and 72.236(g). The UFSAR was also reviewed to determine whether the cask system fulfills the acceptance criteria listed in NUREG-1536 Section 6.

The criticality analysis for the HI-STORM 100U System relies upon the analysis previously performed for the currently approved HI-STORM 100 Cask System as described in the FSAR, Revision 6. The use of the VVM does not significantly affect the criticality design of the system. Analyses for the currently approved HI-STORM 100 Cask System have analyzed for storage conditions with the overpack and MPC fully reflected by water of varying densities (the MPC is dry inside for storage conditions). The maximum k-effective for these conditions (~0.50) is significantly below the limiting k-effective (0.95), that occurs in a fully flooded MPC in a flooded transfer cask. Also, the variations in k-effective were small. Use of the VVM will not significantly affect this result. Therefore, the staff finds reasonable assurance that the HI-STORM 100U System will remain sub-critical, with an adequate safety margin, under all credible normal, off-normal, and accident conditions.

7.0 CONFINEMENT EVALUATION

The objective of the confinement review of the HI-STORM 100U System is to ensure that radiological releases to the environment are within the limits established by the regulations, and that the spent fuel cladding and fuel assemblies will be sufficiently protected during storage against degradation that otherwise might lead to gross ruptures. The objective includes review of the confinement design characteristics and confinement analyses for the HI-STORM 100U System proposed in the application. Since the HI-STORM 100U System uses a MPC that has been previously approved for use with the above-ground HI-STORM 100 Cask System, and there is no change to the confinement system. The application includes an editorial change to Chapter 7 that does not affect either the confinement evaluation or the TS.

The HI-STORM 100U System holds the same internal canister system as the HI-STORM 100 Cask System, and uses a fully welded austenitic stainless steel MPC design to maintain confinement. The confinement boundary on the MPC design includes the following: MPC Shell, bottom baseplate, MPC lids (including vent and drain port cover plates), MPC closure ring, and associated welds. Penetrations to the confinement boundary consist of two penetrations, the MPC vent and drain ports. All components of the confinement boundary are important to safety, Category A, as specified in the UFSAR Table 2.2.6. The MPC confinement boundary is designed, fabricated, inspected, and tested in accordance with ASME Code, Section III, Subsection NB. NRC approved alternatives to the ASME Code are identified in CoC Appendix

A, Table 3-1.

7.1 Evaluation Findings

Based on the NRC staff's review of information provided in the HI-STORM 100U Cask System application, the staff finds the following:

F7.1 UFSAR Chapter 7 adequately describes confinement structures, systems, and components important to safety in sufficient detail to permit evaluation of their effectiveness.

F7.2 The design of the MPC adequately protects the spent fuel cladding against degradation that might otherwise lead to gross ruptures. SER Section 4 discusses any relevant temperature considerations.

F7.3 The design of the MPC provides redundant sealing of the confinement system closure joints using dual welds on the MPC lid and the MPC closure ring.

F7.4 The MPC has no bolted closures or mechanical seals. The confinement boundary contains no external penetrations for pressure monitoring or over-pressure protection. No instrumentation is required to remain operational under accident conditions. Because the MPC uses an entirely welded redundant closure system, no direct monitoring of the closure is required.

F7.5 The staff concludes that the design of the MPC confinement System is in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria have been satisfied. However, the staff makes no new finding regarding performance of the MPC as used in the HI-STORM 100U Cask System.

F7.6 The staff concludes that the design of the confinement system of the HI-STORM 100 Cask System continues to remain in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the confinement system design provides reasonable assurance that the HI-STORM 100 Cask System will continue to allow safe storage of spent fuel. This finding considered the regulation itself, the appropriate regulatory guides, applicable codes and standards, Holtec's analysis, the staff's confirmatory review, and acceptable engineering practices.

8.0 OPERATING PROCEDURES

The objective of review of the operating procedures is to ensure that Holtec's revised CoC application presents acceptable operating sequences, guidance, and generic procedures for key operations.

Only those changes that affect operating procedures are discussed in this section. The staff reviewed the proposed changes to the CoC and associated TS as described in supplied UFSAR sections to ensure the changes in the operating procedures meet the following regulatory requirements: 10 CFR 72.104(b), 72.212 (b)(9), 72.234(f), and 72.236(h) and (i). The submitted changes to the UFSAR were evaluated to determine whether the cask system fulfills the acceptance criteria listed in Section 8 of NUREG-1536.

The changes were reviewed to determine if changes to the operating procedures to accommodate design modifications for the HI-STORM 100 Cask System, as described in the proposed amendment and UFSAR are acceptable to the staff.

The staff's conclusions, summarized below, are based on information provided in the proposed amendment to the CoC as described in the submitted UFSAR sections.

8.1 HI-STORM 100U System

The operating procedures for the HI-STORM 100U System do not substantially differ from those for the aboveground HI-STORM 100 Cask System. One of the greatest differences is the location of the operations for unloading the MPC from the transfer cask into the VVM. For the HI-STORM 100 aboveground VVMs, these operations occur about 18 feet above the ground. For the HI-STORM 100U VVM, the operations occur at essentially ground level. Thus, there would be the opportunity for greater occupational exposures while unloading the MPC from the transfer cask into the VVM. However, the procedures call for the use of supplemental shielding and/or keeping personnel away from the area around the mating device to reduce exposure, with the general licensee providing the necessary actions based upon ALARA considerations. Another difference involves the installation of the closure lid. The closure lid is not bolted to the VVM, but is designed so that a portion extends into the VVM to secure it in place. However, the outlet vent is bolted to the closure lid after the lid is installed on the VVM. Based upon a review from a shielding and radiation protection standpoint, the staff finds the procedures for the HI-STORM100U System to be acceptable

8.2 Helium Leak Test of Lid Welds

To ensure consistency with information and text approved in Amendment 3 of CoC 1014, the staff reviewed the following information submitted in support of this proposed amendment. Using the staff guidance of ISG -18, "The Design/Qualification of Final Closure Welds on Austenitic Stainless Steel Canisters as Confinement Boundary for Spent Fuel Storage and Containment Boundary for Spent Fuel Transportation," Holtec has eliminated the helium leak test normally required of the structural-lid-to-shell weld. Elimination of this test is based upon meeting all the criteria of the ISG, which Holtec has demonstrated. For the remaining welds in the confinement boundary, a helium leak test in accordance with the "leak tight" criteria of ANSI N14.5-1997 is applied, in accordance with staff guidance.

ISG-18 states that any weld that is part of the confinement boundary must be helium leak tested. An exemption from the helium leak test for the structural-lid-to-shell weld only falls within the guidance and intent of ISG-18.

8.3 Evaluation Findings

Based on the staff's review of information provided in the HI-STORM 100 Cask System amendment request, the staff finds the following:

F8.1 The HI-STORM 100 Cask System can be wet loaded and unloaded. General procedure descriptions for these operations are summarized in UFSAR Sections 8.1 and 8.3. The procedures were appropriately modified to include the design modifications made in the amendment. Detailed procedures will need to be developed and evaluated on a site-specific basis.

F8.2 The staff concludes that the generic procedures and guidance for the operation of the

HI-STORM 100 Cask System remain in compliance with 10 CFR Part 72 and that the applicable acceptance criteria have been satisfied. The evaluation of the operating procedure descriptions provided in the UFSAR with the re-incorporation of post-fabrication shop helium leak rate testing requirements for the MPC offers reasonable assurance that the cask will enable safe storage of spent fuel. This finding is based on a review that considered the regulations, appropriate regulatory guides, applicable codes and standards, and accepted practices.

9.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

UFSAR Sections 9.I.1.2 and 9.I.1.3.ii describe the requirements that must be met by the shielding design features and materials and the shielding effectiveness tests performed on the HI-STORM 100U System. These requirements and tests are similar to those that have been previously approved for the aboveground HI-STORM 100 overpacks. The staff reviewed these requirements and tests and finds them acceptable to ensure and demonstrate the effectiveness of the as-fabricated HI-STORM 100U System shielding design.

9.1 Impressed Current Cathodic Protection System

The ICCPS provides reasonable assurance that the aggressive corrosion conditions of some soils will not cause degradation of the CEC (including the bottom plate) to the extent that the CEC structural integrity is challenged, or allow in-leakage of ground water into the storage cavity. During normal operations, the ICCPS must remain operational at all times. Consequently, a monthly surveillance of the ICCPS operation is required (CoC Section B, Bases). Since the ICCPS is an active system, consideration of system outages for maintenance or other reasons must be made.

For ICCPS outages, regardless of cause, a limiting condition of operation (LCO) is established which provides a maximum allowable time limit (of 6 months) for a non-functioning ICCPS. Because corrosion in this case is an intrinsically slow process, there is sufficient time available to perform repairs and other corrective actions. In the event that the LCO period is exceeded, the user may opt to demonstrate continued integrity of the affected CEC components by means of an engineering evaluation, including tests. A time period of one year from the initiation of the ICCPS outage is allowed under this option. Other LCO's are imposed by the TS to address other situations regarding the amount of time the ICCPS has been intermittently inoperable over a period of time.

The staff finds that the surveillance and maintenance programs outlined are sufficient for establishing the continued integrity of the CEC and that appropriate LCO's have been established for the ICCPS.

9.2 Other Surveillance

Other in-service inspection for long-term interior or below-grade degradation shall be performed on a site-specific basis in accordance with Holtec's required long-term maintenance guidelines, and the general licensee's preventive maintenance program. In many cases, this will be a visual inspection of accessible areas. The frequency of in-service inspection is specified in UFSAR Table 9.I.1. Additional in-service inspection activities may include more thorough inspections for corrosion or insulation degradation by use of remote viewing systems or other non-destructive examinations. VVM closure lid removal and temporary MPC transfer into a HI-TRAC shielded transfer vehicle may be warranted if access to a VVM compartment is deemed desirable for a comprehensive examination. Such additional examinations with consequent findings and dispositions would be controlled by the licensee's corrective actions program.

The staff finds these inspections requirements to be acceptable.

9.3 Evaluation Findings

Based on the NRC staff's review of information provided in the HI-STORM 100 Cask System amendment request, the staff finds the following:

F9.1 The staff concludes that the modifications made to the acceptance tests and maintenance program for the amendment to the HI-STORM 100 Cask System remain in compliance with 10 CFR Part 72 and that the applicable acceptance criteria have been satisfied.

10.0 RADIATION PROTECTION EVALUATION

The objective of the review of this section is to ensure that the capability of the radiation protection design features, design criteria, and operating procedures, as appropriate, of the HI-STORM 100U System can meet regulatory dose requirements for the proposed contents. The regulatory requirements for providing adequate radiation protection to site licensee personnel and members of the public include 10 CFR Part 20, 10 CFR 72.104(a), 72.106(b), 72.212(b), and 72.236(d).

Calculated occupational exposures from the HI-STORM 100U System are based on the direct radiation dose rates calculated for the HI-STORM 100 Cask System provided in the FSAR, Revision 6, Chapter 5 as loaded with design-basis contents having the same specifications proposed for the HI-STORM 100U System with the operating procedures for the aboveground HI-STORM 100 Cask System. UFSAR Section 8.I indicated that the operating procedures for the HI-STORM 100U System are nearly the same as those for the aboveground HI-STORM 100 Cask System with some differences resulting from the fixed, subterranean nature of the VVM. Calculated doses to individuals beyond the controlled area boundary (members of the public) are determined from the direct radiation (including skyshine) dose rates calculated in FSAR Revision 6, Chapter 5. The dose calculations were based upon the allowable HI-STORM 100 Cask System contents.

The proposed HI-STORM 100U System was reviewed to determine if the radiation protection design features, as described in the UFSAR, remain acceptable to the staff. The staff’s conclusions, summarized below, are based upon the information provided in the application.

10.1 Radiation Protection Design Criteria and Design Features

The radiological protection design criteria are the limits and requirements of 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106. As required by 10 CFR Part 20 and 10 CFR 72.212, each general licensee is responsible for demonstrating site-specific compliance with these requirements. In addition, CoC Appendix A-100U, TS 5.7 establishes direct radiation dose rate limits and other radiation protection criteria for the cask system. These criteria are based on bounding dose rate values that are used to determine occupational and off-site exposures and other design-specific factors important in the radiation protection system. The radiation protection design features are described in UFSAR Chapter 10.

The staff reviewed the design criteria and found them acceptable. SER Sections 5, 7, and 8 discuss the staff's reviews of the design criteria and features for the shielding system, confinement system, and operating procedures, as appropriate. SER Section 11 discusses staff's review of the capability of the shielding and confinement features during off-normal and accident conditions, as appropriate.

10.2 ALARA

The ALARA objectives, procedures, practices, and policies are the same as those previously approved for the HI-STORM 100 Cask System. Each general licensee will apply its additional site-specific ALARA objectives, policies, procedures, and practices for members of the public and personnel.

The staff considered the previously approved ALARA assessment for the HI-STORM 100 Cask System and found it acceptable for the HI-STORM 100U System for the described dose rates. SER Section 8 discusses the staff's review of the operating procedures with respect to ALARA principles and practices, as appropriate. Operational ALARA objectives, policies, procedures, and practices are the responsibility of the site licensee, as required by 10 CFR Part 20 and 10 CFR 72.104(b). The staff also noted that the allowable contents result in relatively significant direct radiation dose rates. For the HI-STORM 100U System high dose rates are of particular concern for operations involving the transfer cask (i.e., loading, unloading, and transport) and not the storage VVM, which has low dose rates. Therefore, each user may be required to take additional ALARA precautions during these operations to minimize doses to personnel and to make additional use of realistic fuel characteristics and distances to demonstrate compliance with public dose limits in 10 CFR Part 20 and 10 CFR Part 72.

10.3 Occupational Exposures

The staff reviewed the overall occupational dose estimates and found them acceptable. The occupational dose exposure estimates provide reasonable assurance that occupational limits in 10 CFR Part 20, Subpart C can be achieved. The staff expects actual operating times and personnel exposure rates will vary for each system, depending on site-specific operating conditions, including detailed procedures and special measures taken to maintain exposures ALARA. The collective exposures will be distributed among multiple personnel responsible for various tasks. Each general licensee will have an established radiation protection program, as required in 10 CFR Part 20, Subpart B. In addition, each general licensee will demonstrate compliance with occupational dose limits in 10 CFR Part 20, Subpart C and other site-specific 10 CFR Part 50 license requirements with evaluations and measurements. The staff's review of and findings regarding the operating procedures are presented in SER Section 8.

The staff notes that in addition to the personnel activities associated with loading, unloading, transfer, and maintenance activities associated with operation of a HI-STORM 100 Cask System, the HI-STORM 100U System introduces a construction (particularly excavation) activity as an additional aspect to be considered for radiation protection purposes. In order to maintain doses to construction personnel very low, Holtec developed a RPS around an array of VVMs as part of its proposed CoC Appendix A-100U, TS 5.7. The RPS size was established based upon the accident analysis for the most penetrating tornado missile without the retaining wall that was later proposed to address other accident concerns for the design. The initial RPS size was established to ensure that there is a minimum of 10.5 feet of soil between the nearest loaded VVM and the construction area. Based upon the shielding analysis in UFSAR Section 5.I dose rates to personnel would be very small (less than 0.2 mrem/hr) at this RPS boundary under normal conditions. However, due to continuing staff concerns regarding accident evaluations (see SER Section 5.1.1) for an excavation next to an operating ISFSI, the staff revised the CoC to further increase the minimum distance between an operating HI-STORM 100U System and excavation activities, along with disapproval the use of the Holtec proposed retaining wall. Dose rates to personnel will therefore certainly be very small for excavation under normal conditions.

The staff also noted that the unique design of the HI-STORM 100U System introduces possible streaming paths in addition to the inlet and outlet vents. These include the neighboring empty VVMs that are uncovered and the test station for the ICCPS. Holtec evaluated these two features, including performing dose rate calculations. Holtec determined that these features are not significant streaming paths and do not pose an additional radiological concern. The staff reviewed Holtec's evaluation and finds that the empty, uncovered neighboring VVM does not result in significant dose rates. Furthermore, this dose rate is conservative since it is expected the empty VVM will be covered to prevent the ingress of debris. The staff reviewed the evaluation of the ICCPS test station as well. Based upon the proximity of the test station to the VVM lid, and hence the inlet vent, (approximately one foot) and neglect of the test station material, the staff finds the analysis to be conservative. While the surface dose rates increase above those from the TSP/VIP surface at this location, the dose rates from the test station will not be significant.

10.4 Public Exposures from Normal and Off-Normal Conditions

Holtec estimated offsite direct radiation dose rates at the site boundary for a VVM. Based on UFSAR Table 5.I.2 the analyses indicated that a single VVM assuming design-basis fuel and full occupancy can meet the annual dose limit of 25 mrem at 100 meters. Thus, the doses from the HI-STORM 100U System are significantly less than the doses from a single HI-STORM 100 aboveground overpack, that require a minimum distance of 350 meters in order to meet the annual dose limit for design-basis fuel having the same specifications as proposed for the HI-STORM 100U System. While Holtec did not estimate dose rates from an array of VVMs, the comparison between a single VVM and a single aboveground overpack indicates that those dose rates will be bounded by the dose rates from an equivalent array of aboveground overpacks, an analysis for which indicated that the minimum distance necessary to satisfy the annual dose limit is 550 meters for a 2x5 array.

The staff has reasonable assurance that compliance with 10 CFR 72.104(a) can be achieved by each general licensee. The general licensee using the HI-STORM 100U System must perform a site-specific evaluation, as required by 10 CFR 72.212(b), to demonstrate compliance with 10 CFR 72.104(a). The actual doses to an individual beyond the controlled area boundary depend on several site-specific conditions such as fuel characteristics, cask-array configurations, topography, demographics, distances, and use of engineered features (e.g., berm). In addition, the dose limits in 10 CFR 72.104(a) include doses from other fuel cycle activities such as reactor operations. Consequently, final determination of compliance with 10 CFR 72.104(a) is the responsibility of each general licensee. The NRC may inspect the site-specific use of the HI-STORM 100U System for compliance with radiological requirements.

The general licensee will also have an established radiation protection program as required by 10 CFR Part 20, Subpart B and will demonstrate compliance with dose limits to individual members of the public, as required in 10 CFR Part 20, Subpart D, by evaluations and measurements.

Based on its shielding analyses, Holtec developed criteria for the radiation protection program in its proposed CoC Appendix A-100U, TS 5.7 for the 100U storing the allowable HI-STORM 100 system contents. The criteria include the requirements for the cask user to (1) establish cask specific surface dose rate limits based on its 10 CFR 72.212 analyses; (2) assure maximum surface dose rates are below values based on the bounding shielding calculations for the top of the VVM; (3) measure dose rates at specific locations on the cask; and (4) implement specific corrective actions if measured dose rates during operations exceed the limits. The dose rate limits and measurements for the HI-STORM 100U System were proposed based on considerations that are necessary to ensure shielding effectiveness of the as-fabricated HI-STORM 100U System, and with regard to importance to occupational and public dose.

The staff reviewed the proposed limits and measurements with consideration of these parameters and finds that they are acceptable based upon the following. The proposed locations for limits and the respective measurements include the outlet vent screen and the top of the VVM lid, with a maximum limit, based upon the design-basis shielding analysis, for the top of the VVM lid. Staff considered whether a limit was needed for the VIP or Top Surface Pad TSP since this area is also part of the VVM. The staff evaluated Holtec's dose rate analyses including the dose rate profile and the dose rate from the ICCPS test station as well as the other requirements placed on the VIP and TSP. While the dose rate profile indicated that these pads contribute up to about 30% of the annual public dose, the overall annual dose is quite small. Even with a doubling of this contribution, the overall annual dose remains less than 15 mrem at 100 meters. The staff considers that any defect (e.g., void, crack, etc.) from fabrication that can act as a streaming path would be bounded by the analysis for the ICCPS test station, which based upon the test station's location, results in a surface dose rate that is double the dose rate of the surrounding concrete but is still a small dose. Additionally, the TSP and VIP must meet structural requirements set forth in the CoC Appendix B-100U. They must also be able, together with the subgrade, to support the transfer device (crawler) used to move a loaded transfer cask to the HI-STORM 100U location. The staff finds that, based upon these considerations, a TS dose rate limit is not needed for the TSP and VIP.

The staff also considered whether a limit should be set for the inlet vent. Unlike the inlet vents for the aboveground overpacks, the inlet vent for the HI-STORM 100U System extends the entire circumference of the VVM. Additionally, the surface dose rates are highest at the inlet vent, unlike for the aboveground overpacks where the inlet vent has a dose rate that is at most about half of the maximum on the cask surface. Further, it appears from the dose rate profile (refer to the UFSAR table associated with UFSAR Figure 5.I.3) that the vents are significant contributors to the annual dose at 100 meters. However, as remarked in the preceding paragraph, the annual dose at 100 meters is quite low. Even doubling the apparent contribution from the vents results in an annual dose that is still low (less than 15 mrem). Furthermore, the measurement required for the TS limit for the VVM lid covers the same areas of the cask geometry that would be covered by a measurement of the inlet vent; thus any defects (e.g., voids, etc.) from fabrication that would affect the inlet dose rate would also affect the lid dose rate. Additionally, based upon its own radiation protection program, the general licensee will perform radiation surveys and set limits and conditions for work activities around the cask commensurate with the measured dose rates. The staff also notes that the vertical extent of the inlet vent is small and that other factors impacting dose rates are controlled by other considerations such as the minimum depth of the MPC in the VVM to avoid impact by a dropped VVM lid, TS, and allowable contents. Based upon these considerations, the staff finds that a TS dose rate limit is not needed for the inlet vent. Any changes to the conditions relied upon in these determinations may necessitate the revisiting of the need for dose rate limits in these areas.

10.5 Public Exposures from Design-Basis Accidents and Natural Phenomena Events

UFSAR Chapters 5 and 11 provide evaluations of direct radiation dose rates for accident conditions and natural phenomena events to individuals beyond the controlled area. The confinement function of the canister is not affected by design-basis accidents or natural phenomena events. Therefore, there is no credible release of contents. As discussed in SER Sections 5.4.4 and 5.4.5 the accident direct-radiation dose analysis is determined for the worst case shielding conditions, which is the loss of water in the water jacket of a loaded transfer cask. This resulted in a dose at the controlled area boundary that is 50% below the regulatory limit specified in 10 CFR 72.106(b). The submitted UFSAR did not identify an accident that significantly degrades the shielding of the VVM when excavation is not occurring nearby. The shielding may be impacted by accidents during excavation next to the ISFSI since the soil (the shielding) is exposed. As discussed in SER Section 5.4.4 a tornado missile penetrating the soil to the VVM was analyzed, and the dose from this scenario is bounded by the dose from the worst case transfer cask accident. The staff raised further concerns regarding the soil stability and the maintaining of the soil in the RPS with the occurrence of other accidents or natural phenomena (e.g., seismic events) during excavation next to the ISFSI. Holtec then proposed TS requirements for a retaining wall to prevent the loss of the RPS soil during such events. However, due to concerns regarding accident evaluations (see SER Section 5.1.1) for excavation next to an operating ISFSI, the staff modified the TS to further increase the minimum distance between an operating HI-STORM 100U System ISFSI and excavation activities and remove the Holtec proposed retaining wall. UFSAR Chapter 11 discusses the corrective actions for each design-basis accident, as appropriate.

The staff evaluated the public dose estimates for a HI-STORM 100U System storing the proposed contents for accident conditions and natural phenomena events and found them acceptable. Discussions of the staff's review of and findings regarding the shielding and confinement analyses for the relevant design-basis accidents are presented in SER Sections 5 and 7 of this SER. A discussion of the staff's review of and findings regarding the accident conditions and recovery actions are presented in SER Section 11. The staff has reasonable assurance that the effects of direct radiation from bounding design-basis accidents and natural phenomena will be below the regulatory limits in 10 CFR 72.106(b).

10.6 Evaluation Findings

Based on the NRC staff's review of information provided in the HI-STORM 100 Cask System amendment application, the staff finds the following:

F10.1 The UFSAR sufficiently describes the radiation protection design bases and design criteria for the structures, systems, and components important to safety.

F10.2 Radiation shielding and confinement features are sufficient to meet the radiation protection requirements of 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106.

F10.3 The HI-STORM 100 Cask System is designed to provide redundant sealing of the confinement system.

F10.4 The HI-STORM 100U System is designed to facilitate decontamination to the extent practicable.

F10.5 The UFSAR adequately evaluates the HI-STORM 100 Cask System and the ITS SSCs to demonstrate that they will reasonably maintain confinement of radioactive material under normal, off-normal, and accident conditions.

F10.6 The UFSAR sufficiently describes the means for controlling and limiting occupational exposures for the proposed contents within the dose and ALARA requirements of 10 CFR Part 20.

F10.7 Operational restrictions necessary to meet dose and ALARA requirements in 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106 are the responsibility of the site licensee. The HI-STORM 100 Cask System is designed to assist in meeting these requirements.

F10.8 The staff finds the design addresses construction activities involving excavation (for ISFSI expansion) adjacent to the (operating) HI-STORM 100U System addition sufficient to ensure that the shielding features will continue to be sufficient to meet the radiation protection requirements of 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106.

F10.9 The staff concludes that the design of the radiation protection system of the HI-STORM 100 Cask System remains in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the radiation protection system design provides reasonable assurance that the HI-STORM 100 Cask System will provide safe storage of spent fuel. This finding is based on a review that considered the regulation itself, the appropriate regulatory guides, applicable codes and standards, Holtec's analyses, the staff's confirmatory analyses, and acceptable engineering practices.

11.0 ACCIDENT ANALYSIS EVALUATION

11.1 Dose Limits for Off-Normal Events

The staff reviewed the consequences of postulated off-normal events with respect to 10 CFR 72.104(a) dose limits, and found them acceptable. The radiation consequences from off-normal events are essentially the same as for normal conditions of operation for the proposed contents and design. The staff has reasonable assurance that the dose to any individual beyond the controlled area will not exceed the limits in 10 CFR 72.104(a) during off-normal conditions (anticipated occurrences). Sections 5, 7, and 10 of this SER further examine the radiological doses applicable to off-normal events, as appropriate.

11.1.1 Dose Limits for Design-Basis Accidents and Natural Phenomena Events

The staff reviewed the design-basis accident analyses with respect to 10 CFR 72.106(b) dose limits. The staff finds the analyses acceptable with respect to an operating HI-STORM 100U System ISFSI without excavation nearby. As described in earlier sections of this SER (e.g., Section 5.1.1), due to the unique configuration of the HI-STORM 100U System design, staff had concerns regarding accidents and natural phenomena events occurring during excavation next to an operating HI-STORM 100U System ISFSI. While some events were evaluated by Holtec, the staff considers the analysis to be insufficient (as described in the earlier SER sections). Therefore, to address accident and natural phenomena events not analyzed for excavation occurring near the ISFSI, a minimum distance of ten times the excavation depth must be maintained between the excavation site and the ISFSI Radiation Protection Space. The staff finds that the prescribed distance is sufficient to ensure the soil of the ISFSI (which acts as shielding) remains in place during accidents with nearby excavation. Based upon the foregoing, the staff has reasonable assurance that the dose to any individual at or beyond the controlled area boundary of 100 meters will not exceed the limits in 10 CFR 72.106(b) for the proposed design. SER Sections 5, 7, and 10 further examine the estimated radiological doses during accident conditions.

11.3 Evaluation Findings

Based on the NRC staff's review of information provided in the HI-STORM 100 Cask System amendment request, the staff finds the following:

F11.1 Structures, systems, and components of the HI-STORM 100 Cask System continue to remain adequate to prevent accidents and to mitigate the consequences of accidents and natural phenomena events that do occur.

F11.2 Holtec has evaluated the HI-STORM 100 Cask System changes and additions to demonstrate that it will reasonably maintain confinement of radioactive material under off-normal and credible accident conditions.

F11.3 A design-basis accident or a natural phenomena event will not prevent the ready retrieval of spent fuel for further processing or disposal.

F11.4 The spent fuel will be maintained in a subcritical condition under accident conditions.

F11.5 Because instrumentation and control systems are not required, no instruments or control systems are required to remain operational under accident conditions.

F11.6 Holtec has evaluated off-normal and design-basis accident conditions to demonstrate with reasonable assurance that the HI-STORM 100 Cask System radiation shielding and confinement features continue to be sufficient to meet the requirements in 10 CFR 72.104(a) and 10 CFR 72.106(b).

F11.7 The staff concludes that the accident design criteria for the HI-STORM 100 Cask System remain in compliance with 10 CFR Part 72 and that the accident design and acceptance criteria have been satisfied. Holtec’s accident evaluation of the cask adequately demonstrates that it will provide for safe storage of spent fuel during credible accident situations. This finding is reached on the basis of a review that considered independent confirmatory calculations, the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

12.0 CONDITIONS FOR CASK USE — TECHNICAL SPECIFICATIONS

UFSAR Section 12.I. addresses differences in the operating controls and limits between the VVM and the aboveground HI-STORM 100 overpacks. The current application indicates that no site dose rate measurements are required for the HI-STORM 100U System due to its in-ground configuration, making the cask side inaccessible to personnel. The staff finds this acceptable based on the foregoing statement as well as the proposed Appendix A-100U, TS 5.7.9, that ensures a minimum thickness of soil (10.5 feet) be maintained between the nearest loaded VVM and the area of any construction activities near the ISFSI (not considering the additional distance established in Appendix B-100U, TS 3.4.7). As discussed in SER Sections 5 and 10 consideration was given to the need for dose rate limits and measurements at other areas of the HI-STORM 100U System; however, staff finds, as described in the referenced sections, that the proposed limits and measurements are acceptable.

12.1 Conditions for Use

The conditions for use of the HI-STORM 100 Cask System were modified to add descriptions of the design changes proposed in the amendment request. The proposed changes are identified in the SER Summary section.

The staff reviewed the proposed CoC and TS changes and, with the addition of the changes to Appendix A-100U TS 5.7, finds that they are appropriate for the modifications made to the HI-STORM 100 Cask System.

12.2 Technical Specifications

The TS were revised to modify the dose rate limits and account for the underground VVM in the radiation protection program, including the establishment of a RPS enclosing loaded VVMs.

Holtec supplied separate TS for the HI-STORM 100U System due to the major design, construction, and operational differences to the above ground HI-STORM 100 Cask Systems. The staff has reviewed the TS and finds that they are appropriate for the modifications made to the HI-STORM 100 Cask System.

12.3 Approved Contents and Design Features

Holtec proposed revisions to CoC 1014, Appendix B-100U, Approved Contents and Design Features, to reflect the changes to the contents for the HI-STORM 100 Cask System proposed in the amendment request. The staff has reviewed the revisions and finds that they provide sufficient information to ensure that all the contents to be stored in the HI-STORM 100 Cask System meet the design bases evaluated by the staff in SER Sections 3 through 11. To address accidents and natural phenomena events occurring during excavation near an operating HI-STORM 100U System ISFSI, CoC Appendix B-100U, TS 3.4.7 establishes the requirement that a minimum distance of ten times the excavation depth be maintained between the edge of the ISFSI Radiation Protection Space (see Appendix A-100U TS 5.7.9) and the excavation site. The staff finds that, in lieu of evaluations for these conditions during excavation near an operating ISFSI, this distance is sufficient to ensure the soil shielding of the ISFSI will remain in place under these conditions.

12.4 Technical Specification Conditions

The proposed amendment to CoC 1014, Appendix B-100U includes a new section specifying corrosion control requirements for the HI-STORM 100U System design. The HI-STORM 100U VVM/CEC container shell and bottom plate shall be protected from corrosion due to the corrosive nature of most soils by use of one or more listed methods. A choice of the method(s) to use first rests upon characterization of site specific soil corrosivity.

Soil corrosivity is categorized as either mild of aggressive in accordance with the method specified in the UFSAR. That method employs the guidelines of appendix A of ANSI/AWWA C105/A21. This classical soil evaluation method focuses on parameters such as 1) resistivity,

2) pH, 3) redox (oxidation-reduction) potential, 4) sulfides, 5) moisture content, 6) potential for stray current, and 7) experience with existing installations in the area. The soil environment is categorized as either "mild" or "aggressive" depending upon the outcome of the various evaluations.

Given a mild corrosivity index, the corrosion mitigation measures shall include use of an inorganic or inorganic coating on the exterior of the CEC plus choice of either concrete encasement or cathodic protection (or both). For an aggressive (corrosive) soil condition, the coating is required plus a cathodic protection system. Concrete encasement may also be optionally used with the other two measures.

The staff finds the proposal for identifying soil conditions and mitigating corrosion to be acceptable.

12.5 Evaluation Findings

Based on the NRC staff's review of information provided in the HI-STORM 100 Cask System amendment request, the staff finds the following:

F.12.1 The staff concludes that the proposed Conditions for Use, the TS, and the Approved Contents and Design Features contained in CoC 1014 for the HI-STORM 100 Cask System have been revised to provide reasonable assurance that the requirements of 10 CFR Part 72 have been satisfied. The TS provide reasonable assurance that the cask will provide for safe storage of spent fuel. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted practices.

13.0 QUALITY ASSURANCE EVALUATION

The purpose of this review and evaluation is to determine whether Holtec has a quality assurance (QA) program that complies with the requirements of 10 CFR Part 72, Subpart G as applicable to the changes proposed in the amendment request.

The changes requested by Holtec associated with the HI-STORM 100 Cask System have not altered the staff’s previous assessment of the QA program. Therefore, the staff did not reevaluate this area for the amendment request.

14.0 DECOMMISSIONING

The modifications requested by Holtec have not altered the staff’s previous assessment of decommissioning considerations associated with the HI-STORM 100 Cask System. Therefore, the staff did not reevaluate this area for the amendment request.

15.0 CONCLUSIONS

15.1 Overall Conclusion

The staff has reviewed the proposed changes to CoC 1014. With addition of the following staff requirements for the HI-STORM 100U System:

a. Restrict the proposed design of the support foundation to sites where the support foundation rests directly on bedrock or on substrate material having a shear wave velocity equal to or greater than 3500 feet per second (fps),

b. No excavation activities associated with the construction of new VVMs shall take place within a distance from the RPS equal to ten times the depth of the planned excavation,

and based on the statements and representations contained in the UFSAR, and the conditions given in the CoC as amended, the staff concludes that the HI-STORM 100 Cask System continues to meet the requirements of 10 CFR Part 72.

15.2 Conclusions Regarding Analytical Methods

The staff determined that, unless otherwise noted in this SER, all analytical methods used by Holtec that provide the basis for design modifications and the addition to the list of approved cask contents for the HI-STORM 100 Cask System proposed in the amendment request, are acceptable. However, for the purposes of the amendment request review, the staff did not revisit any previously approved methodologies used in the original HI-STORM 100 Cask System application or those reviewed for Amendments 1, 2, 3, 4, 5, and 6 and did not make any new determination on the adequacy of those methodologies unless the methodology was used as the basis for a proposed amendment change.

REFERENCES

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