SAFETY EVALUATION REPORT

DOCKET NO. 72-1014
HOLTEC INTERNATIONAL
HI-STORM 100 CASK SYSTEM
CERTIFICATE OF COMPLIANCE NO. 1014
AMENDMENT NO. 9

SUMMARY

By letter dated September 10, 2010, as supplemented October 1, 2010, July 29, November 14, 2011, April 17 and May 15, 2013, Holtec International (Holtec or applicant) submitted amendment request No. 9 to the U.S. Nuclear Regulatory Commission (NRC) for the HI-STORM 100 Certificate of Compliance (CoC) No. 1014. The applicant proposed the following revisions to CoC No. 1014:

I. Broadening the subgrade requirements for the HI-STORM 100U part of the HI-STORM 100 Cask System, and

II. Updating the thermal model and methodology for the HI-TRAC transfer cask from a two dimensional (2-D) thermal-hydraulic model to a more accurate three dimensional (3-D) model. The re-analyses included the conditions of vacuum drying of the multipurpose canister (MPC), on-site transfer of the dry MPC, and time to boil calculations.

<u>Proposed changes associated with Proposed Revision I were:</u>

A. Removing the restriction that requires the Independent Spent Fuel Storage Installation (ISFSI) support foundation pad (SFP) to rest on a subgrade material with a shear wave velocity greater than or equal to 3500 ft/s or bedrock.

B. Removing the restriction that requires any excavation, near an operating 100U ISFSI, to be a distance of ten times the depth of the excavation away from the ISFSI.

C. Removing the requirement to account for amplification in the seismic analysis.

<u>The proposed CoC and Technical Specifications (TS) modifications to accomplish proposed revision I were:</u>

1. Revising TS Appendix B-100U Section 3.4. (Changes A and B)

Deleting CoC, Condition #12, and renumbering the subsequent Condition. (Change C)

Proposed changes associated with Proposed Revision II were:

D. (1) Removing the requirement for a supplemental cooling system (SCS) for any heat load less than 90% of maximum allowable heat load limits (when MPC contains one or more fuel assemblies with an average burnup greater than 45,000 MWd/MTU) to maintain spent nuclear fuel peak cladding temperatures below the Interim Staff Guidance (ISG) -11, Rev. 3 guidance limits,
(2) Increasing the decay heat thresholds for MPC vacuum drying for both unlimited and time restricted vacuum drying, and
(3) Adding time-to-boil limits for various decay heat loads and initial spent fuel pool temperatures.

E. Re-analyzing the accident scenarios involving the HI-TRAC transfer cask, i.e. loss of water in the water jacket.

The proposed CoC and Technical Specifications (TS) modifications to accomplish proposed revision II were:

3. Revising TS Appendix A, Limiting Condition for Operation (LCO) 3.1.1.
4. Revising TS Appendix A, LCO 3.1.2.
5. Revising TS Appendix A, LCO 3.1.4.
6. Revising TS Appendix A, Table 3-1.
7. Revising TS Appendix A, Table 3-2.
8. Adding TS Appendix A, Table 3-3.
9. Adding TS Appendix A, Table 3-4.
10. Revising TS Appendix A-100, LCO 3.1.1.
11. Revising TS Appendix A-100, LCO 3.1.2.
12. Revising TS Appendix A-100, LCO 3.1.4.
13. Revising TS Appendix A-100, Table 3-1.
14. Revising TS Appendix A-100, Table 3-2.
15. Revising TS Appendix B, Section 3.7.

16. Adding TS Appendix B, Section 3.9.

17. Revising TS Appendix B-100U; Section 3.7.

18. Adding TS Appendix B-100U, Section 3.9.

Additionally, the following editorial (non-substantive) modifications were requested by Holtec in its September 10, 2010, application, or identified by the staff:

19. CoC CONDITIONS, first sentence. Changing “Conditioned” to “Conditional” to provide consistency in the CoC. (staff supplied)

20. Revising Appendix A and Appendix A-100U; SR 3.1.1.3 to “Verify that the helium leak rate through the MPC vent and drain port cover plates (confinement welds and the base metal) meets the leak tight criteria of ANSI N14.5-1997” to be consistent

    with the change made to the CoC, Condition No. 3 in Amendment No. 8. (Holtec supplied)

21. Correcting Appendix A-100U; Table 3-1. “< 30” to ≤ 30” to be consistent with Appendix A. (Holtec supplied)

1.0 REVIEW CRITERIA

This safety evaluation report (SER) documents the NRC staff (staff) review and evaluation of the proposed amendment. The SER uses the same Section-level format provided in NUREG-1536, Rev.1, “Standard Review Plan for Dry Cask Storage Systems,” with some differences implemented for clarity and consistency.

The staff assessment is based on whether the CoC continues to meet the applicable requirements of 10 CFR Part 72 to ensure health and safety to the public. The staff’s assessment focused only on modifications requested in the amendment as supported by submitted revised Final Safety Analysis Report (FSAR) pages and supporting analyses, and did not reassess CoC Amendments previously approved through Amendment No. 8.

2.0 PRINCIPAL DESIGN CRITERIA EVALUATION

There were no requested changes requiring evaluating the principal design criteria related to the structures, systems, and components (SSCs) important to safety to ensure compliance with the relevant general criteria established in 10 CFR Part 72.

3.0 STRUCTURAL EVALUATION

The structural review evaluated Proposed Revision I submitted by the applicant and the associated proposed changes were:

A. Removing the restriction that requires the Independent Spent Fuel Storage Installation (ISFSI) support foundation pad (SFP) to rest on a subgrade material with a shear wave velocity greater than or equal to 3500 ft/s or bedrock.

B. Removing the restriction that requires any excavation, near an operating 100U ISFSI, to be a distance of ten times the depth of the excavation away from the ISFSI.

C. Removing the requirement to account for amplification in the seismic analysis.

The proposed modifications to the CoC and TS were:

1. Revising TS Appendix B-100U Section 3.4. (Changes A and B)
2. Deleting CoC, Condition #12, and renumbering subsequent Condition. (Change C)

CoC No. 1014, Amendment No. 7, Appendix B-100U, Section 3.4 provided a requirement that the ISFSI SFP be placed on a subgrade material with a shear wave velocity of 3500 ft/s or bedrock. The applicant requested the removal of this condition. In order to remove this restriction the applicant had to demonstrate that the design basis earthquake and the design basis seismic model bound the target site characteristics including the lower bounding soil properties. In addition, all important to safety (ITS) components are required by regulations to be designed to resist the loadings that result from the design basis earthquake (DBE) as evaluated by the design basis seismic model. The subgrade surrounding the vertical ventilated module (VVM), the SFP, the VVM interface pad (VIP), the top surface pad (TSP), and the retaining wall (if used) are classified as ITS components (refer to Table 2.I.8 of the FSAR).

In order to remove the CoC 1014, Amendment No. 7, restrictions, per 10 CFR Parts 72.24(d) and 72.212(b)(3), the applicant analyzed and evaluated a target design and determined the specific controlling parameters for that design, so that a prospective general licensee could determine whether the site specific parameters are enveloped by the design parameters. 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)).

3.1 Design Basis Earthquake

The applicant's generic seismic loading establishes the combination of the response spectra of the design basis earthquake (DBE) and potential site characteristics (e.g. soil profile) that maximize internal stresses on SSCs that are ITS and is required per 10 CFR 72.102(f).

In order to determine the DBE the applicant performed a two step seismic analysis (SHAKE/ LS-DYNA) that utilized a lower bound soil shear wave velocity profile representative of most nuclear power plant sites in the United States. The applicant established two sets of response spectra at the SFP elevation and the TSP elevation. These response spectra were obtained from a two step seismic analysis (SHAKE/ LS-DYNA) that utilized a lower bound soil shear wave velocity profile representative of most nuclear power plant sites in the United States.

The applicant's first step of the analysis (SHAKE2000) used methodology in Regulatory Guide 1.60 and NUREG-0800 to generate the rock outcrop (base of soil column) synthetic time history scaled to specified ground surface zero period accelerations (ZPA). The resultant average strain compatible shear wave velocities were then used to specify the minimum material properties for the soil profile used in the second step.

The applicant's second step of the analysis (LS-DYNA) used the developed soil profile, extending from the rock outcrop surface to the free ground surface, and the synthetic time history from step one to verify that the LS-DYNA model would accurately simulate the free field (no ISFSI present) seismic response (ZPAs) obtained from the SHAKE2000 analysis. The LS-DYNA model was subsequently used in the seismic response analysis of the in place ISFSI.

These values were provided in the applicant's September 10, 2010, application.

3.2 Design Basis Seismic Model

The applicant's overall seismic analysis was composed of three steps that include the bounding soil model and bounding acceleration time history development, application of the bounding soils and time history to the in-place ISFSI and determination of the resultant loadings on ISFSI structures, and finally, an evaluation of the overall structural performance of the VVM components.

The initial design basis seismic model was developed as part of the Hi-STORM 100, Amendment No, 7certification and consisted of:

(1) A VVM Array Model
(2) A VVM Array Model with Optional Retaining Wall
(3) A single VVM Model

3.2.1 VVM Array Model

The VVM array model consisted of a fully loaded 5x5 array that the applicant used to evaluate the interaction between the soil and the in-place ISFSI structure and to extract the bounding dynamic loads on the ISFSI structures to facilitate structural design of ITS components.
The VVM array model was also constructed to allow for evaluation of the following:

(1) Presence of the vertical cask transporter (VCT)
(2) Effect of discrete components of the VVM including the MPC, divider shell, the cavity enclosure container (CEC) shell, the closure lid, and the lid ring

3.2.2 VVM Array Model with Optional Retaining Wall

The applicant's subsequent VVM array analysis with optional retaining walls included soil removed down to the SFP to simulate a seismic event during an open pit excavation (limited accident evaluation).

3.2.3 Single VVM Model

The applicant used the single VVM model to demonstrate reasonable assurance of safety of the VVM components, including the MPC during a DBE. The single VVM model was arranged such that the SFP is loaded with one VVM at the periphery of the pad with a representative VCT placed over the loaded VVM. The applicant performed its analysis with the bounding design basis acceleration time history.

3.3 Strength Qualification of the ISFSI Structures

The applicant analyzed the strength qualification of the ISFSI structures under design basis seismic loading by extracting the peak interface loads obtained from the soil structure interaction (SSI) analyses and applying them to a quasi-static finite element analysis. Furthermore, the applicant utilized actual input loads larger than the peak loads obtained from the LS-DYNA analyses to provide additional margin of safety. Table 2.I.2 of the applicant's submitted revised FSAR provides the minimum requirements for the SFP, TSP, and retaining wall(s) if used. The SFP, TSP, and retaining wall meets the American Concrete Institute ACI-318 (2005) strength limits for all load combinations applicable for this design.

The applicant's quasi-static structural analysis utilized the ANSYS finite element analysis software. The following is a summary of the applicant's model formulation:

- SFP, TSP, Subgrade beneath TSP is modeled with elastic SOLID45
- VVM Interface Pad (VIP) is omitted since it has expansion joints
- The lateral subgrade adjacent to the ISFSI is included in the finite element (FE) model
- The element mesh is intentionally kept fine in the areas of load application on the SFP and the TSP.
- The substrate under the SFP is 101 ft below the TSP
- Quarter symmetry is utilized
- Simulation Model II uses a full FE model since it is non-symmetric

The following is a summary of the VVM loading configurations that the applicant considered:

- Simulation Model I: all the storage locations in the ISFSI are populated and experience identical bounding peak vertical seismic loading

- Simulation Model II: Two rows of VVM locations adjacent to the symmetry line loaded

- Simulation Model III*:* single middle row of VVM is loaded

- Simulation Model IV: Single VVM loaded centered near the periphery of the ISFSI

- Simulation Model V: Similar to Model III but with lateral subgrade surrounding the retaining walls removed. Effects of the transporter also not considered since loading activities will be suspended during excavations.

- Simulation Models I, II, III and IV, apply the peak bearing load from the LS-DYNA SSI analysis from a single transporter track as a static load to both transporter tracks footprints simultaneously.

- No credit was taken for the dynamic increase factor of 25% for flexure and 10% for shear permitted by the strength qualification of reinforced concrete.

<u>Governing Load Combination</u>

Load combination of 1.2D + E + L (LC-3) governed due to the large magnitudes of the seismic loading; however, all load combinations were evaluated to verify that LC-3 was the governing case.

Minimum Flexural Factor of Safety

The minimum flexure safety factor is produced by Simulation Model IV, and it is associated with the TSP.

Punching Shear

The punching shear safety factor for the SFP and TSP is summarized in the submitted revised FSAR Table 3.I.11. The minimum safety factor determined by the applicant for the TSP subject to punching shear exceeded 1.0.

Bearing Stress

The peak dynamic transporter load on the TSP and the load from the TSP were used to compute the maximum bearing stress in the substrate surface under the TSP. The resulting minimum safety factor exceeded the minimum value of 2.0 prescribed by the ACI 318.

Retaining Wall

The applicant evaluated the retaining wall for the DBE loads. The applicant determined that the structural demand to the wall under normal operational conditions was small when compared with the loadings due to seismic loads. This is consistent with the governing load combination for the TSP and SFP. The retaining wall is connected with the TSP and SFP through a shear key at the top and dowels at the bottom. The primary structural demand is due to bending stress due to soil loading.

The applicant determined the maximum bending moment of the retaining wall by utilizing results from the LS-DYNA SSI analysis, and positive margins of safety are shown in the revised submitted FSAR Table 3.I.10. The applicant stated the shear connections at the top and bottom of the retaining wall were also evaluated for the loads induced during a DBE, redesigned, and subsequently reported in revised submitted FSAR sections. The results of the strength evaluation were provided in the submitted revised FSAR Table 3.I.13

The applicant stated that the structural analysis of the ISFSI *"conservatively considers the peak dynamic loads from the LS-DYNA SSI analysis. However, it shall be permitted to use equivalent static loads obtained by removing high frequency components that would not contribute to the structural response using appropriate filters."*

The staff finds the applicant's revised analysis is consistent with standard industry practices and LS-DYNA recommendations and finds this acceptable.

3.4 Seismic Event During ISFSI Excavation

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. The HI-STORM 100U System has non-integral shielding (soil) that is susceptible to being stripped from the system during a seismic event occurring during construction activities involving excavation near the installed ISFSI when a retaining wall is not used.

3.4.1 No Retaining Wall Scenario

Section 2.I.2 of the supplied updated FSAR item (vi) states:

> *For the case where a retaining wall is not installed, no excavation activities associated with the construction of a new underground ISFSI shall take place within a distance from the RPS equal to ten times the planned excavation depth. Alternatively, the Excavation Exclusion Zone (EEZ), defined as the minimum distance from the centerline of a VVM located on the periphery of the ISFSI to where the effect of DBE is sufficiently attenuated such that a full depth excavation will not cause collapse of the lateral sub-grade at the RPS boundary during an earthquake, can be determined by a site specific seismic analysis. If a retaining wall is installed at or beyond the RPS then the wall becomes the EEZ boundary.*

3.4.2 Retaining Wall Scenario

In the NRC's June 20, 2011, RAI, the staff requested the following:

> *RAI 3-4 - Demonstrate that defining the retaining wall, when used, as the Excavation Exclusion Zone (EEZ) boundary will not cause adverse effects on the structural integrity of the TSP or SFP under design basis loadings including earthquake.*
>
> *Section 2.1.2 HI STORM 100U WM Components, ISFSI Structures, and Corrosion Mitigation Measures, item (vi) Retaining Wall states: "If a retaining wall is installed at or beyond the RPS then the wall becomes the EEZ boundary."*
>
> *The staff identified a potential excavation depth of 30 feet beyond the bottom surface of the SFP in Section 3.2.3 of the SER for Amendment 7 of the HI-STORM 100 Cask System, which could be as close as the Radiation Protected Space for the ISFSI if a retaining wall is used. The safety concern identified was specific to the loss of shielding of the lateral soil should an earthquake event occur simultaneously with excavation activities.*
>
> *A potential open pit adjacent to the Radiation Protection Space (RPS) with a retaining wall installed also presents a safety concern with respect to the structural integrity of the SFP and TSP for normal, off-normal, or accident conditions. Staff does not have reasonable assurance that the subgrade*

integrity below the SFP has been sufficiently analyzed for excavation activities to demonstrate no adverse effects on the SFP and subsequently the TSP.

This information is required to evaluate compliance with 10 CFR Part 72.212(b)(2)(i)(B).

Holtec provided the following in its July 29, 2011, RAI response:

Section 2.I.2.vi of the HI-STORM 100 FSAR has been revised to clarify the limitations on excavation activities with and without a retaining wall installed. Most notably, when a retaining wall is installed on one or more sides of the 100U ISFSI, excavation activities associated with the construction of a new underground ISFSI can be performed directly adjacent to the retaining wall(s) at depths above the bottom surface of the existing SFP. Soil excavations below the elevation corresponding to the bottom surface of the existing SFP are not permitted within a distance from the RPS equal to ten times the planned excavation depth, regardless of whether a retaining wall is installed or not, unless a site specific seismic analysis is performed demonstrating the stability of the RPS boundary and the structural integrity of the ISFSI structure

In its October 2, 2011, RAI, the staff requested the following:

“If this statement is included in the FSAR as a basis of consideration, then a license condition will be required to be added to the Certificate of Compliance (CoC) to state that "the site-specific seismic analysis performed to demonstrate the stability of the RPS boundary and structural integrity of the ISFSI structure shall be submitted to the NRC for review and approval prior to any excavation taking place."

In its November 14, 2011, RAI response, Holtec proposed that the following condition be incorporated in the Technical Specifications:

Excavation activities contiguous to a loaded ISFSI which contains a retaining Wall on the side facing the excavation can occur down to the depth of the bottom surface of the SFP of the loaded ISFSI considering that there may be minor variations in the depth due to normal construction practices. For all other excavation activities, the site-specific seismic analysis performed to demonstrate the stability of the RPS boundary and structural integrity of the ISFSI structure shall be submitted to the NRC for review and approval prior to any excavation taking place.

The staff finds that ,for excavation activities that are not bounded by the CoC 1014, Amendment No. 9, an amendment request to the NRC in accordance with 10 CFR 72.246 would be required. . A provision has been included to CoC No. 1014, Appendix B - 100, Section 3.4, to capture this requirement. Holtec agreed with this requirement in its February 20, 2012, correspondence to the NRC.

3.5 Review Summary and Evaluation Findings

The staff finds that the applicant has acceptably provided a comprehensive design basis seismic model that included bounding soil properties for most United States nuclear reactor sites, an SSI analysis incorporating bounding soil properties, an SSI analysis with transporter loads included, and a bounding acceleration time history to create a complete design basis to be compared against when performing a site specific analysis. Using the appropriate load combinations, including dead loads, live loads, seismic loads, and long term settlement, the applicant presented a complete design of all ISFSI structures with positive margins of safety. The results also indicate that the CEC shell, divider shell, the MPC shell, MPC top and bottom guides, fuel basket panels, and localized MPC strains all maintain positive margins of safety. As a result of the analysis and subsequent margins demonstrating assurance of safety, the staff finds that the condition restricting the CoC 1014, Amendment No. 7 ISFSI design 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 is no longer required.

Specifically, by incorporating the VCT in the SSI analysis, the staff finds that the applicant has acceptably accounted for pad flexibility and subsequent amplification of the net horizontal acceleration on the ISFSI. Furthermore, since the SSI analysis has also considered bounding soil profiles, no further modifications (i.e. reduction of the unamplified pad net horizontal acceleration an amplification factor) to the site specific seismic analyses are required provided the site parameters are bounded by the general license conditions set forth in CoC 1014, Amendment No. 9.

<u>Findings</u>

3.5.1 The staff reviewed the applicant’s SSI analysis of the ISFSI with excavations down to the SFP and subjected to a DBE (VVM Array Model with Optional Retaining Wall). Furthermore, the staff also reviewed the quasi-static structural evaluation of the same condition (Simulation Model V) and found it acceptable. The staff finds that in both cases, the applicant demonstrated that the conditions evaluated for a bounding earthquake and lower bound soil properties will not adversely impact the structural or operational performance of the retaining wall. The staff finds it acceptable that excavations can occur down to the bottom surface of SFP because the applicant has acceptably demonstrated, as part of their SSI analysis, that there are no safety concerns with excavations to this depth, even directly adjacent to the perimeter retaining walls.

3.5.2 The staff finds that CoC 1014 continues to meet the requirements of 10 CFR 72.122(b) and (c), (Overall requirements, Protection against environmental conditions and natural phenomena and Protection against fires and explosions) and 10 CFR 72.24(c)(3), (Contents of application; Technical information.” The SSCs important to safety are designed to accommodate the combined loads of normal, off-normal, accident, and natural phenomena events with an adequate margin of safety. Stresses at various locations of the cask for various design loads are determined by analysis. Total stresses for the combined loads of normal, off normal, accident, and natural phenomena events are acceptable because they remain within limits of applicable codes, standards, and specifications.

3.5.3 The staff finds that CoC 1014 continues to meet the requirements of 10 CFR 72.124(a), (Design for criticality safety," and 10 CFR 72.236(b), (Design bases and design criteria must be provided for structures, systems, and components important to safety). The structural design and fabrication includes acceptable structural margins of safety for those SSCs important to nuclear criticality safety. The staff finds that the applicant demonstrated acceptable structural safety for the handling, packaging, transfer, and storage under the normal, off-normal, and accident conditions that are identified in the FSAR.

3.5.4 The staff finds that CoC 1014 continues to meet the requirements of 10 CFR 72.236(I), specific requirements for spent fuel storage cask approval and fabrication." The staff evaluated the applicant's analyses and supporting documentation and determined that the applicant has acceptably demonstrated that the cask and other systems important to safety continue to maintain confinement of radioactive material under normal, off-normal, and credible accident conditions identified in the FSAR.

4.0 THERMAL EVALUATION

4.1 Review Objective

The objective of this evaluation is to assess the applicant's revised thermal analyses for the loaded MPC during short-term on-site transfer operations. The applicant proposed to update the thermal model and methodology for the HI-TRAC transfer cask from a 2-D thermal-hydraulic model to a more accurate 3-D model with the intent of determining that a supplemental cooling system (SCS) is only required for onsite transfer for any heat load exceeding 90% of maximum allowable heat load limits when a MPC contains one or more fuel assemblies with an average burnup greater than 45,000 MWd/MTU). The applicant's proposed thermal changes are provided below.

D. The applicant proposed:

   (1) Removing the requirement for a supplemental cooling system (SCS) for any heat load less than 90% of maximum allowable heat load limits (when MPC contains one or more fuel assemblies with an average burnup greater than 45,000 MWd/MTU) to maintain spent nuclear fuel peak cladding temperatures below the Interim Staff Guidance (ISG) -11, Rev. 3 guidance limits,

   (2) Increasing the decay heat thresholds for MPC vacuum drying for both unlimited and time restricted vacuum drying, and

   (3) Adding time-to-boil limits for various decay heat loads and initial spent fuel pool temperatures.

E. The applicant proposed using a more accurate 3-D model to reanalyze the accident scenarios involving the HI-TRAC transfer cask, i.e. loss of water in the water jacket.

The proposed modifications to reflect these in the CoC and TS were:

3. Revising TS Appendix A, Limiting Condition for Operation (LCO) 3.1.1.

4. Revising TS Appendix A, LCO 3.1.2.

5. Revising TS Appendix A, LCO 3.1.4.

6. Revising TS Appendix A, Table 3-1.

7. Revising TS Appendix A, Table 3-2.

8. Adding TS Appendix A, Table 3-3.

9. Adding TS Appendix A, Table 3-4.

10. Revising TS Appendix A-100, LCO 3.1.1.

11. Revising TS Appendix A-100, LCO 3.1.2.

12. Revising TS Appendix A-100, LCO 3.1.4.

13. Revising TS Appendix A-100, Table 3-1.

14. Revising TS Appendix A-100, Table 3-2.

15. Revising TS Appendix B, Section 3.7.

16. Adding TS Appendix B, Section 3.9.

17. Revising TS Appendix B-100U; Section 3.7.

18. Adding TS Appendix B-100U, Section 3.9.

4.2 HI-TRAC Thermal Model

The applicant performed a 3-D thermal analysis using 3-D FLUENT to evaluate the thermal state of a loaded MPC during short-term operations (transfer evolutions). The thermal analyses to determine the margins of safety were performed for the maximum design basis heat load, ~~using the~~using the MPC model that yielded the highest peak cladding temperature (PCT).

The applicant's 3-D FLUENT model of the HI-TRAC transfer cask thermal analysis incorporated the following assumptions:

1) A constant solar flux with maximum permissible heat load and asymptotic steady state conditions to yield the most adverse temperature field in the cask. A theoretically bounding solar absorbtivity of 1.0 was applied to all exposed surface. This was a conservative assumption because it provides for greater heat absorption.

2) The annular gap between MPC shell and HI-TRAC inner shell is explicitly modeled as a fluid zone.

3) Although the HI-TRAC baseplate is in contact with supporting surfaces it was modeled as an insulated boundary condition. This was a conservative assumption because it ignored heat transfer across this surface interface.

4) The HI-TRAC fluids columns in the water jacket and the open air volume above the MPC were assumed to remain in the laminar flow regime.

5) The water density in the water jacket is defined as a function of temperature.

6) Buoyancy driven motion of air above the MPC was assumed in the thermal model.

7) Radiation heat transfer was simulated by the discrete ordinates (DO) model, and

8) The rodded zone, that contains the spent fuel assemblies, is modeled as a homogeneous porous media. The viscous resistance factor of $1x10^{6}$ m^{-2} is used for the bottom inactive zone, active zone, and top inactive zone. The number of $1x10^{6}$ m^{-2} value was derived based on a thermal-hydraulic experiment performed at Sandia National Laboratory for a 17x17 PWR fuel assembly. Specifically, the data was part of a 1 kW separate effect test performed on February 11, 2011, as part of the Organisation for Economic Co-Operation and Development /Nuclear Energy Agency Spent Fuel Pool Project to study pressurized-water reactor spent fuel heat-up and propagation phenomena provided by the NRC staff to the applicant on March 7, 2013 (ADAMS Accession No. ML13199A111).

The applicant performed a grid sensitivity analyses for the following parameters: flow resistance factor of $1x10^{6}$ m^{-2}; 90% of design basis maximum heat load under a regionalization parameter of X = 3.0; and 90°F ambient temperature with insolation. Based on the sensitivity analyses of meshing, mesh grid layout #2 (Mesh 2) provided the reasonably converged results and was selected for normal on-site transfer calculations in this Amendment application. The applicant also performed a grid independence study, per ASME V&V 20-2009, to evaluate the spatial discretization error. The calculation of grid convergence index (GCI), which is a measure of the solution uncertainty, is computed as 0.37%. The staff reviewed the GCI calculation submitted by the applicant and confirmed that the approximate relative error of 0.136% and the GCI of 0.37% are acceptable.

4.2.1 Time-to-Boil for a Water-Filled MPC Evaluation

In the wet transfer operations, forced water circulation is required to maintain decay heat removal from the MPC cavity if the time to boil limit provided in FSAR Table 4.5.3 is exceeded. In the application, Holtec proposed to provide additional flexibility and accuracy for the general user to determine the “time to boil” in addition to that provided in FSAR Table 4.5.3. Specifically the applicant proposed the following:

> The user can determine the maximum allowed time limit for wet transfer or “time to boil limit” using equations ~~4.5.2.1 and 4.5.2.2~~the below equations and substituting the total MPC heat load for Q. The total MPC heat load can be calculated by summing the individual, as-loaded, heat loads in all the storage cells. Similarly, the user can determine M_W using equation 4.5.2.3 and substituting the as-loaded MPC heat load for Q and the temperature of the pool water supply for T_{in}.

$$\frac{dT}{dt} = \frac{Q}{C_h} \qquad \text{(equation 4.5.2.1)}$$

where:

Q = conservatively bounding heat load (Btu/hr) [38 kW = 1.3×10^5 Btu/hr]
C_h = thermal inertia of a loaded HI-TRAC (Btu/°F)
T = temperature of the HI-TRAC cask (°F)
t = time after HI-TRAC transfer cask is removed from the pool (hr)

$$t_{max} = \frac{T_{boil} - T_{initial}}{(dT/dt)} \qquad \text{(equation 4.5.2.2)}$$

where:

T_{boil} = boiling temperature of water (equal to 212°F at the water surface in the MPC cavity)
$T_{initial}$ = initial HI-TRAC temperature when the transfer cask is removed from the pool

$$M_W = \frac{Q}{C_{pW}(T_{max} - T_{in})} \qquad \text{(equation 4.5.2.3)}$$

where:

M_W = minimum water flow rate (lb/hr)
C_{pw} = water heat capacity (Btu/lb-°F)
T_{max} = maximum MPC cavity water mass temperature
T_{in} = temperature of pool water supply to MPC

The staff finds this proposed change acceptable because the applicant's methods and equations provided in the FSAR correctly utilize accepted thermodynamic principles. The staff finds that utilizing this approach to determine minimum water flow to maintain MPC cavity water temperature below boiling with an adequate subcooling margin is therefore acceptable.

4.2.2 MPC Temperatures During Moisture Removal Operations Evaluation

4.2.2.1 Vacuum Drying Operation

In order to investigate effective conductivity of fuel under vacuum drying operations, the applicant developed and evaluated a 3-D FLUENT thermal model of the MPC. The thermal model incorporated the following assumptions:

1) Threshold heat load Q1, provided in the submitted revised FSAR Table 4.5.1, was assumed and steady-state condition reached under Q1 resulted in vacuum drying without time limits.

2) Threshold heat load Q2, defined in the submitted revised FSAR Table 4.5.1, was assumed and a transient calculation was performed to determine the permissible vacuum drying time under Q2. The vacuum drying time started after MPC blowdown.

3) The external surface of the MPC shell was assumed to vary linearly from normal boiling temperature of 100°C (212°F) at the top to elevated pressure boiling temperature of 111°C (231°F) at the bottom to account for the hydrostatic head.

4) The bottom surface of the MPC is insulated.

5) The MPC internal convection heat transfer is suppressed.

6) The top surface of the MPC is in contact with air. Natural convection and radiation cooling from the MPC top is included in the thermal model.

The staff reviewed the applicant's analysis in the revised FSAR 4.5.3.1 and Table 4.5.5 as well as the Table N.5.8 of Holtec's Report HI-2043317. The applicant determined a PCT of 562°C (1043°F) at a uniform heat load of 26 kW and an ambient temperature of 110°F. The staff finds this acceptable because it meets the review guidance temperature of ISG-11, Rev. 3.

The applicant stated that the fuel assemblies with burnups less than 45 GWd/MTU are not likely to have a significant amount of hydride re-orientation due to limited hydride content. The applicant also stated that most of the low burnup fuel has hoop stresses below 90 MPa, and thus, even if hydride reorientation occurred, the network of reoriented hydrides is not expected to be extensive enough in low burnup fuel to cause fuel rod failure. The staff finds this acceptable because it is consistent with the review guidance of ISG-11, Rev. 3.

The staff finds it is acceptable to remove SCS from the vacuum drying operations when MPC contains low burnup fuel and the external surface temperature of MPC shell remains below 231°F.

4.2.2.2. Forced Helium Dehydration (FHD)

The applicant provided a discussion of the design criteria and operation of the FHD system in its supplied revised FSAR 4.5.3.2. The applicant provided an explanation of how the FHD system ensures that the fuel cladding temperature will remain below the applicable PCT limit of 752°F for normal conditions of storage. According to the applicant's explanation, in the event that the FHD system malfunctions, the forced convection state will transition into natural convection, which corresponds to the conditions of normal onsite transport. The applicant's proposed revised FSAR 4.5.3.2 stated that the PCT will approximate the values reached during normal on-site transport when the helium pressure is maintained with no loss due to leakage.

4.2.3 Maximum Temperature under Onsite Transfer Conditions

4.2.3.1 Validation of Bounding Loading Patterns

The applicant used the FLUENT 3-D thermal model of the MPC inside the HI-TRAC transfer cask described in revised FSAR section 4.5.1 to determine temperature distributions during onsite transfer. The applicant performed multiple analyses with loading patterns of X = 0.5 (Q = 36.9 kW) and X = 3.0 (Q = 30.17 kW) using ambient temperatures of 90°F (3-day average, outside an enclosed building) and 110°F (3-day average, inside an enclosed building). The results show that (1) the loading pattern of X = 3.0 was the bounding case for producing the PCT and the basket temperature, while other component temperatures are higher for X = 0.5 loading pattern and (2) the fuel cladding, MPC and HI-TRAC component temperatures are lower than the condition of 90°F ambient temperature with insolation. To provide a bounding PCT result, the applicant used the heat load scenario of X = 3 in all evaluations, with an ambient temperature of 90°F with insolation as the limiting ambient condition. The results of the applicant's analysis are provided in SER Table 4.1 (below).

Table 4.1 PCTs calculated from Holtec's analyses on Regionalized Loading

Ambient Air Temperature (Heat Load)	PCT	
	X = 3.0 (30.17 kW)	X = 3.0 (90% of 30.17 kW) (27.15 kW)
90°F (with insolation)	784°F	734°F
110°F (no insolation)	NA	730°F

For the threshold heat load scenarios defined in Tables N.5.9 (uniform storage) and N.5.10. (regionalized storage) of Holtec's report HI-2043317, the MPC-32 with uniform 28.74 kW heat load is the bounding case and has the bounding PCTs shown in Table 4.2 (below).

Table 4.2 PCTs calculated from Holtec's analyses for Threshold Heat Load Scenarios

Ambient Air Temperature (Heat Load)	PCT	
	100% of Threshold Heat Laod (MPC-32, Q = 28.74 kW)	90% of Threshold Heat Load (MPC-32, Q = 27.15 kW)
90°F (with insolation)	774°F	721°F

The applicant performed the sensitivity study by reducing 10% for both effective thermal conductivity of fuel assembly and heat transfer coefficient. The result, shown in Table 4.3 below, indicated that the PCT under the worst combination effects is still below the temperature limit of 752°F.

Table 4.3 PCTs calculated from Holtec's sensitivity analyses

Ambient Air Temperature (Heat Load)	PCT	
	X = 3.0 (27.15 kW with reference fuel conductivity and h = 5.2 W/m^2-K))	X = 3.0 (27.15 kW with reduced fuel conductivity and h = 4.68 W/m^2-K))
90°F (with insolation)	734°F	743°F

The staff evaluated the applicant's onsite transfer thermal analyses and the bounding loading pattern and determined the following applicant conclusions were acceptable:

1) An SCS is not required to transfer a MPC containing high burnup fuel (> 45,000 MWd/MTU) with up to 90% of the design basis heat load under a 3-day average ambient temperature less than 90°F outside the building and a 3-day average ambient temperature less than 110°F inside the building.

2) An SCS is not required to transfer MPC containing only low burnup fuel (≤ 45,000 MWd/MTU) up to the threshold heat load if the helium backfill pressure specification in Table 4.4 below (or Table N.5.11 of Holtec's Report HI-2043317) is utilized.

Table 4.4 Lower MPC Helium Backfill Pressure Specifications for Threshold Heat Load

Item	Specification
Minimum Pressure	29.3 psig at 70°F Reference Temperature
Maximum Pressure	48.5 psig at 70°F Reference Temperature

4.2.4 Maximum Internal Pressure

The applicant provided results from the thermal analysis of the HI-TRAC transfer cask during handling and onsite transfer operations. MPC pressure is compared with the short term pressure limit provided in FSAR Table 4.5.4. The staff evaluated these results and found that the results meet comply with the design limits, and therefore are acceptable.

4.3. OFF-NORMAL AND ACCIDENT EVENTS

This section provides thermal analyses of limiting off-normal and accident events.

4.3.1 Accident Events

4.3.1.1 HI-TRAC Fire

The applicant performed a fire analysis of a loaded 100-ton HI-TRAC to demonstrate the fuel cladding and MPC pressure boundary integrity under fire exposure. The PCT was calculated by the applicant to be 737°F which is significantly below the accident limit of 1058°F and provides a significant thermal margin. In the applicant's analysis, the contents of the HI-TRAC were conservatively assumed to undergo a transient heat-up. The increased temperatures of the MPC during the fire accident caused the internal MPC pressure to increase. The staff evaluated the results in the revised FSAR Table 4.6.2 and found them to be below the NUREG-1536, Rev.1 accident limit, and therefore found them acceptable.

4.3.1.2 Jacket Water Loss

The applicant evaluated the fuel cladding and MPC boundary integrity for a loss of water from the HI-TRAC water jacket. The thermal model assumed a maximum thermal heat load, 90°F ambient temperatures with insolation, along with a complete loss of water. The applicant's analysis determined the PCT remained below the NUREG-1536, Rev.1 accident limit of 1058° F. The staff finds this acceptable

The applicant re-analyzed the off-normal and accident events with the 3-D model with the fuel viscous resistance factor of the fuel assembly set as $1x10^6$ m^{-2} under 90°F ambient temperature 811°F (X = 0.5) and 837°F (X = 3.0) for jacket water loss accidents. The staff reviewed the model descriptions and determined that the applicant's analyzed SNF PCTs remain below the allowable limit of 1058°F with significant safety margins. The applicant's evaluations reasonably cover (1) the uncertainties existing in the model analysis and (2) the uncertainties between the model simulation and the physical reality for off-normal and accident events. The staff finds this acceptable.

4.4 Evaluation Findings

The staff reviewed the applicant supplied FSAR revisions, the proposed revised TS Appendices A and B, and the applicant's models and calculations for short-term onsite transfer operations. For the model analyses for normal onsite transfer operations, the applicant used the maximum ambient temperatures of 90°F for outside building operations and 110°F for inside building operations. The maximum ambient temperatures of 90°F and 110°F used in the analyses are based on a 72-hour rolling average. The staff found this acceptable with specific conditions to capture these requirements provided in TS. The applicant agreed with the staff's TS conditions in its April 17, 2013, letter to the NRC. The TS conditions are:

1) An SCS is not required to transfer a MPC containing high burnup fuel (> 45,000 MWd/MTU) with up to 90% of the design basis heat load under a 3-day average ambient temperature less than 90°F outside the building and a 3-day average ambient temperature less than 110°F inside the building.

2) An SCS is not required to transfer MPC containing only low burnup fuel (≤ 45,000 MWd/MTU) up to the threshold heat load if the helium backfill pressure specification in Table 4.4 (or Table N.5.11 of Holtec's Report HI-2043317) is utilized.

Findings

F4.1 The thermal design and features important to safety are described in sufficient detail in FSAR Thermal Chapter to enable an evaluation of the thermal effectiveness. The structures, systems, and components (SSCs) continue to remain within their operating temperature ranges.

F4.2 CoC 1014 continues to be designed with a heat-removal capability having verifiability and reliability consistent with its importance to safety.

F4.3 The spent fuel cladding continues to be protected against degradation leading to gross ruptures by maintaining the cladding temperatures below 400°C (752°F) for normal conditions and 570°C (1058°F) for off-normal and accident conditions, and other cask component temperatures continue to be maintained below the allowable limits for the accidents evaluated.

5.0 CONFINEMENT EVALUATION

The applicant did not propose any changes that affect the staff's confinement evaluation provided in the SERs supporting the staff's CoC No. 1014, SER issued May 31, 2000, through ~~the~~ CoC No. 1014, Amendment No. 8 SER issued on February 9, 2012. Therefore, the staff determined that a new evaluation was not required.

6.0 SHIELDING EVALUATION

The applicant did not propose any changes that affect the staff's shielding evaluation provided in the SERs supporting the staff's CoC No. 1014, SER issued May 31, 2000, through ~~the~~ CoC No. 1014, Amendment No. 8 SER issued on February 9, 2012. Therefore, the staff determined that a new evaluation was not required.

7.0 CRITICALITY EVALUATION

The applicant did not propose any changes that affect the staff's criticality evaluation provided in the SERs supporting the staff's CoC No. 1014, SER issued May 31, 2000, through ~~the~~ CoC No. 1014, Amendment No. 8 SER issued on February 9, 2012. Therefore, the staff determined that a new evaluation was not required.

8.0 MATERIALS

The applicant did not propose any changes that affect the staff's materials evaluation provided in the SERs supporting the staff's CoC No. 1014, SER issued May 31, 2000, through ~~the~~ CoC No. 1014, Amendment No. 8 SER issued on February 9, 2012. Therefore, the staff determined that a new evaluation was not required.

9.0 OPERATING PROCEDURES EVALUATION

The applicant did not propose any changes that affect the staff's operating procedures evaluation provided in the SERs supporting the staff's CoC No. 1014, SER issued May 31, 2000, through ~~the~~ CoC No. 1014, Amendment No. 8 SER issued on February 9, 2012. Therefore, the staff determined that a new evaluation was not required.

10.0 ACCEPTANCE TESTS AND MAINTANANCE PROGRAM EVALUATION

The applicant did not propose any changes that affect the staff's acceptance tests and maintenance program evaluation provided in the SERs supporting the staff's CoC No. 1014, SER issued May 31, 2000, through ~~the~~ CoC No. 1014, Amendment No. 8 SER issued on February 9, 2012. Therefore, the staff determined that a new evaluation was not required.

11.0 RADIATION PROTECTION EVALUATION

The applicant did not propose any changes that affect the staff's radiation protection evaluation provided in the SERs supporting the staff's CoC No. 1014, SER issued May 31, 2000, through ~~the~~ CoC No. 1014, Amendment No. 8 SER issued on February 9, 2012. Therefore, the staff determined that a new evaluation was not required.

12.0 ACCIDENT ANALYSIS EVALUATION

The applicant did not propose any changes that affect the staff's accident analysis evaluation provided in the SERs supporting the staff's CoC No. 1014, SER issued May 31, 2000, through ~~the~~ CoC No. 1014, Amendment No. 8 SER issued on February 9, 2012. Therefore, the staff determined that a new evaluation was not required.

13.0 TECHNICAL SPECIFICATIONS

13.1 Review Objective

The staff reviewed the application to ensure that the proposed changes to the operating controls and limits for the TS for the HI-STORM 100 Cask System continue to meet the requirements of 10 CFR Part 72. The evaluation is based on information provided by the applicant in this amendment request, a review of the FSAR, and NUREG 1536, Rev.1. Specifically, the proposed changes were reviewed to ensure that they acceptably supported the changes requested by the applicant. The technical and safety aspects of these TS changes were evaluated by the staff in Sections 3 and 4 of this SER and were found to be acceptable. The applicant proposed the following CoC and TS changes.

1. CoC Condition #12 is deleted and the subsequent Condition is renumbered.
2. TS Appendix B-100U Section 3.4 is revised.
3. Revising TS Appendix A, Limiting Condition for Operation (LCO) 3.1.1.
4. Revising TS Appendix A, LCO 3.1.2.
5. Revising TS Appendix A, LCO 3.1.4.
6. Revising TS Appendix A, Table 3-1.
7. Revising TS Appendix A, Table 3-2.
8. Adding TS Appendix A, Table 3-3.
9. Adding TS Appendix A, Table 3-4.
10. Revising TS Appendix A-100, LCO 3.1.1.
11. Revising TS Appendix A-100, LCO 3.1.2.
12. Revising TS Appendix A-100, LCO 3.1.4.
13. Revising TS Appendix A-100, Table 3-1.
14. Revising TS Appendix A-100, Table 3-2.

15. Revising TS Appendix B, Section 3.7.

16. Adding TS Appendix B, Section 3.9.

17. Revising TS Appendix B-100U; Section 3.7.

18. Adding TS Appendix B-100U, Section 3.9.

The following editorial (non-substantive) changes have also been made:

3. CoC CONDITIONS, first sentence. “Conditioned” is changed to “Conditional” to provide consistency in the CoC. (staff supplied)

4. Appendix A and Appendix A-100U; SR 3.1.1.3 is revised to “Verify that the helium leak rate through the MPC vent and drain port cover plates (confinement welds and the base metal) meet*s* the leak tight criteria of ANSI N14.5-1997” to be consistent with CoC, Condition No. 3 in Amendment No. 8.

5. Appendix A-100U; Table 3-1. “< 30” is corrected to ≤ 30” to be consistent with Appendix A.

13.2 Findings

F13.1 The staff finds that CoC 1014 continues to identify necessary TS to satisfy 10 CFR Part 72 and that the applicable criteria of 10 CFR 72.236 have been satisfied. The proposed TS changes provide assurance that the HI-STORM 100 Cask System will continue to allow safe storage of spent nuclear fuel.

14.0 CONCLUSIONS

Based on its review of amendment request 1014-9, the staff has determined that there is reasonable assurance that: (i) the activities authorized by the amended certificate can be conducted without endangering the health and safety of the public and (ii) these activities will be conducted in compliance with the applicable regulations of 10 CFR Part 72. The staff has further determined that the issuance of the amendment will not be inimical to the common defense and security. Therefore, the amendment should be approved.

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