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, August 11, and November 14, 2011, 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 No. 1014 (1014-9). The applicant proposed the following revisions to CoC No. 1014:

I. Broaden the subgrade requirements for the HI-STORM 100U (underground) part of the HI-STORM 100 Cask System, and

II. Update the thermal model and methodology for the HI-TRAC transfer cask from a two dimensional thermal-hydraulic model to a more accurate three dimensional model.

Changes associated with Proposed Change I are:

A. Removal of the restriction which requires the ISFSI support foundation pad to rest on a subgrade material with a shear wave velocity of 3500 ft/s or bedrock.

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

C. Removal of the requirement to account for amplification in the seismic analysis.

The above results in modifications to the Certificate of Compliance (CoC) and Technical Specifications (TS), specifically the following:

1. CoC; Condition #12 is deleted and the subsequent Conditions are renumbered.

2. TS Appendix B-100U; Section 3.4 is revised.

Changes associated with Proposed Change II are as follows:

D. Re-analysis of short-term operations involving the HI-TRAC transfer cask. These include vacuum drying of the MPC, on-site transport of the dry MPC, and time to boil calculations. Results of this change in methodology are (1) there is no longer a need for a supplemental cooling system to maintain peak cladding temperatures below the Interim Staff Guidance -11, Rev. 3 guidance limits, (2) decay heat thresholds for vacuum drying increased for both unlimited and time restricted vacuum drying, and (3) time-to-boil limits for various decay heat loads and initial spent fuel pool temperatures have been added.

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

The above results in the following modifications to the CoC and TS:

3. CoC; Condition #10, step g. is deleted and the subsequent steps are renumbered.

4. CoC; Condition #11 is deleted and the subsequent Conditions are renumbered.

5. TS Appendix A; LCO 3.1.4 is deleted and LCO 3.1.1 and Table 3-1 are modified.

6. TS Appendix A-100U; LCO 3.1.4 is deleted and LCO 3.1.1 and Table 3-1 are modified.

7. TS Appendix B; Section 3.7 is deleted.

8. TS Appendix B-100U; Section 3.7 is deleted.

1.0 REVIEW CRITERIA

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, Rev.1, “Standard Review Plan for Dry Cask Storage Systems,” with some differences implemented for clarity and consistency.

The NRC staff’s (staff's) assessment is based on whether Holtec meets the applicable requirements of 10 CFR Part 72. 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 the Proposed Change I submitted by Holtec, and revisions associated with that change are:

A. Removal of the restriction which requires the ISFSI support foundation pad to rest on a subgrade material with a shear wave velocity of 3500 ft/s or bedrock.

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

C. Removal of the requirement to account for amplification in the seismic analysis.

The above results in modifications to the Certificate of Compliance (CoC) and Technical Specifications (TS), specifically the following:

1. CoC; Condition #12 is deleted and the subsequent Conditions are renumbered.

2. TS Appendix B-100U; Section 3.4 is revised.

The license condition provided in CoC No. 1014, Amendment No. 7 that requires the ISFSI SFP to rest on a subgrade material with a shear wave velocity of 3500 ft/s or bedrock is based on the following narrative reproduced from the Staff's CoC No. 1014, Amendment No. 7 SER.

> *The HI-STORM 100U System design summary includes the same design basis elements as the above ground HI-STORM 100 Cask System. However, the applicant 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.*
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> *In the absence of an analysis and evaluation of the design of all ITS* [important to safety] *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 the applicant to submit an amendment request to CoC-1014 for staff evaluation.*

The license condition provided in CoC No. 1014, Amendment No. 7 that requires consideration of pad amplification is based on the following narrative reproduced from the Staff's CoC No. 1014, Amendment No. 7 SER:

> *The staff notes that for the second load case (seismic case) no amplification due to TSP* [top surface pad] *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.

The restriction provided in CoC No. 1014, Amendment No. 7 that requires any excavation near an operating ISFSI to be a distance of 10 times the excavation depth away from the radiation protection space (RPS) is based on the following narrative reproduced from the staff's CoC No. 1014, Amendment No. 7 SER:

The addition of the retaining wall(s), as described in the [Technical Specifications] 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 the applicant.

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 regulations in 10 CFR Parts 72.3, 72.24(d) and 72.212(b)(3) require the applicant 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. 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 Seismic Model

3.1.1 Seismic Analysis

The overall seismic analysis was composed of three steps which 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.

3.1.2 Soil-Structure Model Development

The soil structure model development consisted of a two-step process utilizing SHAKE2000 and LS-DYNA to generate the response spectra at various ISFSI elevations with lower bound soil properties which were intended to bound the soil conditions at most U.S. nuclear power plants. The SHAKE analysis was performed first to generate the average strain compatible shear wave velocities as well as to extract the acceleration time history at the base of the soil column which is subsequently used in the LS-DYNA seismic response analysis (no structure present) and the LS-DYNA SSI analysis. This model also forms the basis for comparison of the site specific seismic and SSI analyses to determine whether site conditions are bounded by the general provisions set forth in the Certificate of Compliance.

3.1.3 VVM Array Model

The VVM array model consists of a fully loaded 5x5 array which was 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 Important to Safety components. A subsequent VVM array analysis was also performed with optional retaining walls included and soil removed down to the SFP to simulate a seismic event during an open pit excavation.

3.1.4 VVM Single Model

The single VVM model is arranged such that the SFP is loaded with one VVM at the periphery of the pad. A representative vertical transport is placed over the loaded VVM and the analysis was performed with the bounding design basis acceleration time history.

3.1.5 Summary

The staff has reviewed the methodology, calculation packages, and results of the soil structure model development, the VVM array model, and the VVM single model and has concluded that there is reasonable assurance of safety with the approaches presented. Further discussion of the VVM array model and its use for the strength qualification of ISFSI structures is provided in the next section.

3.2 Strength Qualification of the ISFSI Structures

The strength qualification of the ISFSI structures under design basis seismic loading is achieved by extracting the peak interface loads obtained from the SSI analyses and applying them to a quasi-static finite element analysis. Furthermore, actual input loads are larger than the peak loads obtained from the LS-DYNA analyses to provide additional margin of safety. Table 2.I.2 of the submitted revised FSAR provides the minimum requirements for the SFP, TSP, and retaining wall(s) if used. The SFP, TSP, and retaining wall must also meet the American Concrete Institute (ACI) -319 (2005) strength limits for all load combinations applicable for this design.

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

- SFP, TSP, Subgrade beneath TSP modeled with elastic SOLID45
- VVM Interface Pad (VIP) omitted since it has expansion joints

- The lateral subgrade adjacent to the ISFSI is included in the *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 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 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.

Governing Load Combination

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 for the TSP subject to punching shear exceeds 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 retaining wall was evaluated for the Design Basis Earthquake (DBE) loads. It was 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 observation regarding 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 maximum bending moment of the retaining wall was determined by utilizing results from the LS-DYNA SSI analysis and as shown in Table 3.I.10, exhibit positive margins of safety. Based on a August 11, 2011, request for additional information (RAI) 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 are provided in the submitted revised FSAR Table 3.I.13

The applicant noted 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 has determined that the use of filtering is a potential source of considerable error if not implemented properly and should be avoided to the extent practical. If filtering is to be used, a strong justification shall be provided so that a safety determination can be made.

3.3 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.

3.3.1 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.

3.3.2 Retaining Wall Scenario

In its August 11, 2011, RAI response Holtec provided the following narrative:

> *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 provided Holtec the following response:

> “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 a condition to be incorporated in the Technical Specifications (TS):

> *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 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.*

3.3.3 Summary and Conclusions

The staff has reviewed the SSI analysis illustrating the ISFSI with excavations down to the SFP and subjected to a DBE. Furthermore, the staff has also reviewed the quasi-static structural evaluation of the same condition (Model V). In both cases, the applicant has demonstrated reasonable assurance that the conditions evaluated for a bounding earthquake and bounding soil properties will not adversely impact the structural or operational performance of the retaining wall.

The staff finds that any excavation below the SFP will require review and approval by the NRC as part of a CoC amendment to address a specific site design not bounded by CoC No. 1014, Amendment No. 9. Since the existence of a large open pit excavation near the ISFSI can potentially create unanalyzed loading conditions, this scenario must be evaluated in a new amendment request. A license condition has been added to CoC No. 1014, Appendix B - 100U to provide this requirement in 3.4-10 to capture this requirement.

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

(1) The applicant provided significant information to support the elimination of the requirement to demonstrate that the design was analyzed and evaluated for the combination of loads for which the HI-STORM 100U System will be subjected. These loads include dead load, live load, seismic load and long-term settlement. The applicant also provided a comprehensive design basis seismic model which included bounding soil properties for most US 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. The applicant also presented a complete design of all ISFSI structures with positive margins of safety. As a result of the analysis and subsequent margins demonstrating reasonable assurance of safety, the staff agrees that the restriction of the present 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.

(2) By incorporating the transporter in the Soil Structure Interaction (SSI) analysis, the applicant has accounted for pad flexibility and subsequent amplification of the net horizontal acceleration. Furthermore, as the SSI analysis has also considered bounding soil profiles, no further modifications to the site specific seismic analyses are required provided the site parameters are bounded by the general license conditions set forth in the CoC.

(3) The applicant revised the FSAR and proposed TS to require a site-specific seismic analysis for all construction and excavation activities adjacent to an existing array of VVMs that occur below the SFP and that such analysis will be submitted to the NRC for review and approval. The applicant did not, however, indicate by what mechanism this analysis would be submitted, e.g. a CoC amendment or 10 CFR 72.212 evaluation. The staff agrees that excavations can occur down to the SFP as the applicant has 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. For excavations below the SFP, the staff agrees that the NRC must review and approve any additional analysis demonstrating the structural integrity of the ISFSI during a seismic event, however, the review and approval must be achieved through the CoC amendment process.

3.4 Evaluation Findings

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

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

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

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

F3.4 The applicant has met the requirements of 10 CFR 72.236(l), "Specific Requirements for Spent Fuel Storage Cask Approval." The design analysis and submitted bases for evaluation acceptably demonstrate that the cask and other systems important to safety will reasonably maintain confinement of radioactive material under normal, off-normal, and credible accident conditions.

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

- Design, Fabrication, Erection, and Testing to Acceptable Quality Standards.
- Adequate Structural Protection Against Environmental Conditions and Natural Phenomena, Fires, and Explosions.
- Appropriate Inspection, Maintenance, and Testing.
- Adequate Accessibility in Emergencies.
- A Confinement Barrier that Acceptably Protects the Cladding During Storage.
- Structural Designs that are Compatible with Retrievability of SNF.

4.0 THERMAL EVALUATION

4.1 Review Objective

The objectives of this evaluation were to assess the safety analysis of the thermal design features, the thermal design criteria, and the thermal analysis methodology used to evaluate the expected thermal performance capabilities under normal operations, off-normal operations, accident conditions and natural phenomena events for those SSCs important to safety included in amendment request 1014-9 for the HI-STORM 100 Cask System. The applicant proposed to update the thermal model and methodology for the HI-TRAC transfer cask from a two dimensional thermal-hydraulic model to a more accurate three dimensional (3-D) model. Revisions associated with this proposed change are:

D. Re-analysis of short-term operations involving the HI-TRAC transfer cask. These include vacuum drying of the MPC, on-site transport of the dry MPC, and time-to-boil calculations. Results of this change in methodology are (1) there is no longer a need for a supplemental cooling system to maintain peak cladding temperatures below the Interim Staff Guidance (ISG) -11, Rev. 3 evaluation limits, (2) decay heat thresholds for vacuum drying increased for both unlimited and time restricted vacuum drying, and (3) time-to-boil limits for various decay heat loads and initial spent fuel pool temperatures have been added.

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

The above results in modifications to the CoC and TS, specifically the following:

3. CoC; Condition #10, step g. is deleted and the subsequent steps are renumbered.

4. CoC; Condition #11 is deleted and the subsequent Conditions are renumbered.

5. TS Appendix A; LCO 3.1.4 is deleted and LCO 3.1.1 and Table 3-1 are modified.

6. TS Appendix A-100U; LCO 3.1.4 is deleted and LCO 3.1.1 and Table 3-1 are modified.

7. TS Appendix B; Section 3.7 is deleted.

8. TS Appendix B-100U; Section 3.7 is deleted.

4.2 HI-TRAC Thermal Model

The applicant performed a 3-D thermal model analysis to evaluate the thermal state of a loaded MPC during all short-term operations. All thermal analyses to establish margins of safety are performed for the case of maximum Design Basis heat load and the MPC model that yields the highest peak cladding temperature under the long term storage condition.

The applicant's 3-D FLUENT model of the HI-TRAC transfer cask thermal analysis incorporates the following conservative 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 is applied to all exposed surface.
2) Air motion in the HI-TRAC annulus is neglected. This is a conservative assumption because it ignores the additional heat transfer created by air motion. The MPC is assumed to be concentrically aligned with the cask cavity and the annulus is filled with air.
3) Although the HI-TRAC baseplate is in contact with supporting surfaces it is modeled as an insulated boundary condition. This is a conservative assumption because it ignores heat transfer across this surface interface.
4) The HI-TRAC fluids columns in the water jacket and the open air volume above the MPC are modeled to remain in the laminar flow regime. This is a conservative assumption because it provides a lower heat transfer from the MPC.
5) The HI-TRAC / MPC annular gap shrinks under heat up to operating temperatures. A postulated gap reduction is applied to the thermal model that provides additional conservatism in the analysis.
6) Buoyancy driven motion of air above the MPC is included in the thermal model.
7) Radiation heat transfer is simulated by the Discrete Ordinates (DO) model utilized in the Holtec HI-STAR 180 and HI-STORM FW systems in lieu of the Discrete Transfer Radiation Model previously used in the HI-STORM 100 Cask Storage System.

The staff reviewed amendment request 1014-9 and determined that the model approach for the HI-TRAC transfer cask is consistent with the Holtec CoC No. 1014 Amendment No. 5 that has been previously approved by the staff.

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

The applicant computed the time for a water-filled MPC to reach boiling point during fuel loading operations. The assumptions that were used to determine the available time before the water in the MPC would reach boiling are as follows:

1) Heat loss by natural convection and radiation from the exposed HI-TRAC surfaces to ambient air is neglected.
2) The smaller of the two (i.e., 100-ton and 125-ton) HI-TRAC transfer cask metal mass is credited in the analysis. The 100-ton design has a significantly smaller quantity of metal mass which results in a higher rate of temperature rise.
3) The water mass in the MPC cavity is understated.

The rate of temperature rise of the HI-TRAC was calculated using the ratio Q/C (Q=coincident fuel decay heat in the canister, C= thermal inertia of a loaded HI-TRAC) and the time to boil using the formula $\tau = C(212-T)/Q$ where 212° F has been set as the boiling temperature and T represents the temperature of the pool water under fuel loading operations.

In the case of wet transfer operations, forced water circulation is necessary to maintain the decay heat removal from the MPC cavity. The minimum water flow rate to maintain the MPC cavity water temperature below boiling was acceptably calculated using an MPC cavity water temperature of 150°F, MPC water inlet temperature of 125° F and design basis maximum heat load of 36.9 kW, resulting in 5038 lb/hr (10.1 gpm) of minimum water flow rate. The staff determined the assumptions used in the analysis and the time-to-boil are acceptable.

4.2.2 MPC Temperatures During Moisture Removal Operations Evaluation

<u>4.2.2.1 Vacuum drying Operation</u>

In order to investigate effective conductivity of fuel under vacuum drying operations a 3-D FLUENT thermal model of the MPC was constructed and evaluated by the applicant. To ensure a conservative evaluation the thermal model was incorporated with the following assumptions:

1) Threshold heat load Q1, provided in the submitted revised FSAR Table 4.5.1, is assumed and steady-state condition reached under Q1 results in vacuum drying without time limits.
2) Threshold heat load Q2, defined in the submitted revised FSAR Table 4.5.1, is assumed and a transient calculation is performed to determine the permissible vacuum drying time under Q2.
3) The external surface of the MPC shell is assumed to vary linearly from 100°C (212°F) normal boiling temperature of water at the top to 111°C (231°F) elevated pressure boiling temperature 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 determined the applicant's analysis provided in the submitted revised FSAR Table 4.5.5 demonstrated that fuel temperatures met the review guidance limits of ISG-1, Rev.3 with ample margins, and therefore finds them acceptable.

4.2.2.2. Forced Helium Dehydration (FHD)

The applicant provided a discussion of the design criteria and operation of the FHD system. An explanation was provided of how the FHD system ensures that the fuel cladding temperature will remain below the applicable peak cladding temperature limit, for normal conditions of storage. Also, the applicant provided the peak cladding temperatures for a FHD system malfunction that are approximately the values reached during normal onsite transport.

4.2.2.3. Maximum Temperatures Under Onsite Transport Conditions

The applicant constructed a 3-D FLUENT thermal model of an MPC inside a HI-TRAC transfer cask to evaluate temperature distributions under onsite transport. The heat generation rate in the MPC assumed was the maximum permissible under regionalized storage (Q=36.9 Kw, X=0.5, MPC-32), and the ambient temperature assumed was the maximum ambient temperature for short term operations. The staff evaluated the thermal model of an MPC located inside a HI-TRAC transfer cask as shown in Table 4.5.4 of the HI-STORM 100 FSAR, and found that the computed fuel temperatures in this scenario remain below the respective cladding temperature limits for moderate and high burnup fuel. The staff also found that the results support onsite transport of fuel in the HI-TRAC without the aid of any supplemental cooling for all combinations of fuel burnup and pressure, fuel basket and the HI-TRAC parts temperatures.

4.2.3. Cask Cooldown and Reflood Analysis during Fuel Unloading Operation

In the HI-STORM Flood/Wind (FW), CoC No. 1032, FSAR the integrity of the fuel under direct quenching was evaluated because NUREG-1536, Rev. 1 guidance states that an evaluation of cask cooldown and reflood procedures to support fuel unloading from a dry condition be performed. The integrity of the fuel was evaluated by defining a bounding scenario at time t=0 sec and fuel rod temperature at 752° F (400° C) which is the temperature limit of the fuel cladding. Also, at time t=0.1 sec, a reasonably bounding 80° F quench water temperature was assigned to the lower half of the fuel rod to simulate a thermal shock with a large step change in the cladding temperature. The resulting stress and strain distributions in the fuel rod were evaluated using finite element ANSYS models. The staff finds this method of evaluation acceptable and finds that the results that the maximum stress and strain values remain within the elastic range and remain well within failures strain limit. The staff finds this acceptable.

4.2.4. Maximum Internal Pressure

Results from the thermal analysis of the HI-TRAC transfer cask during handling and on-site transport operations, were in compliance with design limits of internal pressure and MPC temperature when compared with the short term pressure limit provided in FSAR Table 4.5.4. The staff evaluated these results and found that the results are in compliance with the design limits, and therefore are acceptable.

4.2.5. Safety Evaluation of HI-TRAC under Short-Term Operations

The HI-TRAC transfer cask was evaluated under normal handling and onsite transport. The analyses and evaluations showed that HI-TRAC transfer cask thermal design is adequate to satisfy all safety limits under short-term operations. The analyses and evaluations provided in the revised FSAR submittal were reviewed and evaluated by the staff and have been found to be acceptable.

4.3. OFF-NORMAL AND ACCIDENT EVENTS

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

4.3.1 Off-Normal Events

4.3.1.1 Off-Normal Pressure

The applicant performed an analysis to demonstrate that the MPC off-normal design pressure is not exceeded in the event of (a) maximum helium backfill pressure (b) 10% fuel rods rupture and (c) limiting fuel storage configuration. The results showed that pressure is below the off-normal design pressure. The staff finds this acceptable.

4.3.1.2 Off-Normal Environmental Temperature

The results for the off-normal temperature analysis provided in Table 4.6.1 and 4.6.2 of the HI-STORM 100 FSAR were below the off-normal condition temperature and pressure limits. These results were evaluated and found acceptable by the staff.

4.3.1.3 Partial Blockage of Air Inlets

The applicant analyzed the effect of the increased flow resistance on fuel temperature (50% blocked) for the normal ambient temperature and a limiting fuel storage configuration. The calculated temperatures and the corresponding MPC internal pressures were evaluated by the staff and found to be below the NUREG 1536, Rev.1 temperature limits and the FSAR pressure limit for off-normal conditions.

4.3.2 Accident Events

4.3.2.1 Fire Accidents

(a) HI-STORM 100 Cask Fire

The applicant performed a fire analysis using the NUREG-1536, Rev. 1 guidance, and the following modeling parameters were assumed:

1. The average emissivity coefficient was 0.9.

2. The average flame temperature was 1475 °F (800°C)

3. The fuel source was positioned between 1m and 3m beyond the external surface of the cask.

4. The forced convection heat transfer coefficient was 4.5 Btu/ (hr*ft^2*°F).

To evaluate the impact of fire heating on the HI-STORM overpack, a thermal model of the overpack cylinder was created using the ANSYS computer code. The duration of the fire was 3.62 minutes with an initial temperature of the overpack assumed to be the maximum temperature during storage. The transient evaluation was conducted for a period of 5 hours which is sufficient to allow temperatures in the overpack to reach their maximum values and begin to recede.

The applicant evaluated the effects of the fire on the overpack as well as the MPC and fuel assemblies. Heat input to the HI-STORM overpack was calculated along with the heat losses from the outer surfaces of the storage overpack. For the MPC, time constant and temperature increase were calculated. The results of the calculations demonstrated that the targeted fire accident event had only a minor affect on the HI-STORM Overpack, and that the fire event does not adversely affect the temperature of the MPC or fuel. The staff evaluated the methods, calculations and assumptions the applicant used to determine conclusions and found that the ability of the HI-STORM 100 Cask System to continue to provide adequate cooling of the spent nuclear fuel within the NUREG-1536, Rev.1 design temperature limits during and after the fire continues to be acceptable.

(b) <u>HI-TRAC Fire</u>

A fire analysis of a loaded 100-ton HI-TRAC was performed by the applicant to demonstrate the fuel cladding and MPC pressure boundary integrity under fire exposure. The temperature rise was calculated to be 737° F. This temperature remains below the NUREG-1536, Rev.1 guidance of 1058° F. In the 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 results provided in the supplied revised FSAR Table 4.6.2 were evaluated by the staff and found to be below the NUREG-1536, Rev.1 guidance accident limits. The staff finds this acceptable.

<u>4.3.2.2 Jacket Water Loss</u>

The fuel cladding and MPC boundary integrity were evaluated by the applicant for a postulated loss of water from the HI-TRAC water jacket. The thermal model assumed a maximum thermal payload, maximum temperatures, along with a complete loss of water. The analysis determined that the cladding, MPC and HI-TRAC component temperature remained below the NUREG-1536, Rev.1 guidance accident limits. The staff finds this acceptable.

<u>4.3.2.3 Extreme Environmental Temperatures</u>

The effect of the elevated ambient temperature is a temperature rise in the HI-STORM 100 from the baseline normal storage temperatures by the difference between the elevated ambient and the normal ambient temperature. To evaluate the effect of extreme weather conditions, an extreme ambient temperature was assumed to persist for a 3-day period. The applicant stated that due to the large mass of the HI-STORM 100 Cask System, with its corresponding large thermal inertia and the limited duration for the extreme temperature that there was only a minimum impact on MPC content temperature. The staff evaluated the results and found that the fuel remained below NUREG-1536, Rev.1 guidance accident limits. The staff finds this acceptable.

<u>4.3.2.4 100% Blockage of Air Inlets</u>

The applicant analyzed the effect and consequences of a complete blockage of all four bottom inlets. The event was analyzed using FLUENT CFD code. The transient thermal solution of a 3-D model of the HI-STORM 100 Cask System determined that fuel temperatures below the NUREG-1536, Rev.1 guidance accident limits. The staff finds this acceptable.

4.3.2.5 Burial under Debris

Even though burial of the HI-STORM 100 Cask System under debris is not a credible accident, the applicant provided an analysis for this event to provide additional conservatism. The burial time was assumed to be 34.6 hours and the calculated MPC pressure was determined to remain below the FSAR limit.

4.4 Staff Confirmatory Analyses and Conclusions

The staff reviewed amendment request 1014-9 and determined that the updated FSAR sections include accurate information to enable the staff to evaluate the thermal effectiveness of SSCs important to safety and make a determination on the acceptability of the proposed TS changes and licensing bases. The staff evaluation of the licensee's thermal models discussed above included staff confirmatory analyses, confirmation of code input values used in the licensee calculation packages, along with a review of design details used to provide parameters in the computer models. The staff determined, based on its review of the design details, that the licensee used proper material properties and boundary conditions. The staff determined that the licensee's selected code models accurately reflect the specific design parameters. In addition, the staff determined that the licensee's assumptions and modeling parameters are consistent with guidance in NUREG-156, Rev. 1, and therefore determined the assumptions are adequate for the flow and heat transfer characteristics prevailing in the HI-STORM Cask System geometry and analyzed conditions. The staff reviewed the licensee's engineering drawings to verify that adequate geometry dimensions were translated to the analysis models. The staff also reviewed material properties presented in the FSAR to verify that they were appropriately referenced and used. Based on its review of the licensee's thermal models, the staff determined that the licensee's utilization of computer modeling is consistent with the guidance in NUREG-1536. Rev. 1 and ISG - 21, "Use of Computational Software," and is therefore acceptable.

The staff determined that the licensee's analysis to obtain mesh-independent results that provided bounding predictions for all analyzed conditions during normal storage, transfer operations, and off-normal and accident events was acceptable.

Therefore, based on its review and the calculations described above, the staff finds the HI-STORM 100 Cask System thermal analysis and conclusions acceptable and that the HI-STORM 100 Cask System will continue to safely store spent nuclear fuel.

4.5 Evaluation Findings

F4.1 The submitted revised FSAR Chapter 2 describes SSCs important to safety to enable an evaluation of their thermal effectiveness. SSCs important to safety remain within their operating temperature ranges as provided in NUREG-1536, Rev. 1 and ISG -11.

F4.2 The HI-STORM Cask System continues to maintain heat-removal capability having verifiability and reliability consistent with its importance to safety as required by 10 CFR 72.236(f).

F4.3 The thermal design of the HI-STORM Cask System continues to comply with 10 CFR Part 72 and 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, NUREG 1536, Rev. 1, ISG -11, and ISG -21.

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 Preliminary SER issued on August 11, 2011. 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 Preliminary SER issued on August 11, 2011. 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 Preliminary SER issued on August 11, 2011. 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 Preliminary SER issued on August 11, 2011. 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 Preliminary SER issued on August 11, 2011. 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 Preliminary SER issued on August 11, 2011. 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 Preliminary SER issued on August 11, 2011. 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 Preliminary SER issued on August 11, 2011. Therefore, the staff determined that a new evaluation was not required.

13.0 TECHNICAL SPECIFICATIONS

13.1 Review Objective

The objectives of this review were to ensure that the changes to the operating controls and limits or 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, as well as consideration of accepted practices. 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 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 #10, step g. is deleted and the subsequent steps are renumbered.
2. CoC; Condition #11 is deleted and the subsequent Conditions are renumbered.
3. CoC; Condition #12 is deleted and the subsequent Conditions are renumbered.
4. TS Appendix B-100U; Section 3.4 is revised.
5. TS Appendix A; LCO 3.1.4 is deleted and LCO 3.1.1 and Table 3-1 are modified.
6. TS Appendix A-100U; LCO 3.1.4 is deleted and LCO 3.1.1 and Table 3-1 are modified.
7. TS Appendix B; Section 3.7 is deleted.
8. TS Appendix B-100U; Section 3.7 is deleted.

13.2 Findings

F13.1 The staff finds that the conditions for use of the HI-STORM 100 Cask System continue to identify necessary TS to satisfy 10 CFR Part 72 and that the applicable acceptance criteria of 10 CFR 72.234(a) and 10 CFR 72.236 have been satisfied. The proposed TS changes provide reasonable assurance that the HI-STORM 100 Cask System will continue to allow safe storage of Spent Nuclear Fuel. This finding is based on the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted practices.

14.0 CONCLUSIONS

Based on its review of AR-1014-9, as revised and supplemented, 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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