UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

.

PRELIMINARY SAFETY EVALUATION REPORT

DOCKET NO. 72-1014
HOLTEC INTERNATIONAL
HI-STORM 100
MULTIPURPOSE CANISTER STORAGE SYSTEM
CERTIFICATE OF COMPLIANCE NO. 1014
AMENDMENT NO. 12

SUMMARY

This safety evaluation report (SER) documents the U.S. Nuclear Regulatory Commission (NRC) staff's (staff) review and evaluation of the amendment request to amend Certificate of Compliance (CoC) No. 1014 for the HI-STORM 100 Multipurpose Canister (MPC) Storage System submitted by Holtec International (Holtec) by letter dated June 14, 2016 (Holtec, 2016a), and supplemented on July 22, 2016 (Holtec, 2016b), November 4, 2016 (Holtec, 2016c), August 25, 2017 (Holtec, 2017a), November 10, 2017 (Holtec, 2017b), and December 22, 2017 (Holtec, 2017c). The proposed changes include the following:

(1) Add a new regionalized quarter-symmetric heat load (QSHL) pattern for MPC-68M and allow fuel that has been cooled for at least 2 years to be stored in the MPC-68M.
(2) Allow the storage of damaged fuel and fuel debris in damaged fuel container (DFC) under the new regionalized QSHL pattern.
(3) Add a new duplex stainless steel as an allowed material for the MPC confinement boundary in the HI-STORM 100 system.
(4) Add the cyclic vacuum drying for all MPCs.
(5) Update coefficients for burnup calculation equation for fuel assembly with cooling time of 2 through 40 years.

The staff did not evaluate the original request to add a new open loop low pressure drying (LPD) method for MPC-68M. Holtec removed LPD from Amendment No. 12 when responding to NRC's request for additional information (RAI) (Holtec, 2017b Attachment 1).

This revised CoC, when codified through rulemaking, will be denoted as Amendment No. 12, to CoC No. 1014.

This SER documents the staff's review and evaluation of the proposed amendment. The staff followed the guidance in NUREG-1536, Revision 1, "Standard Review Plan for Dry Cask Storage Systems at a General License Facility," July 2010 (NRC, 2010). The staff's evaluation is based on a review of Holtec's application and supplemental information and whether it meets the applicable requirements of Title 10 of *Code of Federal Regulations* (10 CFR) Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level

Radioactive Waste, and Reactor-Related Greater Than Class C Waste," (NRC, 2017) for dry storage of spent nuclear fuel. The staff's evaluation focused only on modifications requested in Amendment No. 12 and did not reassess previous revisions of the final safety analysis report (FSAR) nor previous amendments to the CoC.

1.0 GENERAL INFORMATION EVALUATION

The applicant did not propose any changes that affect the staff's general description evaluation provided in the previous SER for CoC No. 1014, Amendments Nos. 0 through 11. Therefore, the staff determined that a new evaluation was not required.

2.0 PRINCIPAL DESIGN CRITERIA EVALUATION

The applicant did not propose any changes that affect the staff's principal design criteria evaluation provided in the previous SER for CoC No. 1014, Amendments Nos. 0 through 11. Therefore, the staff determined that a new evaluation was not required.

3.0 STRUCTURAL EVALUATION

The staff reviewed the proposed changes in Amendment No. 12 to the HI-STORM 100 storage system to ensure that the applicant had performed adequate structural evaluation to demonstrate the system acceptance. There are three proposed changes that require staff's structural evaluation:

(1) Addition of the new QSHL loading patterns for the multipurpose canister MPC-68M.
(2) Storage of damaged fuel/fuel debris in DFCs under the regionalized QSHL loading pattern.
(3) Use of a duplex stainless steel in the HI-STORM 100 system.

The applicant also proposed to revise the description of the HI-TRAC in the HI-STORM 100 CoC by removing specific weights from the HI-TRAC name. The revised description aligns with the use of transfer casks, which is described in FSAR Revision 13 (Holtec, 2016d) for weight variances in the HI-TRAC series of casks for site-specific requirements. Therefore, the revised description in CoC is acceptable and no further evaluation is needed.

Since the system structural design bases and acceptance criteria remain unchanged from previous amendments, the staff focused its review on the FSAR implementation of structural evaluation assumptions and the results of the applicant's analysis of the three requested changes.

3.1 Addition of a New Loading Patterns for the Multipurpose Canister MPC-68M

In Sections 4.3 of this SER, the staff reviewed the effects of the updated heat load and the new QSHL loading patterns and confirmed that: (1) the enclosure vessel component temperatures are maintained below the design basis limits for which the at-temperature stress allowables are used for evaluating stress safety margins; (2) the maximum enclosure vessel cavity pressures for normal, off-normal, and accident conditions are all below the design basis pressure limits provided in Table 2.2.1 of the FSAR; and (3) the calculated differential expansion values are bounded by the nominal cold gaps depicted in the drawings of the application. Supplement 3.III of FSAR Revision 13 provided structural evaluation of the MPC-68M enclosure vessel constructed with the Alloy X stainless steels and the fuel basket fabricated with the Metamic-HT material.

Supplement 3.III.4.3.3 of FSAR noted that the 60-g side drop deceleration bounds the design basis deceleration limit of 45 g for the non-mechanistic tip over of the HI-STORM storage overpack. In Section 3.2 of this SER, the staff confirmed that the design basis non-mechanistic tip over lateral deceleration of 45 g applicable to the MPC-68M for the regionalized QSHL loading pattern continues to be bounded by the HI-STORM 100 design basis side-drop deceleration of 60 g. Tables 1.A.1, 1.A.2, and 1.A.3 of FSAR Appendix 1.A (Holtec, 2016a) list the stress intensity limits, tensile strengths, and yield strengths for the duplex stainless steel. The limits and strengths for duplex stainless steel exceed the limits and strengths for Alloy X stainless steels, which has received NRC approval. The staff concludes that the previously accepted stress calculations remain valid to demonstrate adequate structural performance of the MPC-68M enclosure vessel constructed with the duplex stainless steel.

In FSAR Section 3.III.4.4.3.1, the applicant evaluated the structural performance of the Metamic-HT fuel basket for a side-drop deceleration of 60 g. As indicated in the proprietary calculation package, HI-2012787 Supplement No. 65 (Holtec, 2016b Attachment 2), the applicant followed the modeling approach used previously to perform an ANSYS finite element analysis (FEA) of the Metamic-HT fuel basket supported laterally with aluminum shims against the enclosure vessel shell. The applicant calculated a peak true stress of 12,780 psi in the basket panels. The staff finds this acceptable because it is below the material ultimate strength of 13,385 psi. Correspondingly, for the gross plastic deformation shown as the permanent basket panel deformation, the applicant calculated a maximum panel deformation of 0.0061 inch relative to its end supports. The staff finds this acceptable because the deformation is markedly below the acceptance limit of 0.03 inch, which is set at 0.5% of the nominal width of 6.05 inch, to be considered for the criticality safety evaluation.

HI-2012787 Supplement No. 65 evaluated the structural performance of the basket shims fabricated with the aluminum alloy (B221 2219-T8511) material and calculated a maximum stress of 8,798 psi in the shims. The staff reviewed the supplement, which presented the fringe plot for the calculated peak true stress in the basket subject to a 60-g side drop. The staff confirmed the calculated peak is less than the material yield strength of 1,400 psi at 550°F. As discussed in Section 8.5.3 of this SER, the staff determined the mechanical properties of the basket shims are acceptable. The staff also determined that the structural performance of basket shims is acceptable.

The staff's evaluation of the critical flaw size for the duplex stainless steel and the Metamic-HT are in Sections 8.5.1 and 8.5.2 of this SER, respectively.

3.2 Storage of Damaged Fuel/Fuel Debris in DFCs Under The Regionalized Loading Pattern

FSAR Table 3.2.1 lists the MPC-68/68F/68FF enclosure vessel design basis weight of 90,000 lb., including storing damaged fuel/fuel debris in DFCs with a maximum fuel assembly weight of 830 lb. for the boiling water reactor (BWR) fuel. In the proprietary report HI-2012787 Supplement No. 65 (Holtec 2016b, Attachment 2), the applicant performed a structural analysis to demonstrate that the increased weight associated with the 16 corner fuel assemblies will not cause unacceptable consequences during the 60-g overpack side drop accident. The staff reviewed the structural analysis, which uses an NRC-approved methodology, and determined results are within acceptance limits. The staff concludes the analysis is acceptable. The gross weight of the MPC-68M enclosure vessel using the regionalized loading pattern includes the assembly weight of 830 lb. at 16 basket corners, and it is bounded by the design basis weight of 90,000 lb. for the MPC enclosure vessel. The staff concluded that the structural evaluation for the 60-g side drop loading demonstrates structural performance of the HI-STORM 100 overpack. And the staff notes the 60-g side drop bounds non-mechanistic tip-over accident design basis lateral deceleration of 45 g, which continues to apply to the MPC-68M enclosure vessel.

Section 4.3.5.4 of this SER evaluated the concrete overpack inlet vent blockage accident associated with the regionalized loading pattern. In Section 8.2 of this SER, the staff reviewed environmental conditions and noted that the maximum concrete temperature of 450°F for a 30-day vent blockage accident could result in concrete strength degradation. In the proprietary report HI-2012769 Supplement Nos. 15 and 25 (Holtec, 2017d Attachment 5), the applicant revised the tornado missile penetration analyses, which include a 50% reduction in concrete compressive strength. The penetration analyses indicated only a slight increase of concrete penetration depth because the resistance provided by the overpack outer steel shell remained essentially unchanged. The staff determined the concrete structure adequate because the design basis tornado missile impact does not result in any perforation of the concrete overpack.

3.3 Use of Certain Duplex Stainless Steel in the HI-STORM 100 System

Section 3.1 of this SER noted the use of duplex stainless steel for fabricating the MPC-68M enclosure vessel. Section 8.1 of this SER reviewed the use of the duplex stainless steel with respect to applicable codes and standards for the HI-STORM 100 system design. Specifically, the applicability of the mechanical properties for structural performance consideration, including the fractural toughness for critical flaw size evaluation, is evaluated in Sections 8.5.1 and 8.5.2 of this SER. As is also evaluated in Section 3.1 of this SER, because all material strength properties of the duplex stainless steel exceed those of the approved Alloy X stainless steels, the staff concluded that the previously accepted stress calculations for Alloy X stainless steels remain valid to demonstrate structural performance of the MPC-68M enclosure vessel constructed with the duplex stainless steel.

3.4 Evaluation Findings

The staff concludes that the structural performance of the structures, systems, and components of the HI-STORM 100 and MPC-68M storage system proposed in Amendment No. 12 are in compliance with the requirements of 10 CFR Part 72, and that the applicable design and acceptance criteria in NUREG-1536 have been satisfied. The staff finds that the HI-STORM 100 and MPC-68M storage system provides reasonable assurance that spent nuclear fuel and damaged fuel/fuel debris in the DFCs will be safely stored in the proposed regionalized QSHL loading patterns. The staff concludes the structures, systems, and components of the HI-STORM 100 and MPC-68M storage system, as amended by Amendment 12, are consistent with relevant regulations, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

4.0 THERMAL EVALUATION

The staff reviewed the proposed Amendment No. 12 changes to the HI-STORM 100 storage system to ensure that the applicant had performed adequate thermal evaluation to demonstrate the system acceptance. There are three proposed changes that require staff's thermal evaluation:

(1) Storage of fuel assemblies with higher per-assembly heat loads in the MPC-68M using a new regionalized QSHL pattern.
(2) Storage of damaged fuel and/or fuel debris in DFCs under the new regionalized QSHL pattern for MPC-68M.
(3) Cyclic vacuum drying with time limits for MPCs loaded with high burnup fuel (HBF) or fuel with total heat load exceeding threshold heat loads.

In its initial request, the applicant proposed the use of LPD as a new drying method for MPC-68M. The staff raised questions about the effectiveness of the method removing moisture. By letter dated November 10, 2017, the applicant withdrew the LPD method from Amendment No. 12 (Holtec, 2017b Attachment 1).

4.1 Thermal System

The applicant performed thermal analyses and evaluated the QSHL pattern, shown in Appendix B, Figure 2.4-1 and FSAR Figure 2.III.1. The design heat load of QSHL pattern is 42.8 kW. The analyses demonstrate that the cask component temperatures will be maintained below the design temperature limits as shown in Table 2.2.3 of the application.

The staff reviewed Supplement 4.III and Appendix B, Figure 2.4-1, and found the information for QSHL pattern is appropriate for thermal evaluation.

4.2 Material Properties

The applicant reported applicable material design temperature limits in FSAR Table 2.2.3 and Table 4.3.1, and the temperature limits of fuel basket and basket shim materials in FSAR Table 4.III.2. The applicant presented material properties of the thermal analyses in Tables 4.2.1 to 4.2.7 and the individual thermal conductivities of Alloy X materials in Appendix 1.A of the application.

The applicant stated in the application that most of the material properties of Alloy X become increasingly favorable as the temperature drops. Conservatively, the material property values at the lowest design temperature for the HI-STORM 100 System (-40°F) have been assumed to be equal to the lowest value (70°F) stated in the ASME Code. The exceptions are the coefficient of thermal expansion and thermal conductivity, as the values decrease with the decreasing temperature. Their values at -40°F are linearly extrapolated from the 70°F value using the difference from 70°F to 100°F.

The staff reviewed the material design temperature limits and material properties of thermal analysis of Alloy X and finds they are consistent with stainless steels previously approved by NRC. The staff concludes the use of Alloy X is acceptable.

4.3 Loading Pattern of Quarter Symmetric Heat Load (QSHL) for MPC-68M

The applicant proposed to add the QSHL pattern for MPC-68M, as shown in Appendix B, Figure 2.4-1. The applicant stated in the application (Holtec, 2016a Attachment 1) that the QSHL pattern allows for storage of fuel assemblies with higher per-assembly heat loads in the MPC-68M. The applicant stated in Supplement 4.III of the application that the maximum permissible heat load in each storage cell is specific to its location within the quadrant and is limited to a unique prescribed value as shown in Appendix B, Figure 2.4-1.

As stated in FSAR Supplement 4.III.0, MPC-68M is a 68-cell BWR canister engineered with a high B-10 containing Metamic-HT basket for enhanced criticality control. The applicant performed bounding evaluation of an MPC-68M with the most flow resistive HI-STORM 100S Version B overpack under normal, off-normal, and accident conditions.

The staff reviewed the proposed changes in Section 4.4.4 and Supplement 4.III and confirmed that (1) HI-STORM 100S Version B has smaller inlet and outlet vents, thus, Version B vent airflow resistances increase; and (2) the HI-STORM 100S Version B is the shortest overpack, and it reduces the chimney height, which minimizes the driving head for air flow. Both conditions will reduce the heat removed by airflow in annulus from the MPC to the overpack. Therefore, the staff accepted the use of the HI-STORM 100S Version B for thermal evaluation in this application because the HI-STORM 100S Version B will have the least heat removal effect and will yield the bounding results in fuel cladding and cask component temperatures.

a. Temperature

The applicant performed the thermal evaluations using an ANSYS FLUENT CFD model previously used in the HI-STORM 100 FSAR and were reviewed and approved by NRC. The peak cladding temperature (PCT) for QSHL pattern under long-term storage in MPC-68M is presented in Table 4.III.3a. Section 4.III.4.2 reported the predicted PCT of QSHL loading pattern (heat load of 42.8 kW) is 708°F, which is higher than 598°F for the scenario with the regionalized loading pattern (heat load of 36.9 kW) defined in FSAR Section 2.1.9. Therefore, the staff accepted that the QSHL loading pattern provides the bounding analyses to demonstrate compliance with the temperature and pressure limits set forth in the application.

The staff concludes that the fuel cladding temperatures will be maintained below the temperature limits in FSAR Table 4.3.1, i.e., the cladding temperature limit will be 752°F under normal long-term storage, 752°F (HBF) and 1,058°F (moderate burnup fuel [MBF]) under short-term operations, and 1,058°F under off-normal and accident conditions. These limits are consistent with Spent Fuel Storage and Transportation (SFST)-Interim Staff Guidance (ISG)-11, Revision 3. The cask component temperatures will also remain below the design temperature limits listed in FSAR Table 2.2.3. The staff found the reported PCT and component temperatures are acceptable for using QHSL in MPC-68M.

b. Pressures and Initial Helium Backfill Pressures

The applicant defined the initial helium backfill pressures (≥ 43.5 psig and ≤ 46.5 psig) in FSAR Table 1.III.1 and CoC Appendix A, Table 3-2 for MPC-68M loaded with QSHL pattern with heat load of ≤ 42.8 kW.

The applicant performed thermal evaluations for normal storage and normal transfer conditions, based on the minimum initial helium backfill pressure of 43.5 psig, and presented the results in the proprietary thermal calculation package HI-2043317 (Holtec, 2016b Attachment 1). The calculated results demonstrate that the PCT and MPC and overpack component temperatures are all below the normal condition temperature limits for storage and transfer.

The applicant performed pressure calculations with the maximum initial helium backfill pressure of 46.5 psig by assuming 1% (normal), 10% (off-normal), and 100% (accident) fuel rupture with 100% release of rod fill gases and fission gases, in accordance with NUREG-1536, Revision 1. The applicant presented the calculated maximum pressures of 99.2 psig (normal condition), 104.0 psig (off-normal condition), and 152.0 psig (accident) in Table 4.III.4 of the application.

The staff reviewed the thermal calculation package HI-2043317 and Table 4.III.4 of the application and accepted that the proposed initial helium backfill pressures (≥ 43.5 psig and ≤ 46.5 psig) for MPC-68M under QSHL pattern are acceptable because the calculated maximum MPC internal pressures and the maximum fuel cladding and cask component temperatures are below the corresponding limits for under short-term operations and normal, off-normal, and accident-level storage conditions.

c. Thermal Expansion

FSAR Section 4.III.4.3 states that the temperature field of the HI-STORM overpack predicted by the FLUENT thermal model was used to calculate the thermal expansions in fuel basket-to-MPC radial gap, fuel basket-to-MPC axial gap, MPC-to-overpack radial gap, and MPC-to-overpack axial gap for MPC-68M (QSHL pattern with a design heat load of 42.8 kW). The applicant presented the differential thermal expansions in Table 4.III.8 of the application and concluded that the calculated differential expansion values are bounded by the nominal cold gaps presented on the drawings of the application.

The staff reviewed the calculated thermal expansions shown in Table 4.III.8 and confirmed that the differential growths by thermal expansion for fuel basket-to-MPC radial gap, fuel basket-to-MPC axial gap, MPC-to-overpack radial gap, and MPC-to-overpack axial gap are bounded by the respective design gaps present in the MPC-68M (with QSHL pattern and a design heat load of 42.8 kW).

4.3.1 Storage of Damaged Fuel/Fuel Debris in DFCs under Regionalized Loading Pattern

Given the current limitation for loading DFCs in only a uniform loading pattern, the applicant proposed to store the damaged fuel/fuel debris in DFCs in the new regionalized QSHL pattern in MPC-68M. The applicant stated in Section 4.4.4 of the application that the damaged fuel is placed in DFCs before long-term storage, and then up to 16 DFCs would be placed for storage in basket peripheral locations within MPC-68M, as shown in Appendix B, Figure 2.4-1.

The applicant performed thermal evaluations using assumptions described in Section 4.III.4.4 of the application and tabulated the calculated results in Table 4.III.11. The applicant noted in Section 4.4.4.1 of the application that (1) since the DFCs are placed in the cold peripheral locations, they do not control the PCT; and (2) as a substantial fraction of basket cells are occupied by intact fuel, the overall effect of DFC fuel storage on the heat dissipation from the basket is small.

The staff reviewed the assumptions described in Section 4.III.4.4 of the application for the thermal evaluation, and the resulting PCT and cask component temperatures tabulated in Table 4.III.11 of the application. The staff found that the reported PCT of 687°F under fuel debris is below the SFST-ISG-11, Revision 3 limit of 752°F, and the cask component temperatures under fuel debris are below their design limits specified in Table 2.2.3 of the application. Therefore, the staff found the storage of damaged fuel/fuel debris in DFCs in MPC-68M using QSHL pattern to be acceptable.

4.3.2 Short-Term Operations

4.3.2.1 Wet Transfer

The applicant stated in Section 4.III.5.2 of the application that the time-to-boil for QSHL pattern (design heat load of 42.8 kW) in MPC-68M was calculated using the methodology previously reviewed by the NRC and described in FSAR Section 4.5.2 and using the thermal inertia in Table 4.III.13 for HI-TRAC loaded with an MPC-68M that contains a Metamic-HT basket and aluminum basket shims. The applicant presented the time-to-boil limits for water in Table 4.III.14 of the application.

The staff reviewed the calculated results shown in Table 4.III.14 of the application. The staff accepted the time-to-boil limits for water in MPC-68M cavity with a QSHL pattern for wet transfer operations completed within the time-to-boil limits listed in Table 4.III.14 of the application because (1) the methodology was previously reviewed and accepted and (2) the fuel temperatures are below the limits per SFST-ISG-11, Revision 3 and water in the MPC doesn’t boil per requirements of NUREG-1536, Revision 1.

4.3.2.2 Drying

(a) Vacuum Drying

The applicant proposed to add the cyclic vacuum drying for all MPCs with time limits. The applicant stated that this addition would allow users to perform vacuum drying of canisters with higher burnup fuel or with total heat load exceeding threshold heat loads.

The applicant provided the maximum MPC-68M temperatures under three vacuum drying scenarios in Table 4.III.5 of the application. Scenario A uses MBF assemblies, regionalized loading with X equals to 0.5, and heat load of 36.9 kW. Scenario B uses one or more HBF assemblies and heat load of 29 kW. Scenario C is for the new QSHL pattern with MBF assemblies and design heat load of 42.8 kW.

In the proprietary thermal calculation package HI-2043317 (Holtec, 2016b Attachment 1), the applicant calculated the maximum temperatures under vacuum drying Scenario C using the same thermal model used for analyzing Scenarios A and B. The applicant performed steady state analysis with boiling of water (232°F) in the HI-TRAC annulus, and insulated bottom surface of MPC-68M.

The staff reviewed the thermal calculation package HI-2043317 and confirmed that the calculated PCT of 896°F under Scenario C (MPC containing MBF assemblies) is below FSAR Table 2.2.3 design temperature limit of 1,058°F under short-term operations, the staff finds this consistent with SFST-ISG-11, Revision 3. The MPC-68M component temperatures are also below their design temperature limits in FSAR Table 2.2.3 and the staff finds this acceptable.

(b) Cyclic Vacuum Drying

The applicant stated in Section 4.III.5.3.1 of the application that under a scenario with MPC-68M loaded with HBF assemblies and a heat load of greater than the threshold, the PCT cannot be maintained below SFST-ISG-11, Revision 3 limit of 400°C under vacuum drying conditions for an infinite time period.

Instead of utilizing vacuum drying for MPCs with heat loads less than the identified threshold heat load, the applicant proposed changes to FSAR Table 4.5.1 and CoC Appendix A, Table 3-1 to allow the users to perform cyclic vacuum drying of MPCs with HBF or with total heat load exceeding threshold heat loads. The cyclic vacuum drying resulting in heat-up followed with cooling by helium are performed with specified time limits until drying criteria is achieved.

The staff reviewed Section 4.III.5.3.1, Table 4.5.1 and thermal analysis in the application. The staff confirmed that the maximum fuel cladding and cask component temperatures for canisters under the threshold heat loads defined in Table 4.5.1 will remain below the allowable design temperature limits. The vacuum drying of the MPC should be limited to the thermal cycles described in SFST-ISG-11, Revision 3. Therefore, the staff accepted the time limits proposed in Table 4.5.1 for each type of drying method, fuel burnup, and threshold heat load used in moisture removal operations.

(c) Forced Helium Dehydration (FHD)

As stated in Sections 4.5.3.2 and 4.III.5.3.2 of the application, the FHD system provides concurrent fuel cooling during moisture removal process through forced convective heat transfer. The FHD system ensures that the fuel cladding temperature will remain below the applicable PCT limit for normal conditions of storage, which is well below the high burnup cladding temperature limit of 752°F (400°C) for all combinations of spent nuclear fuels.

The applicant updated the MPC cavity drying limits for all MPC types in CoC Appendix A, Table 3-1 to include MPC-68M using the new QSHL pattern. As indicated in Appendix A, Table 3-1, the FHD method is applicable for MPC-24/24E/24EF, MPC-32/32F, MPC-68/68F/68EF, and MPC-68M, with specific requirements of heat load and fuel burnup.

The staff reviewed Sections 4.III.5.3.2 and 4.5.3.2 of the application and recognizes that the FHD method is an NRC-approved method for drying operations (approved in Amendment No. 2, [NRC, 2005]). The staff approved the proposed FHD drying method for all MPCs, including the MPC-68M (with a QSHL pattern), because the maximum fuel cladding and cask component temperatures remain below allowable design temperature limits.

4.3.2.3 On-Site Transfer

The applicant described the on-site transfer of MPC-68M with QSHL pattern in Section 4.III.5.5 and presented the PCT and maximum component temperatures in Table 4.III.6. The applicant calculated the temperatures for during on-site transfer with the HI-TRAC annulus filled with air and without aid of the supplemental cooling system (SCS). Based on the steady state analysis, the applicant stated that the SCS cooling is not necessary for ensuring cladding safety during on-site transfer operations for MPC-68M with QSHL pattern with the design heat load of 42.8 kW.

The staff reviewed Section 4.III.5.5 and confirmed that the PCT and component temperatures shown in Table 4.III.6 are below the limit of 752°F specified in SFST-ISG-11, Revision 3 and the allowable design temperature limits in FSAR Table 2.2.3, respectively. The staff also confirmed the SCS is not mandated in the MPC-68M technical specifications, when the MPC-68M is loaded with QSHL pattern and a design heat load of 42.8 kW (limiting condition for operation [LCO] 3.1.4). Therefore, the staff confirms that the maximum steady state HI-TRAC temperatures displayed in Table 4.III.6 are the upper bounding temperatures, which was calculated with the HI-TRAC annulus filled with air.

4.3.3 Normal Storage

The applicant described the thermal analyses of the normal storage conditions in Section 4.III.4.2 of the application. The applicant provided the maximum fuel cladding and component temperatures of MPC-68M (QSHL Pattern) in Table 4.III.3b for normal storage conditions.

The staff reviewed Table 4.III.3b and found that the maximum fuel cladding temperature of 708°F for MPC-68M with a QSHL pattern under design heat load of 42.8 kW is below the limit of 752°F, consistent with the provisions of SFST-ISG-11, Revision 3. Furthermore, the cask component temperatures are below the allowable limits in FSAR Table 2.2.3, with sufficient margins under normal storage conditions.

4.3.4 Off-Normal Storage

The applicant performed thermal analyses for the following off-normal conditions of storage: (1) elevated ambient air temperature defined by a time averaged ambient temperature of 100°F for a 3-day period, which was accepted by the NRC in previous amendments; and (2) partial blockage (50%) of air inlets, as described in Section 4.III.6.1 of the application. The applicant provided the PCT, the maximum cask component temperatures, and the maximum cavity pressures of MPC-68M (QSHL pattern, design heat load of 42.8 kW) in Table 4.III.15 of the application.

The staff reviewed Table 4.III.15 and Section 4.III.6.1 for both off-normal events of elevated ambient air temperature and partial blockage of air inlets for MPC-68M under QSHL pattern with design heat load of 42.8 kW. The staff confirmed that (1) the PCTs are below the 1,058°F limit as specified in SFST-ISG-11, Revision 3, (2) the maximum cask component temperatures are below the allowable design limits, and (3) the maximum MPC pressures are below the allowable design limit of 110 psig under off-normal conditions of storage. With these reasons, the staff determined the MPC-68M using QSHL patter with design heat load of 42.8 kW acceptable under off-normal storage conditions.

4.3.5 Accident Conditions

4.3.5.1 HI-STORM Fire

The applicant described the thermal analysis of MPC-68M (with QSHL pattern and a design heat load of 42.8 kW) under the HI-STORM fire with cask surface emissivity of 0.9 and fire temperature of 1,475°F (800°C) in Section 4.III.6.2(a)(i) of the application. The applicant calculated a 1.25°F increase in fuel temperature for the 3.62-minute fire and concluded that the impacts on the MPC internal helium pressure from a fire event would be minimal and would not adversely raise the temperature of the MPC or the stored fuel.

The staff reviewed HI-STORM fire conditions specified in Section 4.III.6.2(a)(i). The staff finds potential impacts on MPC/fuel temperatures and MPC internal pressure from a fire event of the HI-STORM fire would be minor. The staff also finds the postulated HI-STORM fire would not have significant adverse impact on the MPC-68M loaded with QSHL pattern and a design heat load of 42.8 kW.

4.3.5.2 HI-TRAC Fire

The applicant described the thermal evaluation of MPC-68M (with QSHL pattern and a design heat load of 42.8 kW) under the HI-TRAC fire in Section 4.III.6.2(a)(ii) of the application and stated that the rate of temperature rise of the HI-TRAC depends on the thermal inertia of the cask, the cask initial conditions, the heat load, and the fire heat flux. The applicant performed an analysis using lower-bound thermal inertia, steady state maximum cask temperatures, and a design heat load of 42.8 kW, and calculated a temperature rise of 24.9°F and a pressure increase of 2.9 psig during a fire period of 4.775 minutes. The applicant calculated a PCT of 734°F and a MPC internal pressure of 103.4 psig, as shown in Table 4.III.9 of the application.

The staff reviewed Table 4.III.9 and the HI-TRAC fire conditions specified in Section 4.III.6.2(a)(ii) and determined that there is no significant adverse impact to MPC-68M loaded with QSHL pattern under a design heat load of 42.8 kW because the resulting PCT of 734°F is below the 1,058°F accident limit, as specified in NUREG-1536, Revision 1 and SFST-ISG-11, Revision 3, and the resulting MPC internal pressure of 103.4 psig is below the accident design limit of 200 psig in FSAR Table 2.2.1.

4.3.5.3 Burial under Debris

The applicant stated in Section 4.III.6.2(c) of the application that it used NRC previously accepted methodology for burial under debris evaluation described in FSAR Section 4.6.2.5 for MPC-68M (QSHL pattern and a design heat load of 42.8 kW) to determine the minimum available time for fuel to reach the accident temperature limit of 1,058°F, as specified in SFST-ISG-11, Revision 3. The evaluation, as presented in Table 4.III.16 of the application, shows that it takes 30.7 hours for the PCT to reach the 1,058°F limit, and the maximum MPC cavity pressure of 133.3 psig remains below the accident limit of 200 psig specified in FSAR Table 2.2.1.

The staff reviewed Section 4.III.6.2(c) and Table 4.III.16 of the application and confirmed that, for QSHL pattern and a design heat load of 42.8 kW, the maximum pressure for burial under debris is below the design limit of 200 psig specified in FSAR Table 2.2.1. The staff also confirmed that the time-period of 30.7 hours for the PCT to reach the accident limit of 1,058°F is bounded by Surveillance Requirements (SR) 3.1.2. Therefore, the current surveillance continues to be acceptable.

4.3.5.4 100% Air Duct Blockage

(a) QSHL Pattern

Alloy X thermal conductivities shown in FSAR Table 1.A.5 demonstrate that duplex stainless steel has higher thermal conductivity than Alloy X for a temperature range of 40 – 600°F. For this reason, the staff finds reasonable assurance that (1) there is no significant difference in heat removal capability between Alloy X and duplex stainless steel when used for fabrication of the MPC, and (2) the PCT and maximum cask component temperatures and the maximum pressure will remain below the respective accident limits when duplex stainless steel is adopted to fabricate the MPC. As noted in FSAR Table 1.A.6 and discussed in Section 8.2 of this SER, the temperature limit when using duplex stainless steel is 600°F under short-term events, off-normal, and accident conditions. The staff's conclusions in (1) and (2) of this paragraph support the items (ii) and (iii) discussed below.

The applicant described the thermal analysis of MPC-68M (with QSHL pattern and a design heat load of 42.8 kW) in Section 4.III.6.2(d) under 100% air duct blockage and presented the maximum temperatures and pressure in Table 4.III.7 of the application. Table 4.III.7 presents three scenarios: (1) Case 1 using unified, regionalized pattern from Amendment No. 10 for 32 hours, (2) Case 2 using QSHL pattern for 32 hours, and (3) Case 2 using QSHL pattern for 16 hours.

The applicant noted that the MPC shell temperature for Case 2 for 32 hours is above 600°F. In order to use duplex stainless steel as MPC material, the applicant changed the time limit to 16 hours and thus reduced the shell temperature to be below 600°F. The applicant stated that the information in Table 4.III.7 for the blocked ducts transient support the required action completion times for clearing the inlets in Appendix A, Table 3-5 of the application. The temperatures for Case 2, 32 hours, are for Alloy X except duplex stainless steel, and the temperatures for Case 2, 16 hours, are for Alloy X including duplex stainless steel.

The staff reviewed Table 4.III.7 and Sections 4.III.4.1 and 4.III.6.2(d) for MPC-68M (under the QSHL pattern and Alloy X) and accepted the proposed completion times for actions (Conditions B and C and surveillance frequency provided in Appendix A, Table 3-5) to restore the spent fuel storage cask (SFSC) heat removal system. The staff finds reasonable assurance because of the following findings:

(i) For MPC-68M under QSHL pattern, except duplex stainless steel, at the end of 32-hour duct blockage, the calculated PCT of 849°F is below the limit of 1,058°F (SFST-ISG-11, Revision 3) and the maximum temperature of the cask components are below the respective accident limits provided in FSAR Table 2.2.3. The calculated maximum pressure of 116.3 psig is below the accident limit of 200 psig in FSAR Table 2.2.1.

(ii) For MPC-68M under QSHL pattern, including duplex stainless steel, at the end of 16-hour duct blockage, the calculated PCT of 789°F is below the limit of 1,058°F (SFST-ISG-11, Revision 3) and the maximum temperature of the cask components are below their respective accident limits provided in FSAR Table 1.A.6 (duplex stainless steel) and Table 2.2.3 (other components). The calculated maximum pressure of 109.5 psig is below the accident limit in FSAR Table 2.2.1.

(iii) For MPC-68M under uniform and regionalized loading based on regionalization parameter, including duplex stainless steel, at the end of 32-hour duct blockage, the calculated PCT of 722°F is below the limit of 1,058°F (SFST-ISG-11, Revision 3) and the maximum temperatures of the cask components, including duplex stainless steel, are below their respective accident limits in FSAR Table 1.A.6 (duplex stainless steel) and Table 2.2.3 (other components). The maximum pressure of 111.6 psig is below the accident limit in FSAR Table 2.2.1.

(iv) The proposed completion times for actions to restore heat removal system are provided in Table 3-5 of CoC Appendix A under 100% blockage accident, The time limits of MPC-24, MPC-32, and MPC-68 are derived based on the thermal analyses of MPC-32, as shown in FSAR Table 4.6.5, that bounds MPC-24 and MPC-68 in design heat load.

The staff found that the proposed required completion times for Conditions B and C and the surveillance frequency in this amendment will maintain the fuel cladding and cask components (including the use of duplex stainless steel) below the corresponding accident limits under 100% air inlets blockage accident.

(b) 30-Day 100% Air Duct Blockage Event

The applicant performed the steady-state thermal analysis for MPC-68 at a threshold heat load of 18 kW as described in Section 4.6.2.4 of HI-STORM 100 Amendment No. 11. The applicant demonstrated that the fuel cladding and component temperatures and the MPC cavity pressure remain below their respective 30-day accident limits at or below a threshold heat load as shown in the last row of Appendix A, Table 3-5 in the Amendment No. 12 application. The applicant stated in Section 4.6.2.4 that since the thermal performance of MPC-68M is bounded by MPC-68, the threshold heat load defined in Appendix A, Table 3-5 also applies to MPC-68M (QSHL pattern) in this application. A threshold heat load defined in Table 3-5, at or below which the fuel and component temperatures remain below their accident temperature limits under steady state conditions and therefore the periodic surveillance or vent blockage corrective actions are not necessary. This threshold heat load also applies to MPC-68M (QSHL, including duplex stainless steel).

The staff reviewed Section 4.III.6.2(d) of the application and accepts the completion times in Appendix A, Table 3-5 for actions to restore the heat removal system to be operable because (1) the temperatures of MPC-68M are bounded by the MPC-68 evaluated in Amendment No. 11, and (2) there is no significant change to the cask heat removal capability between Alloy X and duplex stainless steel when used for fabrication of the MPC. For these reasons, the staff determined the surveillance frequency defined in Table 3-5 can also be adopted for MPC-68M (including duplex stainless steel for fabrication of the MPC for QSHL pattern, uniform/regionalized loading per regionalization parameter in Appendix B, Section 2.4, and uniform/regionalized loading per Tables 3-3 and 3-4 in Appendix A) under the condition that the heat load per storage location is below the threshold to maintain the canister pressure and the fuel cladding and cask component temperatures below the corresponding accident limits.

4.3.5.5 100% Rods Rupture

The applicant evaluated 100% rod rupture in Section 4.III.6.2(f) of the application and assumed the release of 100% of the rod fill gases and fission gas in accordance with NUREG-1536 release fractions. The applicant provided maximum pressures under normal long-term storage condition for the MPC-68M (QSHL pattern with a design heat load of 42.8 kW) in Table 4.III.4 of the application.

The staff reviewed Table 4.III.4 and confirmed that the maximum MPC-68M pressure of 152 psig under a 100% rod rupture accident is below the accident limit of 200 psig in FSAR Table 2.2.1.

4.3.5.6 Jacket Water Loss

As described in Section 4.III.6.2(g) of the application, when MPC is in the HI-TRAC, the jacket water loss will cause a temperature increment in the stored fuel from the baseline conditions. The applicant stated in Section 4.III.6.2(g) that because the thermal performance of MPC-68M under QSHL pattern with heat load of 42.8 kW (Table 4.III.6 of the application) is bounded by thermal performance of MPC-32 (FSAR Table 4.5.6), the MPC-68M temperatures (under QSHL with heat load of 42.8 kW) are bounded by the MPC-32 temperatures under a jacket water loss accident.

The staff compared MPC-68M component temperatures in Table 4.III.6 with MPC-32 component temperatures in Table 4.5.6 and confirmed that MPC-68M temperatures are bounded by the MPC-32 temperatures when the MPC is loaded within the HI-TRAC. Therefore, the staff has reasonable assurance that (1) the PCT and maximum MPC-68M component temperatures are bounded by MPC-32 in the jacket water loss accident and are below the respective MPC temperature limits provided in Table 2.2.3 of the application; and (2) the maximum canister pressure is below the pressure limit of 200 psig provided in FSAR Table 2.2.1.

4.3.5.7 Extreme Ambient Temperature

The applicant presented the thermal evaluation, in Section 4.III.6.2(e) of the application, for MPC-68M with a heat load pattern of QSHL and a design heat load of 42.8 kW under the extreme ambient temperature of 125°F. The applicant presented the PCT, maximum cask component temperatures, and maximum canister pressure in Table 4.III.17 of the application.

The staff reviewed Section 4.III.6.2(e) and Table 4.III.17 for MPC-68M (QSHL, 42.8 kW) under the extreme ambient temperature accident. The staff confirmed that the PCT of 753°F is below the accident limit of 1,058°F and is consistent with SFST-ISG-11, Revision 3. The staff also confirmed the maximum cask components are below the respective design limits provided in Table 2.2.3 of the application. The calculated maximum MPC-68M canister pressure of 103.9 psig is also below the accident limit of 200 psig provided in Table 2.2.1 of the application.

Based on the above analyses, the staff determined that the MPC-68M using QSHL pattern with a design heat load of 42.8 kW acceptable under the evaluated accident conditions.

4.4 Evaluation Findings

F4.1 The staff has reasonable assurance that the MPC-68M QSHL pattern and features important to safety are described in sufficient detail in the application to enable an evaluation of the heat removal effectiveness. The structures, systems, and components (SSCs) remain within their operating temperature ranges.

F4.2 The staff has reasonable assurance that the MPC-68M (QSHL pattern with a heat load up to 42.8 kW) continue to be designed with a heat-removal capability having verifiability and reliability consistent with its importance to safety.

F4.3 The staff has reasonable assurance that the fuel cladding of high burnup fuel in the

MPC-68M (QSHL pattern with a heat load up to 42.8 kW) continues to be protected against degradation leading to gross ruptures by maintaining the cladding temperatures below 400°C (752°F) for short-term operations and normal conditions of storage and 570°C (1,058°F) for off-normal and accident conditions of storage, and other cask component temperatures continue to be maintained below the allowable limits for the accidents evaluated.

F4.4 The staff has reasonable assurance that the MPC-68M canister loaded with QSHL pattern and a design heat load of 42.8 kW is able to sustain the pressures under normal, off-normal, and accident-level conditions. The maximum canister pressures are below the design pressures of 100, 110, and 200 psig, respectively, for normal, off-normal, and accident conditions of storage.

F4.5 Based on the evaluations and findings above, the staff has reasonable assurance that the proposed changes to LCO 3.1.1 and Tables 3-1, 3-2, and 3-5 in CoC Appendix A are acceptable.

F4.6 The staff concluded that the thermal design of MPC-68M loaded with a QSHL pattern under a design heat load of 42.8 kW complies with 10 CFR Part 72 and satisfies the applicable design and acceptance criteria. The staff finds thermal design of MPC-68M (QSHL pattern) as described in the application is consistent with relevant regulations, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices. The evaluation of the thermal design provides reasonable assurance that the MPC-68M (QSHL pattern) will allow safe storage of spent fuel in the license period.

5.0 CONFINEMENT EVALUATION

The staff reviewed the applicant's requested changes for Amendment No. 12 to the HI-STORM 100 storage cask to ensure that radiological releases to the environment will be within the limits established by the regulations and that the spent fuel cladding and fuel assemblies will be sufficiently protected during storage against degradation that might otherwise lead to gross rupture.

The staff's evaluation of the duplex stainless steel material for the canister confinement boundary is presented in the materials evaluation in Section 8 of this SER. The thermal evaluation of the canister system is presented in Section 4 of this SER. The staff evaluated the changes to confinement boundary temperature under the regionalized QSHL pattern for the MPC-68M, with the storage of damaged fuel/fuel debris in DFCs under the regionalized QSHL pattern, and with cyclic vacuum drying for all MPCs. The applicant did not request changes to the confinement criteria for SSCs important to safety. For this reason, the staff concludes the confinement criteria continue to comply with the general criteria established in 10 CFR Part 72.

6.0 SHIELDING EVALUATION

The staff reviewed the proposed changes in Amendment No. 12 to CoC No. 1014 for the HI-STORM 100 storage system to ensure the applicant performed an adequate shielding evaluation to demonstrate the system acceptance. Two proposed changes require staff's shielding evaluation:

(1) Addition of new loading patterns for MPC-68M.
(2) Updating the coefficients for burnup equation with cooling times from 2 to 40 years.

The system shielding design bases and acceptance criteria remain unchanged from previous amendments. The staff focused its review primarily on the shielding evaluation, assumptions and the analysis results for the requested changes.

6.1 Addition of New Loading Patterns for MPC-68M

In FSAR Section 2.0.1, the applicant states that each MPC basket, except MPC-68F, allows for two loading strategies: (1) the uniform fuel loading and (2) the regionalized loading with two regions. The applicant proposed an additional 3-region QSHL loading pattern in the MPC-68M only. Also proposed is the storage of damaged fuel and fuel debris in up to 16 DFCs, in peripheral basket locations using the proposed 3-region QSHL loading pattern. The applicant compared dose rates of the uniform loading pattern with the 3-region QSHL pattern (where one region contains 2-year cooled spent nuclear fuel).

The applicant evaluated the various authorized BWR spent fuel assemblies and determined that the GE 7x7 provides a bounding source for the same enrichment, burnup, and cooling time because this fuel assembly design contains the maximum quantity of heavy metal, and selected it as the design basis fuel assembly. The applicant calculated the source terms (both neutron and gamma) with the design basis fuel assembly using the SCALE 5.1 depletion code. Comparison between 3-region loading pattern and uniform loading pattern for both MPC-68 and MPC-68M were performed using the SCALE, version 5.1. The applicant made the following assumptions: (1) shims are modeled to a height of 165 inches which is conservative since higher shims provide more shielding and 18 of the 24 shims have a height of 174 inches; (2) shim material in the bottom flow hole region are completely voided which conservatively neglects shielding material; and (3) overall, some shim and Metamic-HT materials are conservatively neglected in these models.

The applicant presented the dose comparison results in the proprietary shielding calculation package HI-2012702 (Holtec, 2016b Attachment 3) which shows that the dose rates for the 3-region QSHL loading pattern are bounded by the dose rates for the design basis uniform loading pattern. The applicant preformed shielding calculations using the Monte Carlo Code for Neutron and Photon Transport (MCNP). The input files were included in the calculation package.

The staff reviewed the MCNP inputs to determine that all parameters used in the analysis were based on applicant's assumptions. The staff also evaluated the MCNP output results from the comparison between the 3-region QSHL pattern (with 2-years cooled spent fuel) and the uniform pattern. The results show the 3-region QSHL pattern is bounded by uniform pattern, which is within the design basis. The staff approved the loading of both the 3-region QSHL pattern with 2-year cooled spent fuel into the MPC-68M, as well as damaged fuel and fuel debris in DFCs. The staff concludes this is acceptable because the doses from the design basis uniform loading pattern provide bounding dose levels. Therefore, the staff finds that dose rates are within the regulatory limits prescribed in 10 CFR 72.104 and 72.106. The minimum cooling time criteria for spent nuclear fuel contents within the MPC-68M only is revised to 2 years, while the minimum cooling time criteria for other MPC-68 models remain at 3 years.

6.2 Expanding the Coefficients for Burnup Equation with Cooling Times from 2 to 40 Years

The applicant proposed to update the coefficients for the burnup calculation equation in FSAR Section 2.1.9.1.3 and CoC Appendix B, Section 2.4.3, which was previously approved in Amendment No. 2 (NRC, 2005), to coefficients based upon cooling times from 2 to 40 years. Using the previously accepted methodology, the applicant calculated the coefficients and proposed to add the new coefficients in FSAR Tables 2.1.28 and 2.1.29 and Appendix B, Tables 2.4-3 and 2.4-4. The staff found the proposed coefficients for the burnup equation acceptable because they are calculated using the previously approved methodology and expanded to cover the entire range of spent fuel cooling time form 2 years to 40 years consistent with the new proposed loading pattern.

6.3 The Dose Rate Effect of Hydrogen and Water Loss on the Shielding Performance of the Concrete Used In HI-STORM

In response to a RAI (Holtec, 2017b), the applicant evaluated the effect of hydrogen and water loss on the shielding performance of the concrete used in HI-STORM 100. The applicant calculated the dose rates from HI-STORM in a hypothetical 100% duct blockage and extreme ambient temperature accident condition for a duration of 30 days based on the assumption that the entire hydrogen and partial oxygen are lost from the affected region of concrete. The applicant's analyses showed that the hypothetical 100% duct blockage accident condition for HI-STORM system is bounded by the HI-TRAC accident condition discussed in FSAR Section 5.1.2. This demonstrated that the effect of hydrogen and water loss on concrete shielding performance is bounded by previously analyzed conditions. The staff found this evaluation acceptable because the dose rates will not exceed the regulatory limits in 10 CFR 72.104 and 72.106.

6.4 Evaluation Findings

The staff reviewed the application for Amendment No. 12 to amend the CoC of the HI-STORM 100 dry cask spent fuel storage system by revising the system design and its associated shielding analyses. The staff concludes that the proposed design changes to the radiation protection system will meet the regulatory requirements of 10 CFR Parts 20 and 72, based on its review of the application and responses to requests for additional information. The staff finds reasonable assurance that the HI-STORM 100 Cask System will provide adequate protection (1) to the general public onsite or at location on or beyond the control area boundary and (2) to occupational workers from direct radiations and effluents from the normal and off-normal operations and under accident conditions. The staff concludes the radiation protection system is consistent with relevant regulatory guides, applicable codes and standards, the applicant's analyses, the staff's confirmatory analyses, and acceptable engineering practices.

7.0 CRITICALITY EVALUATION

The applicant did not propose changes that affect the staff's criticality evaluation in the SER prepared for CoC No. 1014, Amendments Nos. 0 through 11. Therefore, the staff determined that a new evaluation was not required.

8.0 MATERIALS EVALUATION

The staff reviewed the proposed changes in Amendment No. 12 to the HI-STORM 100 storage system to ensure that the applicant had performed adequate materials evaluation to demonstrate the system acceptance. Four proposed changes require staff's materials evaluation:

(1) Addition of the new QSHL pattern for the MPC-68M.
(2) Storage of damaged fuel/fuel debris in DFCs under the new regionalized QSHL pattern.
(3) Use of a duplex stainless steel in the HI-STORM 100 system.
(4) Addition of cyclic vacuum drying for all MPCs.

The changes proposed in Amendment No. 12 also resulted in changes to the maximum temperatures and pressures for the HI-STORM 100 systems using the MPC-68M. Other than the MPC-68M, the operating environmental conditions are unchanged for the Holtec storage system MPCs, HI-TRAC transfer casks, and HI-STORM overpacks.

The applicant proposed the use of a duplex stainless steel for its improved corrosion resistance properties. The remaining materials used in the fabrication of the HI-STORM 100 Cask System are unchanged and have been used in all previous Holtec storage system MPCs, HI-TRAC transfer casks, and HI-STORM overpacks.

The applicant provided the results of its materials evaluation in Chapters 1, 2, 3, 4, and 9 of the application for Amendment No. 12. The staff evaluated this information using the guidance in Chapter 8 of NUREG-1536, Revision 1, and found reasonable assurance that the HI-STORM 100 materials will perform adequately under normal, off-normal, and accident-level conditions.

8.1 Applicable Codes and Standards for System Design and Materials

As described in FSAR Sections 2.0 and 2.2, the principal codes and standards applied to the HI-STORM 100 components are the ASME Boiler Pressure & Vessel (B&PV) Code, the American Society for Testing and Materials (ASTM) standards, the American Concrete Institute (ACI) codes, and the American National Standards Institute (ANSI) standards. Materials meeting the requirements of these codes and standards conform to acceptable chemical and physical properties and are produced using controlled processes and procedures.

The MPC confinement boundary and associated weld filler materials are procured in accordance with the ASME B&PV Code, Section II (ASME, 1997a, 2015) and Section III, Subsection NB requirements (ASME, 1997b). Alternatives to codes and standards are provided in FSAR Section 2.2.4 and FSAR Table 2.2.15. The applicant stated that as an alternative to ASME SA-240 and SA-182 austenitic stainless steels (Types 304, 304LN, 316, and 316LN), the dry shielded canister (DSC) shell material may be constructed using unified numbering system (UNS) S31803 duplex stainless steel, which has improved corrosion resistance. The UNS S31803 duplex stainless steel is not included in ASME B&PV Code, Section II, Part D, Subpart 1, Tables 2A and 2B, for design stress intensity. However, the applicant stated that UNS S31803 has been accepted for Class 1 components by ASME B&PV Code Case N-635-1 (ASME, 2003), which is endorsed by NRC Regulatory Guide 1.84, "Design, Fabrication, and Materials Code Case Acceptability, ASME Section III," Revision 34, issued October 2007 (NRC, 2007).

The staff reviewed the composition requirements for the duplex stainless steel and confirmed that UNS S31803 is an accepted ASME B&PV Code alternative.

The MPC-68M basket is constructed from Metamic-HT which is a Holtec proprietary (non-ASME code) material and the basket supports are fabricated from an aluminum alloy. In Amendment No. 12, there are no changes to the basket material specifications, materials testing, fabrication methods, NDE requirements or acceptance criteria.

The HI-TRAC transfer casks are fabricated and inspected in accordance with the ASME B&PV Code, Section III, Subsection NF requirements (ASME, 1997b). Alternatives to codes and standards are provided in FSAR Section 2.2.4 and FSAR Table 2.2.15. In Amendment No. 12, there are no changes to the transfer cask material specifications, materials testing, fabrication methods, NDE requirements or acceptance criteria.

Structural steel portions of the HI-STORM overpacks are fabricated and inspected in accordance with the ASME B&PV Code, Section III, Subsection NF requirements (ASME, 1997b). Concrete portions of the overpack are designed in accordance with ACI-349-85 (ACI, 1985). Testing of the concrete portions of the overpack is performed in accordance with applicable ACI and ASTM standards identified in Section 1.D of the FSAR. Alternatives to codes and standards are provided in FSAR Section 2.2.4 and FSAR Table 2.2.15. In Amendment No. 12, there are no changes to the overpack material specifications, materials testing, fabrication methods, NDE requirements or acceptance criteria.

The staff finds that the codes and standards specified for the components in the application are acceptable because they sufficiently control the chemical and physical properties of the materials and they conform to U.S. industry consensus codes and standards, as recommended in NUREG-1536, Revision 1 (NRC, 2010).

8.2 Environmental Conditions

The operational environment for the components addressed in Amendment No. 12 is similar to those described in FSAR Revision 13 (Holtec, 2016d). The principal difference between Amendment No. 12 and earlier amendments is the use of the duplex stainless steel for the MPC shell. Amendment No. 12 also involves higher heat loads for the MPC-68M because fuel will be loaded after cooling for over 2 years instead of 3 years. The higher heat loads result in higher temperatures for the MPC, HI-TRAC Transfer cask, and the HI-STORM overpack. The applicant described design criteria for HI-STORM 100 cask system components in Section 2.2 of the FSAR. FSAR Section 3.4 contains additional information on environmental conditions, and Chapter 4 contains thermal evaluations of the HI-STORM system. The staff reviewed the environmental description to verify its accuracy, and the staff confirmed that the material evaluations in the FSAR account for the effects of the ambient off-normal and accident conditions.

Other than the use of duplex stainless steel and the higher temperatures associated with loading fuel with at least 2 years of cooling, all other operational environments are identical to previous HI-STORM amendments and are not evaluated in this SER.

For the MPC, the applicant stated in the application (Holtec, 2016a Attachment 5) that under normal conditions of storage (Table 4.III.3b) or on-site transfers of the MPC (Table 4.III.6), the MPC shell remains below 500°F and basket remains under 700°F. Under a blocked vent scenario the applicant stated that the MPC shell may reach 599°F and fuel basket could reach temperatures of 818°F (Table 4.III.7) (Holtec, 2017a Attachment 5). In all cases, the component temperatures are below the component temperature limits identified in FSAR Table 2.2.3 and Table 1.A.6 for the duplex stainless steel MPC shell. The staff notes that ASME B&PV Code Case N-635-1 (ASME, 2003) for duplex stainless steel provides allowable stress values only up to a 600°F temperature limit. As discussed in detail below, duplex stainless steel can be susceptible to embrittlement under certain thermal exposures. The applicant showed in FSAR Table 4.III.7 that, under a 100% blocked air inlet accident, the shell temperatures for the MPC may reach 639°F. For MPCs manufactured from duplex stainless steel, the applicant changed the required surveillance from 32 hours to 16 hours to ensure that the MPC shell remains below 600°F.

The applicant provided maximum steady state temperatures for the HI-TRAC during on-site transfers in Table 4.III.6. The applicant showed that the temperatures of the HI-TRAC components do not exceed the design temperature limits shown in FSAR Table 2.2.3.

The applicant provided maximum HI-STORM overpack temperatures under normal long-term storage in FSAR Table 4.III.3b and the proprietary thermal calculation package HI-2043317 (Holtec, 2016b Attachment 1). The maximum overpack inner shell temperature exceeds the maximum overpack steel structure design temperature in FSAR Table 2.2.3. Although the maximum design temperature is exceeded, the applicant indicated that the expected maximum temperature only marginally exceeds the long-term normal condition design temperature limit and there is no risk to the structural integrity of the overpack. The through thickness section average temperatures for concrete do not exceed the design temperatures in Table 2.2.3.

The applicant provided temperatures for the overpack under fuel debris storage and showed that these temperatures are below the overpack material design temperatures in FSAR Table 2.2.3. The applicant also provided temperatures under off-normal maximum temperatures (Table 4.III.15) that showed the overpack body concrete exceeded the maximum long-term, normal condition design temperature limits but was below the off-normal and accident temperature limits for the overpack concrete listed in FSAR Table 2.2.3. The applicant showed that under a 32-hour 100% air inlet blockage accident (Table 4.III.7), the overpack body concrete and lid concrete temperatures exceed the long-term, normal condition design temperature limits, but the temperatures are below the off-normal and accident temperature limits for the concrete overpack listed in FSAR Table 2.2.3. The applicant showed that for extreme environmental accident conditions (Table 4.III.17), the overpack body concrete and lid concrete temperatures exceed long-term, normal condition design temperature limits, however, these temperatures are below the off-normal and accident temperature limits shown in FSAR Table 2.2.3. In response to an RAI (Holtec, 2017a, 2017b) on the effects of elevated temperature exposure on the mechanical properties and shielding properties of concrete, the applicant revised its analysis of the maximum permissible temperature in plain concrete in HI-STORM System. The revised analysis is supported with a review of relevant testing of strength, modulus of elasticity, shielding properties, and consideration of degradation mechanisms including creep, shrinkage, spalling, and dehydration of concrete at elevated temperatures. Based on this analysis, the applicant determined that the maximum allowable off-normal and accident temperature limits was 572°F (300°C). The applicant stated that the maximum concrete temperature for a 30-day 100% vent blockage accident was 450°F (232°C) (Table 2.2.3). The applicant revised the supporting analysis to include a 50% reduction in concrete compressive strength after either a short-term off-normal or accident event or a 30-day accident event. In addition, all cask users are required to follow LCO 3.1.2. Action C.1 of this LCO requires that dose rates are measured around the cask if the vents are blocked for more than the completion time of action B (either 8 or 24 hours, depending on the cask heat load). These measurements are performed in accordance with the users' Radiation Protection Program, every 12 hours, until the blockage is removed. The users' corrective action program will address actions to be taken for any measurements that fall outside acceptable values.

The staff reviewed the applicant's description of the operating environments for the MPC, HI-TRAC transfer cask and the HI-STORM overpack. The staff also reviewed the applicant's descriptions of the operating procedures described in Chapter 8 of the FSAR and the Acceptance Criteria and Maintenance Program described in Chapter 9 of the FSAR. Based on the staff's verification of the information provided by the applicant, the staff determined that the applicant's description of the operating environments is accurate and acceptable. In addition, based on the review of technical literature on the embrittlement of duplex stainless steels documented above, the staff finds the compatibility of these steels with the MPC operating environment to be acceptable because the operational environments are within the acceptable temperature limits defined in the ASME B&PV Code Case N-635-1 (ASME, 2003). The staff found that although the long-term normal condition design temperature for the overpack inner shell temperature exceeds the maximum overpack steel structure design temperature in FSAR Table 2.2.3, the operating environment is acceptable because the overpack inner shell temperature is well below the material temperature limits defined in the ASME B&PV Code Section II Part D.

The staff reviewed the applicant's long-term normal condition design temperature limits, off-normal and accident temperature limits, and 30-day accident condition temperature limits for the overpack concrete listed in FSAR Table 2.2.3, and the off-normal and accident temperatures for concrete in FSAR Tables 4.III.15, 4.III.7, and 4.III.17. The staff also reviewed the applicant's analysis to support the normal, short-term off-normal and accident, and 30-day accident concrete temperature limits. In addition, the staff reviewed available literature on temperature effects on concrete properties, including:

a. NUREG/CR-6900 (Naus, 2006) which contains a summary of the potential concrete degradation mechanisms at elevated temperatures.
b. The work of Carette and Malhorta (1985) for the measured strength of concrete after thermal exposures up to 4 months at temperatures from 75 to 600°C (167 to 1,112°F).
c. The study by Arioz (2007) in which the physical and mechanical properties of various concrete mixtures prepared by ordinary Portland cement were subjected to elevated temperatures ranging from 200 to 1,200°C (392 to 2,192°F).
d. The review by Kassir et al. (1996) that reported decreased modulus of elasticity values as a result of exposure temperature and time at temperature.
e. The report by Peterson (1960) on the shielding properties of ordinary concrete as a function of temperature.

Based on the staff's review of the effects of temperature on the properties of concrete, the staff determined that the applicant's assessment is adequate to account for the effects of temperature on the concrete strength and shielding properties. In addition, the staff determined that the applicant's assessment of the concrete is sufficient to determine the overpack is suitable for continued use because the assessment includes the measurement of dose rates around the cask. The staff also determined that the measurement of dose rates is consistent with the guidance in ACI 349-85 Section A.4.3 for an accident or any other short-term period where the concrete is exposed to temperatures above 177°C (350°F) because the dose rate measurements will be used to determine whether the concrete shielding effectiveness has been altered. The staff found that the descriptions of the operating environments, the use of consensus codes and standards, and the materials evaluation are consistent with the recommendations in NUREG-1536, Revision 1 (NRC, 2010).

8.3 Engineering Drawings

Section 1.5 of the FSAR lists the drawings for the HI-STORM 100 cask system. In prior reviews of the Holtec HI-STORM 100 cask system the staff found the drawings to be acceptable because all materials and subcomponents of the SSCs are properly identified, including the material specifications, quality category, and code criteria. In response to a RAI (Holtec 2017a, 2017b), the applicant provided revised drawings to clarify materials used for the construction of the MPC shell and the MPC basket

The staff reviewed the revised Engineering Drawings in HI-STORM 100 cask system FSAR and determined that the revised drawings are acceptable because they follow the guidance included in NUREG/CR-5502 (Sheaffer et al., 1998). The engineering drawings include an adequate description of the storage system, contents and details of the storage system design features that provide the important to safety functions of the system.

8.4 Material Selection (Structural)

The applicant provided a general description of the materials of construction in FSAR Sections 1.A, 1.D, 2.2, 3.1 and 3.3. The staff reviewed the information contained in these sections and the information presented in the FSAR drawings to determine whether the selected materials are acceptable for their structural applications. This section of the SER documents the staff's evaluations of each of the major component areas.

Except for the addition of duplex stainless steel for the MPC confinement boundary, the materials for Amendment No. 12 are identical to the materials specified in previously approved HI-STORM 100 amendments. This includes materials used in the MPC basket, the HI-TRAC transfer cask, and the HI-STORM overpack. Therefore, staff's evaluation is limited to the duplex stainless steel material for the MPC confinement boundary.

8.4.1 Multipurpose Canister Confinement

The MPC is the primary confinement barrier for the stored SNF. Structural components of the MPC confinement boundary (MPC shell, MPC lid, closure ring, vent and drain port cover plates, and baseplate) are fabricated from either austenitic stainless steels meeting the requirements of ASME SA-240 or SA-182 for Type 304, 304LN, 316 or 316LN, or duplex stainless steel meeting the requirements of UNS S31803. The applicant selected these types of steels because of their strength, ductility, resistance to corrosion, and metallurgical stability.

The staff reviewed the materials for the MPC confinement barrier and determined that the specified materials are approved materials for Class 1 components in ASME B&PV Code, Section III (ASME, 1997b). The staff also determined that the duplex stainless steel UNS S31803 are adequate for the construction of the MPC shell and lids; these materials are approved materials for Class 1 components in accordance with ASME B&PV Code Case N-635-1 (ASME, 2003), which is approved by the NRC in Regulatory Guide 1.84 (NRC, 2007).

8.4.2 Duplex Stainless Steel, Welds, and Weld Heat Affected Zones

As described in the revision to FSAR Section 1.A, the optional duplex stainless steels and their welds are evaluated for susceptibility to brittle fracture by Charpy V-notch fracture toughness testing in accordance with ASTM A923-14 (ASTM, 2015) which states that for UNS 31803 duplex stainless steel, the minimum Charpy impact energy is 40 ft-lb (54 J) for the base metal and the weld heat affected zone, and 25 ft-lb (34 J) for the weld metal.

The staff reviewed the available information on fracture toughness testing of duplex stainless steels welds (Sieurin and Sandstrom, 2006; ASTM, 2015) and determined that Charpy V-notch impact testing is adequate to evaluate the effects of welding processes on the fracture toughness of duplex stainless steel alloys. The staff reviewed the applicant's analysis of fracture toughness for duplex stainless steel and determined that the approach used by the applicant is adequate to account for the potential decreased fracture toughness of the duplex stainless steel welds and the decreased fracture toughness of duplex stainless steel and welds observed at temperatures below 0°C (32°F). The staff determined that the applicant's analysis shows that the duplex stainless steel and the welds will have sufficient fracture toughness to prevent brittle fracture at low temperatures under accident conditions.

8.5 Material Properties

Except for the addition of duplex stainless steel for the MPC confinement boundary, the materials for Amendment No. 12 are identical to the materials specified in previously approved HI-STORM 100 amendments. This includes materials used in the MPC basket, the HI-TRAC transfer cask, and the HI-STORM overpack. However, the staff also reviewed revised calculations for the MPC basket constructed using Metamic-HT and aluminum alloy materials included in the application and found that additional information was needed to assess the performance of these materials for this application. Therefore, this section of the SER is limited to the review of the duplex stainless steel material for the MPC confinement boundary and the assessment of the basket materials.

8.5.1 Duplex Stainless Steels

The applicant provided a general description of the duplex stainless steels in FSAR Sections 1.A. Tables 1.A.1 through 1.A.5 were revised to include the mechanical properties of duplex stainless steel S31803. The mechanical properties include design stress intensity, tensile strength, yield stress, coefficient of thermal expansion, and thermal conductivity as a function of temperature. Tensile strength and yield stress values are provided for both wrought plate (ASME SA-240) and forged (ASME SA-182) materials. Mechanical property values were obtained from ASME B&PV Code Section IID (ASME, 2015).

The staff reviewed the information contained in the FSAR sections and the information presented in the FSAR drawings to determine whether the selected materials are acceptable for their structural applications. The staff reviewed the mechanical property data provided by the applicant and verified that the values stated are consistent with the values in the ASME B&PV Code Section IID (ASME, 2015). The staff found the material properties used in the applicant's structural analyses to be acceptable and appropriate for the expected load conditions because the staff independently verified that the properties are based on consensus codes and standards or other technical references commonly used and accepted in the materials industry.

The applicant provided a revised calculation of the critical flaw size for the MPCs that will be manufactured from duplex stainless steel. In response to an RAI (Holtec, 2017a, 2017b), the applicant revised the critical flaw size calculation to account for the acceptance criteria for welded duplex stainless steels in ASTM A923-14 and the potential loss of ductility at low temperatures for duplex stainless steels with a microstructure having approximately 50% ferritic phase.

The staff reviewed the applicant's revised critical flaw size calculation and determined that the calculation was acceptable because (1) the minimum fracture toughness of the duplex stainless steel weld exceeds the stress intensity factor corresponding to full circumferential 50% through-thickness crack oriented to maximize the potential for Mode II (shear) failure; (2) the calculation considered the acceptance criteria for welded duplex stainless steels in ASTM A923-14; and (3) the calculation used a correlation equation (Roberts and Newton, 1981) that accounted for the potential loss of ductility at low temperatures for duplex stainless steels with a microstructure having approximately 50% ferritic phase.

8.5.2 Metamic-HT

The applicant provided a structural calculation to demonstrate that the Metamic-HT fuel basket would remain intact and free of gross plastic deformation in a non-mechanistic tip-over event. In response to an RAI (Holtec, 2017a, 2017b), the applicant acquired and provided actual fracture toughness data as a function of temperature for Metamic-HT. The applicant showed that for temperatures ranging from room temperature up to 752°F (400°C), the measured fracture toughness of Metamic-HT exceeds the maximum stress intensity in the Metamic-HT plate assuming the existence of a through wall crack in the Metamic-HT plate that meets the acceptable defect size. In addition, the applicant showed that the maximum stresses in the Metamic-HT basket plates during non-mechanistic tip-over events are insufficient to produce gross plastic deformation of the Metamic-HT basket.

The staff reviewed the inputs to the structural calculation including the measured fracture toughness values for Metamic-HT. In addition, the staff reviewed available data on fracture toughness of aluminum metal matrix composites (Flom et al., 1989; Flom and Arsenault, 1989; Lewandowski, 2000; Miserez, 2003; Rabiei et al., 2008) and noted that several factors can influence the fracture toughness of aluminum metal matrix composites, including: (1) particle composition, (2) particle size, (3) particle loading, (4) particle distribution or clustering, (5) alloy composition, and (6) alloy condition for aluminum alloys that can be age hardened. The staff determined that the inputs to the structural calculation were acceptable because (1) the fracture toughness was measured using standardized test methods (ASTM, 2017); (2) the measured fracture toughness of Metamic-HT exceeds the maximum stress intensity in the Metamic-HT plate; and (3) the calculated maximum stress intensity in the Metamic-HT plate conservatively assumes the presence of a maximum acceptable defect size as a through wall crack in the Metamic-HT plate oriented to produce the maximum stress intensity in a non-mechanistic tip-over event. The staff also reviewed the inputs to the calculated stresses in the Metamic-HT panels during a non-mechanistic tip-over event. The staff determined that the inputs to the calculation were acceptable because the calculated stresses are compared to the measured mechanical properties including the yield strength and the ultimate tensile strength of Metamic-HT.

8.5.3 Basket Shims

The applicant provided revised temperature calculations for the aluminum alloy basket shims under three conditions: (1) normal long-term storage (FSAR Table 4.III.3b); (2) under vacuum drying scenarios (FSAR Table 4.III.5); and (3) during on-site transfer operations (FSAR Table 4.III.6). In response to a RAI (Holtec 2017a, 2017b), the applicant provided additional details on the effect of temperature on the mechanical properties of the precipitation hardened aluminum alloy basket shims. The applicant indicated that the shim is not a structural member because it does not withstand any tensile loads. Furthermore, the shim is located in a confined space that prevents uncontrolled deformation under load. The applicant further stated a structural analysis of the fuel basket for the tip-over condition was performed by modeling the shim as an elastic material with a Young's modulus value corresponding to 550°F (288°C). The applicant stated that the maximum stress of the shim obtained from the analysis is significantly smaller than the yield strength of the material after exposure at 550°F (288°C) for 10,000 hours. The applicant concluded that since the shim remains elastic during the tip-over event and the Young's modulus of the shim material does not change over time, any potential local strength degradation in the shim would not affect the deformation.

The staff reviewed the information on the mechanical properties of the aluminum alloy basket shims and of the precipitation hardened aluminum alloy as functions of thermal treatments and exposure temperatures (Rafi Raza et al., 2011; Muraca and Whittick, 1972). The staff compared the applicant's analysis of the effects of temperature and time on the mechanical properties of the aluminum alloy basket shims to data on the effects of thermal exposure on the mechanical properties of the precipitation hardened aluminum alloy reported by Muraca and Whittick (1972) and concludes the applicant's assessment is acceptable.

8.6 Weld Design and Specification

The applicant stated that MPCs will be constructed from rolled and welded plate or forged materials, and the weld seams will be multilayer full-penetration welds. These confinement boundary shell welds will be subjected to surface and volumetric non-destructive examination in accordance with the requirements of ASME B&PV Code, Section III, Subsection NB (ASME, 1997b). Non-confinement boundary welds will be subjected to either surface or surface and volumetric, non-destructive examination. Welds for the MPC closure lids will be inspected using progressive penetrant testing. The staff notes that progressive penetrant testing examination of the closure welds is an NRC-accepted alternative to the ASME B&PV Code. The staff determined that the applicant's submitted drawings include standard welding symbols and notations in accordance with AWS A2.4, "Standard Symbols for Welding, Brazing, and Nondestructive Examination" (AWS, 2007)

The applicant stated that the use of duplex stainless steel is an option for the MPC shell (FSAR Section 1.2.1.1). No changes to the MPC weld design were included in Amendment No. 12. Construction of MPCs using duplex stainless steel S31803 will be similar to MPCs constructed from the Alloy X materials described above. The applicant stated that duplex stainless steel exhibits increased resistance to stress corrosion cracking (SCC); however, resistance to SCC is reduced when the microstructure of the steel is altered due to prolonged exposure to elevated temperatures or improper fabrication methods. The applicant identified a range of weld heat inputs and maximum interpass temperatures to prevent alteration of the weld and weld heat affected zone microstructures. The applicant also identified fabrication and welding parameter controls for duplex stainless steels, which are implemented during cask fabrication and welding. Example of these controls, include a specified range of weld heat inputs and maximum interpass temperatures. Implementation of controls prevents alteration of the weld and the weld heat affected zone microstructures. The applicant also specified standardized evaluation tests with defined acceptance criteria to ensure that degradation of the mechanical properties and corrosion resistance of duplex stainless steels will not occur as a result of MPC construction and closure welding operations.

The staff also reviewed the available information on the chloride induced stress corrosion cracking (CISCC) resistance of duplex stainless steels (Tseng et al., 2003; Cottis and Newman, 1993). The staff determined that UNS S31803 duplex stainless steels are more resistant to CISCC compared to austenitic stainless steels; however, CISCC has been reported in offshore applications when welding practices were used that altered the microstructure of the alloy (Leonard, 2003). The staff reviewed studies conducted by Liou et al. (2002), which showed that increased nitrogen content in Type 2205 stainless steels was beneficial for maintaining a favorable ratio of ferrite to austenite phases that is necessary for CISCC resistance. The staff also found that cooling rates have a significant effect on the resulting microstructure of duplex stainless steels. Cooling rates above 0.41°F/s are necessary to avoid embrittlement from the formation of sigma phase, but cooling rates above 90°F/s result in an unfavorable ratio of ferrite to austenite and diminish CISCC resistance (Sieurin and Sandstrom, 2007). The staff reviewed the applicant's fabrication and welding parameter controls for duplex stainless steels and the applicant's specified standardized evaluation tests and acceptance criteria. Based on the review of information in the fabrication of duplex stainless steel, the staff concludes the fabrication and welding parameter controls and evaluation tests implemented by the applicant are adequate to ensure that degradation of the mechanical properties and corrosion resistance of duplex stainless steel will not occur as a result of MPC construction and closure welding operations.

8.7 Fuel Cladding

8.7.1 Fuel Cladding Temperature Limits

The applicant provided its thermal analysis of fuel cladding in Chapter 4 and Supplement 4.III of the FSAR for the MPC-68M. The applicant provided a revised analysis for MPC-68M to address regionalized QSHL pattern and provided fuel cladding temperatures under normal, off-normal, and accident conditions. FSAR Table 4.III.3a shows the fuel loading pattern screening evaluations. The applicant showed that the new QSHL pattern resulted in the highest PCT. Therefore, the applicant based the revised analysis on the QSHL pattern for all the licensing basis evaluations of fuel storage in MPC-68M.

FSAR Table 4.III.3b provides the maximum temperatures under normal long-term storage. The applicant showed that the maximum cladding temperature was below the 400°C (752°F) identified in NUREG-1536, Revision 1, for normal conditions of storage.

In FSAR Table 4.III.5, the applicant showed that the maximum fuel cladding temperatures for high burnup fuel remain below the 400°C (752°F) temperature limit identified in NUREG-1536, Revision 1. For low burnup fuel, the maximum cladding temperatures under vacuum drying scenarios were above 400°C (752°F). The applicant previously provided an analysis (Lanning and Beyer, 2004) to support the use of a higher temperature for the low burnup fuel that is consistent with the guidance identified in NUREG-1536, Revision 1, which states that a higher short-term temperature limit may be used, if the applicant can show by calculation the best estimate cladding hoop stress is equal to or less than 90 MPa (13,053 psi) for the temperature limit proposed.

FSAR Table 4.III.6 shows the maximum steady state HI-TRAC temperatures and pressures during on-site transfer operations. The applicant showed that the maximum cladding temperature was below the 400°C (752°F) temperature limit identified in NUREG-1536, Revision 1.

FSAR Table 4.III.7 shows the maximum temperatures and pressures under a 32-Hour 100% air inlets blockage accident. The applicant stated that the maximum cladding temperature is consistent with the guidance in NUREG-1536, Revision 1, which states that for off-normal and accident conditions, the maximum cladding temperature should not exceed 570°C (1,058°F).

FSAR Table 4.III.11 shows the HI-STORM temperatures under fuel debris storage. The applicant stated that the maximum cladding temperature was below the 400°C (752°F) temperature limit identified in NUREG-1536, Revision 1.

FSAR Table 4.III.15 shows the off-normal condition maximum HI-STORM temperatures and MPC cavity pressures. The applicant stated that the maximum cladding temperature was below the 570°C (1,058°F) temperature limit identified in NUREG-1536, Revision 1.

FSAR Table 4.III.17 shows the extreme environmental accident condition maximum HI-STORM temperatures and MPC cavity pressure. The applicant shows that the maximum cladding temperature is consistent with the guidance in NUREG-1536, Revision 1, which states that for off-normal and accident conditions, the maximum cladding temperature should not exceed 570°C (1,058°F).

The staff reviewed the applicant's calculated cladding temperatures to confirm that there is reasonable assurance that creep will not cause gross rupture of the cladding and that hydride reorientation will not degrade the mechanical properties of the cladding. The guidance in NUREG-1536, Revision 1, establishes a maximum fuel cladding temperature limit for normal storage conditions, short-term loading operations, off-normal, and accident conditions. For all fuel burnups (low and high), the maximum calculated fuel cladding temperature should not exceed 400°C (752°F) for normal conditions of storage and short-term loading operations (e.g., drying, backfilling with inert gas, and transfer of the cask to the storage pad). However, for low burnup fuel, a higher short-term temperature limit may be used, if the applicant can show by calculation the best estimate cladding hoop stress is equal to or less than 90 MPa (13,053 psi) for the temperature limit proposed. For all fuel burnups the cladding should be limited to a maximum temperature of 570°C (1,058°F) for off-normal and accident conditions. The staff reviewed the applicant's thermal analyses and confirmed that the applicant's calculated temperatures are below these maximum temperature limits. With respect to the applicant's cladding temperature for low burnup fuel under vacuum drying operations, the staff reviewed the analysis referenced by the applicant (Lanning and Beyer, 2004) and the similar work reported by Brown et al. (2004). The staff determined that the temperatures for the low burnup fuel during drying that exceed 400°C (752°F) but remain less than 570°C (1,058°F) are acceptable because the estimated cladding hoop stress is equal to or less than 90 MPa (13,053 psi) and thus follows the guidance in NUREG-1536, Revision 1.

8.7.2 Fuel Cladding Temperature During Moisture Removal Operations

No changes to the forced helium dehydration method were included in Amendment No. 12.

The applicant included cyclic vacuum drying as a permissible method to remove moisture from the MPC during fuel loading operations. The applicant stated that for MPCs containing MBF assemblies only, this operation may be carried out using the vacuum drying method up to the threshold heat loads defined in FSAR Table 4.5.1. The applicant stated that for heat loads greater than the threshold heat load, the PCT cannot be maintained below the SFST-ISG-11, Revision 3 limit of 570°C for MBF under a vacuum condition of infinite duration. Under this scenario, cycles of vacuum drying resulting in heat-up followed with cooling by helium are performed until drying criteria is achieved. The applicant stated that vacuum drying of MPCs containing one or more HBF assemblies is also permitted under time limits and the PCT for drying HBF must be maintained below SFST-ISG-11, Revision 3 limit of 400°C. The applicant stated that per SFST-ISG-11, Revision 3 repeated thermal cycling is limited to less than 10 cycles, with cladding temperature variations less than 65°C (117°F) each cycle.

The applicant stated that the HI-TRAC annulus must remain filled with water during vacuum drying operations, in order to limit fuel temperatures during demoisturization of the MPC-68M by the vacuum drying method. The applicant identified a threshold heat load above which the PCT will exceed the SFST-ISG-11, Revision 3 limit of 400°C. This threshold is reached when HBF is under a vacuum condition of infinite duration. The applicant stated that under this scenario, cycles of vacuum drying resulting in heat-up followed with cooling by helium are performed until drying criteria are achieved. The applicant stated that following the recommendations of SFST-ISG-11, Revision 3, repeated thermal cycling is limited to less than 10 cycles, with cladding temperature variations less than 65°C (117°F) each cycle.

The staff evaluated the applicant’s thermal cycling analysis to ensure that the loading operation will not result in conditions that could promote creep or hydride reorientation. The staff confirmed the loading operations addressed the recommendation in NUREG-1536, Revision 1, to avoid hydride reorientation by limiting thermal cycling in loading operations to less than 10 cycles where cladding temperature variations are more than 65°C. For these reasons, the staff found the applicant’s loading operations acceptable.

8.8 Prevention of Oxidation Damage During Loading of Fuel

No changes to the forced helium dehydration method were included in Amendment No. 12.

The applicant included cyclic vacuum drying as a permissible method to remove moisture from the MPC during fuel loading operations. Both the FHD and the vacuum drying methods utilize helium as an inert gas that both promoted heat transfer and prevents the oxidation of the fuel exposed by pinholes or hairline cracks in the cladding. This approach is consistent with the recommendations in NUREG-1536, Revision 1.

The staff evaluated the applicant’s approach to preventing oxidation damage during loading operations. The staff determined that the applicant’s approach is acceptable because the applicant follows the guidance in NUREG-1536, Revision 1, for preventing oxidation.

8.9 Evaluation Findings

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

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

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

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

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

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

F8.7 The applicant has met the requirements of 10 CFR 72.236(h). The HI-STORM 100 MPC storage system employs materials that are compatible with wet and dry SNF loading and unloading operations and facilities. These materials should not degrade over time or react with one another during any conditions of storage.

The staff concludes that the material properties of the SSCs of the HI-STORM 100 Amendment No. 12 are in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria have been satisfied. The staff finds that the material properties of the SSCs of the HI-STORM 100, as amended by Amendment No. 12, are consistent with relevant regulations, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices. The staff concludes the material properties provide reasonable assurance that the HI-STORM 100 Amendment No. 12 will allow for the safe storage of SNF for a licensed (certified) life of 20 years.

9.0 OPERATING PROCEDURES EVALUATION

The applicant did not propose any changes that affect the staff’s operating procedures evaluation provided in previous SER for CoC No. 1014, Amendments No. 0 through 11. 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 previous SER for CoC No. 1014, Amendments No. 0 through 11. 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 previous SER for CoC No. 1014, Amendments No. 1 through 11. Therefore, the staff determined that a new evaluation was not required.

12.0 ACCIDENT ANALYSES EVALUATION

The only proposed change that requires staff's accident analysis evaluation is the use of the optional QSHL pattern in MPC-68M. The applicant provided thermal accident analyses for the MPC-68M that addressed off-normal pressure, off-normal environmental temperatures, partial blockage of air inlets, HI-STORM fire, HI-TRAC fire, burial under debris, 100% blockage of air inlets, 100% fuel rods rupture, jacket water loss, and extreme environmental temperature. The staff's evaluation of the accident temperatures of the storage system component materials is documented in Section 4.3.5 of this SER. The staff determined that in all cases, the component temperatures are below the component temperature limits identified in FSAR Table 2.2.3 and Table 1.A.6 for the duplex stainless steel MPC shell. The staff confirmed that the accident temperatures for the materials used in the HI-STROM 100 system were within the temperature limits of the codes and standards for the design and construction of the system components. The staff concludes the QSHL pattern in MPC-68M is in compliance with 10 CFR Part 72 and the acceptance criteria have been satisfied.

13.0 TECHNICAL SPECIFICATIONS AND OPERATING CONTROL AND LIMITS EVALUATION

13.1 Appendix A, Table 3-1: MPC Cavity Drying Limit

The applicant updated the MPC cavity drying limits for all MPC types in Appendix A, Table 3-1 to include MPC-68M under QSHL pattern with a design heat load of 42.8 kW. As described in Section 4.3.2.2 of this SER, the staff recognizes the NRC previously accepted the use of vacuum drying system (VDS) and FHD as drying methods. Because the maximum fuel cladding and cask component temperatures are below the allowable design temperature limits, the staff accepted the use of VDS and FHD to MPC-68M under QSHL as specified in Table 3-1.

13.2 Appendix A, Table 3-2: Helium Backfill Limits

The applicant updated MPC helium backfill limits in Appendix A, Table 3-2 to include MPC-68M under QSHL pattern. As discussed in Section 4.3b of this SER, the calculated maximum MPC internal pressures and the maximum fuel cladding and cask component temperatures are below the corresponding limits required for under short-term operations and normal, off-normal, and accident-level storage conditions. Therefore, the staff concluded the update to Table 3-2 is acceptable.

13.3 Appendix A, SR and Completion Time for Actions to Restore Heat Removal System Operable

The applicant updated Appendix A, SR 3.1.2 and Table 3-5 to include MPC-68M under QSHL pattern and the use of duplex stainless steel. As discussed in Section 4.3.5.4 of this SER, the staff found the thermal analyses of MPC-68M, with QSHL pattern at 42.8 kW and uniform loading and regionalized loading based on regionalization parameter, provides bounding condition for MPC-24, MPC-32, and MPC-68 systems. The staff also noted that, when used for fabrication of the MPC, there is no significant difference in heat removal capability between Alloy X and duplex stainless steel, and the PCT and maximum cask component temperatures and the maximum pressure will remain below the respective accident limits. Therefore, the staff determined the changes to Appendix A, SR 3.1.2 and Table 3-5 acceptable.

13.4 Appendix B: Fuel Specification and Loading Conditions

The applicant deleted from Appendix B, Section 2.1.3 the sentence, “Regionalized loading is limited to INTACT FUEL ASSEMBLIES or UNDAMAGED FUEL ASSEMBLIES with ZR cladding.” This is a necessary conforming change since the new regionalized QSHL pattern would allow the loading of damaged fuel and fuel debris. Therefore, the staff found the deletion acceptable.

13.5 Appendix B: Decay Heat Calculation and Associated Tables

In order to address the inclusion of an optional QSHL pattern for MPC-68M, the applicant updated the information on decay heat calculation in Appendix B, Section 3.4.2 and Tables 2.4-2 and 2.4-5. In Section 2.4.2, the applicant introduced Table 2.4-5 that identifies allowable heat loads for damaged fuel and fuel debris in regionalized QSHL pattern. It also added a sentence referring to the optional regionalized loading pattern for MPC-68M in Figure 2.4-1. Table 2.4-2 now references the optional QSHL pattern for MPC-68M. The staff found these changes acceptable, as they reflect necessary conforming changes.

13.6 Appendix B: Burnup Limit Calculation and Associated Tables

The applicant updated the coefficients for the burnup calculation equation in Appendix B, Section 2.4.3 and Tables 2.4-3 and 2.4-4. As discussed in Section 6.2 of this SER, these are necessary changes to conform to the cooling time of 2 to 40 years. The staff found the changes to the coefficients for the burnup equation acceptable because the applicant used a methodology previously accepted by the NRC.

13.7 Appendix B: QSHL Pattern

The applicant added Figure 2.4-1 to demonstrate the new regionalized loading pattern to be used in MPC-68M only. As discussed in Sections 3, 4, 6, and 8, the staff has performed structural, thermal, shielding, and materials evaluations for the new QSHL pattern and determined the QSHL pattern is acceptable to be used in MPC-68M.

13.8 Appendix B: Addition to ASME Code Alternatives

The applicant added duplex stainless steel as an ASME Code alternative to Appendix B, Table 3-1. As discussed in Section 8.1 of this SER, UNS S31803 has been accepted for Class 1 components by ASME B&PV Code Case N-635-1 (ASME, 2003), which is endorsed by NRC Regulatory Guide 1.84. Therefore, the staff accepted the addition of duplex stainless steel to Table 3-1.

14.0 QUALITY ASSURANCE EVALUATION

The applicant did not propose any changes that affect the staff’s quality assurance evaluation provided in previous SER for CoC No. 1014, Amendments No. 0 through 11. Therefore, the staff determined that a new evaluation was not required.

15.0 CONCLUSIONS

Based on its review of the amendment request to CoC No. 1014, Amendment No. 12, the staff has determined that there is reasonable assurance that: (1) the activities authorized by the amended certificate can be conducted without endangering the health and safety of the public, and (2) these activities will be conducted in compliance with the applicable regulations of 10 CFR Part 72.

November 28, 2018

References

ACI, 1985. "Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary," ACI 349-85, American Concrete Institute, Detroit, MI, 1985.

Arioz, 2007. Arioz, O., "Effects of elevated temperatures on properties of concrete," Fire Safety Journal, Volume 42, pp. 516–522, 2007.

ASME, 1997a. "ASME Boiler and Pressure Vessel Code," Section II, "Materials," 1995 Edition with 1997 Addenda, American Society of Mechanical Engineers, New York, NY, 1997.

ASME, 1997b. "ASME Boiler and Pressure Vessel Code," Section III, "Rules for Construction of Nuclear Facility Components," Division 1, Subsection NB, 1995 Edition with 1997 Addenda, American Society of Mechanical Engineers, New York, NY, 1997.

ASME, 2003. "Use of 22Cr-5Ni-3Mo-N (Alloy UNS 531803) Forgings, Plate, Bar, Welded and Seamless Pipe, and/or Tube, Fittings, and Fusion Welded Pipe with Addition of Filler Metal, Classes 1, 2, and 3," Section III, Division 1, ASME Code Case N-635-1, American Society of Mechanical Engineers, New York, NY, 2003.

ASME, 2015. "ASME Boiler and Pressure Vessel Code," Section II, "Materials," 2015 Edition, American Society of Mechanical Engineers, New York, NY, 2015.

ASTM, 2015. "Standard Test Methods for Detecting Detrimental Intermetallic Phase in Duplex Austenitic/Ferritic Stainless Steels," Designation A923-14, ASTM International, West Conshohocken, PA, 2015.

ASTM, 2017. "Standard Test Method for Measurement of Fracture Toughness", Designation E1820-15a (Reapproved 2017), ASTM International, West Conshohocken, PA, 2017.

AWS, 2007. Standard Symbols for Welding, Brazing, and Nondestructive Examination, 6th Edition, AWS A2.4:2007, American Welding Society, Miami, FL, 2007.

Brown et al., 2004. Brown, C., J. Guttmann, C. Beyer, and D. Lanning, "Maximum Cladding Stresses for Bounding PWR Fuel Rods During Short Term Operations for Dry Cask Storage," Proceedings of the 2004 International Meeting on LWR Fuel Performance, Orlando, Florida, September 19-22, 2004, Paper 1106, pp. 459-466, La Grange Park, Il, American Nuclear Society, 2004.

Carette and Malhorta, 1985. Carette, G.G, and V.M. Malhorta, "Performance of Dolostone and Limestone Concretes at Sustained High Temperatures," Temperature Effects on Concrete, ASTM STP 858, pp. 38-67, T.R Naik Ed., American Society for Testing and Materials, Philadelphia, PA, 1985.

Cottis and Newman, 1993. Cottis, R.A., and R.C. Newman, "Stress-Corrosion Cracking Resistance of Duplex Stainless Steels," UMIST Corrosion and Protection Centre, Manchester, UK, December 1993.

Flom et al., 1989. Flom, Y., B.H. Parker, and H.P. Chu, "Fracture Toughness of SiC/Al Metal Matrix Composite," NASA Technical Memorandum 100745, August 1989.

Flom and Arsenault, 1989. Flom, Y., and R. J. Arsenault, "Effect of Particle Size on Fracture Toughness of SiC/Al Composite Material," Acta Metall. Vol. 37, No. 9, pp. 2413-2423, 1989.

Holtec, 2016a. Letter from Holtec International to NRC, "Holtec International HI-STORM 100 Multipurpose Canister Storage System Amendment Request 1014-12." June 14, 2016. Agencywide Document Access and Management System (ADAMS) Accession No. ML16169A363.

Holtec, 2016b. Letter from Holtec International to NRC, "Holtec International HI-STORM 100 Multipurpose Canister Storage System Amendment Request 1014-12 Supporting Calculation Packages." July 22, 2016. This package contains four attachments, and Attachments 1 through 3 are *Proprietary Information and Not Publicly Available.* ADAMS Accession No. ML16210A133.

Holtec, 2016c. Letter from Holtec International to NRC, "HI-STORM 100 Amendment 12 Responses to Requests for Supplemental Information." November 4, 2016. This package contains five attachments, and Attachment 4 is *Proprietary Information and Not Publicly Available.* ADAMS Accession No. ML16313A216.

Holtec, 2016d. Holtec International Final Safety Analysis Report for the HI-STORM 100 Cask System, Revision 13. March 31, 2016. ADAMS Accession No. ML16138A100.

Holtec, 2017a. Letter from Holtec International to NRC, "Submittal of Responses to NRC's RAIs for HI-STORM 100 LAR 1014-12." August 25, 2017. This package contains 13 attachments, and Attachments 1, 5, 7, 8, 9, 10, 11, and 12 are *Proprietary Information and Not Publicly Available.* ADAMS Accession No. ML17251A739.

Holtec, 2017b. Letter from Holtec International to NRC, "Submittal of Supplemental Information on NRC's RAIs for HI-STORM 100 LAR 1014-12." November 10, 2017. This package contains six attachments, and Attachment 1 is *Proprietary Information and Not Publicly Available.* ADAMS Accession No. ML17326A174.

Holtec, 2017c. Letter from Holtec International to NRC, "Submittal of Revised Supplemental Information on NRC's RAIs for HI-STORM 100 LAR 1014-12." December 22, 2017. ADAMS Accession No. ML17362A130.

Holtec, 2017d. Letter from Holtec International to NRC, "Submittal of Responses to NRC's 2nd Round RAIs for HI-STORM 100 LAR 1014-11," September 8, 2017. This package contains seven attachments, and Attachments 1, 5, and 6 are *Proprietary Information and Not Publicly Available.* ADAMS Accession No. ML17261A159.

Kassir et al., 1996. Kassir, M.K., K.K. Bandyopadhyay, and M. Reich, "Thermal Degradation of Concrete in the Temperature Range from Ambient to 315°C (600°F)," BNL-52384, Brookhaven National Laboratory, Upton, New York, October 1996.

Lanning and Beyer, 2004. Lanning, D.D., and C.E. Beyer, "Estimated Maximum Cladding Stresses for Bounding PWR Fuel Rods During Short Term Operations for Dry Cask Storage," January 2004. ADAMS Accession No. ML040290474.

Leonard, 2003. Leonard, A., “Review of external stress corrosion cracking of 22%Cr duplex stainless steel, Phase 1—Operational data acquisition,” HSE RR 129, Her Majesty’s Stationery Office, Norwich, UK., 2003.

Lewandowski, 2000. Lewandowski, J.J., “Fracture and Fatigue of Particulate MMCs, in Comprehensive Composite Materials,” Metal Matrix Composites, Volume 3, T.W. Clyne, Editor, Pergamon, Oxford UK,, pp. 151-187, 2000.

Liou et al., 2002. Liou, H-Y., R-I. Hsieh, and W-T. Tsai, “Microstructure and stress corrosion cracking in simulated heat-affected zones of duplex stainless steels,” *Corrosion Science*, Vol. 44, pp. 2841–2856, 2002.

Miserez, 2003. Miserez, A.G.T., “Fracture and Toughening of High Volume Fraction Ceramic Particle Reinforced Metals,” PhD Thesis, École Polytechnique Fédérale de Lausanne, 2003.

Muraca and Whittick, 1972. Muraca, R.F., and J.S. Whittick, “Materials Data Handbook - Aluminum Alloy 2219,” NASA-CR-123777, Western Applied Research & Development, Inc., San Carlos, CA, March 1972.

Naus, 2006. Naus, D.J., “The Effect of Elevated Temperature on Concrete Materials and Structures—A Literature Review.” NUREG/CR-6900, ORNL/TM-2005/553, Oak Ridge National Laboratory, Oak Ridge, TN, March 2006. ADAMS Accession No. ML060970563.

NRC, 2005. “Safety Evaluation Report, Docket No. 72-1014, Holtec International, HI-STORM 100 Cask System, Certificate of Compliance No. 1014, Amendment No. 2,” U.S. Nuclear Regulatory Commission, June 7, 2005. ADAMS Accession No. ML051580522.

NRC, 2007. “Design, Fabrication, and Materials Code Case Acceptability, ASME Section III,” Regulatory Guide 1.84, Revision 34, U.S. Nuclear Regulatory Commission, October 2007. ADAMS Accession No. ML072070407.

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

NRC, 2017. *Code of Federal Regulations*, Title 10, Energy, Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste,” U.S. Nuclear Regulatory Commission, Washington, D.C., 2017.

Outokumpu High Performance Stainless, “Duplex Stainless Steel,” Information Brochure, Outokumpu, New Castle, IN, 2014.

Peterson, 1960. Peterson, E.G., "Shielding Properties of Ordinary Concretes as a Function of Temperature," HW-65572, Hanford Atomic Products Operation, Richland, Washington, August 2, 1960.

Rabiei et al., 2008. Rabiei, A., L. Vendra, and T. Kishi, “Fracture behavior of particle reinforced metal matrix composites,” Composites, Part A Vol. 39, pp. 294–300, 2008.

Rafi Raza et al., 2011. Rafi Raza, M., F. Ahmad, N. Ikram, R. Ahmad, and A. Salam, “Development and Strengthening of 2219 Aluminum Alloy by Mechanical Working and Heat Treatment,” Journal of Applied Sciences, 2011.

Roberts and Newton, 1981. Roberts, R and C. Newton, “Interpretive Report on Small Scale Test Correlations with KIc Data,” Welding Research Council Bulletin 265, Welding Research Council, New York, NY, February 1981.

SFST-ISG-11, Revision 3, “Cladding Considerations for the Transportation and Storage of Spent Fuel,” U.S. Nuclear Regulatory Commission, November 17, 2003. ADAMS Accession No. ML033230335.

Sheaffer et al., 1998. Sheaffer, M. K., G. R. Thomas, R. K. Dann, and E. W. Russell, “Engineering Drawings for 10 CFR Part 71 Package Approvals,” NUREG/CR-5502, Lawrence Livermore National Laboratory, Livermore, CA, May 1998.

Sieurin and Sandstrom, 2006. Sieurin, H, and R. Sandstrom, “Fracture toughness of a welded duplex stainless steel,” *Engineering Fracture Mechanics*, Vol. 73, pp. 377–390, 2006.

Sieurin and Sandstrom, 2007. Sieurin, H and R. Sandstrom, “Sigma phase precipitation in duplex stainless steel 2205,” Materials Science and Engineering A, Vol. 444, pp. 271–276, 2007.

Tseng et al., 2003. Tseng, C-M., H-Y. Liou, and W-T. Tsai, “Effect of Nitrogen Content on the Environmentally Assisted Cracking Susceptibility of Duplex Stainless Steels,” *Metallurgical and Materials Transactions*, Vol 34A, pp. 95–103, January 2003.

SUBJECT: PRELIMINARY SAFETY EVALUATION REPORT, DOCKET NO. 72-1014, HOLTEC INTERNATIONAL HI-STORM 100 MULTIPURPOSE CANISTER STORAGE SYSTEM, CERTIFICATE OF COMPLIANCE NO. 1014, AMENDMENT NO. 12. DOCUMENT DATE: November 28, 2018

ADAMS Accession No. **ML18087A062**

OFC	NMSS/DSFM	NMSS/DSFM	NMSS/DSFM	NMSS/DSFM	NMSS/DSFM	NMSS/DSFM
NAME	YChen	WWheatley	DTang	JChang	JIreland	ASotomayor-Rivera
DATE	3/2/2018	3/5/2018	2/21/2018	2/16/2018	2/13/2018	3/1/2018
OFC	NMSS/DSFM	NMSS/DSFM	NMSS/DSFM	NMSS/DSFM	OGC/HLW	NMSS/DSFM
NAME	DDunn	YDiaz-Sanabria	HGonzalez	TTate	PJehle	JMcKirgan
DATE	2/20/2018	3/22/2018	3/16/2018	3/27/2018	4/19/2018	5/25/2018

OFFICIAL RECORD COPY