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PRELIMINARY SAFETY EVALUATION REPORT

DOCKET NO. 72-1014
HOLTEC INTERNATIONAL
CERTIFICATE OF COMPLIANCE NO. 1014
HI-STORM 100 CASK SYSTEM
RENEWED AMENDMENT NO. 19

SUMMARY

This safety evaluation report (SER) documents the U.S. Nuclear Regulatory Commission (NRC) staff's review and evaluation of the request to amend Certificate of Compliance (CoC) No. 1014 for the HI-STORM 100 Cask System. By letter dated August 9, 2024 (Agencywide Documents Access and Management System Accession No. ML24222A858), as supplemented in letters dated November 4, 2024 (ML24309A286), and November 13, 2024 (ML24318C533), Holtec International, from here on referred to as the "applicant" or "Holtec," requested that the NRC amend the CoC to include the following change:

> Update the acceptance criteria and method of evaluation (MOE) for the HI-STORM 100 system tipover accident described in the final safety analysis report (FSAR) for equipment combinations involving multi-purpose canisters (MPCs) with Metamic-HT baskets. This involves applying a new stress-based criteria and completing new evaluations consistent with the new tipover acceptance criteria and MOE established in HI-STORM Flood/Wind (FW) MPC Storage System, Amendment No. 7 (ML24199A241). This also involves some adjustments of the existing deflection criteria.

The amendment also includes some minor changes to the FSAR for clarification and updates.

The amended CoC, when codified through rulemaking, will be denoted as Renewed Amendment No. 19 to CoC No. 1014. This SER documents the staff's review and evaluation of the proposed amendment. The staff followed the guidance of NUREG-2215, "Standard Review Plan for Spent Fuel Dry Storage Systems and Facilities" (ML20121A190), when performing technical reviews of spent fuel storage and transportation packaging licensing actions.

The staff's evaluation is based on a review of the applicant's application and whether it meets the applicable requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 72 for dry storage of spent nuclear fuel. The staff's evaluation focused only on modifications to the CoC, and technical specification (TS) requested in the amendment as supported by the submitted revised updated final safety analysis report (UFSAR) (ML24222A863, ML24309A290, and ML24318C539) and did not reassess previous revisions of the UFSAR nor previous amendments to the CoC.

1.0 GENERAL INFORMATION

The objective of this section is to review the changes requested to CoC No. 1014 for the HI-STORM 100 Cask System to ensure that the applicant provided an adequate description of the pertinent features of the storage system and the changes requested in the application. Note that SER sections 2, 13, and 14 are only applicable to site specific license reviews and are not applicable to CoC evaluations.

In the application chapter 1, the applicant added table 1.0.4, which delineates the allowable transfer cask models (HI-TRAC), and enclosure vessel with fuel basket combinations (MPC) that are compatible with each HI-STORM overpack model. The applicant revised supplement 1.I, “General Description of the HI-STORM 100U System,” to refer to table 1.0.4. The applicant also revised supplement 1.II, “General Description of HI-STORM 100 System with Version E Vertical Ventilated Module, HI-TRAC MS, MPC-32M, MPC-32 Version 1 and MPC-68 Version 1,” to refer to table 1.0.4, which replaces table 1.II.2.2. Finally, the applicant revised supplement 1.IV, “General Description: HI-STORM 100 System with Version UVH Overpack,” to refer to Table 1.0.4.

In section 1.5 of the FSAR, the applicant proposed a revision to drawing 7195, revision 17, “Assembly, Fuel Basket, MPC-68M,” increasing the minimum width of an optional shim plate between extruded basket shims.

The staff determined that the proposed description in general information is adequate for the staff to conduct its evaluation as documented in the rest of this SER. Therefore, it satisfies the requirements for the general description under 10 CFR Part 72.

2.0 SITE CHARACTERISTICS FOR DRY STORAGE FACILITIES

This section is not applicable to CoC evaluations.

3.0 PRINCIPAL DESIGN CRITERIA EVALUATION

The staff reviewed the proposed changes in the application chapter 2, “Principal Design Criteria,” to ensure the principal design criteria related to structures, systems, and components (SSCs) important to safety (ITS) comply with the relevant general criteria established in the requirements in 10 CFR Part 72.

The applicant revised supplements 2.II, 2.III, and 2.IV to address the changes in principal design criteria for the following HI-STORM 100 system overpacks and fuel baskets presented in the amendment, respectively: the 100S Version E and Version E1 overpacks loaded with MPC-32M and MPC-32M-CBS baskets, the (original) 100 overpack loaded with the MPC-68M and MPC-68M-CBS, and the 100 Version unventilated high density (UVH) overpack loaded with the MPC-32M and MPC-68M baskets. Note that the “CBS” extension on the basket name denotes the continuous basket shim system is in use for the basket.

3.1 Method of Evaluation and Acceptance Criteria for Metamic-HT Fuel Baskets

The applicant introduced a new MOE and acceptance criteria for the fuel baskets made of Metamic-HT material being evaluated for the non-mechanistic tipover event. For the most part, the MOE and acceptance criteria introduced in this amendment for the fuel baskets during the tipover event reflect those accepted in the HI-STORM FW System Amendment No. 7

(ML24199A241). For this HI-STORM 100 System amendment, however, the applicant introduced an additional step for the determination of the fuel basket maximum permanent deflection criterion, which permits an averaging method to be employed when the maximum deflection permanent deflection limit cannot otherwise be met.

The applicant presents the fuel basket acceptance criteria for the new MOE, a deflection limit coupled with a stress limit, and further defines its applicability in the following FSAR sections: 2.II.0.1.b, 2.II.2.2.b, 2.II.2.4, 2.II.2.6, 2.III.0.1.i, and 2.IV.5. The following FSAR sections clarify which overpack and basket combinations are evaluated in this amendment for the new MOE and their acceptance criteria:

1) section 2.II.2.2.b for the MPC-32M and MPC-32M-CBS baskets loaded in the 100S Version E and E1 overpacks,
2) section 2.III.0.1.1 for the MPC-68M and MPC-68M-CBS baskets loaded in the (original) 100 overpack, and
3) section 2.IV.5 and table 2.IV.2.1 for the MPC-32M and MPC-68M baskets loaded in the 100 Version UVH overpack.

The applicant states in sections 2.II.2.6 and 2.III.0.1.i that the stress and deflection acceptance criteria are applicable to the portion of the fuel basket panels within the active fuel region, which is further defined for different overpacks in tables 2.1.10, 3.II.2.1, and 3.IV.2.1. In table 2.IV.2.1 of the FSAR, for the fuel baskets in the Version UVH overpack, the applicant refers to section 2.II.2.6 for the acceptance criteria for the tipover event. In these sections, the applicant states that the first acceptance criterion is that the panel primary membrane plus bending stress is limited to 90% of the true ultimate strength of the Metamic-HT material, as adjusted for temperature effects.

The second, coupled, acceptance criterion is that the applicant limits the maximum permanent (i.e., plastic) deflection for the fuel basket panels to 0.5% of the basket cell width, as identified in tables 2.II.2.4 and 2.III.4. FSAR section 2.II.2.6.ii further details the deflection criteria to permit an averaging of individual basket cell deflection values over the unsupported panel width in order to determine the maximum permanent deflection. Therefore, this criterion is referred to throughout this SER as the “maximum average permanent deflection.” The applicant states in the note to table 2.II.2.4 that this deflection limit is not applicable to the fuel basket panels located on the basket perimeter.

The applicant states that this limitation on basket panel deflection is a requirement stemming from the criticality analysis in FSAR sections 6.II.3.1 and 6.III.3, and that the averaging process of the total deflection is an acceptable approach to meeting this limit. Refer to section 7.0 of this SER for a discussion of the acceptability of employing the maximum average permanent deflection approach as it applies to the fuel criticality.

Refer to section 4.1 of this SER for a discussion of the acceptability of the introduced fuel basket MOE and acceptance criteria.

3.2 ISFSI Foundation Analysis Input Parameter Changes

The applicant updated tables 2.II.0.1 and 2.IV.0.1 to clarify the ISFSI reference design parameter values of foundation thickness and concrete compressive strength values considered in the non-mechanistic tipover evaluations for the components of the HI-STORM 100S Versions

E and E1 overpacks containing the MPC-68M-CBS basket, and the 100 Version UVH overpack containing the MPC-68M basket.

Refer to section 4.1 of this SER for further details of these parameter changes as they relate to the evaluation of each cask component combination and refer to section 4.3 for further discussions of these changes.

3.3 Fuel Assembly Weight Changes

The applicant updated FSAR table 2.II.1.1 and the TS in CoC appendix D table 2.1-1 to reduce the fuel assembly weight limit for the MPC-32M fuel basket and enclosure vessel, from 2,050 lb. to 1,520 lb.

Refer to section 4.1 of this SER for further details of these weight changes as they relate to the evaluation of each cask component combination and refer to section 4.2 of this SER for further discussion on this topic.

3.4 Method of Evaluation for MPC-68M-CBS Basket Corner Shim Bolts

As described in FSAR 1.2.1.1.B, the peripheral shims for the MPC-68M-CBS fuel basket are attached via bolting. The structural acceptability of the bolts is determined by the applicant by hand for the applied load.

Refer to section 4.1 of this SER for further details of these corner shim bolt evaluations as they relate to the evaluation of each cask component combination and refer to section 4.4 of this SER for further discussion on this topic.

Based on the review that considered the applicable regulations, regulatory guides, codes and standards, and accepted engineering practices, the staff determined that the proposed principal design criteria are acceptable as documented in the following sections of this SER.

4.0 STRUCTURAL EVALUATION

The objective of the structural review is to ensure that the applicant has performed adequate structural analyses to demonstrate that the system, as proposed, is acceptable under normal and off-normal operations, accident conditions, and natural phenomena events. In conducting this evaluation, the staff focused its review on whether the system will maintain confinement, subcriticality, shielding, and retrievability of the fuel, as applicable, under credible loads. The staff reviewed the following proposed changes that are applicable to the structural review:

- Introduce a new MOE and acceptance criteria for Metamic-HT fuel baskets
- Reduce fuel weights for MPC-32M and MPC-32M-CBS fuel baskets
- Revise ISFSI foundation structural analysis input parameters
- Introduce a new MOE for evaluation of MPC-68M-CBS basket corner shim bolts
- Revise shim width for MPC-68M fuel basket
- Delete statements regarding cask parameters in the evaluation of lifting devices and revise statements regarding cask center-of-gravity (CG) height in seismic stability evaluations

4.1 Introduce a New MOE and Acceptance Criteria for Metamic-HT Fuel Baskets

The new MOE and the maximum average permanent deflection acceptance criterion, coupled with the proposed stress-based structural acceptance criterion, applies to all fuel baskets constructed of Metamic-HT in the HI-STORM 100 storage system, i.e., MPC-32M, MPC-32M-CBS, MPC-68M, and MPC-68M-CBS. The Metamic-HT fuel baskets are employed in the following HI-STORM 100 overpacks, as listed in FSAR table 1.0.4:

- 100 (original)
- 100S
- 100S Version B (including Type IS)
- 100S Version E
- 100S Version E1
- 100 Version UVH

The evaluations presented for these cask system component combinations consider the non-mechanistic tipover accident condition, which, the staff notes, is the most significant accident condition for the structure of the fuel basket and for assessing the acceptance criteria. The tipover analysis is intended to demonstrate that the following safety criteria are met:

1) the maximum primary membrane plus bending stress in the fuel basket panels, within the active fuel region, does not exceed 90% of the true ultimate strength of Metamic-HT material at the applicable temperature,
2) the permanent lateral deflection of the basket panels in the active fuel region complies with the deflection criterion,
3) the impact of the MPC guide tubes and the MPC does not cause a thru-wall penetration of the enclosure vessel shell (as applicable),
4) the basket shim stresses are limited such that they provide adequate support to the baskets,
5) the plastic strains in the MPC enclosure vessel remain below the allowable material plastic strain limit,
6) the cask closure lid does not dislodge after the tipover event, i.e., the closure lid bolts remain intact,
7) the closure lid does not suffer any gross loss of shielding, and
8) The shielding capacity of overpack is not compromised by the tip-over accident and there is no gross plastic deformation in the overpack to affect the retrievability of the MPC.

These design criteria ensure the storage system maintains confinement, shielding, and retrievability, and prevent criticality. Note that for the HI-STORM 100 containing the MPC-68M and MPC-68M-CBS baskets, the LS-DYNA tipover analysis performed for the evaluation of the MPC, fuel basket, shims and bolts in this amendment does not address items 6, 7 and 8 of this list, as the overpack and closure lid were previously qualified by the applicant for the limiting cask deceleration of 45 g’s, as discussed in section 4.1.2.3 of this SER.

4.1.1 Fuel Basket Acceptance Criteria

As part of this amendment, the applicant proposed changes to the design criterion for the fuel basket in the following sections of the FSAR: 2.II.0.1.b, 2.II.2.2.b, 2.II.2.4, 2.II.2.6, 2.III.0.1.i, and table 2.IV.2.1. The existing design criterion for the fuel basket consists of a single limit on the deflection of a fuel basket panel that ensures both the structural integrity of the fuel basket and bounds the initial conditions assumed in the criticality analysis (e.g., fuel assembly spacing). Deflections in the basket are caused by lateral loads; the most significant of which is the tipover accident. The current description of the deflection criterion is for the maximum total deflection at any location along a basket panel to be limited to 0.5% of the width of the basket panel (i.e., inner width of a storage cell) at all times. For this amendment, the applicant proposed changing the fuel basket design criteria of the FSAR to consist of two requirements to demonstrate safe performance of the basket: (1) limit the maximum average permanent (i.e., plastic) deflection of a basket panel within the active fuel region, excluding the deflection of the perimeter cells, to 0.5% of the panel width as listed in tables 2.II.2.4 and 2.III.4 of the FSAR; and (2) limit the maximum primary (membrane plus bending) stress of the basket within the active fuel region to 90% of the true ultimate strength of the basket material at its design temperature.

As discussed in sections 2.II.0.1.b, 2.II.2.2.b, 2.II.2.4, 2.II.2.6, 2.III.0.1.i of the FSAR, the applicant requires both criteria to be met to demonstrate adequate structural integrity of the fuel basket. Instead of limiting the total deflection (i.e., elastic plus plastic deflection), the proposed change would limit just the portion of the maximum deflection caused by plastic deformation (i.e., permanent deflection) of the basket panel. Furthermore, the applicant permits an averaging of the permanent deflections along the width of the fuel basket panel (except those along the perimeter of the basket), as required, should the maximum permanent deflection of one cell exceed the dimensionless limit. The steps for determining the maximum average permanent deflection are provided in the notes of FSAR table 3.II.4.14. The methodology for determining this value is discussed further in section 4.1.2 of this SER. The applicant established the permanent deflection limit to ensure the bounding conditions assumed in the criticality analysis were maintained, as described in sections 6.II.3.1 and 6.III.3 of the FSAR. As noted in sections 2.II.2.6.ii and 2.III.0.1.i of the FSAR, the staff considers the primary stress criterion to be similar to the level D stress limits prescribed in the American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel (B&PV) Code Section III, Division 1, Subsection NG, which the staff accepts as design criteria for fuel baskets under accident conditions as discussed in NUREG-2215. ASME subsection NG allows for level D stress limits to include 90% of the ultimate strength in plastic analyses like those in the finite element analyses (FEAs) that the applicant performs to evaluate the fuel baskets for accident conditions.

The staff finds that the proposed primary stress limit provides a similar margin against structural failure of the fuel basket as the ASME level D stress limits. With this limit on the primary basket stresses, it is implicit that the total effective basket stresses are also limited to the true fracture stress. Based on the similarity between the primary stress criterion and the basket stress criteria described in NUREG-2215, the staff finds the proposed design criteria to be acceptable in demonstrating the structural integrity of the fuel basket to meet the criticality safety requirements of 10 CFR 72.124(a), 72.124(b), and 72.236(c) under accident conditions.

4.1.2 Demonstration (MOE) of the Fuel Basket Acceptance Criteria

The proposed changes to the fuel basket MOE described in section 4.1.1 of this SER required the applicant to demonstrate that the proposed new criteria were met for the combinations of overpacks, enclosure vessels, and fuel baskets in this amendment. The staff's review of analyses demonstrating the new design criteria for the cask system component combinations added in this amendment is described below in their respective sections of this SER. To obtain permanent deflection and stress results for the Metamic-HT fuel baskets for combinations of baskets, enclosure vessels, and overpacks in the HI-STORM 100 system, the applicant either revised previously performed FEAs, created new FEAs, or determined that the combination of system components were bounded by these two categories of analyses. To demonstrate that the deflection and primary stress criteria were met for all system component combinations, a select number of cases (e.g., bounding cases) were evaluated, employing a revised FEA basket model, as discussed in FSAR sections 3.II.4.4.2(iii), 3.III.4.4.3.1, and 3.IV.4.3.4.

For those revised or created finite element models (FEMs), the applicant employed half-symmetry FEA models to evaluate the HI-STORM 100 cask system component combinations. In each tipover model, the applicant added a concrete foundation target for the cask to strike using the concrete and subgrade properties.

The applicant explicitly modeled all structural members of the loaded cask as independent parts with non-linear material properties in LS-DYNA, except the fuel basket, which was modeled in multiple parts to capture the different bounding temperatures of the basket regions, and the fuel assemblies, which were modeled as elastic rectangular prisms. The applicant also explicitly modeled the critical weld connecting the MPC enclosure vessel and MPC lid. The applicant modeled the target for each tipover analysis as a concrete pad target, with or without an underlying mudmat, and a deep layer of subgrade soil, as shown in figures 3.II.4.8, 3.II.4.33A, 3.II.4.33B, 3.III.2, and 3.IV.4.9 of the application.

The applicant developed non-linear, true stress-strain material properties for the tipover models in appendix B of each calculation report. The applicant used either the ASME minimum or Metamic-HT minimum guaranteed value material strength data at various normal condition temperatures to determine true-stress-true-strain curves using Hollomon's power law equation. The applicant derived and validated this methodology of true stress-strain curve derivation through benchmarking in the referenced proprietary report HI-2210251, "Benchmarking of Material Stress-Strain Curves in LS-DYNA." The applicant used the Metamic-HT properties from report HI-2084122, "Metamic-HT Qualification Sourcebook," revision 14. The applicant also considered strain rate effects in the FEA, except for the fuel basket material. The applicant considered this exception conservative as it would increase the deformation of the fuel basket. The staff notes that, within the range of uniform elongation (i.e., before necking occurs), engineering stress strain curves can be readily converted to true-stress-true-strain curves.

As described in FSAR sections 3.II.4.4.2(iii), 3.III.4.4.3.1, and 3.IV.4.3.4, the fuel basket was modeled in LS-DYNA using 3-D coupled thick shell elements and the baskets are subdivided into thermal zones, based on the temperature distribution of the basket under normal storage conditions, as defined in proprietary report HI-2043317, "HI-STORM Thermal-Hydraulic Analysis Supporting up to 36.9 KW High Heat Load Amendment." In order to control any element erosion of the Metamic-HT basket material during tipover conditions, a conservative failure strain limit for the basket material at the applicable temperature is chosen. The staff finds the revised modeling approach acceptable as: (1) the changes in basket element formulation provide more realistic structural results, (2) the reduced temperature values for basket thermal zones remain bounding, and (3) the chosen FEA erosion limits produce conservative results.

The applicant described these FEAs in section 3.II.4.4.2(iii), 3.III.4.4.3.1, and 3.IV.4.3.4 of the FSAR with further details in the following proprietary FEA reports: revision 7 of HI-2188448 for baskets in the 100S Version E and Version E1 overpacks; revision 5 of HI-2210290 for baskets in the 100 Version UVH overpack; and revision 1 of HI-2240678 for baskets in the (original) 100 overpack. The staff finds the applicant's methodology for the FEA and stress analysis performed for the HI-STORM 100 cask component combinations subjected to the tipover accident condition to be consistent with the ASME B&PV design code and the guidance on FEA and stress analysis in NUREG-2215 and therefore acceptable.

As described in notes 1 to 7 to table 3.II.4.14 of the FSAR, the applicant determined the maximum average permanent deflections of the fuel basket panels from the tipover model results using the following method: (1) identifying critical times and locations from the stress and strain contour plots; (2) determining the total (i.e., elastic and plastic) deflection of the panel from the displacement of the midspan relative to the displacement of the end points; (3) determining the deflection at yield by repeating the previous steps for a time-step when the maximum stress in the panel is at yield; (4) subtracting the deflection at yield from the total deflection to determine the plastic deflection at the critical time and location, and (5) if the limit is not met using this method, an average permanent deflection is calculated by repeating steps (2) to (4) for all elements along the selected span, ignoring the end cells of the span. An example of the method employed for averaging maximum permanent deflections is presented in section D.4.4 of appendix D of report HI-2240678. The applicant presented the maximum average permanent deflection results, along with the deflection limit for the specific basket type, and the safety factor comparing the results to the limit in FSAR for each component combination evaluated. Note that the only baskets that required using the deflection averaging method were the MPC-68M and MPC-68M-CBS baskets in the 100 overpack. The applicant presented these results in the following tables:

- Table 3.II.4.14 for the 100S version E overpack (for MPC-32M, MPC-32M-CBS, and MPC-68M-CBS)
- Table 3.II.4.15 for the 100S Version E1 overpack (for MPC-32M-CBS and MPC-68M-CBS)
- Table 3.III.4 for the 100 overpack (for MPC-68M and MPC-68M-CBS evaluated for Set A and B foundation parameters)
- Table 3.IV.4.9 for the 100 Version UVH overpack (for MPC-32M and MPC-68M)

These results all show safety factors greater than one, indicating that all baskets meet the maximum average permanent deflection criterion. Furthermore, the example of deflection averaging provided in section D.4.4 of report HI-2240678 indicates that there were a minimal number of locations where there was an exceedance of the maximum deflection limit, and the exceedances extended only a few inches along the basket axis. Therefore, based on the conclusions in the criticality SER section 7.0, and since the instances of deflection exceedances is very limited, the staff finds the fuel baskets continue to maintain appropriate spacing between fuel assemblies to prevent criticality after the tipover event.

The applicant presented the resulting stress contour plots for selected fuel baskets evaluated in the associated calculation reports and the following FSAR figures: 3.II.4.35, 3.II.4.37, 3.III.10, and 3.IV.4.28. The applicant chose to present the stress contours in the FSAR that correlate to those baskets having the lowest safety factors for maximum permanent deflection. These contour plots, generated for each temperature region of the baskets, mostly indicate that stresses in the fuel baskets are below the primary stress limit. However, several figures do show small, localized stress areas exceeding the primary stress limit at discontinuities (e.g., notches where basket panels meet). The staff notes these stress contour plots display total effective stress, not only primary stresses. This means that certain small spots of color may or may not indicate exceedance of the primary stress criterion and require further evaluation and justification by the applicant. As discussed in the associated proprietary calculation reports, the applicant classified these stresses as secondary stresses, which are not subject to the primary stress criterion. The staff notes that increased stresses near structural discontinuities are typically categorized as secondary stresses, and the staff agrees that the analyzed stresses can be considered secondary stresses. Secondary stresses are self-limiting, which means local yielding and minor distortions can occur and alleviate the stress build-up and a single occurrence of an increased secondary stress is not expected to jeopardize structural integrity. The staff reviewed the results of the FEAs for these stresses and finds the applicant's classification of these exceedances as secondary stresses to be consistent with the ASME B&PV Code Section III, Division 1, Subsection NG, and therefore acceptable.

4.1.2.1 Revised basket analyses

In some cases, the applicant relied on FEMs previously created in LS-DYNA to analyze the tipover accident for the basket deflection and stress determination and evaluation of other components. In these cases, the applicant made changes to the fuel basket LS-DYNA models to support this amendment, as described above in section 4.1.2 of this SER. Other changes, such as foundation parameters or fuel weights may also have been made to the FEMs, as noted below.

The following HI-STORM 100 cask component combinations fall into the above category:

- HI-STORM 100S Version E overpack with MPC-32M and MPC-32M-CBS baskets
- HI-STORM 100S Version E1 overpack with MPC-32M-CBS basket
- HI-STORM 100 Version UVH overpack with MPC-32M basket
- HI-STORM 100 Version UVH overpack with MPC-68M basket

4.1.2.1.a HI-STORM 100S Version E overpack with MPC-32M basket

The applicant described the tipover FEA and resulting evaluation in section 3.II.4.4.2(iii) of the FSAR with further details in the main body of proprietary report HI-2188448, revision 7. The applicant evaluated the MPC-32M basket at 2,050 lbs. per fuel assembly and did not reduce the fuel weight, as proposed in table 2.1-1 of CoC, appendix D. Refer to section 4.2 of this SER for further discussion on the use of the higher fuel assembly weight for the tipover evaluation. This tipover analysis employs a 36-inch thick ISFSI pad with a 6,000 psi concrete compressive strength, which provides a more rigid target than the proposed design parameter values presented in FSAR table 2.II.0.1. The complete LS-DYNA tipover model, including mudmat, is shown in FSAR figure 3.II.4.8. The fuel basket thermal zones are defined and assigned material properties are presented in FSAR figure 3.II.4.11.

The applicant stated the resulting deceleration value at the top of the fuel assemblies is 62.4 g's, as shown in FSAR table 3.II.4.16 and FSAR figure 3.II.4.21. The maximum permanent deflection for the fuel basket is presented in FSAR table 3.II.4.14, and is reported to be less than the allowable limit, without consideration of averaging, resulting in a safety factor of greater than one. The resulting basket stresses are shown in report HI-2188448 figures 8a to 8h, and aside from some areas of local secondary stresses, are below the limit of 90% of true ultimate stress. The applicant depicted the stresses in the basket shims from the tipover model results in report HI-2188448 figure 18, which shows the stresses in the shims to largely be below yield with only localized plastic deformation near the point of impact. From these results, the applicant concluded that the structural design criteria of the shims were met in the tipover accident. The applicant reported that the resulting plastic strains of the enclosure vessel, overpack, overpack lid and overpack bolts are within the fracture limit of the materials, as shown in FSAR figures 3.II.4.15 to 3.II.4.19 and tabulated in table 9.1 of report HI-2188448. Although the overpack guide tubes at the impact location are shown to be crushed in the tipover event, per FSAR figure 3.II.4.18, the overpack inner shell and enclosure vessel shells are below the fracture limit, and therefore, enclosure vessel retrievability is maintained.

In hand calculations presented in appendix F of report HI-2188448, the applicant evaluated welds between the lid top plate and lid outer shell as well as the lid ribs and lid baseplate. A shear capacity evaluation of the lid spacer block is also included in this appendix. The applicant evaluated these items for a vertical deceleration of 125 g's and a horizontal deceleration of 20 g's, which are stated to be bounding for the Version E overpack with MPC-32M, MPC-32M-CBS and MPC-68M-CBS baskets. The applicant determined the safety factors for these three evaluations are greater than one.

Staff concludes that, based on these reported results for this cask component combination, the applicant demonstrates that the safety criteria described in section 4.1 of this SER are met for the tipover event.

4.1.2.1.b HI-STORM 100S Version E overpack with MPC-32M-CBS basket

The applicant described the tipover FEA and results evaluation in section 3.II.4.4.2(iii) of the FSAR with further details in appendix E of proprietary report HI-2188448, revision 7. This tipover analysis employs a 36-inch thick ISFSI pad with a 6,000 psi concrete compressive strength, which provides a more rigid impact target than the proposed design parameter values presented in FSAR table 2.II.0.1. The applicant evaluated the MPC-32M-CBS using the reduced fuel weight of 1,520 lbs., as proposed in table 2.1-1 of CoC, appendix D. The complete LS-DYNA tipover model, including mudmat, is shown in FSAR figure 3.II.4.33A. The fuel basket thermal zones are defined and assigned material properties, as presented in FSAR figure 3.II.4.32A.

The resulting deceleration value at the top of the fuel assemblies is 46.6 g's, per FSAR table 3.II.4.16. The maximum permanent deflection for the fuel basket is presented in FSAR table 3.II.4.14, and is reported to be less than the allowable limit, without consideration of averaging, resulting in a safety factor of greater than one. The resulting basket stresses are shown in report HI-2188448 figures E.10a to 10f, and aside from some areas of local secondary stresses, are below the limit of 90% of true ultimate stress. The applicant depicted the stresses in the basket shims from the tipover model results in report HI-2188448 figure E.20, which shows the stresses in the shims to largely be below yield with only localized plastic deformation near the point of impact. From these results, the applicant concluded that the structural design criteria of the shims were met in the tipover accident. The applicant reported that the resulting plastic strains of the enclosure vessel, overpack, overpack lid, and overpack lid bolts are below the fracture limit of the materials, as presented in report HI-2188448 table E.5.1 and shown in figures E.11 to E.14. Although the overpack guide tubes at the impact location are shown to be crushed in the tipover event, per report HI-2188448 figure E.15, the overpack inner shell and enclosure vessel shells are below the fracture limit, and therefore, enclosure vessel retrievability is maintained.

As previously mentioned in section 4.1.2.1.a of this SER, hand calculations presented in appendix F of report HI-2188448 determine that the safety factors are greater than one for (1) weld between the lid top plate and lid outer shell, (2) weld between the lid ribs and lid baseplate, and (3) shear capacity evaluation of the lid spacer block.

Staff concludes that, based on these reported results, this cask combination demonstrates that the safety criteria described in section 4.1 of this SER are met for the tipover event.

4.1.2.1.c HI-STORM 100S Version E1 overpack with MPC-32M-CBS basket

The applicant described the FEA and results evaluation in section 3.II.4.4.2(iii) of the FSAR with further details in appendix H of proprietary report HI-2188448, revision 7. This tipover analysis employs a 36-inch thick ISFSI pad with a 6,000 psi concrete compressive strength, which provides a more rigid target than the proposed design parameter values presented in FSAR table 2.II.0.1. The applicant evaluated MPC-32M-CBS using the reduced fuel weight of 1,520 lbs., as proposed in table 2.1-1 of CoC, appendix D. The fuel basket thermal zones are defined and assigned material properties are presented in FSAR figure 3.II.4.34A. The complete LS-DYNA tipover model, including mudmat, is shown in FSAR figure 3.II.4.33A.

The resulting deceleration value at the top of fuel assemblies is 57.7g's as presented in FSAR table 3.II.4.16. The maximum permanent deflection for the fuel basket is presented in FSAR table 3.II.4.14, and is reported to be less than the allowable limit, without consideration of averaging, resulting in a safety factor of greater than one. The resulting basket stresses are shown in report HI-2188448 figures H.10a to 10f, and aside from some areas of local secondary stresses, are below the limit of 90% of true ultimate stress. The applicant depicted the stresses in the basket shims from the tipover model results in report HI-2188448 figure H.21, which shows the stresses in the shims to largely be below yield with only localized plastic deformation near the point of impact. From these results, the applicant concluded that the structural design criteria of the shims were met in the tipover accident. The applicant reported that the resulting plastic strains of the enclosure vessel, overpack, overpack lid, overpack bolts, and common lid spacers are within the fracture limit of the materials, as shown in figures H.11 to H.16 and tabulated in table H.5.1 of report HI-2188448. Although the overpack guide tubes at the impact location are shown to be crushed in the tipover event, per report HI-2188448 figure H.15, the overpack inner shell and enclosure vessel shells are below the fracture limit, and therefore, enclosure vessel retrievability is maintained.

In hand calculations presented in appendix H of report HI-2188448, the applicant evaluated welds between the lid lifting ribs, outer shell and lid base plate shell, as well as the lid spacer ribs and lid baseplate. The applicant evaluated these items for a vertical deceleration of 116 g's and a horizontal deceleration of 18 g's, which the applicant stated to be bounding for the Version E1 overpack with MPC-32M-CBS basket. The applicant determined the safety factors for these evaluations are greater than one, as presented in report HI-2188448 table H.5.5.

Staff concludes that, based on these reported results for this cask component combination, the applicant demonstrates that the safety criteria described in section 4.1 of this SER are met for the tipover event.

4.1.2.1.d HI-STORM 100 Version UVH overpack with MPC-32M basket

The applicant described the FEA and results evaluation in section 3.IV.4.3.4 of the FSAR with further details in the main body of proprietary report HI-2210290, revision 5. This tipover analysis employs a 36-inch thick ISFSI pad with a 5,000 psi concrete compressive strength, which provides a more rigid target than the proposed design parameter values presented in FSAR table 2.IV.0.1. The applicant evaluated the MPC-32M using the reduced fuel weight of 1,600 lbs., which bounds the proposed weight limit of 1,520 lbs., as shown in FSAR table 2.II.1.1, as cited in section 4.4 of report HI-2210290. The fuel basket thermal zones are defined and assigned material properties are presented in FSAR figure 3.IV.4.12. The complete LS-DYNA tipover model, including mudmat, is shown in FSAR figure 3.IV.4.9.

The resulting deceleration value at the top of the fuel assemblies is 66.6 g's, per FSAR table 3.IV.4.10. The maximum permanent deflection for the fuel basket is presented in FSAR table 3.IV.4.9, and is reported to be less than the allowable limit, without consideration of averaging, resulting in a safety factor of greater than one. The resulting basket stresses are shown in report HI-2210290 figures 11-14 a) to h), and aside from some areas of local secondary stresses, are below the limit of 90% of true ultimate stress. The applicant depicted the stresses in the basket shims from the tipover model results in report HI-2210290 figure 11-15, which shows the stresses in the shims to largely be below yield with only localized plastic deformation near the point of impact. From these results, the applicant concluded that the structural design criteria of the shims were met in the tipover accident. The applicant reported that the resulting plastic strains of the enclosure vessel, overpack, overpack lid, and overpack bolts are within the fracture limit of the materials, as presented in report HI-2210290 table 9-1 and presented in FSAR figures 3.IV.4.16 to 19.

Staff concludes that, based on these reported results for this cask component combination, the applicant demonstrates that the safety criteria described in section 4.1 of this SER are met for the tipover event.

4.1.2.1.e HI-STORM 100 Version UVH overpack with MPC-68M basket

The applicant described the FEA and results evaluation in section 3.IV.4.3.4 of the FSAR with further details in appendix C of proprietary report HI-2210290, revision 5. This tipover analysis employs a 30-inch thick ISFSI pad with a 5,000 psi concrete compressive strength, which is consistent with the design parameter values presented in FSAR table 2.IV.0.1. The fuel basket thermal zones are defined and assigned material properties that are presented in report HI-2210290 figure C.5.5. The complete LS-DYNA tipover model is shown in report HI-2210290 figure C.5.3.

The resulting deceleration value at the top of the fuel assemblies is 70.4 g's, per FSAR table 3.IV.4.10. The maximum permanent deflection for the fuel basket is presented in FSAR table 3.IV.4.9, and is reported to be less than the allowable limit, without consideration of averaging, resulting in a safety factor of greater than one. The resulting basket stresses are shown in FSAR figure 3.IV.4.28 and report HI-2210290 figures C.5.13 a) to h), and aside from some areas of local secondary stresses, are below the limit of 90% of true ultimate stress. The applicant depicted the stresses in the basket shims from the tipover model results in FSAR figure 3.IV.4.29 and report HI-2210290 figure C.5.15, which shows the stresses in the shims to largely be below yield with only localized plastic deformation near the point of impact. The shim stress results presented are taken from a sensitivity run of the tipover FEA where the bottom flat shim boundary conditions were modified to better represent the actual connectivity across the half-model plane, as explained by the applicant in section C.2 of report HI-2210290. From these results, the applicant concluded that the structural design criteria of the shims were met in the tipover accident. The applicant reported that the resulting plastic strains of the enclosure vessel, overpack, overpack lid, and lid bolts are within the fracture limit of the materials, as presented in report HI-2210290 table C.2 and FSAR figures 3.IV.4.23 to 26.

Staff concludes that, based on these reported results for this cask component combination, the applicant demonstrates that the safety criteria described in section 4.1 of this SER are met for the tipover event.

4.1.2.2 New basket analyses

For the analyses of some component combinations, including the MPC-68M or MPC-68M-CBS fuel baskets, the applicant created new LS-DYNA FEMs to analyze the tipover accident for the basket deflection and stress determination and evaluation of other components. The existing analysis of MPC-68M and MPC-68M-CBS baskets were performed using a partial ANSYS model with the static equivalent tipover deceleration load applied to assess the resulting deflections and stresses. The applicant created new LS-DYNA models for the fuel baskets of these component combinations to support this amendment. The applicant followed the established methodology for analyzing the HI-STORM 100 system for a tipover described in FSAR sections 3.II.4.4.2(iii), 3.III.4.4.3.1, and 3.IV.4.3.4.

The following HI-STORM 100 component combinations fall into the above category:

- HI-STORM 100 overpack with MPC-68M basket and MPC-68M-CBS baskets
- HI-STORM 100S Version E overpack with MPC-68M-CBS baskets
- HI-STORM 100S Version E1 overpack with MPC-68M-CBS basket

4.1.2.2.a HI-STORM 100 overpack with MPC-68M and MPC-68M-CBS baskets

The applicant described the FEA and resulting evaluation in section 3.III.4.4.3.1 of the FSAR with further details in appendices C and D of proprietary report HI-2240678, revision 1. For these tipover analyses, the applicant employs the Set A and Set B foundation parameters employed previously, as presented in FSAR table 2.2.9. The fuel basket thermal zones are defined and assigned material properties are presented in FSAR figures 3.III.4 and 3.III.8, for the MPC-68M and MPC-68M-CBS baskets, respectively. The complete LS-DYNA tipover model for the analysis for the MPC-68M basket is shown in FSAR figure 3.III.2, and that for the MPC-68M-CBS basket is shown in report HI-2240678 figure D.1.

Per report HI-2240678 tables C.4.2 and D.4.2, the maximum resulting deceleration values at the top of the fuel basket are 48.4 g's and 54.4 g's, for the MPC-68M and MPC-68M-CBS baskets, respectively. The maximum average permanent deflections for the fuel baskets are presented in FSAR table 3.III.4, and are reported to be less than the allowable limit, resulting in safety factors of greater than one. The resulting basket stresses are shown in report HI-2240678 figures C.7 a) to p) and D.8a to D.8n, for the MPC-68M and MPC-68M-CBS baskets, respectively. Basket stress contours are also presented for the MPC-68M-CBS baskets in FSAR figure 3.III.10. Aside from some areas of local secondary stresses, the reported stresses are below the limit of 90% of true ultimate stress. The applicant depicted the stresses in the basket shims from the tipover model results in report HI-2240678 figures C.11 a) and b) for the MPC-68M basket, and report HI-2240678 figures D.16 for the MPC-68M-CBS basket, all showing the stresses in the shims to largely be below yield with only localized plastic deformation near the point of impact. The shim stress results presented for the MPC-68M-CBS in report figure D.16 are taken from a sensitivity run of the tipover FEA where the bottom flat shim element type was modified to better capture the behavior of the element subjected to both in-plane and out-of-plane forces, as explained by the applicant in section D.4.3 of report HI-2240678. From these results, the applicant concluded that the structural design criteria of the shims were met in the tipover accident.

The applicant reported that the resulting plastic strains of the enclosure vessel containing the MPC-68M basket are below the fracture limit of the materials, as presented in report HI-2240678 table C.4.1 and figure C.8, while the resulting plastic strains for the enclosure vessel containing the MPC-68M-CBS basket are shown in report HI-2240678 table D.4.1 and figure D.9.

In hand calculations presented in appendix D1 of report HI-2240678, the applicant evaluated the CBS corner shim bolts in the MPC-68M-CBS basket for a bounding deceleration of 60 g's. The applicant determined the safety factor for the bolt evaluations is greater than one. Refer to section 4.4 of this SER for further discussion of the MOE for these bolts.

Staff concludes that, based on these reported results, this cask combination demonstrates that the safety criteria described in section 4.1 of this SER are met for the tipover event.

4.1.2.2.b HI-STORM 100S Version E overpack with MPC-68M-CBS basket

The applicant described the tipover FEA and resulting evaluation in section 3.II.4.4.2(iii) of the FSAR with further details in appendix K of proprietary report HI-2188448, revision 7. This tipover analysis employs a 30-inch thick ISFSI pad with a 5,000 psi concrete compressive strength, per FSAR table 2.II.0.1. The complete LS-DYNA tipover model is shown in FSAR figure 3.II.4.33B. The fuel basket thermal zones are defined and assigned material properties are presented in FSAR figure 3.II.4.32B.

Per report FSAR table 3.II.4.16, the resulting deceleration value at the top of fuel assemblies is 52.2 g's. The maximum permanent deflection for the fuel basket is presented in FSAR table 3.II.4.14, and is reported to be less than the allowable limit, without consideration of averaging, resulting in a safety factor of greater than one. The resulting basket stresses are shown in FSAR figure 3.II.4.35 and report HI-2188448 figures K.10 a) to h), and aside from some areas of local secondary stresses, are below the limit of 90% of true ultimate stress. The applicant depicted the stresses in the basket shims from the tipover model results in FSAR figure 3.II.4.36 and report HI-2188448 figure K.20, which shows the stresses in the shims to largely be below yield with only localized plastic deformation near the point of impact. From these results, the applicant concluded that the structural design criteria of the shims were met in the tipover accident. The applicant reported that the resulting plastic strains of the enclosure vessel, overpack, overpack lid, and overpack lid bolts are below the fracture limit of the materials, as presented in report HI-2188448 table K.5.1 and shown in figures K.11 to K.14. Although the overpack guide tubes at the impact location are shown to be crushed in the tipover event, per report HI-2188448 figure K.15, the overpack inner shell and enclosure vessel shells are below the fracture limit, and therefore, enclosure vessel retrievability is maintained.

As previously mentioned in section 4.1.2.1.a of this SER, hand calculations presented in appendix F of report HI-2188448 determine that the safety factors are greater than one for (1) weld between the lid top plate and lid outer shell, (2) weld between the lid ribs and lid baseplate, and (3) shear capacity evaluation of the lid spacer block.

In hand calculations presented in appendix I of report HI-2188448, the applicant evaluated the CBS corner shim bolts for a bounding deceleration of 66 g's, which is stated to be bounding for the Version E and Version E1 overpacks with MPC-68M-CBS baskets. The applicant determined the safety factor for the bolt evaluations is greater than one. Refer to section 4.4 of this SER for further discussion of the MOE for these bolts.

Staff concludes that, based on these reported results, this cask combination demonstrates that the safety criteria described in section 4.1 of this SER are met for the tipover event.

4.1.2.2.c HI-STORM 100S Version E1 overpack with MPC-68M-CBS basket

The applicant described the tipover FEA and results evaluation in section 3.II.4.4.2(iii) of the FSAR with further details in appendix I of proprietary report HI-2188448, revision 7. This tipover analysis employs a 30-inch thick ISFSI pad with a 5,000 psi concrete compressive strength, per FSAR table 2.II.0.1. The complete LS-DYNA tipover model is shown in FSAR figure 3.II.4.33B. The fuel basket thermal zones are defined and assigned material properties are presented in FSAR figure 3.II.4.34B.

Per FSAR table 3.II.4.16, the resulting deceleration value at the top of fuel assemblies is 63 g's. The maximum permanent deflection for the fuel basket is presented in FSAR table 3.II.4.15, and is reported to be less than the allowable limit, without consideration of averaging, resulting in a safety factor of greater than one. The resulting basket stresses are shown in FSAR figure 3.II.4.37 and report HI-2188448 figures I.10a to I.10i, and aside from some areas of local secondary stresses, are below the limit of 90% of true ultimate stress. The applicant depicted the stresses in the basket shims from the tipover model results in FSAR figure 3.II.4.38 and report HI-2188448 figure I.21, which shows the stresses in the shims to largely be below yield with only localized plastic deformation near the point of impact. From these results, the applicant concluded that the structural design criteria of the shims were met in the tipover accident. The applicant reported that the resulting plastic strains of the enclosure vessel, overpack, overpack lid, overpack lid bolts, and common lid spacers are reported by the applicant to be below the fracture limit of the materials, as presented in report HI-2188448 table I.5.1 and shown in figures I.11 to I.16. Although the overpack guide tubes at the impact location are shown to be crushed in the tipover event, per report HI-2188448 figure I.15, the overpack inner shell and enclosure vessel shells are below the fracture limit, and therefore, enclosure vessel retrievability is maintained.

In hand calculations presented in appendix I of report HI-2188448, the applicant evaluated welds between the lid lifting ribs, outer shell and lid base plate shell, as well as the lid spacer ribs and lid baseplate. The applicant evaluated these items for a vertical deceleration of 115 g's and a horizontal deceleration of 19 g's, which are stated to be bounding for the Version E1 overpack with MPC-68M-CBS basket. The applicant determined the safety factors for these evaluations are greater than one, as presented in report HI-2188448 table I.5.5.

In hand calculations presented in appendix I of report HI-2188448, the applicant evaluated the CBS corner shim bolts for a bounding deceleration of 66 g's, which is stated to be bounding for the Version E and Version E1 overpacks with MPC-68M-CBS baskets. The applicant determined the safety factor for the bolt evaluations is greater than one, as presented in report HI-2188448 table I.5.5. Refer to section 4.4 of this SER for further discussion of the MOE for these bolts.

Staff concludes that, based on these reported results, this cask combination demonstrates that the safety criteria described in section 4.1 of this SER are met for the tipover event.

4.1.2.3 Baskets bounded by new or revised analyses

For the evaluation of HI-STORM 100 cask system component combinations other than those described in sections 4.1.2.1 and 4.1.2.2 of this SER, the applicant has determined that these combinations are bounded by the results of the new or revised analyses.

In FSAR section 3.4.10, the applicant explains the basis for the selection of the HI-STORM 100 (original) overpack tipover analyses including the MPC-68M and MPC-68M-CBS fuel baskets as bounding the following overpack and Metamic-HT component combinations:

- HI-STORM 100S overpack with MPC-68M and MPC-68M-CBS baskets
- HI-STORM 100S Version B overpack (including Type IS) with MPC-68M and MPC-68M-CBS baskets

In this section of the FSAR, the applicant explains that due to the rigid body tipover analyses performed for the HI-STORM 100, which limits the deceleration of the cask to 45 g's, the peak impact decelerations of the HI-STORM 100S and the HI-STORM 100S Version B (including the Type IS) dry cask storage system (DCSS), which are shorter and heavier, are determined to be bounded by the deceleration value computed for the HI-STORM 100 overpack.

In FSAR section 3.4.4.2(iii), the applicant explains the basis for the selection of following overpack and Metamic-HT component combinations for the tipover analysis is due to the determination that the CBS-type fuel basket results bound those of the non-CBS type fuel baskets during the tipover analyses:

- HI-STORM 100S Version E overpack with MPC-68M basket
- HI-STORM 100S Version E1 overpack with MPC-32M and MPC-68M baskets

In this section of the FSAR, the applicant explains that, based on basket comparisons performed in the HI-STORM FW FSAR, specifically those discussed in FW FSAR sections 3.4.4.1.4e and quantified in FW FSAR table 3.4.22, it was determined that the CBS-type basket tipover analysis produced deflection and stress result magnitudes that bounded those of the non-CBS-type baskets. The applicant attributed these differences to the reduced joint fixity at the CBS-type basket panel intersections versus the welded joint fixity of the on-CBS-type basket panel intersections.

The staff finds the applicant's basis for selection of basket and overpack combinations to produce bounding tipover analysis results to be acceptable due to the information provided in FSAR sections 3.4.10 and 3.4.4.2(iii), which include technical arguments and numerical evidence to support the selection.

4.1.3 Conclusion

The staff reviewed the results of the tipover analyses and concludes the following for the HI-STORM 100 overpack variations and Metamic-HT fuel basket component combinations detailed in SER section 4.1:

- Based on the FEA results showing that the maximum average permanent deflection and maximum primary stress of the fuel basket are below the allowable limits, the shim stresses are mainly below the yield strength with only limited permanent deformation, the staff finds the applicant has adequately demonstrated that the Metamic-HT fuel baskets have sufficient structural integrity to meet the criticality safety requirements of 10 CFR 72.124(a), 72.124(b) and 72.236(c) under the tipover accident conditions.

- Based on the FEA results showing only minor local plastic strain in the MPC enclosure vessel, the staff finds the applicant has adequately demonstrated that the MPC confinement boundary will not be breached, even by the impact of the guide tubes. Therefore, the staff finds the HI-STORM 100 overpack variations containing the Metamic-HT fuel baskets have sufficient structural integrity to meet the confinement requirements of 10 CFR 72.236(d) and 72.236(l) under the tipover accident conditions.

- Based on the FEA results showing only minor local plastic strain in the overpack and lid, the staff finds the applicant has adequately demonstrated that the shielding capacity of overpack will not be significantly compromised. Based on the plastic strain results of the lid bolts showing only minor plastic strain and the evaluations of the lid welds showing safety factors greater than one, the staff finds the applicant has adequately demonstrated that the closure lid will remain intact and the MPC enclosure vessel will remain within overpack following the tipover accident. Therefore, the staff finds the HI-STORM 100 overpack variations containing the Metamic-HT fuel baskets have sufficient structural integrity to meet the shielding and redundant confinement requirements of 10 CFR 72.236(d) and 72.236(e) under the tipover accident conditions.

- Based on the FEA results showing only minor local plastic strain in the overpack and lid, the staff finds the applicant has adequately demonstrated that the overpack will not suffer gross deformation that would affect the retrievability of the enclosure vessel. Therefore, the staff finds the HI-STORM 100 overpack variations containing the Metamic-HT fuel baskets have sufficient structural integrity to meet the retrievability requirements of 10 CFR 72.122(l) under the tipover accident conditions.

4.2 Reduce Fuel Weights for MPC-32M and MPC-32M-CBS Fuel Baskets

The applicant proposed a reduction in the maximum individual fuel assembly weight permitted to be loaded in the MPC-32M and MPC-32M-CBS fuel baskets: from 2,050 lbs. to 1,520 lbs. The applicant revised CoC appendix D, table 2.1-1 and FSAR table 2.II.1.1 to document this change. Although both tables apply to the HI-STORM 100S Version E and E1 overpacks, the FSAR table 2.II.1.1 is cited as a reference in the HI-STORM 100 Version UVH tipover evaluation report, HI-2210290. Sections 4.1.2.1.a to 4.1.2.1.d of the SER contain further details on the fuel assembly weights employed by the applicant as they relate to the tipover evaluation of each cask component combination.

For the MPC-32M in the Version E overpack, the applicant employs the original fuel assembly weight of 2,050 lbs. in the tipover analysis. The applicant has justified the use of this heavier weight in FSAR section 3.II.4.4.2(iii), as producing conservative fuel basket responses. The applicant explains that the local structural effects of the deceleration of the heavier fuel assembly weight on the basket panels during a tipover event is more significant than the global effect the increased fuel assembly weight has on decreasing the overall system deceleration.

This reduction in fuel assembly weights is acceptable to staff, as, in most cases, its inclusion in the structural tipover analysis models produces more representative basket results, or, where higher fuel assembly weights are employed, produces conservative basket results that would bound those of the reduced fuel assembly weights.

4.3 Revise ISFSI Foundation Structural Analysis Input Parameters

The applicant states in FSAR sections 2.II.0.4.2 and 2.IV.0.1 that the ISFSI foundation parameters employed in the tipover structural analyses are provided in FSAR tables 2.II.0.1 and

2.IV.0.1. The values presented in these tables are clarified in this amendment as the reference ISFSI foundation parameters for the design-basis tipover analyses. The applicant added explanations in the above FSAR sections that, for licensee sites planning to employ the HI-STORM 100 system under the applicant's 10 CFR Part 72 certificate, these tabulated reference parameters are to be verified by the potential licensee to bound those of the site-specific ISFSI foundation. If that is not the case, the potential licensee must perform a site-specific tipover analysis, using the approved methodology described in the FSAR, to demonstrate acceptable DCSS performance. In some cases, the applicant performed tipover analyses using ISFSI foundation parameters that exceed those tabulated in the FSAR, the values of which are cited in the description for each specific tipover analysis.

The revisions to the information presented in the ISFSI foundation parameter tables are acceptable to staff, as they clarify the minimum ISFSI foundation parameter values employed by the applicant in the tipover analyses of specific HI-STORM 100 DCSS overpacks, which serve to produce a lower-bound cask deceleration and structural response during impact with the foundation.

4.4 Introduce a New MOE for MPC-68M-CBS Corner Shim Bolts

As described in FSAR 1.2.1.1.B, the CBS basket panel walls are extended radially (compared to those of the non-CBS type) to allow the shims to be attached to them via bolting. In FSAR sections 3.II.4.4.2(iii) and 3.III.4.4.3.1, the applicant explains that the effect of the bolts attaching shims to the panel extensions are included in the LS-DYNA tipover model. However, bolt design loads for the MPC-68M-CBS baskets are not taken directly from the model; the applicant evaluates the corner bolts for the maximum applicable cask deceleration value by hand, as documented in appendix I of report HI-2188448 for the 100S Version E and E1 overpacks, and appendix D1 of report HI-2240678 for the 100 overpack. Based on these evaluations, the applicant determined that the safety factor for the bolt load is larger than one.

Based on the safety factors of the stress analyses for the CBS shim bolts being greater than one, the staff finds the applicant has adequately demonstrated that the shims will assure the baskets have sufficient structural integrity to meet the criticality safety requirements of 10 CFR 72.124(a), 72.124(b) and 72.236(c) under the tipover accident conditions, because favorable geometry will be maintained. Therefore, the staff concludes that the proposed MOE for evaluation of corner shim bolts for CBS basket designs is acceptable.

4.5 Revise Shim Width for MPC-68M Fuel Basket

The applicant proposed to change the MPC-68M solid shim width in FSAR section 1.5. The applicant states in its proprietary response to RAI 4-12 that this change was made due to the need to mitigate local stresses and deflections from developing in the interfacing fuel basket panels. Staff finds this increase in shim width to be acceptable, as it serves to reduce the fuel basket deflections and stresses from those that would arise using the previous shim length.

4.6 Delete Statements Regarding Cask Parameters in the Evaluation of Lifting Devices and Revise Statements Regarding Cask Center-of-Gravity Height in Seismic Stability Evaluations

The applicant proposes the deletion of a statement requiring that certain weight information be employed for the design of lifting and handling devices for components of the HI-STORM 100S Version E or Version E1 cask system. In FSAR section 3.II.2, "Weights and Centers of Gravity," the applicant refers to tabulated weights and CG locations of the various HI-STORM 100 cask and transport components. The applicant also states that, in lieu of the weight and CG data tabulated in the FSAR, more precise, site-specific weight and CG information may be obtained from the Solidworks models of the cask component being evaluated.

FSAR section 3.II.2 addresses the determination of the vertical CG for use in the stability analysis of the loaded 100S Version E or Version E1 cask under design basis earthquake (DBE) conditions. For the determination of the location of the maximum vertical CG location, along the cask axis from the base of the cask, the applicant directs the user to FSAR table 3.II.2.5. In this amendment, the applicant has proposed language to allow a more accurate, site-specific CG location value to be employed for the DBE stability evaluation, as an alternative to the tabulated location value.

Staff finds these changes to be acceptable, as they allow the licensees the option to remove inherent conservatism by employing site-specific weight and CG parameters in their evaluations of the cask system components for various design conditions.

4.7 Evaluation Findings

Based on the analyses performed and the supporting information provided by the applicant, the staff concludes that the structural design of the HI-STORM 100 system discussed in section 4 of this SER complies with 10 CFR Part 72 and provides adequate protection of the public health and safely. This finding is based on a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices. The following findings are made:

F4.1 The staff reviewed the structural performance of the ITS SSCs designed to maintain subcriticality and concludes that these SSCs have adequate structural integrity to satisfy the criticality safety requirements of 10 CFR 72.124(a).

F4.2 The staff reviewed the structural performance of the ITS SSCs designed to provide and maintain favorable geometry or permanently fixed neutron-absorbing materials and concludes that these SSCs have adequate structural integrity to satisfy the criticality control requirements of 10 CFR 72.124(b).

F4.3 The staff reviewed the design bases and design criteria of the ITS SSCs and concludes that the applicant met the requirements of 10 CFR 72.236(b).

F4.4 The staff reviewed the structural performance of the ITS SSCs designed to maintain the spent nuclear fuel in a subcritical condition under normal, off-normal, and accident conditions and concludes that these SSCs have adequate structural integrity to satisfy the subcriticality requirements of 10 CFR 72.236(c).

F4.5 The staff reviewed the structural performance of the ITS SSCs designed to provide radiation shielding and confinement and concludes that these SSCs have adequate structural integrity to satisfy the radiation shielding and confinement requirements of 10 CFR 72.236(d).

F4.6 The staff reviewed the structural performance of the ITS SSCs designed to provide redundant sealing of confinement systems and concludes that these SSCs have adequate structural integrity to satisfy the requirements of 10 CFR 72.236(e).

F4.7 The staff reviewed the structural performance of the ITS SSCs and concludes that these SSCs have adequate structural integrity to store the spent fuel safely for the term proposed in the application and satisfy the requirements of 10 CFR 72.236(g).

F4.8 The staff reviewed the structural evaluations of the storage cask and its ITS SSCs and concludes that these evaluations considered appropriate tests and means acceptable to the NRC to demonstrate that they will reasonably maintain confinement of radioactive material under normal, off-normal, and credible accident conditions and, therefore, meet the requirements of 10 CFR 72.236(l).

F4.9 The staff reviewed the structural evaluations of the storage cask and its ITS SSCs and concludes that these evaluations demonstrate that they will have sufficient structural integrity to under normal, off-normal, and credible accident conditions to meet the retrievability requirements of 10 CFR 72.122(l).

5.0 THERMAL EVALUATION

There were no changes to the applicant's thermal section of the UFSAR requested in the amendment application.

6.0 SHIELDING EVALUATION

There were no changes to the applicant's shielding section of the UFSAR requested in the amendment application.

7.0 CRITICALITY EVALUATION

The applicant provided a revised structural analysis (Report HI-2240678, Revision 1) evaluating of the CBS baskets to define the maximum average deflection of the basket structure. Report HI-2240678 provided the methodology used in the averaging approach to demonstrate that the average permanent deflection of the basket panels, which is defined as the maximum average across the width of any panel in the inner area of the basket (i.e., except for the panels on the periphery), is limited to a fraction of 0.005 (0.5%) of the panel width. This deflection only applies to the axial section covering the active region of the fuel. Staff noted that any deformations that are outside the active region would be inconsequential from a criticality perspective, as those areas of the basket are conservatively omitted from the calculational models of the HI-STORM 100.

As shown in the analyses provided in FSAR Supplement 3.II, the applicant demonstrated that the permanent deformations of the basket walls during accident conditions are below this limit, on average. To account for this deflection, the applicant assumed that two adjacent cell walls in each cell are deflected to the maximum extent possible over the entire length and width by reducing the cell ID by 0.5% of the cell width for every cell for the MPC-32M and MPC-32M-CBS baskets, and the MPC-68M and MPC-68M-CBS baskets. Based on the response to RAI 4-2 (ML24318C536), the maximum permanent deflection does exceed the 0.5% limit in a very few localized locations, but are not grossly deformed. Staff finds that the modeling assumption used by the applicant to model the maximum average deflection is conservatively representative since this average deflection is applied uniformly for all cells of the basket over the entire basket length. This assumption is adequate to bound any small, localized deformations that may slightly exceed this average deformation. This assumption also allows for the applicant to ignore the panels on the basket periphery from the maximum average deflection assumption, since the neutron loss in these peripheral areas would reduce the impact of the deflection in those panels on reactivity, and large deflections are prevented due to stress limitations. Staff finds that this modelling approach, which was performed assuming a fully flooded MPC, is conservative. Under storage conditions the MPC would remain internally dry, thereby reducing the maximum reactivity.

Based on the information provided by the applicant, staff made the determination that the use of a maximum average permanent deflection of 0.5% over the full basket width is conservative and bounded by the applicant's criticality analysis. Staff finds that due to the inherent conservatisms provided by the applicant in the FSAR, as well as the modeling conservatisms used in the analysis, that the likelihood of an inadvertent criticality event is considered unlikely. The analyses provided by the applicant confirmed staff's initial assessment of the safety of the HI-STORM 100 system, and was based on three criteria:

1) that the internals of the MPC would remain nominally dry (i.e., not flooded), resulting in an under-moderated system that limits k_{eff};
2) that the original analyzed deformation was found to be localized in small areas, and that the applicant conservatively modeled the original maximum deformation over the entire length and width of the MPC cells; and
3) that the applicant modeled postulated worst-case conditions, which assumed all fuel assemblies to be eccentrically located; minimum cell inner diameter; minimum, nominal and increased deformation limits; and minimum wall thickness.

Based on these criteria, the information provided by the applicant, and staff's assessment of the information provided by the applicant in the revised FSAR pages and responses to RAIs, staff has reasonable assurance that the HI-STORM 100 will remain subcritical during an accident event using the maximum average basket deflection of 0.5%.

8.0 MATERIALS EVALUATION

There were no changes to the applicant's materials section of the UFSAR requested in the amendment application.

As described in the renewed certificate of compliance for CoC No. 1014, Condition 14, AMENDMENTS AND REVISIONS FOR RENEWED CoC, "(A)ll future amendments and revisions to this CoC shall include evaluations of the impacts to aging management activities (i.e., time-limited aging analyses and aging management programs) to ensure they remain adequate for any changes to structures, systems, and components within the scope of renewal." The applicant stated in the RAI 8-1 response (ML24309A289) that the amendment did not add any new components or change the materials, environments, or operating conditions of existing components and as a result, no change is required to their aging management requirements. The staff reviewed the proposed changes to the CoC, technical specifications, and the amended SAR and agree that there are no changes that would require modification of the existing aging management activities.

9.0 CONFINEMENT EVALUATION

There were no changes to the applicant's confinement section of the UFSAR requested in the amendment application.

10.0 RADIATION PROTECTION EVALUATION

There were no changes to the applicant's radiation protection section of the UFSAR requested in the amendment application.

11.0 OPERATING PROCEDURES EVALUATION

There were no changes to the applicant's operating procedures section of the UFSAR requested in the amendment application.

12.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM EVALUATION

There were no changes to the applicant's acceptance test and maintenance program requested in the amendment application.

13.0 WASTE MANAGEMENT EVALUATION

This section is not applicable to CoC evaluations.

14.0 DECOMMISSIONING EVALUATION

This section is not applicable to CoC evaluations.

15.0 QUALITY ASSURANCE EVALUATION

There were no changes to the applicant's quality assurance program requested in the amendment application.

16.0 ACCIDENT ANALYSIS EVALUATION

There were no changes to the applicant's accident analysis section of the UFSAR requested in the amendment application.

17.0 CONDITIONS FOR CASK USE - TECHNICAL SPECIFICATIONS

The staff reviewed the proposed amendment to determine that applicable changes made to the conditions in the CoC and to the TS for CoC No. 1014, Renewed Amendment No. 19, would comply with the requirements of 10 CFR Part 72. The staff reviewed the proposed changes to confirm that the changes were properly evaluated and supported in the applicant's revised UFSAR. These modifications were found acceptable based on the staff's findings for the structural, criticality, and materials sections of this SER.

Table 17-1 lists the applicant's proposed changes to the TS:

Table 17-1 – Conforming Change to the Technical Specifications and Operating Control and Limits

Page Number	Reference	Description
Appendix D, page 2-3	Table 2.1-1, V.A.1.g	Change fuel assembly weight from 2,050 lbs. to 1,520 lbs.

Page Number	Reference	Description
Appendix D, page 2-5	Table 2.1-1, V.A.2.g	Change fuel assembly weight from 2,050 lbs. to 1,520 lbs.

The staff finds that the proposed changes to the HI-STORM 100 Cask System conform to the changes requested in the amendment application and do not affect the ability of the cask system to meet the requirements of 10 CFR Part 72. The proposed changes provide reasonable assurance that the HI-STORM 100 Cask System will continue to allow safe storage of spent nuclear fuel.

18.0 CONCLUSIONS

The staff has performed a comprehensive review of the amendment application, during which the following requested change, along with some minor changes to the FSAR for clarification and updates, were considered:

> Update the acceptance criteria and MOE for the HI-STORM 100 system tipover accident described in the FSAR for equipment combinations involving MPCs with Metamic-HT baskets. This involves applying a new stress-based criteria and completing new evaluations consistent with the new tipover acceptance criteria and MOE established in HI-STORM FW MPC Storage System, Amendment No. 7 (ML24199A241). This also involves some adjustments of the existing deflection criteria.

Based on the statements and representations provided by the applicant in its amendment application, as supplemented, the staff concludes that the changes described above to the HI-STORM 100 Cask System do not affect the ability of the cask system to meet the requirements of 10 CFR Part 72. Therefore, Renewed Amendment No. 19 to CoC No. 1014 for the HI-STORM 100 Cask System should be approved.

Issued with Certificate of Compliance No. 1014, Renewed Amendment No. 19
on ________________________.