Response to Request for Additional Information
Holtec International
Docket No. 71-9373
HI-STAR 190 Transportation Package

Chapter 1 – General Information

Licensing Drawings

NRC RAI 1-1

1-1 Revise licensing drawing No. 9841, "HI-STAR 190 Cask Assembly' to reflect the approaches defined in Section 2.2.1.2.5(b, c) of the application, or clarify the basis for exclusion from the drawing.

Note 13 of licensing drawing No. 9841 identifies the approach defined in Section 2.2.1.2.5(a) of the application, which states that the HI-STAR 190 cask interior steel surfaces may be coated with conventional surface preservatives such as Carboline Thermaline® 450 or equivalent surface preservative.

However, the application allows for alternative use of aluminum oxide and other surface passivation methods that provide suitable corrosion resistance [per the acceptance criteria in the table in Section 2.2.1.2.5(a)] along with the heat transfer characteristics used in the thermal analysis. These alternative approaches are not reflected in the licensing drawing for the cask assembly.

The staff recognizes that these coatings are non-important to safety; however, the acceptance criteria for these coatings/liners, as defined in Section 2.2.1.2.5(a) of the application, are necessary to ensure that the safety analyses for the package remain valid.

This information is required to determine compliance with 10 CFR 71.43(d), 71.71 and 71.73.

Holtec Response to RAI 1-1:

We agree with the staff's position on the need for clarification to the application. The following proposed changes have been incorporated in SAR Revision 0.C (provided with this RAI response) for clarification.

- Licensing Drawing 9841 on HI-STAR 190 Cask: [

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- SAR Subparagraph 2.2.1.2.5 on Cask Liner: The last sentence of the first paragraph has been rewritten to refer to Table 8.1.12 in Chapter 8. The criteria table in Subparagraph 2.2.1.2.5 is now Table 8.1.12 in Chapter 8.
- SAR Paragraph 8.1.5.6 on Conventional Surface Preservative Liner has been added with reference to Table 8.1.12.

The above proposed changes ensure that licensing drawing 9841 reflects the approaches defined in Subparagraph 2.2.1.2.5 of the SAR for the cask liner.

NRC RAI 1-2

1-2 Revise Drawings 6505 and 6512 to include the thickness and tolerances of the MPC canister.

From the information in Chapter 5 of the application, it appears as though the shielding analysis is crediting the presence of steel within the MPC canisters for shielding. The staff cannot locate the information on the thickness of the radial shell of the MPC canister in Drawing 6505 for the MPC-37 or 6512 for the MPC-89.

The staff also cannot locate the tolerances of the thickness of the top and bottom plates of the MPCs. The applicant needs to update these drawings to include these dimensions and tolerances for the MPC-37 and MPC-89 canisters.

This information is required to determine compliance with 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 1-2:

The thickness information on the canister Enclosure Vessel has been highlighted in CYAN coloring on the applicable drawings.

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For an additional discussion on toleranced dimensions of the package please see response to RAI 5-1 (a).

Chapter 2 – Structural and Materials Evaluation

NRC RAI 2-1

2-1 Clarify the maximum design load of the Model No. HI-STAR 190 package.

Section 2.5.1 of the application states that “D” denotes the package dead weight and that it must be taken as the bounding value of the dead load being lifted. Throughout the application and the docketed information referenced in the application, there are several discrepancies regarding the design/maximum weight of the package or the components that comprise the package. The table below illustrates some of these discrepancies.

Rows 3 and 4 show the weight of the package used for strength calculations of the upper trunnions and lower trunnion pockets as compared to the calculated weight (Row 2) and reported weight in the application (Row 1). The weight used to calculate the strength of the upper trunnions (Row 3) does not bound those calculated or reported. Rows 5 and 6 indicate that the MPC weight used to calculate the maximum weight of the package (Row 6) does not bound the weight reported for the same MPC in the storage application (Row 5).

Row	Reference	Component	Design Weight (lbs)
1	Table 2.1.11 of SAR	Version XL Transport Package Loaded with Longest MPC-37	414,269
2	Calculation 5 of Reference 2.1.12 of SAR	Version XL Transport Package Loaded with Longest MPC-37	435,800
3	Section 6.1.1 of Calculation 1 of Reference 2.1.12 of SAR (upper trunnions)	Bounding Cask Weight (Maximum Design load on trunnions)	400,000
4	Section 7.1.1 of Calculation 1 of Reference 2.1.12 of SAR (lower trunnion pockets)	Bounding Package Weight	450,000
5	Table 3.2.8 of Reference 2.1.13 of the SAR	Maximum possible weight of a loaded MPC	116,400
6	Table 2.1.11 of SAR	Loaded MPC-37 – longest	109,900

This information is required to determine compliance with10 CFR 71.45(a).

Holtec Response to RAI 2-1:

We agree with the staff’s position on the need for clarification specifically with any discrepancies on design and maximum weights of the package or components that comprise the package that are needed. We have performed a full assessment of this matter and determined there are no discrepancies except as discussed below. More importantly we confirm there is no impact on existing safety analysis.

The following proposed changes have been incorporated in SAR Revision 0.C (provided with this RAI response) to eliminate discrepancies and/or incorporate other enhancements.

SAR Enhancements to Correct Weight Discrepancies

- Table 2.1.11:[
  PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
- Table 2.1.11: [
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Other SAR Enhancements

- SAR Paragraph 2.5.1.1 (first paragraph): Revised the sentence concerning function of the bottom trunnions from "…used as rotation supports when changing package orientation…" to read "…used as rotation supports when changing the cask orientation".
- Table 7.A.1: Relabeled the table entry "Maximum HI-STAR 190 Overpack with Loaded MPC and impact limiters (no personnel barrier) – Note 1" as "Maximum Gross Weight of HI-STAR 190 Package (no personnel barrier) – Note 2"
- Table 7.A.1 (Note 1): Replaced the first sentence "The bounding weight is about 5% heavier than the calculated weight (see Table 2.1.11) for the heaviest MPC and provided for information only." with the sentence "The weight shown is a conservative representation provided for information only." Also replaced the last sentence "Lifting, handling and tie down evaluations shall be performed using bounding weights." with the sentence "Lifting, handling and tie down evaluations shall be performed using weights that match or bound as-built weights."
- Table 7.A.1: Added new Note 2 "The maximum gross weight of the package is conservatively set and intended for package shipment purposes in compliance with the packaging marking requirement of 10CFR 71.85(c))."
- Table 7.A.1: Refer to changes in SAR Revision 0.C for other minor enhancements.

Calculation 5 of Holtec Report HI-2146413 (reference 2.1.12 of the SAR) Enhancements to Correct Weight Discrepancies:

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It is important to note that the weights reported in Table 2.1.11 are already bounding weights. Analyses that require maximum bounding weights may use weights matching those in Table 2.1.11 or more conservative weights.

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NRC RAI 2-2

2-2 Clarify how the upper lifting trunnions will be rendered inoperable as a tie-down device for transportation or provide an analysis to verify that the trunnions meet the requirements of 10 CFR 71.45(b)(1).

Section 2.5.2 of the application states that there are no tie-down devices that are a structural part of the package; however, the upper lifting trunnions could be used for tiedown if not rendered inoperable. Step 6 of Section 7.1.5 of the application states, "If required, the cask lifting appurtenance is removed." The staff assumes this means remove the upper trunnions, but, based on detail DC of Drawing No. 9841, is uncertain how this is accomplished.

This information is required to determine compliance with 10 CFR 71.45(b)(2).

Holtec Response to RAI 2-2:

We agree with the staff's position on the need for clarification. We do not seek the qualification HI-STAR 190 cask top and bottom trunnions as package tie-down devices and therefore all cask trunnions must be rendered inoperable under routine conditions of transport. We also take this opportunity to clarify HI-STAR 190 compliance with 10 CFR 71.45(a). We do not seek qualification of HI-STAR 190 cask top and bottom trunnions to lift the package and therefore all cask trunnions must be rendered inoperable under routine conditions of transport.

The following proposed changes have been incorporated in SAR Revision 0.C (provided with this RAI response) to eliminate discrepancies and/or incorporate other enhancements.

SAR Enhancements Regarding Package Tie-downs

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- Paragraph 1.2.1.1, Subparagraph (f): Text has been revised as follows: “The HI-STAR 190 ~~transport cask~~Package lends itself to horizontal transport as shown in Figure 1.2.4 and is engineered for shipment by ~~both~~ seagoing vessel, railroads and roadways using appropriate supports and restraints. An illustrative example of packaging supports and restraints is provided in Figure 1.2.4. The arrangement of packaging supports and restraints may vary as long as the package is properly secured and qualified for the specific mode of transport. Tapered wedge shims that close the gap between the impact limiters and the axial restraints (longitudinal stops) of the transport vehicle are examples of auxiliary equipment that may be used to restrain the package against axial movement. Packaging supports and restraints ~~considered as auxiliary equipment,~~ such as support saddles, transport cradle, longitudinal stops, slings or straps and wedge shims are not structural parts of the HI-STAR 190 Package and as such are designated as auxiliary equipment ~~and a tie down system are normally necessary as part of the transport on a rail car conveyance. A similar configuration of the auxiliary equipment may be implemented for package transport by road. The HI-STAR 190 transport cask when configured for package transport by rail or road may also be transported by sea going vessel in accordance with applicable 49 CFR requirements as indicated by 10 CFR 71.5. Non-integral appurtenances to the cask, such as the transport cradle, support saddles, and a tie down system are not structural parts of the HI-STAR 190 Package and, as such, are not designated as packaging components.~~

  ~~The HI-STAR 190 Package lends itself to a horizontal packaging assembly for transport as shown in the drawing packaging in Section 1.3. Support saddles, located along the length of the cask body, provide the support surface for the HI-STAR 190 Packaging. Circumferential tie down straps are used to secure the packaging; tapered wedge shims that close the gap between the impact limiters and the axial restraints (longitudinal stops) of the transport vehicle are typically used for enhanced restraint of the package against axial movement.~~

  Packaging supports, ~~tie down straps~~ and ~~other~~ restraints shall be designed as appropriate for either rail, road (i.e. public highway) or seagoing vessel ~~(i.e. sea)~~ transport applications in compliance with the applicable requirements of 10 CFR 71 and ~~the applicable~~ 49 CFR ~~requirements~~ as indicated by 10 CFR 71.5, with additional consideration to the applicable industry (railroad, road and sea transportation) standards. More specifically, 10 CFR 71.45(a) and (b) requirements must be complied with.

  In the transport package configuration, the HI-STAR 190 cask trunnions are not qualified to be used to lift the HI-STAR 190 Package (i.e., loaded cask with impact limiters). In the

~~HI-STAR 190~~ transport package configuration, the HI-STAR 190 cask ~~collapsible~~ trunnions remain attached to the package and are not removable during transport ~~and are designed to ensure compliance with 10 CFR 71.45(a) and 71.45(b)(2), as described in Chapter 2~~. Therefore for compliance with 10CFR71.45 the cask trunnions must be rendered inoperable when HI-STAR 190 is configured as a transport package (i.e. loaded cask with impact limiters) as indicated in Figure 1.2.4."

- Subsection 7.1.5, Step 7: Text has been revised as follows: "The cask trunnions are made inaccessible by cap or cover or other appropriate ancillary device that renders the trunnions inoperable. The package tie-down and restraint system is installed, a cover is installed over at least one of the access tubes on the top impact limiter, and a security seal is installed on the top impact limiter. Security seal serial number(s) are recorded in the shipping documents."

- Figure 7.A.1: Added note: "Longitudinal Stops (axial restraints) not shown. The bottom trunnions are shown engaged by retractable downending device; however, all trunnions must be disengaged and rendered inoperable."
- Figure 7.A.2: Added note: "Longitudinal Stops (axial restraints) not shown."

Additional SAR Enhancements Regarding Package Regarding Lifting Attachments

- Paragraph 1.2.1.7: Text has been revised as follows: "~~Lifting~~ The cask trunnions are not ~~designed~~ qualified to be used to lift the package (loaded cask with impact limiters) and must therefore be rendered inoperable according to ~~in accordance with~~ 10CFR71.45(a) during routine conditions of transport ~~and ANSI N14.6 [1.2.5], manufactured from a high strength alloy and installed in threaded openings. These trunnions are designed to meet the requirements of 10 CFR 71, as detailed in Chapter 2.~~ …"
- Figure 1.2.5: Added "Longitudinal Stops not shown (See Figure 1.2.4)." to Steps 10 and 11.
- Subsection 2.5.1: Text has been revised as follows:
  - "The HI-STAR 190 Package ~~Cask~~ has the following types of interfacing lifting points: ~~four~~ two lifting trunnions located on the upper cask body for lifting the loaded and unloaded cask and threaded holes on the cask closure lid that serve as attachment locations to lift the lid. In addition, two trunnions are located in the lower cask body for rotation of the loaded and unloaded cask."
- Subsection 2.5.2: The following statement has been added to the first paragraph:
  - It should be noted that the cask trunnions are made inaccessible during transport per Subsection 7.1.5.

NRC RAI 2-3

2-3 Provide benchmarking results for the LS-DYNA stress analysis.

Section 2.1 of Holtec Report No. HI-2146321 states that the stresses of critical HI-STAR 190 cask components experienced in the analyzed impact events are directly obtained from LS-DYNA simulations. It further states that it was demonstrated in the HI-STAR 180 application that the cask component stress results obtained from the LS-DYNA finite element analysis (FEA) are comparable with and generally more conservative than those obtained from the corresponding ANSYS static analysis.

The methodology approved for the Model No. HI-STAR 180 package consists of two phases in which LS-DYNA is used to determine deceleration values for the various drop orientations (phase 1) which are then used in an ANSYS quasi static analysis to calculate relevant stress and deformation results (phase 2). This two-phased approach was initially approved for use to qualify the Model No. HI-STAR 100 package based on actual scale model drop tests and component static crush testing of the impact limiter.

While the HI-STAR 180 Safety Evaluation Report (SER) acknowledges the comparison of the ANSY and LS-DYNA stress results, it does not acknowledge, let alone approve, this comparison as a valid benchmarking of LS-DYNA for use in a single phase stress analysis.

A valid benchmarking effort involves the comparison of predicted parameters from an FEA model with parameters that can be physically measured (i.e. strain, deformation, acceleration) in an actual test prototype.

This information is required to determine compliance with 10 CFR 71.41(a).

Holtec Response to RAI 2-3:

In previous transport cask license applications, Holtec used the NRC approved two-phase analysis methodology to perform structural evaluations for transport packages in various hypothetical drop scenarios. In the first phase the peak deceleration of the dropped package, i.e., the inertial load experienced by the loaded transport cask, is determined through physical tests (in the case of HI-STAR 100) or numerical simulations (e.g., HI-STAR 180). Utilizing the HI-STAR 100 drop test data, Holtec was able to demonstrate that the widely used explicit finite element code LS-DYNA can accurately predict the peak deceleration of the transport package. This conclusion was accepted by NRC prior to the submittal of the HI-STAR 180 transport package license application. The structural response of the cask (i.e., stress, strain and deformation solutions) obtained in the phase 2 analysis came from both the static ANSYS analysis and the dynamic LS-DYNA analysis in HI-STAR 60, HI-STAR 180 and HI-STAR 180D license applications, and the two sets of stress and deformation solutions were shown to be comparable.

The two-phase approach for transport cask structural analyses evolved over time, and became the standard approach used by Holtec, primarily for the following two reasons. First, in Holtec's original application for the HI-STAR 100 the design basis package deceleration was pre-established and confirmed by physical testing, which enabled the structural response of the package to be determined using the static finite element code ANSYS. Secondly, the explicit finite element code LS-DYNA was relatively new to the nuclear industry 15 years ago and was not widely used for transport cask structural analyses. It wasn't until after the physical drop testing and successful licensing of the HI-STAR 100 transport package that Holtec performed a rigorous benchmark analysis of LS-DYNA for transport cask drop simulations in Holtec report HI-2073743. This benchmark effort led to the NRC's approval that Holtec can use LS-DYNA numerical simulations to predict the peak deceleration of a transport cask package equipped with aluminum honeycomb impact limiters without conducting physical drop tests. These events firmly established the two-phase analysis approach for future transport cask applications, such as the HI-STAR 60, HI-STAR 180, and HI-STAR 180D.

At this point in time, more analytical data has been collected, further benchmarking has been conducted, and LS-DYNA has gained more acceptance in the nuclear industry, which is what led Holtec to use LS-DYNA in the HI-STAR 190 application to predict not only the peak package deceleration, but also the structural response of the cask as part of one comprehensive analysis. The specific reasons that we find LS-DYNA to be a technically valid and reliable simulation code for the prediction of the HI-STAR 190 structural response are:

i) LS-DYNA has been subjected to computer code verification under Holtec's QA Program by comparing numerical results for a series of dynamic simulations with the solutions to known test problems (Ref. Holtec Report HI-961519);
ii) LS-DYNA drop simulations results (i.e., stresses and strains) for HI-STAR 60, 180, and 180D compare favorably with those obtained using ANSYS as shown in the 10CFR71 Safety Analysis Reports under NRC Docket Nos. 71-9336, 71-9325, and 71-9367, respectively;
iii) LS-DYNA has been used successfully to predict structural response of HI-STORM FW dry storage cask, including stresses and strains, for non-mechanistic tip over in the HI-STORM FW FSAR (NRC Docket No. 72-1032);
iv) LS-DYNA has been further benchmarked against Multi Canister Overpack (MCO) drop tests conducted by Sandia National Laboratory (Ref. Holtec Report HI-2156765).

Irrespective of what specific finite element code is used, the structural loading (i.e., the peak deceleration in the case of a dropped cask) is the key driver that governs the cask structural response (stress, strain and deformation) solutions. As indicated above, Holtec was able to consistently obtain LS-DYNA structural response results that are comparable to the corresponding ANSYS solutions in the cases of HI-STAR 60, HI-STAR 180 and HI-STAR 180D transport cask packages. Although ANSYS solutions were considered to be the "official" structural response results for the analyzed drop events in the three transport cask SARs, the comparable LS-DYNA results (also documented in those SARs) provide added confidence in the safety evaluation. The accuracy of the LS-DYNA predicted structural responses for a structure subjected to a known dynamic loading is also demonstrated in the computer code validation performed by Holtec. As shown in Holtec Report HI-961519, the stress, strain and deformation results obtained by LS-DYNA and ANSYS for a variety of impact loading problems are essentially identical. Furthermore, Holtec recently performed additional LS-DYNA benchmark analyses against two well documented DOE drop tests conducted for a multi-canister overpack (without impact limiter). The LS-DYNA simulation results of the tests obtained by Holtec consistently match the test data (i.e., deformation measurements) and the simulation results predicted by another finite element code ABAQUS as demonstrated in Holtec report HI-2156765. Section 2.7 of the HI-STAR 190 SAR has been updated to include a summary of this latest benchmark work.

Like any finite element code, LS-DYNA must be used in conjunction with good modeling and analysis practices in order to obtain reliable analysis results. The HI-STAR 190 LS-DYNA drop analyses performed by Holtec closely follow the guidelines (i.e., “Guidance Document – Use of Explicit Finite Element Analysis for the Evaluation of Nuclear Transport and Storage packages in Energy-Limited Impact Events”) developed by the ASME, Section III, Division 1 Special Working Group on Computational Modeling for Explicit Dynamics under the leadership of Dr. Gordon Bjorkman of the USNRC. Over the last 20 years, Holtec has also gained extensive experience in using LS-DYNA to perform various dynamic analyses for spent fuel rack and cask projects, such as the cask aircraft impact analysis (for the Private Fuel Storage project), which was accepted by the USNRC Atomic Safety and Licensing Board due to the demonstrated consistency with the third party solutions predicted by a DOE in-house finite element code and positive review conclusions by experts from DOE, NRC, and Purdue University. LS-DYNA has also been used extensively by Holtec for dynamic analysis of cask stack-up configurations and ISFSI pads for HI-STORM casks.

In summary, Holtec believes that the LS-DYNA code has been sufficiently benchmarked and is ideally suited for performing the HI-STAR 190 drop analyses as a one-step solution.

NRC RAI 2-4

2-4 Explain why the discrepancies between the drawings and the LS-DYNA model will have no effect on other aspects of the HI-STAR 190 simulation results.

There are at least three discrepancies between the drawings in Chapter 1 of the application and the LS-DYNA model:

a. There are 48 closure bolts depicted in the drawings and 68 closure bolts used in the LS-DYNA model.
b. The impact limiter bolts in the drawings are 1.5 inches in diameter and the bolts in the model are 1 inch in diameter.
c. The closure bolt material in the drawings is SA-750/654 630 (H1025 condition) or SB-637 N07718 material and the bolt material in the LS-DYNA model is SA-193 B7 (MID 11 assigned to PID 11).

For the first discrepancy, Holtec Report No. HI-2146321states that 68 bolts were explicitly modeled although the final cask design only has 48 bolts, and that the difference is fully compensated by scaling the bolt preload and the elastic modulus in the bolt material by a ratio of 48/68. For the second discrepancy, the stress-strain curve and Young’s modulus were scaled up by a factor of 2.318 for the SA-197 B8S material used for the impact limiter bolts. This was done, to capture the change in axial stiffness and axial strength due to the difference between the diameters of the bolts modeled versus those depicted in the drawings.

Section 2.5.4.1 of NUREG-1617 provides guidance on the evaluation by analysis. NUREG-1617 states that the analysis model should adequately represent the geometry, boundary conditions, loading, material properties and structural behavior of the package analyzed. The additional closure lid bolts affect the boundary conditions between the closure lid and the cask, and the staff is not convinced that scaling the bolt preload and Young’s Modulus will capture the difference between the two configurations in that the gap between bolts is over 1.5 inches larger for the 48 bolt configuration.

Additionally, altering material properties to account for differences in geometry is not a good practice and could lead to unintended anomalies in other results. While the change in the stress-strain curve and Young's Modulus of the impact limiter bolts may satisfy the axial behavior, it will also affect the bending and shear behavior. The staff believes that the model should be accurate and free from "work arounds" that force a desired behavior of the model.

In addition to the material discrepancy in the closure bolts (the third discrepancy), the staff also notes an error in the scaling of Young's Modulus for the closure lid bolts. Based on Table 2.2.2a of the application, Young's Modulus for SA-193 Grade B7 material at 250°F should be 28.75 ksi. When scaled by a factor of 48/68, the result is 20.29 ksi. The value listed for Young's Modulus in the LS-DYNA material model (MID 11) is 22.09 ksi.

This information is required to determine compliance with10 CFR 71.41(a).

Holtec Response to RAI 2-4:

Holtec understands the NRC reviewer's concerns and comments regarding the discrepancies identified in this RAI. To eliminate the discrepancies and potential non-conservative effects on the drop analysis results, the LS-DYNA model of the HI-STAR 190 model has been updated to align completely with the drawings in Chapter 1 of the application and then used to re-perform all affected drop analyses. The list of specific changes to the LS-DYNA model of the HI-STAR 190 package is as follows:

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Results of the updated drop analyses are reported in Sections 2.6 and 2.7 of the revised HI-STAR 190 SAR. The latest revision to the calculation package (HI-2146321 Rev. 1), along with the updated LS-DYNA input and output files, is also provided with this RAI submittal for NRC review.

NRC RAI 2-5

2-5 Provide information on how the number of torqueing cycles for the closure bolts and the closure flange threads will be tracked.

Section 2.6.1.3.2 of the application determines and "sets" the number of permitted loadings for a "set of closure lid bolts," as well as the number of cycles in the service life of the containment closure flange bolt threads. Step 8 of Section 7.1.1 (Preparation of the Overpack for Loading) states, "The closure lid bolts are inspected for distortion and damaged threads and any suspect bolts are replaced."

The staff is unsure how the number of cycles for a set of closure bolts, or the containment closure flange is tracked to ensure that the number of allowed cycles is not exceeded. Additionally, if a bolt within a set of closure bolts is replaced, the staff is unsure how the total number of loadings on each bolt is tracked.

This information is required to determine compliance with 10 CFR 71.51(a)(1).

Holtec Response to RAI 2-5:

The exact method of tracking the number of torqueing cycles for the closure bolts and the closure flange is outside the purview of the HI-STAR 190 SAR. It is the responsibility of the end user to develop a program to manage the number of torqueing cycles so as not to exceed the specific limits established in Subparagraph 2.6.3.1.2 and summarized in Table 8.2.1 of the SAR.
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NRC RAI 2-6

2-6 Provide additional information on how the lead slump was evaluated.

Table 2.7.3 of the application reports the maximum axial and radial lead slump as a result of the HAC drop scenarios (9 meter vertical drop and 9 meter slapdown respectively). The staff was unable to determine how the slump was calculated, because no information was provided in the application on the fabrication process. If the lead is poured, there will be shrinkage as the lead cools from the molten state to the solid state and eventually to ambient temperature. The applicant needs to provide a detailed lead slump calculation for both the radial and bottom lead shields.

This information is required to determine compliance with 10 CFR 71.47 and 51(a)(2).

Holtec Response to RAI 2-6:

The two bounding lead slump results reported in Table 2.7.3 of the HI-STAR 190 SAR are based on the time history deformation results from the LS-DYNA drop analyses, as explained below. To determine the lead slump, the LS-DYNA model of the HI-STAR 190 package explicitly includes the radial gamma shield (item 5 on drawing 9841) and the bottom forging gamma shield (item 17 on drawing 9841) as distinct parts, which are in contact with their surrounding cavity walls. [

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Finally, the lead material in the HI-STAR 190 cask is not poured in place, so lead shrinkage is not a concern. Instead, similar to the HI-TRAC transfer cask, thin sheets of malleable lead are pressed into the gamma shield cavities until the required lead thickness is achieved.

Figure 2-6.1, PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Figure 2-6.2, PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

NRC RAI 2-7

2-7 Revise the application to clarify that Zircaloy-2, Zircaloy-4 and ZIRLOTM are the only cladding type contents allowed for transport in the HI-STAR 190 package, or revise it, as appropriate, to account for the mechanical properties of M5®.

In the initial response to RSI 2-3 (Holtec Letter 5024003, Enclosure 1), the applicant stated that the glossary and Table 7.C.1 in the application states that any zirconium based fuel cladding material authorized for use in a commercial nuclear power plant reactor is allowable for transport in the HI-STAR 190. This statement and conclusion is inconsistent with the cladding mechanical properties used in the Structural Calculation Package (Holtec Report No. HI-2146413). Section 2.0 of this Calculation Package states: “The fuel cladding material for the HI-STAR 190 Design Basis Fuel is Zircaloy.” Further, Table 5.2.1 of the application, “Description of Design Basis Fuel Assembly”, only defines Zircaloy-2 and Zircaloy-4 as the design-basis fuel assemblies.

The staff confirmed that the cladding mechanical properties used in the LS-DYNA structural evaluation correspond to models developed based on a database of mechanical properties of stress-relief annealed Zircaloy-4 with a smaller amount of Zircaloy-2 (Geelhood, et al., PNNL-17700). PNNL-17700 includes an independent assessment using additional data on ZIRLO™ ring tensile tests, which verified consistency with the Zircaloy models. However, PNNL-17700 does not include an assessment of the adequacy of the models for M5® cladding type. Therefore, the structural evaluation has not accounted for the M5® cladding type.

As stated in the revised RSI 2-3 response, the primary safety case for normal conditions of transport (NCT) is based on minimum 3% failed fuel, and the primary safety case for hypothetical accident conditions (HAC) is based on moderator exclusion (with a defense-in-depth). The applicant stated that the minimum fuel failure was chosen to be consistent with the draft Regulatory Information Summary (RIS) for high-burnup fuel (ML14175A203).

The staff clarifies that the use of a 3% failed fuel criterion is only consistent with the draft RIS if the cladding mechanical properties used in the package design correspond to the specific cladding-type for the proposed contents. The 3% failed fuel criterion was devised to allow for defense-in-depth analyses that account for degradation of the mechanical properties due to radial hydrides for a given cladding type. The 3% failed fuel criterion was not devised to account for variability in mechanical properties from one cladding type to another. The structural evaluation in the application must still contain bounding as-irradiated mechanical properties for all cladding types of the package contents.

This information is required to determine compliance with 10 CFR 71.43(f), and 71.51(a).

Holtec Response to RAI 2-7:

In response to the RAI, Holtec performed additional fuel integrity structural evaluation using materials properties adjusted for M5 cladding type. These additional evaluations show that fuel assemblies with M5 type cladding are not vulnerable to cladding failure when exposed to 9-m drop accident in HI-STAR 190 cask. The calculation package HI-2146413 is updated with above mentioned calculation. Below, the individual mechanical properties and justification of their use for M5 cladding are discussed:

Young's Modulus

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Yield Strength

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Failure Strain or Reduction of area

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Thickness of oxidized layer

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Fatique/Endurance Limit for Vibration Analysis

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Density

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

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References for RAI 2-7

1. BAW-10227-A, February 2000, Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel, Non-Proprietary Version, FCF, ML003686365.
2. PNNL-17700, PNNL Stress/Strain correlation for Zircaloy, 2011.
3. NUREG/CR-7024, PNNL-19417, Material Property Correlations: Comparisons between FRAPCON-3.4, FRAPTRAN 1.4, and MATPRO, 2010.
4. NUREG/CR-7023, PNNL-19400, FRAPTRAN 1.4: A Computer Code for the Transient Analysis of Oxide Fuel Rods, 2011.
5. NUREG/CR-7022, PNNL-19418, FRAPCON 3.4: A Computer Code for the Calculation of Steady-State, Thermal-Mechanical Behavior of Oxide Fuel Rods for High Burnup, 2011.
6. Motoe Suzuki, Tomoyuki Sugiyama and Toyoshi Fuketa, Thermal Stress Analysis of High-Burnup LWR Fuel Pellet Pulse-Irradiated in Reactivity-Initiated Accident Condition, Journal of Nuclear Science and Technology, Vol. 45, No. 11, p. 1155–1164 (2008).
7. B. Cazalis et. al., Prometra Program : A Reliable Material Database For Highly Irradiated Zircaloy-4, Zirlo and M5 Fuel Claddings, 18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18), Beijing, China, August 7-12, 2005, SMiRT18-C02-1.

8. B. Beyer & R1 Juknat, "Physical and Mechanical Properties of Zirconium niobium Alloys containing I & 2.4 wt % of niobium," Conference on the Use of Zirconium Alloys in Nuclear Reactors, page 55-75, Marianske Lazne, Czechoslovakia, October 1966.
9. Garat et. al, Quantification of the margins provided by M5 cladding in accidental conditions, 2012 LWR Fuel Performance Meeting.
10. Journal of NUCLEAR SCIENCE and TECHNOLOGY, Vol. 44, No. 10, p. 1275–1280 (2007).
11. O'Donnell, W. J., and B. F. Langer. 1964. "Fatigue Design Basis for Zircaloy Components." In Nuc. Sci. Eng. 20:1. (could not find for free, see for example reference 10)

NRC RAI 2-8

2-8 Regarding MPCs previously in dry storage under a 10 CFR Part 72 license:

1. Revise the application to provide acceptance criteria for the MPC enclosure vessel integrity, which clearly defines allowable degraded conditions prior to transport. The acceptance criteria should demonstrate MPC containment integrity during hypothetical accident conditions.

2. Discuss methods (e.g. transport inspections) used to ensure that the MPC meets the proposed acceptance criteria.

The application (Section 8.2.1, “Structural and Pressure Tests”) states that the MPC maintenance program shall include an Aging Management Program (AMP) (under a 10 CFR Part 72 license) that verifies that the MPC pressure and/or containment boundary is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce the effectiveness of the packaging. However, the application does not define acceptance criteria for other credible degraded conditions (e.g. loss of material due to localized corrosion pits, etching, crevice corrosion; presence of corrosion products) that ensures that cracks will not develop during transport, which could compromise the validity of the leak-tightness criterion during transport.

The structural evaluation of the HI-STAR 190 package does not consider potential degraded conditions of the MPC during dry storage under a Part 72 license. Therefore, the application should describe the methods used to ensure that the acceptance criteria for the MPC enclosure vessel integrity are met. This could include pre- and post-transport inspections that ensure that the safety analyses remain valid and the MPC is free of cracks, pinholes, uncontrolled voids, or other defects that could compromise the enclosure vessel integrity.

The staff notes that sole reliance on a Part 72 AMP is an overly-simplistic and inadequate approach, as the AMP may identify certain aging effects that the Part 72 licensee deems acceptable for continued storage following review under its corrective action program (CAP), but which could potentially compromise the MPC containment integrity during hypothetical accident conditions (HAC). For example, the acceptance criteria in the AMP for localized corrosion and stress corrosion cracking included in Appendix B of draft NUREG-1927, Rev. 1 (ML15180A011) states that any indications of localized corrosion pits, etching, crevice corrosion, stress corrosion cracking, red-orange colored corrosion products require additional examination and disposition under the Part 72 licensee’s CAP.

During the CAP review, the Part 72 licensee may use data from non-destructive examination and other analyses to support the conclusion that a given aging effect (e.g. loss of material due to localized corrosion pits, etching, crevice corrosion; presence of corrosion products) will not compromise the confinement function of the MPC for the expected loads during normal, off-normal and accident conditions of storage. Those loads, however, are not expected to be commensurate with HAC transport loads.

Therefore, reliance on a 10 CFR Part 72 AMP to assure compliance with the HI-STAR 190 structural safety analyses is inadequate.

This information is required to determine compliance with 10 CFR 71.55(e), 71.73 and 71.85(a).

Holtec Response to RAI 2-8:

We agree with staff's position regarding the need for a higher level of confidence with respect to the MPC's containment integrity under the § 71.73 free drop loading scenario than that assured by a Part 72-compliant Aging Management Plan. New Subsection 8.1.8 titled "MPC Enclosure Vessel Shell Surface Defect Inspection" has been incorporated in SAR Revision 0.C (provided with this RAI response) as a remedy to this matter with the following key commitments:

- MPC's containing high burn-up fuel and stored beyond the duration of the initial 20 year license period under the provisions of 10CFR 72 shall undergo an MPC enclosure vessel shell surface defect inspection prior to shipment to ensure that existing defects and flaws do not develop into cracks during hypothetical accident conditions of transport.
- The MPC shall be subject to an Eddy current testing (ECT) regimen that is capable of identifying any surface defect equal or greater than 2 mm deep anywhere on the external cylindrical surface of the enclosure vessel.
- This test may be conducted on the population of MPCs at an ISFSI using a statistical testing approach suggested in Military Standard MIL-STD-105E (1989) titled "Sampling Procedures and Tables for Inspection by Attributes". Not every MPC at a given ISFSI requires inspection.
- Any flaw that exceed 2 mm in depth will disqualify the canister for transport until further investigation is performed and the NRC accepts, under the exemption process or other appropriate licensing action, the owner-provided evidence that the affected canister will survive a HAC.

Inasmuch as the ECT is considered the most definitive detector of cracks, pits and other types of surface flaws and is universally relied upon for detecting minute degradation in the tubing of critical nuclear plant heat transfer equipment such as Steam Generators, we propose to use this proven technology to determine the structural integrity status of the MPC's shell.

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We believe the above commitments provide a robust means to ensure that only those MPCs that have a structurally competent containment boundary to meet the transport accident of §71.73 will be transported in HI-STAR 190.

See Holtec response to RAI 2-12 for additional proposed changes to Section 1.0, Subsection 1.A.3.2, Table 8.2.1, Appendix A and Table 8.A.1 regarding this inspection. In addition, Section 7.0, Subsection 7.1.2, Subsection 7.1.3, Appendix 7.B have been revised to incorporate the surface inspection as appropriate.

NRC RAI 2-9

2-9 Justify that both the hydrogen content and fast neutron fluence used to determine the cladding mechanical properties used for the structural evaluation are commensurate to the design-basis fuel burnup (68.2 GWd/MTU), or revise the mechanical properties, as appropriate.

The application defines cladding mechanical properties assuming hydrogen contents that are not representative of the requested content. For burnups above 45 GWd/MTU and up to 62 GWd/MTU, the total hydrogen content is expected to be in the range of 200–1,200 wppm for Zircaloy-4 (Mardon et al., 2010; Thomazet et al., 2005; King et al., 2002; Bossis et al., 2007; Hanson, 2016) and up to 550± 300 wppm for ZIRLO™ (Billone et al., 2013, Billone et al., 2015). The hydrogen contents for recrystallized annealed alloys (Zircaloy-2 and M5®) is expected to be bounded by stress-relieved annealed cladding types (Zircaloy-4 and ZIRLO™). Therefore, the use of mechanical properties corresponding to a considerably lower hydrogen content should be justified, or the materials properties should be revised to ensure them adequate for all proposed alloy contents.

The staff notes that the range of applicability of the referenced mechanical property models includes excess hydrogen concentrations up to 650 ppm (refer to Table 2 in Geelhood, et al., PNNL-17700). The application should also justify that the assumed neutron fluence is adequate for the burnups and history of the rods to be loaded in the HI-STAR 190 package.

This information is required to determine compliance with 10 CFR 71.33(b)(3).

Holtec Response to RAI 2-9:

Holtec performed fuel integrity structural evaluations using material properties adjusted for high burnup fuel. These evaluations show that fuel assemblies with cladding subjected to high burnup are not vulnerable to cladding failure when exposed to 9-m drop accident in HI-STAR 190 cask. Discussion below provides sources of the material data and their applicability to HI-STAR 190 studies.

Calculation 16 of Holtec report HI-2146413 includes calculations where input values such as yield strength, elastic modulus and strain for high burnup fuel are used.

The elastic modulus correlation for Zircaloy adopted from PNNL-17700 [2] does not depend on hydrogen content. It does, however, depend on neutron fluence. Calculation 16 of HI-2146413 uses an elastic modulus value based on correlations in PNNL-17700 with fast neutron fluence set to approximately 12×10^{25} neutrons/m^2, which is within the range of high burnup fuel (see Note 1). In addition, reference [1] (on page A-8) indicates that the Zircaloy-4 model provides a reasonable representation of the modulus for the M5 alloy. Therefore, it can be concluded that the elastic modulus used in these evaluations is applicable to high burnup fuel of both cladding types.

As discussed in Sections 2.2 and 2.3 of PNNL-17700, the hydrogen content has little effect on the strength coefficient or strain hardening exponent. In Section 3.1, the report finds a good agreement of predicted yield stress with measurements. A small over prediction in yield stress is noted for hydrogen content exceeding 600 ppm, noting that this is rather due to embrittlement. The model is applicable up to 14×10^{25} neutrons/m^2. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

]In addition, this stress is representative of the yield stress of high burnup Zircaloy and Zirlo alloys according to measurement values at 400ºC reported in Table 3 of reference [4]. To evaluate M5 alloy, additional calculations are performed in Calculation 16 of HI-2146413 with a reduced yield stress based on Table 3 of reference [4]. Therefore, it can be concluded that yield stress values used in these evaluations are applicable to high burnup fuel evaluations.

The hydrogen content has an impact on ductility, reducing elongation. However, measurements of total elongation for Zircaloy 4 and Zirlo cladding from high burnup fuel in reference [4] show values between 12 to 23% at 400 ºC. The same measurements show total elongation of about 28% for M5 alloy. On the other hand, reference [5] notes that “permissible strains regarding failure mechanisms for high-burnup fuels are difficult to determine due to limited data, but ongoing work at PNNL has estimated that they are on the order of 1.7 to 3%” for Zircaloy cladding material. Given the limited available data and the uncertainty surrounding the hydrogen concentration for high burnup fuel, [

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] Thus, the failure strain limits used in the HI-STAR 190 fuel cladding evaluations are in agreement with the available data and reasonably conservative for the high burnup fuel.

Note 1) Typical neutron fluxes for high burnup fuel are shown for example in Table 1 of [3]. The table shows that fluxes 10×10^{25} and 13×10^{25} correspond to burnups of 61 and 56 GWD/MTU, respectively.

References

1. BAW-10227-A, February 2000, Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel, Non-Proprietary Version, FCF, ML003686365.
2. PNNL-17700, PNNL Stress/Strain correlation for Zircaloy, 2011.
3. Motoe Suzuki, Tomoyuki Sugiyama and Toyoshi Fuketa, Thermal Stress Analysis of High-Burnup LWR Fuel Pellet Pulse-Irradiated in Reactivity-Initiated Accident Condition, Journal of Nuclear Science and Technology, Vol. 45, No. 11, p. 1155–1164 (2008).
4. B. Cazalis et. al., Prometra Program : A Reliable Material Database For Highly Irradiated Zircaloy-4, Zirlo and M5 Fuel Claddings, 18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18), Beijing, China, August 7-12, 2005, SMiRT18-C02-1.
5. PVP2004-2804, “Spent Nuclear Fuel Structural Response When Subject to an End Impact Accident”, PVP-Vol 483, Transportation, Storage and Disposal of Radioactive Materials-2004, Adkins, Koeppel, and Tang.

NRC RAI 2-10

2-10 Revise Section 2.2.3, “Effects of Radiation on Materials”, of the application to address the technical basis supporting the adequate performance of the elastomeric seals used in the closure lid and port cover.

The discussion on radiation effects does not address performance of the elastomeric seals of the closure lid and port cover under bounding radiation doses.

This information is required to determine compliance with 10 CFR 71.43(d).

Holtec Response to RAI 2-10:

Holtec has performed engineering evaluation to establish bounding maximum service life limits for the elastomeric seals used in HI-STAR 190. A maximum replacement duration based on the evaluation is added to SAR table 8.2.1. SAR Sections 2.2.3, and 8.2.3.6 are updated to include discussions of elastomeric seals.

NRC RAI 2-11

2-11 Clarify the method and justify the approach used to derive yield strength (S_y) and tensile strength (S_u) of impact limiter attachment bolts, as noted in Table 2.2.6 of the application. Clarify the room temperature value assumed in Table 2.2.6.

The yield strength (S_y) and tensile strength (S_u) values at the high temperature in Table 2.2.6 were derived using an unclear approach, in which the room temperature values of S_y and S_u were multiplied by the ratio of the design stress intensities at the elevated temperature (165.6 °C) to the “at room” temperature (the staff assumed 40 °C since a value is not provided in the Table 2.2.6).

The staff reviewed the design stress intensity values in Table 4 of ASME B&PV Code, Section II, Part D, and was unable to reproduce the S_y and S_u values at the elevated temperature. In addition, the S_y value at room temperature listed in Table 2.2.6 is inconsistent with that listed in Table Y-1 of ASME B&PV Code, Section II, Part D. Table 2.2.6 also should define a specific value for “room temperature”.

This information is required to determine compliance with 10 CFR 71.71 and 71.73.

Holtec Response to RAI 2-11:

As discussed in the response to RAI 2-4, the LS-DYNA model of the HI-STAR 190 transport package has been updated and re-analyzed in order to eliminate specific discrepancies associated with the closure lid bolts and the impact limiter attachment bolts. [

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NRC RAI 2-12

2-12 Revise Table 8.A.1 to clarify that an Aging Management Program is also required for MPCs loaded with high-burnup fuel for confirming the integrity of the enclosure vessel.

Table 8.A.1 is inconsistent with response to RSI 8-2, which states: “An Aging Management Program (AMP) applies to MPCs loaded with either moderate-burnup or high-burnup fuel as delineated in Table 8.A.1.” The integrity of the MPC enclosure vessel (for both moderate and high burnup fuel) is an integral part of ensuring that the conditions of ISG-11, Rev. 3 are maintained, which provide reasonable assurance that the spent fuel remains in the as-analyzed configuration.

Therefore, Table 8.A.1 should reflect that the transportability of MPCs loaded with either moderate and high burnup fuel is dependent on an 10 CFR Part 72 AMP being in place, which ensures that aging effects that could compromise the enclosure vessel integrity during dry storage are appropriately dispositioned under the Corrective Action Program of the Part 72 general licensee. The staff recognizes that the requirement for an aging management program is only applicable to MPCs in dry storage during an extended period of operation, per the requirements of 10 CFR 72.42(a) and 72.240(c).

This information is required to determine compliance with 10 CFR 71.71, 71.73 and 71.85(a).

Holtec Response to RAI 2-12:

We agree with the staff’s position on the need for clarification. The following proposed changes have been incorporated in SAR Revision 0.C (provided with this RAI response) for clarification.

SAR Enhancements to Incorporate Clarifications

- Section 1.0 bullet (b): For the principal qualification for HBF the following text is revised/added:

- "Additional defense-in-depth provided by the aging management ~~activities performed~~ of MPC pressure boundary and containment boundary on ~~the~~ MPCs stored beyond the duration of the initial 20 year license period under the provisions of 10CFR 72 ~~during storage~~."
- "Additional defense-in-depth by direct surface inspection of MPC shell exterior surfaces based on a statistical selection of MPCs stored under the provisions of 10CFR 72 at a given ISFSI beyond the duration of the initial 20 year license period."

- Section 1.0 bullet (b): For the MBF the following text is added as a bullet: "Additional defense-in-depth provided by the aging management of MPC pressure boundary on MPC stored beyond the duration of the initial 20 year license period under the provisions of 10CFR 72."
- [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
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- Table 8.A.1: The following text has been revised as indicated: "Enclosure vessel pressure ~~vessel~~ boundary structural integrity confirmation (See Subsection 8.2.1)."
- Table 8.A.1: Enclosure vessel pressure boundary structural integrity confirmation has been checked off as also applicable to MPC loaded with HBF.
- Table 8.A.1: The following text has been deleted: "Enclosure vessel containment integrity confirmation."
- Table 8.A.1: The following statement has been added as a footnote: "The Aging Management Program shall have been specified by and performed under the aegis of the HI-STORM FW FSAR (Docket # 72-1032) or the HI-STORM UMAX FSAR (Docket # 72-1040) to ensure that aging effects that could compromise the MPC enclosure vessel integrity during dry storage are appropriately dispositioned under the Corrective Action Program of a Part 72 general licensee. The Aging Management Program is only applicable for storage durations longer than the initial 20 year license period under the provisions of 10CFR 72."
- Table 8.A.1: The following requirement has been added under the heading of MPC Acceptance Tests and Inspections: "Containment Boundary Integrity Confirmation by Enclosure Vessel Shell Surface Defect Inspection (See Subsection 8.1.8 and Table 8.2.1)" with applicability to only MPCs loaded with HBF.
- Table 8.2.1 (Sheet 2 of 2): The following text has been revised as indicated: MPC "Enclosure Vessel pressure boundary structural integrity ~~and/or containment integrity~~ as confirmed by MPC aging management program for MPCs stored beyond the duration of the initial 20 year license period under the provisions of 10CFR 72 (See Subsection 8.2.1 and Appendix 8.A)."
- Table 8.2.1 (Sheet 2 of 2): The following task has been added: "MPC Enclosure Vessel Shell Surface Defect Inspection for MPCs containing HBF and stored beyond the duration of the initial 20 year license period under the provisions of 10CFR 72. (See Subsection 8.1.8)"

- Subsection 8.2.1: The following text has been revised as indicated: “The MPC maintenance program shall include an aging management program for any storage durations longer than the initial 20 year license period under the provisions of 10CFR 72 that ~~ensures continued radiological safety of the MPC and~~ verifies that the MPC pressure ~~and/or containment~~ boundary ~~(as applicable)~~ is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce the effectiveness of the packaging. See Section 8.1.8, Appendix 8.A and Table 8.2.1.”
- Subsection 8.2.2: The following statement has been added: “Also see Table 8.2.1.”
- Appendix 8.A: The following text has been revised as indicated: “Table 8.A.1 features an applicability column to distinguish whether requirements are applicable to MPCs loaded with MBF (where only the MPC pressure boundary structural integrity is essential to the safety approach as defense-in-depth) or to MPCs loaded with HBF (where in addition to the MPC pressure boundary structural integrity, the MPC containment boundary leaktightness and containment boundary integrity are essential to the safety approach to ensure moderator exclusion under hypothetical accident conditions of transport).”

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Strictly speaking, structural integrity of the MPC enclosure vessel pressure boundary during routine, normal, or hypothetical accident conditions of transport is not required for MPCs loaded with moderate MBF since thermal evaluations of the HI-STAR 190 Package under these transport conditions do not credit convection heat transfer. In other words the MPC internal pressure may drop to equalize with the cask internal pressure and the spent fuel will remain in an analyzed condition with temperature below ISG-11 Rev. 3 temperature limits. Nevertheless the requirement is maintained for defense in depth and also for consistency/compatibility with extended interim storage needs. Note that convection heat transfer is also not credited for MPCs loaded with HBF.

NRC RAI 2-13

2-13 With respect to Table 8.1.4A, “Metamic-HT Production Testing Requirements”, and 8.1.4B, “Tier System for Metamic-HT Production Coupon Testing”:

a. Clarify and justify the number of coupons to be tested for mechanical properties, per extrusion.

b. Justify the adequacy of the proposed Tier No. 4 in Table 8.1.4B, i.e. justify that testing 1% of the extrusions in a given lot, provides reasonable assurance that nonconforming extrusions will be adequately identified (consistent with the CoC holder’s Quality Assurance requirements).

c. Justify the adequacy of the statement in Note 1 on Table 8.1.4B, i.e. provide a basis for the sampling plan used to define the extent of condition.

d. Clarify Note 2 in Table 8.1.4B. The note states: “Testing shall be moved up to the next tier if any MGV property fails in two consecutive lots.” The statement is inconsistent with the Tier numbering. In the event that the MGV property fails, the correct action would be to increase the sampling size, i.e. step down to a lower tier.

This information is required to determine compliance with 10 CFR 71.131 and 71.133.

Holtec Response to RAI 2-13:

The test plan is based on the guidance in Military Standard MILSTD-105E “Sampling Procedures and Tables for Inspection by Attributes”, (10/5/1989), which recommends a graduated testing protocol. The testing protocol is predicated on the lot size which typically consists of up to 400 extrusions. Each extrusion yields 1 extruded Metamic-HT panel from which a sample may be taken. The number of test coupons derived from an extrusion lot is guided by the quantity required to perform the needed tests as articulated in a 2009 presentation to the NRC by Holtec’s Metamic manufacturing consultant Dr. Phil Blue. The presentation is shown below.

MIL Standard 105E has been adopted as a sound methodology to guide production of defect free Metamic HT lots with an emphasis on the prevention of product nonconformances. Thus, basing the testing requirements of production lots on the established practice provides the confidence that the manufactured materials will meet the applicable criteria necessary. Since the inception of Metamic HT production the execution of the quality plan combined with Holtec quality assurance program record keeping and process review provide tangible proof of the quality of the Metamic HT material and production process.

12 Month testing summary for the period of 8-10-2015 to 8-10-2016

# of Metamic HT Lots Tested	Failed MGV Tests	Passed Lots
375	0	375

At the start of the production run the quantity of testing follows Tier 1 in Table 8.1.4B which sets the number of extrusions subjected to testing equal to 20% of extrusions produced in one lot. Thus the number of extrusions tested for a lot of 400 extrusions is 80.

If the mechanical strength properties meet all Certificate-of-Compliance MGVs then the subject lot of extrusions is determined to be acceptable.

If all tested coupons in five consecutive tested lots pass the MGV requirements then the required coupon sample population can be reduced (dropped down) to Tier 2. The drop-down to Tier 3 is permitted according to Table 8.1.4B, only if every measured property meets its MGV.

If a coupon fails with respect to any property, then it can be replaced by two coupons from the same slab of the failed coupon. If the replacement coupons also fail to meet any of the seven properties, then the entire lot is rejected. As an alternative to rejecting the entire lot, testing of the failed MGV value on all panels within the lot may be done to isolate the failed panels from acceptable panels. The descent to Tier 2 and below will remain contingent on meeting the no-discrepant result criterion in the Table 8.1.4B. Tier testing is defined on the basis of sample size. Higher tier testing requires greater percentage of sample testing (i.e. moving up the table).

NRC Sampling Plan Presentation, from ADAMS Number ML091820164

Production Sampling Plan

Dr. Philip Blue
Consultant
Holtec International

June 18, 2009

Production Sampling Plan Based on MIL-STD-105

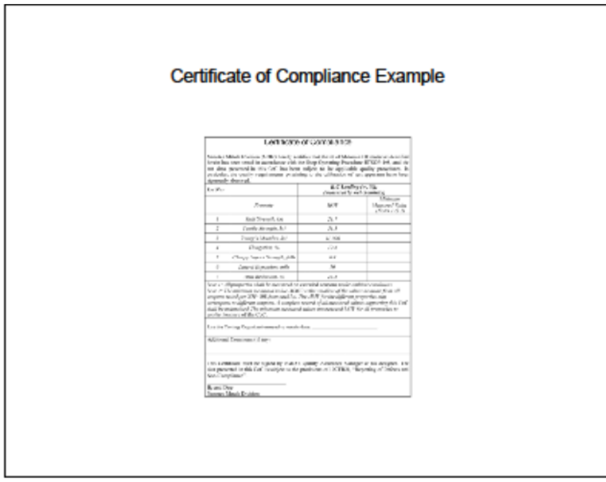
- The Nanotec sampling plan for Metamic HT™ follows the MIL-STD-105 which is a widely accepted and flexible procedure for the measurement of quality attributes of production lots. This plan is referenced in the Metamic HT™ Sourcebook (HTSOP-108).
- The plan describes the procedure for obtaining the samples from the extrusions.
- The acceptance or rejection of a lot is determined by the expected average quality level (AQL) and the sample size which is based on the lot size.
- The AQL for this product is 4.0, corresponding to 4 defects per 100 samples.
- The sample size is based on anticipated lot sizes of 400 extrusions.
- The inspection level specified in MIL-STD-105 are Normal, Loosened or Tightened to reflect quality history.
- Metamic HT™ testing will begin at the Tightened level as a conservative approach until the quality level is established. After 5 consecutive lots are accepted at the Tightened level, the plan will go to the Normal level.

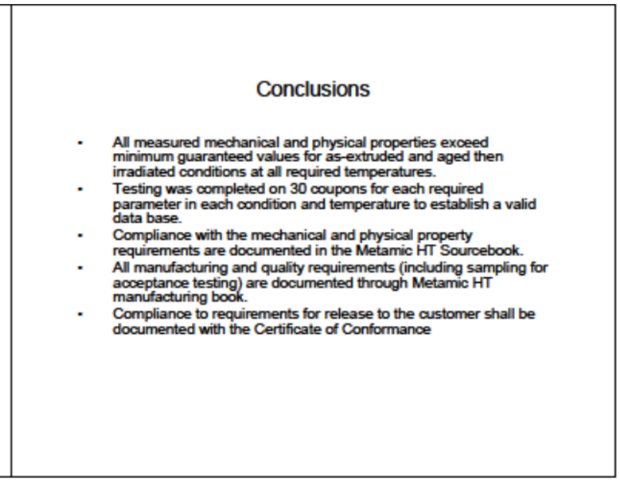
Production Sampling Plan Based on MIL-STD-105

- The sample size is determined from a table incorporating the lot size, AQL and Acceptance Criteria.
- The acceptance criterion is the number of samples which fail a threshold level specified by the table. If the number of failures exceed the allowed number, the lot is rejected.
- If the lot is acceptable with rejects, each rejected sample is replaced by two samples which, after testing, must meet requirements.
- Acceptance of a lot shall be documented with a certificate of conformance which attest to each measured value exceeding the minimum guaranteed value for each required property.
- An example of the application of MIL-STD-105 follows:

Example of Application of MIL-105 to Sampling of Metamic HT™ Extrusions

•A lot is defined as the product consisting of distinct Al and B_4C powder batches, and common mixing, sintering and extrusion operations.
•Lot Size: 400 Billets
•Inspection Level: Tightened (Selected)
•AQL: 4 (Selected)
•Sample Size: 80 (From Table 2b)
•Criteria: Accept 7 Defective; Reject 8 Defective (From Table 2b)
•Retest: Re-test Two Specimens for Each defective;
Both Re-tests Must Be Acceptable.
•After five consecutive acceptable lots, the Inspection Level is reduced to Normal and the sample size and acceptance criterion adjusted per the applicable table (2a).





NRC RAI 2-14

2-14 Clarify the basis for the mechanical properties of lead provided in Table 2.2.9 of the application.

The application states that lead is not considered as a structural member of the HI-STAR 190 Package. However, it is included in the dynamic simulation models for Normal Conditions of Transport and Hypothetical Accident Conditions; therefore, the corresponding mechanical properties were included in Table 2.2.9 of the application.

The staff is unclear the specific data, figure or models used to define the values in Table 2.2.9 from the cited reference (J.H. Evans, "Structural Analysis of Shipping Casks, Volume 8, Experimental Study of Stress-Strain Properties of Lead Under Specified Impact Conditions", ORNL/TM-1312, Vol. 8, ORNL, Oak Ridge, TN, August, 1970).

This information is required to determine compliance with 10 CFR 71.71 and 71.73.

Holtec Response to RAI 2-14:

Lead is used in the HI-STAR 190 transport cask as a gamma shield material, whose shielding performance is not related to its stress level. Therefore, lead is not considered as a structural member of the HI-STAR 190 package. The LS-DYNA model of the HI-STAR 190 package explicitly models lead components based on the material properties listed in Table 2.2.9 so that interactions between lead and adjacent cask parts in the analyzed events under the NCT and HAC can be accurately simulated.

We regret that the reference for the lead properties in Table 2.2.9 is not correct. This error has been corrected in the revised HI-STAR 190 SAR. The correct references are listed below:

1. Tietz, T.E., “Determination of the Mechanical Properties of High Purity Lead and a 0.05% Copper-Lead Alloy,” Stanford Research Institute, Mellon Park, CA, WADC Technical Report 57-695, ASITIA Document No. 151165;
2. Gallagher, C., “NL Industrial Internal Test Report on Tensile Properties of Chemical Lead at Elevated Temperatures,” Central Research laboratory, March 1976.

3. NUREG/CR-0481, "An Assessment of Stress-Strain Data Suitable for Finite Element Elastic-Plastic Analysis of Shipping Containers," H.J. Rack and G.A. Knorovsky, Sandia Laboratories, SAND77-1872, September 1978.
4. Baumeister, T. and L.S. marks, Standard Handbook for Mechanical Engineers, 7^{th} Edition, New York, McGraw-Hill Book Co., 1966.

References 1 and 2 above provide the yield strength data for lead. The modulus of elasticity of lead can be found from Reference 3, and the Poisson's ratio and density data for lead are documented in Reference 4.

NRC RAI 2-15

2-15 Revise Table 3.2.1 to identify the reference for the emissivity values for the aluminum basket shims.

Table 3.2.1, "Summary of HI-STAR Packaging Materials Thermal Property References", does not identify the reference for the emissivity values for the aluminum basket shims. The respective entry cites "Note 1", which relates to Metamic-HT.

This information is required to determine compliance with 10 CFR 71.71 and 71.73.

Holtec Response to RAI 2-15:

The emissivity requirement of aluminum basket shim is specified in Note 26 of MPC-37 drawing 6505 Rev 10 and Note 26 of MPC-89 drawing 6512 Rev 12. It is stated in the note that the shim must also be hard anodized to achieve the emissivity values defined in Table 1.2.8 of HI-STORM FW FSAR, which is same as the emissivity requirement of anodized Metamic-HT basket. This emissivity requirement is explicitly stated in Note 1 of Table 3.2.6 of SAR. Therefore, Note 1 that relates to the emissivity of Metamic-HT also applies for aluminum basket shim. Additional clarification is added to Note 1 of Table 3.2.1.

NRC RAI 2-16

2-16 Justify the use of elastomeric seals past their recommended design-life, and provide acceptance criteria and test methods used to ensure their acceptability for use.

The application (Section 8.2.3.6, "Closure Seals") defines general procedures for use and inspection of the elastomeric seals, and states that closure seals are specified for long-term use and do not require in-service maintenance if not disturbed elastomeric seals may be reused. This Section further states that reused elastomeric seals are subject to replacement based on seal design life as recommended by the seal manufacturer, but they may still be used beyond their recommended design life with proper inspection and engineering justification.

The application does not provide details on what is a "proper inspection" or the test methods/acceptance criteria used to ensure that the seals will perform consistent with the safety analyses in Section 2.6.1.3.4 of the application.

This information is required to determine compliance with 10 CFR 71.55(e), 71.71, and 71.73.

Holtec Response to RAI 2-16:

We agree with the staff's position on the need for justification. We propose to delete the statement "Use of elastomeric seals beyond recommended design life may be acceptable with proper inspection and engineering justification." The proposed change has been incorporated in SAR Revision 0.C (provided with this RAI response).

CHAPTER 2 RAI REFERENCES:

Billone, M.C., T.A. Burtseva, Z. Han, and Y.Y. Liu, "Embrittlement and DBTT of High-Burnup PWR Fuel Cladding Alloys," FCR-UFD-2013-000401, ANL-13/16, Argonne National Laboratory, Lemont, Illinois, 2013.

Billone, M.C., T.A. Burtseva, and Y.Y. Liu. "Characterization and Effects of Hydrides in High-Burnup PWR cladding Alloys." Proceedings of the International High-Level Radioactive Waste Management Conference, Charleston, South Carolina. Paper No. 12617. American Nuclear Society. April 12–16, 2015.

Bossis, P., B. Verhaeghe, S. Doriot, D. Gilbon, V. Chabretou, A. Dalmais, J.P. Mardon, M. Blat and A. Miquet. "In PWR Comprehensive Study of High Burn-up Corrosion and Growth Behaviour of M5 and Recrystallised Low-Tin Zircaloy-4." 15th ASTM International Symposium: Zirconium in the Nuclear Industry–Sun River, Oregon. ASTM International. June 20, 2007.

King, S., R. Kesterson, K. Yueh, R. Comstock, W. Herwig, and S. Ferguson. "Impact of Hydrogen on the Dimensional Stability of ZIRLO Fuel Assemblies." ASTM STP 1423. West Conshohocken, Pennsylvania: ASTM International. 2002.
Mardon, J.P., G.L. Garner, and P.B. Hoffmann. "M5® a Breakthrough in Zr Alloy." Proceedings of 2010 LWR Fuel Performance/TopFuel/WRFPM, September 26–29, 2010. Orlando, Florida: American Nuclear Society. 2010.

PNNL-17700, "PNNL Stress/Strain Correlation for Zircaloy", July 2008.

Thomaz J. et al., "The Corrosion of the Alloy M5™: An Overview." IAEA Technical Committee Meeting on Behavior of High Corrosion Zr-Based Alloys. Buenos Aires, Argentina: October 24–28, 2005.

Chapter 3 – Thermal Evaluation

NRC RAI 3-1

3-1 Clarify if thin solid shim plates are necessary to keep the maximum temperatures below allowable limits.

Page 3.1-2 of the application states that thin solid shim plates may be inserted between the basket and extruded basket shims to ensure a good heat transfer path between the basket and extruded shims. It appears that the thin solid shim plates are optional. The staff needs to know if these plates are part of the thermal design and if they are necessary to keep the maximum temperatures below allowable limits.

This information is required to determine compliance with 10 CFR 71.71 and 71.73.

Holtec Response to RAI 3-1:

The use of solid shim is optional as specified in Note 22 of MPC-37 drawing 6505 Rev 10 and Note 22 of MPC-89 drawing 6512 Rev 12. The evaluation of solid shim plate is described in item (vi) of Section 3.3.1.4 of the SAR and Appendix E of thermal calculation package HI-2146286.
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NRC RAI 3-2

3-2 Demonstrate that the uncertainty in the maximum NCT pressure for the MPC-37 and MPC-89 is sufficiently evaluated such that the very small reported margin of safety is a reliable means of evaluating reasonable assurance of safety. .

Table 3.1.2 of the application provides the calculated HI-STAR 190 cask maximum operating pressures during NCT. However, the calculated pressures are very close to the allowable limit thereby having a very small margin of safety. The staff needs to have assurance the containment system will be maintained to transport safely the contents of the package.

This information is required to determine compliance with 10 CFR 71.71.

Holtec Response to RAI 3-2:

All the thermal evaluations of HI-STAR 190 Package have inherent conservatisms that render bounding results. A list of conservatisms in the thermal evaluations is provided in Section 3.3.1.4 of the SAR. To account for uncertainties, thermal evaluations conservatively assume the following:

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Based on the above discussions, the reported MPC cavity pressures are conservatively over predicted. Even after including the uncertainty due to mesh, the maximum MPC pressure under a 3% rod rupture is still below the normal pressure limit. Therefore, the reported margin of safety even after considering uncertainties provides reliable means of evaluating reasonable assurance of safety.

NRC RAI 3-3

3-3 Provide material thermal properties which will assure that the full expected range of temperatures will be adequately covered.

Tables 3.2.2, 3.2.4, and 3.2.7 of the application provide thermal conductivity and specific heat of HI-STAR 190 cask materials. However, some materials have properties limited to a maximum value which does not seem to cover the entire range. Provide additional values to cover the expected range or provide adequate justification that these values are realistic or conservative in terms of predicted maximum temperatures.

This information is required to determine compliance with 10 CFR 71.71 and 71.73.

Holtec Response to RAI 3-3:

We regret that some thermal properties do not fully cover the expected range of analyzed temperature. Table 3.2.2 has been revised to provide thermal conductivity of HI-STAR 190 cask materials for their full expected range of temperatures during normal and accident conditions. Additionally, all the thermal models were investigated to ensure safety conclusions are unchanged. The following conclusions can be drawn from this investigation:

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NRC RAI 3-4

3-4 Clarify that the fuel cladding thermal conductivity values provided in the application bounds all fuel cladding materials that are included in the allowed contents.

Table 3.2.3 of the application provides the thermal conductivity of fuel assembly materials (including fuel cladding). However, the application does not provide a justification for these values. The staff needs to have assurance the used values will bound all allowable contents.

This information is required to determine compliance with 10 CFR 71.71 and 71.73.

Holtec Response to RAI 3-4:

SAR defined Table 3.2.3 cladding thermal conductivity is evaluated below as reasonable characterization of allowable cladding materials Zr-2, Zr-4, ZIRLO and M5. The allowable materials are explicitly stated in the revised SAR.

Conductivities of allowable claddings materials are obtained from the following source:

"Material Property Correlations: Comparisons between FRAPCON-3.4, FRAPCON 1.4 and MATPRO", NUREG/CR-7024 (PNNL-19417), August 2010.

The above cited source defines a CTHCON correlation suitable for Zr-2, Zr-4, ZIRLO and M5 claddings. The correlation and uncertainty is as follows:

$$K = 7.51 + 2.09*10^{-2}\ T - 1.45*10^{-5}\ T^{2} + 7.67*10^{-9}\ T^{3}$$

$$\sigma_k = 1.01$$

Where:

K = thermal conductivity (W/m-K)
T = Temperature (K)
σ_k = uncertainty (W/m-^{o}K)
Validity: $T < 2098$ K

The cladding conductivities with the uncertainty bars are graphed in Figure 3-4-A. The plot supports following observations:

- SAR conductivities track below the CTHCON correlation
- SAR values not bounded by uncertainty band

To evaluate impact of uncertainties a sensitivity analysis is provided below.

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Figure 3-4-A: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

NRC RAI 3-5

3-5 Provide time-to-boil calculations and results for loading operations under the “load and go” scenario.

Section 3.3.4 of the application provides the thermal evaluation for loading operations under the “load-and-go” scenario. However, the application does not provide the timeto-boils calculations to avoid water boiling in the MPCs in preparation for vacuum drying operations.

This information is required to determine compliance with 10 CFR 71.71.

Holtec Response to RAI 3-5:

The time-to-boil calculations under the “load and go” scenario have been added to Section 3.3.4 of the proposed SAR Revision 0.C and thermal calculation package HI-2146286 Revision 2.

NRC RAI 3-6

3-6 Explain why NCT fuel reconfiguration is not considered given the uncertainties with adequate material properties which would provide assurance spent fuel will remain intact.

The application does not provide evaluation assuming fuel reconfiguration as defense-in-depth due to uncertainty of material properties, as compared to the HI-STAR 180D transport package. The staff needs to have assurance fuel cladding will remain intact during the entire transport period or an adequate evaluation for fuel reconfiguration is provided and justified.

This information is required to determine compliance with 10 CFR 71.71.

Holtec Response to RAI 3-6:

In accordance with NRC's regulatory issue summary (RIS) document on "Considerations in Licensing High Burnup Spent Fuel in Dry Storage and Transportation", a defense-in-depth thermal evaluation has been performed and added to the proposed Revision 0.C of the SAR to address fuel reconfiguration during transport. In accordance with this RIS document, a 3% fuel failure is assumed under normal transport conditions. [

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]PCT and all the component temperatures including containment boundary seals are well below their normal temperature limits. Additionally, MPC cavity pressure is evaluated considering a 3% rod rupture as normal condition and was reported in Table 3.1.2 of the SAR. The reported MPC cavity pressure with 3% rod rupture is below its design limit under normal transport condition.

The structural analyses documented in Section 2.11 of SAR clearly demonstrate that the induced strain in the fuel cladding under the governing 9-meter drop accident is lower than the conservatively established failure strain limit. Therefore, the HI-STAR 190 design-basis fuel cladding is not vulnerable to failure (rupture or breach) as a result of 9-meter end drop accident. This structural analysis provides sufficient assurance that fuel cladding will remain intact during the entire transport period. However, a thermal analysis assuming a punitive hypothetical fuel reconfiguration was performed as a defense-in-depth and presented in Section 3.4.5 of SAR. Conservatively, a 100% fuel failure is assumed. The methodology adopted for the thermal evaluations is made consistent with that provided in the HI-STAR 180D SAR [

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] The results are presented in Table 3.4.4 of SAR Revision 0.C and show that all component temperatures are below their respective accident temperature limits. It should also be noted that the containment seal temperatures is well below its sustained temperature limit. Therefore, the containment boundary remains intact during the non-mechanistic fuel reconfiguration.

NRC RAI 3-7

3-7 Provide adequate operating procedures and/or inspections that could be utilized to ensure spent fuel will remain intact during NCT.

The application states that spent fuel will not degrade or reconfigure during the entire transport period but it does not include any procedures for inspecting the fuel after the transport period to assure fuel remain intact (for example, surface temperature and/or dose measurements, etc.). The staff needs to have assurance fuel cladding will remain intact during the entire transport period.

This information is required to determine compliance with 10 CFR 71.71.

Holtec Response to RAI 3-7:

We agree with the staff's position on the need for clarification. In order to provide additional assurance that fuel cladding will remain intact during the entire transport duration, the following SAR changes are proposed:

Enhancements to Chapter 7

- Subsection 7.1.5 regarding Preparation for Transport.
    - The following statement is proposed to be added to the end of Step 8: "For packages containing HBF, the final radiation survey shall include the dose rate measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Paragraph 8.1.9.2 of this SAR. The final location of measurements and the measurements shall be recorded in the shipping documents."
    - The following statement is proposed to be added to the end of Step 9: "For packages containing HBF, the surface temperature measurements shall include the surface temperature measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Paragraph 8.1.9.2 of this SAR. The final location of measurements, ambient conditions (air temperature, date, time of day, and description of daylight (sunny, cloudy, overcast, in-shade or night time)) and the measurements shall be recorded in the shipping documents. Package surfaces shall be dry at the time of temperature measurements."
- Subsection 7.2.1 regarding Receipt of Package from Carrier.
    - The following statement is proposed to be added to the end of Step 3: "For packages containing HBF, the radiation survey shall include the dose rate measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Paragraph 8.1.9.2 of this SAR. The location of measurements shall correspond to the same locations recorded for Subsection 7.1.5. The measurements shall be recorded in the shipping documents."
    - New Step 4 is proposed to be added as follows: "For packages containing HBF, surface temperature measurements shall include the surface temperature measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Paragraph 8.1.9.2 of this SAR. The final location of

measurements, ambient conditions (air temperature, date, time of day and description of daylight (sunny, cloudy, overcast, in-shade or night time)) and the measurements shall be recorded in the shipping documents. Package surfaces shall be dry at the time of temperature measurements.”

Enhancements to Chapter 8

- Paragraph 8.1.9.2 on Post-Shipment Fuel Integrity Acceptance Test. New paragraph 8.1.9.2 is proposed to be added as follows:

  “For packages containing HBF, cask surface temperatures and cask surface dose rates shall be measured in accordance with the procedures in Chapter 7 as a practical means of monitoring the condition of the fuel assemblies. Fuel reconfiguration and significant fuel cladding damage is not expected after the transportation period of each shipment.

  A total of six measurements of both temperature and dose rate shall be recorded before and after each shipment with the loaded cask configured horizontally with impact limiters and no personnel barrier. Three measurements are taken from each side of the package below the cask axial centerline (below the top cask trunnion, at the middle of the cask (at or below the cask centerline) and below the bottom cask trunnion). The user may select measurement locations within the areas defined by the zones shown in Figure 8.1.1. The post-shipment measurement locations shall correspond to the pre-shipment measurement locations for proper comparison.

  The post-shipment surface temperature measurements should not exceed the pre-shipment surface temperature measurements by more than 5 degrees C when adjusted under the same ambient conditions. The temperature criteria may be adjusted to account for the difference in ambient conditions such as solar insolation.

  The post-shipment surface dose rate measurements should not exceed the pre-shipment surface dose rate measurements by more than 10%.

  Failed tests shall be reported to USNRC within one month of the post-shipment measurement and shall include a description of the package contents, any available engineering justification for failed test(s), and if applicable any special precautions that will be implemented prior to unloading the contents of the package. Package exhibiting tests results equal to or greater than twice the acceptance criteria shall not be unloaded without USNRC authorization.”

- Figure 8.1.1 titled “Measurements Zones for the Post Shipment Fuel Integrity Acceptance Test” has been added for clarity.

It should be noted that this acceptance test is not included in Appendix 8.A since it is not an MPC transportability acceptance test prior to shipment and not an acceptance test directly on the MPC equipment. The requirement for protection from extremely low fuel cladding temperature has been removed from Table 8.A.1.

NRC RAI 3-8

3-8 Provide adequate results which include modeling and application uncertainty of the predicted maximum cladding temperatures during vacuum drying for the "load-and-go" scenarios.

Tables 3.3.11 and 3.3.12 provide maximum temperatures for both MPC-37 and MPC-89 during vacuum drying conditions. The applicant predicted values have small margin. Therefore, the applicant need to either include calculations which will include modeling and application uncertainty (validation) or reduce the total allowable decay heat so adequate margin is assured during vacuum drying conditions.

This information is required to determine compliance with 10 CFR 71.71.

Holtec Response to RAI 3-8:

We regret the confusion caused by the results reported in Tables 3.3.11 and 3.3.12 of SAR Revision 0.B. The steady state thermal evaluation of MPC-37 under the most limiting heat load pattern is 730^{o}F as reported in Table 3.3.11 of the SAR Rev 0.B. The results demonstrate that the predicted PCT is below the ISG-11 Rev 3 temperature limit of 752^{o}F with robust margins. In Table 3.3.12 of the SAR Rev 0.B, two different scenarios were analyzed for MPC-89:

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The steady state temperatures for the above two scenarios were presented in Table 3.3.12 of the SAR Rev 0.B. [

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NRC RAI 3-9

3-9 Explain in greater detail why the HI-STAR 190 thermal performance during HAC is not affected by the drop or puncture events.

Page 3.4-1 of the application states:

"…during drop events, material in the impact limiter is locally crushed. However, the impact limiters survive the drop events without structural collapse and remain attached to the cask during and after the event. During a puncture event the cask's exterior shell may be locally pierced but with no gross damage to the cask or its internals. Because of these reasons the global thermal performance of the HI-STAR 190 cask is unaffected by the drop events."

It is not clear to the staff why crushing of the impact limiters and puncturing the cask will not have any effect on the cask thermal performance.

This information is required to determine compliance with 10 CFR 71.73.

Holtec Response to RAI 3-9:

HI-STAR 190 drop analyses are documented in the structural report HI-2146321 Revision 0.

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With above being said, crushing of the impact limiters and puncturing of the cask will not have any significant impact on the thermal performance of the cask.

NRC RAI 3-10

3-10 Perform an explicit analysis of the HI-STAR 190 cask with MPC-89 during HAC fire event to provide adequate maximum temperatures during this event.

Page 3.4-3 of the application states:

"…the hypothetical fire accident for an MPC-89 placed in HI-STAR 190 overpack is also evaluated since some containment boundary cask component temperatures are bounding for MPC-89 compared to MPC-37 under normal conditions of Transport. The fuel, MPC-89 and cask component temperatures reported in Section 3.1 of the application are calculated by adding the component temperature difference between MPC-37 and MPC-89 under normal conditions to the predicted fire accident temperatures for MPC-37."

This approach does not appear to be consistent because results of two different canisters are mixed and an explicit modeling of the fire conditions is not performed. The staff needs to have assurance that adequate modeling is provided in the application so the results can be properly evaluated against the allowable limit.

This information is required to determine compliance with 10 CFR 71.73.

Holtec Response to RAI 3-10:

We regret the confusion caused due to the text in the SAR. To provide a clear understanding on fire accident evaluations, the following discussion will be added to the proposed SAR Rev 0.C:

HI-STAR 190 loaded with MPC-37 results in bounding fuel cladding temperature and MPC cavity pressure as shown in Tables 3.1.1 and 3.1.2 of the SAR. CFD thermal analysis of the fire accident is therefore performed only for the thermally limiting scenario i.e. MPC-37 loaded with 15x15I short fuel, determined in Section 3.3.1.5 of SAR Rev 0.B. Results from the CFD evaluations under fire accident condition are reported in Table 3.1.3.

Although the PCT and MPC cavity pressure are bounding for MPC-37, some containment boundary component temperatures are higher for MPC-89 during normal conditions (see Table 3.1.1 of SAR). Therefore, to demonstrate all the components of the cask including the containment boundary remains below the prescribed temperature limits during fire accident, an evaluation of these cask components is needed for MPC-89 under the fire accident. For this, an explicit transient thermal CFD calculation is deemed not necessary based on the following justification:

It is reasonable to assume that the temperature increase of cask components due to fire is similar for both MPC-37 and MPC-89, because

(1) Heat from fire is much higher than the decay heat stored inside MPC.

(2) Fire temperature is much higher than the cask external surface temperature under normal condition. Therefore, similar heat from fire is absorbed by the cask with either MPCs, although the surface temperatures are slightly different for the two MPCs under normal condition.
(3) MPC-37 and MPC-89 have the same HI-STAR 190 cask overpack.

Therefore based on the above, an engineering evaluation has been performed as described below:

The cask component temperatures for MPC-89 under fire condition are calculated by adding the cask component temperatures difference between MPC-37 and MPC-89 under normal condition (Table 3.1.1) to the cask component temperatures for MPC-37 under fire (Table 3.1.3). The results of cask component temperature are then reported in Table 3.1.4 for MPC-89. A clarification has been added in Section 3.4 of the proposed SAR Rev 0.C.

NRC RAI 3-11

3-11 Clarify why during the HAC fire accident insolation is applied to exposed external surfaces.

Table 3.4.1 of the application states that during the 30-minute fire insolation is applied. It is not clear to the staff why insolation is applied and the staff is also not clear if the HAC results include insolation during the 30-minute fire so an evaluation of the results can be assessed.

This information is required to determine compliance with 10 CFR 71.73.

Holtec Response to RAI 3-11:

NRC staff's understanding is correct that solar insolation is applied to all the HI-STAR 190 Package exposed external surfaces during the 30-minute fire. Solar insolation is included during the 30-minute fire only as conservatism. Due to the severity of the radiative heat flux into the HI-STAR 190 Package from an all engulfing fire, heat flux from incident solar radiation is negligible. Applied solar insolation therefore has no significant impact on the results.

NRC RAI 3-12

3-12 Obtain the analysis discretization error by calculating the grid convergence index (GCI) following the procedure described in American Society of Mechanical Engineers Verification and Validation 20-2009 (ASME V&V 20-2009), "Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer".

Appendix D of Holtec Report HI-2146286 provides the HI-STAR 190 cask GCI calculations. However, after reviewing these calculations the staff identified the following issues with the procedures and obtained values:

1) The applicant calculated the discretization error using Mesh 4 which is finer than the mesh used in the application (i.e. Mesh 3). The applicant should update the results provided in the application using the results obtained from Mesh 4. The

finest mesh (Mesh 4) should be used to perform all calculations presented in the application.

2) If Mesh 4 is used for the application, only the following grid combinations can be used to perform the GCI calculations.

- Mesh 4, Mesh 3, and Mesh 2
- Mesh 4, Mesh 3, and Mesh 1
- Mesh 4, Mesh 2, and Mesh 1

Grid combination based on Mesh 3, Mesh 2, and Mesh 1 is not applicable for performing GCI calculations since the finest mesh (Mesh 4) will be used in the application. ASME V&V 20-2009 GCI calculation procedures show the GCI is the extrapolated error for the finest mesh (which is Mesh 4 for the HI-STAR 190 Cask).

3) Using the procedures described in ASME V&V 20-2009 the applicant should demonstrate that the calculated peak cladding temperatures are in the asymptotic region for the simulation series.

4) A Factor of Safety (Fs) = 1.25 has not been thoroughly evaluated for unstructured refinement. Scatter in the observed order of accuracy (p), as shown by the applicant in Holtec Report HI-2146286, is to be expected because the grid refinement factor (r) is well defined only for geometrically similar grids. It is generally recommended (see V&V 20-2009) that the more conservative value of Fs = 3 be used to obtain the GCI for unstructured grid refinement. Also, as the grid refinement is not totally systematic an Fs = 3 should be used to obtain the GCI.

5) As the calculated order of accuracy is higher than what is used in the solver, an order of accuracy (p) = 1 should be used to obtain the GCI.

This information is required to determine compliance with 10 CFR 71.73.

Holtec Response to RAI 3-12:

The grid sensitivity study presented in Section 3.3 of the SAR has been revised to address the concerns raised by the reviewer in this RAI. Moreover, the study is also made consistent with that previously approved by NRC in Docket 71-9367 (HI-STAR 180D SAR).

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The revised GCI calculations have been added to the thermal calculation package HI-2146286 Rev 2. The proposed revision 0.C of the SAR has also been updated with the revised GCI calculations.

Chapter 4 Containment Evaluation

NRC RAI 4-1

4-1 Explain in more detail why the analysis in Chapter 3 of the application shows that the containment boundary will not leak under the one-foot free drop event.

Table 4.8.1 Item 3 of the application states that the analysis of Chapter 3 of the application shows that the containment boundary will not leak under the one-foot free drop event. However, details on how this analysis shows containment boundary will not leak under these conditions are not provided. The staff needs to have assurance that, under those conditions, containment of the radioactive material is maintained.

This information is required to determine compliance with 10 CFR 71.71.

Holtec Response to RAI 4-1:

There is an editorial error in the Item 3 text in the "Loading" column of Table 4.8.1. The reference is corrected from "Chapter 3" to "Section 2.6".

The detailed structural analysis and results of the one-foot free drop event are presented in Section 2.6. These structural analyses show that the calculated stresses under the one-foot free drop event are below the allowable stress limits, and therefore the containment boundary is maintained.

NRC RAI 4-2

4-2 Explain in more detail why the bolted joint in the containment boundary maintains its leak-tightness under reduced environmental pressure (3.5 psia) or elevated environmental pressure (20 psia).

Table 4.8.1 Item 4 of the application states that containment boundary maintains its leak-tightness under reduced environmental pressure (3.5 psia) or elevated environmental pressure (20 psia). However, no details are provided on the reasons why leak-tightness is achieved. The staff needs to have a clear explanation and basis for this statement to evaluate the performance of the containment system.

This information is required to determine compliance with 10 CFR 71.71.

Holtec Response to RAI 4-2:

Item 4 text in the "Loading" column of Table 4.8.1 is deleted and replaced with the following, "Does the analysis in Section 2.6 show that the bolted joint in the Containment Boundary maintains its leak-tightness under reduced external pressure (3.5 psia) or increased external pressure (20 psia)?" for consistency with the other rows in the table.

Subsections 2.6.3 and 2.6.4 explain in more detail why the bolted joint in the containment boundary maintains its leak-tightness under the above-mentioned pressures.

NRC RAI 4-3

4-3 Define more clearly the inner containment system boundary for the HI-STAR 190 transport package.

Page 4.9-1 of the application states that the inner containment system boundary for the HI-STAR 190 packaging consists of the shell; baseplate; top lid; and welded joints, seams, and penetrations. However, no definition is provided for the listed items. The staff needs to have a clear definition of the inner containment boundary and its components so an adequate evaluation of the inner containment boundary is performed.

This information is required to determine compliance with 10 CFR 71.31 and 71.33.

Holtec Response to RAI 4-3:

The inner containment system boundary components are shown in the Drawing Package, Section 1.3, Drawings 6505 (MPC 37 Enclosure Vessel) and 6512 (MPC 89 Enclosure Vessel).

- Item #1 is the MPC shell.
- Item #2 is the MPC baseplate.
- Items #4 and #5 are the MPC top lid
- Weld, seam, and penetration details are provided throughout the drawings and additional weld information is provided in a numerical list on the third page of Drawing 6505 and Drawing 6512.

A reference is added on page 4.9-1, “Section 7.1 of Reference [4.5.2] provides further information on MPC welds.”

Chapter 5 Shielding Evaluation

NRC RAI 5-1

5-1 Justify that the tolerances of components credited in the shielding analyses are adequately accounted for in determining compliance with external dose rate regulations.

This RAI is a follow up to RSI 1-4. In RSI 1-4, the staff requested that the applicant include tolerances on components used for shielding. In response to this RSI, the applicant stated that it has added minimum dimensions of the lead thickness and provided the "minimum hydrogen areal density" of the Holtite neutron shield in Table 8.1.9 of the application and that the HI-STAR 190 needs to comply with this density to maintain shielding performance. However, the RSI was more concerned with the tolerances of the components important to shielding and the variations of material properties of these components. The responses to the RSI are not closely related to the questions. The staff requests that the applicant provide the following additional information to address this RSI:

a) The applicant did not provide any discussion on tolerances for any other component used for shielding other than the lead gamma shield and the Holtite neutron shield. Although the Holtite neutron shield and the lead gamma shield are the primary shielding components, other components credited in the shielding analyses also provide radiation attenuation and not accounting for tolerances of these package components is non-conservative. The staff requests that the applicant provide tolerances of all materials credited in the shielding analyses and include an estimate of the potential increase in dose rates to the Section 5.4.6 discussion of best estimate dose rates.

b) Although the staff found the thickness of the lead gamma shield in drawing 9841 Sheet 5 of 5, the staff does not see how this value is differentiated as a minimum and not a nominal value. The staff requests that the applicant clarify how these drawings specify the difference between minimum and nominal values.

c) The staff does not understand how specifying "minimum hydrogen areal density" is equivalent to specifying dimension tolerances of this material. The specification in Table 8.1.9 of the SAR includes this minimum hydrogen areal density. The footnotes of the table says: *The minimum hydrogen areal density may be verified by the product of bulk density, weight fraction of hydrogen and thickness of the main neutron shield.* The staff requires additional clarifying information to fully understand how this is done. Alternatively the staff requests that the applicant discuss the tolerances of this component.

(1) The staff requests that the applicant discuss how the use of minimum hydrogen areal density (in lieu of dimensional tolerances) is an appropriate means of characterizing the neutron shield for its effectiveness in radiation attenuation as the hydrogen also acts as a moderator for boron absorption.

(2) Using the information from Chapter 5 of the application, the product of the bulk density (0.95 g/cm^3 from Table 8.1.9 of the application), weight fraction of hydrogen (0.1081 from Table 5.3.2 of the application) and

thickness of the main neutron shield (9.84cm = 3 7/8" from page 5 of 5 from Drawing 9841) only gives a hydrogen areal density of 1.01, whereas the minimum from Table 8.1.9 of the application is 1.69. It appears that one of the parameters in this product would need to change significantly to achieve this value. The applicant needs to discuss the range of parameters that would likely be increased and how that effects the package safety.

(3) It appears that the units used for "bulk density" and "areal density" in Table 8.1.9 of the SAR are in error. Clarify these units and/or correct them as necessary.

This information is required to determine compliance with 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 5-1:

5-1(a) We recognize that the dimensional tolerances of the materials for the HI-STAR 190 can have an effect on the dose rates around the cask, and its compliance with the regulatory requirements.

In support of our proposed approach to address these tolerances, we believe it is important to recognize how tolerances are handled during the manufacturing process, and what the safety significances of the various tolerances are.

<u>Tolerances during the manufacturing process</u>

In the manufacturing drawings for the components of the HI-STAR 190, which are derived from the licensing drawings in the HI-STAR 190 SAR, all dimensions are provided with tolerances. Tolerances are generally selected based on the specific material, its manufacturing or processing process and its safety significance. During the manufacturing process, <u>all</u> tolerances are checked by the workers performing the corresponding manufacturing step. If a deviation is found, then this is addressed, either through acceptance of the deviation, or rework or replacement of the part. There is a formal process in place for this. This approach gives overall *reasonable* assurance that all dimensions of all components are within tolerance, or that any deviations are addressed.

For dimensions where a tolerance is specified on the licensing drawing, an <u>additional</u> check is performed. For those dimensions, an independent verification is performed by a member of the quality control (QC) organization at our manufacturing facility. This is to give *full* assurance that the dimension is within the specific tolerance. Also, since the tolerances on the licensing drawings are part of the certified design, a deviation is not permissible. So, if any deviation exists, only the rework or replacement options are available. For that reason the tolerance on the manufacturing drawing is often selected to be more restrictive, in order to reduce the probability that a dimension does not meet the tolerance in the licensing drawing. Given this additional, and not insignificant, effort in checking dimensions, we reserve this approach, i.e. tolerance dimensions on licensing drawings, strictly to those that have an effect on the safety of the structure. Further, since any tolerance on the licensing drawing will require some increased margin to ensure that the requirement is met, components may turn out to be thicker and heavier. Since weights are important, and margins to lifting limits also matter, we again tend to restrict the use of tolerances unless really necessary.

Safety significance with respect to Dose Rates around the loaded cask

A review of the results of the dose rate analyses in Chapter 5, Tables in Section 5.1, shows that the location with the smallest margin to the limit is dose location 2 (side dose) at two meters, with a margin between about 2% (MPC-37) and 5% (MPC-89), followed by the same location 2 on the cask surface with margins of about 10% to 30%. Other locations have margins of 50% or more, specifically when considering that for the axial locations 4 and 5 the calculations were performed conservatively neglecting any material in the impact limiters. The dose rates reported in those tables are maximum values, over all permissible loading configurations, and over the entire applicable area for each dose location. For dose location 2, a review of the detailed dose rate calculation shows that the maximum occurs near the axial center of the cask or fuel. This is expected and was the explicit intent of the design of the cask, where the maximum radial shielding covers as much of the axial length of the cask as practically possible. Hence from a safety significance perspective with respect to dose rates, the radial wall of the cask and its layered design receives the primary focus. The construction at the top and bottom, both axially and radially, is of less importance.

It is further important to recognize that dose rates are to a large extent integral values. The change in thickness of a component in a localized area would have a negligible impact on dose rates, as long as the average thickness over a relevant portion of the wall is maintained. This is an important consideration. It would be unreasonable to reject a component due to a deviation that is too small to have any effect on the limiting dose rates around the cask.

Typical Manufacturing Tolerances

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Dimensions and Tolerances on the HI-STAR 190 Licensing Drawings

Based on the discussions above the following approach is selected and proposed for dimensions and tolerances of the HI-STAR 190:

Based on the need to minimize toleranced dimensions on the licensing drawing, on the fact that the area most affected by dimensional tolerances is the side of the cask, and on the fact that the majority of components at the top and bottom are machined and hence have small tolerances, it is proposed to limit tolerances on the licensing drawings to the material layers in the side wall of the cask.

For the various materials, the following approaches are used:

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From an analysis perspective, it would have been acceptable retain the nominal dimensions in the design basis calculations, and address all relevant tolerances in the uncertainty analyses in Section 5.4.6. However, in this case, we selected a slightly different path for the HI-STAR 190, by introducing more conservative dimensions in the design basis calculations, consequently reducing the “burden” on the uncertainty analysis. The assumptions used for this cask are listed below

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As a result of this, all design basis shielding calculations were re-performed. In order to assure that the regulatory limits continue to be met, some changes to the loading requirements listed in Chapter 7 were also mode, adjusting minimum enrichments and/or minimum cooling times for some burnups. Overall, the maximum calculated dose rates are slightly lower than in the initial application.

Note that some shielding studies where certain conditions are compared with a reference case still use the previous design basis calculations as a basis.

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5-1(b) Please see response to RAI 5-1(a) above

5-1(c) Although the practice of specifying “minimum hydrogen areal density” was previously approved by the NRC for the HI-STAR 180 SAR (docket No. 71-9325) and the HI-STAR 180D SAR (docket No. 71-9367), we propose to directly specify the “minimum bulk density” and “minimum hydrogen density” of Holtite-B in Chapter 8 Table 8.1.9. Moreover we provide the following information,

(1) The specification of “minimum hydrogen areal density” is proposed to be replaced with “minimum hydrogen density”.
(2) As stated in response to RAI 5-1(a), the minimum density of Holtite-B in Chapter 8, and the composition and density of Holtite used in shielding calculations in Chapter 5 are updated to be more realistic, but still conservative. It should be noted that the composition and density used in shielding calculations are bounded by the actual composition and density.
(3) The typographical error in the units is proposed to be corrected.

Proposed changes are provided in SAR Revision 0.C included with this response.

In addition to the above proposed changes, Holtec Report HI-2167314, "Holtite-B Sourcebook", Revision 0 is provided with this response to support the values chosen for SAR Table 8.1.9. Holtec Report HI-2167314 replaces Holtec Report 2073684 in reference 1.2.10 of the SAR.

NRC RAI 5-2

5-2 Discuss how all possible loading configurations (burnup/enrichment/cooling time) were analyzed to meet external dose rate limits.

The applicant states in Section 5.1.2 of the application: *"The burnup and cooling time combinations specified in Appendix 7.C were determined strictly based on the shielding analysis in this chapter. Each combination was independently analyzed and it was verified that the calculated dose rates were less than the regulatory limits."* The staff requests that the applicant provide additional information discussing how each combination was independently analyzed.

Given the vast number of burnup/enrichment/cooling time combinations from Tables 7.C.8(a), 7.C.8(b), and 7.C.10 that are suitable for loading per Tables 7.C.7 and 7.C.9, the staff requests that the applicant provide information describing how each loading pattern and all allowable fuel burnup/enrichment/cooling time combinations were determined to meet regulatory dose rate limits for NCT and HAC. The applicant needs to justify that this was done in a bounding way.

This information is required to determine compliance with 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 5-2:

As discussed in Section 5.4.1 of HI-STAR 190 SAR, the dose rates at the various locations were calculated with MCNP using a two-step process. The first step was to calculate the dose rate for each dose location per starting particle for each neutron and gamma group in each basket region for each axial and azimuthal dose location. The second step is to multiply the dose rate per starting particle for each energy group and basket location (i.e., tally output/quantity) by the source strength (i.e. particles/sec) in that group and sum the resulting dose rates for all groups and basket locations in each dose location.

The RAI mentioned discussion in Section 5.1.2 particularly applies to the second step of shielding calculations, where the MCNP results are combined with the source strength. In this step, the shielding calculations are performed for all combinations of source strengths i.e. all possible combinations of fuel loadings. To provide more detailed information, an example is provided for calculation dose rates for PWR fuel.

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NRC RAI 5-3

5-3 Provide additional information justifying the relationship between decay heat and cooling time.

Tables 7.C.7 and 7.C.9 of the application show the burnup, enrichment and cooling time requirements for assemblies meeting the decay heat limits. Holtec calculation file HI-2146423 indicates that there was a “decay heat curve” used to correlate the decay heat to the cooling time. The staff requests that the applicant provide more information on the decay heat curve used and justify that it is appropriately or conservatively used for all fuel specified in Appendix 7.C including high burnup fuel and both PWR and BWR fuel.

This information is required to determine compliance with 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 5-3:

Tables 7.C.7 and 7.C.9 provide heat load limits for fuel assemblies to be loaded into HI-STAR 190. While these limits are loosely based on decay heat calculations, it is the user’s responsibility to satisfy these heat load limits at the time of loading and during the shipment.

Fuel assembly burnup, enrichment and cooling time parameters shown in Tables 7.C.8 and 7.C.10 represent limits with respect to shielding calculations i.e. fuel assemblies within these parameters will satisfy the dose rate limits outlined in Chapter 5. The parameters are not intended not imply that the heat load limits are satisfied. The decay heat load limits must be satisfied independently of fuel burnup, enrichment and cooling times listed in Tables 7.C.8 and 7.C.10. It is the users’ responsibility show compliance with all criteria in Tables 7.C.8 and 7.C.10 which include burnup, enrichment, cooling time and the decay heat. To clarify this point the following footnote is added to Tables 7.C.8 and 7.C.10:

“The decay heat load limits must be satisfied independently of fuel burnup, enrichment and cooling times listed in this table. The listed burnup, enrichment and cooling times are not intended not show compliance with decay heat limits.”

In addition, similar discussion is added in HI-2146423, Appendix D.

NRC RAI 5-4

5-4 Justify the uncertainty of the SAS2H code for evaluating source terms for PWR and BWR fuel up to 68.2 and 65 GWD/MTU, respectively.

In discussing the uncertainty from the SAS2H/ORIGEN-S the applicant references the HI-STAR 180 application. However, the staff was unable to locate appropriate information justifying the use of this code for the HI-STAR 190, particularly for the uncertainty related to source term and decay heat evaluations for high burnup fuel (burnup > 45 GWd/MTU). The staff requests that the applicant provide additional information justifying the use of this code for all of the fuel specified in Appendix 7.C including high burnup PWR and BWR fuel in generating source terms.

a) The staff notes that ORNL no longer supports SAS2H development and has not validated this code up to 68.2 and 65 GWD/MTU and therefore the applicant would need to perform this validation and/or propose and justify an appropriate penalty to account for this uncertainty.

b) The staff requests that the applicant state the cross section library used in the source term calculations and discuss the validation information that covers this cross section set and group structure.

c) The staff requests that the applicant discuss and justify the uncertainty values reported in Table 5.4.18 of the application in the calculation of source term (neutron, gamma, and hardware for both BWR and PWR) for fuel burned up to 68.2 and 65 GWD/MTU for PWR and BWR fuel, respectively.

d) The staff requests that the applicant discuss and justify the uncertainty in the evaluation of decay heat, and discuss if/how this was incorporated into the decay heat limits.

This information is required to determine compliance with 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 5-4:

a) To justify the use of SCALE 5.1 for depletion calculations, a validation is performed based on a comparison of measure and calculated isotopic compositions of spent fuel. [

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c) Table 5.4.18 and its supporting analyses have been updated with respect to the source term uncertainties, for details see new Appendix 5.D.

d) The heat load limits were determined in Chapter 3 of the SAR based only on the thermal analyses that were performed. They do include considerations of uncertainties of those analyses. However, no uncertainties in any depletion analysis to establish the decay heat of an assembly is included. This would depend on the methodology used and hence would be part of showing compliance with the decay heat limits.

NRC RAI 5-5

5-5 Justify the uncertainty in source term as calculated by SAS2H/ORIGEN-S due to variations in depletion parameters.

In discussing the uncertainty of the SAS2H/ORIGEN-S source term and decay heat calculations due to the reactor input (depletion) parameters for the HI-STAR 190, the applicant references the HI-STAR 180 application. However the staff was unable to locate appropriate information justifying this uncertainty for the HI-STAR 190. The HI-STAR 180 application describes a method that is based on Appendix B of NUREG/CR-6802.

a) The staff requests that the applicant justify the applicability of this method for fuel burnup up to 68.2 and 65 GWD/MTU for PWR and BWR fuel as well as for parameters outside of the range of Table B.1 of NUREG/CR-6802 (enrichment and possibly boron loadings).

b) The staff requests that the applicant discuss and justify how it calculated the uncertainty values for “depletion input uncertainty” reported in Table 5.4.18 of the application.

c) The staff requests that the applicant state the cross sections and group structure used in the HI-STAR 190 depletion calculations and if different from those used in NUREG/CR-6802 Appendix B, justify the use of the method.

e) The staff requests that the applicant discuss and justify the uncertainty in the evaluation of decay heat related to the depletion inputs, and discuss if/how this was incorporated into the decay heat limits.

This information is required to determine compliance with 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 5-5:

a) As correctly pointed out, sensitivity studies in NUREG/CR-6802, Appendix B cover mostly lower burned fuel. Therefore, Holtec performed additional calculations following the methodology in NUREG/CR-6802 while using range of depletion input parameters extended to cover both PWR and BWR high burnup fuel. In contrast with NUREG/CR-6802 however, the current study is more rigorous since the impact of the depletion input parameters on the cask's dose rate is directly evaluated through shielding calculations rather than estimated through changes in isotope concentrations in the source terms. The details of these calculations are documented in new Appendix I of revised report HI-2146423, revision 2.

b) The results of the abovementioned revised calculation are used to update depletion code input uncertainties in Table 5.4.18. [

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c) Holtec used the same codes SAS2H/ORIGEN-S of SCALE as indicated in NUREG/CR-6802 to calculate source terms. Appendix B of NUREG/CR-6802 indicates that 44 Group ENDF/B-V library was used to calculate source terms. Holtec used the same library extended to 238 groups. According to section S.2.2.1 of SAS2H manual [reference 1 of HI-2146423], both the 238-group and the 44-group libraries are recommended for use in the depletion analysis. Both of these libraries are ENDF/B-V-based and include neutron cross sections for most of the evaluated actinide and fission product isotopes in ENDF/B required to accurately simulate irradiated fuel.

   As mentioned above, impact of depletion input parameters on the cask's dose rate is directly evaluated through shielding calculations rather than estimated through changes in isotope concentrations in the source terms. In these calculations the same cross sections and group structure is used as discussed in shielding calculations in Subsection 5.2 of Chapter 5.

d) Not used.

e) Please refer to response to RAI 5-3.

NRC RAI 5-6

5-6 Clarify the lead slump assumptions in the dose rate evaluation.

Page 5.3-2 of the SAR says: *"To model the lead slump of the lead in the base plate (Bottom Forging Gamma Shield), it is conservatively assumed that 12.7 cm (5 inches) radially from the outer part of the lead are replaced with a void. To model the lead slump of the lead in the annular space around the Containment Shell (Gamma Shield), it is* *conservatively assumed that 5.08 cm (2 inches) of the lead in the top and bottom areas are replaced with void. The lead slump assumption is conservative since in reality no lead would be removed."*

a) To clarify the above statements, the applicant needs to include details on where the slump was applied for each location where they evaluated the external dose rate (side, top and bottom) and justify these assumptions are appropriate or conservative. For example, for a drop on the cask's side, a reduction in the radial thickness of the radial shield on one side is conceivable and the reduction of lead shield would increase HAC dose rates in the radial direction. It appears that the applicant has chosen to reduce the radial thickness of the bottom plate, equally on either side. Therefore this physical phenomenon should be applied to one side as it creates a streaming path at the bottom and dose rates are evaluated near this streaming path, however the staff does not have enough information to determine how this was done nor if it is conservative.

b) In addition, the lead slump information in Section 5.3.1.1 does not correspond to that in Chapter 2 (Structural Evaluation). Table 2.7.3 of the application states that the lead slump assumed in the shielding evaluation is 10 inches in the axial direction and 2 inches in the radial direction. With the calculated value being 6.9 inches in the axial and 0.9 inches radially. The staff requests that the applicant clarify this discrepancy and discuss if these values are applicable to the radial shield or base plate.

This information is required to determine compliance with 10 CFR 71.51(a)(2).

Holtec Response to RAI 5-6:

5-6(a)

Figure 5-6-1 below shows the locations of the lead voided for the design basis accident condition. [

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The results of the sensitivity study calculations are documented in Section 5.4 of the SAR and in the shielding calc package (HI-2146294). Also, it is clarified in Chapter 5 how the lead slump is modeled.

Figure 5-6-1 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Figure 5-6-2 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

5-6(b)
The locations and dimensions of the lead slump voided in Design basis accident condition model are clarified in the above response, and matches the values provided in Table 2.7.3 for shielding evaluation. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

NRC RAI 5-7

5-7 Provide additional information on the dose rate analyses assuming reconfiguration for HBF under NCT.

The applicant discusses the dose rate analyses performed assuming reconfiguration for HBF under NCT in Section 5.4.5 of the application. The staff needs additional information to evaluate these analyses assumptions.

a) Specifically the staff requests the applicant to provide more details and justifications on if/how it assumed the axial source distribution (i.e. did the applicant assume that fuel from the top relocated to the bottom, or hotter fuel from the center relocated to the bottom).

b) Additionally the staff requests that the applicant provide details and justify where the dose rates were evaluated. Section 5.4.4 of the application states that the dose locations identified in Table 5.4.3 of the application do not correspond to single dose rate locations but the highest value as chosen from multiple axial and azimuthal segments. The applicant needs to show the location of the highest dose rate and if this was the same for all the fuel relocation evaluations. For example, there might be an increase in Dose Location 1 from Figure 5.1.1 of the application, as this appears to be the location outside the neutron shield. The staff requests that the applicant discuss if they evaluated the dose rate at this location for the NCT reconfiguration analyses.

This information is required to determine compliance with 10 CFR 71.47.

Holtec Response to RAI 5-7:

5-7(a)

The additional information of fuel geometry, material densities, and radiation sources for Scenarios 1 and 2 of fuel reconfiguration under normal conditions of transport (NCT) are provided below.

NCT, Scenario 1: 10% Axially Fuel Collapse

The MCNP model for this scenario is directly based on the MCNP model of the normal condition without any fuel collapse (Section 5.3 of HI-STAR 190 SAR) with the following modifications:

- Fuel Geometry:
  - o Active Region: length reduced by 10% (by multiplying the active-region length by 0.9), i.e. from 144” to 129.6”.
  - o Upper and lower end fittings: unchanged, i.e. the support structure of the assembly is assumed to remain in place.
  - o A sketch of the MCNP model for this scenario is provided in Appendix D of HI-2146294R2.
- Material Densities:
  - o Active Region: Fuel density (density of material in the active region) increased by 10% (by dividing the active-region density by 0.9).
  - o Upper and lower end fittings: unchanged
- Source terms:
  - o Active Region: The source term per unit length is increased by 10%, so the total source term remains unchanged.
  - o Upper and lower end fittings: unchanged
- Axial profile: The principal profile remains unchanged, but is compressed by 10% to match the active region.

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All Scenarios

All scenarios are evaluated for all permissible burnup, cooling time and enrichment combinations to determine the peak dose rates reported. It is demonstrated that there is a sufficient margin for fuel reconfiguration scenarios for all loadings per Appendix 7.C

5-7(b)
The analyzed scenarios of reconfiguration for HBF under NCT use the same tallies and segmentations as the design basis NCT. This is clarified in Section 5.4 of HI-STAR 190 SAR.

The location of the highest dose rate for each evaluated scenario is added to the shielding calc package (HI-2146294), including a discussion on the location of these highest dose rates.

NRC RAI 5-8

5-8 Justify the fuel parameters and loading pattern selection for HBF reconfiguration analyses.

The staff requests that the applicant clarifies, with detailed justifications, how the source terms produced from various burnup/enrichment/cooling time combinations were used in the HBF reconfiguration analyses.

Tables 5.4.2 and 5.4.3 of the application show results for a nominal reference case. The staff requests that the applicant discuss the fuel enrichment/cooling time/burnup chosen for this case and how it was chosen as representative or bounding for all possible fuel loadings per Appendix 7.C of the application (including BWR fuel). For example fuel that produces the highest neutron source may be more bounding for HAC but not necessarily for NCT.

This information is required to determine compliance with 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 5-8:

All scenarios are evaluated for all permissible burnup, cooling time and enrichment combinations to determine the peak dose rates reported.

The fuel reconfiguration cases for BWR fuel are evaluated and documented in Section 5.4. It is demonstrated that there is a sufficient margin for fuel reconfiguration scenarios for all loadings (including various fuel types and permissible burnup, cooling time and enrichment combinations) per Appendix 7.C.

NRC RAI 5-9

5-9 Provide additional information on the axial burnup profile assumed for both PWR and BWR fuel.

The applicant cites references to various other dockets in Section 5.4.1 of the application in discussing the method used to model the axial burnup profile. However the staff did not locate enough information to evaluate the burnup profile for the HI-STAR 190 with respect to the following subject areas.

a) The staff requests that the applicant provide additional information on the shape of the profile used in modeling the active fuel region for both BWR and PWR fuel for the HI-STAR 190 and justify that it/they are conservative for all allowable burnups (specifically for low burnup fuel) and possible features such as control rod insertions, axial power shaping rods, axial blankets and part-length rods that are allowed from Appendix 7.C of the SAR.

b) The staff requests that the applicant justify that the peak relative burnup of 1.15 is representative or bounding for BWR fuel up to the allowable burnup.

c) The staff requests that the applicant justify the relationship to neutron source to the 4.2 power with burnup to implement the axial burnup profile considering that any nodes with relative normalized burnup less than 1 would be significantly reduced in an area where there could be streaming outside the neutron shield. The applicant should provide a comparison of this method as it is implemented in the HI-STAR 190 to that of a source term with axial distribution produced by depleting each axial node to the appropriate burnup to demonstrate it is equivalent or conservative. Alternatively the applicant could provide a specific reference where this has been approved from a previous docket and discuss how it is applicable to the HI-STAR 190. The staff could not find this information in any of the referenced dockets. Any uncertainties in the axial burnup profile should be included in the best estimate evaluation in Section 5.4.6 of the application.

This information is required to determine compliance with the regulations limiting external dose rates in 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 5-9:

5-9(a):

To justify the use of the profiles shown in Table 1.2.5 of the SAR, and/or develop considerations for specific conditions such as low burnups or partial rods, extensive evaluations are performed based on publicly available profiles from PWR and BWR spent fuel assemblies in comparison with the profiles in Table 1.2.5. This evaluation is provided in new Appendix 5.C of the SAR.

5-9(b)
For additional clarification on the axial burnup profiles, the corresponding paragraph in subsection 5.4.1 is updated with the following text taken from Section 5.4 of HI-STORM FW FSAR (Docket 72-1032):

“The peak relative burnups listed in Table 2.1.5 for the PWR and BWR fuels are 1.105 and 1.195 respectively. Using the power of 4.2 relationship results in a 37.6% (1.1054.2/1.105) and

76.8% (1.1954.2/1.195) increase in the neutron source strength in the peak nodes for the PWR and BWR fuel, respectively. The total neutron source strength increases by 15.6% for the PWR fuel assemblies and 36.9% for the BWR fuel assemblies."

5-9(c)

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NRC RAI 5-10

5-10 Verify the units of mSv/hr in Table 5.4.18.

It appears that the units of mSv/hr in the table are incorrect and may be in reality mRem/hr.

This information is required to determine compliance with 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 5-10:

In the SAR Table 5.4.18, mSv/hr is changed to mrem/hr. Holtec apologizes for the error.

NRC RAI 5-11

5-11 Justify the uncertainty in the selection of the design basis fuel, Westinghouse 17x17 for PWR and the GE 10x10 for BWR.

In justifying the fuel assembly selections as appropriate for all of the analyses, the applicant compared it to fuel assemblies with a higher UO_2 mass, the B&W 15x15 for PWR and the GE 7x7 for BWR.

a) For the PWR assemblies, the applicant shows the differences in the surface dose rate for various locations around the package in Table 5.4.4(a) of the application. These results show that the design basis fuel (Westinghouse 17x17) produces higher surface dose rates for all locations around the package except the top. However, since the fuel burnup is specified as per MTU and the B&W 15x15 fuel has higher fuel load per assembly, it is expected that for the same burnup per MTU, the heavier fuel assembly will produce higher source. It was not clear why the WE 17x17 would give higher dose rates. The staff requests that the applicant discuss the differences between the assemblies and analyses parameters (such as burnup profile) that could produce these results.

b) As shown in Tables 5.4.5(a) and (b) of the application, both the B&W 15x15 and the GE 7x7 have higher dose rates at the limiting 2 meter location at the side of the package than the design basis fuel. The applicant has considered that these are “relatively equivalent.” The staff is concerned about any non-conservative analysis assumption because the margins to the regulatory dose rate limit at 2 meters as shown by Table 5.1.3 and 5.1.4 of the application are small for this package. The staff requests that the applicant quantify this uncertainty and include it in the best estimate evaluation in Section 5.4.6 for both BWR and PWR fuel respectively. In doing so the applicant should determine a maximum uncertainty that covers all possible burnup values of the fuel as the difference in source term between the limiting and representative assemblies could be higher at higher burnups.

This information is required to determine compliance with 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 5-11:

5-11(a)

The fuel assembly geometry has resulted that at some surface locations, Westinghouse 17x17 bounds B&W 15x15. Figure 5-11-1 below shows part of the axial cross sectional view of HI-STAR 190 with W 17x17 and B&W 15x15 fuel assemblies. As can be seen W 17x17 fuel has a smaller bottom nozzle than B&W 15x15. Thus, the W 17x17 fuel active region is closer to dose locations 1, 5 and 2 (the dose location 2 is maximum in front of the bottom trunnions). In fact, preliminarily evaluation show that at the surface dose location in front of trunnions, the n dose rate is about 37% more for W 17x17 than B&W 15x15 (difference in source terms is not accounted).

Figure 5-11-2 shows the side surface dose rates for 3 tallies (45 and 90 degrees apart) for W 17x17 and B&W 15x15 Fuel Assemblies, for a conservative representative loading pattern. As can be seen, the surface dose rate is the highest in front of the trunnion (Tally 103) for 17x17. At other locations, the dose rates are relatively low.

These fuel assembly configurations justify the fuel assembly selection for the shielding analyses. These two fuel assemblies have the highest mass per unit length among the PWR fuel assemblies. Also, the location of the active fuel region in W 17x17 is such that the dose rate at the bottom portion of the cask maximized, while the location of the active fuel region in B&W 15x15 is such that the dose rate at the top portion of the cask maximized.

This evaluation is documented in more detail in the shielding calc package (HI-2146294).

Figure 5-11-1 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Figure 5-11-2 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

5-11(b)
The best estimate evaluation in Section 5.4.6 is updated to include both BWR and PWR, as requested by the NRC reviewer.

Additionally, the permissible loading patterns in Appendix 7.C are updated to increase the margin to the regulatory dose rate limit at 2 meters.

NRC RAI 5-12

5-12 Clarify the best estimate calculation to evaluate uncertainty.

In lieu of evaluating the uncertainty in the calculated dose rates, the applicant has performed a best estimate evaluation to show that the conservatisms in the analysis parameters would compensates for any calculation uncertainty. This evaluation is presented in Section 5.4.6 of the application.

a) This section only includes a best estimate evaluation of the PWR design basis fuel. The staff requests that the applicant justify only evaluating PWR fuel or include a best estimate evaluation of uncertainties when considering BWR fuel.

b) The staff also requests that the applicant justify the conditions used to determine the uncertainties for the best estimate evaluation. For example, the uncertainty in the isotope inventory would be higher at higher burn-up. This may be particularly true for actinides that produce neutron and fission gamma sources.

This information is required to determine compliance with 10 CFR 71.47 and 71.51(a)(2).

Holtec Response to RAI 5-12:

5-12(a) Holtec understand the staff's comment. The best estimate of uncertainties for BWR fuel is added to the SAR.

5-12(b) The conditions used to determine the uncertainties for best estimate evaluation is re-evaluated as described in the SAR.

Chapter 6 Criticality Evaluation

NRC RAI 6-1

6-1 Revise Drawings 6506 and 6507 to include the minimum required $_{10}B$ in the Metamic-HT neutron absorber sheets for the MPC-37 and MPC-89 baskets, respectively.

Note 18 on both Drawing 6506 for the MPC-37 basket and 6507 for the MPC-89 basket include a reference to Table 1.2.2 of the application for the minimum required $_{10}B$ content of the Metamic-HT neutron absorber panels. Table 1.2.2 of the application does not contain minimum $_{10}B$ requirements for neutron absorber panels.

This information is required to determine compliance with 10 CFR 71.33.

Holtec Response to RAI 6-1:

We agree with the staff's position on the need for clarification. Although the Metamic-HT minimum B_4C loading was provided in HI-STAR 190 Transport SAR Table 8.1.4A, Holtec drawings 6506 and 6507 submitted with the initial application do not reference this table. Proposed changes have been made to Holtec drawings 6506 and 6507 drawings as well as to SAR Table 1.5.1 to show proper reference to SAR Table 8.1.4A.

Upon further review of the HI-STAR 190 licensing drawing package, similar enhancements needed for proper reference to the HI-STAR 190 Transport SAR locations have been proposed to Holtec drawings 6505, 6506, 6507 and 6512. Markups of Holtec drawings 6505, 6506, 6507 and 6512 correspond to SAR Revision 0.C and are provided with this RAI response.

As a result of the proposed drawing changes, new SAR Table 8.1.10 titled "Emissivity of Metamic-HT and Fuel Basket Shims" has been added and SAR Table 1.5.2 titled "Properties of Metamic-HT" has been revised to reference new SAR Table 8.1.10. The proposed SAR changes have been incorporated in SAR Revision 0.C provided with this RAI response.

NRC RAI 6-2

6-2 Revise the application to demonstrate that the 15x15B, 16x16A, and 10x10A are appropriate to bound all PWR and BWR fuel assemblies, or provide a reference to where this has been demonstrated previously.

Throughout the criticality analysis in Chapter 6 of the application, the 15x15B fuel assembly class is used to bound all 15x15 and 17x17 fuel assembly classes, the 16x16 fuel assembly class is used to bound all 16x16 fuel assembly classes, and the 10x10A is used to bound all BWR fuel assembly classes. However, the application does not appear to include an analysis to support that these are in fact bounding fuel assembly classes. The application should be revised to include such an analysis, or to provide a reference to where this analysis has been previously performed. Note that analyses performed to demonstrate most reactive fuel assembly classes for PWR fuel in storage may not be applicable, as those analyses have been performed for fresh fuel in borated water, and the HI-STAR 190 analyses are performed for spent fuel compositions in fresh water.

This is necessary in order to demonstrate that the applicant has identified the most reactive credible configuration consistent with the chemical and physical form of the material.

This information is required to determine compliance with 10 CFR 71.55(b).

Holtec Response to RAI 6-2:

As discussed in Subsection 6.2.2, the 15x15B and 10x10A fuel assembly classes have been selected as the representative (reference) PWR and BWR fuel assemblies, since they were expected to be the most reactive fuel designs. All studies and evaluations to determine the design basis condition were therefore performed using these representative assemblies. For the same reason, the 16x16A fuel assembly class has been selected as the representative fuel for the set of all 16x16 assemblies (establishment of loading curves). These selections are based on the study calculations documented in Appendix C, Table 6.0.1 of the supporting document HI-2156424 “Criticality Evaluation of HI-STAR 190” that was submitted with the HI-STAR 190 license application. It should be noted that the comparison of PWR and BWR assembly classes may be also found in Table 6.2.1. Nevertheless, the design basis calculations have been performed and documented in Appendix C of HI-2156424 for all PWR (see Tables 6.B.23(c), 6.B.23(d) and 6.1.1) and BWR (see Table 6.1.2) assembly classes to validate the loading curves (PWR) and the maximum enrichment (BWR) and to show compliance with the regulatory requirements. The BWR results for all assembly classes are presented in Table 6.1.2, while only the most reactive PWR results for the representative 15x15B and 16x16A assembly classes are presented in Tables 6.1.1 and 6.B.23 of Chapter 6.

NRC RAI 6-3

6-3 Revise the application to clarify the burnup assumed for PWR high burnup fuel for the defense-in-depth analysis in Section 6.6, and to clarify the maximum k_{eff} for this analysis.

Table 1.2.3 of the application states that the burnup assumed for potentially reconfigured PWR fuel for the defense-in-depth analysis performed in Section 6.6 is 45 GWd/MTU. However, Table 6.6.2 of the application states that the assumed burnup for this analysis is 45.29 GWd/MTU. Additionally, Table 1.2.3 of the application states that the k_{eff} limit for high burnup fuel with major reconfiguration for the defense-in-depth analysis is 0.95,while the k_{eff}s reported for PWR high burnup fuel in Table 6.6.2 are in excess of this value. The application should be revised to correct these apparent discrepancies.

This information is required to determine compliance with 10 CFR 71.59.

Holtec Response to RAI 6-3:

As discussed in Subsection 6.2.6, “the criticality calculations for HI-STAR 190 apply additional burnup for the HBF, and hence show that the reactivity effect of potential fuel reconfiguration is more than compensated by the higher burnup. The minimum required burnup, specified in Table 6.1.1 (but not less than 45 GWd/mtU) is used for PWR HBF“. In other words, the fuel burnup for PWR HBF is increased to 45 GWd/mtU (if it is less than 45 GWd/mtU) to offset the potential fuel reconfiguration by HBF burnup. However, if the minimum burnup requirement is already above the HBF threshold of 45 GWd/mtU, such as for the 15x15 loading curve at 3 years cooling time, the actual burnup is used for HBF. Table 1.2.3 is revised to make it consistent with the approach used in Chapter 6.

NRC RAI 6-4

6-4 Revise Appendix 6.B of the application to demonstrate that the potential effects of integral burnable absorbers are bounded by the assumed irradiation conditions of the PWR fuel for the burnup credit analysis.

Section 6.B.2.2 contains a discussion of integral burnable absorbers, and summarizes NUREG/CR-6760, "Study of the Effect of Integral Burnable Absorbers for PWR Burnup Credit." This study shows a positive effect of integral burnable absorbers that do not cover the ends of the fuel rods in a PWR fuel assembly. Section 6.B.2 of the SAR does not address integral burnable absorbers further. NUREG/CR-6760 recommends that PWR burnup credit analyses include either: 1) a small reactivity bias to bound the effect of integral burnable absorber, or 2) demonstration that the effects of integral burnable absorbers are bounded by the effects of other modeling assumptions (e.g., BPR exposure).

This is necessary in order to demonstrate that the applicant has identified the most reactive credible configuration consistent with the chemical and physical form of the material.

This information is required to determine compliance with 10 CFR 71.55(b).

Holtec Response to RAI 6-4:

The discussion of the integral burnable absorbers in Subsection 6.B.2.2 is revised, as follows:

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PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

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PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

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PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

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NRC RAI 6-5

6-5 Revise the isotopic bias determination in Section 6.B.3.1.3 to correct the least squares fit and to evaluate trends in the bias as a function of burnup.

This section of the application states that the least squares fit of calculated versus measured reactivity differences in Figures 6.B.1 and 6.B.2 was calculated to intercept 0 delta-k at 0 burnup. This may not be appropriate, as the bias will be non-linear as it nears zero burnup (i.e., will potentially jump significantly from zero burnup to a burnup value that requires isotopic depletion calculations). Additionally, Section 6.B.3.1.3 states that the slope of the fit can be shown to be statistically insignificant, but no such demonstration is provided. The bias appears to vary as much as 0.01 over the burnup range from 10 to 60 GWd/MTU, which is significant from a criticality safety perspective.

This information is required to demonstrate compliance with 10 CFR 71.55 and 71.59.

Holtec Response to RAI 6-5:

Following the guidance in ISG-8 Revision 3, the direct difference method was applied to validate the depletion code. The differences in reactivity between two sets of the calculations with the measured and calculated isotopic composition were determined, and the mean value with the uncertainty as well as the least squares fit is calculated. The results presented in Table 6.B.12 showed that the average difference (bias) is positive and sufficiently large, while the least squares fit presented in Figures 6.B.1 and 6.B.2 visually showed a small correlation with the burnup. Because of small slope and large positive bias, which is conservatively truncated (see Table 6.B.14), no explicit statistical analysis is performed to calculate correlation coefficient and/or the bias as a function of the burnup. In other words, no attempt was made to derive the isotopic bias for the design basis calculations using the least squares fit and latter were shown for information purpose only. Instead, a conservatively truncated zero bias and the bias uncertainty determined per ISG-8 Revision 3 have been used in the design basis calculations.

NRC RAI 6-6

6-6 Revise Section 6.B.5 of the application to clarify the establishment of loading curves for MPC-37 loading Configuration 3.

Section 6.B.5 of the application states that “the minimum burnup requirement is first determined for the spent fuel assemblies in the Configuration 3 with the fuel enrichment of 5.0 wt% $_{235}$U. The damaged fuel assembly with 5.0 wt% $_{235}$U enrichment and this minimum required burnup is used with the other spent undamaged fuel assemblies with lower enrichments to ensure that the derived loading curve is acceptable for any combination of undamaged and damaged fuel assemblies.” This appears to conflict with the definition of Configuration 3 in Table 7.C.5, which states that the minimum burnup applies to all assemblies. Section 6.B.5 should be revised to clarify which initial enrichment and assembly average burnup assumptions were used to generate the loading curve for Configuration 3.

This information is required to determine compliance with 10 CFR 71.55 and 71.59.

Holtec Response to RAI 6-6:

It should be noted that Table 7.C.5 includes the assembly specification for operation of various basket loading configurations, while the modeling approaches, which were used to establish the bounding loading curves, are documented in Section 6.B.5. Both statements are valid and further clarification is provided below.

[

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

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NRC RAI 6-7

6-7 Revise Section 6.B.5.1 to clarify the use of a combined loading curve for cooling times greater than three years to be used with 16x16A class fuel assemblies.

This section of the application states that the three and seven year cooling time loading curves for 16x16A class fuel assemblies are combined into a single loading curve for a regionalized basket loading applicable for fuel cooled three years or more.

However, the loading curves shown in Table 7.C.4(a) still show separate 16x16A loading curves for three and seven years cooling time. The applicant should revise Section

6.B.5.1, and Table 7.C.4(a), as necessary, to clarify the use of loading curves for regionalized loading configurations of 16x16A class fuel assemblies in the MPC-37 basket.

This information is required to determine compliance with 10 CFR 71.55 and 71.59.

Holtec Response to RAI 6-7:

We agree with the staff's position on the need for clarification to the application. Table 7.C.4(a) has been revised to present a combined 3 year minimum cooling time loading curve for the set of all 16x16 assemblies consistent with the combined loading curve provided in SAR Table 6.B.1 and the discussion in Subsection 6.B.5.1. While the two additional curves (3 and 7 years) in Table 6.B.1 are technically correct, supported by the calculations, and presented in Chapter 6, the combined (3 year) loading curve has been adopted by Table 7.C.4(a) as specification for the allowable contents. The proposed changes to Table 7.C.4(a) and new Subsection 6.B.5.1 have been incorporated in SAR Revision 0.C (provided with this RAI response) for clarification.

NRC RAI 6-8

6-8 Revise Appendix 6.C of the application to clarify which axial burnup profile is used for the BWR potential high burnup fuel reconfiguration analysis.

Section 6.C.3 of the application states that a bounding axial burnup profile is used in estimating margin and is applied to a calculation performed with 27 actinide and fission product isotopes and 45 GWd/MTU burnup.

However, this section does not state what axial burnup profile is used for the partial burnup credit approach for BWR fuel at 15 GWd/MTU burnup. Section 6.C.3 should be revised to include this information.

This information is required to determine compliance with 10 CFR 71.55 and 71.59.

Holtec Response to RAI 6-8:

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PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

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PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

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Chapter 8 Acceptance Tests and Maintenance Program Evaluation

NRC RAI 8-1

8-1 Provide additional information (including performance tests) which demonstrate that the package service conditions (temperature and pressure) will not challenge the capabilities of the seals.

Page 8.1-5 of the application states that cask closure seals are specified in the drawing package referenced in the CoC to provide a high degree of assurance of leak tightness under normal and accident conditions of transport. It also states that seal tests under the most severe package service conditions including performance at pressure under high and low temperatures will not challenge the capabilities of these seals and thus are not required.

However, the application did not provide any data to demonstrate seal performance under these conditions. The staff needs to have assurance seals will perform at these conditions to provide containment of the contents.

This information is required to determine compliance with 10 CFR 71.71 and 71.73.

Holtec Response to RAI 8-1:

We agree with the staff's position on the need for seal information.

In the same manner as the HI-STAR 60 Transport Package SAR (Docket No. 71-9336), HI-STAR 190 SAR (Chapter 2 Table 2.2.11) specifies the required seal characteristics of the elastomeric seals. Containment boundary seals are purchased from reputable seal manufacturers under Holtec QA program and Holtec approved vendor list (AVL) which ensure seals are appropriately qualified for the intended service conditions as reflected by the required characteristics in SAR Table 2.2.11. Seal temperature limits are set in Table 2.2.11 based on results of the thermal safety analysis. Elastomeric seals have pressure limits in the range of thousands of psi (typically in the range of 5,000 psi or greater) and thus many times higher than that required by the HI-STAR 190 pressure and containment boundaries. The intent of the statement "Seal tests under the most severe package service conditions including performance at pressure under high and low temperatures will not challenge the capabilities of these seals and thus are not required" is that no further special tests (beyond those deemed necessary by the seal manufacturer to ensure seal characteristics of the selected seal comply with those in Table 2.2.11) are required to be specified as part of the acceptance criteria in Chapter 8 of the HI-STAR 190 Transport Package SAR. Based on the information provided above no changes are proposed to the HI-STAR 190 Transport Package SAR with the exception of the following editorial changes:

- Table 2.2.11: The title of the table is revised as indicated in the following: "Required Characteristics of ~~the Closure Lid~~ Containment Boundary Seals".
- Table 2.2.11: Clarified the table to indicate that the seal springback characteristic applies to the Closure Lid seal.

The above proposed change has been incorporated in SAR Revision 0.C (provided with this RAI response) for clarification.

NRC RAI 8-2

8-2 Clarify what pre-specified threshold temperature during transportation is required for the fuel cladding temperature so protective measure are not required for extremely low temperatures.

Page 8.1-10 of the application states that for MPCs with HBF, protective measures from extremely low fuel cladding temperatures that may cause brittle fracture during transportation shall be in place if required by Chapter 7 of this SAR. It also states that protective measures are not required if fuel cladding temperatures are evaluated to remain above a pre-specified threshold temperature during transportation.

However, a pre-specified threshold temperature is not specified in the application. The staff needs to have assurance fuel cladding will remain above these temperature so the fuel cladding remains intact during the entire transport period.

This information is required to determine compliance with 10 CFR 71.71.

Holtec Response to RAI 8-2:

We agree with the staff's position on the need for clarification to the application. Based on a materials evaluation of cladding from high burnup fuel, the minimum cladding temperature to prevent ductile-to-brittle transition (DBTT) has been identified in Table 8.1.11 of the SAR. The temperature limit is specific to the fuel assembly cladding type and the cladding hoop stress. Subsection 8.1.9 of the SAR has been revised to show the required values. In addition, a discussion has been added in Section 2.11 of the SAR to justify the proposed threshold temperatures. Lastly, Appendix 7.B and Subsection 7.1.2 have been revised and require the evaluation of HBF against the criteria specified in Section 8.1.9.

The proposed changes have been incorporated in SAR Revision 0.C (provided with this RAI response) for clarification. What follows is the technical justification for the proposed changes.

The Draft Regulatory Information Summary (RIS) for high-burnup fuel [8-2.2] states that if the minimum fuel cladding temperature remains above the DBTT then a) ISG-11[8-2.1] can be used to determine the maximum cladding temperature and b) it has to be verified that the minimum temperature maintains ductility of the cladding. In other words the temperature during drying must remain low enough to avoid dissolution and unfavorable precipitation of hydrides, while during shipment the temperature must remain high enough to avoid brittle fracture. If a) and b) are satisfied the structural analysis of the fuel can use properties of the cladding considering hydrides oriented in parallel with the hoop stresses. It should be noted that the stresses within the cladding, namely the hoop stress, can also influence formation of hydride precipitates and thus influence ductility of the alloy. In reference [8-2.3] a series of tests are performed on several zirconium alloys samples (namely Zircaloy-4, ZIRLO) exposed to high burnups to evaluate DBTTs. A summary of DBTTs for all measurements is provided in Table 8-2.1 of this RAI. The table shows the maximum DBTT temperature varies with cladding material and the hoop stress.

Cladding alloy M5 is not addressed in Reference [8-2.3]. However, more recent studies of M5 alloy [8-2.4] show hydrogen content reduced by factor of 10, when compared of other Zr cladding alloys. In addition, total elongation of HBF M5 measured in hoop tensile test show ductility increased by factor of 1.2 to 2.2 when compared with other zirconium alloys [8-2.5]. In summary, M5 studies show that due to low hydrogen absorbed content the alloy keeps a significant residual ductility and it is expected that the DBTT for M5 alloy will be bounded by DBTT reported for Zircaloy.

Table 8-2.1: Summary of DBTTs		
Cladding Type	**DBTT (°C)**	
Hoop Stress	**<110 MPa**	**<140MPa**
Zircaloy [8-2.3]	20	55
ZIRLO [8-2.3]	125	185
M5 (see text)	≤Zircaloy	≤Zircaloy

References for RAI 8-2 Response:

[8-2.1] Spent Fuel Project Office Interim Staff Guidance - 11, Revision 3.

[8-2.2] NRC Draft Regulatory Issue Summary 2015-XX: Considerations in Licensing High Burnup Spent Fuel in Dry Storage and Transportation, ML14175a203, US NRC Office Of Nuclear Material Safety And Safeguards, 2015.

[8-2.3] M.C. Billone, T.A. Burtseva, and Y. Yan, Ductile-to-Brittle Transition Temperature for High-Burnup Zircaloy-4 and ZIRLO™ Cladding Alloys Exposed to Simulated Drying-Storage Conditions, Argonne National Laboratory, September 28, 2012, ML12181A238.

[8-2.4] Garat et. al, Quantification of the margins provided by M5 cladding in accidental conditions, 2012 LWR Fuel Performance Meeting.

[8-2.5] B. Cazalis et. al., Prometra Program : A Reliable Material Database For Highly Irradiated Zircaloy-4, Zirlo and M5 Fuel Claddings, 18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18), Beijing, China, August 7-12, 2005, SMiRT18-C02-1.

It should be noted that DBTT criterion for HBF has not been added to Appendix 8.A since it is not a requirement on the MPC equipment but on its contents.

NRC RAI 8-3

8-3 Clarify what the criteria are to determine that a maintenance leakage rate test of the HISTAR 190 cask's seals prior to the pre-shipment leakage rate test is optional.

Page 8.2-3 of the application states that a maintenance leakage rate test of the HI-STAR 190 cask's seals prior to the pre-shipment leakage rate test is optional. However, the application does not provide any criteria to determine when a maintenance leakage rate is necessary. The staff needs to have assurance all tests are performed per maintenance program so containment of the contents is demonstrated.

This information is required to determine compliance with 10 CFR 71.71.

Holtec Response to RAI 8-3:

We agree with the staff's position on the need for leakage rate test clarification. The following proposed changes have been incorporated in SAR Revision 0.C (provided with this RAI response):

- Paragraph 8.2.3.6: The following text has been deleted: “A maintenance leakage rate test prior to the pre-shipment leakage rate test is optional.”
- Table 8.2.1: The following text has been deleted from the table entry for Maintenance Leakage Rate Test of Cask containment boundary: “(optional for seal replacement)”.
- Table 8.1.2: The following notes were inserted at the end of Table 8.1.2 for clarification

“2) Purpose of Leakage Rate Tests per ANSI N14.5-1997:
  - Fabrication Leakage Rate Test: To demonstrate that the containment system, as fabricated, will provide the required level of containment
  - Pre-shipment Leakage Rate Test: To confirm that the containment system is properly assembled for shipment.
  - Maintenance Leakage Rate Test: To confirm that any maintenance, repair, or replacement of components has not degraded the containment system.
  - Periodic Leakage Rate Test: To confirm that the containment capabilities of the packagings built to an approved design have not deteriorated during a period of use.

3) For a pre-shipment test implementing the alternative pre-shipment leakage rate acceptance criterion specified in Note 2 of Table 8.1.1, alternative types of leak rate tests may be used as supported by ANSI N14.5-1997.”

As a result of the deletions proposed above, new note 2 to Table 8.1.2 has been added as enhancement that ensures the purpose of each leakage rate test according to ANSI N14.5-1997 is known to the user. In addition, new note 3 to Table 8.1.2 is an enhancement to provide flexibility to the extent allowed by ANSI N14.5-1997.

NRC RAI 8-4

8-4 Explain what criteria are applicable to perform a proper inspection on the HI-STAR 190 cask’s seals, to determine they can be used beyond recommended design life.

Page 8.2-3 of the application states that use of elastomeric seals beyond recommended design life may be acceptable with proper inspection and engineering justification. However, the application does not provide any acceptable criteria to determine this. The staff needs to have assurance seals will perform their function so containment of the contents is demonstrated.

This information is required to determine compliance with 10 CFR 71.71 and 71.73.

Holtec Response to RAI 8-4:

We agree with the staff’s position on the need for justification. As indicated in Holtec’s response to RAI 2-16, we propose to delete the statement “Use of elastomeric seals beyond recommended design life may be acceptable with proper inspection and engineering justification.” The proposed change has been incorporated in SAR Revision 0.C (provided with this RAI response).

NRC RAI 8-5

8-5 Explain how the in-service test verifies a continued adequate rate of heat dissipation from the cask to the environment. Provide monitored parameters and/or variables that are measured to demonstrate this along with adequate procedures to perform the in-service test.

Page 8.2-4 of the application states that a periodic thermal performance test shall be performed at least once within the 5 years prior to shipment to demonstrate that the thermal capabilities of the cask remain within its design basis. This test may be performed immediately after a HI-STAR 190 is loaded with approved contents. The in-service test is performed to verify a continued adequate rate of heat dissipation from the cask to the environment.

However, the application does not provide any details on how the in-service test is performed. The staff needs to have assurance that an in-service test will provide meaningful measured parameters that will correlate with adequate rate of heat dissipation and predicted fuel cladding temperatures.

This information is required to determine compliance with 10 CFR 71.71 and 71.73.

Holtec Response to RAI 8-5:

We agree with the staff's position that information in Subsection 8.2.4 is insufficient. A complete revision of Subsection 8.2.4 has been incorporated in SAR Revision 0.C (provided with this RAI response) to provide the necessary details on how the in-service test is performed.

NRC RAI 8-6

8-6 Clarify why enclosure vessel pressure vessel integrity confirmation is not applicable to MPCs loaded with HBF.

Table 8.A.1 (MPC Aging Management Program) of the application states that enclosure vessel pressure vessel integrity confirmation is not applicable to MPCs loaded with HBF. It appears that this confirmation would apply to HBF as well. Since the HI-STAR 190 cask features double containment barrier, the staff needs to have assurance pressure vessel integrity confirmation is demonstrated for HBF.

This information is required to determine compliance with 10 CFR 1.71 and 71.73.

Holtec Response to RAI 8-6:

We agree with the staff's position on the need for clarification. Please refer to the proposed changes provided in Holtec's response to RAI 2-12. It should be noted that Table 8.A.1 has been revised to be compatible with the first paragraph of Appendix 1.A which states that the MPC pressure boundary structural integrity is applicable to MPCs loaded with HBF.