Responses to Request for Additional Information

Docket No. 72-1014
Certificate of Compliance No. 1014
HI-STORM 100 Dry Cask Storage System
Amendment No. 12

Chapter 4 – Thermal Evaluation

4-1 Clarify the inconsistency regarding the Basket-to-MPC Radial Growth between Holtec Report HI-2043317, Appendix P, Section P.5.2(a)) and Note 17 to Drawing No. 7195, Rev. 11 of HI-STORM 100 FSAR Rev. 13.

In Holtec Report, HI-2043317, Appendix P, Section P.5.2(a), thermal expansion calculations for Basket-to-MPC Radial Growth state that the combined radial cold gap between the basket and basket shim, and the basket shim and MPC shell is less than or equal to 0.28125 inch (7.14 mm). However, Note 17 on the Drawing No. 7195, Rev. 11 of HI-STORM 100 FSAR, Rev. 13, states that the average as-built total combined radial air gap between the basket, extruded shims and the enclosure shell shall be a minimum of 0.101 inch and a maximum of 0.175 inch. These values appear to be inconsistent. The values in the drawing note are assumed to be at assembly temperatures; therefore, the computed radial expansion at operating temperature would be greater than the minimum total as-built gap specified.

This information is needed to determine compliance with 10 CFR 72.236(f).

Holtec Response:

We regret the inconsistency regarding the radial cold gap between the basket, basket shim and MPC shell between Holtec report HI-2043317 and Holtec Drawing 7195. The *maximum* value of this cold radial gap is indeed 0.175”. Holtec Report HI-2043317 Appendix P, Section P.5.2(a) will be updated to correct this documentation error.

It is noted that the thermal expansion values reported in the proposed FSAR and Holtec Report HI-2043317 are conservatively overestimated. For a more realistic evaluation, the differential thermal expansion calculation is revised by removing excessive conservatisms. The calculation is summarized below:

The radial growth (δ_1) of the fuel basket relative to the MPC shell upon heating from a 21°C (70°F) reference temperature (T_o) to storage temperatures is computed as follows:

$$\delta_1 = R_{basket}\alpha_1\left[T_1 - T_o\right] - R_{shell}\alpha_2\left[T_2 - T_o\right] + \alpha_3 T_{shims}\left[T_3 - T_o\right]$$

Where:

R_{basket}: Fuel Basket radius

R_{shell}: MPC shell inner radius

T_{shims}: Thickness of aluminum shims

α_1, α_2, α_3: Coefficients of thermal expansion for fuel basket, MPC shell (lower bound value corresponding to duplex stainless steel) and aluminum shims at T_1, T_2 and T_3 respectively

T_1: Maximum cross-section surface average temperature of basket

T_2: Maximum cross-section surface average temperature of MPC shell at the same height where T_1 is reported

T_3: Maximum cross-section surface average temperature of Basket shims at the same height where T_1 is reported

Using the above formula, the differential thermal expansion calculation is revised and produced in the EXCEL file “thermal-exp-amd12-rev.xls” provided to the Staff for review. The differential radial thermal expansion is computed to be 0.107". The minimum cold gap requirement (controlled through Holtec shop procedure) is accordingly revised to 0.11” to preclude the potential of internal interference between MPC internal components. Both the FSAR and Holtec Report HI-2043317 have been updated to report the updated differential thermal expansion and cold gap values.

4-2 Clarify the inconsistency in the thermal expansion values for the Fuel Basket-to-MPC Radial Gap.

The applicant calculated thermal expansion in the Fuel Basket-to-MPC Radial Gap, as shown in the proposed FSAR Supplement, Table 4.III.8 and Holtec Report, HI-2043317, Appendix P, Table P.2. However, the thermal expansion of 3.24 mm (0.128 inch) in FSAR Supplement Table 4.III.8 is different from that of 3.03 mm (0.119 inch) in Holtec Report HI-2043317, Appendix P, Table P.2. This inconsistency should be corrected.

This information is needed to determine compliance with 10 CFR 72.236(f).

Holtec Response:
We regret the inconsistency in the thermal expansion values documented in FSAR and Holtec Report HI-2043317. As explained in the response to RAI 4-1, the differential radial thermal expansion between basket, basket shims and MPC shell has been revised. FSAR supplement Table 4.III.8 and Holtec Report HI-2043317, Appendix P, Table P.2 have been revised for consistency.

4-3 (a) Clarify the differences in thermal inertias between FSAR Table 4.5.2 and proposed FSAR Table 4.III.13 (and Holtec Report HI-2043317, Appendix P, Table P.8), and (b) provide calculations or the results to show how the time-to-boil for water in the MPC-68M at QSHL and 42.8 kW, shown in proposed FSAR Table 4.III.14, are derived.

The applicant stated in the proposed FSAR Supplement Section 4.III.5.2 and Holtec Report HI-2043317 Appendix P Section P.5.4 that the time to boil for QSHL pattern was calculated using the methodology described in FSAR Section 4.5.2 and using the thermal inertia of the constituent components in the proposed FSAR Supplement Table 4.III.13 and Appendix P Table P.8. The applicant presented the results in the proposed FSAR Supplement Table 4.III.14 and Appendix P Table P.9.

The staff finds that some thermal inertias (e.g., Alloy-X MPC, fuel, MPC cavity water) in FSAR Table 4.5.2 “HI-TRAC Transfer Cask Lowerbound Weights and Thermal Inertias” are different from those in the proposed FSAR Supplement Table 4.III.13 (and Appendix P Table P.8) “HI-TRAC Transfer Cask with MPC-68M: Lowerbound Weights and Thermal Inertias.”

This information is needed to determine compliance with 10 CFR 72.236(f).

Holtec Response:

(a) The thermal inertia reported in FSAR Table 4.5.2 (also consistent with Table C.5.4 in Appendix C of Holtec Report HI-2043317) is based on a HI-TRAC loaded with an MPC-32 that contains a stainless steel basket. The thermal inertia reported in FSAR Table 4.III.13 (also reported in Table P.8 of Appendix P of Holtec Report HI-2043317) is based on HI-TRAC loaded with an MPC-68M that contains a Metamic-HT basket and aluminum basket shims.

Since the MPC internals are different between MPC-32 and MPC-68M, the thermal inertia for these canisters is also different. The difference in thermal inertias between FSAR Table 4.5.2 (MPC-32) and Table 4.III.13 (MPC-68M) is due to several factors, viz.:

a. MPC-32 is loaded with PWR fuel assemblies while MPC-68M is loaded with BWR fuel assemblies. Fuel assembly weights are therefore different.
b. MPC-32 contains a basket made of Alloy-X while MPC-68M contains a basket made of Metamic-HT.
c. MPC-68M contains aluminum basket shims while these are not present in MPC-32.
d. MPC cavity free volume inside a loaded MPC-32 and MPC-68M are different, which results in a different thermal inertia of MPC cavity water in FSAR Table 4.5.2 and Table 4.III.13.

(b) The calculation of time-to-boil for water in MPC-68M for QSHL pattern (equal to 42.8 kW) during loading operations is documented in "TTB-amd12.xlsx", which is listed in Section P.4 of Holtec Report HI-2043317, Appendix P. This excel sheet ("TTB-amd12.xlsx") is provided to the staff for review.

4-4 Clarify/revise the inconsistency in the gas dew point described in Appendix A (Note 9 to Table 3-1) and FSAR Supplement Section 4.III.5.3.3.

The applicant stated in Appendix A, Table 3-1 (Note 9) that “LPD means an open loop drying method. The acceptance criteria is MPC cavity pressure shall be ≤ 3 torr for ≥ 30 minutes or gas dew point exiting the MPC shall be **≤ 22.9°F** for ≥ 30 minutes.” Then the applicant described in FSAR Supplement Section 4.III.5.3.3 that “Therefore, at or below QL, the vacuum drying operation can be continued for as long as necessary to achieve the target vacuum pressure of 3 torr (or dew point of the contained helium gas **<21°F**)” and “The “dew point” of the exiting vapor (target ≤ 21°F) provides the definitive proof as to whether the canister has been dried to the requisite level.”

The applicant should clarify or revise inconsistency in gas dew point described in Appendix A and FSAR Supplement.

This information is needed to determine compliance with 10 CFR 72.236(f).

Holtec Response:

We regret the inconsistency in dew point of helium gas in FSAR and CoC. The dryness acceptance criteria under LPD method in FSAR Section 4.III.5.3.3 has been fixed to state the gas dew point exiting the canister must be ≤ 22.9°F for ≥ 30 minutes and is also consistent with CoC Appendix A, Table 3-1. Note 9 of CoC Appendix A, Table 3-1 is also revised to remove the acceptance criteria on MPC cavity pressure ≤ 3 torr.

4-5 Provide information to show how the low pressure drying (LPD) moisture removal method can be performed and controlled effectively to maintain the PCT below 400°C in the drying operations.

In order for the LPD moisture removal method to have no limitations on time duration, the mass flow rate of helium through the canister (as described in the proposed FSAR Supplement Section 4.III.5.3.3) must be sufficient to remove the total decay heat from the fuel to maintain conditions where the PCT is below the 400°C (752°F) limit. The canister pressure is maintained in the range 0.5 to 1.0 atm (see FSAR Chapter 8, Section 8.5.1, newly added comments/notes in Step 6, per response to request for supplemental information (RSI)). This criterion suggests that the flow rate of helium through the canister must be fairly high throughout the duration of the LPD operation. In normal storage conditions with external air ventilation, the MPC is pressurized to at least 5 atm in order to increase the heat-carrying capacity of the helium gas circulating through the cavity by means of the natural thermo-siphon. At the lower pressure of no more than 1 atm during LPD operation, and consequently lower helium gas density, the rate of helium gas circulation within the cavity must be much higher than the natural circulation rate at a density corresponding to 5 to 7 atm of pressurization in order to remove an equivalent amount of heat. Yet an explicit requirement of the LPD approach is that the “feed and bleed” must be slow enough to encourage “quiescent conditions” in the cavity to allow the gas mixture to stratify to some degree. The heavier water vapor is expected to drift preferentially downward to near the bottom of the cavity, such that the gas mixture removed through the drain line would tend to contain more moisture than it would if the two gases were fully mixed.

Beside the mass flow rate of helium, the mixing of helium fed into the MPC must be sufficient inside the MPC to remove moisture from all fuel assemblies, basket cells and the interior of the MPC.

> a) Demonstrate that the mixing of helium gas fed into the MPC for the LPD will be sufficient inside the MPC to flow through all basket cells, instead of a limited number of basket cells, to keep the spatial distribution of cladding temperatures below 400°C.
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> b) Explain how the “quiescent conditions” in the cavity required for efficient operation of this process will be achieved, while at the same time maintaining sufficiently high flow rate of helium through the canister to assure that the peak clad temperature is maintained below the 400°C (752°F) limit at all times during the operation.
>
> c) Explain how the helium through the cavity will be monitored and maintained at sufficiently high flow rate and sufficient mixing to assure an essentially steady-state heat removal rate for the given decay heat load in the specific MPC undergoing drying with this methodology.

This information is needed to determine compliance with 10 CFR 72.236(f).

Holtec Response:
During the LPD process, the MPC/annulus is filled with water which, combined with the high conductivity of the Metamic HT basket material (~10 times that of stainless steel) allows the Canister to reject sufficient amount of heat to maintain the cladding temperature below the ISG-11 Rev 3 limit even at sub-atmospheric pressure levels in the Canister. For practical guidance, the user (operator) is instructed to keep the internal helium pressure at ~500 mm of Hg. At this sub-atmospheric pressure, the lack of heat rejection assist from thermo-siphon action is made up by the following facts:

- Canister’s external surface temperature is kept low by its wetting by the water in the annulus.

- Metamic-HT basket's thermal conductivity is high

In summary, the success of the LPD process owes to the high conductivity of the basket material and to maintaining water around the external surface of the Canister. (For conservatism, thermal evaluations assume the annulus water to be at boiling which will occur only if the gravity feeding of water to the annulus were to be somehow interrupted.)

As explained in response to RAI 4-6, the effectiveness of the LPD process rests on three key predicates:

1. Moisture free helium gas, light in molecular weight, is introduced through the top vent connection while an equal amount of (helium & associated moisture) is extracted from the drain port which collects the gases via its drain pipe which extends down to the bottom reaches of the Canister.
2. The rates of injection and withdrawal of helium are equal and very slow (merely 2.8 lb per hour suggested in in Table 4.III.10 to encourage stratification of the contained gas in the Canister.
3. The pressure in the Canister is maintained as close to 500 mm of Hg as practicable.

The steady state peak cladding temperature under the condition when MPC cavity is filled with static helium during LPD process under the QSHL pattern is evaluated and described in Section 4.III.5.3 of the FSAR. By assuming static helium, the thermo-siphon effect by helium motion inside the canister is discounted. The simulated PCT assuming quiescent helium is presented in Table 4.III.10 of the FSAR which is below the ISG-11 temperature limit of 400^{o}C (752^{o}F). During the LPD operation, the actual PCT will be lower than that presented in Table 4.III.10 since the thermal evaluation conservatively ignores the heat removal by the convective helium entering the vent port and leaving the drain port of the canister. Therefore, the LPD method can keep the PCT below the ISG-11 temperature limit without any requirement on the mass flow rate of the helium injection.

4-6 Explain how the slow withdrawal of gas through the drain port is expected to preferentially remove water vapor, rather than helium gas, from the cavity in the LPD operation.

The discussion in the proposed FSAR Supplement Section 4.III.5.3.3 specifically states that the slow withdrawal of the gas mixture through the drain line during the LPD operation, "...steadily dew scavenges the water vapor from the cask, reducing the helium mass' relative humidity." As a technical term, "scavenging" implies some particular affinity for one material to bond with another, generally as an aid in its removal from a system. Helium, being a noble gas, has no noticeable affinity for other gases within a mixture, beyond that resulting from similar velocities in response to a pressure gradient or other external physical force. Therefore, slow withdrawal of gas at the drain port may tend to pull more helium out of the cavity and leave the heavier water vapor behind.

The applicant needs to explain how the slow withdrawal of gas through the drain port is expected to preferentially remove water vapor, rather than helium gas, from the cavity assuming that the desired "quiescent conditions" can actually be achieved within the cavity during this operation.

This information is needed to determine compliance with 10 CFR 72.236(f).

Holtec Response:

The LPD method is a modified vacuum drying (VD) method wherein the chief weakness of the VD method, namely thermal cycling of the fuel, is largely eliminated. The LPD process begins just like the classical vacuum drying process with the water residual extracted from the canister drain port until the

PCT approaches a certain temperature, which is set to be below 400°C (752°F). At that point, instead of continuing to vacuum as the classical vacuum drying process ordains, further vacuuming is stopped and enough helium is introduced to stem the canister's continuing temperature increase. For operational simplicity, the operator is required to add enough helium to raise the internal pressure to nominally 500 mm Hg (sub-atmospheric state), which will keep the PCT below 400°C (752°F) as explained in the response to RAI 4-5. The slow injection of helium through the top vent port into the canister cavity is then initiated.

Moisture, with the molecular weight of 18 g/mole is much heavier than helium which has a molecular weight of 4 g/mole and thus the water vapor would preferentially collect near the bottom of the canister. This is the same phenomenon witnessed during welding near a low level confined space in an industrial setting. The argon gas used for shielding the weld will typically collect in the low lying areas around the weld process and oxygen monitoring is initiated to insure that workers are not asphyxiated by the argon displacing the air. Therefore, it is evident that injecting helium very slowly at the top of the canister internal space would tend to push down the moisture laden helium to the lower region of the canister. Thus, the lower part of the canister cavity would have more moisture than the upper part. In order to maintain the pressure in the canister, gas is removed from the bottom of the canister in an amount equal to the gas injected in the top of the gas. This process is illustrated in Figure 4-6.1. Because of the process of slow feed to the top space and slow bleed from the bottom, helium extracted from the bottom space in the canister will be richer in moisture content than the canister as a whole. Therefore, checking the canister dryness by measuring the dew point of the extracted helium would give a conservative result relative to the bulk average. When the dew point of the bled helium reaches 22.9°F and stays at or below it for 30 minutes, the target dryness is deemed to have been achieved. It should be noted that the "22.9°F dew point" acceptance criterion has proved out repeatedly in practice whenever FHD is used to dry a Canister.

In summary, the effectiveness of the LPD process rests on three key predicates:

1. Moisture free helium gas, light in molecular weight, is introduced through the top vent port while an equal amount of moisture laden helium is extracted from the drain port at the bottom of the canister.
2. The rates of injection and withdrawal of helium are equal and very slow (merely 2.8 lb per hour suggested in Table 4.III.10 of the FSAR) to encourage stratification of the contained gas in the canister.
3. The pressure in the canister is maintained as close to 500 mm Hg as practicable.

During LPD operation, the fuel remains below the ISG-11 Rev 3 limit at all times while the relatively moisture-rich helium in the bottom region of the canister is extracted. It is true that the effectiveness of this method is premised on physical reasoning just as several classical liquid vapor separation technology rely on density guided separation techniques.

Figure 4-6.1: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

4-7 Clarify how the fuel within an MPC-68M, being dried by the LPD method, does not undergo thermal cycling in excess of the maximum of 10 cycles with the allowed range of change in the PCT of no more than 65°F.

The LPD methodology defines an operational envelope for a specific MPC-68M canister based on a steady-state result obtained with the FLUENT model for the given decay heat load and applicable boundary conditions. In the actual drying operation, the fuel within the canister will be undergoing a transient of potentially very long duration, with the flow of helium through the system repeatedly adjusted in some manner to maintain the cavity pressure at nominally 0.5 to 1 atm throughout the operation. The proposed FSAR Supplement Section 4.III specifically makes the point that this process avoids “cyclic heating and quenching of the fuel” that is provisionally permitted for up to 10 cycles (per ISG-11, Rev. 3) for vacuum drying operations (FSAR Supplement Section 4.III.5.3.1). However, the LPD process has the potential to subject the fuel within the cavity to an unanalyzed thermal transient that may involve multiple cycles of increasing and decreasing PCTs, which could be more than 10 cycles of unknown duration and amplitude, depending on how the pressure and flow rate is controlled in the actual operation for a particular canister.

ISG-11 Rev 3 and NUREG-1536 Revision 1 Section 8.8 show that thermal cycling of cladding can enhance the amount of hydrogen that eventually re-precipitates in the form of radial hydrides. The formation of radial hydrides can significantly alter the mechanical properties of cladding which in turn may pose post-operational safety problems with respect to the removal of the fuel from storage.

The intent of the thermal cycling acceptance criteria in ISG-11 Rev 3 and NUREG-1536 Revision 1 Section 8.8 is to limit precipitation of radial hydrides during loading operations. The requirements of 10 CFR 72.236(m) seek to ensure safe fuel storage and handling and to minimize post-operational safety problems with respect to the removal of the fuel from storage. In accordance with this regulation, the spent fuel cladding must be protected during storage against degradation that leads to gross rupture of the fuel and must be otherwise confined such that degradation of the fuel during storage will not pose operational problems with respect to its removal from storage. Additionally, 10 CFR 72.236(m) require that the storage system be designed to allow ready retrieval of the spent fuel from the storage system for further processing or disposal.

a) Provide additional information which demonstrates that the fuel within an MPC-68M being dried by the LPD method does not undergo thermal cycling in excess of the maximum of 10 cycles with the allowed range of change in the PCT of no more than 65°F, as specified in ISG-11, Rev.3.

b) Specifically define how it will be assured, that the LPD method is consistent with the thermal cycling limitations defined in ISG-11, Rev. 3, during moisture removal operations.

This information is needed to determine compliance with 10 CFR 72.236(f).

Holtec Response:
As explained in response to RAI 4-6, the LPD method is a modified vacuum drying (VD) method wherein the chief weakness of the VD method, namely thermal cycling of the fuel, is largely eliminated by arresting the increase in cladding temperatures when helium is injected into the canister and the internal pressure is controlled via the measured injection of helium coupled with the removal of helium and water vapor at a constant pressure. Additionally, as explained in response to RAI 4-5, the peak cladding temperature (PCT) under steady state conditions with static helium inside the canister (i.e. heat removal by helium motion due to slow injection into the MPC cavity is completely ignored) remains below the ISG-11 Rev 3 temperature limit of 400^{o}C. By holding the helium pressure inside the MPC cavity to a prescribed sub-atmospheric range, the temperature variation in the MPC cavity space and the PCT will be held to minor variations over time (no transients) due only to changes in the external ambient conditions. Any thermal stress from an essentially steady thermal-hydraulic process will not challenge the endurance limit of the cladding material.

4-8 Explain how the drying criteria for the LPD method would detect the effect of residual water in the liquid phase remaining in the canister, based on the “drying criteria” proposed in Amendment No. 12.

The "drying criteria" for the LPD method is defined as achieving conditions where the water vapor in the gas mixture of helium and water vapor extracted from the cavity has a saturation value of 21°F or lower. A gas mixture extracted from a canister undergoing moisture removal by the LPD method would be expected to initially be at a temperature significantly above 21°F since the helium gas is removing the decay heat from the fuel such that the PCT is maintained below the 400°C (752°F) limit. If this gas mixture contains more water vapor than what could be held in the vapor phase at 21°F, the gas mixture would condense as ice or frost when cooled to 21°F.

The proposed FSAR presents the "drying criteria" as simply being able to demonstrate that the gas mixture can be cooled to below 21°F before the water vapor will change phase. In the proposed FSAR, this is called the "dew point," which is interpreted as evidence that the partial pressure of water vapor in the gas mixture is at or slightly below 3 torr. This is correct, in that the saturation pressure for water at this temperature is, indeed, 3 torr for equilibrium conditions, as per the standard phase diagram for water (generally available in any thermodynamics textbook). However, as a drying criteria, it is incomplete in that for the LPD operation, it is only one measurement point that provides an estimate of a lower bound on the partial pressure of water vapor in the gas mixture within the cavity for the extracted sample.

The common practice for demonstrating a sufficiently dry canister has been the ability to demonstrate that the sealed cavity can *maintain total pressure below 3 torr without vacuum pumping* for a period of time, usually defined as 30 minutes. The test is to demonstrate that there is no significant source of residual liquid water left in the cavity, and any modest increase in pressure over the time period of the test can be reasonably attributed simply to thermal expansion of the gas mixture and not to additional evolution of water changing from the liquid phase to the vapor phase. Experience with vacuum drying operations has shown that this test can generally be met fairly easily, except for systems with components where liquid water has been absorbed into porous material, such as ceramic Boral plates. In such systems, the liquid water must have some finite time to migrate out of the ceramic matrix and evaporate or sublimate into the surrounding gas, before the system is likely to be dry enough to pass the test of a 30-minute "hold" at or below the target pressure. The test is in the stability of the system in holding the target pressure, not the specific pressure of 3 torr, in and of itself.

As described in the proposed FSAR for Amendment No. 12, it appears that the drying criteria for the LPD method would not necessarily detect the effect of residual water in the liquid phase remaining in the canister, even if the specified "drying criteria" were met.

Explain how the drying criteria for the LPD method would detect the effect of residual water in the liquid phase remaining in the canister, by using the specified "drying criteria" documented in the proposed FSAR.

This information is needed to determine compliance with 10 CFR 72.236(f).

Holtec Response:
Experience shows that conventionally used pressure rise test is indeed able to cause "pressure rebound" when the moisture is caught inside porous materials such as Boral. However, the test is often ineffective when the fuel is waterlogged because of minute pinholes in the cladding as was the case in the Trojan defueling project (ca 2002-03) and more notably at Chernobyl where the contractor struggled to dry the fuel after years of dogged effort (1998-2007). In both cases, the Forced Helium Dehydration (FHD) technology provided the solution. The key concept behind the FHD method is thoroughly turbulating the

helium inside the canister with a high flow rate of circulation and testing the dew point of the helium exiting the MPC cavity. The veracity of the dew point measurement technique to insure the requisite level of dryness has been confirmed by the 'pressure rise test' in numerous early canisters dried by FHD (after 2001). It should be noted that the dew point test criterion in the case of FHD uses the representative helium gas from the canister.

The LPD method's use of the dew point criterion is more conservative because it samples the helium drawn from the bottom of the canister which is apt to be the richest in entrained water molecules. Dry helium is added to the canister that essentially contains less than 50 ppm water vapor. Any residual liquid water inside the canister will increase the water vapor concentration to 17757 ppm at the exit dew point of 22.9^{o}F. With approximately 2.8 lb/hr helium flow rate into the canister, this results in approximately 0.4 g/min of water, which is small enough to be detected if there were water leaking through a pin hole. Measuring at low dew point verifies there is no liquid water present inside the canister.

We regret the inconsistency in dew point of helium gas in the FSAR and CoC. The dryness criterion has been corrected in FSAR and made consistent with CoC Appendix A, Table 3-1 which states the gas dew point exiting the canister to be $\leq$ 22.9^{o}F for $\geq$ 30 minutes. It must be noted that drying test will be performed to ensure dew point temperature is maintained for 30 minutes.

4-9 Clarify whether the LPD method is applicable only to the MPC-68M, in any loading patterns or only for QSHL, with decay heat load above 29 kW. Provide additional documentation in FSAR to specify the use of the LPD method.

As documented in the proposed FSAR for Amendment No. 12, it appears that the LPD method is applicable only to the MPC-68M, with decay heat load above 29 kW. If this is the intent, state this explicitly in the FSAR. If not, provide additional documentation specifying any other MPC configurations that the LPD method will be applied to.

This information is needed to determine compliance with 10 CFR 72.236(f).

Holtec Response:
The staff is correct in their understanding that *the LPD method is applicable only to MPC-68M* with decay heat load above 29 kW. CoC Appendix A, Table 3-1 has been updated to explicitly state this requirement. At this time, the LPD method has been proposed only for fuel baskets made of Metamic-HT (MPC-68M) for drying canisters containing HBF. HBF has a much lower peak cladding temperature limit than MBF in ISG-11 Rev 3 which requires cyclic vacuum drying at heat loads greater than 29 kW. The proposed CoC explicitly limits LPD to MPC-68M; the FSAR text has been amended to make this stipulation clear.

Additionally, FSAR Table 4.III.5 and Section 4.III.5.3.1 have been updated to include the computed temperatures for vacuum drying of MPC-68M containing only moderate burnup fuel (MBF) under QSHL pattern.

4-10 Provide the surface temperatures at/near the weld surface areas for applicability of liquid penetrant examination during loading operations to ensure weld integrity and confinement effectiveness for MPC-68M (QSHL pattern with a heat load up to 42.8 kW).

The applicant stated in FSAR Rev. 13, Section 1.2.2.2, Sequence of Operation, for loading operation with MPC placed in the HI-TRAC:

> a) MPC water level is lowered slightly and the MPC lid is sealed-welded using automated welding system or other approved welding process. Liquid penetrant examination is also performed on the MPC lid-to-shell weld to ensure weld integrity.
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> b) Following moisture removal, the MPC is backfilled with a pre-determined amount of helium gas. Cover plates are installed and seal-welded over the MPC vent and drain ports with liquid penetrant examinations performed on the welds to ensure weld integrity.
>
> c) The MPC closure ring is then placed on the MPC, aligned, tacked in place, and seal welded, providing redundant closure of the MPC lid and cover plates confinement closure welds. Tack welds are visually examined and the root and final welds are inspected using the liquid penetrant examination to ensure weld integrity.

Compared to a temperature of 309°F at lid bottom plate under normal storage for the MPC-68M with a QSHL pattern and a heat load up to 42.8 kW (Holtec Report HI-2043317, Appendix P Table P.1), it's expected that the weld areas mentioned above in items A, B, and C may have temperatures higher than 309°F when liquid penetrant examinations are performed during loading operations.

Given that liquid penetrant examination is applicable for the weld surface temperatures below 250°F, the applicant should provide the weld surface temperatures at/near MPC lid, vent port, drain port and MPC cover plate when liquid penetrating test is performed at loading operations, as described in item A, B and C, to ensure weld integrity and confinement effectiveness.

This information is needed to determine compliance with 10 CFR 72.236(e) and (f).

Holtec Response:

Based on extensive field experience, we respectfully posit that the MPC lid temperature during the NDE of the MPC Lid-to-Shell weld (Item A above) will remain well within the applicable temperature range for normal liquid penetrant products. This is due to the presence of water both inside the canister and around the annular region. The presence of water limits the lid temperature to below the boiling point of water and standard loading operations include steps to recirculate water through the cavity in the event that the time-to-boil limit for the canister is approached.

However, after the water in the Canister is removed and the Canister is backfilled with helium [Item B & C in the RAI] then the temperature of the top lid begins to rise. Under steady state conditions for a design basis heat load MPC in HI-TRAC (Reference Appendix P of Holtec Report HI-2043317) the temperature of the top surface of the MPC lids is indicated to be 466 °F, which as the Staff correctly observes, would preclude use of standard liquid penetrant materials for post- weld NDE of the cover plate and closure ring welds. [By way of information, we should observe that high temperature liquid penetrants suitable for use at temperatures up to 350 °F (e.g., Sherwin Williams HI-TEMP® Penetrant

Inspection System) are available in the industry, but even that would not be acceptable if the heat load is high enough]. In such a case the loading procedure calls for local cooling of the MPC following final closure weld operations to insure the local metal temperatures are within the operating range of the liquid penetrant system. This local cooling may take the form best suited to the condition at a plant, such as targeted direct water spray on the top surface of the lid or placement of a heat sink on the MPC lid to draw the heat out of the lid. The methods mentioned hitherto are provided as examples and irrespective of the method used for local cooling, the lid temperature is required to be monitored during the NDE operation to confirm that it remains within the operating limits.

4-11 Provide justification for the proposed new standard methodology for calculating decay heats and identify any conservatisms included in the proposed methodology.

The proposed FSAR Section 5.2.5.3 describes a new methodology to calculate heat loads for zircaloy clad fuel. The applicant relies on comparisons of its method to RG 3.54 and an assessment of RG 3.54 to a limited set of measurements. While the applicant's assessment suggests the proposed methodology yields conservative results, the applicant has not provided information to justify the stated conservatism. The proposed FSAR states that "(T)his conservatism is sufficient to offset the 1 to 3% difference between RG 3.54 and the methodology proposed here." It is not clear whether 1 to 3% would be conservative and whether any safety factor has been considered in the applicant's methodology. The applicant's justification appears only to be based on comparisons to a limited set of assembly measurements, and it is not clear how the applicant's approach handles additional uncertainties when the method extends beyond the measured data range. For example, is there any consideration for assemblies with longer cooling times, such as beyond 30 years? In addition, there is no discussion of the actual methodology in the attachment, thus, the NRC staff would not be able to evaluate the applicant's analysis beyond the comparisons cited.

Lastly, justify why the proposed methodology does not include uncertainty for assembly burnup.

This information is needed to determine compliance with 10 CFR 72.236(f).

Holtec Response:

For expediency of NRC's safety review, we are withdrawing our proposal to change this methodology.

Tables 2.1.29 and 2.1.30 of the FSAR which contain the coefficients used in the calculations relating decay heat, burn up and enrichment as a function of cooling time, and Tables 2.4.3 and 2.4.4 of Appendix B of the CoC, have been updated with revised coefficients for fuel assembly cooling times 2 years through 40 years. Since a wider decay heat limits range is used in these calculations, including a new loading pattern in Figure 2.4-1 of Appendix B of the CoC, the existing coefficients for cooling times range 3 to 20 years are also slightly modified. The additional changes are made in Section 5.2.5.3 and in Appendix 5.F to reflect the abovementioned changes.

Chapter 8 – Materials Evaluation
8-1 Revise Table 3-1 of Appendix B, List of ASME Code Alternatives for HI-STORM 100 Cask System, to identify ASME Code Case N-635-1 for the use of duplex stainless steel UNS S31803 for MPC NB-2121.

The current text is consistent with the initial amendment application (prior to RSI), which listed a duplex stainless steel that was not included in a NRC-approved ASME Code Case.

This information is necessary to assure compliance with 10 CFR 72.236(b).

Holtec Response:
Table 3-1 of Appendix B of CoC No. 1014, List of ASME Code Alternatives for HI-STORM 100 Cask System, is revised to identify ASME Code Case N-635-1 for the use of duplex stainless steel UNS S31803 for MPC NB-2121.

Specifically, Table 3-1 is updated using the following text -

"Certain duplex stainless steels are not included in Section II, Part D, Tables 2A and 2B. UNS S31803 duplex stainless-steel alloy is evaluated in the HI-STORM 100 FSAR and meets the required design criteria for use in the HI-STORM 100 system per ASME Code Case N-635-1."

SAR Table 2.2.15 is also updated accordingly.

8-2 Revise FSAR sections that call out "Alloy X" for the MPC basket.

It is apparent from the proposed FSAR Section 1.A.1 that duplex stainless steels were intended for the MPC shell and not the MPC basket. As such, the following changes are needed:

a) Revise SAR Section 1.2.1.1, Multi-Purpose Canisters: "Any steel part in an MPC may be fabricated from any of the acceptable Alloy X materials listed below, except that the steel pieces comprising the MPC shell (i.e., the 1/2" thick cylinder) must be fabricated from the same Alloy X stainless steel type."
b) Revise materials for the MPC Basket and internal components included in SAR Table 2.2.6;
c) Revise SAR Section 3.1.2.3, "Brittle Fracture," to address the use of duplex stainless steels;
d) Revise SAR Section 3.3.1.1, "AIloy X";
e) Revise tables in SAR Chapter 3, as necessary;
f) Revise description of basket materials and tables in SAR Chapter 4;
g) Revise SAR Tables 7.1.1 and 7.1.4

This information is necessary to assure compliance with 10 CFR 72.236(b).

Holtec Response:
a) SAR Section 1.2.1.1 is revised to address the material selection of MPC Baskets appropriately, and the Section has been appended with the following text matter – "Any steel part in an MPC enclosure vessel may be fabricated from any of the acceptable Alloy X materials listed above. Additional material grades (viz. duplex stainless steel, UNS S31803) are adopted in the Alloy X roster in Appendix 1.A. These duplex steels shall <u>not</u> be used for the fabrication of MPC Baskets and MPC internal components."

b) Materials used to manufacture MPC Basket and internal components are revised appropriately in Table 2.2.6. To avoid further confusion, the following text is appended to Section 1.A.1 of Appendix 1.A

– “It is noted that duplex stainless-steel material shall not be used for the fabrication of MPC baskets and MPC internal components.” In addition to that, the following text is appended to Table 2.2.3 – “Temperature limits in Table 1.A.6 shall take precedence if Duplex Stainless Steels are used for the fabrication of confinement boundary components.”

c) SAR Section 3.1.2.3, “Brittle Fracture”, is revised to address the use of duplex stainless steels and the Section is modified as follows – “The MPC canister and basket are constructed from a series of stainless steels termed Alloy X. Austenitic stainless steels do not undergo a ductile-to-brittle transition (DBT) in the operating temperature range of the HI-STORM 100 System. Therefore, brittle fracture is not a concern for the MPC components fabricated using austenitic stainless steel. Such an assertion cannot be made a’ priori for the MPC confinement boundary components fabricated using duplex stainless-steel grade of Alloy X, or for the HI-STORM storage overpack and the HI-TRAC transfer cask that contain ferritic steel parts.

The use of duplex stainless-steel grade of Alloy X material is limited to the MPC confinement boundary components and shall be restricted to the maximum temperatures specified in Table 1.A.6 as the material may suffer from precipitation of brittle micro-constituents above 600°F.

The duplex stainless steel material undergoes DBT below the temperature of -40°F/-40°C [3.1.4] (which is equal to the Lowest Service Temperature (LST) of MPC). In addition, Holtec Position Paper DS-213 [9.1.6] demonstrates that crack propagation in MPC lid-to-shell weld is not-credible for austenitic and duplex stainless-steel grades of Alloy X. Therefore, brittle fracture is not a concern for the MPC confinement boundary components fabricated using duplex stainless-steel grade of Alloy X as well.”

[3.1.4] Practical Guidelines for the Fabrication of Duplex Stainless Steels, Second Edition 2009, International Molybdenum Association (IMOA), London, UK – ISBN: 978-1-907470-00-4.

[9.1.6] Holtec International Position Paper DS-213, “Acceptable Flaw Size in MPC Lid-to-Shell Welds”, Revision 4.

d) SAR Subsection 3.3.1.1, “Alloy X” is revised and the text is modified as follows – “The maximum temperatures in some MPC components may exceed the long term normal allowable temperature limits during short term loading operations, off-normal events, or storage accident events. However, it is ensured that the maximum temperature of austenitic stainless-steel grades of Alloy X used for or within the confinement boundary does not exceed 1000°F under any condition and the maximum temperature of duplex stainless-steel grade (UNS S31803) of Alloy X used for the confinement boundary does not exceed 600°F under any condition. As shown in ASME Code Case N-47-33 (Class 1 Components in Elevated Temperature Service, 1995 Code Cases, Nuclear Components), the strength properties of austenitic stainless steels do not change due to exposure to 1000°F temperature for up to 10,000 hours. In addition, per ASME Code Case N-635-1 (Use of 22Cr-5Ni-3Mo-N (Alloy UNS S31803) Forgings, Plate, Bar, Welded and Seamless Pipe, and/or Tube, Fittings, and Fusion Welded Pipe with Additional of Filler Metal, Classes 1, 2, and 3, Section III, Division 1), the maximum permissible temperature for duplex stainless-steel grade of Alloy X is 600°F.”

e) Subsection 3.3.1.1 of SAR Chapter 3 is revised to clearly state that MPC Basket and MPC internal components shall not be fabricated using duplex stainless-steel grade of Alloy X. In addition, notes in Tables 3.1.13, 3.1.15 and 3.3.1 of SAR Chapter 3 are either added or revised for clarification. As mentioned earlier in the response to RAI 8-2b, Section 1.A.1 the following text is appended in Appendix

1.A – “Duplex stainless-steel material shall not be used in the fabrication of MPC baskets and MPC internal components.” The revised FSAR text is provided for Staff’s review.

f) The following text is appended to Table 4.2.2 in Chapter 4 - "Individual thermal conductivities of the alloys that comprise the Alloy X materials are reported in Appendix 1.A. Lower-bound Alloy X thermal conductivity is tabulated herein." The revised FSAR text is provided for Staff’s review.

g) SAR Tables 7.1.1 and 7.1.4 are revised as below.

Table 7.1.1

SUMMARY OF CONFINEMENT BOUNDARY DESIGN SPECIFICATIONS

Design Condition	Design Pressure (psig)	Design Temperature* (°F)
Normal	100	See Table 2.2.3
Off-Normal/Short-Term	110	
Accident	200	
*Temperature limits in Table 1.A.6 shall take precedence in case Duplex Stainless Steels are used for the fabrication of confinement boundary components.		

Table 7.1.4

COMPARISON OF HOLTEC MPC DESIGN WITH ISG-18 GUIDANCE FOR STORAGE

DESIGN / QUALIFICATION GUIDANCE	HOLTEC MPC DESIGN	FSAR REFERENCE
The canister is constructed from Alloy X type material.	The MPC enclosure vessel is constructed entirely from Alloy X material. Alloy X is defined as Type 304, 304LN, 316, 316LN or duplex stainless-steel material. It is noted that duplex material shall not be used for the fabrication of MPC baskets and MPC internal components.	Section 1.2.1.1 and Appendix 1.A

8-3 Justify the 650°F allowable temperature for duplex stainless steel S31803 in the proposed FSAR Table 1.A.6.

ASME Code Case N-635-1 states that the maximum permissible temperature for duplex stainless steel S31803 is 600°F. Similarly, ASME Code, Section II, Part D, Table 1A (applicable to ASME Section III, Class 2 systems) also lists the maximum use temperature of 600°F for UNS S31803 (Page 126 of 2015 version).

This information is necessary to assure compliance with 10 CFR 72.236(b).

Holtec Response:
Holtec agrees with Staff's comments that the maximum permissible temperature for Duplex stainless steel (UNS S31803) is 600°F per ASME Codes. To address Staff's concern, the maximum allowable temperature for Duplex stainless steel under short-term events, off-normal and accident condition limits in Table 1.A.6 has been revised to 600°F to make it compliant with the ASME Code Case N-635-1 and ASME Code, Section II, Part D, Table 1A.

8-4 Provide technical justification for not requiring an engineering evaluation and a recovery plan for MPC shells constructed using duplex stainless steel S31803 after a 100% Air Inlets Blockage Accident, where the MPC shell temperature may exceed the maximum permissible temperature of 600°F specified in ASME Code Case N-635-1.

The proposed FSAR Table 4.III.7, "Maximum Temperatures and Pressures Under 32-Hour 100% Air Inlets Blockage Accident," indicates that the MPC shell temperature may reach 639°F. While the time at temperatures above 600°F may be too short for any significant embrittlement for a single incident, the blocked vent accident conditions could potentially occur multiple times during ISFSI operation.

This information is necessary to assure compliance with 10 CFR 72.236(b) and 10 CFR 72.236(g).

Holtec Response:
As stated in response to RAI 8-3, the maximum allowable temperature for Duplex stainless steel under short-term events, off-normal and accident condition limits in Table 1.A.6 has been revised to 600°F to make it compliant with the requirements of ASME Code Case N-635-1 and ASME Code, Section II, Part D, Table 1A. Holtec acknowledges that the MPC-68M confinement boundary component temperatures at design basis QSHL pattern exceed this duplex stainless steel temperature limit of 600^{o}F under 32-hour 100% vent blockage accident event. However, these component temperatures remain below the 600^{o}F temperature limit under a 16-hour 100% vent blockage accident. The surveillance requirement for vent blockage accident therefore has been revised in the FSAR and CoC for canisters made of duplex and loaded under QSHL pattern.

Additionally, it has also been observed that the MPC lid and MPC shell temperatures of the most limiting canister i.e., MPC-32 under 100% vent blockage accident exceed duplex steel's temperature limit. To ensure the temperature of MPC confinement boundary made with duplex stainless-steel alloy remain within its temperature limits under the most severe 100% vent blockage accident, LCO 3.1.2 in Appendix A of the CoC has been revised to clarify the required completion times and surveillance frequencies of all MPC types. Table 3-5 has been added in Appendix A of the CoC to provide this clarification. Sections 4.6.2.4 and 4.III.6.2, and Tables 4.6.5 and 4.III.7 of the proposed FSAR have been revised to support the required action completion times postulated in CoC Appendix A Table 3-5. FSAR text in Chapters 11 and 12 have also been amended to make this stipulation consistent.

The above ensures MPC confinement boundary temperatures remain below the temperature limits postulated in Table 1.A.6 of the FSAR under all conditions.

8-5 Provide a justification for the overpack inner shell maximum temperature during normal storage with a MPC-68M (proposed FSAR Table 4.III.3b) which exceeds the long-term normal design temperature limits in FSAR, Rev. 13, Table 2.2.3.
This information is necessary to assure compliance with 10 CFR 72.236(b).

Holtec Response:
The long-term normal design temperature limit for overpack inner shell ("Remainder of overpack steel structure" in Table 2.2.3) was increased to 400 ^{o}F from 350 ^{o}F via ECO-5014-252 and 10CRF72.48 #1207, under Holtec's NRC approved 72.48 program. All corresponding updates to the affected calculation packages and results in FSAR were also made via the same ECO.

The increased temperature limit value of 400 ^{o}F for overpack inner shell in Table 2.2.3 of FSAR (as modified by ECO/72.48) is higher than the calculated value of 358 ^{o}F reported in Table 4.III.3b of proposed FSAR (LAR 1014-12).

8-6 Provide an analysis to support the local maximum concrete temperature (355°F) under normal long-term storage in Table P.1 of the thermal calculation package in Holtec Report HI-2043317. The maximum concrete temperature exceeds the both the normal and accident temperature limits for concrete listed in ACI-349-85.

Note also that ACI 349-85 Appendix A Section A.4 - Concrete temperatures states:

> *A.4.1- The following temperature limitations are for normal operation or any other long term period. The temperatures shall not exceed 150°F except for local areas, such as around penetrations, which are allowed to have increased temperatures not to exceed 200°F.*
>
> *A.4.2 - The following temperature limitations are for accident or any other short term period, The temperatures shall not exceed 350°F for the surface. However, local areas are allowed to reach 650°F from steam or water jets in the event of a pipe failure.*

This information is necessary to assure compliance with 10 CFR 72.236(b).

Holtec Response:
The acceptance criteria for temperature limits for plain (non-structural) concrete and its basis are provided in Table 1.D.1 of HI-STORM 100 FSAR, which is unchanged in this application. The concrete temperature limits are summarized below:

1. Thru thickness section average temperature of concrete must remain below 300^{o}F under long term conditions.
2. Local maximum temperature of concrete must remain below 650^{o}F under short-term, off-normal and accident conditions (except fire).

The thru thickness section average concrete temperature under long term storage (equal to 257^{o}F) reported in Table P.1 of Holtec report HI-2043317 is below FSAR Table 1.D.1 temperature limit of 300^{o}F. Local maximum temperature of concrete in Table P.1 is reported to facilitate downstream calculations as explained below.

The acceptance criteria on concrete under short-term, off-normal and accident conditions is on its local maximum temperature. The component temperatures under off-normal ambient (Table P.10) and extreme ambient (Table P.12) temperatures are obtained by adding a suitable temperature adder to the component temperatures computed under normal storage conditions (Table P.1). It is for this reason that local concrete temperatures are reported in Table P.1. The results confirm that the local maximum concrete temperature remain below its limit of 650^{o}F.

Therefore, the concrete temperatures meet the acceptance criteria in the FSAR under all conditions of storage.

8-7 Provide a justification or analysis to support the off-normal and accident temperatures for concrete in the proposed FSAR Tables 4.III.7, 4.III.15, and 4.III.17 that exceed the maximum accident temperature limits for concrete listed in ACI-349-85. In addition, clarify the required recovery plan for the overpack following the off-normal and accident conditions where the concrete temperatures exceed the maximum accident temperature limits in ACI-349-85.

NUREG/CR-6900 (NRC, 2006) includes a summary of the potential concrete degradation mechanisms that occur at elevated temperatures. The analysis should include an assessment of these degradation mechanisms and their effects on the safety function of the concrete in the HI-STORM overpack.

This information is necessary to assure compliance with 10 CFR 72.236(b).

Holtec Response:
The acceptance criteria on concrete temperature limits under off-normal and accident conditions are defined in FSAR Table 1.D.1 (also see response to RAI 8-6). Specifically, local maximum temperature of concrete must remain below 650^{o}F under short-term, off-normal and accident conditions per Table 1.D.1 of HI-STORM 100 FSAR. The local maximum concrete temperature reported in FSAR Tables 4.III.7, 4.III.15 and 4.III.17 remain below its temperature limit of 650^{o}F with robust margins.

8-8 Revise the notes for the MPC basket drawings.

It is apparent from the proposed FSAR Section 1.A.1 that duplex stainless steels were intended for the MPC shell and not the MPC basket. As such, the following changes are needed:

a) Update notes on Drawing 3923 MPC shell to include duplex stainless steels as Alloy X materials.
b) Clarify or update notes on Drawing 3925 (MPC-24E/24EF basket) to be consistent with the proposed use of duplex SS as 'Alloy X' material.
c) Clarify or update notes on Drawing 3926 (MPC-24 basket) to be consistent with the proposed use of duplex SS as 'Alloy X' materials.
d) Clarify or update notes on Drawing 3927 (MPC-32 basket) to be consistent with the proposed use of duplex SS as 'Alloy X' materials.
e) Clarify or update notes on Drawing 3928 (MPC-68/68F/68FF basket) to be consistent with the proposed use of duplex SS as 'Alloy X' materials.

This information is necessary to assure compliance with 10 CFR 72.236(b).

Holtec Response:

To correct this unintended discrepancy between the drawing notes and the intent to preclude the use of duplex stainless steels in MPC baskets, the drawing notes are modified as follows:

Enclosure Vessel Drawing 3923: General Note 5 (Sheet 1) is revised to "ALL ENCLOSURE VESSEL STRUCTURAL MATERIALS ARE "ALLOY X" UNLESS OTHERWISE NOTED. MPC ENCLOSURE VESSEL (I.E.

CYLINDRICAL SHELL) WILL BE FABRICATED FROM PIECES MADE OF THE SAME TYPE OF STAINLESS STEEL. WELD MATERIAL COMPLIES WITH ASME SECTION II, PART C."

Basket Drawings 3925, 3926, 3927 and 3928: General Note 9 (Sheet 1) is revised to "UNLESS OTHERWISE NOTED, ALL STRUCTURAL MATERIALS ARE ALLOY "X", WITH THE EXCEPTION THAT DUPLEX STAINLESS STEEL SHALL NOT BE USED FOR BASKET COMPONENTS AND OTHER INTERNAL MPC COMPONENTS (BASKET SUPPORTS, SHIMS, ETC.)."

These changes to the drawing General Notes remove the references to the specific material types that are defined in the FSAR as Alloy "X", as this information is redundant with the information provided in Appendix 1.A of the FSAR. To bring the notes into conformance with the design intent, the enclosure vessel drawing (Drawing 3923) note allows use of the full range of designated Alloy "X" materials, while the basket drawing notes (Drawings 3925, 3926, 3927 and 3928) preclude the use of duplex stainless steel.

8-9 Revise Position Paper DS-213 to be consistent with required acceptance criteria for duplex stainless steel welds.

SAR Appendix 1.A, Section 1.A.1 (as revised in the RSI response) states:

> *Holtec will implement a test program to insure that the weldments are tested for the absence of detrimental intermetallic phases. The test program will comply with ASTM A923 and will use metallographic examination, impact testing and corrosion testing to demonstrate the absence of such detrimental phases.*

ASTM A923-14, Table 2 (ASTM International, 2015) identifies an acceptance criteria of 25 ft-lb for UNS 31803 welds and 40 ft-lb for the UNS S31803 base metal and weld heat affected zones.

The calculation of fracture toughness from the Charpy values in Holtec position paper DS-213 uses a relationship developed for ferritic steels applicable to the upper shelf temperature range (Roberts and Newton, 1981). Originally, Holtec position paper DS-213 only addressed austenitic stainless steels which do not have an observed ductile-to-brittle transition temperature. For austenitic stainless steels, the use of a correlation equation that is applicable to the upper shelf temperature range should yield conservative values of fracture toughness from Charpy data. However, duplex stainless steels have a microstructure with both austenitic and ferritic phases and previous testing has shown that duplex stainless steels and their welds can undergo a ductile-to-brittle transition around −40°C [−40°F] (Sieurin and Sandstrom, 2006). The duplex stainless steel MPCs may be exposed to a range of operating environments and temperatures. A fracture toughness correlation developed for ferritic steels that is limited to the upper shelf temperature range is unlikely to be appropriate for estimating the low temperatures behavior of duplex stainless steels with a microstructure having approximately 50% ferritic phase.

Holtec Positon Paper DS-213 should be revised to include the following:

> a) Actual specified minimum fracture toughness value for the duplex stainless steel welds that are consistent with the acceptance criteria in the referenced ASTM standard.

b) Provide information to justify the use of a fracture toughness correlation based on Charpy data for duplex stainless steels that demonstrated the calculated values of fracture toughness bound the contribution from the ferritic phase at low temperatures.

This information is necessary to assure compliance with 10 CFR 72.236(b) and 10 CFR 72.236(g).

Holtec Response:
As requested, Holtec Position Paper DS-213 has been revised to account for the minimum specified fracture toughness value (25 ft-lb) per ASTM A923, and it has also been updated to utilize the fracture toughness correlation developed by Barsom [8-9a] for ferritic steels in the transition temperature range. Although the calculated fracture toughness of the UNS 31803 welds has reduced as a result of these changes, the final conclusion remains the same. That is, the minimum fracture toughness of duplex stainless steel exceeds the critical stress intensity factor corresponding to a 50% thru-thickness crack in the MPC lid-to-MPC shell weld.

A copy of the revised Holtec Position Paper DS-213 (Rev. 4) is provided as Attachment 8 to this RAI response letter.

[8-9a] Barsom, J.M., “Development of the AASHTO Fracture Toughness Requirements for Bridge Steels,” Engineering Fracture Mechanics, 7 (1975): 605-618.

8-10 Revise Attachment 2 for Holtec Letter 5014812, “Structural Calculation Package for MPC,” (Holtec Report HI-2012787) and provide the following:

a) Fracture toughness estimations for Metamic-HT as a function of temperature using the mechanical properties reported in “Metamic-HT Qualification Sourcebook,” (Holtec Report HI-2084122 Revision 10) to support the calculation of a minimum flaw size for crack propagation.
b) Additional information with respect to the composition of Metamic-HT including the minimum and maximum boron carbide and aluminum oxide loading to allow a comparison of the estimated fracture toughness values for Metamic-HT to measured fracture toughness values of particle reinforced aluminum metal matrix composites.

In applicant’s structural calculation analysis, the Metamic-HT fracture toughness value provided was stated to be based on an estimate by NRC staff using Charpy impact data and a correlation between Charpy data and fracture toughness based on pressure vessel steels. The applicant stated that: “[…] *Based on CVE correlations for steels, the critical stress intensity factor of Metamic-HT basket was estimated by the NRC reviewer [1] to be KIC = 30 ksi in1/2* […].” The applicant further stated that the estimated value of fracture was comparable to the range of fracture toughness for aluminum alloys, which tend to be in the range of 18.2 to 45.5 ksi in1/2. Based on the estimated fracture toughness value, the applicant calculated a minimum flaw size for crack propagation, α, using the equation for the stress intensity for a plate with an edge crack (Holman and Langland, 1981) to be 1.275 inches or more than 20× greater than the allowable or detection flaw size stated by the applicant to be 1/16” (0.0625”).

The staff reviewed the applicant’s analysis and determined that the statement claiming that NRC staff estimated a value for the Metamic-HT critical stress intensity factor is not accurate. A review of the conversation record (ML092330054 and ML092440495) show that the NRC staff at the time were questioning the fracture toughness of Metamic-HT. The NRC staff estimation of the fracture toughness of an aluminum metal matrix composite (MMC) using a correlation developed for pressure vessel steels was understood to be an estimate. In addition, the staff note that estimating the fracture toughness for aluminum MMCs using data for aluminum alloys is not an established practice. Fracture toughness of aluminum alloys is dependent on a number of factors, including composition and condition for aluminum alloys that can be age hardened (ASM, 1998).

The Metamic-HT Qualification Sourcebook (Holtec Report HI-2084122 Revision 10) includes mechanical properties of Metamic-HT over a wide range of temperatures. Although fracture toughness is not directly measured, the Metamic-HT Qualification Sourcebook Attachment E includes: (1) calculation of the required fracture toughness as a function of peak stress and crack size and (2) a correlation equation developed for structural steels that can be used to calculate fracture toughness using the Charpy V-Notch (Cv) data and Young's Modulus (E) data.

The staff notes that the estimation of fracture toughness for Metamic-HT using a correlation equation developed for structural steel is not an established practice. Estimated values of fracture toughness for Metamic-HT can be compared to measured values of fracture toughness for particle reinforced aluminum metal matrix composites if the composition of Metamic-HT including the minimum and maximum boron carbide and aluminum oxide loading are provided. This is necessary to show that the use of the correlation equation for pressure vessel steels provides similar values of fracture toughness compared to reported fracture toughness values for analogous particle reinforced aluminum metal matric composites. The staff reviewed the available literature on fracture toughness measurements for aluminum metal matrix composites (Flom et al., 1989; Flom and Arsenault, 1989; Lewandowski, 2000; Miserez, 2003; Rabiei et al., 2008). Numerous aluminum MMCs exist which utilize a variety of aluminum alloys and ceramic particle compositions. Commonly used particle compositions include SIC, Al2O3, and B4C. Based on the available information on fracture toughness of aluminum MMCs, the range of fracture toughness values spans from 8 to 30 ksi·in1/2. Several factors can influence the fracture toughness of aluminum metal matrix composites including: (1) particle composition, (2) particle size, (3) particle loading, (4) particle distribution or clustering, (5) alloy composition and, (6) alloy condition for aluminum alloys that can be age hardened. The applicant should consider whether technical information in addition to the Metamic-HT composition should be provided to support a comparison of the fracture toughness values for Metamic-HT.

This information is necessary to assure compliance with 10 CFR 72.236(b).

Holtec Response:
Holtec agrees with the reviewer's comment that the specific correlation used by NRC staff for estimating the fracture toughness from Charpy energy might not be accurate for Metamic-HT. Attachment E to the Metamic-HT Sourcebook (HI-2084122, Revision 10) contains a calculation using the above-mentioned correlation to demonstrate that significant safety margins exist in the Holtec Metamic-HT fuel basket designs based on a conservatively established minimum Charpy energy value (4.0 ft-lbf) and lower bound Young's Moduli at elevated temperatures. The calculation leads to a conclusion in the sourcebook that crack propagation in the Metamic-HT material under the "cold" condition is not a realistic concern and therefore the Charpy energy value of the material is just an ancillary structural property for Metamic-HT. It is also noted that a survey of the test data accumulated from recent Charpy tests of the production lots shows energy values greater than 7 ft-lb.

Holtec is currently carrying out a detailed test program, in accordance with ASTM E1820-01, to measure the fracture toughness (K_{IC}) of extruded Metamic-HT panels used in the fabrication of the spent fuel baskets. [

PROPRIETARY INFORMATON WITHHELD PER 10CFR2.390

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Since the fracture toughness of Metamic-HT is being measured through a detailed test program, Holtec does not believe that there is a need to provide additional information with respect to the composition of Metamic-HT (for the NRC's proposed fracture toughness comparison against available literature). However, it is noted that there is at least 85% of pure aluminum in Metamic-HT (per Chapter 2 of HI-STAR 80 SAR, HI-2146261) and literature review suggests that fracture toughness is not a concern for metal matrix composites with such high percentage of aluminum.

8-11 Provide information on potential strength degradation of aluminum basket shims by thermal over-aging of precipitation-hardened microstructure.

The application addressed the use of aluminum alloy basket shims primarily in thermal performance. The applicant assumes aluminum alloy to be effective for the short duration dynamic loading from the tip-over accident. Aluminum alloy, such as Alloy 2219, used by Holtec is precipitation-hardened alloy. The application shows the shims temperature could be as high as 295˚C (563°F) under normal conditions (FSAR Table 3.III.3 and Table 4.III.3b). Literature data shows that over-aging and accompanying strength degradation could occur at 210 – 240 ˚C in a few hours (for Alloy 2219 in Rafi Raza et al., 2011).

It is unclear to the staff whether the structural analysis adequately accounts for potential degradation of strength of aluminum alloy for prolonged conditions including normal conditions as discussed in HI-STAR SAR Section 2.2 (Holtec International, 2017). The staff requests that the applicant (i) provide justification that the current tip-over analysis in the design basis is valid, (ii) revise the analysis to adequately account for the degradation of aluminum alloy strength, or (iii) state that the type of Alloy 2219 (e.g., 2219-O) is in the annealed conditions which would not be subject to degradation of strength due to over-aging. This information is needed to determine compliance with 10 CFR 72.236(b).

Holtec Response:
Per HI-STORM 100 FSAR reference [3.III.2], the specific aluminum shim material 2219-T8511 in the extruded form does not suffer significant strength degradation at the temperatures of 500^{o}F or lower

for a duration up to 10,000 hours. In addition, the Young's modulus of the material remains constant over time under the elevated temperature condition. Although the reported peak temperature in the basket shim is 563^{o}F, the same thermal analysis indicates that the cross-sectional average of the shim at the peak temperature location is about 500^{o}F and the volumetric average temperature of the shim is less than 450^{o}F (both values are not reported in the FSAR). It is also noted that the shim temperature drops over time, and the initial temperature drop is more rapid for the high heat load case of this amendment due to the nature of decay heat (typically, the fuel decay heat drops by 30% between 3rd year and 4th year).

Strictly speaking, the shim is not a structural member because it does not withstand any tensile loads, and the shim is in a confined space which would prevent its uncontrolled deformation under load. The fuel basket structural analysis for the tip-over condition was performed by modeling the shim as an elastic material with a Young's modulus value corresponding to 550^{o}F. The maximum stress of the shim obtained from the analysis is reported to be 8,798 psi (per Supplement 65 of HI-2012787), which is significantly smaller than the yield strength (14,000 psi) of the material at 550^{o}F for 10,000 hours (per HI-STORM 100 FSAR reference [3.III.2]). Since the shim remains elastic during the tip-over event and the Young's modulus of the shim material does not change over time, any potential local strength degradation in the shim would not affect the deformation (controlled by stress and Young's modulus) or function of the shim. Therefore, potential strength degradation of the MPC 68M fuel basket shim material for prolonged storage conditions is not a realistic structural concern.