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December 15, 2017

Jose Cuadrado Project Manager – Licensing Branch
Division of Spent Fuel Management
Office of Nuclear Material Safety and Safeguards

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Docket No. 72-1008, Certificate of Compliance (CoC) No. 1008

Subject: Submittal of Responses to NRC's 2nd Round RAIs for HI-STAR 100 Amendment Number 3

Reference(s): [1] "Second Request for Additional Information – Amendment No. 3 to Certificate of Compliance No. 1008 for the HI-STAR 100 Cask Storage System" (Letter from Jose Cuadrado (NRC) to Kimberly Manzione (Holtec) dated November 30, 2017)

Dear Mr. Cuadrado:

By letter dated November 30, 2017 [1], NRC staff requested additional information (RAIs) needed to complete their detailed technical review of HI-STAR 100 Amendment 3 to the Certificate of Compliance No. 1008.

Attachment 1 to this letter contains the responses to the RAIs. Attachment 3 contains the proposed FSAR changed pages. The FSAR utilizes track changes, and yellow highlighting to identify the changes specific to these RAI responses, to differentiate them from track changes used for previous RAI and RSI responses.

If you have any questions please contact me at 856-797-0900 ext. 3951.

Sincerely,

Kimberly Manzione
Licensing Manager,
Holtec International

NMSS26

cc: (via email)
Mike Layton (USNRC)
John McKirgan (USNRC)
Meraj Rahimi (USNRC)

Attachments:

Attachment 1: Responses to Requests for Additional Information (RAIs) for HI-STAR 100 LAR 1008-3
Attachment 2: HI-STAR 100 FSAR Proposed Changed pages (Proposed Rev. 4.B)

Second Request for Additional Information

Docket No. 72-1008
Certificate of Compliance No. 1008
HI-STAR 100 Cask Storage System
Amendment No. 3

By letter dated September 25, 2015, as supplemented on January 15, and April 29, 2016, Holtec International (Holtec) submitted a request to the U.S. Nuclear Regulatory Commission (NRC or staff) to amend Certificate of Compliance (CoC) No. 1008 for the HI-STAR 100 Cask Storage System.

This request for additional information (RAI) identifies additional information needed by the NRC staff in connection with its review of the amendment application. The requested information is listed by topic and/or page number in the application and associated documentation. NUREG-1536, Revision 1, "Standard Review Plan for Dry Cask Storage Systems" was used by the staff in its review of the application.

Each individual RAI section describes information needed by the staff to complete its review of the application and to determine whether the applicant has demonstrated compliance with the regulatory requirements.

4.0 Thermal Evaluation

4-1 Provide additional justifications, more specific incorporation by reference, and/or thermal analyses that demonstrate how the thermal performance of the MPC-68 canister bounds that of the MPC-32 canister when loaded in the HI-STAR 100 Cask Storage System in vertical and horizontal orientation for normal, off-normal, and accident storage conditions, and evaluate the resulting peak cladding temperature and SSCs maximum temperatures, thermal stresses, and canister cavity pressures in Chapter 4 of the application.

In its response to the first RAI, the applicant provided additional descriptions of the HI-TRAC and HI-STAR 100 dimensions, design features, and heat transfer mechanisms and states that because the thermal analyses for the HI-STORM 100 Cask Storage System (CoC No. 1004) demonstrate that the MPC-68 bounds the MPC-32 in the HI-TRAC transfer cask, then a similar result will be expected for the HI-STAR 100 overpack and that the MPC-68 results will bound the MPC-32. However, the amendment application does not address the specific differences, if any, between the HI-TRAC and HI-STAR 100 thermal models used to calculate the maximum temperatures for the MPC-32 and MPC-68, respectively; nor does it provide sufficient description or references for how the thermal model of the HI-TRAC transfer cask (referenced from the HI-STORM 100 FSAR) adequately considers normal, off normal, and accident conditions of storage for the MPC-32 in the HI-STAR 100 Cask Storage System. During the review of Holtec's application for Amendment No. 11 to the HI-STORM 100 System (Docket No. 72-1014, ADAMS Accession No. ML16323A118), the staff raised similar questions concerning the assumption that the thermal model for the MPC-68 bounds the MPC-32, which resulted in the reduction of the MPC-32 canister decay heat. If the applicant chooses to provide additional justification or incorporation by reference to address the

Enclosure

staff's request, it should ensure that the information provided is thoroughly discussed and/or properly referenced in its proposed Final Safety Analysis Revision (FSAR). Alternatively, if the applicant chooses to provide additional thermal analyses to address the staff's request, the applicant should submit any associated input and output files with its response.

This information is necessary to demonstrate compliance with 10 CFR 72.236(f).

Holtec Response: To address the reviewer's query in the most direct manner, the steady state thermal analysis of a vertically-oriented HI-STAR 100 under the normal condition of storage containing an MPC-32 has been performed using the licensing-basis Fluent model[1]. For reference purposes, the analysis for the case with HI-STAR 100 containing an MPC-68 is also tabulated below. Two columns in the table below provide the post-processed results for the vertically-oriented HI-STAR 100 containing an MPC-32 and an MPC-68, respectively. Results for both fission product barriers (i.e., the cladding of intact fuel and the limiting MPC confinement boundary component, which is the MPC shell) are presented.

Table 4-1.1: MPC-68 and MPC-32 Results in Vertical Orientation

Component	**MPC-32 Vertical (Licensing Basis Heat Load = 18.5 kW)**	**MPC-68 Vertical (Licensing Basis Heat Load = 18.5 kW) Note 1**	**Normal Storage Allowable Note 2**
Maximum Contents and Components Temperatures			
Fuel Cladding	710°F	741°F	752°F
MPC Shell	315°F	331°F	450°F
Confinement Boundary Pressure Note 3			
MPC Internal Pressure	46.6 psig	57.5 psig	100 psig

Notes

1. The temperature and MPC cavity pressure results for MPC-68 are extracted from Tables 4.4.11 and 4.4.15 of HI-STAR 100 FSAR [1].
2. The temperature and pressure limits are extracted from Tables 2.2.3 and 2.2.1 of HI-STAR 100 FSAR [1].
3. The initial helium backfill pressures used to compute the confinement boundary pressures are 36.9 psia for the MPC-32 and 43.2 psia for the MPC-68, both at a 70°F reference temperature. These conservatively bound the nominal backfill requirements from Table 2-1 in Appendix A of the proposed technical specifications.

These results indicate that, in the vertical orientation, the MPC-68 case provides a higher temperature for the fuel cladding compared to MPC-32 under normal conditions of storage. Most important, all safety-significant temperatures and pressure are found to be well below their respective limits (provided in the last column of the above table).

For a horizontally-oriented HI-STAR 100, the steady state thermal analysis results for the normal condition of transport from the HI-STAR 100 SAR is incorporated by reference. Two columns in the

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[1] These calculations were performed using the methodology described in Section 4.4 of the HI-STAR 100 FSAR.

table below provide the results for the horizontally-oriented HI-STAR 100 containing a PWR MPC and a BWR MPC from Chapter 3 of HI-STAR 100 SAR. Results for both fission product barriers (i.e., the cladding of intact fuel and the limiting MPC confinement boundary component, which is the MPC shell) are presented.

Table 4-1.2: MPC-68 and MPC-32 Results in Horizontal Orientation

Component	**MPC-32 Horizontal (Licensing Basis Heat Load = 20 kW)** Note 1	**MPC-68 Horizontal (Licensing Basis Heat Load = 18.5 kW)** Note 2	**Normal Storage Allowable** Note 3
Maximum Contents and Components Temperatures			
Fuel Cladding	701°F	713°F	752°F
MPC Shell	315°F	306°F	450°F
Confinement Boundary Pressure Note 4			
MPC Internal Pressure	89.3 psig	85.8 psig	100 psig

Notes
1. The temperature and MPC cavity pressure results for MPC-32 are incorporated by reference from Tables 3.4.10 and 3.4.15 of HI-STAR 100 SAR [2].
2. The temperature and MPC cavity pressure results for MPC-68 are incorporated by reference from Tables 3.4.11 and 3.4.15 of HI-STAR 100 SAR [2].
3. The temperature and pressure limits are extracted from Tables 2.2.3 and 2.2.1 of HI-STAR 100 FSAR [1].
4. The initial helium backfill pressure used to compute the confinement boundary pressures is 42.8 psig at a 70°F reference temperature, the maximum backfill level from Table 2-1 in Appendix A of the proposed technical specifications.

These results indicate that, in the horizontal orientation, the MPC-68 case provides a higher temperature for the fuel cladding compared to MPC-32. Most important, all safety-significant temperatures and pressure are found to be well below their respective limits (provided in the last column of the above table).

Sub-Section 4.4.2.1 of the FSAR will be revised to provide the above clarifications. Since MPC-68 bounds MPC-32, safety conclusions made for off-normal and accident conditions in Chapter 11 of HI-STAR 100 FSAR for both horizontally and vertically oriented casks remain applicable.

References:

[1] HI-STAR 100 Storage FSAR, Holtec Report HI-2012610, Proposed Revision 4.

[2] HI-STAR 100 Transport SAR, Holtec Report HI-951251, Revision 16.

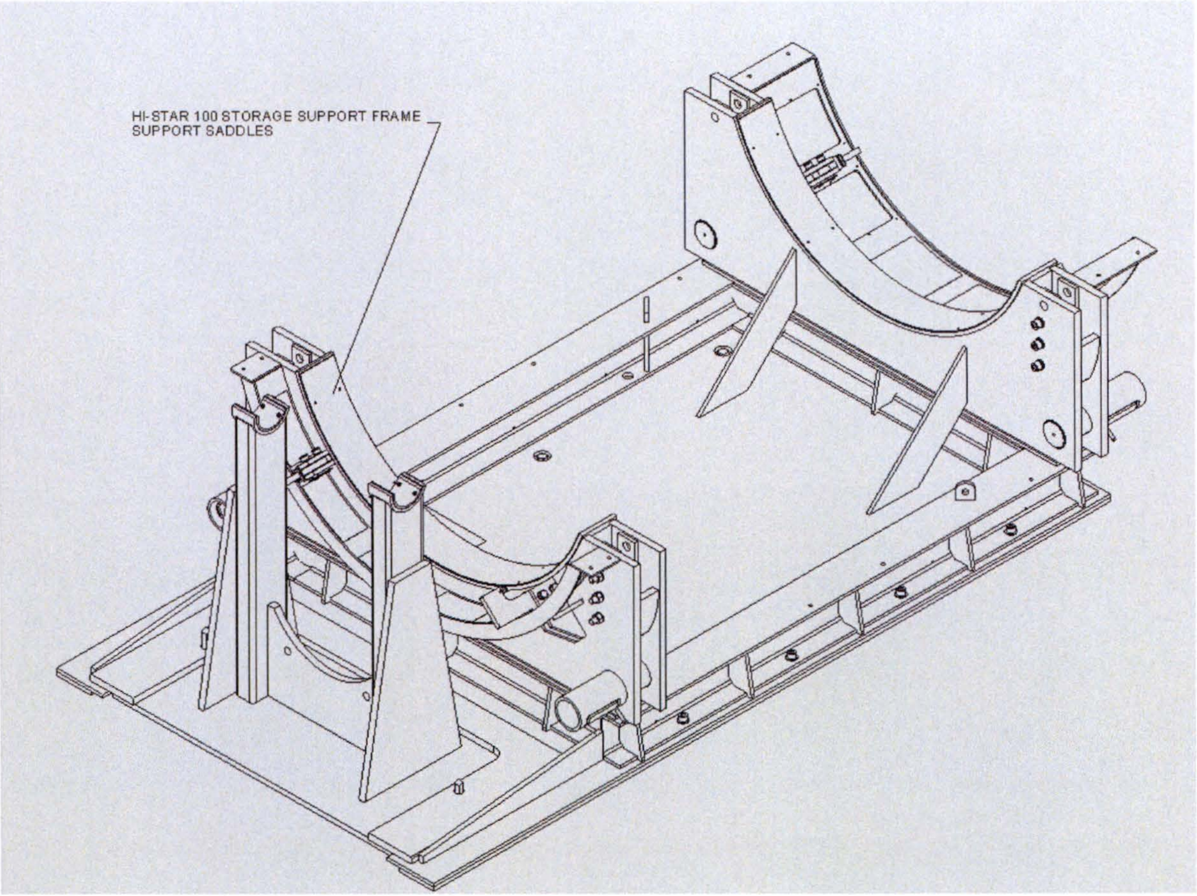
4-2 Provide additional discussion, descriptions, more specific incorporation by reference, or thermal analyses, to address how the physical attributes of the horizontal emplacement structure affects the thermal performance characteristics of the HI-STAR 100 Cask Storage System when emplaced in a horizontal orientation, for normal, off-normal, and accident conditions.

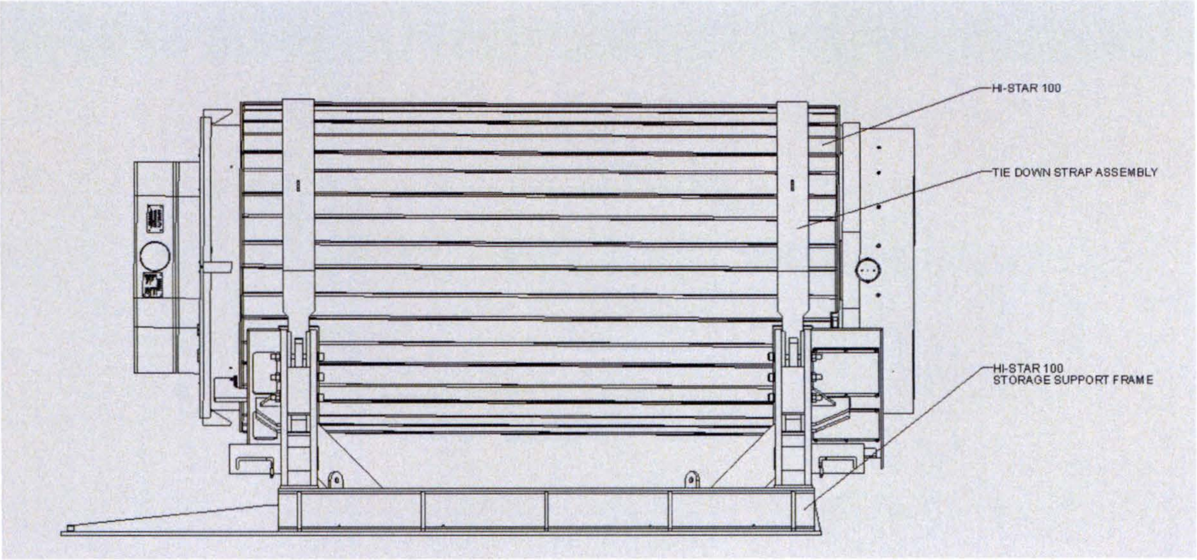
In its first RAI, staff sought additional design information for the emplacement structure to be used to maintain the cask in a horizontal orientation. In its response, Holtec stated that it considers the proposed horizontal emplacement structure as not important to safety because it has analyzed the effect of cask drops from a height higher than the proposed height of the horizontal emplacement structure. However, in its response, Holtec does not discuss or evaluate the effects that this horizontal emplacement structure may have on the thermal performance of the cask or if it presents unique boundary conditions that need to be considered.

The staff needs additional information, either through design drawings, detailed descriptions, incorporation by reference, or thermal analyses, to verify that the boundary conditions accorded by the horizontal emplacement structure do not affect the thermal performance characteristics of the HI-STAR 100 in storage. The applicant should ensure that the most bounding MPC type is addressed. Because the horizontal emplacement of the HI-STAR 100 System has not been previously discussed or analyzed by the applicant, the method by which a HI-STAR 100 cask system would be placed on a storage pad at an ISFSI or interim storage facility is not known. The means of emplacement are an important element in determining off-normal and accident conditions that could occur during the movement of the HI-STAR 100 cask system to its storage configuration. Postulated off-normal and accident conditions (including a fire during the movement evolution, or a seismic event during storage, for example) would be different for a cask being placed in a horizontal vs. a vertical storage configuration. The off-normal and accident conditions that could occur during the emplacement of the HI-STAR 100 cask system in a horizontal storage configuration should be considered and analyzed to demonstrate that the cask maintains its safety functions under these conditions. The emplacement structure, and its effect on the cask system, should also be considered in these analyses. If the applicant chooses to provide additional justification or incorporation by reference to address the staff's request, it should ensure that the information provided is thoroughly discussed and/or properly referenced in its proposed FSAR revision. Alternatively, if the applicant chooses to provide additional thermal analyses to address the staff's request, the applicant should submit any associated input and output files with its response.

This information is necessary to demonstrate compliance with 10 CFR 72.236(f)

Holtec Response: In the horizontal orientation for storage, the HI-STAR 100 is supported by saddle-type supports located near the cask's extremities as shown in the following figures. As can be seen from the figures below, the saddles cover on the order of 40% of the cask circumference. Metal tie-down straps wrap around the remainder of the circumference at the same axial locations to secure the cask to the saddles. A tilting plate bolted to the cask base surface assists in rotating the cask from vertical to horizontal, and is left in place afterwards to provide additional gamma and neutron shielding.





The relevant dimensions of the saddle supports and tie-down straps are listed in the following table.

Table 4-2.1: Horizontal Emplacement Structure Dimensions		
Dimension	**S.I Value**	**U.S. Value**
Saddle Center-to-Center Spacing	3632 mm	143 in
Saddle Radius	1226 mm	48 9/32 in
Saddle Arc Length	140 deg.	140 deg.
Saddle Width	290 mm	11 13/32 in
Cask Centerline Height	1780 mm	70 1/8 in
Tie-Down Strap Width	230 mm	9 1/16 in
Tie-Down Strap Radius	1244 mm	48 3/16 in
Tie-Down Strap Thickness	25 mm	31/32 in

These saddle dimensions shall be used whenever the HI-STAR 100 cask is held horizontally. The above figures and horizontal emplacement structure dimensions will be added to the FSAR.

As can be inferred from the above figure, the configuration of the HI-STAR 100 cask in horizontal storage emulates its configuration in transport, with the notable difference that there is are no impact limiters to reduce the rejection of heat from the cask's ends. This deduction is borne out by the Fluent analysis summarized below.

Normal Conditions of Horizontal Storage

Thermal evaluations of the horizontally disposed HI-STAR 100 cask positioned on the above saddle supports was performed for both MPC-68 and MPC-32 cases under their respective Licensing Basis heat loads. These evaluations are performed using the methodology described in Section 3.4 of the HI-STAR 100 SAR. This methodology is consistently used for evaluating all horizontally-oriented casks, whether in storage or transportation. The following tables present comparisons of normal horizontal storage and normal horizontal transport (the latter excerpted from the HI-STAR 100 SAR Tables 3.4.10 and 3.4.11) for PWR and BWR canisters, respectively. Results for both fission product barriers (i.e., the cladding of intact fuel and the MPC confinement boundary) are presented.

Table 4-2.2: HI-STAR 100 with BWR Canister Normal Transport Incorporated by Reference vs. Normal Storage and Allowables			
	Normal Horizontal Transport Note 1	**Normal Horizontal Storage** Note 2	**Normal Storage Allowable** Note 3
Ambient Temperature			
Normal Condition	100°F	80°F	N/A
Component Temperatures			
Fuel Cladding	713°F	639°F	752°F
MPC Shell	306°F	288°F	450°F
Internal Pressure Note 4			
MPC Cavity Pressure	85.8 psig	85.2 psig	100 psig

Table 4-2.2: HI-STAR 100 with BWR Canister
Normal Transport Incorporated by Reference vs. Normal Storage and Allowables

Notes

1. The temperature and MPC cavity pressure results for normal transport are incorporated by reference from Tables 3.4.11 and 3.4.15 of HI-STAR 100 SAR [2].
2. Thermal evaluations of a horizontal HI-STAR 100 cask positioned on the saddle supports was performed under the Licensing Basis heat loads. These evaluations are performed using the methodology described in Section 3.4 of HI-STAR 100 SAR [2].
3. The temperature and pressure limits are extracted from Tables 2.2.3 and 2.2.1 of HI-STAR 100 FSAR [1].
4. The initial helium backfill pressure used to compute the confinement boundary pressures is 42.8 psig at a 70°F reference temperature, the maximum backfill level from Table 2-1 in Appendix A of the proposed technical specifications.

Table 4-2.3: HI-STAR 100 with PWR Canister
Normal Transport Incorporated by Reference vs. Normal Storage and Allowables

	Normal Horizontal Transport Note 1	**Normal Horizontal Storage** Note 2	**Normal Storage Allowable** Note 3
Ambient Temperature			
Normal Condition	100°F	80°F	N/A
Component Temperatures			
Fuel Cladding	701°F	698°F	752°F
MPC Shell	315°F	306°F	450°F
Internal Pressure Note 4			
MPC Cavity Pressure	89.3 psig	89.2 psig	100 psig

Notes

1. The temperature and MPC cavity pressure results for normal transport are incorporated by reference from Tables 3.4.10 and 3.4.15 of HI-STAR 100 SAR [2].
2. Thermal evaluations of a horizontal HI-STAR 100 cask positioned on the saddle supports was performed under the Licensing Basis heat loads. These evaluations are performed using the methodology described in Section 3.4 of HI-STAR 100 SAR [2].
3. The temperature and pressure limits are extracted from Tables 2.2.3 and 2.2.1 of HI-STAR 100 FSAR [1].
4. The initial helium backfill pressure used to compute the confinement boundary pressures is 42.8 psig at a 70°F reference temperature, the maximum backfill level from Table 2-1 in Appendix A of the proposed technical specifications.

As these two tables show, the thermal performance of the cask under horizontal storage conditions while mounted in the support structure is essentially the same as or somewhat superior to the horizontal transport conditions incorporated by reference. More critically, it is shown that all fission product boundary temperatures and internal pressures remain below their respective limits. It is concluded, therefore, that the safety analysis for the transport condition does conservatively represent the thermal performance under the horizontal normal storage condition.

The above conclusion is based on the support system geometry described above, added to the FSAR, and adopted in the analysis.

Off-Normal and Accident Condition of Horizontal Storage

Off-normal and accident conditions of storage, as tabulated below, are characterized by elevated ambient temperatures. The permissible temperatures are also correspondingly higher. A first-order estimate of the margin-to-limit for each component may be obtained by assuming that they will increase in direct proportion to the rise in the ambient temperature (a reasonable assumption for a natural convection controlled problem). The results summarized in the table below show that the margins for the off-normal and accident conditions are even larger than those for the normal condition of storage.

Table 4-2.4: Margins-to-Limit for HI-STAR 100 with PWR Canister in Horizontal Storage Under Various Conditions at Licensing Basis Heat Load

Component	Horizontal Normal Condition (80°F ambient)		Horizontal Off-Normal Condition (100°F ambient)	
	Component Temperature (from table above)	Margin to Limit	Estimated Component Temperature	Margin to Limit
Fuel Cladding	698°F	54	718°F	340°F
MPC Shell	306°F	144	326°F	449°F
MPC Baseplate	289°F	111	309°F	466°F
MPC Lid	171°F	379	191°F	584°F
	Horizontal Accident Condition (125°F ambient)			
	Estimated Component Temperature	Margin to Limit		
Fuel Cladding	743°F	315°F		
MPC Shell	351°F	424°F		
MPC Baseplate	334°F	441°F		
MPC Lid	216°F	559°F		

Design Basis Fire Event

The fire event for storage assumes the same flame temperature and all-enveloping fire as those required by transport (Part 71), but the latter has a longer duration (30 minutes vs. 5.1 minutes as stated in Paragraph 11.2.3.2 of the HI-STAR 100 FSAR). As a result, the part temperatures under the storage fire event can be reasonably assumed to be bounded by the transport condition safety analysis reported in Section 3.5 of the HI-STAR 100 SAR (Report HI-951251). Because the thermal margins reported in the above SAR are quite large (see Table 3.5.4), it is concluded that the storage fire event will not adversely challenge the positive safety margins in the cask.

As is true of all site implementations, site-specific fire events that are not bounded by the FSAR will require a site specific 10CFR72.212 evaluation.

4-3 Provide more detailed and specific references to the thermal analyses from the HI-STAR 100 Transportation Cask System Safety Analysis Report (SAR), including the specific chapters, sub-sections, or revision numbers) that will be used to demonstrate that the HI-STAR 100 Cask Storage System in a horizontal orientation meets the applicable limits and addresses the peak cladding temperature, SSCs maximum temperatures, thermal stresses, and canister cavity pressures; and provide additional discussions, within the HI-STAR 100 Cask Storage System FSAR, that explain how the referenced analyses are applicable to the horizontal storage configuration during normal, off-normal, and accident conditions of storage

In its application and RAI response, the applicant seeks to incorporate by reference the thermal analyses from the SAR for the HI-STAR 100 Transportation Cask System. However, the applicant does not provide the specific version or revision of the HI-STAR 100 Transportation Cask System SAR that it seeks to incorporate by reference, nor does it reference the specific sub-sections, chapters, or supplemental analyses that it intends to rely on to demonstrate compliance with 10 CFR Part 72 storage requirements. The applicant needs to provide clear and specific discussions, explanations, and/or justifications, within the HI-STAR 100 Storage Cask System FSAR, that discuss how these referenced transportation thermal analyses are applicable to the horizontal storage configuration, and specifically indicate which portions of the thermal analyses from the transportation SAR are used to support the analysis of normal, off-normal, and accident conditions of storage, which address the peak cladding temperature, SSCs maximum temperatures, thermal stresses, and canister cavity pressures. In addition, the applicant should ensure that the thermal analyses adequately consider the effects of the horizontal emplacement structure (see RAI 4-2).

This information is necessary to demonstrate compliance with 10 CFR 72.236(f).

Holtec Response: Throughout Chapter 4 of the submitted proposed FSAR, references made to the HI-STAR 100 transportation SAR cite the specific section or subsection or paragraph being referenced. In addition, every such citation also invokes Reference 4.0.1, which does identify the specific revision of the HI-STAR 100 transportation SAR being referenced as Revision 15. To further improve convenience of access to the information incorporated by reference, a summary table like those provided by Holtec on other dockets (e.g., Table 4.0.1 in the HI-STORM UMAX FSAR) will be added to Section 4.0.

4-4 Provide discussion and results of the thermal analysis in Section 4.4.1.1.7 of the FSAR that addresses the thermal interaction among casks in an array that ensures the cask array pitch or center-to-center spacing is bounding for all cask contents/MPCs, considers the most bounding combination of vertical and/or horizontal cask orientation, and provides justification for the most bounding combination of vertical and/or horizontal cask orientation.

The thermal interaction among casks in an array for the most bounding combination of vertical and/or horizontal cask orientation has not been described in Section 4.4.1.1.7, "Heat Rejection from Overpack Exterior Surfaces," of the HI-STAR 100 Cask Storage System FSAR. It is not clear if both horizontally and vertically oriented casks will be mixed, if the calculated cask array pitch (12 feet) is bounding for any combination of cask orientations, or if the minimum spacing is bounding for any type of canister models (e.g. MPC-24, MPC-32, and MPC-68).

This information is necessary to demonstrate compliance with 10 CFR 72.236(f).

Holtec Response: The required minimum cask-to-cask pitch of 12 feet in both orthogonal directions, specified in Section 1.4 of the proposed FSAR, is applicable to arrays of vertically-oriented casks only. For arrays of horizontally-oriented casks, a minimum lateral cask-to-cask pitch of 18 feet and a minimum axial cask-to-cask clearance of 5 feet is proposed (as shown in the following sketch).

Vertically-oriented and horizontally-oriented casks will not be combined within an array, and a separation of at least 18 feet will be maintained between adjacent arrays.

Evaluations of a horizontally-oriented HI-STAR 100 cask in the proposed array configuration are performed. All casks are mounted on the supports as described in the response to RAI 4-2, above. These evaluations are performed using the methodology described in Section 3.4 of the HI-STAR 100 SAR. This methodology is consistently used for evaluating all horizontally-oriented casks, whether in storage or transportation. The effects of neighboring casks in the array is implemented using the same approach described in Subparagraph 4.4.1.1.7 of the HI-STAR 100 FSAR; that is calculating cask-to-cask blockage factors, reducing the cask-to-ambient view factor by the blockage factor, and multiplying the cask surface emissivity by the reduced view factor. The following tables present normal storage performance results for BWR and PWR canisters. Results for both fission product barriers (i.e., the cladding of intact fuel and the MPC confinement boundary) are presented.

Table 4-4.1: HI-STAR 100 with BWR Canister – Normal Horizontal Storage In An Array

	Normal Horizontal Storage (Note 1)	**Normal Storage Allowable (Note 2)**
Component Temperatures		
Fuel Cladding	644°F	752°F
MPC Shell	298°F	450°F
MPC Baseplate	281°F	400°F
MPC Lid	180°F	550°F
Internal Pressure Note 3		
MPC Cavity Pressure	86 psig	100 psig

Notes

1. Thermal evaluations of a horizontal HI-STAR 100 cask positioned on the saddle supports was performed under the Licensing Basis heat loads. These evaluations are performed using the methodology described in Section 3.4 of HI-STAR 100 SAR [2].
2. The temperature and pressure limits are extracted from Tables 2.2.3 and 2.2.1 of HI-STAR 100 FSAR [1].
3. The initial helium backfill pressure used to compute the confinement boundary pressures is 42.8 psig at a 70°F reference temperature, the maximum backfill level from Table 2-1 in Appendix A of the proposed technical specifications.

Table 4-4.2: HI-STAR 100 with PWR Canister – Normal Horizontal Storage In An Array

	Normal Horizontal Storage (Note 1)	**Normal Storage Allowable (Note 2)**
Component Temperatures		
Fuel Cladding	703°F	752°F
MPC Shell	316°F	450°F
MPC Baseplate	300°F	400°F
MPC Lid	180°F	550°F

Internal Pressure [Note3]		
MPC Cavity Pressure	90 psig	100 psig

Notes

1. Thermal evaluations of a horizontal HI-STAR 100 cask positioned on the saddle supports was performed under the Licensing Basis heat loads. These evaluations are performed using the methodology described in Section 3.4 of HI-STAR 100 SAR [2].
2. The temperature and pressure limits are extracted from Tables 2.2.3 and 2.2.1 of HI-STAR 100 FSAR [1].
3. The initial helium backfill pressure used to compute the confinement boundary pressures is 42.8 psig at a 70°F reference temperature, the maximum backfill level from Table 2-1 in Appendix A of the proposed technical specifications.

As these two tables show, for the cask under horizontal storage conditions arrayed at the proposed pitches, all fission product boundary temperatures and internal pressures remain below their respective limits. The increase in the components' temperatures is minor. It is concluded, therefore, that the proposed separation between the horizontally stored casks is suitable for horizontal deployment of HI-STAR 100 Systems.

The cask pitch and supporting thermal evaluations will be added to the HI-STAR 100 FSAR.

- Material Degradation
- Maintenance and Inspection Provisions

MPC

- Corrosion
- Structural Fatigue Effects
- Maintenance of Helium Atmosphere
- Allowable Fuel Cladding Temperatures
- Neutron Absorber Boron Depletion

The adequacy of the HI-STAR 100 System for its design life is discussed in sub-sections 3.4.10 and 3.4.11.

1.2.1.6 Support Structure for Horizontal Casks

In the horizontal orientation for storage, the HI-STAR 100 is supported by saddle-type supports located near the cask's extremities as shown in Figure 1.2.13. As can be seen in the figure, the saddles support the cask from below. Steel tie-down straps wrap around the remainder of the circumference at the same axial locations to secure the cask to the saddles. A tilting plate bolted to the cask base surface assists in rotating the cask from vertical to horizontal, and is left in place afterwards to provide additional gamma and neutron shielding

Basic dimensions of the saddle supports and tie-down straps are presented in Table 1.2.7. These saddle dimensions shall be used whenever the HI-STAR 100 cask is held horizontally.

1.2.2 Operational Characteristics

1.2.2.1 Design Features

The HI-STAR 100 System is engineered to store different types of MPCs for varying PWR and BWR fuel characteristics.

The HI-STAR 100 System can safely store spent nuclear fuel with minimum cooling times. The maximum thermal decay heat load and SNF enrichments for each of the MPCs are identified in Chapter 2. The decay heat emitted by the spent nuclear fuel is dissipated in an entirely passive mode without any mechanical or forced cooling.

Both the free volume of the HI-STAR 100 MPCs and the annulus between the external surface of the MPC and the inside surface of the overpack are inerted with commercially pure helium gas during the spent nuclear fuel loading operations. Table 1.2.2 specifies the helium pressure to be placed in the MPC internal cavity.

The primary heat transfer mechanisms are metal conduction and surface radiation for the HI-STAR 100 System. The MPC internal helium atmosphere, in addition to providing a noncorrosive dry

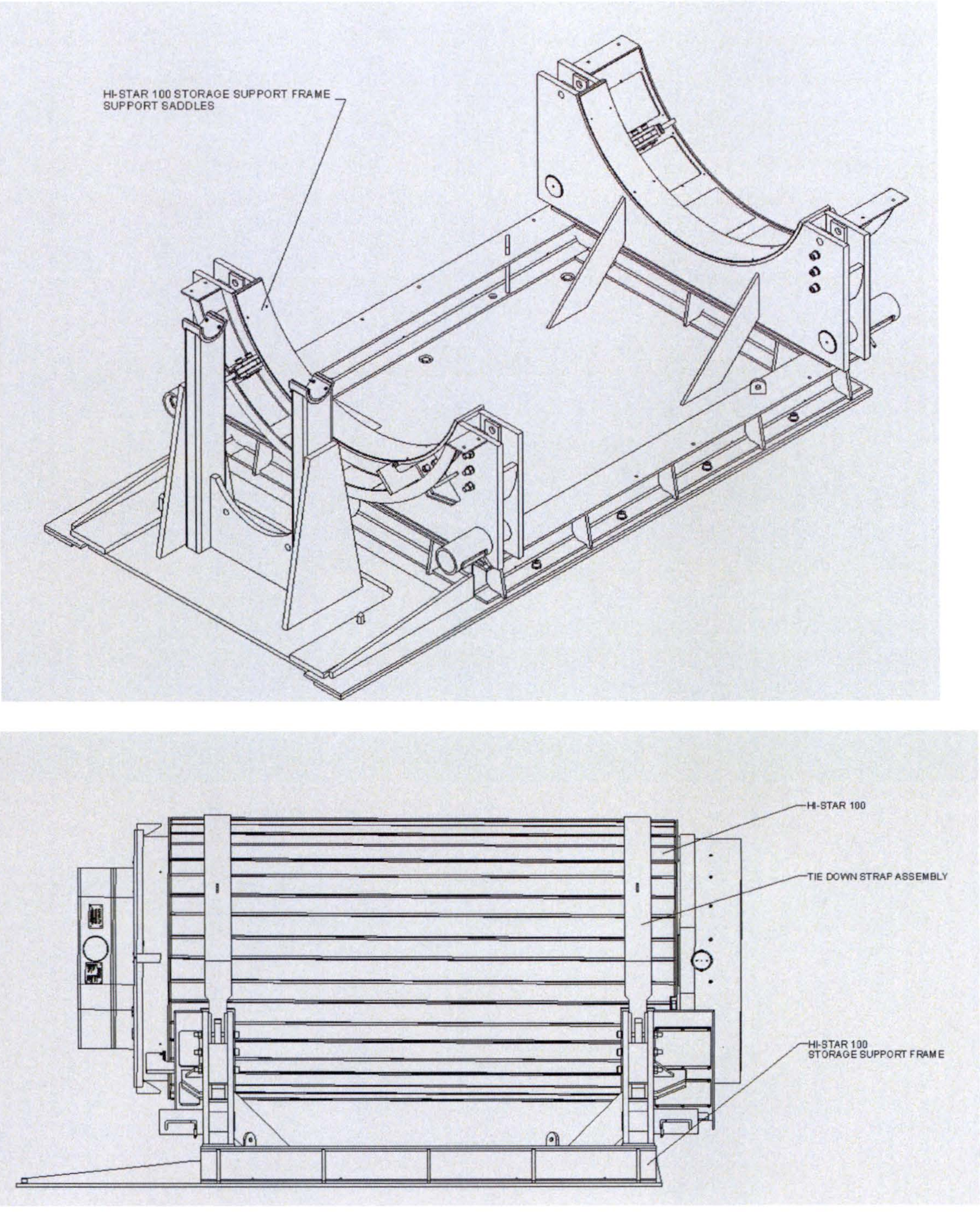
TABLE 1.2.7

DIMENSIONS OF SUPPORT STRUCTURE FOR HORIZONTAL-ORIENTATION CASKS

Dimension	**S.I Value**	**U.S. Value**
Saddle Center-to-Center Spacing	3632 mm	143 in
Saddle Radius	1226 mm	48 9/32 in
Saddle Arc Length	140 deg.	140 deg.
Saddle Width	290 mm	11 13/32 in
Cask Centerline Height	1780 mm	70 1/8 in
Tie-Down Strap Width	230 mm	9 1/16 in
Tie-Down Strap Radius	1244 mm	48 3/16 in
Tie-Down Strap Thickness	25 mm	31/32 in

FIGURE 1.2.13

SUPPORT STRUCTURE FOR HORIZONTAL-ORIENTATION CASKS



1.4 GENERIC CASK ARRAYS

The only system required for storage of the HI-STAR 100 System is the loaded overpack itself. The HI-STAR 100 System is stored in either a vertical or horizontal orientation. A typical vertical-orientation ISFSI storage pattern is illustrated in Figure 1.4.1, which shows an array in a rectangular layout pattern. The required center-to-center spacing between the modules (layout pitch), guided by heat transfer considerations, is specified to be 12 feet in both orthogonal directions. The pitch may be increased to suit facility considerations.

A typical horizontal-orientation ISFSI storage pattern is illustrated in Figure 1.4.2. In horizontal storage, the design-basis lateral distance between cask centerlines is 18 feet (5.5 m) to provide practical access for handling equipment and the design-basis axial cask-to-cask clearance is 5 feet (1.5 m). Site-specific layouts for arrays of horizontal casks are evaluated pursuant to 10CFR72.212.

Vertically-oriented and horizontally-oriented casks will not be combined within an array, and a separation of at least 18 feet (5.5 m) will be maintained between adjacent groups of vertical and horizontal casks.

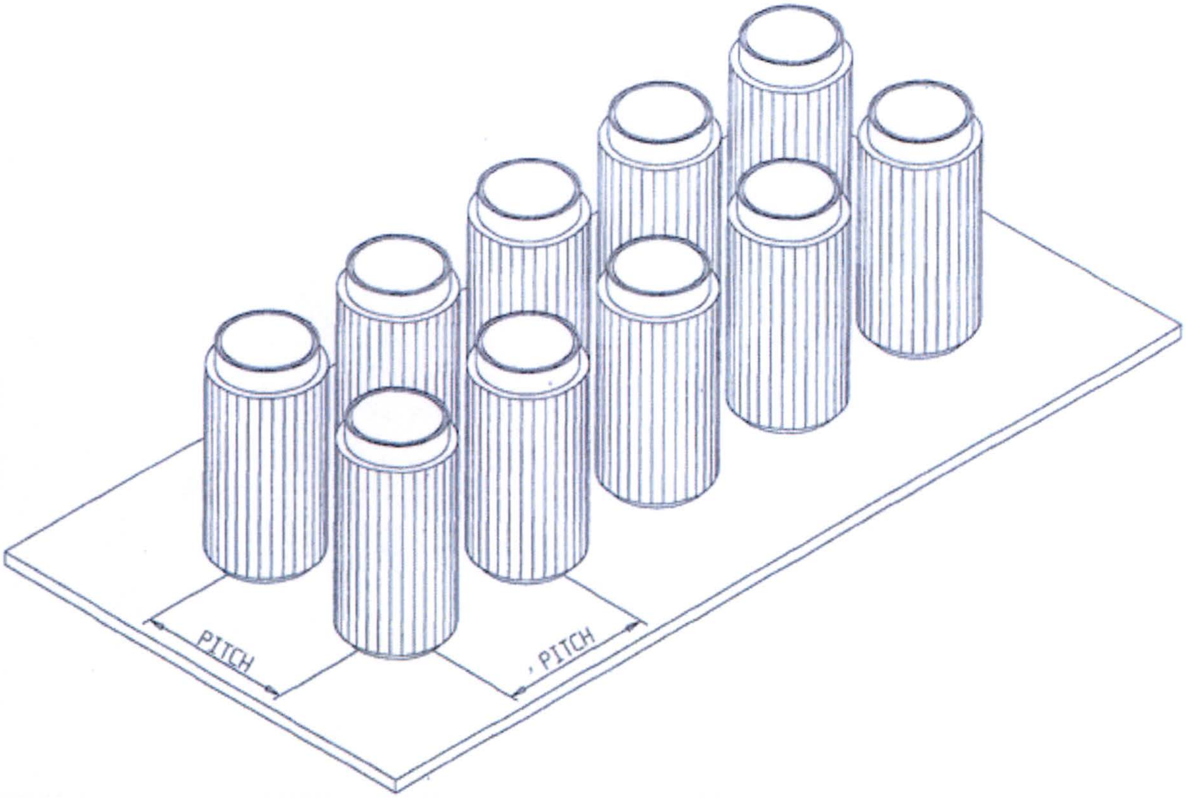


FIGURE 1.4.1; HI-STAR 100 TYPICAL ISFSI STORAGE PATTERN FOR VERTICAL STORAGE

FIGURE 1.4.2; HI-STAR 100 TYPICAL ISFSI STORAGE PATTERN FOR HORIZONTAL STORAGE

TABLE 4.0.1

HI-STAR 100 TRANSPORT SAR MATERIAL GERMANE TO THE EVALUATIONS IN THIS FSAR

Location in This Storage FSAR	**Subject of Reference**	**Location in HI-STAR 100 Transport SAR**
Subparagraph 4.4.1.1.4	Fuel Basket In-Plane Conductive Heat Transport	Subparagraph 3.4.1.1.4
Subparagraph 4.4.1.1.5	Heat Transfer in Fuel Basket Peripheral Regions	Subparagraph 3.4.1.1.5
Subparagraph 4.4.1.1.7	Heat Transfer from Overpack Peripheral Surfaces	Subparagraph 3.4.1.1.7
Subparagraph 4.4.1.1.11	Fluent Model for Temperature Field Computation	Subparagraph 3.4.1.1.12
Paragraph 4.4.2.1	Maximum Temperatures Under Normal Storage Conditions	Figures 3.4.16 & 3.4.17 Tables 3.4.10 & 3.4.11
Subsection 4.4.4	Maximum Internal Pressure	Tables 3.4.13 & 3.4.15
Subsection 4.4.5	Maximum Thermal Stress	Table 3.4.24

model developed is shown in Figure 4.4.5. In this figure, a center HI-STAR 100 System cask is shown surrounded by two rows of casks on all sides. The ANSYS solution determines view factors between this most adversely located system in the middle with all other neighboring casks. A sum of all these individual blockages gives the total blockage factor. Thus, the view factor $F_{1,A}$ between this most adversely affected HI-STAR 100 System and outside air is determined by the following relationship:

$$F_{1,A} = 1 - \sum_{K} F_{1,K}$$

where $F_{1,K}$ is the view factor between HI-STAR 100 System 1 and a neighboring system K. This factor is determined by a series of ANSYS solutions as a function of ISFSI cask array pitch, and the results are shown in Figure 4.4.6.

For the surfaces of a horizontally-oriented cask, blocking factors due to adjacent casks are determined in the lateral direction (i.e., blocking by casks in parallel rows) and the axial direction (i.e., blocking of the lid surface of a cask by the base of an adjacent cask in the same row). View factors are determined for each of these surfaces (cask side = lateral; cask lid = axial) using the same equation for F1,A above. The design-basis spacing from Section 1.4 is evaluated.

4.4.1.1.8 Determination of Solar Heat Input

The intensity of solar radiation incident on an exposed surface depends on a number of time varying terms. The solar heat flux strongly depends upon the time of the day as well as on latitude and day of the year. Also, the presence of clouds and other atmospheric conditions (dust, haze, etc.) can significantly attenuate solar intensity levels. Rapp [4.4.2] has discussed the influence of such factors in considerable detail.

Consistent with the guidelines in NUREG-1536 [4.1.3], solar input to the exposed surfaces of the overpack is determined based on 12-hour insolation levels recommended in 10CFR71 (averaged over a 24-hour period) and applied to the most adversely located cask after accounting for partial blockage of incident solar radiation on the lateral surfaces of the cask by surrounding casks. The blocking factor is identical to the radiative blocking considered for cooling of outside surfaces to the ambient environment. This is conservative compared to the case of an isolated cask with significantly improved radiative cooling and higher insolation levels because the cask is emitting much more heat than the insolation heat input. The imposed steady insolation level for the exposed top lid is based on a view factor equal to unity. The solar absorptivity of all exposed cask surfaces is assumed to be a conservatively bounding value of unity.

4.4.1.1.9 Effective Thermal Conductivity of Holtite Neutron Shielding Region

In order to minimize heat transfer resistance limitations due to the poor thermal conductivity of the Holtite-A neutron shield material, a large number of thick radial channels of high strength and conductivity carbon steel material are embedded in the neutron shield region. The legs of the radial channels form highly conducting heat transfer paths for efficient heat removal. Each channel leg is welded to the outside surface of the outermost intermediate shell. Enclosure shell

4.4.1.2 Test Model

A detailed analytical model for thermal design of the HI-STAR 100 System was developed using the FLUENT CFD code and the industry standard ANSYS modeling package, as discussed in Subparagraph 4.4.1.1. As discussed throughout this chapter and specifically in Subsection 4.4.6, the analysis incorporates significant conservatisms so as to predict the fuel cladding temperature with considerable margins. Furthermore, compliance with specified limits of operation is demonstrated with adequate margins. In view of these considerations, the HI-STAR 100 System thermal design complies with the thermal criteria set forth in the design basis (Sections 2.1 and 2.2) for long-term storage under normal conditions. Additional experimental verification of the thermal design is therefore not required.

4.4.2 Maximum Temperatures

4.4.2.1 Maximum Temperatures Under Normal Storage Conditions

The MPC basket designs developed for the HI-STAR 100 System have been analyzed to determine the temperature distribution under long-term normal storage conditions. The MPC baskets are considered to be loaded at design basis maximum heat loads with PWR or BWR fuel assemblies, as appropriate. The systems are considered to be arranged in an ISFSI array and subjected to design basis normal ambient conditions with insolation.

Applying the radiative blocking factor applicable for the worst case cask location, converged temperature contours are shown in Figures 4.4.17 and 4.4.18 for the MPC-24, and MPC-68 basket designs in a vertical orientation. The temperatures in these two figures are in degrees Kelvin. Analogous figures for horizontal orientation storage of the MPC-24 and MPC-68 are presented in Figures 3.4.16 and 3.4.17 of the HI-STAR 100 transportation SAR. The calculated temperatures presented in this chapter are based on an array of analyses that incorporate many conservatisms. As such, the calculated temperatures are upper bound values which would exceed actual temperatures.

The maximum fuel clad temperatures for zircaloy clad fuel assemblies in vertically-oriented casks are listed in Tables 4.4.10 and 4.4.11, which also summarize maximum calculated temperatures in different parts of the HI-STAR 100 System. Figures 4.4.21 and 4.4.22 show the axial temperature variation of the hottest fuel rod in the MPC-24 and MPC-68 basket designs, respectively. Figures 4.4.24 and 4.4.25 show the radial temperature profile in the MPC-24 and MPC-68 basket designs, respectively, in the horizontal plane where maximum fuel cladding temperature is indicated.

Applying the radiative blocking factor applicable for the worst case cask location, the maximum fuel clad temperature for zircaloy clad fuel assemblies in an MPC-32 in a vertically-oriented HI-STAR 100 System is listed in Table 4.4.12, which also summarizes maximum calculated temperatures in different parts of the HI-STAR 100 System.

Comparing the fuel cladding temperatures and the temperatures of the bounding confinement boundary component (the MPC shell) in Tables 4.4.11 and 4.4.12, the MPC-68 results in higher temperatures than the MPC-32. It is therefore concluded that the MPC-68 bounds the MPC-32 when both are in vertically-oriented casks.

The maximum fuel clad temperatures for zircaloy clad fuel assemblies in horizontally-oriented casks are listed in Tables 3.4.10 and 3.4.11 of the HI-STAR 100 transportation SAR [4.0.1], which also summarize maximum calculated temperatures in different parts of the HI-STAR 100 System. Comparing the fuel cladding temperatures and the temperatures of the bounding confinement boundary component (the MPC shell) in these two SAR tables, the MPC-68 results in higher temperatures than the MPC-32. It is therefore concluded that the MPC-68 bounds the MPC-32 when both are in horizontally-oriented casks.

The horizontally-oriented casks are supported by structures that holds the casks and prevents their movement during design-basis events. This structure covers the cask surface at two locations along its length as shown in Figure 1.2.13. The transportation thermal performance incorporated by reference from the HI-STAR 100 SAR is compared to the normal storage condition with due consideration of the support structure, as shown in Table 4.4.26. As this table shows, the thermal performance of the cask under horizontal storage conditions while mounted in the support structure is essentially the same as or somewhat superior to the horizontal transport conditions incorporated by reference. More critically, it is shown that all fission product boundary temperatures and internal pressures remain below their respective limits. It is concluded, therefore, that the safety analysis for the transport condition does conservatively represent the thermal performance under the horizontal normal storage condition.

Similarly, the effects of array blocking for an array of horizontally-oriented casks is evaluated in the same manner as described in Subparagraph 4.4.1.1.7 for the normal storage condition and compared to the transportation thermal performance incorporated by reference from the HI-STAR 100 SAR in Table 4.4.27. As this table shows, for the cask under horizontal storage conditions arrayed at the proposed pitches, all fission product boundary temperatures and internal pressures remain below their respective limits. The increase in the components' temperatures is minor. It is concluded, therefore, that the proposed separation between the horizontally stored casks is suitable for horizontal deployment of HI-STAR 100 Systems.

As discussed in Subsection 4.4.1.1.1, the thermal analysis is performed using a submodeling process where the results of an analysis on an individual component are incorporated into the analysis of a larger set of components. Specifically, the submodeling process yields directly computed fuel temperatures from which fuel basket temperatures are indirectly calculated. This modeling process differs from previous analytical approaches wherein the basket temperatures were evaluated first and then a basket-to-cladding temperature difference calculation by Wooten-Epstein or other means provided a basis for cladding temperatures. Subsection 4.4.1.1.2 describes the calculation of an effective fuel assembly thermal conductivity for an equivalent homogenous region. It is important to note that the result of this analysis is a function for thermal conductivity versus temperature. This function for fuel thermal conductivity is then input to the fuel basket effective thermal conductivity calculation described in Subsection 4.4.1.1.4. This calculation uses a finite-element methodology, wherein each fuel cell region containing multiple finite-elements has temperature varying thermal conductivity properties. The resultant

Table 4.4.12

HI-STAR 100 SYSTEM LONG-TERM VERTICAL ORIENTATION NORMAL STORAGE[†] MAXIMUM TEMPERATURES (32-PWR ASSEMBLIES, MPC)

	Maximum Temperature (°F [°C])	Normal Condition Design Temperature (°F [°C])
Fuel Cladding	710 [377]	752 [400]
MPC Basket Centerline	677 [358]	725 [385]
MPC Basket Periphery	382 [194]	725 [385]
MPC Outer Shell Surface	315 [157]	350 [177]
MPC/Overpack Helium Gap Outer Surface	275 [135]	400 [204]
Neutron Shield Inner Surface	251 [122]	300 [149]
Overpack Outer Enclosure Surface	212 [100]	350 [177]
Overpack Bolted Closure Plate[††]	149 [65]	400 [204]
Overpack Bottom Plate[††]	219 [104]	350 [177]

[†] Ambient Temperature = 80°F (27°C)
Cask Array Pitch = 3 x Cask Radius = 12 ft. (3.66 m)

[††] Overpack closure plate and vent/drain port plug seals normal condition design temperature is 400°F (204°C). The maximum seals temperatures are bounded by the reported closure plate and bottom plate maximum temperatures. Consequently, a large margin of safety exists to permit safe operation of seals in the overpack helium retention boundary.

Table 4.4.15

SUMMARY OF MPC CONFINEMENT BOUNDARY PRESSURES[†] FOR NORMAL VERTICAL ORIENTATION LONG-TERM STORAGE

Condition	**Pressure (psig [kPa])**
MPC-24[††]:	
Initial backfill (at 70°F / 21°C) Normal condition	22.2 [153] 43.8 [302]
With 1% rods rupture With 10% rods rupture With 100% rods rupture	44.3 [305] 49.1 [339] 97.3 [671]
MPC-68:	
Initial backfill (at 70°F / 21°C) Normal condition	28.5 [197] 57.5 [396]
With 1% rods rupture With 10% rods rupture With 100% rods rupture	57.8 [399] 60.2 [415] 84.6 [583]
MPC-32[††]:	
Initial backfill (at 70°F / 21°C) Normal condition	20.3 [140] 42.9 [296]
With 1% rods rupture With 10% rods rupture With 100% rods rupture	43.4 [299] 48.1 [332] 99.0 [683]

[†] Pressure analysis is based on NUREG-1536 criteria (i.e., 100% of rods fill gas and 30% of radioactive gases are available for release from a ruptured rod).

[††] PWR fuel storage includes hypothetical BPRA rods rupture in the pressure calculations.

[††] PWR fuel storage includes hypothetical BPRA rods rupture in the pressure calculations.

Table 4.4.26

COMPARISON OF TRANSPORTATION RESULTS INCORPORATED BY REFERENCE WITH NORMAL HORIZONTAL STORAGE ON SUPPORT STRUCTURE

Normal Transport Incorporated by Reference vs. Normal Storage and Allowables HI-STAR 100 with BWR Canister			
	Normal Horizontal Transport [Note 1]	**Normal Horizontal Storage** [Note 2]	**Normal Storage Allowable** [Note 3]
Ambient Temperature			
Normal Condition	100°F	80°F	N/A
Component Temperatures			
Fuel Cladding	713°F	639°F	752°F
MPC Shell	306°F	288°F	450°F
Internal Pressure [Note 4]			
MPC Cavity Pressure	85.8 psig	85 psig	100 psig
HI-STAR 100 with PWR Canister			
	Normal Horizontal Transport [Note 5]	**Normal Horizontal Storage** [Note 2]	**Normal Storage Allowable** [Note 3]
Ambient Temperature			
Normal Condition	100°F	80°F	N/A
Component Temperatures			
Fuel Cladding	701°F	698°F	752°F
MPC Shell	315°F	306°F	450°F
Internal Pressure [Note 4]			
MPC Cavity Pressure	89.3 psig	89 psig	100 psig

Notes

1. The temperature and MPC cavity pressure results for normal transport are incorporated by reference from Tables 3.4.11 and 3.4.15 of HI-STAR 100 SAR [2].
2. Thermal evaluations of a horizontal HI-STAR 100 cask positioned on the saddle supports was performed under the Licensing Basis heat loads. These evaluations are performed using the methodology described in Section 3.4 of HI-STAR 100 SAR [2].
3. The temperature and pressure limits are extracted from Tables 2.2.3 and 2.2.1 of HI-STAR 100 FSAR [1].
4. The initial helium backfill pressure used to compute the confinement boundary pressures is 42.8 psia at a 70°F reference temperature, the maximum backfill level from Table 2-1 in Appendix A of the proposed technical specifications.
5. The temperature and MPC cavity pressure results for normal transport are incorporated by reference from Tables 3.4.10 and 3.4.15 of HI-STAR 100 SAR [2].

TABLE 4.4.27

COMPARISON OF TRANSPORTATION RESULTS INCORPORATED BY REFERENCE WITH NORMAL HORIZONTAL STORAGE OF AN ARRAY OF CASKS

Normal Horizontal Storage In An Array **HI-STAR 100 with BWR Canister**		
	Normal Horizontal Storage (Note 1)	**Normal Storage Allowable (Note 2)**
Component Temperatures		
Fuel Cladding	644°F	752°F
MPC Shell	298°F	450°F
MPC Baseplate	281°F	400°F
MPC Lid	180°F	550°F
Internal Pressure Note 3		
MPC Cavity Pressure	86 psig	100 psig
HI-STAR 100 with PWR Canister		
	Normal Horizontal Storage (Note 1)	**Normal Storage Allowable (Note 2)**
Component Temperatures		
Fuel Cladding	703°F	752°F
MPC Shell	316°F	450°F
MPC Baseplate	300°F	400°F
MPC Lid	180°F	550°F
Internal Pressure Note3		
MPC Cavity Pressure	90 psig	100 psig

Notes

1. Thermal evaluations of a horizontal HI-STAR 100 cask positioned on the saddle supports was performed under the Licensing Basis heat loads. These evaluations are performed using the methodology described in Section 3.4 of HI-STAR 100 SAR [2].
2. The temperature and pressure limits are extracted from Tables 2.2.3 and 2.2.1 of HI-STAR 100 FSAR [1].
3. The initial helium backfill pressure used to compute the confinement boundary pressures is 42.8 psia at a 70°F reference temperature, the maximum backfill level from Table 2-1 in Appendix A of the proposed technical specifications.

For vertically-oriented HI-STAR 100 Systems, the maximum temperatures for components that have temperatures close to their design basis temperatures are listed in Tables 4.4.10 and 4.4.11. These temperatures are conservatively calculated at an environmental temperature of 80°F (27°C). The maximum off-normal environmental temperature is 100°F (38°C), which is an increase of 20°F (11°C). The bounding off-normal component temperatures are calculated by adding 20°F (11°C) to the maximum normal temperatures from the highest component temperature from either the MPC-68 or the MPC-24 (whichever bounds). Table 11.1.1 lists the maximum off-normal temperatures. As illustrated by the table, all the maximum off-normal temperatures are well below the off-normal condition design basis temperatures. Under these conditions, the HI-STAR 100 System maximum off-normal temperatures meet the design requirements specified in Table 2.2.3.

For horizontally-oriented systems, Chapter 3 the HI-STAR 100 transport SAR considers 100°F (38°C) as the normal condition ambient temperature. As described in Section 4.4.2, however, this transport condition is bounding for normal storage conditions. Therefore, it is necessary to increase the horizontal transport temperatures by 20°F for account for off-normal conditions of storage. Table 11.1. lists the temperatures and all are well below off-normal condition design basis temperatures.

In addition, the off-normal environmental temperature generates a pressure which is evaluated in Section 11.1.1. The off-normal MPC cavity pressure is less than the design basis normal/off-normal pressures listed in Table 2.2.1.

The off-normal event considering an environmental temperature of -40°F (-40°C), no decay heat, and no solar insolation for a duration sufficient to reach thermal equilibrium is evaluated with respect to material design temperatures. The HI-STAR 100 System is conservatively assumed to reach -40°F (-40°C) throughout the structure. All structural analysis is performed at the material design basis temperature, which is set higher than the component would experience with the design basis heat load under normal conditions. Assuming the HI-STAR 100 System is -40°F (-40°C) would only serve to increase the safety margins as the material strength increases with decreasing temperatures. Subsection 3.1.2.3 details the structural analysis performed to evaluate brittle fracture at the lowest service temperature. Subsection 3.4.5 provides a structural evaluation of the effects of an environmental temperature of -40°F (-40°C) and demonstrates that there is no reduction in the performance of the HI-STAR 100 System. Based on this evaluation, it is concluded that the off-normal environmental temperatures do not affect the safe operation of the HI-STAR 100 System.

Structural

The effect on the MPC for the maximum off-normal temperature condition is an increase in the internal pressure. As shown in Section 11.1.1.3, the resultant pressure is well below the normal/off-normal design pressure of 100 psig (689 kPa) used in the structural analysis. The effect of the minimum off-normal temperature conditions results in an evaluation of the potential for brittle fracture which is discussed in Section 3.1.2.3.