TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS

IN

HI-STORM 100 AND HI-STORM FW SYSTEMS

By

Holtec International
Holtec Technology Campus
One Holtec Boulevard
Camden, NJ 08104
(holtecinternational.com)

Holtec Project 5014
Holtec Report No. HI-2200343-A

Non-Proprietary Version

TABLE OF CONTENTS

SECTION A

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

September 14, 2021

SUBJECT: FINAL SAFETY EVALUATION FOR HOLTEC INTERNATIONALTOPICAL REPORT HI-2200343, REVISION 2, “TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS IN HI-STORM 100 AND HI-STORM FW SYSTEMS” (EPID: L-2020-TOP-0018)

Dear Ms. Manzione,

By letter dated March 19, 2020 (Agencywide Documents Access and Management System (ADAMS) Package Accession No. ML20101N174), Holtec International (Holtec) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review the Topical Report (TR) HI-2200343 Revision 0, “Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW [Flood Wind] Systems.” By letter dated April 2, 2021 (ADAMS Package Accession No. ML21092A162), Holtec submitted revised TR HI-2200343, Revision 2, “Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW [Flood Wind] Systems,” and responses to the NRC staff’s open items in the draft safety evaluation (SE). Non-proprietary copies of the responses have been placed in the NRC Public Document Room and are available in ADAMS Accession No. ML21092A165.

The NRC staff has found the TR acceptable for incorporation in a HI-STORM 100 or HI-STORM FW storage cask certificate of compliance (CoC) amendment to the extent specified and under the limitations delineated in the TR and in the enclosed final SE which defines the basis for our acceptance of the TR. A copy of Enclosure 2 to the final SE, which contains proprietary information, was provided to you via the NRC box.com folder.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the accepted material described in the TR. When the TR appears as a reference in a HI-STORM 100 or HI-STORM FW storage cask CoC, our review will ensure that the material presented applies to the specific storage cask system involved. CoC amendment requests that deviate from this TR will be subject to a cask-specific review in accordance with applicable review standards.

If future changes to the NRC’s regulatory requirements affect the acceptability of this TR, Holtec will be expected to revise the TR appropriately and incorporate it through a CoC amendment. Alternatively, any HI-STORM 100 or HI-STORM FW CoC holders referencing this existing TR would be expected to justify its continued applicability.

NOTICE: Enclosure 2 to this letter contains Proprietary Information. Upon separation from Enclosure 2, this letter is DECONTROLLED.

In accordance with the guidance provided on the NRC website, we request that Holtec publish accepted versions of the proprietary and nonproprietary TR within three months of receipt of the date of this letter. The accepted versions shall incorporate this letter and the enclosed proprietary and non-proprietary versions SE after the title page. Also, the accepted version must contain all historical review information, and shall include an "-A" (designating accepted) following the TR identification symbol.

If you have any questions, please contact the Project Manager for the review, Ekaterina Lenning at 301-415-3151 or via electronic mail at Ekaterina.Lenning@nrc.gov.

Sincerely,

Zahira Cruz Perez, Acting Branch Chief
Containment, Thermal, Chemical, and Fire
Protection Branch
Division of Fuel Management
Office of Nuclear Material Safety and
Safeguards

Docket Nos.: 07201014 and 07201032

Enclosures:

1. Final SE (Non-Proprietary)
2. Final SE (Proprietary)

SUBJECT: FINAL SAFETY EVALUATION FOR HOLTEC INTERNATIONALTOPICAL REPORT HI-2200343, REVISION 2, "TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS IN HI-STORM 100 AND HI-STORM FW SYSTEMS" (EPID: L-2020-TOP-0018) DATED SEPTEMBER 14, 2021

DISTRIBUTION:
NON-PUBLIC (Enclosure 2)
PUBLIC (Letter and Enclosure 1)
RidsNrrDorlLlpb
RidsNrrLADHarrison
RidsOgcMailCenter
RidsACRS_MailCTR
JPiotter, NMSS
JIreland, NMSS
JMcKirgan, NMSS
ZCruzPerez, NMSS
ACoggins, OGC
RidsResOd
RidsNrrDorl
DMorey, NRR
ELenning, NRR

ADAMS Accession Nos.:
ML21125A186 (Package)
ML21125A191 (Letter)
ML21216A181 (Non-Proprietary SE Enclosure 1)
ML21125A629 (Proprietary SE Enclosure 2)

OFFICE	NRR/DORL/LLPB/ PM	NRR/DORL/LLPB/ LA	NMSS/DFM/ CTCB	NMSS/DFM/ CTCFB	OGC - NLO
NAME	ELenning	DHarrison	JIreland	JPiotter	ACoggins
DATE	5/5/2021	5/7/2021	5/14/2021	5/14/2021	7/22/2021
OFFICE	NRR/DORL/LLPB/ BC	NMSS/DFM/STLB/ BC	NMSS/DFM/ CTCFB/BC (A)		
NAME	DMorey	JMcKirgan	ZCruzPerez		
DATE	7/27/2021	9/3/2021	9/14/2021		

OFFICIAL RECORD COPY

U.S NUCLEAR REGULATORY COMMISSION

FINAL SAFETY EVALUATION BY THE

OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS

FOR THE HOLTEC INTERNATIONAL

TOPICAL REPORT HI-2200343, REVISION 2, "TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS IN HI-STORM 100 AND HI-STORM FW [FLOOD WIND] SYSTEMS"

DOCKET NOS. 721014 AND 721032

1.0 INTRODUCTION

In a letter dated March 19, 2020 (Agencywide Documents Access and Management System (ADAMS) Package Accession No. ML20101N174), Holtec International (Holtec) submitted Topical Report (TR) HI-2200343, Revision 0, "Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW[Flood Wind] Systems" (Ref. 1), for U.S. Nuclear Regulatory Commission (NRC) review and approval. Subsequently, in a letter dated October 6, 2020, Holtec supplemented the TR (Ref. 2) following a regulatory audit to provide responses to NRC questions (Ref 6), and then, in a letter dated April 2, 2021, further supplemented the TR (Ref. 3) documenting their response to NRC developed open items (Ref. 8).

This safety evaluation (SE) report addresses whether the evaluation of decay heat loading patterns, which include thermal modeling of the cask design and subsequent temperature outputs for cask components, can be achieved for a range of decay heat loading patterns with a generically approved methodology, without NRC review and approval of the specific heat load patterns. This TR (Ref. 3) and SE only consider the thermal evaluation methodology for a range of decay heat loading patterns.

The review for the TR consisted of an acceptance review (ADAMS Accession No. ML20141L621), a technical review, including a technical audit (Ref. 6 and Ref. 7), and development and resolution of open technical issues that remained during the development of the draft safety evaluation (SE).

1.1 General Considerations for the Topical Report Technical Review

This SE documents the technical review and approval of the TR methodology for evaluating a range of decay heat load patterns, which relies, in part, upon previously approved evaluations for fixed heat load patterns. The technical review includes cross-referencing evaluations previously presented in the final safety analysis reports (FSARs) for the HI-STORM 100 and HI-STORM FW systems as well as evaluating any variations not explicitly documented in those previously approved evaluations.

The NRC's review of this TR, in part, included a review of the safety evaluations for previous CoC approvals of alternate heat load patterns. Language in those previous Safety Evaluation Reports (SERs) for the HI-STORM 100 and the HI-STORM FW directly indicated that the technical review relied on previously reviewed and approved evaluations. This technical review approach, namely relying on previously reviewed and approved evaluations, is also consistent across other docket/designs for those CoC amendments that are seeking approval for an alternate heat load pattern.

This TR (Ref. 3) is a stand-alone document which contains the information necessary to fully evaluate a range of decay heat load patterns for both the HI-STORM 100 and the HI-STORM FW. It was asserted by Holtec that each section is the same as the evaluation methodology for the fixed heat load patterns that were presented in the previously reviewed and approved FSARs and subsequent CoCs for the HI-STORM 100 and HI-STORM FW.

2.0 SUMMARY OF CURRENT COC TECHNICAL REVIEW PROCESS FOR ALTERNATE FIXED HEAT LOAD PATTERNS

Specific thermal evaluations from prior SERs for the HI-STORM 100 (Amendment 12 and Amendment 14) and HI-STORM FW (Amendment 5) are excerpted in Section 2.1 of this SE. The purpose for including the specific examples is to show how technical reviews have been performed when changes to heat load patterns are a proposed change in a CoC amendment.

2.1 Summary of Previous NRC CoC Amendments Proposing Alternate Heat Load Patterns

The excerpts below are from previously issued NRC SERs detailing the technical reviews performed for changes to heat loads in the specific spent fuel storage systems noted.

2.1.1 HI-STORM 100 Amendment 12 (Application – ADAMS Accession No. ML16169A363, SER – ADAMS Accession No. ML18355A383)

Application proposed change

> **[**
>
> **]**

SER technical review conclusions

> (1) Section 4.3 (a) of the SER (ML18355A383): "The applicant performed the thermal evaluations using an *ANSYS FLUENT computational fluid dynamics (CFD) model previously used in the HI-STORM 100 FSAR and were reviewed and approved by NRC*.
> **[**
>
> **]**

> *(2)* Section 4.3 (a) of the SER (ML18355A383): "*The NRC staff concludes that the fuel cladding temperatures will be maintained below the temperature limits in FSAR* Table 4.3.1, i.e., the cladding temperature limit will be 752 °F under normal long-term storage,

752 °F (HBF) and 1,058 °F (moderate burnup fuel (MBF)) under short-term operations, and 1,058 °F under off-normal and accident conditions. These limits are consistent with Spent Fuel Storage and Transportation (SFST)-Interim Staff Guidance (ISG)-11, Revision 3. *The cask component temperatures will also remain below the design temperature limits listed in FSAR Table 2.2.3. The NRC staff found the reported PCT and component temperatures are acceptable…" (Emphasis added)*

(3) Section 4.3 (b) of the SER (ML18355A383): "The staff reviewed the **[** **]** and accepted that the proposed initial helium backfill pressures (≥ 43.5 psig and ≤ 46.5 psig) for MPC-68M under QSHL pattern *are acceptable because the calculated maximum MPC internal pressures and the maximum fuel cladding and cask component temperatures are below the corresponding limits* for under short-term operations and normal, off-normal, and accident-level storage conditions." *(Emphasis added)*

2.1.2 HI-STORM 100 A.14 (Application – ADAMS Accession No. ML18331A056, SER – ADAMS Accession No. ML19295C576)

Application proposed change

[

]

SER technical review conclusions

(1) Section 4.3 of the SER (ML19295C576): "The applicant performed thermal analyses, using an ANSYS/FLUENT computational fluid dynamics (CFD) model, for the following regionalized QSHL patterns in the MPC-68M placed inside HI-STORM 100 Casks. *The ANSYS/FLUENT CFD modeling approach was previously used for evaluation of the cask design in Amendment No. 7 to CoC No. 1014 and reviewed by the NRC* (NRC, 2009)" *(Emphasis added)*.

(2) Section 4.3 (a) of the SER (ML19295C576): "The applicant stated in FSAR Supplement 4.III.4.2 that "*no change was made to the existing thermal model and the selected heat loads in Figures 2.III.2, 2.III.3, and 2.III.4 are suitably limited to ensure that the peak cladding temperatures (PCTs) in the MPC remain below the PCT for the bounding MPC (MPC-32) analyzed in the FSAR under all thermal scenarios*." FSAR Table 4.III.3a shows that the PCTs for QSHL-2, QSHL-3, and QSHL-4 patterns are lower than the PCT for the previously analyzed and approved **[** **]** The applicant concluded that the additional QSHL-2, QSHL-3, and QSHL-4 patterns are bounded by the QSHL pattern." (*Emphasis added)*

2.1.3 HI-STORM FW Amendment 5 (Application – ADAMS Accession No. ML18179A100, SER – ADAMS Accession No. ML20163A706)

Application proposed changes

(A) Add new heat load patterns for the MPC-89 and MPC-37 (long, standard, and short length).

(B) Use ANSYS FLUENT analysis model to revise the calculation for evaluating effective fuel conductivities.

[

]

SER technical review conclusions

(1) Section 4.1 of the SER (ML20163A706): "The staff reviewed the applicant's description of the HI-STORM FW system thermal model. Based on the information provided in the application regarding the thermal model, the staff determined that the application is consistent with guidance provided in NUREG-1536, Section 4.4.4, "Analytical Methods, Models, and Calculations." Therefore, the staff concludes that the description of the thermal model is acceptable, as the description is consistent with NUREG-1536, and satisfies the regulatory requirements of 10 CFR 72.236(b), 72.236(f), 72.236(g), and 72.236(h)." *(Emphasis added)*

(2) Section 4.2 of the SER (ML20163A706): **[** **]** *These temperatures bound all heat loading patterns. Therefore, the previously approved licensing basis models continue to be applicable to the new heat load patterns* for either the MPC-37 or MPC-89, and no further evaluation of the new heat load patterns is required." *(Emphasis added)*

2.1.4 Conclusions

As identified in the examples above, the technical review approach and conclusions specifically identify the following:

(a) **[** **]**
(b) There was specific reliance in making the safety determination on the thermal models utilized by the previously approved bounding loading condition with no further investigation of the thermal model with respect to its range of validity.
(c) The basis for accepting the safety analysis relied on the degree of variability of the updated component temperatures and pressures when compared with the bounding case, and subsequently the acceptance criteria.

As such, the NRC determines that within the limits analyzed in this TR, the thermal models used to evaluate fixed alternate heat load patterns for applicable storage conditions within the HI-STORM 100 and the HI-STORM FW FSARs have been previously reviewed and approved by the NRC.

3.0 Thermal Evaluation Methodologies for HI-STORM 100 SYSTEM and HI-STORM FW System Heat Load Patterns

[

]

3.1 General Considerations for Thermal Evaluations of Heat Load Patterns

As stated in SE Section 1.0, Holtec asserted that there is a substantial justification for finding that the previously approved evaluations of alternate decay heat load patterns can provide accurate results supporting a reasonable assurance of adequate protection finding, because the evaluations presented in this TR are unchanged from the evaluations used in the latest versions of the FSARs for both the HI-STORM 100 (Ref. 4) and HI-STORM FW (Ref. 5) systems. Consistent with the discussion in SE Sections 1.1 and 2.1, alternate decay heat load evaluations presented in previous CoC actions for the HI-STORM 100 and HI-STORM FW systems are considered approved methodologies for calculating component temperatures and subsequent system pressures. The NRC noted in the audit plan (Ref. 6) that past SERs may not be explicit on necessary limitations for decay heat. Specifically, defined individual assembly decay heat values and total system decay heat are identified in those previous licensing actions and are part of the approved evaluation as an input to the thermal models. Any deviation from those defined values are changes to inputs to the thermal models requiring an amendment for NRC review and approval.

3.2 Acceptance Criteria

The resultant temperatures from heat load patterns in this evaluation must remain within the acceptance criteria limits as specified in the TR (Ref. 3) (Tables 2.1 and 2.2, Tables 4.1 and 4.2) and the FSARs for the CoCs. Holtec proposed a normal conditions PCT limit lower than the limits set forth in ISG-11, Revision 3 (now incorporated into NUREG-2215 (Ref. 9)). Similarly, Holtec also proposed a limit on the normal conditions MPC cavity pressure lower than the limit set forth in the latest revisions of the HI-STORM 100 (Ref. 4) and HI-STORM FW (Ref. 5) FSARs.

Holtec asserted that the distribution of decay heat in the MPC and total decay heat are self-limited with the acceptance criteria presented in the TR (Ref. 3) because the acceptance criteria are more conservative than those used for any heat load patterns submitted as part of a CoC review. The NRC notes that the models that predict the calculated temperatures and pressures used to compare with the acceptance criteria must have reasonable accuracy for their intended purpose; specifically, the thermal model should not be used with a decay heat input that is outside of a range of applicability that is valid for the parameters of the thermal model. This is addressed further in section 3.4.3.3 of this SE.

3.3 Elements of the Thermal Evaluation of Heat Load Patterns

3.3.1 HI-STORM 100 Thermal Models, Operational Limits, and Condition Evaluations

3.3.1.1 Design Basis Thermal Models

The design basis thermal models were presented in Section 2.3 of the TR (Ref. 3). These included: a (1) design description and discussion of the material properties to be used, (2) description of HI-STORM 100 thermal model, (3) description of the HI-TRAC transfer cask thermal model, and (4) vacuum drying thermal model. The thermal models presented in this section were identified by Holtec as the same as those presented in the HI-STORM 100 FSAR (Ref. 4). The NRC considered the inclusion of the thermal models in this manner as an incorporation by reference and the staff review consisted of cross-referencing the information presented in the TR (Ref. 3) with the information presented in the HI-STORM 100 FSAR (Ref. 4). This review approach is reasonable because evaluations used in previously approved CoCs are considered reviewed and approved by the NRC. Further, the review approach used in various CoC amendments incorporating alternate heat loads regularly cite prior use of thermal models as reviewed and approved.

3.3.1.2 Operational Limits and Condition Evaluations

Section 2.3 of the TR (Ref. 3) provided helium backfill limits and examples to time to boil calculations as well as descriptions of the various condition evaluations including partial vent blockage, off-normal ambient temperature event, extreme ambient temperature accident, 100 percent vent blockage, burial under debris, loss of water from water jacket, fire, and differential thermal expansion. The NRC cross-referenced these evaluations and found that they are consistent with those presented in the FSAR.

3.3.2 HI-STORM FW Thermal Models, Operational Limits, and Condition Evaluations

3.3.2.1 Design Basis Thermal Models

The design basis thermal models were presented in Section 4.3 of the TR (Ref. 3). These included: (1) design description and discussion of the material properties to be used, (2) description of the HI-STORM FW 3-D thermal model, (3) description of the HI-TRAC VW transfer cask thermal model, and (4) vacuum drying thermal model. The models presented in this section were identified by Holtec as the same as those presented in the HI-STORM FW FSAR (Ref. 5). The NRC considered the inclusion of the thermal models in this manner as an incorporation by reference and the staff review consisted of cross-referencing the information presented in the TR (Ref. 3) with the information presented in the HI-STORM FW FSAR (Ref. 5). This approach was appropriate as the NRC has concluded that evaluations used in previously approved CoCs are considered reviewed and approved by the NRC. Further, the review approach used in various CoC amendments incorporating alternate heat loads regularly cites prior use of the thermal models as reviewed and approved, based on the thermal models remaining the same except for the change in alternate heat load.

3.3.2.2 Operational Limits and Condition Evaluations

Section 4.3 of the TR (Ref. 3) provided helium backfill limits and example time to boil calculations, as well as descriptions of the various condition evaluations including partial vent blockage, off-normal ambient temperature event, extreme ambient temperature accident, 100 percent vent blockage, burial under debris, loss of water from water jacket, fire, and differential thermal expansion. The NRC cross-referenced these evaluations and found that they are consistent with those presented in the FSAR.

The NRC's review of the information summarized above from the TR (Ref. 3) and subsequent cross-referencing with the FSARs, demonstrated that the thermal evaluations for decay heat loading patterns presented in the TR (Ref. 3) were consistent across both FSARs for the HI-STORM 100 (Ref.4) and HI-STORM FW (Ref. 5).

3.4 Implementation of the Thermal Evaluation Methodology for Decay Heat Loading Patterns

3.4.1 General

Sections 2.3 and 4.3 of the TR (Ref. 3) outline the process for evaluating the normal long-term storage condition for a heat load pattern using the approved thermal models. The thermal evaluation specifies that all component temperatures and the cavity pressure shall remain below the limits specified in the TR (Ref. 3) (Tables 2.1 and 2.2, Tables 4.1 and 4.2) for the pattern to be considered acceptable. **[**

]

[

]

[**]**

Sections 2.3.18, **[**

]

[

]

To support this proposal, Holtec provided initial justification **[**

] The results of this evaluation demonstrated that the PCT over time was lower for the accident condition using the TR example decay heat pattern even though the allowable per cell decay heat for the example pattern was higher than the design basis per cell limiting decay heat. **[**

]

In response to questions raised during discussions of the proposed screening evaluation during the regulatory audit (Ref. 6 and Ref. 7), Holtec provided additional justification submitted in Revision 2 of the TR (Ref. 3). The additional information included the three CoC amendment examples summarized in Section 2.2 of this SE (HI-STORM 100 amendment 12, HI-STORM 100 Amendment 14, and HI-STORM FW Amendment 5). These examples demonstrate that in cases where the value of Q/I exceeded the design basis value, all transient or conditions of storage events were subsequently evaluated and, in the cases, where Q/I was bounded by the design basis value, only the long-term storage condition was evaluated.

[

]

The NRC concludes that this approach is acceptable based on the evaluation provided by Holtec in the TR (Ref. 3) which demonstrates that the long-term storage condition with a candidate heat load pattern is a bounding condition. Additionally, this approach is consistent with the technical approach presented by Holtec for the CoC amendment examples described in Section 2.1 of this SE.

3.4.3 Decay Heat Loading Evaluation

3.4.3.1 Decay Heat Load Excursions – Individual Fuel Assemblies

As an outcome of the regulatory audit (Ref. 7), Holtec provided examples (HI-STORM 100 Amendment 14, HI-STORM FW Amendment 5) which demonstrated that there have been alternate heat load patterns submitted to the NRC for review and approval with individual fuel assembly decay heats that exceeded what had been previously approved by the NRC. A review of these examples showed no deviation in the technical review process followed by the NRC and that those same technical review processes were consistent with cases where the proposed individual assembly decay heats were less than what was previously reviewed and approved.

3.4.3.2 Decay Heat Load Excursions – Total Decay Heat

As identified in Section 3.1 of this SE regarding enhancement to the evaluation methodology discussion, heat load patterns which exceed the total decay heat previously approved in a CoC needed additional justification to demonstrate that the thermal models are still valid for those increases in total decay heat.

As an outcome of the regulatory audit (Ref. 7), Holtec provided examples (HI-STORM 100 Amendment 14, HI-STORM FW Amendment 5) which demonstrated that there have been alternate heat load patterns submitted to the NRC for review and approval with total decay heats that exceeded what had been previously approved by the NRC. A review of these examples showed no deviation in the technical review process followed by the NRC and that those same technical review processes were consistent with cases where the proposed total decay heat was less than what was previously reviewed and approved. As another outcome of the regulatory audit (Ref. 7), Holtec also provided supplemental justification demonstrating that the validity of the thermal modeling approach is not dependent on the magnitude of the decay heat either on an individual fuel assembly basis or a total system basis. This justification is evaluated further in Section 3.4.3.3 of this SE.

3.4.3.3 Thermal Model Range of Applicability

As noted in Section 3.1 as well as Sections 3.4.3.1 and 3.4.3.2 of this SE and an outcome of the regulatory audit (Ref. 7), Holtec made certain enhancements to the evaluation methodology justification to demonstrate the loading scenarios described above would not result in proposed decay heat load patterns in which the thermal models and subsequent evaluations would produce invalid temperature results. Holtec submitted additional information in the revised TR (Ref. 3)
[

]

[

]

The staff concludes that the justification is reasonable for determining whether the evaluation remains valid for alternate heat load patterns with decay heat above previously approved design basis values (Section 3.4.3.1 and 3.4.3.2 of this SE), because it demonstrates that the physics underpinning the evaluation is invariant or self-limiting with respect to decay heat. If a thermal model with a proposed heat load pattern does not align with these justifications, then the pattern is not suitable for use because the thermal models producing component temperature outputs have not been evaluated for acceptability beyond the justifications presented above.

4.0 LIMITATIONS ON THE EVALUATION METHODOLOGY

L4.1 The approval for use of the evaluations in the TR (Ref. 3) is not intended to provide a generic approval for the use of those evaluations, including supporting thermal models, beyond selecting alternate heat load patterns for the HI-STORM 100 and HI-STORM FW systems.

L4.2 The previously approved thermal models for the design configurations listed in Appendix 1 of this SE were identified as invariant, which means that no changes to the models, modeling choices, boundary conditions, other inputs, or thermal model manipulations are allowed if used with the TR (Ref. 3). The only exceptions to altering the thermal models are: (1) the use of mirror symmetry of the existing model formulation, and (2) changes to the per cell decay heat values identified for a given candidate heat load pattern.

L4.3 The thermal models that predict the calculated temperatures, and subsequently system pressures, used to compare with the acceptance criteria must have reasonable accuracy for their intended purpose; therefore, the thermal models cannot be used with decay heat inputs that may render the thermal models as outside their range of applicability.

L4.4 Acceptability of cask and fuel assembly heat loads are solely determined by safety evaluations performed by the user of this TR and the established temperature and pressure acceptance criteria. Any heat load pattern that does not comply with all applicable safety limits under any design basis condition (normal, off-normal, accident or short-term operations) is not a qualified heat load pattern.

5.0 CONCLUSIONS

Based upon the review of the TR (Refs. 1 to 3) and confirmation of the docketed information in the regulatory audit (Ref. 7), the NRC concludes that Holtec's general methodology to evaluate alternate candidate heat load patterns is acceptable as a means to calculate component temperatures and pressures and to evaluate those results against the appropriate acceptance criteria. When implementing TR HI-2200343, Revision 2, the user must ensure compliance with the limitations listed in Section 4.0 of this SE.

7.0 REFERENCES

1. "Submittal of Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems," HI-2200343 Revision 0, April 2020 (ADAMS Package Accession No. ML20101N174).

2. "Submittal of Updated Thermal Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems," HI-2200343 Revision 1, 2020 (ADAMS Package Accession No. ML20280A773).

3. "Submittal of Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems," HI-2200343 Revision 2, 2021 (ADAMS Package Accession No. ML21092A162).

4. "Final Safety Analysis Report for the Holtec International Storage and Transfer Operation Reinforced Module Cask System (HI-STORM 100 Cask System)," USNRC Docket No. 72-1014, Holtec Report HI-2002444, Revision 20, 2020.

5. "Final Safety Analysis Report on the HI-STORM FW MPC Storage System," USNRC Docket No. 72-1032, Holtec Report HI-2114830, Revision 6, 2019.

6. Letter from M. Diaz, NRC, to K. Manzione, Holtec International, "September 9, 2020 - Regulatory Audit Plan for Holtec International (Holtec) Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems," (ADAMS Accession No. ML20244A023).

7. "Audit Report Regarding the September 9, 2020, Regulatory Audit for Holtec International Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems," November 2020, USNRC (ADAMS Package Accession No. ML20282A525).

8. Letter from D. Mitra-Majumdar, Holtec International, to L. Perkins, NRC, “Submittal of Holtec Proprietary Information Review and Response to Open Items on the Thermal Topical Report on the HI-STORM 100 and HI-STORM FW Systems,” April 2021 (ADAMS Accession No. ML21092A162).

9. NUREG-2215, “Standard Review Plan for Spent Fuel Dry Storage Systems and Facilities – Final Report,” April 2020 (ADAMS Accession No. ML20121A190).

10. Regulatory Guide 3.72, Revision 1, “Guidance for Implementation of 10 CFR 72.48, ‘Changes, Tests, and Experiments’,” dated October 2020 (ADAMS Accession No. ML20211L879).

APPENDIX 1

The methodology in this report is considered applicable to and limited according to L4.2 to the following design variants for the HI-STORM 100 and HI-STORM FW:

MPCs - 24/24E/24EF
MPCs - 32/32F
MPCs - 68/68F/68FF/68M
MPC - 37
MPC - 89

HI-TRAC Transfer casks 100/125/100D/125D/100G/VW/VW Version P

HI-STORM 100 overpacks 100/100S/100S Version B/100A

HI-STORM FW overpacks FW/Version XL/Version E

Principal Contributors: Jason Piotter
JoAnn Ireland

Date: September 14, 2021

SECTION B

HOLTEC INTERNATIONAL
Holtec Technology Campus, One Holtec Blvd, Camden, NJ 08104
Telephone (856) 797-0900
Fax (856) 797-0909

March 19, 2019

Andrea Kock, Director
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. 72-1014, Certificate of Compliance (CoC) No. 1014
72-1032, Certificate of Compliance (CoC) No. 1032

Subject: Submittal of Thermal Topical Report on the HI-STORM 100 and HI-STORM FW Systems

Reference: [1] Public Meeting between Holtec and NRC, November 21, 2019
[2] Holtec International Request for Amendment to HI-STORM FW Certificate of Compliance, ML20052D786

Dear Ms. Kock:

Holtec is pleased to submit a Thermal Topical Report on the HI-STORM 100 and HI-STORM FW Systems. This report has been previously discussed with your staff [1] and Holtec believes it will be a large benefit in reducing the number of necessary amendments to the Certificates of Compliance (CoCs). We request that the NRC staff review this topical report, with the intent of incorporating it for use in the CoCs via a separate, future licensing action. An example of what that licensing action would look like was submitted as Proposed Change 2 in Reference [2].

The report is included as Attachment 1 to this letter, and supporting calculations are included in Attachments 2 and 3. Since these documents are considered proprietary, Attachment 4 includes an affidavit according to 10CFR2.390 requesting that it be withheld from public disclosure.

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

Sincerely,

Kimberly Manzione
Licensing Manager,
Holtec International

Attachments:

Attachment 1: HI-2200343 Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems (proprietary)
Attachment 2: HI-2043317, Appendix P, Thermal Evaluation of MPC-68M in HI-STORM and HI-TRAC under QSHL Patterns (proprietary)
Attachment 3: HI-2094400, Appendix L, Thermal Evaluation of MPC-37 in HI-STORM FW Supporting Amendment 1 of CoC 1032 (proprietary)
Attachment 4: Affidavit Pursuant to 10 CFR 2.390 to Withhold Information from Public Disclosure

cc:
Johnathan Rowley (NRC)
Yoira Diaz-Sanabria (NRC)
John McKirgan (NRC)

SECTION C

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

September 1, 2020

Kimberly Manzione
Licensing Manager
Holtec International
1 Holtec Boulevard
Camden, NJ 08104

SUBJECT: SEPTEMBER 9, 2020, REGULATORY AUDIT PLAN FOR HOLTEC INTERNATIONAL TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS IN HI-STORM 100 AND HI-STORM FW SYSTEMS (EPID L-2020-TOP-0018)

Dear Ms. Manzione:

By letter dated March 19, 2020 (Agencywide Documents Access Management System Package Accession No. ML20101N174), Holtec International submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval "Topical Report [(TR)] for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems."

The NRC staff technical review of this TR is ongoing. The NRC staff determined that a regulatory audit is needed in order to facilitate the review. The NRC staff will perform a virtual regulatory audit on September 9, 2020, beginning at 9:00 a.m. Enclosed for your information is a copy of the plan the NRC staff will follow at the audit.

Please contact Ngola Otto at 301-415-6695 or via e-mail at Ngola.Otto@nrc.gov with any questions you may have regarding this letter.

Sincerely,

/RA/

Marilyn Diaz, Acting Branch Chief
Containment, Thermal, Chemical, and Fire
Protection Branch
Division of Fuel Management
Office of Nuclear Materials and Safeguards

Docket Nos. 72-1014 and 72-1032

NOTICE: Enclosure transmitted herewith contains proprietary information. When separated from Enclosure, this transmittal document is decontrolled.

Project No. 5014

Enclosure:
Audit Plan (Proprietary)

SUBJECT: SEPTEMBER 9, 2020, REGULATORY AUDIT PLAN FOR HOLTEC INTERNATIONAL TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS IN HI-STORM 100 AND HI-STORM FW SYSTEM (EPID L-2020-TOP-0018) DATED SEPTEMBER 1, 2020

DISTRIBUTION:
PUBLIC (Letter)
RidsNmssTa
RidsNmssOdRids
NrrDorl Resource
RidsNrrDorlLlpb Resource
RidsOgcMailCenter Resource
RidsACRS_MailCTR Resource
MDiaz, NMSS
JPiotter NMSS
NOtto, NRR
JIreland, NMSS
YDiaz-Sanabria, NMSS

ADAMS Accession Nos.:
ML20244A020 (Package)
ML20244A023 (Letter)
ML20244A024 (Audit Plan) ***Via e-mail**

OFFICE	NRR/DORL/LLPB/PM*	NRR/DORL/LLPB/LA*	NMSS/DFM/CTCFPB/BC
NAME	NOtto	DHarrison	MDiaz
DATE	08/21/2020	08/31/2020	09/01/2020

OFFICIAL RECORD COPY

SECTION D

HOLTEC
INTERNATIONAL

Holtec Technology Campus, One Holtec Blvd, Camden, NJ 08104
Telephone (856) 797-0900
Fax (856) 797-0909

October 6, 2020

Leslie Perkins, Project Manager
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

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

Docket No. 72-1014, Certificate of Compliance (CoC) No. 1014
72-1032, Certificate of Compliance (CoC) No. 1032

Subject: Submittal of Updated Thermal Topical Report on the HI-STORM 100 and HI-STORM FW Systems

Reference: [1] "September 9, 2020, Regulatory Audit Plan for Holtec International Topical Report for Allowance of Hat Load Patterns in HI-STORM 100 and HI-STORM FW Systems (EPID L-2020-TOP-0018), Letter Dated September 1, 2020, from M. Diaz (NRC) to K. Manzione (Holtec)

Dear Ms. Perkins:

Holtec is pleased to submit an updated version of the Thermal Topical Report on the HI-STORM 100 and HI-STORM FW Systems. This report was discussed with your staff during a recent audit [1] and Holtec has made a number of changes to the report based on these discussions to hopefully facilitate the staff's review. The revised report is included as Attachment 1 to this letter. Additionally, during the audit, it became clear to Holtec that a list of applications where similar approaches were taken would be beneficial to the staff. This list is included as Attachment 2.

Since the topical report is considered proprietary, Attachment 3 includes an affidavit according to 10CFR2.390 requesting that it be withheld from public disclosure.

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

Sincerely,

Kimberly Manzione

Holtec Technology Campus, One Holtec Blvd, Camden, NJ 08104
Telephone (856) 797-0900
Fax (856) 797-0909

Licensing Manager,
Holtec International

Attachments:

Attachment 1: HI-2200343 Revision 1 Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems (proprietary)
Attachment 2: List of Previous Holtec Applications which Justify Use of Q/I (non-proprietary)
Attachment 3: Affidavit Pursuant to 10 CFR 2.390 to Withhold Information from Public Disclosure

cc:
Yoira Diaz-Sanabria (NRC)
John McKirgan (NRC)
Jason Piotter (NRC)

SECTION E

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

November 2, 2020

Kimberly Manzione, Director
Licensing Manager
Holtec International
1 Holtec Boulevard
Camden, NJ 08104

SUBJECT: AUDIT REPORT REGARDING THE SEPTEMBER 9, 2020, REGULATORY AUDIT FOR HOLTEC INTERNATIONAL TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS IN HI-STORM 100 AND HI-STORM FW SYSTEMS (EPID: L-2020-TOP-0018)

Dear Ms. Manzione:

By letter dated March 19, 2020 (Agencywide Documents Access Management System (ADAMS) Package Accession No. ML20101N174), Holtec International submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval “Topical Report [(TR)] for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems.”

The NRC staff conducted a virtual regulatory audit on September 9, 2020, to gather information and to resolve questions pertaining to the Method of Evaluation, Incorporation by Reference, Screening Evaluation for Limited Calculations, Implementation Strategy and Notification of Implementation for the TR approval. The audit report documents the audit results, provides additional information to support the NRC staff safety evaluation (SE) of the TR, and will be referenced in the SE. Information regarding the audit plan can be found in ADAMS Package Accession No. ML20244A020. The audit report is enclosed.

If you have any questions, please contact me at (301) 415-2375 or Lesile.Perkins@nrc.gov.

Sincerely,

/RA/

Leslie Perkins, Project Manager
Licensing Projects Branch
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Enclosures:
1. Audit Report (Non-Proprietary)
2. Audit Report (Proprietary)

Docket Nos. 72-1014 and 72-1032
Project No. 5014

NOTICE: The Enclosure transmitted herewith contains Official Use Only - Proprietary Information. When separated from the Enclosure, this transmittal document is decontrolled.

SUBJECT: AUDIT REPORT FOR THE SEPTEMBER 9, 2020, REGULATORY AUDIT FOR HOLTEC INTERNATIONAL TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS IN HI-STORM 100 AND HI-STORM FW SYSTEMS (EPID: L-2020-TOP-0018) DATE: NOVEMBER 2, 2020

DISTRIBUTION:
PUBLIC (Letter and Nonproprietary Audit Report)
NONPUBLIC (Proprietary Audit Report)
RidsNmssTa
RidsNmssOdRids
NrrDorl Resource
RidsNrrDorlLlpb Resource
RidsOgcMailCenter Resource
RidsACRS_MailCTR Resource
MDiaz, NMSS
JPiotter NMSS
NOtto, NRR
LPerkins, NRR
JIreland, NMSS
YDiaz-Sanabria, NMSS

ADAMS Accession Nos.:
Cover Letter- ML20282A526
Audit Report (Non-Proprietary)- ML20282A527
Audit Report (Proprietary)- ML20282A528
Package- ML20282A525 *** Concurrence by email**

OFFICE	NRR/DORL/LLPB/PM*	NRR/DORL/LLPB/LA*	NMSS/DFM/CTCFPB/BC	NRR/DORL/LLPB/PM*
NAME	LPerkins*	DHarrison*	MDiaz	LPerkins*
DATE	10/21/2020	10/21/2020	11/02/2020	11/02/2020

OFFICIAL RECORD COPY

AUDIT REPORT

AUDIT REPORT FOR HOLTEC TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS IN HI-STORM 100 AND HI-STORM FW SYSTEMS
PROJECT NO. 5014
(EPID L-2020-TOP-0018)

1.0 BACKGROUND

In a letter dated March 19, 2020 (Agencywide Documents Access and Management System(ADAMS) Package Accession No. ML20101N174), Holtec International (Holtec) submitted Topical Report (TR) HI-2200343, Revision 0, “Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems,” for U.S. Nuclear Regulatory Commission (NRC) review and approval. Holtec requested the NRC staff review its generic methodology for evaluating the heat load patterns, with the intent of incorporating it for use in the HI-STORM 100 and HI-STORM FW certificate of compliance (CoCs) via a separate, future licensing action.

2.0 REGULATORY AUDIT OBJECTIVES

The Topical Report will be used to demonstrate compliance, in part, with Title 10 of the *Code of Federal Regulations* (10 CFR) Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-level Radioactive Waste, and Reactor-related Greater than Class C Waste.” The NRC staff completed its acceptance review on May 22, 2020, and found that the material presented was sufficient to begin its review (ADAMS Accession No. ML20141L621). After an initial review, the NRC staff identified some areas requiring further discussion and determined that it was necessary to conduct a regulatory audit to address NRC staff concerns regarding TR HI-2200343 Revision 0. The scope and objectives were defined in an audit plan (ADAMS Package Accession No. ML20244A020). A virtual audit was conducted via Skype on September 9, 2020.

Audit Participants

Name	**Organization**
Marilyn Diaz-Maldonado	NRC
JoAnn Ireland	NRC
Ngola Otto	NRC
Jason Piotter	NRC
Leslie Perkins	NRC
Tae Ahn	NRC
Ricardo Rodriguez	NRC
John Wise	NRC
Kim Manzione	Holtec
Debu Majumdar	Holtec
Abrar Mohammed	Holtec

Enclosure 1

3.0 AUDITED MATERIAL AND DISCUSSIONS

The five open items identified in the audit plan are discussed below.

Item #1 Method of Evaluation (MOE)

1a Defining Limitations

The NRC staff determined that enhancements to the MOE in the TR HI-2200343, Revision 0, was needed because 1) a broad array of inputs for both heat load patterns and total decay heat were never considered as part of previous approvals of the HI-STORM 100 and HI-STORM FW MOEs; and 2) the range of inputs were not clearly defined.

There were two scenarios discussed as part of the audit:

> Scenario 1, which includes heat load patterns in which the total decay heat is less than what has been previously approved for each design.
>
> Scenario 2, which includes heat load patterns in which the total decay heat is greater than what has been previously approved for each design.

The discussion regarding Scenario 1 initially focused on what was meant by ‘significant departure from a previously approved per cell heat load’ as discussed in the audit plan. The NRC identified that this concern was not specifically focused on defining ‘significant departure,’ rather that there was no identified objective approach to determine that increasing per cell decay heat values would not produce an unanalyzed condition. This unanalyzed condition is such that it would challenge previous assumptions and effective usage of the computational fluid dynamics (CFD) models to produce accurate temperature and pressure results.

The unanalyzed condition concern also extended to Scenario 2 in that increasing total decay heats over a range not previously considered may render certain assumptions and/or calculations in the MOE, including the numerical models, as invalid. The consideration here is whether or not a systematic and objective approach is employed to verify that the increasing decay heats, above what has been previously approved, do not challenge the range of applicability of the MOE.

Holtec’s response to this concern and scenarios focused on the invariance (see also Baseline HI-STORM 100 and HI-STORM FW Thermal Models) of the previously approved CFD models and also the self-limiting materials and pressure limit acceptance criteria. **[**

].

The NRC staff generally agreed that the acceptance criteria in this instance can be considered self-limiting given that conservative (lower than existing CoC acceptance criteria) values are used, however the calculated values derived from a CFD model need to have a robust pedigree to ensure a reasonable degree of accuracy and allow for meaningful comparisons. Holtec concurred with the discussion regarding the acceptance criteria being self-limiting, however, the discussion did not extend into identifying specific elements of a reasonable objective approach to provide assurance that the models are operating in their range of applicability, with increasing decay heat.

Disposition

Holtec committed to enhancing the discussion within the MOE to demonstrate that the CFD models are able to produce reasonably accurate results for the intended purpose over the range of expected decay heat beyond those that have been previously approved. As noted above, part of this enhancement should include specific elements of a reasonably systematic and objective approach to provide assurance that the models are operating in their range of applicability, with increasing decay heat.

1b Baseline HI-STORM 100 and HI-STORM FW Thermal Models

The use of the baseline CFD models submitted by Holtec identified no limitations or exclusions with respect to what changes or alterations that were allowed within TR HI-2200343, Revision 0.

Holtec confirmed during the audit that the two examples CFD models (HI-STORM 100 and HI-STORM FW) submitted as part of TR HI-2200343, Revision 0, are considered as the baseline models that will be used in conjunction with the MOE identified in TR HI-2200343, Revision 0.

Disposition

The CFD models were identified as invariant which means that no changes to the models, modeling choices, boundary conditions, or other inputs or numerical manipulations are allowed if used with TR HI-2200343, Revision 0. The only exception to altering the CFD models is the use of mirror symmetry of the existing model formulation and changes to the per cell decay heat values identified for a given candidate heat load pattern.

Item #2 Incorporation by Reference

TR HI-2200343 utilizes significant incorporation by reference which requires the NRC staff to piece together the entire MOE being described by the applicant, without clear and specific crosswalks to the information being referenced.

For the purposes of post audit activities, the NRC requested that Holtec provide:

(1) a more thorough crosswalk between TR HI-2200343, Revision 0, and relevant sections of the HI-STORM 100 and HI-STORM FW final safety analysis report (FSAR) including appendices and supplemental calculations that is clear and specific, or

(2) update TR HI-2200343, Revision 0, to be a stand-alone document with all relevant information self-contained within the TR, or

(3) a combination of (1) or (2).

Holtec agreed that some enhancements were needed to the TR HI-2200343, Revision 0, to address this issue.

Disposition

Holtec committed to having internal discussions and making adjustments to the TR contents consistent with those discussions and the options identified in the audit plan and subsequent audit discussions.

Item #3 Screening Evaluation - Limited Calculations

The NRC staff identified two concerns related to only using the long-term storage evaluation as a bounding calculation:

(1) higher variability in per cell decay heats that would be allowed with adoption of the TR and potential effects on short-term operations calculations, and

(2) a limited data set available to justify that only using the long-term storage condition.

The NRC staff and Holtec discussed the proposed screening evaluation which identifies two screening criteria that are used to determine the relative number of additional operating conditions which must be evaluated to accept a candidate heat load pattern. Specifically, if both screening criteria are met when performing the long-term storage evaluation, then no other storage conditions, including short-term and transfer operations, need to be considered.

The discussion then focused on either adding additional justification for this approach, which assumed that the long-term storage condition evaluation alone is sufficient as a stand-alone bounding calculation or providing additional language in the TR that would require other operating conditions that must be evaluated.

Holtec identified examples where this approach was used in previous CoC amendments and the NRC will consider these items as part of an approved MOE.

Disposition

As identified above, Holtec identified examples where this approach was used in previous CoC amendments and the NRC is going to review these items to determine whether they are consistent with the approach cited in TR HI-2200343, Revision 0. These examples will be appropriately considered in the safety evaluation in light of the concerns identified above. Holtec has committed to identify the specific CoC amendment(s) where this approach was used.

Item #4 Implementation Strategy

The NRC staff and Holtec had preliminary discussions during the post submittal meeting on July 17, 2020 (ADAMS Accession No. ML20202A658) on this issue to confirm how the requirements of 72.236, “Specific Requirements for Spent Fuel Storage Cask Approval and Fabrication,”(a) “maximum heat designed to be dissipated”, would be met. The NRC staff and Holtec discussed implementation scenarios, as well as how Holtec intended to meet the regulatory and safety functions with respect to other technical disciplines, such as shielding and structural.

The discussion on implementation as it relates to satisfying the regulatory requirement of identifying the maximum decay heat of a system, per 72.236(a), confirmed that this information would be provided during a CoC amendment that incorporates the use of TR HI-2200343, Revision 0. The discussion also confirmed that it is Holtec's intent to not identify a limiting maximum total decay heat for the system or for individual fuel assemblies.

The technical discussion regarding additional disciplines affected by the implementation of the TR focused on the adoption of TR HI-2200343, Revision 0, via a CoC amendment. Holtec identified that during the CoC amendment, that various sections of the FSAR and/or supporting documentation would make reviewers in those technical disciplines aware that TR HI-2200343, Revision 0, was incorporated and how it would affect those sections as applicable. One example that was identified was the use of Fuel Qualification Tables. Holtec identified that the requirements and procedures for determining that the loaded fuel meets the acceptance criteria and safety goals for shielding or other technical disciplines would not be altered by the incorporation of TR HI-2200343, Revision 0.

Disposition

This issue will be revisited separately from the TR HI-2200343, Revision 0, as part of implementation.

Item #5 Notification of Implementation of Thermal Topical Report

Since certain elements of the MOE, including aspect of numerical model implementation, will be conducted outside of explicit NRC review and approval through the existing CoC amendment process, the NRC staff believes that it may be appropriate to consider a reporting requirement, submitted to the NRC when TR HI-2200343, Revision 0, is invoked as part of a loading campaign.

Disposition

This item was briefly discussed, and it was determined that it was out of scope for the purposes of this audit. This issue will be revisited separately from the TR HI-2200343, Revision 0, as part of implementation.

4.0 REGULATORY AUDIT CONCLUSIONS AND FINDINGS

All of the regulatory audit objectives listed in Section 2.0 were covered and all audit items were closed with the exception of the commitments identified above. These commitments as well as any additional items within this audit report necessary to make a safety determination will be further address and dispositioned in the Safety Evaluation Report.

SECTION F

From: Perkins, Leslie
To: Debu Majumdar
Cc: Bajwa, Chris; Piotter, Jason
Subject: DRAFT SAFETY EVALUATION FOR HOLTEC INTERNATIONALTOPICAL REPORT HI-2200343, “TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS IN HI-STORM 100 AND HI-STORM FW SYSTEMS”
Date: Wednesday, February 17, 2021 1:32:00 PM

Dear Dr. Mitra-Majumdar,

By letter dated March 19, 2020 (Agencywide Documents Access and Management System (ADAMS) Package Accession No. ML20101N174), Holtec International (Holtec) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review the Topical Report (TR) HI-2200343 Revision 0, “Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems.”

A copy of the draft safety evaluation (SE) with open items has been placed in the box.com folder. Holtec has been given access to the folder. The draft SE is being provided for proprietary information review and for Holtec to provide responses to the NRC staff’s open items. If Holtec provides comments on other areas, the NRC staff will exercise its discretion on whether to address those comments.

Pursuant to Section 2.390 of Title 10 of the *Code of Federal Regulations* (10 CFR), we have determined that the draft SE may contain proprietary information. If you believe that any information in the draft SE is proprietary, please identify such information line-by-line and define the basis pursuant to the criteria of 10 CFR 2.390. Use double brackets and yellow highlight to identify any [[proprietary information]]. After 10 working days, the draft SE will be made publicly available, if appropriate.

Your response must be via a letter from an authorized individual. In addition, please provide an electronic redline/strikeout Word version of the SE either via email or the box.com folder. It helps expedite the NRC staff response to comments if Holtec provides in the formal transmittal and in a separate Word file, a table with the following columns; Comment No., Page No., and Line No., Comment Type (if comments other than proprietary information are provided (i.e., clarity, accuracy)), Suggested Revision, and a blank column NRC Disposition. However, Holtec may provide its comments in any format it chooses. The final SE will be issued after making any necessary changes.

Note that at this stage of the process, the NRC staff has completed its review of the submitted information and will only entertain technical discussions regarding the open items identified in the draft SE. The staff conclusions and conditions will not change unless new information is provided that was not available during our review. If Holtec would like to discuss the draft SE in detail, we can do that in a noticed meeting that can be closed if proprietary information will be discussed.

Both this email and the draft SE have been placed in ADAMS and made Official Agency Records. The draft SE is declared as nonpublic because it may contain proprietary information. This email is declared public.

If you have any questions, please feel free to contact me at 301-415-2375 or by email at Leslie.Perkins@nrc.gov.

Sincerely,
Leslie Perkins
Project Manager, Licensing Projects Branch
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation
e-mail: Leslie.Perkins@nrc.gov
Phone: 301-415-2375

Docket Nos.: 72-1014 & 72-1032

SECTION G

HOLTEC
INTERNATIONAL

Holtec Technology Campus, One Holtec Blvd, Camden, NJ 08104
Telephone (856) 797-0900
Fax (856) 797-0909

April 2, 2021

Leslie Perkins, Project Manager
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

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

Docket No. 72-1014, Certificate of Compliance (CoC) No. 1014
72-1032, Certificate of Compliance (CoC) No. 1032

Subject: Submittal of Holtec Proprietary Information Review and Response to Open Items on the Thermal Topical Report on the HI-STORM 100 and HI-STORM FW Systems

Reference: [1] Perkins, Leslie (NRC), "Draft Safety Evaluation for Holtec International Topical Report HI-2200343, "Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems", Email to Dr. Debu Mitra-Majumdar (Holtec) (ML21034A596), February 17, 2021

Dear Ms. Perkins:

By email dated February 17, 2021 [1], Holtec received a copy of the draft safety evaluation (SE) with open items for the Thermal Topical Report on the HI-STORM 100 and HI-STORM FW Systems (HI-2200343) from the U.S. Nuclear Regulatory Commission (NRC). Holtec has reviewed the draft SE for proprietary information and a copy of the draft SE with proprietary information marked (via yellow highlight) is included as Attachment 1 to this letter.

Attachment 2 to this letter contains a proprietary version of Hotlec's responses to the NRC staff's open items. A non-proprietary copy of Holtec's responses is provide in Attachment 3. Attachment 4 contains the updated version of the proprietary Thermal Topical Report on the HI-STORM 100 and HI-STORM FW Systems in support of the responses to the NRC staff's open items.

Since this letter contains proprietary attachments, Attachment 5 to this letter is an affidavit prepared in accordance with 10 CFR 2.390 requesting that this attachment be withheld from public disclosure.

If you have any questions, please contact me at 856-797-0900 ext. 3663.

Sincerely,

Debabrata (Debu) Mitra-Majumdar
Senior Director,
Holtec International

Attachments:

Attachment 1: Draft Safety Evaluation with Holtec Identified Proprietary Information (proprietary)
Attachment 2: Responses to NRC Staff's Open Items (proprietary)
Attachment 3: Responses to NRC Staff's Open Items (non-proprietary)
Attachment 4: HI-2200343 Revision 2 Topical Report for Allowance of Heat Load Patterns in HI-STORM 100 and HI-STORM FW Systems (proprietary)
Attachment 5: Affidavit Pursuant to 10 CFR 2.390 to Withhold Information from Public Disclosure

cc:
Ekaterina Lenning (NRC)
Jason Piotter (NRC)

HOLTEC INTERNATIONAL

Holtec Technology Campus, One Holtec Blvd, Camden, NJ 08104
Telephone (856) 797-0900
Fax (856) 797-0909

April 9, 2021

Ekaterina Lenning, Project Manager
Division of Fuel Management
Office of Nuclear Material Safety and Safeguards

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

Docket No. 72-1014, Certificate of Compliance (CoC) No. 1014
72-1032, Certificate of Compliance (CoC) No. 1032

Subject: Submittal of Holtec Proprietary Information Review and Response to Open Items on the Thermal Topical Report on the HI-STORM 100 and HI-STORM FW Systems – Updated Attachment

Reference: [1] "Submittal of Holtec Proprietary Information Review and Response to Open Items on the Thermal Topical Report on the HI-STORM 100 and HI-STORM FW Systems", Letter to Perkins, Leslie (NRC) from Dr. Debu Mitra-Majumdar (Holtec) dated April 2, 2021

Dear Ms. Lenning:

It has come to our attention that in Reference [1], Attachment 2 (ML21092A164) had some incorrectly marked proprietary information. Please use Attachment 1 to this letter to replace Attachment 2 (ML21092A164) in Reference [1].

Since this letter contains a proprietary attachment, Attachment 2 to this letter is an affidavit prepared in accordance with 10 CFR 2.390 requesting that this attachment be withheld from public disclosure.

If you have any questions, please contact me at 856-797-0900 ext. 3663.

Sincerely,

Debabrata (Debu) Mitra-Majumdar
Senior Director,
Holtec International

Attachments:

Attachment 1: Responses to NRC Staff's Open Items (proprietary)
Attachment 2: Affidavit Pursuant to 10 CFR 2.390 to Withhold Information from Public Disclosure

cc:
Jason Piotter (NRC)

SECTION H

Nuclear Power Division	5014
Sponsoring Company	**Project No.**

HI-2200343	5	18 Jan 2024
Company Record Number	**Revision No.**	**Issue Date**

Report	Non-Proprietary Information
Record Type	**Proprietary Classification**
Nuclear	No
Quality Class	**Export Control Applicability**

Record Title:

TOPICAL REPORT FOR ALLOWANCE OF HEAT LOAD PATTERNS IN HI-STORM 100 AND HI-STORM FW SYSTEMS

Prepared by:	**Reviewed by:**	**Approved by:**
A.Mohammad, 17 Jan 2024	K.Manzione, 18 Jan 2024	D.Mitra-Majumdar, 18 Jan 2024

Signature histories are provided here for reference only. Company electronic signature records are traceable via the provided Verification QR Code and are available for review within the secure records management system. A valid Verification QR Code and the presence of this covering page indicates this record has been approved and accepted.

Verification QR Code:

Proprietary Classification

This record is the non-proprietary version of a report that contains proprietary information owned by the company.

Export Control Status

Export Control restrictions do not apply to this record.

TABLE OF CONTENTS

SUMMARY OF REVISION

Revision 0: Original Issue.

Revision 1: Report is revised to clarify the applicability of thermal modeling methodology. Additionally, editorial changes are made to provide further clarity in certain sections of the report. All changes are marked with revision bars in the right margin.

Revision 2: Report is revised to address NRC's comments on the draft SER. All changes are marked with revision bars in the right margin.

Revision 3: Report is revised to include temperature limit table from the FSAR. All changes are marked with revision bars in the right margin.

Revision 4: Table 2.1 is revised to clarify the temperature limits for consistency with HI-STORM 100 FSAR. All changes are marked with revision bars in the right margin.

Revision 5: A note in Table 2.1 is revised for consistency with HI-STORM 100 FSAR. Further, the footer is also revised.

1.0 BACKGROUND AND PURPOSE

The HI-STORM 100 System as illustrated in Figure 1.1 is designed for long-term storage of Spent Nuclear Fuel (SNF). The system was initially licensed by the Nuclear Regulatory Commission (NRC) in 2000 [1] to permit fuel storage under modest cask heat load limits (20.88 kW, PWR & 21.52 kW, BWR). These limits were adequate for addressing storage of old and cold fuel at nuclear power plants. Since then Holtec has secured over ten HI-STORM amendments wherein the heat load capabilities of the system have been upgraded, in terms of the per-assembly heat load limits and the cask heat load limits (current values in Table 2.5), to meet the demands for storing higher heat load fuels due to depletion of old and cold fuel and accumulation of high burnup fuel inventories. The need to store fuel with higher per-assembly heat load fuels is projected to grow further as cask designers are challenged by shuttering nuclear plants.

Similarly, the HI-STORM FW System as illustrated in Figure 1.2 is also designed for long-term storage of SNF. It was originally licensed in 2011 for higher cask heat loads (47.05 kW for PWR and 46.36 kW for BWR). The need to store higher per assembly heat loads than currently licensed is also expected to grow for shuttering nuclear plants.

The general goal of the cask loading strategy is to move the spent fuel from the pool to dry storage as early as possible. While maintaining the same level of safety, this allows a significant reduction in the extent of the safety significant systems that need to be maintained, such as the spent fuel pool cooling systems. For this, loading plans have to be developed that allow the loading of the entire pool inventory in a relatively short time, which includes assemblies with a large variation of burnups and cooling times, i.e. a large variation of the decay heat of the assemblies. Previous loading patterns of the spent fuel baskets used what was called "regionalized" loading, where 2 or 3 concentric regions of cells in the basket were defined with different decay heat limits. This was to support dose rate optimization when loading casks in ongoing plant operation. Since the entire inventory of fuel from the pool was available, but only a few casks were loaded at a given time, a limited number of generic decay heat patterns was sufficient for that purpose. However, when loading the entire pool, this approach is no longer appropriate, due to the large variation of decay heat loads, and the need to load *every* assembly from the pool. If only a single assembly could not find an appropriate spot in one of the casks, unloading the pool would be delayed. Hence loading patterns have now been developed that assign decay heat limits on a cell-by-cell basis, to allow meeting the goal of emptying the pool, while also meeting all other regulatory limits. However, the experience with developing such patterns shows that it is not possible to find a single bounding pattern that would allow optimal loading at every plant. In fact, even for the different units at a 2-unit site with almost identical pool inventories, the optimal patterns are somewhat different for the two pools. And even a small misalignment between the pool inventory and the available pattern could result in significant delays in loading, much more so than for the 2 or 3 region patterns.

One approach to address this issue, that has been used by Holtec in the past, is to separate the decay heat limit for the entire basket from the decay heat limits of the individual cell locations. For example, for the HI-STAR 180 (USNRC Docket# 71-9325), the sum of the individual cell decay heat limits in a quarter of the cask is 11.825 kW, while the actual, allowable total for every quarter can only be 8 kW. This allows some flexibility in the assignment of assemblies to cells. However, finding a bounding pattern to be used in the safety analyses that demonstrates that both the total decay heat and the individual cell limit are appropriate and justified is difficult for this approach. Additionally, it does add additional conservatism, depending on the loading. This is therefore not seen as a possible solution here. Hence under the current licensing approach, many separate loading patterns would have to be licensed, potentially one or more for each spent fuel pool. This does not appear to be an efficient licensing strategy, since it results in an ongoing stream of license amendments.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

The following sections address all those items in further detail. Section 3 then present two examples, which are also to be used as templates to document the evaluations and results to qualify newly developed candidate loading patterns through the approach presented here.

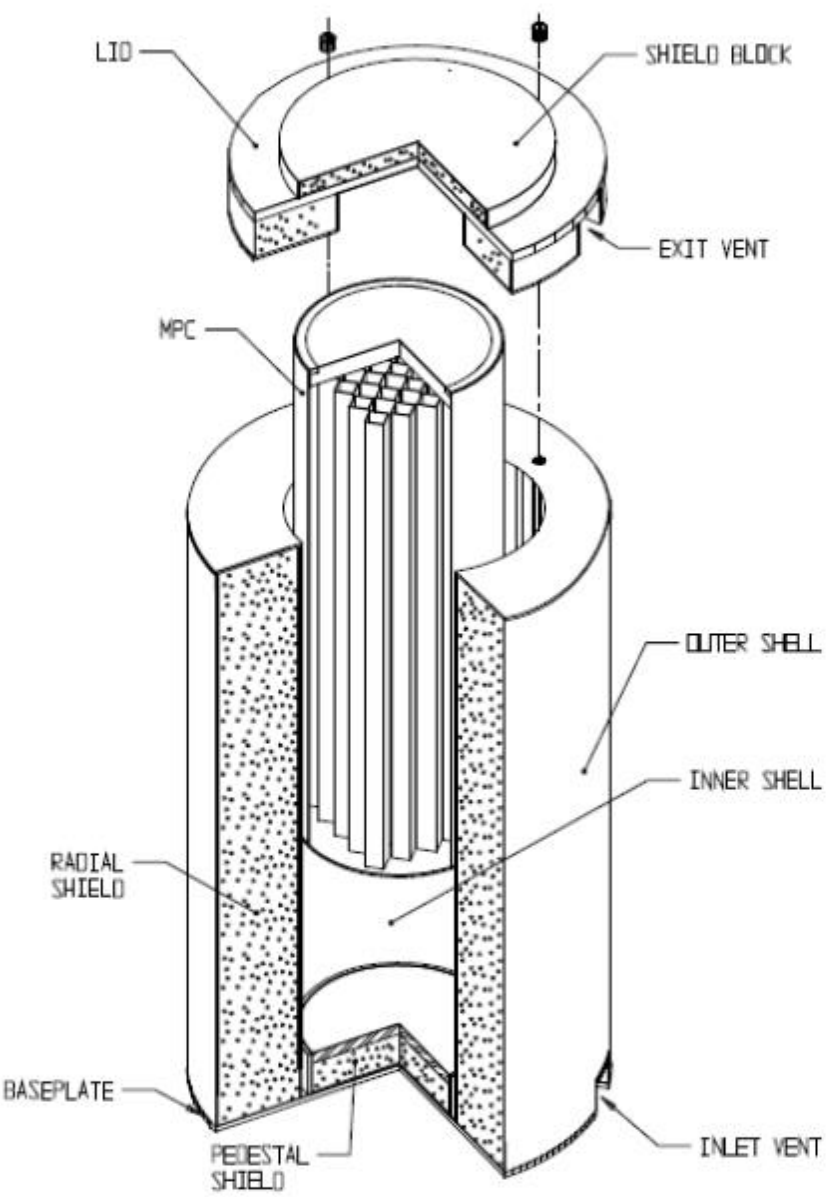

Figure 1.1: HI-STORM 100 Spent Fuel Storage System

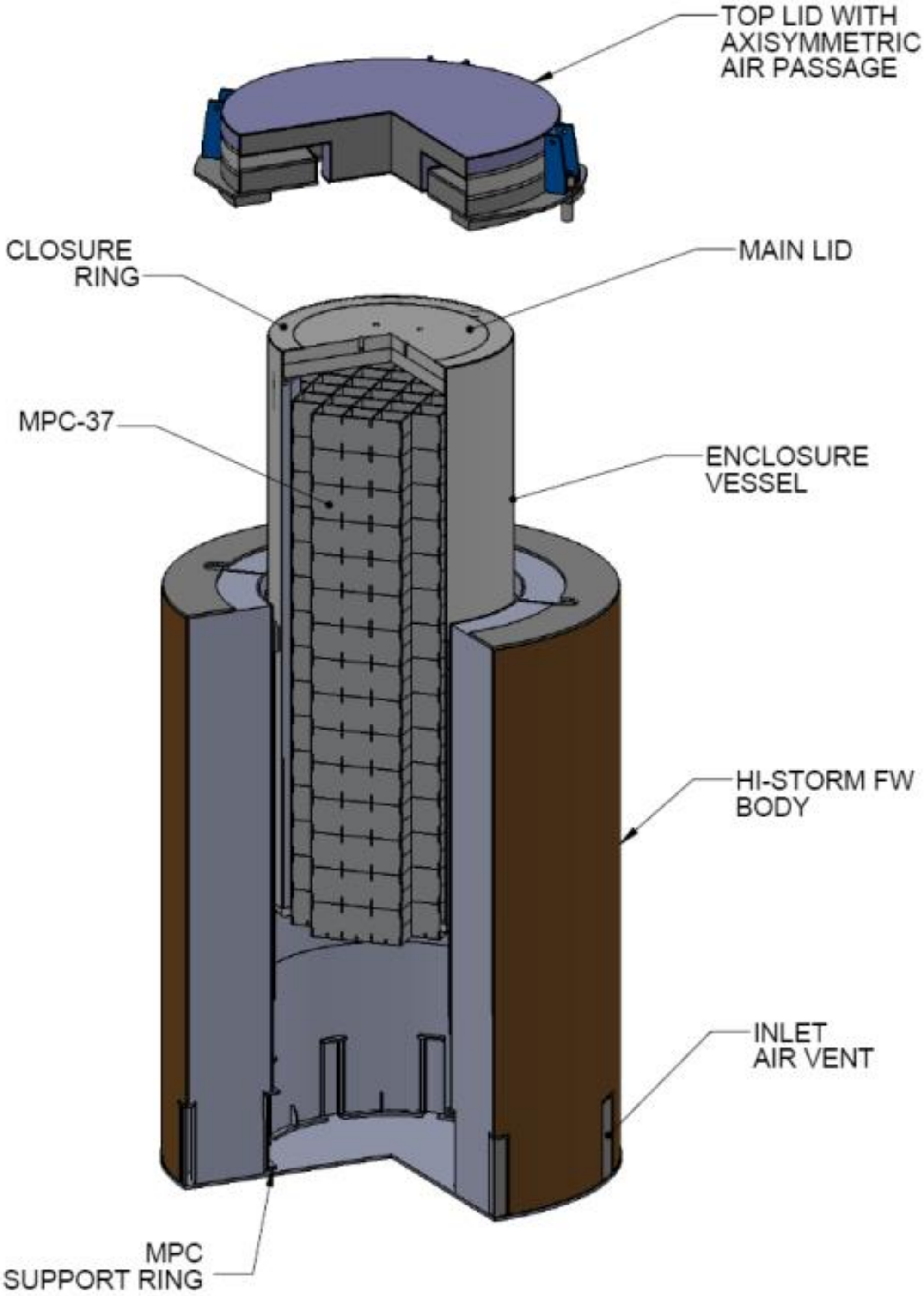

Figure 1.2: HI-STORM FW Spent Fuel Storage System

2.0 HEAT LOAD PATTERN EVALUATION METHODOLOGY FOR HI-STORM 100 SYSTEM

2.1 Inputs

Inputs to the methodology and calculations are any candidate heat load patterns, for given casks or baskets. These would come out of the evaluation of pool inventories, but the development of those patterns is not part of this report and therefore not discussed here. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

].

2.2 Acceptance Criteria

The resultant temperatures from candidate heat load patterns are required to remain within licensed limits. To ensure this requirement, **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

]. A review of HI-STORM 100 SERs did not result in any limitation that restrict the validity of the methodology adopted for all thermal evaluations. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

]. Additionally, HI-STORM 100 Structures Systems and Components (SSC) safety limits from the FSAR are adopted in Tables 2.1 and 2.2. To muster qualification, candidate patterns shall remain below the limits defined in these tables. The complete qualification process is illustrated in the examples in Section 3.

2.3 Methodology

As described in Section 1.0, this TR establishes the principal methodology to qualify candidate loading patterns that satisfy temperature limits established in Sections 2.2 or 4.2, for the applicable system. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

].

Additionally, the following ensure the thermal model developed following the methodology presented in Sections 2.3 or 4.3 of this report is robust to capture the physical phenomenon irrespective of the total MPC decay heat and distribution of decay heat in the MPC:

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

2.3.1 HI-STORM 100 Description[1]

The HI-STORM 100 System is a Multi-Purpose Canister (MPC) based system wherein fuel is stored in a sealed stainless vessel and emplaced in a steel shell reinforced concrete overpack. The HI-STORM 100 overpack is designed to facilitate ventilation cooling as illustrated in Figure 2.1. The System is illustrated in Figure 1.1. The MPC consists of fuel storage baskets in four distinct geometries to hold 24 or 32 PWR, or 68 BWR fuel assemblies. An example MPC-32 fuel basket designed to store 32 PWR fuel assemblies is shown in Figure 2.2.

The fuel basket is a matrix of interconnected square compartments designed to hold the fuel assemblies in a vertical position under long term storage conditions. The basket is a honeycomb structure of stainless steel (Alloy X) plates or Metamic-HT panels. In the case of stainless-steel construction, the basket is equipped with neutron absorber plates sandwiched between the box wall and a stainless-steel sheathing plate over the full length of the active fuel region. The neutron absorber plates used in MPCs containing stainless steel baskets are made of an aluminum-based, boron carbide-containing material to provide criticality control, while maximizing heat conduction capabilities. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

---

[1] To facilitate review excerpts of the description, methodology and models articulated in the HI-STORM 100 FSAR [2] is provided herein.

]. Prior to sealing the MPC it is helium pressurized to certain backfill specifications to support closed loop internal convection cooling of the stored fuel. This cooling action is illustrated in Figure 2.3.

Thermal analysis of the HI-STORM 100 System is performed using the FLUENT computer code [3] as a coupled buoyancy driven heat dissipation system consisting of ventilation air flow in the overpack annulus (Figure 2.1) and MPC circulating helium flow in the assemblies and the MPC downcomer (Figure 2.2). The principal attributes of the thermal model are described in the following:

i. While the rate of heat conduction through metals is a relatively weak function of temperature, radiation heat exchange is a highly nonlinear function of surface temperatures.

ii. Heat generation in the MPC is axially non-uniform due to non-uniform axial burnup profiles in the fuel assemblies.

iii. Inasmuch as the transfer of heat occurs from inside the basket region to the outside, the temperature field in the MPC is spatially distributed with the maximum values reached in the central core region.

2.3.2 Description of the 3-D Thermal Model

The methodology and assumptions presented in the sub-sections below are essentially directly obtained from Chapter 4 of HI-STORM 100 FSAR [2].

2.3.2.1 MPCs with Stainless Steel Basket

2.3.2.1.1 Introduction

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

2.3.2.1.2 Details of the 3-D Model

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390.

].

The 3-D model described above is illustrated for an example MPC-68 in Figure 2.6. The model described above is consistent with that adopted for licensing basis evaluations presented in Chapter 4 of the FSAR. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

]. The principal 3-D modeling conservatisms are listed below:

1) The storage cell spaces are loaded with fuel under candidate heat load scenario.
2) The axial heat distribution in each fuel assembly is assumed to be non-uniformly distributed with peaking in the active fuel mid-height region as shown in Table 2.8 (It is consistent with HI-STORM 100 axial burnup ([2], Table 2.1.11).
3) Axial dissipation of heat by the fuel pellets is neglected.
4) Axial dissipation of heat by radiation in the fuel bundle is neglected.
5) **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**.]

6) The most severe environmental factors for long-term normal storage – licensing basis ambient temperature and 10CFR71 insolation levels - coincidentally applied on the system.

7) **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].**

8) To understate MPC internal convection heat transfer, the helium pressure is understated.

9) **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].**

10) Heat dissipation by fuel basket peripheral supports is neglected.

11) [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

The above methodology and assumptions are consistent with that approved in Section 4.4 of HI-STORM 100 FSAR [2].

2.3.2.2 MPCs with Metamic-HT Basket

2.3.2.2.1 Introduction

Except for the fuel basket, basket support, and basket shim materials, the information in Section 2.3.2.1 remains applicable to the MPC-32M and MPC-68M analysis. Further details of the thermal models provided below:

2.3.2.2.2 Details of the 3-D Model

The MPC-68M thermal design is similar to the MPC-68 design. It features a 68 cells capacity fuel basket for storing BWR fuel. Similarly, MPC-32M design is similar to the MPC-32 design. The principal differences are in the basket material of construction (Metamic-HT), the installation of aluminum basket shims in the basket peripheral spaces and replacement of the cell walls sandwich construction by monolithic (i.e. gaps free) basket panels.

The thermal evaluations use the same aboveground MPC 3-D thermal modeling methodology and the same 3-Zone porous media model used in the thermal analysis of the aboveground overpack defined in Section 2.3.2.1, to represent the flow resistance of bounding BWR and PWR fuel assemblies. The key attributes of MPC-68M and MPC-32M thermal model are as follows:

1. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].**
2. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].**
3. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].**

4. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.
5. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

   ].
6. The material properties defined in HI-STORM 100 FSAR Section 4.III.2 [2] are used for analysis of the candidate heat load pattern evaluations.
7. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

   ].
8. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

   ].

2.3.2.3 HI-TRAC Thermal Model

Prior to placement in a HI-STORM 100 overpack, an MPC must be loaded with fuel, outfitted with closures, dewatered, dried, backfilled with helium and transported to the HI-STORM 100 module. In the unlikely event that the fuel needs to be returned to the spent fuel pool, these steps shall be performed in reverse. Finally, if required, transfer of a loaded MPC between HI-STORM 100 overpacks or between a HI-STAR transport overpack and a HI-STORM 100 storage overpack must be carried out in an assuredly safe manner. All of the above operations, henceforth referred to as “short term operations”, are short duration events that would likely occur no more than once or twice for an individual MPC.

The device central to all of the above operations is the HI-TRAC transfer cask. There are various designs for the HI-TRAC that can be summarized into the following two:

a. Unventilated HI-TRAC such as HI-TRAC 125D that has a small annulus gap between the MPC and HI-TRAC.
b. Ventilated HI-TRAC such as HI-TRAC MS that has openings at the bottom and a large annulus gap between the MPC and HI-TRAC to allow airflow.

The HI-TRAC transfer cask is a short-term host for the MPC; therefore, it is necessary to establish that, during all thermally challenging operation events, the permissible temperature limits presented in Table 2.1 are not exceeded. The following discrete thermal scenarios, all of short duration, involving the HI-TRAC transfer cask, have been identified as warranting thermal analysis.

c. Post-Loading Wet Transfer Operations
d. MPC Cavity Vacuum Drying
e. Normal Onsite Transport
f. MPC Cooldown and Reflood for Unloading Operations

Within a loaded HI-TRAC, heat generated in the MPC is transported from the contained fuel assemblies to the MPC in the manner described in Section 2.3.2.2. From the outer surface of the MPC to the ambient air, heat is transported by a combination of conduction, thermal radiation and natural convection. For evaluation of the thermal state of a loaded canister during all short-term operations, the three dimensional (3D) thermal model of the MPC described in Section 2.3.2.2 is utilized. Transport of heat within HI-TRAC occurs through multiple concentric layers of air, steel and shielding materials. A small gap exists between the outer surface of the MPC and the inner surface of the HI-TRAC overpack. Heat is transported across this gap by the parallel mechanisms of natural convection, conduction and thermal radiation. Assuming that the MPC is centered and does not contact the transfer cask walls conservatively minimizes heat transport across this gap. Heat is transported through the cylindrical wall of the HI-TRAC transfer cask by conduction through successive layers of steel, lead, and steel. A water jacket, which provides neutron shielding for the HI-TRAC transfer cask, surrounds the cylindrical steel wall. The water jacket is essentially an array of carbon steel radial ribs with welded, connecting enclosure plates. Heat is dissipated by conduction and natural convection in the water cavities and by conduction in the radial ribs. Heat is passively rejected to the ambient from the outer surface of the HI-TRAC transfer cask by natural convection and thermal radiation.

The HI-TRAC transfer cask thermal analysis is based on a 3D FLUENT model that incorporates several conservative features, namely:

a. A constant solar flux is assumed with maximum permissible heat load and asymptotic steady state conditions to yield the most adverse temperature field in the cask. A theoretically bounding solar absorbtivity of 1.0 is applied to all exposed surfaces.

b. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

c. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

d. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

e. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

f. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

g. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

h. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

i. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

].

The computational fluid dynamics model of the HI-TRAC transfer cask captures all essential details of the cask body including the radial ribs, lead, steel shells and the water jacket. The above methodology and assumptions are consistent with that approved in Section 4.5.1 of HI-STORM 100 FSAR [2]. In case of HI-TRAC MS design, the modeling features are exactly the same as described above except the following, which are consistent with that described in Section 4.II.5.2 of [2]:

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

2.3.2.4 Vacuum Drying Thermal Model

To evaluate the vacuum drying scenario, the MPC model described in Section 2.3.2.2 is adopted. The principal features of the thermal model are as follows:

a. The water in the HI-TRAC annulus is conservatively assumed to be boiling (212ºF).
b. The bottom surface of the MPC is insulated.

A bounding steady-state analysis is performed under the candidate heat load. As fuel temperatures of casks loaded with high burnup fuel are challenged under high decay heat, cycles of vacuum drying resulting in heatup followed with cooling by helium is necessary in such cases. Cyclic drying is articulated below.

A suitable methodology is prescribed below to compute heat load specific cyclic drying durations using the 3D thermal model articulated herein:

1. Compute steady state temperatures under vacuum conditions. If PCT is below ISG-11, Rev. 3 limits then vacuum drying is acceptable without time limits. If PCT exceeds ISG-11, Rev. 3 limits then follow cyclic drying steps below.
2. Cycle 1 (Heatup) – A transient thermal evaluation is performed under the loading specific heat loads in vacuum conditions. The time $\tau 1$ required for the fuel to heatup from an initial temperature of 100ºC (212ºF) to 380ºC (716ºF) under high burnup fuel loading is computed. If drying completion criteria is not met, then the cask cavity or MPC shall be backfilled with helium to facilitate cooling as defined in the next step below.
3. Cycle 1 (Cooldown) – The MPC cavity is backfilled with helium to 1 atm absolute pressure. Fuel cooling under helium is evaluated to compute the time $\tau 2$ used in operations for fuel temperatures to decreases by temperatures less than or equal to 65ºC (117ºF).

4. Cycle 2 (Heatup) - The drying process switches to vacuum drying and time τ3 required to reach 380ºC (716ºF).
5. Up to 9 additional cycles of heatup and cooldown drying using the times τ3 and τ2 computed above may be performed until the drying completion criteria are met.

If a total of 10 drying cycles fail to meet drying criteria, then other competent means to dry fuel (such as FHD) shall be used or the MPC must be de-fueled.

The above methodology and assumptions are consistent with that approved in Section 4.5.3 of HI-STORM 100 FSAR [2].

2.3.3 Evaluation of DFCs/DFIs

A limited number of fuel assemblies defined in the HI-STORM 100 Technical Specification classified as damaged fuel are permitted to be stored in the MPC inside Damaged Fuel Containers (DFCs) or Damaged Fuel Isolators (DFIs). A DFC or DFI can only be stored in locations identified in Appendices B and D of the Tech. Spec. DFC or DFI emplaced fuel assemblies have a higher resistance to helium flow because of the debris screens. The thermal methodology for modeling the fuel basket, basket shims, MPC and overpack remains the same as discussed in Section 2.3.2.2 except that the fuel within the DFC is modeled as porous medium with effective thermal properties as tabulated in Table 2.4. Debris screens in the DFIs and DFCs are modeled as porous jump.

2.3.4 Heat Load Map for Analysis

Candidate heat load pattern define fuel heat q_i in all MPC storage locations i = 1 thru N where N is the number of fuel storage cells. These patterns may be defined to support an on-going fuel loading operation in which case q_i is defined by actual loaded cask heat loads or to support fuel management and on-site storage planning wherein suitable bounding heat loads are defined and qualified for use.

2.3.5 Limitations on Heat Load Patterns

Acceptability of cask and fuel assembly heat loads are solely guided by safety evaluations and the established temperature and pressure limits. Any heat load pattern that does not comply with <u>all</u> applicable safety limits under <u>any</u> design basis condition (normal, off-normal, accident or short-term operations) is not considered qualified.

Note that there may be additional requirements and limits specified in the FSAR and CoC where this TR is incorporated.

2.3.6 Helium Backfill Limits

To support internal convection cooling MPCs are helium backfilled to minimum limits as informed by FLUENT thermal calculations. An upperbound limit is also defined to meet FSAR mandated MPC pressure limits. Helium backfill limits under each candidate heat load pattern shall be established using the equations provided below.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

2.3.7 Material Properties

The same material properties defined in HI-STORM 100 FSAR Sections 4.2 and 4.III.2 [2] are used for analysis of the candidate heat load pattern evaluations.

2.3.8 Time to Boil

Fuel loading operations are conducted with the HI-TRAC transfer cask and its contents submerged in pool water. Under these conditions, the HI-TRAC transfer cask is essentially at the pool water temperature. When the HI-TRAC transfer cask and the loaded MPC under water-flooded conditions is removed from the pool and staged in an ambient air environment, the water, MPC, and HI-TRAC transfer cask metal absorb the decay heat emitted by the fuel assemblies. This results in a slow temperature rise of the HI-TRAC transfer cask with time, starting from an initial pool water temperature. The rate of temperature rise is limited by the thermal inertia of the HI-TRAC transfer cask. Sites must evaluate the time limit to prevent boiling of the water in the MPC.

The available time before the water in the MPC would reach boiling is computed under a conservative set of assumptions summarized below:

i. Heat loss by natural convection and radiation from the exposed HI-TRAC surfaces to ambient air is neglected (i.e., an adiabatic heat-up calculation is performed).

ii. The water mass in the MPC cavity is understated.

The rate of temperature rise of the HI-TRAC transfer cask and contents during an adiabatic heat-up is given by the ratio Q/C where:

Q = Coincident fuel decay heat in the canister (Btu/hr)

C = Thermal inertia of a loaded HI-TRAC (Btu/°F)

Therefore, the time-to-boil, τ is given by the simple algebraic formula $\tau = C(212-T)/Q$ where 212°F has been set as the boiling temperature and T represents the temperature of the pool water under fuel loading operations. The time-to-boil clock starts when the HI-TRAC is no longer submerged in the pool water. The calculation of time-to-boil for a loaded canister shall be made using the above formula. An alternate method using the FLUENT thermal model described in Paragraph 2.3.2.3 can be adopted to evaluate the time for water within the MPC to boil using site-specific conditions.

As set forth in the HI-STORM 100 operating procedures, in the unlikely event that the maximum allowable time is found to be insufficient to complete wet transfer operations, a forced water circulation shall be initiated and maintained to remove the decay heat from the MPC cavity. In this case, relatively cooler water will enter via the MPC lid drain port connection and heated water will exit from the vent port. The minimum water flow rate required to maintain the MPC cavity water temperature below boiling with an adequate subcooling margin is determined as follows:

$$M_W = \frac{Q}{C_{pW}\,(T_{max} - T_{in})}$$

where:

M_W = minimum water flow rate (lb/hr)
C_{pw} = water heat capacity (Btu/lb-°F)
T_{max} = maximum MPC cavity water mass temperature (must be less than 212°F)
T_{in} = MPC water inlet temperature
Q = Coincident fuel decay heat in the canister (Btu/hr)

2.3.9 Partial Blockage of HI-STORM 100 Inlet Vents

The HI-STORM 100 System is designed with debris screens installed on the inlet and outlet openings. These screens ensure the air passages are protected from entry and blockage by foreign objects. Therefore, to meet the system design criteria, it is postulated that the HI-STORM 100 air inlet vents are 50% blocked. The resulting decrease in flow area increases the flow resistance of the inlet ducts. The effect of the increased flow resistance on fuel temperature is analyzed for the normal ambient temperature using the model described in Subsection 2.3.2. The computed temperatures and pressure shall be below the acceptance criteria in Tables 2.1 and 2.2, respectively.

2.3.10 Off-Normal Ambient Temperature

This event is defined by a time-averaged ambient temperature of 100°F for a 3-day period, applied to the FLUENT model described in Subsection 2.3.2. The computed temperatures and pressures shall be below the acceptance criteria in Tables 2.1 and 2.2.

2.3.11 Extreme Ambient Temperature Accident.

To evaluate the effect of extreme weather conditions (ambient temperature of 125°F), an extreme ambient temperature is postulated to persist for a 3-day period. For a conservatively bounding evaluation the extreme temperature is assumed to last for a sufficient duration to allow the system to reach steady state conditions. Because of the large mass of the HI-STORM 100 System, with its corresponding large thermal inertia and the limited duration for the extreme temperature, this assumption is conservative. The computed temperatures and pressures shall be below the acceptance criteria in Tables 2.1 and 2.2.

2.3.12 100% Duct Blockage of HI-STORM 100 Inlet Vents

This event is defined as a complete blockage of all four bottom inlets. The immediate consequence of a complete blockage of the air inlets is that the normal circulation of air for cooling the MPC is stopped. An amount of heat will continue to be removed by localized air circulation patterns in the overpack annulus and outlet ducts, and the MPC will continue to radiate heat to the relatively cooler storage overpack. As the temperatures of the MPC and its contents rise, the rate of heat rejection will increase correspondingly. Under this condition, the temperatures of the overpack, the MPC and the stored fuel assemblies will rise as a function of time.

As a result of the considerable inertia of the storage overpack, a significant temperature rise is possible if the inlets are substantially blocked for extended durations. This accident condition is, however, a short duration event that is identified and corrected through scheduled periodic surveillance. Nevertheless, this event is conservatively analyzed assuming a substantial duration of blockage. The event is analyzed using the FLUENT CFD code. For MPC heat load up to the full design basis, the HI-STORM 100 thermal model is the same 3-Dimensional model constructed for normal storage conditions except for the bottom inlet ducts, which are assumed to be impervious to air. Using this model, a transient thermal solution of the HI-STORM 100 System starting from normal storage conditions is obtained. The results of the blocked ducts transient in combination with the required action completion times for clearing the inlets shall be below the acceptance criteria in Tables 2.1 and 2.2.

A threshold heat load is defined for all MPCs in Section 4.6 of the HI-STORM 100 FSAR [2] at or below which fuel and component temperatures remain below the FSAR prescribed temperature limits under a 30-day accident. The TR does not intend to modify these threshold total decay heats already established in the FSAR and CoC. Therefore, 30-day 100% vent blockage accident is not included in the TR.

2.3.13 Burial Under Debris

Burial of the HI-STORM 100 System under debris is not a credible accident. During storage at the ISFSI there are no structures over the casks. Minimum regulatory distances from the ISFSI to the nearest ISFSI security fence precludes the close proximity of substantial amount of vegetation. There is no credible mechanism for the HI-STORM 100 System to become completely buried under debris. However, for conservatism, complete burial under debris is considered.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

The results of this analysis shall demonstrate that pressures and temperatures are below the acceptance criteria in Tables 2.1 and 2.2 considering the burial time.

2.3.14 Loss of Water from Water Jacket

The fuel cladding and MPC boundary integrity is evaluated for a postulated loss of water from the HI-TRAC water jacket. The HI-TRAC is equipped with an array of water compartments filled with water. For a bounding analysis, all water compartments are assumed to lose their water and be replaced with air. Heat dissipation by natural convection and radiation in the air space is included in the thermal model. The HI-TRAC is assumed to have the maximum thermal payload (design heat load) and assumed to have reached steady state (maximum) temperatures. Under these assumed set of adverse conditions, the maximum temperatures are computed using the 3D HI-TRAC thermal model constructed above with the water in water jacket spaces replaced with air. The computed temperatures and pressures shall be below the acceptance criteria in Tables 2.1 and 2.2.

2.3.15 Fire Accident

Although the probability of a fire accident affecting a HI-STORM 100 System during storage operations is low due to the lack of combustible materials at an ISFSI, a licensing-basis fire event has been assumed and analyzed. Under the postulated fire, the outer layers of HI-TRAC or HI-STORM 100 overpacks are heated for the duration of fire by the incident thermal radiation and forced convection heat fluxes. The amount of combustible material for the postulated fire is limited to a volume of 50 gallons.

2.3.15.1 HI-STORM 100 Fire

The fuel tank fire is conservatively assumed to surround the HI-STORM 100 Overpack. Accordingly, all exposed overpack surfaces are heated by radiation and convection heat transfer from the fire. Based on NUREG-1536 and 10 CFR 71 guidelines, the following fire parameters are assumed:

1. The average emissivity coefficient must be at least 0.9. During the entire duration of the fire, the painted outer surfaces of the overpack are assumed to remain intact, with an emissivity of 0.85. It is conservative to assume that the flame emissivity is 1.0, the limiting maximum value corresponding to a perfect blackbody emitter. With a flame emissivity conservatively assumed to be 1.0 and a painted surface emissivity of 0.85, the effective emissivity coefficient is 0.85. Because the minimum required value of 0.9 is greater than the actual value of 0.85, use of an average emissivity coefficient of 0.9 is conservative.

2. The average flame temperature must be at least 1475°F (800°C). Open pool fires typically involve the entrainment of large amounts of air, resulting in lower average flame temperatures. Additionally, the same temperature is applied to all exposed cask surfaces, which is very conservative considering the size of the HI-STORM 100 cask. It is therefore conservative to use the 1475°F (800°C) temperature.

3. The fuel source must extend horizontally at least 1 m (40 in), but may not extend more than 3 m (10 ft), beyond the external surface of the cask. Use of the minimum ring width of 1 meter yields a deeper pool for a fixed quantity of combustible fuel, thereby conservatively maximizing the fire duration.

4. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

   ].

Based on the 50-gallon fuel volume, the overpack outer diameter and the 1 m fuel ring width, the fuel ring surrounding the overpack and depth are computed. From this depth and a constant fuel consumption rate of 0.15 in/min, the fire duration is calculated. The fuel consumption rate of 0.15 in/min is a lowerbound value from Section 4.6.2 of HI-STORM 100 FSAR [2]. Use of a lowerbound fuel consumption rate conservatively maximizes the duration of the fire.

To evaluate the impact of fire heating of the HI-STORM 100 overpack, a thermal model of the overpack cylinder is constructed using the ANSYS computer code. The initial temperature of the overpack is conservatively assumed to be the maximum temperature field during storage. In this model the outer surface and top surface of the overpack were subjected for the duration of fire to the fire conditions defined in this subsection. In the post-fire phase, the ambient conditions preceding the fire are restored. The transient study is conducted for a sufficient period to allow temperatures in the overpack to reach their maximum values and begin to recede.

Due to the severity of the fire condition radiative heat flux, heat flux from incident solar radiation is negligible and is not included. Furthermore, the smoke plume from the fire would block most of the solar radiation. It is recognized that the ventilation air in contact with the inner surface of the HI-STORM 100 Overpack with design-basis decay heat and normal ambient temperature conditions varies between 80°F at the bottom and 220°F at the top of the overpack. It is further recognized that the inlet and outlet ducts occupy a miniscule fraction of area of the cylindrical surface of the massive HI-STORM 100 Overpack. Due to the short duration of the fire event and the relative isolation of the ventilation passages from the outside environment, the ventilation air is expected to experience little intrusion of the fire combustion products. As a result of these considerations, it is conservative to assume that the air in the HI-STORM 100 Overpack ventilation passages is held constant at a temperature of 300°F during the entire duration of the fire event.

The thermal transient response of the storage overpack is determined using the ANSYS finite element program. Time-histories for points in the storage overpack are monitored for the duration of the fire and the subsequent post-fire equilibrium phase.

Heat input to the HI-STORM 100 Overpack while it is subjected to the fire is from a combination of an incident radiation and convective heat fluxes to all external surfaces. This can be expressed by the following equation:

$$q_F = h_{fc}(T_A - T_S) + \sigma\varepsilon\left[(T_A + C)^4 - (T_S + C)^4\right]$$

where:

q_F =Surface Heat Input Flux (Btu/ft^2-hr)
h_{fc} = Forced Convection Heat Transfer Coefficient (4.5 Btu/ft^2-hr-°F)
σ = Stefan-Boltzmann Constant
T_A = Fire Temperature (1475°F)
C= Conversion Constant (460 (°F to °R))
T_S = Surface Temperature (°F)
ε = Average Emissivity (0.90 per 10 CFR 71.73)

The forced convection heat transfer coefficient is based on the results of large pool fire thermal measurements.

After the fire event, the ambient temperature is restored and the storage overpack cools down (post-fire temperature relaxation). Heat loss from the outer surfaces of the storage overpack is determined by the following equation:

$$q_S = h_S(T_S - T_A) + \sigma\varepsilon\left[(T_S + C)^4 - (T_A + C)^4\right]$$

where:

q_S =Surface Heat Loss Flux (W/m^2 (Btu/ft^2-hr))
h_S = Natural Convection Heat Transfer Coefficient (Btu/ft^2-hr-°F)
T_S = Surface Temperature (°F))
T_A = Ambient Temperature (°F)
σ = Stefan-Boltzmann Constant
ε = Surface Emissivity
C= Conversion Constant (460 (°F to °R))

In the post-fire temperature relaxation phase, h_s is obtained using literature correlations for natural convection heat transfer from heated surfaces.

A two-dimensional, axisymmetric model was developed for this analysis. Material thermal properties used were taken from Section 4.2 of the HI-STORM 100 FSAR. The outer surface and top surface of the overpack are exposed to the ambient conditions (fire and post-fire), and the base of the overpack is insulated. The transient study is conducted for a sufficiently long period to allow temperatures in the overpack to reach their maximum values and begin to recede.

Having evaluated the effects of the fire on the overpack, the effects on the MPC and contained fuel assemblies are evaluated. Guidance for the evaluation of the MPC and its internals during a fire event is provided by NUREG-1536 (4.0,V,5.b), which states:

> "For a fire of very short duration (i.e., less than 10 percent of the thermal time constant of the cask body), the NRC finds it acceptable to calculate the fuel temperature increase by assuming that the cask inner wall is adiabatic. The fuel temperature increase should then be determined by dividing the decay energy released during the fire by the thermal capacity of the basket-fuel assembly combination."

The time constant of the cask body (i.e., the overpack) can be determined using the formula:

$$\tau = \frac{c_p \times \rho \times L_c^2}{k}$$

where:

c_p = Overpack Specific Heat Capacity (Btu/lb-°F)
ρ = Overpack Density (lb/ft^3)
L_c = Overpack Characteristic Length (ft)
k = Overpack Thermal Conductivity (Btu/ft-hr-°F)

The concrete contributes the majority of the overpack mass and volume, so the specific heat capacity (0.156 Btu/lb-°F), density (142 lb/ft^3) and thermal conductivity (1.05 Btu/ft-hr-°F) of concrete are used for the time constant calculation. The characteristic length of a hollow cylinder is its wall thickness. The characteristic length for the HI-STORM 100 Overpack is therefore 29.5 in, or approximately 2.46 ft. Substituting into the equation, the overpack time constant is determined as:

$$\tau = \frac{0.156 \times 142 \times 2.46^2}{1.05} = 128\,hrs$$

One-tenth of this time constant is approximately 12.8 hours (768 minutes). If this is substantially longer than the fire duration, the MPC and its internals are evaluated by considering the MPC canister as an adiabatic boundary.

$$\Delta T_{fuel} = \frac{Decay\ Heat\ x\ Time\ Duration}{(MPC + Fuel) heat\ capacities}$$

An alternate method using the FLUENT thermal model described in Section 2.3.2 can be adopted to evaluate HI-STORM 100 site-specific fire accident event. Principal modeling steps and acceptance criteria are defined in Table 2.9.

2.3.15.2 HI-TRAC Fire

During the handling of the HI-TRAC transfer cask, the transporter fuel tank capacity must be limited to a 50-gallon. The duration of the 50-gallon fire under the conservatively postulated spill defined in the HI-STORM 100 fire evaluation is computed. In this analysis, the contents of the HI-TRAC are conservatively postulated to undergo a transient heat-up as a lumped mass from the decay heat input and heat input from the short duration fire. Using thermal inertia of the HI-TRAC and design heat load, the temperature rise rate is computed. Therefore, the temperature rise is computed as the product of this rate and the fire duration. In this manner, the maximum cladding temperature obtained by adding the temperature rise to the initial condition.

The elevated temperatures as a result of the fire accident will cause the pressure in the water jacket to increase and the overpressure relief valves to vent steam to the atmosphere. It is conservatively assumed, for dose calculations, that all the water in the water jacket is lost. In the 125-ton HI-TRAC and HI-TRAC 100G, which use Holtite in the lids for neutron shielding, the elevated fire temperatures would cause the Holtite to exceed its design accident temperature limits. This condition is conservatively addressed by ignoring neutron shield in the accident dose calculations.

Due to the increased temperatures of the MPC during fire accident the internal MPC pressure increases. The fire accident pressure is computed assuming the MPC cavity temperature rises by the fire accident temperature rise computed in this section.

An alternate method using the FLUENT thermal model described in Section 2.3.2.3 can be adopted to evaluate HI-TRAC site-specific fire accident event. Principal modeling steps and acceptance criteria are defined in Table 2.10.

2.3.16 Differential Thermal Expansion

To demonstrate that the fuel basket and MPC are free to expand without restraint, it is required to show that differential thermal expansion from fuel heatup is less than the as-built gaps that exist in the HI-STORM 100 System. The HI-STORM 100 System is engineered with gaps for the fuel basket and MPC to expand thermally without restraint of free end expansion. The following gaps shall be evaluated:

a. Fuel Basket-to-MPC Radial Gap
b. Fuel Basket-to-MPC Axial Gap
c. MPC-to-Overpack Radial Gap
d. MPC-to-Overpack Axial Gap

The FLUENT thermal model provides the 3-D temperature field in the HI-STORM 100 system from which the changes in the above gaps can be directly computed.

2.3.17 MPC Cavity Pressure Calculations

During storage conditions, the gas temperature within the MPC rises to its maximum operating basis temperature. The gas pressure inside the MPC will also increase with rising temperature to its maximum operating pressure. The pressure rise is determined using the ideal gas law.

The MPC maximum gas pressure is computed for a postulated release of fission product gases from fuel rods into this free space. For these scenarios, the amounts of each of the release gas constituents in the MPC cavity are summed and the resulting total pressures determined from the ideal gas law. Based on fission gases release fractions in NUREG-1536 and the net free volume and initial fill gas pressure of the fuel rods, maximum gas pressures with 1% (normal), 10% (off-normal) and 100% (accident condition) rod rupture are calculated. The maximum computed gas pressures shall remain below the MPC internal design pressures for normal, off-normal and accident conditions specified in Table 2.2.

2.3.18 Justification

The methodology has been developed over many years and has been used in its current form in numerous approved licensing applications for a large range of cask and assembly heat loads. A list of the systems analyzed, with the ranges of heat loads and conditions, is presented in Table 2.5.

The methodology uses a state-of-the-art code which enables it to model all relevant heat transfer mechanisms, namely conduction, convection and thermal radiation. The different applications had different splits of the heat transfer between these mechanisms. For example, systems with a Metamic-HT basket have a higher fraction of thermal transport through conductivity than steel baskets, due to the higher thermal conductivity of the Metamic; storage systems have a higher fraction of convection than transport systems; and cases for vacuum drying have a higher fraction of thermal radiation. The methodology has been evaluated to provide reasonably accurate temperatures in all cases. PWR casks, specifically with high heat load assemblies, have a higher contribution of the thermal gradient within the assembly to the overall temperature profile than BWR casks.

None of these evaluations have ever shown unexpected results that would have put into question the general validity of the methodology.

The SERs of all the cases listed in Table 2.5 have been reviewed to ensure that no conditions exist that would limit the applicability of the respective safety analysis to the discussions in this report.

In summary, it can therefore be concluded that the methodology is equally applicable to any other heat load patterns, for the same systems and temperature ranges, and no further validations are considered necessary in support of this. This even extends to conditions where individual assembly or cask heat loads slightly exceed those in previous approved analyses, although this would naturally be limited by the applied temperature limits.

2.3.19 Analysis of Candidate Pattern

This topical report outlines the process for evaluating the normal long-term storage condition for a candidate heat load pattern using the model described in Section 2.3.2. All component temperatures and the cavity pressure shall remain below the limits specified in Tables 2.1 and 2.2 for the pattern to be considered acceptable.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

The PCT, component temperatures and MPC pressures are limited to those prescribed in Tables 2.1, 2.2, 4.1 and 4.2, irrespective of the distribution of decay heat in the MPC and total decay heat. The acceptance criteria are therefore self-limiting given that conservative (lower than existing FSAR acceptance criteria) values are adopted. Additionally, as described in Section 2.3, the thermal model developed following the methodology presented in Sections 2.3 or 4.3 of this report is robust to capture the physical phenomenon irrespective of the total MPC decay heat and distribution of decay heat in the MPC.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

2.3.20 Other Disciplines

There are other disciplines and safety analyses that may be affected to a smaller degree by the heat load patterns and/or temperature distributions. These are not addressed in this TR, but the FSAR/TS that invokes this TR must address them. These briefly discussed in the following sections:

2.3.20.1 Shielding

Different decay heat loading patterns are associated with different loading patterns in terms of the burnup, enrichment and cooling times of the assemblies. The CoC where this TR is implemented may have specific limitations on burnup, enrichment and cooling times. These fuel qualification parameters need to be satisfied independent of the qualification of the heat load patterns through the methodology in this TR. Both the HI-STORM 100 and HI-STORM FW CoCs contain specific equations that identify the allowable contents based on these burnup, enrichment, and cooling time combinations. The shielding performance of the system has been shown to be acceptable based on bounding source terms from these equations. This thermal topical report does not make any changes to those requirements, so there is no change to the shielding performance as currently approved.

2.3.20.2 Structural

Structural analyses utilize temperatures from the thermal analysis in the licensing basis evaluations performed in the FSAR. If the temperature results from any pattern analyzed under this report are not bounded by those currently utilized in the FSAR licensing basis evaluation, the impact of the revised temperatures on the structural performance of the system will be evaluated under 10 CFR 72.48 to determine if the pattern can be used without further NRC approval. The topical report will need to be included in the CoC via an amendment. At that time, Holtec plans on adding implementation instructions to the FSAR to ensure that all users are aware of the need to confirm continued compliance with the FSAR structural analysis.

2.3.21 Implementation

This topical report cannot be utilized until it is explicitly referenced in an approved CoC amendment. Such an amendment would be submitted separately from this TR.

Table 2.1: SSC Temperature Limits for Evaluation of Candidate Heat Load Patterns Note 1

Sub-component or Part	Long Term, Normal Condition Temperature Limits (° F)	Short-Term Events Temperature Limits (° F)	Off-Normal and Accident Condition Temperature Limits Note 2 (° F)
MPC shell Note 3	600	775	775
MPC basket	752	1058	1058
MPC Extruded Aluminum shims	752	932	932
MPC Neutron Absorber	752	1058	1058
MPC lid Note 3	600	775	775
MPC closure ring Note 3	500	775	775
MPC baseplate Note 3	400	775	775
HI-TRAC inner shell	-	500	800
HI-TRAC transfer lid	-	350	800
HI-TRAC pool lid	-	400	800
HI-TRAC top lid	-	400	800
HI-TRAC top flange	-	400	700
HI-TRAC pool lid seals	-	400	N/A
HI-TRAC bottom lid bolts	-	350	800
HI-TRAC bottom flange	-	350	800
HI-TRAC top lid neutron shielding	-	300	350
HI-TRAC radial neutron shield	-	307	N/A
HI-TRAC radial lead gamma shield	-	350	600
Remainder of HI-TRAC	-	350	800
Fuel Cladding Note 4	734	1040 (MBF) 734 (HBF)	1040
Overpack concrete	300	572 (on local temperature of shielding concrete)	572 (on local temperature of shielding concrete except under fire)
Overpack Lid Top and Bottom Plate	450	700	800
Remainder of overpack steel structure	400	700	800

Notes

1. Except for the fuel cladding temperature limits, all component temperature limits are consistent with those specified in Table 2.2.3 of the HI-STORM 100 FSAR [2]. 30-day 100% vent blockage accident is not included in the TR as explained in Sub-section 2.3.12.
2. For the ISFSI fire event, the local temperature limit of HI-STORM concrete is 1100°F (Appendix 1.D of [8]), and the steel structure is required to remain physically stable (i.e., so there will be no risk of structural instability such as gross buckling, the maximum temperature shall be less than approximately 50% of the component's melting temperature and the specific temperature limits in this table do not apply). Concrete that exceeds 1100°F shall be considered unavailable for shielding of the overpack.
3. Temperature limits in HI-STORM 100 FSAR, Table 1.A.6 [8] shall take precedence if duplex stainless steels are used for the fabrication of confinement boundary components.
4. To ensure positive safety margins, the temperature limits are defined to be below the HI-STORM 100 safety limits from [8].

Table 2.2: MPC Pressure Limits for Evaluation of Candidate Heat Load Patterns

Condition	Pressure (psig)
MPC-68M and Alloy-X Basket Equipped Canisters Note 1	
Long-Term Normal Note 2	98
Off-Normal / Short Term Operations	110
Accident	200
MPC-32M and Alloy-X Basket Version 1 Canisters Note 3	
Long-Term Normal Note 2	108
Off-Normal / Short Term Operations	120
Accident	225

Notes:

1. Design pressure limits are consistent with those specified in Table 2.2.1 of the HI-STORM 100 FSAR [8].
2. To ensure positive safety margins, the pressure limits are defined to be below HI-STORM 100 safety limits from [8].
3. Design pressure limits are consistent with those specified in Table 1.II.2.3 of the HI-STORM 100 Amendment 15 LAR [8].

Table 2.3: Flow Resistance in Porous Media

Scenario	Flow Resistance, $1/m^2$
PWR Fuel (Note 1)	**[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**
BWR Fuel (Note 2)	**[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

Notes

1. Flow resistance values are consistent with those adopted in safety evaluations presented in Chapter 4 of the HI-STORM 100 FSAR [2], [8].
2. Flow resistance values are consistent with those adopted in safety evaluations presented in Chapter 4 of the HI-STORM 100 FSAR [2], [8]. The values are summarized in [4].

Table 2.4: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.5: Summary of Holtec Systems and Decay Heat Range

Cask	Assembly type (PWR/BWR)	Number of assemblies	Basket Material	Condition	Total Decay Heat Limits, kW	Assembly Decay Heat Range (kW)	
						From	To
HI-STAR 60	PWR	12	Steel	Transport	10.5	0.875	0.875
HI-STAR 80	PWR	12	Metamic-HT	Transport	50.0	3.76	5.0
	BWR	32			54.0	1.68	2.25
HI-STAR 100	PWR	24	Steel	Transport	20.0	0.833	0.833
	PWR	32			20.0	0.625	0.625
	BWR	68			18.5	0.272	0.272
HI-STAR 100	PWR	24	Steel	Storage	20.0	0.792	0.792
	PWR	32			20.0	0.625	0.625
	BWR	68			18.5	0.272	0.272
HI-STAR 100MB	PWR	24, 32	Metamic-HT	Transport	32	0.906	1.33
HI-STAR 180	PWR	32, 37	Metamic-HT	Transport	32	0.5	2.1
HI-STAR 180D	PWR	32, 37	Metamic-HT	Transport	36.4	0.4	1.46
HI-STAR 190	PWR	37	Metamic-HT	Transport	32.09	0.38	1.7
	BWR	89			32.15	0.15	0.62
HI-STORM 100	PWR	24, 32	Steel	Storage	36.9	0.538	2.05
	BWR	68			36.9	0.228	0.71
	PWR	32	Metamic-HT	Storage	41.2 [Note 1]	0.6	3.255
	BWR	68			42.8 [Note 2]	0.1	1.66
HI-STORM FW	PWR	37	Metamic-HT	Storage	45.0	0.45	3.5
	BWR	89			46.36 [Note 3]	0.1	1.45
HI-STORM UMAX	PWR	37	Metamic-HT	Storage	37.06	0.873	1.89
	BWR	89			36.72	0.387	0.607
ALL	PWR	--	--	--	50.0	0.4	5.0
	BWR	--	--	--	54.0	0.1	2.25

Notes

1. Approved under HI-STORM 100 LAR 1014-15.
2. Approved under HI-STORM 100 LAR 1014-14.
3. Currently under review with USNRC under HI-STORM FW LAR 1032-5

Table 2.6: List of all Safety Thermal Evaluations Required for Candidate Heat Load Pattern[†]

Scenario No.	Scenario
1	Long-Term Storage Condition
2	Short-Term Normal Onsite Transfer
3	Vacuum Drying
4	Partial Blockage of HI-STORM Inlet Vents
5	Off-Normal Ambient Temperature
6	Extreme Ambient Temperature Accident
7	100% Duct Blockage of HI-STORM Inlet Vents
8	Burial under Debris Accident
9	Transfer Accident - Loss of Water from Water Jacket
10	Fire Accident
11	Time-to-Boil
12	MPC Cavity Pressure
13	Differential Thermal Expansion

[†] The listed evaluations are required if the candidate heat load pattern does not satisfy the screening requirements presented in Sections 2.3.19 and 4.3.17 for HI-STORM 100 and HI-STORM FW systems respectively.

Table 2.7: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.8: Normalized Distribution Based on Burnup Profile

PWR DISTRIBUTION		
Interval	**Axial Distance from Bottom of Active Fuel (% of Active Fuel Length)**	**Normalized Distribution**
1	0% to 4-1/6%	0.5485
2	4-1/6% to 8-1/3%	0.8477
3	8-1/3% to 16-2/3%	1.0770
4	16-2/3% to 33-1/3%	1.1050
5	33-1/3% to 50%	1.0980
6	50% to 66-2/3%	1.0790
7	66-2/3% to 83-1/3%	1.0501
8	83-1/3% to 91-2/3%	0.9604
9	91-2/3% to 95-5/6%	0.7338
10	95-5/6% to 100%	0.4670

BWR DISTRIBUTION		
Interval	**Axial Distance from Bottom of Active Fuel (% of Active Fuel Length)**	**Normalized Distribution**
1	0% to 4-1/6%	0.2200
2	4-1/6% to 8-1/3%	0.7600
3	8-1/3% to 16-2/3%	1.0350
4	16-2/3% to 33-1/3%	1.1675
5	33-1/3% to 50%	1.1950
6	50% to 66-2/3%	1.1625
7	66-2/3% to 83-1/3%	1.0725
8	83-1/3% to 91-2/3%	0.8650
9	91-2/3% to 95-5/6%	0.6200
10	95-5/6% to 100%	0.2200

Table 2.9: Principal HI-STORM 100 Fire Accident Modeling Steps

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.10: Principal HI-TRAC Fire Accident Modeling Steps

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

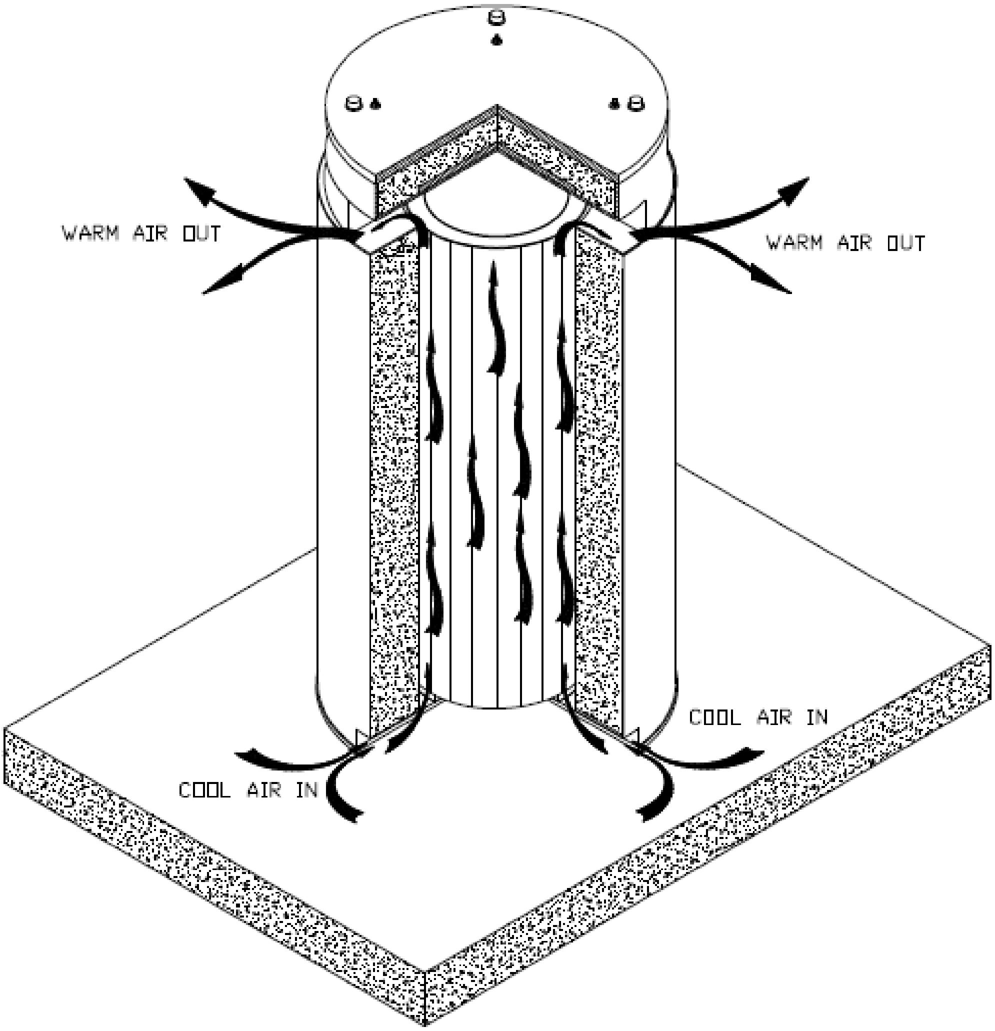

Figure 2.1: Ventilation Cooling in a HI-STORM 100 Overpack

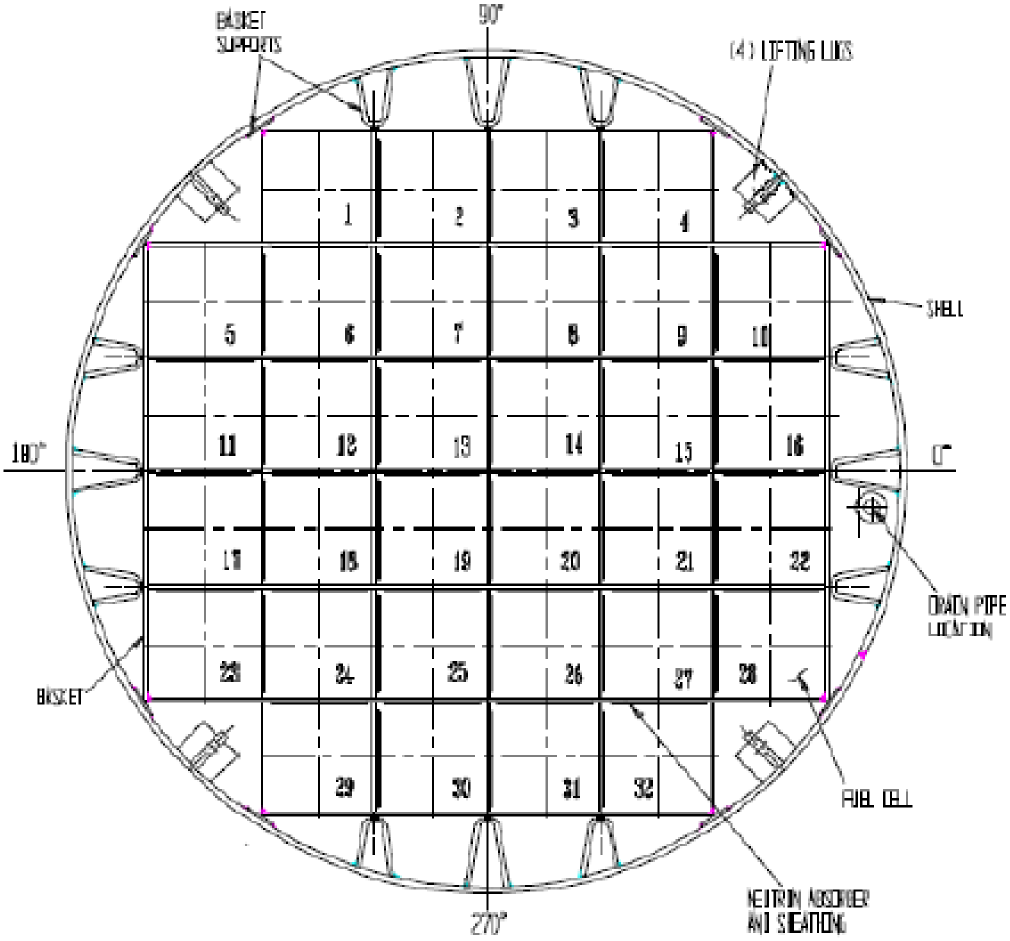

Figure 2.2: MPC-32 PWR FUEL Basket

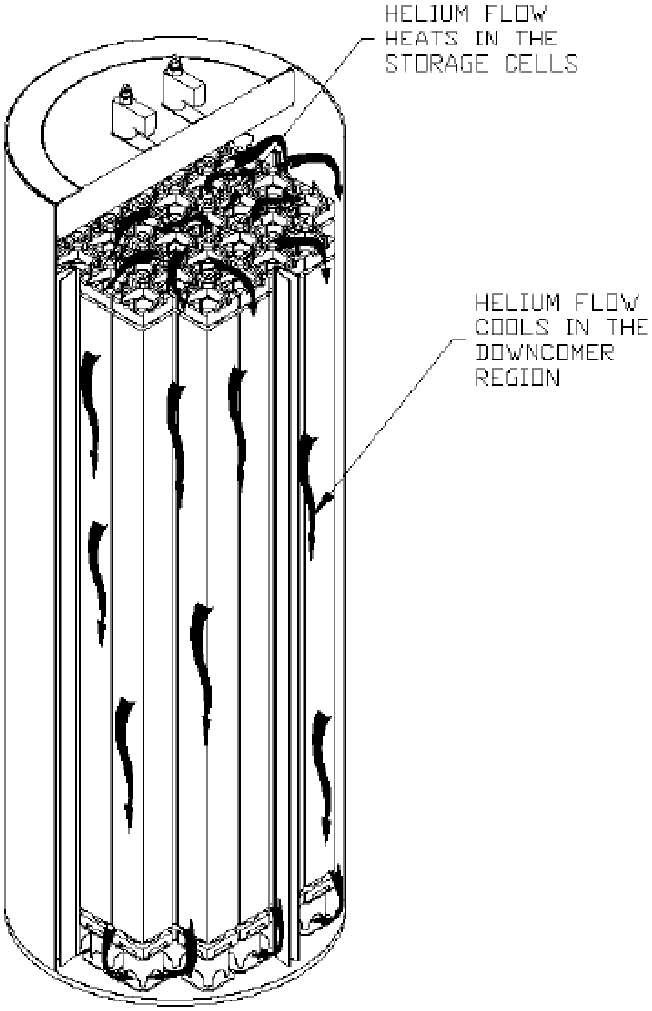

Figure 2.3: MPC Internal Helium Circulation

Figure 2.4: **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

Figure 2.5: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.6: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

3.0 EXAMPLE HEAT LOAD PATTERN EVALUATIONS FOR HI-STORM 100 SYSTEM

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

4.0 HEAT LOAD PATTERN EVALUATION METHODOLOGY FOR HI-STORM FW SYSTEM

4.1 Inputs

Inputs to the methodology and calculations are any candidate heat load patterns, for given casks or baskets similar to HI-STORM 100 System in Section 2.0. In principal, a pattern could be completely unique, in the sense that every cell in a basket has a different heat load limit. From a practical perspective, patterns with some symmetry would be selected, either half, quarter or even eights symmetry, since this reduces the calculational effort. And even for a half symmetry, the patterns in the two quarters should be similar, or, at least, the combined heat load should be similar. Additionally, since the HI-STORM FW system is variable height [10], spent fuel parameters such as height, active height, etc. are also inputs as they dictate the height of the HI-STORM FW system. This is essentially the same as Chapter 2 for HI-STORM 100.

4.2 Acceptance Criteria

The resultant temperatures from candidate heat load patterns are required to remain within licensed limits. To ensure this requirement, **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

]. A review of HI-STORM FW SERs did not result in any limitation that restrict the validity of the methodology adopted for all thermal evaluations. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

]. Additionally, HI-STORM FW Structures Systems and Components (SSC) safety limits from the FSAR are adopted in Tables 4.1 and 4.2. To muster qualification, candidate patterns shall remain below the limits defined in these tables. The complete qualification process is illustrated in the examples in Section 5.

4.3 Methodology

The aboveground HI-STORM FW system consists of a sealed MPC situated inside a vertically oriented, ventilated storage overpack. Air inlet and outlet ducts that allow for air cooling of the stored MPC are located at the bottom and top, respectively, of the cylindrical overpack (see Figure 4.1). The SNF assemblies reside inside the MPC, which is sealed with a welded lid to form the Confinement Boundary. The MPC contains a Metamic-HT fuel basket structure with square-shaped compartments of appropriate dimensions to allow insertion of the fuel assemblies prior to welding of the MPC lid and closure ring. The MPC is backfilled with helium to the design-basis pressures to support closed loop internal convection cooling of the stored fuel. This cooling action is illustrated in Figure 4.2. This also provides a stable, inert environment for long-term storage of the SNF. Heat is rejected from the SNF in the HI-STORM FW system to the environment by passive heat transport mechanisms only.

Safe thermal performance during on-site loading, unloading and transfer operations, collectively referred to as short-term operations are performed in the HI-TRAC VW transfer cask. To ensure a high level of confidence in the thermal evaluation, 3-dimensional models of the MPC, HI-STORM FW overpack and HI-TRAC VW transfer cask are constructed to evaluate fuel integrity under normal (long-term storage), off-normal and accident conditions and in the HI-TRAC VW transfer cask under short-term operation and hypothetical accidents.

The methodology and assumptions presented in the sub-sections below are essentially directly obtained from Chapter 4 of HI-STORM FW FSAR [10].

4.3.1 Overview of the Thermal Model

The basket is a matrix of interconnected square compartments designed to hold the fuel assemblies in a vertical position under long term storage conditions. The basket is a honeycomb structure of Metamic-HT plates that are slotted and arrayed in an orthogonal configuration to form an integral basket structure. The height of the PWR MPC cavity can vary within a rather large range to accommodate spent nuclear fuel of different lengths in the MPCs[1]. The MPC cavity height (which determines the external height of the MPC) is set based on the nominal fuel length (along with control components, if any). Table 4.3 provides the height of the internal cavities and bottom-to-top external dimension of all system components. The cavity heights of the HI-STORM FW overpack and the HI-TRAC VW transfer cask are set greater than the MPC height by fixed amounts to account for differential thermal expansion and manufacturing tolerances. Table 4.3 provides the height data on HI-STORM FW, HI-TRAC VW, and the MPC as the adder to the MPC cavity length.

4.3.1.1 Description of the 3-D Thermal Model

The HI-STORM FW System is equipped with three MPC designs, MPC-37, MPC-32ML, and MPC-89 engineered to store 37, 32 PWR and 89 BWR fuel assemblies respectively. The interior of the MPC is a 3-D array of square/hexagonal shaped cells inside an irregularly shaped basket outline confined inside the cylindrical space of the MPC cavity. To ensure an adequate representation of these features, a 3-D geometric model of the MPC is constructed using the FLUENT CFD code pre-processor [3]. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

---

[1] MPC-32ML is a fixed fuel length canister.

].

4.3.1.2 Details of the 3-D Model

The modeling details of the HI-STORM FW fuel basket is provided in the following:

The MPC-37, MPC-32ML and MPC-89 fuel baskets are essentially an array of square cells within an irregularly shaped basket outline. The fuel basket is confined inside a cylindrical cavity of the MPC shell. Between the fuel basket-to-shell spaces, thick Aluminum basket shims may be installed to facilitate heat dissipation. To ensure an adequate representation of the fuel basket a geometrically accurate 3D model of the array of square cells and Metamic-HT plates is constructed using the FLUENT pre-processor. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

]. The basket shims, if present, are explicitly modeled in the peripheral spaces. The fuel basket is surrounded by the MPC shell and outfitted with a solid welded lid above and a baseplate below. All of these physical details are explicitly articulated in a 3D thermal model of the HI-STORM FW.

4.3.1.3 Fuel Region Effective Planar Conductivity

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

4.3.1.4 Heat Rejection from External Surfaces

The exposed surfaces of the HI-STORM FW dissipate heat by radiation and external natural convection heat transfer. Radiation is modeled using classical equations for radiation heat transfer (Rohsenow & Hartnett [11]). Jakob and Hawkins [12] recommend the following correlations for natural convection heat transfer to air from heated vertical and horizontal surfaces:

Turbulent range:

$$h = 0.19\,(\Delta T)^{1/3}\ (\text{Vertical}, \mathrm{GrPr} > 10^9)$$
$$h = 0.18\,(\Delta T)^{1/3}\ (\text{Horizontal Cylinder}, \mathrm{GrPr} > 10^9)$$
$$(\text{in conventional U.S. units})$$

Laminar range:

$$h = 0.29\,\left(\frac{\Delta T}{L}\right)^{1/4}\ (\text{Vertical}, \mathrm{GrPr} < 10^9)$$
$$h = 0.27\,\left(\frac{\Delta T}{D}\right)^{1/4}\ (\text{Horizontal Cylinder}, \mathrm{GrPr} < 10^9)$$

(in conventional U.S. Units)

where ΔT is the temperature differential between the cask's exterior surface and ambient air.

4.3.1.5 Determination of Solar Heat Input

The insolation energy absorbed by the HI-STORM FW is the product of incident insolation and surface absorbtivity. To model insolation heating a reasonably bounding absorbtivity equal to 0.85 is incorporated in the thermal models. The HI-STORM FW thermal analysis is based on 12-hour daytime insolation specified in Article 71.71(c) (1) of 10CFR71. During long-term storage, the HI-STORM FW Overpack is cyclically subjected to solar heating during the 12-hour daytime period followed by cooling during the 12-hour nighttime. Due to the large mass of metal and the size of the cask, the dynamic time lag exceeds the 12-hour heating period. Accordingly, the HI-STORM FW model includes insolation on exposed surfaces averaged over a 24-hour time period.

4.3.1.6 Principal Attributes of the 3D Model

The 3-D model has the following key attributes:

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

The model described above is consistent with that adopted for licensing basis evaluations presented in Chapter 4 of the FSAR. The thermal model adopted in the FSAR is quarter-symmetric. In an event that the candidate heat load pattern is not quarter-symmetric, the quarter-symmetric model can be duplicated with the same geometry and mesh to create a half-symmetric or a full model as needed.

The principal 3-D modeling conservatisms are listed below:

1) Axial dissipation of heat by conduction in the fuel pellets is neglected.
2) Dissipation of heat from the fuel rods by radiation in the axial direction is neglected.
3) **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.
4) The most severe environmental factors for long-term normal storage – ambient temperature and 10CFR71 insolation levels – are coincidentally imposed on the system.
5) **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**
].
6) To understate MPC internal convection heat transfer, the helium pressure is understated.
7) **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**
].
8) Heat dissipation by fuel basket peripheral supports is neglected.
9) **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

4.3.1.7 Bounding Flow Resistance Data

The flow resistance coefficients required to compute the in-cell flow of helium in PWR storage cells and of in-channel flow of channeled BWR assemblies placed in a BWR storage cell form the basis for the thermal-hydraulic analyses in HI-STORM 100 FSAR [2]. These resistance coefficients (Table 2.3) are appropriate and conservative for HI-STORM FW analysis because of the following reasons:

i. The coefficients define the upperbound pressure drop per unit length of fueled space.
ii. The storage cell opening in the MPC-37 (PWR fuel) is equal to or greater than the cell openings of the PWR MPCs (such as MPC-32) licensed in the HI-STORM 100 System [2]. In the case of BWR fuel storage the channeled fuel located inside the storage cell is modeled explicitly as shown in Figure 2.4. The bounding flow resistance coefficients cited in Table 2.3 is applied to the channeled space porous media.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

4.3.1.8 HI-TRAC VW Thermal Model

The HI-TRAC VW transfer cask is used to load and unload the HI-STORM FW concrete storage overpack, including onsite transport of the MPCs from the loading facility to an ISFSI pad. Within a loaded HI-TRAC VW, heat generated in the MPC is transported from the contained fuel assemblies to the MPC shell through the fuel basket and the basket-to-shell gaps via conduction and thermal radiation. From the outer surface of the MPC to the ambient atmosphere, heat is transported within across multiple concentric layers, representing the air gap, the HI-TRAC VW inner shell, the lead shielding, the HI-TRAC VW outer shell, the water jacket space and the jacket shell. From the surface of the HI-TRAC VW's enclosure shell heat is rejected to the atmosphere by natural convection and radiation.

A water jacket that provides neutron shielding for the HI-TRAC VW overpack is attached to the outer cylindrical steel wall of the HI-TRAC VW standard version and version V. Heat is transported through the water jacket by a combination of conduction through steel ribs and convection heat transfer in the water spaces. A variation of HI-TRAC VW version V is version V2 where the water jacket is removed and replaced with a removable neutron shield cylinder (NSC). All versions of HI-TRAC VW are an open top construction which is modeled as an opening to allow air exchange with the ambient.

Version V of the HI-TRAC VW transfer cask differs from the standard version only in respect of a larger MPC-to-cask radial gap and a natural ventilation path for ambient air to flow past the canister shell which results in a greater extraction of heat from the canister.

Similar to HI-TRAC VW Version V, HI-TRAC VW Version V2 is also designed with a larger MPC-to-cask radial gap and a natural ventilation path for ambient air to flow past the canister shell. In addition, the HI-TRAC VW Version V2 adopts a neutron shielding cylinder (NSC) instead of a water jacket. The annular gap between the HI-TRAC VW outer shell and the NSC provides a natural ventilation path for ambient air to flow past the HI-TRAC VW outer shell. The air flow in both annulus regions is modeled as turbulent with k-ω turbulence model.

The HI-TRAC VW Transfer Cask thermal analysis is based on a detailed heat transfer model that conservatively accounts for all modes of heat transfer in the MPC and HI-TRAC VW. The thermal model incorporates several conservative features listed below:

i. Severe levels of environmental factors - bounding ambient temperature and constant solar flux - were coincidentally imposed on the thermal design. A bounding solar absorbtivity of 0.85 is applied to all exposed surfaces.

ii. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

].

iii. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390
].

iv. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

v. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

].

To evaluate on-site transfer operations in a conservative manner a HI-TRAC VW thermal model is constructed and candidate heat load pattern evaluated. The model adopts the MPC thermal modeling methodology described in previous sub-sections.

The above methodology and assumptions are consistent with that in Section 4.5 of HI-STORM FW FSAR [10].

4.3.1.9 Vacuum Drying Thermal Model

To evaluate the vacuum drying scenario, the MPC model described in Section 4.3.1.2 is adopted. The principal features of the thermal model are as follows:

a) The water in the HI-TRAC annulus is conservatively assumed to be boiling (212°F).

b) The bottom surface of the MPC is insulated.

A suitable methodology is prescribed below to compute heat load specific cyclic drying durations using the 3D thermal model articulated herein:

1. Compute steady state temperatures under vacuum conditions. If PCT is below ISG-11, Rev. 3 limits then vacuum drying is acceptable without time limits. If PCT exceeds ISG-11, Rev. 3 limits then follow cyclic drying steps below.
2. Cycle 1 (Heatup) – A transient thermal evaluation is performed under the loading specific heat loads in vacuum conditions. The time τ1 required for the fuel to heatup from an initial temperature of 100ºC (212ºF) to 380ºC (716ºF) under high burnup fuel loading is computed. If drying completion criteria is not met, then the cask cavity or MPC must be backfilled with helium to facilitate cooling as defined in the next step below.
3. Cycle 1 (Cooldown) – The MPC cavity is backfilled with helium to 1 atm absolute pressure. Fuel cooling under helium is evaluated to compute the time τ2 used in operations for fuel temperatures to decreases by temperatures less than or equal to 65ºC (117ºF).
4. Cycle 2 (Heatup) - The drying process switches to vacuum drying and time τ3 required to reach 380ºC (716ºF).
5. Up to 9 additional cycles of heatup and cooldown drying using the times τ3 and τ2 computed above may be performed until the drying completion criteria are met.

If a total of 10 drying cycles fail to meet drying criteria, then other competent means to dry fuel (such as FHD) shall be used or the MPC must be de-fueled.

The above methodology and assumptions are consistent with that approved in Section 4.5.3 of HI-STORM FW FSAR [10].

4.3.2 Evaluation of DFCs/DFIs

A limited number of fuel assemblies defined in the HI-STORM FW Technical Specification classified as damaged fuel are permitted to be stored in the MPC inside Damaged Fuel Containers (DFCs) or Damaged Fuel Isolators (DFIs). A DFC or DFI can only be stored in locations identified in Appendix B of the Tech. Spec. DFC or DFI emplaced fuel assemblies have a higher resistance to helium flow because of the debris screens. The thermal methodology for modeling the fuel basket, basket shims, MPC and overpack remains the same as discussed in Section 4.3.1 except that the fuel within the DFC is modeled as porous medium with effective thermal properties. Debris screens in the DFIs and DFCs are modeled as porous jump.

4.3.3 Heat Load Map for Analysis

Candidate heat load pattern define fuel heat q_i in all MPC storage locations i = 1 thru N where N is the number of fuel storage cells. These patterns may be defined to support an on-going fuel loading operation in which case q_i is defined by actual loaded cask heat loads or to support fuel management and on-site storage planning wherein suitable bounding heat loads are defined and qualified for use.

4.3.4 Limitations on Heat Load Patterns

Acceptability of cask and fuel assembly heat loads are solely guided by safety evaluations and the established temperature and pressure limits. Any heat load pattern that does not comply with all applicable safety limits under any design basis condition (normal, off-normal, accident or short-term operations) is not considered qualified.

Note that there may be additional requirements and limits specified in the FSAR and CoC where this TR is incorporated.

4.3.5 Helium Backfill Limits

To support internal convection cooling MPCs are helium backfilled to minimum limits as informed by FLUENT thermal calculations. An upperbound limit is also defined to meet FSAR mandated MPC pressure limits. Helium backfill limits under each candidate heat load pattern shall be established using the equations provided below.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

4.3.6 Material Properties

The same material properties defined in HI-STORM FW FSAR Section 4.2 [10] are used for analysis of the candidate heat load pattern evaluations.

4.3.7 Time to Boil

Fuel loading operations are conducted with the HI-TRAC VW transfer cask and its contents submerged in pool water. Under these conditions, the HI-TRAC VW transfer cask is essentially at the pool water temperature. When the HI-TRAC transfer cask and the loaded MPC under water-flooded conditions is removed from the pool and staged in an ambient air environment, the water, MPC, and HI-TRAC transfer cask metal absorb the decay heat emitted by the fuel assemblies. This results in a slow temperature rise of the HI-TRAC transfer cask with time, starting from an initial pool water temperature. The rate of temperature rise is limited by the thermal inertia of the HI-TRAC transfer cask. Sites must evaluate the time limit to prevent boiling of the water in the MPC.

The available time before the water in the MPC would reach boiling is computed under a conservative set of assumptions summarized below:

i. Heat loss by natural convection and radiation from the exposed HI-TRAC surfaces to ambient air is neglected (i.e., an adiabatic heat-up calculation is performed).

ii. The water mass in the MPC cavity is understated.

The rate of temperature rise of the HI-TRAC transfer cask and contents during an adiabatic heat-up is given by the ratio Q/C where:

Q = Coincident fuel decay heat in the canister (Btu/hr)

C = Thermal inertia of a loaded HI-TRAC (Btu/°F)

Therefore, the time-to-boil, τ is given by the simple algebraic formula $\tau = C(212-T)/Q$ where 212°F has been set as the boiling temperature and T represents the temperature of the pool water under fuel loading operations. The time-to-boil clock starts when the HI-TRAC is no longer submerged in the pool water. The calculation of time-to-boil for a loaded canister shall be made using the above formula. An alternate method using the FLUENT thermal model described in Paragraph 4.3.1.8 can be adopted to evaluate the time for water within the MPC to boil using site-specific conditions.

As set forth in the HI-STORM FW operating procedures, in the unlikely event that the maximum allowable time is found to be insufficient to complete wet transfer operations, a forced water circulation shall be initiated and maintained to remove the decay heat from the MPC cavity. In this case, relatively cooler water will enter via the MPC lid drain port connection and heated water will exit from the vent port. The minimum water flow rate required to maintain the MPC cavity water temperature below boiling with an adequate subcooling margin is determined as follows:

$$M_W = \frac{Q}{C_{pW}\,(T_{max} - T_{in})}$$

where:

M_W = minimum water flow rate (lb/hr)
C_{pw} = water heat capacity (Btu/lb-°F)
T_{max} = maximum MPC cavity water mass temperature (must be less than 212°F)
T_{in} = MPC water inlet temperature
Q = Coincident fuel decay heat in the canister (Btu/hr)

4.3.8 Partial Blockage of HI-STORM FW Inlet Vents

The HI-STORM FW System is designed with debris screens installed on the inlet and outlet openings. These screens ensure the air passages are protected from entry and blockage by foreign objects. Therefore, to meet the system design criteria, it is postulated that the HI-STORM FW air inlet vents are 50% blocked.

The resulting decrease in flow area increases the flow resistance of the inlet ducts. The effect of the increased flow resistance on fuel temperature is analyzed for the normal ambient temperature using the model described in Subsection 4.3.1. The computed temperatures and pressure shall be below the acceptance criteria in Tables 4.1 and 4.2, respectively.

4.3.9 Off-Normal Ambient Temperature

This event is defined by a time-averaged ambient temperature of 100ºF for a 3-day period, applied to the FLUENT model described in Subsection 4.3.1. The computed temperatures and pressures shall be below the acceptance criteria in Tables 4.1 and 4.2.

4.3.10 Extreme Ambient Temperature Accident.

To evaluate the effect of extreme weather conditions (ambient temperature of 125ºF), an extreme ambient temperature is postulated to persist for a 3-day period. For a conservatively bounding evaluation the extreme temperature is assumed to last for a sufficient duration to allow the system to reach steady state conditions. Because of the large mass of the HI-STORM FW System, with its corresponding large thermal inertia and the limited duration for the extreme temperature, this assumption is conservative. The computed temperatures and pressures shall be below the acceptance criteria in Tables 4.1 and 4.2.

4.3.11 100% Duct Blockage of HI-STORM FW Inlet Vents

This event is defined as a complete blockage of all inlets. The immediate consequence of a complete blockage of the air inlets is that the normal circulation of air for cooling the MPC is stopped. An amount of heat will continue to be removed by localized air circulation patterns in the overpack annulus and outlet ducts, and the MPC will continue to radiate heat to the relatively cooler storage overpack. As the temperatures of the MPC and its contents rise, the rate of heat rejection will increase correspondingly. Under this condition, the temperatures of the overpack, the MPC and the stored fuel assemblies will rise as a function of time.

As a result of the considerable inertia of the storage overpack, a significant temperature rise is possible if the inlets are substantially blocked for extended durations. This accident condition is, however, a short duration event that is identified and corrected through scheduled periodic surveillance. Nevertheless, this event is conservatively analyzed assuming a substantial duration of blockage. The event is analyzed using the FLUENT CFD code. For MPC heat load up to the full design basis, the HI-STORM FW thermal model is the same 3-Dimensional model constructed for normal storage conditions except for the bottom inlet ducts, which are assumed to be impervious to air. Using this model, a transient thermal solution of the HI-STORM FW System starting from normal storage conditions is obtained. The results of the blocked ducts transient in combination with the required action completion times for clearing the inlets shall be below the acceptance criteria in Tables 4.1 and 4.2.

4.3.12 Burial Under Debris

Burial of the HI-STORM FW System under debris is not a credible accident. During storage at the ISFSI there are no structures over the casks. Minimum regulatory distances from the ISFSI to the nearest ISFSI security fence precludes the close proximity of substantial amount of vegetation. There is no credible mechanism for the HI-STORM FW System to become completely buried under debris. However, for conservatism, complete burial under debris is considered.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

The results of this analysis shall demonstrate that pressures and temperatures are below the acceptance criteria in Tables 4.1 and 4.2 considering the burial time.

4.3.13 Loss of Water from Water Jacket

The fuel cladding and MPC boundary integrity is evaluated for a postulated loss of water from the HI-TRAC water jacket. The HI-TRAC is equipped with an array of water compartments filled with water. For a bounding analysis, all water compartments are assumed to lose their water and be replaced with air. Heat dissipation by natural convection and radiation in the air space is included in the thermal model. The HI-TRAC is assumed to have the maximum thermal payload (design heat load) and assumed to have reached steady state (maximum) temperatures. Under these assumed set of adverse conditions, the maximum temperatures are computed using the 3D HI-TRAC thermal model constructed above with the water in water jacket spaces replaced with air. The computed temperatures and pressures shall be below the acceptance criteria in Tables 4.1 and 4.2.

4.3.14 Fire Accident

Although the probability of a fire accident affecting a HI-STORM FW system during storage operations is low due to the lack of combustible materials at an ISFSI, a conservative fire event has been assumed and analyzed. The only credible concern is a fire from an on-site transport vehicle fuel tank. Under a postulated fuel tank fire, the outer layers of HI-TRAC VW or HI-STORM FW overpacks are heated for the duration of fire by the incident thermal radiation and forced convection heat fluxes.

4.3.14.1 HI-STORM FW Fire

The fuel tank fire is conservatively assumed to surround the HI-STORM FW overpack. Accordingly, all exposed overpack surfaces are heated by radiation and convection heat transfer from the fire. Based on NUREG-1536 and 10 CFR 71 guidelines, the following fire parameters are assumed:

1. The average emissivity coefficient must be at least 0.9. During the entire duration of the fire, the painted outer surfaces of the overpack are assumed to remain intact, with an emissivity of 0.85. It is conservative to assume that the flame emissivity is 1.0, the limiting maximum value corresponding to a perfect blackbody emitter. With a flame emissivity conservatively assumed to be 1.0 and a painted surface emissivity of 0.85, the effective emissivity coefficient is 0.85. Because the minimum required value of 0.9 is greater than the actual value of 0.85, use of an average emissivity coefficient of 0.9 is conservative.

2. The average flame temperature must be at least 1475°F (802°C). Open pool fires typically involve the entrainment of large amounts of air, resulting in lower average flame temperatures. Additionally, the same temperature is applied to all exposed cask surfaces, which is very conservative considering the size of the HI-STORM FW cask. It is therefore conservative to use the 1475°F (802ºC) temperature.

3. The fuel source must extend horizontally at least 1 m (40 in), but may not extend more than 3 m (10 ft), beyond the external surface of the cask. Use of the minimum ring width of 1 meter yields a deeper pool for a fixed quantity of combustible fuel, thereby conservatively maximizing the fire duration.

4. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390**

   ].

Based on the 50-gallon fuel volume, the overpack outer diameter and the 1 m fuel ring width, the fuel ring surrounding the overpack and depth are calculated. From this depth and the fuel consumption rate of 0.15 in/min, the calculated fire duration is computed. The fuel consumption rate of 0.15 in/min is a lowerbound value from a Sandia National Laboratories report. Use of a lowerbound fuel consumption rate conservatively maximizes the duration of the fire.

To evaluate the impact of fire heating of the HI-STORM FW overpack, a thermal model of the overpack cylinder was constructed using FLUENT. A transient study is conducted for the duration of fire and post-fire of sufficient duration to reach maximum temperatures. The steady state HI-STORM FW normal storage temperatures are adopted as the initial condition for the fire accident (fire and post-fire) evaluation. The transient study was conducted for a sufficiently long period to allow temperatures in the overpack to reach their maximum values and begin to recede.

Due to the severity of the fire condition radiative heat flux, heat flux from incident solar radiation is negligible and is not included. Furthermore, the smoke plume from the fire would block most of the solar radiation. The thermal transient response of the storage overpack is determined using FLUENT. Time-histories for points in the storage overpack are monitored for the duration of the fire and the subsequent post-fire equilibrium phase.

Heat input to the HI-STORM FW overpack while it is subjected to the fire is from a combination of incident radiation and convective heat flux to all external surfaces. This can be expressed by the following equation:

$$q_F = h_{fc} (T_A - T_S) + \sigma\varepsilon [(T_A + C)^4 - (T_S + C)^4]$$

where:

q_F =Surface Heat Input Flux (Btu/ft^2-hr)
h_{fc} = Forced Convection Heat Transfer Coefficient (4.5 Btu/ft^2-hr-°F)
σ = Stefan-Boltzmann Constant
T_A = Fire Temperature (1475°F)
C= Conversion Constant (460 (°F to °R))
T_S = Surface Temperature (°F)
ε = Average Emissivity (0.90 per 10 CFR 71.73)

The forced convection heat transfer coefficient is based on the results of large pool fire thermal measurements (Section 4.6.2 of HI-STORM FW FSAR [10]).

After the fire event, the ambient temperature is restored and the storage overpack cools down (post-fire temperature relaxation). Heat loss from the outer surfaces of the storage overpack is determined by the following equation:

$$q_S = h_S (T_S - T_A) + \sigma\varepsilon [(T_S + C)^4 - (T_A + C)^4]$$

where:

q_S =Surface Heat Loss Flux (W/m^2 (Btu/ft^2-hr))
h_S = Natural Convection Heat Transfer Coefficient (Btu/ft^2-hr-°F)
T_S = Surface Temperature (°F))
T_A = Ambient Temperature (°F)
σ = Stefan-Boltzmann Constant
ε = Surface Emissivity
C= Conversion Constant (460 (°F to °R))

In the post-fire temperature relaxation phase, h_s is obtained using literature correlations for natural convection heat transfer from heated surfaces (Section 4.3.1.4). Solar insolation was included during post-fire event (Section 4.3.1.5). An emissivity of bare carbon steel is used for all the cask outer surfaces during post-fire analysis.

4.3.14.2 HI-TRAC VW Fire

In this subsection the fuel cladding and MPC pressure boundary integrity under an exposure to a short duration fire event is demonstrated. The HI-TRAC VW is initially (before fire) assumed to be loaded to candidate decay heat pattern and has reached steady-state maximum temperatures. The analysis assumes a fire from a 50-gallon transporter fuel tank spill. The fuel spill, as discussed in Subsection 4.3.14.1 is assumed to surround the HI-TRAC VW in a 1 m wide ring. The fire parameters are same as that assumed for the HI-STORM FW fire discussed in this preceding subsection. In this analysis, the HI-TRAC VW and its contents are conservatively postulated to undergo a transient heat-up as a lumped mass from the decay heat and heat input from the fire.

Based on the specified 50-gallon fuel volume, HI-TRAC VW cylinder diameter, and fuel ring width, the fuel ring area and depth are computed. From this depth and the fuel consumption rate of 0.15 in/min, the fire duration τ_f is calculated. The fuel consumption rate of 0.15 in/min is a lowerbound value as specified in Section 4.6.2 of HI-STORM FW FSAR [10]. Use of a lowerbound fuel consumption rate conservatively maximizes the duration of the fire.

From the HI-TRAC VW fire analysis, a bounding rate of temperature rise is determined. Therefore, the total temperature rise is computed as the product of the rate of temperature rise and τ_f.

4.3.15 Differential Thermal Expansion

To demonstrate that the fuel basket and MPC are free to expand without restraint, it is required to show that differential thermal expansion from fuel heatup is less than the as-built gaps that exist in the HI-STORM FW System. The HI-STORM FW System is engineered with gaps for the fuel basket and MPC to expand thermally without restraint of free end expansion. The following gaps shall be evaluated:

a. Fuel Basket-to-MPC Radial Gap
b. Fuel Basket-to-MPC Axial Gap
c. MPC-to-Overpack Radial Gap
d. MPC-to-Overpack Axial Gap

The FLUENT thermal model provides the 3-D temperature field in the HI-STORM FW system from which the changes in the above gaps can be directly computed.

4.3.16 MPC Cavity Pressure Calculations

During storage conditions, the gas temperature within the MPC rises to its maximum operating basis temperature. The gas pressure inside the MPC will also increase with rising temperature to its maximum operating pressure. The pressure rise is determined using the ideal gas law.

The MPC maximum gas pressure is computed for a postulated release of fission product gases from fuel rods into this free space. For these scenarios, the amounts of each of the release gas constituents in the MPC cavity are summed and the resulting total pressures determined from the ideal gas law. Based on fission gases release fractions in NUREG-1536 and the net free volume and initial fill gas pressure of the fuel rods, maximum gas pressures with 1% (normal), 10% (off-normal) and 100% (accident condition) rod rupture are calculated. The maximum computed gas pressures shall remain below the MPC internal design pressures for normal, off-normal and accident conditions specified in Table 4.2.

4.3.17 Analysis of Candidate Pattern

This topical report outlines the process for evaluating the normal long-term storage condition for a candidate heat load pattern using the model described in Section 4.3.1. All component temperatures and the cavity pressure shall remain below the limits specified in Tables 4.1 and 4.2 for the pattern to be considered acceptable.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

].

4.3.18 Other Disciplines

There are other disciplines and safety analyses that may be affected to a smaller degree the heat load patterns and/or temperature distributions. These are not addressed in this TR, but the FSAR/TS that invokes this TR must address them. These briefly discussed in the following sections

4.3.18.1 Shielding

Different decay heat loading patterns are associated with different loading patterns in terms of the burnup, enrichment and cooling times of the assemblies. The CoC where this TR is implemented may have specific limitations on burnup, enrichment and cooling times. These fuel qualification parameters need to be satisfied independent of the qualification of the heat load patterns through the methodology in this TR.

4.3.18.2 Structural

Structural analyses utilize temperatures from the thermal analysis in the licensing basis evaluations performed in the FSAR. If the temperature results from any pattern analyzed under this report are not bounded by those currently utilized in the FSAR licensing basis evaluation, the impact of the revised temperatures on the structural performance of the system will be evaluated under 10 CFR 72.48 to determine if the pattern can be used without further NRC approval.

4.3.19 Implementation

This topical report cannot be utilized until it is explicitly referenced in an approved CoC amendment. Such an amendment would be submitted separately from this TR.

Table 4.1: Temperature Limits for Evaluation of Candidate Heat Load Pattern Note 1

Component	**Normal Condition and Design (°F)**	**Short Term Operations (°F)**	**Off-Normal and Accident Condition Note 2 (°F)**
Fuel Cladding Note 4	734	1040 (MBF) 734 (HBF)	1040
Damaged Fuel Isolator	752	932	932
MPC shell	600 550 (Duplex)	800 600 (Duplex)	800 600 (Duplex)
MPC basket	752	932	932
MPC basket shims	752	932	932
MPC lid	600 550 (Duplex)	800 600 (Duplex)	800 600 (Duplex)
MPC closure ring	500	800 600 (Duplex)	800 600 (Duplex)
MPC baseplate	400	800 600 (Duplex)	800 600 (Duplex)
Overpack concrete	300	300	572
Overpack Lid Top and Bottom Plate	450	450	572
Remainder of overpack steel structure	350	350	700
HI-TRAC VW inner shell	-	600	700
HI-TRAC VW outer shell	-	500	700
HI-TRAC VW bottom lid	-	500	700
HI-TRAC VW water jacket shell	-	500	700Note 3
HI-TRAC VW top flange	-	500	650
HI-TRAC VW bottom lid seals	-	400	N/A
HI-TRAC VW bottom lid bolts	-	400	800
HI-TRAC VW bottom flange	-	400	700
HI-TRAC VW radial neutron shield	-	311	N/A
HI-TRAC VW radial lead gamma shield	-	600	600
HI-TRAC VW Version V2 NSC steel	-	400	600
HI-TRAC VW Version V2 NSC Holtite-A	-	300	350

Note 1: Except for the fuel cladding temperature limits, all component temperature limits are consistent with those specified in Table 2.2.3 of the HI-STORM FW FSAR [10].

Note 2: For accident conditions that involve heating of the steel structures and no mechanical loading (such as the blocked air duct accident), the permissible metal temperature of the steel parts is defined by Table 1A of ASME Section II (Part D) for Section III, Class 3 materials as 700°F. For the fire event, the structure is required to remain physically stable (no specific temperature limits apply).

Note 3: For fire accidents, the steel structure is required to remain physically stable similar to HI-STORM FW overpack.

Note 4: To ensure positive safety margins, the temperature limits are defined to be below the HI-STORM FW safety limits [10].

Table 4.2: MPC Pressure Limits for Evaluation of Candidate Heat Load Patterns Note 1

Pressure Location	Condition	Pressure (psig)
MPC Internal Pressure	Design / Long-Term Normal Note 2	97
	Short-Term Operations	115
	Off-Normal	120
	Accident	200
HI-TRAC Water Jacket Internal Pressure	Accident	65
HI-TRAC VW Version V2 NSC Internal Pressure	Accident	35

Note 1: Design pressure limits are consistent with those specified in Table 2.2.1 of the HI-STORM FW FSAR [10].
Note 2: To ensure positive safety margins, the pressure limit is defined to be below HI-STORM FW safety limits from [10].

Table 4.3: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 4.4: Fuel Storage Configurations

Storage Scenario	MPC	Fuel
PWR: 15x15I Short Fuel	Minimum Height MPC-37 for 15x15I fuel assembly array	15x15I in Table 2.1.2 of [10]
PWR: Short Fuel	Minimum Height MPC-37 for all fuel assembly arrays except 15x15I	14x14 Ft. Calhoun
PWR: Standard Fuel	Reference Height MPC-37	W-17x17
PWR: XL Fuel	Maximum Height MPC-37	AP1000
PWR: 16x16D	MPC-32ML	16x16D
BWR	MPC-89	GE-10x10

Table 4.5: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 4.6: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

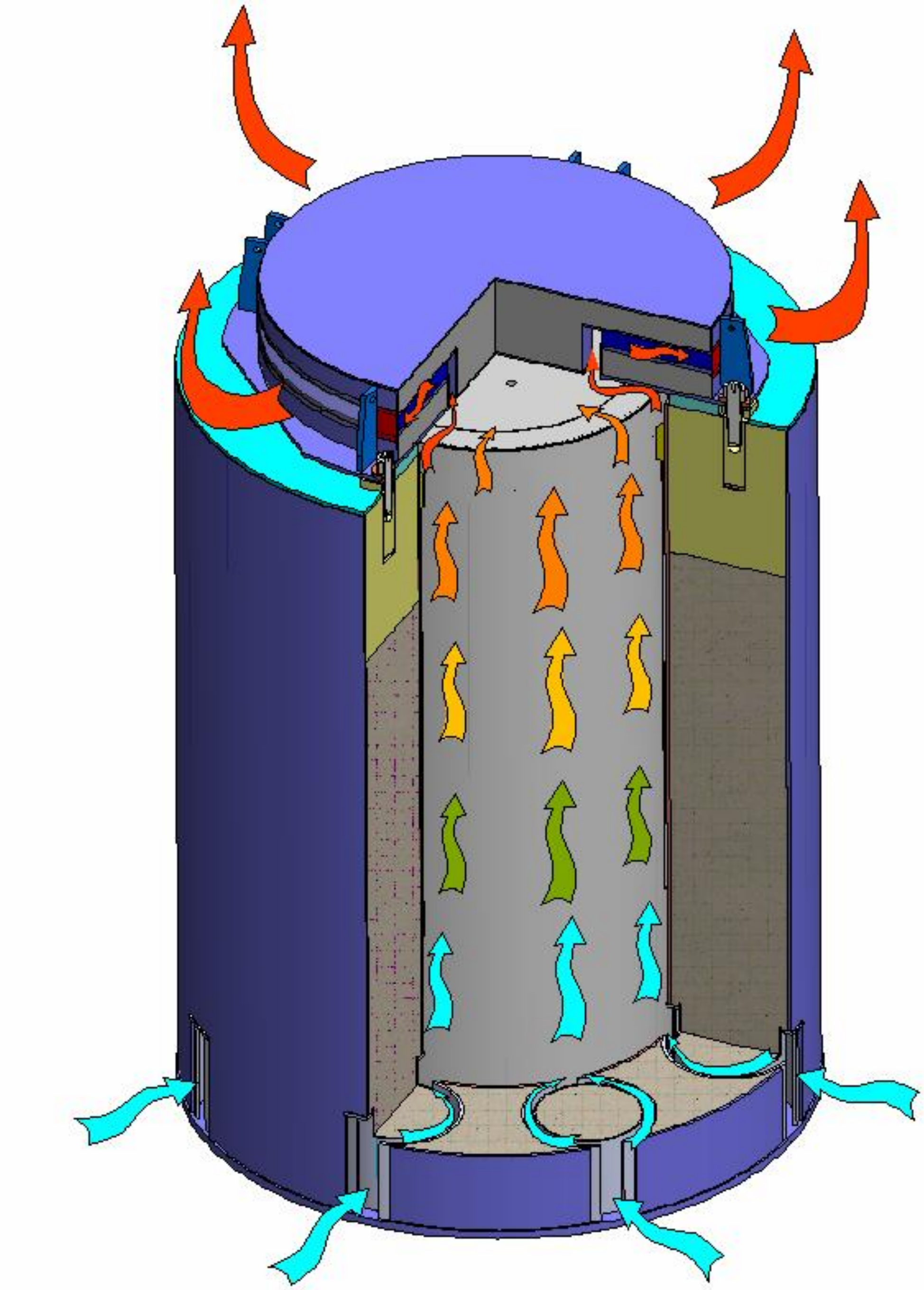

Figure 4.1: Ventilation Flow in the HI-STORM FW System

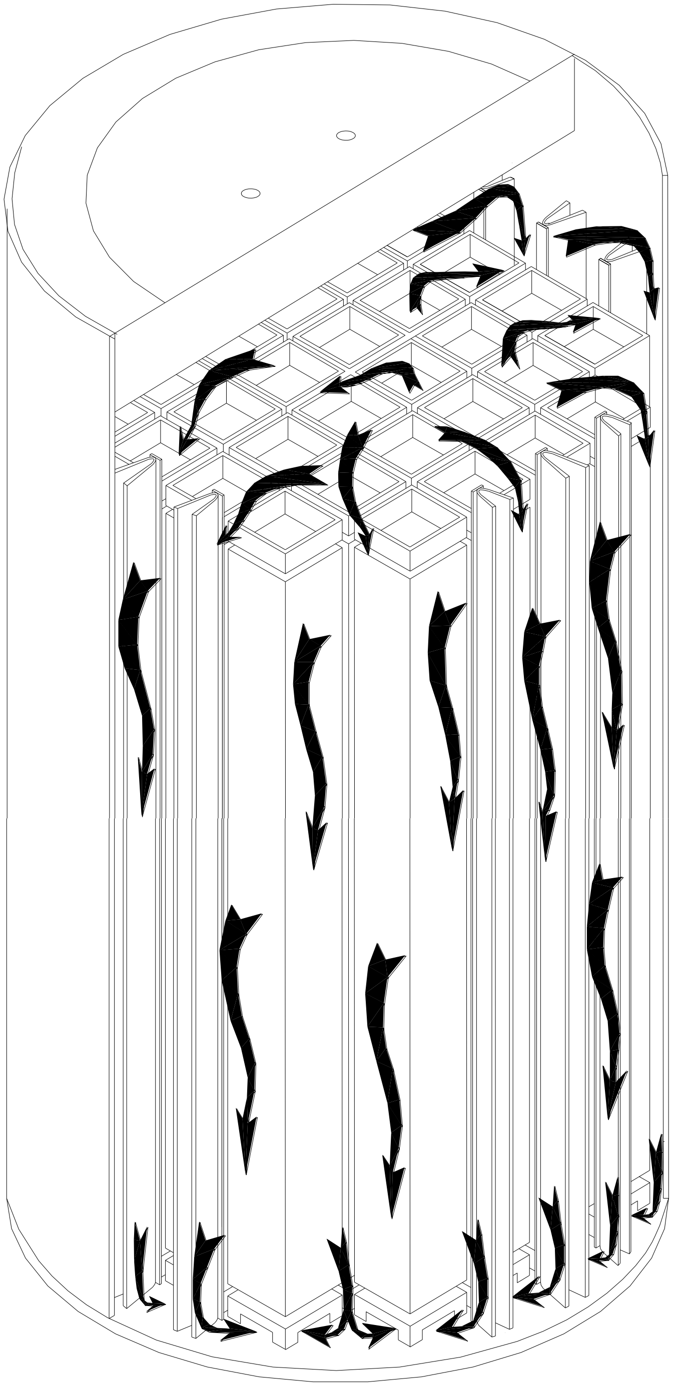

Figure 4.2: Illustration of MPC Internal Helium Circulation

5.0 EXAMPLE HEAT LOAD PATTERN EVALUATION FOR HI-STORM FW SYSTEM

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

6.0 CONCLUSIONS

This topical report provides the methodology for evaluating candidate heat load patterns, and when used in conjunction with a potential future amendment to the Certificate of Compliance should provide the ability for sites to more efficiently and safely load their spent fuel into dry storage.

7.0 REFERENCES

[1] HI-STORM 100 Certificate of Compliance, Amendment 0, Docket No. 72-104, Effective Date 05/31/00.

[2] "Final Safety Analysis Report for the Holtec International Storage and Transfer Operation Reinforced Module Cask System (HI-STORM 100 Cask System)", NRC Docket No. 72-1014, Holtec Report HI-2002444, Latest Revision.

[3] FLUENT Computational Fluid Dynamics Software, Ansys, Inc., 2600 ANSYS Drive, Canonsburg, PA 15317.

[4] **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

[5] ANSYS Finite Element Modeling Package, Ansys, Inc., 2600 ANSYS Drive, Canonsburg, PA 15317.

[6] USNRC Docket No. 72-1032, "Final Safety Analysis Report on the HI-STORM FW MPC Storage System", Holtec Report HI-2114830, Latest Revision.

[7] "Cladding Considerations for the Transportation and Storage of Spent Fuel," Interim Staff Guidance – 11, Revision 3, USNRC, Washington, DC.

[8] Docket No. 72-1014: HI-STORM 100 Amendment 15 Request Letter, from J. Tomlinson (Holtec) to J. McKirgan (USNRC), Dated March 20, 2019.

[9] **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

[10] "Final Safety Analysis Report on the HI-STORM FW MPC Storage System", NRC Docket No. 72-1032, Holtec Report HI-2114830, Latest Revision.

[11] Rohsenow, W.M. and Hartnett, J.P., "Handbook of Heat Transfer," McGraw Hill Book Company, New York, (1973).

[12] Jakob, M. and Hawkins, G.A., "Elements of Heat Transfer," John Wiley & Sons, New York, (1957).

[13] **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.

[14] **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**.