HOLTEC
INTERNATIONAL

Holtec Center, 555 Lincoln Drive West, Marlton, NJ 08053
Telephone (856) 797-0900
Fax (856) 797-0909

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U.S. Nuclear Regulatory Commission
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Reference:
1. USNRC Docket No. 72-1014 (HI-STORM 100), TAC L23850
2. Holtec Project 5014

Subject: License Amendment Request (LAR) #3 to HI-STORM 100 CoC

Dear Sir:

We herewith submit a revision to LAR #3 that addresses the short-term operations. As discussed and agreed with NRC, the short term operation limits are now based on the approved requirements and limits in CoC Amendment No. 2, as supported by the HI-STORM FSAR Rev. 4. Specifically, threshold heat load limits above which the use of active cooling systems (i.e., Forced Helium Dehydration (FHD) System for MPC dehydration operations and Supplemental Cooling System (SCS) for onsite handling of HI-TRAC) are needed are set to the maximum decay heat load in CoC Amendment 2. The 3-D model of the HI-TRAC/MPC assemblage, which could not be reviewed during the scheduled RAI cycles for this LAR and which would have relaxed the heat load limits, has been designated as inoperative for this LAR in the revised FSAR text matter. Instead, MPC thermal requirements during short-term operations are entirely premised on the current licensing basis (CoC 1014, Revisions 2 & 3).

Holtec plans to submit a new LAR to update the requirements for short-term operations in the very near future, to obviate the use of SCS at intermediate heat loads. We trust that the Staff will have the proper opportunity to review the analysis methodology and results in a comprehensive manner in the next LAR cycle.

Because only minor changes and clarifications to this current LAR are required, only replacement pages are provided in most cases. The pages attached to this letter consist of the following:

- CoC Appendix A: Pages 3.1.4-1 and 3.4-1 (2 Pages)
- FSAR Chapter 2, Pages 2.0-3 and 2.0-9 (2 Pages)
- FSAR Section 4.5 (12 Pages). For clarity, this section is shown in its final form without strikeouts. The following changes were made to this section since the last revision:

NMSS01

NRC NMSS

HOLTEC INTERNATIONAL
Holtec Center, 555 Lincoln Drive West, Marlton, NJ 08053
Telephone (856) 797-0900
Fax (856) 797-0909

- Removed: Last paragraph of 4.5; Fourth to last paragraph of 4.5.3.1; 4.5.4; 4.5.7; Tables 4.5.1 and 4.5.4
- Renumbered: Section 4.5.5 to 4.5.4; Tables 4.5.2 and 4.5.3 to 4.5.1 and 4.5.2
- Revised: Section 4.5.6
- New: Section 4.5.5

- FSAR Section 4.6: Page 4.6-6 (1 Page). Note that Table 4.6.7 is deleted
- FSAR Section 11: Pages 11.1-11 and 11.2-30 (2 Pages)

Note that all new text on the FSAR pages is shown in a different font (Arial) to distinguish it from the previously submitted text.

Please contact us if you have any questions.

Sincerely,

Evan Rosenbaum, P.E.
Project Manager, LAR 1014-3

Approval:

Stefan Anton, Dr.-Ing.
Licensing Manager

cc: Mr. Christopher Regan, NRC
Mr. Edwin Hackett, NRC
Mr. Bill Brach, NRC
Group 1, Holtec

Attachment: LAR 1014-3, Rev. 3.K, 19 Pages

3.1 SFSC INTEGRITY

3.1.4 Supplemental Cooling System

LCO 3.1.4 The Supplemental Cooling System (SCS) shall be operable

---NOTE---

Upon reaching steady state operation, the SCS may be temporarily disabled for a short duration (≤ 7 hours, ~~unless supported by site-specific analysis performed in accordance with 10 CFR 72.212)~~ to facilitate necessary operational evolutions, such as movement of the TRANSFER CASK through a door way, or other similar operation.

APPLICABILITY: This LCO is applicable when the loaded MPC is in the TRANSFER CASK and:

a. Within 4 hours of the completion of MPC drying operations in accordance with LCO 3.1.1 or within 4 hours of transferring the MPC into the TRANSFER CASK if the MPC is to be unloaded

AND

b. The MPC contains one or more fuel assemblies with an average burnup > 45,000 MWD/MTU

~~AND~~ OR MPC Heat Load > 28.74 kW

~~c. The steady-state peak fuel cladding temperature without the Supplemental Cooling System is predicted to exceed 400°C.~~

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. SFSC Supplemental Cooling System inoperable.	A.1 Restore SFSC Supplemental Cooling System to operable status.	7 days
B. Required Action A.1 and associated Completion Time not met.	B.1 Remove all fuel assemblies from the SFSC.	30 days

Table 3-1
MPC Cavity Drying Limits

Fuel Burnup (MWD/MTU)	MPC Heat Load (kW)	Method of Moisture Removal (Notes 1 and 2)
All Assemblies ≤ 45,000	≤ ~~28.74~~29 (MPC-24/24E/24EF) ≤ 26 (MPC-32/32F) ≤ 26 (MPC-68/68F/68FF)	VDS or FHD
All Assemblies ≤ 45,000	> 29 (MPC-24/24E/24EF) > 26 (MPC-32/32F) > 26 (MPC-68/68F/68FF)	FHD
One or more assemblies > 45,000	≤ ~~28.74~~36.9	FHD

Notes:

1. VDS means Vacuum Drying System. The acceptance criterion for VDS is MPC cavity pressure shall be ≤ 3 torr for ≥ 30 minutes.

2. FHD means Forced Helium Dehydration System. The acceptance criterion for the FHD System is gas temperature exiting the demoisturizer shall be ≤ 21°F for ≥ 30 minutes or gas dew point exiting the MPC shall be ≤ 22.9°F for ≥ 30 minutes .

Fuel Burnup (MWD/MTU)	MPC Heat Load (KW)	Method of Moisture Removal (Notes 1 and 2)
All Assemblies ≤ 45,000	≤ 28.74	VDS or FHD
One or More Assemblies > 45,000	≤ 28.74	FHD
All Burnups	> 28.74	FHD

iii. The maximum fuel cladding temperature as a result of an off-normal or accident event must not exceed 570°C (1058°F).

iv. For High Burnup Fuel (HBF), operating restrictions are imposed to limit the maximum temperature excursion during short-term operations to 65°C (117°F).

To achieve compliance with the above criteria, certain design and operational changes are necessary, as summarized below.

i. The peak fuel cladding temperature limit (PCT) for long term storage operations and short term operations is generally set at 400°C (752°F). However, for MPCs containing <u>all</u> moderate burnup fuel, the fuel cladding temperature limit for short-term operations is set at 570°C (1058°F) because fuel cladding stress is shown to be less than approximately 90 MPa per Reference [2.0.9]. Appropriate analyses have been performed as discussed in Chapter 4 and operating restrictions added to ensure these limits are met (see Section 4.5).

ii. For MPCs containing at least one high burnup fuel (HBF) assembly *or if the MPC heat load is greater than 28.74 kW,* the forced helium dehydration (FHD) method of MPC cavity drying must be used to meet the normal operations PCT limit and satisfy the 65°C temperature excursion criterion for HBF.

iii. The off-normal and accident condition PCT limit remains unchanged (1058°F).

iv. For *MPCs loaded with one or more* high burnup fuel *assemblies or if the MPC heat load is greater than 28.74 kW* ~~*with a decay heat load that would yield a peak HBF cladding temperature above the long-term temperature limit,*~~ the Supplemental Cooling System (SCS) is required to ensure fuel cladding temperatures remain below the applicable temperature limit (see Section 4.5). The design criteria for the SCS are provided in Appendix 2.C.

The MPC cavity is dried using either a vacuum drying system, or a forced helium dehydration system (see Appendix 2.B). The MPC is backfilled with 99.995% pure helium in accordance with the limits in Table 1.2.2 during canister sealing operations to promote heat transfer and prevent cladding degradation.

The *normal condition* design temperatures for the structural steel components of the MPC are based on the temperature limits provided in ASME Section II, Part D, tables referenced in ASME Section III, Subsection NB and NG, for those load conditions under which material properties are relied on for a structural load combination. The specific design temperatures for the components of the MPC are provided in Table 2.2.3.

The MPCs are designed for a bounding thermal source term, as described in Section 2.1.6. The maximum allowable fuel assembly heat load for each MPC is limited as specified in Section 2.1.9.

material. This material has a maximum allowable temperature in accordance with the manufacturer's test data. The specific allowable temperatures for the structural steel and shielding components of the HI-TRAC are provided in Table 2.2.3. The HI-TRAC is designed for off-normal environmental cold conditions, as discussed in Section 2.2.2.2. The structural steel materials susceptible to brittle fracture are discussed in Section 3.1.2.3.

The HI-TRAC is designed for the maximum heat load analyzed for storage operations. When the MPC contains any high burnup fuel assemblies *or if the MPC decay heat is greater than 28.74 kW,* the Supplemental Cooling System (SCS) will be required for certain time periods while the MPC is inside the HI-TRAC transfer cask (see Section 4.5). The design criteria for the SCS are provided in Appendix 2.C. The HI-TRAC water jacket maximum allowable temperature is a function of the internal pressure. To preclude over pressurization of the water jacket due to boiling of the neutron shield liquid (water), the maximum temperature of the water is limited to less than the saturation temperature at the shell design pressure. In addition, the water is precluded from freezing during off-normal cold conditions by limiting the minimum allowable temperature and adding ethylene glycol. The thermal characteristics of the fuel for each MPC for which the transfer cask is designed are defined in Section 2.1.6. The working area ambient temperature limit for loading operations is limited in accordance with the design criteria established for the transfer cask.

Shielding

The HI-TRAC transfer cask provides shielding to maintain occupational exposures ALARA in accordance with 10CFR20, while also maintaining the maximum load on the plant's crane hook to below either 125 tons or 100 tons, or less, depending on whether the *HI-TRAC 125 or* HI-TRAC *100* transfer cask is utilized. The HI-TRAC calculated dose rates are reported in Section 5.1. These dose rates are used to perform a generic occupational exposure estimate for MPC loading, closure, and transfer operations, as described in Chapter 10. A postulated HI-TRAC accident condition, which includes the loss of the liquid neutron shield (water), is also evaluated in Section 5.1.2. In addition, HI-TRAC dose rates are controlled in accordance with plant-specific procedures and ALARA requirements (discussed in Chapter 10).

The HI-TRAC 125 and 125D provide better shielding than the 100 ton HI-TRAC. Provided the licensee is capable of utilizing the 125 ton HI-TRAC, ALARA considerations would normally dictate that the 125 ton HI-TRAC should be used. However, sites may not be capable of utilizing the 125 ton HI-TRAC due to crane capacity limitations, floor loading limits, or other site-specific considerations. As with other dose reduction-based plant activities, individual users who cannot accommodate the 125 ton HI-TRAC should perform a cost-benefit analysis of the actions (e.g., modifications) which would be necessary to use the 125 ton HI-TRAC. The cost of the action(s) would be weighed against the value of the projected reduction in radiation exposure and a decision made based on each plant's particular ALARA implementation philosophy.

The HI-TRAC provides a means to isolate the annular area between the MPC outer surface and the HI-TRAC inner surface to minimize the potential for surface contamination of the MPC by spent fuel pool water during wet loading operations. The HI-TRAC surfaces expected to require

4.5 *THERMAL EVALUATION OF SHORT TERM OPERATIONS*

Prior to placement in a HI-STORM overpack, an MPC must be loaded with fuel, outfitted with closures, dewatered, dried, backfilled with helium and transported to the HI-STORM module. In the unlikely event that the fuel needs to be returned to the spent fuel pool, these steps must be performed in reverse. Finally, if required, transfer of a loaded MPC between HI-STORM overpacks or between a HI-STAR transport overpack and a HI-STORM 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 that, as stated in Chapter 1, is available in two anatomically similar weight ratings (100- and 125-ton). 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 involving either the 100-ton or 125-ton HI-TRAC, the permissible temperature limits presented in Section 4.3 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.

- *i. Post-Loading Wet Transfer Operations*
- *ii. MPC Cavity Vacuum Drying*
- *iii. Normal Onsite Transport in a Vertical Orientation*
- *iv. MPC Cooldown and Reflood for Unloading Operations*

Onsite transport of the MPC occurs with the HI-TRAC in the vertical orientation, which preserves the thermosiphon action within the MPC. To avoid excessive temperatures, transport with the HI-TRAC in the horizontal condition is generally not permitted. However, it is recognized that an occasional downending of a HI-TRAC may become necessary to clear an obstruction such as a low egress bay door opening. In such a case the operational imperative for HI-TRAC downending must be ascertained and the permissible duration of horizontal configuration must be established on a site-specific basis and compliance with the thermal limits of ISG-11 [4.1.4] must be demonstrated as a part of the site-specific safety evaluation.

The fuel handling operations listed above place a certain level of constraint on the dissipation of heat from the MPC relative to the normal storage condition. Consequently, for some scenarios, it is necessary to provide additional cooling when decay heat loads are such that long-term cladding temperature limits would be exceeded. For such situations, the Supplemental Cooling System (SCS) is required to provide additional cooling during short term operations. The SCS is required by the CoC for any MPC carrying one or more high burnup fuel assemblies when the MPC heat load is such that long-term cladding temperature limits of the high burnup fuel assemblies would be exceeded. The specific design of an SCS must accord with site-specific needs and resources, including the availability of plant utilities. However, a set of specifications to ensure that the *performance objectives of the SCS are satisfied by plant-specific designs are set forth in Appendix 2.C.*

4.5.1 HI-TRAC Thermal Model

The HI-TRAC transfer cask is used to load and unload the HI-STORM concrete storage overpack, including onsite transport of the MPCs from the loading facility to an ISFSI. Section views of the HI-TRAC have been presented in Chapter 1. Within a loaded HI-TRAC, heat generated in the MPC is transported from the contained fuel assemblies to the MPC shell in the manner described in Section 4.4. From the outer surface of the MPC to the ambient air, heat is transported through the HI-TRAC overpack by a combination of conduction, thermal radiation and natural convection. For evaluation of a loaded canister during short-term operations (including vacuum drying) the 3-Dimensional thermal model of the MPC described in Section 4.4 is adopted. Thermal modeling of the HI-TRAC overpack is provided in the following.

Two HI-TRAC transfer cask designs, namely, the 125-ton and the 100-ton versions, are developed for onsite handling and transport, as discussed in Chapter 1. The two designs are principally different in terms of lead thickness and the thickness of the heat dissipating ribs (radial connectors) in the water jacket region. The analytical model developed for HI-TRAC thermal characterization conservatively accounts for these differences by applying the higher shell thickness and thinner radial connectors' thickness to the model. In this manner, the HI-TRAC overpack resistance to heat transfer is overestimated, resulting in higher predicted MPC internals and fuel cladding temperature levels.

The 100-ton and 125-ton HI-TRAC designs incorporate 2.5 inch and 4.5 inch annular lead spaces, respectively, formed between a 3/4-inch thick steel inner shell and a 1-inch thick steel outer shell. To ensure that lead forms a heat conduction continuum in the HI-TRAC body, lead in the form of bricks or plates are not utilized in Holtec transfer casks. Rather, lead is poured in a molten state. The interior steel surfaces are cleaned, sandblasted and fluxed in preparation for the molten lead that will be poured in the annular cavity. The appropriate surface preparation technique is essential to ensure that molten lead sticks to the steel surfaces, which will form a metal to lead bond upon solidification during the lead pour process. The formation of gap-free interfacial bonds between the solidified lead and steel surfaces initiates a process of lead crystallization from the molten pool onto the solid surfaces. Static pressure from the column of molten lead further aids in retaining the solidified lead layer to the steel surfaces. The melt-solid interface growth occurs by freezing of successive layers of molten lead as the heat of fusion is dissipated by the solidified metal and steel structure enclosing it. This growth stops when all the molten lead is used up and the annulus is filled with a solid lead plug. The shop fabrication procedures, developed in conjunction with the manufacture of the HI-TRAC transfer casks contain detailed step-by-step instructions devised to eliminate the incidence of annular gaps in the lead space of the HI-TRAC. Accordingly the HI-TRAC transfer cask lead spaces are treated in the thermal models as continuous media.

Transport of heat within HI-TRAC occurs through multiple concentric layers of air, steel and shielding materials. From the surface of the enclosure shell heat is rejected to the atmosphere by natural convection and radiation.

A small diametral air 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 conduction and thermal radiation. Assuming that the MPC is centered and does not contact the transfer overpack walls conservatively minimizes heat transport across this gap. Thermal expansion would act to minimize this gap. At operating conditions, this gap would be quite small. For the purposes of evaluating heat transport across this gap, however, it is conservatively assumed that the gap is reduced to one-half of its nominal value. Heat is transported through the cylindrical wall of the HI-TRAC overpack by conduction through successive layers of steel, lead and steel. A water jacket, which provides neutron shielding for the HI-TRAC overpack, 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 overpack by natural convection and thermal radiation.

The HI-TRAC bottom is conservatively modeled as an insulated surface. The HI-TRAC top lid and sides are modeled as insolation heated surfaces cooled by convection and radiation. Insolation on exposed surfaces is conservatively based on 12-hour insolation inputs from 10CFR71 averaged on a 24-hour basis.

4.5.1.1 Effective Thermal Conductivity of Water Jacket

The HI-TRAC water jacket is composed of an array of radial ribs equispaced along the circumference of the HI-TRAC. Enclosure plates are welded to these ribs, creating an array of water compartments. Holes in the radial ribs connect all the individual compartments in the water jacket. The annular region between the HI-TRAC outer shell and the enclosure shell is an array of steel ribs and water spaces.

The effective radial thermal conductivity of this array of steel ribs and water spaces is determined by combining the heat transfer resistance of individual components (steel ribs and water spaces) in a parallel network. A bounding calculation is assured by using a minimum available metal thickness (product of number of radial ribs and rib thickness) for radial heat transfer.

The water in the jacket is free to move under the effects of buoyancy forces. The effect of this water motion on heat transfer is characterized by the Nusselt number (Nu), which can be defined as follows for a vertical enclosure [4.5.1]:

$$Nu = 0.046 \times Ra^{1/3}$$

where Ra is the Rayleigh number. For a conservatively determined Rayleigh number, based on the radial width of the water space, the Nusselt number for the water in the water jacket is approximately 79. This value is used as a multiplier on the thermal conductivity of water in the water jacket to reflect the effects of water motion on heat transfer in this region.

4.5.1.1.2 Heat Rejection from Overpack Exterior Surfaces

The following relationship is used for modeling heat loss from exposed cask surfaces:

$$q_s = 0.19\,(T_s - T_A)^{4/3} + 0.1714\varepsilon\,[(\frac{T_s + 460}{100})^4 - (\frac{T_A + 460}{100})^4]$$

where:

T_S = *cask surface temperatures (°F)*
T_A = *ambient atmospheric temperature (°F)*
q_s = *surface heat flux (Btu/ft² ×hr)*
ε = *surface emissivity*

The second term in this equation the Stefan-Boltzmann formula for thermal radiation from an exposed surface to ambient. The first term is the natural convection heat transfer correlation recommended by Jacob and Hawkins [4.2.9]. This correlation is appropriate for turbulent natural convection from vertical surfaces, such as the vertical overpack wall. Although the ambient air is conservatively assumed to be quiescent, the natural convection is nevertheless turbulent.

Turbulent natural convection correlations are suitable for use when the product of the Grashof and Prandtl (Gr×Pr) numbers exceeds 10^9. *This product can be expressed as* $L^3 \times \Delta T \times Z$, *where L is the characteristic length,* ΔT *is the surface-to-ambient temperature difference, and Z is a function of the surface temperature. The characteristic length of a vertically oriented HI-TRAC is its height of approximately 17 feet. The value of Z, conservatively taken at a surface temperature of 340°F, is* 2.6×10^5. *Solving for the value of* ΔT *that satisfies the equivalence* $L^3 \times \Delta T \times Z = 10^9$ *yields* ΔT = *0.78°F. The natural convection will be turbulent, therefore, provided the surface to air temperature difference is greater than or equal to 0.78°F.*

4.5.1.3 Determination of Solar Heat Input

The thermal evaluations use the 10CFR71 specified 12-hour insolation as a 24-hour averaged heat flux on exposed HI-TRAC surfaces. This is appropriate, as the HI-TRAC cask possesses a considerable thermal inertia that precludes it from reaching steady state during a 12-hour insolation period.

4.5.2 Maximum Time Limit During Wet Transfer Operations

In accordance with NUREG-1536, water inside the MPC cavity during wet transfer operations is not permitted to boil. Consequently, uncontrolled pressures in the de-watering, purging, and recharging *system that may result from two-phase conditions are completely avoided. This requirement is accomplished by imposing a limit on the maximum allowable time duration for fuel to be submerged in water after a loaded HI-TRAC cask is removed from the pool and prior to the start of vacuum drying operations.*

Fuel loading operations are typically conducted with the HI-TRAC and it's contents (water filled MPC) submerged in pool water. Under these conditions, the HI-TRAC 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, the water, fuel, MPC and HI-TRAC metal absorb the decay heat emitted by the fuel assemblies. This results in a slow temperature rise of the HI-TRAC with time, starting from an initial (pool water) temperature. The rate of temperature rise is limited by the thermal inertia of the HI-TRAC system. To enable a bounding heat-up rate determination, the following conservative assumptions are utilized:

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. *Design maximum decay heat input from the loaded fuel assemblies is assumed.*

iii. *The smaller of the two (i.e., 100-ton and 125-ton) HI-TRAC transfer cask designs is credited in the analysis. The 100-ton design has a significantly smaller quantity of metal mass, which will result in a higher rate of temperature rise.*

iv. *The water mass in the MPC cavity is understated.*

Table 4.5.1 summarizes the weights and thermal inertias of several components in the loaded HI-TRAC transfer cask. The rate of temperature rise of the HI-TRAC transfer cask and contents during an adiabatic heat-up is governed by the following equation:

$$\frac{dT}{dt} = \frac{Q}{C_h}$$

where:

Q = *conservatively bounding heat load (Btu/hr) [38 kW = $1.3x10^5$ Btu/hr]*
C_h = *thermal inertia of a loaded HI-TRAC (Btu/°F)*
T = *temperature of the HI-TRAC cask (°F)*
t = *time after HI-TRAC transfer cask is removed from the pool (hr)*

A bounding heat-up rate for the HI-TRAC transfer cask contents is determined to be equal to 4.99°F/hr. From this adiabatic rate of temperature rise estimate, the maximum allowable time duration (t_{max}) for fuel to be submerged in water is determined as follows:

$$t_{max} = \frac{T_{boil} - T_{initial}}{(dT/dt)}$$

where:

T_{boil} = *boiling temperature of water (equal to 212°F at the water surface in the MPC cavity)*

$T_{initial}$ = *initial HI-TRAC temperature when the transfer cask is removed from the pool*

Table 4.5.2 provides a summary of t_{max} *at several representative initial temperatures.*

As set forth in the HI-STORM operating procedures, in the unlikely event that the maximum allowable time provided in Table 4.5.2 is found to be insufficient to complete all 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*

T_{in} = *temperature of pool water supply to MPC*

With the MPC cavity water temperature limited to 150°F, MPC inlet water maximum temperature equal to 125°F and at the design basis maximum heat load, the water flow rate is determined to be 5210 lb/hr (10.5 gpm).

4.5.3 MPC Temperatures During Moisture Removal Operations

4.5.3.1 Vacuum Drying Operation

The initial loading of SNF in the MPC requires that the water within the MPC be drained and replaced with helium. For MPCs containing moderate burnup fuel assemblies only, this operation may be carried out using the conventional vacuum drying approach. In this method, removal of the last traces of residual moisture from the MPC cavity is accomplished by evacuating the MPC for a short time after draining the MPC. Vacuum drying of MPCs containing any high burnup fuel assemblies is not permitted. High burnup fuel drying is performed by a forced flow helium drying process as described in Appendix 2.B.

Prior to the start of the MPC draining operation, both the HI-TRAC annulus and the MPC are full of water. The presence of water in the HI-TRAC annulus ensures adequate fuel cooling even under *high vacuum (~1 torr) for extended durations. As the heat generating active fuel length is uncovered during MPC draining operation, the fuel and basket mass will undergo a gradual heat up from the initially cold conditions when the heated surfaces were submerged under water.*

4.5.3.2 Forced Helium Dehydration

To reduce moisture to trace levels in the MPC using a Forced Helium Dehydration (FHD) system, a closed loop dehumidification system consisting of a condenser, a demoisturizer, a compressor, and a pre-heater is utilized to extract moisture from the MPC cavity through repeated displacement of its contained helium, accompanied by vigorous flow turbulation. A vapor pressure of 3 torr or less is assured by verifying that the helium temperature exiting the demoisturizer is maintained at or below the psychrometric threshold of 21°F for a minimum of 30 minutes. See Appendix 2.B for detailed discussion of the design criteria and operation of the FHD system.

The FHD system provides concurrent fuel cooling during the moisture removal process through forced convective heat transfer. The attendant forced convection-aided heat transfer occurring during operation of the FHD system ensures that the fuel cladding temperature will remain below the applicable peak cladding temperature limit for normal conditions of storage, which is well below the high burnup cladding temperature limit 752°F (400°C) for all combinations of SNF type, burnup, decay heat, and cooling time. Because the FHD operation induces a state of forced convection heat transfer in the MPC, (in contrast to the quiescent mode of natural convection in long term storage), it is readily concluded that the peak fuel cladding temperature under the latter condition will be greater than that during the FHD operation phase. In the event that the FHD system malfunctions, the forced convection state will degenerate to natural convection, which corresponds to the conditions of normal onsite transport. As a result, the peak fuel cladding temperatures will approximate the values reached during normal onsite transport as described elsewhere in this chapter.

4.5.4 Cask Cooldown and Reflood Analysis During Fuel Unloading Operation

NUREG-1536 requires an evaluation of cask cooldown and reflooding to support fuel unloading from a dry condition. Past industry experience generally supports cooldown of cask internals and fuel from hot storage conditions by direct water quenching. For high heat load MPCs, the extremely rapid cooldown rates to which the hot MPC internals and the fuel cladding can be subjected during water injection may, however, result in high thermal stresses. Additionally, water injection may also result in some steam generation. To limit the fuel cladding from thermal strains from direct water quenching, the MPCs may be cooled using appropriate means prior to the introduction of water in the MPC cavity space.

Because of the continuous gravity driven circulation of helium in the MPC which results in heated helium gas in sweeping contact with the underside of the top lid and the inner cylindrical surface of the enclosure vessel, utilizing an external cooling means to remove heat from the MPC is quite effective. The external cooling process can be completely non-intrusive such as extracting heat from the outer surface of the enclosure vessel using chilled water. Extraction of heat from the external *surfaces of an MPC is very effective largely because of the thermosiphon induced internal transport of heat to the peripheral regions of the MPC. The non-intrusive means of heat removal is preferable to an intrusive process wherein helium is extracted and cooled using a closed loop system such as a Forced Helium Dehydrator (Appendix 2.B), because it eliminates the potential for any radioactive crud to exit the MPC during the cooldown process. Because the optimal method for MPC cooldown is heavily dependent on the location and availability of utilities at a particular nuclear plant, mandating a specific cooldown method cannot be prescribed in this FSAR. Simplified calculations are presented in the following to illustrate the feasibility and efficacy of utilizing an intrusive system such as a recirculating helium cooldown system.*

Under a closed-loop forced helium circulation condition, the helium gas is cooled, via an external chiller. The chilled helium is then introduced into the MPC cavity from connections at the top of the MPC lid. The helium gas enters the MPC basket and moves through the fuel basket cells, removing heat from the fuel assemblies and MPC internals. The heated helium gas exits the MPC from the lid connection to the helium recirculation and cooling system. Because of the turbulation and mixing of the helium contents in the MPC cavity by the forced circulation, the MPC exiting temperature is a reliable measure of the thermal condition inside the MPC cavity. The objective of the cooldown system is to lower the bulk helium temperature in the MPC cavity to below the normal boiling temperature of water (212°F). For this purpose, the rate of helium circulation shall be sufficient to ensure that the helium exit gas temperature is below this threshold limit with a margin.

An example calculation for the required helium circulation rate is provided below to limit the helium temperature to 200°F. The calculation assumes no heat loss from the MPC boundaries and a conservatively bounding heat load (38 kW (1.3×10^5 Btu/hr)). Under these assumptions, the MPC helium is heated adiabatically by the MPC decay heat from a given inlet temperature (T_1) to a temperature (T_2). The required circulation rate to limit T_2 to 200°F is computed as follows:

$$m = \frac{Q_d}{C_p(T_2 - T_1)}$$

where:

- Q_d = *Design maximum decay heat load (Btu/hr)*
- *m = Minimum helium circulation rate (lb/hr)*
- *Cp = Heat capacity of helium (1.24 Btu/lb-°F (Table 4.2.5))*
- T_1 = *Helium supply temperature (assumed 15°F in this example)*

Substituting the values for the parameters in the equation above, m is computed as 567 lb/hr.

4.5.5 Mandatory Limits for Short Term Operations

The 3-D thermal models described in the foregoing in this Section for short term operations under Vacuum Drying and Onsite Transport have not been reviewed by the NRC. The description of these models is therefore included for reference only. These models are not to be used to support changes under 10CFR72.48.

The mandated requirements and limits for the short term operations shall be the same as those in CoC 1014, Amendment 2, as supported by the analysis in Section 4.5 of the HI-STORM FSAR Rev. 4, with the additional provision that the SCS or FHD shall be used for MPC heat loads greater than 28.74 kW. Furthermore, the SCS shall be designed for a heat removal capacity of 36.9 kW if the MPC heat load exceeds 28.74 kW (CoC 1014, Amendment 2 limit). An SCS thus sized will insure that the fuel cladding temperature will be substantially below the regulatory limit.

Finally, the use of the FHD designed in accordance with Appendix 2.B, as explained in Paragraph 4.5.3.2, unconditionally guarantees that the peak cladding temperature remains below 400°C.

The requirements and limits are stated in the paragraphs 4.5.5.1 and 4.5.5.2, below.

4.5.5.1 HI-TRAC Transport in a Vertical Orientation

The requirements and limits are listed in the following table:

Condition	Fuel in MPC	MPC Heat Load (kW)	SCS Required
1*	All MBF	≤ 28.74	NO
2	All MBF	> 28.74	YES
3	One or more HBF	any	YES

* The highest temperatures are reached under this un-assisted cooling threshold heat load scenario. Under other conditions the mandatory use of the Supplemental Cooling System, sized to extract 36.9 kW from the MPC, will lower the fuel temperatures significantly assuring ISG 11, Rev. 3 compliance with large margins.

Conditions 1 and 3 are identical to the requirement in CoC 1014, Amendment 2, as supported by HI-STORM FSAR Rev. 4. Condition 2 mandates the use of the SCS at heat loads greater than 28.74 kW for MBF. This will assure that cladding temperature limits are met at these higher heat loads. See Appendix 2.C for the SCS requirements.

It is recognized that, due to increased thermosiphon action, the temperature in the MPC under 7 atmospheres internal pressure (required in this amendment) will be lower than that for the 5 atmospheres case (in CoC 1014, Amendment 2) on which Condition 1 is based.

Therefore, there is an additional implicit margin in the fuel cladding temperatures incorporated in the short term operations by the use of the FSAR heat load limits corresponding to CoC 1014-2 herein.

4.5.5.2 Moisture Removal Limits and Requirements

Vacuum Drying (VD) is permitted for MBF under certain conditions. If these conditions are not met, or if the MPC also contains HBF, then the FHD must be used for moisture removal. The requirements and limits are listed in the following table:

Condition	*Fuel in MPC*	*HI-TRAC Annulus Cooling Requirement*	*MPC Heat Load (kW)*	*Moisture Removal Method*
1	*All MBF*	*Standing Water*	*PWR: ≤ 20.88* *BWR: ≤ 21.52*	*VD**
2	*All MBF*	*Circulating Water*	*≤ 28.74*	*VD**
3	*All MBF*	*None*	*> 28.74*	*FHD*
4	*One or more HBF*	*None*	*any*	*FHD*
** The FHD drying method is also acceptable under the Condition 1 and Condition 2 heat loads, in which case HI-TRAC annulus cooling is not required.*				

Conditions 1, 2 and 4 are identical to the requirement in CoC 1014, Amendment 2, as supported by HI-STORM FSAR Rev. 4. Condition 3 mandates the use of the FHD at higher heat loads for MBF drying. This will assure that cladding temperature limits are met at these higher heat loads (See Paragraph 4.5.3.2).

4.5.6 Maximum Internal Pressure

After fuel loading and vacuum drying, but prior to installing the MPC closure ring, the MPC is initially filled with helium. During handling and on-site transfer operations in the HI-TRAC transfer cask, the gas temperature will correspond to the thermal conditions within the MPC. As stated before, the gas temperature in the MPC at any given heat load will be less than that reported in Table 4.5.2 of the HI-STORM FSAR Rev. 4 for the CoC 1014-2 conditions which provided for approximately 30% less helium than that prescribed for Amendment 1014-4. In accordance with ideal gas law the gas pressure rises in direct proportion to the increase in the average temperature of the MPC cavity from ambient temperature upto operating conditions. A lesser rise in temperature (due to increased thermosiphon action *under Amendment 1014-4 helium backfill requirements) will result in a corresponding smaller rise in gas pressure. An approximately 40% increase in the initial gas pressure in CoC 1014-4 over that in CoC 1014-2, therefore, is mitigated by a smaller rise in the gas pressure. Noting that the maximum gas pressure in CoC 1014-2 condition had over 100% margin against the analyzed maximum permissible pressure (200 psig per Table 2.2.1) the maximum pressure in the MPC is guaranteed to remain below 200 psig and thus the physical integrity of the confinement boundary is assured.*

Table 4.5.1

HI-TRAC TRANSFER CASK LOWERBOUND WEIGHTS AND THERMAL INERTIAS

Component	***Weight (lbs)***	***Heat Capacity (Btu/lb-°F)***	***Thermal Inertia (Btu/°F)***
Water Jacket	*7,000*	*1.0*	*7,000*
Lead	*52,000*	*0.031*	*1,612*
Carbon Steel	*40,000*	*0.1*	*4,000*
Alloy-X MPC (empty)	*39,000*	*0.12*	*4,680*
Fuel	*40,000*	*0.056*	*2,240*
*MPC Cavity Water**	*6,500*	*1.0*	*6,500*
			26,032 (Total)

* *Conservative lower bound water mass.*

Table 4.5.2

MAXIMUM ALLOWABLE TIME FOR WET TRANSFER OPERATIONS

Initial Temperature (°F)	***Time Duration (hr)***
115	*19.4*
120	*18.4*
125	*17.4*
130	*16.4*
135	*15.4*
140	*14.4*
145	*13.4*
150	*12.4*

(b) HI-TRAC Fire

The acceptability of fire-accident HI-TRAC condition following a 50-gallon fuel spill fire at a co-incident decay heat load of 28.74 kW has been ascertained under the HI-STORM CoC 1014, Amendment 2, as supported by HI-STORM FSAR Rev. 4. This fire accident evaluation is bounding up to the HI-TRAC un-assisted cooling threshold heat load, 28.74 kW, defined in Section 4.5.5 . At greater heat loads forced cooling of the MPC using the Supplemental Cooling System (SCS) defined in Section 2.C is mandatory (See Subsection 4.5.5.1, Conditions 2 and 3). The SCS, sized for 36.9 kW heat removal capacity, will insure that the cladding temperatures will be well below the temperatures under the threshold heat load scenario, when the SCS is not used. As such the SCS cooled HI-TRAC pre-fire thermal condition is bounded by the threshold heat load scenario. The principal HI-TRAC thermal loading during this accident (50-gallon fire heat input) is bounded by the CoC 1014-2 evaluation referenced above. Therefore the fire accident consequences are likewise bounded.

4.6.2.2 Jacket Water Loss

In this subsection, 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. As an additional measure of conservatism, the air in the water jacket is assumed to be motionless (i.e. natural convection neglected) and radiation heat transfer in the water jacket spaces ignored. 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 and reported in Table 4.6.3. The results of jacket water loss evaluation confirm that the cladding, MPC and HI-TRAC component temperatures are below the limits prescribed in Chapter 2 (Table 2.2.3). The co-incident MPC pressure is also computed and compared with the MPC accident design pressure (Table 2.2.1). The result (Table 4.6.2) is confirmed to be below the limit.

4.6.2.3 Extreme Environmental Temperatures

To evaluate the effect of extreme weather conditions, an extreme ambient temperature (Table 2.2.2) 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 HI-STORM 100 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. Starting from a baseline condition evaluated in Section 4.4 (normal ambient temperature and limiting fuel storage configuration) the temperatures of the HI-STORM 100 System are conservatively assumed to rise by the difference between the extreme and normal ambient temperatures (45°F). The HI-STORM extreme ambient temperatures computed in this manner are reported in Table 4.6.4. The co-incident MPC pressure is also computed (Table 4.6.2)

11.1.6.3 <u>*Analysis of Effects and Consequences of FHD Malfunction*</u>

<u>*Structural*</u>

The FHD System is required to be equipped with safety relief devices§ to prevent the MPC structural boundary pressures from exceeding the design limits. Consequently there is no adverse effect.

<u>*Thermal*</u>

Malfunction of the FHD System is categorized as an off-normal condition, for which the applicable peak cladding temperature limit is 1058°F (Table 2.2.3). The FHD System malfunction event is evaluated assuming the following bounding conditions:

1) *Steady state maximum temperatures have been reached*
2) *Design basis heat load*
3) *Standing column of air in the annulus*
4) *MPCs backfilled with the minimum helium pressure required by the Technical Specifications*

It is noted that operator action may be required to raise the helium regulator set point to ensure that condition 4 above is satisfied. These conditions are bounded by the HI-TRAC Jacket Water Loss accident evaluation in Subsection 4.6.2.2. *The results demonstrate that the peak fuel cladding temperatures remain below the* off-normal *limit* (Table 2.2.3) *in the event of a prolonged unavailability of the FHD system.*

<u>*Shielding*</u>

There is no effect on the shielding performance of the system as a result of this off-normal event.

<u>*Criticality*</u>

There is no effect on the criticality control of the system as a result of this off-normal event.

<u>*Confinement*</u>

There is no effect on the confinement function of the MPC as a result of this off-normal event. As discussed in the structural evaluation above, the structural boundary pressures cannot exceed the design limits.

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§ *The relief pressure is below the off-normal design pressure (Table 2.2.1) to prevent MPC overpressure and above 7 atm to enable MPC pressurization for adequate heat transfer.*

11.2.15.3 Extreme Environmental Temperature Dose Calculations

The extreme environmental temperature will not cause the concrete to exceed its normal design temperature. Therefore, there will be no degradation of the concrete's shielding effectiveness. The elevated temperatures will not cause a breach of the confinement system and the short-term fuel cladding temperature is not exceeded. Therefore, there is no radiological impact on the HI-STORM 100 System for the extreme environmental temperature and the dose calculations are equivalent to the normal condition dose rates.

11.2.15.4 Extreme Environmental Temperature Corrective Action

There are no consequences of this accident that require corrective action.

11.2.16 Supplemental Cooling System (SCS) Failure

The SCS system is a forced fluid circulation device used to provide supplemental HI-TRAC cooling. For fluid circulation, the SCS system is equipped with active components requiring power for normal operation. Although an SCS System failure is highly unlikely, for defense-in-depth an accident condition that renders it inoperable for an extended duration is postulated herein.

11.2.16.1 Cause of SCS Failure

Possible causes of SCS failure are: (a) Simultaneous loss of external and backup power, or (b) Complete loss of annulus water from an uncontrolled leak or line break.

11.2.16.2 Analysis of Effects and Consequences of SCS Failure

Structural

See discussion under thermal evaluation below.

Thermal

In the event of a SCS failure due to (a), the following sequence of events occur:

i) *The annulus water temperature rises to reach it's boiling temperature (~212°F).*
ii) *A progressive reduction of water level and dryout of the annulus.*

In the event of an SCS failure due to (b), a rapid water loss occurs and annulus is replaced with air.

In both cases the SCS failure condition is bounded by the HI-TRAC Jacket Water loss accident evaluation in Section 4.6.2.2 which models the loss of water in both the water jacket and annulus. The results show that the peak fuel cladding temperature remains below the accident limit (Table 2.2.3).