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 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.

To ensure a bounding evaluation for the array of fuel storage configurations permitted in Section 2.1, a limiting storage condition is evaluated in this section. The limiting storage condition[1] is determined in Table 4.4.4 to be MPC-68 (based on the bounding axisymmetric thermal model) with regionalization parameter X = 0.5.

1 *Limiting fuel storage condition is defined as the fuel loading scenario that yields the highest computed fuel temperatures. From the array of analyses presented on Section 4.4, it is found that the highest clad temperatures co-incidentally occur with the highest permitted MPC heat load (i.e. for X = 0.5). Therefore the limiting scenario also yields the highest confinement boundary and overpack temperatures.*

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 certain threshold heat loads are 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 in excess of a conservatively postulated threshold (Q = 25 kW). For compliance with this specification, the MPC heat load is computed based on the discussion provided in Section 2.1 for uniform loading. In accordance with Section 2.1, the MPC heat load (Q) is computed by multiplying the number of fuel storage cells by the decay heat of the most emissive assembly loaded for storage. The SCS is required when Q exceeds Q*. 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.*

The short term operations listed above are described and evaluated in the following subsections. A map of HI-TRAC thermal evaluations is provided in Table 4.5.1.

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 by a combination of conduction, thermal radiation and natural convection. The axi-symmetric thermal model used for modeling the MPC is described in Section 4.4 and adopted for evaluation of short-term operations in a HI-TRAC overpack. Thermal modeling of the HI-TRAC transfer overpack is provided in this subsection.

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 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 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, solid lead bricks 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. The molten *lead is poured to fill the annular cavity. The molten lead in the immediate vicinity of the steel surfaces, upon cooling by the inner and outer shells, solidifies forming a melt-solid interface. The initial formation of a gap-free interfacial bond 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 transfer 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/ft^2×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 4.5.2 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 4.5.3 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 4.5.3 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.

Vacuum drying is evaluated assuming the MPC space is filled with water vapor at a very low pressure (1 torr) and bounding steady state temperatures have reached. For allowing vacuum drying of MBF without time limit restrictions MPC dependent threshold heat load are specified below:

MPC-24/24E: 29 kW
MPC-32: 26 kW
MPC-68: 26 kW

For total decay heat loads up to threshold heat loads, vacuum drying of the MPC is permitted with the annular gap between the MPC and the HI-TRAC filled with water. The presence of water in this annular gap will maintain the MPC shell temperature approximately equal to the saturation temperature of the annulus water. In the vacuum drying thermal analysis a bounding MPC shell temperature (232^{o}F) is conservatively assumed. Axisymmetric FLUENT thermal models of the PWR and BWR MPCs (MPC-24/24E, MPC-32 and MPC-68) are constructed, employing the following bounding assumptions:

- *i. Bounding steady-state condition.*
- *ii. The MPC shell is postulated to be at a bounding maximum temperature of 232°F.*
- *iii. The top surface of the MPC is cooled to the ambient*
- *iv. The bottom surface of the MPC is insulated.*

An axisymmetric FLUENT thermal model of the MPC is constructed for vacuum drying of moderate burnup fuel[2]*. Each MPC is analyzed at its respective threshold heat load defined previously and fuel cladding temperatures below prescribed limit for MBF (Table 4.3.1) confirmed.*

4.5.3.2 <u>Forced Helium Dehydration</u>

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^{o}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^{o}F (400^{o}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 <u>Maximum Temperatures Under Onsite Transport Conditions</u>

An axisymmetric FLUENT thermal model of an MPC inside a HI-TRAC transfer cask was constructed to evaluate temperature distributions for onsite transport. A bounding steady-state analysis of the HI-TRAC transfer cask has been performed for a limiting fuel storage configuration (X = 0.5, MPC-68). While the duration of onsite transport may be short enough to preclude the MPC and HI-TRAC from reaching steady-state, a steady-state analysis is conservative.

The maximum HI-TRAC onsite transport temperatures are reported in Table 4.5.4. The results satisfy the temperature limits for moderate burnup fuel (see Table 4.3.1). For high burnup fuel (HBF) the maximum computed fuel cladding temperature reported in Table 4.5.4 is greater than the temperature limit of 752°F for HBF. Consequently, it is necessary to utilize the SCS described at the beginning of this section and specified in Appendix 2.C during onsite transfer of an MPC with a

2 *Vacuum drying of high burnup fuel is not permitted. MPCs containing one or more HBF assemblies shall be de-moisturized using the FHD drying method.*

greater than threshold heat load and containing one or more HBF assemblies. As stated earlier, the exact design and operation of the SCS is necessarily site-specific. The design is required to satisfy the design and operational requirements of Appendix 2.C to ensure compliance with ISG-11 [4.1.4] temperature limits.

4.5.5 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^{o}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^{o}F. The calculation assumes no heat loss from the MPC boundaries and a *conservatively bounding heat load (38 kW ($1.3x10^5$ 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^oF 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-^oF (Table 4.2.5))
T_1 = Helium supply temperature (assumed 15^oF in this example)

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

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 within the MPC rises to its maximum operating temperature as determined based on the thermal analysis methodology described previously. The gas pressure inside the MPC will also increase with rising temperature. The pressure rise is determined based on the ideal gas law. The maximum MPC internal pressure is determined using a bounding set of assumptions, namely:

a) Limiting fuel storage condition
b) Steady state maximum temperatures have reached
c) HI-TRAC in a 80^oF quiescent ambient temperature
d) HI-TRAC annulus is filled with a stationary air column
e) Exposed surfaces of cask heated by insolation
f) MPC backfilled with helium to Technical Specification maximum level

Under the adverse set of conditions defined above the maximum MPC pressure is computed and compared with the short term (off-normal) pressure limit specified in Table 2.2.1. The computed result (See Table 4.5.4) meets the pressure limit with a margin.

4.5.7 Evaluation of HI-TRAC Performance for Short Term Operations

The HI-TRAC transfer cask thermal analysis is based on a detailed heat transfer model that conservatively accounts for all modes of heat transfer in various portions of the MPC and HI-TRAC. The thermal model incorporates several conservative features, which are listed below:

i. A constant solar flux is imposed in the thermal model. A bounding solar absorbtivity of 1.0 is applied to all insolation surfaces.

ii. *The MPC is considered to be concentrically aligned within the cask cavity. This is a worst-case scenario since any eccentricity ~~will~~ improve**s** conductive heat transport in this region.*

iii. *No credit is considered for cooling of the HI-TRAC baseplate while in contact with a supporting surface. An insulated boundary condition is applied in the thermal model on the bottom baseplate face.*

Temperature distribution results (Tables 4.5.4) obtained from this conservative thermal model show that the fuel cladding and cask component temperature limits are met with adequate margins for MBF. For HBF, supplemental cooling is specified to comply with the applicable temperature limits. Expected margins during HI-TRAC operations will be larger due to the many conservative assumptions incorporated in the analysis. Corresponding MPC internal pressure remains below the short-term condition design pressure. The maximum local neutron shield temperature is lower than design limits. Therefore, it is concluded that the HI-TRAC transfer cask thermal design is adequate to maintain fuel cladding integrity for short-term onsite handling and transfer operations.

The water in the water jacket of the HI-TRAC provides necessary neutron shielding. During normal handling and onsite transfer operations this shielding water is contained within the water jacket, which is designed for an elevated internal pressure. It is recalled that the water jacket is equipped with pressure relief valves set at 60 psig and 65 psig. This set pressure elevates the saturation pressure and temperature inside the water jacket, thereby precluding boiling in the water jacket under normal conditions. Under normal handling and onsite transfer operations, the bulk temperature inside the water jacket reported in Table 4.5.4 is less than the coincident saturation temperature at 60 psig (307°F), so the shielding water remains in its liquid state. The bulk temperature is determined via a conservative analysis, presented earlier, for a limiting fuel storage configuration.

During a hypothetical fire accident ~~conditions~~ these relief valves allow venting of steam to prevent overpressurizing the water jacket. In this manner, a portion of the fire heat flux input to the HI-TRAC outer surfaces is expended in vaporizing water in the water jacket, thereby mitigating the magnitude of the heat input to the MPC during a fire.

During vacuum drying operations, the annular gap between the MPC and the HI-TRAC is filled with water. The saturation temperature of the annulus water bounds the maximum temperatures of all HI-TRAC components, which are located radially outside the water-filled annulus. As previously stated (see Subsection 4.5.3) the maximum annulus water temperature is 232°F, so the HI-TRAC water jacket temperature will be less than the 307°F saturation temperature.

Table 4.5.1

MATRIX OF HI-TRAC TRANSFER THERMAL EVALUATIONS

Scenario	***Description***	***Ultimate Heat Sink***	***Analysis Type***	***Principal Input Parameters***	***Results in FSAR Subsection***
1	*Onsite Transport*	*Ambient*	*SS(B)*	Q_D, *ST, SC*	*4.5.4*
3	*Vacuum*	*HI-TRAC Annulus Water*	*SS(B)*	Q_D	*4.5.3*
3	*Wet Transfer Operation*	*Cavity Water and Cask Internals*	*AH*	Q_D	*4.5.2*
4	*Fuel Unloading*	*Helium Circulation*	*TA*	Q_D	*4.5.5*
5	*Fire Accident*	*Jacket Water, Cask Internals*	*TA*	Q_D, *F*	*4.6.2*
6	*Jacket Water Loss Accident*	*Ambient*	*SS(B)*	O_T, Q_D, *ST, SC*	*4.6.2*

Legend:

Q_D *- Design Basis Maximum Heat Load*
ST - Insolation Heating (Top Surface)
SC - Insolation Heating (Curved Surfaces)
F - Fire Heating (1475°F)

SS(B) – Bounding Steady State
TA - Transient Analysis
AH - Adiabatic Heating

Table 4.5.2

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 4.5.3

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*

Table 4.5.4

HI-TRAC ONSITE TRANSPORT MAXIMUM TEMPERATURES AND PRESSURES

Component	***Temperature [°F]****
Fuel Cladding	*777***
MPC Basket	*764*
Basket Periphery	*601*
MPC Outer Shell Surface	*507*
HI-TRAC Inner Shell	*386*
HI-TRAC Enclosure Shell	*269*
Water Jacket Bulk Water	*252*
Axial Neutron Shield	*328*
Pressure (psig)	
MPC	106.8
** The reported temperatures are below the HI-TRAC short-term temperature limits (Table 2.2.3).* *** The reported temperature exceeds the allowable temperature limit for HBF fuel. The Supplemental Cooling System described in Appendix 2.C is required for greater than threshold heat load MPCs containing one or more HBF assemblies. (See threshold heat load discussion near the beginning of Section 4.5.)*	