~~T_o = initial MPC bulk average temperature in the HI-STAR system (equal to 439°F)~~

~~t = time after start of forced circulation (hrs)~~

~~Q_D = decay heat load (Btu/hr) (equal to Design Basis maximum 19.0 kW (i.e., 64,847 Btu/hr))~~

~~m = helium circulation rate (lb/hr)~~

~~C_p = helium heat capacity (Btu/lb-°F) (equal to 1.24 Btu/lb-°F)~~

~~Q_c = heat rejection from cask exposed surfaces to ambient (Btu/hr) (conservatively neglected)~~

~~C_h = thermal capacity of the loaded MPC (Btu/°F)~~

~~(For a bounding upper bound 100,000 lb loaded MPC weight, and heat capacity of Alloy X equal to 0.12 Btu/lb-°F, the heat capacity is equal to 12,000 Btu/°F.)~~

~~T_i = MPC helium inlet temperature (°F)~~

~~The differential equation is analytically solved, yielding the following expression for time-dependent MPC bulk temperature.~~

$$\cancel{T(t) = \left(T_i + \frac{Q_D}{m\ C_p}\right)\left(1 - e^{-\frac{m\ C_p}{C_h} t}\right) + T_o\ e^{-\frac{m\ C_p}{C_h} t}}$$

~~This equation is used to determine the minimum helium mass flow rate which would cool the MPC cavity down from initially hot conditions to less than 200°F in 72 hours. The required helium mass flow rate is 546 lb/hr (i.e., 817 SCFM).~~

~~Once the helium gas circulation has cooled the MPC internals to less than 200°F, water can be injected to the MPC without risk of boiling and the associated thermal stress concerns. Because of the relatively long cooldown period, the thermal stress contribution to the total cladding stress would be negligible, and the total stress would therefore be bounded by the normal (dry) condition. The elimination of boiling eliminates any concern of over-pressurization due to steam production.~~

4.4.1.1.16 HI-STAR Temperature Field With Low Emitting Fuel

The HI-STAR 100 thermal evaluations for BWR fuel are divided in two groups of fuel assemblies proposed for storage in MPC-68. These groups are classified as Low Heat Emitting (LHE) fuel assemblies and Design Basis (DB) fuel assemblies. The LHE group of fuel assemblies are characterized by low burnup, long cooling time, and short active fuel lengths.

Consequently, their heat loads are dwarfed by the DB group of fuel assemblies. The Dresden-1 (6x6 and 8x8), Quad+, and Humboldt Bay (7x7 and 6x6) fuel characteristics warrant their classification as LHE fuel. These characteristics, including burnup and cooling time limits imposed on this class of fuel, are presented in Table 2.1.6. This fuel (except Quad$^+$) is permitted to be loaded when encased in Damaged Fuel Containers (DFCs). As a result of interruption of radiation heat exchange between the fuel assembly and the fuel basket by the DFC boundary, this loading configuration is bounding for thermal evaluation. In Subparagraph~~section~~ 4.4.1.1.2, two canister designs for encasing LHE fuel are evaluated – a previously approved Holtec Design (Holtec Drawing-1783) and an existing canister in which some of the Dresden-1 fuel is currently stored (Transnuclear D-1 canister). The most resistive fuel assembly determined by analytical evaluation is considered for thermal evaluation (see Table 4.4.6). The MPC-68 basket effective conductivity, loaded with the most resistive fuel assembly from the LHE group of fuel (encased in a canister) is provided in Table 4.4.7. To this basket, LHE decay heat load is applied and a HI-STAR 100 System temperature field obtained. The low heat load burden limits the initial peak cladding temperature to 595°F (313°C) which is substantially below the long-term temperature limit~~ for long-cooled fuel (~643°F)~~.

A thoria rod canister designed to hold a maximum of 20 fuel rods arrayed in a 5x4 configuration is currently stored at the Dresden-1 spent fuel pool. The fuel rods contain a mixture of enriched UO_2 and Thorium Oxide in the fuel pellets. The fuel rods were originally constituted as part of an 8x8 fuel assembly and used in the second and third cycle of Dresden-1 operation. The maximum fuel burnup of these rods is quite low (~14,400 MWD/MTU). The thoria rod canister internal design is a honeycomb structure formed from 12 gage stainless steel plates. The rods are loaded in individual square cells and are isolated from each other by the cell walls. The few number of rods (18 per assembly) and very low burnup of fuel stored in these Dresden-1 canisters render them as miniscule sources of decay heat. The canister all-metal internal honeycomb construction serves as an additional means of heat dissipation in the fuel cell space. In accordance with the~~preferential fuel~~ loading requirements imposed in the Technical Specifications, ~~low burnup~~thoria fuel shall be loaded toward the basket periphery (i.e., away from the hot central core of the fuel basket). All these considerations provide ample assurance that these fuel rods will be stored in a benign thermal environment and therefore remain protected during long-term storage.

4.4.1.2 Test Model

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