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

May 4, 2000

Mr. K. P. Singh
President and CEO
Holtec International
Holtec Center
555 Lincoln Center
Marlton, NJ 08053

SUBJECT: CERTIFICATE OF COMPLIANCE FOR THE HOLTEC INTERNATIONAL HI-STORM 100 CASK SYSTEM (TAC NO. L22982)

Dear Mr. Singh:

As requested by your application dated October 26, 1995, as supplemented, enclosed is Certificate of Compliance No. 1014 for the Holtec International HI-STORM 100 Cask System. This certificate is issued pursuant to 10 CFR Part 72 for a term of 20 years. As stated in the Federal Register (65 FR 25241, 05/01/00), the effective date of this certificate is May 31, 2000. We request that you update and submit the final safety analysis report to conform to the certificate, as required by 10 CFR 72.248.

This certificate constitutes the approval and conditions for use of the HI-STORM 100 Cask System for storage of spent nuclear fuel under the general licensing provisions of 10 CFR 72.210. A general license has been granted to all holders of licenses for nuclear power reactors issued under 10 CFR Part 50.

If you have any questions regarding this certificate, please contact me or Marissa Bailey of my staff at 301-415-8500.

Sincerely,

E. William Brach, Director
Spent Fuel Project Office
Office of Nuclear Material Safety
and Safeguards

Docket No.: 72-1014

Enclosures: 1. Certificate of Compliance No. 1014
2. Safety Evaluation Report

CERTIFICATE OF COMPLIANCE FOR SPENT FUEL STORAGE CASKS

The U.S. Nuclear Regulatory Commission is issuing this Certificate of Compliance pursuant to Title 10 of the Code of Federal Regulations, Part 72, "Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste" (10 CFR Part 72). This certificate is issued in accordance with 10 CFR 72.238, certifying that the storage design and contents described below meet the applicable safety standards set forth in 10 CFR Part 72, Subpart L, and on the basis of the Final Safety Analysis Report (FSAR) of the cask design. This certificate is conditional upon fulfilling the requirements of 10 CFR Part 72, as applicable, and the conditions specified below.

Certificate No.	Effective Date	Expiration Date	Docket Number	Amendment No.	Amendment Date	Package Identification No.
1014	05/31/00	06/01/20	72-1014	0		USA/72-1014

Issued To: (Name/Address)

Holtec International
Holtec Center
555 Lincoln Drive West
Marlton, NJ 08053

Safety Analysis Report Title

Holtec International Inc., Final Safety Analysis Report for the HI-STORM 100 Cask System
Docket No. 72-1014

CONDITIONS

This certificate is conditioned upon fulfilling the requirements of 10 CFR Part 72, as applicable, the attached Appendix A (Technical Specifications) and Appendix B (Approved Contents and Design Features), and the conditions specified below:

1. CASK

   a. Model No.: HI-STORM 100 Cask System

   The HI-STORM 100 Cask System (the cask) consists of the following components: (1) interchangeable multi-purpose canisters (MPCs), which contain the fuel; (2) a storage overpack (HI-STORM 100), which contains the MPC during storage; and (3) a transfer cask (HI-TRAC), which contains the MPC during loading, unloading and transfer operations. The cask stores up to 24 pressurized water reactor (PWR) fuel assemblies or 68 boiling water reactor (BWR) fuel assemblies.

   b. Description

   The HI-STORM 100 Cask System is certified as described in the Topical Safety Analysis Report (SAR) and in NRC's Safety Evaluation Report (SER) accompanying the Certificate of Compliance. The cask comprises three discrete components: the MPCs, the HI-TRAC transfer cask, and the HI-STORM 100 storage overpack.

CERTIFICATE OF COMPLIANCE
FOR SPENT FUEL STORAGE CASKS
Supplemental Sheet

1. b. Description (continued)

The MPC is the confinement system for the stored fuel. It is a welded, cylindrical canister with a honeycombed fuel basket, a baseplate, a lid, a closure ring, and the canister shell. It is made entirely of stainless steel except for the neutron absorbers and aluminum heat conduction elements. The canister shell, baseplate, lid, vent and drain port cover plates, and closure ring are the main confinement boundary components. The honeycombed basket, which is equipped with Boral neutron absorbers, provides criticality control.

There are three types of MPCs: the MPC-24, the MPC-68, and the MPC-68F. The MPC-24 holds up to 24 PWR fuel assemblies that must be intact. The MPC-68 holds up to 68 BWR fuel assemblies that may be intact or damaged (i.e., with known or suspected cladding defects greater than hairline cracks or pinholes). The MPC-68F holds up to 68 BWR fuel assemblies that may be intact, damaged, or in the form of fuel debris (i.e., with known or suspected defects such as ruptured fuel rods, severed fuel rods, and loose fuel pellets). All three MPCs have the same external dimensions.

The HI-TRAC transfer cask provides shielding and structural protection of the MPC during loading, unloading, and movement of the MPC from the spent fuel pool to the storage overpack. The transfer cask is a multi-walled (carbon steel/lead/carbon steel) cylindrical vessel with a water jacket attached to the exterior. Two types of HI-TRAC transfer casks are available: the 125-ton HI-TRAC and the 100-ton HI-TRAC. The weight designation is the maximum weight of a loaded transfer cask during any loading, unloading, or transfer operation. Both transfer cask types have identical cavity diameters. The 125-ton HI-TRAC transfer cask has thicker lead and water shielding and larger outer dimensions than the 100-ton HI-TRAC transfer cask.

The HI-STORM 100 storage overpack provides shielding and structural protection of the MPC during storage. The overpack is a heavy-walled, steel and concrete, cylindrical vessel. Its side wall consists of plain concrete that is enclosed between inner and outer carbon steel shells. The overpack has four air inlets at the bottom and four air outlets at the top to allow air to circulate naturally through the cavity to cool the MPC inside. The inner shell has channels attached to its interior surface to guide the MPC during insertion and removal, provide a flexible medium to absorb impact loads, and allow cooling air to circulate through the overpack. A loaded MPC is stored within the HI-STORM 100 storage overpack in a vertical orientation.

2. OPERATING PROCEDURES

Written operating procedures shall be prepared for cask handling, loading, movement, surveillance, and maintenance. The user's site-specific written operating procedures shall be consistent with the technical basis described in Chapter 8 of the SAR.

3. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Written cask acceptance tests and maintenance program shall be prepared consistent with the technical basis described in Chapter 9 of the SAR.

4. QUALITY ASSURANCE

Activities in the areas of design, purchase, fabrication, assembly, inspection, testing, operation, maintenance, repair, modification of structures, systems and components, and decommissioning that are important to safety shall be conducted in accordance with a Commission-approved quality assurance program which satisfies the applicable requirements of 10 CFR Part 72, Subpart G, and which is established, maintained, and executed with regard to the cask system.

5. HEAVY LOADS REQUIREMENTS

Each lift of an MPC, a HI-TRAC transfer cask, or a HI-STORM 100 overpack must be made in accordance with the existing heavy loads requirements and procedures of the licensed facility at which the lift is made. A plant-specific safety review (under 10 CFR 50.59 or 10 CFR 72.48, if applicable) is required to show operational compliance with existing plant-specific heavy loads requirements. Lifting operations outside of structures governed by 10 CFR Part 50 must be in accordance with Section 3.5 of Appendix B to this certificate.

6. APPROVED CONTENTS

Contents of the HI-STORM 100 Cask System must meet the fuel specifications given in Appendix B to this certificate.

7. DESIGN FEATURES

Features or characteristics for the site, cask, or ancillary equipment must be in accordance with Appendix B to this certificate.

8. CHANGES TO THE CERTIFICATE OF COMPLIANCE

The holder of this certificate who desires to make changes to the certificate, which includes Appendix A (Technical Specifications) and Appendix B (Approved Contents and Design Features), shall submit an application for amendment of the certificate.

9. AUTHORIZATION

The HI-STORM 100 Cask System, which is authorized by this certificate, is hereby approved for general use by holders of 10 CFR Part 50 licenses for nuclear reactors at reactor sites under the general license issued pursuant to 10 CFR 72.210, subject to the conditions specified by 10 CFR 72.212, and the attached Appendix A and Appendix B.

FOR THE U. S. NUCLEAR REGULATORY COMMISSION

E. William Brach, Director
Spent Fuel Project Office
Office of Nuclear Material Safety
and Safeguards

Attachments:
1. Appendix A
2. Appendix B

CERTIFICATE OF COMPLIANCE NO. 1014

APPENDIX B

APPROVED CONTENTS AND DESIGN FEATURES

FOR THE HI-STORM 100 CASK SYSTEM

DESIGN FEATURES (continued)

3.4 Site-Specific Parameters and Analyses

Site-specific parameters and analyses that will require verification by the system user are, as a minimum, as follows:

1. The temperature of 80° F is the maximum average yearly temperature.

2. The allowed temperature extremes, averaged over a 3-day period, shall be greater than -40° F and less than 125° F.

3. The resultant horizontal acceleration (vectorial sum of two horizontal ZPA's at a three-dimensional seismic site), G_H, and vertical acceleration, G_V, expressed as fractions of 'g', shall satisfy the following inequality:

$$G_H + \mu G_V \leq \mu$$

where μ is the Coulomb friction coefficient for the HI-STORM 100/ISFSI pad interface. Unless demonstrated by appropriate testing that a higher value of μ is appropriate for a specific ISFSI, the value of μ used shall be 0.53. Representative values of G_H and G_V combinations for μ = 0.53 are provided in Table 3-2.

Table 3-2

Representative DBE Acceleration Values to Prevent HI-STORM 100 Sliding (μ = 0.53)

Equivalent Vectorial Sum of Two Horizontal ZPA's (G_H in g's)	Corresponding Vertical ZPA (G_V in g's)
0.445	0.160
0.424	0.200
0.397	0.250

(continued)

HOLTEC INTERNATIONAL

HI-STORM 100 CASK SYSTEM

SAFETY EVALUATION REPORT

4.0 THERMAL EVALUATION

The thermal review ensures that the cask component and fuel material temperatures of the HI-STORM 100 Cask System will remain within the allowable values or criteria for normal, off-normal, and accident conditions. These objectives include confirmation that the fuel cladding temperature will be maintained below specified limits throughout the storage period to protect the cladding against degradation that could lead to gross ruptures. This portion of the review also confirms that the cask thermal design has been evaluated using acceptable analytic techniques and/or testing methods.

4.1 Spent Fuel Cladding

The thermal design criteria for preventing fuel cladding degradation are presented in Section 4.3 of the SAR. The applicant used the method developed by the Commercial Spent Fuel Management (CSFM) at Pacific Northwest National Laboratory[1] to establish long-term dry storage temperatures limits for zircaloy clad spent nuclear fuel. The applicant assumed bounding values of zircaloy fuel rod cladding oxide thickness that correspond to a maximum allowable HI-STORM PWR and BWR fuel burnup of 45,000 MWD/MTU.

The applicant calculated the peak rod internal gas temperature based on its analysis of the MPC internal temperature distribution. The analyses assumed bounding fuel pin pressures at end-of-life for the peak power rod at in-core operating condition, based on PNL-6189 report (CSFM), dated May 1987. Since publication of that report, new analytic techniques and data have shown that the peak fuel pin pressure is significantly lower than the reactor operating pressure (for example, the peak pressure for the peak power rod would be about 1600 psia for PWRs and about 900 psia for BWRs; however, the applicant used 2416 psia for the PWR fuel rod pressure and 1094 psia for the BWR fuel rod pressure). Use of the PNL-6189 operating pressures, as implemented by Holtec, alleviates the need for calculating the fission product gases released by the fuel pellets during plant operation and significantly bounds the calculated internal fuel rod pressure at dry storage conditions. In addition, the applicant's analyses assumed bounding design basis decay heat generated by the fuel. The rod internal gas temperature for the peak rod was calculated by averaging the pellet outer edge temperature and rod gas plenum outer edge temperature axial distribution. The active fuel region temperatures were averaged over 24 axial segments for the pellet stack region and two axial segments for the plenum region. The trapezoidal rule was used to calculate an average temperature for each axial segment. The bulk average rod gas temperature was then calculated by the applicant over the total plenum and gap volumes. The peak fuel rod internal pressure recommended in the CSFM method was then adjusted, using average rod gas temperature and the ideal gas law to determine the rod internal gas pressure. The rod internal gas pressure was then used to calculate the cladding hoop stress in the CSFM method. The staff reviewed the Holtec calculations of the peak rod pressures and found them acceptable.

The applicant identified the bounding PWR and BWR fuel design that provided the highest calculated zircaloy cladding hoop stress. This was determined by evaluating the design characteristics of each specific fuel design that impact the CSFM method results. The long-term zircaloy cladding dry storage temperature limits, calculated by the applicant and confirmed by the staff, are presented in Table 4-6 below.

The applicant evaluated the long-term dry storage temperature limit for stainless steel clad spent nuclear fuel based on in-reactor irradiation and wet pool and dry storage experience coupled with an assessment of failure mechanisms for irradiated stainless steel cladding, as presented in an Electric Power Research Institute (EPRI) report[2]. This report concludes that long-term stainless steel clad spent fuel temperatures of 806°F (430°C) in dry storage will not result in cladding failure for storage times of up to 50 years. The applicant also noted that the stainless steel clad spent nuclear fuel has a longer cooling time and lower decay heat than the design basis zircaloy clad spent fuel. Thus, based on its lower decay heat and a higher long-term dry storage cladding temperature limit, the applicant concluded that the zircaloy clad fuel temperature limits, listed on Table 4-6, are bounding for fuels with stainless steel clad. The staff finds the applicant's evaluation acceptable.

The applicant selected a short-term fuel cladding temperature limit of 1058°F (570°C) for all zircaloy and stainless steel clad spent nuclear fuel. This limit is consistent with the criteria listed in NUREG-1536. Test data for a time period of 740 to 1,000 hours cited by the applicant also corroborates this value of short-term cladding temperature limit.

4.2 Cask System Thermal Design

The cask system thermal design for the HI-STORM 100 overpack containing a loaded MPC is presented in Sections 1.2, 2.1.6, and 4 of the SAR.

4.2.1 Design Criteria

The applicant addressed the HI-STORM 100 Cask System design criteria developed to meet 10 CFR Part 72 requirements for 20 years of storage of spent nuclear fuel. These design criteria encompass normal, off-normal, and postulated accident conditions.

The thermal design criteria for the HI-STORM 100 overpack with the loaded MPC are given in Section 2.2.1.5 of the SAR. Table 4-1 lists the design temperature limits for the concrete and steel components of the HI-STORM spent fuel storage system.

Table 4-1
HI-STORM 100 Component Normal, Off-normal, and Accident Temperature Limits

HI-STORM 100 Component	Normal Condition Design Temperature Limit, °F	Off-Normal and Accident Condition Temperature Limit, °F
Overpack Outer Steel Shell	350	600
Overpack Concrete	200	350
Overpack Inner Steel Shell	350	400
Overpack Lid Top Steel Plate	350	550
Remainder of Overpack Steel Structure	350	400

4.2.2 Design Features

The thermal design features of the HI-STORM 100 overpack with the loaded MPC consist of:

(a) internal labyrinthine air flow passage with four air inlets and four air outlets;
(b) carbon steel inner and outer cylindrical shells;
(c) carbon steel baseplate;
(d) carbon steel top plate;
(e) concrete encased within steel cylindrical shells; and
(f) helium backfill gas in the basket.

The helium backfill gas used in the MPC provides superior heat conduction from the fuel to the basket wall, when compared to other inert gases, as well as an inert atmosphere. The effectiveness of the helium gas was demonstrated on full scale casks at the Idaho National Engineering and Environmental Laboratory. The internal air passage of the overpack (formed by the MPC outer surface and the baseplate and inner cylindrical shell) provides the primary means of MPC decay heat removal by natural convection cooling. The cooling is passive in that it uses differential air density buoyancy to drive the air flow past the MPC outer wall. The four air inlets and four air outlets provide a redundant and geometrically separate means of supplying air and discharging air from the internal passage. Along with natural convection, radiation and conduction heat transfer occurs from the MPC outer surface across the air passage to the inner liner of the HI-STORM 100 overpack.

The concrete overpack is encased in carbon steel cylindrical shells. The heat that is not removed by the air passage is primarily conducted through the steel cylindrical shells. The concrete mass also represents a large thermal inertia (heat capacity) that, for some accident scenarios such as blocked air inlets and fire, introduces a significant time delay before material temperature limits are reached in the HI-STORM 100 Cask System.

The staff verified that all methods of heat transfer internal and external to the HI-STORM 100 Cask System are passive. Sections 1.5 and 4 of the SAR provide information relative to materials of construction, general arrangement, dimensions of principal structures, and description of all structures, systems, and components important to safety, in sufficient detail to support a finding that the design will satisfy the design bases with an adequate margin, as required by 10 CFR 72.24(c)(3).

4.3 Thermal Load Specification/Ambient Temperature

The thermal load specifications for an overpack loaded with the MPC are given in Sections 2.2 and 4.4 of the SAR. Table 4-6 lists the maximum allowable decay heat load that can be stored in the MPC-24 and in the MPC-68 as a function of time following removal of the fuel assemblies from the reactor core (e.g., fuel decay time). These limits on decay heat loads are based on the calculated maximum cladding temperature limits for normal conditions. Solar thermal loads, as listed in 10 CFR 71.71, were also incorporated into the analysis, as appropriate. The thermal loads apply to normal, off-normal, and accident conditions except for the fire accident. During a postulated fire accident, the thermal loads on the overpack include heat generated from the enveloping fire that is added to the MPC decay heat.

The ambient temperatures assumed as design bounding values for the thermal evaluation of the HI-STORM 100 system are listed in Table 4-2. The 80 °F normal annual average temperature assumed in the evaluation exceeds the highest annual average temperature recorded in the continental USA. The staff validated that number through data collected by NOAA and found it acceptable.

Table 4-2
HI-STORM 100 System Design Ambient Temperatures

Condition	Temperature (°F)
Normal Annual Average	80
Normal Soil Annual Average	77
Off-Normal Maximum 3-Day Average	100
Off-Normal Minimum 3-Day Average	-40
Accident Maximum 3-Day Average	125

The staff has reviewed and confirmed the design basis decay heat load for the specific fuel designs. The staff has also verified that the bounding decay heats have been properly calculated.

4.4 Model Specification

The thermal model specification is presented in Section 4.4.1 of the SAR and discussed below.

4.4.1 Configuration

The thermal-fluid dynamic analysis was performed using the FLUENT[3] computer code that models the HI-STORM 100 system in three-dimensional space. The model includes the MPC volume, the HI-STORM steel encased concrete overpack, and a surrounding cylindrical tank region. The overall model of the HI-STORM 100 system consists of 3,933 asymmetric elements. The MPC is modeled as solid with 1,188 axisymmetric elements and temperature dependent thermal conductivity. The internal air passages, air inlets, and air outlets were simulated by hydraulically equivalent resistance porous media. The external surface of the overpack is enclosed in a cylindrical tank region which models the effect of adjacent casks on an ISFSI pad. The model configuration includes a conduction heat transfer path from the overpack through the ISFSI concrete pad and to the soil below.

The equivalent thermal conductivity of regions within the MPC was calculated using the ANSYS computer code. ANSYS was also used to model the thermal transient response of the HI-STORM 100 overpack to the postulated fire accident. In addition, the ANSYS fuel assembly effective thermal conductivity analysis was used to benchmark the FLUENT computer code analysis of fuel assembly effective thermal conductivity.

The staff reviewed the analytic assumptions used by the applicant in modeling the components of the MPC, the HI-STORM overpack, and the HI-TRAC transfer cask. The assumptions maximized the resistance for heat transfer through the MPC, overpack, and transfer cask. The applicant used bounding assumptions in its analyses. Some of the more significant conservatisms assumed in this analysis included: (1) neglect of convective cooling of the helium gas inside the MPC, thereby maximizing the calculated peak clad temperature; (2) for the maximum average ambient temperature, the applicant assumed 125 °F ambient temperature with maximum solar heat input (insolation) for a period of three days*; (3) maximizing the thermal resistance between two materials (e.g., imposing a 2 mil air gap between Boral and its casing, using the properties of air rather than helium where only microscopic gaps would exist in the MPC, imposing a uniform gap of air between the lead and steel in the HI-TRAC transfer cask); and (4) assuming all of the fuel assemblies are at the maximum design thermal limit.

Other conservatisms are addressed in the SAR, and were reviewed by the staff and found acceptable.

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* Note: It takes three days for the HI-STORM System to reach steady-state thermal conditions. This bounding assumption exceeds the highest short-term NOAA recorded continental USA temperature of 124 °F. The NOAA data indicates that the temperature variation for that hot day was 40 °F. In other words, the high ambient temperature for the day was 124 °F and the low was 84 °F. Assuming a 125 °F ambient condition for three days with a high solar energy input (sun never sets assumption) clearly bounds the consequences of the postulated event.

4.4.2 Material Properties

The material properties used in the thermal analysis are presented in Section 4.2 of the SAR. This section identifies the temperature dependent thermal conductivity, emissivity, density, heat capacity, and viscosity (for gases) for all the materials used in the HI-STORM 100 system. The three material properties used in the overpack are air (present within the internal air passage), carbon steel, and concrete. The MPC is composed of helium, stainless steel, aluminum alloy 1100, zircaloy, uranium dioxide, and Boral. When a range of possible numerical values for these material properties was available from suitable references, the applicant selected the value(s) that resulted in the most bounding thermal calculation results.

4.4.3 Boundary Conditions

The boundary conditions in the thermal analysis are specified in Section 4.4 of the SAR. The off-normal and accident high ambient temperature cases include a solar insolation boundary condition on the top and side surfaces of the overpack.

The cylindrical tank region around the overpack in the FLUENT model configuration provides an external boundary condition for the overpack that simulates the presence of adjacent casks on an ISFSI pad. This region models the hydraulic resistance from nearby casks which effects flow to the air inlets. In addition, this tank region reflects back all heat which is radiated from the outside surface of the overpack, thereby, simulating the effect of adjacent casks radiating heat back to an interior cask in an ISFSI array. This boundary condition conservatively precludes any heat loss from the overpack surface by radiation heat transfer.

The soil below the overpack is assumed to be at a constant temperature commensurate with the high numerical value presented in Section 4.3 of this SER. This high constant soil temperature results in a bounding low heat loss from the HI-STORM 100 system to the earth below it.

The applicant uses bounding thermal boundary conditions for the postulated fire accident analysis in accordance with NUREG-1536. The fire is postulated to have a duration of 3.6 minutes based on 50 gallons of diesel fuel, the maximum allowed by Appendix B of the Certificate of Compliance at an ISFSI site. The applicant assumed bounding surface convection heat transfer coefficients, fire dimensions, flame temperature, surface emissivity, and overpack ventilation passage air temperature both during and after the fire. The staff concludes that the total energy available from burning 50 gallons of combustible fuel would have insignificant impact on the HI-STORM overpack and HI-TRAC transfer cask, given the large heat capacity of those designs.

4.5 Thermal Analysis

4.5.1 Computer Programs

The FLUENT and ANSYS[4] computer programs are used in thermal analyses of the HI-STORM 100 system. FLUENT is a finite volume computational fluid dynamics computer code which is capable of both steady state and transient analyses. The applicant has previously used FLUENT in the HI-STAR 100 Cask System application that has been reviewed and accepted by the staff. ANSYS is a three-dimensional finite element heat transfer and stress computer code which is also capable of both steady state and transient analyses. ANSYS is cited in NUREG-1536 as an acceptable computer code for thermal evaluation of dry spent fuel storage cask systems.

4.5.2 Temperature Calculations

The results of temperature calculations for normal, off-normal, and accident conditions are presented in Sections 4.4, 11.1, and 11.2 of the SAR for both the PWR MPC-24 and the BWR MPC-68. The normal and off-normal temperature calculations were performed at the two different assumed ambient temperatures which were discussed in Section 4.3 of this SER. The accident temperature calculations were performed for an extreme ambient temperature, as discussed in Section 4.3 of this SER, and for a hypothetical maximum fire enveloping a loaded HI-STORM overpack. All cases assumed the maximum design basket-specific decay heat load. Key calculated or assumed HI-STORM 100 system component temperatures under normal, off-normal, and accident conditions for both MPC designs are in Table 4-3.

All the calculated component material temperatures for normal, off-normal, and accident conditions remain below their respective material temperature limits with the exception of the outer 1-inch layer of the concrete overpack which exceeds the concrete short term temperature limit for the fire accident scenario. This transient thermal response of a small fraction of the concrete is allowable for a fire condition as discussed in NUREG-1536. It should be noted that the concrete in the HI-STORM overpack is not a structural component. Therefore, exceeding the temperature limit does not present a safety issue. The staff reviewed the applicant's bounding analyses and found the consequences superficial (see Figure 11.2.2 in the SAR) and acceptable.

The applicant calculated the effect of the numerical value of zircaloy fuel cladding surface thermal emissivity on calculated maximum cladding temperature. The applicant assumed a value of 0.8 for this emissivity, which is based on several references cited in the SAR. To assess the impact of a bounding low emissivity of 0.4, the applicant calculated the maximum cladding temperature with this lower value. The resulting peak cladding temperature increased by approximately 5 °C. This small change in calculated maximum cladding temperature indicates that the selected zircaloy emissivity is adequate for this analysis. The staff notes that the emissivity of stainless steel fuel cladding may be lower than that of zircaloy because of its higher corrosion resistance. However, any increase in calculated maximum cladding temperature for stainless steel clad spent fuel due to lower emissivity would be small in comparison to the decrease in cladding temperature due to the fact that the design basis stainless steel clad fuel has a lower burnup, longer cooling time, and therefore lower decay heat than the design basis zircaloy clad fuel.

The applicant performed an analysis of the off-normal condition of partial blockage of air inlets and an accident analysis assuming full blockage of all air inlets. Both cases were analyzed with an assumed 80°F ambient air temperature and the same models and methodology that were used for the normal condition thermal analyses. For the bounding off-normal, partial air inlet blockage scenario of three of the four air inlets completely blocked, the calculated maximum component temperatures are presented in Table 4-4. The applicant also analyzed the thermal response of a complete blockage of all air inlets to identify the time when a component material temperature limit is exceeded. Results for this accident up to the time when the concrete short-term limit is reached (i.e., about 33 hours) are also presented in Table 4-4.

Table 4-3
Calculated Maximum HI-STORM 100 System Component Temperatures

Component	Normal MPC-24 °F	Normal MPC-68 °F	Extreme (125°F) Ambient °F	Maximum Fire °F
Fuel Cladding	692	742	774 (PWR) 790 (BWR)	730 (PWR) 746 (BWR)
MPC Basket	657	722	770	690 (PWR) 726 (BWR)
Basket Periphery	417	366	NR	NR
MPC Outer Shell	295	301	352	NR
Overpack Inner Shell	166	171	217	300
Average Concrete	149	151	NR	184
Overpack Outer Shell	131	131	176	570
Overpack Bottom Plate (Max.)	183	183	NR	NR
Overpack Lid Top Plate	157	159	NR	NR
Air Inlet	80	80	125	300*
Air Outlet	179	185	231	300*

* Analytical assumption; NR=Not reported or not required for the evaluation of these conditions.

Table 4-4
Calculated Maximum HI-STORM 100 Component Temperatures
for Air Inlet Blockage Accidents

Component	Partial Blockage - 3 Inlet Ducts Blocked (°F)	Complete Blockage of all Air Inlets, at 33 Hours (°F)
Fuel Cladding	778	846
Overpack Inner Shell (Maximum Concrete)	232	348
Overpack Outer Shell	149	145

4.5.3 Pressure Analysis

The applicant presented HI-STORM 100 system MPC calculated pressures for normal, off-normal, and accident conditions in Section 4.4.4 of the SAR. The maximum internal pressure was calculated using the free volume of the MPC, ideal gas law, and accounted for the backfill helium gas along with a fraction of the stored fuel helium fill gas and fission product gas. The normal, off-normal, and accident conditions were differentiated by the assumption of the fraction of stored spent fuel which contributed fill gas and fission gas to the MPC. These fractions were 1%, 10%, and 100%, respectively for the normal, off-normal, and accident cases, which are in agreement with NUREG-1536. In each case, 100% of the fuel rod fill gas and 30% of all fission product gases were assumed to be released to the MPC interior volume. The resulting MPC-24 and MPC-68 pressures are summarized in Table 4-5.

Table 4-5
Calculated Maximum MPC Pressures for Normal, Off-Normal, and Accident Conditions

Condition	MPC-24 Pressure (psig)	MPC-68 Pressure (psig)
Normal (1% fuel failure)	59.3	57.6
Off-Normal (10% fuel failure)	62.8	60.3
Accident (100% fuel failure)	97.6	87.4

The calculated maximum pressure for both MPC designs and all conditions remains below its appropriate design pressure.

4.5.4 Confirmatory Analysis

The staff's review of the HI-STORM application encompassed the inputs, assumptions, methodology, and results of the applicant's temperature and pressure analyses which were submitted in support of the SAR, including the MPC, the transfer cask, and the overpack. All the assumptions were found to be in compliance with NUREG-1536, Section 4.V.5.(c). Input parameters are consistent with design values for the MPC, the HI-STORM overpack, and the HI-TRAC transfer cask. The staff finds that the applicant selected suitably bounding and appropriate boundary conditions for normal, off-normal, and accident conditions. In addition, the staff reviewed the results of a validation of the computer code and analytic method used by Holtec in the HI-STORM analyses; this validation compared the code results with test data performed by DOE and the Energy Power Research Institute (EPRI) on a full scale spent fuel cask instrumented and tested at the Idaho National Engineering and Environmental Laboratory. The results of Holtec's analytic method showed good agreement with the DOE/EPRI test data. Based on the staff's review, these validation results, and the FLUENT code's recognized value as an analytic tool in conducting thermal analyses, the staff finds that the applicant's analytic methods for calculating the thermal responses of the MPC, oveprack, and transfer cask are acceptable. In addition, although the HI-STAR anslyses and staff evaluation hereof are not relied upon in the thermal evaluation in this SER, the staff notes that previous staff evaluation of the applicant's HI-STAR 100 SAR's FLUENT computer code results, using the ANSYS finite element computer code, confirmed the temperature calculation results shown by Holtec's analysis, thus confirming Holtec's ability to utilize the FLUENT code correctly.

The staff also reviewed the form loss and friction loss coefficients used by the applicant to simulate the hydraulic characteristics of the internal air passage. The applicant's form loss coefficients were found to be suitably bounding and applicable to the specific geometry of the HI-STORM 100 air passages.

The staff evaluated and accepted the applicant's selected heat transfer coefficients. The temperature and pressure results were found to be correctly calculated using the identified inputs, assumptions, and methodology.

The staff evaluated the applicant's peak fuel rod internal gas average temperature calculation, used to determine the long-term dry storage temperature limits for zircaloy clad fuel rods. To calculate the maximum fuel rod temperature limit for long-term storage, the applicant volume-averaged the temperature of the gases within the gap and plenum of the limiting fuel rod assuming bounding fuel pin pressures, as identified in the PNL-6189 CSFM report. Using the derived pressure, a corresponding cladding stress was calculated and a fuel age dependent temperature limit was identified. The CSFM method has been used and accepted by the staff in previous ISFSI license applications. The staff performed confirmatory calculations for the dry storage temperature limits. Table 4-6 lists the permissible Fuel Temperature and Allowable Heat Loads for the MPC-24 and MPC-68.

Table 4-6
Maximum Allowable MPC Decay Heat Limits and Heat Load As a Function of Fuel Decay Time

Fuel Decay Time (years)	PWR MPC-24 Fuel Temperature Limit (°C)	PWR Maximum MPC-24 Allowable Decay Heat Load (kW)	BWR MPC-68 Fuel Temperature Limit (°C)	BWR Maximum MPC-68 Allowable Decay Heat Load (kW)
5	366.6 (692 °F)	20.88	394.4 (742 °F)	21.52
6	358.6 (677 °F)	20.17	379.2 (714 °F)	20.31
7	335.6 (636 °F)	18.18	354.8 (671 °F)	18.41
10	330.2 (626 °F)	17.72	348.8 (660 °F)	17.95
15	323.8 (615 °F)	17.17	342.1 (648 °F)	17.45

The staff concludes that the MPC decay heat limits in Table 4-6 assure that all material temperature limits are not exceeded and no gross ruptures would occur in a dry helium storage environment for the license period of 20 years.

4.6 HI-TRAC Thermal Review

The HI-TRAC transfer cask is a short-term container used to load and unload the HI-STORM concrete storage overpack. The HI-TRAC transfer cask is used for various plant operations, such as, normal onsite transport of spent nuclear fuel, MPC cavity vacuum drying, post-loading wet transfer operations, and MPC cooldown and reflood required for unloading spent nuclear fuel. Holtec designed the HI-TRAC transfer cask to ensure that fuel integrity is maintained through adequate rejection of decay heat from the spent nuclear fuel. Heat generated from the MPC outer surface is transmitted across an air gap to an inner shell steel liner, through a lead-to-steel air gap, through a lead shield, through an outer shell steel liner, through a water jacket, through the enclosure shell of the water jacket, and to the atmosphere. Where uncertainties exist, bounding assumptions are made. For example, a maximum gap distance between the MPC and the HI-TRAC inner shell is assumed for degrading the heat transfer characteristics of the design. Thermal expansion that could minimize the gap is not credited. The water jacket, used for neutron shielding, surrounds the cylindrical steel wall. The water jacket is composed of carbon steel channels with welded connecting enclosure plates. An artificial gap was assumed between the steel inner shell and the lead shielding material to maximize the thermal resistance of the HI-TRAC transfer cask.

In the vertical position, the bottom face of the HI-TRAC transfer cask is in contact with the supporting surface. Heat transfer from the bottom face is not credited. The remaining outer surfaces are insolated using 10 CFR Part 71 insolation criteria, averaged on a 24-hour basis. The staff reviewed the assumptions used by the applicant in modeling the HI-TRAC transfer cask and found them acceptable.

The thermal characteristic of the HI-TRAC transfer cask is documented in Section 4 of the SAR. The use of the FLUENT computer code to evaluated the temperature distributions for onsite transport conditions is acceptable. Use of the FLUENT code on spent fuel cask designs was validated with comparison to data from a full scale storage cask loaded with 24 canisters of consolidated PWR spent fuel assemblies. The thermal heat generated by the spent fuel was 23 kW. The tests were performed by the Pacific Northwest National Laboratory and the Idaho National Engineering and Environmental Laboratory. The results from the FLUENT thermal code showed good agreement with the data.

In Appendix B of the Certificate of Compliance, the minimum ambient temperature for onsite transport operations is limited to 0°F. HI-TRAC was analyzed under 0°F conditions. Further, procedures were developed that ensure safe operations (e.g., requiring the addition of antifreeze).

4.6.1 Loading of the MPC with Spent Nuclear Fuel

HI-TRAC transfers the MPC to the spent fuel pool for loading. Once loaded, the HI-TRAC system removes the MPC from the pool for vacuum drying and filling with helium fill gas. From the time the HI-TRAC is removed from the spent fuel pool, plant procedures require that the vacuum drying operation be initiated prior to the water temperature in the MPC reaching saturation. An adiabatic temperature rise calculation is performed to determine the maximum time limit before the water in the MPC reaches saturation temperature during wet transfer operation. The maximum allowable time for wet transfer is a function of initial temperature of the water inside the MPC. Table 4-7 lists the allowable time durations for wet transfer operations under design load conditions.

Table 4-7
HI-TRAC Allowable Time Duration for Wet Transfer Operations Under Design Load Conditions

Initial Water Temperature (°F) for Wet Transfer of SNF	Maximum Allowable Time Duration for Wet Transfer Operation (hr)
115	35.2
120	33.4
125	31.5
130	29.7
135	27.9
140	26.1
145	24.3
150	22.5

In the event that the maximum allowable time identified above is found to be insufficient to complete all wet transfer operations, forced water circulation will be initiated and maintained to remove the decay heat from the MPC cavity.

The staff reviewed the applicant's analytic assumptions and results for loading of the MPC and finds the wet transfer evaluations acceptable.

4.6.2 Vacuum Drying Operation

Long term storage of spent nuclear fuel is done with the MPC filled with inert helium gas. HI-TRAC removes the MPC from the refueling pool for decontamination and vacuum drying. The vacuum drying of the MPC is performed with the annular gap between the MPC and the HI-TRAC filled with water. The water in the gap between the MPC and HI-TRAC will maintain the MPC shell temperature around the saturation temperature of the water in the annular gap. Using the FLUENT code, a thermal analysis of the MPC during vacuum drying was performed to assess the peak clad temperature at design basis heat loads. Table 4-8 lists the results of the thermal analysis under vacuum conditions.

Table 4-8
HI-TRAC Thermal Analysis Under Vacuum Conditions

Component Under Vacuum Conditions	MPC-24 (°F)	MPC-68 (°F)
Flue Clad	827	822
MPC Basket	759	786
MPC Basket Periphery	442	315
MPC Outer Shell Surface	232	232

The calculated temperatures are below the maximum short-term limits. The staff reviewed the methods and assumptions used by the applicant in support of its vacuum drying procedures and finds these results acceptable.

4.6.3 Cask Cooldown and Reflood Analysis During Fuel Unloading Operation

Holtec evaluated the consequences of cask cooldown and reflood procedures to support fuel unloading from a dry condition. The procedures for cask cooldown and reflooding the MPC were developed to ensure that uncontrolled thermal stressing and failure in structural members would not occur and that injection of water would not result in significant steam formation that leads to significant over-pressurization of the confinement boundary. This is accomplished through gradually cooling of the helium by a forced flow helium circulation system (e.g., Cool-Down System). The Cool-Down System uses an external water chiller as the heat sink. Once the Cool-Down System cools the MPC internals to less than 200 °F, water can be injected into the MPC without concern of significant boiling and excessive thermal stress.

The Technical Specifications for cask cooldown prevent filling the MPC with water if the helium temperature exceeds 200 °F. In the event that the Cool-Down System fails to reduce the helium temperature to below 200 °F, LCO 3.1.3 was established to ensure that the MPC and the overpack remain in a safe condition. As the operators attempt to restore the gas temperature to within the 200 °F temperature limit, the operators must also ensure proper cooling of the MPC. Should the overpack be placed in a relatively open area, such as an unobstructed refueling floor, no additional actions are necessary since adequate cooling is maintained by ambient conditions. However, if the overpack is located in a structure such as a decontamination pit or fuel vault, additional actions may be necessary depending on the heat load of the stored fuel. Acceptable actions include, removal of the overpack from the pit or vault and placing it in an open area, such as a refueling floor with a reasonable amount of clearance around the cask and not near a significant source of heat, or by supplying nominally 1000 SCFM of ambient (or cooler) air to the space inside the vault at the bottom of the overpack. These measures ensure that the fuel cladding remains below the short term temperature limit. The staff reviewed the applicant's analytic methods and assumptions used in the unloading operations and finds them acceptable.

4.6.4 Maximum Temperatures Under Onsite Transport Conditions

Holtec analyzed the maximum temperatures under onsite transport conditions for the HI-TRAC design. A bounding steady-state analysis of the HI-TRAC transfer cask was performed using design-basis insolation levels. Table 4-9 summarizes the calculated maximum temperatures for the HI-TRAC transfer cask and MPC.

Table 4-9
Calculated Maximum Temperatures for the HI-TRAC Transfer Cask and MPC

Component	Temperature (°F)
Fuel Clad	902
MPC Basket	884
Basket Periphery	527
MPC Outer Shell Surface	459
HI-TRAC Inner Surface	323
Water Jacket Inner Surface	315
Enclosure Shell Outer Surface	223
Water Jacket Bulk Water	269
Axial Neutron Shield	175

The staff reviewed the applicant's analytic methods and assumptions used in support of onsite transport and finds the results of these analyses acceptable.

4.6.5 Maximum Internal Pressure

Following fuel loading and vacuum drying, but prior to installing the MPC closure ring, the MPC is initially filled with helium. During handling in the HI-TRAC transfer cask, the gas temperature within the MPC rises to its maximum operating temperature. The gas pressure inside the MPC will increase accordingly. The maximum MPC internal pressure was calculated for normal onsite transport conditions, as well as off-normal conditions that assume 1% and 10% failed fuel rods (in accordance with NUREG-1536). The calculated peak pressures are listed in Table 4-10. All pressures were within the design limit. The staff reviewed the applicant's analytic methods and assumptions used to evaluate the internal pressure of the MPC and finds the results acceptable.

Table 4-10
HI-TRAC Pressure Calculations and Associated Design Pressures

Condition	Calculated Pressure (psig)	Design Pressure (psia)
MPC-24:		
Initial Backfill (at 70°F)	28.3	100
Normal Condition	66.6	
With 1% Rods Ruptured	67.0	
With 10% Rods Ruptured	70.0	
MPC-68:		100
Initial Backfill (at 70 °F)	28.5	
Normal Condition	67.0	
With 1% Rods Ruptured	67.3	
With 10% Rods Ruptured	70.8	

4.7 Evaluation Findings

10 CFR Part 72 requires an analysis and evaluation of the dry cask storage system thermal design and performance to demonstrate that the cask will permit safe storage of the spent fuel for a minimum of 20 years. This section reviewed the thermal design and performance of the long-term storage overpack (HI-STORM 100) and the associated spent fuel transfer cask (HI-TRAC) used to load and unload the dry cask storage system and for various plant operations, such as onsite transport of SNF, including loading and unloading operations of SNF in the MPC. The staff concludes that the HI-STORM overpack and HI-TRAC transfer cask designs fulfill the following acceptance criteria:

1. Fuel cladding temperature at the beginning of the dry cask storage is below the anticipated damage-threshold temperatures for normal conditions.

2. Fuel cladding temperatures (zircaloy) are maintained below 570 °C (1058 °F) for short-term accident conditions, short-term off-normal conditions, and fuel transfer operations (e.g., vacuum drying of the cask or dry transfer).

3. The maximum internal pressure of the cask remains within the design pressures for normal, off-normal, and accident conditions assuming rupture of 1%, 10%, and 100% of the fuel rods, respectively. Assumptions for pressure calculations include release of 100% of the fill gas and 30% of the significant radioactive gases in the fuel rods.

4. Cask and fuel materials are maintained within their minimum and maximum temperature criteria for normal, off-normal, and accident conditions in order to enable components to perform their intended safety functions.

5. For each fuel type proposed for storage, the dry cask storage system provides reasonable assurance that the degradation will not lead to gross ruptures or the fuel must be otherwise

confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage.

6. Fuel cladding degradation resulting from creep cavitation are limited to 15 percent of the original cross-sectional area during dry storage.

7. The cask system is passively cooled.

8. The thermal performance of the cask is within the allowable design criteria specified in Section 2 (e.g., materials, decay heat specifications) and Section 3 (e.g., thermal stress analysis) of the SAR for normal, off-normal, and accident conditions.

Tt e following summarizes the staff's finding on the HI-STORM 100 Cask System:

F4.1 Structures, systems, and components important to safety are described in sufficient detail in Sections 1.2 and 2.3 of the SAR to enable an evaluation of their thermal effectiveness. Structures, systems, and components important to safety remain within their operating temperature ranges.

F4.2 The HI-STORM 100 overpack with the loaded MPC-24 or MPC-68 is designed with a heat-removal capability that is verifiable and reliable, consistent with its importance to safety. The cask is designed to provide adequate heat removal capacity without active cooling systems.

F4.3 The staff finds, in accordance with 10 CFR 72.122(h), that the spent fuel cladding is protected against degradation leading to gross ruptures by maintaining the cladding temperature for zircaloy and stainless steel clad below the temperature limits listed in Table 4-6 in a helium gas environment. Protection of the cladding against degradation is expected to allow ready retrieval of spent fuel for further processing or disposal.

F4.4 The staff concludes that the thermal design in the SAR is in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the thermal design provides reasonable assurance that the HI-STORM 100 overpack with the loaded MPC-24 or MPC-68 cask will allow safe handling and storage of spent fuel for a certified life of 20 years. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

4.7 References

1. Pacific Northwest Laboratory, "Recommended Temperature Limits For Dry Storage Of Spent Light Water Reactor Zircaloy-Clad Fuel Rods In Inert Gas," PNL-6189, May 1987.

2. Electric Power Research Institute, "Evaluation of Expected Behavior of LWR Stainless Steel-Clad Fuel in Long-Term Dry Storage," EPRI TR-106440, April 1996.

3. FLUENT, Inc., "FLUENT Computational Fluid Dynamics Software."

4. Swanson Analysis Systems, Inc., "ANSYS Finite Element Modeling Package," 1993.