Holtec International Report HI-2125191, "Three Dimensional Thermal-Hydraulic Analyses for Diablo Canyon Site-Specific HI-STORM System with up to 28.74kW Decay Heat," Revision 0, Non-Proprietary Version

HOLTEC INTERNATIONAL

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THREE-DIMENSIONAL THERMAL-HYDRAULIC ANALYSES FOR DIABLO CANYON SITE-SPECIFIC HI-STORM SYSTEM WITH UPTO 28.74 KW DECAY HEAT

FOR

PG&E

Holtec Report No: HI-2125191

Holtec Project No: 1073

Sponsoring Holtec Division: NPD

Report Class : SAFETY RELATED

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SUMMARY OF REVISIONS

Revision 0: Original Revision.

PREFACE

This work product has been labeled a *safety-significant* document in Holtec's QA System. In order to gain acceptance as a *safety significant* document in the company's quality assurance system, this document is required to undergo a prescribed review and concurrence process that requires the preparer and reviewer(s) of the document to answer a long list of questions crafted to ensure that the document has been purged of all errors of any material significance. A record of the review and verification activities is maintained in electronic form within the company's network to enable future retrieval and recapitulation of the programmatic acceptance process leading to the acceptance and release of this document under the company's QA system. Among the numerous requirements that a document of this genre must fulfill to muster approval within the company's QA program are:

- The preparer(s) and reviewer(s) are technically qualified to perform their activities per the applicable Holtec Quality Procedure (HQP).

- The input information utilized in the work effort must be drawn from referencable sources. Any assumed input data is so identified.

- All significant assumptions, as applicable, are stated.

- The analysis methodology, if utilized, is consistent with the physics of the problem.

- Any computer code and its specific versions that may be used in this work has been formally admitted for use within the company's QA system.

- The format and content of the document is in accordance with the applicable Holtec quality procedure.

- The material content of this document is understandable to a reader with the requisite academic training and experience in the underlying technical disciplines.

Once a safety significant document produced under the company's QA System completes its review and certification cycle, it should be free of any materially significant error and should not require a revision unless its scope of treatment needs to be altered. Except for regulatory interface documents (i.e., those that are submitted to the NRC in support of a license amendment and request), revisions to Holtec *safety-significant* documents to amend grammar, to improve diction, or to add trivial calculations are made only if such editorial changes are warranted to prevent erroneous conclusions from being inferred by the reader. In other words, the focus in the preparation of this document is to ensure accuracy of the technical content rather than the cosmetics of presentation.

In accordance with the foregoing, this Calculation Package has been prepared pursuant to the provisions of Holtec Quality Procedures HQP 3.0 and 3.2, which require that all analyses utilized in support of the design of a safety-related or important-to-safety structure, component, or system be fully documented such that the analyses can be reproduced at *any time in the future* by

a specialist trained in the discipline(s) involved. HQP 3.2 sets down a rigid format structure for the content and organization of Calculation Packages that are intended to create a document that is complete in terms of the exhaustiveness of content. The Calculation Packages, however, lack the narrational smoothness of a Technical Report, and are not intended to serve as a Technical Report.

Because of its function as a repository of all analyses performed on the subject of its scope, this document will require a revision only if an error is discovered in the computations or the equipment design is modified. Additional analyses in the future may be added as numbered supplements to this Package. Each time a supplement is added or the existing material is revised, the revision status of this Package is advanced to the next number and the Table of Contents is amended. Calculation Packages are Holtec proprietary documents. They are shared with a client only under strict controls on their use and dissemination.

This Calculation Package will be saved as a Permanent Record under the company's QA System.

1.0 Introduction

The HI-STORM System consists of three major cask components: a multipurpose canister (MPC), a storage overpack (HI-STORM) and a transfer cask (HI-TRAC). Pacific Gas and Electric (PG&E) uses the HI-STORM 100SA System at an Independent Spent Fuel Storage Installation (ISFSI) at the Diablo Canyon nuclear power plant site. The purpose and function of each of these major HI-STORM System components at the DC ISFSI is described in a site-specific 10 CFR 72 (Part 72) license [1] and a supporting site-specific Safety Analysis Report (SAR) [2].

The HI-STORM System, used at the Diablo Canyon site, consists of an MPC-32 placed inside the cavity of a HI-STORM 100SA overpack. The overpack is a layered cylindrical structure engineered with openings at the top and bottom for air ventilation. The MPC consists of a fuel basket inside a sealed and helium pressurized stainless steel vessel. The basket design is a matrix of square compartments designed to hold the fuel assemblies in a vertical position. The basket is a honeycomb structure of alloy steel plates with full-length edge-welded intersections to form an integral basket configuration. The basket interior cell walls are provided with neutron absorber plates (Metamic) sandwiched between the box wall and a stainless steel sheathing plate to cover the full length of the active fuel region.

The HI-STORM System is designed for long-term storage of Spent Nuclear Fuel (SNF). In this report calculations supporting the thermal evaluation of HI-STORM 100SA System, using the methodologies approved in Revision 7 of Holtec's generic HI-STORM FSAR [5], are documented. The HI-STORM 100SA thermal evaluation adopts NUREG-1536 [3] and ISG-11 guidelines [4] to demonstrate safe storage of Commercial Spent Fuel (CSF). These guidelines are stated below:

1. The fuel cladding temperature for long term storage shall be limited to 400°C (752°F).
2. The fuel cladding temperature for short-term operations shall be limited to 400°C (752°F) for high burnup fuel and 570°C (1058°F) for low burnup fuel.
3. The fuel cladding temperature should be maintained below 570°C (1058°F) for off-normal and accident conditions.

4. The internal pressure of the cask should remain within its design pressures for normal, off-normal, and accident conditions.
5. The cask materials should be maintained within their minimum and maximum temperature criteria under normal, off-normal, and accident conditions.
6. The HI-STORM System should be passively cooled.

The purpose of this calculation package is to document calculations supporting evaluation of the HI-STORM 100SA System under normal, short-term operations, off-normal and accident conditions, in compliance with the methodology approved in the HI-STORM 100 FSAR [5]. All conditions, viz. long term normal, off-normal and accident conditions, are evaluated using 3-dimensional thermal models articulated in Chapter 4 of the HI-STORM 100 FSAR [5]. The short term operations in a HI-TRAC 125D transfer cask are also evaluated using 3-dimensional thermal models. Licensing drawings for the modified HI-STORM 100SA System components [B-7 to B-9, C-6] provide all of the component dimensional details. Table 1.4 presents a listing of the primary changes, made to the generic Holtec component designs to yield the DC ISFSI designs, which can affect thermal performance. The following are the principal differences between the Diablo Canyon HI-STORM 100SA System and the generic HI-STORM 100 System, which impacts the thermal performance or requires considerations for specific thermal evaluations:

1. HI-STORM 100SA System has shortened MPC and HI-TRAC
2. HI-STORM 100SA loading operations are performed in an underground Cask Transfer Facility (CTF) and a separate thermal evaluation is required for this scenario.

1.1 Description of the HI-STORM 100SA System

The HI-STORM 100SA System is a large ventilated concrete overpack having an internal cavity for emplacement of a canister (MPC) containing Spent Nuclear Fuel (SNF). For long-term storage the MPC-32 and its contained SNF is situated inside a vertically oriented overpack. Prior to its emplacement in the HI-STORM, the MPC-32 internal space is pressurized with helium. The HI-STORM Overpack is equipped with four large ducts at each of its bottom and top

extremities. The design of the system includes an annular gap between the MPC-32 and the overpack cylindrical cavity. The ducted overpack construction, together with an engineered annular space between the MPC-32 cylinder and the HI-STORM cavity enables cooling of the MPC-32 external surfaces by natural ventilation.

The MPC-32 consists of a fuel basket having an array of square shaped fuel cells for storing spent nuclear fuel. The fuel basket and the stored fuel are enclosed in an all welded pressure boundary formed by a MPC-32 baseplate, top lid and a cylindrical shell. The interior space is required to be pressurized with helium. For this purpose the MPC-32 is initially backfilled with helium up to design-basis pressures listed in Table 1.1. This ensures an adequate helium pressure[1] to support MPC-32 internal heat transfer and also provides a stable, inert environment for long-term storage of SNF. The pressurized helium environment together with certain features engineered in the MPC-32 design described next render a very effective means of heat dissipation in the MPC-32 space by internal convection. The fuel basket design includes top and bottom plenums formed by flow holes (cut outs at the top and bottom of the basket walls to allow helium circulation) at the base and top of basket walls. Between the fuel basket and the MPC-32 shell is the downcomer space that connects to the top and bottom plenums. In this manner, the MPCs feature a fully connected helium space consisting of the fuel basket cells, top and bottom plenums and a peripheral downcomer gap.

It is apparent from the geometry of the MPC-32 that the basket metal, the fuel assemblies and its contained helium will be at their peak temperature at or near the longitudinal axis of the MPC-32. As a result of conduction along the metal walls and radiant heat exchange from the fuel assemblies to the MPC-32 metal mass the temperatures will attenuate with increasing radial distance from the axis, reaching their lowest values in the downcomer space. As a result the bulk temperatures of the helium columns in the fuel basket are elevated above the bulk temperature of the downcomer space. Since two fluid columns with different temperatures in communicative contact cannot remain in static equilibrium, the temperature field guarantees the incipience of heat transfer by internal convection.

[1] MPC absolute pressure under normal operating conditions (design heat load and normal ambient temperature) is defined in Table 1.3.

1.2 Normal Long Term Storage, Off-Normal and Accident Conditions

Normal long term storage refers to the condition when a fully loaded MPC resides in the HI-STORM at rest in its designated storage location on the ISFSI pad, after all on-site handling and transfer operations are completed. Off-normal conditions and accident conditions are also evaluated as required by NUREG 1536 and HI-STORM FSAR [5]. Thermal evaluations of these conditions are performed using the USNRC approved methodology [5]. The methodology includes credit for internal MPC convection heat transfer has been developed and it has been successfully employed by Holtec for licensing spent fuel casks by the USNRC (Dockets 72-1014 (HI-STORM) and 72-17 (Trojan Nuclear Plant)) and Spain's regulatory authority CSN (Jose Cabrera Nuclear Plant). These evaluations are documented in Appendix B of this report.

1.3 Short Term Operations

Prior to placement in a HI-STORM overpack, an MPC-32 must be loaded with fuel, outfitted with closures, dewatered, dried, backfilled with helium and transferred to a 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-32 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 are short duration events that would likely occur no more than once or twice for an individual MPC-32.

The device central to performing the above short-term operations is the HI-TRAC 125D transfer cask. The HI-TRAC 125D transfer cask is a short-term host for the MPC-32; therefore it is necessary to establish that during all thermally challenging operations, the temperature limits for short-term operations are not exceeded. To ensure maximum fuel cooling the HI-TRAC transfer operations are conducted in the vertical orientation. In this manner the internal convection cooling in the MPC-32 is preserved and the fuel temperatures minimized. The following discrete thermal scenarios involving the HI-TRAC transfer cask are evaluated:

i. Loaded MPC-32 transfer in the HI-TRAC
ii. HI-TRAC Accidents – Water Jacket Loss and Fire

The HI-TRAC thermal evaluations are presented in Appendices C and D of this report. The HI-STORM loading in the Cask Transfer Facility (CTF) is also a short-term operation and is evaluated in Appendix B of this report.

1.4 Design Heat Loads

The HI-STORM 100SA is evaluated for two storage scenarios described in Table 1.3. The two heat load patterns mentioned in the table are evaluated in this report.

1.5 Design Ambient Conditions

To evaluate the effects of ambient conditions on the HI-STORM 100SA System, the following temperatures are defined:

(a) Normal Temperature

For evaluating the effect of ambient temperatures on long-term storage of SNF, a normal storage temperature defined as the annual average temperature of air is specified. Likewise, for including heat dissipation from HI-STORM bottom, an annual average soil temperature is specified.

(b) Off-Normal & Accident Temperatures

For evaluating the effects of temperature excursions, an Off-Normal and Accident temperature defined as a 72-hour average air temperature is specified. The 72-hour average temperature used in the definition of the off-normal temperature recognizes the considerable thermal inertia of the HI-STORM 100SA storage system, which minimizes the effect of undulations in instantaneous temperature on the storage of SNF. It is recognized that daily site temperatures may exceed the temperatures specified herein. However, for thermal evaluations to remain bounding, the time-averaged ambient temperatures specified herein must not be exceeded.

A reasonably bounding set of ambient temperatures are defined in Table 1.2 and adopted in the thermal evaluation for all design-basis analyses. It is to be noted that the ambient

temperatures except the normal long-term storage ambient temperature used in the thermal evaluations are those established for the HI-STORM 100 System, which bound the DC ISFSI conditions. The normal long-term storage temperature used in the thermal evaluations bounds the annual ambient temperature of 55°F based on the site meteorological measurements (Section 2.3 of Reference 2).

2.0 INPUTS

Inputs specific to individual calculations are documented within the calculations presented in the appendices. The global inputs define the key thermal hydraulic characteristics of an MPC loaded with Design Basis Fuel (DBF) for MPC-32 (W-17x17) [5].

The MPC is characterized by the following effective properties:

a) Fuel storage cell planar and axial conductivities
b) Fuel density and specific heat
c) Axial flow resistances

The effective properties and axial flow resistances are consistent with HI-STORM 100 FSAR [5]. Material properties reported in the HI-STORM 100 FSAR [5] are used.

3.0 METHODOLOGY

The methodologies used in all the analyses for HI-STORM 100SA documented in this report are identical to those described in the HI-STORM 100 FSAR [5]. However, the grid sensitivity studies documented in the appendices to achieve a mesh independent temperature field in the HI-STORM 100SA System are performed based on ASME V&V guidance [B-17]. Pressure calculations are similar to those of the HI-STORM 100 FSAR, but include additional characterization for IFBA [6], as was done in the thermal calculations reviewed by the NRC for the current Diablo Canyon ISFSI license [1]. The methodology for thermal analyses of an MPC-32 placed in the HI-STORM 100SA is described in Appendix B of this report. All the storage conditions in HI-STORM 100SA overpack are evaluated using 3-dimensional thermal models articulated in Chapter 4 of HI-STORM 100 FSAR [5]. Appendix C describes the thermal analysis of HI-TRAC transfer cask. The thermal model developed for the HI-TRAC transfer cask is also three-dimensional. The methodology adopted for the thermal evaluations of transfer using HI-TRAC cask is consistent with the methodology approved in the HI-STORM FW FSAR (Docket 72-1032).

4.0 ACCEPTANCE CRITERIA

The thermal-hydraulic performance of the HI-STORM 100SA System must satisfy the following criteria:

- The fuel cladding temperatures should be below the ISG-11 Rev. 3 temperature limit for all scenarios.
- All the components temperature and MPC internal pressure must satisfy the requirements specified in Diablo Canyon ISFSI FSARU [2].

5.0 ASSUMPTIONS

The HI-STORM 100SA thermal analysis employs an array of conservatisms to conservatively predict the fuel, MPC and overpack temperatures. For HI-STORM 100SA System thermal evaluation a numbered list of conservatisms is provided in Appendix B. The principal assumptions that maximize HI-TRAC computed temperatures are stated in the thermal modeling discussions in Appendix C.

6.0 COMPUTER CODES AND FILES

FLUENT Version 6.3.26 computer code is used in the HI-STORM 100SA thermal calculations. The input/output files used in the HI-STORM and HI-TRAC analyses are presented in the individual appendices.

7.0 RESULTS AND CONCLUSIONS

All the calculations and results pertaining to the evaluation of normal, off-normal and accident conditions of HI-STORM 100SA System are reported in Appendix B of this report. The thermal analyses of HI-TRAC System are reported in Appendix C of this report. The Diablo Canyon specific storage system meets the requirements for processing and storing high-burnup fuel at maximum cask uniform heat load of 28.74 kW[2] and a regionalized heat load pattern defined in Section 1.4. The use of supplemental cooling system is not required for the HI-TRAC to maintain fuel cladding temperatures within allowable temperature limit.

[2] The permissible heat load in every storage cell location and the total MPC decay heat loads are provided in Section 1.4.

8.0 REFERENCES

[1] Materials License No. SNM-2511 Amendment 2, Docket 72-26, dated 19 January 2012.

[2] "Diablo Canyon Spent Fuel Storage Installation Final Safety Analysis Report Update", Revision 4, March 2012, Docket 72-26.

[3] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," U.S. Nuclear Regulatory Commission, Revision 1, July 2010.

[4] Interim Staff Guidance 11 (ISG-11), "Cladding Considerations for the Transportation and Storage of Spent Fuel", U.S. nuclear Regulatory Commission, Revision 3.

[5] "Final Safety Analysis Report for the HI-STORM 100 Cask System", Holtec Report HI-2002444, Revision 7.

[6] "Evaluation of IFBA Fuel Storage in the HI-STORM System," Holtec Position Paper DS-265, Revision 1.

Table 1.1

MPC-32 HELIUM BACKFILL PRESSURE SPECIFICATIONS

Item	Specification
Minimum Gauge Pressure	234.4 kPa @ 21.1°C Reference Temperature [34 psig @ 70°F Reference Temperature]
Maximum Gauge Pressure	275.7 kPa @ 21.1°C Reference Temperature [40 psig @ 70°F Reference Temperature]

Table 1.2

DESIGN AMBIENT TEMPERATURES

Normal Temperatures Ambient Soil	 65°F[Note 1] 77°F
Off-Normal Ambient Temperature	100°F for 3 days
Accident Ambient Temperature	125°F for 3 days
Short Term Operation Ambient Temperature	80°F
Note 1: DC ISFSI FSARU Section 2.3 states that the annual ambient temperature is 55 degrees F based on site meteorological measurements. An additional 10 degrees F is added to this value to allow additional margin for monthly variations.	

Table 1.3

DESIGN HEAT LOAD SCENARIOS

Storage Pattern	Maximum Permissible Inner Region Cell Heat Load (kW)	Maximum Permissible Outer Region Cell Heat Load (kW)	Total Permissible MPC Heat Load (kW)	MPC Absolute Operating Pressure (atm)
Scenario 1 - Uniform	0.898	0.898	28.74	5.5
Scenario 2 - Regionalized	1.131	0.6	25.572	5.3

Note 1: The number of cells in the inner and outer regions of the MPC-32 is 12 and 20 respectively. See Figure 10.2-3 of the Diablo Canyon ISFSI FSARU [2] for storage cell numbering and fuel storage regions.

Note 2: The fuel storage heat load includes the decay heat from the fuel and non-fuel hardware.

Table 1.4

PRIMARY DESIGN DIFFERENCES BETWEEN GENERIC HI-STORM 100S VERSION B SYSTEM AND DIABLO CANYON HI-STORM 100SA SYSTEM

MPC	
Overall Height	Reduced by 9 inches
Internal Cavity Height	Reduced by 9 inches
Fuel Basket Height	Reduced by 14 inches
Closure Lid	1-7/8" × 5" C-channels mounted on bottom surface
HI-STORM Overpack	
Overall Height	Same as 100S-229
Internal Cavity Height	Same as 100S-218
Inlet Duct Height	Increased by 7 inch
Inlet Duct Width	Reduced by 3 inch
MPC Base Support	Increased by 14 inch
Duct Debris Screens	Changed from screen to perforated plate
Annulus Channels	Replaced by small guide plates
HI-TRAC Transfer Cask	
Overall Height	Reduced by 9 inches

Appendix A

Holtec Approved Computer Program List
(Total 11 pages)

HOLTEC APPROVED COMPUTER PROGRAM LIST [1]							REV. 221 June 20, 2012	
PROGRAM (Category)	APPROVED IN USNRC PART 50 & 71/72 SER: (Docket #) [2]	VERSION (Executable)	CERTIFIED USERS FOR "A" CODES	CODE EXPERT	REMARKS: See report indicated for special limitations	OPERATING SYSTEM & VERSION (Service pack[4])	APPROVED COMPUTERS: Listed by ID	Indicate Computer ID(s) used
ANSYS (A)	DOC 50-298 DOC 72-1014	11.0	MA, SPA, AB, CWB, RJ, PK, AL, HP, VRP, ER, IR, AIS, ZY, JZ	CWB	HI-2012627	Windows XP (2)	1017, 1018, 1019, 1039, 1060	
		12.0	MA, SPA, AB, CWB, RJ, PK, AL, HP, VRP, ER, IR, AIS, ZY, JZ	CWB	HI-2012627	Windows XP (2)	1016, 1017	
		12.1	MA, SPA, AB, CWB, RJ, PK, AL, HP, VRP, ER, IR, AIS, ZY, JZ	CWB	HI-2012627	Windows XP (2)	1019, 1060	
						Windows 7 (0,1)	1021, 1023, 1025, 1031, 1032, 1044, 1093	
		13.0	MA, SPA, AB, CWB, RJ, PK, AL, HP, VRP, ER, IR, AIS, ZY, JZ, YC, VM	CWB	HI-2012627	Windows XP (2)	1017, 1018, 1019	
						Windows 7 (0,1)	1023, 1025, 1031, 1038, 1044, 1127, 1139, 1187, 1888, 1189, 1190, 1179	
COMPRESS		Build 7140	N/A	VM	HI-2125173	Windows XP (2)	1058	

Note 1: All codes on this list have been validated under Holtec's QA program.
Note 2: Programs with docket numbers listed have been identified by name in the SER by the USNRC. This column is for information only.
Note 3: Only computers identified on the ACPL may use SolidWorks for computing weights and center of gravity values on safety significant work. However, reports do not need to indicate which computers were used for the drawings referenced.
Note 4: A zero indicated as the service pack is equivalent to an operating system having no service pack.

HOLTEC APPROVED COMPUTER PROGRAM LIST [1]							REV. 221 June 20, 2012	
PROGRAM (Category)	APPROVED IN USNRC PART 50 & 71/72 SER: (Docket #) [2]	VERSION (Executable)	CERTIFIED USERS FOR "A" CODES	CODE EXPERT	REMARKS: See report indicated for special limitations	OPERATING SYSTEM & VERSION (Service pack[4])	APPROVED COMPUTERS: Listed by ID	Indicate Computer ID(s) used
CASMO (A)	DOC 50-271 DOC 71-9336	4 – 2.05.14	SPA, BDB, KB, HF, SVF, TH, BK, DMM, VIM, ES, PS	SPA	HI-2104750	Windows XP (3)	1006	
CASMO (A)	DOC 50-271 DOC 71-9336	5M - 1.06.00	SPA, BDB, KB, HF, SVF, TH, BK, DMM, VIM, ES, PS	SPA	HI-2104750	Windows XP (2)	1008, 1013	
CORRE		1.3	N/A	CWB	N/A	Windows XP (3)	1020	
CORRE		1.3	N/A	CWB	N/A	Windows 7 (0,1)	1049	
DECAY		1.6	N/A	ER	N/A	Windows XP (2)	1016	
DECAY		1.6	N/A	ER	N/A	Windows XP (3)	1016	
DECOR	DOC 50-423	1.3	N/A	ER	N/A	Windows XP (2)	1016	
DECOR	DOC 50-423	1.3	N/A	ER	N/A	Windows XP (3)	1016	
DECOR	DOC 50-423	1.3	N/A	ER	N/A	Windows 7 (0,1)	1027	
Dr. Beam Pro		1.0.5	N/A	CWB	N/A	Windows 7 (0,1)	1031	

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PROGRAM (Category)	**APPROVED IN USNRC PART 50 & 71/72 SER: (Docket #) [2]**	**VERSION (Executable)**	**CERTIFIED USERS FOR "A" CODES**	**CODE EXPERT**	**REMARKS: See report indicated for special limitations**	**OPERATING SYSTEM & VERSION (Service pack[4])**	**APPROVED COMPUTERS: Listed by ID**	**Indicate Computer ID(s) used**
DYNAMO Suite (A)		1.0	AIS, CWB, VRP, HP, KKG	CWB	HI-2114848	Windows 7 (0,1)	1044, 1021	
Fluent (A)	DOC 50-368 DOC 72-1014	4.56	ER, IR, DMM, AHM, YL, INP, MH, JGR	ER	HI-981921	Windows XP (2)	1016	
						Windows XP (3)	1022	
						Windows 7 (0,1)	1027	
Fluent (A)	DOC 50-368 DOC 72-1014	6.3.26	ER, IR, DMM, AHM, YL, INP, MH, JGR	DMM	HI-2084036	Windows XP (2)	1002, 1003, 1016, 2003	1002, 1003
						Windows XP (3)	1001	
						Windows 7 (0,1)	1026, 1193	
						Red Hat Ent. (3.4.3-9.EL4) Linux (2.6.9-5)	1004	1004
						Red Hat Ent. (4.4.2-48) Linux (2.6.18-194.el5) Server Release 5.5	1027, 1070, 1071, 1072, 1135	1070, 1071, 1072
GENEQ		1.3	N/A	AIS, CWB	N/A	Windows XP (3)	1028	

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HTRI XIST		6.00	N/A	KK	N/A	Windows XP (3)	1057	
LONGOR	DOC 50-305	1.1	N/A	ER	N/A	Windows XP (2)	1016	
						Windows XP (3)	1016	
LS-DYNA (A)	DOC 50-298 DOC 72-1014	971 (ls971sR4.2)	AB, SPA, RJ, AL, HP, VRP, KPS, AIS, JZ, ZY	JZ	N/A	Windows XP (2)	1018	
		971 (ls971sR5.0)	AB, SPA, RJ, AL, HP, VRP, KPS, AIS, JZ, ZY	JZ	N/A	Windows 7 (0,1)	1031, 1032	
		971 (ls971dR5.0)	AB, SPA, RJ, AL, HP, VRP, KPS, AIS, JZ, ZY	JZ	N/A	Windows 7 (0,1)	1025, 1093	
LS-DYNA (A)	DOC 50-298 DOC 72-1014	971 (mpp971dR5.0)	AB, SPA, RJ, AL, HP, VRP, KPS, AIS, JZ, ZY	JZ	N/A	Windows Server HPC 2008	1033, 1034, 1035, 1036, 1037	

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		971 (mpp971sR5.0)	AB, SPA, RJ, AL, HP, VRP, KPS, AIS, JZ, ZY	JZ	N/A	Windows Server HPC 2008	1033, 1034, 1035, 1036, 1037	
MACCS2		1.13.1	N/A	SPA	HI-2104750	Windows XP (3)	1041	
MCNP (A)	DOC 50-368 DOC 71-9336	4A	SPA, BDB, KB, HF, SVF, TH, BK, DMM, VIM, ES, PS	KB	HI-2104750	Windows XP (2)	1008, 1002	
						Windows XP (3)	1006, 1009, 1010, 2001, 2002, 2004, 2005, 2006, 2007	
						Windows 7 (0,1)	1011, 1013, 1014, 1015, 1030, 1051, 1113, 1114, 1115	
		4B	SPA, BDB, KB, HF, SVF, TH, BK, DMM, VIM, ES, PS	KB	HI-2104750	Windows XP (3)	2001, 2002	
						Windows 7 (0,1)	1051	
		5.1.40	SPA, BDB, KB, HF, SVF, TH,	KB	HI-2104750	Windows XP (2)	1002, 1003, 1008	

Note 1: All codes on this list have been validated under Holtec's QA program.
Note 2: Programs with docket numbers listed have been identified by name in the SER by the USNRC. This column is for information only.
Note 3: Only computers identified on the ACPL may use SolidWorks for computing weights and center of gravity values on safety significant work. However, reports do not need to indicate which computers were used for the drawings referenced.
Note 4: A zero indicated as the service pack is equivalent to an operating system having no service pack.

PROGRAM (Category)	APPROVED IN USNRC PART 50 & 71/72 SER: (Docket #) [2]	VERSION (Executable)	CERTIFIED USERS FOR "A" CODES	CODE EXPERT	REMARKS: See report indicated for special limitations	OPERATING SYSTEM & VERSION (Service pack[4])	APPROVED COMPUTERS: Listed by ID	Indicate Computer ID(s) used
			BK, DMM, VIM, ES, PS			Windows XP (3)	1006, 1009, 1010, 1012, 2001, 2002, 2004, 2005, 2006, 2007	
						Windows 7 (0,1)	1011, 1014, 1015, 1051, 1113, 1114, 1115,	
		5.1.51	SPA, BDB, KB, HF, SVF, TH, BK, DMM, VIM, ES, PS	KB	HI-2104750	Windows XP (2)	1002, 1003, 1008, 2003	
						Windows XP (3)	1006, 1009, 1010, 2001, 2002, 2005, 2006, 2007	
						Windows 7 (0,1)	1011, 1013, 1014, 1015, 1051, 1076, 1113, 1114, 1115	
MULPOOLD		2.3	N/A	ER	N/A	Windows XP (2)	1016	
						Windows XP (3)	1016	

Note 1: All codes on this list have been validated under Holtec's QA program.
Note 2: Programs with docket numbers listed have been identified by name in the SER by the USNRC. This column is for information only.
Note 3: Only computers identified on the ACPL may use SolidWorks for computing weights and center of gravity values on safety significant work. However, reports do not need to indicate which computers were used for the drawings referenced.
Note 4: A zero indicated as the service pack is equivalent to an operating system having no service pack.

HOLTEC APPROVED COMPUTER PROGRAM LIST [1]							REV. 221 June 20, 2012	
PROGRAM (Category)	APPROVED IN USNRC PART 50 & 71/72 SER: (Docket #) [2]	VERSION (Executable)	CERTIFIED USERS FOR "A" CODES	CODE EXPERT	REMARKS: See report indicated for special limitations	OPERATING SYSTEM & VERSION (Service pack[4])	APPROVED COMPUTERS: Listed by ID	Indicate Computer ID(s) used
						Windows 7 (0,1)	1026	
Nanotec Wet Chemistry		1.0	N/A	Pravin Kumar	N/A	Windows Server 2003 revision 2	1146	
ONEPOOL		1.7	N/A	ER	N/A	Windows XP (2)	1016	
						Windows XP (3)	1016	
ORIGEN2		486	N/A	ER	HI-92784	Windows XP (2)	1016	
						Windows XP (3)	1016	
ORIGEN-S, SAS2H, KENO-Va, NITAWL & BONAMI (Modules of SCALE 4.3)	DOC 50-346 DOC 71-9336	4.3	KB, SPA, BK	KB, SPA	N/A	Windows 2000 (2)	1050	

Note 1: All codes on this list have been validated under Holtec's QA program.
Note 2: Programs with docket numbers listed have been identified by name in the SER by the USNRC. This column is for information only.
Note 3: Only computers identified on the ACPL may use SolidWorks for computing weights and center of gravity values on safety significant work. However, reports do not need to indicate which computers were used for the drawings referenced.
Note 4: A zero indicated as the service pack is equivalent to an operating system having no service pack.

HOLTEC APPROVED COMPUTER PROGRAM LIST [1]							REV. 221 June 20, 2012	
PROGRAM (Category)	**APPROVED IN USNRC PART 50 & 71/72 SER: (Docket #) [2]**	**VERSION (Executable)**	**CERTIFIED USERS FOR "A" CODES**	**CODE EXPERT**	**REMARKS: See report indicated for special limitations**	**OPERATING SYSTEM & VERSION (Service pack[4])**	**APPROVED COMPUTERS: Listed by ID**	**Indicate Computer ID(s) used**
ORIGEN-S & SAS2H (Modules of SCALE 4.4)	DOC 50-346 DOC 71-9336	4.4	N/A	KB, SPA	N/A	Windows XP (3)	1006, 1009, 1010, 2004, 2005, 2007	
ORIGEN-S, SAS2H & KENO-VI (Modules of SCALE 5.1)		5.1	KB, SPA, BK	KB, SPA	N/A	Windows 7 (0,1)	1011, 1013, 1113, 1015, 1076, 1088	
						Windows XP (3)	2002, 2004, 2005, 2007	
SHAKE 2000		7.6.0	N/A	AIS	N/A	Windows 7 (0,1)	1044, 1093, 1025	
		7.7.0	N/A	AIS	N/A	Windows 7 (0,1)	1021	
ShapeBuilder		4.0	N/A	VRP	HI-2053361	Windows XP (3)	1020	
						Windows 7 (0,1)	1038, 1049	
		6.0	N/A	VRP	HI-2053361	Windows 7 (0,1)	1044	
SolidWorks 2010 [3]		4.0	N/A	LDV	HI-2012761	Windows XP (2)	1077, 1081, 1082, 1083, 1085, 1086	N/A

Note 1: All codes on this list have been validated under Holtec's QA program.
Note 2: Programs with docket numbers listed have been identified by name in the SER by the USNRC. This column is for information only.
Note 3: Only computers identified on the ACPL may use SolidWorks for computing weights and center of gravity values on safety significant work. However, reports do not need to indicate which computers were used for the drawings referenced.
Note 4: A zero indicated as the service pack is equivalent to an operating system having no service pack.

HOLTEC APPROVED COMPUTER PROGRAM LIST [1]							REV. 221 June 20, 2012	
PROGRAM (Category)	APPROVED IN USNRC PART 50 & 71/72 SER: (Docket #) [2]	VERSION (Executable)	CERTIFIED USERS FOR "A" CODES	CODE EXPERT	REMARKS: See report indicated for special limitations	OPERATING SYSTEM & VERSION (Service pack[4])	APPROVED COMPUTERS: Listed by ID	Indicate Computer ID(s) used
						Windows 7 (0,1)	1078, 1079, 1080, 1084	N/A
STER		5.04	N/A	ER	N/A	Windows XP (3)	1016	
SX		1.0	N/A	KB	N/A	Windows 7 (0, 1)	1011, 1013, 1015, 1051, 1076, 1088, 1108, 1113, 1114, 1115	
						Windows XP (2)	2004, 2005, 2006, 2007, 1008	
						Windows XP (3)	1006, 1009, 1010	
TBOIL		1.11	N/A	ER	N/A	Windows XP (2)	1016	
						Windows XP (3)	1016	
VERSUP		1.0	N/A	AIS	N/A	Windows XP (2)	1016	
Visual Nastran	DOC 50-133 DOC 72-27	2004	N/A	AIS, CWB	N/A	Windows XP (2)	1017, 1018	
						Windows XP (3)	1020, 1028	

Note 1: All codes on this list have been validated under Holtec's QA program.
Note 2: Programs with docket numbers listed have been identified by name in the SER by the USNRC. This column is for information only.
Note 3: Only computers identified on the ACPL may use SolidWorks for computing weights and center of gravity values on safety significant work. However, reports do not need to indicate which computers were used for the drawings referenced.
Note 4: A zero indicated as the service pack is equivalent to an operating system having no service pack.

HOLTEC APPROVED COMPUTER PROGRAM LIST [1]							REV. 221 June 20, 2012	
PROGRAM (Category)	APPROVED IN USNRC PART 50 & 71/72 SER: (Docket #) [2]	VERSION (Executable)	CERTIFIED USERS FOR "A" CODES	CODE EXPERT	REMARKS: See report indicated for special limitations	OPERATING SYSTEM & VERSION (Service pack[4])	APPROVED COMPUTERS: Listed by ID	Indicate Computer ID(s) used
						Windows 7 (0,1)	1044, 1045	

Note 1: All codes on this list have been validated under Holtec's QA program.
Note 2: Programs with docket numbers listed have been identified by name in the SER by the USNRC. This column is for information only.
Note 3: Only computers identified on the ACPL may use SolidWorks for computing weights and center of gravity values on safety significant work. However, reports do not need to indicate which computers were used for the drawings referenced.
Note 4: A zero indicated as the service pack is equivalent to an operating system having no service pack.

Appendix B

Thermal Analysis of MPC-32 in HI-STORM 100SA System
(Total 43 pages)

B.1 INTRODUCTION

In this appendix, thermal evaluations of MPC-32 fuel basket placed in HI-STORM 100SA system using three-dimensional CFD models are presented. These 3-D thermal models incorporate the 3-zone flow resistance model articulated in a companion Holtec report [B-1]. Normal storage analyses are performed for two different scenarios listed in Section 1.4. Off-normal and accident analyses are also performed and results are presented in this appendix.

B.2 METHODOLOGY AND ASSUMPTIONS

One of the central objectives in the design of the HI-STORM 100SA system is to ensure that all SNF discharged from the reactor and not yet loaded into dry storage systems can be stored in a HI-STORM 100SA MPC. The methodology used in the all of the analyses documented in this appendix are identical to those described in the USNRC approved HI-STORM 100 FSAR [B-2]. However, the grid sensitivity studies discussed in Section B.5.1 to achieve a mesh independent temperature field in the HI-STORM 100SA System are performed based on ASME V&V guidance [B-17]. To ensure an adequate representation of the features of MPC-32, fuel basket within MPC-32 and the HI-STORM 100SA system, a quarter-symmetric 3-D geometric model of the MPC is constructed using the FLUENT CFD code pre-processor (Gambit) [B-3], as shown in Figure B.2.2. Transport of heat from the heat generation region (fuel assemblies) to the outside environment (ambient air or ground) is analyzed broadly using three-dimensional models. The 3-D models implemented to analyze the HI-STORM 100SA system have the following key attributes:

1. The interior of the MPC is a 3-D array of square shaped cells inside an irregularly shaped basket outline confined inside the cylindrical space of the MPC cavity.
2. The fuel bundle inside the fuel cell for the PWR fuel assemblies are replaced by an equivalent porous media using the flow impedance properties computed using a rigorous (CFD) approach [B-1]. The equivalent effective thermal properties of the porous medium are the same as that used in Reference B-2.
3. The internals of the MPC cavity, including the basket cross-section, bottom flow holes and plenums are modeled explicitly.

4. The stainless steel plates in the MPC basket wall have Metamic panels and sheathing attached [B-7]. The arrangement of metal layers results in the composite wall having different thermal conductivities in the in-plane (parallel to panel) and out-of-plane (perpendicular to panel) directions. The effective thermal properties of the basket sandwich are consistent with the values used in the thermal evaluations supporting Reference B-2.

5. **[PROPRIETARY**

   ].

6. The inlet and outlet vents in the HI-STORM 100SA overpack are modeled explicitly as shown in Figure B.2.2.

7. The model includes all three modes of heat transfer – conduction, convection and radiation.

8. For including MPC internal convection heat transfer, the benchmarked solution methodologies described in a Holtec topical report [B-6] is employed. The helium flow within the MPC is modeled as laminar.

9. Surface to surface thermal radiation heat transfer is modeled using the **[PROPRIETARY**

   ].

10. The airflow through the annular space between the MPC and the overpack is modeled as **[PROPRIETARY**] to incorporate the effect of air turbulence on the systems thermal performance. This model is approved by USNRC for HI-STORM 100 [B-2].

11. Insolation on the outer surface of HI-STORM 100SA is conservatively based on the 12-hour levels prescribed in 10CFR71 averaged on a 24-hours basis.

12. The flow resistance of Westinghouse 17x17 fuel assemblies calculated using rigorous CFD methods [B-1] are used in the thermal analyses. **[PROPRIETARY**

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13. Grid sensitivity studies are performed as discussed in Subsections B.5.1 and B.5.5 to assess uncertainty in the predicted results in the HI-STORM thermal model and HI-STORM in the CTF thermal model, respectively.

A cross-section of the 3-D model of the HI-STORM 100SA system loaded with an MPC-32 is illustrated in Figure B.2.1. The 3-D model has the following major assumptions that render the results conservative.

1) The fuel bundles are generating heat at the limiting heat loads defined in Section 1.4 of this report.
2) Axial dissipation of heat by the fuel pellets is neglected.
3) Axial dissipation of heat by radiation in the fuel bundle is neglected.
4) The most severe environmental factors for long-term normal storage under the Diablo Canyon specific condition - ambient temperature of 65°F and 10CFR71 insolation levels - were coincidentally imposed on the system.
5) The thermosiphon effect in the MPC-32, which is intrinsic to the HI-STORM 100SA fuel basket design, is included in the thermal analyses.
6) For simplicity, the MPC basket flow holes are modeled as rectangular openings with understated flow area.
7) The absorbtivity of the external surfaces of the HI-STORM 100SA is assumed to be equal to 1.0. The emissivity of the painted carbon steel surface is set as 0.85, which is an approved and conservative value.
8) No credit is taken for contact between fuel assemblies and the MPC basket wall or between the MPC basket and the basket supports. The fuel assemblies and MPC-32 basket are conservatively considered to be in concentric alignment.
9) **[PROPRIETARY**

].

10) To understate MPC internal convection heat transfer, the MPC helium pressure[1] is understated. During accident conditions, the MPC pressure is higher than the minimum MPC absolute pressure specified in Table 1.3. Conservatively, the higher pressure is not credited in the thermal evaluations of the accidents.

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

12) The MPC-32 free volume for pressure calculations is conservatively understated by using bounding volume of basket supports and fuel weight.

13) The CTF is a steel cylinder backed by concrete. **[PROPRIETARY**

].

B.3 INPUT DATA

The principal input data for the thermal-hydraulic evaluations of the MPC-32 placed in HI-STORM 100SA overpack, used in these analyses, are taken from design drawings [B-7, B-8, B-9 and B-10]. The input data used for the simulation of the Multi-purpose Canister (MPC) and the fuel assemblies, stored in MPC-32, are obtained from References B-1 and B-2. The physical properties of materials present within the HI-STORM 100SA system, such as carbon steel, stainless steel, concrete, air and helium, are reported in Reference B-2. The effective properties of the fuel and basket composite wall are consistent with the values used in the thermal evaluations supporting the HI-STORM 100 FSAR [B-2]. An MPC internal operating pressure based on the minimum helium backfill pressure and MPC cavity average temperature is used in the calculations. The operating pressure used in the calculations for Scenario 1 and Scenario 2 listed in Table 1.3 is 5.5 and 5.3 atmospheres absolute, respectively. The design ambient temperature used in the analysis is 65°F. The bottom of the HI-STORM 100SA overpack base is

1 MPC absolute pressure used in the analysis is specified in Table 1.3 under normal operating conditions (design heat load and normal ambient temperature).

assumed supported on a subgrade at 77°F [B-2]. 10CFR71 insolation levels were coincidentally imposed on the system.

The fuel assembly axial burnup distribution used in the analysis is provided in Reference B-2. Surface emissivity data for key materials of construction are also provided in Reference B-2. The emissivity properties of painted external surfaces are generally excellent. In the HI-STORM 100SA thermal analysis, an emissivity of 0.85 is applied to painted surfaces. A solar absorptivity coefficient of 1.0 is applied to all exposed overpack surfaces. Literature data on the surface emissivity of stainless steel material are widely available. Values as high as 0.80 [B-12] have been reported in the literature. Conservatively, a lower value of 0.587 [B-4], which is typical of oxidized stainless steel, has been used for plate, and an even lower value of 0.36 [B-4] has been used for machined forgings in these evaluations.

The spent fuel assemblies inside fuel storage cells are modeled as a homogeneous porous media. Separate CFD calculations are performed to determine the pressure drop characteristics for flow of helium through the fuel assemblies and the fuel basket. The inputs to the FLUENT CFD model to simulate the pressure drop through the porous media are detailed in Reference B-1. The HI-STORM 100SA system is evaluated for different heat load scenarios as specified in Section 1.4 of the main report.

B.4 COMPUTER PROGRAM AND FILES

The computer code FLUENT Version 6.3.26 [B-3] is used in these thermal calculations. A list of computer files supporting the bounding (licensing basis) calculations is provided below.

GAMBIT

```
HI-STORM
Directory  of  G:\Projects\1073\REPORTS\Thermal  Reports-HI-2125191\Gambit\HI-
STORM
04/11/2012  04:37 PM      187,695,104    historm-mesh1.dbs
04/11/2012  04:28 PM      102,146,467    historm-mesh1.msh
04/11/2012  04:56 PM      212,860,928    historm-mesh2.dbs
04/11/2012  04:55 PM      149,619,934    historm-mesh2.msh
04/23/2012  01:16 PM      238,026,752    historm-mesh3.dbs
04/23/2012  01:13 PM      197,758,422    historm-mesh3.msh
04/25/2012  11:32 AM      268,435,456    historm-mesh4.dbs
04/25/2012  11:02 AM      266,576,229    historm-mesh4.msh
06/06/2012  04:26 PM      462,536,704    historm-mesh5.dbs
```

06/06/2012	04:05 PM	638,806,034	historm-mesh5.msh

HI-STORM in CTF

Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Gambit\CTF

03/07/2012	05:50 PM	238,026,752	ctf-mesh1.dbs
03/07/2012	05:54 PM	171,545,381	ctf-mesh1.msh
03/09/2012	05:18 PM	271,581,184	ctf-mesh2.dbs
03/09/2012	05:13 PM	240,979,216	ctf-mesh2.msh
05/09/2012	05:40 PM	314,572,800	ctf-mesh3.dbs
05/09/2012	05:30 PM	332,050,235	ctf-mesh3.msh
05/09/2012	04:54 PM	362,807,296	ctf-mesh4.dbs
05/09/2012	05:03 PM	444,878,087	ctf-mesh4.msh
06/12/2012	11:28 AM	637,173,760	ctf-mesh5.dbs
06/12/2012	09:28 AM	979,328,269	ctf-mesh5.msh

FLUENT

Normal Onsite Storage - Uniform Loading

Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Fluent\HI-STORM

04/25/2012	08:53 AM	57,919,748	historm-mesh1.cas
04/24/2012	11:50 PM	914,713,260	historm-mesh1.dat
04/26/2012	03:54 PM	83,925,720	historm-mesh2.cas
04/26/2012	11:24 AM	1,294,495,166	historm-mesh2.dat
04/26/2012	04:10 PM	110,237,368	historm-mesh3.cas
04/24/2012	07:16 PM	1,676,716,409	historm-mesh3.dat
06/20/2012	03:51 PM	145,364,533	historm-mesh4.cas
04/26/2012	09:46 AM	2,204,272,987	historm-mesh4.dat
06/11/2012	06:32 AM	335,151,800	historm-mesh5.cas
06/11/2012	06:33 AM	4,733,659,760	historm-mesh5.dat

Normal Onsite Storage - Regionalized Loading

Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Fluent\HI-STORM

05/25/2012	09:04 AM	145,363,854	historm-mesh4-reg.cas
05/24/2012	09:57 PM	2,204,291,051	historm-mesh4-reg.dat

HI-STORM in CTF

Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Fluent\CTF

06/14/2012	02:20 PM	95,008,237	ctf-mesh1.cas
06/14/2012	02:22 PM	1,427,314,150	ctf-mesh1.dat
06/21/2012	01:20 PM	126,419,846	ctf-mesh2.cas
06/21/2012	01:20 PM	1,943,982,970	ctf-mesh2.dat
06/14/2012	02:16 PM	176,226,345	ctf-mesh3.cas
06/14/2012	02:17 PM	2,569,749,215	ctf-mesh3.dat
06/25/2012	11:11 AM	232,319,956	ctf-mesh4.cas
06/25/2012	11:04 AM	3,367,644,358	ctf-mesh4.dat
06/14/2012	06:23 AM	503,818,511	ctf-mesh5.cas
06/14/2012	06:24 AM	6,945,347,426	ctf-mesh5.dat

Partial Duct Blockage (Off-Normal)

```
Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Fluent\PDB

04/27/2012  11:00 AM      145,363,345   historm-mesh4-pdb.cas
04/27/2012  11:01 AM    2,204,304,238   historm-mesh4-pdb.dat
```

All Ducts Blocked (Accident)

```
Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Fluent\ADB

05/21/2012  08:38 AM    2,271,207,082   historm-mesh4-ADB-115200.dat
06/14/2012  04:40 PM      145,363,193   historm-mesh4-ADB.cas
```

Fire (Accident)

```
Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Fluent\FIRE

06/09/2012  08:20 PM    2,271,198,963   historm-mesh4-fire-240.dat
06/09/2012  11:20 AM      145,366,482   historm-mesh4-fire.cas
06/19/2012  01:34 AM    2,271,233,142   historm-mesh4-postfire-10800.dat
06/19/2012  01:07 PM    2,271,233,142   historm-mesh4-postfire-12600.dat
06/28/2012  06:04 PM    2,271,201,848   historm-mesh4-postfire-132000.dat
06/28/2012  06:49 PM    2,271,221,048   historm-mesh4-postfire-135600.dat
06/28/2012  07:36 PM    2,271,240,248   historm-mesh4-postfire-139200.dat
06/19/2012  09:48 PM    2,271,233,142   historm-mesh4-postfire-14400.dat
06/15/2012  05:48 PM    2,271,235,445   historm-mesh4-postfire-3600.dat
06/17/2012  09:14 AM    2,271,235,445   historm-mesh4-postfire-7200.dat
06/12/2012  11:47 AM      145,366,413   historm-mesh4-postfire.cas
```

UDF

```
Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Fluent

05/22/2012  02:17 PM            2,689   udf-diablo-25.572kw.c
09/15/2010  05:24 PM            2,689   udf-diablo-28.74kw.c
```

MISCELLANEOUS

```
Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191

04/13/2012  03:36 PM           25,600   heat-gen-rate.xls
06/29/2012  11:00 AM           56,320   mpc_pres.xls
```

B.5 RESULTS AND CONCLUSIONS

B.5.1 Normal Long-Term Storage Temperatures

Grid Sensitivity Studies

To achieve grid independent CFD results, a grid sensitivity study is performed on HI-STORM 100SA thermal model. **[PROPRIETARY**

]. A number of grids are generated to study the effect of mesh refinement on the fuel and component temperatures. All sensitivity analyses were carried out for Scenario 1 listed in Table 1.3. Table B.5.1 gives a brief summary of the different sets of grids evaluated and PCT results. Per ASME V&V [B-17], it is recommended that the mesh refinement in 3D be atleast 2.2 times the previous mesh. However, this recommendation may lead to significantly large number of mesh cells, thereby increasing the computational time tremendously. This recommended criterion is satisfied by Mesh 1, 4 and 5 specified in Table B.5.1. To provide additional assurance, intermediate meshes such as Mesh 2 and 3 are generated to show that the effect of mesh refinement is small considering the margins to safety.

As can be seen from Table B.5.1, the finest mesh (Mesh 5) is **[PROPRIETARY]** times the total mesh size of the baseline mesh (Mesh 1). Even with such a large mesh refinement, the change in PCT is extremely small. The solutions from the different grids used are in the asymptotic range. The small PCT difference between the meshes is negligible compared to the available PCT safety margin. Therefore it can be concluded that Mesh 4 reports the reasonably converged results. To provide further assurance of convergence, the sensitivity results are evaluated in accordance with the ASME V&V 20-2009 [B-17]. Towards this end the Grid Convergence Index (GCI), which is a measure of the solution uncertainty, is computed in Appendix E of this report. Since Meshes 1, 4 and 5 satisfy the recommended criterion specified in Reference B-17, the GCI is computed using these three meshes and it is computed as **[PROPRIETARY]**. Based on the above results, Mesh 4 grid layout is adopted for the thermal analysis of the HI-STORM 100SA System.

Maximum Temperatures

The converged mesh obtained above is used to perform thermal evaluations of normal long-term storage of two heat load scenarios described in Section 1.4. The peak cladding temperatures and other cask components are reported in Table B.5.2. Following conclusions can be drawn from the results:

i) The peak cladding temperatures are below the ISG-11 temperature limit 400°C (752°F).
ii) The fuel, MPC and overpack component temperatures are highest for Scenario 1.
iii) All the temperatures for Scenario 1 and 2 are below their respective temperature limits.
iv) This bounding storage scenario is therefore adopted for analyzing off-normal (50% inlet vents blockage) and accident scenarios i.e. all inlets vents blockage and hypothetical fire accident.

B.5.2 Thermal Expansion Computations

In this subsection, thermal expansions of free-standing HI-STORM 100SA components in the radial and axial directions are computed for the bounding scenario. The calculations address the following thermal expansions:

a) Fuel Basket-to-MPC Radial Growth
b) Fuel Basket-to-MPC Axial Growth
c) MPC-to-Overpack Radial Growth
d) MPC-to-Overpack Axial Growth

(a) Fuel Basket-to-MPC Radial Growth

The two potential points that could be impacted by differential thermal expansion are at the touch points between the basket and the supports (Method 1), and between the corner of the basket and the MPC shell (Method 2). The radial growth of the fuel basket relative to the MPC (δ) upon heating from a 65°F reference temperature (T_o) to storage temperatures is computed by the above mentioned two different methods and is reported as follows:

Method 1:

Method 1 evaluates the thermal expansion between the basket and the basket supports. To determine the limiting thermal expansion it is first necessary to determine the minimum MPC

basket internal radius. Since the minimum radius is based on the gap between the basket and the shell, the point A, which is the maximum basket radius, must be determined. The panel at point A is beveled at the edge as shown in the drawing [B-7]. The dimension of the farthest point is calculated as follows:

L = **[PROPRIETARY]** [B-18] Maximum cell panel 1B dimension
W = **[PROPRIETARY]** [B-18] Maximum width of cells 1-4
C = 0.1875 in [B-7] Minimum chamfer dimension

$$R_{max} = \sqrt{\left(\frac{L}{2}\right)^2 + \left(\frac{W}{2} - C\right)^2} = 33.513 \text{ in (Dimension of the farthest point on the basket)}$$

A conservatively lower minimum radial gap between the basket and MPC shell of 0.07 in as compared to 0.08 in [B-19] is used in order to reduce the minimum inner radius of MPC shell and thereby maximizing the differential thermal expansion.

G_{min} = **[PROPRIETARY]** [B-19] (minimum radial gap between the basket and MPC shell, conservatively lower)

R_1 = **[PROPRIETARY]** [B-18] (Half of maximum width of the widest basket panel)

$R_3 = R_{max} + G_{min}$ = **[PROPRIETARY]** (Minimum inner radius of MPC shell)

The configuration of the MPC in the subject area is on the gap between the supports, therefore with the minimum shell radius, the width of the basket support will be:

X = **[PROPRIETARY]** [B-19] (Minimum spacing between the supports including the tolerance)

$H = R_3 - X/2$ = **[PROPRIETARY]** (Width of basket support)

The temperatures T_1, T_2 and T_3 are obtained from FLUENT case and data file "historm-mesh4" listed in Section B.4. α_1, α_2 and α_3 are the coefficients of thermal expansion of alloy-X at temperatures T_1, T_2 and T_3 respectively.

$T_0 = 65^oF$ (Reference temperature)
$T_1 = 622^oF$ (Radial average fuel basket temperature along the widest panel i.e. panel 1, at the hottest axial location – see Figure B.5.1)
$T_2 = 529^oF$ (Maximum temperature of the basket support at the hottest axial location)
$T_3 = 388^oF$ (MPC shell temperature at the hottest axial location)

$\alpha_1 = 9.69 \times 10^{-6}\,^{o}F^{-1}$ [B-2]
$\alpha_2 = 9.50 \times 10^{-6}\,^{o}F^{-1}$ [B-2]
$\alpha_3 = 9.17 \times 10^{-6}\,^{o}F^{-1}$ [B-2]

The radial thermal expansion δ is calculated using the equation below:

$$\delta = R_1\alpha_1(T_1 - T_0) + H\alpha_2(T_2 - T_0) - R_3\alpha_3(T_3 - T_0) \quad \text{-------------- (Eq. B.5.2)}$$

Substituting in eq. B.5.2, the net thermal expansion is δ = 0.076 inch. The cold radial gap between the widest panel and basket support is 0.0925 inch (calculated as R_3-R_1-H).

Method 2:

This method is to calculate the net thermal expansion of the farthest point on the basket i.e. point A as shown in Figure B.5.1. The net thermal expansion in this method is calculated based on the combined thermal expansion of Panel 1 and Panel 2 (see Figure B.5.1). The calculations are shown below:

Radial Thermal Expansion of the MPC Shell

R_3 = **[PROPRIETARY]** (Minimum inner radius of MPC shell, see Method 1)
$T_3 = 388^oF$ (Maximum MPC shell temperature at the hottest axial location)
$\alpha_3 = 9.17 \times 10^{-6}\,^{o}F^{-1}$ [B-2] (coefficient of thermal expansion of alloy-X at temperature T_3)
$\delta_{shell} = R_3\alpha_3(T_3-T_0)$ = **[PROPRIETARY]**

Thermal expansion of panel 1

$R_1 = 55.95/2 = 27.975$ in [B-7]
$T_1 = 622^oF$ (Radial average fuel basket temperature along the widest panel i.e. panel 1, at the hottest axial location)
$\alpha_1 = 9.69 \times 10^{-6}\,^{o}F^{-1}$
$\delta_1 = R_1\alpha_1(T_1-T_0) = 0.151$ in

Thermal expansion of panel 2

$R_2 = 37.28/2 = 18.64$ in [B-7]
$T_2 = 480^oF$ (Radial average fuel basket temperature along panel 2 at the hottest axial location)
$\alpha_2 = 9.42 \times 10^{-6}\,^{o}F^{-1}$
$\delta_2 = R_2\alpha_2(T_2-T_0) = 0.0729$ in

All the temperatures are obtained from FLUENT case and data file "historm-mesh4" listed in Section B.4.

Net thermal expansion of point A

$\delta_{net} = \sqrt{\delta_1^2 + \delta_2^2}$

$\delta_{net} = 0.1677$ in

Radial thermal expansion

$\delta = \delta_{net} - \delta_{shell}$

The net thermal expansion is $\delta = 0.0687$ inch. The worst case thermal expansion is lower than the minimum radial gap between the fuel basket and MPC shell (i.e. 0.08 inch). Since the radial gap between the basket and MPC is smaller in Method 2, the thermal expansion obtained from Method 2 is reported in Table B.5.3.

(b) Fuel Basket-to-MPC Axial Growth

The axial growth of the fuel basket relative to the MPC (δ_2) upon heating from a 65°F reference temperature to storage temperatures is computed as follows:

$$\delta_2 = H_b \alpha_1 [T_1 - T_o] - H_{cav} \alpha_2 [T_2 - T_o] \quad \text{--------------- (Eq. B.5.3)}$$

Where:

H_b: Maximum fuel basket height
H_{cav}: Minimum MPC cavity height
α_1, α_2: Coefficients of thermal expansion for fuel basket and MPC shell at T_1 and T_2 respectively for Alloy-X
T_1: Maximum average fuel basket temperature along the axial direction
T_2: Average MPC shell inner surface temperature

For conservatism in computing δ_2, the fuel basket thermal expansion coefficient (α_1) is overstated and that of MPC (α_2) understated. The temperatures T_1 and T_2 are obtained from FLUENT case and data file "historm-mesh4" listed in Section B.4. The required data for computing δ_1 is provided below:

$\alpha_1 = 9.42 \times 10^{-6}\ ^\circ F^{-1}$ (Table 3.3.1 [B-2])
$\alpha_2 = 8.97 \times 10^{-6}\ ^\circ F^{-1}$ (Table 3.3.1 [B-2])
H_b = **[PROPRIETARY]** [B-18]
H_1 = **[PROPRIETARY]** [B-19] (Minimum MPC cavity height including the fuel spacer)
H_2 = **[PROPRIETARY]** [B-19] (Maximum height of the fuel spacer)
$H_{cav} = H_2 - H_1$ = **[PROPRIETARY]**
T_1 = 470°F (conservatively overstated)
T_2 = 300°F (conservatively understated)

$T_o = 65°F$

Substituting the above data in Eq. B.5.3, the fuel basket axial growth is computed as $\delta_2 = 0.276$ in. The cold axial gap between the fuel basket and MPC is 0.9375 in.

c) <u>MPC-to-Overpack Radial Growth</u>

The radial growth of the MPC shell residing in the HI-STORM relative to the overpack upon heating from a 65°F reference temperature to storage temperatures is computed as follows:

$$\theta_1 = R_{shell}\alpha_1(T_1 - T_o) + R_g\alpha_3(T_3 - T_o) - R_{ovp}\alpha_2(T_2 - T_o) \quad \text{---------------- (Eq. B.5.4)}$$

where:

R_{shell}:	Maximum MPC shell outer radius
R_{ovp}:	Minimum Overpack inner shell inner radius
R_g:	Width of guide vanes on the overpack inner shell
α_1, α_2, α_3:	Coefficients of thermal expansion for MPC shell, overpack inner shell and guide vanes at T_1, T_2 and T_3 respectively
T_1:	Maximum temperature of MPC shell
T_2:	Minimum temperature of overpack inner shell
T_3:	Maximum temperature of guide vanes

The temperatures T_1, T_2 and T_3 are obtained from FLUENT case and data file "historm-mesh4" listed in Section B.4. The required data for computing θ_1 is provided below:

$R_{shell} = 34.25$ in [B-19]
$R_{ovp} = 36.5$ in [B-20]
D_{min} = **[PROPRIETARY]** [B-20], Minimum spacing between the guides
$R_g = R_{ovp} - D_{min}/2$ = **[PROPRIETARY]**
$\alpha_1 = 9.32\text{x}10^{-6}\ °F^{-1}$ (Table 3.3.1 [B-2])
$\alpha_2 = 5.53\text{x}10^{-6}\ °F^{-1}$ (Table 3.3.2 [B-2])
$\alpha_3 = 6.27\text{x}10^{-6}\ °F^{-1}$ (Table 3.3.2 [B-2])
$T_1 = 410°F$ (conservatively overstated)
$T_2 = 90°F$ (conservatively understated)
$T_3 = 255°F$ (conservatively overstated)
$T_o = 65°F$

Substituting the above data in Eq. B.5.4, θ_1 is computed as 0.107 in. The radial cold gap between the MPC and overpack inner shell is 0.25 in (calculated as $D_{min}/2 - R_{shell}$).

d) MPC-to-Overpack Axial Growth

The axial growth of the MPC shell residing in the HI-STORM relative to the overpack upon heating from a 65°F reference temperature to storage temperatures is computed as follows:

$$\theta_2 = H_{shell}\alpha_1(T_1 - T_o) - H_{ovp}\alpha_2(T_2 - T_o)) \qquad \text{---------------- (Eq. B.5.5)}$$

where:

H_{shell}:	MPC shell height
H_{ovp}:	Overpack cavity length
α_1, α_2:	Coefficients of thermal expansion for MPC shell and overpack inner shell at T_1 and T_2 respectively
T_1:	Average temperature of MPC shell outer surface
T_2:	Average temperature of overpack inner shell inner surface

The temperatures T_1 and T_2 are obtained from FLUENT case and data file "historm-mesh4" listed in Section B.4. The required data for computing θ_2 is provided below:

H_{shell} = **[PROPRIETARY]** [B-19]
H_{ovp} = **[PROPRIETARY]** [B-20]
$\alpha_1 = 9.11*10^{-6}$ °F^{-1} (Table 3.3.1 [B-2])
$\alpha_2 = 5.71*10^{-6}$ °F^{-1} (Table 3.3.2 [B-2])
T_1 = 310°F (conservatively overstated)
T_2 = 190°F (conservatively understated)
T_o = 65°F

Substituting the above data in Eq. B.5.5, θ_2 is computed as 0.264 in. The axial cold gap between the overpack and MPC is 16.1875 in.

The thermal expansion calculation results are summarized in Table B.5.3. All the differential expansions are less than the nominal gap.

B.5.3 MPC-32 Pressure Calculations

In this subsection, cavity pressures within the MPC-32 as a result of heatup from fuel decay heat are computed for the bounding scenario reported in Section B.5.1. The calculations cover the following conditions:

i) Minimum and Maximum MPC helium backfill pressures

ii) Normal long-term storage

iii) Hypothetical rod ruptures

The MPC-32, prior to sealing, is backfilled with helium. The helium backfill must be sufficient to produce an operating pressure (P_o) of 5.5 atm absolute (80.85 psia) at design basis maximum heat load of 28.74 kW. The required helium backfill pressure is specified as a minimum backfill pressure (P_b) at 70°F reference temperature. P_b is computed from Ideal Gas Law as follows:

$$P_b = \frac{460 + T_b}{460 + T_{cav}} P_o$$

where,

T_b = Reference temperature in °F (21°C (70°F))

T_{cav} = Average MPC cavity temperature at design heat load for normal long-term storage in °F

A helium backfill specification is set forth in Table 1.1 of the main report. Having defined the helium backfill specifications in Table 1.1 and based on fission gases release fractions (NUREG 1536 criteria [B-11]), MPC net free volume and initial fill gas pressure, maximum MPC-32 gas pressures with 1% (normal), 10% (off-normal) and 100% (accident condition) rod rupture are conservatively computed assuming:

1) Helium backfill pressure is at its maximum specified value (Table 1.1)
2) Rod fill gas volume based on IFBA fuel [B-14]
3) Design basis maximum heat load (28.74 kW)
4) Design ambient temperatures (Table 1.2)

For hypothetical rod rupture accident condition, MPC-32 pressures are conservatively computed assuming:

1) Bounding fuel burnup (70,000 MWD/MTU) [B-14]
2) 100% of rods fill gas and 30% fission gas release from ruptured fuel rods [B-14]. A concomitant effect of rod ruptures is the increased pressure and molecular weight of the cavity gases with enhanced rate of heat dissipation by internal helium convection and lower cavity temperatures. Though the effects are substantial under large rod ruptures, the 100% rod rupture accident is calculated

with no credit for increased heat dissipation under increased molecular weight of the cavity gases or due to increased pressure.

3) Lower bound MPC-32 free volume [B-16]
4) PWR non-fuel hardware (BPRA control elements and thimble plugs) are also included in the MPC pressure calculations. The presence of non-fuel hardware increases the effective basket conductivity, thus enhancing heat dissipation and lowering fuel temperatures as well as the temperature of the gas filling the space between fuel rods. The gas volume displaced by the mass of non-fuel hardware lowers the cavity free volume. These two effects, namely, temperature lowering and free volume reduction, have opposing influence on the MPC cavity pressure. The first effect lowers gas pressure while the second effect raises it. In the HI-STORM 100SA thermal analysis, the computed temperature field (with non-fuel hardware excluded) has been determined to provide a conservatively bounding temperature field. The MPC cavity free space is computed based on volume displacement with non-fuel hardware included. This approach ensures conservative bounding pressures. The pressure calculations assume all the 32 fuel locations to have BPRAs.

Employing the assumptions listed above, MPC-32 pressures (including helium from BPRAs) are computed in the EXCEL spreadsheet "mpc_pre" listed in Section B.4 and results reported in Table B.5.9. The MPC boundary pressures are below the design pressure limits specified in DC ISFSI FSAR [2].

B.5.4 Off-Normal and Accident Events

This section reports the temperature and pressure during the off-normal and accident events defined in the HI-STORM 100 FSAR. It is to be noted that postulation of 100% rods rupture coincident with off-normal and accident events is not required. It was eliminated because the peak fuel cladding temperatures for the accident conditions never exceed the regulatory accident temperature limit, which ensures no significant cladding failures would occur. This is consistent with the latest NRC guidance on fuel cladding in dry storage casks [B-5], which states "In order

to assure integrity of the cladding material ... For off-normal and accident conditions, the maximum cladding temperature should not exceed 570°C (1058°F)." The same result is confirmed for all accidents evaluated for the DC ISFSI. Therefore, no coincident 100% rod rupture postulations with an accident are evaluated. This is supported by the HI-STORM 100 CoC, Amendment 5.

To support the evaluation of off-normal and accident events defined in the HI-STORM 100 FSAR (Chapter 4, Section 4.6 [B-2]), the following conditions are analyzed:

(a) Off-Normal Pressure

This condition is defined as an off-normal ambient temperature (Table 1.2 of main report) co-incident with 10% rods rupture. The maximum helium backfill specified in Table 1.1 is used for the calculations reported in this sub-section. The principal effect of an off-normal ambient temperature is an increase of HI-STORM 100SA system temperatures by the difference (Δ) between the off-normal and normal ambient temperatures (Table 1.2 of main report). The effect of rods rupture has a direct effect on increasing the MPC-32 gas density which enhances MPC-32 thermosiphon cooling. For conservatism, effect of gas density increase is ignored and HI-STORM 100SA temperatures obtained by adding Δ to the baseline solution for normal storage conditions. The increased MPC-32 pressure is computed in EXCEL ("mpc_pre" computer file listed in Section B.4) and results are reported in Table B.5.10. The result confirms that the MPC off-normal pressure is below the off-normal design pressure [2].

(b) Off-Normal Ambient Temperature

This condition is defined as an off-normal ambient temperature (Table 1.2 of main report). The consequences of this event are bounded by the analysis for Off-Normal Pressure for Scenario 1. The principal effect of an off-normal ambient temperature is an increase of HI-STORM system temperatures by the difference (Δ) between the off-normal and normal temperatures (Table 1.2 of main report). These temperatures are reported in Table B.5.4. All the MPC and HI-STORM 100SA component temperatures are below their temperature limits. The MPC pressure due this event is bounded by the event (a) discussed above.

(c) Partial Blockage of Air Inlets

This condition is defined as 50% blockage of all the inlet ducts. The resulting decrease in flow area increases the inlet air flow resistance. The effect of increased flow resistance on fuel temperature is analyzed on FLUENT under baseline operation (normal ambient temperature) and bounding scenario.

The fuel cladding, MPC and HI-STORM 100SA component temperatures obtained from the FLUENT simulations are reported in Table B.5.4. All the reported temperatures are below their temperature limits. It is also to be noted that the temperatures remain not only below the off-normal event limits, but the temperatures for all SFSC components remain below their short-term limits for this event. The MPC-32 pressure is computed in EXCEL and is reported in Table B.5.10. The result is below the off-normal design pressure (specified in DC ISFSI FSAR [2])

(d) Fire Accidents

The HI-STORM fire accident is evaluated based on the fire conditions specified in Section 4.6 of Reference B-2. Based on NUREG-1536 [B-11] guidelines and 10 CFR 71 [B-15], the following fire parameters are assumed:

1. The average emissivity coefficient on the overpack outer surfaces is 0.9.
2. The average flame temperature is 1475°F (800°C).
3. The fuel source extends horizontally by 1 m (40 in) beyond the external surface of the cask.
4. A conservative forced convection heat transfer coefficient of 4.5 Btu/(hr $\times$ ft^2 $\times$ °F) is applied to exposed overpack surfaces during the short-duration fire.
5. No solar insolation is applied during the duration of fire. However, solar insolation is applied after the fire extinguishes i.e. during post-fire conditions.

Based on the 189 liters (50 gallon) fuel volume, HI-STORM 100SA overpack outer diameter (3.3655 m (11.04 ft)) and the 1 m fuel ring width, the fuel ring surrounding the overpack

covers 13.715 m^2 (147.62 ft^2) and has a depth of 1.38 cm (0.543 in). From this depth and a linear fuel consumption rate of 0.381 cm/min (0.15 in/min), the fire duration is calculated to be 3.62 minutes (217 seconds). The linear fuel consumption rate of 0.381 cm/min (0.15 in/min) is a lowerbound value from Sandia Report [B-13]. Use of a lowerbound linear fuel consumption rate conservatively maximizes the duration of the fire. However, a transient study is conducted for conservative fire duration of 240 seconds.

Since Scenario 1 listed in Section 1.4 of this report results in the most limiting temperature field, it is adopted as the initial condition for fire accident transient evaluation. The results of this evaluation are presented in Table B.5.5. Post-fire evaluations are continued till temperatures of all the components of MPC and overpack reach their maximum temperatures and begin to recede. The post-fire transient analysis results are summarized in Table B.5.5. The results show that the fuel temperature rise is small. All MPC and overpack components' temperatures remain below temperature limits specified in Reference 2. Consequently, the impact on the MPC internal helium pressure will be small and the value is reported in Table B.5.10.

(e) <u>100% Blockage of Inlet Ducts</u>

This event is defined as a complete blockage of all four bottom inlets. The immediate consequence of a complete blockage of the air inlet ducts is that the normal circulation of air for cooling the MPC-32 is stopped. **[PROPRIETARY**

]. As the temperatures of the MPC-32 and its contents rise, the rate of heat rejection will increase correspondingly. Under this condition, the temperatures of the overpack, the MPC-32 and the stored fuel assemblies will rise as a function of time.

This accident condition is a short duration event that will be identified and corrected by scheduled periodic surveillance at the ISFSI site. The worst possible scenario is a complete loss of ventilation air for the period between scheduled surveillances (24 hours). To conservatively evaluate the effect of complete loss of air supply through the bottom inlets, a

substantially greater duration blockage (32 hrs) is assumed. The thermal model is same as that constructed for normal storage conditions except for the bottom inlet ducts which are assumed to be impervious to air. Using this blocked duct model, a transient thermal solution of the HI-STORM 100SA System, with the normal storage steady state temperature field as the initial condition, is obtained. The results of the blocked ducts transient analysis are presented in Table B.5.6. The co-incident MPC pressure is also computed and reported in Table B.5.10. The result is confirmed to be below the accident pressure limit (specified in DC ISFSI FSAR [2]).

(f) Extreme Ambient Temperature

This event is defined as a substantially elevated temperature 52°C (125°F) that is postulated to persist for a 3-day period (Table 1.2 of main report). To bound the event the evaluation assumes that the extreme temperature persists for a sufficient duration to reach steady state conditions. Using the baseline condition (steady state conditions, normal ambient temperature and design heat load) the temperatures of the HI-STORM 100SA system are conservatively assumed to rise by the difference between the extreme and normal ambient temperatures. The HI-STORM 100SA extreme ambient temperatures computed in this manner are reported in Table B.5.7. The MPC and HI-STORM 100SA temperatures are well below the accident temperature limits.

The co-incident MPC-32 pressure is computed (EXCEL file "mpc_pres.xls" listed in Section B.4) and reported in Table B.5.10. The result is below the accident design pressure limit (specified in DC ISFSI FSAR [2]).

(g) Burial Under Debris Accident

At the storage site, no structures are permitted over the casks. Minimum regulatory distances from the storage site to the nearest site boundary precludes close proximity of vegetation. There is no credible mechanism for the HI-STORM 100SA System to become completely buried under debris. However, for conservatism, a complete burial under debris scenario is evaluated.

To demonstrate the inherent safety of the HI-STORM 100SA System, a bounding analysis that considers the debris to act as a perfect insulator is assumed. Under this scenario, the contents of the HI-STORM System will undergo a transient heat up under adiabatic conditions. The minimum available time (Δτ) for the fuel cladding to reach the accident limit depends on the following: (i) thermal inertia of the cask, (ii) the cask initial conditions, (iii) the spent nuclear fuel decay heat generation and (iv) margin between the initial cladding temperature and accident temperature limit. To obtain a lowerbound on Δτ the HI-STORM 100SA thermal inertia (item (i)) is understated, the cask initial temperature (item (ii)) is maximized, maximum permissible decay heat (item (iii)) assumed and cladding temperature margin (item (iv)) understated. A set of conservatively postulated input parameters for items (i) through (iv) are summarized in Table B.5.8. Using these parameters Δτ is computed as follows:

$$\Delta\tau = \frac{m \times c_p \times \Delta T}{Q}$$

where:
Δτ = Allowable burial time (sec)
m = Mass of HI-STORM 100SA System (kg)
c_p = Specific heat capacity (J/kg×°C)
ΔT = Permissible temperature rise (°C)
Q = Decay heat load (W)

Substituting the parameters from Table B.5.8, a substantial allowable burial time 261,870 sec (72.7 hrs) is obtained for the design basis decay heat load. The burial under debris accident pressure is reported in Table B.5.10 and is below the accident design pressure limit (specified in DC ISFSI FSAR [2]).

B.5.5 HI-STORM in Cask Transfer Facility (CTF)

This condition consists of a loaded HI-STORM overpack that cannot be removed from the CTF [B-10] because of a failure of the equipment that lifts the HI-STORM. Under such a condition, the flow of air to the bottom inlet vents would be restricted. A steady state evaluation for this condition has been performed using the 3-D FLUENT CFD model for the bounding heat load scenario i.e. Scenario 1 listed in Section 1.4. For the evaluation of the loaded HI-STORM in the

CTF, the diameter of the hypothetical reflecting cylinder that surrounds the cask matches the CTF cylinder inner diameter. **[PROPRIETARY**

]. A quarter symmetric 3D model of a HI-STORM placed in the CTF is shown in Figure B.5.2. The airflow outside the HI-STORM system is modeled as **[PROPRIETARY**

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This is in accordance with the turbulence modeling methodology approved by the USNRC in the HI-STORM 100 docket [B-2]. For the k-ω turbulence model, y^+ should be less than 4 or 5 to ensure an adequate level of mesh to resolve the viscosity affected region near the wall [B-3]. **[PROPRIETARY**

]. The HI-STORM in the CTF configuration is modeled without the CTF wedge assemblies. Based on the previous thermal analysis (Appendix H in [B-16]), the effect of CTF wedge assemblies on the temperature field is extremely small. Therefore, it is considered safe to ignore them in this analysis.

To provide an additional assurance on the thermal analysis results for the condition of HI-STORM 100SA system placed in the CTF, a grid sensitivity study is performed similar to that discussed in Section B.5.1. Since the airflow between the CTF and HI-STORM system is critical to the thermal performance of the system, the mesh in this region is also modified. A total of three meshes are constructed and a brief summary of the different sets of grids evaluated is provided in Table B.5.11. A number of grids are generated to study the effect of mesh refinement on the fuel and component temperatures. All sensitivity analyses were carried out for Scenario 1 listed in Table 1.3. Table B.5.11 gives a brief summary of the different sets of grids evaluated and PCT results. Per ASME V&V [B-17], it is recommended that the mesh refinement in 3D be atleast 2.2 times the previous mesh. However, this recommendation may lead to significantly large number of mesh cells, thereby increasing the computational time tremendously. This recommended criterion is satisfied by Mesh 1, 4 and 5 specified in Table B.5.11. To provide additional assurance, intermediate meshes such as Mesh 2 and 3 are generated to show that the effect of mesh refinement is small considering the margins to safety.

As can be seen from Table B.5.11, the finest mesh (Mesh 5) is approximately **[PROPRIETARY]** times the total mesh size of the baseline mesh (Mesh 1). Even with such a

large mesh refinement, the change in PCT is extremely small. The solutions from the different grids used are in the asymptotic range. The small PCT difference between the meshes is negligible compared to the available PCT safety margin. Therefore it can be concluded that Mesh 4 reports the reasonably converged results. To provide further assurance of convergence, the sensitivity results are evaluated in accordance with the ASME V&V 20-2009 [B-17]. Towards this end the Grid Convergence Index (GCI), which is a measure of the solution uncertainty, is computed in Appendix E of this report. Since Meshes 1, 4 and 5 satisfy the recommended criterion specified in Reference B-17, the GCI is computed using these three meshes and it is computed as **[PROPRIETARY]**. Based on the above results, Mesh 4 grid layout is adopted for the thermal analysis of the HI-STORM 100SA System. Therefore, the thermal analysis of the HI-STORM 100SA System in the CTF is reasonably accurate and the safety of the system during this condition is not challenged.

The results from the converged mesh of HI-STORM placed in the CTF are reported in Table B.5.12. The fuel cladding temperature and other MPC and overpack temperatures are well below their respective long-term temperature limits. Therefore, the HI-STORM can be loaded inside the CTF for an indefinite time for the Diablo Canyon design basis maximum heat load of up to 28.74 kW. The co-incident MPC-32 pressure is computed (EXCEL file "mpc_pre" listed in Section B.4) and reported in Table B.5.12. The result is below the normal design pressure limit (specified in DC ISFSI FSAR [2]).

B.5.6 **[PROPRIETARY**

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B.5.7 Summary and Conclusions

The results of the evaluations described in the previous sub-sections indicate that the thermal-hydraulic performance of the HI-STORM 100SA System components continues to satisfy all applicable component temperature and MPC internal pressure limits for the two different scenarios discussed in Section 1.4. It can therefore be concluded that the HI-STORM 100SA System thermal design is in compliance with 10CFR 72 requirements for Diablo Canyon specific heat load.

B.6 REFERENCES

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[B-8] "Diablo Canyon Enclosure Vessel", Holtec Drawing 4459, Revision 10.

[B-9] "HI STORM 100SA Assembly", Holtec Drawing 4461, Revision 14.

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[B-18] "Diablo Canyon MPC-32 Fuel Basket", Holtec Drawing 4407, Revision 18.

[B-19] "Diablo Canyon MPC-32 Enclosure Vessel", Holtec Drawing 4408, Revision 22.

[B-20] "HI-STORM 100SA", Holtec Drawing 4425, Revision 18.

Table B.5.1

NORMAL LONG-TERM STORAGE TEMPERATURES FOR UNIFORM LOADING USING DIFFERENT MESHES

Mesh No	Total Mesh Size	PCT (°C)	Permissible Limit (°C)	Clad Temperature Margin (°C)
1			400	
2			400	
3			400	
4 (Licensing Basis Mesh)			400	
5			400	

Note 1: The grid sensitivity studies are performed for Scenario 1 i.e. uniform storage condition specified in Table 1.3.

Note 2: Because the flow field in the annulus between MPC shell and overpack inner shell is in the transitional turbulent regime, the value of y^+ at the wall-adjacent cell should be on the order of 1 to ensure the adequate level of mesh refinement is reached to resolve the viscosity affected region near the wall [B-3]. For each above mesh, y^+ is maintained at about **[PROPRIETARY]**.

Note 3: Mesh 4 is adopted for all licensing basis calculations.

Table B.5.2

BOUNDING HI-STORM 100SA NORMAL LONG-TERM STORAGE MPC AND OVERPACK TEMPERATURES

Component	Scenario 1 Temperature °C (°F)	Scenario 2 Temperature °C (°F)	Temperature Limit °C (°F)
Fuel Cladding			400 (752)
MPC Basket			385 (725)
Basket Periphery			385 (725)
MPC Shell			232 (450)
Overpack Inner Shell			177 (350)
Overpack Outer Shell			177 (350)
Lid Bottom Plate			177 (350)
Lid Top Plate			177 (350)
Overpack Body Concrete[2]			149 (300)
Overpack Lid Concrete[2]			149 (300)
Average Air Outlet			-
Note 1: Since the PCT and cask component temperatures are higher in Scenario 1, it is adopted for all licensing basis calculations.			

2 Maximum section average temperature is reported.

Table B.5.3

HI-STORM 100SA DIFFERENTIAL THERMAL EXPANSIONS DURING LONG TERM NORMAL STORAGE

Gap Description	**Cold Gap (U), (inch)**	**Differential Expansion (V), (inch)**	**Is Free Expansion Criteria Satisfied (i.e. U > V)**
Fuel Basket-to-MPC Radial Gap	0.08	0.0687	Yes
Fuel Basket-to-MPC Axial Gap	0.9375	0.276	Yes
MPC-to-Overpack Radial Gap	0.25	0.107	Yes
MPC-to-Overpack Axial Gap	16.1875	0.264	Yes

Table B.5.4

OFF-NORMAL CONDITION MAXIMUM HI-STORM 100SA TEMPERATURES

Component	Off-Normal Ambient Temperature[3] °C (°F)	Partial Inlet Ducts Blockage °C (°F)	Off-Normal Limit °C (°F)
Fuel Cladding			570 (1058)
MPC Basket			510 (950)
Basket Periphery			510 (950)
MPC Shell			413 (775)
Overpack Inner Shell			204 (400)
Overpack Outer Shell			316 (600)
Lid Bottom Plate			204 (400)
Lid Top Plate			288 (550)
Overpack Body Concrete[4]			177 (350)
Overpack Lid Concrete[4]			177 (350)

3 Obtained by adding the difference between off-normal ambient and normal temperature difference (19.4°C (35°F)) to bounding normal condition temperatures (Scenario 1) reported in Table B.5.2.

4 Maximum section average temperature is reported.

Table B.5.5

HI-STORM 100SA FIRE AND POST-FIRE ACCIDENT ANALYSIS RESULTS

Component	Initial Condition °C (°F)	End of Fire Condition °C (°F)	Post-Fire Cooldown °C (°F)	Time to Reach Maximum Temperature[5]	Temperature Limit °C (°F)
Fuel Cladding					570 (1058)
MPC Basket					510 (950)
Basket Periphery					510 (950)
MPC Shell					413 (775)
Overpack Inner Shell					204 (400)
Overpack Outer Shell		6	6		316 (600)
Overpack Body Concrete[7]					177 (350)
Overpack Lid Concrete[7]					177 (350)

5 Time starts after the beginning of fire.

6 Volume average temperature is reported. An extremely localized area near the inlet ducts experiences higher temperatures.

7 Maximum section average temperature is reported.

Table B.5.6

RESULTS OF HI-STORM 100SA 32-HOURS BLOCKED INLET DUCTS THERMAL ANALYSIS

Component	Initial Condition °C (°F)	Final Condition °C (°F)	Accident Temperature Limit °C (°F)
Fuel Cladding			570 (1058)
MPC Basket			510 (950)
Basket Periphery			510 (950)
MPC Shell			413 (775)
Overpack Inner Shell			204 (400)
Overpack Outer Shell			316 (600)
Lid Bottom Plate			204 (400)
Lid Top Plate			288 (550)
Overpack Body Concrete[8]			177 (350)
Overpack Lid Concrete[8]			177 (350)

8 Maximum section average temperature is reported.

Table B.5.7

EXTREME ENVIRONMENTAL CONDITION MAXIMUM HI-STORM 100SA TEMPERATURES

Component	Temperature[9] °C (°F)	Accident Limit °C (°F)
Fuel Cladding		570 (1058)
MPC Basket		510 (950)
Basket Periphery		510 (950)
MPC Shell		413 (775)
Overpack Inner Shell		204 (400)
Overpack Outer Shell		316 (600)
Lid Bottom Plate		204 (400)
Lid Top Plate		288 (550)
Overpack Body Concrete[10]		177 (350)
Overpack Lid Concrete[10]		177 (350)

9 Obtained by adding the difference between extreme ambient and normal temperature difference (33.3°C (60°F)) to bounding normal condition temperatures (Scenario 1) reported in Table B.5.2.

10 Maximum section average temperature is reported.

Table B.5.8

SUMMARY OF INPUTS FOR BURIAL UNDER DEBRIS ANALYSIS

Thermal Inertia Inputs[11]: M (Lowerbound HI-STORM 100SA Weight) Cp (Carbon steel heat capacity)[12]	 99790 kg (220,000 lb) 419 J/kg-K (0.1 Btu/lbm-°F)
Cask initial temperature (clad max. temperature assumed)	
Q (Decay heat)	28.74 kW (0.0982 MBtu/hr)
ΔT (clad temperature margin)[13]	

11 Thermal inertia of fuel, basket and MPC is conservatively neglected.

12 Used carbon steel's specific heat since it has the lowest heat capacity among the principal materials employed in MPC and overpack construction (carbon steel, stainless steel and concrete).

13 The clad temperature margin is conservatively understated in this table.

Table B.5.9

SUMMARY OF MPC CONFINEMENT BOUNDARY PRESSURES[14]

Condition	Gauge Pressure kPa (psig)[15]	Pressure Limit kPa (psig)	MPC Cavity Average Temperature °C (°F)
Maximum Initial backfill at 21.1°C (70°F) Normal condition (no rods rupture) Normal condition (1% rods ruptured)		- 689.3 (100) 689.3 (100)	
Off-normal (10% rods ruptured)		689.3 (100)	
Accident (100% rods ruptured)		1378.6 (200)	

14 Per NUREG-1536, pressure analyses with postulated rods rupture is performed assuming release of 100% of ruptured fuel rods fill gas and 30% of the significant radioactive gaseous fission products.

15 The pressures reported in this table are computed assuming the helium backfill pressure is at its upper bound limit (Table 1.1 of main report).

Table B.5.10

OFF-NORMAL AND ACCIDENT CONDITION MAXIMUM MPC PRESSURES

Condition	MPC Cavity Average Temperature °C (°F)	Gauge Pressure kPa (psig)	Pressure Limit kPa (psig)
Off-Normal Conditions			
Off-Normal Pressure			689.3 (100)
Partial Blockage of Inlet Ducts			689.3 (100)
Accident Conditions			
Extreme Ambient Temperature			1378.6 (200)
100% Blockage of Air Inlets @ 32 Hr			1378.6 (200)
HI-STORM Fire Accident			1378.6 (200)
Burial Under Debris @ Maximum Allowable Burial Time			1378.6 (200)

Table B.5.11

PEAK CLADDING TEMPERATURES FOR HI-STORM 100SA IN CTF USING DIFFERENT MESHES

Mesh No	Total Mesh Size	PCT (°C)	Permissible Limit (°C)	Clad Temperature Margin (°C)
1			400	
2			400	
3			400	
4 (Licensing Basis Mesh)			400	
5			400	

Note 1: The grid sensitivity studies are performed for Scenario 1 i.e. uniform storage condition specified in Table 1.3.

Note 2: Because the flow field in the annulus between MPC shell & overpack inner shell and overpack outer shell and CTF wall is in the turbulent regime, the value of y^+ at the wall-adjacent cell should be on the order of 1 to ensure the adequate level of mesh refinement is reached to resolve the viscosity affected region near the wall [B-3]. **[PROPRIETARY]**

Table B.5.12

HI-STORM 100SA NORMAL STORAGE MPC AND OVERPACK TEMPERATURES AND PRESSURE IN THE CASK TRANSFER FACILITY (CTF)[16]

Component	Temperature °C (°F)	Temperature Limit °C (°F)
Fuel Cladding		400 (752)
MPC Basket		385 (725)
Basket Periphery		385 (725)
MPC Shell		232 (450)
Overpack Inner Shell		177 (350)
Overpack Outer Shell		177 (350)
Lid Bottom Plate		177 (350)
Lid Top Plate		177 (350)
Overpack Body Concrete[17]		149 (300)
Overpack Lid Concrete[17]		149 (300)
Average Air Outlet		-
MPC Cavity Pressure kPa (psig)		
Normal Condition (No Rod Rupture)		689.3 (100)

16 The temperatures and cavity pressure for HI-STORM in the CTF bounds the normal long term storage temperatures and pressure.

17 Maximum section average temperature is reported.

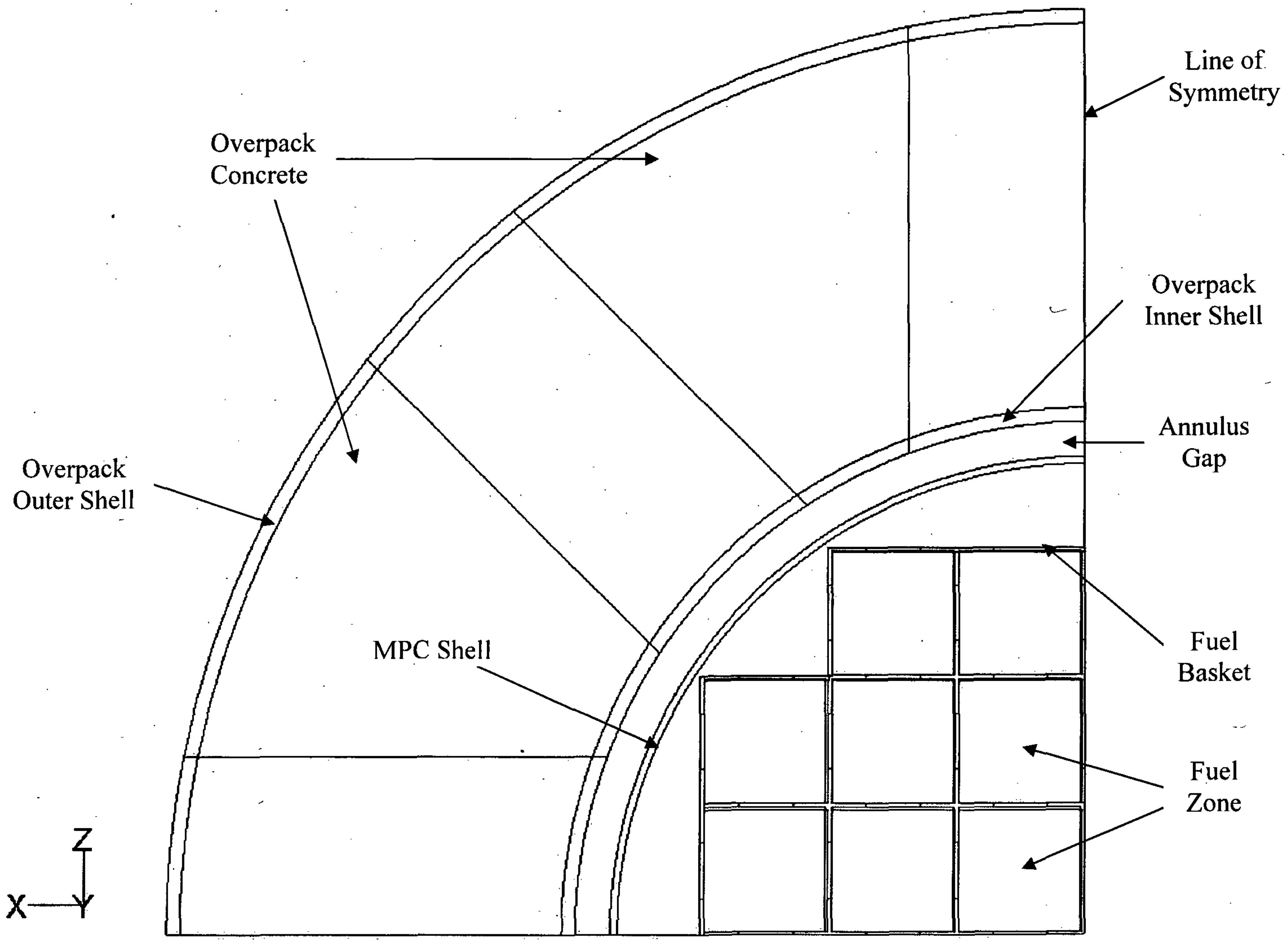

Figure B.2.1: Planar View of HI-STORM 100SA MPC- 32 Quarter Symmetric 3-D Model

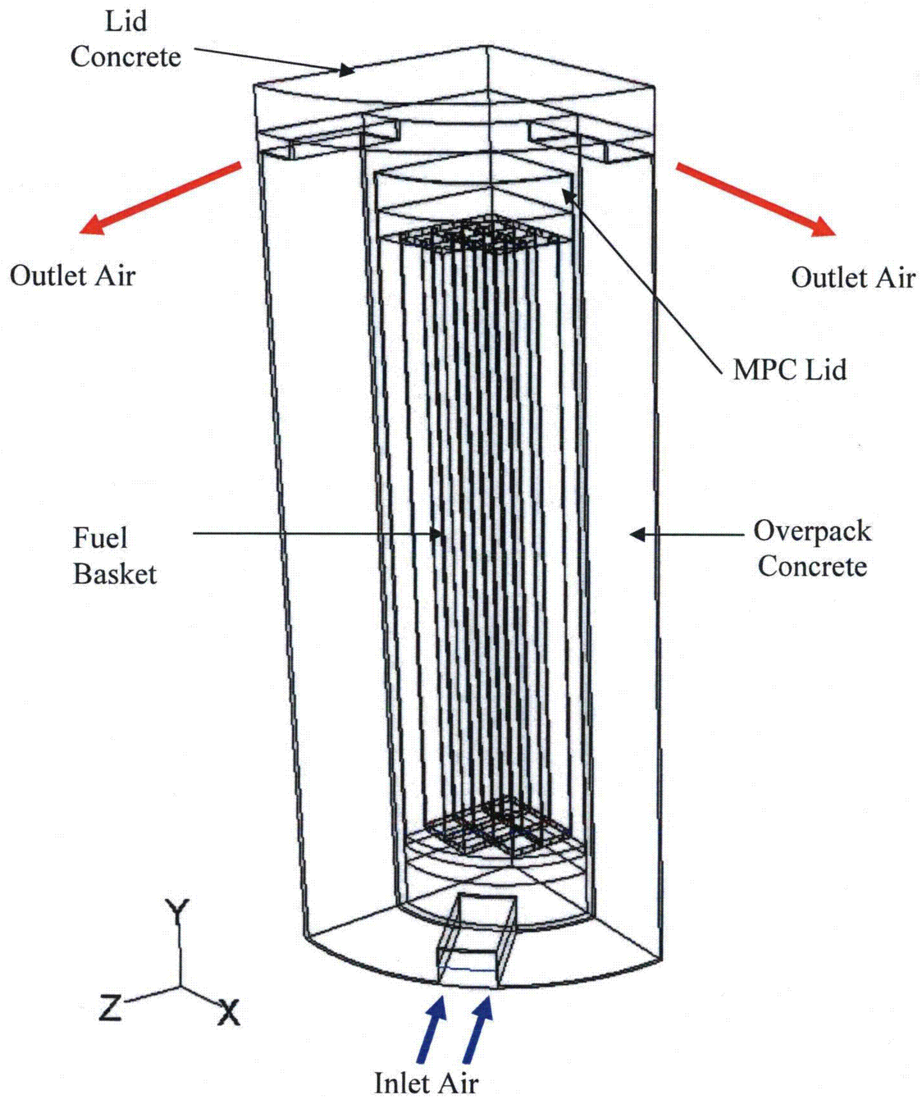

Figure B.2.2: HI-STORM 100SA MPC- 32 Quarter Symmetric 3-D Model

[PROPRIETARY]

Figure B.5.1: Basket Geometry

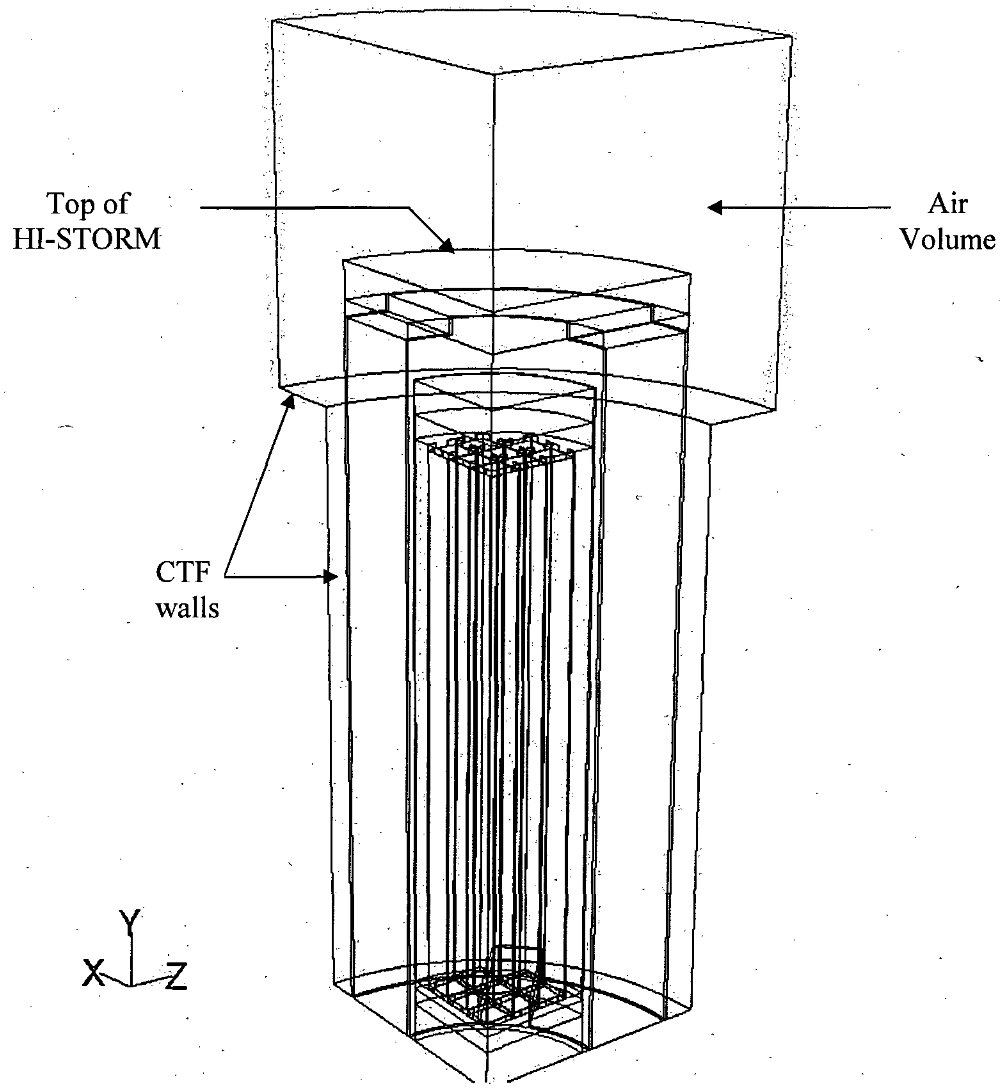

Figure B.5.2: Quarter Symmetric 3-D Model of HI-STORM 100SA Placed in CTF

Appendix C

Thermal Analysis of MPC-32 in HI-TRAC
(Total 20 Pages)

C.1 INTRODUCTION

Calculations to evaluate the temperature and pressure fields in the HI-TRAC loaded MPC-32 when the HI-TRAC is in a vertical (upright) orientation are presented in this appendix with a 3-D modeling methodology. The 3D methodology to model the MPC in the HI-TRAC with credit for thermosiphon action within the MPC and in the water jacket has been approved by the USNRC in HI-STORM FW FSAR (Docket 72-1032). The thermal analysis methodology adopted and documented in this appendix is exactly the same as that approved in the HI-STORM FW FSAR. For a bounding evaluation, the limiting fuel storage configuration, i.e. Scenario 1 in Table 1.3, is analyzed. Conditions evaluated include normal on-site transfer, water loss accident condition, fire accident and tornado missile impact.

C.2 METHODOLOGY AND ASSUMPTIONS

The thermal analysis methodologies and assumptions used in modeling MPC-32 have been presented in Appendix B of this report. The specific approaches and assumptions used to perform the calculations in this appendix are presented in the following.

The calculations to determine the temperature fields during normal on-site transfer and water loss accident conditions are performed using 3-D Computational Fluid Dynamics (CFD) models. The steps performed for each evaluated condition are as follows:

1. The CFD model of the MPC and HI-TRAC is generated using a pre-processor of FLUENT [C-2] program. To ensure an adequate representation of the features of the fuel and basket within the MPC, MPC-32 and HI-TRAC Overpack, a 3-D quarter symmetric model is constructed.
2. Material thermal-hydraulic properties are applied to the model.
3. Loads and boundary conditions are applied to the model, and steady-state thermal solutions are obtained.

The 3-D models implemented to analyze the HI-TRAC have the following key attributes:

1. The MPC portion of the model contains a porous medium to represent the fuel, the top and bottom plenum, and a fluid (helium) zone in the basket-to-shell downcomer region.

2. Radiation heat transfer between the periphery of the fuel basket and the inner surface of the MPC shell is included using **[PROPRIETARY]**.

3. In the radial direction, the HI-TRAC portion of the model explicitly contains five layered solid zones that represent the inner shell, the radial lead shield, the outer shell, the water jacket and the enclosure shell.

4. In the axial direction, the pool lid steel and lead layers are explicitly modeled below the MPC, and the top lid and associated air space are explicitly modeled above the MPC.

5. The model includes all three modes of heat transfer – conduction, convection and radiation. The thermosiphon mechanism within the MPC cavity and water jacket is included.

6. **[PROPRIETARY]**

7. For modeling natural convection heat dissipation from external surfaces of HI-TRAC, a conservatively postulated surface heat transfer coefficient is employed [C-1]. **[PROPRIETARY**

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There are several features of the CFD models that differ from the equipment designs. These differences are modeling simplifications that introduce small conservatisms in the thermal analysis. The following differences exist:

1. A small portion of the HI-TRAC top flange is not modeled as solid carbon steel ring. Instead, the inner and outer shells and the intermediate radial lead are extended to occupy this small portion of flange space. This results in carbon steel being replaced with lower conductivity lead and is, therefore, conservative.

2. The circular hole in the HI-TRAC lid is modeled as a rectangular opening. The modeled opening area is lower than the actual area, therefore conservatively reduces the convective heat transfer from the top of the MPC.

3. The outer diameter of HI-TRAC lid is modeled equal to the outer diameter of the outer shell. This results in an area of the top lid that is normally exposed directly to the ambient being occupied with additional material through which any heat might flow and is, therefore, conservative.

4. The outer diameter of lead shield in the pool lid is modeled to align with the outer diameter of radial lead shield. This results in carbon steel being replaced with lower conductivity lead and is, therefore, conservative.

5. The height of bottom flange is modeled as 2.5" instead of 2". This results in a small portion of lower conductivity lead being replaced by carbon steel. Considering that there is no significant heat transfer at the bottom of HI-TRAC, this will not affect the thermal performance significantly.

6. A vertical wall is located near the HI-TRAC overpack when MPC is loaded in the HI-TRAC. The closest distance between the vertical wall and HI-TRAC outer surface is 25 inch [C-8], which is significantly larger than the boundary layer thickness due to natural convection. There is no other obstruction that may block the air flow to the HI-TRAC. Therefore, the side wall is not modeled in the analysis.

7. The insolation on the exposed MPC lid top surface is not considered in the model. The effect of insolation energy on exposed MPC lid is expected to small, due to the short transfer time and the small diameter of HI-TRAC lid hole.

8. The most severe environment factor for short-term operation – bounding ambient temperature 100°F and 10CFR71 insolation level-were coincidentally imposed on the system.

9. **[PROPRIETARY**

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[PROPRIETARY

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C.3 INPUT DATA

The first step in evaluating the normal and accident on-site transport conditions is to calculate the effective thermal conductivities of the annular gap between the MPC and the HI-TRAC inner shell. These calculations are performed in a MathCAD file, k-airgap.xmcd, listed in Section C.4.

Geometric data for the fuel basket and MPC are taken from the drawings [C-4] and [C-5]. The fuel basket flow resistance inputs are taken from the Holtec topical report on hydraulic resistance [C-3]. Geometric data for the HI-TRAC 125D, subject to the modeling differences listed in section C.2, are taken from the HI-TRAC drawing [C-6]. The thermal properties of individual component material and effective fuel and basket properties are referenced from HI-STORM FSAR [C-1].

The thermal evaluations of normal on-site transfer are performed for the bounding scenario discussed in Appendix B. A solar absorptivity coefficient of 1.0 is applied to all exposed overpack surfaces.

C.4 COMPUTER PROGRAM AND FILES

For the normal and accident conditions of on-site transfer, the HI-TRAC is analyzed for the limiting scenario (Scenario 1 in Section 1.4).

The computer code FLUENT Version 6.3.26 is used in these thermal calculations. The list of input and output files is presented below:

GAMBIT

```
Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Gambit\HI-TRAC

06/05/2012  01:45 PM       214,958,080    hitrac-mesh1b.dbs
```

```
06/05/2012  01:41 PM       112,654,595   hitrac-mesh1b.msh
06/08/2012  10:09 AM       300,036,096   hitrac-mesh2b.dbs
06/08/2012  10:02 AM       271,359,526   hitrac-mesh2b.msh
06/11/2012  08:11 AM       513,527,808   hitrac-mesh3b.dbs
06/11/2012  07:52 AM       722,369,194   hitrac-mesh3b.msh
```

FLUENT

```
Normal Onsite Transfer
Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Fluent\HI-TRAC

06/06/2012  10:19 PM     1,163,531,866   hitrac-mesh1b.dat
06/06/2012  08:18 AM        65,970,943   hitrac-mesh1b.cas
06/10/2012  10:23 PM     2,458,333,891   hitrac-mesh2b.dat
06/08/2012  01:52 PM       153,020,387   hitrac-mesh2b.cas
06/12/2012  10:02 PM     5,703,241,346   hitrac-mesh3b.dat
06/13/2012  06:23 AM       382,405,611   hitrac-mesh3b.cas
```

```
Water Jacket Loss Accident
Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191\Fluent\WJL

06/15/2012  08:24 AM       382,405,627   hitrac-mesh3b-waterloss.cas
06/15/2012  08:26 AM     5,703,182,300   hitrac-mesh3b-waterloss.dat
```

MISCELLANEOUS

```
Directory of G:\Projects\1073\REPORTS\Thermal Reports-HI-2125191

06/26/2012  02:41 PM            30,720   Boil_calculation.xls
05/18/2010  01:53 PM            61,195   k-airgap.xmcd
```

C.5 RESULTS AND CONCLUSIONS

C.5.1 Normal On-site Transfer Temperatures

[PROPRIETARY

]Grid Sensitivity Studies

To achieve grid independent CFD results, a grid sensitivity study is performed on HI-TRAC 100SA thermal model similar to grid sensitivity studies carried out in Appendix B. **[PROPRIETARY]**. A number of grids are generated to study the effect of mesh refinement on the fuel and component temperatures. All sensitivity analyses were carried out for Scenario 1 listed in Table 1.3. Table C.1 gives a brief summary of the different sets of grids evaluated and PCT results. Per ASME V&V [B-17], it is recommended that the mesh refinement in 3D be at least 2.2 times the previous mesh. However, this recommendation may lead to significantly large number of mesh cells (as seen in Table C.1), thereby increasing the computational time tremendously. Based on the discussion reported in Section B.5.1, though more than three meshes are evaluated, the PCT is essentially the same. Therefore, it is sufficient to perform the thermal analysis of HI-TRAC on three meshes to show mesh convergence.

As can be seen from Table C.1, the finest mesh (Mesh 3) is **[PROPRIETARY]** times the total mesh size of the baseline mesh (Mesh 1). Even with such a large mesh refinement, the change in PCT is extremely small. The solutions from the different grids used are in the asymptotic range. The small PCT difference between the meshes is negligible compared to the available PCT safety margin. Therefore it can be concluded that Mesh 3 reports the reasonably converged results. To provide further assurance of convergence, the sensitivity results are evaluated in accordance with the ASME V&V 20-2009 [B-17]. Towards this end the Grid Convergence Index (GCI), which is a measure of the solution uncertainty, is computed in Appendix E of this report. Since Meshes 1, 2 and 3 satisfy the recommended criterion specified in Reference B-17, the GCI is computed using these three meshes and it is computed as **[PROPRIETARY]**. Based on the above results, Mesh No 3 grid layout is adopted for the thermal analysis of the HI-TRAC accident conditions.

<u>Maximum Temperatures</u>

The HI-TRAC was evaluated for the limiting Scenario 1 decay heat load distribution (see Section 1.4). The results of the FLUENT CFD analyses for normal on-site transfer conditions are obtained and the results are post-processed interactively with the FLUENT program with discrete numeric results are presented in Table C.2. The results show that the peak fuel cladding temperature during

normal on-site transfer conditions is below its temperature limit for both moderate and high burnup fuel. Therefore, use of a Supplemental Cooling System (SCS) is not mandatory.

C.5.2 Water Loss Accident Transfer Temperatures

The thermal analysis for the complete loss of water from water jacket (accident condition) is performed and the results are reported in Table C.3. The peak fuel cladding temperatures for such an accident is below its temperature limit. All the MPC & HI-TRAC overpack component temperatures are also below their respective temperature limits.

C.5.3 Fire Accident On-site Transfer Temperatures

The purpose of this calculation is to determine the duration and effects of an assumed 50-gallon flammable liquid fuel fire on the HI-TRAC transfer cask. The duration of the fire is calculated based on the fuel volume and fuel consumption rate. The thermal inertia of the loaded HI-TRAC is determined based on component weights and specific heat capacities. The heat input from the fire and SNF decay is determined, and a bounding temperature rise of the HI-TRAC components is determined assuming an adiabatic heatup with uniform heat generation. The ablation of the jacket water is credited to reduce the heat input to the HI-TRAC internals.

The calculations are presented in Appendix D of this report. The calculation shows that the maximum temperature rises by 9°C (17°F). The fuel cladding and MPC component temperatures are tabulated in Table C.4. The results show that fuel cladding and all component temperatures are below than their accident temperature limits.

C.5.4 Tornado Missile Impact (Accident)

During a tornado, it is possible for a tornado-driven missile to breach the water jacket on the HI-TRAC transfer cask. From a thermal-hydraulic performance perspective, this is identical to the water jacket loss accident condition evaluated in Subsection C.5.2.

C.5.5 MPC Cavity Pressure

The MPC-32, prior to sealing, is backfilled with helium. The helium backfill pressure specification for MPC-32 is reported in Table 1.1. For normal on-site transfer and accident conditions, the MPC-

32 pressures while placed inside the HI-TRAC are computed by using Ideal Gas Law in an EXCEL spreadsheet listed in Section B.4, and results are tabulated in Table C.5. The MPC boundary pressures are below the design pressure limits specified both in DC ISFSI FSAR [2].

C.5.6 Thermal Expansion Computations

In this subsection, the radial thermal expansion of MPC-to-HI-TRAC is computed to justify the calculation of the effective thermal conductivities of air in the annular gap between the MPC and the HI-TRAC inner shell, presented in section C.5.1.

The radial growth of the MPC shell relative to the HI-TRAC inner shell (δ) upon heating from a 65°F reference temperature to operation temperatures is computed as follows:

$$\delta = R_1\alpha_1[T_1 - T_o] - R_2\alpha_2[T_2 - T_o] \quad \text{(Eq. C.5.1)}$$

Where:

- R_1: MPC shell outer radius
- R_2: HI-TRAC inner shell inner radius
- T_1: MPC shell average temperature during normal on-site transfer condition
- T_2: HI-TRAC inner shell average temperature during normal on-site transfer condition
- α_1: Coefficient of thermal expansion for MPC shell T_1 for Alloy-X
- α_2: Coefficient of thermal expansion for HI-TRAC inner shell at T_2 for Carbon Steel

The required data for computing δ_1 is provided below:

$\alpha_1 = 9.05*10^{-6}\ {}^{o}F^{-1}$ (Table 3.3.1 [C-1])

$\alpha_2 = 6.16*10^{-6}\ {}^{o}F^{-1}$ (Table 3.3.2 [C-1])

R_1 = 34.25 in [C-5]

R_2 = 34.375 in [C-6]

T_1 = 325°F (FLUENT file "hitrac-mesh3b" listed in Section C.4)

T_2 = 246°F (FLUENT file "hitrac-mesh3b" listed in Section C.4)

T_o = 65°F (reference temperature)

Substituting the above data in Eq. C.5.1, the radial growth is computed as $\delta = 0.042$ in. The nominal cold gap between MPC shell and HI-TRAC inner shell is 0.125in. The cold gap will be reduced by 34% due to thermal expansion. **[PROPRIETARY**

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C.5.7 Time-to-Boil for a Water-Filled MPC

In accordance with NUREG-1536 [C-7], boiling of water in the MPC cavity is not permitted during wet loading operations. This requirement is met by prescribing a limit on allowable time duration for fuel to be submerged in water upon removal of a loaded HI-TRAC cask from pool or placement of MPC lid. For loading operations, a time-to-boil based on an adiabatic heatup of the cask is computed as described next.

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

i. Heat loss by natural convection and radiation from the exposed HI-TRAC surfaces to ambient air is neglected (i.e. an adiabatic heat-up calculation is performed).
ii. Bounding design basis heat loads (Scenario 1 and 2) are evaluated.
iii. The water mass in the MPC cavity is understated.

Table C.6 summarizes the lower bound weights and thermal inertias of the constituent 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:

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

where

Q = Fuel decay heat in the canister (Btu/hr)
C = Thermal inertia of a loaded HI-TRAC (Btu/°F) (See Table C.6)
T = Temperature of HI-TRAC cask and contents (°F)
t = time after HI-TRAC cask is removed from pool (hr)

Therefore, the time-to-boil, τ is given by the simple algebraic formula $\tau = C(212-T)/Q$ where 212 deg F. has been set as the boiling temperature and T represents the temperature of the pool water under fuel loading operations. Table C.7 provides a summary of τ at several representative heat loads and initial temperatures.

In the event that the maximum allowable time provided in Table C.7 is found to be insufficient to complete wet transfer operations, a forced water circulation shall be initiated and maintained to remove the decay heat from the MPC cavity. In this case, relatively cooler water will enter via the MPC lid drain port connection and heated water will exit from the vent port. The minimum water flow rate required to maintain the MPC cavity water temperature below boiling with an adequate subcooling margin is determined as follows:

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

where:

M_W = minimum water flow rate (lb/hr)

C_{pw} = water heat capacity (Btu/lb-°F)

T_{max} = maximum MPC cavity water mass temperature (must be less than 212°F)

T_{in} = MPC water inlet temperature

For example, the MPC cavity water temperature limited to 150°F, MPC water inlet temperature at 125°F and design basis maximum heat load (28.74 kW), the water flow rate computes as 3926 lb/hr.

C.6 REFERENCES

[C-1] HI-STORM FSAR, Report HI-2002444, Revision 7.

[C-2] FLUENT Computational Fluid Dynamics Software, Fluent Inc.

[C-3] "Pressure Loss Characteristics for In-Cell Flow of Helium in PWR and BWR MPC Storage Cells", Holtec Report HI-2043285, Rev. 7

[C-4] "Diablo Canyon MPC-32 Fuel Basket Assembly," Holtec Drawing 4458, Revision 9.

[C-5] "Diablo Canyon Enclosure Vessel," Holtec Drawing 4459, Revision 10.

[C-6] "125 Ton HI-TRAC 125D Assembly," Holtec Drawing 4460, Revision 4.

[C-7] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," U.S. Nuclear Regulatory Commission, Revision 1, July 2010.

[C-8] "CWA Wall Mount Platform Assembly," Holtec Drawing 5279, Revision 10.

Table C.1

NORMAL ON-SITE TRANSFER TEMPERATURES FOR UNIFORM LOADING USING DIFFERENT MESHES

Mesh No	Total Mesh Size	PCT (°C)	Permissible Limit (°C)	Clad Temperature Margin (°C)
1			400	
2			400	
3 (Licensing Basis Mesh)			400	
Note 1: The grid sensitivity studies are performed for Scenario 1 i.e. uniform storage condition specified in Table 1.3. Note 2: Mesh 3 is adopted for all licensing basis calculations.				

Table C.2

MAXIMUM MPC AND HI-TRAC TEMPERATURES DURING NORMAL ON-SITE TRANSFER CONDITION FOR LIMITING SCENARIO

Component	**Temperature °C (°F)**	**Short-Term Operation Temperature Limit °C (°F)**
Fuel Cladding		Moderate Burnup Fuel: 570 (1058) High Burnup Fuel: 400 (752)
MPC Basket		510 (950)
Basket Periphery		510 (950)
MPC Shell		413 (775)
HI-TRAC Inner Shell		204 (400)
Water Jacket Outer Shell		177 (350)
Water Bulk Temperature in Water Jacket		153 (307)
Axial Neutron Shield[1]		149 (300)

1 Maximum section average temperature is reported.

Table C.3

MAXIMUM MPC AND HI-TRAC TEMPERATURES DURING WATER LOSS ACCIDENT CONDITION FOR LIMITING SCENARIO

Component	Temperature °C (°F)	Accident Temperature Limit °C (°F)
Fuel Cladding		570 (1058)
MPC Basket		510 (950)
Basket Periphery		510 (950)
MPC Shell		413 (775)
HI-TRAC Inner Shell		316 (600)
Water Jacket Outer Shell		371 (700)
Axial Neutron Shield[2]		149 (300)

2 Maximum section average temperature is reported.

Table C.4

MAXIMUM MPC AND FUEL CLADDING TEMPERATURES DURING FIRE ACCIDENT CONDITION FOR LIMITING SCENARIO

Component	Temperature °C (°F)	Accident Temperature Limit °C (°F)
Fuel Cladding		570 (1058)
MPC Basket		510 (950)
Basket Periphery		510 (950)
MPC Shell		413 (775)

Table C.5

MPC-32 CONFINEMENT BOUNDARY PRESSURE DURING ON-SITE TRANSFER FOR LIMITING SCENARIO

Conditions	Cavity Average Temperature °C (°F)	Pressure kPa (psig)	Pressure Limit kPa (psig)
Normal Condition (No Rod Rupture)			689.3 (100)
Water Loss Accident Condition			1378.6 (200)
Fire Accident Condition			1378.6 (200)

Table C.6

HI-TRAC WEIGHTS AND THERMAL INERTIAS

Component	**Weight *** **kg (lbs)**	**Heat Capacity [C-1]** **J/kg-°C (Btu/lb-°F)**	**Thermal Inertia** **J/°C (Btu/°F)**
		HI-TRAC	
Water in Water Jacket		4182 (0.999)	
Lead		130 (0.031)	
Carbon Steel		419 (0.1)	
		MPC	
Alloy-X		502 (0.12)	
Metamic		921 (0.22)	
Fuel		234 (0.056)	
MPC Cavity Water		4182 (0.999)	
Total value			

Note: * . The components' weight are referenced from their corresponding Holtec drawings [C-4, C-5, C-6].

\+ Only 50% of MPC cavity water is credited.

Table C.7

MAXIMUM PERMISSIBLE TIME DURATION FOR FLOODED MPC-32 OPERATIONS

Initial Temperature °C (°F)	Time (hours) @ Q = 28.74 kW	Time (hours) @ Q = 25.572 kW
37.8 (100)		
43.3 (110)		
48.9 (120)		
54.4 (130)		
60.0 (140)		
65.6 (150)		

Appendix D

HI-TRAC Fire Event Calculations
(Total 5 pages)

[PROPRIETARY]

Appendix E

Gird Convergence Index
(Total 10 Pages)

[PROPRIETARY]

Holtec Affidavit for Holtec International Report HI-2125191, "Three Dimensional Thermal-Hydraulic Analyses for Diablo Canyon Site-Specific HI-STORM System with 28.74kW Decay Heat," Revision 0 – Proprietary Version, and associated discs of proprietary data files on optical storage medium (OSM) DVD-ROM

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AFFIDAVIT PURSUANT TO 10 CFR 2.390

I, Joseph Cascio, depose and state as follows:

(1) I am the Holtec International Project Manager for the Diablo Canyon Independent Spent Fuel Storage Installation Project and have reviewed the information described in paragraph (2) which is sought to be withheld, and am authorized to apply for its withholding.

(2) The information sought to be withheld is Revision 0 of Holtec Report HI-2125191 and the accompanying External Drive with computer data files therefrom, which contains Holtec Proprietary information and is appropriately marked as such.

(3) In making this application for withholding of proprietary information of which it is the owner, Holtec International relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4) and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10CFR Part 9.17(a)(4), 2.390(a)(4), and 2.390(b)(1) for "trade secrets and commercial or financial information obtained from a person and privileged or confidential" (Exemption 4). The material for which exemption from disclosure is here sought is all "confidential commercial information", and some portions also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, <u>Critical Mass Energy Project v. Nuclear Regulatory Commission</u>, 975F2d871 (DC Cir. 1992), and <u>Public Citizen Health Research Group v. FDA</u>, 704F2d1280 (DC Cir. 1983).

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(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by Holtec's competitors without license from Holtec International constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

c. Information which reveals cost or price information, production, capacities, budget levels, or commercial strategies of Holtec International, its customers, or its suppliers;

d. Information which reveals aspects of past, present, or future Holtec International customer-funded development plans and programs of potential commercial value to Holtec International;

e. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs 4.a and 4.b, above.

(5) The information sought to be withheld is being submitted to the NRC in confidence. The information (including that compiled from many sources) is of

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a sort customarily held in confidence by Holtec International, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by Holtec International. No public disclosure has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to the NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within Holtec International is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his designee), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside Holtec International are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information classified as proprietary was developed and compiled by Holtec International at a significant cost to Holtec International. This information is classified as proprietary because it contains detailed descriptions of analytical

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approaches and methodologies not available elsewhere. This information would provide other parties, including competitors, with information from Holtec International's technical database and the results of evaluations performed by Holtec International. A substantial effort has been expended by Holtec International to develop this information. Release of this information would improve a competitor's position because it would enable Holtec's competitor to copy our technology and offer it for sale in competition with our company, causing us financial injury.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to Holtec International's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of Holtec International's comprehensive spent fuel storage technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology, and includes development of the expertise to determine and apply the appropriate evaluation process.

The research, development, engineering, and analytical costs comprise a substantial investment of time and money by Holtec International.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

Holtec International's competitive advantage will be lost if its competitors are able to use the results of the Holtec International experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

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The value of this information to Holtec International would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive Holtec International of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

Executed at Marlton, New Jersey, this 6th day of July, 2012.

Joseph Cascio
Holtec International