Holtec International Report HI-2104625, "Three Dimensional Thermal-Hydraulic Analyses for Diablo Canyon Site-Specific HI-STORM System Design," Revision 9 (Non-proprietary version)

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

THREE DIMENSIONAL THERMAL-HYDRAULIC ANALYSES FOR DIABLO CANYON SITE-SPECIFIC HI-STORM SYSTEM DESIGN

FOR

PG&E

Holtec Report No: HI-2104625

Holtec Project No: 1073

Sponsoring Holtec Division: HTS

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT ISSUANCE AND REVISION STATUS[1]

DOCUMENT NAME:	THREE DIMENSIONAL THERMAL-HYDRAULIC ANALYSES FOR DIABLO CANYON SITE-SPECIFIC HI-STORM SYSTEM DESIGN		
DOCUMENT NO.:	HI-2104625	CATEGORY: ☐	GENERIC
PROJECT NO.:	1073	☑	PROJECT SPECIFIC

Rev. No.[2]	Date Approved	Author's Initials	VIR #
9	11/22/2011	A.Mohammad	61141

DOCUMENT CATEGORIZATION

In accordance with the Holtec Quality Assurance Manual and associated Holtec Quality Procedures (HQPs), this document is categorized as a:

- ☑ Calculation Package[3] (Per HQP 3.2)
- ☐ Technical Report (Per HQP 3.2) (Such as a Licensing Report)
- ☐ Design Criterion Document (Per HQP 3.4)
- ☐ Design Specification (Per HQP 3.4)
- ☐ Other (Specify):

DOCUMENT FORMATTING

The formatting of the contents of this document is in accordance with the instructions of HQP 3.2 or 3.4 except as noted below:

DECLARATION OF PROPRIETARY STATUS

☑ Nonproprietary ☐ Holtec Proprietary ☐ Privileged Intellectual Property (PIP)

This document contains extremely valuable intellectual property of Holtec International. Holtec's rights to the ideas, methods, models, and precepts described in this document are protected against unauthorized use, in whole or in part, by any other party under the U.S. and international intellectual property laws. Unauthorized dissemination of any part of this document by the recipient will be deemed to constitute a willful breach of contract governing this project. The recipient of this document bears sole responsibility to honor Holtec's unabridged ownership rights of this document, to observe its confidentiality, and to limit use to the purpose for which it was delivered to the recipient. Portions of this document may be subject to copyright protection against unauthorized reproduction by a third party.

Notes

1. This document has been subjected to review, verification and approval process set forth in the Holtec Quality Assurance Procedures Manual. Password controlled signatures of Holtec personnel who participated in the preparation, review, and QA validation of this document are saved on the company"s network. The Validation Identifier Record (VIR) number is a random number that is generated by the computer after the specific revision of this document has undergone the required review and approval process, and the appropriate Holtec personnel have recorded their password-controlled electronic concurrence to the document.

2. A revision to this document will be ordered by the Project Manager and carried out if any of its contents including revisions to references is materially affected during evolution of this project. The determination as to the need for revision will be made by the Project Manager with input from others, as deemed necessary by him.

3. Revisions to this document may be made by adding supplements to the document and replacing the fTable of Contentsf, this page and the fRevision Logf.

TABLE OF CONTENTS

SUMMARY OF REVISIONS

Revision 0: Original Revision.

Revision 1: The following changes are made to the report.

- A mesh sensitivity study is performed for HI-STORM 100SA System to obtain a converged grid.
- All the off-normal and accident conditions are updated based on the converged grid temperature solution.
- A steady state thermal evaluation is performed with credit for the increased molecular weight of the cavity gases to calculate the cavity pressure during the 100% rod ruptures accident.

- Thermal evaluations are performed for both normal storage and transfer conditions with two different sets of MPC decay heat loads.
- All the pressure tables are updated to incorporate the changes due to change in the MPC cavity temperatures.
- HI-STORM in CTF calculations are revised with the Diablo Canyon maximum heat load.
- Free volume calculations are revised.
- The thermal expansion calculations during normal conditions of storage are revised.

All the changes in the report are marked by revision bars.

Revision 2: Incorporated client comments. The off-normal temperature limits are made consistent with Diablo Canyon SAR Rev. 3. All the changes in the report are marked by revision bars.

Revision 3: The footnotes in Appendix B are fixed and an editorial change was made in Section 4.0 of the main text of the report.

Revision 4: A mesh sensitivity analysis is performed for the case when HI-STORM 100SA is in the Cask Transfer Facility (CTF). An estimate of numerical uncertainty is provided by the calculation of Grid Convergence Index (GCI) for this condition and also for the normal storage condition. The GCI calculations are presented in Appendix F of the report. All the changes in the report are marked by revision bars.

Revision 5: Appendix G is added to the report to address a potential non-conservatism in the radiation solver of FLUENT version 6.3.26. All the changes in the report are marked by revision bars.

Revision 6: Following sensitivity studies are performed to support responses to RAIs from USNRC:

- To evaluate the effect of operating density parameter used in FLUENT based on inlet air conditions
- To include the CTF wedge assemblies in the HI-STORM System in CTF configuration

All other changes in the report are marked by revision bars.

Revision 7: A thermal evaluation of the SCS system with water in the HI-TRAC annulus in level with the bottom surface of the MPC lid is added to Appendix C.

Revision 8: MPC decay heat load for Scenario 1 is changed to 24 kW. A thermal evaluation of the HI-STORM System in the CTF is performed with a uniformly loaded MPC cask for Scenario 1. Sensitivity studies on the operating density, CTF wedge assemblies and thermal evaluation of 28.74 kW are moved to Appendix H. Appendix F that documents the GCI calculations is removed.

Revision 9: Editorial changes are made. A reference is added in Appendix B. All changes in the report are marked by revision bars.

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 1.3 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 for two different heat load scenarios listed in Section 1.4. 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

[1] MPC absolute pressure under normal operating conditions is specified for two different heat loads in Section 1.4.

contact cannot remain in static equilibrium, the temperature field guarantees the incipience of heat transfer by internal convection.

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, D and E 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 the following decay heat scenarios:

	Q (kW)	**Storage Pattern†**	**Operating Pressure (atm)**	**Reference**
Scenario 1	24	Uniform, X=1	4.8	-
Scenario 2	36.9	Regionalized, X=0.5	7	[5]

The heat load pattern, Scenario 1 mentioned in the table above is evaluated in this report. Diablo requests license amendment of Scenario 1. Based on the thermal evaluations presented and approved in the HI-STORM FSAR [5], a decay heat load of 36.9 kW with regionalized scheme described in [5] results in worst case fuel cladding temperatures and cavity pressures. Therefore, of all the heat load scenarios specified in [5], Scenario 2 is the most limiting and hence is the only scenario among the ones discussed in [5] that is evaluated in the current 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,

† The parameter X is defined in Reference 5.

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 used in the thermal evaluations are those established for the HI-STORM 100 System, which bound the DC ISFSI conditions.

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]. 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.

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.
- For Scenario 2 listed in Section 1.4, all the component temperature and MPC internal pressure must satisfy the requirements of Holtec generic licensing documents [5].
- For Scenario 1 listed in Section 1.4, all component temperature and MPC internal pressure must satisfy the requirements of the DC ISFSI SAR [2], with the following exceptions:
  A. The normal long-term storage concrete temperature limit has been increased to 300°F. An increase in the maximum normal storage temperature of concrete from 200°F to 300°F was incorporated into the HI-STORM FSAR Revision 2. The basis for the change was two reports [10] and [11]. These references provided previous research and testing to support the long-term temperature limit of 300°F. The change in the limit was permitted as long as dolomite was not used as one of the coarse aggregate materials. Holtec concrete placement procedures have incorporated these requirements since 2005. PG&E will need to ensure that their HI-STORM concrete placement procedure includes approved requirements for obtaining concrete that meet the 300°F long term limit. A review of the DC ISFSI specific design and analysis have verified that concrete properties are consistent with concrete allowed within the new limit for the design life of the components.
  B. The accident temperature limit for all the HI-STORM overpack steel is increased to 800°F. This change was proposed in HI-STORM 100 License Amendment Request 1014-3 [8] and approved by the NRC in the Safety Evaluation Report for Amendment #5 to Certificate of Compliance 72-1014 (ML082030122).
  C. The accident temperature limit for Holtite in the HI-TRAC lid is increased from 300°F to 350°F. This change was proposed in a supplement to HI-STORM 100 License Amendment Request 1014-2 [9] and approved by the NRC in the Safety Evaluation Report for Amendment #2 to Certificate of Compliance 72-1014 (ML051580522). The creation of a short-term temperature limit for Holtite-A

which is used only in the HI-TRAC 125 transfer cask, is based on test data summarized in [7]. This report was submitted to the NRC in May, 2003 on Docket 71-9261.

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 heat load of 24 kW. However, a supplemental cooling system is required for the HI-TRAC containing high burnup fuel.

8.0 REFERENCES

[1] Materials License No. SNM-2511 Amendment 1, Docket 72-26, dated 10 February 2010.

[2] "Diablo Canyon Independent Spent Fuel Storage Installation Final Safety Analysis Report," Revision 3, March 2010.

[3] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," U.S. Nuclear Regulatory Commission, January 1997.

[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.

[7] "Holtite A: Development History and Thermal Performance data", Holtec Report HI-2002396, Revision 3.

[8] Holtec Letter 5014612, dated December 22, 2006.

[9] Holtec Letter 5014490, dated August 6, 2003.

[10] Carette and Malhorta, "Performance of Dolostone and Limestone Concretes at Sustained High Temperatures," Temperature Effects on Concrete, ASTM STP 858.

[11] Schneider and Horvath, "Behaviour of Ordinary Concrete at High Temperature," Vienna Technical University – Institute for Building Materials and Fire Protection, Research Report Volume 9.

Table 1.1

MPC-32 HELIUM BACKFILL PRESSURE SPECIFICATIONS

Scenario*	**Item**	**Specification**
Scenario 1	Minimum Gauge Pressure	202.0 kPa @ 21.1°C Reference Temperature [29.3 psig @ 70°F Reference Temperature]
	Maximum Gauge Pressure	229.5 kPa @ 21.1°C Reference Temperature [33.3 psig @ 70°F Reference Temperature]
Scenario 2	Minimum Gauge Pressure	292.9 kPa @ 21.1°C Reference Temperature [42.5 psig @ 70°F Reference Temperature]
	Maximum Gauge Pressure	313.6 kPa @ 21.1°C Reference Temperature [45.5 psig @ 70°F Reference Temperature]

* The scenarios are listed in Section 1.4 of this report.

Table 1.2

DESIGN AMBIENT TEMPERATURES[Note 1]

Normal Temperatures Ambient Soil	 80°F 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

Table 1.3

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 7 pages)

HOLTEC APPROVED COMPUTER PROGRAM LIST 24, 2010							REV. 145 November	
PROGRAM (Category)	APPROVED IN USNRC PART 50 & 71/72 SER: (List docket #)	VERSION (Executable)	CERTIFIED USERS FOR "A" CODES	CODE EXPERT	REMARKS: See report indicated for specific limitations	OPERATING SYSTEM & VERSION (Service pack)	APPROVED COMPUTERS: Listed by ID	Indicate Computer ID(s) used
ANSYS (A)	DOC 50-298 DOC 72-1014	11.0	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	SPA, AB, CWB, RJ, PK, AL, HP, VRP, ER, IR, AIS, ZY, JZ	CWB	HI-2012627	Windows XP (2)	1016, 1017	
		12.1	SPA, AB, CWB, RJ, PK, AL, HP, VRP, ER, IR, AIS, ZY, JZ	CWB	HI-2012627	Windows XP (2)	1019	
						Windows 7	1021, 1031, 1044	
CASMO (A)	DOC 50-271 DOC 71-9336	4 - 2.05.14	SPA, DMM, BDB, VIM, KB, SF, ES	SPA	HI-2104750	Windows XP (3)	1006	
		5M - 1.06.00	SPA, DMM, BDB, VIM, KB, SF, ES	SPA	HI-2104750	Windows XP (2)	1008	
Fluent (A)	DOC 50-368 DOC 72-	4.56	ER, IR, DMM, AHM, YL, INP	ER	HI-981921	Windows XP (2,3)	1016, 1022	

PROGRAM (Category)	APPROVED IN USNRC PART 50 & 71/72 SER: (List docket #)	VERSION (Executable)	CERTIFIED USERS FOR "A" CODES	CODE EXPERT	REMARKS: See report indicated for specific limitations	OPERATING SYSTEM & VERSION (Service pack)	APPROVED COMPUTERS: Listed by ID	Indicate Computer ID(s) used
	1014	6.3.26	ER, IR, DMM, AHM, YL, INP	DMM	HI-2084036	Windows XP (2,3)	1001, 1002, 1003, 1016, 2003	1002 1003
						Red Hat Enterprise Linux (2.6.9-5)	1004	
LS-DYNA 3D (A)	DOC 50-298 DOC 72-1014	971 (ls971sR4.2)	SPA, VRP, KPS, AIS, JZ	JZ	N/A	Windows XP (2)	1018	
		971 (ls971sR5.0)	SPA, VRP, KPS, AIS, JZ	JZ	N/A	Windows 7	1032	
		971 (mpp971d R5.0)	SPA, VRP, KPS, AIS, JZ	JZ	N/A	Windows Server HPC 2008	1033, 1034, 1035, 1036, 1037	

PROGRAM (Category)	APPROVED IN USNRC PART 50 & 71/72 SER: (List docket #)	VERSION (Executable)	CERTIFIED USERS FOR "A" CODES	CODE EXPERT	REMARKS: See report indicated for specific limitations	OPERATING SYSTEM & VERSION (Service pack)	APPROVED COMPUTERS: Listed by ID	Indicate Computer ID(s) used
		971 (mpp971s R5.0)	SPA, VRP, KPS, AIS, JZ	JZ	N/A	Windows Server HPC 2008	1033, 1034, 1035, 1036, 1037	
MCNP (A)	DOC 50-368 DOC 71-9336	4A	SPA, DMM, BDB, SF, ES, VIM, KB	KB	HI-2104750	Windows XP (2,3)	1006, 1008, 1009, 1010, 2001, 2002, 2004, 2005, 2006, 2007	
						Windows 7	1011, 1013, 1014, 1015, 1030, 1051	

HOLTEC APPROVED COMPUTER PROGRAM LIST 24, 2010							REV. 145 November	
PROGRAM (Category)	**APPROVED IN USNRC PART 50 & 71/72 SER: (List docket #)**	**VERSION (Executable)**	**CERTIFIED USERS FOR "A" CODES**	**CODE EXPERT**	**REMARKS: See report indicated for specific limitations**	**OPERATING SYSTEM & VERSION (Service pack)**	**APPROVED COMPUTERS: Listed by ID**	**Indicate Computer ID(s) used**
		5.1.40	SPA, DMM, BDB, SF, ES, VIM, KB	KB	HI-2104750	Windows XP (2,3)	1006, 1008, 1009, 1010, 1012, 2001, 2002, 2004, 2005, 2006, 2007	
						Windows 7	1011, 1014, 1015	

PROGRAM (Category)	APPROVED IN USNRC PART 50 & 71/72 SER: (List docket #)	VERSION (Executable)	CERTIFIED USERS FOR "A" CODES	CODE EXPERT	REMARKS: See report indicated for specific limitations	OPERATING SYSTEM & VERSION (Service pack)	APPROVED COMPUTERS: Listed by ID	Indicate Computer ID(s) used
		5.1.51	SPA, DMM, BDB, SF, ES, VIM, KB	KB	HI-2104750	Windows XP (2,3)	1006, 1008, 1009, 1010, 2001, 2002, 2003, 2005, 2006, 2007	
						Windows 7	1014, 1015, 1051	
SCALE: Modules ORIGEN-S & SAS2H	DOC 50-346 DOC 71-9336	4.3	N/A	KB	N/A	Windows 2000 (2)	1050	
		4.4	N/A	KB	N/A	Windows XP (2,3)	1006, 1009, 1010, 2004, 2005, 2007	
Visual	DOC 50-133	2004	N/A	AIS,	N/A	Windows XP (2)	1017	

HOLTEC APPROVED COMPUTER PROGRAM LIST 24, 2010							REV. 145 November	
PROGRAM (Category)	**APPROVED IN USNRC PART 50 & 71/72 SER: (List docket #)**	**VERSION (Executable)**	**CERTIFIED USERS FOR "A" CODES**	**CODE EXPERT**	**REMARKS: See report indicated for specific limitations**	**OPERATING SYSTEM & VERSION (Service pack)**	**APPROVED COMPUTERS: Listed by ID**	**Indicate Computer ID(s) used**
Nastran	DOC 72-27			CWB		Windows 7	1044, 1045	

Appendix B

Thermal Analysis of MPC-32 in HI-STORM 100SA System
(Total 53 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]. 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 **[PROPRIETARY**

   ] in FLUENT.
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**

]

13. Grid sensitivity studies are performed as discussed in Subsections B.5.1.2 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 - ambient temperature of 80°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) The fuel assembly length is conservatively modeled to be equal to the fuel basket length. This is conservative because it maximizes the flow resistance of the fuel region. However, the length of the active fuel is modeled exactly the same as the active fuel height of a Westinghouse 17x17 fuel assembly.

10) To understate MPC internal convection heat transfer, the MPC helium pressure[1] is understated. The minimum operation pressure, 7 atm absolute, is set as the operation pressure for Scenario 2 in Section 1.4 while it is set as 4.8 atm absolute for Scenario 1 in Section 1.4. During accident conditions, the MPC pressure is higher than this minimum MPC absolute pressure. 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 of 7 atmospheres absolute is used in the calculations pertaining to Scenario 2 in Section 1.4, whereas an operating pressure of 4.8 atmospheres absolute is used for the DC ISFSI licensed heat load (Scenario 1 in Section 1.4). The design ambient temperature used in the analysis is

1 MPC absolute pressure is 7 atm (min.) under normal operating conditions (design heat load and normal ambient temperature).

80°F. The bottom of the HI-STORM 100SA overpack base is 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

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

09/16/2010  03:18 PM     259,686,400   DC-HI-STORM-finest-CTF-28.74kw.dbs
09/16/2010  03:21 PM     210,680,792   DC-HI-STORM-finest-CTF-28.74kw.msh
04/12/2011  05:05 PM     254,803,968   CTF-28.74kw-mesh1.dbs
04/12/2011  05:14 PM     202,047,084   CTF-28.74kw-mesh1.msh
04/11/2011  04:37 PM     268,435,456   CTF-28.74kw-mesh3.dbs
04/11/2011  04:44 PM     234,651,174   CTF-28.74kw-mesh3.msh
04/15/2010  02:31 PM     180,355,072   DC-HI-STORM-SPACER.dbs
04/15/2010  02:30 PM      87,598,673   DC-HI-STORM-SPACER.msh
05/20/2010  10:15 AM     179,306,496   DC-HI-STORM.dbs
05/20/2010  10:19 AM      88,313,369   DC-HI-STORM.msh
```

06/15/2010	04:24 PM	187,695,104	DC-HI-STORM-fine.dbs
06/15/2010	04:23 PM	102,146,459	DC-HI-STORM-fine.msh
06/15/2010	08:51 PM	188,743,680	DC-HI-STORM-finer.dbs
06/15/2010	08:53 PM	107,679,695	DC-HI-STORM-finer.msh
06/16/2010	01:41 PM	210,763,776	DC-HI-STORM-finest.dbs
06/16/2010	01:40 PM	147,665,477	DC-HI-STORM-finest.msh
08/23/2011	12:44 PM	281,018,368	DC-HI-STORM-finest-CTF-wedge-28.74kw.dbs
08/23/2011	12:43 PM	221,209,085	DC-HI-STORM-finest-CTF-wedge-28.74kw.msh

FLUENT

Normal Onsite Storage

Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\steady-state

04/20/2010	05:07 PM	50,692,154	DC-HI-STORM-X=0.5.cas
03/24/2010	03:12 PM	821,838,647	DC-HI-STORM-X=0.5.dat

HI-STORM in CTF (28.74 kW)

Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\steady-state

09/20/2010	10:16 AM	118,935,523	DC-HI-STORM-finest-CTF-28.74kw.cas
09/17/2010	08:40 AM	1,815,636,840	DC-HI-STORM-finest-CTF-28.74kw.dat

Sensitivity Study of HI-STORM in CTF

Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\CTF-mesh sensitivity

04/13/2011	09:06 AM	112,546,942	CTF-28.74kw-mesh1.cas
04/13/2011	05:49 AM	1,734,709,623	CTF-28.74kw-mesh1.dat
04/18/2011	04:52 PM	128,354,280	CTF-28.74kw-mesh3.cas
04/12/2011	08:44 AM	1,935,321,440	CTF-28.74kw-mesh3.dat

HI-STORM in CTF with Wedge Assemblies (28.74 kW)

Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\CTF-wedge

08/30/2011	11:46 AM	121,948,653	DC-HI-STORM-finest-CTF-wedge-28.74kw.cas
08/30/2011	03:56 PM	1,855,883,982	DC-HI-STORM-finest-CTF-wedge-28.74kw.dat

HI-STORM in CTF (Scenario 1)

Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\CTF-diff-heat-loads

11/14/2011	03:32 PM	118,936,052	DC-HI-STORM-finest-CTF-24kw.cas
11/14/2011	03:36 PM	1,815,624,770	DC-HI-STORM-finest-CTF-24kw.dat

Sensitivity Study of Fuel Spacer

Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\steady-state

04/20/2010	05:15 PM	50,258,200	DC-HI-STORM-SPACER.cas
04/15/2010	08:21 PM	815,209,407	DC-HI-STORM-SPACER.dat

Grid Sensitivity Studies
Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\Grid Sensitivity

06/18/2010	08:49 AM	57,927,518	DC-HI-STORM-FINE-36.9kw.cas
06/18/2010	04:56 AM	914,718,131	DC-HI-STORM-FINE-36.9kw.dat
06/18/2010	02:13 PM	60,833,242	DC-HI-STORM-FINER-36.9kw.cas
06/18/2010	02:14 PM	952,338,328	DC-HI-STORM-FINER-36.9kw.dat
06/17/2010	04:06 PM	83,170,154	DC-HI-STORM-FINEST-36.9kw.cas
06/17/2010	03:45 PM	1,310,907,908	DC-HI-STORM-FINEST-36.9kw.dat

Lower Heat Load (28.74 kW)
Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\Q=28.74kw

06/21/2010	08:10 AM	83,170,123	DC-HI-STORM-FINEST-28.74kw.cas
06/21/2010	08:11 AM	1,310,907,908	DC-HI-STORM-FINEST-28.74kw.dat

100% Fuel Rod Rupture
Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\100pct-rod-rupture

06/24/2010	08:41 AM	83,170,495	DC-HI-STORM-FINEST-36.9kw-100RR.cas
06/24/2010	02:07 AM	1,310,907,908	DC-HI-STORM-FINEST-36.9kw-100RR.dat

Partial Duct Blockage (Off-Normal)
Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\Partial-Duct-Blocked

09/15/2010	05:11 PM	50,692,011	DC-HI-STORM-PDB.cas
09/15/2010	05:11 PM	821,798,979	DC-HI-STORM-PDB.dat

All Ducts Blocked (Accident)
Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\All-Ducts-Blocked

04/19/2010	07:06 PM	842,216,181	DC-HI-STORM-ADB-115200.dat
04/13/2010	08:47 AM	50,691,505	DC-HI-STORM-ADB.cas

Fire (Accident)
Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\fire

04/15/2010	11:41 AM	841,772,997	DC-HI-STORM-fire-240.dat
04/21/2010	09:57 AM	50,693,126	DC-HI-STORM-fire.cas
05/13/2010	08:19 PM	841,790,858	DC-HI-STORM-postfire-111600.dat
04/17/2010	09:26 PM	841,811,399	DC-HI-STORM-postfire-1800.dat
04/19/2010	08:03 AM	841,811,399	DC-HI-STORM-postfire-3600.dat
05/04/2010	02:52 PM	50,692,318	DC-HI-STORM-postfire.cas

Sensitivity Studies (Operating Density Parameter)
Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent\Operating Density

08/25/2011	08:06 AM	83,170,105	DC-HI-STORM-FINEST-28.74kw-den.cas
08/25/2011	08:08 AM	1,310,907,880	DC-HI-STORM-FINEST-28.74kw-den.dat
08/26/2011	12:29 PM	118,935,421	DC-HI-STORM-finest-CTF-28.74kw-den.cas
08/26/2011	12:07 PM	1,815,698,314	DC-HI-STORM-finest-CTF-28.74kw-den.dat

UDF

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

03/04/2010	06:05 PM	2,407	udf-diablo-X=0.5.c
09/15/2010	05:24 PM	2,689	udf-diablo-28.74kw.c
08/23/2011	03:16 PM	2,691	udf-diablo-28.74kw-wedge.c
11/07/2011	05:10 PM	2,689	udf-diablo-24kw.c

MISCELLANEOUS

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

12/14/2010	02:05 PM	15,872	heat-gen-rate.xls
11/17/2011	06:18 PM	51,712	mpc_pres_R8.xls

B.5 RESULTS AND CONCLUSIONS

B.5.1 Normal Long-Term Storage Temperatures

B.5.1.1 Initial Evaluation

Initial calculations were performed using a baseline mesh (see section B.5.1.2 below for mesh sensitivity studies) for Scenario 2 defined in Section 1.4 of the main report. The storage scenario was adopted for grid sensitivity studies (Section B.5.1.2). The temperatures of all the components of the MPC and HI-STORM 100SA from the normal storage baseline mesh evaluation are reported in Table B.5.2 and are below their temperature limits [B-2].

B.5.1.2 Grid Sensitivity Studies

The HI-STORM 100SA is engineered with flow passages to facilitate heat dissipation by ventilation action. During fuel storage ambient air is drawn from intake ducts by buoyancy forces generated by the heated column of air in the HI-STORM annulus. The upward moving air extracts heat from the MPC external surfaces by convection heat transfer. As the vast majority of the heat is removed by annulus air flow, the adequacy of the grid deployed to model annulus flow and heat transfer must be confirmed.

The grid discretization of the MPC spaces and the HI-STORM/MPC annulus region must be sufficient to insure a grid-independent solution. Because the flow field in the annulus is in the turbulent transition regimes, the grid size and distribution are critical to insuring a converged solution. The mesh sensitivity study was accordingly performed on the annulus region outside the MPC and the grid size in the axial direction within the MPC. All the mesh sensitivity analyses were carried out for the 36.9 kW design maximum heat load (Scenario 2 in Section 1.4).

B.5.1.2.1 HI-STORM Annulus Radial Mesh Distribution Studies

The HI-STORM 100SA annulus grid sensitivity results are tabulated below. [**PROPRIETARY**]Three different grids are generated to study the effect of mesh refinement in the annulus region on the predicted temperatures. The table below summarizes the mesh used and the result obtained.

Mesh	**Number of Radial Cells**	**y^+**	**PCT (°C)**	**Permissible Limit (°C)**	**Clad Temperature Margin (°C)**
Baseline					
Fine					
Finer					
Note 1: The y^+ reported in the third column above is a measure of grid adequacy provided by the FLUENT code. Values of y^+~1 indicate an adequate level of mesh refinement is reached to resolve the viscosity affected region near the wall. **[PROPRIETARY**]					

As can be seen from the above table, the thermal solution is sensitive to the grid density in the annulus region. The above results show that finer mesh is reasonably converged. Having obtained grid convergence in the annulus region, the finer mesh is adopted for further grid sensitivity studies below.

B.5.1.2.2 Fuel Region Axial Mesh Studies

In addition to employing the finer mesh in the annulus region, the fuel region axial mesh density was also increased. A summary of these studies is provided below:

Mesh	**Number of Axial Cells**	**PCT (°C)**	**Permissible Limit (°C)**	**Clad Temperature Margin (°C)**
Finer			400	
Finest			400	
Note 1: As explained below the finest grid is adopted for thermal evaluation of the HI-STORM 100SA.				

The above results show that the solution is essentially unchanged by further grid refinement in the axial direction.

B.5.1.2.3 Applying the Results of the Grid Sensitivity Studies

Based on the above results, finest grid layout is adopted for the normal storage thermal analysis of the HI-STORM 100SA. The temperatures of all the components of the MPC and HI-STORM 100SA for the finest mesh are reported in Table B.5.2 and are compared with the baseline mesh results. The temperature difference due to mesh refinement is also reported in Table B.5.2. The finest mesh was used in the analysis of HI-STORM in the CTF under Scenario 1 conditions.

To address the effect of grid sensitivity on all the other off-normal and accident conditions, the results for these conditions presented in this report were calculated using baseline mesh and then the temperature adder representing the mesh density studies, as shown in Table B.5.2, were applied.

B.5.1.3 Thermal Evaluations supporting DC ISFSI License (Scenario 1)*

This evaluation was performed to support the Diablo Canyon ISFSI license that loads up to a uniform heat of 24 kW (Scenario 1). The finest mesh that results in highest cladding and component temperatures during normal on-site storage is used to evaluate the MPC-32 in HI-STORM 100SA with a uniform heat load of 24 kW and a helium backfill of 29.3 psig at 70°F (Table 1.1). The operating pressure inside the MPC used in the analysis is 4.8 atmospheres absolute. The normal long-term storage condition of the HI-STORM System on the ISFSI pad will conservatively be bounded by the HI-STORM System in the CTF configuration since the flow of air to the bottom inlet vents would be restricted in the CTF. Therefore, the HI-STORM System in the CTF configuration is evaluated in Section B.5.5 and the results are reported in Table B.5.18. The fuel, MPC and HI-STORM component temperatures are well below their respective temperature limits. The fuel, MPC and HI-STORM component temperatures obtained for Scenario 2 (see Section 1.4) bounds the other decay heat scenario evaluated. Therefore, all the off-normal and accident evaluations presented in this report are performed for this limiting scenario except for the HI-STORM in the CTF condition, which is evaluated for Scenario 1.

* See Section 1.4 for Scenario 1.

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. 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 70°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 = 55.95 in	[B-18]	Maximum cell panel 1B dimension
W = 37.28 in	[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} = 0.07 in [B-19] (minimum radial gap between the basket and MPC shell, conservatively lower)

R_1 = 28.13 in [B-18] (Half of maximum width of the widest basket panel)

$R_3 = R_{max} + G_{min}$ = 33.583 in (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:

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

[PROPRIETARY] (Width of basket support)

The temperatures T_1, T_2 and T_3 are obtained from FLUENT case and data file "DC-HI-STORM-FINEST-36.9kw" 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 = 70°F (Reference temperature)
T_1 = 685°F (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 = 580°F (Maximum temperature of the basket support at the hottest axial location)
T_3 = 464°F (MPC shell temperature at the hottest axial location)

$\alpha_1 = 9.76\text{x}10^{-6}\,{}^{o}F^{-1}$ [B-2]
$\alpha_2 = 9.60\text{x}10^{-6}\,{}^{o}F^{-1}$ [B-2]
$\alpha_3 = 9.28\text{x}10^{-6}\,{}^{o}F^{-1}$ [B-2]

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

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

Substituting in eq. B.5.2, the net thermal expansion is δ = 0.0723 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

$R_3 = 33.583$ in (Minimum inner radius of MPC shell, see Method 1)

$T_3 = 464^oF$ (Maximum MPC shell temperature at the hottest axial location)

$\alpha_3 = 9.28x10^{-6}\,{}^oF^{-1}$ [B-2] (coefficient of thermal expansion of alloy-X at temperature T_3)

$\delta_{shell} = R_3\alpha_3(T_3-T_0) = 0.123$ in

Thermal expansion of panel 1

$R_1 = 55.95/2 = 27.975$ in [B-7]

$T_1 = 685^oF$ (Radial average fuel basket temperature along the widest panel i.e. panel 1, at the hottest axial location)

$\alpha_1 = 9.76x10^{-6}\,{}^oF^{-1}$

$\delta_1 = R_1\alpha_1(T_1-T_0) = 0.1679$ in

Thermal expansion of panel 2

$R_2 = 37.28/2 = 18.64$ in [B-7]

$T_2 = 556^oF$ (Radial average fuel basket temperature along panel 2 at the hottest axial location)

$\alpha_2 = 9.5x10^{-6}\,{}^oF^{-1}$

$\delta_2 = R_2\alpha_2(T_2-T_0) = 0.0861$ in

All the temperatures are obtained from FLUENT case and data file "DC-HI-STORM-FINEST-36.9kw" listed in Section B.4.

Net thermal expansion of point A

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

$\delta_{net} = 0.1887$ in

Radial thermal expansion

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

The net thermal expansion is $\delta = 0.0655$ 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 70°F reference temperature to storage temperatures is computed as follows:

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

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 "DC-HI-STORM-FINEST-36.9kw" listed in Section B.4. The required data for computing δ_1 is provided below:

$\alpha_1 = 9.50*10^{-6}$ °F^{-1} (Table 3.3.1 [B-2])
$\alpha_2 = 9.10*10^{-6}$ °F^{-1} (Table 3.3.1 [B-2])
H_b = 162.625 in [B-18]
[PROPRIETARY] (Minimum MPC cavity height including the fuel spacer)
[PROPRIETARY] (Maximum height of the fuel spacer)
$H_{cav} = H_2 - H_1$ = 163.5625 in
T_1 = 515°F (conservatively overstated)
T_2 = 360°F (conservatively understated)
T_o = 70°F

Substituting the above data in Eq. B.5.3, the fuel basket axial growth is computed as δ_2 = 0.256 in. The cold axial gap between the fuel basket and MPC is 0.9375 in.

c) MPC-to-Overpack Radial Growth

The radial growth of the MPC shell residing in the HI-STORM relative to the overpack upon heating from a 70°F reference temperature to storage temperatures is computed as follows:

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

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 "DC-HI-STORM-FINEST-36.9kw" 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]
$D_{min} = 69$ in [B-20] Minimum spacing between the guides
$R_g = R_{ovp} - D_{min}/2 = 2$ in
$\alpha_1 = 9.42 \times 10^{-6}$ $^oF^{-1}$ (Table 3.3.1 [B-2])
$\alpha_2 = 5.53 \times 10^{-6}$ $^oF^{-1}$ (Table 3.3.2 [B-2])
$\alpha_3 = 6.59 \times 10^{-6}$ $^oF^{-1}$ (Table 3.3.2 [B-2])
$T_1 = 475^oF$ (conservatively overstated)
$T_2 = 95^oF$ (conservatively understated)
$T_3 = 335^oF$ (conservatively overstated)
$T_o = 70^oF$

Substituting the above data in Eq. B.5.4, θ_1 is computed as 0.129 in. The radial cold gap between the MPC and overpack inner shell is 0.25 in (calculated as $D_{min}/2 - R_{shell}$).

d) <u>MPC-to-Overpack Axial Growth</u>

The axial growth of the MPC shell residing in the HI-STORM relative to the overpack upon heating from a 70°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 "DC-HI-STORM-FINEST-36.9kw" listed in Section B.4. The required data for computing θ_2 is provided below:

H_{shell} = 181.3125 in [B-19]
H_{ovp} = 197.5 in [B-20]
$\alpha_1 = 9.21*10^{-6}\ ^oF^{-1}$ (Table 3.3.1 [B-2])
$\alpha_2 = 5.89*10^{-6}\ ^oF^{-1}$ (Table 3.3.2 [B-2])
$T_1 = 365^oF$ (conservatively overstated)
$T_2 = 235^oF$ (conservatively understated)
$T_o = 70^oF$

Substituting the above data in Eq. B.5.5, θ_2 is computed as 0.301 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 both scenarios reported in Section 1.4 (for finest mesh). The calculations cover the following conditions:

i) Minimum and Maximum MPC helium backfill pressures
ii) Normal long-term storage
iii) Hypothetical rod ruptures

B.5.3.1 MPC-32 Cavity Pressure for Scenario 2

The MPC-32, prior to sealing, is backfilled with helium. The helium backfill must be sufficient to produce an operating pressure (P_o) of 7 atm absolute (102.9 psia) at design basis maximum heat load of 36.9 kW. The required helium backfill pressure is specified as a minimum backfill pressure (P_b) at 70^oF 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 (computed as 257°C (495°F))

Using the above data, the minimum backfill pressure is computed as 42.4 psig. A theoretical upper limit on the helium backfill pressure also exists and is defined by the design pressure (P_d) of the MPC-32 vessel (114.7 psia [B-2]). To compute the upper limit of helium backfill pressure, the operating pressure P_o is assumed to reach the design pressure (P_d) and P_b defined above is computed. The maximum allowable backfill pressure computes as 49.0 psig. To bound the minimum and maximum backfill pressures with a margin, 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 (36.9 kW) [B-2]
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. As these effects are substantial under large rod ruptures, the 100% rod rupture accident is evaluated with due credit for increased heat dissipation under increased molecular weight of the cavity gases. Molecular weight used in the analysis is conservatively understated.
3) Lower bound MPC-32 free volume (Appendix D)

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 <u>excluded</u>) 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 <u>included</u>. 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_pres_R8.xls" listed in Section B.4 and results reported in Table B.5.11. The MPC boundary pressures are below the design pressure limits specified in Chapter 2 of Reference B-2.

B.5.3.2 <u>MPC-32 Cavity Pressure for Scenario 1</u>

At the DC ISFSI, the limiting MPC-32 will be loaded with a uniform decay heat load of 24 kW and a helium backfill conditions consistent with Diablo Canyon FSAR [2]. Based on the methodology described in sub-section B.5.3.1, the helium backfill for MPC-32 loaded upto 24 kW and lower, is specified in Table 1.1.

The MPC-32 pressures (including helium from BPRAs) are computed in the EXCEL spreadsheet "mpc_pres_R8.xls" listed in Section B.4 and results reported in Table B.5.14. No credit for increased molecular weight is considered under 100% rod rupture accident event at the lower heat load. The MPC boundary pressures are below the design pressure limits specified both in DC ISFSI SAR [2] and Chapter 2 of Reference B-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

Scenario 1

This condition is defined as an off-normal ambient temperature (Table 1.2 of main report) co-incident with 10% rods rupture for Scenario 1. The maximum helium backfill specified for Scenario 1 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_pres_R8.xls" computer file listed in Section B.4) and results are reported in Table B.5.14. The result confirms that the MPC off-normal pressure is below the off-normal design pressure [2].

Scenario 2

This event is defined as a combination of (a) maximum helium backfill pressure (Table 1.1), (b) 10% fuel rods rupture, and (c) limiting fuel storage configuration. The principal objective of the analysis is to demonstrate that the MPC off-normal design pressure is not exceeded. The MPC-32 pressure is computed for Scenario 2 in EXCEL ("mpc_pres_R8.xls" computer file listed in Section B.4) and results are reported in Table B.5.11. The result confirms that the MPC off-normal pressure is below the off-normal design pressure limit [B-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 increased MPC-32 pressure is computed in EXCEL ("mpc_pres_R8.xls" computer file listed in Section B.4) and results are reported in Table B.5.12. The result confirms that the MPC pressure under off-normal ambient temperature is below the off-normal design pressure (specified in DC ISFSI SAR [2]).

(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 heat load of 36.9 kW (Scenario 2).

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.5.12. The result is below the off-normal design pressure (specified in DC ISFSI SAR [2])

(d) <u>Fire Accidents</u>

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] and 10 CFR 71 guidelines [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 × ft^2 × ° 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 2 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 B-2. Consequently, the impact on the MPC internal helium pressure will be small and the value is reported in Table B.5.12.

(e) 100% Blockage of Inlet Ducts

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.5.12. The result is confirmed to be below the accident pressure limit (specified in DC ISFSI SAR [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 27°C (80°F) 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 25°C (45°F). 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_R8.xls" listed in Section B.4) and reported in Table B.5.12. The result is below the accident design pressure limit (specified in DC ISFSI SAR [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 ($\Delta\tau$) 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 $\Delta\tau$ 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 $\Delta\tau$ is computed as follows:

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

where:
$\Delta\tau$ = 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 188640 sec (52.4 hrs) is obtained for the design basis decay heat load. The burial under debris accident pressure is reported in Table B.5.12 and is below the accident design pressure limit (specified in DC ISFSI SAR [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 DC ISFSI heat load 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. An air volume up to a height of 5 feet is modeled above the HI-STORM System. A quarter symmetric 3D model of a HI-STORM placed in the CTF is shown in Figure B.5.2. The thermal evaluation of this configuration is performed with the MPC uniformly loaded with a decay heat of 24 kW i.e. maximum per storage cell heat is limited to 750 Watts. An MPC operating pressure of 4.8 atmospheres absolute is used in this evaluation based on the lower helium backfill of 29.3 psig (specified in Table 1.1) and MPC cavity average temperature. An operating density based on air inlet operating pressure of 101325 Pa and temperature of 80°F i.e. a value of 1.17 kg/m^3 is used in this evaluation. The results of the analysis of HI-STORM placed in the CTF are reported in Table B.5.18. The fuel cladding temperature and other MPC and overpack temperatures are below their respective longt-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 24 kW.

The fuel, MPC and HI-STORM component temperatures obtained for Scenario 2 (see Section 1.4) bounds the thermal evaluation in this subsection. Therefore, short-term operations, all the off-normal and accident evaluations for an MPC with uniform heat load of 24 kW are bounded by the evaluations presented in Section B.5.4 and Appendix C. Also, if the MPC is loaded with one or more high burnup fuel (HBF), the use of Supplemental Cooling System (SCS) is mandatory.

The co-incident MPC-32 pressure is computed (EXCEL file "mpc_pres_R8.xls" listed in Section B.4) and reported in Table B.5.9. The result is below the normal design pressure limit (specified in DC ISFSI SAR [2]).

The finest mesh for the HI-STORM internal, discussed in Sub-section B.5.1.2, was used for the evaluation of the condition of HI-STORM 100SA system placed in the CTF and results reported in Table B.5.18. The airflow outside the HI-STORM system is modeled as turbulent flow using k-ω turbulence model to incorporate the effect of air turbulence on the systems thermal performance. 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**

]. However, 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. 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 modified. A total of three meshes are constructed and a brief summary of the different sets of grids evaluated is provided below:

Mesh	Number of Radial Cells	y^+	PCT (°C)	Permissible Limit (°C)
Mesh 1 - Coarse				400
Mesh 2 - Fine[Note 1]				400
Mesh 3 - Finest				400
Note 1: The grid sensitivity analysis for HI-STORM System in the CTF configuration reported in this table is performed with a reference heat load of 28.74 kW and an operating pressure of 5 atm. The purpose of this study is only to determine the converged mesh. Note 2: The y^+ reported in the third column above is a measure of grid adequacy provided by the FLUENT code. Values of $y^+\sim1$ indicate an adequate level of mesh refinement is reached to resolve the viscosity affected region near the wall.				

The fine mesh reported in the above table is used for the thermal analysis of this configuration with a heat load of 24 kW (Scenario1) and is presented in Table B.5.18. 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.

An array of sensitivity analysis have been performed to study the effect of potential FLUENT error (Appendix G), operating air density input in FLUENT (Appendix H) and CTF wedge assemblies (Appendix H) on the fuel cladding and cask component temperatures. These sensitivity analysis show that the effects are small and are well within the margins to temperature limits for Scenario 1

B.5.6 **[PROPRIETARY**

]

B.5.7 NOT USED

B.5.8 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 at a maximum cask heat load of 24 kW. 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

[B-1] "Pressure Loss Characteristics for In-Cell Flow of Helium in PWR and BWR MPCs", Holtec Report HI-2043285, Revision 7.

[B-2] "Final Safety Analysis Report for the HI-STORM 100 Cask System", Holtec Report HI-2002444, Revision 7.

[B-3] FLUENT Computational Fluid Dynamics Software, Version 6.3.26 (Fluent Inc., 10 Cavendish Court, Lebanon, NH – 03766).

[B-4] "Scoping Design Analyses for Optimized Shipping Casks Containing 1-, 2-, 3-, 5-, 7-, or 10- Year Old PWR Spent Fuel", Oak Ridge National Lab, 1983.

[B-5] "Cladding Considerations for the Transportation and Storage of Spent Fuel", Interim Staff Guidance – 11, U.S. Nuclear Regulatory Commission, Revision 3.

[B-6] "Topical Report on the Thermal Analysis Model for the HI-STAR/HI-STORM Systems and Benchmarking with Full-Size Test Data", Holtec Report HI-992252, Revision 1.

[B-7] "Diablo Canyon MPC-32 Fuel Basket Assembly", Holtec Drawing 4458, Revision 7.

[B-8] "Diablo Canyon Enclosure Vessel", Holtec Drawing 4459, Revision 9.

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

[B-10] "Underground Cask Transfer Facility", Holtec Drawing 4431, Revision 11.

[B-11] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," U.S. Nuclear Regulatory Commission, January 1997.

[B-12] "Nuclear Systems Materials Handbook", Volume 1, Oak Ridge National Laboratory, TID 26666, Volume 1.

[B-13] "Thermal Measurements in a Series of Large Pool Fires", Gregory, J.J., et. al., SAND85-1096, Sandia National Laboratories, Albuquerque, NM, (August 1987).

[B-14] "Evaluation of IFBA Fuel Storage in the HI-STORM System", DS-265, Revision 1.

[B-15] United States Code of Federal Regulations, Title 10, Part 71.

[B-16] HI-STORM 100 CoC, Amendments 1 to 4, USNRC Docket No. 72-1014.

[B-17] HI-STORM 100 CoC, Amendment 5, USNRC Docket No. 72-1014.

[B-18] "Diablo Canyon MPC-32 Fuel Basket", Holtec Drawing 4407, Revision 16.

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

[B-20] "HI-STORM 100SA", Holtec Drawing 4425, Revision 16.

[B-21] Deleted.

[B-22] A. Zigh and J. Solis, "Computational Fluid Dynamics Best Practice Guidelines in the Analysis of Storage Dry Cask", WM2008 Conference, Phoenix, AZ, 2008.

Table B.5.1

DELETED

Table B.5.2

BOUNDING HI-STORM 100SA NORMAL STORAGE MPC AND OVERPACK TEMPERATURES (SCENARIO 2)[2]

Component	Temperature for Baseline Mesh °C (°F)	Temperature for Finest Mesh °C (°F)	Temperature Change Due to Mesh Refinement °C (°F)	Temperature Limit °C (°F)
Fuel Cladding				400 (752)
MPC Basket				385 (725)
Basket Periphery				385 (725)
MPC Shell				260 (500)
Overpack Inner Shell				177 (350)
Overpack Outer Shell				177 (350)
Lid Bottom Plate				232 (450)
Lid Top Plate				232 (450)
Overpack Body Concrete[3]				149 (300)
Overpack Lid Concrete[3]				149 (300)
Average Air Outlet				-
MPC Cavity Average				-

2 The temperatures reported in this table for the limiting storage Scenario 2 are below the design temperatures specified in Table 2.2.3 of Reference B-2.

3 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	0.0655	Yes
Fuel Basket-to-MPC Axial Gap	0.9375	0.256	Yes
MPC-to-Overpack Radial Gap	0.25	0.129	Yes
MPC-to-Overpack Axial Gap	16.1875	0.301	Yes

Table B.5.4

OFF-NORMAL CONDITION MAXIMUM HI-STORM 100SA TEMPERATURES

Component	Off-Normal Ambient Temperature[4] °C (°F)	Partial Inlet Ducts Blockage[5] °C (°F)	Off-Normal Limit[Note 1] °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[6]			177 (350)
Overpack Lid Concrete[6]			177 (350)
Note 1: The off-normal temperature limits of all the components satisfy the more conservative Diablo Canyon specific off-normal temperature limits obtained from [2] in Section 8.0 of this report and therefore the Diablo Canyon limits are listed here.			

4 Obtained by adding the difference between off-normal ambient and normal temperature difference (11.1°C (20°F)) to normal condition temperatures (finest mesh) reported in Table B.5.2.

5 The temperatures tabulated herein include the temperature adder reported in Table B.5.2 for all the components.

6 Maximum section average temperature is reported.

Table B.5.5

HI-STORM 100SA FIRE AND POST-FIRE ACCIDENT ANALYSIS RESULTS[7]

Component	Initial Condition °C (°F)	End of Fire Condition °C (°F)	Post-Fire Cooldown °C (°F)	Time to Reach Maximum Temperature[8]	Temperature Limit °C (°F)
Fuel Cladding				31 hr	570 (1058)
MPC Basket				31 hr	510 (950)
Basket Periphery				31 hr	510 (950)
MPC Shell				240 sec	413 (775)
Overpack Inner Shell				240 sec	427 (800)
Overpack Outer Shell				240 sec	427 (800)
Overpack Body Concrete[9]				1 hr	177 (350)
Overpack Lid Concrete[9]				0.5 hr	177 (350)

7 All the temperatures tabulated herein include the temperature adder reported in Table B.5.2 for all the components.
8 Time starts after the beginning of fire.
9 Maximum section average temperature is reported.

Table B.5.6

RESULTS OF HI-STORM 100SA 32-HOURS BLOCKED INLET DUCTS THERMAL ANALYSIS[10]

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			427 (800)
Overpack Outer Shell			427 (800)
Lid Bottom Plate			427 (800)
Lid Top Plate			427 (800)
Overpack Body Concrete[11]			177 (350)
Overpack Lid Concrete[11]			177 (350)

10 All the temperatures tabulated herein include the temperature adder reported in Table B.5.2 for all the components.

11 Maximum section average temperature is reported.

Table B.5.7

EXTREME ENVIRONMENTAL CONDITION MAXIMUM HI-STORM 100SA TEMPERATURES

Component	**Temperature**[12] **°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		427 (800)
Overpack Outer Shell		427 (800)
Lid Bottom Plate		427 (800)
Lid Top Plate		427 (800)
Overpack Body Concrete[13]		177 (350)
Overpack Lid Concrete[13]		177 (350)

12 Obtained by adding the difference between extreme ambient and normal temperature difference (25°C (45°F)) to normal condition temperatures (finest mesh) reported in Table B.5.2.

13 Maximum section average temperature is reported.

Table B.5.8

SUMMARY OF INPUTS FOR BURIAL UNDER DEBRIS ANALYSIS

Thermal Inertia Inputs[14]: M (Lowerbound HI-STORM 100SA Weight) Cp (Carbon steel heat capacity)[15]	 99790 kg (220,000 lb) 419 J/kg-K (0.1 Btu/lbm-°F)
Cask initial temperature (clad max. temperature assumed)	
Q (Decay heat)	36.9 kW (0.126 MBtu/hr)
ΔT (clad temperature margin)[16]	

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

15 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).

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

Table B.5.9

DELETED

Table B.5.10

[PROPRIETARY]

Component			Temperature Limit °C (°F)
Fuel Cladding	390 (734)	387 (729)	400 (752)
MPC Basket[Note 1]	386 (727)	384 (723)	385 (725)
Basket Periphery	322 (612)	320 (608)	385 (725)
MPC Shell	241 (466)	245 (473)	260 (500)
Overpack Inner Shell	164 (327)	164 (327)	177 (350)
Overpack Outer Shell	74 (165)	73 (163)	177 (350)
Lid Bottom Plate	138 (280)	124 (255)	232 (450)
Lid Top Plate	88 (190)	85 (185)	232 (450)
Overpack Body Concrete[19]	106 (223)	105 (221)	149 (300)
Overpack Lid Concrete[20]	111 (232)	103 (217)	149 (300)
Average Air Outlet	94 (201)	93 (199)	-
[PROPRIETARY]			

17 All the temperatures tabulated herein include the temperature adder reported in Table B.5.2 for all the components.

18 These results are reported for the finest mesh in Table B.5.2.

19 Maximum section average temperature is reported.

Table B.5.11

SUMMARY OF MPC CONFINEMENT BOUNDARY PRESSURES[20] FOR SCENARIO 2

Condition	**Gauge Pressure kPa (psig)[21]**	**Pressure Limit[Note 1] 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)		758.2 (110)	
Accident (100% rods ruptured)		1378.6 (200)	
Note 1: The cavity pressure for Scenario 2 must satisfy the pressure limits specified in [B-2].			

20 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.

21 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.5.12

OFF-NORMAL AND ACCIDENT CONDITION MAXIMUM MPC PRESSURES (SCENARIO 2)

Condition	**MPC Cavity Average Temperature °C (°F)**	**Gauge Pressure kPa (psig)**	**Pressure Limit[Note1] kPa (psig)**
Off-Normal Conditions			
Off-Normal Ambient[22]			689.3 (100)
Partial Blockage of Inlet Ducts[23]			689.3 (100)
Accident Conditions			
Extreme Ambient Temperature			1378.6 (200)
100% Blockage of Air Inlets @ 32 Hr[24]			1378.6 (200)
HI-STORM Fire Accident[24]			1378.6 (200)
Burial Under Debris @ Maximum Allowable Burial Time			1378.6 (200)
Note 1: Since all the off-normal and accident scenarios mentioned in this table satisfy the more conservative Diablo Canyon specific pressure limits [2] in Section 8.0 of this report, the Diablo Canyon limits are listed here.			

22 The off-normal pressure event defined in Part (a) of Section B.5.4 for Scenario 2 bounds the pressure during the off-normal ambient temperature event (Part (b) in Section B.5.4).

23 MPC pressure is calculated based on the cavity average temperature that include the temperature adder reported in Table B.5.2.

Table B.5.13

DELETED

Table B.5.14

SUMMARY OF MPC CONFINEMENT BOUNDARY PRESSURES FOR SCENARIO 1[Note 1]

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

Note 1: The pressures presented in this table are for Scenario 1 listed in Section 1.4 at helium backfill specifications reported in Table 1.1 to maintain a MPC cavity pressure of at least 4.8 atm absolute.

Note 2: Conservatively, an MPC cavity average temperature of HI-STORM in the CTF configuration is used for the pressure calculations.

Table B.5.15

DELETED

Table B.5.16

DELETED

Table B.5.17

DELETED

Table B.5.18

HI-STORM 100SA NORMAL STORAGE MPC AND OVERPACK TEMPERATURES IN THE CASK TRANSFER FACILITY (CTF) FOR SCENARIO 1[24]

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[25]		149 (300)
Overpack Lid Concrete[36]		149 (300)
Average Air Outlet		-
Pressure kPa (psig)		
MPC Cavity		689.3 (100)

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

[25] Maximum section average temperature is reported.

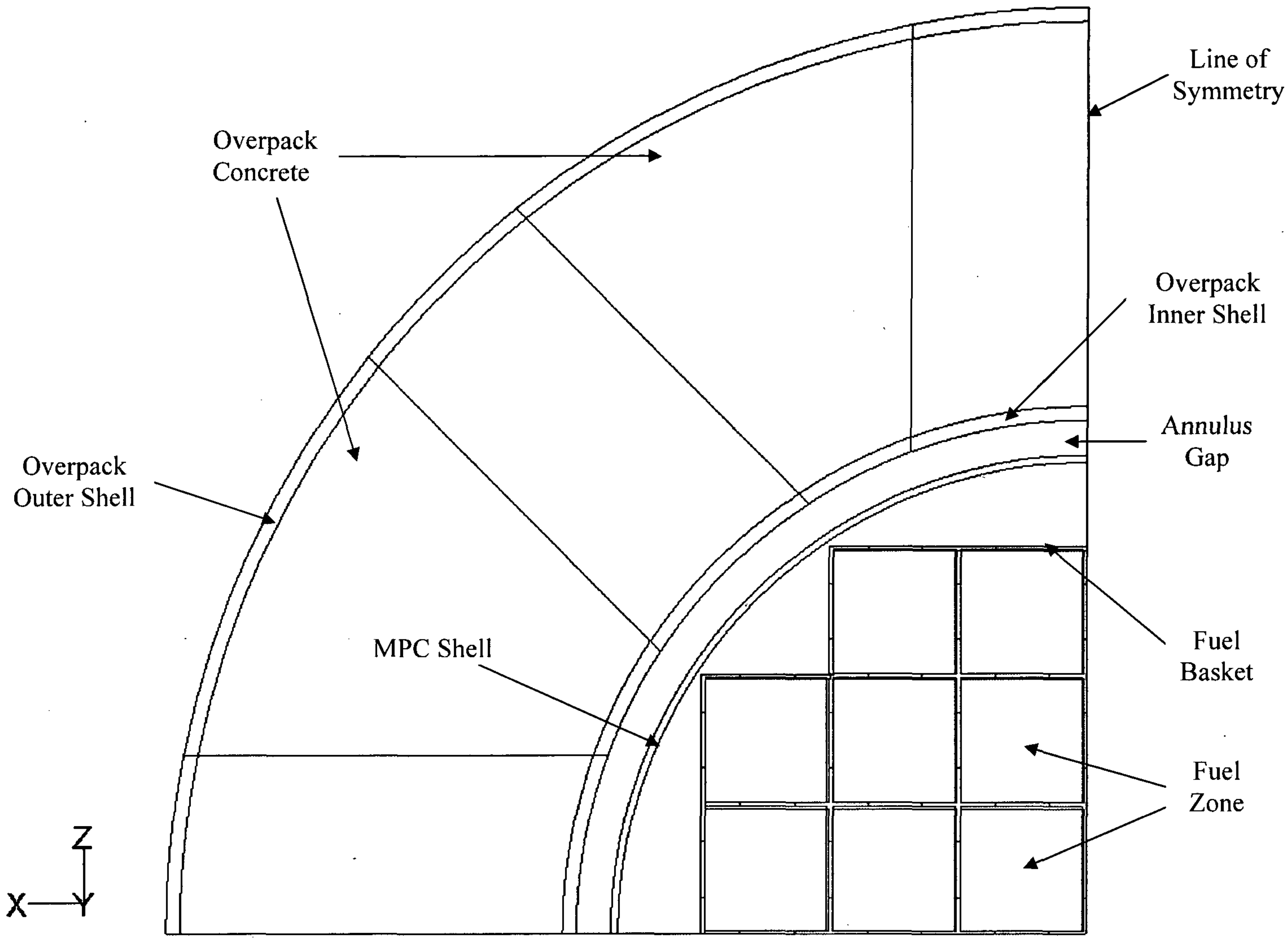

Figure B.2.1: Planar View of HI-STORM 100SA MPC- 32 Quarter Symmetric 3-D Model

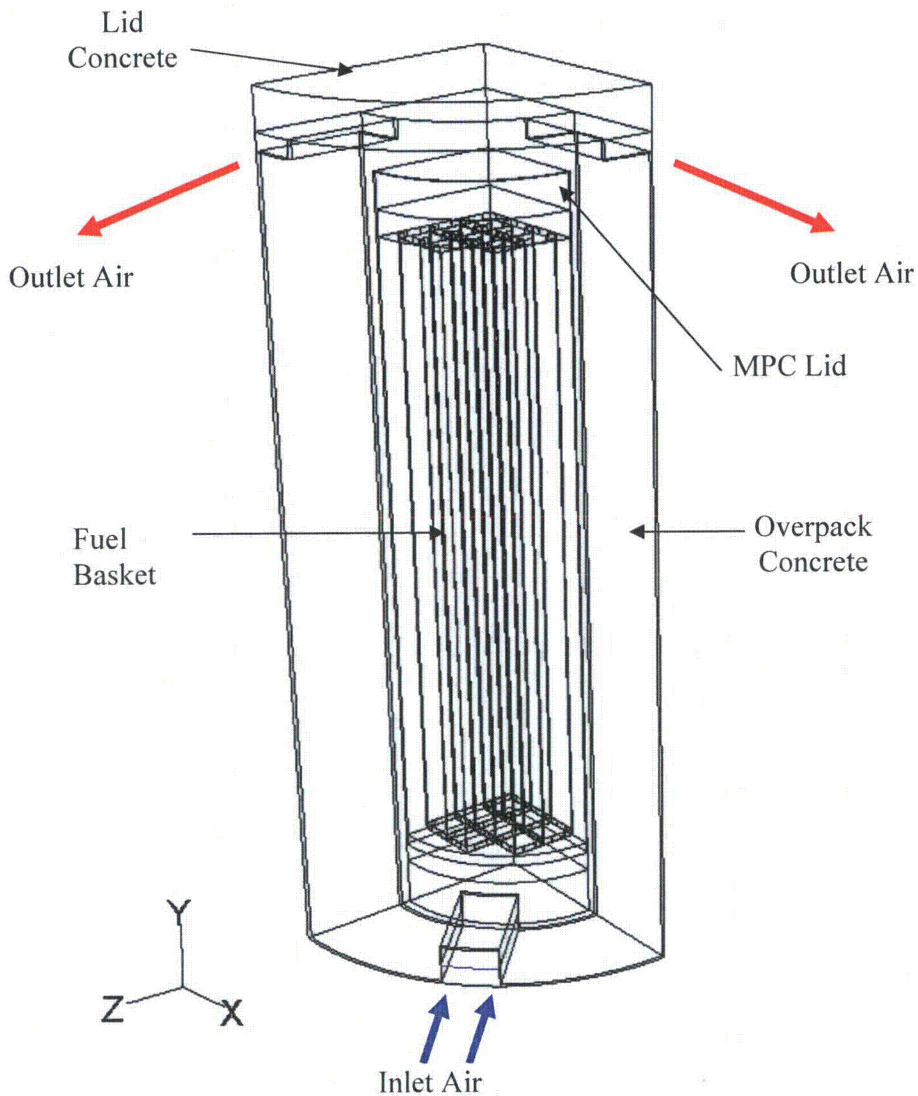

Figure B.2.2: HI-STORM 100SA MPC- 32 Quarter Symmetric 3-D Model

[PROPRIETARY]

Figure B.5.1: Basket Geometry

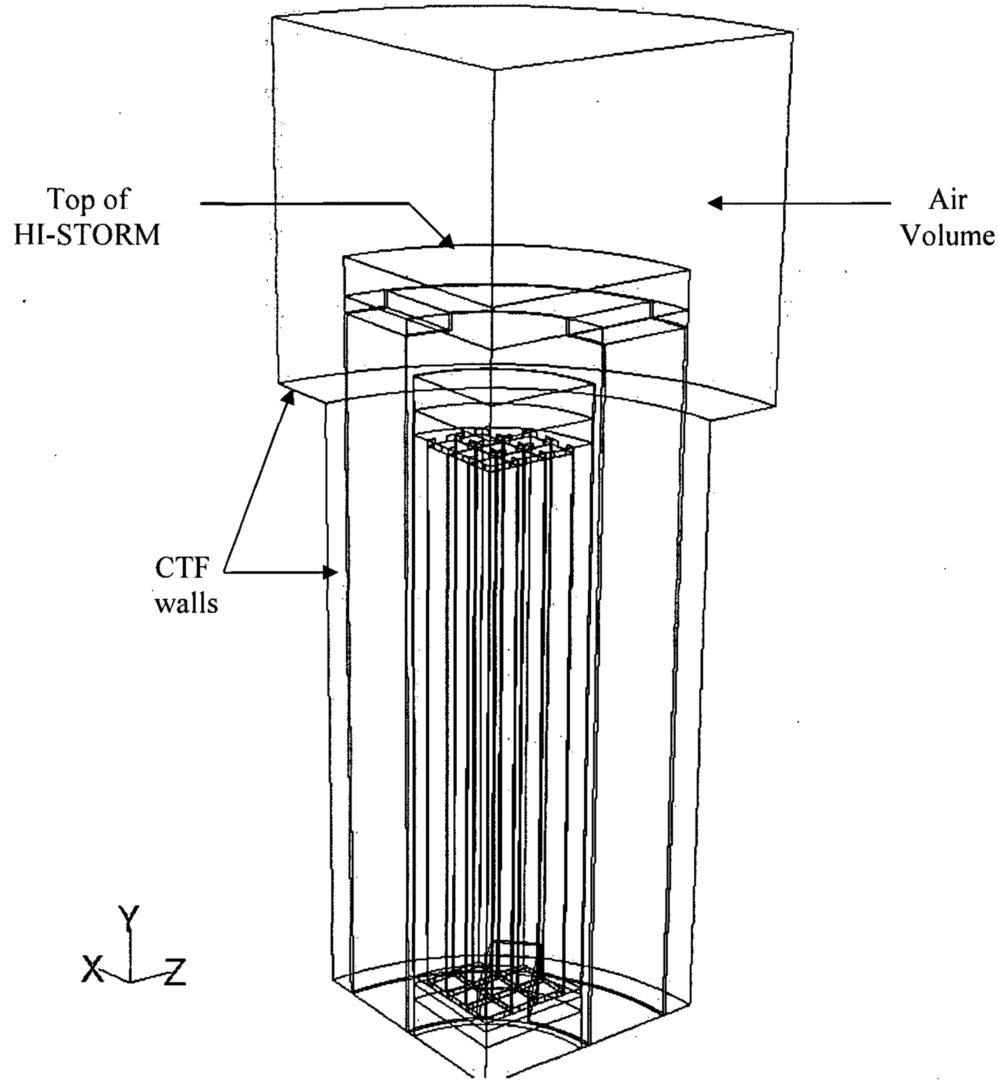

Figure B.5.2: Quarter Symmetric 3-D Model of HI-STORM 100SA Placed in CTF

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. For a bounding evaluation, the limiting fuel storage configuration, i.e. Scenario 2 in Section 1.4, 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 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 **[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.

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 bottom flange extension outside the enclosure shell envelope is not modeled. This simplification conservatively ignores bottom fin cooling. Also 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. Natural convection of water or air inside the water jacket is conservatively neglected.

7. 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. **[PROPRIETARY]**

8. **[PROPRIETARY**

]

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

10. **[PROPRIETARY**

]

[PROPRIETARY

]

C.3. INPUT DATA

[PROPRIETARY

]

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].

A helium absolute pressure of 7 atm is conservatively used for MPC internal convection heat transfer. **[PROPRIETARY**

] A solar absorptivity coefficient of 1.0 is applied to all exposed overpack surfaces.

C.4 COMPUTER PROGRAM AND FILES

For the normal conditions of on-site transfer, the HI-TRAC is analyzed for the limiting scenario (Scenario 2 in Section 1.4). For the accident condition (i.e., water jacket filled with air instead of water), the model is evaluated at the design-basis decay heat load but with air instead of water inside the water jacket.

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

G:\Projects\1073\REPORTS\Thermal Reports\HI-TRAC\gambit

March 10, 2010, 10:24:56 AM	188,743,680 bytes	DC-HI-TRAC.S.dbs
March 10, 2010, 10:26:51 AM	88,788,445 bytes	DC-HI-TRAC.S.msh

G:\Projects\1073\REPORTS\Thermal Reports\HI-TRAC\fluent

Normal On-site Transfer:

May 19, 2010, 3:38:53 PM	52,963,873 bytes	DC-HI-TRAC.SW-X=0.5.cas
May 19, 2010, 3:39:40 PM	966,018,915 bytes	DC-HI-TRAC.SW-X=0.5.dat
March 04, 2010, 6:05:33 PM	2,407 bytes	udf-diablo-x=0.5.c

Water Jacket Loss Accident:

May 19, 2010, 3:15:18 PM	52,964,452 bytes	DC-HI-TRAC.SA-X=0.5.cas
May 19, 2010, 3:16:08 PM	966,018,627 bytes	DC-HI-TRAC.SA-X=0.5.dat

Heat Load Q=28.74 kW:

June 18, 2010, 8:49:40 AM	52,963,854 bytes	DC-HI-TRAC-water-28.74kw.cas

June 18, 2010, 8:50:19 AM 966,059,839 bytes DC-HI-TRAC-water-28.74kw.dat

G:\Projects\1073\REPORTS\Thermal Reports\HI-TRAC\
May 18, 2010, 1:53:47 PM 61,195 bytes k-airgap.xmcd

C.5 RESULTS AND CONCLUSIONS

C.5.1 Normal and Water Loss Accident On-site Transfer Temperatures (Scenario 2)

[PROPRIETARY

]

The HI-TRAC was evaluated for the limiting Scenario 2 decay heat load distribution (see Section 1.4). The results of these FLUENT CFD analyses for on-site transfer conditions are presented for two conditions: (i) Water filled jacket (normal condition) and (ii) Complete loss of water (accident condition). The results are post-processed interactively with the FLUENT program. Discrete numeric results are presented in Tables C.1 and C.2. The results show that the peak fuel cladding temperature during normal on-site transfer conditions is below its temperature limit for moderate burnup fuel but exceeds the allowable limit for high-burnup fuel. A Supplemental Cooling System (SCS) will be required to be used to maintain the maximum cladding temperature for high burnup fuel below the 400°C temperature limit for an MPC that contains one or more high burnup fuel assemblies. The SCS is discussed in Section C.5.7 of this appendix. All the MPC & HI-TRAC overpack component temperatures **[PROPRIETARY**] are below their respective temperature limits for normal on-site transfer conditions. **[PROPRIETARY**

] Table C.2 shows that the peak fuel cladding temperatures for water loss accident is below its temperature limit. All the MPC & HI-TRAC overpack component temperatures are also below their respective temperature limits.

C.5.2 Thermal Evaluations supporting DC ISFSI License (Scenario 1)*

This evaluation was performed to support the Diablo Canyon ISFSI license that loads upto a uniform heat of 24 kW. However, for conservatism normal on-site transfer of an MPC-32 placed in the HI-TRAC is evaluated for a uniform heat load of 28.74 kW in this sub-section. The temperatures and cavity pressure for a uniform heat load of 28.74 kW will bound the Scenario 1. The operating pressure inside the MPC is 5 atmospheres absolute. The peak cladding temperature result of this evaluation is tabulated in Table C.6 and is bounded by the Scenario 2 results presented in Table C.1. Therefore, all the off-normal and accident evaluations of the HI-TRAC presented in this appendix are performed for the limiting (Scenario 2 in Section 1.4) scenario.

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. **[PROPRIETARY**

]

The calculations are presented in Appendix E 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.3. The results show that fuel cladding and all component temperatures are below than their accident temperature limits.

* See Section 1.4 for Scenario 1.

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.5.1.

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.4 for Scenario 2 (limiting heat load).

At the DC ISFSI, the limiting MPC-32 will be loaded with a uniform decay heat load of 24 kW (Scenario 1) and a helium backfill conditions consistent with Diablo Canyon FSAR [2]. Since the cavity temperatures for 28.74 kW scenario bounds Scenario 1, the MPC cavity pressures are conservatively reported for the case with 28.74 kW. The MPC-32 pressures are computed in the EXCEL spreadsheet "mpc_pres_R8.xls" listed in Section B.4 and results reported in Table C.7 for this scenario. The MPC boundary pressures are below the design pressure limits specified both in DC ISFSI SAR [2] and Chapter 2 of Reference C-1.

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 70°F reference temperature to operation temperatures is computed as follows:

$$\delta = R_1\alpha_1[T_1 - T_o] - R_2\alpha_2[T_2 - T_o] \quad \text{(Eq. C.5.2)}$$

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:

$\alpha_1 = 9.278*10^{-6}$ °F^{-1} (Table 3.3.1 [C-1])

$\alpha_2 = 6.58*10^{-6}$ °F^{-1} (Table 3.3.2 [C-1])

R1 = 34.25 in [C-5]

R2 = 34.375 in [C-6]

T_1 = 439°F

T_2 = 370°F

T_o = 70°F

Substituting the above data in Eq. C.5.2, the radial growth is computed as δ = 0.05 in. The nominal cold gap between MPC shell and HI-TRAC inner shell is 0.125in. The cold gap will be reduced by 40% due to thermal expansion. Therefore it is conservative to use 30% gap reduction in the calculation of the effective thermal conductivity of air in the annular gap.

C.5.7 Mandatory Limits for Short Term Operations – Supplemental Cooling System (SCS)

In some cases, it is necessary to provide additional cooling when decay heat loads are such that short-term cladding temperature limits would be exceeded. For such situations, the Supplemental Cooling System (SCS) is required to provide additional cooling during short term operations. An SCS is required by the HI-STORM CoC for any MPC carrying one or more high burnup fuel assemblies or when the MPC heat load is such that short-term cladding temperature limits would be exceeded. The requirements and limits for the HI-STORM CoC Amendment 5 SCS are listed in the following table:

Condition	Fuel in MPC	MPC Heat Load (kW)	SCS Required
1*	All MBF	≤ 28.74	NO
2	All MBF	> 28.74	YES
3	One or more HBF	any	YES
* The highest temperatures are reached under this un-assisted cooling threshold heat load scenario. Under other conditions the mandatory use of the Supplemental Cooling System, sized to extract 36.9 kW from the MPC, will lower the fuel temperatures significantly assuring ISG 11, Rev. 3 compliance with large margins.			

The DC ISFSI license has a limit of 24 kW (Scenario 1 in Section 1.4). The peak cladding temperature computed for normal transfer of fuel in the HI-TRAC for this scenario is 808°F (see Table C.6) which is substantially lower than the temperature limit of 1058°F for moderate burnup fuel (MBF)†. Consequently, cladding integrity assurance is provided by large safety margins (in excess of 200°F) during onsite transfer of an MPC containing MBF emplaced in a HI-TRAC cask.

For high burnup fuel (HBF), however, the maximum computed fuel cladding temperature reported in Table C.6 is significantly greater than the temperature limit of 752°F for HBF. Consequently, it is necessary to utilize an SCS that will maintain the cladding temperatures below 400°C (752°F), during onsite transfer of an MPC containing HBF emplaced in a HI-TRAC transfer cask. Therefore, an SCS is only required for the high burnup fuel condition.

The maximum temperature of the outer surface of the MPC shell during normal on-site transfer for Scenario 1 is 453°F. If standing water is maintained in the MPC/HI-TRAC annulus space, the temperature of the MPC surface will be at the boiling temperature of water (~232°F). Therefore, in this condition, since the MPC outer surface temperature is about 220°F lower, the fuel cladding temperatures will be lower than the fuel cladding temperature limit of 752°F. Therefore, the fuel cladding temperature is maintained below its temperature limit with an SCS that maintains the presence of standing water in the MPC/HI-TRAC annulus space.

† MBF is an abbreviation for Moderate Burnup Fuel while HBF stands for High Burnup Fuel.

C.5.8 Evaluation of SCS System with MPC Lid Outer Surfaces Exposed to Air

From the discussion in the previous sub-section, it is evident that a SCS system is required at Diablo during an onsite transfer of an MPC containing high burnup fuel. The presence of this system ensures sufficient cooling of the MPC by having water in the MPC/HI-TRAC annulus space. The SCS system requires that the entire MPC inside the HI-TRAC be covered with water. However, to address a scenario at Diablo where the water level inside the HI-TRAC is below the MPC lid top surface, a thermal evaluation is performed with part of the MPC exposed to air. The water level in the annulus gap between the MPC and HI-TRAC is conservatively postulated to be in level with the bottom surface of the MPC lid. This would result in the MPC lid outer surfaces exposed to air. A thermal evaluation of this configuration of the SCS system with water in the HI-TRAC annulus in level with the bottom surface of the MPC lid is evaluated in this sub-section.

The CFD model used in this analysis is exactly the same as that discussed in Subsection C.5.2. All the inputs, methodology and assumptions are the same except the following:

1. **[PROPRIETARY]**.
2. The MPC lid surfaces are exposed to air.
3. Based on helium backfill for Scenario 1 (Table 1.1) and MPC cavity temperatures, an MPC operating pressure of 4.7 atmospheres absolute is used in the calculations.

A bounding steady state analysis is performed with the MPC decay heat load set equal to 28.74 kW. The peak cladding temperature of this analysis is **[PROPRIETARY]** which is well below the temperature limit of 400°C (752°F). All MPC and HI-TRAC components are also below their respective temperature limits. Therefore, supplemental cooling of MPC-32 loaded with decay heat upto 28.74 kW is permitted with water level in the HI-TRAC annulus equal to the MPC lid bottom surface.

C.6 REFERENCES

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

[C-5] "Diablo Canyon Enclosure Vessel," Holtec Drawing 4459, Revision 9.

[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, January 1997.

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

[C-9] HI-STORM 100 CoC, Amendments 1 to 4, USNRC Docket 72-1014.

[C-10] HI-STORM 100 CoC, Amendment 5, USNRC Docket 72-1014.

[C-11] "Cladding Considerations for the Transportation and Storage of Spent Fuel," Interim Staff Guidance – 11, Revision 3, USNRC, Washington, DC.

Table C.1

MAXIMUM MPC AND HI-TRAC TEMPERATURES DURING NORMAL ON-SITE TRANSFER CONDITION FOR LIMITING HEAT LOAD (SCENARIO 2)

Component	**Temperature °C (°F)**	**Short-Term Operation Temperature Limit[Note 1] °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[2]		149 (300)

Note 1: The temperature limits are obtained from [C-1].

Note 2: The HI-TRAC inner shell temperature limit in the currently approved HI-STORM 100 FSAR is 400°F. But, the temperature of the inner shell is higher than the limit. See Section C.5.1 of this report for details.

1 This calculated value exceeds the allowable limit for high-burnup fuel. A Supplemental Cooling System that satisfies the criteria in Appendix 2.C of Reference C-1 shall be used to comply with applicable temperature limits when an MPC contains one or more high burnup fuel assemblies or exceeds a threshold heat load (see Section 4.5.5.1 of Reference C-1).

2 Maximum section average temperature is reported.

Table C.2

MAXIMUM MPC AND HI-TRAC TEMPERATURES DURING WATER LOSS ACCIDENT CONDITION FOR LIMITING HEAT LOAD (SCENARIO 2)

Component	**Temperature °C (°F)**	**Accident Temperature Limit[Note 1] °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[3]		177 (350)
Note 1: The temperature limits of all the components except the axial neutron shield are obtained from [2] in Section 8.0 of this report.		

3 Maximum section average temperature is reported.

Table C.3

MAXIMUM MPC AND FUEL CLADDING TEMPERATURES DURING FIRE ACCIDENT CONDITION FOR LIMITING HEAT LOAD (SCENARIO 2)

Component	Temperature °C (°F)	Accident Temperature Limit[Note1] °C (°F)
Fuel Cladding		570 (1058)
MPC Basket		510 (950)
Basket Periphery		510 (950)
MPC Shell		413 (775)
MPC Lid[4]		413 (775)
Note 1: The temperature limits are obtained from [2] in Section 8.0 of this report.		

4 Maximum section average temperature is reported

Table C.4

MPC-32 CONFINEMENT BOUNDARY PRESSURE DURING ON-SITE TRANSFER FOR LIMITING HEAT LOAD (SCENARIO 2)

Conditions	Cavity Average Temperature °C (°F)	Pressure kPa (psig)	Pressure Limit kPa (psig)
Normal Condition (No Rod Rupture)	308 (586)	718.2 (104.2)	758.2 (110)
Water Loss Accident Condition	333 (631)	753.4 (109.3)	1378.6 (200)
Fire Accident Condition	317 (603)	730.6 (106.0)	1378.6 (200)

Table C.5

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	3821 (8424)	4182 (0.999)	15.98×10^6 (8416)
Lead	36521 (80514)	130 (0.031)	4.75×10^6 (2496)
Carbon Steel	24064 (53052)	419 (0.1)	10.08×10^6 (5305)
MPC			
Alloy-X	13523 (29813)	502 (0.12)	6.79×10^6 (3578)
Metamic	276 (609)	921 (0.22)	0.25×10^6 (134)
Fuel	23529 (51872)	234 (0.056)	5.51×10^6 (2905)
MPC Cavity Water	3131 (6904)$^+$	4182 (0.999)	13.09×10^6 (6897)
Total value	-		56.45×10^6 (29731)

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.6

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

Component	Temperature for Scenario 2[Note 1] °C (°F)	Temperature for Scenario 1[Note 1] °C (°F)	Short-Term Operation Temperature Limits[Note 3] °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[5]			149 (300)

Note 1: These scenarios are defined in Section 1.4 of this report. The temperatures reported under Scenario 1 correspond to a bounding uniform heat load of 28.74 kW. The actual fuel and component temperatures will be lower than the values presented herein since the heat load for Scenario 1 is much lower than 28.74 kW.

Note 2: The HI-TRAC inner shell temperature limit in the currently approved HI-STORM 100 FSAR is 400°F. But, the temperature of the inner shell is higher than the limit. See Section C.5.1 of this report for details.

Note 3: The temperature limits are obtained from [2] in Section 8.0 of this report.

5 Maximum section average temperature is reported.

Table C.7

MPC-32 CONFINEMENT BOUNDARY PRESSURE DURING ON-SITE TRANSFER FOR SCENARIO 1[6]

Conditions	Cavity Average Temperature °C (°F)	Pressure kPa (psig)	Pressure Limit kPa (psig)
Normal Condition (No Rod Rupture)			689.3 (100)

[6] The MPC cavity pressure is conservatively reported based on the cavity temperatures obtained for an MPC with a heat load 28.74 kW. This bounds Scenario 1 listed in Section 1.4.

Appendix D

MPC-32 Free Volume Calculations
(Total 3 pages)

[PROPRIETARY]

Appendix E

HI-TRAC Fire Event Calculations
(Total 5 pages)

[PROPRIETARY]

Appendix F

Deleted

[PROPRIETARY]

Appendix G

Evaluation of Potential Error in FLUENT Code
(Total 4 pages)

G.1 INTRODUCTION

The thermal analyses for Diablo Canyon Dry Storage were performed and presented in this report. Version 6.3.26 of CFD code FLUENT [G-2] was used to perform the analyses. [**PROPRIETARY**

]. This appendix evaluates the effect of this potential FLUENT error on the calculations that support dry storage system at Diablo Canyon.

G.2 METHODOLOGY AND RESULTS

To address the issue mentioned in the previous section, an additional analysis is performed reported in this appendix, to determine the impact of potential FLUENT error on the thermal evaluations performed in this report. The steady state evaluation of the loaded HI-STORM placed in the Cask Transfer Facility (CTF) discussed in Section H.2 of Appendix H was re-performed for this purpose, since that analysis had the least margin to the Peak Cladding Temperature limit. The converged mesh discussed in sub-section B.5.5 was used in the analysis presented in this appendix. **[PROPRIETARY**

] The thermal models, methodology and assumptions also remain unchanged. The results of the new evaluations are summarized in Table G.1. From the results presented in the table, it is concluded that the potential error in the FLUENT code has a small effect on the predicted component temperatures presented in this report and all the components will remain below their respective temperature limits for all evaluated conditions. **[PROPRIETARY**

]

G.3 COMPUTER CODES AND FILES

The computer code FLUENT Version 6.3.26 is used in the thermal calculation.

```
Directory of G:\Projects\1073\REPORTS\Thermal Reports\HI-STORM\fluent
04/14/2011  09:03 AM       118,935,350    CTF-28.74kw-mesh2-emm=0.cas
04/14/2011  05:40 AM     1,815,698,288    CTF-28.74kw-mesh2-emm=0.dat
```

09/15/2010 05:24 PM   2,689   udf-diablo-28.74kw.c

G.4 REFERENCES

[G-1] "Final Safety Analysis Report for the HI-STORM 100 Cask System", Holtec Report HI-2002444, Revision 7.

[G-2] FLUENT Computational Fluid Dynamics Software, Version 6.3.26 (Fluent Inc., 10 Cavendish Court, Lebanon, NH – 03766).

Table G.1

EFFECT OF POTENTIAL FLUENT ERROR ON HI-STORM 100SA NORMAL STORAGE MPC AND OVERPACK TEMPERATURES IN THE CASK TRANSFER FACILITY (CTF) WITH A HEAT LOAD OF 28.74 kW

Component			
Fuel Cladding			
MPC Basket			
Basket Periphery			
MPC Shell			
Overpack Inner Shell			
Overpack Outer Shell			
Lid Bottom Plate			
Lid Top Plate			
Overpack Body Concrete[2]			
Overpack Lid Concrete[2]			
Average Air Outlet			
Pressure kPa (psig)			
MPC Cavity			

[1] The results correspond to converged mesh (Mesh 2) for HI-STORM in CTF condition discussed in Appendix H.
[2] Maximum section average temperature is reported.

Appendix H

Sensitivity Studies

(Total 9 pages)

H.0 Introduction

The purpose of this appendix is to document all the thermal evaluations that were performed for a reference heat load of 28.74 kW and an MPC operating pressure of 5 atm absolute. The normal long term storage and HI-STORM System in the CTF configurations were evaluated for this reference condition. This appendix also discusses the effect of various parameters like operating density in FLUENT code, presence of CTF wedge assemblies on the temperature field.

H.1 Normal Long-Term Storage Temperatures for an MPC with a Heat Load of 28.74 kW[1]

This evaluation was performed to support a HI-STORM System with an MPC that loads up to a uniform heat of 28.74 kW. The finest mesh that results in highest cladding and component temperatures during normal on-site storage discussed in Section B.5.1.2 is used to evaluate the MPC-32 in HI-STORM 100SA with a uniform heat load of 28.74 kW and a helium backfill of 29.3 psig at 70°F (Table 1.1). The operating pressure inside the MPC used in the analysis is 5 atmospheres absolute. The peak cladding temperature result of this evaluation is tabulated in Table H.1 and is all below their respective temperature limits.

H.2 HI-STORM in Cask Transfer Facility (CTF)

This condition is discussed in detail in Section B.5.5 of this report. A steady state evaluation for this condition has been performed using the 3-D FLUENT CFD model for a uniform heat load of 28.74 kW. All the inputs except the heat load and operating pressure of 5 atm absolute, methodology and assumptions remain exactly the same as discussed in Section B.5.5. The results of the analysis of HI-STORM placed in the CTF for this heat load are reported in Table H.2. The co-incident MPC-32 pressure is computed (EXCEL file "mpc_pres_R8.xls" listed in Section B.4) and reported in Table H.2. The result is below the normal design pressure limit (specified in DC ISFSI SAR [2]).

[1] Please note that all the calculation files that support the calculations in this appendix are reported in Appendix B.

H.3 Evaluation of effect of CTF wedge assemblies on HI-STORM 100SA System temperature field

The HI-STORM System in the CTF is modeled without the CTF wedge assemblies. The reason for ignoring all the four CTF wedge assemblies is that the area occupied by them is less than 3% of the annulus flow area between the HI-STORM and CTF wall. This will have no significant impact on the peak fuel and other cask component temperatures. It is also to be noted that, the thermal analysis of HI-STORM in CTF configuration is conservative since it assumes that the CTF walls are thermally insulated. However, to provide an additional assurance, a steady state evaluation was performed to include all the four CTF wedges in the annulus region. All the wedge assemblies are explicitly modeled and no other changes to the existing thermal model for this configuration were made. The heat load evaluated is 28.74 kW. The CTF walls are thermally insulated thereby ignoring any heat transfer through conduction from the wedge assemblies to the CTF walls. The principal temperature results of the analysis are presented in Table H.3. The effect of including the CTF wedge assemblies in the thermal model is small and therefore, it is safe to ignore them in the analysis.

H.4 Sensitivity Studies of Operating Density Parameter in FLUENT

A reference density of **[PROPRIETARY]** was used as operating density parameter in FLUENT for all the thermal evaluations of the HI-STORM 100SA System. The FLUENT user manual [B-3] indicates that the operating density should be equivalent to the volumetric average density of the fluid. The following excerpt is from Section 13.2.5 of the FLUENT 6.3 user's manual:

*"By default, **FLUENT** will compute the operating density by averaging over all cells. In some cases, you may obtain better results if you explicitly specify the operating density instead of having the solver compute it for you ……Therefore, you should explicitly specify the operating density rather than use the computed average. The specified value should, however, be representative of the average value. In some cases the specification of an operating density will improve convergence behavior, rather than the actual results. For such cases use the approximate bulk density value as the operating density and be sure that the value you choose is appropriate for the characteristic temperature in the domain."*

However, a conference paper by Zigh and Solis [B-22] studies the effect of operating density in the analysis of dry storage casks. In accordance with the conference paper [B-22], it was validated that an appropriate operating density in the analysis of dry storage casks corresponds to the density evaluated at the air inlet condition of pressure and temperature. The density of air based on air inlet conditions of pressure at **[PROPRIETARY]**. Even though the reference density used in the evaluations is within 5% of the value of density based on air inlet conditions, a sensitivity study is performed for normal storage conditions with a heat load of 28.74 kW with an operating air density corresponding to air inlet conditions. The result of such an evaluation is presented Table H.4.

It can be concluded from Table H.4 that the predicted fuel cladding, MPC and overpack cask component temperatures changes by a small amount due to the variation in the air operating density used in the analyses and all components still remain well below their respective temperature limits. The safety of the system is not challenged since all the cask component temperatures and MPC cavity pressure remain well below their respective limits.

A similar evaluation is performed for the HI-STORM in the CTF to study the effect of operating air density on temperatures since it has least margin to temperature limits for a heat load of 28.74 kW. The results are tabulated in Table H.5 for reference density of **[PROPRIETARY]**. It can be noted from the results that the fuel cladding and cask component temperatures decrease with the change in operating density now based on inlet air conditions. The temperatures and pressures essentially remain unchanged for the HI-STORM in the CTF configuration.

The sensitivity studies show that small variations in the operating density has a relatively small effect on the predicted temperatures and pressures and in these particular thermal evaluations, all the safety conclusions remain unchanged.

Table H.1

HI-STORM 100SA PEAK TEMPERATURES DURING LONG TERM STORAGE FOR AN MPC WITH 28.74 kW[2]

Component	Temperature °C (°F)	Temperature Limit[Note 1] °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[3]		149 (300)
Overpack Lid Concrete[11]		149 (300)
Average Air Outlet		-
Note 1: The temperature limits of all the components except concrete are obtained from [2] in Section 8.0 of this report.		

2 The peak cladding temperatures presented in the table are based on the finest mesh.
3 Maximum section average temperature is reported.

Table H.2

BOUNDING HI-STORM 100SA NORMAL STORAGE MPC AND OVERPACK TEMPERATURES IN THE CASK TRANSFER FACILITY (CTF) FOR AN MPC WITH A HEAT LOAD OF 28.74 kW

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[4]		149 (300)
Overpack Lid Concrete[12]		149 (300)
Average Air Outlet		-
Pressure kPa (psig)		
MPC Cavity		689.3 (100)

[4] Maximum section average temperature is reported.

Table H.3

EFFECT OF CTF WEDGE ASSEMBLIES ON HI-STORM 100SA MPC AND OVERPACK TEMPERATURES FOR AN MPC WITH 28.74 kW

Component	No Wedge Assemblies Temperature[5] °C	With Wedge Assemblies Temperature °C	Temperature Limit °C (°F)
Fuel Cladding			400 (752)
MPC Basket			385 (725)
MPC Shell			232 (450)
Overpack Inner Shell			177 (350)

[5] These temperatures are obtained from Table H.2

Table H.4

EFFECT OF OPERATING DENSITY PARAMETER ON HI-STORM 100SA SYSTEM TEMPERATURES FOR AN MPC WITH 28.74 kW[6]

Component	(Reference Density) Temperature[7] °C (°F)	(Density Based on Air Inlet Condition) Temperature[8] °C (°F)	Temperature Limit °C (°F)
Fuel Cladding			400 (752)
MPC Basket			385 (725)
MPC Shell			232 (450)
Overpack Inner Shell			177 (350)
Lid Bottom Plate			177 (350)
Overpack Body Concrete[9]			149 (300)
Overpack Lid Concrete[17]			149 (300)
Average Air Outlet			-
Pressure kPa (psig)			
MPC Cavity			689.3 (100)

6 The peak cladding temperatures presented in the table are based on the finest mesh.
7 These temperatures are reported in Table H.1
8 These temperatures are obtained with operating density parameter based on air inlet conditions.
9 Maximum section average temperature is reported.

Table H.5

EFFECT OF OPERATING DENSITY PARAMETER ON HI-STORM 100SA SYSTEM TEMPERATURES IN THE CASK TRANSFER FACILITY (CTF) FOR AN MPC WITH 28.74 kW

Component	**(Reference Density) Temperature[10] °C (°F)**	**(Density Based on Air Inlet Condition) Temperature[11] °C (°F)**	**Temperature Limit °C (°F)**
Fuel Cladding			400 (752)
MPC Basket			385 (725)
MPC Shell			232 (450)
Overpack Inner Shell			177 (350)
Overpack Body Concrete[12]			149 (300)
Overpack Lid Concrete[20]			149 (300)
Average Air Outlet			-
Pressure kPa (psig)			
MPC Cavity			689.3 (100)

10 These temperatures are reported in Table H.2
11 These temperatures are obtained with operating density parameter based on air inlet conditions.
12 Maximum section average temperature is reported.

Technical Specification Page Markups

TABLE OF CONTENTS

1.1 Definitions (continued)

INTACT FUEL ASSEMBLY	INTACT FUEL ASSEMBLY is a fuel assembly without known or suspected cladding defects greater than pinhole leaks or hairline cracks and which can be handled by normal means. A fuel assembly shall not be classified as INTACT FUEL ASSEMBLY unless solid Zircaloy or stainless steel rods are used to replace missing fuel rods and which displace an amount of water equal to that displaced by the original fuel rod(s).
LOADING OPERATIONS	LOADING OPERATIONS include all licensed activities on a TRANSFER CASK while its contained MPC is being loaded with its approved contents. LOADING OPERATIONS begin when the first fuel assembly is placed in the MPC and end when the TRANSFER CASK is suspended from or secured on the transporter. LOADING OPERATIONS does not include MPC transfer between the TRANSFER CASK and the OVERPACK.
MINIMUM ENRICHMENT	*MINIMUM ENRICHMENT is the minimum assembly average enrichment. Natural uranium blankets are not considered in determining minimum enrichment.*
MULTI-PURPOSE CANISTER (MPC)	MPC is a sealed SPENT NUCLEAR FUEL container that consists of a honeycombed fuel basket contained in a cylindrical canister shell which is welded to a baseplate, lid with welded port cover plates, and closure ring. The MPC provides the confinement boundary for the contained radioactive materials.
NONFUEL HARDWARE	NONFUEL HARDWARE is defined as burnable poison rod assemblies (BPRAs), thimble plug devices (TPDs), rod control cluster assemblies (RCCAs), ~~and~~ wet annular burnable absorbers (WABAs)*, neutron source assemblies (NSAs), instrument tube tie rods (ITTRs), and components of these devices such as individual rods*.
OPERABLE/OPERABILITY	A system, component, or device shall be OPERABLE or have OPERABILITY when it is capable of performing its specified safety function(s) and when all necessary attendant instruments, controls, normal or emergency electrical power, and other auxiliary equipment that are required for the system, component, or device to perform its specific safety function(s) are also capable of performing their related support function(s).

(continued)

1.1 Definitions (continued)

OVERPACK	OVERPACK is a cask that receives and contains a sealed MPC for interim storage in the independent spent fuel storage installation (ISFSI). It provides gamma and neutron shielding, and provides for ventilated air flow to promote heat transfer from the MPC to the environs. The OVERPACK does not include the TRANSFER CASK.
SPENT FUEL STORAGE CASKS (SFSCs)	SFSCs are containers approved for the storage of spent fuel assemblies, FUEL DEBRIS, and associated NONFUEL HARDWARE at the ISFSI. The HI-STORM 100 SFSC System consists of the OVERPACK and its integral MPC loaded with any approved contents.
SPENT NUCLEAR FUEL	SPENT NUCLEAR FUEL means fuel that has been withdrawn from a nuclear reactor following irradiation, has undergone at least one year's decay since being used as a source of energy in a power reactor and has not been chemically separated into its constituent elements by reprocessing. SPENT NUCLEAR FUEL includes the special nuclear material, byproduct material, source material, and other radioactive materials associated with fuel assemblies.
STORAGE OPERATIONS	STORAGE OPERATIONS include all licensed activities that are performed at the ISFSI while a SFSC containing approved contents is sitting on a storage pad within the ISFSI perimeter. STORAGE OPERATIONS does not include MPC transfer between the TRANSFER CASK and the OVERPACK.
TRANSFER CASK	TRANSFER CASKs are containers designed to contain the MPC during and after loading of its approved contents and to transfer the loaded MPC to or from the OVERPACK.
TRANSPORT OPERATIONS	TRANSPORT OPERATIONS include all licensed activities performed on an OVERPACK or TRANSFER CASK loaded with any approved contents when it is being moved to and from the ISFSI. TRANSPORT OPERATIONS begin when the OVERPACK or TRANSFER CASK is first suspended from or secured on the transporter and end when the OVERPACK or TRANSFER CASK is at its destination and no longer secured on or suspended from the transporter. TRANSPORT OPERATIONS include transfer of the MPC between the OVERPACK and the TRANSFER CASK.

(continued)

2.3 Alternate MPC-32 Fuel Selection Criteria

The maximum allowable fuel assembly average burnup for a given MINIMUM ENRICHMENT is calculated as described below for minimum cooling times between 5 and 20 years using the maximum permissible decay heat determined in Table 2.1-7. Different fuel assembly average burnup limits may be calculated for different minimum enrichments (by individual fuel assembly) for use in choosing the fuel assemblies to be loaded into a given MPC.

a. Choose a fuel assembly minimum enrichment E_{235}.

b. Calculate the maximum allowable fuel assembly average burnup for a minimum cooling time between 5 and 20 years using the following equation below:

$$Bu = (A \times q) + (B \times q^2) + (C \times q^3) + [D \times (E_{235})^2] + (E \times q \times E_{235}) + (F \times q^2 \times E_{235}) + G$$

Where:

Bu = Maximum allowable average burnup per fuel assembly (MWD/MTU)

q = Maximum allowable decay heat per storage location, in kilowatts, determined from Table 2.1-7 (e.g. 750 watts, use 0.750)

E_{235} = Minimum fuel assembly average enrichment (wt% ^{235}U) (e.g., for 4.05 wt%, use 4.05)

A through G = Coefficients from Table 2.3-1.

c. Calculated burnup limits shall be rounded down to the nearest integer.

d. Calculated burnup limits greater than 68,200 MWD/MTU must be reduced to be equal to this value.

e. Linear interpolation of calculated burnups between cooling times for a given fuel assembly maximum decay heat and minimum enrichment is permitted. For example, the allowable burnup for a cooling time of 5.5 years may be interpolated between those burnups calculated for 5 year and 6 years.

f. Each ZR-clad fuel assembly to be stored must have a MINIMUM ENRICHMENT greater than or equal to the value used in Step 2.3.a.

g. When complying with the maximum fuel storage location decay heat limits, users must account for the decay heat from both the fuel assembly and any NON-FUEL HARDWARE, as applicable for the particular fuel storage location, to ensure the decay heat emitted by all contents in a storage location does not exceed the limit.

TABLE 2.1-1

MPC-24 FUEL ASSEMBLY LIMITS

A. Allowable Contents

1. Uranium oxide, INTACT FUEL ASSEMBLIES listed in Table 2.1-5, with or without NONFUEL HARDWARE and meeting the following specifications (Note 1):

Cladding type	Zr (Note 2)
Initial enrichment	As specified in Table 2.1-5 for the applicable fuel assembly.
Post-irradiation cooling time and average burnup per assembly:	
Fuel	As specified in Tables 2.1-6 or 2.1-8.
NONFUEL HARDWARE	As specified in Table 2.1-10.
Decay heat per assembly	As specified in Tables 2.1-7 or 2.1-9.
Fuel assembly length	≤ 176.8 inches (nominal design)
Fuel assembly width	≤ 8.54 inches (nominal design)
Fuel assembly weight	≤ 1,680 lb (including NONFUEL HARDWARE)

B. Quantity per MPC: Up to 24 fuel assemblies.

C. DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS are not authorized for loading into the MPC-24.

D. One NSA is authorized for loading in an MPC-24.

NOTE 1: Fuel assemblies containing BPRAs, WABAs, or TPDs may be stored in any fuel cell location. Fuel assemblies containing RCCAs *or NSAs* may only be loaded in fuel storage locations 9, 10, 15, and/or 16 of Figure 2.1-1. These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

NOTE 2: Zr designates fuel-cladding material made of Zircaloy-2, Zircaloy-4 and ZIRLO.

TABLE 2.1-2 Sheet 2 of 2

A. Quantity per MPC: Up to four (4) DAMAGED FUEL ASSEMBLIES in DAMAGED FUEL CONTAINERS, stored in fuel storage locations 3, 6, 19 and/or 22 of Figure 2.1-2. The remaining MPC-24E fuel storage locations may be filled with INTACT FUEL ASSEMBLIES meeting the applicable specifications.

B. FUEL DEBRIS is not authorized for loading in the MPC-24E.

C. One NSA is authorized for loading in an MPC-24E.

NOTE 1: Fuel assemblies containing BPRAs, WABAs, or TPDs may be stored in any fuel storage location. Fuel assemblies containing RCCAs *or NSAs* must be loaded in fuel storage locations 9, 10, 15 and/or 16 of Figure 2.1-2. These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

NOTE 2: Zr designates fuel-cladding material, which is made of Zircaloy-2, Zircaloy-4 and ZIRLO.

TABLE 2.1-3

A. Quantity per MPC: Up to four (4) DAMAGED FUEL ASSEMBLIES and/or FUEL DEBRIS in DAMAGED FUEL CONTAINERS, stored in fuel storage locations 3, 6, 19 and/or 22 of Figure 2.1-2. The remaining MPC-24EF fuel storage locations may be filled with INTACT FUEL ASSEMBLIES meeting the applicable specifications.

B. One NSA is authorized for loading in an MPC-24EF.

NOTE 1: Fuel assemblies containing BPRAs, WABAs, or TPDs may be stored in any fuel storage location. Fuel assemblies containing RCCAs *or NSAs* must be loaded in fuel storage locations 9, 10, 15 and/or 16 of Figure 2.1-2. These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

NOTE 2: The total quantity of FUEL DEBRIS permitted in a single DAMAGED FUEL CONTAINER is limited to the equivalent weight and special nuclear material quantity of one INTACT FUEL ASSEMBLY.

NOTE 3: Zr designates fuel-cladding material, which is made of Zircaloy-2, Zircaloy-4 and ZIRLO.

TABLE 2.1-4

MPC-32 FUEL ASSEMBLY LIMITS

A. Allowable Contents

1. Uranium oxide, INTACT FUEL ASSEMBLIES listed in Table 2.1-5, with or without NONFUEL HARDWARE and meeting the following specifications (Note 1):

Cladding type	Zr (Note 2)
Initial enrichment	As specified in Table 2.1-5 for the applicable fuel assembly.
Post-irradiation cooling time and average burnup per assembly:	
Fuel	As specified in Tables 2.1-6 or 2.1-8*, or Section 2.3.*
NONFUEL HARDWARE	As specified in Table 2.1-10.
Decay heat per assembly	As specified in Tables 2.1-7 or 2.1-9.
Fuel assembly length	≤ 176.8 inches (nominal design)
Fuel assembly width	≤ 8.54 inches (nominal design)
Fuel assembly weight	≤ 1,680 lb (including NONFUEL HARDWARE)

B. Quantity per MPC: Up to 32 intact fuel assemblies.

C. DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS are not authorized for loading in the MPC-32.

D. One NSA is authorized for loading in an MPC-32.

NOTE 1: Fuel assemblies*, with or without ITTRs,* containing BPRAs, WABAs, or TPDs*,* may be stored in any fuel storage location. Fuel assemblies*, with or without ITTRs,* containing RCCAs *or NSAs* must be loaded in fuel storage locations 13, 14, 19 and/or 20 of Figure 2.1-3. These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

NOTE 2: Zr designates fuel-cladding material, which is made of Zircaloy-2, Zircaloy-4 and ZIRLO.

TABLE 2.1-5

FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Type *(Note 6)*	Vantage 5	Standard, or LOPAR
Cladding Material	Zr (Note 5)	Zr (Note 5)
Design Initial U (kg/assy.) (Note 2)	≤ 467	≤ 467
Initial Enrichment (MPC-24, 24E, and 24EF without soluble boron credit) (wt% ^{235}U) (Note 4)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, or 32 with soluble boron credit) (wt% ^{235}U) (Notes 3 and 4)	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	264	264
Fuel Rod Cladding O.D. (in.)	≥ 0.360	≥ 0.372
Fuel Rod Cladding I.D. (in.)	≤ 0.3150	≤ 0.3310
Fuel Pellet Dia. (in.)	≤ 0.3088	≤ 0.3232
Fuel Rod Pitch (in.)	≤ 0.496	≤ 0.496
Active Fuel Length (in.)	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	25	25
Guide/Instrument Tube Thickness (in.)	≥ 0.016	≥ 0.014

NOTE 1: All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies.

NOTE 2: Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or DCPP. For each fuel assembly, the total uranium weight limit specified in this table may be increased up to 2.0 percent for comparison with DCPP fuel records to account for manufacturer's tolerances.

NOTE 3: Soluble boron concentration per Technical Specification LCO 3.2.1.

NOTE 4: For those MPCs loaded with both INTACT FUEL ASSEMBLIES and DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, the maximum initial enrichment of the INTACT FUEL ASSEMBLIES is limited to the maximum initial enrichment of the DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS (i.e., 4.0 wt.% ^{235}U).

NOTE 5: Zr designates fuel-cladding material, which is made of Zircaloy-2, Zircaloy-4 and ZIRLO.

NOTE 6: Fuel assemblies meeting the characteristics may be loaded under the requirements for the listed Fuel Assembly Type, even if the name is different.

TABLE 2.1-6

FUEL ASSEMBLY COOLING AND MAXIMUM AVERAGE BURNUP
(UNIFORM FUEL LOADING)

Post-Irradiation Cooling Time (years)	MPC-24 Assembly Burnup (INTACT FUEL ASSEMBLIES) (MWD/MTU)	MPC-24E/24EF Assembly Burnup (INTACT FUEL ASSEMBLIES) (MWD/MTU)	MPC-24E/24EF Assembly Burnup (DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS) (MWD/MTU)	MPC-32 Assembly Burnup (INTACT FUEL ASSEMBLIES) (MWD/MTU) *(Note 2)*
≥ 5	40,600	41,100	39,200	32,200
≥ 6	45,000	45,000	43,700	36,500
≥ 7	-	-	44,500	37,500
≥ 8	-	-	45,000	39,900
≥ 9	-	-	-	41,500
≥ 10	-	-	-	42,900
≥ 11	-	-	-	44,100
≥ 12	-	-	-	45,000
≥ 13	-	-	-	-
≥ 14	-	-	-	-
≥ 15	-	-	-	-

NOTE 1: Linear interpolation between points is permitted.

NOTE 2: Burnup *limits* for fuel assemblies ~~with cladding made of ZIRLO is limited to 45,000 MWD/MTU or the value in this table, whichever is less~~*in an MPC-32 may alternatively be calculated using Section 2.3*.

TABLE 2.1-7

FUEL ASSEMBLY COOLING AND MAXIMUM DECAY HEAT
(UNIFORM FUEL LOADING)

Post-Irradiation Cooling Time (years)	MPC-24 Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts)	MPC-24E/24EF Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts)	MPC-24E/24EF Assembly Decay Heat (DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS) (Watts)	MPC-32 Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts) *[BU ≤45,000 MWd/MTU]*	*MPC-32 Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts) [BU >45,000 MWd/MTU]*
≥ 5	1157	1173	1115	898	*750*
≥ 6	1123	1138	1081	873	*750*
≥ 7	1030	1043	991	805	*750*
≥ 8	1020	1033	981	800	*750*
≥ 9	1010	1023	972	794	*750*
≥ 10	1000	1012	962	789	*750*
≥ 11	996	1008	958	785	*750*
≥ 12	992	1004	954	782	*750*
≥ 13	987	999	949	773	*750*
≥ 14	983	995	945	769	*750*
≥ 15	979	991	941	766	*750*

NOTE 1: Linear interpolation between points is permitted.

NOTE 2: Includes all sources of heat (i.e., fuel and NONFUEL HARDWARE).

TABLE 2.1-8

FUEL ASSEMBLY COOLING AND MAXIMUM AVERAGE BURNUP
(REGIONALIZED FUEL LOADING)

Post-Irradiation Cooling Time (years)	MPC-24 Assembly Burnup for Region 1 (MWD/MTU)	MPC-24 Assembly Burnup for Region 2 (MWD/MTU)	MPC-24E/24EF Assembly Burnup for Region 1 (MWD/MTU)	MPC-24E/24EF Assembly Burnup for Region 2 (MWD/MTU)	MPC-32 Assembly Burnup for Region 1 (MWD/MTU)	MPC-32 Assembly Burnup for Region 2 (MWD/MTU)
≥ 5	45,000	32,200	45,000	32,200	39,800	22,100
≥ 6	-	37,400	-	37,400	43,400	26,200
≥ 7	-	41,100	-	41,100	44,500	29,100
≥ 8	-	43,800	-	43,800	45,000	31,200
≥ 9	-	45,000	-	45,000	-	32,700
≥ 10	-	-	-	-	-	34,100
≥ 11	-	-	-	-	-	35,200
≥ 12	-	-	-	-	-	36,200
≥ 13	-	-	-	-	-	37,000
≥ 14	-	-	-	-	-	37,800
≥ 15	-	-	-	-	-	38,600
≥ 16	-	-	-	-	-	39,400
≥ 17	-	-	-	-	-	40,200
≥ 18	-	-	-	-	-	40,800
≥ 19	-	-	-	-	-	41,500
≥ 20	-	-	-	-	-	42,200

NOTE 1: Linear interpolation between points is permitted.

NOTE 2: These limits apply to INTACT FUEL ASSEMBLIES, DAMAGED FUEL ASSEMBLIES, and FUEL DEBRIS.

NOTE 3: Burnup for fuel assemblies with cladding made of ZIRLO is limited to 45,000 MWD/MTU or the value in this table, whichever is less.

TABLE 2.1-9

FUEL ASSEMBLY COOLING AND MAXIMUM DECAY HEAT
(REGIONALIZED FUEL LOADING)

Post-Irradiation Cooling Time (years)	MPC-24 Assembly Decay Heat for Region 1 (Watts)	MPC-24 Assembly Decay Heat for Region 2 (Watts)	MPC-24E/24EF Assembly Decay Heat for Region 1 (Watts)	MPC-24E/24EF Assembly Decay Heat for Region 2 (Watts)	MPC-32 Assembly Decay Heat for Region 1 (Watts)	MPC-32 Assembly Decay Heat for Region 2 (Watts)
≥ 5	1470	900	1540	900	1131	600
≥ 6	1470	900	1540	900	1072	600
≥ 7	1335	900	1395	900	993	600
≥ 8	1301	900	1360	900	978	600
≥ 9	1268	900	1325	900	964	600
≥ 10	1235	900	1290	900	950	600
≥ 11	1221	900	1275	900	943	600
≥ 12	1207	900	1260	900	937	600
≥ 13	1193	900	1245	900	931	600
≥ 14	1179	900	1230	900	924	600
≥ 15	1165	900	1215	900	918	600
≥ 16	-	-	-	-	-	-
≥ 17	-	-	-	-	-	-
≥ 18	-	-	-	-	-	-
≥ 19	-	-	-	-	-	-
≥ 20	-	-	-	-	-	-

NOTE 1: Linear interpolation between points is permitted.

NOTE 2: Includes all sources of decay heat (i.e., fuel and NONFUEL HARDWARE).

NOTE 3: These limits apply to INTACT FUEL ASSEMBLIES, DAMAGED FUEL ASSEMBLIES, and FUEL DEBRIS.

TABLE 2.1-10

NONFUEL HARDWARE COOLING AND AVERAGE ACTIVATION

Post-Irradiation Cooling Time (years)	BPRA and WABA Burnup (MWD/MTU)	TPD *and NSA* Burnup (MWD/MTU)	RCCA Burnup (MWD/MTU)
≥3	≤ 20,000	NA	NA
≥4	≤ 25,000	≤ 20,000	NA
≥ 5	≤ 30,000	≤ 25,000	≤ 630,000
≥ 6	≤ 40,000	≤ 30,000	-
≥ 7	≤ 45,000	≤ 40,000	-
≥ 8	≤ 50,000	≤ 45,000	-
≥ 9	≤ 60,000	≤ 50,000	-
≥10	-	≤ 60,000	-
≥ 11	-	≤ 75,000	-
≥ 12	-	≤ 90,000	-
≥ 13	-	≤ 180,000	-
≥ 14	-	≤ 630,000	-

NOTE 1: Linear interpolation between points is permitted, except that TPD *and NSA* burnups > 180,000 MWD/MTU and ≤ 630,000 MWD/MTU must be cooled ≥ 14 years.

NOTE 2: Applicable to uniform loading and regionalized loading.

NOTE 3: NA means not authorized for loading.

NOTE 4: Non-fuel hardware burnup and cooling times are not applicable to ITTRs since they are installed post-irradiation.

NOTE 5: Only one NSA is authorized for loading in any MPC.

Table 2.3-1 (page 1 of 2)

Fuel Assembly Time-Dependent Coefficients

Cooling Time (years)	Vantage 5 fuel						
	A	B	C	D	E	F	G
≥ 5	40315.9	-9724	1622.89	-140.459	3170.28	-547.749	425.136
≥ 6	49378.5	-15653.1	3029.25	-164.712	3532.55	-628.93	842.73
≥ 7	56759.5	-21320.4	4598.78	-190.58	3873.21	-698.143	975.46
≥ 8	63153.4	-26463.8	6102.47	-201.262	4021.84	-685.431	848.497
≥ 9	67874.9	-30519.2	7442.84	-218.184	4287.23	-754.597	723.305
≥ 10	72676.8	-34855.2	8928.27	-222.423	4382.07	-741.243	387.877
≥ 11	75623	-37457.1	9927.65	-232.962	4564.55	-792.051	388.402
≥ 12	80141.8	-41736.5	11509.8	-232.944	4624.72	-787.134	-164.727
≥ 13	83587.5	-45016.4	12800.9	-230.643	4623.2	-745.177	-428.635
≥ 14	86311.3	-47443.4	13815.2	-228.162	4638.89	-729.425	-561.758
≥ 15	87839.2	-48704.1	14500.3	-231.979	4747.67	-775.801	-441.959
≥ 16	91190.5	-51877.4	15813.2	-225.768	4692.45	-719.311	-756.537
≥ 17	94512	-55201.2	17306.1	-224.328	4740.86	-747.11	-1129.15
≥ 18	96959	-57459.9	18403.8	-220.038	4721.02	-726.928	-1272.47
≥ 19	99061.1	-59172.1	19253.1	-214.045	4663.37	-679.362	-1309.88
≥ 20	100305	-59997.5	19841.1	-216.112	4721.71	-705.463	-1148.45

Table 2.3-1 (page 2 of 2)

Fuel Assembly Time-Dependent Coefficients

Cooling Time (years)	Standard, and LOPAR fuel						
	A	B	C	D	E	F	G
≥ 5	36190.4	-7783.2	1186.37	-130.008	2769.53	-438.716	519.95
≥ 6	44159	-12517.5	2209.54	-150.234	3042.25	-489.858	924.151
≥ 7	50399.6	-16780.6	3277.26	-173.223	3336.58	-555.743	1129.66
≥ 8	55453.9	-20420	4259.68	-189.355	3531.65	-581.917	1105.62
≥ 9	59469.3	-23459.8	5176.62	-199.63	3709.99	-626.667	1028.74
≥ 10	63200.5	-26319.6	6047.8	-203.233	3783.02	-619.949	805.311
≥ 11	65636.3	-28258.3	6757.23	-214.247	3972.8	-688.56	843.457
≥ 12	68989.7	-30904.4	7626.53	-212.539	3995.62	-678.037	495.032
≥ 13	71616.6	-32962.2	8360.45	-210.386	4009.11	-666.542	317.009
≥ 14	73923.9	-34748	9037.75	-207.668	4020.13	-662.692	183.086
≥ 15	76131.8	-36422.3	9692.32	-203.428	4014.55	-655.981	47.5234
≥ 16	77376.5	-37224.7	10111.4	-207.581	4110.76	-703.37	161.128
≥ 17	80294.9	-39675.9	11065.9	-201.194	4079.24	-691.636	-173.782
≥ 18	82219.8	-41064.8	11672.1	-195.431	4043.83	-675.432	-286.059
≥ 19	84168.9	-42503.6	12309.4	-190.602	4008.19	-656.192	-372.411
≥ 20	86074.2	-43854.4	12935.9	-185.767	3985.57	-656.72	-475.953

3.1 SPENT FUEL STORAGE CASK (SFSC) INTEGRITY

3.1.1 MULTI-PURPOSE CANISTER (MPC)

LCO 3.1.1 The MPC shall be dry and helium filled.

APPLICABILITY: During TRANSPORT OPERATIONS and STORAGE OPERATIONS

ACTIONS

---NOTE---

Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION		COMPLETION TIME
A. MPC cavity ~~vacuum~~ drying ~~pressure or~~ demoisturizer exit gas temperature limit not met.	A.1.	Perform an engineering evaluation to determine the quantity of moisture left in the MPC.	7 days
	<u>AND</u>		
	A.2	Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	30 days
B. MPC helium backfill pressure limit not met.	B.1	Perform an engineering evaluation to determine the impact of helium pressure differential.	72 hours
	<u>AND</u>		
	B.2	Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	14 days

(continued)

ACTIONS (continued)

CONDITION	REQUIRED ACTION		COMPLETION TIME
C. MPC helium leak rate limit for vent and drain port cover plate welds not met.	C.1	Perform an engineering evaluation to determine the impact of increased helium leak rate on heat removal capability and offsite dose.	24 hours
	AND		
	C.2	Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	7 days
D. Required Actions and associated Completion Times not met.	D.1	Remove all fuel assemblies from the MPC.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1.1	~~Verify MPC cavity vacuum drying pressure is ≤ 3 torr for ≥ 30 min.~~ ~~OR~~While recirculating helium through the MPC cavity, verify that the gas temperature exiting the demoisturizer is ≤ 21°F for ≥ 30 min.	Once, prior to TRANSPORT OPERATIONS.
SR 3.1.1.2	Verify MPC helium backfill pressure is ≥ 29.3 psig and ≤ 33.3 psig *at a reference temperature of 70° F*.	Once, prior to TRANSPORT OPERATIONS.
SR 3.1.1.3	Verify that the total helium leak rate through the MPC vent and drain port confinement welds meets the leaktight criteria of ANSI N14.5-1997.	Once, prior to TRANSPORT OPERATIONS.

3.1 SPENT FUEL STORAGE CASK (SFSC) INTEGRITY

3.1.2 Spent Fuel Storage Cask (SFSC) Heat Removal System

LCO 3.1.2 The SFSC Heat Removal System shall be operable.

APPLICABILITY: During STORAGE OPERATIONS

ACTIONS

---NOTE---
Separate Condition entry is allowed for each SFSC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. ~~LCO not met.~~*SFSC Heat Removal System operable, but partially (< 50%) blocked.*	A.1 *Remove blockage.* ~~Restore SFSC Heat Removal System to operable status.~~ ~~OR~~ ~~A.2.1 Verify adequate heat removal to prevent exceeding short-term fuel temperature limit;~~ ~~AND~~ ~~A.2.2 Restore SFSC Heat Removal System to operable status.~~	8 hours ~~Immediately~~ ~~30 days~~
B. SFSC Heat Removal System inoperable.	*B.1 Restore SFSC Heat Removal System to operable status.*	*8 hours*
~~B~~*C*. Required Action~~s~~ *B.1* and associated Completion Time not met.	~~B~~*C*.1 *Measure SFSC dose rates in accordance with the Radiation Protection Program.* *AND* *C.2.1 Restore SFSC Heat removal System to operable status.* *OR* *C.2.2* Transfer the MPC into a TRANSFER CASK.	Immediately *and once per 12 hours thereafter.* *24 hours* *24 hours*

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.2.1	Verify all SFSC inlet and outlet air duct screens are free of blockage.	24 hours

3.1 SPENT FUEL STORAGE CASK (SFSC) INTEGRITY

3.1.4 ~~Intentionally left blank~~*Supplemental Cooling System*

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

-----NOTE-----

Upon reaching steady state operation, the SCS may be temporarily disabled for a short duration (≤ 7 hours) to facilitate necessary operational evolutions, such as movement of the TRANSFER CASK through a doorway, or other similar operations.

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

a.1.a. Bulk water has been removed from the MPC

AND

a.1.b FHD has been secured for greater than 4 hours.

OR

a.2. Within 4 hours of transferring the MPC into the TRANSFER CASK if the MPC is to be unloaded.

AND

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

ACTIONS

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

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	*FREQUENCY*
SR 3.1.4.1 Verify Supplemental Cooling System is operable	*2 hours*

4.0 DESIGN FEATURES

4.1 Design Features Significant to Safety

4.1.1 Criticality Control

a. MULTI-PURPOSE CANISTER (MPC) MPC-24

1. Flux trap size: ≥ 1.09 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0267 g/cm^2 (Boral) and ≥ 0.0223 g/cm^2 (METAMIC)

b MPC-24E and MPC-24EF

1. Flux trap size:
   - Cells 3, 6, 19, and 22: ≥ 0.776 in.
   - All Other Cells: ≥ 1.076 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0372 g/cm^2 (Boral) and ≥ 0.0310 g/cm^2 (METAMIC)

c. MPC-32

1. Fuel cell pitch: ≥ 9.158 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0372 g/cm^2 (Boral) and ≥ 0.0310 g/cm^2 (METAMIC)

4.1.2 Design Features Important to Criticality Control

a. Fuel spacers shall be sized to ensure that the active fuel region of intact fuel assemblies remain within the neutron poison region of the MPC basket with the water in the MPC.

b. The B_4C content in METAMIC shall be ≤ 33.0 wt%.

c. Neutron Absorber Test

The minimum ^{10}B for the neutron absorber shall meet the minimum requirements for each MPC model specified in Section 4.1.1 above.

(continued)

5.0 ADMINISTRATIVE CONTROLS (continued)

5.1.3 MPC and SFSC Loading, Unloading, and Preparation Program

This program shall be established and maintained to implement Diablo Canyon ISFSI SAR Section 10.2 requirements for loading fuel and components into MPCs, unloading fuel and components from MPCs, and preparing the MPCs for storage in the SFSCs. The requirements of the program for loading and preparing the MPC shall be complete prior to removing the MPC from the fuel handling building/auxiliary building. The program provides for evaluation and control of the following requirements during the applicable operation:

a. Verify that no transfer cask handling operations are allowed at environmental temperatures below -18 °C [0 °F].

b. Verify that the water is maintained to provide adequate cooling in the annular gap between the loaded MPC and the transfer cask during MPC *reflooding operations (unloading).* ~~moisture removal operations under use of vacuum drying process for low burnup fuel (≤45,000 MWD/MTU). Verify that there is no water present in the annular gap between the loaded MPC and the transfer cask during MPC moisture removal operations under use of forced helium dehydration process.~~

c. The water temperature of a water-filled or partially filled loaded MPC shall be shown by analysis to be less than boiling at all times.

d. Verify that the drying times and pressures assure that fuel cladding temperature limit is not violated and the MPC is adequately dry.

e. Verify that the inerting backfill pressure and purity assure adequate heat transfer and corrosion control.

f. Verify that leak testing assures adequate MPC integrity and consistency with offsite dose analysis.

g. Verify surface dose rates on the TRANSFER CASK are adequate to assure proper loading and consistency with the offsite dose analysis.

h. Verify surface dose rates on the SFSCs are adequate to assure proper storage and consistency with the offsite dose analysis.

i. During MPC re-flooding, verify the helium exit temperature is such that water quenching or flashing does not occur.

j. Verify that combustible gases in the MPC are monitored and controlled to avoid combustion during MPC lid-to-shell welding or MPC cutting activities.

k. For the MPC lid-to-shell weld and the MPC enclosure vessel and lid, the weld must be at minimum of three weld layers. If PT alone is used, it will be tested at least three different weld layers, including the root and final weld layers and each approximately 3/8-inch of weld depth.

l. Very that fuel cladding is not exposed to an oxidizing environment by maintaining the cladding in water or an inert atmosphere.

(continued)

Enclosure
Attachment 5
PG&E Letter DIL-11-006

Retyped Technical Specification Pages

TABLE OF CONTENTS

1.1 Definitions (continued)

INTACT FUEL ASSEMBLY	INTACT FUEL ASSEMBLY is a fuel assembly without known or suspected cladding defects greater than pinhole leaks or hairline cracks and which can be handled by normal means. A fuel assembly shall not be classified as INTACT FUEL ASSEMBLY unless solid Zircaloy or stainless steel rods are used to replace missing fuel rods and which displace an amount of water equal to that displaced by the original fuel rod(s).
LOADING OPERATIONS	LOADING OPERATIONS include all licensed activities on a TRANSFER CASK while its contained MPC is being loaded with its approved contents. LOADING OPERATIONS begin when the first fuel assembly is placed in the MPC and end when the TRANSFER CASK is suspended from or secured on the transporter. LOADING OPERATIONS does not include MPC transfer between the TRANSFER CASK and the OVERPACK.
MINIMUM ENRICHMENT	MINIMUM ENRICHMENT is the minimum assembly average enrichment. Natural uranium blankets are not considered in determining minimum enrichment.
MULTI-PURPOSE CANISTER (MPC)	MPC is a sealed SPENT NUCLEAR FUEL container that consists of a honeycombed fuel basket contained in a cylindrical canister shell which is welded to a baseplate, lid with welded port cover plates, and closure ring. The MPC provides the confinement boundary for the contained radioactive materials.
NONFUEL HARDWARE	NONFUEL HARDWARE is defined as burnable poison rod assemblies (BPRAs), thimble plug devices (TPDs), rod control cluster assemblies (RCCAs), wet annular burnable absorbers (WABAs), neutron source assemblies (NSAs), instrument tube tie rods (ITTRs), and components of these devices such as individual rods.
OPERABLE/OPERABILITY	A system, component, or device shall be OPERABLE or have OPERABILITY when it is capable of performing its specified safety function(s) and when all necessary attendant instruments, controls, normal or emergency electrical power, and other auxiliary equipment that are required for the system, component, or device to perform its specific safety function(s) are also capable of performing their related support function(s).

(continued)

1.1 Definitions (continued)

OVERPACK	OVERPACK is a cask that receives and contains a sealed MPC for interim storage in the independent spent fuel storage installation (ISFSI). It provides gamma and neutron shielding, and provides for ventilated air flow to promote heat transfer from the MPC to the environs. The OVERPACK does not include the TRANSFER CASK.
SPENT FUEL STORAGE CASKS (SFSCs)	SFSCs are containers approved for the storage of spent fuel assemblies, FUEL DEBRIS, and associated NONFUEL HARDWARE at the ISFSI. The HI-STORM 100 SFSC System consists of the OVERPACK and its integral MPC loaded with any approved contents.
SPENT NUCLEAR FUEL	SPENT NUCLEAR FUEL means fuel that has been withdrawn from a nuclear reactor following irradiation, has undergone at least one year's decay since being used as a source of energy in a power reactor and has not been chemically separated into its constituent elements by reprocessing. SPENT NUCLEAR FUEL includes the special nuclear material, byproduct material, source material, and other radioactive materials associated with fuel assemblies.
STORAGE OPERATIONS	STORAGE OPERATIONS include all licensed activities that are performed at the ISFSI while a SFSC containing approved contents is sitting on a storage pad within the ISFSI perimeter. STORAGE OPERATIONS does not include MPC transfer between the TRANSFER CASK and the OVERPACK.
TRANSFER CASK	TRANSFER CASKs are containers designed to contain the MPC during and after loading of its approved contents and to transfer the loaded MPC to or from the OVERPACK.
TRANSPORT OPERATIONS	TRANSPORT OPERATIONS include all licensed activities performed on an OVERPACK or TRANSFER CASK loaded with any approved contents when it is being moved to and from the ISFSI. TRANSPORT OPERATIONS begin when the OVERPACK or TRANSFER CASK is first suspended from or secured on the transporter and end when the OVERPACK or TRANSFER CASK is at its destination and no longer secured on or suspended from the transporter. TRANSPORT OPERATIONS include transfer of the MPC between the OVERPACK and the TRANSFER CASK.

(continued)

2.3 Alternate MPC-32 Fuel Selection Criteria

The maximum allowable fuel assembly average burnup for a given MINIMUM ENRICHMENT is calculated as described below for minimum cooling times between 5 and 20 years using the maximum permissible decay heat determined in Table 2.1-7. Different fuel assembly average burnup limits may be calculated for different minimum enrichments (by individual fuel assembly) for use in choosing the fuel assemblies to be loaded into a given MPC.

a. Choose a fuel assembly minimum enrichment E_{235}.

b. Calculate the maximum allowable fuel assembly average burnup for a minimum cooling time between 5 and 20 years using the following equation below:

$$Bu = (A \times q) + (B \times q^2) + (C \times q^3) + [D \times (E_{235})^2] + (E \times q \times E_{235}) + (F \times q^2 \times E_{235}) + G$$

Where:

Bu = Maximum allowable average burnup per fuel assembly (MWD/MTU)

q = Maximum allowable decay heat per storage location, in kilowatts, determined from Table 2.1-7 (e.g. 750 watts, use 0.750)

E_{235} = Minimum fuel assembly average enrichment (wt% ^{235}U) (e.g., for 4.05 wt%, use 4.05)

A through G = Coefficients from Table 2.3-1.

c. Calculated burnup limits shall be rounded down to the nearest integer.

d. Calculated burnup limits greater than 68,200 MWD/MTU must be reduced to be equal to this value.

e. Linear interpolation of calculated burnups between cooling times for a given fuel assembly maximum decay heat and minimum enrichment is permitted. For example, the allowable burnup for a cooling time of 5.5 years may be interpolated between those burnups calculated for 5 year and 6 years.

f. Each ZR-clad fuel assembly to be stored must have a MINIMUM ENRICHMENT greater than or equal to the value used in Step 2.3.a.

g. When complying with the maximum fuel storage location decay heat limits, users must account for the decay heat from both the fuel assembly and any NON-FUEL HARDWARE, as applicable for the particular fuel storage location, to ensure the decay heat emitted by all contents in a storage location does not exceed the limit.

TABLE 2.1-1

MPC-24 FUEL ASSEMBLY LIMITS

A. Allowable Contents

1. Uranium oxide, INTACT FUEL ASSEMBLIES listed in Table 2.1-5, with or without NONFUEL HARDWARE and meeting the following specifications (Note 1):

Cladding type	Zr (Note 2)
Initial enrichment	As specified in Table 2.1-5 for the applicable fuel assembly.
Post-irradiation cooling time and average burnup per assembly:	
Fuel	As specified in Tables 2.1-6 or 2.1-8.
NONFUEL HARDWARE	As specified in Table 2.1-10.
Decay heat per assembly	As specified in Tables 2.1-7 or 2.1-9.
Fuel assembly length	≤ 176.8 inches (nominal design)
Fuel assembly width	≤ 8.54 inches (nominal design)
Fuel assembly weight	≤ 1,680 lb (including NONFUEL HARDWARE)

B. Quantity per MPC: Up to 24 fuel assemblies.

C. DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS are not authorized for loading into the MPC-24.

D. One NSA is authorized for loading in an MPC-24.

NOTE 1: Fuel assemblies containing BPRAs, WABAs, or TPDs may be stored in any fuel cell location. Fuel assemblies containing RCCAs or NSAs may only be loaded in fuel storage locations 9, 10, 15, and/or 16 of Figure 2.1-1. These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

NOTE 2: Zr designates fuel-cladding material made of Zircaloy-2, Zircaloy-4 and ZIRLO.

TABLE 2.1-2 Sheet 2 of 2

A. Quantity per MPC: Up to four (4) DAMAGED FUEL ASSEMBLIES in DAMAGED FUEL CONTAINERS, stored in fuel storage locations 3, 6, 19 and/or 22 of Figure 2.1-2. The remaining MPC-24E fuel storage locations may be filled with INTACT FUEL ASSEMBLIES meeting the applicable specifications.

B. FUEL DEBRIS is not authorized for loading in the MPC-24E.

C. One NSA is authorized for loading in an MPC-24E.

NOTE 1: Fuel assemblies containing BPRAs, WABAs, or TPDs may be stored in any fuel storage location. Fuel assemblies containing RCCAs or NSAs must be loaded in fuel storage locations 9, 10, 15 and/or 16 of Figure 2.1-2. These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

NOTE 2: Zr designates fuel-cladding material, which is made of Zircaloy-2, Zircaloy-4 and ZIRLO.

TABLE 2.1-3 Sheet 2 of 2

A. Quantity per MPC: Up to four (4) DAMAGED FUEL ASSEMBLIES and/or FUEL DEBRIS in DAMAGED FUEL CONTAINERS, stored in fuel storage locations 3, 6, 19 and/or 22 of Figure 2.1-2. The remaining MPC-24EF fuel storage locations may be filled with INTACT FUEL ASSEMBLIES meeting the applicable specifications.

B. One NSA is authorized for loading in an MPC-24EF.

NOTE 1: Fuel assemblies containing BPRAs, WABAs, or TPDs may be stored in any fuel storage location. Fuel assemblies containing RCCAs or NSAs must be loaded in fuel storage locations 9, 10, 15 and/or 16 of Figure 2.1-2. These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

NOTE 2: The total quantity of FUEL DEBRIS permitted in a single DAMAGED FUEL CONTAINER is limited to the equivalent weight and special nuclear material quantity of one INTACT FUEL ASSEMBLY.

NOTE 3: Zr designates fuel-cladding material, which is made of Zircaloy-2, Zircaloy-4 and ZIRLO.

TABLE 2.1-4

MPC-32 FUEL ASSEMBLY LIMITS

A. Allowable Contents

1. Uranium oxide, INTACT FUEL ASSEMBLIES listed in Table 2.1-5, with or without NONFUEL HARDWARE and meeting the following specifications (Note 1):

Cladding type	Zr (Note 2)
Initial enrichment	As specified in Table 2.1-5 for the applicable fuel assembly.
Post-irradiation cooling time and average burnup per assembly:	
Fuel	As specified in Tables 2.1-6 or 2.1-8, or Section 2.3.
NONFUEL HARDWARE	As specified in Table 2.1-10.
Decay heat per assembly	As specified in Tables 2.1-7 or 2.1-9.
Fuel assembly length	≤ 176.8 inches (nominal design)
Fuel assembly width	≤ 8.54 inches (nominal design)
Fuel assembly weight	≤ 1,680 lb (including NONFUEL HARDWARE)

B. Quantity per MPC: Up to 32 intact fuel assemblies.

C. DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS are not authorized for loading in the MPC-32.

D. One NSA is authorized for loading in an MPC-32.

NOTE 1: Fuel assemblies, with or without ITTRs, containing BPRAs, WABAs, or TPDs, may be stored in any fuel storage location. Fuel assemblies, with or without ITTRs, containing RCCAs or NSAs must be loaded in fuel storage locations 13, 14, 19 and/or 20 of Figure 2.1-3. These requirements are in addition to any other requirements specified for uniform or regionalized fuel loading.

NOTE 2: Zr designates fuel-cladding material, which is made of Zircaloy-2, Zircaloy-4 and ZIRLO.

TABLE 2.1-5

FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Type (Note 6)	Vantage 5	Standard, or LOPAR
Cladding Material	Zr (Note 5)	Zr (Note 5)
Design Initial U (kg/assy.) (Note 2)	≤ 467	≤ 467
Initial Enrichment (MPC-24, 24E, and 24EF without soluble boron credit) (wt% ^{235}U) (Note 4)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, or 32 with soluble boron credit) (wt% ^{235}U) (Notes 3 and 4)	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	264	264
Fuel Rod Cladding O.D. (in.)	≥ 0.360	≥ 0.372
Fuel Rod Cladding I.D. (in.)	≤ 0.3150	≤ 0.3310
Fuel Pellet Dia. (in.)	≤ 0.3088	≤ 0.3232
Fuel Rod Pitch (in.)	≤ 0.496	≤ 0.496
Active Fuel Length (in.)	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	25	25
Guide/Instrument Tube Thickness (in.)	≥ 0.016	≥ 0.014

NOTE 1: All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies.

NOTE 2: Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or DCPP. For each fuel assembly, the total uranium weight limit specified in this table may be increased up to 2.0 percent for comparison with DCPP fuel records to account for manufacturer's tolerances.

NOTE 3: Soluble boron concentration per Technical Specification LCO 3.2.1.

NOTE 4: For those MPCs loaded with both INTACT FUEL ASSEMBLIES and DAMAGED FUEL ASSEMBLIES or FUEL DEBRIS, the maximum initial enrichment of the INTACT FUEL ASSEMBLIES is limited to the maximum initial enrichment of the DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS (i.e., 4.0 wt.% ^{235}U).

NOTE 5: Zr designates fuel-cladding material, which is made of Zircaloy-2, Zircaloy-4 and ZIRLO.

NOTE 6: Fuel assemblies meeting the characteristics may be loaded under the requirements for the listed Fuel Assembly Type, even if the name is different.

TABLE 2.1-6

FUEL ASSEMBLY COOLING AND MAXIMUM AVERAGE BURNUP
(UNIFORM FUEL LOADING)

Post-Irradiation Cooling Time (years)	MPC-24 Assembly Burnup (INTACT FUEL ASSEMBLIES) (MWD/MTU)	MPC-24E/24EF Assembly Burnup (INTACT FUEL ASSEMBLIES) (MWD/MTU)	MPC-24E/24EF Assembly Burnup (DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS) (MWD/MTU)	MPC-32 Assembly Burnup (INTACT FUEL ASSEMBLIES) (MWD/MTU) (Note 2)
≥ 5	40,600	41,100	39,200	32,200
≥ 6	45,000	45,000	43,700	36,500
≥ 7	-	-	44,500	37,500
≥ 8	-	-	45,000	39,900
≥ 9	-	-	-	41,500
≥ 10	-	-	-	42,900
≥ 11	-	-	-	44,100
≥ 12	-	-	-	45,000
≥ 13	-	-	-	-
≥ 14	-	-	-	-
≥ 15	-	-	-	-

NOTE 1: Linear interpolation between points is permitted.
NOTE 2: Burnup limits for fuel assemblies in an MPC-32 may alternatively be calculated using Section 2.3.

TABLE 2.1-7

FUEL ASSEMBLY COOLING AND MAXIMUM DECAY HEAT
(UNIFORM FUEL LOADING)

Post-Irradiation Cooling Time (years)	MPC-24 Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts)	MPC-24E/24EF Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts)	MPC-24E/24EF Assembly Decay Heat (DAMAGED FUEL ASSEMBLIES and FUEL DEBRIS) (Watts)	MPC-32 Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts) [BU ≤45,000 MWd/MTU]	MPC-32 Assembly Decay Heat (INTACT FUEL ASSEMBLIES) (Watts) [BU >45,000 MWd/MTU]
≥ 5	1157	1173	1115	898	750
≥ 6	1123	1138	1081	873	750
≥ 7	1030	1043	991	805	750
≥ 8	1020	1033	981	800	750
≥ 9	1010	1023	972	794	750
≥ 10	1000	1012	962	789	750
≥ 11	996	1008	958	785	750
≥ 12	992	1004	954	782	750
≥ 13	987	999	949	773	750
≥ 14	983	995	945	769	750
≥ 15	979	991	941	766	750

NOTE 1: Linear interpolation between points is permitted.

NOTE 2: Includes all sources of heat (i.e., fuel and NONFUEL HARDWARE).

TABLE 2.1-8

FUEL ASSEMBLY COOLING AND MAXIMUM AVERAGE BURNUP
(REGIONALIZED FUEL LOADING)

Post-Irradiation Cooling Time (years)	MPC-24 Assembly Burnup for Region 1 (MWD/MTU)	MPC-24 Assembly Burnup for Region 2 (MWD/MTU)	MPC-24E/24EF Assembly Burnup for Region 1 (MWD/MTU)	MPC-24E/24EF Assembly Burnup for Region 2 (MWD/MTU)	MPC-32 Assembly Burnup for Region 1 (MWD/MTU)	MPC-32 Assembly Burnup for Region 2 (MWD/MTU)
≥ 5	45,000	32,200	45,000	32,200	39,800	22,100
≥ 6	-	37,400	-	37,400	43,400	26,200
≥ 7	-	41,100	-	41,100	44,500	29,100
≥ 8	-	43,800	-	43,800	45,000	31,200
≥ 9	-	45,000	-	45,000	-	32,700
≥ 10	-	-	-	-	-	34,100
≥ 11	-	-	-	-	-	35,200
≥ 12	-	-	-	-	-	36,200
≥ 13	-	-	-	-	-	37,000
≥ 14	-	-	-	-	-	37,800
≥ 15	-	-	-	-	-	38,600
≥ 16	-	-	-	-	-	39,400
≥ 17	-	-	-	-	-	40,200
≥ 18	-	-	-	-	-	40,800
≥ 19	-	-	-	-	-	41,500
≥ 20	-	-	-	-	-	42,200

NOTE 1: Linear interpolation between points is permitted.

NOTE 2: These limits apply to INTACT FUEL ASSEMBLIES, DAMAGED FUEL ASSEMBLIES, and FUEL DEBRIS.

NOTE 3: Burnup for fuel assemblies with cladding made of ZIRLO is limited to 45,000 MWD/MTU or the value in this table, whichever is less.

TABLE 2.1-9

FUEL ASSEMBLY COOLING AND MAXIMUM DECAY HEAT
(REGIONALIZED FUEL LOADING)

Post-Irradiation Cooling Time (years)	MPC-24 Assembly Decay Heat for Region 1 (Watts)	MPC-24 Assembly Decay Heat for Region 2 (Watts)	MPC-24E/24EF Assembly Decay Heat for Region 1 (Watts)	MPC-24E/24EF Assembly Decay Heat for Region 2 (Watts)	MPC-32 Assembly Decay Heat for Region 1 (Watts)	MPC-32 Assembly Decay Heat for Region 2 (Watts)
≥ 5	1470	900	1540	900	1131	600
≥ 6	1470	900	1540	900	1072	600
≥ 7	1335	900	1395	900	993	600
≥ 8	1301	900	1360	900	978	600
≥ 9	1268	900	1325	900	964	600
≥ 10	1235	900	1290	900	950	600
≥ 11	1221	900	1275	900	943	600
≥ 12	1207	900	1260	900	937	600
≥ 13	1193	900	1245	900	931	600
≥ 14	1179	900	1230	900	924	600
≥ 15	1165	900	1215	900	918	600
≥ 16	-	-	-	-	-	-
≥ 17	-	-	-	-	-	-
≥ 18	-	-	-	-	-	-
≥ 19	-	-	-	-	-	-
≥ 20	-	-	-	-	-	-

NOTE 1: Linear interpolation between points is permitted.

NOTE 2: Includes all sources of decay heat (i.e., fuel and NONFUEL HARDWARE).

NOTE 3: These limits apply to INTACT FUEL ASSEMBLIES, DAMAGED FUEL ASSEMBLIES, and FUEL DEBRIS.

TABLE 2.1-10

NONFUEL HARDWARE COOLING AND AVERAGE ACTIVATION

Post-Irradiation Cooling Time (years)	BPRA and WABA Burnup (MWD/MTU)	TPD and NSA Burnup (MWD/MTU)	RCCA Burnup (MWD/MTU)
≥3	≤ 20,000	NA	NA
≥4	≤ 25,000	≤ 20,000	NA
≥ 5	≤ 30,000	≤ 25,000	≤ 630,000
≥ 6	≤ 40,000	≤ 30,000	-
≥ 7	≤ 45,000	≤ 40,000	-
≥ 8	≤ 50,000	≤ 45,000	-
≥ 9	≤ 60,000	≤ 50,000	-
≥10	-	≤ 60,000	-
≥ 11	-	≤ 75,000	-
≥ 12	-	≤ 90,000	-
≥ 13	-	≤ 180,000	-
≥ 14	-	≤ 630,000	-

NOTE 1: Linear interpolation between points is permitted, except that TPD and NSA burnups > 180,000 MWD/MTU and ≤ 630,000 MWD/MTU must be cooled ≥ 14 years.

NOTE 2: Applicable to uniform loading and regionalized loading.

NOTE 3: NA means not authorized for loading.

NOTE 4: Non-fuel hardware burnup and cooling times are not applicable to ITTRs since they are installed post-irradiation.

NOTE 5: Only one NSA is authorized for loading in any MPC.

Table 2.3-1 (page 1 of 2)

Fuel Assembly Time-Dependent Coefficients

Cooling Time (years)	Vantage 5 fuel						
	A	B	C	D	E	F	G
≥ 5	40315.9	-9724	1622.89	-140.459	3170.28	-547.749	425.136
≥ 6	49378.5	-15653.1	3029.25	-164.712	3532.55	-628.93	842.73
≥ 7	56759.5	-21320.4	4598.78	-190.58	3873.21	-698.143	975.46
≥ 8	63153.4	-26463.8	6102.47	-201.262	4021.84	-685.431	848.497
≥ 9	67874.9	-30519.2	7442.84	-218.184	4287.23	-754.597	723.305
≥ 10	72676.8	-34855.2	8928.27	-222.423	4382.07	-741.243	387.877
≥ 11	75623	-37457.1	9927.65	-232.962	4564.55	-792.051	388.402
≥ 12	80141.8	-41736.5	11509.8	-232.944	4624.72	-787.134	-164.727
≥ 13	83587.5	-45016.4	12800.9	-230.643	4623.2	-745.177	-428.635
≥ 14	86311.3	-47443.4	13815.2	-228.162	4638.89	-729.425	-561.758
≥ 15	87839.2	-48704.1	14500.3	-231.979	4747.67	-775.801	-441.959
≥ 16	91190.5	-51877.4	15813.2	-225.768	4692.45	-719.311	-756.537
≥ 17	94512	-55201.2	17306.1	-224.328	4740.86	-747.11	-1129.15
≥ 18	96959	-57459.9	18403.8	-220.038	4721.02	-726.928	-1272.47
≥ 19	99061.1	-59172.1	19253.1	-214.045	4663.37	-679.362	-1309.88
≥ 20	100305	-59997.5	19841.1	-216.112	4721.71	-705.463	-1148.45

Table 2.3-1 (page 2 of 2)

Fuel Assembly Time-Dependent Coefficients

Cooling Time (years)	Standard, and LOPAR fuel						
	A	B	C	D	E	F	G
≥ 5	36190.4	-7783.2	1186.37	-130.008	2769.53	-438.716	519.95
≥ 6	44159	-12517.5	2209.54	-150.234	3042.25	-489.858	924.151
≥ 7	50399.6	-16780.6	3277.26	-173.223	3336.58	-555.743	1129.66
≥ 8	55453.9	-20420	4259.68	-189.355	3531.65	-581.917	1105.62
≥ 9	59469.3	-23459.8	5176.62	-199.63	3709.99	-626.667	1028.74
≥ 10	63200.5	-26319.6	6047.8	-203.233	3783.02	-619.949	805.311
≥ 11	65636.3	-28258.3	6757.23	-214.247	3972.8	-688.56	843.457
≥ 12	68989.7	-30904.4	7626.53	-212.539	3995.62	-678.037	495.032
≥ 13	71616.6	-32962.2	8360.45	-210.386	4009.11	-666.542	317.009
≥ 14	73923.9	-34748	9037.75	-207.668	4020.13	-662.692	183.086
≥ 15	76131.8	-36422.3	9692.32	-203.428	4014.55	-655.981	47.5234
≥ 16	77376.5	-37224.7	10111.4	-207.581	4110.76	-703.37	161.128
≥ 17	80294.9	-39675.9	11065.9	-201.194	4079.24	-691.636	-173.782
≥ 18	82219.8	-41064.8	11672.1	-195.431	4043.83	-675.432	-286.059
≥ 19	84168.9	-42503.6	12309.4	-190.602	4008.19	-656.192	-372.411
≥ 20	86074.2	-43854.4	12935.9	-185.767	3985.57	-656.72	-475.953

3.1 SPENT FUEL STORAGE CASK (SFSC) INTEGRITY

3.1.1 MULTI-PURPOSE CANISTER (MPC)

LCO 3.1.1 The MPC shall be dry and helium filled.

APPLICABILITY: During TRANSPORT OPERATIONS and STORAGE OPERATIONS

ACTIONS

-----NOTE-----
Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. MPC cavity drying demoisturizer exit gas temperature limit not met.	A.1. Perform an engineering evaluation to determine the quantity of moisture left in the MPC.	7 days
	AND	
	A.2 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	30 days
B. MPC helium backfill pressure limit not met.	B.1 Perform an engineering evaluation to determine the impact of helium pressure differential.	72 hours
	AND	
	B.2 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	14 days

(continued)

ACTIONS (continued)

CONDITION	REQUIRED ACTION		COMPLETION TIME
C. MPC helium leak rate limit for vent and drain port cover plate welds not met.	C.1	Perform an engineering evaluation to determine the impact of increased helium leak rate on heat removal capability and offsite dose.	24 hours
	AND		
	C.2	Develop and initiate corrective actions necessary to return the MPC to an analyzed condition.	7 days
D. Required Actions and associated Completion Times not met.	D.1	Remove all fuel assemblies from the MPC.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1.1	While recirculating helium through the MPC cavity, verify that the gas temperature exiting the demoisturizer is ≤ 21°F for ≥ 30 min.	Once, prior to TRANSPORT OPERATIONS.
SR 3.1.1.2	Verify MPC helium backfill pressure is ≥ 29.3 psig and ≤ 33.3 psig at a reference temperature of 70° F.	Once, prior to TRANSPORT OPERATIONS.
SR 3.1.1.3	Verify that the total helium leak rate through the MPC vent and drain port confinement welds meets the leaktight criteria of ANSI N14.5-1997.	Once, prior to TRANSPORT OPERATIONS.

3.1 SPENT FUEL STORAGE CASK (SFSC) INTEGRITY

3.1.2 Spent Fuel Storage Cask (SFSC) Heat Removal System

LCO 3.1.2 The SFSC Heat Removal System shall be operable.

APPLICABILITY: During STORAGE OPERATIONS

ACTIONS

-----NOTE-----
Separate Condition entry is allowed for each SFSC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. SFSC Heat Removal System operable, but partially (< 50%) blocked.	A.1 Remove blockage.	8 hours
B. SFSC Heat Removal System inoperable.	B.1 Restore SFSC Heat Removal System to operable status.	8 hours
C. Required Action B.1 and associated Completion Time not met.	C.1 Measure SFSC dose rates in accordance with the Radiation Protection Program.	Immediately and once per 12 hours thereafter.
	<u>AND</u>	
	C.2.1 Restore SFSC Heat removal System to operable status.	24 hours
	OR	
	C.2.2 Transfer the MPC into a TRANSFER CASK.	24 hours

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.2	Verify all SFSC inlet and outlet air duct screens are free of blockage.	24 hours

3.1 SPENT FUEL STORAGE CASK (SFSC) INTEGRITY

3.1.4 Supplemental Cooling System

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

--NOTE--

Upon reaching steady state operation, the SCS may be temporarily disabled for a short duration (≤ 7 hours) to facilitate necessary operational evolutions, such as movement of the TRANSFER CASK through a doorway, or other similar operations.

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

a.1.a. Bulk water has been removed from the MPC

AND

a.1.b FHD has been secured for greater than 4 hours.

OR

a.2. Within 4 hours of transferring the MPC into the TRANSFER CASK if the MPC is to be unloaded.

AND

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

ACTIONS

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

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.4.1	Verify Supplemental Cooling System is operable	2 hours

4.0 DESIGN FEATURES

4.1 Design Features Significant to Safety

4.1.1 Criticality Control

a. MULTI-PURPOSE CANISTER (MPC) MPC-24

1. Flux trap size: ≥ 1.09 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0267 g/cm^2 (Boral) and ≥ 0.0223 g/cm^2 (METAMIC)

b MPC-24E and MPC-24EF

1. Flux trap size:
   - Cells 3, 6, 19, and 22: ≥ 0.776 in.
   - All Other Cells: ≥ 1.076 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0372 g/cm^2 (Boral) and ≥ 0.0310 g/cm^2 (METAMIC)

c. MPC-32

1. Fuel cell pitch: ≥ 9.158 in.
2. ^{10}B loading in the Boral neutron absorbers: ≥ 0.0372 g/cm^2 (Boral) and ≥ 0.0310 g/cm^2 (METAMIC)

4.1.2 Design Features Important to Criticality Control

a. Fuel spacers shall be sized to ensure that the active fuel region of intact fuel assemblies remain within the neutron poison region of the MPC basket with the water in the MPC.

b. The B_4C content in METAMIC shall be ≤ 33.0 wt%.

c. Neutron Absorber Test

The minimum ^{10}B for the neutron absorber shall meet the minimum requirements for each MPC model specified in Section 4.1.1 above.

(continued)

5.0 ADMINISTRATIVE CONTROLS (continued)

5.1.3 MPC and SFSC Loading, Unloading, and Preparation Program

This program shall be established and maintained to implement Diablo Canyon ISFSI SAR Section 10.2 requirements for loading fuel and components into MPCs, unloading fuel and components from MPCs, and preparing the MPCs for storage in the SFSCs. The requirements of the program for loading and preparing the MPC shall be complete prior to removing the MPC from the fuel handling building/auxiliary building. The program provides for evaluation and control of the following requirements during the applicable operation:

a. Verify that no transfer cask handling operations are allowed at environmental temperatures below -18 °C [0 °F].

b. Verify that the water is maintained to provide adequate cooling in the annular gap between the loaded MPC and the transfer cask during MPC reflooding operations (unloading).

c. The water temperature of a water-filled or partially filled loaded MPC shall be shown by analysis to be less than boiling at all times.

d. Verify that the drying times and pressures assure that fuel cladding temperature limit is not violated and the MPC is adequately dry.

e. Verify that the inerting backfill pressure and purity assure adequate heat transfer and corrosion control.

f. Verify that leak testing assures adequate MPC integrity and consistency with offsite dose analysis.

g. Verify surface dose rates on the TRANSFER CASK are adequate to assure proper loading and consistency with the offsite dose analysis.

h. Verify surface dose rates on the SFSCs are adequate to assure proper storage and consistency with the offsite dose analysis.

i. During MPC re-flooding, verify the helium exit temperature is such that water quenching or flashing does not occur.

j. Verify that combustible gases in the MPC are monitored and controlled to avoid combustion during MPC lid-to-shell welding or MPC cutting activities.

k. For the MPC lid-to-shell weld and the MPC enclosure vessel and lid, the weld must be at minimum of three weld layers. If PT alone is used, it will be tested at least three different weld layers, including the root and final weld layers and each approximately 3/8-inch of weld depth.

l. Very that fuel cladding is not exposed to an oxidizing environment by maintaining the cladding in water or an inert atmosphere.

(continued)