HOLTEC INTERNATIONAL

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THERMAL ANALYSIS OF HI-TRAC CS TRANSFER CASK

FOR

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Generic Report & ACPL Information	
Generic Report # invoked in this Calc Package, if applicable	N/A
Code(s) name(s) (must be listed in the ACPL)	Fluent
Code(s) version # (must be approved in the ACPL)	14.5.7
[PROPRIETARY PER 10CFR2.390]	[PROPRIETARY PER 10CFR2.390]
[PROPRIETARY PER 10CFR2.390]	[PROPRIETARY PER 10CFR2.390]

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2	Are you aware that you must be specifically certified if you use any Category A computer code (as defined in HQP 2.8 in the preparation of this document?	Yes
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4	Is the input data used in this work fully sourced (i.e., references are provided)?	Yes
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6	Is (Are) Category A computer code(s) (if used) listed in the Company's "Approved Computer program list"?	Yes
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8	Are you aware that you must observe all internal requirements on needed margins of safety published in Holtec's internal memos, if applicable (which may exceed those in the reference codes and standards or the specification)?	Yes
9	Have you performed numerical convergence checks to ensure that the solution is fully converged?	Yes
10	Is it true that you did not receive more than 10 quality infraction points in the past calendar year or thus far this year?	Yes

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SUMMARY OF REVISIONS

Revision 0: Initial Issue

1.0 INTRODUCTION

The HI-TRAC CS is the transfer cask to carry out all the onsite transfer operations of the MPC (Multi-Purpose Canister) at the HI-STORE CIS facility [1]. The HI-TRAC CS is a variation of HI-TRAC VW transfer cask licensed in docket number 72-1032 for the HI-STORM FW system and later adopted for the HI-STORM UMAX system in docket number 72-1040. HI-TRAC CS utilizes steel and densified concrete to provide dose attenuation [2]. HI-TRAC CS is also characterized by a split bottom lid (shield gate) configuration with each half designed to retract (open)/approach (close) symmetrically. The key thermal design feature of the HI-TRAC CS is the inlet vents provided in the shield gates that allow air to enter the HI-TRAC-to-MPC annular space. This allows for enhanced dissipation of decay heat from the MPC during transfer operations through natural convection.

The major onsite transfer operations involving HI-TRAC CS are as follows [1]:
[PROPRIETARY PER 10CFR2.390

].

The purpose of this report is to evaluate and document the thermal performance of the HI-TRAC CS cask during the onsite transfer operations at the HI-STORE CIS facility and the associated hypothetical accident scenarios. Thermal analyses are carried out using three-dimensional models constructed using ANSYS FLUENT [8]. The HI-TRAC CS thermal evaluation adopts NUREG-1536 [6] and ISG-11 guidelines [7] to demonstrate the safe transfer of Commercial Spent Fuel (CSF). These guidelines are stated below:

1. 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 moderate burnup fuel.
2. The fuel cladding temperature should be maintained below 570°C (1058°F) for off-normal and accident conditions.
3. The internal pressure of the MPC should remain within its design pressures for normal, off-normal, and accident conditions.
4. The component materials should be maintained within their minimum and maximum temperature criteria under normal, off-normal, and accident conditions.

This calculation package serves as the thermal design justification for the HI-TRAC CS system loaded with MPC-37 and MPC-89 canisters under normal and accident conditions to support the HI-STORE CIS Licensing Report [1].

1.1 MPC Decay Heat

As discussed in Section A.1 of Appendix A, the MPC-37 canister with [PROPRIETARY PER 10CFR2.390] (as defined in HI-STORM FW FSAR [3]) is the most limiting for casks in vertical orientation and is hence adopted for thermal analyses of HI-TRAC CS at HI-STORE site.

The HI-TRAC CS is analyzed for the bounding heat load pattern (Pattern 1) from Table 4.1.1 of HI-STORE CIS SAR [1]. As demonstrated in Table 3.3.4 of [5], this pattern is limiting for both the peak cladding temperature and MPC internal pressure and is hence adopted for all thermal evaluations of HI-TRAC CS documented herein.

1.2 Helium Backfill Pressure

The MPC is pressurized with Helium before transportation to the HI-STORE CIS site in a HI-STAR 190 transport cask to provide an inert atmosphere and to enhance heat transfer. The backfill pressure range for MPC-37s transferred at the HI-STORE site is specified in Table 4.1.3 of HI-STORE CIS SAR [1] and duplicated in Table 1.2 of this report.

1.3 Design Ambient Conditions

The HI-TRAC CS thermal evaluations are performed for site specific ambient conditions defined in Chapter 2 of the HI-STORE Site Specific Licensing Report [1]. The ambient conditions used for the normal onsite transfer scenario are listed in Table 1.1.

Table 1.1: Site Specific Parameters Applicable to Thermal Analyses of HI-TRAC CS

Parameter	Value
Ambient Temperature for Short Term Operations	91°F
Site Elevation	[PROPRIETARY PER 10CFR2.390]
Note 1: Elevation above sea level adopted for thermal evaluations conservatively bounds the site maximum elevation of [PROPRIETARY PER 10CFR2.390] [1].	

Table 1.2 Helium Backfill Range for MPCs Stored at HI-STORE CIS Site (Reproduced from [1])

MPC Type	**Pressure Range (Note 1)**
MPC-37	$\geq$ 39.0 psig and $\leq$ 46.0 psig
Note 1: Helium used for backfill of MPC shall have a purity of $\geq$ 99.995%. The pressure range is based on a reference temperature of 70°F.	

2.0 METHODOLOGY AND ASSUMPTIONS

The overall thermal analysis principles and methodology adopted here is based on the HI-STORM FW FSAR [3] and the HI-STORM UMAX FSAR [4]. The detailed methodology and assumptions used for the evaluations are discussed in the respective appendices.

3.0 ACCEPTANCE CRITERIA

The acceptance criteria applicable for the various scenarios during the onsite transfer for MPC in the HI-TRAC CS is outlined in the corresponding Appendices.

4.0 INPUT DATA

The input data necessary for the thermal analysis of normal onsite transfer scenario is listed in Section A.4 and the input information used for the accident condition analyses are listed in Section B.4.

5.0 COMPUTER CODES AND FILES

All thermal calculations documented in this report are performed using FLUENT Version 14.5 code [8]. The input/output files used in the HI-TRAC CS analyses are presented in the individual appendices.

6.0 CALCULATION AND RESULTS

All the normal onsite transfer and accident conditions are evaluated and presented in the appendices of this report. The predicted results demonstrate that the peak fuel temperature, HI-TRAC and MPC component temperatures, and MPC internal pressure during normal onsite transfer scenario are in compliance with the acceptance criteria listed in HI-STORE CIS SAR [1].

7.0 REFERENCES

[1] Licensing Report on the HI-STORE CIS Facility Holtec Report HI-2167374, Revision 0.

[2] HI-TRAC CS Licensing Drawing, Holtec Drawing 10868, Revision 0.

[3] Final Safety Analysis Report on the HI-STORM FW MPC Storage System, Holtec Report HI-2114830 Revision 4.

[4] "Final Safety Analysis Report on the HI-STORM UMAX Storage System", Holtec Report HI-2115090, Revision 3.

[5] Safety Analysis Report on the HI-STAR 190 Package, Holtec Report HI-2146214, Revision 0.D.

[6] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," USNRC, Revision 1 (July 2010).

[7] "Cladding Considerations for the Transportation and Storage of Spent Fuel", Interim Staff Guidance – 11, Revision 3, 2003.

[8] Fluent 14.5, ANSYS Theory Guide 117 (2012).

[9] MPC-37 Enclosure Vessel, Holtec Drawing 6505, Revision 17.

[10] Assembly, MPC 37 Fuel Basket, Holtec Drawing 6506, Revision 12.

[11] Effective Thermal Properties of PWR Fuel to Support Thermal Evaluation of HI-STORM FW, Holtec Report HI-2094356, Revision 5.

[12] HI-STORM FW License Amendment Request, 1032-5.

[13] Thermal Evaluations of HI-STORM UMAX at HISTORE CIS Facility, HI-2177591 Revision 0.

Appendix A:

Thermal Analysis of HI-TRAC CS During Normal Onsite Transfer

A.1 INTRODUCTION

The thermal analysis of the HI-TRAC CS during normal onsite transfer is presented in this Appendix. One of the central objectives of this report is to establish that the MPCs transported to the storage site in the HI-STAR 190 casks can be safely transferred to the UMAX storage systems using the HI-TRAC CS. The HI-TRAC CS is analyzed under a bounding configuration during the onsite transfer of MPC from the HI-STAR 190 cask to the VVM for storage. The bounding scenarios for onsite transfer are established based on the configurations evaluated in the HI-STAR 190 SAR [5] and the HI-STORM UMAX FSAR [4].

The bounding configuration includes the following:

1. Limiting MPC Type and Heat Load Pattern: As discussed in Section 2.0 of UMAX storage report [13], MPC-37 loaded with the PWR short fuel under the heat load pattern 1 from Table 4.1.1 of HI-STORE CIS SAR [1] is the most limiting thermal configuration. Therefore, this bounding configuration is adopted for all analyses presented in this report.

2. [PROPRIETARY PER 10CFR2.390

   ].

3. Solar insolation: The HI-TRAC is assumed to be outdoors and subjected to 10CFR71 solar insolation levels. 24-hour averaged insolation is applied considering the high thermal inertia of the system.

A 3-D thermal model is developed for the above configuration using the ANSYS Fluent [8] as described in the following sections. Although the onsite transfer would preclude the HI-TRAC CS/MPC reaching steady state due to the high thermal inertia of the system, a steady state analysis of HI-TRAC CS, with MPC in vertical orientation, during onsite transfer is performed here.

A.2 METHODOLOGY

To ensure an adequate representation of the thermally significant features of the HI-TRAC CS package such as air flow, fuel basket, basket shims, MPC and the various components of the cask, three-dimensional computational fluid dynamics (CFD) models of the MPC-37 loaded with the PWR Short Fuel (discussed in Section A.1) placed in the HI-TRAC CS cask are constructed. The MPC-37 model is adopted from the HI-STORM FW LAR [12]. The HI-TRAC CS cask is modelled around the existing MPC-37 model. The overall modelling approach and solution methodology used here is largely adopted from the thermal evaluations presented in the HI-STORM FW FSAR [3] and HI-STORM UMAX FSAR [4].

These HI-TRAC CS/MPC-37 3-D models have the following key features:

[PROPRIETARY PER 10CFR2.390

].

A.3 ASSUMPTIONS

The HI-TRAC CS thermal analysis employs an array of conservatisms to predict the maximum fuel, basket, MPC, and cask component temperatures. Following is a list of key features and conservative assumptions made in the thermal analysis of HI-TRAC CS during normal onsite transfer:

1. Axial heat transfer through fuel pellets is neglected in accordance with NUREG 1536.
2. [PROPRIETARY PER 10CFR2.390].
3. [PROPRIETARY PER 10CFR2.390].
4. [PROPRIETARY PER 10CFR2.390].
5. [PROPRIETARY PER 10CFR2.390].
6. [PROPRIETARY PER 10CFR2.390].
7. [PROPRIETARY PER 10CFR2.390

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8. [PROPRIETARY PER 10CFR2.390

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9. [PROPRIETARY PER 10CFR2.390

].

10. The effective thermal conductivities of fuel assemblies are conservatively reduced by 10% from the calculated value reported in Reference [11].

11. The HI-TRAC CS air inlet opening is conservatively understated reducing the inlet area for air flow.

A.4 INPUT DATA

The principal geometric input data for the thermal-hydraulic evaluations of the HI-TRAC CS cask, used in these analyses, are taken from design drawing [2]. The geometric data for the MPC-37 with the PWR short fuel is adopted from the HI-STOR FW FSAR [3].

Materials present in the HI-TRAC CS cask include structural steels, and concrete. The physical properties of these materials are adopted from [4]. The properties of the MPC-37 component materials are adopted from HI-STORM FW FSAR [3].

[PROPRIETARY PER 10CFR2.390

].

As outlined in Section A1.1, the heat load Pattern 1 from HI-STORE SAR [2] is used for the analyses presented here.

The natural convection surface heat transfer coefficient on the cask external surface, used in the quarter-symmetric models, is based on the correlations provided in Chapter 4 of HI-STORM FW FSAR [3]. Conservatively understated convection coefficient (*h*) is used in the thermal model.

Solar insolation, that bounds the 10CFR71 prescribed insolation data (see Table A.2.1), have been applied to all external surfaces of the HI-TRAC CS cask. [PROPRIETARY PER 10CFR2.390].

The site specific ambient temperature is listed in Table 1.1.

A.5 ACCEPTANCE CRITERIA

The HI-TRAC CS thermal evaluation acceptance criteria are listed below:

1. The peak cladding temperature under normal onsite transfer must be below 400°C for MPCs containing one or more high burnup fuel assemblies and 570°C for MPCs containing all moderate burnup fuel assemblies [7].

2. The HI-TRAC CS steel and concrete temperatures must be within the temperature limits presented in Table 4.4.1 of HI-STORE CIS SAR [1].

3. The MPC component temperatures and internal cavity pressure must be below the limits discussed in Section 4.3 of HI-STORE CIS SAR [1].

A.6 COMPUTER PROGRAM AND FILES

The commercial CFD code, FLUENT version 14.5.7 [8] is used in these thermal calculations. A list of the computer files supporting the calculations is provided below.

[PROPRIETARY PER 10CFR2.390

]

A.7 RESULTS AND CONCLUSIONS

A.7.1 Normal Onsite Transfer

A.7.1.1 Maximum Temperatures during Normal Onsite Transfer

Steady state analysis is performed using the 3-D thermal model described in Section A.2. The computed temperatures are listed in Table A.7.1 The peak cladding temperature, MPC and HI-TRAC component temperatures are well within the limits outlined in Section A.5.

The temperature contours for the normal onsite transfer scenario are provided in Figure A.7.1 through A.7.8.

A.7.1.2 Maximum Normal Operating Pressure (MNOP) during Normal Onsite Transfer

Per the HI-STAR 190 SAR [5], the MPC cavity is de-moisturized and backfilled with dry helium after fuel loading and prior to MPC lid closures. During the onsite transfer, the MPC internal pressure reaches a value depending upon the steady state temperature. The steady state MPC cavity pressure during onsite transfer in HI-TRAC CS is calculated using the Ideal Gas Law.

The MPC cavity pressure calculated using Ideal Gas Law and based on the maximum initial backfill pressure from Table 1.2 of this report, is reported in Table A.7.2 of this Appendix. The maximum cavity pressure is below the MPC design pressure limit under normal conditions specified in Chapter 4 of HI-STORE CIS SAR [1].

A.7.1.3 Thermal Expansion Computations

In this subsection, thermal expansion of free-standing HI-TRAC CS/MPC-37 components in the radial and axial directions is computed for the bounding scenario described in Section A.1. The calculations address the following thermal expansions:

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

(a) Fuel Basket-to-MPC Radial Growth

The radial growth (δ_1) of the fuel basket relative to the MPC shell upon heating from a 21°C (70°F) reference temperature (T_o) to steady state temperatures is computed as follows:

[PROPRIETARY PER 10CFR2.390]--------------- (Eq. A.7.1)

[PROPRIETARY PER 10CFR2.390

]

The fuel basket radial growth is computed in the spreadsheet listed in Section A.6, and reported in Table A.7.3. This differential growth is bounded by the minimum design gap engineered between the fuel basket and the MPC shell (see Table A.7.3).

[PROPRIETARY PER 10CFR2.390

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(b) Fuel Basket-to-MPC Axial Growth

The axial growth of the fuel basket relative to the MPC shell (δ_2) upon heating from a 21°C (70°F) reference temperature to steady state temperatures is computed as follows:

[PROPRIETARY PER 10CFR2.390] --------------- (Eq. A.7.2)

[PROPRIETARY PER 10CFR2.390

]

The net fuel basket axial growth is computed in the spreadsheet listed in Section A.6, and reported in Table A.7.3. This differential growth is bounded by the design gap engineered between the fuel basket and the MPC lid (see Table A.7.3).

(c) MPC-to-Cask Radial Growth

The radial growth (δ_3) of the MPC shell residing in the HI-TRAC CS cask relative to the cask upon heating from a 21°C (70°F) reference temperature (T_o) to steady state temperatures is computed as follows:

[PROPRIETARY PER 10CFR2.390] --------------- (Eq. A.7.3)

[PROPRIETARY PER 10CFR2.390

]

The fuel basket radial growth is computed in the spreadsheet listed in Section A.6, and reported in Table A.7.3. This differential growth is bounded by the design gap engineered between the MPC and HI-TRAC CS cask (see Table A.7.3).

(d) MPC-to-Cask Axial Growth

The axial growth of the fuel relative to the HI-TRAC inner shell (δ_4) upon heating from a 21°C (70°F) reference temperature to storage temperatures is computed as follows:

[PROPRIETARY PER 10CFR2.390]---------- (Eq. A.7.4)

[PROPRIETARY PER 10CFR2.390

].

The net MPC axial growth is computed in the spreadsheet listed in Section A.6, and reported in Table A.7.3. This differential growth is bounded by the design gap engineered between the MPC and cask shield ring (see Table A.7.3).

A.7.2 Additional Discussions:

A.7.2.1 Acceptability of Sub-Design Heat Load:

A sub-design basis (SDB) heat load pattern with wider helium backfill range is defined for both MPC-37 and MPC-89 is also permitted to be transported in the HI-STAR 190 cask as discussed in Section 3.3.5 of HI-STAR 190 SAR [5]. Since the SDB heat load pattern allows a higher backfill upper limit, explicit analysis was performed in the HI-STAR 190 SAR [5] (Table 3.3.8) demonstrating that the design basis MNOP is higher than the sub design basis MPC pressure. This conclusion therefore can be extended to the normal onsite transfer scenario in HI-TRAC CS. Additionally, the MPC cavity pressure during onsite transfer, reported in table A.7.3 is lower than the normal transport condition pressures reported in Table 3.1.5 of HI-STAR 190 SAR [5]. Therefore, the temperatures and pressures under SDB heat load patterns defined in HI-STAR 190 SAR will meet the acceptance criteria in Section A.5 for onsite transfer in HI-TRAC CS.

A.7.2.2 16x16A Intact Fuel in Damage Fuel Containers (DFCs):

The HI-STAR 190 is permitted to transport of 16x16A intact fuel assemblies placed within DFCs and loaded in MPC-37 canisters as discussed in section 3.3.6 of HI-STAR 190 SAR [5]. The PCT, component temperatures and MPC cavity pressures are all bounded by the licensing basis normal transport scenario reported in Table 3.1.1 of the HI-STAR 190 SAR [5]. Therefore, it can also be concluded that the maximum temperatures and cavity pressure during onsite transfer MPC-37 loaded with 16x16A intact fuel assemblies placed in DFCs, in HI-TRAC CS is bounded by the bounding onsite transfer scenario evaluated in Section A.7.1.

Table A.2.1: 24 Hours Averaged Solar Insolation Data from 10CFR71

Form and location of surface	Total insolation averaged over a 24-hour period (g cal/cm^2)
Flat surfaces transported horizontally; Base Other surfaces	 None 400
Flat surfaces not transported horizontally	100
Curved surfaces	200

Table A.7.1

Maximum Temperatures for HI-TRAC CS/MPC-37 loaded with PWR Short Fuel under Heat Load Patter 1 during Normal Onsite Transfer

Material/Components	Maximum Temperatures °C (°F)	Temperature Limits °C (°F)
Fuel Cladding	354 (669)	400 (752) or 570 (1058) Note 2
Fuel Basket	324 (615)	500 (932)
Basket Shims	264 (507)	500 (932)
MPC Shell	238 (461)	427 (800)
MPC Lid Note 1	213 (416)	427 (800)
MPC Baseplate Note 1	173 (343)	427 (800)
HI-TRAC Concrete Note 1	133 (271)	149 (300)
HI-TRAC Outer Shell	93 (200)	316 (600)
HI-TRAC Inner Shell	178 (352)	316 (600)
Shield Gate Top Flange	142 (288)	316 (600)
Shield Gate Door	169 (336)	316 (600)

Note 1: Maximum Section Average Temperature is reported for this component.

Note 2: The 1058°F temperature limit applies to MPCs containing all moderate burnup fuel. The limit for MPCs containing one or more high burnup fuel assemblies is 752°F.

Table A.7.2

MPC Cavity Pressure during Normal Onsite Transfer in HI-TRAC CS

Condition	Pressure kPa (psig)	Pressure Limit kPa (psig)
Normal Onsite Transfer	661.6 (96.0)	827.1 (120)

Table A.7.3

Differential Thermal Expansions during Normal Onsite Transfer

Gap Description	**Nominal Gap (U), mm (inch)**	**Differential Expansion (V), mm (inch)**	**Is Free Expansion Criteria Satisfied? (i.e. U > V)**
Fuel Basket-to-MPC Radial Gap	[PROPRIETARY PER 10CFR2.390]	[PROPRIETARY PER 10CFR2.390]	Yes
Fuel Basket-to-MPC Axial Gap	[PROPRIETARY PER 10CFR2.390]	[PROPRIETARY PER 10CFR2.390]	Yes
MPC-to-Cask Radial Gap	[PROPRIETARY PER 10CFR2.390]	[PROPRIETARY PER 10CFR2.390]	Yes
MPC-to-Cask Axial Gap	[PROPRIETARY PER 10CFR2.390]	[PROPRIETARY PER 10CFR2.390]	Yes
Note 1: The MPC height used for the thermal evaluations is that corresponding to the PWR short fuel as explained in Section A.1 resulting in bounding temperatures. However, the minimum cold gap obtained using the longest MPC-37 height of [PROPRIETARY PER 10CFR2.390] is used as the acceptance criteria, here. This is conservative.			

[PROPRIETARY PER 10CFR2.390]

Figure A.3.1: HI-TRAC CS/MPC-37 Thermal Model

[PROPRIETARY PER 10CFR2.390]

Figure A.7.1 Temperature Contours of HI-TRAC CS/MPC-37 under the Normal Onsite Transfer

[PROPRIETARY PER 10CFR2.390]

Figure A.7.2 Temperature Contours at hottest cross section of HI-TRAC CS/MPC-37 under the Normal Onsite Transfer scenario.

[PROPRIETARY PER 10CFR2.390]

Figure A.7.3 Temperature Contour of MPC Shell under the Normal Onsite Transfer scenario.

[PROPRIETARY PER 10CFR2.390]

Figure A.7.4 Temperature Contour of MPC Baseplate under the Normal Onsite Transfer scenario.

[PROPRIETARY PER 10CFR2.390]

Figure A.7.5 Temperature Contour of MPC Lid under the Normal Onsite Transfer scenario.

[PROPRIETARY PER 10CFR2.390]

Figure A.7.6 Temperature Contour of MPC Lid top surface under the Normal Onsite Transfer scenario.

[PROPRIETARY PER 10CFR2.390]

Figure A.7.7 Temperature Contour of HI-TRAC CS components in the vicinity of trunnions.

[PROPRIETARY PER 10CFR2.390]

Figure A.7.8 Temperature Contours of HI-TRAC CS bottom shield gate assembly under the Normal Onsite Transfer scenario. Bulk temperature of this component is 142^{o}C.

Appendix B:

Thermal Analysis of HI-TRAC CS Hypothetical Accident Scenarios

B.1 INTRODUCTION

The thermal analysis of the HI-TRAC CS during hypothetical accident scenarios postulated in [1] is presented in this Appendix.

B.1.1 VCT Fire Accident:

During the Onsite Transfer, the HI-TRAC CS loaded with MPC is transported from the CTB to the UMAX Storage Modules using a VCT. The hypothetical fire accident is assumed to be occurred during this onsite transport of HI-TRAC CS using the VCT, with a gator/utility vehicle nearby. The relative position of HI-TRAC CS, VCT and a gator/utility vehicle cask considered for the analysis is illustrated in Figure D.1.

The liquid fire duration is calculated based on the fuel and hydraulic fluid inventory of the VCT as well as a gator/golf cart/utility vehicle in the vicinity. To evaluate the effect of liquid fire on HI-TRAC CS and loaded MPC, a transient CFD analysis is performed and the calculation is continued after the postulated fire duration, until the peak cladding temperature reaches its maxima and starts decreasing. The fire evaluations are performed based on the requirements set forth in 10CFR71 (outlined in Chapter 6 of [1]).

The effect of solid fire resulting from the hypothetical scenario of the gator/utility vehicle wheels being ignited is also evaluated following the methodology outlined in Section B.2.

The sources of combustible materials considered for the evaluation include:

- [PROPRIETARY PER 10CFR2.390
-
-
-]

The quantities of these combustibles are listed in Table B.1.1. The assumed parameters for the utility vehicle wheels are listed in Table B.1.2.

B.1.2 Canister Transfer Building (CTB) Collapse Accident:

As outlined in Chapter 6 of [1], the CTB is assumed to collapse and [PROPRIETARY PER 10CFR2.390] is assumed to block parts of the HI-TRAC CS cask. The effect of flow blockage due to the corrugated sheets, as well as the radiation blockage are captured in the thermal model in a bounding manner. A steady state analyses is performed under this condition to ensure that the bounding temperatures are predicted. The design basis accident as defined in the HI-STORE CIS Licensing Report [1] is adopted for the evaluations of the CTB collapse event.

The bounding fuel assembly type, heat load and MPC type as justified in Appendix A is used for all the analyses presented here.

B.2 METHODOLOGY AND ASSUMPTIONS

The thermal model used for the accident analyses are directly adopted from the normal onsite transfer calculations presented in Appendix A. Changes are made to the boundary conditions to evaluate the specific accidents. The changes made to the model and assumptions involved in the analyses are listed in this section.

B.2.1 Hypothetical Fire Accident:

The fire event involving the VCT and gator/utility vehicle is postulated to consist of three phases as follows:

[PROPRIETARY PER 10CFR2.390

].

B.2.1.1 Liquid Phase Fire:

The methodology and major assumptions adopted for liquid fire analysis is listed below:

[PROPRIETARY PER 10CFR2.390

].

B.2.1.2 Solid Phase Fire:

The following methodology is adopted for evaluating the temperature difference due to the solid phase fire:

[PROPRIETARY PER 10CFR2.390

].

B.2.2 Hypothetical CTB Collapse event:

The 3-D thermal model used for the CTB collapse event is adopted from the thermal model for normal onsite transfer analysis. The boundary conditions are altered in the Fluent model to reflect the design basis event. The following modifications and assumption are involved in the thermal analysis:

[PROPRIETARY PER 10CFR2.390

].

A steady state analysis is performed for the hypothetical CTB collapse accident to obtain bounding maximum temperatures.

B.3 INPUT DATA

The thermal model is directly adopted from Appendix A of this report. The source and quantity of liquid and solid combustibles used for the fire analysis are listed in Table B.1.1. The relevant parameters of the gator/utility vehicle adopted for the solid phase fire are listed in Table B.1.2.

The additional input data used for the calculation of fire durations are listed in Appendix C and Appendix D.

B.4 ACCEPTANCE CRITERIA

The acceptance criteria for the HI-TRAC CS accident scenarios are outlined in Section 4.3 of the HI-STORE CIS SAR [1]. Specifically, under accident scenarios:

1. The Peak Cladding Temperature must be below 570^{o}C (1058^{o}F) during accident conditions [7].

2. The HI-TRAC CS component temperatures must be below the limits specified in Table 4.4.1 of [1]. The portion of concrete that exceeds the limit of 1100^{o}F will be considered unavailable for shielding as per Table 4.4.1 of HI-STORE CIS SAR [1].

3. For the fire accident, the temperature of carbon steel components directly exposed to the fire must be below 50% of the melting point given in [B-2], as per the requirement set forth in Table 4.4.1 of [1].

4. The MPC component temperatures and internal pressure must be below the accident conditions limits discussed n Section 4.3 of the HI-STORE SAR [1].

B.5 COMPUTER PROGRAM AND FILES

The commercial CFD code, FLUENT version 14.5.7 [8] is used in these thermal calculations. A list of the computer files supporting the calculations is provided below.

[PROPRIETARY PER 10CFR2.390

]

B.6 RESULTS AND CONCLUSIONS

B.6.1 Maximum Temperatures and MPC Pressure During the VCT Fire Event:

B.6.1.1 Liquid Phase Fire

The bounding steady state HI-TRAC CS normal on-site transfer temperatures (see Table A.7.1) are adopted as the initial condition for the transient fire accident (fire and post-fire) evaluation. The transient study was conducted for a sufficiently long period to allow temperatures in the overpack to reach their maximum values and begin to recede. The maximum temperature for each component during and after the fire accident is obtained from the transient analysis and reported in Table B.6.1.1.

As shown in Figure B.6.1.1, the peak cladding temperature reaches the maximum value at about [PROPRIETARY PER 10CFR2.390] after the start of the fire event.

The MPC cavity bulk temperature reaches its maxima at around [PROPRIETARY PER 10CFR2.390] after the start of fire. The maximum MPC pressure during the post fire duration is listed in Table B.6.1.2.

Due to direct exposure to the hypothetical fire (modelled as 1475^{o}F heat source), some part of the HI-TRAC CS concrete exceeds the temperature limit. As stated in Chapter 4 of the HI-STORE CIS Licensing Report [1], the concrete that exceeds 1100^{o}F shall be considered unavailable for shielding. The regions of concrete that exceed this limit is shown in Figure B.6.1.2. As shown in the figure a negligible portion of concrete exceeds 1100^{o}F at the end of fire.

The peak cladding temperature, maximum component temperature and MPC cavity pressures reported in Tables B.6.1.1 and B.6.1.2 are within their respective limits provided in Chapter 4 of [1].

B.6.1.1 Solid Phase Fire

The total heat flux incident on HI-TRAC CS cask from the solid phase fire is calculated in Appendix D. Based on the calculations presented in the spreadsheet [PROPRIETARY PER 10CFR2.390

], the temperatures will essentially be the same as that reported in Table B.6.1.1 and the maximum MPC cavity pressure will be essentially same as that reported in Table B.6.1.2.

B.6.2 Maximum Temperatures and MPC Pressure During CTB Collapse Event:

A steady state analysis is performed using the thermal model described in Section B.2 for the CTB collapse accident. The maximum peak cladding temperature and HI-TRAC/MPC component temperatures are presented in Table B.6.2.1. The maximum MPC pressure for the CTB collapse event is reported in Table B.6.2.2. The PCT, component temperatures and MPC internal pressures are within their respective accident condition limits specified in Chapter 4 of the HI-STORE CIS Licensing Report [1].

B.7 REFERENCES:

[B-1] "Thermal Measurements in a Series of Large Pool Fires", SAND85-1096, Sandia National Laboratories, (August 1987).

[B-2] "Carbon Steel Handbook", EPRI, Palo Altom CA: 2007. 1014670.

Table B.1.1

Source and Quantity of Combustible for the Hypothetical Fire Accident

Source	Quantity	Reference
VCT Diesel Fuel	[PROPRIETARY PER 10CFR2.390]	[PROPRIETARY PER 10CFR2.390]
VCT Hydraulic Fluid	[PROPRIETARY PER 10CFR2.390]	[PROPRIETARY PER 10CFR2.390]
Utility Vehicle Diesel Fuel	[PROPRIETARY PER 10CFR2.390]	[PROPRIETARY PER 10CFR2.390]
Total Rubber Mass from Utility Vehicle Tires	[PROPRIETARY PER 10CFR2.390]	[PROPRIETARY PER 10CFR2.390]

Table B.1.2

Gator/Utility Vehicle Parameters adopted for Solid Phase Fire

Parameter	Value
Tire Diameter	[PROPRIETARY PER 10CFR2.390]
Number of Wheels	[PROPRIETARY PER 10CFR2.390]

Table B.6.1.1

Maximum Temperatures for HI-TRAC CS/MPC-37 during VCT Fire Accident

Material/Components	Temperature ºC (°F)		Temperature Limit ºC (°F) [1]
	End of Fire	Post Fire	
Fuel	354 (670)	372 (701)	570 (1058)
Fuel Basket	324 (615)	343 (650)	570 (1058)
Basket Shims	264 (508)	281 (537)	570 (1058)
MPC Shell	267 (512)	267 (512)	570 (1058)
MPC Lid Note 1	245 (474)	245 (474)	570 (1058)
MPC Baseplate Note 1	219 (426)	275 (527)	570 (1058)
HI-TRAC Concrete	749 (1380)	749 (1380)	593 (1100)
HI-TRAC Outer Shell Note 3	589 (1092)	589 (1092)	713 (1315) Note 4
HI-TRAC Inner Shell	474 (886)	474 (886)	713 (1315) Note 4
Shield Gate Top Flange Note 3	371 (700)	371 (700)	713 (1315) Note 4

Note 1: Maximum Section Average Temperature is reported for this component.

Note 2: The volume of concrete that exceeds the temperature limit is shown in Figure B.6.2.1 and shall be considered unavailable for shielding.

Note 3: Bulk temperature reported for this component.

Note 4: 50% of melting point of carbon steel from [B-2].

Table B.6.1.2

Maximum MPC Pressure during VCT Fire Accident

Condition	Bulk Temperature ºC (°F)	Pressure kPa (psig)
VCT Fire Accident	284 (542) Note 1	691 (100.2)

Note 1: The maximum cavity average temperature is obtained at [PROPRIETARY PER 10CFR2.390] after the start of fire.

Table B.6.2.1

Maximum Temperatures for HI-TRAC CS/MPC-37 after the CTB Collapse Accident

Material/Components	Maximum Temperatures °C (°F)	Temperature Limits [1] °C (°F)
Fuel	492 (918)	570 (1058)
Fuel Basket	465 (869)	570 (1058)
Basket Shims	403 (757)	570 (1058)
MPC Shell	381 (718)	570 (1058)
MPC Lid **Note 1**	343 (649)	570 (1058)
MPC Baseplate **Note 1**	339 (642)	570 (1058)
HI-TRAC Concrete	338 (640)	343 (650)
HI-TRAC Outer Shell	177 (351)	371 (700)
HI-TRAC Inner Shell	339 (642)	371 (700)
Shield Gate Top Flange	293 (559)	371 (700)
Shield Gate Door	336 (637)	371 (700)
Note 1: Maximum Section Average Temperature is reported for this component.		

Table B.6.2.2

Maximum MPC Pressure after the CTB Collapse Accident

Condition	Bulk Temperature °C (°F)	Pressure kPa (psig)
VCT Fire Accident	408 (766) **Note 1**	867 (125.8)

[PROPRIETARY PER 10CFR2.390]

[PROPRIETARY PER 10CFR2.390]

Appendix C:

Calculation of Liquid Phase Fire Duration

C.1 WORKSHEET-SPECIFIC INTRODUCTION

The purpose of this calculation is to determine the duration of a combustible liquid fire involving a tracked VCT carrying a HI-TRAC CS cask. The procedure is as follows:

[PROPRIETARY PER 10CFR2.390

].

This approach to calculating the duration of the fire is consistent with the methodology described in the HI-STORM FW FSAR [B-1] which is in accordance with NRC Regulations, 10CFR71.

C.2 WORKSHEET-SPECIFIC REFERENCES

[C-1] "HI-STORM FW Final Safety Analysis Report," Holtec Report HI-2114830, Revision 4.

[C-2] [PROPRIETARY PER 10CFR2.390].

[C-3] "HI-TRAC CS Licensing Drawing" Holtec Drawing 10868R0.

[C-4] [PROPRIETARY PER 10CFR2.390]

[C-5] NRC Regulations (10CFR), Part 71.73.

[C-6] “Thermal Measurements in a Series of Large Pool Fires”, SAND85-1096, Sandia National Laboratories, (August 1987).

[C-7] [PROPRIETARY PER 10CFR2.390

]

C.3 WORKSHEET-SPECIFIC INPUT DATA

[PROPRIETARY PER 10CFR2.390

]

C.4 WORKSHEET-SPECIFIC CACULATIONS

C.4.1 Calculate Area of Fuel Spread

[PROPRIETARY PER 10CFR2.390

].

Appendix D:

Calculation of Heat Flux from Utility Vehicle Tire Fire

D.1 WORKSHEET-SPECIFIC INTRODUCTION

The purpose of this calculation is to determine the heat flux from the burning gator/golf cart tire rubber that impinges on the HI-TRAC cask. The procedure is as follows:

[PROPRIETARY PER 10CFR2.390

].

The duration of the burning tire rubber is also determined.

D.2 WORKSHEET-SPECIFIC REFERENCES

[D-1] [PROPRIETARY PER 10CFR2.390
].

[D-2] Not used

[D-3] “HI-TRAC CS Licensing Drawing", Holtec Drawing 10868 Revsion 0.

[D-4] "Fire Test With a Front Wheel Loader", SP Report P801596, 15 October 2008.

[D-5] Howell, J.R., "A Catalog of Radiation Heat Transfer Configuration Factors," 3rd Edition, online at www.engr.uky.edu/rtl/Catalog/.

D.3 WORKSHEET-SPECIFIC INPUT DATA FOR GATOR TIRE FIRE

[PROPRIETARY PER 10CFR2.390

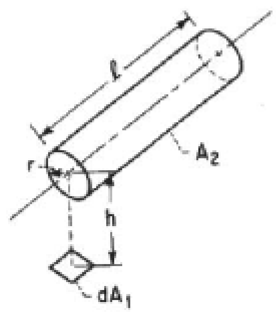
].

Attachment D-1: View Factor Calculation from Reference [D-5]:

SECTION B
Factors From Differential Elements to Finite Areas

B-31: Plane element to right circular cylinder of finite length and radius, normal to element passes through one end of a cylinder and is perpendicular to cylinder axis.

Reference: Hamilton and Morgan, 1952



Definitions: L=l/r; H=h/r; X=$(1+H)^2+L^2$; Y=$(1-H)^2+L^2$

Governing equation:

$$F_{d1-2} = \frac{1}{\pi H}\tan^{-1}\frac{L}{\sqrt{H^2-1}} + \frac{L}{\pi}\left[\frac{X-2H}{H\sqrt{XY}}\tan^{-1}\sqrt{\frac{X(H-1)}{Y(H+1)}} - \frac{1}{H}\tan^{-1}\sqrt{\frac{H-1}{H+1}}\right]$$