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

EVALUATION OF FIRES FOR THE HBPP ISFSI

FOR

PG&E

Holtec Report No: HI-2033006

Holtec Project No: 1125

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT NUMBER: ___HI-2033006___ PROJECT NUMBER: ___1125___

DOCUMENT ISSUANCE AND REVISION STATUS

DOCUMENT NAME: Evaluation of Fires for the HBPP ISFSI_

DOCUMENT CATEGORY: ☐ GENERIC ☒ PROJECT SPECIFIC

No.	Document Portion	REVISION No.: 0			REVISION No.: 1			REVISION No.: 2		
		Author's Initials	Date Approved	VIR #	Author's Initials	Date Approved	VIR #	Author's Initials	Date Approved	VIR #
1.	Non-Engulfing Fires	KK	10/24/2003	947529	ER	12/16/2003	414950			
2.	Engulfing Fire	ER	10/24/2003	94581	ER	12/16/2003	557417			
3.										
4.										
5.										
6.										
7.										
8.										
9.										
10.										
11.										

HOLTEC INTERNATIONAL

DOCUMENT NUMBER: ___HI-2033006___ PROJECT NUMBER: ___1125___

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

- [O] Nonproprietary
- ☐ Holtec Proprietary
- ☐ Privileged Intellectual Property (PIP)

Documents labeled Privileged Intellectual Property contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 in the N-drive of 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 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 "Table of Contents", this page and the "Revision Log".

TABLE OF CONTENTS

Proprietary Information Deleted

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

Section 6.2.7 of the specification [1] for the Humboldt Bay Power Plant (HBPP) Independent Spent Fuel Storage Installation (ISFSI) require evaluations of the HBPP site fire hazards. This section also lists the fire hazards that could possibly affect proposed ISFSI structures, systems and components (SSCs) that are important-to-safety. This report documents the analyses performed to quantify the effects, if any, of the postulated fire hazards on the both the underground vault of the HBPP ISFSI and on the dry fuel storage casks that will be used at the ISFSI.

Paragraph 72.122(c) of Title 10 of the Code of Federal Regulations (10CFR) [2] defines the requirements for licensing basis evaluations of fire events for storage of spent nuclear fuel at a proposed ISFSI. Paragraph 71.73(c)(4) of 10CFR [3] defines the requirements for licensing basis evaluations of a fire event for offsite transportation of spent nuclear fuel.

The following sections of this document present the computational methods and input data used to perform the fire hazard evaluations (Sections 2.0, 4.0 and 5.0), the acceptance criteria applied to the computational results (Section 3.0), the evaluations themselves (Section 6.0), and the numeric calculation results and final conclusions (Section 7.0).

2.0 Methodology

2.1 Evaluation of Fire Potentials

A total of sixteen possible site fire hazards [1, 4] have been identified for storage operations at the HBPP ISFSI. Before performing calculations to evaluate the effects of these possible hazards, an engineering evaluation is performed to determine the actual potential for fire posed by each identified hazard. If the fire potential for an individual hazard is negligible, no subsequent calculations of fire effects are required.

The engineering evaluation performed for each postulated hazard consists of a review of the applicable physical and chemical properties of the materials involved. Each potential fire hazard is evaluated for fire potential on the basis of its fire hazard rating. The fire hazard rating and explosion hazard ratings for a commercially available material are typically found on the manufacturer's material safety data sheet (MSDS).

2.2 Evaluation of Fire Effects

2.2.1 Engulfing Fires

If a flammable material fire occurs such that it can completely surround a cask and the flames are close enough that convection heat transfer is significant, the resulting event is an engulfing fire. During an engulfing fire, heat is input to the affected cask SSCs via both natural convection and thermal radiation heat transfer mechanisms on all surfaces. For evaluating fires that engulf a cask, the following methodology is applied.

Proprietary Information Deleted regarding statements 1 and 2.

1.

2.

Proprietary Information Deleted regarding statement 3.

3.

2.2.2 Non-Engulfing Fires

If a flammable material fire occurs at some distance such that the convection heat transfer mode is negligible compared to the thermal radiation mode, the fire is termed non-engulfing.

Proprietary Information Deleted.

be estimated by modeling the ISFSI as a rectangular area and the fire as a perpendicular planar wall of flame. The surface temperature of the cask or ISFSI (T_{target}) will rise during the duration of any fire event, so the maximum rate of heat input will occur at the start of the event.

The following set of equations [7], for a cylinder with its axis parallel to a rectangle of equivalent height, can be used to calculate the fire-to-cask view factor:

Proprietary Information Deleted

Proprietary Information Deleted

3.0 Acceptance Criteria

3.1 Evaluation of Fire Potential

These evaluations are performed to determine if a potential fire hazard poses a real hazard to the cask systems. The following criterion is applied in making these determinations.

1. For flammable vaporized liquids or gases mixed with air, a postulated hazard will be determined to pose a real hazard if an MSDS sheet lists the fire hazard rating as other than none.

2. Materials for which an MSDS are not available will be considered to pose a real hazard.

3. Any naturally occurring event (i.e., grass fires, forest fires, etc.) will be considered to pose a real hazard.

If any of these criteria is met for a postulated hazard, the hazard will be deemed a real hazard and evaluated further.

3.2 Evaluation of Fire Effects

These evaluations are performed to determine the effects, on the casks systems and the ISFSI itself, of all postulated fire hazards identified as real hazards. The following acceptance criteria are applied in making these determinations.

1. For all real engulfing fire hazards, the maximum temperatures for all cask system contents and components must not exceed accident condition design (cask components) or allowable (cask contents) temperatures.

2. For all real non-engulfing fire hazards affecting the cask systems, the cask system temperature rise resulting from the fire heat flux must not result in temperatures that exceed accident condition design or allowable temperatures.

3. For all real non-engulfing fire hazards affecting the ISFSI, the heat input to the ISFSI vault covers must not cause a temperature rise that would cause any stored cask system contents and components from exceeding accident condition design or allowable temperatures. The temperature increase must not cause long term temperature degradation to the vault and cover.

If meeting these criteria requires limiting the duration of the heat flux on the cask (i.e., extinguish the fire or remove the cask to an area away from the fire) appropriate time limits will be determined.

4.0 Assumptions

4.1 Evaluation of Fire Potential

No assumptions required.

4.2 Evaluation of Fire Effects

1. For engulfing fire events, end effects are neglected. This yields higher initial cask component temperatures and is a reasonable modeling simplification given the low risk of an actual engulfing fire and the use of the conservative 10CFR71 fire parameters.

2. Proprietary Information Deleted regarding statements 2 and 3.

3.

4. Deleted.

5. Deleted.

6. All non-engulfing fire event evaluations are performed at the minimum fire to cask and/or fire-to-ISFSI separation distance, including the separation distances along the transport route from the reactor building to the ISFSI. This will maximize the fire heat flux input to the cask and/or ISFSI.

7. For all fire events, the average flame temperature of 1475°F from 10CFR71 [3] is imposed. This severe fire condition, intended to bound any offsite transportation fire hazard, should be conservative for the fires hazards of on-site transport.

8. Proprietary Information Deleted regarding statement 8.

9. For all fire events, it is assumed that large tanks (i.e., greater than 1000 gallons) are sufficiently separated to prevent the combustion of one tank from igniting an adjacent tank. This is typically required by fire protection codes for large tank installations.

10. For all fire events, radiation scattering and absorption by atmospheric elements (i.e., air, dust, water vapor, etc.) is neglected. Inclusion of these effects would only reduce the amount of heat input to the cask and/or, to their neglect is conservative.

11. For all fire events, elevation differences between the fire hazards and the casks and/or ISFSI are neglected. The reactor building is located lower than the ISFSI, as are most of the fire hazards. Thus, most of the transport route and the ISFSI location would be partially shielded by elevation. It is conservative to neglect any such partial shielding.

12. The analyses of the heat input from a site vegetation fire do not recognize any attempt at fire suppression. Any suppression actions would reduce the severity of the fire, so it is conservative to neglect them.

13. It is assumed that casks will not be transported to or from the ISFSI during any site vegetation fire event. This recognizes that personnel performing these operations will take reasonable precautions to avoid exposing loaded casks to avoidable hazards.

14. It is assumed that all areas within the ISFSI nuisance fence are covered with either gravel or concrete. This assumption excludes the presence of any vegetation within the ISFSI boundary. This assumption is in accordance with the PG&E specification [1], which states: “There will be no vegetation within 20 feet of the vault in any direction.”

15. It is assumed that the entire heat energy of the site vegetation fire released at the fireline is directed toward the ISFSI. This neglects the omni-directional behavior of thermal radiation heat transfer, conservatively maximizing the heat input to a cask.

16. The fire-to-ISFSI view factor for the site vegetation fire event is calculated assuming the fire-to-ISFSI distance is the minimum separation distance throughout the event duration. This conservatively maximizes the view factor and, consequently, the resulting heat input to the ISFSI.

17. Proprietary Information Deleted regarding statement 17.

5.0 Input Data

5.1 Evaluation of Fire Potential

All input data necessary to perform these engineering evaluations are presented within the evaluations themselves (Section 6.1) and are not repeated here.

5.2 Evaluation of Fire Effects

The finite-element model used for evaluating engulfing fire events requires geometric and material properties inputs as well as boundary conditions. The following table presents the input data used to construct the finite-element model.

Input Parameter	Value	Source
Geometric Parameters		
Fuel Basket Diameter	63.386 in.	[9]
MPC-HB Enclosure Vessel Outer Diameter	68.375 in.	[15]
MPC-HB Enclosure Vessel Shell Thickness	0.5 in.	[15]
HI-STAR HB Inner Diameter	68.75 in.	[10]
HI-STAR HB Inner Shell Thickness	2.5 in.	[10]
HI-STAR HB Layered Shells Thickness	6.0 in.	[10]
HI-STAR HB Enclosure Shell Outer Diameter	96.0 in.	[10]
HI-STAR HB Enclosure Shell Thickness	0.5 in.	[10]
Material Properties		
Fuel Basket Thermal Conductivity	0.894 Btu/(hr×ft×°F)	[9]
Fuel Basket Heat Capacity	0.05 Btu/(lb×°F)	[9]
Fuel Basket Density	136.0 lb/ft^3	[9]
Stainless Steel Thermal Conductivity	10.6 Btu/(hr×ft×°F)	[11]
Stainless Steel Heat Capacity	0.12 Btu/(lb×°F)	[11]
Stainless Steel Density	501.0 lb/ft^3	[11]
Helium Thermal Conductivity	0.1289 Btu/(hr×ft×°F)	[11]
Helium Heat Capacity	1.24 Btu/(lb×°F)	[11]
Helium Density in MPC	0.034 lb/ft^3	[16]
Carbon Steel Thermal Conductivity	23.9 Btu/(hr×ft×°F)	[11]
Carbon Steel Heat Capacity	0.1 Btu/(lb×°F)	[11]
Carbon Steel Density	489.0 lb/ft^3	[11]
HI-STAR HB Layered Shells Thermal Conductivity	8.724 Btu/(hr×ft×°F)	[14]

Input Parameter	Value	Source
HI-STAR HB Neutron Absorber Thermal Conductivity	1.0 Btu/(hr×ft×°F)	Section 4.2
HI-STAR HB Neutron Absorber Heat Capacity	0.39 Btu/(lb×°F)	[11]
HI-STAR HB Neutron Absorber Density	105.0 lb/ft^3	[11]
Emissivity of Stainless Steel	0.36	[11]
Emissivity of Carbon Steel	0.66	[11]
Fire Parameters		
Outer Surfaces Emissivity During Fire	1.0	[3]
Forced Convection Heat Transfer Coefficient During Fire	4.5 Btu/(hr×ft^2×°F)	[6]
Initial Ambient Temperature	100°F	[3]
Fire Average Flame Temperature	1475°F	[3]
On-Site Transporter Fuel Tank Capacity	50 gal.	[13]
Liquid Fuel Consumption Rate	0.15 in./min.	[6]
Decay Heat Parameters		
Bounding Decay Heat Load	2 kW	[12]
Minimum Active Fuel Length	77 1/8 in.	[1]
Maximum Axial Peaking Factor	1.195	[11]

All input data necessary to perform for the calculations for the non-engulfing fire events are presented within the calculations themselves (Appendix B) and are not repeated here.

6.0 Calculations

6.1 Evaluation of Fire Potential

A total of sixteen potential fire hazards are identified. These potential hazards are as follows:

Hazard ID	Hazard Description
F-1	Unit 1 Residual No. 6 Fuel Oil Storage Tank – 2,760,169 gallons
F-2	Unit 1 Residual No. 6 Fuel Oil Service Tank – 120,120 gallons
F-3	Unit 2 Residual No. 6 Fuel Oil Storage Tank – 2,760,169 gallons
F-4	Unit 2 Residual No. 6 Fuel Oil Service Tank – 120,120 gallons
F-5	Diesel Fuel Oil Tank – 84,940 gallons
F-6	Diesel North Service Tank – 9,500 gallons
F-7	Diesel South Service Tank – 10,350 gallons
F-8	Propane Storage Tank – 2,098 gallons
F-9	Unit 3 Transformers - 4,170 gallons
F-10	Natural Gas Pipeline
F-11	Cask Transporter Fuel Tank – 50 gallons
F-12	Site Vegetation
F-13	Fuel Oil Tanker – 6,720 gallons
F-14	Diesel Fuel Tanker – 7,500 gallons
F-15	Propane Tanker – 2,900 gallons
F-16	Gasoline Tanker – 3,000 gallons

Upon completion of this evaluation, all of the postulated hazards that are identified as having a meaningful potential for fire will be evaluated for their explosion effects. Each of these postulated hazards is evaluated, using the methodology presented in Section 2.1, to determine its actual fire potential in the following subsections.

6.1.1 Evaluation of Fire Potential for Hazards F-1 through F-4 and F-13

These storage tanks and tanker truck contain Number 6 fuel oil. An MSDS for this material is included in Appendix C. As stated on the MSDS, this material is a “combustible liquid” and a “moderate fire hazard,” and has NFPA and NMIS fire hazard ratings of 2 (moderate). As the fire rating is positive for fire (Section 3.1, criterion 1), the fuel oil storage and service tanks and the fuel oil tanker truck do present real fire hazards that must be evaluated to determine their effects

6.1.2 Evaluation of Fire Potential for Hazards F-5 through F-7 and F-14

These storage tanks and tanker truck contain diesel fuel. An MSDS for this material is included in Appendix C. As stated on the MSDS, this material is “combustible” and has an NFPA flammability rating of 2 (moderate). As the fire rating is positive for fire (Section 3.1, criterion 1), the diesel fuel tanks and the diesel tanker truck do present real fire hazards that must be evaluated to determine their effects.

6.1.3 Evaluation of Fire Potential for Hazards F-8 and F-15

This storage tank and tanker truck contain liquefied propane gas. An MSDS for this material is included in Appendix C. As stated on the MSDS, vaporized propane is an “extremely flammable gas” and has NFPA and NMIS fire hazard ratings of 4 (extreme). As the fire rating is positive for fire (Section 3.1, criterion 1), the propane tank and propane tanker truck do present real fire hazards that must be evaluated to determine their effects.

6.1.4 Evaluation of Fire Potential for Hazard F-9

These transformers contain the dielectric oil Diala AX. An MSDS for this material is included in Appendix C. As stated on the MSDS, this material will burn if preheated, and has an NFPA fire hazard rating of 1 (slight). Although the MSDS indicates that there is a very low probability of fire, the fire rating is positive for fire (Section 3.1, criterion 1) so the transformers do present a real fire hazard that must be evaluated to determine its effects.

6.1.5 Evaluation of Fire Potential for Hazard F-10

This pipeline transports natural gas. An MSDS for this material is included in Appendix C. As stated on the MSDS, natural gas is a “flammable gas” and has an NFPA flammability rating of 4 (extreme). As the fire rating is positive for fire (Section 3.1, criterion 1), the natural gas pipeline does present a real fire hazard that must be evaluated to determine its effects.

6.1.6 Evaluation of Fire Potential for Hazard F-11

The cask transporter fuel tank contains diesel fuel. Section 6.1.2 evaluates the fire potential for diesel fuel and concludes that it presents a real fire hazard.

6.1.7 Evaluation of Fire Potential for Hazard F-12

This potential fire hazard is a naturally occurring environmental condition (Section 3.1, criterion 3) and presents a real fire hazard that must be evaluated to determine its effects.

6.1.8 Evaluation of Fire Potential for Hazard F-16

This tanker truck contains gasoline. An MSDS for this material is included in Appendix C. As stated on the MSDS, this material is “extremely flammable” and has an NFPA flammability rating of 3 (high). As the fire rating is positive for fire (Section 3.1, criterion 1), the gasoline tanker truck does present a real fire hazard that must be evaluated to determine its effects.

6.2 Evaluation of Fire Effects

As described in Section 6.1, an engineering evaluation was performed to determine which potential fire hazards pose real hazards. Some of the identified real hazards affect only exposed casks, while others affect only the ISFSI and some affect both. The following table identifies whether an individual identified real fire hazards affects exposed casks and/or the ISFSI vault and which are engulfing fires.

Hazard ID	Hazard Description	Affects Exposed Cask	Affects Vault
F-1	Unit 1 Fuel Oil Storage Tank	Y	Y
F-2	Unit 1 Fuel Oil Service Tank	Y	Y
F-3	Unit 2 Fuel Oil Storage Tank	Y	Y
F-4	Unit 2 Fuel Oil Service Tank	Y	Y
F-5	Diesel Fuel Oil Tank	Y	Y
F-6	Diesel North Service Tank	Y	N
F-7	Diesel South Service Tank	Y	N
F-8	Propane Storage Tank	Y	Y
F-9	Unit 3 Transformers	Y	N
F-10	Natural Gas Pipeline	Y	Y
F-11	Cask Transporter Fuel Tank	Y (engulfing)	N
F-12	Site Vegetation	N	Y
F-13	Fuel Oil Tanker	N	Y
F-14	Diesel Fuel Tanker	N	Y
F-15	Propane Tanker	N	Y
F-16	Gasoline Tanker	N	Y

The determination of whether a particular fire hazard affects exposed casks and/or the ISFSI vault and why a particular fire is engulfing or not is discussed in the evaluation scenario descriptions below.

F-1: Unit 1 Fuel Oil Storage Tank Fire

Fire hazard F-1, Unit 1 Fuel Oil Storage Tank Fire, affects both exposed cask and ISFSI vault.

F-2: Unit 1 Fuel Oil Service Tank Fire

Fire hazard F-2, Unit 1 Fuel Oil Storage Tank Fire, affects both exposed cask and ISFSI vault.

F-3: Unit 2 Fuel Oil Storage Tank Fire

Fire hazard F-3, Unit 2 Fuel Oil Storage Tank Fire, affects both exposed cask and ISFSI vault.

F-4: Unit 2 Fuel Oil Service Tank Fire

Fire hazard F-4, Unit 2 Fuel Oil Storage Tank Fire, affects both exposed cask and ISFSI vault.

F-5: Diesel Fuel Oil Tank Fire

Fire hazard F-5, Diesel Oil Storage Tank Fire, affects both exposed cask and ISFSI vault.

F-6: Diesel North Service Tank Fire

Fire hazard F-6, Diesel North Service Tank Fire, only affects the exposed cask and not the ISFSI Vault, since the plant is between the tank and the vault and as a result the heat flux is blocked.

F-7: Diesel South Service Tank Fire

Fire hazard F-7, Diesel South Service Tank Fire, only affects the exposed cask and not ISFSI Vault, since the plant is between the tank and the vault and as a result the heat flux is blocked.

F-8: Propane Storage Tank Fire

Fire hazard F-8, Propane Storage Tank Fire, affects both exposed cask and ISFSI Vault.

F-9: Unit 3 Transformer Fire

Fire hazard F-9, the Unit 3 transformers, affects only exposed casks because the reactor building completely blocks the view from the hazard to the ISFSI [9].

F-10: Natural Gas Pipeline Fire

Fire hazard F-10, the natural gas pipeline, only affects the ISFSI because this line will be depressurized when transporting a cask from the reactor building to the ISFSI [8]. However, 12-inch supply line upstream of the valve station will be considered for both the cask and the vault.

F-11: Cask Transporter Fuel Tank Fire

Fire hazard F-11, the cask transporter fuel tank, affects only exposed casks because the transporter will be equipped with a removable fuel tank to prevent approach of the tank to the ISFSI.

F-12: Site Vegetation Fire

Fire hazard F-12, the site vegetation fire, only affects the ISFSI because it is assumed (Section 4.3) that casks would not be transported to or from the ISFSI during such an event.

F-13: Fuel Oil Tanker Fire

Fire hazards F-13, Fuel Oil Tanker Fire, only affects the ISFSI because such tankers will be prevented from entering the ISFSI access road during cask transfer operations [8].

F-14: Diesel Fuel Tanker Fire

Fire hazards F-14, Diesel Fuel Tanker Fire, only affects the ISFSI because such tankers will be prevented from entering the ISFSI access road during cask transfer operations [8].

F-15: Propane Tanker Fire

Fire hazards F-15, Propane Tanker Fire, only affects the ISFSI because such tankers will be prevented from entering the ISFSI access road during cask transfer operations [8].

F-16: Gasoline Tanker Fire

Fire hazards F-16, Gasoline Tank Fire, only affects the ISFSI because such tankers will be prevented from entering the ISFSI access road during cask transfer operations [8].

6.3 Evaluation of Fire Events

6.3.1 Engulfing Fires

Only a single engulfing fire is identified, F-11. This event is postulated as the release and subsequent combustion of all on-site transporter fuel and hydraulic fluid (see Section 4.2). Using 10CFR71 [3] requirements for the fire event, the duration of this fire event is determined as follows:

Proprietary Information Deleted

The ANSYS input script and the corresponding results file for this evaluation is presented in Appendix B.

6.3.2 Non-Engulfing Fires

These fire effects have been evaluated in Appendix B using the methodology discussed in Section 2.2. Calculations have been performed for the determination of conservatively high temperature rises in the cask and the ISFSI vault covers.

The results of the analysis have been summarized in the following section.

7.0 Results and Conclusions

Results of the evaluations described in Subsections 6.1 and 6.2 are presented in Subsections 7.1 and 7.2, respectively. The overall conclusion that can be drawn from the results of these evaluations is that the postulated fire hazards do not expose the HI-STAR casks to heat inputs beyond those previously evaluated and demonstrated to be safe.

7.1 Evaluation of Fire Potential

As described previously (Section 6.1), this screening evaluation identified all postulated hazards as fire hazards that must be evaluated to determine their effects on the ISFSI vault and/or casks.

7.2 Evaluation of Fire Effects

7.2.1 Engulfing Fires

Only a single engulfing fire was identified, F-11. This event was evaluated, using the methodology described in Section 2.2.1 and Section 6.3.1. The results are presented in the following table.

Cask System Component	Maximum Temperature (°F)	Time After Start of Fire (min)
Fuel Cladding	813.6	374
Fuel Basket Periphery	587.7	374
MPC-HB Enclosure Vessel Inner Surface	259.2	370
MPC-HB Enclosure Vessel Outer Surface	258.9	370
HI-STAR HB Inner Shell Inner Surface	251.1	370
HI-STAR HB Inner Shell Outer Surface / Intermediate Shells Inner Surface	250.5	367
HI-STAR HB Intermediate Shells Outer Surface / Neutron Absorber Inner Surface	249.5	227
HI-STAR HB Neutron Absorber Outer Surface / Enclosure Shell Inner Surface	1189.4	30
HI-STAR HB Enclosure Shell Outer Surface	1208.7	30

All of these calculated temperatures are less than the accident condition temperature limits [11].

Because the on-site transporter must enter the ISFSI to place the loaded casks into the vault, it is not possible to exclude the potential for a ruptured fuel tank to cause a fire inside the vault. This event, however, is likely bounded by the results presented in this section. The heat input to the cask from the engulfing fire comes from both thermal radiation and convection. With respect to thermal radiation, the relatively small clearance between the vault ID and the cask OD precludes flames of sufficient optical thickness to emit substantial amounts of heat by this mechanism.

With respect to convection, the lack of a low-resistance air inlet to the bottom of the vault requires that combustion air be drawn in from above the vault. This constricts the air flow into the vault and the combustion products flow our of the vault, precluding velocities of the magnitude that occur in open pool fires and limiting the heat input from this mechanism.

7.2.2 Non-Engulfing Fires

The following table present the temperature rises of the cask surface due to the fire events discussed before.

Hazard ID	Fire-to-Cask View Factor	Cask Surface Temperature Rise (°F)	Heat Flux to Cask (Btu/hr)
F-1	2.500×10^{-4}	212.1	130.10×10^{3}
F-2	4.800×10^{-4}	109.1	57.49×10^{3}
F-3	4.200×10^{-4}	313.1	220.50×10^{3}
F-4	6.900×10^{-4}	147.1	82.17×10^{3}
F-5	5.100×10^{-4}	56.9	27.59×10^{3}
F-6	17.800×10^{-4}	237.9	151.30×10^{3}
F-7	17.800×10^{-4}	237.9	151.30×10^{3}
F-8	21.600×10^{-4}	43.1	20.47×10^{3}
F-9	103.000×10^{-4}	169.0	97.47×10^{3}
F-10	1.600×10^{-4}	8.6	3.85×10^{3}

The cask surface temperature rises calculated above are extremely conservative. These are bounded by the temperature differences between the normal condition temperature and the design accident conditions for all HI-STAR components except for the neutron shielding (Holtite). This concludes that the neutron shielding may fail locally due to certain postulated fire events (e.g., F-3, F-6 and F-7).

The following table present the temperature rises of the vault covers due to the fire events discussed before.

Hazard ID	Fire-to-Vault Cover View Factor	Vault Cover Temperature Rise (°F)	Heat Flux to Vault Cover (Btu/hr)
F-1	3.289×10^{-5}	58.12	17.19×10^{3}
F-2	6.234×10^{-5}	26.47	7.43×10^{3}
F-3	6.860×10^{-5}	111.43	35.85×10^{3}
F-4	10.270×10^{-5}	42.45	12.24×10^{3}
F-5	4.730×10^{-5}	9.45	2.58×10^{3}

Hazard ID	Fire-to-Vault Cover View Factor	Vault Cover Temperature Rise (°F)	Heat Flux to Vault Cover (Btu/hr)
F-8	0.508×10^{-5}	0.2	48.09
F-10	1.184×10^{-5}	1.0	280.05
F-12	12.940×10^{-4}	96.7	30.590×10^{3}
F-13	8.601×10^{-4}	149.3	50.850×10^{3}
F-14	8.601×10^{-4}	149.3	50.850×10^{3}
F-15	1.037×10^{-5}	2.3	612.91
F-16	8.601×10^{-4}	149.3	50.850×10^{3}

These temperature rise calculations are extremely conservative and still bounded by the temperature rises established in the HI-STAR FSAR [11] between the normal condition and the accident condition limits. This concludes that the ISFSI vault covers are not affected by any postulated fire events. The temperature rise of all cask components when stored within the vault is bounded by the increase in the vault cover temperature, because the fire does not reduce the rate of heat transfer out through the sides and bottom of the vault. Therefore, since the temperature rise of the cover is less than the difference between the normal and accident condition cask temperature limits, it is concluded the acceptance criteria is met.

8.0 References[a]

[1] PG&E Specification HBPP-2001-01.

[2] Code of Federal Regulations, Title 10, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-level Radioactive Waste," Subpart F, Section 122.

[3] Code of Federal Regulations, Title 10, Part 71, "Packaging and Transportation of Radioactive Material," Subpart F, Section 73.

[4] Letter from L. Pulley (PG&E) to E. Lewis (Holtec), dated 11 March 2003.

[5] "QA Documentation for ANSYS," HI-2012627, Rev. 1.

[6] Gregory, Mata and Keltner, "Thermal Measurements in a Series of Large Pool Fires," Sandia Report SAND85-0196, TTC-0659, UC-71, August 1987.

[7] Rohsenow and Hartnett, "Handbook of Heat Transfer," McGraw-Hill, Inc, 1973.

[8] Letter from L. Pulley (PG&E) to E. Lewis (Holtec), dated 23 May 2003.

[9] Effective Thermal Property Evaluations for HBPP Fuel Assemblies and MPC-HB, Holtec Report HI-2033005, Revision 0.

[10] HI-STAR HB Drawing, Holtec Drawing No. 4082, Revision 0.

[11] HI-STAR 100 System FSAR, HI-2012610, Revision 1.

[12] "HBPP Fuel Assembly Decay Heat Calculations," Holtec Report HI-2033023, Rev. 1.

[13] "Functional Specification for the Diablo Canyon Cask Transporter," Holtec Report HI-2002501, Revision 5.

[14] "HI-STAR 100 System Overpack Effective Thermal Property Calculations," Holtec Report HI-971784, Revision 1.

[15] MPC-HB Enclosure Vessel Drawing, Holtec Drawing No. 4102, Revision 0.

[a] The revision status of Holtec documents cited above is subject to updates as the project progresses. This document will be revised if a revision to any of the above-referenced Holtec work products materially affects the instructions, results, conclusions or analyses contained in this document. Otherwise, a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supersede the revision numbers cited above. The Holtec Project Manager bears the undivided responsibility to ensure that there is no inter-document conflict with respect to the information contained in all Holtec generated documents on a safety significant project.

[16] Extracted from Files hb_vault.cas and hb_vault.dat from HI-2033033, Revision 0.

Appendix A – Holtec QA Approved Computer Programs Listing

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 64 October 10, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
ANSYS (A)	5.3, 5.4, 5.6,5.6.2,5.7,7.0	JZ, EBR, PKC, CWB, SPA, AIS, IR, SP, JRT,AK	Windows		**7.0**
AC-XPERT	1.12		Windows		
AIRCOOL	5.2I, 6.1		Windows		
BACKFILL	2.0		DOS/ Windows		
BONAMI (Scale)	4.3, 4.4		Windows		
BULKTEM	3.0		DOS/ Windows		
CASMO-4 (A)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ELR, SPA, DMM, KC, ST,VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects. The user should refer to the error notice documented in c4ser.04-results.pdf located in \generic\library\ nuclear\error notices\ concerning the use of version 1.13.04. Library N should be used with version 2.05.03 for all new reports issued after June 1st, 2003. Revisions to reports issued prior to June 1st, 2003 may continue to use the old Library L.	
CASMO-3 (A)	4.4, 4.7	ELR, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		
CHANBP6 (A)	1.0	SJ, PKC, CWB, AIS, SP,JRT	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		
DÉCOR	1.0		DOS/Windows		
DR.BEAMPRO	1.0.5		Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 64 October 10, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
DR.FRAME	2.0		Windows		
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ, JRT	DOS/Windows	Personnel qualified to use MR216 are automatically qualified to use DYNAMO.	
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.48, 4.56, 5.1 (see error notice), 4.2.8 (UNS),5.5, 6.1.18	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
HXFLOW	1.0		DOS/Windows		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST,VJB	Windows		
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950, 960, 970	JZ, AIS, SPA, SP, JRT	Windows		
MAXDIS16	1.0		DOS/Windows		
MCNP (A)	4A, 4B	ELR, SPA, KC,ST,DMM, VJB, MAP	Windows/ UNIX	CASMO-4 Lumped Fission Products (IDs 401 and 402) and Isotope Pm148M (ID 61248) can be modeled in MCNP 4A using the cross sections documented in HI-2033031. Use of these cross sections is restricted to MCNP 4A, and to material specifications in atom densities.	
MASSINV	1.4, 1.5, 2.1		DOS/Windows		
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PKC, SJ,JRT	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	
MSREFINE	1.3, 2.1		DOS/Windows		

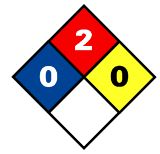
HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 64 October 10, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4,2002, 2003		Windows		
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		
ORIGENS (Scale)	4.3, 4.4		Windows		
PD16	1.1, 1.0, 2.0		Windows		
PREDYNA1	1.5, 1.4		DOS/Windows		
PSD1	1.0		DOS/Windows		
QAD	CGGP		Windows		
SAS2H (Scale)	4.3, 4.4		Windows		
SFMR2A	1.0		DOS/Windows		
SHAPEBUILDER	3.0		DOS/Windows		
SIFATIG	1.0		DOS/Windows		
SOLIDWORKS	2001PLUS		DOS/Windows	This program may be used to calculate Weight, Volume, Centroid and Moment of Inertia. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session.	

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 64 October 10, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
				If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0, 1.4.0		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

NOTES:
1. XXXX = ALPHANUMERIC COMBINATION
2. GENERAL PURPOSES UTILITY CODES (MATHCAD, EXCEL, ETC.) MAY BE USED ANYTIME.

Appendix B - Calculation of Fire Effects - Proprietary Appendix Deleted

Appendix C - MSDS Sheets for Flammable Materials



AMERADA HESS CORPORATION

NFPA 704 (Section 16)

MATERIAL SAFETY DATA SHEET

No. 6 Fuel Oil **MSDS No. 9907**

1. CHEMICAL PRODUCT and COMPANY INFORMATION (rev. Jan-98)

Amerada Hess Corporation
1 Hess Plaza
Woodbridge, NJ 07095-0961

EMERGENCY TELEPHONE NUMBER (24 hrs): CHEMTREC (800) 424-9300
COMPANY CONTACT (business hours): Corporate Safety (732) 750-6000

SYNONYMS: #6 Fuel Oil; 6 Oil; Bunker C; Bunkers; High Sulfur Residual Fuel Oil; Low Sulfur Residual Fuel Oil; Residual Fuel Oil

See Section 16 for abbreviations and acronyms.

2. COMPOSITION and INFORMATION ON INGREDIENTS (rev. Jan-98)

INGREDIENT NAME	EXPOSURE LIMITS	CONCENTRATION PERCENT BY WEIGHT
Fuel Oil, Residual CAS NUMBER: 68476-33-5	OSHA PEL-TWA: 5 mg/m^3 as mineral oil mist ACGIH TLV-TWA: 5 mg/m^3 as mineral oil mist* *1997 NOIC: sum of 15 NTP-listed polynuclear aromatic hydrocarbons 0.005 mg/m^3, A1	100
Hydrogen Sulfide (H_2S) CAS NUMBER: 7783-06-4	OSHA PEL-Ceiling/Peak: 20 / 50 ppm ACGIH TLV-TWA/STEL: 10 / 15 ppm	< trace - see below >

A complex combination of heavy (high boiling point) petroleum hydrocarbons. The amount of sulfur varies with product specification and does not affect the health and safety properties as outlined in this Material Safety Data Sheet.

Hydrogen Sulfide (H_2S) may be present in trace quantities (by weight), but may accumulate to toxic concentrations such as in tank headspace. The presence of H_2S is highly variable, unpredictable and does not correlate with sulfur content. Studies with similar products have shown that 1 ppm H_2S by weight in liquid may produce 100 ppm or more H_2S in the vapor headspace of the storage tank .

3. HAZARDS IDENTIFICATION (rev. Jan-98; Tox-98)

EMERGENCY OVERVIEW
CAUTION!
COMBUSTIBLE LIQUID - SLIGHT TO MODERATE IRRITANT - EFFECTS CENTRAL NERVOUS SYSTEM - HARMFUL OR FATAL IF SWALLOWED

Moderate fire hazard. Avoid breathing vapors or mists. May cause dizziness and drowsiness. May cause moderate eye irritation and skin irritation. Long-term, repeated exposure may cause skin cancer. Hot liquid may cause thermal burns. If ingested, do NOT induce vomiting, as this may cause chemical pneumonia (fluid in the lungs).

HYDROGEN SULFIDE (toxic gas) may accumulate in tank vapor space. High concentration may cause immediate unconsciousness - death may result unless victim is promptly and successfully resuscitated. Hydrogen sulfide causes eye irritation.

EYES

Contact with eyes may cause mild to moderate irritation.

SKIN

May cause skin irritation with prolonged or repeated contact. Practically non-toxic if absorbed following acute (single) exposure. May cause dermal sensitization. Liquid may be hot (typically 110 - 120 ^{o}F) which could cause 1st, 2nd, or 3rd degree thermal burns.

INGESTION

This material has a low order of acute toxicity. If large quantities are ingested, nausea, vomiting and diarrhea may result. Ingestion may also cause effects similar to inhalation of the product. Aspiration may result in chemical pneumonia (fluid in the lungs), severe lung damage, respiratory failure and even death.

INHALATION

Because of its low vapor pressure, this product presents a minimal inhalation hazard at ambient temperature. Upon heating, fumes may be evolved. Inhalation of fumes or mist may result in respiratory tract irritation and central nervous system (brain) effects may include headache, dizziness, loss of balance and coordination, unconsciousness, coma, respiratory failure, and death.

WARNING: the burning of any hydrocarbon as a fuel in an area without adequate ventilation may result in hazardous levels of combustion products, including carbon monoxide, and inadequate oxygen levels, which may cause unconsciousness, suffocation, and death.

WARNING: Irritating and toxic hydrogen sulfide gas may be found in confined vapor spaces. Greater than 15 - 20 ppm continuous exposure can cause mucous membrane and respiratory tract irritation. 50 - 500 ppm can cause headache, nausea, and dizziness, loss of reasoning and balance, difficulty in breathing, fluid in the lungs, and possible loss of consciousness. Greater than 500 ppm can cause rapid or immediate unconsciousness due to respiratory paralysis and death by suffocation unless the victim is removed from exposure and successfully resuscitated.

The "rotten egg" odor of hydrogen sulfide is not a reliable indicator for warning of exposure, since olfactory fatigue (loss of smell) readily occurs, especially at concentrations above 50 ppm. At high concentrations, the victim may not even recognize the odor before becoming unconscious.

CHRONIC and CARCINOGENICITY

Similar products produced skin cancer and systemic toxicity in laboratory animals following repeated applications. The significance of these results to human exposures has not been determined - see Section 11, Toxicological Information.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE

Irritation from skin exposure may aggravate existing open wounds, skin disorders, and dermatitis (rash).

FUEL OIL COMBUSTION ASH

Trace amounts of nickel, vanadium, and other metals in slurry oil can become concentrated in the oxide form in combustion ash deposits. Vanadium is a toxic metal affecting a number of organ systems. Nickel is a suspect human carcinogen (lung, nasal, sinus), an eye, nose, and throat irritant, and can cause allergic skin reaction in some individuals. See Section 7 for appropriate work practices.

4. FIRST AID MEASURES (rev. Jan-98; Tox-98)

EYES

In case of contact with eyes, immediately flush with clean, low-pressure water for at least 15 min. Hold eyelids open to ensure adequate flushing. Seek medical attention.

SKIN

Remove contaminated clothing. Wash contaminated areas thoroughly with soap and water or waterless hand cleanser. Obtain medical attention if irritation or redness develops. Thermal burns require immediate medical attention depending on the severity and the area of the body burned.

INGESTION

DO NOT INDUCE VOMITING. Do not give liquids. Obtain immediate medical attention. If spontaneous vomiting occurs, lean victim forward to reduce the risk of aspiration. Monitor for breathing difficulties. Small amounts of material which enter the mouth should be rinsed out until the taste is dissipated.

INHALATION

Remove person to fresh air. If person is not breathing provide artificial respiration. If necessary, provide additional oxygen once breathing is restored if trained to do so. Seek medical attention immediately.

5. FIRE FIGHTING MEASURES (rev. Oct-96)

FLAMMABLE PROPERTIES:

FLASH POINT:	> 150 ^{o}F (>65.5 ^{o}C) (minimum) ASTM D-93
AUTOIGNITION TEMPERATURE:	> 765 ^{o}F (>407 ^{o}C)
OSHA/NFPA FLAMMABILITY CLASS:	3A (COMBUSTIBLE)
LOWER EXPLOSIVE LIMIT (%):	N/D
UPPER EXPLOSIVE LIMIT (%):	N/D

FIRE AND EXPLOSION HAZARDS

Vapors may be ignited rapidly when exposed to heat, spark, open flame or other source of ignition. When mixed with air and exposed to an ignition source, flammable vapors can burn in the open or explode in confined spaces. Being heavier than air, vapors may travel long distances to an ignition source and flash back. Runoff to sewer may cause fire or explosion hazard.

CAUTION: flammable vapor production at ambient temperature in the open is expected to be minimal unless the oil is heated above its flash point. However, industry experience indicates that light hydrocarbon vapors can build up in the headspace of storage tanks at temperatures below the flash point of the oil, presenting a flammability and explosion hazard. Tank headspaces should be regarded a potentially flammable, since the oil's flash point can not be regarded as a reliable indicator of the potential flammability in tank headspaces.

EXTINGUISHING MEDIA

SMALL FIRES: Any extinguisher suitable for Class B fires, dry chemical, CO2, water spray, fire fighting foam, or Halon.

LARGE FIRES: Water spray, fog or fire fighting foam. Water may be ineffective for fighting the fire, but may be used to cool fire-exposed containers.

FIRE FIGHTING INSTRUCTIONS

Small fires in the incipient (beginning) stage may typically be extinguished using handheld portable fire extinguishers and other fire fighting equipment.

Firefighting activities that may result in potential exposure to high heat, smoke or toxic by-products of combustion should require NIOSH/MSHA- approved pressure-demand self-contained breathing apparatus with full facepiece and full protective clothing.

Isolate area around container involved in fire. Cool tanks, shells, and containers exposed to fire and excessive heat with water. For massive fires the use of unmanned hose holders or monitor nozzles may be advantageous to further minimize personnel exposure. Major fires may require withdrawal, allowing the tank to burn. Large storage tank fires typically require specially trained personnel and equipment to extinguish the fire, often including the need for properly applied fire fighting foam.

See Section 16 for the NFPA 704 Hazard Rating.

6. ACCIDENTAL RELEASE MEASURES (rev. Jan-98)

ACTIVATE FACILITY'S SPILL CONTINGENCY OR EMERGENCY RESPONSE PLAN.

Evacuate nonessential personnel and remove or secure all ignition sources. Consider wind direction; stay upwind and uphill, if possible. Evaluate the direction of product travel, diking, sewers, etc. to confirm spill areas.

Carefully contain and stop the source of the spill, if safe to do so. Protect bodies of water by diking, absorbents, or absorbent boom, if possible. Do not flush down sewer or drainage systems, unless system is designed and permitted to handle such material. The use of fire fighting foam may be useful in certain situations to reduce vapors.

Take up with sand or other oil absorbing materials. Carefully shovel, scoop or sweep up into a waste container for reclamation or disposal. Response and clean-up crews must be properly trained and must utilize proper protective equipment.

7. HANDLING and STORAGE (rev. Jan-98)

HANDLING PRECAUTIONS

Product is generally transported and stored hot (typical 110 - 120 ^oF). Handle as a combustible liquid. Keep away from heat, sparks, and open flame! Electrical equipment should be approved for classified area. Bond and ground containers during product transfer to reduce the possibility of static-initiated fire or explosion.

STORAGE PRECAUTIONS

Keep away from flame, sparks, excessive temperatures and open flame. Use approved vented containers. Keep containers closed and clearly labeled. Empty product containers or vessels may contain explosive vapors. Do not pressurize, cut, heat, weld or expose such containers to sources of ignition.

Store in a well-ventilated area. This storage area should comply with NFPA 30 "Flammable and Combustible Liquid Code". Avoid storage near incompatible materials. The cleaning of tanks previously containing this product should follow API Recommended Practice (RP) 2013 "Cleaning Mobile Tanks In Flammable and Combustible Liquid Service" and API RP 2015 "Cleaning Petroleum Storage Tanks".

Hydrogen sulfide may accumulate in tanks and bulk transport compartments. Consider appropriate respiratory protection (see Section 8). Stand upwind. Avoid vapors when opening hatches and dome covers. Confined spaces should be ventilated prior to entry.

WORK/HYGIENIC PRACTICES

Emergency eye wash capability should be available in the near proximity to operations presenting a potential splash exposure. Use good personal hygiene practices. Avoid repeated and/or prolonged skin exposure. Wash hands before eating, drinking, smoking, or using toilet facilities. Do not use as a cleaning solvent on the skin. Do not use gasoline or solvents (naphtha, kerosene, etc.) for washing this product from exposed skin areas. Waterless hand cleaners are effective. Promptly remove contaminated clothing and launder before reuse. Use care when laundering to prevent the formation of flammable vapors which could ignite via washer or dryer. Consider the need to discard contaminated leather shoes and gloves.

OTHER/GENERAL PROTECTION

Petroleum industry experience indicates that a program providing for good personal hygiene, proper use of personal protective equipment, and minimizing the repeated and prolonged exposure to liquids and fumes, as outlined in this MSDS, is effective in reducing or eliminating the carcinogenic risk of high boiling aromatic oils (polynuclear aromatic hydrocarbons) to humans.

FUEL OIL ASH PRODUCTS

Personnel exposed to ash should wear appropriate protective clothing (example, DuPont Tyvek ®), wash skin thoroughly, launder contaminated clothing separately, and wear respiratory protection approved for use against toxic metal dusts (such as HEPA filter cartridges). Wetted-down combustion ash may evolve toxic hydrogen sulfide (H_2S) - confined spaces should be tested for H_2S prior to entry if ash is wetted.

8. EXPOSURE CONTROLS and PERSONAL PROTECTION (rev. Jan-98)

ENGINEERING CONTROLS

Use adequate ventilation to keep vapor concentrations of this product below occupational exposure and flammability limits, particularly in confined spaces.

EYE/FACE PROTECTION

Safety glasses or goggles are recommended where there is a possibility of splashing or spraying

SKIN PROTECTION

Gloves constructed of nitrile, neoprene, or PVC are recommended. Chemical protective clothing such as of E.I. DuPont Tyvek QC®, Saranex®, TyChem® or equivalent recommended based on degree of exposure. Note: The resistance of specific material may vary from product to product as well as with degree of exposure. Consult manufacturer specifications for further information

RESPIRATORY PROTECTION

If a hydrogen sulfide hazard is present (that is, exposure potential above H_2S permissible exposure limit), use a positive-pressure SCBA or Type C supplied air respirator with escape bottle.

Where it has been determined that there is no hydrogen sulfide exposure hazard (that is, exposure potential below H_2S permissible exposure limit), a NIOSH/ MSHA-approved air-purifying respirator with organic vapor cartridges or canister may be permissible under certain circumstances where airborne concentrations are or may be expected to exceed exposure limits or for odor or irritation. Protection provided by air-purifying respirators is limited. Refer to OSHA 29 CFR 1910.134, ANSI Z88.2-1992, NIOSH Respirator Decision Logic, and the manufacturer for additional guidance on respiratory protection selection.

Use a positive pressure, air-supplied respirator if there is a potential for uncontrolled release, exposure levels are not known, in oxygen-deficient atmospheres, or any other circumstance where an air-purifying respirator may not provide adequate protection.

9. PHYSICAL and CHEMICAL PROPERTIES (rev. Jan-01)

APPEARANCE

Black, viscous liquid

ODOR

Heavy, petroleum/asphalt-type odor

Hydrogen sulfide (H_2S) has a rotten egg "sulfurous" odor. This odor should not be used as a warning property of toxic levels because H_2S can overwhelm and deaden the sense of smell. Also, the odor of H_2S in heavy oils can easily be masked by the petroleum-like odor of the oil. Therefore, the smell of H_2S should not be used as an indicator of a hazardous condition - a H_2S meter or colorimetric indicating tubes are typically used to determine the concentration of H_2S.

BASIC PHYSICAL PROPERTIES

BOILING RANGE:	> 500 ^oF (> 260 ^oC)
VAPOR PRESSURE:	<0.1 psia @ 70 ^oF (21 ^oC)
VAPOR DENSITY (air = 1):	NA
SPECIFIC GRAVITY (H_2O = 1):	0.876 – 1.000 (API 30.0 – 10.0)
PERCENT VOLATILES:	Negligible
EVAPORATION RATE:	negligible
SOLUBILITY (H_2O):	negligible

10. STABILITY and REACTIVITY (rev. Jan-94)

STABILITY: Stable. Hazardous polymerization will not occur.

CONDITIONS TO AVOID and INCOMPATIBLE MATERIALS

Avoid high temperatures, open flames, sparks, welding, smoking and other ignition sources. Keep away from strong oxidizers.

HAZARDOUS DECOMPOSITION PRODUCTS:

Carbon monoxide, carbon dioxide and non-combusted hydrocarbons (smoke).

11. TOXICOLOGICAL PROPERTIES (rev. Jan-98)

ACUTE TOXICITY

Acute dermal LD50 (rabbits): > 5 ml/kg
Primary dermal irritation: slightly irritating (rabbits)
Guinea pig sensitization: mildly sensitizing
Acute oral LD50 (rats): 5.1 ml/kg
Draize eye irritation: mildly irritating (rabbits)

CHRONIC EFFECTS AND CARCINOGENICITY

Carcinogenicity: **OSHA:** NO **IARC:** 2B (animal) **NTP:** YES **ACGIH:** 1997 NOIC: A1

This material contains polynuclear aromatic hydrocarbons (PNAs), some of which are animal carcinogens. Studies have shown that similar products produce skin tumors in laboratory animals following repeated applications without washing or removal. The significance of this finding to human exposure has not been determined. Other studies with active skin carcinogens have shown that washing the animal's skin with soap and water between applications reduced tumor formation.

The presence of carcinogenic PNAs indicates that precautions should be taken to minimize repeated and prolonged inhalation of fumes or mists.

MUTAGENICITY (genetic effects)

Materials of similar composition have been positive in mutagenicity studies.

12. ECOLOGICAL INFORMATION (rev. Jan-98)

Keep out of sewers, drainage and waterways. Report spills and releases, as applicable, under Federal and State regulations.

13. DISPOSAL CONSIDERATIONS (rev. Jan-98)

Consult federal, state and local waste regulations to determine appropriate disposal options. Combustion ash may be a characteristic hazardous waste.

14. TRANSPORTATION INFORMATION (rev. Jan-98)

PROPER SHIPPING NAME:	Combustible liquid, n.o.s. (No. 6 Fuel Oil)
HAZARD CLASS and PACKING GROUP:	Combustible Liquid , PG III
DOT IDENTIFICATION NUMBER:	NA 1993
DOT SHIPPING LABEL:	None

15. REGULATORY INFORMATION (rev. Feb-01)

U.S. FEDERAL, STATE and LOCAL REGULATORY INFORMATION

This product and its constituents listed herein are on the EPA TSCA Inventory. Any spill or uncontrolled release of this product, including any substantial threat of release, may be subject to federal, state and/or local reporting requirements. This product and/or its constituents may also be subject to other regulations at the state and/or local level. Consult those regulations applicable to your facility/operation.

CLEAN WATER ACT (OIL SPILLS)

Any spill or release of this product to "navigable waters" (essentially any surface water, including certain wetlands) or adjoining shorelines sufficient to cause a visible sheen or deposit of a sludge or emulsion must be reported immediately to the National Response Center (1-800-424-8802) or, if not practical, the U.S. Coast Guard with follow-up to the National Response Center, as required by U.S. Federal Law. Also contact appropriate state and local regulatory agencies as required.

CERCLA SECTION 103 and SARA SECTION 304 (RELEASE TO THE ENVIRONMENT)

The CERCLA definition of hazardous substances contains a “petroleum exclusion” clause which exempts crude oil, refined, and unrefined petroleum products and any indigenous components of such. However, other federal reporting requirements (e.g., SARA Section 304 as well as the Clean Water Act if the spill occurs on navigable waters) may still apply.

SARA SECTION 311/312 - HAZARD CLASSES

ACUTE HEALTH	CHRONIC HEALTH	FIRE	SUDDEN RELEASE OF PRESSURE	REACTIVE
X	X	X	--	--

SARA SECTION 313 - SUPPLIER NOTIFICATION

This product may contain listed chemicals below the *de minimis* levels which therefore are not subject to the supplier notification requirements of Section 313 of the Emergency Planning and Community Right-To-Know Act (EPCRA) of 1986 and of 40 CFR 372. If you may be required to report releases of chemicals listed in 40 CFR 372.28, you may contact Amerada Hess Corporate Safety if you require additional information regarding this product.

CANADIAN REGULATORY INFORMATION (WHMIS)

Class B, Division 3 (Combustible Liquid)

16. OTHER INFORMATION (rev. Feb-01)

NFPA® HAZARD RATING	HEALTH:	0	Negligible
	FIRE:	2	Moderate
	REACTIVITY:	0	Negligible
HMIS® HAZARD RATING	HEALTH:	1*	Slight
	FIRE:	2	Moderate
	REACTIVITY:	0	Negligible
			*Chronic

SPECIAL HAZARDS: Container vapor space may contain hydrogen sulfide (poison gas).

SUPERSEDES MSDS DATED: 01/05/01

ABBREVIATIONS:

AP = Approximately	< = Less than	> = Greater than
N/A = Not Applicable	N/D = Not Determined	ppm = parts per million

ACRONYMS:

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute (212)642-4900
API	American Petroleum Institute (202)682-8000
CERCLA	Comprehensive Emergency Response, Compensation, and Liability Act
DOT	U.S. Department of Transportation [General info: (800)467-4922]
EPA	U.S. Environmental Protection Agency
HMIS	Hazardous Materials Information System
IARC	International Agency For Research On Cancer
MSHA	Mine Safety and Health Administration
NFPA	National Fire Protection Association (617)770-3000
NIOSH	National Institute of Occupational Safety and Health
NOIC	Notice of Intended Change (proposed change to ACGIH TLV)
NTP	National Toxicology Program
OPA	Oil Pollution Act of 1990
OSHA	U.S. Occupational Safety & Health Administration
PEL	Permissible Exposure Limit (OSHA)
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit (NIOSH)
SARA	Superfund Amendments and Reauthorization Act of 1986 Title III
SCBA	Self-Contained Breathing Apparatus
SPCC	Spill Prevention, Control, and Countermeasures
STEL	Short-Term Exposure Limit (generally 15 minutes)
TLV	Threshold Limit Value (ACGIH)
TSCA	Toxic Substances Control Act
TWA	Time Weighted Average (8 hr.)

WEEL	Workplace Environmental Exposure Level (AIHA)	WHMIS	Canadian Workplace Hazardous Materials Information System

DISCLAIMER OF EXPRESSED AND IMPLIED WARRANTIES

Information presented herein has been compiled from sources considered to be dependable, and is accurate and reliable to the best of our knowledge and belief, but is not guaranteed to be so. Since conditions of use are beyond our control, we make no warranties, expressed or implied, except those that may be contained in our written contract of sale or acknowledgment.

Vendor assumes no responsibility for injury to vendee or third persons proximately caused by the material if reasonable safety procedures are not adhered to as stipulated in the data sheet. Additionally, vendor assumes no responsibility for injury to vendee or third persons proximately caused by abnormal use of the material, even if reasonable safety procedures are followed. Furthermore, vendee assumes the risk in their use of the material.

170019-31 DIESEL FUEL (MRDUS)
MATERIAL SAFETY DATA BULLETIN

---

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: DIESEL FUEL (MRDUS)
SUPPLIER: MOBIL OIL CORP.
NORTH AMERICA MARKETING AND REFINING
3225 GALLOWS RD.
FAIRFAX, VA 22037

24 - Hour Emergency (call collect):	609-737-4411	
Product and MSDS Information:	800-662-4525	609-224-4644
CHEMTREC:	800-424-9300	202-483-7616

2. COMPOSITION/INFORMATION ON INGREDIENTS

CHEMICAL NAMES AND SYNONYMS: HYDROCARBONS AND ADDITIVES
INGREDIENTS CONSIDERED HAZARDOUS TO HEALTH:

Substance Name	Wt%
DIESEL FUEL (68334-30-5)	100

See Section 15 for European Label Information.
See Section 8 for exposure limits (if applicable).

3. HAZARDS IDENTIFICATION

US OSHA HAZARD COMMUNICATION STANDARD: Product assessed in accordance with OSHA 29 CFR 1910.1200 and determined to be hazardous.
EFFECTS OF OVEREXPOSURE: Respiratory irritation, dizziness, nausea, loss of consciousness. Prolonged, repeated skin contact may result in skin irritation or more serious skin disorders. Low viscosity material-if swallowed may enter the lungs and cause lung damage.
Note: This product contains polycyclic aromatic hydrocarbons, some of which have been reported to cause skin cancer in humans under conditions of poor personal hygiene, prolonged repeated contact, and exposure to sunlight. Toxic effects are unlikely to occur if good personal hygiene is practiced.
EMERGENCY RESPONSE DATA: Clear (May Be Dyed) Liquid. Material is combustible. DOT ERG No. -128

4. FIRST AID MEASURES

EYE CONTACT: Flush thoroughly with water. If irritation occurs, call a physician.
SKIN CONTACT: Remove contaminated clothing. Dry wipe exposed skin and cleanse yourself with waterless hand cleaner and follow by washing thoroughly with soap and water. For those providing assistance, avoid further contact to yourself or others. Wear impervious gloves. Launder contaminated clothing separately before reuse. Discard contaminated articles that cannot be laundered.

INHALATION: Remove from further exposure. If respiratory irritation, dizziness, nausea, or unconsciousness occurs, seek immediate medical assistance. If breathing has stopped, assist ventilation with bag-valve-mask device or use mouth-to-mouth resuscitation.
INGESTION: Seek immediate medical attention. Do not induce vomiting.
NOTE TO PHYSICIANS: Material if aspirated into the lungs may cause chemical pneumonitis. Treat appropriately.

---

5. FIRE-FIGHTING MEASURES

EXTINGUISHING MEDIA: Carbon dioxide, foam, dry chemical and water fog.
SPECIAL FIRE FIGHTING PROCEDURES: Use water to keep fire exposed containers cool. If a leak or spill has not ignited, use water spray to disperse the vapors and to protect personnel attempting to stop leak. Water spray may be used to flush spills away from exposures. Prevent runoff from fire control or dilution from entering streams, sewers, or drinking water supply.
SPECIAL PROTECTIVE EQUIPMENT: For fires in enclosed areas, fire fighters must use self-contained breathing apparatus.
UNUSUAL FIRE AND EXPLOSION HAZARDS: Material is combustible. Flash Point C(F): > 52(125) (ASTM D-93). Flammable limits - LEL: 0.6%, UEL: 7.0%.
NFPA HAZARD ID: Health: 1, Flammability: 2, Reactivity: 0
HAZARDOUS DECOMPOSITION PRODUCTS: Carbon monoxide.

---

6. ACCIDENTAL RELEASE MEASURES

NOTIFICATION PROCEDURES: Report spills as required to appropriate authorities. U. S. Coast Guard regulations require immediate reporting of spills that could reach any waterway including intermittent dry creeks. Report spill to Coast Guard toll free number (800) 424-8802. In case of accident or road spill notify CHEMTREC (800) 424-9300.
PROCEDURES IF MATERIAL IS RELEASED OR SPILLED: Adsorb on fire retardant treated sawdust, diatomaceous earth, etc. Shovel up and dispose of at an appropriate waste disposal facility in accordance with current applicable laws and regulations, and product characteristics at time of disposal.
ENVIRONMENTAL PRECAUTIONS: Prevent spills from entering storm sewers or drains and contact with soil.
PERSONAL PRECAUTIONS: See Section 8

---

7. HANDLING AND STORAGE

HANDLING: Harmful in contact with or if absorbed through the skin. Avoid inhalation of vapors or mists. PORTABLE CONTAINERS approved for storing fuel must be placed on the ground and the nozzle must stay in contact with the container when filling to prevent build up and discharge of static electricity.
STORAGE: Store in a cool area. A flammable atmosphere can be produced in storage tank headspaces even when stored at a temperature below the flashpoint. Monitor and maintain headspace gas concentrations below flammable limits. Ensure that there are no ignition sources in the area immediately surrounding filling and venting operations. Avoid sparking conditions. Ground and bond all transfer equipment. Store in a cool area.

---

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

VENTILATION: Use in well ventilated area. Ventilation desirable and equipment should be explosion proof.
RESPIRATORY PROTECTION: No special requirements under ordinary conditions of use and with adequate ventilation.
EYE PROTECTION: If splash with liquid is possible, chemical type goggles should be worn.
SKIN PROTECTION: Impervious gloves must be worn. If contact is likely oil impervious clothing must be worn.
EXPOSURE LIMITS: This product does not contain any components which have recognized exposure limits.

---

9. PHYSICAL AND CHEMICAL PROPERTIES

Typical physical properties are given below. Consult Product Data Sheet for specific details.
APPEARANCE: Liquid
COLOR: Clear (May Be Dyed)
ODOR: Hydrocarbon
ODOR THRESHOLD-ppm: NE
pH: NA
BOILING POINT C(F): > 149(300)
MELTING POINT C(F): NA
FLASH POINT C(F): > 52(125) (ASTM D-93)
FLAMMABILITY: NE
AUTO FLAMMABILITY: NE
EXPLOSIVE PROPERTIES: NA
OXIDIZING PROPERTIES: NA
VAPOR PRESSURE-mmHg 20 C: 0.5
VAPOR DENSITY: > 2.0
EVAPORATION RATE: NE
RELATIVE DENSITY, 15/4 C: 0.82-0.87
SOLUBILITY IN WATER: Negligible
PARTITION COEFFICIENT: NE
VISCOSITY AT 40 C, cSt: > 1.0
VISCOSITY AT 100 C, cSt: NE
POUR POINT C(F): < -7(20)
FREEZING POINT C(F): NE
VOLATILE ORGANIC COMPOUND: NE
NA=NOT APPLICABLE NE=NOT ESTABLISHED D=DECOMPOSES
FOR FURTHER TECHNICAL INFORMATION, CONTACT YOUR MARKETING REPRESENTATIVE

---

10. STABILITY AND REACTIVITY

STABILITY (THERMAL, LIGHT, ETC.): Stable.
CONDITIONS TO AVOID: Heat, sparks, flame and build up of static electricity.
INCOMPATIBILITY (MATERIALS TO AVOID): Halogens, strong acids, alkalies, and oxidizers.
HAZARDOUS DECOMPOSITION PRODUCTS: Carbon monoxide.
HAZARDOUS POLYMERIZATION: Will not occur.

---

11. TOXICOLOGICAL DATA

---ACUTE TOXICOLOGY---

ORAL TOXICITY (RATS): Practically non-toxic (LD50: greater than 2000 mg/kg). ---Based on testing of similar products and/or the components.
DERMAL TOXICITY (RABBITS): Practically non-toxic (LD50: greater than 2000 mg/kg). ---Based on testing of similar products and/or the components.
INHALATION TOXICITY (RATS): Practically non-toxic (LC50: greater than 5 mg/l). ---Based on testing of similar products and/or the components.
EYE IRRITATION (RABBITS): Practically non-irritating. (Draize score: greater than 6 but 15 or less). ---Based on testing of similar products and/or the components.
SKIN IRRITATION (RABBITS): Practically non-irritating. (Primary Irritation Index: greater than 0.5 but less than 3). ---Based on testing of similar products and/or the components.

---SUBCHRONIC TOXICOLOGY (SUMMARY)---

Repeated dermal application to rats for 13 weeks was carried out with aromatic oils similar to some of the components of this product. Resulting effects included increased mortality and decreased body and thymus weights. Severe skin irritation was also observed at the site of application.

---REPRODUCTIVE TOXICOLOGY (SUMMARY)---

Repeated dermal application to pregnant rats was carried out using aromatic oils similar to some of the components used in this product. Results included maternal toxicity, decreased fetal body weights and decreased fetal survival in some cases. No fetal malformations were observed.

---CHRONIC TOXICOLOGY (SUMMARY)---

Expected to be carcinogenic in lifetime mouse skin painting bioassays.

---OTHER TOXICOLOGY DATA---

Skin cleansing studies with aromatic oils show that toxic effects are not likely to occur in humans if good personal hygiene practices are used. Overexposure to diesel exhaust fumes may result in eye irritation, headaches, nausea, and respiratory irritation. Animal studies involving lifetime exposure to high levels of diesel exhaust have produced variable results, with some studies indicating a potential for lung cancer. Limited evidence from epidemiological studies suggest an association between long-term occupational exposure to diesel engine emissions and lung cancer. Diesel engine exhaust typically consists of gases and particulates, including carbon dioxide, carbon monoxide, nitrogen compounds, oxides of sulfur, and hydrocarbons. Diesel exhaust composition will vary with fuel, engine type, load cycle, engine maintenance, tuning and exhaust gas treatment. Use of adequate ventilation and/or respiratory protection in the presence of diesel exhaust is recommended to minimize exposures.

---

12. ECOLOGICAL INFORMATION

ENVIRONMENTAL FATE AND EFFECTS: Not established.

---

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL: Product is suitable for burning for fuel value i compliance with applicable laws and regulations.
RCRA INFORMATION: Disposal of unused product may be subject to RCRA regulations (40 CFR 261) due to the characteristic(s)/chemical(s) listed below. Disposal of the used product may also be regulated due to ignitability, corrosivity, reactivity, or toxicity as

determined by the Toxicity Characteristic Leaching Procedure
(TCLP).
FLASH: > 52(125) C(F)

----

14. TRANSPORT INFORMATION

NOTE:The flash point of this material is > 125F. Regulatory classifications vary as follows:

DOT:	Flammable Liquid OR Combustible Liquid - (49CFR 173.120(b)(2))
OSHA:	Combustible Liquid
IATA/IMO:	Flammable Liquid

USA DOT:

SHIPPING NAME:	Diesel Fuel
HAZARD CLASS & DIV:	COMBUSTIBLE LIQUID
ID NUMBER:	NA1993
ERG NUMBER:	128
PACKING GROUP:	PG III
STCC:	NE
DANGEROUS WHEN WET:	No
POISON:	No
LABEL(s):	NA
PLACARD(s):	Combustible
PRODUCT RQ:	NA
MARPOL III STATUS:	NA

In accordance with 49 CFR 173.150(f)(2), non-bulk quantities of this material (<119 gallons per container) may be shipped as non regulated for USA domestic shipments.

RID/ADR:

HAZARD CLASS:	3
HAZARD SUB-CLASS:	31(c)
LABEL:	3
DANGER NUMBER:	30
UN NUMBER:	1202
SHIPPING NAME:	Gas Oil
REMARKS:	NA

IMO:

HAZARD CLASS & DIV:	3.3
UN NUMBER:	1202
PACKING GROUP:	PG III
SHIPPING NAME:	Gas Oil
LABEL(s):	Flammable Liquid
MARPOL III STATUS:	NA

ICAO/IATA:

HAZARD CLASS & DIV:	3
ID/UN Number:	1202
PACKING GROUP:	PG III
SHIPPING NAME:	Gas Oil
SUBSIDIARY RISK:	NA
LABEL(s):	Flammable Liquid

----

15. REGULATORY INFORMATION

Governmental Inventory Status: All components comply with TSCA, and EINECS/ELINCS.
EU Labeling:
Symbol: Xn Harmful.
Risk Phrase(s): R10-40-65.
Flammable. Possible risks of irreversible effects. Harmful: may cause lung damage if swallowed.
Safety Phrase(s): S24-2-36/37-61-62.

Avoid contact with skin. Keep out of the reach of children. Wea suitable protective clothing and gloves. Avoid release to the environment. Refer to special instructions/Safety data sheets. If swallowed, do not induce vomiting: seek medical advice immediately and show this container or label.
Contains: Gas oil - unspecified.
U.S. Superfund Amendments and Reauthorization Act (SARA) Title III:
This product contains no "EXTREMELY HAZARDOUS SUBSTANCES".
SARA (311/312) REPORTABLE HAZARD CATEGORIES:
FIRE CHRONIC ACUTE
This product contains no chemicals reportable under SARA (313) toxic release program.
The following product ingredients are cited on the lists below:

CHEMICAL NAME	CAS NUMBER	LIST CITATIONS
DIESEL OIL..C9-20	68334-30-5	21, 26

--- REGULATORY LISTS SEARCHED ---

1=ACGIH ALL	6=IARC 1	11=TSCA 4	16=CA P65 CARC	21=LA RTK
2=ACGIH A1	7=IARC 2A	12=TSCA 5a2	17=CA P65 REPRO	22=MI 293
3=ACGIH A2	8=IARC 2B	13=TSCA 5e	18=CA RTK	23=MN RTK
4=NTP CARC	9=OSHA CARC	14=TSCA 6	19=FL RTK	24=NJ RTK
5=NTP SUS	10=OSHA Z	15=TSCA 12b	20=IL RTK	25=PA RTK
				26=RI RTK

Code key: CARC=Carcinogen; SUS=Suspected Carcinogen; REPRO=Reproductive

---

16. OTHER INFORMATION

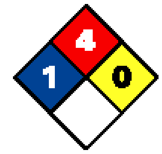
Precautionary Label Text:
CONTAINS DIESEL OIL.. C9-20
WARNING!
COMBUSTIBLE LIQUID AND VAPOR. MAY CAUSE NOSE, THROAT AND LUNG IRRITATION, DIZZINESS, NAUSEA, LOSS OF CONSCIOUSNESS. LOW VISCOSITY MATERIAL-IF SWALLOWED, MAY BE ASPIRATED AND CAN CAUSE SERIOUS OR FATAL LUNG DAMAGE.
MAY CAUSE SKIN CANCER ON PROLONGED, REPEATED SKIN CONTACT. ANIMAL SKIN ABSORPTION STUDIES RESULTED IN INCREASED MORTALITY, EFFECTS ON BOD WEIGHT, THE IMMUNE SYSTEM AND THE UNBORN CHILD. PROLONGED, REPEATED SKI CONTACT MAY CAUSE IRRITATION. DIESEL EXHAUST IS SUSPECT OF CAUSING LUNG CANCER.
Keep away from heat and flame. Avoid prolonged or repeated overexposure by skin contact or inhalation. Use with adequate ventilation. Keep container closed. Keep out of reach of children. Approved portable containers must be properly grounded when transferring fuel.
FIRST AID: If inhaled, remove from further exposure. If respiratory irritation, dizziness, nausea, or unconsciousness occurs, seek immediate medical assistance. If breathing has stopped, assist ventilation with a bag-valve-mask device or use mouth-to-mouth resuscitation. In case of contact, remove contaminated clothing. Dry wipe the exposed skin and cleanse with waterless hand cleaner and follow by washing thoroughly with soap and water. For those providing assistance, avoid further skin contact to yourself and others. Wear impervious gloves. If swallowed, seek immediate medical attention. Do not induce vomiting. Only induce vomiting at the instruction of a physician.
Empty container may contain product residue, including flammable or explosive vapors. Do not cut, puncture, or weld on or near container. All label warnings and precautions must be observed until container ha been thoroughly cleaned or destroyed.
Chemicals known to the State of California to cause cancer, birth defects, or other reproductive harm are created by the combustion of this product. Refer to product Material Safety Data Bulletin for further safety and health information.

USE: DIESEL FUEL
NOTE: MOBIL PRODUCTS ARE NOT FORMULATED TO CONTAIN PCBS.

INGREDIENT DESCRIPTION	PERCENT	CAS NUMBER
DIESEL OIL..C9-20	100	68334-30-5

For Internal Use Only: MHC: 1* 1* 1* 1* 1*, MPPEC: C, TRN: 170019-31, REQ: US - MARKETING, SAFE USE: C
EHS Approval Date: 30JUN1998

Legally required information is given in accordance with applicable Information given herein is offered in good faith as accurate, but without guarantee. Conditions of use and suitability of the product for particular uses are beyond our control; all risks of use of the product are therefore assumed by the user and WE EXPRESSLY DISCLAIM ALL WARRANTIES OF EVERY KIND AND NATURE, INCLUDING WARRANTIES O MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE IN RESPECT TO THE USE OR SUITABILITY OF THE PRODUCT. Nothing is intended as a recommendation for uses which infringe valid patents or as extending any license under valid patents. Appropiate warnings and safe handling procedures should be providedto handlers and users. Use or re-transmission of the information contained herein in any other format than the format as presented is strictly prohibited. Mobil neither represents nor warrants that the format, content or product formulas contained in this document comply with the laws of any other country except the United States of America.



NFPA 704 (Section 16)

AMERADA HESS CORPORATION

MATERIAL SAFETY DATA SHEET

Propane **MSDS No. 6182**

1. CHEMICAL PRODUCT and COMPANY INFORMATION (rev. Mar-98)

Amerada Hess Corporation
1 Hess Plaza
Woodbridge, NJ 07095-0961

EMERGENCY TELEPHONE NUMBER (24 hrs): CHEMTREC (800)424-9300
COMPANY CONTACT (business hours): Corporate Safety (732)750-6000

SYNONYMS: Dimethylmethane; Liquefied Petroleum Gas (LPG); Sales Propane
See Section 16 for abbreviations and acronyms.

2. COMPOSITION and INFORMATION ON INGREDIENTS (rev. Mar-00)

INGREDIENT NAME	EXPOSURE LIMITS		CONCENTRATION PERCENT BY VOLUME
Propane CAS NUMBER: 74-98-6	OSHA PEL-TWA: ACGIH TLV-TWA:	1000 ppm NOIC: 2500 ppm	70 min.
Propylene CAS NUMBER: 115-07-1	None established by OSHA or ACGIH Simple asphyxiant		30 max.
Ethane CAS NUMBER: 74-84-0	None established by OSHA or ACGIH Simple asphyxiant		< 2
Mixed hydrocarbons [butane (C4) and higher]	N/A - Limits above will predominate		< 2.5

Light gases from distilled and catalytically-cracked petroleum oil consisting of hydrocarbons having carbon numbers in the range of C3 through C4, predominantly propane and propylene. This MSDS describes Propane, C_3H_8; other constituents exhibit similar hazards - significant differences are noted as appropriate. Odorized with trace amounts of odorant (typically well below 0.1% ethyl mercaptan).

3. HAZARDS IDENTIFICATION (rev. Mar-98; Tox-98)

EMERGENCY OVERVIEW
DANGER!
EXTREMELY FLAMMABLE GAS - MAY CAUSE FLASH FIRE OR EXPLOSION! - COMPRESSED GAS

High concentrations may exclude oxygen and cause dizziness and suffocation . Contact with liquid or cold vapor may cause frostbite or freeze burn .

EYES

Vapors are not irritating. However, contact with liquid or cold vapor may cause frostbite, freeze burns, and permanent eye damage

SKIN

Vapors are not irritating. Direct contact to skin or mucous membranes with liquefied product or cold vapor may cause freeze burns and frostbite. Ingestion is unlikely. Contact to mucous membranes with liquefied product may cause frostbite and freeze burns. Signs of frostbite include a change in the color of the skin to gray or white, possibly followed by blistering. Skin may become inflamed and painful.

INGESTION

Ingestion is unlikely. Contact with mucous membranes with liquefied product may cause frostbite and freeze burns.

INHALATION

This product is considered to be non-toxic by inhalation. Inhalation of high concentrations may cause central nervous system depression such as dizziness, drowsiness, headache, and similar narcotic symptoms, but no long-term effects. Numbness, a "chilly" feeling, and vomiting have been reported from accidental exposures to high concentrations.

This product is a simple asphyxiant. In high concentrations it will displace oxygen from the breathing atmosphere, particularly in confined spaces. Signs of asphyxiation will be noticed when oxygen is reduced to below 16%, and may occur in several stages. Symptoms may include rapid breathing and pulse rate, headache, dizziness, visual disturbances, mental confusion, incoordination, mood changes, muscular weakness, tremors, cyanosis, narcosis and numbness of the extremities. Unconsciousness leading to central nervous system injury and possibly death will occur when the atmospheric oxygen concentration is reduced to about 6% to 8% or less.

WARNING: The burning of any hydrocarbon as a fuel in an area without adequate ventilation may result in hazardous levels of combustion products, including carbon monoxide, and inadequate oxygen levels, which may cause unconsciousness, suffocation, and death.

CHRONIC and CARCINOGENICITY

None expected - see Section 11.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE

Individuals with pre-existing conditions of the heart, lungs, and blood may have increased susceptibility to symptoms of asphxia.

4. FIRST AID MEASURES (rev. Mar-98; Tox-98)

EYES

In case of liquid contact with the eyes, open eyelids wide to allow liquid to evaporate. Cover eyes to protect from light. Seek immediate medical attention.

SKIN

In case of blistering, frostbite or freeze burns seek immediate medical attention.

INGESTION

Risk of ingestion is extremely low. However, in cases of ingestion or oral exposure, seek immediate medical attention.

INHALATION

Remove person to fresh air. If person is not breathing, ensure an open airway and administer CPR. If necessary, provide additional oxygen once breathing is restored if trained to do so. Seek medical attention immediately.

5. FIRE FIGHTING MEASURES (rev. Nov-95)

FLAMMABLE PROPERTIES:

FLASH POINT:	-156 ^{o}F (-104 ^{o}C)
AUTOIGNITION POINT:	842 ^{o}F (450 ^{o}C)
OSHA/NFPA FLAMMABILITY CLASS:	FLAMMABLE GAS
LOWER EXPLOSIVE LIMIT (%):	2.1
UPPER EXPLOSIVE LIMIT (%):	9.5

FIRE AND EXPLOSION HAZARDS

Liquid releases flammable vapors at well below ambient temperatures and readily forms a flammable mixture with air. Dangerous fire and explosion hazard when exposed to heat, sparks or flame. Vapors are heavier than air and may travel long distances to a point of ignition and flash back. Container may explode in heat or fire. Runoff to sewer may cause fire or explosion hazard.

EXTINGUISHING MEDIA

Dry chemical, carbon dioxide, Halon or water. However, fire should not be extinguished unless flow of gas can be immediately stopped.

FIRE FIGHTING INSTRUCTIONS

Gas fires should not be extinguished unless flow of gas can be immediately stopped. Shut off gas source and allow gas to burn out. If spill or leak has not ignited, determine if water spray may assist in dispersing gas or vapor to protect personnel attempting to stop leak.

Use water to cool equipment, surfaces and containers exposed to fire and excessive heat. For large fire the use of unmanned hose holders or monitor nozzles may be advantageous to further minimize personnel exposure.

Isolate area, particularly around ends of storage vessels. Let vessel, tank car or container burn unless leak can be stopped. Withdraw immediately in the event of a rising sound from a venting safety device. Large fires typically require specially trained personnel and equipment to isolate and extinguish the fire.

Firefighting activities that may result in potential exposure to high heat, smoke or toxic by-products of combustion should require NIOSH/MSHA- approved pressure-demand self-contained breathing apparatus with full facepiece and full protective clothing.

See Section 16 for the NFPA Hazard Rating.

6. ACCIDENTAL RELEASE MEASURES (rev. Mar-98)

ACTIVATE FACILITY'S SPILL CONTINGENCY or EMERGENCY RESPONSE PLAN

Evacuate nonessential personnel and secure all ignition sources. No road flares, smoking or flames in hazard area. Consider wind direction, stay upwind and uphill, if possible. Evaluate the direction of product travel. Vapor cloud may be white, but color will dissipate as cloud disperses - fire and explosion hazard is still present!

Stop the source of the release, if safe to do so. Do not flush down sewer or drainage systems. Do not touch spilled liquid (frostbite/freeze burn hazard!). Consider the use of water spray to disperse vapors. Isolate the area until gas has dispersed. Ventilate and gas test area before entering.

7. HANDLING and STORAGE (rev. Mar-98)

HANDLING and STORAGE PRECAUTIONS

Keep away from flame, sparks and excessive temperatures. Store only in approved containers. Bond and ground containers. Use only in well ventilated areas. See also applicable OSHA regulations for the handling and storage of this product, including, but not limited to, 29 CFR 1910.110 Storage and Handling of Liquefied Petroleum Gases.

8. EXPOSURE CONTROLS and PERSONAL PROTECTION (rev. Nov-95)

ENGINEERING CONTROLS

Use adequate ventilation to keep gas and vapor concentrations of this product below occupational exposure and flammability limits, particularly in confined spaces. Use explosion-proof equipment and lighting in classified/controlled areas.

EYE/FACE PROTECTION

Where there is a possibility of liquid contact, wear splash-proof safety goggles and faceshield.

SKIN PROTECTION

Where contact with liquid may occur, wear apron, faceshield, and cold-impervious, insulating gloves.

RESPIRATORY PROTECTION

Use a NIOSH/MSHA approved positive-pressure, supplied air respirator with escape bottle or self-contained breathing apparatus (SCBA) for gas concentrations above occupational exposure limits, for potential for uncontrolled release, if exposure levels are not known, or in an oxygen-deficient atmosphere.

CAUTION: Flammability limits (i.e., explosion hazard) should be considered when assessing the need to expose personnel to concentrations requiring respiratory protection.

Refer to OSHA 29 CFR 1910.134, ANSI Z88.2-1992, NIOSH Respirator Decision Logic, and the manufacturer for additional guidance on respiratory protection selection.

9. PHYSICAL and CHEMICAL PROPERTIES (rev. Apr-96)

APPEARANCE

Colorless gas. Cold vapor cloud may be white but the lack of visible gas cloud does not indicate absence of gas. A colorless liquid under pressure.

ODOR

Odorless when pure, but may have a “natural gas” type odor when treated with odorizing agent (usually ethyl mercaptan).

BASIC PHYSICAL PROPERTIES

BOILING POINT:	-43.8 ^{o}F (-42.1 ^{o}C)
VAPOR PRESSURE:	109.73 psig @ 70 ^{o}F (21.1 ^{o}C)
VAPOR DENSITY (air = 1):	1.56 @ 32 ^{o}F (0 ^{o}C)
SPECIFIC GRAVITY (H_2O = 1):	0.531 @ 32 ^{o}F (0 ^{o}C)
SOLUBILITY (H_2O):	slight (62.4 ppm) @ 77 ^{o}F (25 ^{o}C)

10. STABILITY and REACTIVITY (rev. Nov-95)

STABILITY: Stable. Hazardous polymerization will not occur.

CONDITIONS TO AVOID and INCOMPATIBLE MATERIALS

Keep away from strong oxidizers, ignition sources and heat. Explosion hazard when exposed to chlorine dioxide. Heating barium peroxide with propane causes violent exothermic reaction. Heated chlorine-propane mixtures are explosive under some conditions.

HAZARDOUS DECOMPOSITION PRODUCTS

Carbon monoxide, carbon dioxide and non-combusted hydrocarbons (smoke).

11. TOXICOLOGICAL PROPERTIES (rev. Mar-98; Tox-98)

ACUTE TOXICITY

Propane exhibits some degree of anesthetic action and is mildly irritating to the mucous membranes. At high concentrations propane acts as a simple asphyxiant without other significant physiological effects. High concentrations may cause death due to oxygen depletion.

CARCINOGENICITY

Carcinogenicity: **OSHA:** NO **IARC:** NO **NTP:** NO **ACGIH:** NO

12. ECOLOGICAL INFORMATION (rev. Nov-95)

Liquid release is only expected to cause localized, non-persistent environmental damage, such as freezing. Biodegradation of this product may occur in soil and water. Volatilization is expected to be the most important removal process in soil and water. This product is expected to exist entirely in the vapor phase in ambient air.

13. DISPOSAL CONSIDERATIONS (rev. Apr-96)

Consult federal, state and local waste regulations to determine appropriate waste characterization of material and allowable disposal methods.

14. TRANSPORTATION INFORMATION (rev. Apr-96)

PROPER SHIPPING NAME:	Propane
HAZARD CLASS:	2.1
DOT IDENTIFICATION NUMBER:	UN 1978
DOT SHIPPING LABEL:	FLAMMABLE GAS

PROPER SHIPPING NAME:	Petroleum Gas, Liquefied
HAZARD CLASS:	2.1
DOT IDENTIFICATION NUMBER:	UN 1075
DOT SHIPPING LABEL:	FLAMMABLE GAS

15. REGULATORY INFORMATION (rev. Mar-00)

U.S. FEDERAL, STATE, and LOCAL REGULATORY INFORMATION

This product and its constituents listed herein are on the EPA TSCA Inventory.

Any spill or uncontrolled release of this product, including any substantial threat of release, may be subject to federal, state, and/or local reporting requirements. Consult those regulations applicable to your facility/operation. This product and/or its constituents may also be subject to other regulations at the state and/or local level. Consult those regulations applicable to your facility/operation.

CERCLA SECTION 103 and SARA SECTION 304 (RELEASE TO THE ENVIRONMENT)

The CERCLA definition of hazardous substances contains a "petroleum exclusion" clause which exempts natural gas and synthetic gas usable for fuel and any indigenous components of such from the CERCLA Section 103 reporting requirements. However, other federal reporting requirements, including SARA Section 304, may still apply.

SARA SECTION 311/312 - HAZARD CLASSES

ACUTE HEALTH	CHRONIC HEALTH	FIRE	SUDDEN RELEASE OF PRESSURE	REACTIVE
--	--	X	X	--

SARA SECTION 313 - SUPPLIER NOTIFICATION

This product contains the following chemicals subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right-To-Know Act (EPCRA) of 1986 and of 40 CFR 372.

INGREDIENT NAME		CONCENTRATION PERCENT BY VOLUME
Propylene	CAS NUMBER: 115-07-1	30 max.

CANADIAN REGULATORY INFORMATION (WHMIS)

Class A (Compressed Gas) Class B, Division 1 (Flammable Gas)

16. OTHER INFORMATION (rev. Mar-00)

NFPA® HAZARD RATING	HEALTH:	1	Slight
	FIRE:	4	Extreme
	REACTIVITY:	0	Negligible
HMIS® HAZARD RATING	HEALTH:	1	Slight
	FIRE:	4	Extreme
	REACTIVITY:	0	Negligible

SUPERSEDES MSDS DATED: 02/25/99

ABBREVIATIONS:

AP = Approximately	< = Less than	> = Greater than
N/A = Not Applicable	N/D = Not Determined	ppm = parts per million

ACRONYMS:

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute (212)642-4900
API	American Petroleum Institute (202)682-8000
CERCLA	Comprehensive Emergency Response, Compensation, and Liability Act
DOT	U.S. Department of Transportation [General info: (800)467-4922]
EPA	U.S. Environmental Protection Agency
HMIS	Hazardous Materials Information System
IARC	International Agency For Research On Cancer
MSHA	Mine Safety and Health Administration
NFPA	National Fire Protection Association (617)770-3000
NIOSH	National Institute of Occupational Safety and Health
NOIC	ACGIH TLV Notice of Intended Change
NTP	National Toxicology Program
OPA	Oil Pollution Act of 1990
OSHA	U.S. Occupational Safety & Health Administration
PEL	Permissible Exposure Limit (OSHA)
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit (NIOSH)
SARA	Superfund Amendments and Reauthorization Act of 1986 Title III
SCBA	Self-Contained Breathing Apparatus
SPCC	Spill Prevention, Control, and Countermeasures
STEL	Short-Term Exposure Limit (generally 15 minutes)
TLV	Threshold Limit Value (ACGIH)
TSCA	Toxic Substances Control Act
TWA	Time Weighted Average (8 hr.)
WEEL	Workplace Environmental Exposure Level (AIHA)
WHMIS	Canadian Workplace Hazardous Materials Information System

DISCLAIMER OF EXPRESSED AND IMPLIED WARRANTIES

Information presented herein has been compiled from sources considered to be dependable, and is accurate and reliable to the best of our knowledge and belief, but is not guaranteed to be so. Since conditions of use are beyond our control, we make no warranties, expressed or implied, except those that may be contained in our written contract of sale or acknowledgment.

Vendor assumes no responsibility for injury to vendee or third persons proximately caused by the material if reasonable safety procedures are not adhered to as stipulated in the data sheet. Additionally, vendor assumes no responsibility for injury to vendee or third persons proximately caused by abnormal use of the material, even if reasonable safety procedures are followed. Furthermore, vendee assumes the risk in their use of the material.

Print Close

Shell Lubricants in the USA

MATERIAL SAFETY DATA SHEET

MSDS Number: 60030E - 13

24 Hour Emergency Assistance: CHEMTEL (877) 276-7283
General Assistance Number: (877) 276-7285

SECTION 1 PRODUCT IDENTIFICATION

MATERIAL IDENTITY: DIALA® Oil AX

PRODUCT CODES: 68702, 69702
COMPANY ADDRESS: Equilon Enterprises LLC, P. O. Box 4453, Houston, TX. 77210-4453

SECTION 2 PRODUCT/INGREDIENTS

CAS#	CONCENTRATION	INGREDIENTS
Mixture	100 %volume	Dielectric Oil
64742-53-6	100 %volume	Hydrotreated light naphthenic distillate

---

SECTION 3 HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
Appearance & Odor: Bright and Clear Liquid. Oil Type Odor.
Health Hazards: May be harmful or fatal if swallowed. Do not induce vomiting. May cause aspiration pneumonitis.
Physical Hazards: No known physical hazards.
NFPA Rating (Health, Fire, Reactivity): 0, 1, 0
Hazard Rating:Least - 0 Slight - 1 Moderate - 2 High - 3 Extreme - 4

Inhalation:
Inhalation of vapors (generated at high temperatures only) or oil mist may cause mild irritation of the nose, throat, and respiratory tract.

Eye Irritation:
Lubricating oils are generally considered no more than minimally irritating to the eyes.

Skin Contact:
Lubricating oils are generally considered no more than minimally irritating to the skin. Prolonged and repeated contact may result in defatting and drying of the skin that may cause various skin disorders such as dermatitis, folliculitis or oil acne.

Ingestion:

This material may be harmful or fatal if swallowed. Ingestion may result in vomiting; aspiration (breathing) of vomitus into lungs must be avoided as even small quantities may result in aspiration pneumonitis.

Signs and Symptoms:
Irritation as noted above. Aspiration pneumonitis may be evidenced by coughing, labored breathing and cyanosis (bluish skin); in severe cases death may occur.

Aggravated Medical Conditions:
Pre-existing eye, skin and respiratory disorders may be aggravated by exposure to this product.

For additional health information, refer to section 11.

SECTION 4 FIRST AID MEASURES

Inhalation:
Remove victim to fresh air and provide oxygen if breathing is difficult. Get medical attention.

Skin:
Remove contaminated clothing and shoes and wipe excess from skin. Flush skin with water, then wash with soap and water. If irritation occurs, get medical attention. Do not reuse clothing until cleaned.

Eye:
Flush with water. If irritation occurs, get medical attention.

Ingestion:
Do NOT induce vomiting. If vomiting occurs spontaneously, keep head below hips to prevent aspiration of liquid into lungs. Get medical attention.

SECTION 5 FIRE FIGHTING MEASURES

Flash Point [Method]: 295 ^{o}F/146.11 ^{o}C [Cleveland Open Cup]

Extinguishing Media:
Material will float and can be re-ignited on surface of water. Use water fog, 'alcohol foam', dry chemical or carbon dioxide (CO_2) to extinguish flames. Do not use a direct stream of water.

Fire Fighting Instructions:
Material will not burn unless preheated. Clear fire area of all non-emergency personnel. Only enter confined fire space with full gear, including a positive pressure, NIOSH-approved, self-contained breathing apparatus. Cool surrounding equipment, fire-exposed containers and structures with water. Container areas exposed to direct flame contact should be cooled with large quantities of water (500 gallons water per minute flame impingement exposure) to prevent weakening of container structure.

SECTION 6 ACCIDENTAL RELEASE MEASURES

Protective Measures:
May burn although not readily ignitable.

Wear appropriate personal protective equipment when cleaning up spills. Refer to Section 8.

Spill Management:
FOR LARGE SPILLS: Remove with vacuum truck or pump to storage/salvage vessels.

FOR SMALL SPILLS: Soak up residue with an absorbent such as clay, sand or other suitable material. Place in non-leaking container and seal tightly for proper disposal.

Reporting:
CERCLA: Product is covered by EPA's Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) petroleum exclusion. Releases to air, land, or water are not reportable under CERCLA (Superfund).

CWA: This product is an oil as defined under Section 311 of EPA's Clean Water Act (CWA). Spills into or leading to surface waters that cause a sheen must be reported to the National Response Center, 1-800-424-8802.

SECTION 7 HANDLING AND STORAGE

Precautionary Measures:
Wash with soap and water before eating, drinking, smoking, applying cosmetics, or using toilet. Launder contaminated clothing before reuse. Properly dispose of contaminated leather articles such as shoes or belts that cannot be decontaminated. Avoid heat, open flames, including pilot lights, and strong oxidizing agents. Use explosion-proof ventilation to prevent vapor accumulation. Ground all handling equipment to prevent sparking.

Storage:
Store in a cool, dry place with adequate ventilation. Keep away from open flames and high temperatures.

Container Warnings:
Keep containers closed when not in use. Containers, even those that have been emptied, can contain explosive vapors. Do not cut, drill, grind, weld or perform similar operations on or near containers.

SECTION 8 EXPOSURE CONTROLS/PERSONAL PROTECTION

Oil mist, mineral	ACGIH TLV	TWA: 5 mg/m3	STEL: 10 mg/m3
Oil mist, mineral	OSHA PEL	TWA: 5 mg/m3	

EXPOSURE CONTROLS
Adequate ventilation to control airborne concentrations below the exposure

guidelines/limits.

PERSONAL PROTECTION
Personal protective equipment (PPE) selections vary based on potential exposure conditions such as handling practices, concentration and ventilation. Information on the selection of eye, skin and respiratory protection for use with this material is provided below.

Eye Protection:
Chemical Goggles, or Safety glasses with side shields

Skin Protection:
Use protective clothing which is chemically resistant to this material. Selection of protective clothing depends on potential exposure conditions and may include gloves, boots, suits and other items. The selection(s) should take into account such factors as job task, type of exposure and durability requirements.

Published literature, test data and/or glove and clothing manufacturers indicate the best protection is provided by:
Neoprene, or Nitrile Rubber

Respiratory Protection:
If engineering controls do not maintain airborne concentrations to a level which is adequate to protect worker health, an approved respirator must be worn. Respirator selection, use and maintenance should be in accordance with the requirements of the OSHA Respiratory Protection Standard, 29 CFR 1910.134.

Types of respirator(s) to be considered in the selection process include:
For Mist: Air Purifying, R or P style NIOSH approved respirator. For Vapors: Air Purifying, R or P style prefilter & organic cartridge, NIOSH approved respirator. Self-contained breathing apparatus.

SECTION 9 PHYSICAL AND CHEMICAL PROPERTIES

Appearance & Odor: Bright and Clear Liquid. Oil Type Odor.
Substance Chemical Family: Petroleum Hydrocarbon
Boiling Point: > 400 °F

Dielectric Strength: 20 KV - 30 KV

Evaporation Rate: N/A

Flash Point: 295 °F [Cleveland Open Cup]

Pour Point: -40 °F

Solubility (in Water): Negligible

Specific Gravity: 0.8833

Viscosity: 10 cSt - 20 cSt @ 40 °C

SECTION 10 REACTIVITY AND STABILITY

Stability:
Material is stable under normal conditions.

Conditions to Avoid:
Avoid heat and open flames.

Materials to Avoid:
Avoid contact with strong oxidizing agents.

Hazardous Decomposition Products:
Thermal decomposition products are highly dependent on combustion conditions. A complex mixture of airborne solids, liquids and gases will evolve when this material undergoes pyrolysis or combustion. Carbon Monoxide, Carbon Dioxide and other unidentified organic compounds may be formed upon combustion.

SECTION 11 TOXICOLOGICAL INFORMATION

Acute Toxicity
- Dermal LD50 >2 g/kg(Rabbit) OSHA: Non-Toxic Based on components(s)
- Inhalation LC50 2.18 mg/l(Rat) OSHA: Non-Toxic Based on components(s)
- Oral LD50 >5 g/kg(Rat) OSHA: Non-Toxic Based on components(s)

Carcinogenicity Classification
Dielectric Oil
NTP: No IARC: Not Reviewed by IARC ACGIH: No OSHA: No

SECTION 12 ECOLOGICAL INFORMATION

Environmental Impact Summary:
There is no ecological data available for this product. However, this product is an oil. It is persistent and does not readily biodegrade. However, it does not bioaccumulate.

SECTION 13 DISPOSAL CONSIDERATIONS

RCRA Information:
Under RCRA, it is the responsibility of the user of the material to determine, at the time of the disposal, whether the material meets RCRA criteria for hazardous waste. This is because material uses, transformations, mixtures, processes, etc. may affect the classification. Refer to the latest EPA, state and local regulations regarding proper disposal.

SECTION 14 TRANSPORT INFORMATION

US Department of Transportation Classification
This material is not subject to DOT regulations under 49 CFR Parts 171-180.

Oil: This product is an oil under 49CFR (DOT) Part 130. If shipped by rail or highway in a tank with a capacity of 3500 gallons or more, it is subject to these requirements. Mixtures or solutions containing 10% or more of this product may also be subject to this rule.

International Air Transport Association
Not regulated under IATA rules.

International Maritime Organization Classification
Not regulated under International Maritime Organization rules.

SECTION 15 REGULATORY INFORMATION

FEDERAL REGULATORY STATUS

OSHA Classification:
Product is hazardous according to the OSHA Hazard Communication Standard, 29 CFR 19.10.1200, because it carries the occupational exposure limit for mineral oil mist.

Ozone Depleting Substances (40 CFR 82 Clean Air Act):
This material does not contain nor was it directly manufactured with any Class I or Class II ozone depleting substances.

Superfund Amendment & Reauthorization Act (SARA) Title III:

There are no components in this product on the SARA 302 list.

SARA Hazard Categories (311/312):
Immediate Health:NO Delayed Health:NO Fire:NO Pressure:NO Reactivity:NO

SARA Toxic Release Inventory (TRI) (313):
There are no components in this product on the SARA 313 list.

Toxic Substances Control Act (TSCA) Status:
All component(s) of this material is(are) listed on the EPA/TSCA Inventory of Chemical Substances.

Other Chemical Inventories:
Component(s) of this material is (are) listed on the Australian AICS, Canadian DSL, Chinese Inventory, European EINECS, Korean Inventory, Philippines PICCS

State Regulation
This material is not regulated by California Prop 65, New Jersey Right-to-Know Chemical List or Pennsylvania Right-To-Know Chemical List. However for details on your regulation requirements you should contact the appropriate agency in your state.

California Safe Drinking Water and Toxic Enforcement Act (Proposition 65).

WARNING: This product contains a chemical(s) known to the State of California to cause cancer.

SECTION 16 OTHER INFORMATION

HMIS Rating (Health, Fire, Reactivity): 0, 1, 0

Revision#: 13
Revision Date: 04/01/2002
Revisions since last change (discussion): This Material Safety Data Sheet (MSDS) has been newly reviewed to fully comply with the guidance contained in the ANSI MSDS standard (ANSI Z400.1-1998). We encourage you to take the opportunity to read the MSDS and review the information contained therein.

SECTION 17 LABEL INFORMATION

READ AND UNDERSTAND MATERIAL SAFETY DATA SHEET BEFORE HANDLING OR DISPOSING OF PRODUCT. THIS LABEL COMPLIES WITH THE REQUIREMENTS OF THE OSHA HAZARD COMMUNICATION STANDARD (29 CFR 1910.1200) FOR USE IN THE WORKPLACE. THIS LABEL IS NOT INTENDED TO BE USED WITH PACKAGING INTENDED FOR SALE TO CONSUMERS AND MAY NOT CONFORM WITH THE REQUIREMENTS OF THE CONSUMER PRODUCT SAFETY ACT OR OTHER RELATED REGULATORY REQUIREMENTS.

PRODUCT CODES: 68702, 69702

DIALA® Oil AX

CAUTION!

ASPIRATION HAZARD IF SWALLOWED - CAN ENTER LUNGS AND CAUSE DAMAGE. PROLONGED OR REPEATED SKIN CONTACT MAY CAUSE OIL ACNE OR DERMATITIS.

Precautionary Measures:
Avoid prolonged or repeated contact with eyes, skin and clothing. Do not take internally. Wash thoroughly after handling.

FIRST AID

Inhalation: Remove victim to fresh air and provide oxygen if breathing is difficult. Get medical attention.
Skin Contact: Remove contaminated clothing and shoes and wipe excess from skin. Flush skin with water, then wash with soap and water. If irritation occurs, get medical attention. Do not reuse clothing until cleaned.
Eye Contact: Flush with water. If irritation occurs, get medical attention.
Ingestion: Do NOT induce vomiting. If vomiting occurs spontaneously, keep head below hips to prevent aspiration of liquid into lungs. Get medical attention.

FIRE

In case of fire, Material will float and can be re-ignited on surface of water.

SPILL OR LEAK
Dike and contain spill.
FOR LARGE SPILLS: Remove with vacuum truck or pump to storage/salvage vessels.

FOR SMALL SPILLS: Soak up residue with an absorbent such as clay, sand or other suitable material. Place in non-leaking container and seal tightly for proper disposal.

CONTAINS: Hydrotreated light naphthenic distillate, 64742-53-6

NFPA Rating (Health, Fire, Reactivity): 0, 1, 0
HMIS Rating (Health, Fire, Reactivity): 0, 1, 0

TRANSPORTATION
US Department of Transportation Classification
This material is not subject to DOT regulations under 49 CFR Parts 171-180.

Oil: This product is an oil under 49CFR (DOT) Part 130. If shipped by rail or highway in a tank with a capacity of 3500 gallons or more, it is subject to these requirements. Mixtures or solutions containing 10% or more of this product may also be subject to this rule.

CAUTION: Misuse of empty containers can be hazardous. Empty containers can be hazardous if used to store toxic, flammable, or reactive materials. Cutting or welding of empty containers might cause fire, explosion or toxic fumes from residues. Do not pressurize or expose to open flames or heat. Keep container closed and drum bungs in place.

Name and Address
Equilon Enterprises LLC
P. O. Box 4453
Houston, TX 77210-4453

TRANSPORTATION EMERGENCY CHEMTEL (877) 276-7283

HEALTH EMERGENCY CHEMTEL (877) 276-7283

ADMINISTRATIVE INFORMATION
COMPANY ADDRESS: Equilon Enterprises LLC, P. O. Box 4453, Houston, TX. 77210-4453
Company Product Stewardship & Regulatory Compliance Contact: Timothy W Childs
Phone Number: (281) 874-7708
MSDS FAX-BACK Phone Number: (877) 276-7285

THE INFORMATION CONTAINED IN THIS DATA SHEET IS BASED ON THE DATA AVAILABLE TO US AT THIS TIME, AND IS BELIEVED TO BE ACCURATE BASED UPON THAT DATA. IT IS PROVIDED INDEPENDENTLY OF ANY SALE OF THE PRODUCT, FOR PURPOSE OF HAZARD COMMUNICATION. IT IS NOT INTENDED TO CONSTITUTE PRODUCT PERFORMANCE INFORMATION, AND NO EXPRESS OR IMPLIED WARRANTY OF ANY KIND IS MADE WITH RESPECT TO THE PRODUCT, UNDERLYING DATA OR THE INFORMATION CONTAINED HEREIN. YOU ARE URGED TO OBTAIN DATA SHEETS FOR ALL PRODUCTS YOU BUY, PROCESS, USE OR DISTRIBUTE, AND ARE ENCOURAGED TO ADVISE THOSE WHO MAY COME IN CONTACT WITH SUCH PRODUCTS OF THE INFORMATION CONTAINED HEREIN.

TO DETERMINE THE APPLICABILITY OR EFFECT OF ANY LAW OR REGULATION WITH RESPECT TO THE PRODUCT, YOU SHOULD CONSULT WITH YOUR LEGAL ADVISOR OR THE APPROPRIATE GOVERNMENT AGENCY. WE WILL NOT PROVIDE ADVICE ON SUCH MATTERS, OR BE RESPONSIBLE FOR ANY INJURY FROM THE USE OF THE PRODUCT DESCRIBED HEREIN. THE UNDERLYING DATA, AND THE INFORMATION PROVIDED HEREIN AS A RESULT OF THAT DATA, IS THE PROPERTY OF EQUIVA SERVICES LLC AND IS NOT TO BE THE SUBJECT OF SALE OR

EXCHANGE WITHOUT THE EXPRESS WRITTEN CONSENT OF EQUIVA SERVICES LLC.

BCG #526

BC GAS - Material Safety Data Sheet (MSDS)

PRODUCT NAME(S) : Natural Gas (Pipeline Quality)
PREPARATION DATE : January 31, 2002

SECTION 1 PRODUCT INFORMATION

Manufacturer

WESTCOAST ENERGY INC
1333 West Georgia Street
Vancouver, BC
V6E 3K9

EMERGENCY #: (604) 691-5566

Supplier

BC GAS INC.
16705 Fraser Highway
Surrey, BC
V3S 2X7

EMERGENCY #: 1-800-663-9911

Material Use	:	Fuel
TDG Shipping Name	:	N/A
TDG Class	:	2.1
Chemical Family	:	Simple Hydro Carbon
Chemical Formula	:	CH_4 (Methane)
Molecular Weight	:	16.04 (Methane)
CAS Number	:	74-82-8
Trade Names and Synonyms	:	Marsh Gas , Methane
Hazard Ratings		
Health	:	
Flammability	:	4
Reactivity	:	
Personal Protection	:	
UN/PIN Number 1971	:	
WHMIS Class	:	A B1

SECTION II HAZARDOUS INGREDIENTS

Hazardous Ingredients	Approx. Conc %	CAS Number	Exposure Limits	LD50 / LC50 Species and Route
Methane	95%	74-82-8	Simple Asphyxiant	N/A
Ethane	3%	74-84-0	Simple Asphyxiant	N/A
Propane	1%	74-98-6	Simple Asphyxiant	N/A
Inert Gas	<1%	N/AV	N/AV	N/AV
Sulphur Compounds	Trace	N/AV	N/AV	N/AV
Mercaptan Odourant	3 ppm	Mixture	0.5 ppm TWA	N/AV

SECTION III PHYSICAL DATA

Physical State	:	Gas
Odour/Appearance	:	Gassy odour, colourless
Specific Gravity (Water = 1)	:	N/A
Odour Threshold (ppm)	:	2500
Vapour Pressure (mm Hg)	:	N/A
Vapour Density (Air =1)	:	0.59
Evaporation Rate	:	N/A (Gas at room temperature)
Boiling Point (C)	:	-160 deg C
Freezing Point (C)	:	N/A
Solubility in Water (20 C)	:	Slight
% Volatile (by volume)	:	N/AV
pH	:	N/AV
Density (g/ml)	:	N/AV
Coefficient of Water/Oil Distribution	:	N/AV

SECTION IV FIRE AND EXPLOSION DATA

Flammable	:	YES Can be ignited by flame or spark
Means of Extinction	:	Dry Chemical, carbon dioxide, water spray, fog,
Special Procedures	:	Shut off flow of gas from a safe location. Use full protective equipment and SCBA. DO not extinguish flame until gas flow is shut off. Use gas detectors in confined spaces. Evaporate area if cooling of containers is not possible.
Hazardous Combust Products	:	Carbon Monoxide, Carbon Dioxide
Flash Pt. (C) & Method	:	Flammable Gas
Upper Explosion Limit (% by Volume)	:	15%
Lower Explosion Limit (% by Volume)	:	5 %
Auto Ignition Temp	:	537 C
Sensitivity to Static Discharge	:	Flammable
Sensitivity to Mechanical Impact	:	None
Explosive Power	:	N/AV
Rate of Burning	:	N/AV
TDG Flammability Class	:	2.1

SECTION V REACTIVITY DATA

Chemical Stability	:	Yes
Incompatibility with other Substances	:	No
Reactivity and under what conditions	:	Strong Oxidizing agents increase risk of fire (peroxides, perchlorates, chlorine, liquid oxygen)
Hazardous Decomposition Products	:	COx, luminous clean flame on combustion.

SECTION VI REACTIVITY DATA

Route of Entry

Skin Contact	[ ]	Skin Absorption	[ ]
Eye Contact	[ ]	Inhalation Acute	[X]
Inhalation Chronic	[ ]	Ingestion	[ ]

Effects of Acute Exposure to Product : Non Toxic. At high concentrations, natural gas can displace oxygen and cause asphyxiation.

Effects of Chronic Exposure to Product: None reported

LD50	: N/A	LC50	: N/A
Exposure Limits	: N/AV	Synergistic Effects	: N/AV

Carcinogen	[ ]	Reproductive Effects	[ ]	Teratogen	[ ]
Mutagen	[ ]	Irritant	[ ]	Sensitizer	[ ]

SECTION VII PREVENTIVE MEASURES

Personal Protective Equipment

Gloves : No specific Requirement
Respiratory : If engineering controls and work practices are not effective in controlling exposure to natural gas, then wear suitable respiratory protection. Supplied air or SCBA
Eye : No specific requirement
Footwear : No specific requirement
Clothing : No specific requirement
Other : none
Engineering Controls: All installations must conform to code requirements
Leak and Spill Procedure : Evacuate area. Call emergency services and gas supplier
Waste Disposal : Vent to outside atmosphere
Handling Procedures and Equipment : Observe handling regulations for compressed gases and flammable materials.
Storage Requirements: No smoking or open flames in storage area. Comply with storage regulations for compressed gases and flammable materials
Special Shipping Information : Handle as extremely flammable gas. Electronically ground/bond during transfer to avoid static accumulation. Precaution should be taken to minimize inhalation of natural gas.

SECTION VIII FIRST AID MEASURES

Skin : N/AV
Eye : N/AV
Inhalation : Ensure your own safety before attempting to rescue. Move victim to fresh air. If breathing has stopped administer oxygen. If heart beat can not be detected begin CPR. If person is overcome or been adversely affected by the emergency, obtain medical attention immediately.

Ingestion   : N/AV
General Advice : N/AV

SECTION IX   PREPARATION OF M.S.D.S.

Prepared by	Phone Number	Preparation Date
Safety and Occupational Health Services	1-800-66309911	02/01/31

Sources   : CCINFO
Additional Information and Comments

While BC Gas believes that the data contained herein is accurate and derived from qualified sources, BC Gas does not in any way warrant or represent the accuracy of the data and assumes no responsibility to determine safe conditions and any use of the data be determined by you to be in accordance with applicable laws and regs.

N/AV not available
N/A   not applicable

15024-34 AUTOMOTIVE GASOLINE, UNLEADED (NAM&R)
MATERIAL SAFETY DATA BULLETIN

---

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: AUTOMOTIVE GASOLINE, UNLEADED (NAM&R)
SUPPLIER: MOBIL OIL CORP.
NORTH AMERICA MARKETING AND REFINING
3225 GALLOWS RD.
FAIRFAX, VA 22037

24 - Hour Emergency (call collect):	609-737-4411	
Product and MSDS Information:	800-662-4525	856-224-4644
CHEMTREC:	800-424-9300	202-483-7616

2. COMPOSITION/INFORMATION ON INGREDIENTS

CHEMICAL NAMES AND SYNONYMS: HYDROCARBONS AND ADDITIVES
INGREDIENTS CONSIDERED HAZARDOUS TO HEALTH:

Substance Name	Wt%
GASOLINE (8006-61-9)	100
COMPONENT(S) OF PRODUCT INGREDIENTS INCLUDE:	
METHYL T-BUTYL ETHER (1634-04-4)	15
ETHANOL (64-17-5)	11
XYLENE (1330-20-7)	10
ISOPENTANE (78-78-4)	9
TOLUENE (108-88-3)	5
PSEUDOCUMENE (95-63-6)	5
BUTANE (106-97-8)	4
2-METHYLPENTANE (107-83-5)	4
PENTANE (109-66-0)	4
TRIMETHYL BENZENE (25551-13-7)	3
3-METHYLPENTANE (96-14-0)	2
BENZENE (71-43-2)	2
2,3-DIMETHYLBUTANE (79-29-8)	2
N-HEXANE (110-54-3)	2
ETHYL BENZENE (100-41-4)	2
3- METHYLHEXANE (589-34-4)	2
2- METHYLHEXANE (591-76-4)	1
METHYLCYCLOHEXANE (108-87-2)	1

NOTE: THIS MSDB ALSO COVERS REFORMULATED AND CARB PHASE 2 GASOLINE. The concentration of the components shown above may vary substantially. Because of volatility considerations, gasoline vapor may have concentrations of components very different from those of liquid gasoline. The major components of gasoline vapor are: butane, isobutane, pentane and isopentane. Federal RFG (reformulated) and Carb Phase 2 gasoline will contain oxygenates such as MTBE or ethanol at a concentration to provide a minimum oxygen content of 1.5 Wt%. The reportable component percentages, shown in the Regulatory Information section, are based on API's evaluation of a typical gasoline mixture.
See Section 15 for European Label Information.
See Section 8 for exposure limits (if applicable).

---

3. HAZARDS IDENTIFICATION

US OSHA HAZARD COMMUNICATION STANDARD: Product assessed in accordance with OSHA 29 CFR 1910.1200 and determined to be hazardous.
EFFECTS OF OVEREXPOSURE: Eye irritation, respiratory irritation, dizziness, nausea, loss of consciousness. Skin irritation. Studies (sponsored by API) conducted in the U.S. examining the mortality experience (causes of death) of distribution workers with long-term exposure to gasoline have not found any gasoline-related health effects. Case reports of chronic gasoline abuse (such as gasoline sniffing) and chronic misuse of gasoline as a solvent or as a cleaning agent have reported a range of neurological effects (nervous system effects), sudden deaths from cardiac arrest (heart attacks), hematologic changes (blood effects) and leukemia. These effects are not expected to occur at exposure levels encountered in the distribution and use of gasoline as a motor fuel. Low viscosity material-if swallowed may enter the lungs and cause lung damage.
EMERGENCY RESPONSE DATA: Clear (May Be Dyed) Liquid. Extremely flammable. Vapor accumulation could flash and/or explode if in contact with open flame. DOT ERG No. -128

---

4. FIRST AID MEASURES

EYE CONTACT: Flush thoroughly with water. If irritation occurs, call a physician.
SKIN CONTACT: Wash contact areas with soap and water. Remove contaminated clothing. Launder contaminated clothing before reuse.
INHALATION: Remove from further exposure. If respiratory irritation, dizziness, nausea, or unconsciousness occurs, seek immediate medical assistance. If breathing has stopped, assist ventilation with bag-valve-mask device or use mouth-to-mouth resuscitation.
INGESTION: Seek immediate medical attention. Do not induce vomiting.
NOTE TO PHYSICIANS: Material if ingested may be aspirated into the lungs and can cause chemical pneumonitis. Treat appropriately.

---

5. FIRE-FIGHTING MEASURES

EXTINGUISHING MEDIA: Carbon Dioxide, Foam, Dry Chemical, Water Fog.
SPECIAL FIRE FIGHTING PROCEDURES: Evacuate area. For large spills, fire fighting foam is the preferred agent and should be applied in sufficient quantities to blanket the gasoline surface. Water spray may be used to flush spill away from exposures, but good judgement should be practiced to prevent spreading of the gasoline into sewers, streams or drinking water supplies. If a leak or spill has not ignited, apply a foam blanket to suppress the release of vapors. If foam is not available, a water spray curtain can be used to disperse vapors and to protect personnel attempting to stop the leak.
SPECIAL PROTECTIVE EQUIPMENT: For fires in enclosed areas, fire fighters must use self-contained breathing apparatus.
UNUSUAL FIRE AND EXPLOSION HAZARDS: Extremely flammable. Vapor accumulation could flash and/or explode if in contact with open flame. Flash Point C(F): < -40(-40) (ASTM D-56). Flammable limits - LEL: 1.4%, UEL: 7.6%.
NFPA HAZARD ID: Health: 1, Flammability: 3, Reactivity: 0
HAZARDOUS DECOMPOSITION PRODUCTS: Carbon monoxide.

---

6. ACCIDENTAL RELEASE MEASURES

NOTIFICATION PROCEDURES: Report spills as required to appropriate authorities. U. S. Coast Guard regulations require immediate reporting of spills that could reach any waterway including intermittent dry creeks. Report spill to Coast Guard toll free number (800) 424-8802. In case of accident or road spill notify CHEMTREC (800) 424-9300.
PROCEDURES IF MATERIAL IS RELEASED OR SPILLED: Eliminate all ignition sources. Runoff may create fire or explosion hazard in sewer system. Adsorb on fire retardant treated sawdust, diatomaceous earth, etc. Shovel up and dispose of at an appropriate waste disposal facility in accordance with current applicable laws and regulations, and product characteristics at time of disposal.
ENVIRONMENTAL PRECAUTIONS: Prevent spills from entering storm sewers or drains and contact with soil.
PERSONAL PRECAUTIONS: See Section 8

7. HANDLING AND STORAGE

HANDLING: NEVER SIPHON GASOLINE BY MOUTH. GASOLINE SHOULD NOT BE USED AS A SOLVENT OR AS A CLEANING AGENT. Use non-sparking tools an explosion-proof equipment. Avoid contact with skin. Avoid inhalation of vapors or mists. Use in well ventilated area away from all ignition sources. PORTABLE CONTAINERS approved for storing fuel must be placed on the ground and the nozzle must stay in contact with the container when filling to prevent build up and discharge of static electricity.
STORAGE: Drums must be grounded and bonded and equipped with self-closing valves, pressure vacuum bungs and flame arresters. Store away from all ignition sources in a cool area equipped with an automatic sprinkling system. Outside or detached storage preferred. Storage containers should be grounded and bonded.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

VENTILATION: Use in well ventilated area with local exhaust ventilation. Ventilation required and equipment must be explosion proof. Use away from all ignition sources.
RESPIRATORY PROTECTION: Approved respiratory equipment must be used when airborne concentrations are unknown or exceed the TLV.
EYE PROTECTION: If splash with liquid is possible, safety glasses with side shields or chemical goggles should be worn.
SKIN PROTECTION: Impervious gloves should be worn. Good personal hygiene practices should always be followed.

Substance Name (CAS-No.)	Source	---TWA--- ppm	mg/m3	----STEL--- ppm	mg/m3	NOTE
GASOLINE (8006-61-9)						
	OSHA	300	900	500	1500	
	ACGIH	300	890	500	1480	
METHYL T-BUTYL ETHER (1634-04-4)						
	ACGIH	40	144			
ETHANOL (64-17-5)						
	OSHA	1000	1900			
	ACGIH	1000	1880			
XYLENE (1330-20-7)						
O, M, P, -Isomers	OSHA	100	435	150	655	

O, M, P, -Isomers	ACGIH	100	434	150	651
ISOPENTANE (78-78-4)					
All Isomers	ACGIH	600	1770		
TOLUENE (108-88-3)					
	OSHA	100	375	150	560
Skin	ACGIH	50	188		
PSEUDOCUMENE (95-63-6)					
	OSHA	25	125		
	ACGIH	25	123		
BUTANE (106-97-8)					
	OSHA	800	1900		
	ACGIH	800	1900		
2-METHYLPENTANE (107-83-5)					
Isomer of N-Hexane	ACGIH	500	1760	1000	3500
PENTANE (109-66-0)					
	OSHA	600	1800	750	2250
All Isomers	ACGIH	600	1770		
TRIMETHYL BENZENE (25551-13-7)					
	OSHA	25	125		
	ACGIH	25	123		
3-METHYLPENTANE (96-14-0)					
Isomer of N-Hexane	ACGIH	500	1760	1000	3500
BENZENE (71-43-2)					
	OSHA	1		5	
Skin	ACGIH	0.5	1.6	2.5	8
2,3-DIMETHYLBUTANE (79-29-8)					
Isomer of N-Hexane	ACGIH	500	1760	1000	3500
N-HEXANE (110-54-3)					
	OSHA	50	180		
N-Hexane Skin	ACGIH	50	176		
Other Isomers	ACGIH	500	1760	1000	3500
ETHYL BENZENE (100-41-4)					
	OSHA	100	435	125	545
	ACGIH	100	434	125	543
3- METHYLHEXANE (589-34-4)					
	MOBIL	400	1640		
2- METHYLHEXANE (591-76-4)					
	MOBIL	400	1640		
METHYLCYCLOHEXANE (108-87-2)					
	OSHA	400	1600		
	ACGIH	400	1610		

NOTE: Limits shown for guidance only. Follow applicable regulations.

---

9. PHYSICAL AND CHEMICAL PROPERTIES

Typical physical properties are given below. Consult Product Data Sheet for specific details.

APPEARANCE: Liquid
COLOR: Clear (May Be Dyed)
ODOR: Gasoline
ODOR THRESHOLD-ppm: NE
pH: NA
BOILING POINT C(F): > 35(95)
MELTING POINT C(F): NA
FLASH POINT C(F): < -40(-40) (ASTM D-56)
FLAMMABILITY: NE
AUTO FLAMMABILITY: NE
EXPLOSIVE PROPERTIES: NA
OXIDIZING PROPERTIES: NA

VAPOR PRESSURE-mmHg 20 C: > 400.0
VAPOR DENSITY: 3.0
EVAPORATION RATE: NE
RELATIVE DENSITY, 15/4 C: 0.79
SOLUBILITY IN WATER: Negligible
PARTITION COEFFICIENT: NE
VISCOSITY AT 40 C, cSt: < 1.0
VISCOSITY AT 100 C, cSt: NA
POUR POINT C(F): NA
FREEZING POINT C(F): NE
VOLATILE ORGANIC COMPOUND: NE
NA=NOT APPLICABLE NE=NOT ESTABLISHED D=DECOMPOSES
FOR FURTHER TECHNICAL INFORMATION, CONTACT YOUR MARKETING REPRESENTATIVE

---

10. STABILITY AND REACTIVITY

STABILITY (THERMAL, LIGHT, ETC.): Stable.
CONDITIONS TO AVOID: Heat, sparks, flame and build up of static electricity.
INCOMPATIBILITY (MATERIALS TO AVOID): Halogens, strong acids, alkalies, and oxidizers.
HAZARDOUS DECOMPOSITION PRODUCTS: Carbon monoxide.
HAZARDOUS POLYMERIZATION: Will not occur.

---

11. TOXICOLOGICAL DATA

---ACUTE TOXICOLOGY---

ORAL TOXICITY (RATS): Practically non-toxic (LD50: greater than 2000 mg/kg). ---Based on testing of similar products and/or the components.
DERMAL TOXICITY (RABBITS): Practically non-toxic (LD50: greater than 2000 mg/kg). ---Based on testing of similar products and/or the components.
INHALATION TOXICITY (RATS): Practically non-toxic (LC50: greater than 5 mg/l). ---Based on testing of similar products and/or the components.
EYE IRRITATION (RABBITS): Practically non-irritating. (Draize score: greater than 6 but 15 or less). ---Based on testing of similar products and/or the components.
SKIN IRRITATION (RABBITS): Irritant. (Primary Irritation Index: 3 or greater but less than 5). ---Based on testing of similar products and/or the components.
OTHER ACUTE TOXICITY DATA: Inhalation of vapors/mists may cause respiratory system irritation. HAZARDS OF COMBUSTION PRODUCTS: Exposure to high concentrations of carbon monoxide can cause loss of consciousness, heart damage, brain damage and death. Exposure to high concentrations of carbon dioxide can cause simple asphyxiation by displacing oxygen. May be harmful or fatal if swallowed due to aspiration pneumonitis.

---OTHER TOXICOLOGY DATA---

Gasoline and Refinery Streams: Studies conducted by the American Petroleum Institute examined a reference unleaded gasoline for mutagenic, teratogenic and sensitization potential; no evidence of these hazards was found. However, isolated constituents of gasoline may display these or other potential hazards in laboratory tests. There were no significant adverse effects in three-month subchronic inhalation studies in rats or monkeys, or in a two-year skin cancer study in mice. Studies with laboratory animals have shown that gasoline vapors administered at high concentrations over a prolonged period of time caused kidney damage and kidney cancer in male rats and liver cancer in female mice. The kidney tumors resulted from formation of a compound unique to male rats and is not considered relevant to humans. The relationship of liver cancer in mice to humans is not known. Studies carried out by Mobil's Environmental and Health Sciences Laboratory on some of the major refinery streams from which gasoline is formulated support the results of the API studies. There was no evidence of significant adverse systemic or reproductive effects for light catalytic cracked naphthas and reformed naphthas. Components: Gasoline consists of a complex blend of petroleum/processing derived paraffinic, olefinic, naphthenic and aromatic hydrocarbons which include up to 5% benzene (with 1-2% typical in the U.S.), n-hexane, mixed xylenes, toluene, ethylbenzene and trimethyl benzene. Repeated exposures to low levels of benzene have been reported to result in blood abnormalities including anemia and, in rare cases, leukemia in both animals and humans. Prolonged exposure to n-hexane may result in nervous system damage, including numbness of the extremities and, in extreme cases, paralysis. The adverse effects associated with these components have not been observed in studies with gasoline or the refinery streams from which it is formulated. Generally, human exposures to gasoline vapors are considerably less than those used in the animal toxicity studies. As far as scientists know, low level or infrequent exposures to gasoline vapor are unlikely to be associated with cancer or other serious diseases in humans. Methyl Tertiary Butyl Ether (MTBE) was tested for carcinogenicity, neurotoxicity, chronic, reproductive, and developmental toxicity. The NOAEL for all end points evaluated in three animal species was 400 ppm or greater. An increase in kidney tumors/damage and liver tumors was observed in animals exposed to high concentrations of MTBE. Some embryo/fetal toxicity and birth defects were observed in the offspring of pregnant mice exposed to maternally toxic doses of MTBE, however the offspring of exposed pregnant rabbits were unaffected. The significance of the animal findings at high exposures are not believed to be directly related to potential human health hazards in the workplace.

----

12. ECOLOGICAL INFORMATION

ENVIRONMENTAL FATE AND EFFECTS: Not established.

----

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL: Product is suitable for burning for fuel value i compliance with applicable laws and regulations.
RCRA INFORMATION: Disposal of unused product may be subject to RCRA regulations (40 CFR 261). Disposal of the used product may also be regulated due to ignitability, corrosivity, reactivity, or toxicity as determined by the Toxicity Characteristic Leaching Procedure (TCLP).

BENZENE: 2.3200 PCT (TCLP)
FLASH: < -40(-40) C(F)

----

14. TRANSPORT INFORMATION

USA DOT:

SHIPPING NAME:	Gasoline
HAZARD CLASS & DIV:	3
ID NUMBER:	UN1203

ERG NUMBER:	128
PACKING GROUP:	PG II
STCC:	NE
DANGEROUS WHEN WET:	No
POISON:	No
LABEL(s):	Flammable Liquid
PLACARD(s):	Flammable
PRODUCT RQ:	NA
MARPOL III STATUS:	NA
RID/ADR:	
HAZARD CLASS:	3
HAZARD SUB-CLASS:	3(b)
LABEL:	3
DANGER NUMBER:	33
UN NUMBER:	1203
SHIPPING NAME:	Hydrocarbons, liquid having a flash point below 21deg C
REMARKS:	NA
IMO:	
HAZARD CLASS & DIV:	3.1
UN NUMBER:	1203
PACKING GROUP:	PG II
SHIPPING NAME:	Gasoline
LABEL(s):	Flammable Liquid
MARPOL III STATUS:	NA
ICAO/IATA:	
HAZARD CLASS & DIV:	3
ID/UN Number:	1203
PACKING GROUP:	PG II
SHIPPING NAME:	Gasoline
SUBSIDIARY RISK:	NA
LABEL(s):	Flammable Liquid

---

15. REGULATORY INFORMATION

Governmental Inventory Status: All components comply with TSCA, and EINECS/ELINCS.
EU Labeling:
Symbol: F+ T Extremely flammable, Toxic.
Risk Phrase(s): R12-45-38-65.
Extremely flammable. May cause cancer. Irritating to skin.
Harmful: may cause lung damage if swallowed.
Safety Phrase(s): S53-45-2-23-24-29-43-62.
Avoid exposure - obtain special instructions before use. In case o accident or if you feel unwell, seek medical advice immediately (show the label where possible). Keep out of the reach of children. Do not breathe vapor. Avoid contact with skin. Do not empty into drains. In case of fire use carbon dioxide, foam, dry chemical or water fog. If swallowed, do not induce vomiting: seek medical advice immediately and show this container or label.
Contains: Low Boiling Point Naphtha.
U.S. Superfund Amendments and Reauthorization Act (SARA) Title III:
This product contains no "EXTREMELY HAZARDOUS SUBSTANCES".
SARA (311/312) REPORTABLE HAZARD CATEGORIES:
FIRE CHRONIC ACUTE
This product contains the following SARA (313) Toxic Release Chemicals:

CHEMICAL NAME	CAS NUMBER	CONC.
BENZENE(COMPONENT ANALYSIS)	71-43-2	2.32%
PSEUDOCUMENE(COMPONENT ANALYSIS)	95-63-6	4.55%
ETHYL BENZENE(COMPONENT	100-41-4	1.6%

ANALYSIS)		
TOLUENE(COMPONENT ANALYSIS)	108-88-3	4.65%
N-HEXANE(COMPONENT ANALYSIS)	110-54-3	1.69%
XYLENES(COMPONENT ANALYSIS)	1330-20-7	9.9%
METHYL-TERT-BUTYL ETHER(COMPONENT ANALYSIS)	1634-04-4	15.1%

The following product ingredients are cited on the lists below:

CHEMICAL NAME	CAS NUMBER	LIST CITATIONS
ETHYL ALCOHOL (COMPONENT ANALYSIS)	64-17-5	1, 6, 10, 18, 19, 20, 21, 23, 25, 26
BENZENE (COMPONENT ANALYSIS) (2.32%)	71-43-2	1, 2, 4, 6, 9, 10, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26
ISOPENTANE (COMPONENT ANALYSIS)	78-78-4	1, 19, 24, 25
2,3-DIMETHYLBUTANE (COMPONENT ANALYSIS)	79-29-8	1, 19, 25
PSEUDOCUMENE (COMPONENT ANALYSIS)	95-63-6	1, 20, 24, 25
PENTANE, 3-METHYL- (COMPONENT ANALYSIS)	96-14-0	1, 19, 25
METHYL CYCLOPENTANE (COMPONENT ANALYSIS)	96-37-7	19, 25, 26
ETHYL BENZENE (COMPONENT ANALYSIS)	100-41-4	1, 8, 10, 18, 19, 20, 21, 23, 24, 25, 26
BUTANE (COMPONENT ANALYSIS)	106-97-8	1, 10, 18, 19, 20, 21, 23, 24, 25, 26
PENTANE, 2-METHYL- (COMPONENT ANALYSIS)	107-83-5	1, 19, 23, 25
METHYLCYCLOHEXANE (COMPONENT ANALYSIS)	108-87-2	1, 10, 18, 19, 20, 21, 23, 25, 2
TOLUENE (COMPONENT ANALYSIS) (4.65%)	108-88-3	1, 10, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26
PENTANE (COMPONENT ANALYSIS)	109-66-0	1, 10, 18, 19, 20, 21, 23, 24, 25, 26
N-HEXANE (COMPONENT ANALYSIS)	110-54-3	1, 10, 18, 19, 20, 21, 23, 24, 25, 26
2-METHYL 2-BUTENE (COMPONENT ANALYSIS)	513-35-9	19, 25
3-METHYLHEXANE (COMPONENT ANALYSIS)	589-34-4	19, 25
HEXANE, 2-METHYL- (COMPONENT ANALYSIS)	591-76-4	19, 25
1-HEXENE (COMPONENT ANALYSIS)	592-41-6	1, 19, 25
XYLENES (COMPONENT ANALYSIS) (9.90%)	1330-20-7	1, 10, 18, 19, 20, 21, 22, 23, 24, 25, 26
METHYL-TERT-BUTYL ETHER (COMPONENT ANALYSIS)	1634-04-4	1, 11, 15, 21, 24, 25
GASOLINE	8006-61-9	1, 8, 10, 18, 19, 20, 21, 23, 26
TRIMETHYL BENZENE (COMPONENT ANALYSIS)	25551-13-7	1, 10, 18, 19, 20, 21, 23, 25, 2

--- REGULATORY LISTS SEARCHED ---

1=ACGIH ALL	6=IARC 1	11=TSCA 4	16=CA P65 CARC	21=LA RTK
2=ACGIH A1	7=IARC 2A	12=TSCA 5a2	17=CA P65 REPRO	22=MI 293
3=ACGIH A2	8=IARC 2B	13=TSCA 5e	18=CA RTK	23=MN RTK
4=NTP CARC	9=OSHA CARC	14=TSCA 6	19=FL RTK	24=NJ RTK
5=NTP SUS	10=OSHA Z	15=TSCA 12b	20=IL RTK	25=PA RTK
				26=RI RTK

Code key: CARC=Carcinogen; SUS=Suspected Carcinogen; REPRO=Reproductive

---

16. OTHER INFORMATION

Precautionary Label Text:
CONTAINS GASOLINE
DANGER!
EXTREMELY FLAMMABLE LIQUID AND VAPOR. VAPOR MAY CAUSE FLASH FIRE. MAY CAUSE SKIN, NOSE, THROAT, AND LUNG IRRITATION, DIZZINESS, NAUSEA, AND LOSS OF CONSCIOUSNESS. LOW VISCOSITY MATERIAL-IF SWALLOWED, MAY BE ASPIRATED AND CAN CAUSE SERIOUS OR FATAL LUNG DAMAGE
LONG-TERM EXPOSURE TO GASOLINE VAPOR HAS CAUSED KIDNEY AND LIVER CANCER IN LABORATORY ANIMIALS.
Keep away from heat, sparks, and flame. Avoid all personal contact. Avoid prolonged breathing of vapor. Use with adequate ventilation. Kee container closed. Approved portable containers must be properly grounded when transferring fuel. For use as a motor fuel only. Misuse of gasoline may cause serious injury or illness. Never siphon by mouth. Not to be used as a solvent or skin cleaning agent.
FIRST AID: In case of contact, wash skin with soap and water. Remove contaminated clothing. Destroy or wash clothing before reuse. If swallowed, seek immediate medical attention. Do not induce vomiting. Only induce vomiting at the instruction of a physician.
Empty container may contain product residue, including flammable or explosive vapors. Do not cut, puncture, or weld on or near container. All label warnings and precautions must be observed until container ha been thoroughly cleaned or destroyed.
This warning is given to comply with California Health and Safety Code 25249.6 and does not constitute an admission or a waiver of rights. This product contains a chemical known to the State of California to cause cancer, birth defects, or other reproductive harm. Chemicals known to the State of California to cause cancer, birth defects, or other reproductive harm are created by the combustion of this product. Refer to product Material Safety Data Bulletin for further safety and health information.

USE: UNLEADED MOTOR FUEL
NOTE: MOBIL PRODUCTS ARE NOT FORMULATED TO CONTAIN PCBS.

INGREDIENT	PERCENT	CAS NUMBER
GASOLINE	100.00	8006-61-9

****

For Internal Use Only: MHC: 1* 1* 1* 1* 2*, MPPEC: CF, TRN: 15024-34, REQ: US - MARKETING, SAFE USE: S
EHS Approval Date: 12MAY2000

****

****

****

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

CRITICALITY EVALUATION FOR THE HUMBOLDT BAY ISFSI PROJECT

FOR

PG&E

Holtec Report No: HI-2033010

Holtec Project No: 1125

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT ISSUANCE AND REVISION STATUS[1]

DOCUMENT NAME: Criticality Evaluation for the Humboldt Bay ISFSI Project

DOCUMENT NO.:	2033010	CATEGORY: ☐ GENERIC
PROJECT NO.:	1125	☒ PROJECT SPECIFIC

Rev. No. [2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	10/7/03	SPA	36015				
1	10/10/03	SPA	336545				

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)

Documents labeled TOP SECRET contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 in the N-drive of 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 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 "Table of Contents", this page and the "Revision Log".

Summary of Revisions

Revision 0

Original Issue

Revision 1

A discussion is added to Section 7.2 regarding an extra poison panel on the periphery of the basket. This issue had already been identified and evaluated for the MPC-68 basket which is the basis for the MPC-HB. This is an editorial change to provide clarification, and no changes were made to any existing results or conclusions of the report. All changes are marked with revision bars in the right page margin.

Table of Contents

1. Introduction

1.1 Statement of Purpose

This report documents the criticality evaluations for the MPC-HB and HI-STAR HB to be used in the ISFSI Project for the Humboldt Bay Power Plant (HBPP) [1]. The MPC-HB [2] and HI-STAR HB [2] are directly based on Holtec's standard designs MPC-68F and HI-STAR 100 [3],[5], respectively, with the following changes relevant to the criticality analyses:

- Number of Cells increased from 68 to 80
- Cell Pitch decreased from 6.053" to 5.89"
- Wall thickness decreased from 0.25" to 3/16"
- Poison Material changed from Boral to Metamic
- Poison Plate dimensions change to 4" wide x 88" high x 0.05" thick
- MPC height reduced to 114.5"
- HI-STAR height reduced to 127-7/16"

The Damaged Fuel Container (DFC) for the MPC-HB [2] is also based on the standard design [3],[5], with the same cross section, but modified end sections to account for the different MPC height.

However, despite these differences in design details, the design principles for the MPC-HB and HI-STAR HB are the same as for the standard designs. Therefore, the principles of the criticality evaluations performed for the standard designs, as documented in the HI-STAR FSAR [3] and SAR [5], are directly applicable to the HB designs. These principles will be referenced in this report as appropriate. The differences in design details make it necessary to perform criticality calculations specifically for the HB designs in order to demonstrate that the design is safe from a criticality perspective and fulfills the requirements of 10CFR71 and 10CFR72. The calculations and evaluations to demonstrate criticality safety are documented in this report. The methodology and calculations for the HI-STAR HB and MPC-HB are consistent with [3], Chapter 6, and [5], Chapter 6, and are therefore in conformance with NUREG-1536 and NUREG-1617.

1.2 About This Document

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 and justified.
- The analysis methodology 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.

2. General Methodology

The principal method for the criticality analysis is the general three-dimensional continuous energy Monte Carlo N-Particle code MCNP4a [6] developed at the Los Alamos National Laboratory. MCNP4a was selected because it has been extensively used and verified and has all of the necessary features for this analysis. MCNP4a calculations used continuous energy cross-section data based on ENDF/B-V, as distributed with the code [6]. Independent verification calculations for the MPC-68 basket, which is similar to the MPC-HB, show very good agreements [3]. Benchmark calculations were made to compare MCNP4a results with experimental data, using experiments selected to encompass, insofar as practical, the design parameters of the HI-STAR System. These benchmark calculations are presented in Appendix 6.A of [3], and establish a bias and bias uncertainty of 0.0021 and 0.0006, respectively. Full three-dimensional calculations were used conservatively neglecting the absorption in the overpack neutron shielding material. Although the neutron absorber panels are 88 inches in length, which is longer than the active fuel length (maximum of 79.06 inches), they are assumed equal to the active fuel length in the calculations. The calculational model explicitly defines the fuel rods and cladding, the water rods and neutron absorber panels on the stainless steel walls of the basket cells. Calculations were made with dimensions assumed to be at their most conservative value with respect to criticality, consistent with the studies performed for the MPC-68 basket in [3], i.e., minimum cell pitch and minimum box ID re used in the calculations. For further details of the methodology used in the criticality evaluations for the MPC see [3], Chapter 6, and [5], Chapter 6.

3. Acceptance Criteria

The effective multiplication factor (k_{eff}), including all biases and uncertainties at the 95-percent confidence level, must not exceeds 0.95 under all credible normal, off-normal and accident conditions. The effective multiplication factor is calculated as described in [3], Section 6.4.3.

To show compliance with 10CFR71 (Transportation), the following conditions are specifically addressed:

- A single package, under the conditions of 10 CFR 71.55(b), (d), and (e);
- An array of undamaged packages, under the conditions of 10 CFR 71.59(a)(1); and
- An array of damaged packages, under the conditions of 10 CFR 71.59(a)(2)

The bounding condition under 10CFR72 (Storage, specifically 10CFR72.124) is the fully flooded condition during loading and unloading. This conditions is bounded by the conditions listed above for 10CFR71. Therefore, no additional calculations specific to 10CFR72 need to be performed to show compliance with 10CFR72.

4. Assumptions

The criticality evaluations are based on a significant number of conservative assumptions (see [3], Section 6.1). The major conservative assumptions are listed below.

- The MPC is assumed to contain the most reactive fuel authorized to be loaded.

- No credit for fuel burnup is assumed, either in depleting the quantity of fissile nuclides or in producing fission product poisons.

- The criticality analyses assume 75% of the manufacturer's minimum Boron-10 content for the neutron absorber.

- The fuel stack density is assumed to be 96% of theoretical (10.522 g/cm^3) for all criticality analyses (The fuel stack density is approximately equal to 98% of the pellet density. Therefore, while the pellet density of some fuels might be slightly greater than 96% of theoretical, the actual stack density will still be less).

- When flooded, the moderator is assumed to be water at a temperature corresponding to the highest reactivity within the expected operating range (i.e., water density of 1.000 g/cc).

- Neutron absorption in minor structural members is neglected, i.e., spacer grids, basket supports and similar structures are replaced by water.

- The worst hypothetical combination of tolerances (most conservative values within the range of acceptable values), consistent with Section 6.3 in [3], is assumed.

- When flooded, the fuel rod pellet-to-clad gap regions are assumed to be flooded.

- Planar-averaged enrichments are assumed for BWR fuel. Analyses are presented in Appendix 6.B of [3] to demonstrate that the use of planar-average enrichments produces conservative results.

- Fuel-related burnable neutron absorbers, such as the Gadolinia, are neglected.

- For evaluation of the reactivity bias, all benchmark calculations that result in a k_{eff} greater than 1.0 are conservatively truncated to 1.0000.

- Regarding the position of assemblies in the basket, configurations with centered and eccentric positioning of assemblies in the fuel storage locations are considered.

5. Input Data

Input data used in this evaluation is listed or identified and referenced in Table 5.1.

Consistent with the assumption in [3] and [5], only 75% of the minimum ^{10}B loading of 0.01 g/cm^2 of the poison is credited in the analyses, i.e. 0.01 g/cm^2 * 75% = 0.0075 g/cm^2†. The corresponding material composition used in the analysis is shown in Table 5.2.

The fuel material composition for the enrichment of 2.6 wt% ^{235}U used in the analysis is shown in Table 5.3.

6. Computer Codes

All criticality evaluations are performed with the computer code MCNP4a [6].

7. Analysis and Results

7.1 Bounding Fuel Assembly Dimensions

According to the evaluations performed in [3], the bounding fuel parameters are a combination of the maximum active length, the maximum pellet OD, the minimum cladding OD, the maximum cladding ID, and the maximum channel thickness. Based on the fuel dimensions listed in [1], and additional fuel dimensions taken from [8], the bounding dimensions are determined in Table 7.1 for the 6x6 assembly type used at HBPP and in Table 7.2 for the 7x7 assembly type used at HBPP. For the 6x6 assembly types, both the minimum and maximum pellet OD is analyzed. Additionally, the EXXON Type IV is analyzed explicitly, to demonstrate that it is bounded by the calculations using the maximum pellet OD. This assembly type contains rods with different pellet ODs: the 20 rods on the assembly periphery have an OD of 0.461 inches, whereas the remaining 16 rods have an OD of 0.481 inches (see [1], Appendix B). The bounding planar average enrichment for all fuel types is 2.6 wt% ^{235}U. The fuel composition used in the analysis is shown in Table 5.3. There are two assemblies in the HBPP inventory with a single higher enriched fuel rod. For a discussion of these assemblies see Section 7.3.3.

7.2 Criticality Model

A radial cross section of a representative criticality model is shown in Figure 7.1. The configuration shown contains DFCs in all peripheral cells, and intact assemblies in all other cells. The cross section was generated with the MCNP 2-dimensional plotter direct from the corresponding MCNP input file. The corresponding axial cross section is shown in Figure 7.2. For further discussions regarding the damaged fuel container configuration and content see Section 7.3.2.

† Note that the MPC-68F in [3] and [5] uses a slightly more conservative value of 67%. However, the approach taken here, i.e. using 75% of the minimum value, is consistent with the relevant regulatory guides NUREG-1536 and NUREG-1617, and consistent with the approach for the other MPCs in [3] and [5].

Note that the geometric model contains the following three minor inconsistencies:

- Holtec Proprietary
- Holtec Proprietary
- Holtec Proprietary

7.3 Configurations

Various different configurations were analyzed. Some configurations correspond directly to requirements listed in the 10CFR71 or 10CFR72 regulations, while other configurations were analyzed for additional information or to determine the most reactive condition. The configurations differ in the extent of water moderation and in the presence, configuration and modeling of damaged fuel and fuel debris. The configurations are discussed in the following sections, and results are presented later in this chapter.

7.3.1 Moderation Conditions

Standard Conditions

The majority of the calculations are performed for a single cask system with the MPC flooded with water, but no external reflection. This is considered the standard condition since most of the calculations in [3] and [5] are performed for this condition, and since the studies regarding the different water moderation conditions presented in [3] and [5] show that this condition either bounds, or is equivalent to other water moderation conditions. During the storage evolution, this would be the condition of the system after it has been loaded and taken out of the pool, but before the drying process is finished. During transportation, this could be a condition after an accident that resulted in flooding of the MPC.

Full Water Reflection of the Containment System

This condition is analyzed specifically to address the requirements in 10CFR71.55(b)(3). The containment system is modeled as 2.5” of steel all around the fuel basket. The containment is surrounded by water with a sufficient thickness on all sides to ensure full water reflection. Only selected cases are analyzed under this condition.

Full Water Reflection of the Cask System

This condition is analyzed specifically to address the requirements in 10CFR71.55(b)(3). This condition is analyzed to show that the materials of the cask outside the containment system do not provide a greater reflection than the water assumed in the previous condition. Only selected cases are analyzed under this condition.

Dry System

For this condition, the model consists of a cask containing an internally dry MPC. This corresponds to the normal condition during storage and transportation of the system. To bound all possible external condition, including the possible neutron reflection in the storage vault, full water reflection is assumed on the outside of the cask.

Cask Arrays

To address the requirements of 10CFR71.59, arrays of casks, axially and radially infinite, are analyzed with and without water moderation.

7.3.2 Intact and Damaged Fuel

Intact Fuel

For calculations with intact fuel only, all 80 basket cells are assumed to contain a 6x6 or 7x7 assembly with the bounding dimensions determined in Section 7.1. Also, all intact assemblies are assumed to have a channel, since the presence of the channel has been determined in [3] and [5] to result in a higher reactivity. In addition, cases are considered where the intact assemblies are placed into DFCs. This condition potentially exists for contamination control during loading and unloading operations. The intact assembly type and condition resulting in the highest reactivity will then be used as the intact assembly in all calculations with intact fuel and damaged fuel/fuel debris in the basket.

Damaged Fuel and Fuel Debris :Holtec Proprietary

Proprietary Information Deleted

Configuration 1: Damaged Fuel/Fuel Debris is only placed in cells on the periphery of the basket. These cells are defined as cells that have at least one side not facing another cell. The configuration is shown in Figure 7.3, and allows a total of 28 DFCs in one basket.

Configuration 2: Damaged Fuel/Fuel Debris is placed in a checkerboard pattern with intact fuel. This configuration is shown in Figure 7.4, and allows a total of 40 DFCs in one basket.

Note again that in any case the actual number of DFCs in the basket could be higher than the numbers specified above, since there could also be intact assemblies placed in DFCs.

Proprietary Information Deleted

Note that the damaged fuel/fuel debris model used in the analysis does not assume a limit on the quantity of fuel within one DFC.

7.3.3 Other Variations

Most Reactive Configuration

Consistent with the evaluations performed in [3] and [5], the majority of calculations are performed for the worst combination of basket tolerances, and with the assemblies or DFCs centered in the individual basket cells. To address the requirements for 10CFR71.55(b)(1), a selected number of cases are also analyzed with the assemblies and/or DFCs placed as close as possible to the center of the basket. This condition conservatively bounds all possible configurations of fuel and/or DFCs in the basket cells, although the configuration itself is not considered credible.

Potential Damage to the Neutron Poison Plates :Holtec Proprietary

Proprietary Information Deleted

Highly Enriched Fuel Rods

Four of the assemblies at HBPP contained initially one fuel rod each with an enrichment of 5.5 wt% ^{235}U (see Section 2.3 in Appendix B in [1]). From two of these assemblies, the rod has subsequently been removed (see Section 2.5 in Appendix B in [1]), which leaves two assemblies where this highly enriched rod is still present. At least one of these two assemblies is considered damaged [1]. These assemblies have a planar average enrichment of 2.43 wt% ^{235}U.

For intact fuel is has been demonstrated in [3], Appendix B, that distributed enrichments are bounded by analyses using a planar average enrichment. Further, the assemblies with the highly enriched rods have a planar average enrichment of 2.43 wt% ^{235}U, which is less than the value of 2.6 wt% ^{235}U conservatively used in the analyses. For intact fuel, these assemblies are therefore bounded by the current analysis, and no specific calculations are necessary for these assemblies.

Proprietary Information Deleted

7.4 Results

7.4.1 Intact Fuel

The results of the calculations for intact fuel are summarized in Table 7.3. For each case, the table shows a unique case number, the MCNP input file, the conditions, and the results in the form of the calculated k_{eff}, the standard deviation and the maximum k_{eff}[†]. The following conclusions are drawn from the results:

- For the 6x6 assembly type, the case with the maximum pellet OD is bounding.
- The 6x6 assembly type results in higher reactivities than the 7x7 assembly type and is therefore used in all further calculations.
- Intact assemblies in DFCs show a lower reactivity that intact assemblies without DFCs
- The presence of potential damage to all neutron poison plate has potentially a small positive reactivity effect (about 0.002 delta-k).
- Moving all assemblies to the center of the basket has a small but noticeable reactivity effect (about 0.008 delta-k).
- Full water reflection around the containment does not have a significant reactivity effect compared to the standard condition.
- As bounding cases, calculations were performed with the 6x6 assembly without a DFC, eccentric fuel positioning, potential damage to the poison plates, and full water reflection (Cases 11 through 15).
- All results are well below the regulatory limit of 0.95, the highest reactivity (Case 12) calculated is 0.8410.
- Results for the various cases with water in the MPC (Cases 11,12 and 14) show statistically equivalent results.
- The transportation index is 0 (zero) since all results for cask arrays are below the regulatory limit.
- The reactivity for the dry condition is very low, with the highest calculated value below 0.39.

7.4.2 Damaged Fuel and Fuel Debris

Results for calculations with damaged fuel and fuel debris are presented in tables 7.4 through 7.6. Table 7.4 shows results for the damaged fuel/fuel debris model using the bare fuel rods. Calculations are performed for the damaged fuel/fuel debris on the periphery, and for the checkerboard with intact fuel. In addition, two different fuel rod diameters are used in the evaluations, which correspond to the minimum and maximum fuel rod diameters of the 6x6 and 7x7 assembly type. The information is presented in the same way as for the intact assemblies in Table 7.3. The condition with the highest reactivity is calculated for the checkerboard configuration with a 7x7 array of bare fuel rods with a rod diameter of 0.488 inches. As for the

[†] The term “maximum k_{eff}” or “max k-eff” used in the text and the tables means the highest possible k-effective, including bias, uncertainties, and calculational statistics.

intact assemblies, moving all assemblies and DFCs towards the center of the basket results in an increase of the reactivity of about 0.008 delta-k. Table 7.5 shows results for smaller fuel fragments. In these calculations, the size of the fuel fragment is varied between 0.02 inches and 1.0 inches in up to eight steps, and the fuel-to-water volume ratio is varied between 0.2 and 0.8 in up to six steps. The maximum k_{eff} is is slightly lower than the result for the bare fuel rod arrays (both for DFCs centered in the cells). The damaged fuel/fuel debris model based on bare fuel rods therefore conservatively bounds all possible fuel conditions. For these calculations with fuel fragments, only the input file name and the maximum k_{eff} are shown for each case, and no case numbers are assigned. Table 7.6 shows the calculations for the bounding conditions (Cases 44 and 48). These calculations were performed for the DFC checkerboard case with the highest reactivity (Case 30), eccentric fuel positioning, potential damage to the poison plates[†], and various conditions of water reflection. The results are consistent with the results obtained for intact fuel, with the highest maximum k_{eff} larger (0.9003) due to the conservative damaged fuel modeling.

7.4.3 Other Conditions not Specifically Analyzed

Partial Flooding

The evaluations in [3] demonstrate that partial flooding of the MPC results in a reduced reactivity, and that therefore the fully flooded condition is bounding. This applies directly to the MPC-HB, since the principal design of the MPC-HB is the same as the generic design.

Preferential Flooding of the MPC

The evaluations in [3] demonstrate that preferential flooding of the MPC is not possible due to the presence of the semi-circular cut-outs (“mouse holes”) at the bottom of the basket. This applies directly to the MPC-HB, since the MPC-HB design uses the same design feature.

Preferential Flooding of DFCs

The evaluations in [3] demonstrate that preferential flooding of the DFC is not possible since the mesh size of the DFC only allows a small amount of water in a DFC when the MPC is drained. This applies directly to the DFC for HB, since the same mesh size is used.

† Case 40 shows a small reduction in reactivity for the ppoison plate damage, although the difference is within the statistical uncertainty. Conservatively, the poison plate damage is assumed for the bounding cases. Note that typically such a small damage has a statistically insignificant effect.

8. Computer Files

All computer input files are located on the Holtec server under projects\1125\spa\HI2033010. The input file names of all cases analyzed are listed in Tables 7.3 through 7.6.

9. Summary

For various conditions during transportation and storage, the following maximum effective multiplication factors k_{eff} are evaluated:

- The maximum k_{eff} for a flooded MPC loaded with intact assemblies only is 0.8410. If damaged fuel and/or fuel debris is present in the MPC, the maximum k_{eff} is 0.9003.
- The transportation index for criticality is 0 (zero).
- For the normal condition of storage, i.e. the internally dry MPC-HB inside the concrete vault, the maximum calculated k_{eff} is very low, about 0.39.

In summary, the criticality evaluations demonstrate that under all normal, off-normal and accident conditions of transportation and storage, the effective multiplication factor k_{eff} for the MPC-HB in the HI-STAR HB, evaluated with a 95% probability at the 95% confidence level, does not exceed 0.95. The results demonstrate that in terms of criticality safety, the system complies with the requirements in 10CFR71 and 10CFR72, and is in conformance with NUREG-1536 and NUREG-1617.

10. References†

[1] Humboldt Bay Specification HB-2001-01 for Contract 3500120394

[2] Holtec Drawings 4082 Rev. 0, 4102 Rev. 0, 4103 Rev. 0, 4113 Rev. 0.

[3] HI-STAR 100 Final Safety Analysis Report, NRC Docket No. 72-1008, Holtec Report HI-2012610, Rev. 1, December 2002.

[4] Dimensions And Weights for the Humboldt Bay ISFSI Project, Holtec Report HI-2032999, Rev. 0.

[5] Safety Analysis Report for the HI-STAR 100 Cask System, NCR Docket No. 71-9261, Holtec Report HI-951251, Rev. 9.

[6] J.F. Briesmeister, Ed., "MCNP - A General Monte Carlo N-Particle Transport Code, Version 4A," Los Alamos National Laboratory, LA-12625-M (1993).

[8] HBPP DWG 655438, Sheet 8

[9] PG&E Transmittal of Engineering Documents and Information, HBIP File No. 72.10.05, from Lawrence Pulley, PG&E, to Eric Lewis, Holtec, dated May 5, 2003

† Note: This revision status of Holtec documents cited above is subject to updates as the project progresses. This document will be revised if a revision to any of the above-referenced Holtec work products materially affects the instructions, results, conclusions or analyses contained in this document. Otherwise, a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supersede the revision numbers cited above. The Holtec Project Manager bears the undivided responsibility to ensure that there is no intra-document conflict with respect to the information contained in all Holtec-generated documents on a *safety-significant* project. The latest revision number of all documents produced by Holtec International in a *safety-significant* project is readily available from the company's Document Transmittal Form (DTF) database.

Table 5.1 Input Data for Criticality Evaluations

Description	**Value**	**Reference**
MPC HB Basket and Enclosure Vessel		
Cell Pitch	5.83 inches min. (5.89 inches nom.)	[2]
Cell ID, cells with poison plates	5.55 inches min. (5.61 inches nom.)	[2]
Cell Wall Thickness	3/16 inches	[2]
Poison Plate Dimensions	4 inches x 88 inches x 0.05 inches	[2]
B-10 Loading Minimum	0.01 g/cm^2	[2]
Sheathing Thickness	0.035 inches	[2]
Poison Plate Pocket Thickness	0.057 inches	[4]
MPC Cavity Height	102.5 inches	[2]
Enclosure Vessel ID	67 3/8 inches	[2]
Enclosure Vessel Wall Thickness	0.5 inches	[2]
MPC Lid Thickness	9.5 inches	[2]
MPC Base Plate Thickness	2.5 inches	[2]
HI-STAR HB		
Wall Thickness	8.5 inches	[2]
Bottom flange thickness	6 inches	[2]
Lid Thickness	6 inches	[2]
DFC Dimensions		
DFC Tube Inner Dimension	4.93 inches	[2]
DFC Tube Thickness	0.12 inches	[2]
Material Specifications of Materials other than Fuel and Poison	see [3], Table 6.3.4	[3]
Fuel Dimensions	see Section 7.1	[1]

Table 5.2 Material Composition of the Metamic Poison Material

METAMIC (0.0075 g $^{10}B/cm^2$), DENSITY = 2.667 g/cm^3	
Nuclide	**Atom Density (atoms/barn*cm)**
^{10}B	3.5529E-03
^{11}B	1.4721E-02
C	4.5656E-03
Al	5.0402E-02

Table 5.3 Material Composition for the Fuel

UO_2, 2.6 wt% INITIAL ENRICHMENT, DENSITY = 10.522 g/cm^3	
Nuclide	**Wgt. Fraction**
^{235}U	0.02292
^{238}U	0.85858
O	0.11850

Table 7.1: Bounding Parameters for the 6x6 Assembly type at HBPP (from [1] unless otherwise noted)

Parameter	GE Type III	Exxon Type III	Exxon Type IV	Value used in the Analysis
No of Rods	36	36	36	36
Clad OD (Inches)	0.563	0.563	0.5625 ± 0.002 0.5585 – 0.5599†	0.5585 (minimum)
Clad Thickness (Inches)	0.032 ± 0.003	0.032 ± 0.003	0.0337 – 0.0430	(not used as input)
Clad ID (Inches)	0.493 – 0.505‡	0.493 – 0.505‡	0.4725 - 0.4925	0.505 (maximum)
Pellet OD (Inches)	0.4880	0.4880	0.4610 – 0.4810	0.4880 (maximum) and 0.461 (minimum)
Rod Pitch (Inches)	0.740	0.740	0.740††	0.740
Active Length (Inches)	77.5	77.5	79	80 (upper bound)
Channel Thickness [8] (Inches)	0.060	0.060	0.060	0.060
Planar Average Enrichment (wt% ^{235}U)	2.37 – 2.51	2.35	2.40 – 2.41	2.60 (upper bound)
Fuel Density (g/cm^3)	10.3 ± 0.2	10.3 ± 0.2	93.5% ± 1.5% (~10.25 ± 0.16)‡	10.522 (upper bound)

† This range was calculated from Table in Section 2.2.d in Appendix B to [1]
‡ Calculated from other values in this table
†† from [9]

Table 7.2: Bounding Parameters for the 7x7 Assembly type at HBPP (from [1] unless otherwise noted)

Parameter	GE II P1	GE II P2	Value used in the Analysis
No of Rods	49	49	49
Clad OD (Inches)	0.486	0.486	0.486
Clad Thickness (Inches)	0.033 ± 0.003	0.033 ± 0.003	(not used as input)
Clad ID (Inches)	0.414 – 0.426†	0.414 – 0.426†	0.426 (maximum)
Pellet OD (Inches)	0.411	0.411	0.411
Rod Pitch (Inches)	0.631	0.631	0.631
Active Length (Inches)	79.06	79	80 (upper bound)
Channel Thickness [8] (Inches)	0.060	0.060	0.060
Planar Average Enrichment (wt% ^{235}U)	2.31	2.09	2.60 (upper bound)
Fuel Density (g/cm^3)	10.3 ± 0.2	10.3 ± 0.2	10.522 (upper bound)

† Calculated from other values in the table.

Table 7.3: Results of Criticality Evaluation for Intact Fuel

Case	Filename	Intact Assembly Class	DFC Pattern	DFC Rod Array	DFC Rod Diameter	k-calc	sigma	max. k-eff	Difference to Standard Condition, delta-k	Notes
Intact Assemblies only										
Standard Condition										
1	8r6ch01	6x6	none	none	none	0.8279	0.0006	0.8318		
2	8r7ah01	7x7	none	none	none	0.8198	0.0006	0.8237		
Variations										
3	8r6ch03	6x6	none	none	none	0.8174	0.0006	0.8213	-0.0105	(1)
3a	8r6chv1	6x6	none	none	none	0.8095	0.0005	0.8133	-0.0185	(2)
3b	8r6chv2	6x6	none	none	none	0.8289	0.0006	0.8328	0.0010	(3)
Intact Assemblies in DFCs										
4	8r6ch02	6x6	none	none	none	0.8030	0.0006	0.8069	-0.0249	
5	8r7ah02	7x7	none	none	none	0.7927	0.0006	0.7966	-0.0271	
Potential Poison Plate Damage										
6	8r6chf1	6x6	none	none	none	0.8296	0.0006	0.8335	0.0017	
Eccentric Fuel Positioning										
7	8r6chg1	6x6	none	none	none	0.8363	0.0005	0.8401	0.0083	
Full External Water Reflection around Containment System										
8	8r6chr2	6x6	none	none	none	0.8293	0.0005	0.8330	0.0012	
Full External Water Reflection around Overpack										
9	8r6chr1	6x6	none	none	none	0.8286	0.0006	0.8325	0.0007	
Dry MPC										
10	8r6chr3	6x6	none	none	none	0.3342	0.0007	0.3383		
Bounding Condition										
	- 6x6 Assembly, no DFC									
	- Potential Poison Plate Damage									
	- Eccentric Fuel Positioning									
	- Full External Water Reflection around Containment System (10CFR71.55(b), (d) and (e))									
11	8r6chx2	6x6	none	none	none	0.8357	0.0005	0.8394		
	- Full External Water Reflection around Overpack (10CFR71.55(b), (d) and (e))									
12	8r6chx3	6x6	none	none	none	0.8371	0.0006	**0.8410**		
	- Full External Water Reflection around Containment System, Internally Dry MPC									
13	8r6chx4	6x6	none	none	none	0.3379	0.0007	0.3420		
	- Infinite Array of Damaged Packages (Full internal and external reflection, 10CFR71.59(a)(2))									
14	8r6chx5	6x6	none	none	none	0.8361	0.0006	0.8400		
	- Infinite Array of Intact Packages (internally and externally dry, 10CFR71.59(a)(1))									
15	8r6chx6	6x6	none	none	none	0.3763	0.0007	0.3804		
Notes:										
(1)	Minimum Pellet OD									
(2)	Exxon Type IV with 2 Pellet ODs									
(3)	Extra Panel on Basket Periphery removed									

Table 7.4: Results of Criticality Evaluation for Intact Fuel and Damaged Fuel/Fuel Debris (Damaged Fuel/Fuel Debris modeled as bare fuel rod arrays)

Case	Filename	Intact Assembly Class	DFC Pattern	DFC Rod Array	DFC Rod Diameter	k-calc	sigma	max. k-eff	Difference to Standard Condition, delta-k
Intact Assemblies and Damaged Fuel/Fuel Debris									
Standard Condition									
16	8r6chc5	6x6	Periphery	5x5	0.488"	0.8268	0.0006	0.8307	
17	8r6chc6	6x6	Periphery	6x6	0.488"	0.8352	0.0005	0.8389	
18	8r6chc7	6x6	Periphery	7x7	0.488"	0.8406	0.0005	**0.8444**	
19	8r6chc8	6x6	Periphery	8x8	0.488"	0.8384	0.0005	0.8422	
20	8r6chc9	6x6	Periphery	9x9	0.488"	0.8333	0.0006	0.8372	
21	8r6chca	6x6	Periphery	10x10	0.488"	0.8292	0.0006	0.8331	
22	8r6chd6	6x6	Periphery	6x6	0.411"	0.8286	0.0005	0.8324	
23	8r6chd7	6x6	Periphery	7x7	0.411"	0.8344	0.0006	0.8383	
24	8r6chd8	6x6	Periphery	8x8	0.411"	0.8395	0.0005	0.8433	
25	8r6chd9	6x6	Periphery	9x9	0.411"	0.8410	0.0006	**0.8449**	
26	8r6chda	6x6	Periphery	10x10	0.411"	0.8363	0.0005	0.8400	
27	8r6chdb	6x6	Periphery	11x11	0.411"	0.8314	0.0005	0.8352	
28	8r6cha5	6x6	Checkerboard	5x5	0.488"	0.8055	0.0005	0.8092	
29	8r6cha6	6x6	Checkerboard	6x6	0.488"	0.8645	0.0005	0.8682	
30	8r6cha7	6x6	Checkerboard	7x7	0.488"	0.8868	0.0005	**0.8906**	
31	8r6cha8	6x6	Checkerboard	8x8	0.488"	0.8809	0.0005	0.8846	
32	8r6cha9	6x6	Checkerboard	9x9	0.488"	0.8565	0.0005	0.8602	
33	8r6chaa	6x6	Checkerboard	10x10	0.488"	0.8304	0.0006	0.8343	
34	8r6chb6	6x6	Checkerboard	6x6	0.411"	0.8197	0.0005	0.8234	
35	8r6chb7	6x6	Checkerboard	7x7	0.411"	0.8646	0.0005	0.8684	
36	8r6chb8	6x6	Checkerboard	8x8	0.411"	0.8837	0.0005	**0.8875**	
37	8r6chb9	6x6	Checkerboard	9x9	0.411"	0.8838	0.0005	0.8875	
38	8r6chba	6x6	Checkerboard	10x10	0.411"	0.8703	0.0006	0.8742	
39	8r6chbb	6x6	Checkerboard	11x11	0.411"	0.8475	0.0005	0.8512	
Potential Poison Plate Damage									
30	8r6cha7	6x6	Checkerboard	7x7	0.488"	0.8868	0.0005	0.8906	Standard Condition
40	8r6chf7	6x6	Checkerboard	7x7	0.488"	0.8859	0.0005	0.8896	-0.0010
Eccentric Fuel Positioning									
29	8r6cha6	6x6	Checkerboard	6x6	0.488"	0.8645	0.0005	0.8682	Standard Condition
41	8r6chg6	6x6	Checkerboard	6x6	0.488"	0.8706	0.0005	0.8743	0.0061
30	8r6cha7	6x6	Checkerboard	7x7	0.488"	0.8868	0.0005	0.8906	Standard Condition
42	8r6chg7	6x6	Checkerboard	7x7	0.488"	0.8941	0.0006	0.8981	0.0075
31	8r6cha8	6x6	Checkerboard	8x8	0.488"	0.8809	0.0005	0.8846	Standard Condition
43	8r6chg8	6x6	Checkerboard	8x8	0.488"	0.8890	0.0005	0.8927	0.0081

Table 7.5: Results of Criticality Evaluation for Intact Fuel and Damaged Fuel/Fuel Debris (Damaged Fuel/Fuel Debris modeled as 3-dimensional arrays of fuel fragements)

Fuel Fragments									
	Filename								
	fuel to water volume ratio ->		0.2	0.3	0.4	0.5	0.6	0.8	
	fuel OD	Codes	1	5	2	6	3	4	
	1	1		8r6ch51	8r6ch21	8r6ch61	8r6ch31		
	0.7	7		8r6ch57	8r6ch27	8r6ch67	8r6ch37		
	0.5	2	8r6ch12	8r6ch52	8r6ch22	8r6ch62	8r6ch32	8r6ch42	
	0.35	8		8r6ch58	8r6ch28	8r6ch68	8r6ch38		
	0.2	3	8r6ch13	8r6ch53	8r6ch23	8r6ch63	8r6ch33	8r6ch43	
	0.1	4	8r6ch14	8r6ch54	8r6ch24	8r6ch64	8r6ch34	8r6ch44	
	0.05	5	8r6ch15		8r6ch25		8r6ch35	8r6ch45	
	0.02	6	8r6ch16		8r6ch26		8r6ch36	8r6ch46	
	Maximum k-eff								
	fuel to water volume ratio ->		0.2	0.3	0.4	0.5	0.6	0.8	max
	fuel OD								
	1			0.8084	0.8093	0.8290	0.8540		
	0.7			0.8538	0.8810	0.8778	0.8675		
	0.5		0.7756	0.8498	0.8805	0.8834	0.8713	0.8701	0.8834
	0.35			0.8676	0.8578	0.8736	0.8828		0.8828
	0.2		0.8123	0.8533	0.8725	0.8709	0.8734	0.8740	0.8740
	0.1		0.8195	0.8539	0.8681	0.8695	0.8687	0.8643	0.8695
	0.05		0.8208		0.8627		0.8658	0.8620	0.8658
	0.02		0.8157		0.8575		0.8626	0.8615	0.8626
	max		0.8208	0.8676	0.8805	0.8834	0.8828	0.8740	**0.8834**

Table 7.6: Results of Criticality Evaluation for Intact Fuel and Damaged Fuel/Fuel Debris (Bounding Cases)

Case	Filename	Intact Assembly Class	DFC Pattern	DFC Rod Array	DFC Rod Diameter	k-calc	sigma	max. k-eff
Bounding Condition								
	- 6x6 Intact Assembly, Checkerboard with DFCs, 7x7 rods in DFC							
	- Potential Poison Plate Damage							
	- Eccentric Fuel Positioning							
	- Full External Water Reflection around Containment System (10CFR71.55(b), (d) and (e))							
44	8r6chy2	6x6	Checkerboard	7x7	0.488"	0.8949	0.0005	0.8986
	- Full External Water Reflection around Overpack							
45	8r6chy3	6x6	Checkerboard	7x7	0.488"	0.8952	0.0005	0.8990
	- Full External Water Reflection around Containment System, Internally Dry MPC							
46	8r6chy4	6x6	Checkerboard	7x7	0.488"	0.3463	0.0006	0.3502
	- Infinite Array of Damaged Packages (Full internal and external reflection, 10CFR71.59(a)(2))							
47	8r6chy5	6x6	none	none	none	0.8965	0.0005	**0.9003**
	- Infinite Array of Intact Packages (internally and externally dry, 10CFR71.59(a)(1))							
48	8r6chy6	6x6	none	none	none	0.3816	0.0007	0.3857

Proprietary Information Deleted

Figure 7.1: Radial Cross Section of Criticality Model (Intact Assemblies) generated by MCNP

Proprietary Information Deleted

Figure 7.2: Axial Cross Section of Criticality Model (Intact Assemblies and DFCs) generated by MCNP

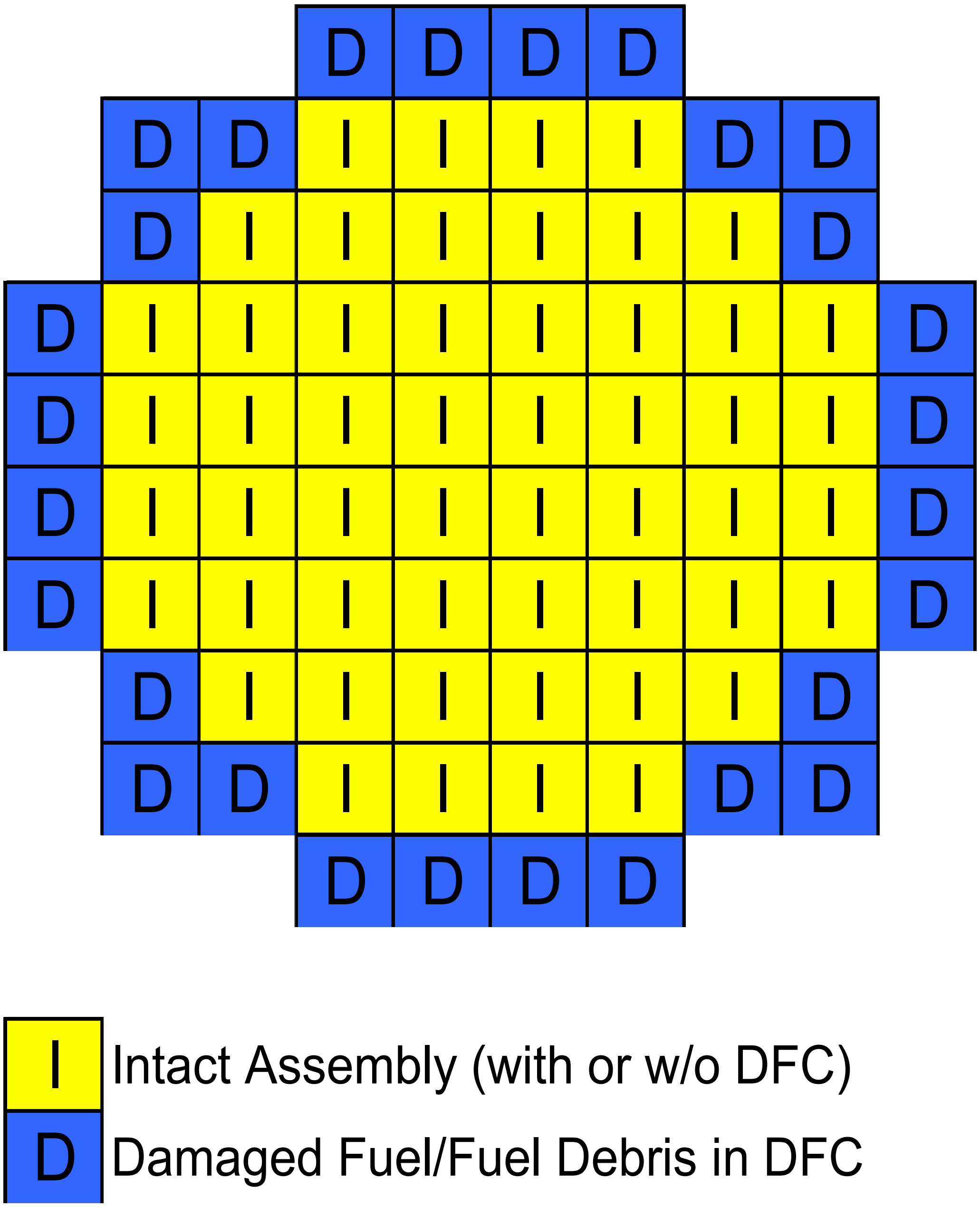


Figure 7.3: Configuration 1: Damaged Fuel/Fuel Debris in Peripheral Cells of Basket only

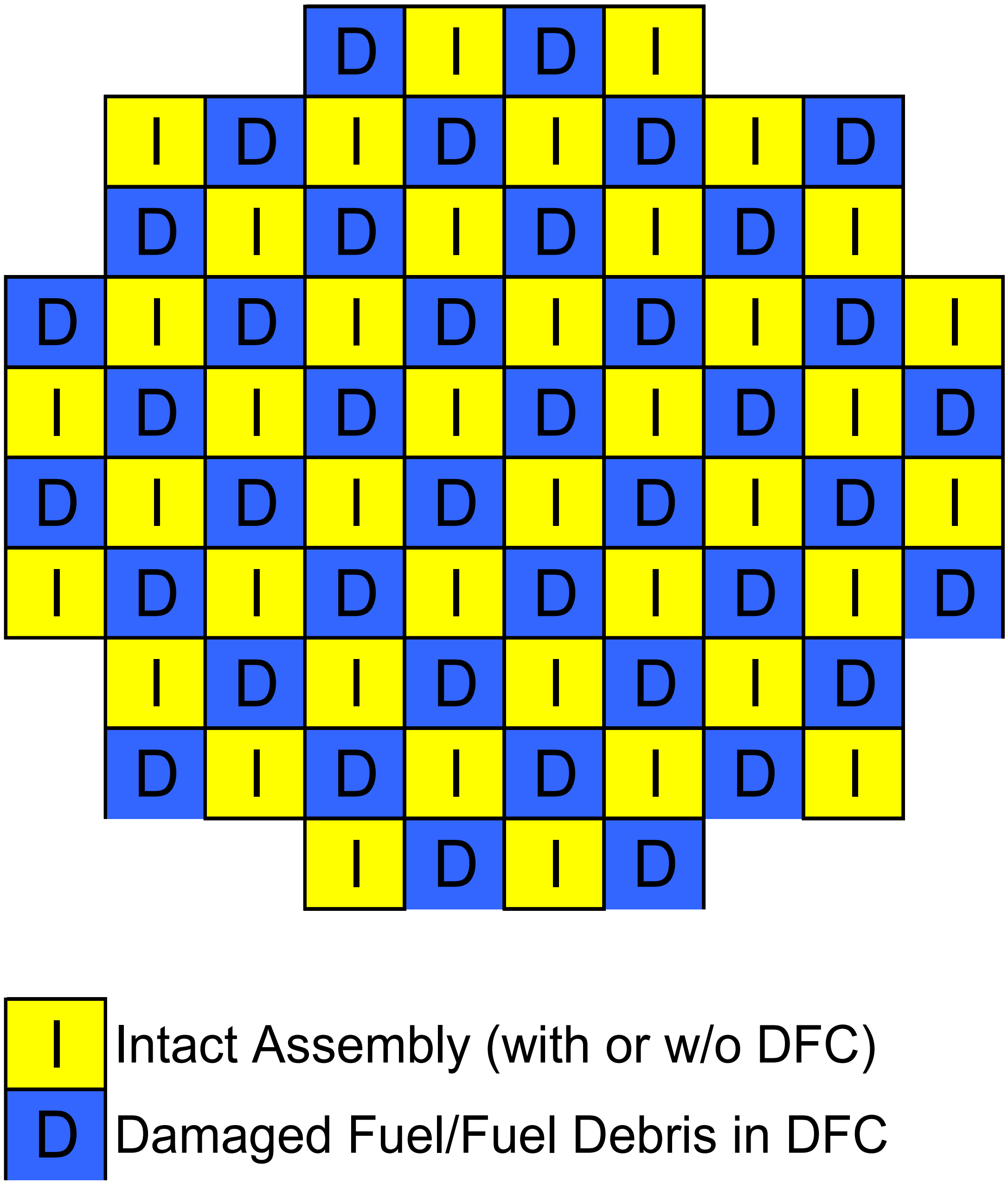


Figure 7.4: Configuration 2: Checkerboard of Damaged Fuel/Fuel Debris and Intact Fuel

Appendix A: Holtec Approved Computer Program List (5 Pages)

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 62 October 2, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
ANSYS (A)	5.3, 5.4, 5.6,5.6.2,5.7,7.0	JZ, EBR, PKC, CWB, SPA, AIS, IR, SP, JRT,AK	Windows		
AC-XPERT	1.12		Windows		
AIRCOOL	5.2I, 6.1		Windows		
BACKFILL	2.0		DOS/ Windows		
BONAMI (Scale)	4.3, 4.4		Windows		
BULKTEM	3.0		DOS/ Windows		
CASMO-4 (A)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ELR, SPA, DMM, KC, ST,VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects. The user should refer to the error notice documented in c4ser.04-results.pdf located in \generic\library\ nuclear\error notices\ concerning the use of version 1.13.04. Library N should be used with version 2.05.03 for all new reports issued after June 1st, 2003. Revisions to reports issued prior to June 1st, 2003 may continue to use the old Library L.	
CASMO-3 (A)	4.4, 4.7	ELR, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		
CHANBP6 (A)	1.0	SJ, PKC, CWB, AIS, SP,JRT	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST REV. 62 October 2, 2003					
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		
DÉCOR	1.0		DOS/Windows		
DR.BEAMPRO	1.0.5		Windows		
DR.FRAME	2.0		Windows		
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ, JRT	DOS/Windows	Personnel qualified to use MR216 are automatically qualified to use DYNAMO.	
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.48, 4.56, 5.1 (see error notice), 4.2.8 (UNS),5.5, 6.1.18	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST,VJB	Windows		
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950, 960, 970	JZ, AIS, SPA, SP, JRT	Windows		
MAXDIS16	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST REV. 62 October 2, 2003					
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
MCNP (A)	4A, 4B	ELR, SPA, KC,ST,DMM , VJB, MAP	Windows/ UNIX	CASMO-4 Lumped Fission Products (IDs 401 and 402) and Isotope Pm148M (ID 61248) can be modeled in MCNP 4A using the cross sections documented in HI-2033031. Use of these cross sections is restricted to MCNP 4A, and to material specifications in atom densities.	**4A**
MASSINV	1.4, 1.5, 2.1		DOS/Windows		
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PKC, SJ,JRT	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	
MSREFINE	1.3, 2.1		DOS/Windows		
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4,2002, 2003		Windows		
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		
ORIGENS (Scale)	4.3, 4.4		Windows		
PD16	1.1, 1.0, 2.0		Windows		
PREDYNA1	1.5, 1.4		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 62 October 2, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
PSD1	1.0		DOS/Windows		
QAD	CGGP		Windows		
SAS2H (Scale)	4.3, 4.4		Windows		
SFMR2A	1.0		DOS/Windows		
SHAPEBUILDER	3.0		DOS/Windows		
SIFATIG	1.0		DOS/Windows		
SOLIDWORKS	2001		DOS/Windows	This program may be used to calculate Weight, Volume, Centroid and Moment of Inertia. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session. If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0, 1.4.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST October 2, 2003				REV. 62	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

NOTES:

1. XXXX = ALPHANUMERIC COMBINATION
2. GENERAL PURPOSES UTILITY CODES (MATHCAD, EXCEL, ETC.) MAYBE USED ANYTIME.

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

HUMBOLDT BAY CASK STORAGE VAULT STRUCTURAL ANALYSIS

FOR

PG&E

Holtec Report No: HI-2033013

Holtec Project No: 1125

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT ISSUANCE AND REVISION STATUS[1]

DOCUMENT NAME: HUMBOLDT BAY CASK STORAGE VAULT STRUCTURAL ANALYSIS

DOCUMENT NO.:	HI-2033013	CATEGORY: ☐	GENERIC
PROJECT NO.:	1125	☒	PROJECT SPECIFIC

Rev. No.[2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	12/16/03	JRT	20450				

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)

Documents labeled "Privileged Intellectual Property" contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 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 "Table of Contents", this page and the "Revision Log".

Revision Log

Revision 0: Initial Issue.

Preface

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 narration smoothness of a Technical Report, and are not intended to serve as a Technical Report.

Because of the Calculation Package's function as a repository of all analyses performed on the subject of its scope, this document is typically revised only if an error is discovered in the computations or the equipment design is modified. Additional analyses in the future will 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.

Table of Contents

List of Appendices **# of Pages**

1.0 Introduction

The Cask Storage Vault (or Independent Spent Fuel Storage Installation (ISFSI)) is a reinforced concrete structure to be used for the storage of five HI-STAR HB casks (Holtec International Storage, Transport, and Repository Cask System, Humboldt Bay) and one Greater Than Class C waste storage cask. The storage vault is located on a relatively flat area of the Buhne Point Hill approximately 300 feet northeast of the Unit 2 Fuel Oil Tank and approximately 70 feet of the bluff cut in the hill that overlooks Humboldt Bay [2, fig 7-1]. The vault is to be buried in the soil so that its top is flush with surrounding soil and roadway. The vault is designed as a stand-alone structure independent of the power plant facilities. The vault is to be loaded with casks in a sequential order beginning at one end and continuing loaded adjacent cells.

This calculation package qualifies the reinforced concrete Cask Storage Vault subject to loadings of the HI-STAR HB casks, earthquake, and others specified in [1] and described in Section 8.3 to the acceptance criteria specified in [1].

2.0 Methodology

The reinforced concrete Cask Storage Vault is analyzed using the finite element method to determine forces and moments on critical sections of the structure. The force and moment output is compared to the capacities of the section through interaction diagrams and safety factors are computed. Two loading conditions of the vault are considered. The first is a single cell loaded and the remaining five cells empty, and the second with all cells loaded with casks.

Proprietary Information Deleted

The Cask Storage Vault rests on a foundation of 3-D finite elements to establish the proper elastic foundation using soil properties. The surrounding soil along the walls of the vault is not modeled. Its lateral pressures from self-weight and seismic conditions are applied as pressure to the walls of the vault. These calculations are performed in Appendix A.

A quasi-static method of seismic analysis is used to apply the earthquake loads to the Cask Storage Vault. Since the vault is considered a stiff structure, the Zero Period Accelerations (ZPA) are applied. The Newmark 100%-40%-40% method of combining orthogonal seismic components is used to preserve the sign (direction) of the response. Reversibility of the horizontal seismic components is considered.

Additional dead, live, and seismic mechanical loads are applied from the HI-STAR and vault lid. These loads are calculated and further described in Appendix E.

The thermal analysis of the Cask Storage Vault is a two-step process consisting of calculating the temperature distribution then the thermal stresses. For the temperature distribution, a loaded cell has the maximum allowable local temperature applied to its inner surface. Empty cells are considered with adiabatic boundary conditions (i.e., zero heat transfer across the surface) applied to their inner surface. The far-field boundary condition is set at the site annual average soil temperature. Adiabatic boundary conditions also exist over the top surface of the soil and vault. Thermal conductivities are applied to the different materials in the model and the temperature distribution is computed for both loading conditions. A steady-state solution method is used to solve for the nodal temperatures. The nodal temperatures are then used as input to the thermal stress analysis. The resistance to expansion of the vault from the soil is conservatively neglected since it produces compressive loads in the concrete thus increasing its load carrying capacity. The steel liner is not considered in the finite element model when solving for the temperature distribution. Since the liner is thin, it is expected that the temperature through the thickness will be uniform. The shell elements of the liner share common nodes with the adjacent brick elements representing the concrete. Therefore, the nodal temperature distribution is not altered by not including the shell elements in the thermal solution. When computing thermal stresses from the temperature distribution, the shell elements are included and a differential coefficient of thermal expansion between steel and concrete produces thermal stresses.

Results at limiting sections of the reinforced concrete vault are compared to the allowable limits set forth by ACI 349 [14]. General post-processing commands in Ansys [18] are used to sum the force and moment about the centroid of the concrete sections. These results are compared to the capacities of the simplified interaction diagram derived from ShapeBuilder [13].

3.0 References

[1] Specification HBPP-2001-01, Specific Conditions.

[2] Determination of Potential Earthquake-induced Displacements of Critical Slides at HBIP ISFSI Site, Pacific Gas and Electric Company, Geosciences Department Calculation Document Number GEO.HBIP.02.07, revision 0.

[3] Humboldt Bay Power Plant Data Report E, Soil Laboratory Test Data, Humboldt Bay Power Plant ISFSI, revision 0.

[4] Foundation Analysis and Design, 5th Edition, Joseph E. Bowles, McGraw-Hill, 1996.

[5] HI-STAR Dry Fuel Storage Cask Vault, PG&E Humboldt Bay, Holtec International Drawing Number 4105, revision 0.

[6] Dry Cask Vault Layout, PG&E Humboldt Bay, Holtec International Drawing Number 4110, revision 0.

[7] Seismic Analysis of Safety-Related Nuclear Structures and Commentary, ASCE 4-98, American Society of Civil Engineers

[8] Minimum Design Loads for Buildings and Other Structures, ASCE 7-02, American Society of Civil Engineers (ASCE).

[9] Dimensions and Weights for the Humboldt Bay ISFSI Project, Holtec International Report Number HI-2032999, revision 0.

[10] Theory of Elasticity, 3rd Edition, S. P. Timoshenko and J. N. Goodier, McGraw-Hill, 1970.

[11] Vibration Problems in Engineering, 3rd Edition, S. Timoshenko and D. H. Young, D. van Nostrand Company, Inc., 1955.

[12] Mechanical Design and Systems Handbook, 2nd Edition, Harold A. Rothbart, McGraw-Hill, 1985.

[13] ShapeBuilder 3.0, version 3.00.002, Integrated Engineering Software, Inc., 2002.

[14] Code Requirements for Nuclear Safety Related Concrete Structures (ACI-349-01) and Commentary (ACI-349R-01), American Concrete Institute (ACI), 2001.

[15] Fault Normal Fling Response Spectra and Time History, file: G:\Projects\1125\Time Histories\ISFSI Time Histories\Final Spectra\FN_Fling_Spectra.xls, created by Humboldt Bay.

[16] Fault Parallel Response Spectra and Time History, file: G:\Projects\1125\Time Histories\ISFSI Time Histories\Final Spectra\FP_Spectra.xls, created by Humboldt Bay

[17] Vertical Fling Response Spectra and Time History, file: G:\Projects\1125\Time Histories\ISFSI Time Histories\Final Spectra\Vert_Fling_Spectra.xls, created by Humboldt Bay.

[18] Ansys 7.0, Ansys, Inc., October 12, 2002

[19] Seismic Response of HI-STAR HB in Vault Subject to DBE, Holtec International Report Number HI-2033014, revision 0.

[20] Functional Specification for the Diablo Canyon Cask Transporter, Holtec International Report Number HI-2002501, revision 5.

[21] Humboldt Bay Thermal / Hydraulic Analysis, Holtec International Report Number HI-2033033, revision 0.

[22] Heating, Ventilating, and Air-Conditioning Systems and Applications, 1987 ASHRAE Handbook, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

[23] ASME Boiler and Pressure Vessel Code, 1995, Section III, Division 1, Subsection NF, Supports, The American Society of Mechanical Engineers.

[24] Evaluation of Explosion for the HBPP ISFSI, Holtec International Report Number HI-2033041, revision 1.

[25] Not Used.

[26] NUREG-1536, Standard Review Plan for Dry Cask Storage Systems, January 1997.

[27] NUREG-1567, Standard Review Plan for Spent Fuel Dry Storage Facilities, March 2000.

[28] Regulatory Guide 1.142, Safety-Related Concrete Structures for Nuclear Power Plants (Other Than Reactor Vessels and Containments), revision 2, November 2001.

[29] Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement, American Society for Testing and Materials (ASTM) Designation A 615 / A 615M – 96a, 1996.

[30] ASME Boiler and Pressure Vessel Code, 1995, Section II, Part D, Properties, The American Society of Mechanical Engineers.

[31] HI-STAR FSAR, Holtec International Storage, Transport, and Repository Cask System, Final Safety Analysis Report, Report Number HI-2012610, revision 1.

[32] Reinforced Concrete Design, 6th Edition, Chu-Kia Wang and Charles G. Salmon, John Wiley and Sons, Inc., 2002.

[33] Heating, Ventilating, and Air-Conditioning Systems and Applications, ASHRAE Handbook, 1997, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

[34] ACI 340.1R-91, Design Handbook, Volume 1, Beams, One-Way Slabs, Brakcets, Footings, and Pile Caps, Publication SP-17(91), American Concrete Institute (ACI), April 1991.

[35] Not Used.

[36] Theory of Plates and Shells, S. Timoshenko, McGraw-Hill, 1940.

[37] Letter from Humboldt Bay to Holtec International, dated: August 1st, 2003, subject: Humboldt Bay ISFSI Project, Transmittal of Engineering Documents and Information (soil properties). Letter with two attachments, total pages: 11.

[38] Email from Lawrence Pulley of Humboldt Bay to Eric Lewis of Holtec International, dated: Tuesday May 20th, 2003, subject: Time History Polarity.

[39] Miscellaneous Calculations for the HI-STAR HB, Holtec International Report Number HI-2033042, revision 0.

[40] Letter from Humboldt Bay to Holtec International, dated: August 12st, 2003, subject: Humboldt Bay ISFSI Project, Estimates of Passive Earth Pressure for HBPP ISFSI.

4.0 Input

4.1 The geometry and weight of the vault and liner are taken from drawings [5 and 6].

4.2 The soil properties are taken from [2 and 37] and elastic properties are calculated in Appendix A.

4.3 The ZPA in the fault normal, fault parallel, and vertical directions are taken from [15, 16, and 17], respectively, and used to determine the seismic accelerations in accordance with the Newmark 100%-40%-40% Method in Appendix C.

4.4 The location and orientation of the Cask Storage Vault at the Humboldt Bay site is shown in [2, fig 7.1] and Appendix D. The orientation given in Appendix D is used to transform the seismic accelerations originally parallel and perpendicular to the fault line into a coordinate system orthogonal to the vault in Appendix C.

4.5 Appendix E contains miscellaneous load input used in the finite element model.

4.6 Appendix F uses ShapeBuilder [13] to calculate the reinforced concrete capacities and interaction diagrams of the analyzed sections as described in Section 8.8. All reinforcement bars specified in [5] are #9 spaced at 12".

Accelerations

Fault normal ZPA	1.316 g
Fault parallel ZPA	1.316 g
Vertical ZPA	1.673 g

5.0 Acceptance Criteria

The acceptance criterion for the reinforced concrete vault is the strength design method of ACI 349-01 [14] as specified in [1, app H and app D]. Reference [1, app H] specifies ACI 349-97 while [1, app D] lists ACI 349-01 (2001). Given the conflicting versions of the ACI 349 code, the most recent is chosen as the acceptance criteria.

6.0 Assumptions

6.1 The reinforced concrete density is taken as 150 lbf / ft^3 [32, pg 7].

6.2 The top edge of the upper gussets [6, item 11] is co-planar with the bottom edge of the lid ring [6, item 3]. This is a modeling simplification that has no adverse impacts on the results. The actual overlap between components is approximately 1" [6, sheet 4].

6.3 The steel liner's mid-plane surface is modeled on a 108" diameter. The actual mid-plane diameter is 107 ½". This is a modeling simplification allowing the shell elements of the liner to be modeled on coincident nodes with the adjacent brick elements of the concrete.

6.4 The square anchor blocks under the lid ring are not modeled since they are not relevant to the global behavior of the vault.

6.5 A uniformly distributed load representing the weight of the lids is assumed to be present on all lid rings regardless of the loading scenario considered.

6.6 Seismic induced crawler loads on the vault are not considered in this analysis. They are addressed by a Probability Risk Assessment (PRA).

6.7 The maximum downward acceleration is assumed to be 1.0 g as to keep the vault from leaving the ground. This is a realistic assumption.

6.8 The maximum cask-to-vault impact loads are assumed to occur in phase and simultaneously in each cell.

6.9 The steel liner shell elements share coincident nodes with the concrete brick elements. This couples the movement of the steel shell to the concrete. This is an appropriate assumption since attached calculations have shown that the shearing stress between the liner and concrete due to differential thermal expansion is small compared to the bond strength between smooth reinforcement and concrete.

6.10 The lids are not modeled in the analysis. However, their weight is applied as a uniformly distributed pressure in mechanical loads cases. This conservatively neglects any increase in stiffness of the vault provided by the lid.

6.11 Cracked section properties are considered for thermal loads where the tensile stress exceeds the tensile stress of the section. This is consistent with [14, app A, sec A.3.3].

6.12 All materials are assumed to be homogeneous, isotropic, and linear elastic.

6.13 The maximum local temperature of 200°F is assumed as the temperature of the inside of cells. This conservatively produces a larger thermal gradient through the concrete vault. Empty cells are assumed to have adiabatic boundary conditions.

6.14 For the all cells loaded condition, all six cells are assumed to be loaded with casks. The sixth cell is actually loaded with Greater Than Class C waste, which is bounded by the weight of the HI-STAR. This is conservative.

6.15 Cask seismic impact loads recommended by [19] are used in this analysis. They are distributed over an area approximately equal to the size of the backing plate of the gusset assembly. This load redistribution has no adverse effects on the global behavior of the vault. Their local effects are considered in the appendices of this report.

6.16 The gusset impact loads are assumed to occur on one top and one bottom gusset. This concentrates the impact load to one area. An additional load case is created from the load combination producing the lowest safety factors that evenly distributes the impact loads over two gussets.

6.17 The geometry input of the finite element model is based on a preliminary design and differs from the dimensions given in [5]. The overall height of the vault has increased by 1 ½" and the crawler track has been raised 3" from its original elevation. These increases raise the weight of the vault, which has been included in the calculation but has no significant impact. The change in the overall height increases the bending properties of the vault cross-section. Therefore, neglecting these geometry changes are conservative.

6.18 Structural calculations for the steel liner are not performed. The primary purpose of the liner is to provide a form for the pouring the concrete. However, the gussets will be designed to transfer the seismic impact loads of the HI-STAR to the concrete in another report.

6.19 Flood loads are inapplicable since the flood is defined as + 12' 6" MLLW [1, sec 6.2.4] and the vault site is at approximately + 44' MLLW [2, fig 7.1].

6.20 Thermal stresses in vault are computed without the resistance of the surrounding soil. This is conservative since the stiffness of the soil would introduce compression in the vault.

7.0 Computer Codes

This report is prepared using Microsoft Word, 2000, Microsoft Corporation. Many of the appendices are prepared using Mathcad 2000 Professional, Mathsoft, Inc. The Holtec quality approved program ShapeBuilder 3.0 [13] is used to compute the capacities of reinforced concrete sections. The Holtec quality approved program Ansys 7.0 [18] is used to perform the finite element analysis. All Holtec quality approved programs are listed in Appendix AA.

8.0 Analysis

8.1 Model Description

A generic finite element model (geometry only) is created as the common foundation for the mechanical analysis, thermal analysis, and post-processing. A second thermal model includes soil extending to the top of the vault to determine the temperature distribution in the concrete and surrounding soil. Then, the nodal temperatures are used as input to a thermal model that does not include the soil on the sides of the vault so that thermal stresses in the concrete can be calculated without the influence of resisting soil loads.

The dimensional input is taken from drawings [5 and 6]. Figure 1 shows the dimensional information used on the input file of Appendix H. From the symmetry of the vault, the geometry for a quarter cell is created, extruded through the height, reflected to complete a single cell, and then copied for each cell.

Holtec Proprietary Figure

Figure 1

Figure 1 also shows discrete element division lines that allow for controlled output sampling locations such as the thinnest section between adjacent cells and a cross-section of the vault as a whole. Figure 2 shows the complete finite element model of the vault without the soil. The element discretization is such that it produces low stress gradients amongst adjacent elements as shown in the Section 10.0.

Proprietary Information Deleted regarding Figure 2

Figure 2

The concrete portions of the vault are modeled using 8-node brick elements. The steel liner is modeled with 4-node shell elements (plate) and 8-node brick elements (lid ring). The soil is modeled with 8-node brick elements.

Proprietary Information Deleted regarding Figure 3

Figure 3

The steel liner shell elements share nodes with the inside face of the brick elements that model the concrete. Therefore, the steel liner and concrete are coupled. This is a reasonable assumption supported by additional calculations that show the shear stresses developed between the liner and concrete due to the difference in coefficients of thermal expansion are small compared to the bond strength between smooth steel and concrete. The mid-plane of the steel liner shell elements is modeled at the surface of the concrete elements. A local cylindrical coordinate system is located at the intersection of the centerline axis and bottom plate of each cell shown in Figure 4. The cells are numbered as follows in the finite element input files: cell 11 is at the far left in Figures 3 and 4 and each cell is sequentially numbered to the right ending at cell 16. The global Cartesian system triad in Figure 5 shows the positive X, Y and Z direction. The true location of the global Cartesian coordinate system is at the geometric center of the vault in between cells 13 and 14 at an elevation equivalent to the bottom of the cells in Figure 4.

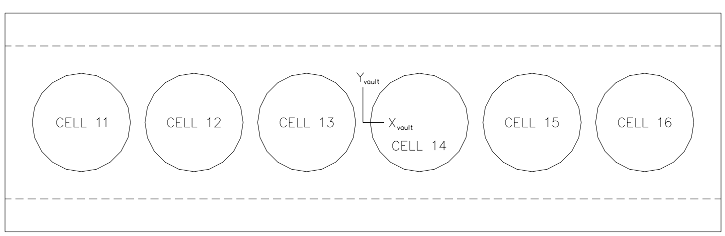


Figure 4

Proprietary Information Deleted regarding Figure 5

Figure 5

Figure 5 shows the finite element model of the vault and soil foundation. The soil is modeled out to three characteristic vault dimensions to ensure the boundary conditions do not influence the results local to the vault.

The reinforcement is not included in the model; therefore, the stiffness of the model is based solely on the properties of concrete. This is consistent with standard modeling practice.

8.2 Boundary Conditions

Three characteristic dimensions in all directions of soil are modeled surrounding the Cask Storage Vault. This is considered far enough away from the vault that boundary condition effects will not influence the results. The dimensions of the soil modeled are mentioned in Appendix A.

Mechanical Boundary Conditions

The mechanical boundary conditions consist of fixing the far-field boundaries of the soil against translation and rotation in all directions. The vault is supported by a linear elastic continuum of elements representing the soil foundation. The top of the vault and soil are free from restraint against translation and rotation.

Thermal Boundary Conditions

The thermal boundary conditions are summarized in the table below.

Description	Value	Reference
Far-field soil temperature	52°F	[33, sec 12, table 3, Eureka, CA]
Soil/vault-air interface temperature	52°F	[1, sec 6.4.11.1, average annual]
Soil/vault-air interface	Adiabatic	(see Section 6)
Loaded cell temperature*	200°F	[1, sec 6.4.8] (see Section 6)
Unloaded cell	Adiabatic	(see Section 6)

* Local vault concrete temperature upper limit

8.3 Loads

This section describes the loads applicable to the vault as specified in [1, sec 6.1.6.1]. The loads described here are applied to the steel shell liner and reinforced concrete structure. The values of each load used in the finite element model are calculated in Appendix E.

Dead Loads, D

The dead load consists of the weight of the reinforced concrete vault and steel shell liner. The weight of the HI-STAR is included as a uniformly distributed pressure load over the area of the drain ring. The weight of the lid is included as a uniformly distributed pressure over the area of the lid ring. The weight of all six lids is present in all loading configurations.

Live Loads, L

The live load of the Transporter (crawler) is modeled as a uniformly distributed load over its track length. The crawler is assumed to be in two worst-case positions. For a single cell loaded with a cask, the crawler is located at the end of the vault approximately centered over Cell 11. For all of the cells loaded with casks, the crawler is approximately centered over the length of the vault. The loading from the crawler is applied to elements that have centerlines wider than that of the crawler tracks. This conservatively produces more bending on the crawler track extensions of the vault. However, when qualifying the crawler track extensions of the vault, mechanics of materials methods are used with the crawler loading properly located. The live load of the crawler always assumes it is carrying a HI-STAR for the one cell loaded case and not carrying a HI-STAR for the all cells loaded case.

Additional live loads from snow and rain (including the 1.7 load factor) are negligible and bounded by the tsunami load and/or explosion loads. By observing the site climate conditions of [1, sec 6.4.11], it is highly unlikely that snow loads would even occur in Eureka, California. Also, the average annual rainfall (including the 1.7 live load factor) is almost bounded by the tsunami load.

Thermal Loads, T_o

The thermal loads are calculated using the finite element method to solve a heat transfer problem in a separate model and nodal temperatures are subsequently used to determine thermal stresses in the vault. The maximum local temperature of 200°F [1, sec 6.4.8] is applied to the inside of the cell. The average annual soil temperature of 52°F [33, table 3, pg 12.7, Eureka, CA] is applied at the far-field boundaries of the model. The top of the soil and top of the vault are given adiabatic boundary conditions at 52°F. For the case of a single cell loaded, the remaining cells are also given adiabatic boundary conditions at 52°F. Using the maximum local temperature throughout the inside of the cell will conservatively produce the maximum temperature gradient through the vault walls towards the soil. The thermal conductivity values used in the analysis are documented in Appendix E. The soil surrounding the vault is modeled to determine the temperature distribution.

Thermal stresses develop in the concrete due to temperature gradients and differences between coefficients of thermal expansion between the concrete and steel liner. The assumption of modeling the shell liner attached at the nodes of the concrete elements is a valid assumption since differential axial expansion does not produce significant shear stresses between the concrete and steel.

The soil surrounding the vault is not modeled when determining thermal stresses in the vault. The passive earth pressure is negligible due to thermal expansion. As per Reference [40], the vault needs to expand about 6" to develop a full passive pressure of 31,180 lbf per foot of wall. As shown in Figure 11 the total longitudinal expansion of the vault is about 1". Using Reference [40], the passive earth pressure coefficient, K_p, reduced from 3.0 to about 1.0. This reduces the total load on the vault from the passive earth pressure to a negligible force of approximately 156,000 lbf.

Material properties of the steel liner are based on the maximum local temperature given in [1, sec 6.4.8] and listed in Section 8.6.

Initially, the analysis is performed considering un-cracked sections of concrete. In accordance with [14, app A, sec A.3.3], if the tensile stress on any section exceeds the tensile stress capacity, the section may be considered cracked. A section between adjacent cells does exceed the tensile capacity for the single cask loaded case; therefore, the cracked section properties are calculated in Appendix F.

Pressure Loads, P_n

There are no applicable pressure loads that effect the Cask Storage Vault except for those classified as other loads listed below in this section.

Earthquake Loads, DBE

A quasi-static method for calculating seismic accelerations is used to determine the earthquake loads applied to the Cask Storage Vault. The vault structure is considered rigid, therefore, the ZPA for the fault normal, fault parallel, and vertical components as taken from [15 thru 17]. The acceleration is taken at 7% critical damping for reinforced concrete structures as per [1, sec 6.2.5.3]. The Design Basis Earthquake (DBE) is used to analyze the Cask Storage Vault as per [1, sec 6.2.5.1].

The longitudinal axis of the Cask Storage Vault is oriented 19^{o} clockwise from the normal of the Bay Entrance fault as shown in Appendix D. A coordinate transformation is performed to align the fault normal and fault parallel components of the earthquake to the longitudinal and transverse axes of the vault, respectively in Appendix C. The quasi-static method of combining the seismic components is the Newmark 100-40-40 Method specified in [1, sec 6.2.5.5 IV].

Cask-to-vault impact loads that are recommended by [19] are used. The impact loads consist of downward vertical forces uniformly distributed over the bearing area of the drain ring. Also, top and bottom gusset lateral forces uniformly distributed over elements with areas approximately equal to the projection of the load distribution through the gussets. The orientation of the gusset impact loads is directed radially and applied in a direction consistent with the larger of the horizontal accelerations. The vertical and horizontal impact loads are assumed to occur in-phase and simultaneously. This is conservative since it is highly unlikely that all HI-STARs will produce the maximum impact load simultaneously. These impact loads are independent of the inertia forces and therefore are always applied at 100% of their capacity. Also, an additional load case is considered where the impact loads are evenly distributed over two gussets.

Wind Loads, W

Wind loads are bounded by tornado winds.

Tornado Wind Loads, W_t

As with the wind loads, the tornado wind loads are inapplicable since the vault is buried. The pressure differential specified in [1, sec 6.2.2.3] reduces the dead weight load of the soil pressure and lid weight.

Tornado Generated Missiles

Given the massiveness of the reinforced concrete vault, tornado missiles and their impacts on the reinforced concrete structure will not produce any adverse structural effects. While local spalling can occur, the structural integrity of the vault will remain intact. The tornado missiles considered are as per [1, sec 6.2.2.5], defined in NUREG-0800, Section 3.5.1.4, “Missiles Generated by Natural Phenomena”.

Blast and Explosion Overpressures

The upper and lower explosion overpressures bound the tsunami pressure. Since explosion and tsunami loadings occur in similar load combinations, only the upper and lower explosion loads are considered [24].

Tsunami, A

The tsunami load considers six feet of water over the top of the vault. The tsunami load is bounded by the explosion load.

Flood

Flood loads are inapplicable to the vault site.

Lateral Earth Pressure, H

The lateral earth pressure is determined from the type of soil and [8].

Soil Surcharge Pressure

The crawler load on the crawler track extensions will not give rise to significant soil surcharge pressures on the walls of the vault since the crawler track is positioned partially over the bulk section of the vault (see Appendix F for a sketch).

External Man-Induced Events

There are no external man-induced events perceivable at the Cask Storage Vault. Therefore, no loads of this category are considered.

8.4 Load Combinations

In accordance with [1, sec 6.4.12.2 and app D], the loads are to be combined by ACI-349-01 [14, sec 9.2.1] for the reinforced concrete portions of the structure. Reference [1, sec. 6.1.6.2] specifies [26, sec. 3.0 IV], [27, sec. 5.4.3.2], and [28, sec. B] for structures licensed under 10 CFR 72. However, their load combinations are either included or bounded by ACI 349-01 [14] with some exceptions noted below. Although [28] states the 1997 edition of ACI 349 to be used, [1, sec. 6.4.12.2, and app D] references the 2001 edition, therefore, the vault structural analysis will comply to the 2001 edition load cases and combinations. The load cases as given in [14, sec. 9.2.1] are:

8.4.1 Reinforced Concrete

ACI 349-01 Load Combinations [14]

1. $U = 1.4D + 1.4F + 1.7L + 1.7H + 1.7R_o$

2. $U = 1.4D + 1.4F + 1.7L + 1.7H + 1.7E_o + 1.7R_o$

3. $U = 1.4D + 1.4F + 1.7L + 1.7H + 1.7W + 1.7R_o$

4. $U = D + F + L + H + T_o + R_o + E_{ss}$

5. $U = D + F + L + H + T_o + R_o + W_t$

6. $U = D + F + L + H + T_a + R_a + 1.25P_a$

7. $U = D + F + L + H + T_a + R_a + 1.15P_a + 1.0(Y_r + Y_j + Y_m) + 1.15E_o$

8. $U = D + F + L + H + T_a + R_a + 1.0P_a + 1.0(Y_r + Y_j + Y_m) + 1.0E_{ss}$

9. $U = 1.05D + 1.05F + 1.3L + 1.3H + 1.05T_o + 1.3R_o$

10. $U = 1.05D + 1.05F + 1.3L + 1.3H + 1.3E_o + 1.05T_o + 1.3R_o$

11. $U = 1.05D + 1.05F + 1.3L + 1.3H + 1.3W + 1.05T_o + 1.3R_o$

NUREG 1536 Applicable Accident Load Combination [26]

$U = D + L + H + T_o + A$

ACI 349-01 Definitions

U = required strength to resist factored loads.
D = dead loads including piping and equipment dead loads.
F = loads due to weight and pressures of fluids with well-defined densities and controllable maximum heights.
L = live loads.
H = loads due to weight and pressure of soil, water in soil, or other materials.
R_o = piping and equipment reactions which occur under normal operating and shutdown conditions, excluding dead load and earthquake reactions.
E_o = load effects of operating basis earthquake (OBE) including OBE-induced piping and equipment reactions.
W = operating basis wind load (OBW).
T_o = internal moments and forces caused by temperature distributions within the concrete structure occurring as a result of normal operating or shutdown conditions.
E_{ss} = load effects of safe shutdown earthquake (SSE) including SSE-induced piping and equipment reactions.
W_t = loads generated by the design basis tornado (DBT). These include loads due to tornado wind pressure, tornado created differential pressure, and tornado generated missiles.

T_a = internal moments and forces caused by temperature distributions within the concrete structure occurring as a result of accident conditions generated by a postulated pipe break and including T_o.

R_a = piping and equipment reactions under thermal conditions generated by a postulated pipe break and including R_o.

P_a = differential pressure load generated by a postulated pipe break.

Y_j = jet impingement load on the structure generated by a postulated pipe break.

Y_m = missile impact load on structure generated by a postulated pipe break.

Y_r = loads on structure generated by the reaction of the broken pipe during a postulated break.

NUREG 1536 [26, sec. 3] Definitions

A = accident loads attributable to the direct and secondary effects of an off-normal or design basis accident, as could result from and explosion, crash, drop, impact, collapse, gross negligence, or other man-induced occurrences, or from severe natural phenomena not separately defined.

Inapplicable and/or Bounded Loads for the vault analysis

F, R_o, E_o, W, R_a, P_a, Y_j, Y_m, Y_r, T_a

Load Interpretations

"E_{ss}" is be taken as the DBE. "A" is considered the tsunami or explosion loads.

Load Factor Modifications

The only applicable load with a factor to be modified is T_o. ACI 349-01 [14, sec. 9.2.1] specifies a load factor of 1.05 in case 9, 10, and 11. Reg. Guide 1.142 [28, page 1.142-7] specifies to increase the load factor on T_o in case 9, 10, and 11 from 1.05 to 1.2. NUREG 1536 [26, page 3-40] uses a factor on T_o of 1.275. Since NUREG 1536 is bounding for the load factor on T_o, it will be used. All other load factors and combinations are bounded by the ACI 349 code. Also, T_a of load case 8 is an accident temperature associated with a postulated pipe break. Since there are no accident temperatures associated with the cask in the vault, the normal operation temperature T_o, will replace T_a, when the E_{ss} event is considered. The load combinations of ACI 349 reduce to:

$$U = 1.4D + 1.7L + 1.7H$$

$$U = D + L + H + T_o + W_T$$

$$U = D + L + H + T_o + E_{ss}$$

$$U = 1.05D + 1.3L + 1.3H + 1.275T_o$$

$U = D + L + H + T_o + A$

The load combination including the seismic loading, E_{ss}, is expanded to include the reversibility of the horizontal components and all permutations of the Newmark 100-40-40 Method. The load combination including the explosion pressure, A, is expanded to include the maximum and minimum pressures. A Probability Risk Assessment addresses the likelihood of the crawler being on the vault during a seismic event. Therefore, the live load and crawler seismic reactions are not included in the $U = D + L + H + T_o + E_{ss}$ load combination.

8.4.2 Finite Element Input Files

The following tables describe the finite element input files of Appendices J, K, M, N, and Z. When creating the loads in the finite element database, unit loads are used where possible.

Applied Loads in Finite Element Model

Load case identifier	**Used for categories**	**Applied to component**	**Description**
Mechanical Loads, results file: mech.rst			
1	D, H		Acceleration in Z_{global} 386 in/s^2 (1g) vert
2	D, E_{ss}	dr_11	Cell 11 HI-STAR drain ring 1.0 psi
3	D, E_{ss}	dr_12	Cell 12 HI-STAR drain ring 1.0 psi
4	D, E_{ss}	dr_13	Cell 13 HI-STAR drain ring 1.0 psi
5	D, E_{ss}	dr_14	Cell 14 HI-STAR drain ring 1.0 psi
6	D, E_{ss}	dr_15	Cell 15 HI-STAR drain ring 1.0 psi
7	D, E_{ss}	dr_16	Cell 16 HI-STAR drain ring 1.0 psi
8	D, E_{ss}, A	lidring	All lid ring loadings 1.0 psi
9	H	soil_ovb	Soil overburden pressure 1.0 psi
10	H	foot_top	Soil Overburden pressure on footing 1.0 psi
11	H		Lateral Soil Pressure
12	L, E_{ss}	crwl_11	Crawler load cell 11 loaded only 1.0 psi

13	L, E_{ss}	crwl_full	Crawler load all cells loaded 1.0 psi
14	W_T, A	soil_top, vaulttop	Tornado reduction in atm pressure load, 1.0 psi
15	W_T		Tornado reduction in soil pressure
16	W_T		Tornado vertical bolt load, 1.0 lbf
17	A		Lateral soil pressure increase from explosion and tsunami 1.0 psi
Thermal Loads, results file: therm.rst			
1	T_o		cell 11 loaded, 200°F inside, 52°F soil, 0 heat flux b.c. in remaining cells and soil and vault –air interface
2	T_o		cells 11 thru 12 loaded, 200°F inside, 52°F soil, 0 heat flux b.c. in remaining cells and soil and vault –air interface
3	T_o		cells 11 thru 13 loaded, 200°F inside, 52°F soil, 0 heat flux b.c. in remaining cells and soil and vault –air interface
4	T_o		cells 11 thru 14 loaded, 200°F inside, 52°F soil, 0 heat flux b.c. in remaining cells and soil and vault –air interface
5	T_o		cells 11 thru 15 loaded, 200°F inside, 52°F soil, 0 heat flux b.c. in remaining cells and soil and vault –air interface
6	T_o		cells 11 thru 16 loaded, 200°F inside, 52°F soil, 0 heat flux b.c. on soil and vault –air interface

Applied Loads in Finite Element Model			
Load case identifier	**Used for categories**	**Applied to component**	**Description**
Seismic Loads, results file: seismic.rst			
1	E_{ss}		Acceleration in Z_{global} 1.0 in/s^2 vert
2	E_{ss}		Acceleration in X_{global} 1.0 in/s^2
3	E_{ss}		Acceleration in Y_{global} 1.0 in/s^2
4	E_{imp}	tr_11pp	Cell 11 top gusset impact load, 1.0 psi
5	E_{imp}	br_11pp	Cell 11 bottom gusset impact load, 1.0 psi
6	E_{imp}	tr_12pp	Cell 12 top gusset impact load, 1.0 psi
7	E_{imp}	br_12pp	Cell 12 bottom gusset impact load, 1.0 psi
8	E_{imp}	tr_13pp	Cell 13 top gusset impact load, 1.0 psi
9	E_{imp}	br_13pp	Cell 13 bottom gusset impact load, 1.0 psi
10	E_{imp}	tr_14pp	Cell 14 top gusset impact load, 1.0 psi
11	E_{imp}	br_14pp	Cell 14 bottom gusset impact load, 1.0 psi
12	E_{imp}	tr_15pp	Cell 15 top gusset impact load, 1.0 psi
13	E_{imp}	br_15pp	Cell 15 bottom gusset impact load, 1.0 psi
14	E_{imp}	tr_16pp	Cell 16 top gusset impact load, 1.0 psi
15	E_{imp}	br_16pp	Cell 16 bottom gusset impact load, 1.0 psi
16	E_{ss}	crwl_end	Crawler Y-direction friction load 1.0 lbf
17	E_{ss}	crwl_end	Crawler X-direction friction load 1.0 lbf

18	E_{ss}	crwl_mid	Crawler Y-direction friction load 1.0 lbf
19	E_{ss}	crwl_mid	Crawler X-direction friction load 1.0 lbf
20	E_{ss}		Bolt X-direction load 1.0 lbf
21	E_{ss}		Bolt Y-direction load 1.0 lbf
22	E_{ss}	soil_plt	Lateral soil pressure
23	E_{ss}	soil_plt	Lateral soil pressure
24	E_{ss}	soil_pet	Lateral soil pressure
25	E_{ss}	soil_pet	Lateral soil pressure
26	E_{ss}	soil_plm	Lateral soil pressure
27	E_{ss}	soil_plm	Lateral soil pressure
28	E_{ss}	soil_pem	Lateral soil pressure
29	E_{ss}	soil_pem	Lateral soil pressure
30	E_{ss}	soil_plb	Lateral soil pressure
31	E_{ss}	soil_plb	Lateral soil pressure
32	E_{ss}	soil_peb	Lateral soil pressure
33	E_{ss}	soil_peb	Lateral soil pressure
34	E_{imp}		Impact load over two gussets 1.0 psi

8.5 Cask Loading Configurations

Reference [1, sec 6.4.5] states that the vault analysis shall consider the loading schemes from only one cell loaded to all cells loaded. For the all cells loaded case, all six cell will be loaded with casks, therefore, bounding the Greater Than Class C waste cask. The cask loading configurations considered in this analysis are only a single cell loaded (cell 11 shown in Figure 7) and all cells loaded. The cask loading configurations for two through five cells loaded are considered bounded by two configurations by inspection. The input files for these load combinations are created with the individual loads given in the tables above and listed in Appendices O and P.

8.6 Material Properties

Reinforced Concrete

Property	Value	Reference
Compressive Strength	4,000 psi	[6, sheet 2]
Modulus of Elasticity*	3.6×10^{6} psi	[14, sec 8.5]
Poisson's Ratio	0.17	[7, sec 3.1.2.1.1]
Reinforcement Yield Strength**	60,000 psi	[6, sheet 2], [29]
Thermal Conductivity	1.0 Btu / ft-hr-^{o}F	[21]
Coefficient of Thermal Expansion	5.5×10^{-6} in / in / ^{o}F	[14, app A]

Density	150 lbf / ft^3	(see Section 6)

* $57{,}000 \times \sqrt{f_c}$, where f_c is the compressive strength of concrete

** ASTM A 615 grade 60

Carbon Steel Shell Liner, ASME SA-36*

Property	Value	Reference
Modulus of Elasticity**	28.8×10^6 psi	[30, table TM-1]
Poisson's Ratio	0.3	[31, sec 3.3.1.2]
Thermal Conductivity	20.0 Btu / ft-hr-^{o}F	[21]
Coefficient of Thermal Expansion***	5.89×10^{-6} in / in / ^{o}F	[30, table TE-1]
Density	0.283 lbf / in^3	[31, sec 3.3.1.2]

* Property values at 200^{o}F

** Carbon steel with C < 0.30%

*** Mean coefficient of thermal expansion for Material Group C, C-Mn-Si steels

Soil

All soil properties are calculated in Appendix A from [2 and 37] and summarized in the table below. See Appendix A for methodology and references.

Property	Value
Static Shear Modulus	33,952 psi
Static Modulus of Elasticity	90,311 psi
Seismic Shear Modulus	11,875 psi
Seismic Modulus of Elasticity	32,000 psi
Poisson's ratio	0.33
Density	130 lbf / ft^3
Thermal Conductivity*	0.833 Btu / ft-hr-^{o}F [21]

8.7 Evaluation of Reinforced Concrete Properties

The capacities of the reinforced concrete sections considered in the analysis are calculated using ShapeBuilder [13]. Axial tension and compression capacities are obtained directly from the tables given below the section view of the portion of the vault considered in Appendix F. The positive and negative balance force and moment are obtained by inspection of the uni-axial bending force-moment interaction diagrams. The largest positive and negative moments and their corresponding axial force are used. The x-axis in [13] is the horizontal axis while the y-axis is the vertical axis. As shown in Figure 7, the x-axis in [13] corresponds to the y-axis in the finite element model and the y-axis in [13] corresponds to the z-axis in the finite element model. The capacities calculated by [13] are un-factored. Appendix F applies the capacity reduction factors in accordance with [14] and simplifies the interaction diagrams by linearization. The final factored interaction diagrams are shown in Appendix F. From these diagrams, a linear interpolation with a given axial force input calculates an allowable moment. The interpolation formulae are used in post-processing input files (Appendices Q, R, and S) to calculate safety factors for each critical section. Appendix F contains capacities for the thinnest section between adjacent cells, the cross-section of the vault through a cell, and the cantilevered crawler track extension.

Cracked section properties are used in the section between adjacent cells where the axial tension is excessive. During preliminary evaluations, a large tensile load was calculated in a section between adjacent cells in the single cask loaded scenario. The cracked moment of inertia is calculated in accordance with [34, commentary on design aids, deflection 4, pg 358]. To avoid modifying the geometry of the finite element model to update the new cracked moment of inertia, an effective modulus of elasticity is defined. Assuming that the stiffness of the cross-section under consideration is based on flexural properties, the stiffness is then the product of the moment of inertia and the modulus of elasticity. By maintaining the same value for the product and varying the modulus of elasticity by the ratio of the cracked moment of inertia to the un-cracked moment of inertia gives an effective modulus of elasticity.

$$E_{effective} = \frac{I_{cracked}}{I_{uncracked}} * E_{uncracked}$$

The cracked moment of inertia and modulus of elasticity are calculated in Appendix F. The extent of the cracked section properties spans about six elements along the thinnest section between adjacent cells and is applied to one section between cells over the depth of the cell. The cracked section is shown in Figure 6 in darker blue.

Proprietary Information Deleted

Figure 6

Shear capacities are calculated in Appendix F. The shear capacity of the adjacent section between cells and vault u-section includes shear reinforcement from stirrups. Shear force / axial force interaction is considered in the finite element post-processing files and these formulae are given in Appendix F.

8.8 Post-Processing

Concrete Vault

Post-processing is performed through two critical sections of the vault as shown in Figure 7. The adjacent section between cells is considered as the full height of the cell.

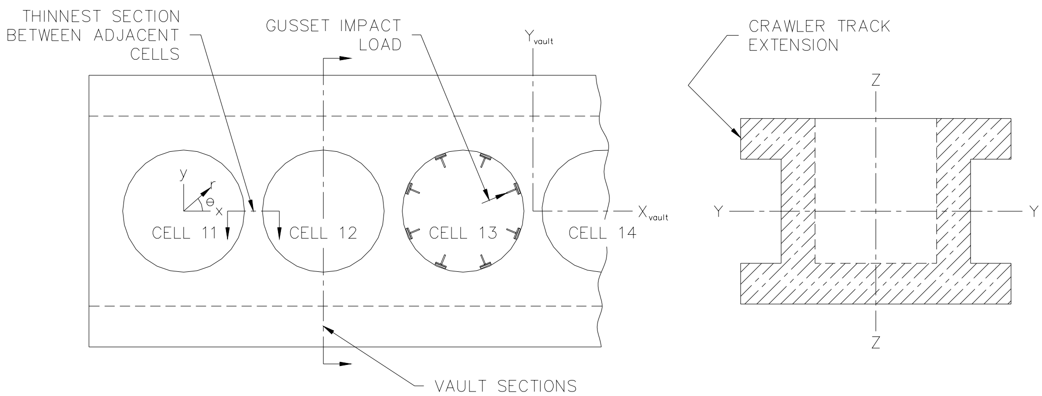


Figure 7

A section cut through the entire vault passing through the center of each cell as shown in Figure 7 considers the global behavior of the vault. Sections through the side of the vault are not considered since there thickness is greater than the section between cells and they are backed by the crawler track.

The elements at the thinnest section between adjacent cells are selected and the force and moment resultants over the section are obtained using built-in ANSYS functions. A temporary local coordinate system is located at the centroid of the current section being processed so that the results are about the neutral axis of the section. The post-processing file loops through and obtains results for each section between adjacent cells. For the vault section, the same rational is used for obtaining results.

The output is listed in Appendices T, U, V, W, X, and Y. The local results coordinate system is parallel to the global coordinate system, so the triad shown in Figures 9 and 10 can be used to orient the direction of the output. Each combination of axial force and bending moment are input into the interaction formulas to determine the allowable moment based on the magnitude of the axial force and calculate safety factors.

Local calculations of the cell bottom and cell side wall adjacent to the soil are performed and contained in Appendix AB.

Vault Lid

The function of the vault lid is to provide long-term shielding. From the dynamic analysis [19] of the casks in the vault, no cask-to-lid impacts occur. Therefore, the lid serves no structural function. However, additional vault lid calculations are performed in Appendix AC.

9.0 Computer Files

The following file listing is maintained on Holtec's computer network.

Address G:\Projects\1125\jtoy\vault\capacities

a-sec.sbf	cell base.sbf	c-sec.sbf	u-sec.sbf

Address G:\Projects\1125\jtoy\vault\mech

comp.inp	mech.inp	mech.page	scratch.hlp
mech.db	mech.lock	mech.rst	vault.inp
mech.err	mech.log	menust.tmp	

Address G:\Projects\1125\jtoy\vault\report

app A.mcd	app D.pdf	app F.mcd
app C.mcd	app E.mcd	HI-2033013.doc

Address G:\Projects\1125\jtoy\vault\seismic

comp.inp	seismic.s03	seismic.s14	seismic.s25
scratch.hlp	seismic.s04	seismic.s15	seismic.s26
seismic.db	seismic.s05	seismic.s16	seismic.s27
seismic.dbb	seismic.s06	seismic.s17	seismic.s28
seismic.esav	seismic.s07	seismic.s18	seismic.s29
seismic.full	seismic.s08	seismic.s19	seismic.s30
seismic.inp	seismic.s09	seismic.s20	vault.err
seismic.mntr	seismic.s10	seismic.s21	vault.inp
seismic.rst	seismic.s11	seismic.s22	vault.log
seismic.s01	seismic.s12	seismic.s23	vault.page
seismic.s02	seismic.s13	seismic.s24	

Address G:\Projects\1125\jtoy\vault\therm

comp.inp	lc6-temp.out	therm6.dbb
comp-vault-temp.inp	lc6-temp.prn	therm6.esav
lc1-temp.out	lc6-temp.xls	therm6.full
lc1-temp.prn	mech-temps.inp	therm6.inp
lc1-temp.xls	post.inp	therm6.mntr
lc2-temp.out	post-asf.inp	therm6.rst
lc2-temp.prn	scratch.hlp	therm6.s01
lc2-temp.xls	temp-dist.db	Thermal Analysis
lc3-temp.out	therm1.db	therm-loads.inp
lc3-temp.prn	therm1.dbb	vault.err
lc3-temp.xls	therm1.esav	vault.inp
lc4-temp.out	therm1.full	vault.log
lc4-temp.prn	therm1.inp	vault.page
lc4-temp.xls	therm1.mntr	vault-nd.lis
lc5-temp.out	therm1.rst	vault-nd.xls
lc5-temp.prn	therm1.s01	vault-temp.inp
lc5-temp.xls	therm6.db	


Address
G:\Projects\1125\jtoy\vault\post
1loaded.db
1loaded.dbb
1loaded.err
1loaded.inp
1loaded.l58
1loaded.l59
1loaded.l60
1loaded.l61
1loaded.l62
1loaded.l63
1loaded.l64
1loaded.l65
1loaded.l66
1loaded.l67
1loaded.l68
1loaded.l69
1loaded.l70
1loaded.l71
1loaded.l72
1loaded.l73
1loaded.l74
1loaded.l75
1loaded.l76
1loaded.l80
1loaded.l81
1loaded.l82
1loaded.l83
1loaded.l84
1loaded.l85
1loaded.l86
1loaded.l87
1loaded.l88
1loaded.l89
1loaded.l90
1loaded.l91
1loaded.l92
1loaded.l93
1loaded.log
1loaded.page
6loaded.db
6loaded.dbb
6loaded.err
6loaded.inp
6loaded.l58
6loaded.l59
6loaded.l60
6loaded.l61
6loaded.l62
6loaded.l63
6loaded.l64
6loaded.l65
6loaded.l66
6loaded.l67
6loaded.l68
6loaded.l69
6loaded.l70
6loaded.l71
6loaded.l72
6loaded.l73
6loaded.l74
6loaded.l75
6loaded.l76
6loaded.l80
6loaded.l81
6loaded.l82
6loaded.l83
6loaded.l84
6loaded.l85
6loaded.l86
6loaded.l87
6loaded.l88
6loaded.l89
6loaded.l90
6loaded.l91
6loaded.l92
6loaded.l93
6loaded.log
6loaded.page
6-thermal-exp.jpg
asfb_1_80.out
asfb_1_81.out
asfb_1_82.out
asfb_1_83.out
asfb_1_84.out
asfb_1_85.out
asfb_1_86.out
asfb_1_87.out
asfb_1_88.out
asfb_1_89.out
asfb_1_90.out
asfb_1_91.out
asfb_1_92.out
asfb_1_93.out
asfb_6_80.out
asfb_6_81.out
asfb_6_82.out
asfb_6_83.out
asfb_6_84.out
asfb_6_85.out
asfb_6_86.out
asfb_6_87.out
asfb_6_88.out
asfb_6_89.out
asfb_6_90.out
asfb_6_91.out
asfb_6_92.out
asfb_6_93.out
asfv_1_80.out
asfv_1_81.out
asfv_1_82.out
asfv_1_83.out
asfv_1_84.out
asfv_1_85.out
asfv_1_86.out
asfv_1_87.out
asfv_1_88.out
asfv_1_89.out
asfv_1_90.out
asfv_1_91.out
asfv_1_92.out
asfv_1_93.out
asfv_6_80.out
asfv_6_81.out
asfv_6_82.out
asfv_6_83.out
asfv_6_84.out
asfv_6_85.out
asfv_6_86.out
asfv_6_87.out
asfv_6_88.out
asfv_6_89.out
asfv_6_90.out
asfv_6_91.out
asfv_6_92.out
asfv_6_93.out
comp.inp
mech.rst
post-asfb.inp
post-asfv.inp
post-usf.inp
scratch.hlp
seismic.rst
therm1.rst
therm6.rst
usfvy_1_80.out
usfvy_1_81.out
usfvy_1_82.out
usfvy_1_83.out
usfvy_1_84.out
usfvy_1_85.out
usfvy_1_86.out
usfvy_1_87.out
usfvy_1_88.out
usfvy_1_89.out
usfvy_1_90.out
usfvy_1_91.out
usfvy_1_92.out
usfvy_1_93.out
usfvy_6_80.out
usfvy_6_81.out
usfvy_6_82.out
usfvy_6_83.out
usfvy_6_84.out
usfvy_6_85.out
usfvy_6_86.out
usfvy_6_87.out
usfvy_6_88.out
usfvy_6_89.out
usfvy_6_90.out
usfvy_6_91.out
usfvy_6_92.out
usfvy_6_93.out
usfvz_1_80.out
usfvz_1_81.out
usfvz_1_82.out
usfvz_1_83.out
usfvz_1_84.out
usfvz_1_85.out
usfvz_1_86.out
usfvz_1_87.out
usfvz_1_88.out
usfvz_1_89.out
usfvz_1_90.out
usfvz_1_91.out
usfvz_1_92.out
usfvz_1_93.out
usfvz_6_80.out
usfvz_6_81.out
usfvz_6_82.out
usfvz_6_83.out
usfvz_6_84.out
usfvz_6_85.out
usfvz_6_86.out
usfvz_6_87.out
usfvz_6_88.out
usfvz_6_89.out
usfvz_6_90.out
usfvz_6_91.out
usfvz_6_92.out
usfvz_6_93.out
usfy_1_80.out
usfy_1_81.out
usfy_1_82.out
usfy_1_83.out
usfy_1_84.out
usfy_1_85.out
usfy_1_86.out
usfy_1_87.out
usfy_1_88.out
usfy_1_89.out
usfy_1_90.out
usfy_1_91.out
usfy_1_92.out
usfy_1_93.out
usfy_6_80.out
usfy_6_81.out
usfy_6_82.out
usfy_6_83.out
usfy_6_84.out
usfy_6_85.out
usfy_6_86.out
usfy_6_87.out
usfy_6_88.out
usfy_6_89.out
usfy_6_90.out
usfy_6_91.out
usfy_6_92.out
usfy_6_93.out
usfz_1_80.out
usfz_1_81.out
usfz_1_82.out
usfz_1_83.out
usfz_1_84.out
usfz_1_85.out
usfz_1_86.out
usfz_1_87.out
usfz_1_88.out
usfz_1_89.out
usfz_1_90.out
usfz_1_91.out
usfz_1_92.out
usfz_1_93.out
usfz_6_80.out
usfz_6_81.out
usfz_6_82.out
usfz_6_83.out
usfz_6_84.out
usfz_6_85.out
usfz_6_86.out
usfz_6_87.out
usfz_6_88.out
usfz_6_89.out
usfz_6_90.out
usfz_6_91.out
usfz_6_92.out
usfz_6_93.out
vault.err
vault.inp

Figure 8

10.0 Results

Concrete Vault

The results of the reinforced concrete vault are calculated in Appendices T, U, V, W, X, and Y and summarized in the tables below.

One Cell Loaded

Loading	Load Combination	Location	Minimum Safety Factor
Bending of Adjacent Section Between Cells	85	Between Cells 11 and 12	4.46
Shear of Adjacent Section Between Cells	85	Between Cells 12 and 13	1.16
Y-Axis Bending of Vault Section	93	Cell 16	1.85
Z-Axis Bending of Vault Section	83	Cell 11	3.69
Y-Direction Shear of Vault Section	83	Cell 11	2.15
Z-Direction Shear of Vault Section	93	Cell 14	2.15

Six Cells Loaded

Loading	Load Combination	Location	Minimum Safety Factor
Bending of Adjacent Section Between Cells	85	Between Cells 11 and 12	5.03
Shear of Adjacent Section Between Cells	84	Between Cells 11 and 12	1.23
Y-Axis Bending of Vault Section	93	Cell 16	2.40
Z-Axis Bending of Vault Section	82	Cell14	1.94
Y-Direction Shear of Vault Section	83	Cell 11	1.31
Z-Direction Shear of Vault Section	87	Cell 14	2.16

The crawler track analysis considers the actual location of the crawler tracks on the vault as shown in Appendix F. In the finite element model, it was convenient to locate the crawler track load on the elements cantilevered off the side of the vault. This has no adverse impact on the global response of the vault, however, it over estimates the bending moment on the crawler track extension for the local analysis. The width of the beam section is taken as the length of the crawler track and treated as a cantilever beam with a partial uniformly distributed load equivalent to the live load with its load factor and the vertical seismic load.

The temperature distribution through the vault for the single cell loaded and all cells loaded condition are shown in Figures 9 and 10.

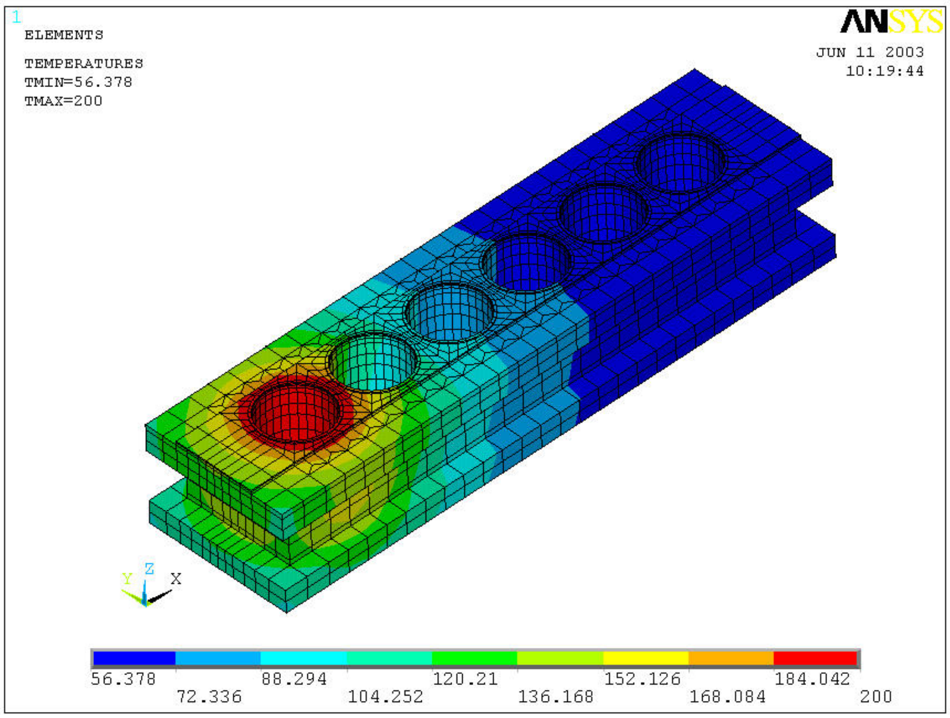


Figure 9

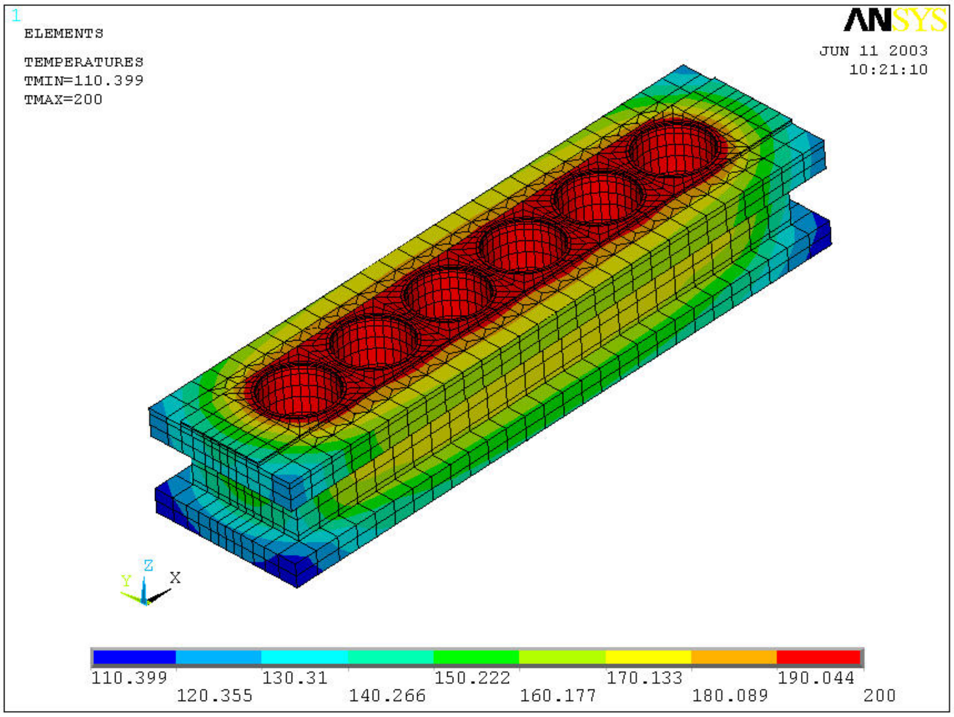


Figure 9

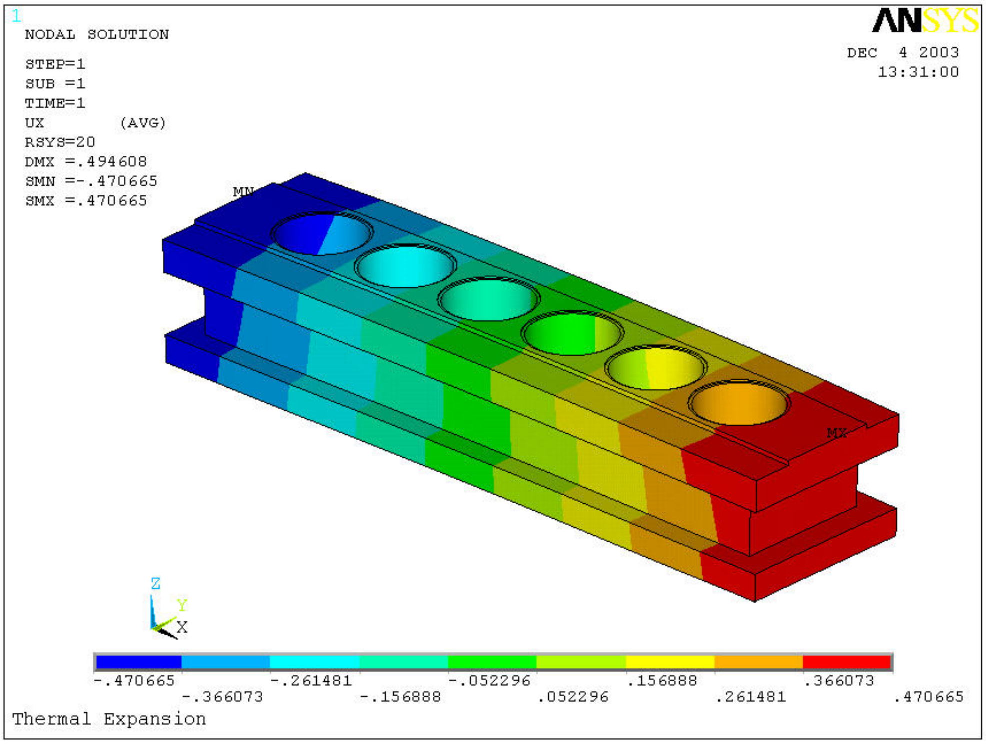


Figure 11

11.0 Summary

The Cask Storage Vault for Humboldt Bay has been analyzed to the conditions set forth by Specification HBPP-2001-01 [1] and all safety factors are greater than 1.0 for the reinforced concrete structure against bending and shear. Therefore, the design of the Cask Storage Vault is acceptable.

Note that all Appendices Contain Proprietary Information and have been Deleted

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

SEISMIC RESPONSE OF HI-STAR HB IN VAULT SUBJECT TO DBE

FOR

PG&E

Holtec Report No: HI-2033014

Holtec Project No: 1125

Report Class : SAFETY RELATED

DOCUMENT NAME: Seismic Response of HI-STAR HB in Vault Subject to DBE							
DOCUMENT NO.:	2033014	CATEGORY: ☐ GENERIC					
PROJECT NO.:	1125	X PROJECT SPECIFIC					
Rev. No. [2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	12/16/03	AIS	703625	3			
1							
2							

DOCUMENT CATEGORIZATION

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

X 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 does not follow HQP requirements but follows a format more suited for an ASME Code Calculation report.

DECLARATION OF PROPRIETARY STATUS

This document is labeled:

☒ Nonproprietary   Holtec Proprietary   ☐ TOP SECRET

Documents labeled TOP SECRET contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 in the N-drive of 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 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 Calculation Packages may be made by adding supplements to the document and replacing the "Table of Contents", and the "Revision Log".

HOLTEC SAFETY SIGNIFICANT DOCUMENTS

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 this document must fulfill, as applicable, 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 is drawn from referencable sources. Any assumed input data is so identified.
- ❖ All significant assumptions are stated.
- ❖ The analysis methodology is consistent with the physics of the problem.
- ❖ Any computer code and its specific versions used in the work have 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 the report is understandable to a reader with the requisite academic training and experience in the underlying technical disciplines.

Once a safety significant document, such as this report, 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), editorial revisions to Holtec *safety significant* documents are not made unless such editorial changes are deemed necessary by the Holtec Project Manager to prevent erroneous conclusions from being inferred by the reader. In other words, the focus in the preparation of this document is to ensure correctness of the technical content rather than the cosmetics of presentation.

REVISION LOG

Revision 0: Original Issue

EXECUTIVE SUMMARY

Six HI-STAR HB casks will be stored in the Humboldt Bay ISFSI Vault. In accordance with the Humboldt Bay Specification for the dry storage system, the design basis seismic events (DBE's) are applied as an input 3-D motion to the vault structure. Four separate DBE events are considered as input data for dynamic simulation of the cask response to an earthquake. In this report, the response of the casks to each of the input seismic events is determined by performing a dynamic simulation. The results from the analyses are time histories of contact forces at the eight peripheral centering shim locations at both the top of the vault and at the base of the vault, and the time history solution for the vertical contact load between the base of the cask and the base of the steel vault tube.

The results for contact forces provide design basis inputs for the vault design [11]. The recommended design loads are:

Upper Shim Location – 750 kips
Lower Shim Location – 1,200 kips
Vertical Load on Base – 854 kips or greater

The calculated loads are based on shims that remain in the linear elastic range up to the above loads with each upper shim having stiffness no greater than 1623 kips/inch. These shim requirements will be imposed on the shim structural evaluation.

TABLE OF CONTENTS

1.0 INTRODUCTION

Six HI-STAR HB casks will be stored in the Humboldt Bay ISFSI Vault. In accordance with the Specification [1], Section 6.2.5.1, the design basis seismic events (DBE's) are applied as an input 3-D motion to the vault structure. Four separate DBE events are considered as input data for dynamic simulation of the cask response to an earthquake. During an earthquake, each storage cask, enclosed in one of the vault tubes, is subject to the effects of the specified motion of the vault through contact with the base of the vault tube and with the discrete upper and lower shim plates. The shim plates serve to position the cask in the vault and to transmit lateral loads from the cask to the vault tube during a seismic event.

In this report, the response of the casks to each of the input seismic events is determined by performing a dynamic simulation. Specifically, the impact force time history response is computed at the base of the vault tube and at every centering shim location. The forces are summarized for use in detailed vault structural design (in a separate report) in accordance with the applicable concrete design code. The analyses are performed with the vertical seismic event directed to produce final free field vertical position "up" from the starting position.

2.0 METHODOLOGY

The dynamic simulations are performed using VisualNastran Desktop (VN) [2]. This code is capable of modeling large motions of rigid bodies that may contact each other during the event. The VN simulation code (previously denoted as "Working Model) has been employed elsewhere [3-5] and has been subject to NRC scrutiny. The various bodies making up a simulation can be constructed directly in the VN program, or may be imported from a Computer Aided Design (CAD) program. Herein, the HI-STAR HB overpack is modeled as a solid body using Solidworks [6]. This CAD system has been subject to appropriate QA validation and has been demonstrated to produce accurate mass, inertia properties and location of the center of gravity. Therefore, mass and inertia properties are preserved after input of the rigid body cask overpack model into the dynamic simulation code. The cask lid and the loaded MPC are modeled as separate rigid bodies and imported into the VN model. Finally, the vault tube steel liner is imported into the VN simulation model and is assumed driven by the seismic events. Figure 1 shows the complete dynamic model with initial clearances between shim and HI-STAR HB assigned to each of the sixteen lateral shim locations (eight top and eight bottom). Shims are modeled with spheres (having negligible mass) rigidly connected to the driven vault tube. The vault tube lid is not included in the model so that maximum upward movement of the cask, relative to the tube, can be predicted. Custom contact models are defined between the overpack and each sphere and between the base of the cask and the bottom of the vault tube. The contact force-time history, from these interface contact elements, is archived and provides input loads for vault structural design performed in a separate report.

3.0 REFERENCES[1]

[1] HB Specification HB-2001-01

[2] VisualNastran, Version 2002, MSC Software, 2002 and Validation Manual for VisualNastran 2002, HI-2022896, Revision 0.

[3] HI-2002507, Seismic Analysis of Loaded HI-TRAC in Diablo Canyon Fuel Building, Project 1073, Revision 1.

[4] HI-STAR 100 SAR, HI-951251, Revision 9.

[5] HI-2022878, Supplemental Seismic Stability Analysis for PFSF, Project 70651, 2002, Revision 0.

[6] Solidworks 2001 Plus, Solidworks, Inc.

[7] HI-STAR FSAR, HI-2019610, Revision 1

[8] HI-2032999, Dimensions and Weights for the Humboldt Bay ISFSI Project, Project 1125, 2003, Revision 0.

---

[1] This revision status of Holtec documents cited above is subject to updates as the project progresses. This document will be revised if a revision to any of the above-referenced Holtec work products materially affects the instructions, results, conclusions or analyses contained in this document. Otherwise, a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supersede the revision numbers cited above. The Holtec Project Manager bears the undivided responsibility to insure that there is no intra-document conflict with respect to the information contained in all Holtec generated documents on a safety significant project".

[9] Humboldt Bay DBE Time Histories (Fault Normal, Fault Parallel, and Vertical Response Spectra and Time Histories), 4 sets provided by PG&E (Letter of 1/21/03 citing Report GEO.HBIP.02.05).

[10] Fax from Larry Pulley (HBIP) to Alan Soler (Holtec) dated 5/12/2003 and attached as Appendix B to this report.

[11] HI-2033013, Humboldt Bay Cask Storage Vault Structural Analysis, Revision 0

4.0 ACCEPTANCE CRITERIA

As the major purpose of the analysis is to provide input loading for the vault structural design analysis, the acceptability of this analysis is judged by satisfaction of the following requirements:

Dynamic analyses must be performed for a duration exceeding the observed strong motion region of each seismic event to ensure that maximum impact loads are captured in the response.

Demonstrate that impact forces do not impose a deceleration loading on the cask that exceeds the cask design basis [7].

5.0 ASSUMPTIONS

The cask and contents are modeled as multiple rigid bodies with known geometry and weight. This is conservative since all energy loss from cask structural deformation is neglected.

The cask lid, while initially modeled as a separate body, is rigidly attached to the overpack for the dynamic analyses. This is realistic and preserves the mass and inertia distribution of the real system.

The internal loaded Multi-Purpose Canister (MPC) is assumed to be free to rattle inside the overpack when a seismic event occurs. This is realistic.

Contact between the internal MPC and the inside cavity of the HI-STAR HB overpack is simulated by a classical impulse-momentum relationship with a specified coefficient of restitution and coefficient of friction. This assumption is realistic and accounts for energy losses during internal impacts. This assumption has been previously employed in previous dynamic simulations that have undergone review by the USNRC [3].

Appropriate values of coefficient of friction at contacting surfaces are chosen based on expected “average values”.

6.0 INPUT DATA

6.1 HI-STAR HB

The cask is represented as a homogeneous, rigid cylinder containing a loaded MPC. The HI-STAR lid mass is input separately and the lid rigidly attached at the top of the overpack. The mass and geometry data input used for the analyses in the vault is obtained from [8] and from [4].

HI-STAR Overpack – 93,860 lb.

Loaded MPC - 59,000 lb.

HI-STAR Lid - 8,363 lb.

The total cask mass is 161,223 lb., which is in essential agreement with the total value given in [8]. Figure 2 shows the VN input screens where the mass data is entered.

6.2 Target Surfaces (Shims and Liner Base)

The input data required is a force-deformation relation characterizing the response of the target surface to a vertical surface load over the interface area. The input is in the form of an interface stiffness value (lb/inch, for example). Values are determined in Appendix A, using a representative shim geometry for the interface between the overpack and the lateral shims, and also determined between the base of the overpack and the bottom of the steel liner. Figure 3 shows the data input screens to the VN model (for shim stiffness vertical stiffness at interface for the case where upper and lower shim locations are assumed to have large stiffness values. Initial shim clearances were set in the model to approximately 0.125” on the top shims and 0.875” on the bottom shims.

A detailed shim stress analysis is not performed herein; rather, to ensure the validity of the computed loads, a commitment is made to ensure that the final shim design will behave as a linear elastic structure having the calculated stiffness used in the analysis, and will behave in that manner up to a load equal to 1.5 times the actual calculated load.

The coefficient of friction at the shim location was set at 0.0, while coefficient of friction between steel cask base and steel liner was set at 0.5.

6.3 Target Surfaces (Cask/MPC)

The cask/MPC contact interface is simulated using a classical impulse-momentum algorithm built into the VN simulation code. The coefficient of restitution and the coefficient of friction between the bodies was set as:

Proprietary Information Deleted

These input values are consistent with the values employed in similar analyses supporting the Diablo Canyon ISFSI license submittal. A justification of the Coefficient of Restitution value, based on expected physical responses to an impact, is summarized in Appendix C, which contains slides supporting testimony at the ASLB hearings for the Private Fuel storage Facility (2002). Appendix C discusses the response of three rigid spheres allowed to drop onto a rigid surface. Three cases are performed with each case having a different coefficient of restitution assumed.

Proprietary Information Deleted

6.4 Input Loading

Input time histories of different durations have been provided by PG&E [9] for four (4) sets of seismic events, denoted as the "DBE" event (Sets 1-4). Each data set is in the form of vault acceleration vs. time. For each set of data consisting of three orthogonal acceleration time histories (fault normal, fault parallel, and vertical), the problem is re-formulated into a fixed vault liner and a moving cask subject to three components of imposed inertia forces applied at the mass centers of the overpack, the lid, and the loaded MPC, respectively. The vertical acceleration of the vault is applied in a direction that causes the vault to end up at a higher elevation than its starting position [10]. Figure 4 shows the equations for the three components of inertia force applied to the MPC for the Set 2 DBE event. Dividing by the negative of the MPC weight recovers the input acceleration components for Set 2. Similar inertia forces are applied to the lid and to the overpack, differing only by the multiplying component weight.

7.0 ANALYSES

The simulation model described above is subject to the four DBE events. The duration of the simulation for each event was continued to a point well past the time at which fault fling occurred to ensure that the maximum force response of the system was captured. Simulations were performed using a Kutta-Merson Predictor Corrector integration scheme.

Figures 5-12 summarize the collected data on cask and MPC maximum accelerations, and impact force-time histories that produced the maximum value of impact force during the event. All results are archived in Excel spreadsheet form; the files are listed in Appendix D. For seismic events DBE1 and DBE4, upper bound stiffness values were used for both the upper and lower shim locations. Refined stiffness values for the upper shim locations are defined in Appendix A; these more realistic lower values are used in the simulations for DBE sets 2 and 3.

The shim loads are identified using the following nomenclature:
The notation "b…..", and "t…." identify a shim location on the vault at the bottom or top, respectively. For example, "bxpym" represents the shim located at the bottom of the vault in the positive x, negative y quadrant.

8.0 RESULTS

Figures 5-12 present summaries of the key results from the four seismic simulations. There are 16 lateral contact locations around the periphery of the vault tube (8 at the top and 8 at the bottom), plus a contact interface at the base of the cask and the floor of the vault tube. For each simulation, the maximum impact load from the 8 locations at the top of the cask and from the eight locations at the bottom of the cask, together with the vertical contact load at the base of the cask are plotted. Also summarized in the graphs are the peak values of acceleration at the top and bottom of the HI-STAR and the MPC, respectively. Finally, for each simulation, the peak force pulse is plotted for the short duration when it occurs. All data generated and identified as "meters" is archived in a companion Excel spreadsheet. The maximum values from the graphical results are summarized below:

Peak Impact Loads from Dynamic Analyses

Seismic Event	Lateral Impact Force At Base (kip)	Lateral Impact Force at Top (kip)	Vertical Impact Force at Base of Vault Liner (kips)	Figures
DBE 1	476.8	573.6	810.6	5, 6
DBE 2	750.9	294.2	653.6	7, 8
DBE 3	799.0	457.5	853.3	9, 10
DBE 4	750.0	525.0	515.0	11, 12

The maximum vertical displacement of the cask, relative to the vault liner, did not exceed 0.5" for any of the four simulations; since this is less than the clearance between the vault closure lid bottom plate and the top of the HI-STAR HB, the vault top lid and its associated bolting need not consider any loading from the confined cask during a seismic event. The following table summarizes the maximum vertical excursion of the mass center of the MPC:

MPC Mass Center – Maximum Vertical Movement

Seismic Event	Vertical Excursion (inch)
DBE1	Not archived
DBE2	0.3
DBE3	0.3
DBE4	Not archived

Note: Excursions labeled “not archived” means that no meter was defined for that run to track vertical movement. However, visual examination of the real time configuration showed that no contact with the top lid occurs.

From the results of the four analyses, an effective shim loading can be defined for input into a structural model of the vault. This being a non-linear analysis subject to 4 sets of time histories all enveloping the same design spectra, it is permissible to average the peak results from the four cases (per SRP 3.7.1 guidelines). It is noted that the same top shim stiffness is not used in all four analyses (see Appendix A). Simulations DBE1 and DBE4 were performed prior to finalizing the design details for the top shims. Therefore, an overestimate of top shim stiffness was used and is reflected by the higher shim forces produced. Simulations DBE2 and DBE3, however, were performed using the more realistic shim stiffness based on the final design. Therefore, for vault structural integrity analyses, averaging of peak results is performed for the top shim forces, the averaged result is conservative since the top shim forces for DBE1 and DBE4 are higher than would be expected if lower, more realistic, stiffness values were used to establish top shim forces. Averaging the four peak loads for the top shims gives:

.25*(573.6+294.2+457.5+525) = 463 kips

Therefore, for an input design loading to the vault structural analysis, a bounding value of 500 kips (or higher) is acceptable.

No averaging is performed for the lower shim loads since the results for the DBE1 and DBE4 simulations may be expected to rise slightly if these analyses were rerun using the realistic upper stiffness. For vault design purposes, the peak result from the DBE3 simulation is set as the bounding input.

Consistent with the above remarks, the following values may be used to structurally analyze the upper and lower shims, and also to serve as minimum bounding inputs for the overall vault structural integrity analysis.

Effective Design Loads and Amplification Factor for Vault Structural Integrity Analysis

Upper Impact Location (kips)	*Lower Impact Location (kips)*	*Vertical Load (kips)*
500 x 1.5 = 750	800 x 1.5 = 1,200	854

Note that the result for “Vertical Load” includes the dead weight of the cask. Also, note that a factor of 1.5 has been imposed on the calculated average shim loads from the four runs. This additional margin is imposed to provide a bounding design input for the vault structural design report [11] that accounts for any sensitivity of the loads to variation of the coefficient of friction at the cask base-to-vault contact interface.

The above results are dependent on the stiffness values assigned to the shims and assume that the shims themselves are designed to produce this stiffness (or less) and to remain in the elastic range through the duration of the seismic event. Therefore, the final shim configuration will be designed to ensure linear elastic behavior with the designated stiffness (1623 kips/inch) up to 150% of the effective design loads.

Results for peak accelerations (in "g's") at the top and bottom of the cask are tracked for all runs. The peak acceleration from all simulations 37.1 g's, which is well below the design basis limiting value (60 g's) for the cask and contents. Therefore, no additional stress analyses are required to confirm that the cask and its contents meets CFR Part 72 structural integrity requirements.

9.0 SUMMARY

Seismic analyses have been performed to evaluate the loads applied to the ISFSI vault liner from the loaded HI-STAR HB. Four sets of seismic events have been considered and impact load-time histories have been developed. After appropriately averaging the peak loads from the four analyses, an upper bound on design static load at the upper shim locations to be used in the vault structural design analysis is reported. Similar design inputs are defined for the lower shim loads and for the vertical impact load from the cask on the liner base.

Bounding impact loads to be used in the vault structural design analysis [11] are:

Top Shim Location – 750 kips
Bottom Shim Location – 1,200 kips
Vertical load on Base - 854 kips or greater

The results from the simulations demonstrate that the loaded MPC does not impact the vault lid under any of the seismic events considered.

Also reported are peak accelerations at the top and bottom of the cask and the MPC. The results demonstrate that the peak accelerations of the cask and its contents remain below the design basis limit for the cask and its contents.

The commitment for shim design is:

Shims remain elastic up to the recommended input loads for the vault design
Upper shim stiffness does not exceed 1623 kips/inch.

10. FIGURES

Proprietary Information Deleted

FIGURE 1 – VisualNastran Cask Model with Shim Clearances

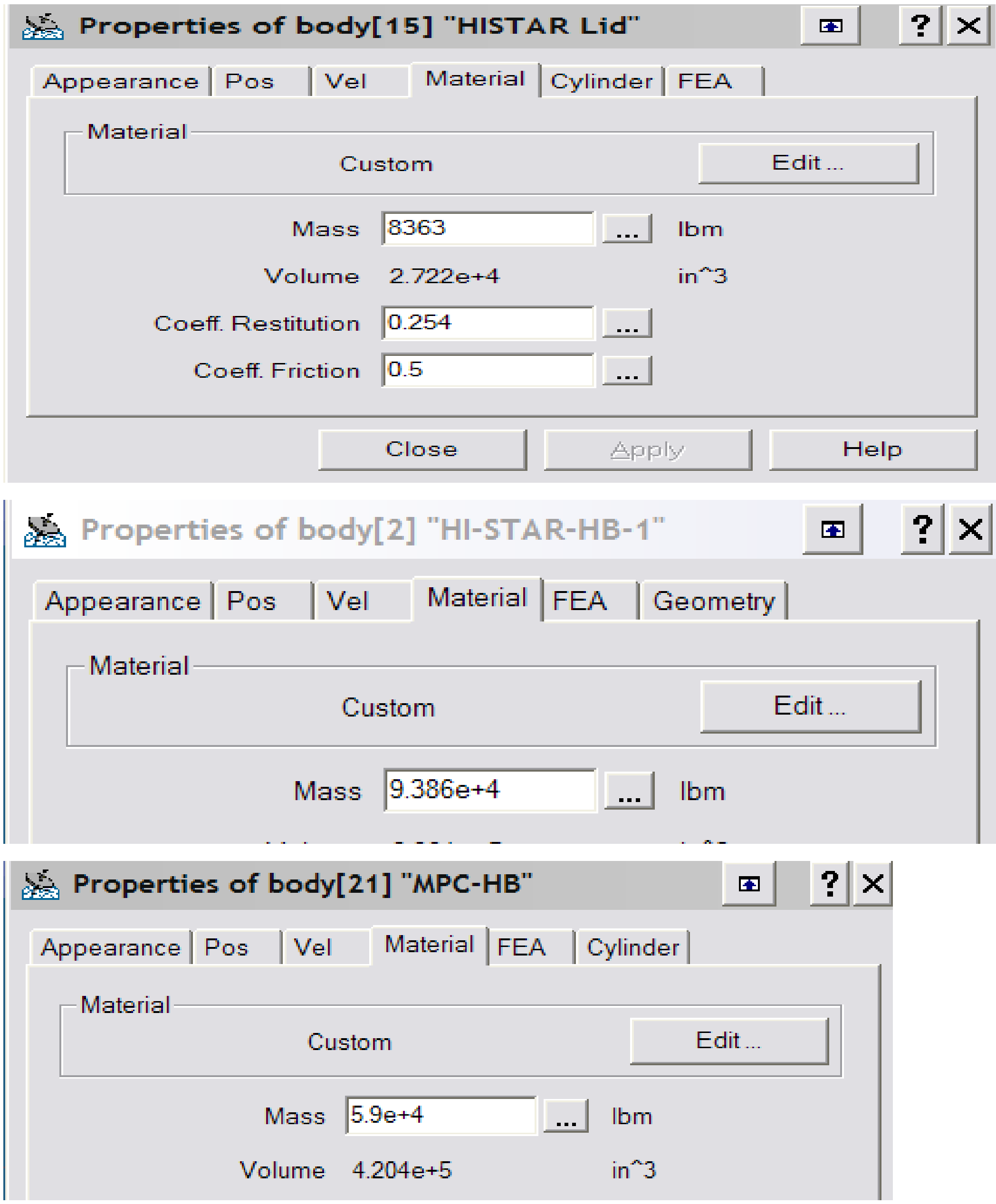


FIGURE 2 Component Mass Values

Proprietary Information Deleted

FIGURE 3 Interface Contact Stiffness/Damping Values for HI-STAR/Liner Lateral Shims and for HI-STAR/Liner Base (bounding high values)

Proprietary Information Deleted

FIGURE 4 Input Inertia Force for HI STAR HB Overpack (no lid) – Values shown are for Set 2 DBE

Proprietary Information Deleted

FIGURE 5 DBE 1 – General Results

Proprietary Information Deleted

FIGURE 6 DBE1 – Details of Maximum Lateral Impact Force vs. Time

Proprietary Information Deleted

FIGURE 7 DBE2 – General Results

Proprietary Information Deleted

FIGURE 8 DBE 2 - Details of Maximum Lateral Impact Force vs. Time

Proprietary Information Deleted

FIGURE 9 DBE 3 – General Results

Proprietary Information Deleted

FIGURE 10 DBE 3 - Details of Maximum Lateral Impact Force vs. Time

Proprietary Information Deleted

FIGURE 11 DBE 4 – General Results

Proprietary Information Deleted

FIGURE 12 DBE 4 - Details of Maximum Lateral Impact Force vs. Time

11. APPENDICES

Appendix A - Calculations Supporting VisualNastran Simulations HOLTEC PROPRIETARY

Appendix B - Fax from L. Pulley to A. Soler Providing QA Validation for Direction of DBE Vertical Earthquakes

Appendix C – Supporting Material for Coefficient of Restitution = 0.254 HOLTEC PROPRIETARY

Appendix D – Computer Files for This Report and Approved Computer Code List

Facsimile Cover Sheet

To: Alan Soler
Department: Holtec
Phone: 856-797-0900
Fax: 856-797-0909

From: Larry Pulley
Department: HBIP
Phone: 707-444-0859
Fax: 707-444-0736

Date: 5/12/2003
Pages including this cover page: 5

Alan:

I have enclosed the 4 sets of vertical time history plots from calculation GEO.HBIP.02.05, Rev 0. Per this calculation, the time histories are to be run in the direction they are provided. This shows that the final permanent displacement is "up" at the location of the ISFSI.

The use of this calculation is QA validation for only running vertical time histories in one direction.

Please call me if you have any questions.

Thanks;

Larry Pulley

PROJ 1125
RPT 2033014

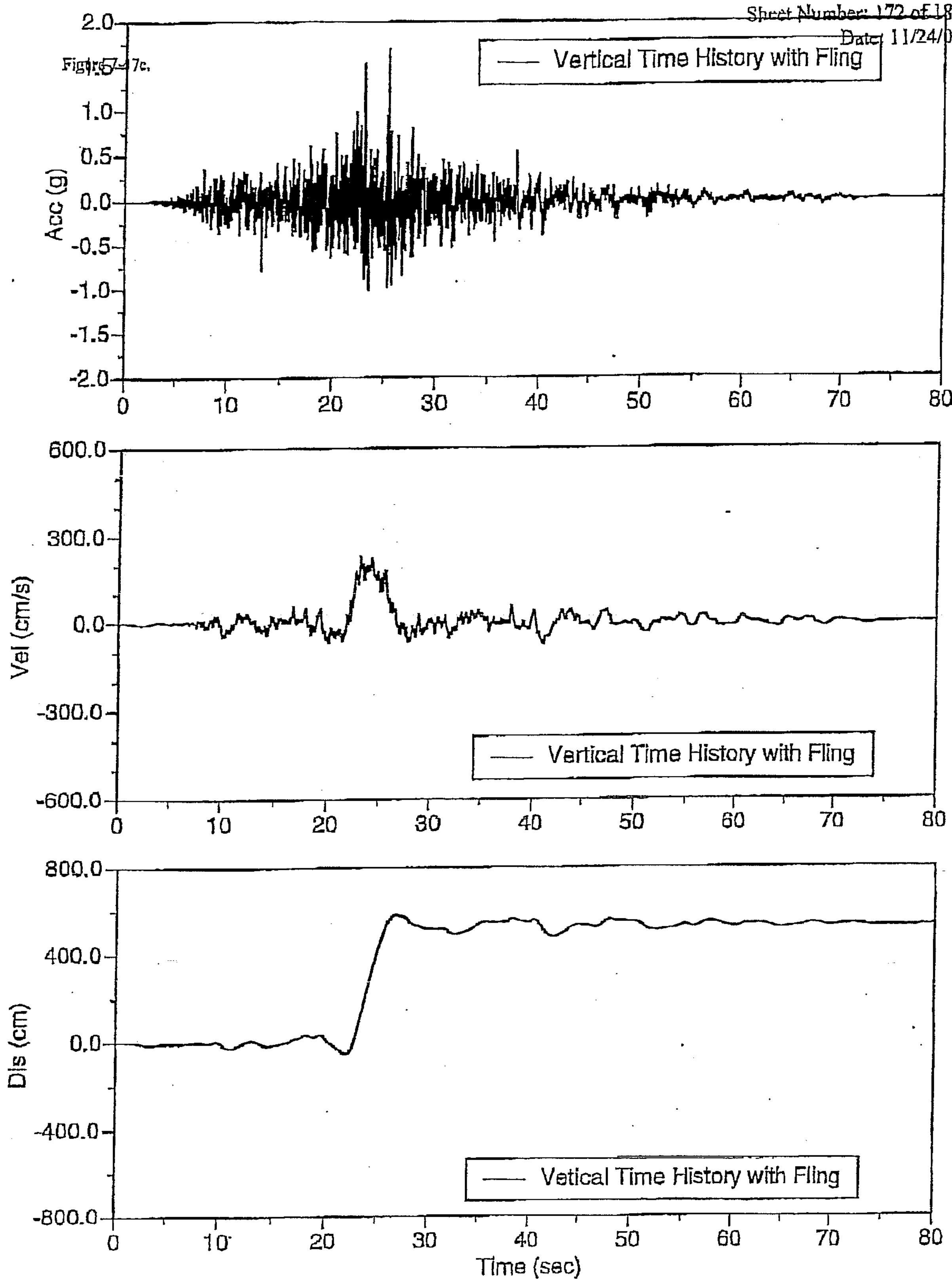


Figure 7-47c. Synchronous Set1 vertical modified acceleration, velocity, and displacement time histories with fling.

Proj. 1125
HI-2033014

B-2 of 5

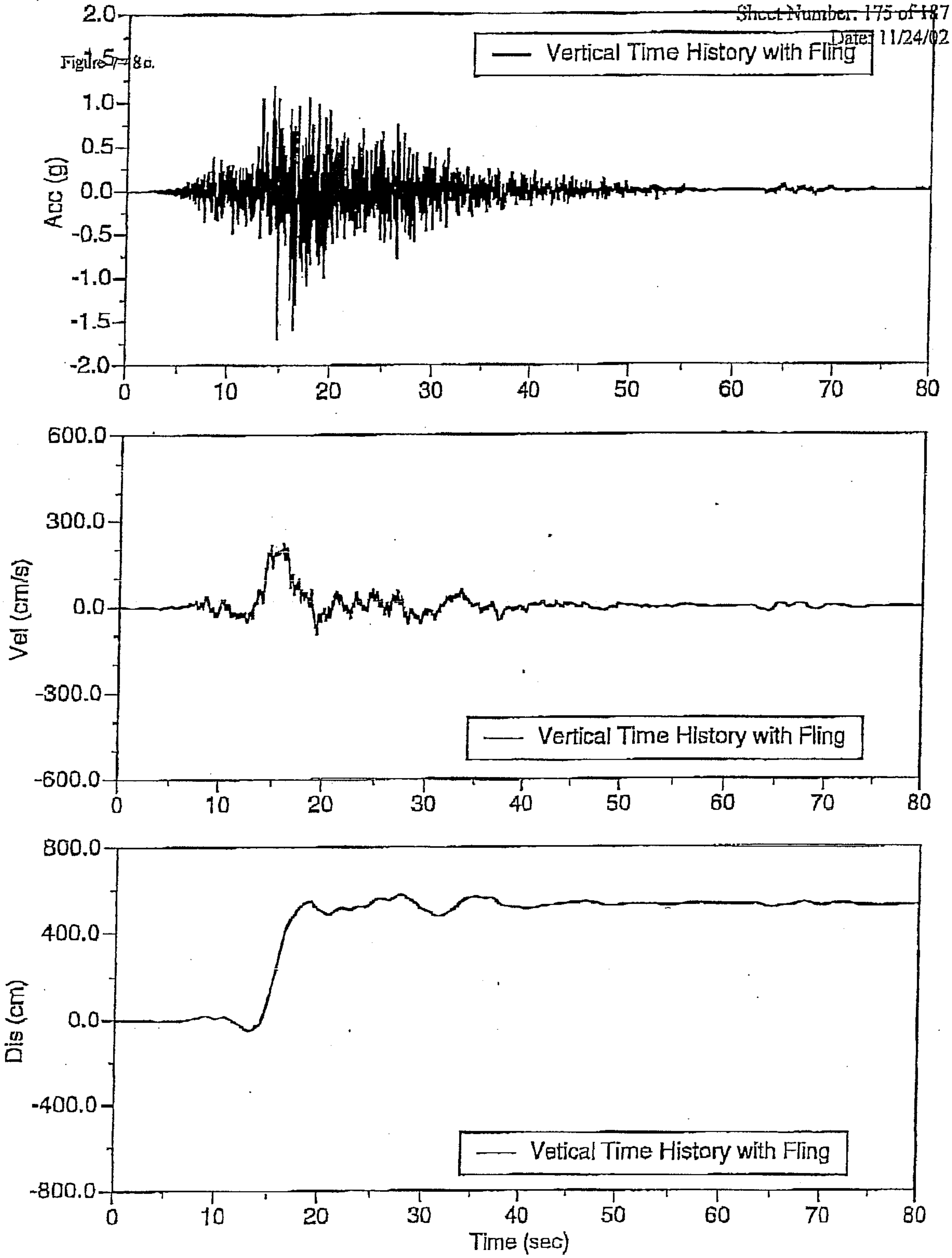


Figure 7-48c. Synchronous Set2 vertical modified acceleration, velocity, and displacement time histories with fling.

Proj. 1125
HI 2033014

Figure 7-49c.

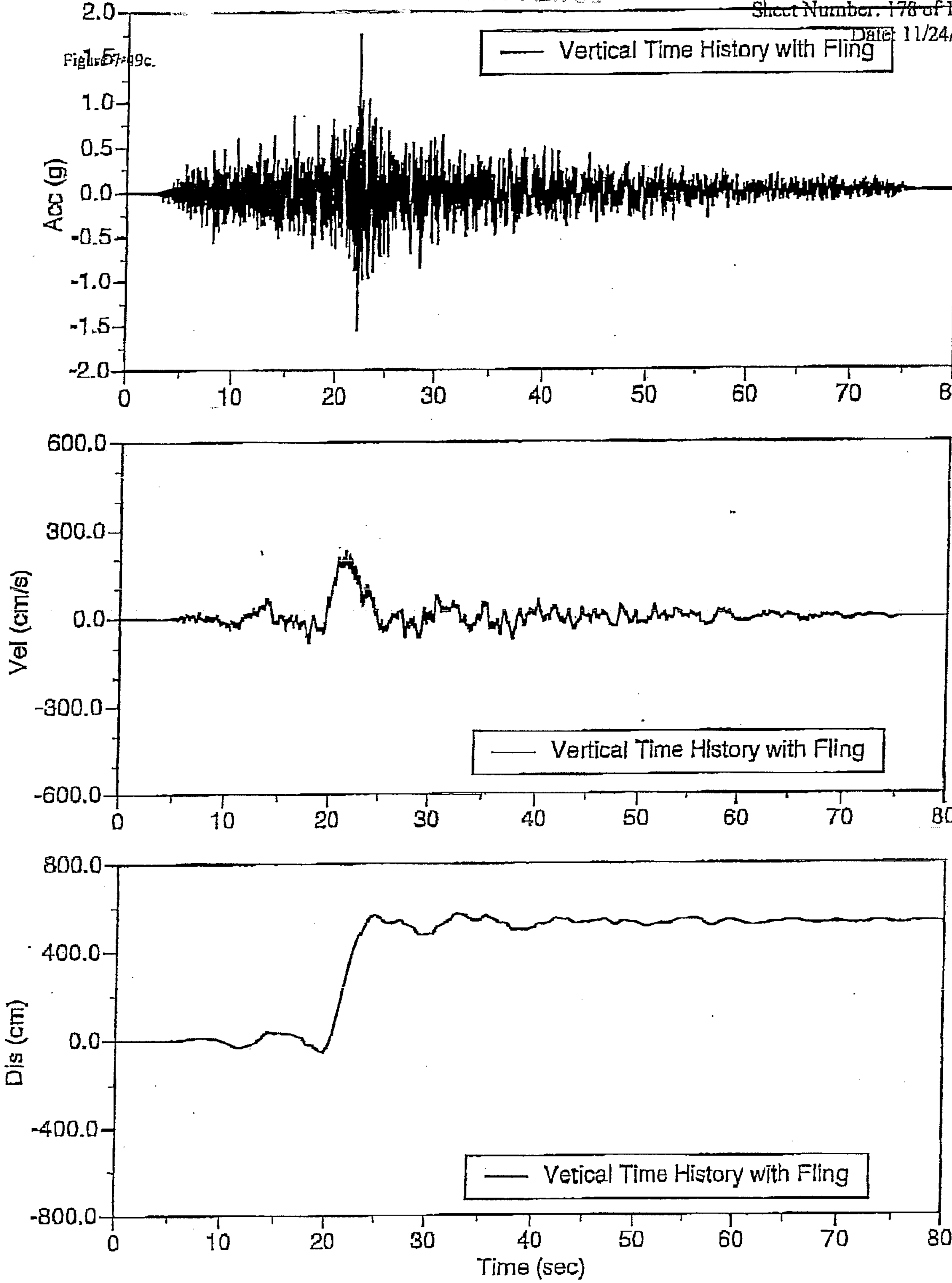


Figure 7-49c. Synchronous Set3 vertical modified acceleration, velocity, and displacement time histories with fling.

Proj. 1125
HI - 2033014

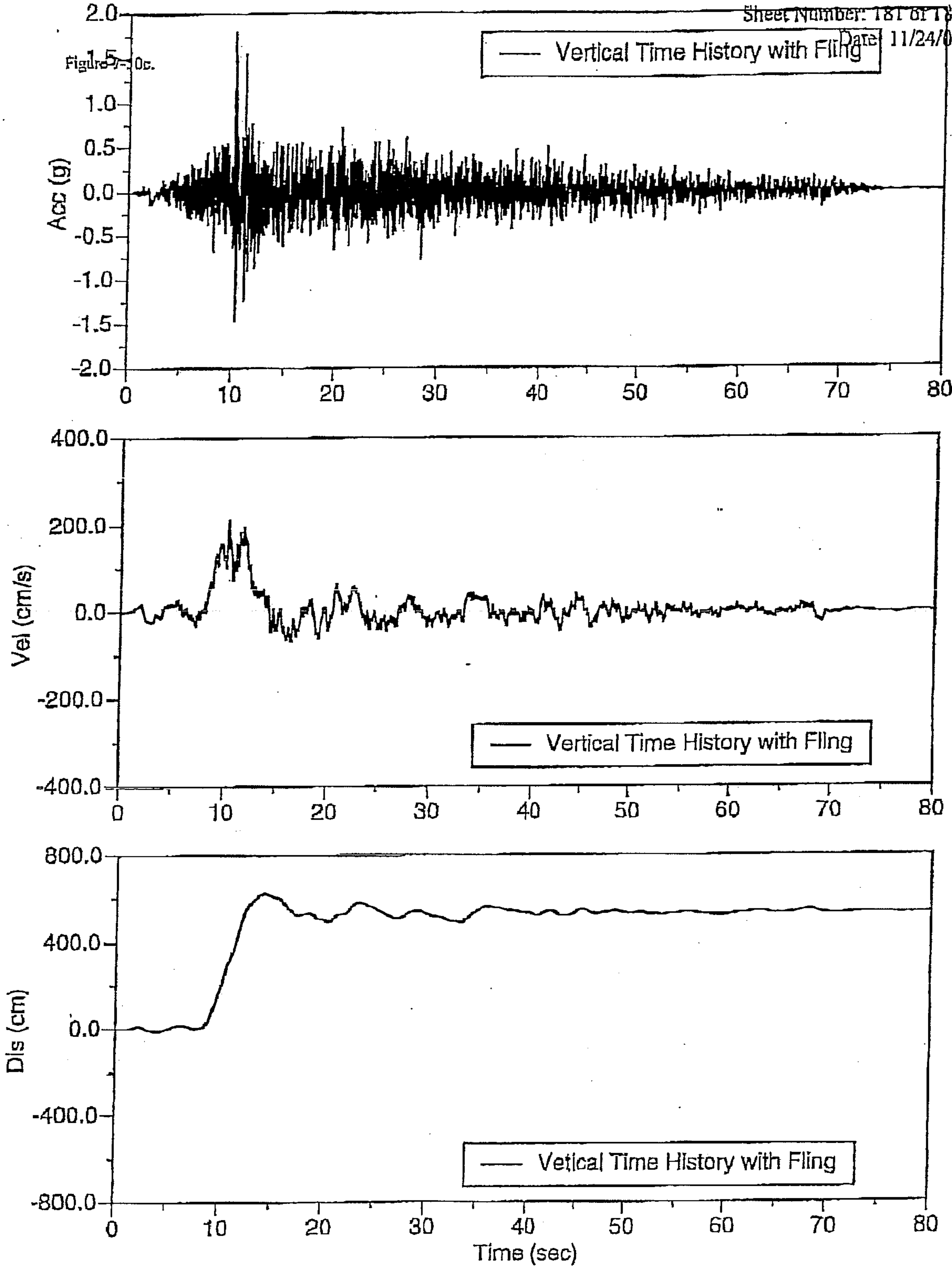


Figure 7-50c. Synchronous Set4 vertical modified acceleration, velocity, and displacement time histories with fling.

Proj. 1125
HI 2033014

B5 of 5

HOLTEC APPROVED COMPUTER PROGRAM LIST

(Total No. of Pages = 5)

PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
HOLTEC APPROVED COMPUTER PROGRAM LIST				**REV. 61 July 25, 2003**	
ANSYS (A)	5.3, 5.4, 5.6,5.6.2,5.7,7.0	JZ, EBR, PKC, CWB, SPA, AIS, IR, SP, JRT,AK	Windows		
AC-XPERT	1.12		Windows		
AIRCOOL	5.2I, 6.1		Windows		
BACKFILL	2.0		DOS/ Windows		
BONAMI (Scale)	4.3, 4.4		Windows		
BULKTEM	3.0		DOS/ Windows		
CASMO-4 (A)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ELR, SPA, DMM, KC, ST,VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects. The user should refer to the error notice documented in c4ser.04-results.pdf located in \generic\library\nuclear\error notices\ concerning the use of version 1.13.04. Library N should be used with version 2.05.03 for all new reports issued after June 1st, 2003. Revisions to reports issued prior to June 1st, 2003 may continue to use the old Library L.	
CASMO-3 (A)	4.4, 4.7	ELR, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		
CHANBP6 (A)	1.0	SJ, PKC, CWB, AIS, SP,JRT	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
DÉCOR	1.0		DOS/Windows		
DR.BEAMPRO	1.0.5		Windows		
DR.FRAME	2.0		Windows		
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ, JRT	DOS/Windows	Personnel qualified to use MR216 are automatically qualified to use DYNAMO.	
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.48, 4.56, 5.1 (see error notice), 4.2.8 (UNS),5.5, 6.1.18	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST,VJB	Windows		
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950, 960, 970	JZ, AIS, SPA, SP, JRT	Windows		
MAXDIS16	1.0		DOS/Windows		
MCNP (A)	4A, 4B	ELR, SPA, KC,ST,DMM, VJB, MAP	Windows/ UNIX	CASMO-4 Lumped Fission Products (IDs 401 and 402) and Isotope Pm148M (ID 61248) can be modeled in MCNP 4A using the cross sections documented in HI-2033031. Use of these cross sections is restricted to MCNP 4A, and to material specifications in atom densities.	
MASSINV	1.4, 1.5, 2.1		DOS/Windows		
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PKC, SJ,JRT	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
MSREFINE	1.3, 2.1		DOS/Windows		
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4,2002, 2003		Windows		2002
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		
ORIGENS (Scale)	4.3, 4.4		Windows		
PD16	1.1, 1.0, 2.0		Windows		
PREDYNA1	1.5, 1.4		DOS/Windows		
PSD1	1.0		DOS/Windows		
QAD	CGGP		Windows		
SAS2H (Scale)	4.3, 4.4		Windows		
SFMR2A	1.0		DOS/Windows		
SHAPEBUILDER	3.0		DOS/Windows		
SIFATIG	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
SOLIDWORKS	2001		DOS/Windows	This program may be used to calculate Weight, Volume, Centroid and Moment of Inertia. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session. If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

NOTES:
1. XXXX = ALPHANUMERIC COMBINATION
2. GENERAL PURPOSES UTILITY CODES (MATHCAD, EXCEL, ETC.) MAYBE USED ANYTIME.

Name	Size	Type	Date Modified
Response to Comments		File Folder	9/24/2003 6:10 PM
~$AppenD.doc	1 KB	Microsoft Word Docu...	9/25/2003 1:04 PM
AppenB.pdf	123 KB	Adobe Acrobat Docu...	5/13/2003 3:50 PM
AppenD.doc	88 KB	Microsoft Word Docu...	9/25/2003 1:06 PM
AppenD.pdf	164 KB	Adobe Acrobat Docu...	6/23/2003 2:28 PM
AppendA.mcd	3,420 KB	Mathcad Document	9/25/2003 12:55 PM
AppendA.pdf	171 KB	Adobe Acrobat Docu...	6/23/2003 2:30 PM
Appendix C.doc	19 KB	Microsoft Word Docu...	8/5/2003 4:06 PM
Appendix C.pdf	196 KB	Adobe Acrobat Docu...	9/16/2003 10:18 AM
CoverPage.pdf	10 KB	Adobe Acrobat Docu...	5/1/2003 4:17 PM
DBE1 5-13-03 000125.zip	32,851 KB	WinZip File	5/14/2003 10:39 AM
DBE2 6-18-03 final revision to stif...	30,625 KB	WinZip File	6/19/2003 9:48 AM
dbe3 5-28-03 t=001 new stiff rel...	42,778 KB	WinZip File	6/14/2003 10:27 AM
dbe3t_1.txt	1 KB	Text Document	6/22/2003 9:02 AM
DBE4 5-13-03 000125 top shim...	29,608 KB	WinZip File	5/14/2003 12:27 PM
DROPSD1.M	6 KB	Matlab files	6/23/2003 12:09 AM
fn1_F.txt	294 KB	Text Document	1/29/2003 6:02 PM
fn2_F.txt	211 KB	Text Document	1/30/2003 11:38 AM
fn3_f.txt	269 KB	Text Document	1/30/2003 3:00 PM
fn4_f.txt	269 KB	Text Document	1/30/2003 4:48 PM
fp1.txt	269 KB	Text Document	1/29/2003 7:00 PM
fp2.txt	211 KB	Text Document	1/30/2003 11:39 AM
fp3.txt	268 KB	Text Document	1/30/2003 3:01 PM
fp4.txt	268 KB	Text Document	1/30/2003 4:50 PM
fz1_f.txt	269 KB	Text Document	1/29/2003 7:01 PM
fz2_f.txt	211 KB	Text Document	1/30/2003 11:39 AM
fz3_f.txt	269 KB	Text Document	1/30/2003 3:01 PM
fz4_f.txt	269 KB	Text Document	1/30/2003 4:54 PM
HI2033014 R0.zip	141,165 KB	WinZip File	8/5/2003 4:11 PM
HI2033014.DOC	1,415 KB	Microsoft Word Docu...	9/25/2003 10:01 AM
HI2033014R0.pdf	1,802 KB	Adobe Acrobat Docu...	8/5/2003 4:10 PM
HI2033014r0text.pdf	1,294 KB	Adobe Acrobat Docu...	8/5/2003 3:55 PM
HI2033014text.pdf	2,560 KB	Adobe Acrobat Docu...	6/23/2003 10:04 PM

Files are in g\projects\1125\reports\HI2033014

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

HBPP FUEL ASSEMBLY DECAY HEAT CALCULATIONS

FOR

PG&E

Holtec Report No: HI-2033023

Holtec Project No: 1125

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT ISSUANCE AND REVISION STATUS[1]

DOCUMENT NAME: HBPP Fuel Assembly Decay Heat Calculations

DOCUMENT NO.:	HI-2033023	CATEGORY: ☒ GENERIC ☐ PROJECT SPECIFIC
PROJECT NO.:	1125	

Rev. No.[2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	05/28/2003	ER	404972				
1	09/12/2003	ER	920054				

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

This document is labeled:

☒ Nonproprietary ☐ Holtec Proprietary ☐ TOP SECRET

Documents labeled TOP SECRET contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 in the N-drive of 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 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 Calculation Packages may be made by adding supplements to the document and replacing the "Table of Contents", the "Review and Certification" page and the "Revision Log".

TABLE OF CONTENTS

SUMMARY OF REVISIONS

Revision 0 - Original Revision

Revision 1 – Modified text in Sections 2.0, 6.0, 7.0 and 8.0 in response to Client comments. No calculations are performed or modified.

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 planned Independent Spent Fuel Storage Installation (ISFSI) at the Humboldt Bay Power Plant (HBPP) is designed to store all of the fuel assemblies currently located in the HBPP spent fuel pool. These 390 fuel assemblies will be transferred into MPC-HBs each capable of holding up to 80 fuel assemblies. The continuing radioactive decay of the transuranic elements in the fuel assemblies generates heat. This report is issued to document fuel assembly and loaded MPC-HB decay heat calculations.

2.0 ANALYSIS METHODOLOGY

Due to the exponential nature of radioactive decay, the heat generation in a fuel assembly will always decrease with increasing decay time. The decay heat of the HBPP fuel assemblies will, therefore, be constantly reducing with time. The rate at which the decay heat reduces also decreases with time so, as a result of the considerable age of the HBPP fuel assemblies, the decay heat is now reducing very slowly. The decay heats of these fuel assemblies can therefore be conservatively treated as constant, neglecting any future reduction in their decay heats.

The decay heats of the previously offloaded fuel is determined using version 1.0 of the Holtec QA validated computer program LONGOR [1], which incorporates the Oak Ridge National Laboratory (ORNL) ORIGEN2 computer code [2] for performing decay heat calculations.

With respect to the methods used to calculate decay heat loads for dry storage cask applications, NUREG-1536 (4.0,V,3) [5] states:

> “Decay heat is generally calculated using the same computer codes as those used to determine radiation source terms.”

The ORIGEN2 computer code has been widely used in the nuclear power industry for calculating radiation source terms and has been used extensively for calculating fuel decay heats. ORIGEN2 is the progenitor of the ORIGEN-S computer code, used by Holtec to calculate radiation source terms for the HI-STAR System. Comparison of decay heats calculated using ORIGEN2 and ORIGEN-S has shown that the two codes give essentially the same results.

3.0 ACCEPTANCE CRITERIA

The analyses documented in this report are performed to generate inputs to subsequent HBPP ISFSI thermal modeling. No acceptance criteria are applied to these intermediate analyses.

4.0 ASSUMPTIONS

In order to ensure that the analyses documented in this report produce conservatively bounding results, the following conservative assumptions are made.

- The fuel assembly decay heats are calculated for a future date of 01 January 2005. The HBPP ISFSI is not scheduled to be operational until after this date. This conservatively reduces the amount of post-irradiation decay time for the assemblies, yielding slightly higher calculated decay heats.

- The fuel assembly decay heats are assumed to be constant over time. Because the fuel assembly decay heats will reduce over time, a consequence of the exponential nature of radioactive decay, this yields conservative heats for any date after 01 January 2005.

- The date that each fuel assembly was removed from the reactor is used as the reactor shutdown date. Some of the fuel assemblies were not removed from the reactor until months or even years after reactor shutdown. This conservatively reduces the amount of post-irradiation decay time for these assemblies, yielding higher calculated decay heats.

5.0 INPUT DATA

The input data used to perform the thermal-hydraulic analyses documented in this report are summarized below and in Table 1.

Input Data Parameter	**Value**	**Source(s)**
Reactor Type	BWR	[3]
Reactor Thermal Power (MWt)	240	[4]
Number of Assemblies in Reactor Core	172	[4]
Fuel Assembly Parameters	Table 1	[3]
Number of Fuel Assemblies per MPC-HB	80	[3]

6.0 CALCULATIONS

Based on the input data presented in Section 5.0 and the discharge schedule provided in Table 1, the decay heat of each HBPP fuel assembly is determined as described in Section 2.0. Several post-processed values are obtained from the directly calculated results, as follows:

1. Minimum Fuel Assembly Decay Heat – The lowest individual fuel assembly heat.

2. Maximum Fuel Assembly Decay Heat – The highest individual fuel assembly heat.

3. Average Fuel Assembly Decay Heat – The total heat of all 390 fuel assemblies divided by the total number of fuel assemblies.

4. Average MPC-HB Decay Heat – The average fuel assembly decay heat (Item 3) multiplied by the average number of fuel assemblies in an MPC-HB (390 ÷ 5 = 78).

5. Maximum MPC-HB Decay Heat – The total heat of the eighty highest fuel assembly decay heats. It should be noted that this value might exceed the MPC-HB decay heat permitted by the system thermal analysis, requiring that fuel assemblies of higher and lower decay heats be mixed in a single MPC-HB.

6. Single Assembly Averaged MPC-HB Decay Heats – The total heat of each MPC-HB, determined by uniformly distributing the fuel assemblies among the five MPC-HBs and pairing the highest individual decay heat fuel assembly with the lowest individual decay heat fuel assembly, etc.

7. Twenty Assembly Averaged MPC-HB Decay Heats – The total heat of each MPC-HB, determined by pairing the twenty highest decay heat fuel assemblies with the twenty lowest decay heat fuel assemblies, etc. MPC-HBs 1 through 4 will each contain 80 fuel assemblies and the final MPC-HB will contain 70 assemblies.

Subsequent thermal modeling of the HBPP ISFSI may assume that the assemblies are distributed among the MPC-HBs so as to provide the most uniform MPC-HB decay heat loads. Items 6 and 7 in the above list are determined as examples of methods to obtain such uniformity. Other methods undoubtedly exist and would also be acceptable.

The following computer files are used or created in performing these calculations.

```
 Volume in drive G is Data Drive 1
 Volume Serial Number is F252-144B

 Directory of G:\PROJECTS\1125\EBR\FUELHEAT

05/19/03  02:25p                 8,899 PartA.inp
05/19/03  02:25p                 8,762 PartB.inp
05/19/03  03:18p                13,761 PartA.res
05/19/03  04:12p                13,761 PartB.res
05/22/03  12:44p               245,760 fueldata.xls
```

The two input file (*.inp) each contain the information for 195 fuel assemblies. Two files must be used because the LONGOR program has a limit of 200 lines of fuel information in a single input file. The results files (*.res) contain the corresponding fuel assembly decay heat results. The Excel spreadsheet (fueldata.xls) is used to format the input data into a convenient form for generating the input files and to perform the post-processing described above.

7.0 RESULTS AND CONCLUSIONS

These decay heat evaluations were performed as described in Section 6.0. The post-processed results of these calculations are summarized in the following table.

Post-Processed Decay Heat	**Value in Watts**	**Value in Btu/hr**
Minimum Fuel Assembly Decay Heat	2.14	7.29
Maximum Fuel Assembly Decay Heat	39.13	133.54

Post-Processed Decay Heat	Value in Watts	Value in Btu/hr
Average Fuel Assembly Decay Heat	24.41	83.30
Average MPC-HB Decay Heat	1903.76	6497.53
Maximum MPC-HB Decay Heat	2629.26	8973.76
Single Assembly Averaged MPC-HB Decay Heats		
MPC-HB #1	1898.47	6479.48
MPC-HB #2	1902.13	6491.99
MPC-HB #3	1903.04	6495.05
MPC-HB #4	1906.16	6505.68
MPC-HB #5	1908.99	6515.45
Twenty Assembly Averaged MPC-HB Decay Heats		
MPC-HB #1	1857.33	6339.03
MPC-HB #2	1936.11	6608.04
MPC-HB #3	1959.86	6689.12
MPC-HB #4	1997.65	6817.89
MPC-HB #5	1767.84	6033.57

It is observed that the maximum MPC-HB decay heat is considerably (38%) higher than the average MPC-HB decay heat. As the MPC-HB decay heat permitted by the system thermal analysis is expected to be approximately 2000 W, mixing of fuel assemblies with higher and lower decay heats in a single MPC-HB will likely be required.

Comparing the post-processed results of the two group sizes for obtaining averaged MPC-HB decay heats (i.e., single assembly groups and twenty assembly groups), it is observed that the use of larger groups yields more variation between the MPC-HB heat loads. This is not unexpected, as more of the mid-range decay heat assemblies are grouped in a single MPC-HB and the average fuel assembly decay heat is higher than the mean of the highest and lowest fuel assembly decay heats. Thus, it can be concluded that the use of smaller groups for averaging will result in more uniformity among the MPC-HBs.

It should be recognized that the two fuel assembly decay heat averaging schemes evaluated herein are not the only possible schemes and that many other schemes will yield acceptable results as well. The assignment of individual fuel assemblies to a given MPC-HB must be performed as part of an overall loading plan that considers many factors, including decay heat averaging.

These calculated results are used as input data for subsequent ISFSI thermal modeling. No direct acceptance criteria are applied to these results.

8.0 REFERENCES[1]

[1] "QA Documentation for LONGOR," Holtec Report HI-951390, Revision 0.

[2] A.G. Croff, "ORIGEN2 - A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code," ORNL-5621, Oak Ridge National Laboratory, 1980.

[3] Pacific Gas and Electric Specification No. HBPP-2001-01, Contract No. 3500120394.

[4] Letter from L. Pulley (PG&E) to E. Lewis (Holtec), dated 5 May 2003.

[5] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," USNRC, (January 1997).

[1] Note: This revision status of Holtec documents cited above is subject to updates as the project progresses. This document will be revised if a revision to any of the above-referenced Holtec work products materially affects the instructions, results, conclusions or analyses contained in this document. Otherwise, a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supersede the revision numbers cited above. The Holtec Project Manager bears the undivided responsibility to ensure that there is no intra-document conflict with respect to the information contained in all Holtec-generated documents on a *safety-significant* project. The latest revision number of all documents produced by Holtec International in a *safety-significant* project is readily available from the company's Document Transmittal Form (DTF) database.

Table 1 Fuel Assembly Input Parameters					
Assembly ID	**^{n}U Weight (g)**	**Init. Enrich. (wt.% ^{235}U)**	**Exposure (MWD/MTU)**	**Unload Date (mm/dd/yyyy)**	**Total Weight (lb)**
B013	76337	2.31	18626.52	6/20/1971	246
B014	76414	2.31	15795.5	6/21/1971	246
B017	76357	2.31	19361.03	6/20/1971	246
B018	76486	2.31	16300.55	6/20/1971	246
B029	76364	2.31	19087.03	6/11/1971	246
B034	76171	2.31	16159.29	6/10/1971	246
B036	76157	2.31	19126.86	6/11/1971	246
B050	76363	2.31	19180.1	6/10/1971	246
B073	76914	2.31	18962.68	6/11/1971	246
B076	76650	2.31	17501.72	6/19/1971	246
C001	77091	2.08	16377.3	6/20/1971	246
C002	77007	2.08	17163.91	9/9/1972	246
C003	76753	2.08	18954.49	9/11/1973	246
C004	76703	2.08	16963.47	6/11/1971	246
C005	76853	2.08	18357.84	9/8/1972	246
C006	76856	2.08	18087.45	9/10/1972	246
C007	76212	2.08	18723.04	9/11/1972	246
C008	76405	2.08	17629.87	6/22/1971	246
C009	76569	2.08	18281.78	9/14/1972	246
C010	76296	2.08	18810.46	9/9/1972	246
C011	76253	2.08	20481.84	9/13/1973	246
C012	76306	2.08	20207.67	9/15/1973	246
C013	76254	2.08	18152.17	9/11/1972	246
C014	76247	2.08	18443.41	9/9/1972	246
C015	76263	2.08	17255.14	9/10/1972	246
C016	76250	2.08	20770.04	9/10/1973	246
C017	76224	2.08	18319.72	9/6/1972	246
C018	76572	2.08	18965.75	9/7/1972	246
C019	76652	2.08	17979.92	9/5/1972	246
C020	76620	2.08	17992.52	9/9/1972	246
C021	76343	2.08	18071.9	9/11/1972	246
C022	76399	2.08	17207.19	9/9/1972	246
C023	76100	2.08	18440.96	9/10/1972	246
C024	76251	2.08	18364.48	9/14/1972	246
C025	76314	2.08	18133.87	9/7/1972	246
C026	76313	2.08	17567.17	9/8/1972	246
C027	76364	2.08	18020.27	9/8/1972	246
C028	76300	2.08	17756.68	6/22/1971	246
C029	76251	2.08	18992.3	9/10/1972	246

Table 1 Fuel Assembly Input Parameters					
Assembly ID	**^{n}U Weight (g)**	**Init. Enrich. (wt.% ^{235}U)**	**Exposure (MWD/MTU)**	**Unload Date (mm/dd/yyyy)**	**Total Weight (lb)**
C030	76208	2.08	18366.33	9/11/1972	246
C031	76376	2.08	18016.82	6/11/1971	246
C032	76291	2.08	16681.4	6/11/1971	246
C033	76168	2.08	18127.59	9/5/1972	246
C034	76011	2.08	17307.38	9/10/1972	246
C035	76286	2.08	17572.4	6/22/1971	246
C036	76312	2.08	17671.31	6/22/1971	246
C037	76226	2.08	19112.36	9/3/1972	246
C038	75867	2.08	17934.91	9/10/1972	246
C039	75822	2.08	17687.58	9/10/1972	246
C040	75827	2.08	17803.42	9/6/1972	246
C041	75809	2.08	17627.85	6/11/1971	246
C042	75823	2.08	18679.01	9/10/1972	246
C043	75829	2.08	17982.21	9/10/1972	246
C044	75830	2.08	17054.9	6/20/1971	246
C046	76346	2.1	18058.93	9/9/1972	246
C047	76540	2.1	15135.71	6/9/1971	246
C048	76364	2.1	18945.56	6/20/1971	246
C049	76145	2.1	18323.18	9/8/1972	246
C051	76231	2.1	17781.37	6/20/1971	246
C052	76354	2.1	20031.78	9/14/1973	246
C053	76210	2.1	18246.98	9/14/1972	246
C054	76161	2.1	18026.07	9/3/1972	246
C055	76301	2.1	18360.14	9/6/1972	246
C056	76185	2.1	19750.55	9/2/1972	246
C057	76279	2.1	19042.96	6/11/1971	246
C058	76297	2.1	18756.96	9/7/1972	246
C059	76240	2.1	18279.43	9/9/1972	246
C060	76342	2.1	18125.39	9/9/1972	246
C062	76477	2.1	17725.83	6/23/1971	246
C063	76158	2.1	18631.26	9/9/1972	246
C064	76476	2.1	16587.94	6/11/1971	246
C065	76230	2.1	17540.14	6/22/1971	246
C066	76367	2.1	18689.76	9/7/1972	246
C067	76371	2.1	18219.96	9/7/1972	246
C068	76367	2.1	18320.42	9/11/1972	246
C069	76332	2.1	18668.89	9/11/1972	246
C071	76193	2.1	18364.81	9/14/1972	246
C074	76257	2.1	18269.85	9/8/1972	246
C077	76165	2.1	17791.49	6/11/1971	246

Table 1 Fuel Assembly Input Parameters					
Assembly ID	**^{n}U Weight (g)**	**Init. Enrich. (wt.% ^{235}U)**	**Exposure (MWD/MTU)**	**Unload Date (mm/dd/yyyy)**	**Total Weight (lb)**
C078	76411	2.1	16258.77	6/23/1971	246
C079	76299	2.1	17776.46	6/11/1971	246
C080	76355	2.1	18962.38	6/21/1971	246
C081	76263	2.1	17541.24	6/21/1971	246
C082	76547	2.1	19603.51	9/7/1973	246
C083	76264	2.1	18534.51	9/5/1972	246
C084	76225	2.1	18618.79	9/7/1972	246
C085	76192	2.1	19107.01	6/15/1971	246
C087	76327	2.1	20196.32	9/12/1973	246
HD01	76238	2.37	15397.22	9/7/1973	269
HD02	76260	2.37	21098.21	9/11/1973	269
HD03	76287	2.37	15438.14	9/7/1973	269
HD04	76168	2.37	17012.57	9/13/1973	269
HD05	76280	2.37	17909.5	9/9/1973	269
HD06	76130	2.37	15751.15	9/10/1973	269
HD07	76110	2.37	16678.9	11/8/1974	269
HD08	76137	2.37	17076.05	9/9/1973	269
HD09	76154	2.37	16877.17	9/13/1973	269
HD10	76256	2.37	15296.32	9/17/1973	269
HD11	76244	2.37	20852.54	9/14/1973	269
HD12	76282	2.37	19246.83	9/12/1973	269
HD13	76241	2.37	16476.53	9/13/1973	269
HD14	76211	2.37	15860.76	9/11/1973	269
HD15	76230	2.37	20423.19	9/14/1973	269
HD16	76334	2.37	14700.2	9/15/1973	269
HD17	76278	2.37	18310.1	9/11/1973	269
HD18	76246	2.37	17192.88	9/14/1973	269
HD19	76082	2.37	19480.57	9/14/1973	269
HD20	76031	2.37	16205.6	9/6/1972	269
HD21	76083	2.37	15929.78	9/1/1972	269
HD22	76098	2.37	18325.46	9/13/1973	269
HD23	76035	2.37	18907.7	9/15/1973	269
HD24	76111	2.37	17935.83	9/13/1973	269
HD25	76229	2.37	17311.35	9/12/1973	269
HD26	76210	2.37	15525.31	9/17/1973	269
HD27	76121	2.37	18073.31	9/11/1973	269
HD28	76117	2.37	17092.13	9/14/1973	269
HD29	76186	2.37	15624.44	9/15/1973	269
HD30	76365	2.37	16933.11	9/11/1973	269
HD31	76267	2.37	18257.8	9/12/1973	269

Table 1 Fuel Assembly Input Parameters					
Assembly ID	**^{n}U Weight (g)**	**Init. Enrich. (wt.% ^{235}U)**	**Exposure (MWD/MTU)**	**Unload Date (mm/dd/yyyy)**	**Total Weight (lb)**
HD32	76121	2.37	20573.27	9/9/1973	269
HD33	76198	2.37	19520.44	9/13/1973	269
HD34	76263	2.37	16480.66	9/15/1973	269
HD35	76141	2.37	16161.35	9/10/1973	269
HD36	76202	2.37	19817.26	9/10/1973	269
HD37	76127	2.37	20644.38	9/13/1973	269
HD38	76171	2.37	17173.07	9/10/1973	269
HD39	76138	2.37	18187.93	9/10/1973	269
HD40	76218	2.37	16319.07	9/11/1973	269
HD41	76289	2.37	11301.67	6/13/1971	269
HD42	76253	2.37	11283.12	6/15/1971	269
HD43	76377	2.37	20633.04	9/12/1973	269
HD44	76361	2.37	11600.81	6/19/1971	269
HD45	76308	2.37	11641.05	6/10/1971	269
HD46	76432	2.37	20853.56	9/14/1973	269
HD47	76396	2.37	16099.19	9/5/1973	269
HD48	76182	2.37	11275.46	6/10/1971	269
HD49	76172	2.37	16943.11	9/3/1972	269
HD50	76219	2.37	16989.73	9/10/1972	269
HD51	76134	2.37	20528.97	9/11/1973	269
HD52	76219	2.37	15650.52	9/15/1973	269
HE01	76309	2.36	6453.88	6/19/1971	269
HE02	76260	2.36	20331.78	6/26/1975	269
HE03	76315	2.36	18792.66	11/7/1974	269
HE04	76183	2.36	22357.69	7/18/1976	269
HE05	76241	2.36	19665.34	6/26/1975	269
HE06	76314	2.36	6119.33	6/30/1971	269
HE07	76094	2.36	19696.57	6/9/1975	269
HE08	76151	2.36	19598.32	11/13/1974	269
HE09	76237	2.36	21935.45	11/9/1974	269
HE10	76254	2.36	10367.45	9/6/1972	269
HE11	76076	2.36	20562.74	6/11/1975	269
HE12	76018	2.36	20044.82	11/14/1974	269
HE13	76016	2.36	19674.99	6/8/1975	269
HE14	76032	2.36	19330.06	11/9/1974	269
HE15	76245	2.36	19547.92	6/9/1975	269
HE16	76575	2.36	19555.64	6/10/1975	269
HE17	76404	2.36	22876.47	7/11/1976	269
HE18	76499	2.36	20702.73	11/14/1974	269
HE19	76316	2.36	19640.02	6/26/1975	269

Table 1
Fuel Assembly Input Parameters

Assembly ID	^{n}U Weight (g)	Init. Enrich. (wt.% ^{235}U)	Exposure (MWD/MTU)	Unload Date (mm/dd/yyyy)	Total Weight (lb)
HE20	76235	2.36	16934.23	7/17/1976	269
HE21	76411	2.36	20760.02	11/13/1974	269
HE22	76437	2.36	19126.55	6/19/1975	269
HE23	76436	2.36	11149.29	9/2/1972	269
HE24	76536	2.36	15587.02	11/6/1974	269
HE25	76412	2.36	15191.41	9/6/1973	269
HE26	76359	2.36	18848.13	11/9/1974	269
HE27	76311	2.36	21128.15	11/14/1974	269
HE28	76265	2.36	20002.83	11/11/1974	269
HE29	76337	2.36	14483.73	11/6/1974	269
HE30	76292	2.36	19547.76	11/14/1974	269
HE31	76287	2.36	19614.6	6/12/1975	269
HE32	76201	2.36	19612.47	11/10/1974	269
HE33	76287	2.36	20918.26	11/10/1974	269
HE34	76307	2.36	16376.97	6/9/1975	269
HE35	76330	2.36	20773.42	11/13/1974	269
HE36	72002	2.35	19798.35	11/13/1974	269
HE37	72073	2.35	19795.89	11/7/1974	269
HE38	72105	2.35	19810.38	11/12/1974	269
HE39	72207	2.35	19799.47	11/12/1974	269
HE40	74192	2.35	20653.99	11/11/1974	269
HE41	75592	2.44	13809.22	9/8/1973	269
HE42	76158	2.43	16196.93	6/26/1975	269
HE43	76121	2.43	10631.3	9/4/1972	269
HE44	75898	2.43	17168.62	6/12/1975	269
HF01	76641	2.51	19789.87	7/18/1976	269
HF02	76692	2.51	15492.07	2/16/1984	269
HF03	76657	2.51	16561.91	7/19/1976	269
HF04	76561	2.5	17603.4	6/15/1975	269
HF05	76774	2.51	17945.47	7/17/1976	269
HF06	76695	2.51	20283.82	7/20/1976	269
HF07	76862	2.51	20139.02	7/19/1976	269
HF08	76693	2.5	16632.77	7/21/1976	269
HF09	76764	2.51	16768.54	7/12/1976	269
HF10	76710	2.51	16604.96	6/8/1975	269
HF11	76770	2.5	15100.78	11/7/1974	269
HF12	76814	2.51	17065.14	6/10/1975	269
HF13	76738	2.51	17564.05	7/11/1976	269
HF14	76683	2.51	17263.44	6/12/1975	269
HF15	76675	2.51	16258.06	7/18/1976	269

Table 1
Fuel Assembly Input Parameters

Assembly ID	^{n}U Weight (g)	Init. Enrich. (wt.% ^{235}U)	Exposure (MWD/MTU)	Unload Date (mm/dd/yyyy)	Total Weight (lb)
HF16	76694	2.51	15074.42	11/10/1974	269
HF17	76615	2.51	15112.62	6/14/1975	269
HF18	76507	2.51	17259.1	6/15/1975	269
HF19	76676	2.51	19132.42	7/20/1976	269
HF20	76673	2.51	18165.33	7/13/1976	269
HF21	76667	2.51	16279.75	6/6/1975	269
HF22	76646	2.51	16579.91	7/18/1976	269
HF23	76726	2.51	17526.5	7/20/1976	269
HF24	76723	2.51	21264.35	7/14/1976	269
HF25	76716	2.51	19966.55	7/14/1976	269
HF26	76816	2.51	17029.93	7/11/1976	269
HF27	76722	2.51	17698.63	10/14/1976	269
HF28	76822	2.51	20814.69	7/11/1976	269
HF29	76710	2.51	15663.11	6/4/1975	269
HF30	76654	2.51	20940.4	7/12/1976	269
HF31	76590	2.51	15314.22	6/6/1975	269
HF32	76805	2.51	15452.97	11/9/1974	269
HF33	76850	2.51	17376.36	7/13/1976	269
HF34	76775	2.51	17527.94	6/10/1975	269
HF35	76756	2.51	16653.11	6/14/1975	269
HF36	76690	2.51	18152.28	7/21/1976	269
HF37	76590	2.51	14986.58	11/9/1974	269
HF38	76517	2.51	17506.29	6/12/1975	269
HF39	76455	2.51	17545.66	7/21/1976	269
HF40	76708	2.51	19226.12	7/21/1976	269
HF41	76868	2.51	17267.15	6/12/1975	269
HF42	76849	2.5	17178.97	7/21/1976	269
HF43	76834	2.51	15499.08	6/4/1975	269
HF44	76936	2.51	15077.96	11/9/1974	269
HG01	76621	2.51	16880.92	7/19/1976	269
HG02	76537	2.51	15399.7	2/3/1984	269
HG03	76576	2.52	15345.18	2/3/1984	269
HG04	76564	2.51	20213.66	1/27/1977	269
HG05	76656	2.52	20390.55	7/11/1976	269
HG06	76608	2.51	14484.24	2/21/1984	269
HG07	76494	2.51	14248.67	2/10/1984	269
HG08	76503	2.51	15687.53	2/22/1984	269
HG09	76500	2.51	16011.86	2/22/1984	269
HG10	76685	2.52	20426.73	7/13/1976	269
HG11	76856	2.51	13458.79	2/15/1984	269

Table 1
Fuel Assembly Input Parameters

Assembly ID	^{n}U Weight (g)	Init. Enrich. (wt.% ^{235}U)	Exposure (MWD/MTU)	Unload Date (mm/dd/yyyy)	Total Weight (lb)
HG12	76817	2.52	12340.08	2/14/1984	269
HG13	76797	2.51	15263.75	2/17/1984	269
HG14	76869	2.51	17714.91	2/19/1977	269
HG15	76889	2.51	16598.16	7/12/1976	269
HG16	76830	2.51	14849.42	2/8/1984	269
HG17	76825	2.51	15976.41	2/21/1984	269
HG18	76833	2.51	15244.08	2/14/1984	269
HG19	76747	2.51	17974.05	1/25/1977	269
HG20	76673	2.51	14345.3	2/7/1984	269
HG21	76674	2.51	9742.79	6/24/1975	269
HG22	76682	2.51	16695.93	7/12/1976	269
HG23	76949	2.51	14517.07	2/7/1984	269
HG24	76948	2.51	15274.77	2/10/1984	269
HG25	76894	2.52	16060.27	2/16/1984	269
HG26	76811	2.51	16240.97	7/13/1977	269
HG27	76961	2.52	14639.16	2/13/1984	269
HG28	77000	2.51	16215.21	7/21/1976	269
HG29	77001	2.51	19736.88	7/18/1976	269
HG30	76948	2.51	18317.38	7/18/1976	269
HG31	76876	2.51	18296.29	7/13/1976	269
HG32	77038	2.52	14824.2	2/16/1984	269
HG33	76859	2.51	15571.29	2/15/1984	269
HG34	76849	2.51	14173.83	6/5/1975	269
HG35	76925	2.51	16540.43	2/22/1984	269
HG36	76888	2.52	16068.59	2/14/1984	269
JN01	73805	2.35	20388.6	6/17/1975	240
JN02	73483	2.35	22376.5	6/25/1975	240
JN03	73762	2.35	18362.51	6/10/1975	240
UD6A	69291	2.4	15546.17	2/17/1984	240
UD6B	69504	2.4	12138.63	2/17/1984	240
UD6C	69433	2.4	14098.57	2/15/1984	240
UD6D	69475	2.4	15045.56	2/15/1984	240
UD6E	69336	2.4	15851.36	2/6/1984	240
UD6F	69307	2.4	10506.98	1/17/1984	240
UD6H	69423	2.4	10139.04	2/22/1984	240
UD6J	69355	2.4	14357.44	2/16/1984	240
UD6K	69524	2.4	15032.99	2/6/1984	240
UD6L	69454	2.4	15155.55	2/14/1984	240
UD6N	69315	2.4	8504.55	6/4/1975	240
UD6P	69277	2.4	7894.9	2/21/1984	240

Table 1 Fuel Assembly Input Parameters					
Assembly ID	**^{n}U Weight (g)**	**Init. Enrich. (wt.% ^{235}U)**	**Exposure (MWD/MTU)**	**Unload Date (mm/dd/yyyy)**	**Total Weight (lb)**
UD6Q	69346	2.4	13276.85	2/9/1984	240
UD6R	69327	2.4	10265.61	2/22/1984	240
UD6S	69285	2.4	16241.65	2/18/1977	240
UD6T	69399	2.4	15914.02	2/22/1984	240
UD6U	69257	2.4	10229.17	2/6/1984	240
UD6V	69313	2.4	8727.2	2/17/1984	240
UD6W	69290	2.4	14996.05	2/15/1984	240
UD6X	69330	2.4	16118.97	2/18/1977	240
UD6Y	69301	2.4	11865.66	2/8/1984	240
UD6Z	69250	2.4	15797.34	2/13/1984	240
UD68	69464	2.4	12668.58	2/15/1984	240
UD69	69317	2.4	15929.25	2/16/1984	240
UD7A	69372	2.4	7629.16	2/8/1984	240
UD7B	69337	2.4	7306.28	2/17/1984	240
UD7C	69342	2.4	9914.51	2/9/1984	240
UD7D	69485	2.4	10037.55	2/7/1984	240
UD7E	69360	2.4	14346.33	2/13/1984	240
UD7F	69496	2.4	14967.41	2/9/1984	240
UD7G	69473	2.4	8308.75	2/7/1977	240
UD7H	69528	2.4	14252.3	2/9/1984	240
UD7J	69381	2.4	15451.77	2/13/1984	240
UD7K	69459	2.4	14957.01	2/9/1984	240
UD7L	69317	2.4	13853.05	2/22/1984	240
UD7M	69362	2.4	15101.25	2/6/1984	240
UD7N	69323	2.4	12091.6	2/9/1984	240
UD7P	69204	2.4	14811.47	2/14/1984	240
UD70	69319	2.4	10103.01	2/13/1984	240
UD71	69360	2.4	10565.59	2/17/1984	240
UD72	69311	2.4	12138.91	2/21/1984	240
UD73	69371	2.4	11650.28	1/30/1984	240
UD75	69357	2.4	11001.03	2/10/1984	240
UD76	69260	2.4	15041.55	2/3/1984	240
UD78	69203	2.4	11541.12	2/8/1984	240
UD79	69351	2.4	15849.97	2/16/1984	240
UD8F	69297	2.4	15269.02	2/13/1984	240
UD8G	69332	2.4	10675.78	2/7/1977	240
UD8H	69387	2.4	10197.05	2/21/1984	240
UD8J	69358	2.4	9060.78	2/9/1984	240
UD8K	69326	2.4	13764.6	2/17/1984	240
XB01	69372	2.4	8523.14	2/15/1984	240

Table 1
Fuel Assembly Input Parameters

Assembly ID	^{n}U Weight (g)	Init. Enrich. (wt.% ^{235}U)	Exposure (MWD/MTU)	Unload Date (mm/dd/yyyy)	Total Weight (lb)
XB02	69742	2.4	8556.13	2/16/1984	240
XB03	69863	2.4	8480.19	2/10/1984	240
XB04	69874	2.4	5286.31	2/8/1984	240
XB05	69859	2.4	6724.31	2/14/1984	240
XB06	69846	2.4	9187.63	2/16/1984	240
XB07	69874	2.4	9437.16	2/16/1984	240
XB08	69849	2.4	8380.38	2/17/1984	240
XB09	69866	2.4	8501.14	2/14/1984	240
XB10	69879	2.4	6507.36	2/14/1984	240
XB11	69828	2.4	9620.37	2/14/1984	240
XB12	69868	2.4	6826.24	2/21/1984	240
XB13	69853	2.4	3367.21	2/17/1984	240
XB14	69838	2.4	8408.98	2/10/1984	240
XB15	69881	2.4	9503.85	2/15/1984	240
XB16	69858	2.4	8995.58	2/8/1984	240
XB17	69855	2.4	7410.47	2/16/1984	240
XB18	69934	2.4	7974.86	2/16/1984	240
XB19	69878	2.4	5007.36	2/17/1984	240
XB20	69843	2.4	8688.31	2/10/1984	240
XB21	69811	2.4	7474	2/16/1984	240
XB22	69877	2.4	6651.18	2/10/1984	240
XB23	69835	2.4	6528.59	2/8/1984	240
XB24	69804	2.4	4883.17	2/10/1984	240
XB25	69847	2.4	5750.12	2/15/1984	240
XB26	69872	2.4	8243.07	2/21/1984	240
XB27	69825	2.39	7443.28	2/13/1984	240
XB28	69819	2.4	8550.97	2/14/1984	240
XC01	69819	2.41	2677.53	2/22/1984	240
XC02	69770	2.41	6088.85	2/3/1984	240
XC03	69787	2.41	6789.93	1/31/1984	240
XC04	69798	2.41	5164.84	2/1/1984	240
XC05	69770	2.41	5483.94	2/1/1984	240
XC06	69766	2.41	4503.71	2/2/1984	240
XC07	69892	2.41	5594.55	1/30/1984	240
XC08	69904	2.41	6144.88	1/31/1984	240
XC09	69837	2.41	6172.24	2/2/1984	240
XC10	69835	2.41	5159.73	2/1/1984	240
XC11	69849	2.41	6625.14	2/1/1984	240
XC12	69828	2.41	4973.17	2/1/1984	240
XC13	69859	2.41	5296.59	1/31/1984	240

Table 1 Fuel Assembly Input Parameters					
Assembly ID	**^{n}U Weight (g)**	**Init. Enrich. (wt.% ^{235}U)**	**Exposure (MWD/MTU)**	**Unload Date (mm/dd/yyyy)**	**Total Weight (lb)**
XC14	69733	2.41	2329.9	1/30/1984	240
XC15	69801	2.41	5689.22	2/2/1984	240
XC16	69769	2.41	5590.41	2/2/1984	240
XC17	69906	2.41	3186.92	2/15/1984	240
XC18	69712	2.41	5232.6	1/31/1984	240
XC19	69874	2.41	2486.31	2/6/1984	240
XC20	69852	2.41	4952.53	1/30/1984	240
XC21	69922	2.41	6686.68	2/1/1984	240
XC22	69889	2.41	2700.17	2/8/1984	240
XC23	69685	2.41	5481.46	2/2/1984	240
XC24	69817	2.41	3235.46	2/21/1984	240
XC25	69864	2.41	5897.55	1/30/1984	240
XC26	69868	2.41	6968.84	1/30/1984	240
XC27	69853	2.41	2914.63	2/8/1984	240
XC28	69855	2.41	6690.75	1/30/1984	240
XC29	69852	2.41	6117.89	1/31/1984	240
XC30	69874	2.41	3772.98	2/6/1984	240
XC31	69908	2.41	5840.66	2/2/1984	240
XC32	69636	2.41	2371.61	2/21/1984	240
XC33	69896	2.41	1307.18	2/17/1984	240
XC34	69785	2.41	6125.27	1/31/1984	240
XC35	69904	2.41	6051.94	2/1/1984	240
XC36	69872	2.41	6618.14	2/2/1984	240
XC37	69826	2.41	3999.89	2/13/1984	240
XC38	69836	2.41	2525.45	2/9/1984	240
XC39	69866	2.41	5648.11	1/31/1984	240
XC40	69944	2.41	5170.54	1/31/1984	240
XC41	69837	2.41	6530.71	1/31/1984	240
XC42	69811	2.41	4178.94	2/22/1984	240
XC43	69710	2.41	6310	2/1/1984	240
XC44	69789	2.41	7087.4	1/31/1984	240

Appendix A

Holtec QA Approved Computer Programs List

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 54 May 20, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
ANSYS (A)	5.3, 5.4, 5.6,5.6.2,5.7,7.0	JZ, EBR, PKC, CWB, SPA, AIS, IR, SP, JRT,AK	Windows		
AC-XPERT	1.12		Windows		
AIRCOOL	5.2I, 6.1		Windows		
BACKFILL	2.0		DOS/ Windows		
BONAMI (Scale)	4.3, 4.4		Windows		
BULKTEM	3.0		DOS/ Windows		
CASMO-4 (A)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ELR, SPA, DMM, KC, ST,VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects. The user should refer to the error notice documented in c4ser.04-results.pdf located in \generic\library\nuclear\error notices\ concerning the use of version 1.13.04.	
CASMO-3 (A)	4.4, 4.7	ELR, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		
CHANBP6 (A)	1.0	SJ, PKC, CWB, AIS, SP,JRT	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		
DÉCOR	1.0		DOS/Windows		
DR.BEAMPRO	1.0.5		Windows		
DR.FRAME	2.0		Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 54 May 20, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ, JRT	DOS/Windows	Personnel qualified to use MR216 are automatically qualified to use DYNAMO.	
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.48, 4.56, 5.1 (see error notice), 4.2.8 (UNS),5.5	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST,VJB	Windows		
LONGOR	1.0		DOS/Windows		**1.0**
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950,960	JZ, AIS, SPA, SP	Windows		
MAXDIS16	1.0		DOS/Windows		
MCNP (A)	4A, 4B	ELR, SPA, KC, ST, DMM,VJB	Windows/ UNIX		
MASSINV	1.4, 1.5, 2.1		DOS/Windows		
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PKC, SJ,JRT	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	
MSREFINE	1.3, 2.1		DOS/Windows		
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4,2002		Windows		
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 54 May 20, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
ORIGENS (Scale)	4.3, 4.4		Windows		
PD16	1.1, 1.0, 2.0		Windows		
PREDYNA1	1.5, 1.4		DOS/Windows		
PSD1	1.0		DOS/Windows		
QAD	CGGP		Windows		
SAS2H (Scale)	4.3, 4.4		Windows		
SFMR2A	1.0		DOS/Windows		
SHAPEBUILDER	3.0		DOS/Windows		
SIFATIG	1.0		DOS/Windows		
SOLIDWORKS	2001		DOS/Windows	This program may be used to calculate Weight, Volume, Centroid and Moment of Inertia. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session. If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 54 May 20, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

NOTES:

1. XXXX = ALPHANUMERIC COMBINATION
2. GENERAL PURPOSES UTILITY CODES (MATHCAD, EXCEL, ETC.) MAY BE USED ANYTIME.

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

HUMBOLDT BAY THERMAL ANALYSIS

FOR

PG&E

Holtec Report No: HI-2033033

Holtec Project No: 1125

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT ISSUANCE AND REVISION STATUS[1]

DOCUMENT NAME: HUMBOLDT BAY THERMAL ANALYSIS

DOCUMENT NO.:	HI-2033033	CATEGORY: ☒ GENERIC	
PROJECT NO.:	1125	☐ PROJECT SPECIFIC	

Rev. No.[2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	12/16/03	IR	762590				

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)

Documents labeled "Privileged Intellectual Property" contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 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 "Table of Contents", this page and the "Revision Log".

SUMMARY OF REVISIONS LOG
Holtec Report HI-2033033
Rev. 0

Number of Pages List

Title Page	1
Document Issuance and Review Status	1
Summary of Revisions Log	1
Table of Contents	2
Text	40
Figures	5
Appendix A	5
Attachment I	8
Attachment II	2

TABLE OF CONTENTS
(Report HI-2033033)

Section Page

List of Figures

List of Appendices

List of Attachments

1.0 INTRODUCTION

The Unit 3 at Humboldt Bay Power Plant (HBPP) is a 65 MW Boiling Water Reactor (BWR) owned by Pacific Gas and Electric Company (PG&E). The nuclear unit is located approximately 3 miles south of Eureka in Humboldt County, California. The Unit 3 was operated from 1963 for 11 cycles until it was permanently shutdown on July 2, 1976. The fuel was removed from the reactor in 1984 and placed in the Spent Fuel Pool (SFP). The Humboldt Bay SFP holds 390 fuel assemblies. PG&E has contracted Holtec [1] to design a below-ground dry storage facility to store all of the SFP fuel. The fuel is proposed to be sealed in an 80-cell Multi Purpose Canister (MPC), emplaced in a HI-STAR overpack and stored in a Subterranean Vault (SV).

For ensuring a safe thermal environment for the fuel and cask, a thermal evaluation is necessary. To this end, an outline of thermal methodologies appropriate for Humboldt Bay dry storage facility is provided. The methodologies discussed herein are in full accord with prior work done by Holtec in licensing the HI-STAR/HI-STORM Systems. In other words the approaches discussed herein provide a framework for constructing a product suitable for NRC certification.

For the purpose of minimizing hot spots, the Humboldt Bay vault is evaluated for a lowest practicable MPC decay heat of 2 kW[1]. This heat load is adopted as the design basis cask heat load (Q_d). Actual heat loads at the time of fuel loading (circa 2008) shall be verified to be below this limit.

In accordance with HI-STAR FSAR [11], thermal evaluations are performed for three storage conditions:

<u>Normal Condition</u>

Normal storage addresses the long-term effects of ambient temperatures on fuel cladding. This is a cumulative effect of cladding creep at elevated temperatures over the duration of fuel storage. The effect is principally dependent on time-averaged environmental conditions prevailing at a site. Accordingly, the annual average ambient temperatures are adopted for evaluation of normal conditions of storage.

[1] This manner of limiting the cask decay heat is illustrated in Holtec's decay heat calculation report HI-2033023 [17].

Short-Term Conditions

Short term conditions are deviations from normal ambient temperatures that are reasonably expected to occur on an infrequent basis (off normal condition) or on a rare occasion (accident condition). To demonstrate the robustness of the storage casks, the Humboldt Bay storage facility is evaluated for two postulated temperatures:

(i) Off-Normal ambient temperature: $60^{o}F$

(ii) Accident temperature: $90^{o}F$

The Off-Normal temperature bounds the summer average temperatures and the Accident temperature bounds the highest recorded temperature (See Table 7).

1.1 About This Document

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 is saved as a Permanent Record under the company's QA System.

2.0 METHODOLOGY

The Humboldt Bay (HB) dry storage facility features a dual-purpose cask design – MPC in a HI-STAR overpack. The MPC is an all-welded stainless steel canister having a honeycombed fuel basket. For dry storage in an inert environment the canister is pressurized with helium and seal welded. The fuel basket is a honeycomb construction with square cells sized to accommodate the Humboldt Bay fuel assemblies. The HI-STAR overpack is a thick walled cylindrical vessel with a bolted lid. The overpack walls feature a multi-layered construction for preventing crack propagation. The overpacks are emplaced in a below-ground concrete vault (SV). The SV is a thick walled reinforced concrete structure for holding HI-STAR overpacks in oversized cylindrical cavities with covered tops.

Transport of heat from the heat generation region (fuel assemblies) to the outside environment is analyzed broadly by three interdependent thermal models.

i. The first model considers transport of heat from the fuel assembly to the basket cell walls. This model recognizes the combined effects of conduction (through helium) and radiation and neglects heat dissipation by convection and fuel assembly grid spacers.

ii. The second model considers heat transport within an MPC by conduction, radiation and internal convection heat transfer. An effective thermal conductivity of the fuel-basket region is obtained from a combined fuel assembly/basket conduction-radiation model is obtained. Internal convection in the fuel-basket zone is modeled by rendering it as a porous media region zone.

iii. The third model deals with the transmission of heat from the MPC exterior surface to the external environment (heat sink). From the MPC shell to the cask exterior surface, heat is conducted through an array of concentric shells representing the MPC-to-overpack helium gap, the overpack inner shell, the intermediate shells, the Holtite-A neutron shielding and finally the overpack outer shell. Heat rejection from the outside cask surfaces is considered by accounting for natural convection and radiation to ambient air and conduction to soil.

The mathematical models devised to articulate the temperature field in the HB dry storage facility begins with the method to characterize the heat transfer behavior of the prismatic (square) opening referred to as the "fuel space" containing a heat emitting fuel assembly. The methodology utilizes a finite-element procedure to replace the heterogeneous SNF/fuel space region with an equivalent solid body having a well-defined temperature-dependent conductivity. This is followed by a method to replace the composite honeycomb basket walls of the fuel basket cells with equivalent "solid" walls. Having created the mathematical equivalents for the SNF/fuel spaces and the fuel basket walls, the method to represent the MPC cylinder containing the fuel basket by an equivalent cylinder whose thermal conductivity is a function of the spatial location and coincident temperature is obtained. These calculations are documented in the effective properties calculation package for Humboldt Bay [4]. As stated previously, the fuel basket region is rendered as a porous media zone having effective hydraulic properties to model internal convection. The hydraulic properties are computed in a MATHCAD file "fuel_PM.mcd" listed in Section 8.

Consistent with HI-STAR/HI-STORM licensing, modeling of the HB dry storage facility requires an evaluation of the heat dissipation characteristics of the Humboldt Bay fuel. For this purpose a planar conduction-radiation model of the HB fuel rod arrays is constructed and an effective conductivity of the cell space occupied by the HB fuel obtained. Following the footsteps of the HI-STAR/HI-STORM modeling process, the MPC cross-section is replaced by an equivalent two-zone model – (i) Fuel basket zone and (ii) Downcomer zone. The downcomer is a helium filled annular gap. In storage, heated helium, propelled by buoyancy forces moves down and cools by rejecting heat to the MPC shell.

In summary, appropriate finite element models are used to replace the MPC cross section with an equivalent two-region homogeneous conduction lamina whose local conductivity is a known function of coincident absolute temperature. Thus, the MPC cylinder containing discrete fuel assemblies, helium, and fuel basket walls is replaced with a right circular cylinder whose material conductivity will vary with radial and axial position as a function of the coincident temperature.

The MPC-to-overpack gap is modeled as stagnant helium filled space having an equivalent conductivity that reflects the conduction and radiation modes of heat transfer. The overpack is a radially symmetric structure readily accommodated in the modeling process by including the layers as concentric shells with appropriate material properties. In this manner, a HI-STAR overpack containing a loaded MPC is replaced with a right circular cylinder with spatially varying temperature-dependent conductivity. Heat is generated within the basket space in this cylinder in the manner described in the HI-STAR thermal modeling [5]. The HI-STAR model is augmented to include the SV structure, namely an enclosing steel liner with cover plate and reinforced concrete. Heat is dissipated from the SV exterior surfaces to ambient air (from top) by natural convection and radiation. Soil is modeled as an infinite half-space with conduction heat transfer from the sides and bottom (See Figure 2). A global thermal model of the HI-STAR overpack in a vault is constructed on the QA validated FLUENT Computational Fluid Dynamics computer code, thermal solutions obtained and temperature results confirmed to comply with applicable temperature limits.

3.0 ACCEPTANCE CRITERIA

To demonstrate a safe operating thermal environment for the HB fuel and dry storage facility, appropriate temperature limits are adopted in the thermal design work. These limits pertain to three areas viz.:

i) Fuel clad temperature limits

ii) Cask component temperature limits

iii) Concrete vault temperature limits

The principal limit (item (i) above) pertains to ensuring the integrity of HB fuel cladding. For this purpose, the latest NRC criteria (ISG-11, Rev. 2 [2]) is adopted. In accordance with this criteria, the fuel cladding temperature for long term normal and short term operations (including vacuum drying) shall not exceed 400^{o}C (752^{o}F) and for off-normal and accident events, below 570^{o}C (1058^{o}F).

For ensuring safe fuel storage in the HI-STAR cask, certain critical component temperatures are evaluated herein. These are the maximum neutron shield and MPC shell temperatures. The corresponding limits obtained from the generic HI-STAR System [11] are provided hereunder:

i) Neutron Shield Temperature Limit: 300^{o}F

ii) MPC Shell Temperature Limit: 450^{o}F (Normal), 775^{o}F (Off-normal & Accident)

To ensure that the concrete vault operates in a safe thermal environment, the following limits for long-term storage and for short-term conditions shall be met by the thermal design:

I) Long Term Storage ([1], [18])

a) Bulk Temperature Limit: 150^{o}F

b) Local Temperature Limit: 200^{o}F

II) Off-Normal and Accident Conditions [18]

Maximum Temperature Limit: 350^{o}F

4.0 ASSUMPTIONS

The following assumptions are employed for a conservative portrayal of the Humboldt Bay vault temperature field:

- i) Conductivity enhancement by the embedded steel in the SV concrete is ignored.
- ii) To maximize insolation heating, a black surface is assumed for the Vault exposed surfaces.
- iii) To maximize fuel temperatures, a high decay heat in the 16 innermost MPC cells (50 W/assy) is assumed.
- iv) The fuel basket conductivity is understated (~20%) in the thermal models.
- v) To maximize flow resistance, cell flow area outside the envelope of a fuel rods array is ignored.
- vi) Theoretical bounding loss factors employed for fuel flow resistance.
- vii) Employ lowerbound active fuel length[2] to maximize local heat generation.
- viii) Employ upperbound fuel length to maximize pressure drop.
- ix) The fuel basket is loaded with canisterized fuel (i.e. stored in a DFC) in all fuel locations. This assumption maximizes thermal and hydraulic resistances of the fuel basket.
- x) All six cask locations in the HB vault are loaded with casks at design heat load.
- xi) Helium and air spaces outside the MPC envelope are modeled as stagnant gaps (i.e. convection heat dissipation in these spaces is ignored).
- xii) A lowerbound Holtite-A neutron shield conductivity (0.8 W/m-^{o}K)[3] is employed in the thermal models.
- xiii) For minimizing heat dissipation area to soil, the below ground vault height is understated (See Table 3).
- xiv) For maximizing vault axial thermal resistance, the aboveground step height of concrete is overstated (See Table 3 and Figure 5).
- xv) The vault lid is modeled as a 11.75 in thick concrete block with no metal reinforcements.

[2] Fuel lengths are employed in two calculations, viz. (a) Volumetric heat generation and (b) Flow resistance. As stated in assumptions (vii) and (viii), the calculations employ appropriately bounding values.
[3]

5.0 INPUT DATA

In this section, the principal inputs for thermal analysis of the HB dry storage facility are provided. These inputs include site-specific data for ambient air and soil temperatures and insolation data. The information is provided below:

Annual Average Ambient[4] Temperatures (T_{amb}) [1]: 52°F

Annual Average Soil Temperature (T_∞) [3]: 52°F

Maximum Insolation (S) [1]: 602 g-cal/cm^2 for a 24-hr period.

(In SI Units, S is equivalent to a heat flux of 291.5 W/m^2)

Table 1 provides thermal conductivities for the SV materials (carbon steel liner, reinforced concrete) and surrounding soil. The tabulated properties are deliberately understated to provide a robust margin in the thermal solutions: In Tables 2, 3 and 4 pertinent construction data for Humboldt Bay MPC, Vault and Overpack are provided. Tables 5 and 6 list the Humboldt Bay fuel array data and bounding length data.

5.1 Material Property Conservatisms

The principal materials of construction of the Humboldt Bay SV are carbon steel and reinforced concrete (RC). As the SV is a below ground structure, much of the heat generated inside it is dissipated to ground. As the soil is the principal heat sink, an employ of lowerbound soil conductivity ensures a robust margin in the thermal solutions. As stated in Table 1, the thermal properties of soil and SV materials are understated in the thermal evaluations. In the following, we provide information from referenced sources to support the tabulated data.

i) Conductivity of Carbon Steels

For carbon steel, thermal conductivity properties from ASME Code [12] are provided. The properties cover a representative range of temperatures for commonly used carbon steels for steel construction.

A) Carbon-Silicon Steels

Temperature Range: 70°F to 300°F

Conductivity: 35.1 to 32.3 Btu/ft-hr-°F

[4] Summer and winter ambient temperatures are provided in Table 7 [1].

B) Carbon-Manganese Steels

Temperature Range: 70°F to 300°F

Conductivity: 27.5 to 27.2 Btu/ft-hr-°F

C) C-Mn-Si Steels

Temperature Range: 70°F to 300°F

Conductivity: 23.6 to 24.4 Btu/ft-hr-°F

Based on the data for carbon steels provided herein, the conductivities of carbon steels well in excess of 20 Btu/ft-hr-°F is confirmed. The Table 1 property for carbon steel is therefore conservative.

ii) Conductivity of Concrete

The thermal conductivity of concrete, (Marks Handbook [13]) is provided below:

Concrete Conductivity: 1.05 Btu/ft-hr-°F

The Marks' data is conservative as even higher values (as much as 2.1 Btu/ft-hr-°F) are reported in a classical work by Neville [14]. This data provides a reasonable basis to confirm that the Table 1 properties for concrete are conservative. As an additional measure of conservatism, the heat dissipation contribution of steel reinforcement in the RC is ignored (assumption (i) in Section 4.0).

iii) Conductivity of Soil

The conductivity of soils [15] is principally characterized by soil density (R) and moisture content (M). Based on an experimental study by the University of Minnesota Institute of Technology (UMIT) [15], the conductivity of soils is represented as contours of constant soil conductivity (Iso-K contours) on an R vs M chart. To confirm that the conductivity inputs for soil are conservative, the UMIT charts are used.

The physical properties of Humboldt Bay soil are well characterized in a Geomatrix report [16]. In this report, results of 22 physical property measurements (15 moisture measurements and 7 density measurements) are provided. To characterize the bulk properties of Humboldt Bay soil, mean soil properties are obtained by averaging the moisture and density measurements. The measured data and the mean soil properties (Ro and Mo for density and moisture respectively) are reported in Attachment I. For ready reference, the numerical results are provided next:

$$Ro = 108.41 \text{ lb/ft}^3$$

$$Mo = 19.34 \%$$

To obtain the soil conductivity, the soil properties (Ro and Mo) are plotted on the UMIT chart as shown in Attachment I, Page 2. Based on a visual read of the chart, the following result is obtained:

$$\text{Soil Conductivity } (K_{soil}) \cong 16 \text{ Btu-inch/ft}^2\text{-hr-}^o\text{F}$$

In conventional US units, the above reported value for K_{soil} is 1.33 Btu/ft-hr-^{o}F, which is well above the soil conductivity input for thermal evaluation (Table 1).

TABLE 1: THERMAL CONDUCTIVITIES[5] EMPLOYED IN THERMAL MODELS

Material	Conductivity [Btu/ft-hr-^{o}F]
Carbon Steel	20
Reinforced Concrete	1
Soil	0.833

[5] The values tabulated herein are deliberately understated. See discussion in Section 5.1.

TABLE 2: MPC-HB CONSTRUCTION DATA [9,10]

Number of Cells	80
Cell Pitch	5.89 in
Cell Panels Thickness	3/16 in
Cell Opening[6]	5.61 in
Mouseholes Diameter[7]	2.5 in
MPC Height	114.5 in
OD	68.375 in
Cavity Height	102.5 in
Lid Thickness	9.5 in
Baseplate Thickness	2.5 in
Shell Thickness	0.5 in

[6] Inside dimensions of a cell.
[7] Diameter of lateral semi-circular flow holes.

TABLE 3: CONCRETE VAULT CONSTRUCTION DATA [6,7]

Bottom Slab Thickness	3 ft
Lateral Thickness	3 ft
Mid-Section Width	15 ft
Height Below Ground[8]	13.1 ft
Step Height[9]	0.5 ft
Step Width	11 ft
Overall Length	76.67 ft
Cavity Height	10.71 ft
Liner Thickness	1/2 in
Liner OD	9 ft
Baseplate Thickness	3/4 in
Bottom Drain Shim	1/4 in
Top HI-STAR Clearance	13/16 in
Lid Ring OD	115 in
Lid OD	122 in

[8] Conservatively understated (See assumption xiii in Section 4.0).
[9] Conservatively overstated (See assumption xiv in Section 4.0).

TABLE 4: HI-STAR HB OVERPACK CONSTRUCTION DATA [8]

Overall Height	127.4375 in
Diameter	96 in
Cavity Height	115.3125 in
Cavity Diameter	68.75 in
Bottom Thickness	6 in
Top Plate Thickness	6 in
Outer Shell Thickness	1/2 in
Inner Shell Thickness	2.5 in
Gamma Shells Overall Thickness	6 in
Neutron Shield Length	97.3125 in
Neutron Shield Bottom Clearance	8.75 in

TABLE 5: HB FUEL ARRAY DATA [4]

Array Size	Cladding OD (in)	Rods Pitch (in)
7x7 Array	0.486 (GE II)	0.631
6x6 Array	0.563 (GE III & Exxon III) 0.5625 (Exxon IV)	0.740

TABLE 6: BOUNDING FUEL LENGTH DATA [1]

Upperbound Length	96.91 in
Lowerbound Active Fuel Length	77.125 in

TABLE 7: HUMBOLDT BAY SUMMER AND WINTER TEMPERATURES [1]

Winter Average Temperature	46°F
Summer Average Temperature	56°F
Highest Recorded Temperature	87°F
Lowest Recorded Temperature	20°F

6.0 COMPUTER CODES

The QA validated FLUENT codes (versions 4.56 and 6.1.18) are used in the Humboldt Bay thermal modeling.

7.0 ANALYSIS AND CALCULATIONS

In this section, calculations addressing modeling features specific to the Humboldt Bay design (namely the concrete vault) are described in detail. Calculations specific to generic thermal modeling are archived in files listed in Section 8.0. In these files[10] fuel resistance parameters, decay heat source terms and MPC HB downcomer areas used in constructing the thermal model are provided.

7.1 Effective Concrete Conductivity

The Humboldt Bay (HB) dry storage facility consists of a reinforced concrete vault having six cavities in a linear array for emplacement of HI-STAR casks. This configuration with the principal vault dimensions is illustrated in Figure 1. For a bounding thermal evaluation, all cavities are assumed occupied with HI-STAR casks emitting heat at the design basis level (Q_d = 2 kW).

It is physically apparent that casks loaded in cavities located away from the ends will reach higher temperatures. Therefore, for a bounding evaluation it is necessary to consider an interior cavity location furthermost from the ends. This location is shown cross-hatched in Figure 1. For an axi-symmetric model rendering, the concrete section 'abcd' is replaced with an annular section with an effective conductivity. The annular section obtained in this manner has the same heat dissipation characteristics as that of the rectangular lamina shown in this figure.

The effective conductivity is computed by constructing a planar model of the concrete section on FLUENT. Two sides of this section (sides 'cd' and 'ab') are conservatively assumed insulated. For modeling heat flow in this section, reference temperatures of 50^{o}F and 0^{o}F are applied to the cavity interior and vault exterior boundaries. For thermal equivalence, heat flow in the concrete section and the annular section are equal. For this purpose the mean cavity heat flux (q_o) is obtained from the FLUENT model and effective conductivity (Kceff) established via an analytical formula derived below.

Proprietary Information Deleted in section 7.1

7.2 Soil Conduction Resistance Model

Proprietary Information Deleted regarding statement 7.2

[10] The pertinent files are: "fuel_PM.mcd", "MPC_Volh.xls" and "downcomer.xls".

7.3 Boundary Conditions for FLUENT HB Thermal Model

To model heat dissipation to soil, the FLUENT HB thermal model includes a soil boundary (SB).

Proprietary Information Deleted regarding statements 7.3

7.4 HB Thermal Model Construction

Employing the HB Vault, MPC and Overpack construction data (Tables 3, 4 and 5), an axi-symmetric model of a HI-STAR emplaced in the HB vault is constructed. The layout of the vault and HI-STAR HB in the thermal model is shown with principal dimensions in figures 3 and 4 respectively. The model includes the vault parameters computed in Section 7 (effective conductivity and soil boundary specifications). To this model, insolation S (See Section 5.0) is applied as described next.

For the purpose of maximizing solar heating, the position of the sun is assumed to be directly overhead. Proprietary Information Deleted regarding statements 7.4

As stated in Section 4.0, the helium space between the HI-STAR HB and MPC and air space between the HI-STAR HB and vault are modeled as stagnant gaps (Assumption (xi)). This assumption has the effect of maximizing gap resistances as convection heat dissipation in these fluid spaces is ignored.

Consistent with the generic HI-STAR MPC design, the Humboldt Bay MPC (MPC HB) is engineered for internal circulation of helium. Helium circulates under the action of buoyancy forces through interconnected paths formed by the fuel basket cells, the peripheral downcomer space and basket top and bottom openings. The fuel basket and top and bottom openings are modeled as porous media with equivalent flow resistances. The MPC HB downcomer space is modeled as an annular gap filled with helium. To overstate downcomer resistance a concentric partition is added in the annulus. Prior to sealing an MPC HB, it is backfilled with helium to a sufficient pressure for adequate heat transfer. The helium backfill requirements are specified in Table 8. The requirements are set forth to ensure a minimum helium pressure of 4.5 atm at design basis heat load. As confirmed by results of thermal calculations (See results presented in Subsection 9.1), the backfill requirements are sufficient to yield an internal helium pressure in excess of 4.5 atm. For conservatism, the minimum helium pressure (4.5 atm) is adopted in thermal modeling.

Proprietary Information Deleted regarding statement 7.5

7.5 Time-to-Boil Limit

In accordance with NUREG-1536, water present inside the MPC HB cavity during wet transfer operations is not permitted to boil. This requirement is ensured by imposing a limit on the maximum allowable time duration for fuel to be submerged in water after a loaded HI-STAR HB cask is removed from the pool.

When a loaded HI-STAR HB is removed from the pool, the combined mass of the water, the fuel, the MPC, and the HI-STAR HB overpack absorb the decay heat emitted by the fuel assemblies. This results in a gradual temperature rise of the entire system with time. To obtain a lowerbound time-to-boil limit the following conservative assumptions are imposed:

i. The HI-STAR HB cask heats up adiabatically.

ii. Design maximum decay heat input from the loaded fuel assemblies is assumed.

iii. Thermal inertia of fuel is neglected.

iv. Weights of HI-STAR HB overpack and MPC HB are understated.

The rate of temperature rise of the HI-STAR HB assuming an adiabatic heat-up is governed by the following equation:

Proprietary Information Deleted in section 7.5

Table 9 summarizes the weight and thermal inertia for the HI-STAR HB. Using Eq. (13) the heat-up rate dT/dt computes as 0.36°F/hr.

Proprietary Information Deleted in section 7.5

During fuel loading operations, the temperature of the HI-STAR HB is well approximated by the pool water temperature. Accordingly, $T_{initial}$ is set equal to the pool water temperature in the adiabatic heat-up calculations. Table 10 provides numerical results for t_{max} at several pool water temperatures.

Proprietary Information Deleted in section 7.5

Table 8 - Proprietary Information Deleted

Table 9 - Proprietary Information Deleted

[11] MPC HB free volumes are computed in a Holtec calculation package [4].

TABLE 10: TIME LIMIT FOR WET OPERATIONS

Pool Temperature (^oF)	Time Duration (hr)
80	366
90	338
100	311
110	283
120	255
130	227
140	200
150	172

8.0 COMPUTER FILES

In this section all computer files supporting the calculations described in this report for Humboldt Bay thermal evaluation are listed. The calculations employ the FLUENT code (versions 4.56 and 6.1.18) for finite-element modeling and general-purpose programs (EXCEL and MATHCAD) for numerical computations. The files are listed below:

(Vault model files (FLUENT version 4.56))

```
Directory of G:\Projects\1125\ir\fl
06/02/03  09:17a              293,540 hb_vault.cas
06/02/03  09:17a              889,310 hb_vault.dat
```

(Effective Conductivity files (FLUENT version 6.1.18))

```
Directory of G:\Projects\1125\ir\fl
05/16/03  04:08p            1,048,576 geom1.dbs
05/16/03  04:08p               77,319 geom1.jou
05/16/03  02:00p              300,072 geom1.msh
05/16/03  04:08p                1,084 geom1.trn
05/16/03  05:12p              209,920 hbquad1.cas
05/16/03  05:12p               38,144 hbquad1.dat
08/25/03  09:08a               37,888 plots.xls
```

(MATHCAD and EXCEL Files)

```
Directory of G:\Projects\1125\ir\misc
06/04/03  05:03p                6,554 c_inf.mcd
06/01/03  03:47p               45,523 fuel_PM.mcd
06/02/03  09:03a               16,896 MPC_Volh.XLS
06/03/03  11:24a               20,480 Vault_bulk.XLS
06/05/03  09:35a               14,848 downcomer.xls
08/27/03  09:52a               23.552 Gap_Cond.xls
10/09/03  11:58a               20,480 MPC_Pressure.xls
```

9.0 RESULTS AND CONCLUSIONS

9.1 Normal Storage

To evaluate the long-term effect of ambient temperatures on fuel cladding, storage temperatures at annual average site conditions (defined as normal storage conditions in Section 1) are calculated.

The design basis decay heat (Q_d) is non-uniformly distributed in accordance with the generic HI-STAR modeling [5]. The ambient and soil temperature inputs (T_{amb} and T_∞ from Section 5.0) are applied to the model and a steady state temperature field obtained. A radial temperature profile in the hottest cask section is graphed in Figure 5. From the steady state temperature field, the MPC HB cavity average temperature is obtained (T_C = 251.81^{o}F) and operating pressures computed from an initial backfill pressure (Table 8) using Ideal Gas Law:

$$P_N = P_B (T_C + 460) / (T_R + 460) \qquad \text{--------------------(15)}$$

Where:

P_N = Normal condition pressure, in absolute units (atm)

P_B = Backfill Pressure, in absolute units (atm)

T_C = Cavity average temperature (^{o}F)

T_R = Backfill reference temperature (^{o}F)

The MPC HB normal storage pressure results are provided in Table 11. Consistent with HI-STAR generic licensing [11], MPC integrity[12] under postulated rod ruptures is evaluated at 1% (normal), 10% (off-normal) and 100% (accident) conditions. These calculations employ gas quantities available for release for BWR fuel [5] suitably adjusted for Humboldt Bay fuel burnups as described next: Proprietary Information Deleted

The results of postulated rods rupture calculations are provided in Table 12. The results are acceptable as the MPC HB pressures are bounded by the design limits (see footnote on previous page) for normal, off-normal and accident pressures.

Compliance of Humboldt Bay thermal design to cask and vault temperature limits (Section 3.0) are demonstrated hereunder:

---

12 MPC integrity is evaluated in accordance with latest criteria [20], viz. 100 psig for normal and off-normal conditions and 200 psig for accident conditions.

13 The gas volumes computed using Eq. (16) are confirmed to be conservative [22].

A) Peak Clad Temperature: 373°F
Limit: 752°F
Margin: 379°F

B) Maximum Neutron Shield Temperature: 195°F
Limit: 300°F
Margin: 105°F

C) Maximum MPC Shell Temperature: 203°F
Limit: 450°F
Margin: 247°F

D) Maximum Local Concrete Temperature: 175°F
Limit: 200°F
Margin: 25°F

E) Bulk Concrete Temperature: 145°F
Limit: 150°F
Margin: 5°F

Note that for evaluation of concrete (Items D and E above), temperatures of the limiting part (the concrete vault) are reported.

9.1.1 Summer Evaluation

It is heuristically obvious that ambient temperatures reached during summer are hotter relative to temperatures during other parts of the year. Insofar as evaluation of short-duration temperatures elevations are concerned, summer temperature peaking is covered by the evaluation in Subsection 9.2. For seasonal temperature elevations, an evaluation is provided next.

From the ambient temperature data for Humboldt Bay, the average summer temperatures (Table 7) is 56°F relative to winter (46°F) and annual average temperatures (52°F, Section 5.0). As bulk of the concrete vault is below ground (See Figure 2), the storage temperatures are relatively unaffected by ambient temperature variations. For a bounding evaluation, the normal condition storage system temperature field is assumed to be elevated by the same amount as the summer temperature elevation. The results are provided below:

Annual average temperature: 52°F

Summer average temperature: 56°F
Summer temperature elevation: 4°F

Maximum Summer Temperatures			
Component	Normal Temperature [°F]	Summer Temperature Elevation [°F]	Summer Temperature [°F]
Cladding	373	4	377
Neutron Shield	195	4	199
MPC Shell	203	4	207
Local Concrete	175	4	179
Bulk Concrete	145	4	149

The maximum storage temperatures (last column in table above) are below their corresponding temperature limits listed in (A) through (E) in Subsection 9.1.

9.2 Off-Normal and Accident Conditions

As stated in Section 1.0, the Humboldt Bay storage system is evaluated for the following ambient conditions:

(i) Off-Normal temperature: 60°F

(ii) Accident temperature: 90°F

The bulk of the concrete vault, as depicted in Figure 2, is below ground. As a result of this storage configuration, the storage temperatures are relatively unaffected by ambient temperature variations. For a bounding evaluation, the normal condition storage system temperature field is assumed to be elevated by the same amount as the off-normal and accident ambient temperature elevations provided below:

Ambient Temperatures
Normal temperature (X): 52°F
Off-normal temperature (Y): 60°F
Accident temperature (Z): 90°F

Off-normal temperature elevation (Y –X): 8°F
Accident temperature elevation (Z – X): 38°F

Adding the ambient temperature elevations to the results for normal ambient temperature, the following results are obtained:

Maximum Off-normal and Accident Temperatures			
Component	Off-Normal	Accident Temperatures	Temperature Limit

	Temperatures [°F]	[°F]	[°F]
Cladding	381	411	1058
Neutron Shield	203	233	300
MPC Shell[14]	211	241	775
Concrete	183	213	350

As observed by a comparison with temperature limits included in the table above, the component temperatures under off-normal and accident conditions comply with the acceptance criteria set forth in Section 3.0.

Following the approach outlined above, the MPC pressure is obtained assuming that the cavity temperature T_C reported in Sub-section 9.1 rises by the same amount as the ambient temperature elevation. The MPC pressures for the off-normal and accident conditions are:

Off-normal ambient condition: 71.54 psig

Accident ambient condition: 75.14 psig

9.3 Heat Load Compliance

For the purpose of minimizing hot spots in the Humboldt Bay storage facility, a lowest practicable cask heat load (2 kW) is proposed as the design limit. This limit is ensured at cask loading by including a mix of cold and hot fuel for storage in an MPC. This manner of limiting the cask decay heat is illustrated in Holtec's decay heat calculation report HI-2033023 [17]. The report confirms that the design heat load limit can be met at the time of fuel loading (circa 2006).

9.4 Short Term Operations

Prior to placement dry storage, an MPC residing in a HI-STAR overpack must be loaded with fuel, outfitted with closures, dewatered, dried, backfilled with helium transported and transferred to the Humboldt Bay concrete vault. In the unlikely event that the fuel needs to be returned to the spent fuel pool, these steps must be performed in reverse. All of the above operations are short duration events that would likely occur no

[14] The MPC temperatures reported herein bound the HI-STAR overpack temperatures. The temperatures are below the off-normal and accident metal temperature limits for the HI-STAR overpack [11].

more than once or twice for an MPC. Thermal scenarios warranting a focused attention are:

i) Loading Operations with Flooded MPC

ii) Drying of the MPC Cavity

iii) MPC Cooldown and Reflood for Defueling Operations

Scenario (i) is addressed in Subsection 7.5. The scenarios (ii) and (iii) are addressed in the HI-STAR FSAR [11] in the following subsections:

Thermal Evaluation for Short Term Operations		
Scenario	Applicable HI-STAR Subsection	Description
Scenario (ii)	4.4.1.1.12	Evaluation of vacuum drying
Scenario (iii)	4.4.1.1.15	Evaluation of fuel cooldown prior to fuel unloading

The Humboldt Bay design heat loads are an order of magnitude lower than the HI-STAR licensing basis heat loads [11]. As the MPCs feature the same full-length welded honeycomb basket construction employed in the generic design for the HI-STAR System, their heat dissipation characteristics are on the same order. The low decay heat duties for which the Humboldt Bay casks are designed render the generic evaluations referenced above as bounding.

TABLE 11: MPC HB NORMAL STORAGE PRESSURE

Lowerbound Pressure	5.47 atm (65.75 psig)
Upperbound Pressure	5.80 atm (70.58 psig)

TABLE 12: MPC-HB PRESSURES UNDER POSTULATED ROD RUPTURE CONDITIONS

Normal (1%)	5.82 atm (70.89 psig)
Off-Normal (10%)	6.01 atm (73.63 psig)
Accident (100%)	7.88 atm (101.10 psig)

10.0 REFERENCES[15]

[1] Humboldt Bay ISFSI Specification HBPP-2001-01.

[2] "Cladding Considerations for the Transportation and Storage of Spent Fuel", Interim Staff Guidance – 11, Revision 2, (7/30/02).

[3] 1987 ASHRAE Handbook, HVAC Systems and Applications, Page 12.7, Table entry for Eureka California.

[4] "Effective thermal property evaluations for HBPP fuel assemblies and MPC-HB", Holtec Report HI-2033005, Rev. 0.

[5] "HI-STAR 100 System Storage & Transport Condition Thermal Evaluation", Holtec Report HI-971826, Rev. 6.

[6] "HI-STAR Dry Fuel Storage Cask Vault", Holtec Dwg. 4105, Rev. 0.

[7] "Dry Cask Vault Assembly", Holtec Dwg. 4110, Rev. 0.

[8] "HI-STAR HB Overpack", Holtec Dwg. 4082, Rev. 0.

[9] "MPC-HB Fuel Basket", Holtec Dwg. 4103, Rev. 0.

[10] "MPC-HB Enclosure Vessel". Holtec Dwg. 4102, Rev. 0.

[11] HI-STAR FSAR, Holtec Report HI-2012610, Rev. 1.

[12] "1998 ASME Boiler and Pressure Vessel Code", Part D, Table TCD, Page 592.

[13] "Marks' Standard Handbook for Mechanical Engineers", 8th Ed., McGraw Hill Book Company, (1978).

[14] "Properties of Concrete", Neville, A.M., (4th Edition).

---

[15] "Note: The revision status of Holtec documents cited herein are subject to updates as the project progresses. This document will be revised if a revision to any of the above-referenced Holtec work products materially affects the instructions, results, conclusions or analyses contained in this document. Otherwise, a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supersede the revision numbers cited above. The Holtec Project Manager bears the undivided responsibility to ensure that there is no intra-document conflict with respect to the information contained in all Holtec-generated documents on a *safety-significant* project. The latest revision number of all documents produced by Holtec International in a *safety-significant* project is readily available from the company's Document Transmittal Form (DTF) database."

[15] “Thermal Properties of Soils”, Miles, K.S., Bulletin No. 28, University of Minnesota Institute of Technology, Engineering Experiment Station, Vol. LII, No. 21, (June 1949).

[16] “Humboldt Bay Power Plant Data Report E, Soil Laboratory Test Data, Rev. 0, (5/10/02).

[17] “HBPP Fuel Assembly Decay Heat Calculations”, Holtec Report HI-2033023, Rev. 0.

[18] “Code Requirements for Nuclear Safety Related Concrete Structures & Commentary”, ACI 349-01/349R-01, American Concrete Institute, (Appendix A, Subsection A.4.2).

[19] “Holtite A: Development History and Thermal Performance Data”, Holtec Report HI-2002396, Rev. 3.

[20] HI-STORM FSAR, Holtec Report HI-2002444, Rev. 1.

[21] “Dimensions and Weights for the Humboldt Bay ISFSI Project”, Holtec Report 2032999, Rev. 0.

[22] “Fission gas release for Humboldt Bay fuel”, Holtec internal E-mail[16] from E. Redmond to I. Rampall, (9/16/03).

[16] A hardcopy is included in this repost as Attachment II.

Proprietary Information Deleted

FIGURE 1: EFFECTIVE CONCRETE CONDUCTIVITY MODEL

Proprietary Information Deleted

FIGURE 2: SOIL CONDUCTION RESISTANCE MODEL

Proprietary Information Deleted

FIGURE 3: AXI-SYMMETRIC VAULT MODEL LAYOUT

Proprietary Information Deleted

FIGURE 4: HI-STAR HB MODEL LAYOUT

Proprietary Information Deleted

FIGURE 5: HOTTEST CASK SECTION RADIAL TEMPERATURE PROFILE

APPENDIX A

HOLTEC APPROVED COMPUTER PROGRAM LIST

(Total No. of Pages = 5)

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
ANSYS (A)	5.3, 5.4, 5.6,5.6.2,5.7,7.0	JZ, EBR, PKC, CWB, SPA, AIS, IR, SP, JRT,AK	Windows		
AC-XPERT	1.12		Windows		
AIRCOOL	5.2I, 6.1		Windows		
BACKFILL	2.0		DOS/ Windows		
BONAMI (Scale)	4.3, 4.4		Windows		
BULKTEM	3.0		DOS/ Windows		
CASMO-4 (A)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ELR, SPA, DMM, KC, ST,VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects. The user should refer to the error notice documented in c4ser.04-results.pdf located in \generic\library\nuclear\error notices\ concerning the use of version 1.13.04. Library N should be used with version 2.05.03 for all new reports issued after June 1st, 2003. Revisions to reports issued prior to June 1st, 2003 may continue to use the old Library L.	
CASMO-3 (A)	4.4, 4.7	ELR, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		
CHANBP6 (A)	1.0	SJ, PKC, CWB, AIS, SP,JRT	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		
DÉCOR	1.0		DOS/Windows		

Proprietary Information Deleted

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
DR.BEAMPRO	1.0.5		Windows		
DR.FRAME	2.0		Windows		
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ, JRT	DOS/Windows	Personnel qualified to use MR216 are automatically qualified to use DYNAMO.	
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.48, 4.56, 5.1 (see error notice), 4.2.8 (UNS),5.5, 6.1.18	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	4.56 6.1.18
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST,VJB	Windows		
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950, 960, 970	JZ, AIS, SPA, SP, JRT	Windows		
MAXDIS16	1.0		DOS/Windows		
MCNP (A)	4A, 4B	ELR, SPA, KC,ST,DMM, VJB, MAP	Windows/ UNIX	CASMO-4 Lumped Fission Products (IDs 401 and 402) and Isotope Pm148M (ID 61248) can be modeled in MCNP 4A using the cross sections documented in HI-2033031. Use of these cross sections is restricted to MCNP 4A, and to material specifications in atom densities.	
MASSINV	1.4, 1.5, 2.1		DOS/Windows		
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PKC, SJ,JRT	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	
MSREFINE	1.3, 2.1		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4,2002, 2003		Windows		
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		
ORIGENS (Scale)	4.3, 4.4		Windows		
PD16	1.1, 1.0, 2.0		Windows		
PREDYNA1	1.5, 1.4		DOS/Windows		
PSD1	1.0		DOS/Windows		
QAD	CGGP		Windows		
SAS2H (Scale)	4.3, 4.4		Windows		
SFMR2A	1.0		DOS/Windows		
SHAPEBUILDER	3.0		DOS/Windows		
SIFATIG	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
SOLIDWORKS	2001		DOS/Windows	This program may be used to calculate Weight, Volume, Centroid and Moment of Inertia. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session. If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				**REV. 61** **July 25, 2003**	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

NOTES:

1. XXXX = ALPHANUMERIC COMBINATION
2. GENERAL PURPOSES UTILITY CODES (MATHCAD, EXCEL, ETC.) MAYBE USED ANYTIME.

ATTACHMENT I

HUMBOLDT BAY SOIL THERMO-PHYSICAL PROPERTY WORKSHEETS

(Report HI-2033033)

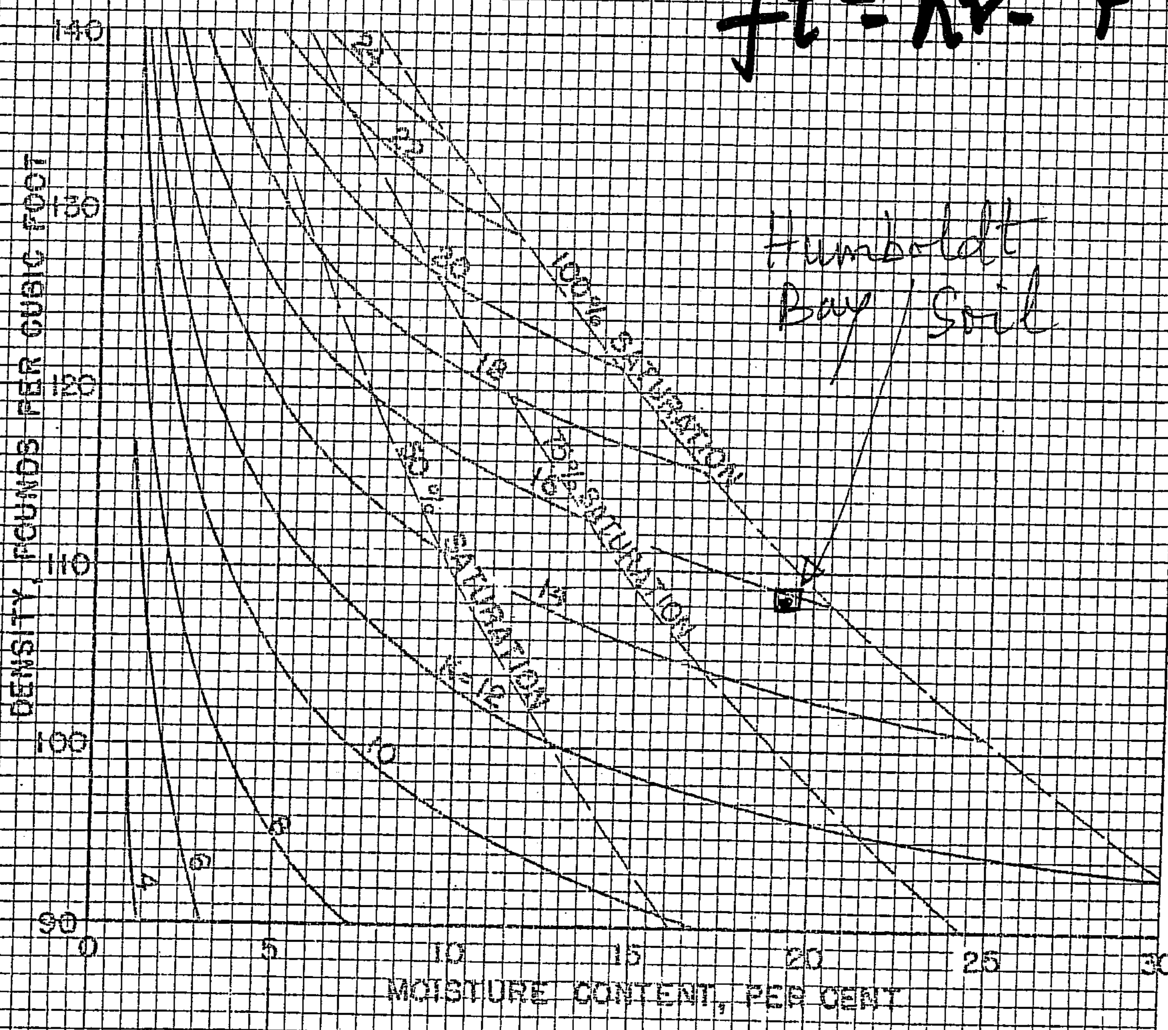
(Section 5.1 provides a description of the contents in this attachment)

FIG. 31
DIAGRAM OF THERMAL CONDUCTIVITY FOR SANDY SOILS

UNFROZEN, MEAN TEMPERATURE 40°F.

DEGREE OF ACCURACY ±25 PER CENT

$K_{soil} \approx 16 \frac{Btu\text{-}inch}{ft^2\text{-}hr\text{-}°F}$



ATTACHMENT 1

HUMBOLDT BAY ISFSI DATA REPORT E

SOIL LABORATORY TEST RESULTS

Moisture Measurements (15)
20.4%, 18.4%, 14.1%, 16.9%, 18.7%
10.2%, 18.6%, 26.7%, 21.7%, 21.2%
22.8%, 28.2%, 17.4%, 21.6%, 13.3%
} Mean = 19.34%

Density Measurements (pcf)
108.7, 106.4, 105.7, 96.3, 111.5
105.2, 125.1
} Mean = 108.41 $\frac{lb}{ft^3}$

COOPER TESTING LABS

MOISTURE DENSITY - POROSITY DATA SHEET

Job #	109-253
Client	Geomatrix
Project/Location	5117.02
Date	4/20/99

Boring #	99-1, 8	10	11	13	15
Depth (ft)	16.5-18	25-26.5	30-31.5	40	50-50.8
Soil Type	brown silty SAND	brown silty SAND w/ gravel	brown silty SAND	brown clayey SAND	grayish brown SAND w/ silt
Specific Gravity					
Volume Total cc					
Volume of Solids					
Volume of Voids					
Void Ratio					
Porosity %					
Saturation %					
Moisture %	20.4%	18.4%	14.1%	16.9%	18.7%
Dry Density (pcf)					

Remarks

COOPER TESTING LABS

MOISTURE DENSITY - POROSITY DATA SHEET

Job #	109-253A
Client	Geomatrix
Project/Location	5117.02
Date	4/20/99

Boring #	99-1, 20	22	99-2, 27		
Depth (ft)	70-70.9	80-80.9	200-201.5		
Soil Type	gray brown SAND w/ gravel	olive brown silty SAND	gray SILT		
Specific Gravity					
Volume Total cc					
Volume of Solids					
Volume of Voids					
Void Ratio					
Porosity %					
Saturation %					
Moisture %	10.2%	18.6%	26.7%		
Dry Density (pcf)					

Remarks

COOPER TESTING LABS

MOISTURE DENSITY - POROSITY DATA SHEET

Job #	109-253B
Client	Geomatrix
Project/Location	5117.02
Date	4/28/99

Boring #	99-1, 3	99-1, 18	99-2, 5	99-2, 6-3	99-2, 13
Depth (ft)	5.5-7.5	61-63	10-13	13.5-14	40-41.3
Soil Type	orange brown clayey SAND	brown SAND	yellow gray silty SAND	gray CLAY, (silty)	graybrown mottled orange clayey SAND
Specific Gravity	2.80 ASSUMED	2.70 ASSUMED	2.80 ASSUMED	2.80 ASSUMED	2.70 ASSUMED
Volume Total cc	381.569	810.613	496.563	274.671	464.155
Volume of Solids	237.234	511.857	300.140	151.270	307.117
Volume of Voids	144.335	298.756	196.423	123.401	157.038
Void Ratio	0.608	0.584	0.654	0.816	0.511
Porosity %	37.8%	36.9%	39.6%	44.9%	33.8%
Saturation %	99.9%	98.1%	97.5%	96.8%	91.9%
Moisture %	21.7%	21.2%	22.8%	28.2%	17.4%
Dry Density (pcf)	108.7	106.4	105.7	96.3	111.5

Remarks

COOPER TESTING LABS

MOISTURE DENSITY - POROSITY DATA SHEET

Job # Client Project/Location Date	109-253C Geomatrix 5117.02 4/28/99				
Boring #	99-2, 18				
Depth (ft)	70-73				
Soil Type	gray brown SAND				
Specific Gravity	2.70 ASSUMED				
Volume Total cc	606.329				
Volume of Solids	378.442				
Volume of Voids	227.887				
Void Ratio	0.602				
Porosity %	37.6%				
Saturation %	96.8%				
Moisture %	21.6%				
Dry Density (pcf)	105.2				

Remarks

COOPER TESTING LABS

MOISTURE DENSITY - POROSITY DATA SHEET

Job #	109-276
Client	Geomatrix
Project/Location	5117.08
Date	1/21/00

Boring #	99-5 16-4				
Depth (ft)	61.4-61.9				
Soil Type	gry silty SAND, trace gravel				
Specific Gravity	2.75 ASSUMED				
Volume Total cc	336.385				
Volume of Solids	245.206				
Volume of Voids	91.179				
Void Ratio	0.372				
Porosity %	27.1%				
Saturation %	98.4%				
Moisture %	13.3%				
Dry Density (pcf)	125.1				

Remarks

ATTACHMENT II

HOLTEC INTERNAL E-MAIL

(Report HI-2033033)

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

STRUCTURAL CALCULATION PACKAGE FOR MPC-HB

FOR

PG&E

Holtec Report No: HI- 2033035

Holtec Project No: 1125

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT ISSUANCE AND REVISION STATUS[1]

DOCUMENT NAME: STRUCTURAL CALCULATION PACKAGE FOR MPC-HB

DOCUMENT NO.:	HI-2033035	CATEGORY: ☐ GENERIC	
PROJECT NO.:	1125	☒ PROJECT SPECIFIC	

Rev. No. [2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	10/7/03	CWB	510198				

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)

Documents labeled "Privileged Intellectual Property" contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 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 "Table of Contents", this page and the "Revision Log".

REVISION LOG

Revision 0 – Original Issue

The original issue of this report contains Supplements 1 through 3.

PREFACE

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 narration smoothness of a Technical Report, and are not intended to serve as a Technical Report.

Because of the Calculation Package's function as a repository of all analyses performed on the subject of its scope, this document is typically revised only if an error is discovered in the computations or the equipment design is modified. Additional analyses in the future will 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.

1.0 INTRODUCTION AND SCOPE

This Calculation Package is compiled to provide archival information to supplement the material presented in the upcoming License Application for an Independent Spent Fuel Storage Installation (ISFSI) at Humboldt Bay. In particular, this Calculation Package contains calculations related to the MPC-HB, a multi-purpose canister designed specifically for use at Humboldt Bay. The MPC-HB is similar in many respects to other previously licensed MPC designs (e.g., MPC-68). As a result, some of the previous work, which was done in support of Holtec's generic MPC designs, is equally valid for the MPC-HB (e.g., MPC top closure analysis) or, in some cases, serves as a bounding analysis (e.g., buckling analysis of MPC shell). These calculations are identified, with appropriate references, in Section 7.0 of the report. The new calculations presented in this Package deal with those aspects of the MPC-HB that are unique or different from previous designs and cannot be bounded by existing structural calculations.

Because of its function as a repository of analyses performed on the subject of its scope, this document will be revised only if an error is discovered in the computations or the equipment design is modified. Additional analyses in the future, supporting either a new SAR amendment or a change supported by a 72.48 evaluation, will 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).

In order to fully understand the format and layout of this Calculation Package, it is necessary to understand its two key attributes. First, unlike most calculation packages, this package contains a multitude of discrete analyses, all of which share a common body of input data, but are otherwise entirely distinct in their methods, models, and computer simulations. This calculation package is in fact a compendium of an array of distinct calculations.

2.0 METHODOLOGY

Calculation specific supplements are attached to this report. In general, the problem descriptions are provided in the introductory section of each calculation. The problem descriptions, unique to each calculation, include the description of the component to be analyzed, the nature and source of the applied loading on the component, and the acceptance criteria. All structural calculations are either based on classical strength of materials solutions, or are based on finite element numerical analysis. Each calculation contains detailed explanation of the analysis methods.

3.0 ACCEPTANCE CRITERIA

This calculation package contains one or more supplements that deal with specific calculation items. If acceptance criteria are different for the individual calculations, then the appropriate acceptance criteria associated with each individual calculation are stated within the specific supplement.

The design criteria for the MPC-HB are identical to the criteria given in Chapter 2.0 of the HI-STAR and HI-STORM FSARs [11.2.1, 11.2.2]. The design criteria represent the basis for the acceptance criteria for the design of the MPC-HB. The stress intensity limit for the confinement and the nonconfinement boundaries are listed in FSAR Tables 2.2.10 and 2.2.11 [11.2.1, 11.2.2]. (The ASME Code stress allowable associated with the stress intensity limits are listed in the FSAR in Tables 3.1.6 through 3.1.17.) The applicable design codes for MPC components are listed in the HI-STORM FSAR in Tables 2.2.6 and 2.2.7, and in similar tables in the HI-STAR FSAR.

4.0 ASSUMPTIONS

In general, each calculation in this package contains a unique set of conservative analysis assumptions. In most cases these assumptions are listed under a separate section in each of the calculations; for some calculations that are similar to work already detailed in an FSAR or in another calculation, references are made to the originating document section for the assumptions.

5.0 INPUT DATA

Input data is provided in the calculation supplements as needed for the specific analysis**.** Data input requirements for geometry, material properties, and applicable load combinations are provided below.

The sources for the input data that are specific to a calculation are provided within that calculation.

The sources of the input data that are repetitively used are listed as references in Section 11. The global sources of input data are compiled below for quick reference. All dimensional data for the MPC-HB is obtained from the drawings [11.2.4].

MPC Weight:

Item	Bounding Weight, lbf (from [11.2.3])
Fuel Basket	7,800
Enclosure Vessel including Lid and Upper Fuel Spacers	19,200
Eighty (80) Damaged Fuel Containers	8,000
Eighty (80) Fuel Assemblies	24,000
TOTAL WEIGHT	**59,000**

Center of Gravity of Loaded MPC-HB: 61” [11.2.3]

Design Pressure: Table 2.2.1 of [11.2.1]
Component Design Temperature: Table 2.2.3 of [11.2.1]
Mechanical Properties: Tables 3.3.1 through 3.3.5 of [11.2.1]
Material Strength: Tables 3.1.6 through 3.1.17 of [11.2.1]

6.0 COMPUTER CODES

The main section of this report is written using Microsoft Word (Office 2000), while the calculation supplements are prepared using MathCad (Version 2000 unless otherwise noted below), or are also written in MS Word and contain manual calculations and/or finite element results. The computer codes used are documented and referenced within each supplement.
All computer codes used for the analysis and design of the MPC-HB are approved under Holtec's QA program. A complete listing of all of the computer codes used in this report, including all supplements, is maintained in Appendix A.

7.0 ANALYSES

Analyses supporting the MPC-HB design are contained either within this Package as calculation supplements or, where the MPC-HB is similar to other MPC designs, in the generic MPC or HI-STAR Calculation Packages [11.2.5, 11.2.6]. The following table lists the calculations outside of this report that support the MPC-HB design.

Report No.	Supplement No.	Description
HI-2012787	3	MPC Lid Analyses – Calculations for Case of Dual Lids
HI-2012787	14	Analysis of MPC Top Closure
HI-2012787	15	Structural Qualification of MPC Baseplate
HI-2012786	6	Code Case N-284 Stability Calculations

As new supporting calculations are added, the revision log and the table of contents will note the additions or modifications to this document.

8.0 COMPUTER FILES

All relevant computer files associated with this calculation package are archived on the Holtec Server. A directory listing appropriate to the supplements is included within each supplement.

9.0 RESULTS OF ANALYSES

The results of each calculation are presented within the individual supplements. The adequacy of the design is conclusively demonstrated by the computation of positive safety margins. The results of the analyses, along with the model description, methodology, assumptions, etc., will be summarized in the upcoming ISFSI License Application.

10.0 SUMMARY AND CONCLUSIONS

This calculation package supports the structural integrity evaluation of the MPC-HB design required by the 10CFR71 and 10CFR72 License Submittals and also supports interim 72.48 evaluations, as needed. All analysis calculations and documentation meet Holtec's Q.A requirements and procedures.

11.0 REFERENCES

11.1 Generic References

A comprehensive list of all references that may be applicable to some or all of the specific calculations performed within this document are given below. Not all references need to be cited within this document to be contained in this comprehensive listing.

[11.1.1] NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," United States Nuclear Regulatory Commission, July 1980.

[11.1.2] ANSI N14.6-1993, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10000 Pounds (4500 kg) or More for Nuclear Materials," American National Standards Institute, Inc.

[11.1.3] D. Burgreen, Design Methods for Power Plant Structures, Arcturus Publishers, 1975.

[11.1.4] NUREG/CR-1815, “Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick”.

[11.1.5] ASME Boiler & Pressure Vessel Code, Section II, Part D, 1995 Edition with Addenda through 1997.

[11.1.6] Deleted.

[11.1.7] Deleted.

[11.1.8] ASME Boiler & Pressure Vessel Code, Section III, Subsection NF, 1995 Edition with Addenda through 1997.

[11.1.9] ASME Boiler & Pressure Vessel Code, Section III, Appendices, 1995 Edition with Addenda through 1997.

[11.1.10] ASME Boiler & Pressure Vessel Code, Section III, Subsection NB, 1995 Edition with Addenda through 1997.

[11.1.11] Theory of Elastic Stability, S.P. Timoshenko and J. Gere, McGraw Hill, 2nd Edition.

[11.1.12] Marks Standard Handbook for Mechanical Engineering, 9th Ed.

[11.1.13] ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, 1995 Edition with Addenda through 1997.

[11.1.14] Manual of Steel Construction – Load and Resistance Factor Design, 1st Edition, AISC, 1986.

[11.1.15] Manual of Steel Construction, AISC, Ninth Edition.

[11.1.16] Mechanical Engineering Design, J. Shigley, and C. Mischke, 5th Edition, McGraw-Hill, 1989.

[11.1.17] Mechanical Design of Heat Exchangers and Pressure Vessel Components, K.P. Singh, and A.I. Soler, Arcturus Publishers, 1984.

[11.1.18] Strength of Materials, S.P Timoshenko, Vols. I, and II, 3rd Edition, Van Nostrand, 1955.

[11.1.19] Mechanical Design and Systems Handbook, H. Rothbart, Editor, 2nd Edition, McGraw-Hill, 1985.

[11.1.20] Theory of Elasticity, S.P. Timoshenko, and J. Goodier, 3rd Edition, McGraw-Hill, 1951.

[11.1.21] Theory of Elastic Stability, S.P. Timoshenko, and J.M. Gere, 2nd Edition, Mcgraw-Hill, 1961.

11.2 Specific References

In addition to the comprehensive reference list provided in Section 11.1, additional project specific references are cited below. If any reference cited below conflicts with an identical reference in Section 11.1 (e.g., a different applicable year for a Code or Standard), then the specific reference takes precedence.

[11.2.1] HI-STAR FSAR, HI-2012610, Latest Approved Revision.

[11.2.2] HI-STORM FSAR, HI-2002444, Latest Approved Revision.

[11.2.3] Holtec Report HI-2032999, “Dimensions and Weights for the Humboldt Bay ISFSI Project,” Latest Revision.

[11.2.4] Holtec Drawing Nos. 4102 and 4103, Latest Revisions.

[11.2.5] Holtec Report HI-2012787, “Structural Calculation Package for MPC,” Revision 4.

[11.2.6] Holtec Report HI-2012786, “Structural Calculation Package for HI-STAR Overpack,” Revision 0.

12.0 LIST OF SUPPLEMENTS

Supplement No.	Description	In Support of	Revision	Specific Locations in SAR
1	Finite Element Analysis of MPC-HB Under 60-g Design Basis Deceleration	Humboldt Bay ISFSI SAR	0	TBD
2	Strength Evaluation of MPC-HB Fuel Basket Spacers	Humboldt Bay ISFSI SAR	0	TBD
3	Structural Integrity of Fuel Spacers	Humboldt Bay ISFSI SAR	0	TBD

HOLTEC CALCULATION

Title: __Finite Element Analysis of MPC-HB Under 60-g Design Basis Deceleration______

PROJECT No. – ECO No. – REV. No.:	**__1125___ - ___N/A___ - ___N/A___**		
Calculation Package No. for **MPC (X) HI-TRAC (_); HI-STAR (_); HI-STORM (_); Other (_)**	**HI-2033035**	**Supplement No.:**	**1**

CALCULATION SUMMARY INFORMATION

Scope: The following calculation demonstrates that the stresses in the MPC-HB fuel basket and shell under the design basis 60-g deceleration meet ASME Code Level D stress limits. This calculation also establishes the minimum fillet weld sizes used to join the cell plates.

Method: The finite element method is used to perform the analysis. A 2-D cross sectional model of the MPC-HB is built using ANSYS. The method of analysis and the model are very similar to those used previously to license the generic MPC designs (e.g., MPC-68).

UPDATES REQUIRED TO FSAR, TO DRAWINGS

Text Modifications (Chapter): N/A

Table Modifications: N/A

Drawing Modifications: N/A

REVISION LOG

Rev. No.	Preparer Initials /Date	Reviewer Initials /Date
0	CWB / 7-10-03	AIS / 7-23-03
1		
2		

The Calculation presented herein provides the analytical basis to adopt the proposed change contemplated by the ECO (see Note 1). The Design Verification Checklist (DVC) documenting the technical review of this calculation is associated with the applicable ECO in the computerized ECO network database.

This Calculation is technically reviewed and QA validated in accordance with HQP 5.1.

This Calculation is archived in the above-referenced Calculation Package as a labeled supplement. This document may be shared as an autonomous piece of work with external organizations and revised, if necessary, to secure their concurrence to the proposed change.

Note 1: All analyses performed to respond to a query or to initiate a design change are archived in a new Calculation Package or added to an existing Calculation Package as a Supplement and the revision number of the Calculation Package is advanced. A supplement to a Calculation Package may consist of one analysis or a number of discrete analyses (each containing this cover sheet) supporting a number of ECOs.

Purpose

The purpose of this calculation is to demonstrate that the stresses in the MPC-HB fuel basket and shell under the 60-g design basis deceleration meet ASME Code Level D stress limits. The 60-g deceleration is the bounding impact load that would result from a 30-ft side drop of a fully loaded HI-STAR HB Cask System. The method of analysis, including the finite element program, the modeling assumptions, and the acceptance limits, is identical to the method previously used to license Holtec's generic MPC designs (e.g., MPC-24, MPC-32, MPC-68, etc.).

Model Description

The finite element model used for this analysis is nearly identical to the MPC model described in Subsection 3.4.4.3.1.1 of the HI-STAR FSAR. The only differences are slight variations in basket geometry and the modeling of certain weld connections.
. In Figure 1, the
contact nodes that define the interface between the fuel basket and the basket support structure are marked with asterisks (*).

Proprietary Information Deleted

Analysis

The analysis simulates a 30-foot side drop of the HI-STAR HB with the MPC-HB stored inside. Consistent with the HI-STAR 100 FSAR, the drop analysis is divided into two cases depending on the orientation of the MPC-HB inside the overpack (i.e., 0 degree or 45 degree orientation). Figures 3 and 4, respectively, show the applied loadings and the boundary conditions for the 0 degree and 45 degree drop analyses. The finite element models assume that every cell location is occupied by a damaged fuel container (DFC) and a fuel assembly, which weigh 400 lb combined.

Proprietary Information Deleted

The input and output files associated with this analysis are stored under the network directory labeled **\\projects\1125\cbullard\MPC-HB\Side Drop\Final Solution**. An excerpt from the file *mpc-hb.inp*, which shows the key input data used to generate the ANSYS finite element model, is included at the end of this supplement.

<u>Results</u>

The results of the analysis are presented below.

FINITE ELEMENT RESULTS FOR THE MPC-HB

	30 Ft. Side Drop – 0 Degrees	30 Ft. Side Drop – 45 Degrees
Fuel Basket – Primary Membrane (P_m)	-15,523 (2.38)	-12,316 (3.00)
Fuel Basket – Local Membrane plus Primary Bending ($P_L + P_b$)	27,511 (2.02)	47,518 (1.17)
Enclosure Vessel – Primary Membrane (P_m)	6,066 (7.16)	5,801 (7.49)
Enclosure Vessel – Local Membrane plus Primary Bending ($P_L + P_b$)	19,252 (3.39)	16,904 (3.86)
Basket Supports – Primary Membrane (P_m)	-8,397 (5.17)	-6,948 (6.25)
Basket Supports – Local Membrane plus Primary Bending ($P_L + P_b$)	50,294 (1.30)	39,659 (1.64)

Notes:
1. All stresses are reported in psi units.
2. The numbers shown in parentheses are the corresponding safety factors.

The minimum safety factor, including a dynamic amplification factor of 1.1 per Appendix 3.X of the HI-STAR FSAR, is 1.06 (= 1.17/1.1), which is above the ASME Code allowable limit of 1.0. The stress distribution in the fuel basket, which corresponds to the minimum safety factor, is plotted in Figure 5.

At the pinned joints, the maximum resultant force per inch of weld is equal to 1,440.5 lb/in. Based on an allowable weld stress of 27,930 psi (per Appendix 3.M of HI-STAR FSAR) and a weld efficiency factor of 0.35 (per ASME Subsection NG), the minimum required weld size is

$$t = \frac{\sqrt{2} \cdot (1{,}440.5 \text{lb/in})}{(0.35) \cdot (27{,}930 \text{psi})} = 0.208 \text{in}$$

Thus, a 7/32" fillet weld (single sided) is adequate to join the perimeter cell plates to the main basket structure.

The following equation, which is developed in Appendix 3.M of the HI-STAR FSAR, establishes the relationship between the weld size “t”, the fuel basket panel wall thickness “h”, and the ratio of allowable weld strength “S_W” to base metal allowable strength “S_p”.

$$h^2 = 1.698 \frac{S_w}{S_p} (ht + t^2)$$

This equation is used to determine the *minimum* fillet weld size to be specified on the MPC-HB design drawings for all double sided fuel basket welds, which insures a factor of safety of 1.0 for all normal and accident conditions. To establish the minimum permissible weld size, Sp is replaced in the above formula by (S_px(DAF/SF)) and the ratio t/h is computed. The following results are obtained:

MINIMUM WELD SIZE FOR MPC-HB FUEL BASKET					
Item	Safety Factor (SF)	Dynamic Amplification Factor (DAF)	t/h	h (inch)	t (inch)
MPC-HB	1.17	1.1	0.662	0.1875	0.124

Thus, the minimum size for all double sided fuel basket welds is 1/8”.

Proprietary Information Deleted

Figure 1 – MPC-HB Finite Element Model

Proprietary Information Deleted

Figure 2 – Detailed View of Fuel Basket Model

Proprietary Information Deleted

Figure 3 – Loads and Boundary Conditions for 0 Degree Drop Analysis

Proprietary Information Deleted

Figure 4 – Loads and Boundary Conditions for 45 Degree Drop Analysis

Proprietary Information Deleted

Figure 5 – Local Membrane plus Primary Bending Stress Intensity in Fuel Basket (45 Degree Drop)

Proprietary Information Deleted

Proprietary Information Deleted

Proprietary Information Deleted

HOLTEC CALCULATION

Title: __Strength Evaluation of MPC-HB Fuel Basket Spacers_______________________
____

PROJECT No. – ECO No. – REV. No.:	**__1125___ - ___N/A___ - ___N/A___**		
Calculation Package No. for **MPC (X) HI-TRAC (_); HI-STAR (_); HI-STORM (_); Other (_)**	**HI-2033035**	**Supplement No.:**	**2**

CALCULATION SUMMARY INFORMATION

Scope: The following calculation demonstrates that the fuel basket spacers, and their attachment welds, are structurally adequate to withstand the normal and accident condition loads.

Method: The stresses are calculated using strength of materials formula and compared with the appropriate stress limit from Subsection NG of the ASME Code.

UPDATES REQUIRED TO FSAR, TO DRAWINGS

Text Modifications (Chapter): N/A

Table Modifications: N/A

Drawing Modifications: N/A

REVISION LOG

Rev. No.	Preparer Initials /Date	Reviewer Initials /Date
0	CWB / 6-6-03	AIS / 7-23-03
1		
2		

The Calculation presented herein provides the analytical basis to adopt the proposed change contemplated by the ECO (see Note 1). The Design Verification Checklist (DVC) documenting the technical review of this calculation is associated with the applicable ECO in the computerized ECO network database.

This Calculation is technically reviewed and QA validated in accordance with HQP 5.1.

This Calculation is archived in the above-referenced Calculation Package as a labeled supplement. This document may be shared as an autonomous piece of work with external organizations and revised, if necessary, to secure their concurrence to the proposed change.

Note 1: All analyses performed to respond to a query or to initiate a design change are archived in a new Calculation Package or added to an existing Calculation Package as a Supplement and the revision number of the Calculation Package is advanced. A supplement to a Calculation Package may consist of one analysis or a number of discrete analyses (each containing this cover sheet) supporting a number of ECOs.

1. Introduction

The height of the storage cavity inside the MPC-HB enclosure vessel is 102.5 inches [3], which is large enough to accomodate a damaged fuel container. Intact fuel assemblies, however, are shorter than a damaged fuel container, and therefore they require a spacer device to maintain their position relative to the fuel basket. As shown on Holtec Drawing 4102 [3], the fuel spacers consist of W4 x 13 stainless steel beams, which are welded to the underside of the MPC lid. Because of the design of the fuel spacers, MPC-HB fuel basket is reduced in height to 97 inches. Thus, to prevent the fuel basket from impacting the upper fuel spacers during a top end drop, the fuel basket is equipped with eight spacer bars, which extend from the top of the MPC fuel basket to just below the MPC lid.

The following calculation demonstrates that the fuel basket spacers, and their attachment welds, are structurally adequate to withstand the normal and accident condition loads. The stresses are calculated using strength of materials formula and compared with the appropriate stress limit from Subsection NG of the ASME Code. The fuel spacers are analyzed separately in Supplement 3 of this report.

2. References

[1] HI-STAR FSAR, HI-2012610, Rev. 1
[2] Holtec Drawing 4103, MPC-HB Fuel Basket, Revision 0.
[3] Holtec Drawing 4102, MPC-HB Enclosure Vessel, Revision 0.
[4] Holtec Report HI-2032999, Dimensions and Weights for Humboldt Bay ISFSI Project, Rev. 0

3. Input Data

$accel := 60g$ — **Accident Acceleration [1], Table 3.1.2**

$T_{ref} := 725F$ — **Reference Temperature for Load Case F3, [1] Table 3.1.17**

$S_{allow\_acc} := 36900psi$ — **Allowable under Accident conditions [1], Table 3.1.17**

$E := 24.625 \cdot 10^6 psi$ — **Youngs Modulus, [1], Table 3.3.1, interpolated for 725F**

$\nu := 0.3$ — **Poisson's Ratio [1], Subsection 3.3.1.1**

Basket Dimensions:

$t_{wall} := \frac{3}{16} in$ — **Basket Wall Thicknesses [2]**

$t_{sheathing} := 0.035in$ — **Sheathing Thickness [2]**

$n_{walls} := 2 \cdot (2 \cdot 4 + 4 \cdot 8 + 5 \cdot 10)$ $\quad n_{walls} = 180$ — **Wall Segments [2]**

$Pitch := 5.89in$ — **Cell Pitch [2]**

$H_{basket} := 97in$ — **Basket Height [2]**

$m_{basket} := 7800 \cdot lb$	**Mass of Fuel Basket [4]**
$h_s := 4.5in$	**Height of Integrated Spacers [2]**
$t_s := 1in$	**Spacer Thickness [2]**
$w_s := 2in$	**Spacer Width [2]**
$l_s := 30in$	**Spacer Length [2]**
$n_s := 8$	**Number of Spacers [2]**
$d_{weld} := 0.125in$	**Weld Size**

4. Strength Compliance for Spacer

Cross Section Area:

$A_s := n_s \cdot w_s \cdot t_s$ $\qquad A_s = 16\,in^2$

Stress Calculation:

Accident Load

$F_{max} := m_{basket} \cdot accel$ $\qquad F_{max} = 4.68 \times 10^5\,lbf$

Stress under accident load

$S_{max} := \frac{F_{max}}{A_s}$ $\qquad S_{max} = 2.925 \times 10^4\,psi$

This is less than the allowable under accident conditions of

$S_{allow\_acc} = 3.69 \times 10^4\,psi$

The safety factor is

$\frac{S_{allow\_acc}}{S_{max}} = 1.262$

5. Stability Compliance for Spacer

As a simplifying assumption, a square profile is used for calculating the moment of inertia, based on the thickness of the spacer.

Proprietary Information Deleted

The critical stress by far exceeds the allowable stress. Therefore, buckling of the spacer is not credible under accident conditions.

6. Strength Compliance for Cell Walls

To demonstrate strength compliance for the cell walls, the compressive load carried by a single spacer is distributed over two intersecting cell walls, each having a width equal to one cell pitch. This is a very conservative approach, as the load is distributed across the basket and not carried by single cell walls.

Local area of cell walls

Proprietary Information Deleted

Stress

Safety Factor, Ratio of allowable to actual stress:

Proprietary Information Deleted

7. Stability Compliance for Cell Walls

Stability of the basket panels, under longitudinal deceleration loading, is demonstrated using the method employed in Subsection 3.4.4.3.1.3 of [1]. Namely, the average compressive stress in the basket cross section, under a 60g load, is compared with the critical buckling stress for a flat panel. The results are as follows:

$n_{walls} := 2 \cdot (2 \cdot 4 + 4 \cdot 8 + 5 \cdot 10)$ $n_{walls} = 180$ **Number of basket cell walls [2]**

$A_{basket} := n_{walls} \cdot Pitch \cdot t_{wall}$ $A_{basket} = 198.8\,in^2$ **Cross sectional (metal) area of fuel basket**

Proprietary Information Deleted

It is noted that the critical axial stress is an order of magnitude greater than the computed basket axial stress reported in the foregoing and demonstrates that elastic stability under longitudinal deceleration load is not a concern.

8. Strength Compliance for Welds between Spacers and Basket Walls

$l_{weld} := (l_s - h_s) \cdot 2$ $l_{weld} = 51\,in$ **Weld length per spacer**

$w_{weld} := \frac{d_{weld}}{\sqrt{2}}$ $w_{weld} = 0.088\,in$ **Weld width**

$A_{weld} := l_{weld} \cdot w_{weld}$ $A_{weld} = 4.508\,in^2$ **Weld Area**

Proprietary Information Deleted

Safety Factor, Ratio of allowable to actual stress

$$\frac{S_{allow\_weld}}{S_{weld}} = 1.137$$

9. Conclusions

All computed safety factors are above 1.0. Therefore, the fuel basket spacers, and their attachment welds, are structurally adequate to withstand the normal and accident condition loads.

HOLTEC CALCULATION

Title: __Structural Integrity of Fuel Spacers____

PROJECT No. – ECO No. – REV. No.:	**__1125___ - ___N/A___ - ___N/A___**		
Calculation Package No. for **MPC (X) HI-TRAC (_); HI-STAR (_); HI-STORM (_); Other (_)**	**HI-2033035**	**Supplement No.:**	**3**

CALCULATION SUMMARY INFORMATION

Scope: The following calculation demonstrates that the upper fuel spacers, which are fabricated from W4 x 13 beams and welded to the underside of the MPC lid, are structurally adequate to withstand the normal and accident condition loads applicable to the MPC-HB.

Method: The stresses are calculated using strength of materials formula and compared with the appropriate stress limit from Section III, Subsection NF of the ASME Code. Materials properties are taken from ASME Section II, Part D.

UPDATES REQUIRED TO FSAR, TO DRAWINGS

Text Modifications (Chapter): N/A

Table Modifications: N/A

Drawing Modifications: N/A

REVISION LOG

Rev. No.	Preparer Initials /Date	Reviewer Initials /Date
0	CWB / 6-6-03	AIS / 7-23-03
1		
2		

The Calculation presented herein provides the analytical basis to adopt the proposed change contemplated by the ECO (see Note 1). The Design Verification Checklist (DVC) documenting the technical review of this calculation is associated with the applicable ECO in the computerized ECO network database.

This Calculation is technically reviewed and QA validated in accordance with HQP 5.1.

This Calculation is archived in the above-referenced Calculation Package as a labeled supplement. This document may be shared as an autonomous piece of work with external organizations and revised, if necessary, to secure their concurrence to the proposed change.

Note 1: All analyses performed to respond to a query or to initiate a design change are archived in a new Calculation Package or added to an existing Calculation Package as a Supplement and the revision number of the Calculation Package is advanced. A supplement to a Calculation Package may consist of one analysis or a number of discrete analyses (each containing this cover sheet) supporting a number of ECOs.

STRUCTURAL INTEGRITY OF FUEL SPACER

The following calculation demonstrates that the upper fuel spacers, which are fabricated from W4 x 13 beams and welded to the underside of the MPC lid, are structurally adequate to withstand the normal and accident condition loads applicable to the MPC-HB. The stresses are calculated using strength of materials formula and compared with the appropriate stress limit from Section III, Subsection NF of the ASME Code [1]. The welds connecting the upper fuel spacer to the MPC lid are also analyzed to confirm that they remain intact under a 60g bottom end drop. Materials properties are taken from ASME Section II, Part D [2] at 550 degrees F, which is consistent with the normal design temperature of the MPC lid (refer to Table 2.2.3 of [4]).

The following input data is used in the calculation.

Maximum fuel assembly OD	$d_{assy} := 4.70 \cdot in$	[3]
Maximum weight of stored fuel assembly plus DFC	$w_{assy} := 400 \cdot lbf$	[3]
Design basis deceleration	$a := 60$	[4, Table 3.1.2]
Yield strength of the beam material (304 S/S @ 550F)	$S_y := 18800 \cdot psi$	[2]
Ultimate strength of the beam material (304 S/S @ 550F)	$S_u := 63500 \cdot psi$	[2]
Elastic modulus of the beam material (304 S/S @ 550 F)	$E := 25.55 \cdot 10^6 \cdot psi$	[2]
Weight of the beam	$w_{beam} := 13 \cdot \frac{lbf}{ft}$	[5]
Height of the beam	$h_{beam} := 4.16 \cdot in$	[5]
Width of the beam	$w_{flange} := 4.06 \cdot in$	[5]
Web thickness of the beam	$t_{web} := 0.280 \cdot in$	[5]
Flange thickness of the beam	$t_{flange} := 0.345 \cdot in$	[5]
Distance from outer face of flange to web toe of fillet	$k_{beam} := 0.6875 \cdot in$	[5]
Cell pitch of MPC-HB fuel basket	$pitch := 5.89 \cdot in$	[7]
Size of fillet weld connecting upper fuel spacer to MPC lid	$t_{weld} := 0.125 \cdot in$	[8]

Length of weld per foot [8]

Local Web Yielding

Per the requirements of NF-3322.6 [1] and Appendix F [6], the governing equation for local web yielding for Level D Service Conditions is

Proprietary Information Deleted

where R = concentrated transverse load applied to the beam, lbf
t = beam web thickness, in
N = length of applied load, in
k = distance between outer face of column flange and web toe of its fillet

For the upper fuel spacer, the quantity on the left hand side is equal to

Proprietary Information Deleted

and the resulting safety factor is

Proprietary Information Deleted

ASME Section II, Appendix F [6] also requires that, under Level D Service Conditions, the compressive load on a structure shall not be greater than 2/3 of the critical buckling load. Based on the assumption that the fuel spacer behaves like a slender bar built in at one end and free at the opposite end, the critical load is computed as follows (refer to page 148 of [9])

Proprietary Information Deleted

Therefore, in accordance with the ASME Code, the factor of safety against compressive failure is

Proprietary Information Deleted

Weld Shear Stress

The upper fuel spacer is connected to the MPC lid by intermittent fillet welds along the edges of its flange. The following calculation determines the shear stress in those welds due to the amplified weight of the beam under a 60g bottom end drop.

Proprietary Information Deleted

All of the computed safety factors are above 1.0. Therefore, the upper fuel spacers are structurally adequate to withstand the normal and accident condition loads applicable to the MPC-HB.

References

[1] ASME Boiler & Pressure Vessel Code, Section III, Subsection NF, 1995 Edition.

[2] ASME Boiler & Pressure Vessel Code, Section II, Part D, 1995 Edition.

[3] Holtec Report HI-2032999, Dimensions and Weights for Humboldt Bay ISFSI Project, Revision 0.

[4] HI-STAR FSAR, HI-2012610, Revision 1.

[5] AISC Manual of Steel Construction, Eighth Edition.

[6] ASME Boiler & Pressure Vessel Code, Section II, Appendices, 1995 Edition.

[7] Holtec Drawing No. 4103, Revision 0.

[8] Holtec Drawing No. 4102, Revision 0.

[9] S. Timoshenko, Strength of Materials - Part II - Advanced Theory and Problems, Third Edition.

APPENDIX A

HOLTEC APPROVED COMPUTER PROGRAM LIST

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
ANSYS (A)	5.3, 5.4, 5.6,5.6.2,5.7,7.0	JZ, EBR, PKC, CWB, SPA, AIS, IR, SP, JRT, AK	Windows		5.7
AC-XPERT	1.12		Windows		
AIRCOOL	5.2I, 6.1		Windows		
BACKFILL	2.0		DOS/Windows		
BONAMI (Scale)	4.3, 4.4		Windows		
BULKTEM	3.0		DOS/Windows		
CASMO-4 (A)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ELR, SPA, DMM, KC, ST, VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects. The user should refer to the error notice documented in c4ser.04-results.pdf located in \generic\library\ nuclear\error notices\ concerning the use of version 1.13.04. Library N should be used with version 2.05.03 for all new reports issued after June 1st, 2003. Revisions to reports issued prior to June 1st, 2003 may continue to use the old Library L.	
CASMO-3 (A)	4.4, 4.7	ELR, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				**REV. 61** **July 25, 2003**	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
CHANBP6 (A)	1.0	SJ, PKC, CWB, AIS, SP, JRT	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		
DÉCOR	1.0		DOS/Windows		
DR.BEAMPRO	1.0.5		Windows		
DR.FRAME	2.0		Windows		
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ, JRT	DOS/Windows	Personnel qualified to use MR216 are automatically qualified to use DYNAMO.	
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.48, 4.56, 5.1 (see error notice), 4.2.8 (UNS),5.5, 6.1.18	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST, VJB	Windows		
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950, 960, 970	JZ, AIS, SPA, SP, JRT	Windows		
MAXDIS16	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
MCNP (A)	4A, 4B	ELR, SPA, KC, ST, DMM, VJB, MAP	Windows/ UNIX	CASMO-4 Lumped Fission Products (IDs 401 and 402) and Isotope Pm148M (ID 61248) can be modeled in MCNP 4A using the cross sections documented in HI-2033031. Use of these cross sections is restricted to MCNP 4A, and to material specifications in atom densities.	
MASSINV	1.4, 1.5, 2.1		DOS/Windows		
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PKC, SJ, JRT	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	
MSREFINE	1.3, 2.1		DOS/Windows		
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4,2002, 2003		Windows		
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		
ORIGENS (Scale)	4.3, 4.4		Windows		
PD16	1.1, 1.0, 2.0		Windows		
PREDYNA1	1.5, 1.4		DOS/Windows		
PSD1	1.0		DOS/Windows		
QAD	CGGP		Windows		
SAS2H (Scale)	4.3, 4.4		Windows		
SFMR2A	1.0		DOS/Windows		
SHAPEBUILDER	3.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 61 July 25, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
SIFATIG	1.0		DOS/Windows		
SOLIDWORKS	2001		DOS/Windows	This program may be used to calculate Weight, Volume, Centroid and Moment of Inertia. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session. If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

NOTES: 1. XXXX = ALPHANUMERIC COMBINATION

2. GENERAL PURPOSES UTILITY CODES (MATHCAD, EXCEL, ETC.) MAYBE USED ANYTIME.

HOLTEC
INTERNATIONAL

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

SEISMIC RESPONSE OF THE HI STAR HB AND TRANSPORTER TO THE DBE EVENT

FOR

PG&E

Holtec Report No: HI- 2033036

Holtec Project No: 1125

Report Class : SAFETY RELATED

DOCUMENT NAME: Seismic Response of HI-STAR HB and Transporter to the DBE Event							
DOCUMENT NO.:		2033036		CATEGORY: ☐ GENERIC			
PROJECT NO.:		1125		X PROJECT SPECIFIC			
Rev. No.[2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	10/8/03	AIS	140288	3			
1							
2							

DOCUMENT CATEGORIZATION

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

X 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 does not follow HQP requirements but follows a format more suited for an ASME Code Calculation report.

DECLARATION OF PROPRIETARY STATUS

This document is labeled:

☐ Nonproprietary   Holtec Proprietary   ☐ TOP SECRET

Documents labeled TOP SECRET contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 in the N-drive of 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 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 Calculation Packages may be made by adding supplements to the document and replacing the "Table of Contents", and the "Revision Log".

HOLTEC SAFETY SIGNIFICANT DOCUMENTS

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 this document must fulfill, as applicable, 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 is drawn from referencable sources. Any assumed input data is so identified.
- ❖ All significant assumptions are stated.
- ❖ The analysis methodology is consistent with the physics of the problem.
- ❖ Any computer code and its specific versions used in the work have 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 the report is understandable to a reader with the requisite academic training and experience in the underlying technical disciplines.

Once a safety significant document, such as this report, 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), editorial revisions to Holtec *safety significant* documents are not made unless such editorial changes are deemed necessary by the Holtec Project Manager to prevent erroneous conclusions from being inferred by the reader. In other words, the focus in the preparation of this document is to ensure correctness of the technical content rather than the cosmetics of presentation.

REVISION LOG

Revision 0: Original Issue

EXECUTIVE SUMMARY

Six HI-STAR HB casks will be stored in the Humboldt Bay ISFSI Vault. In accordance with the Humboldt Bay Specification for the dry storage system, the design basis seismic events (DBE's) are applied as an input 3-D motion to the HI-STAR HB carried by the Transporter at various locations on the path from the Reactor Fuel Building (RFB) to the ISFSI vault. Four separate DBE events are considered as input data for dynamic simulation of the cask response to an earthquake. In this report, the response of the cask/transporter assemblage to each of the input seismic events is determined by performing a dynamic simulation. The results from the analyses are the maximum excursions of the transporter so that the propensity for the transporter to remain on the roadway may be assessed.

Analyses are performed for the transporter/cask system on flat ground with the horizontal component of the seismic event containing "fault fling" (the fault normal component) oriented perpendicular to the transporter track. Results for transporter/ground interface coefficient of friction equal to 0.4 are obtained for all four DBE sets. An additional analysis using a transporter/ground interface coefficient of friction equal to 0.8 is performed for one seismic set and demonstrates that the center-of-gravity of the transporter/cask assembly is low enough that tipover of the transporter is not credible. Finally, the four DBE sets are applied to the cask/transporter assembly assuming that the loaded transporter is climbing an 8.5% grade and that the earthquake component containing fault fling is oriented parallel to the transporter track to maximize sliding down the grade. The results from the suite of analyses are presented in the following table. The seismic event designated as DBE3 results in the largest excursions in the direction of the Fault Normal earthquake (horizontal seismic acceleration direction with fault fling) for both level and inclined roadway.

Maximum Transporter Excursions

Seismic Event	Level Ground – Max. Excursion Perpendicular to Track (inch)	8.5% Grade – Max. Excursion Parallel to Track (inch)	8.5% Grade – Max. Excursion Perpendicular to Track (inch)	Remarks
DBE 1	108	289	81.	COF=0.4
DBE 2	175	297	20	COF=0.4
DBE 3	258	449	63	COF=0.4
DBE 4	213	341	42	COF=0.4
DBE 3	-	215	282	COF=0.4 with FN perpendicular to roadway
DBE3	136 (base of transporter) 136.40 (top of transporter)	-	-	COF=0.8
0.5 x DBE3	60.8	-	-	COF=0.4
0.25 x DBE3	1.59	-	-	COF=0.4

TABLE OF CONTENTS

1.0 INTRODUCTION

Six HI-STAR HB casks will be stored in the Humboldt Bay ISFSI Vault. In accordance with the Specification [1], Section 6.2.5.1, the design basis seismic events (DBEs) are applied as an input 3-D motion to the HI-STAR HB while being moved to the ISFSI by the cask transporter. Four separate DBE events are considered as input data for dynamic simulation of the cask/transporter assembly response to an earthquake. The purpose of the dynamic simulations performed herein is to assess the overall stability and the extent of movement of the transporter relative to the defined travel path.

The analyses are performed with the vertical seismic event directed to produce final free field vertical position “up” from the starting position. The horizontal component of the seismic event containing fault fling is oriented perpendicular to the transporter track for evaluations on level ground and is oriented both parallel and perpendicular to the transporter track for analyses on the 8.5% grade up to the ISFSI. Included in the set of analyses is a parametric analysis of the effect of seismic strength on the extent of the transporter excursion from its initial location.

Proprietary Information Deleted

2.0 METHODOLOGY

The dynamic simulations are performed using VisualNastran Desktop (VN) [2]. This code is capable of modeling large motions of rigid bodies that may contact each other during the event. The VN simulation code (previously denoted as "Working Model") has been employed elsewhere [3-5] and has been subject to NRC scrutiny.

Proprietary Information Deleted

The mass and inertia properties associated with the HI-STAR HB are adjusted to include a loaded MPC with 80 Humboldt Bay fuel assemblies.

Proprietary Information Deleted

Figure 1 shows the complete dynamic model of the transporter carrying the HI-STAR HB.

Proprietary Information Deleted

3.0 REFERENCES[1]

[1] Humboldt Bay Specification for Dry Cask Storage HB-2001-01

[2] VisualNastran Version 2002, MSC Software, 2002, and Validation Manual for VisualNastran 2002, HI-2022896, Revision 0.

[3] HI-2002507, Seismic Analysis of Loaded HI-TRAC in Diablo Canyon Fuel Building, Project 1073, Revision 1.

[4] HI-STAR 100 SAR, HI-951251, Revision 9.

[5] HI-2022878, Supplemental Seismic Stability Analysis for PFSF, Project 70651, 2002, Revision 0.

[6] Solidworks 2001 Plus, Solidworks, Inc.

[7] HI-STAR FSAR, HI-2019610, Revision 1

---

[1] This revision status of Holtec documents cited above is subject to updates as the project progresses. This document will be revised if a revision to any of the above-referenced Holtec work products materially affects the instructions, results, conclusions or analyses contained in this document. Otherwise, a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supersede the revision numbers cited above. The Holtec Project Manager bears the undivided responsibility to insure that there is no intra-document conflict with respect to the information contained in all Holtec generated documents on a safety significant project".

[8] HI-2032999, Dimensions and Weights for the Humboldt Bay ISFSI Project, Project 1125, 2003, Revision 0.

[9] Humboldt Bay DBE Time Histories (Fault Normal, Fault Parallel, and Vertical Response Spectra and Time Histories), 4 sets provided by PG&E (Letter of 1/21/03 citing Report GEO.HBIP.02.05).

[10] HI-2012501, Functional Specification for the Diablo Canyon Transporter, Rev. 5, Holtec Project 1073.

[11] HI-2012768, Transporter Stability on Diablo Canyon Dry Storage Paths, Rev. 2, Holtec Project 1073.

4.0 ACCEPTANCE CRITERIA

The results from the analyses quantify the maximum excursions, relative to the roadway, that may occur if a DBE event occurs during movement to or from the ISFSI. The results from this report may be used to assess the requirement for a Probability Risk Assessment (PRA).

5.0 ASSUMPTIONS

The cask and contents are modeled as multiple rigid bodies with known geometry and weight. This is conservative since all energy loss from cask structural deformation is neglected.

Proprietary Information Deleted

The coefficient of friction between transporter track and ground is set at 0.4 for all but one simulation. This value is identical to the value used for the Diablo Canyon transporter analyses and has been justified in that project [11].

This is a conservative and

simplifying assumption. The contact algorithm is identical to that used with similar analyses supporting the ISFSI licensing effort for Diablo Canyon.

Proprietary Information Deleted

6.0 INPUT DATA

6.1 HI-STAR HB and Cask Transporter

The HI-STAR HB cask is represented as a homogeneous, rigid cylinder containing a loaded MPC. The mass and geometry data input used for the analyses in the vault is obtained from [8] and from [4]. The dimensions and weight for the transporter are obtained from [11] since the Diablo Canyon transporter will be used at Humboldt Bay

HI-STAR Overpack with Loaded MPC – 161,200 lb.

Cask Transporter – 170,000 lb.

Figure 2 shows the VN input screens where the mass data is entered.

6.2 Input Loading

Input time histories of different durations have been provided by PG&E [9] for four (4) sets of seismic events, denoted as the “DBE” event (Sets 1-4). The data is in the form of ground acceleration vs. time. In accordance with the specification, Soil Structure Interaction (SSI) need not be considered so the vault acceleration time history is that of the ground. For each set of data consisting of three orthogonal acceleration time histories (fault normal, fault parallel, and vertical), the problem is re-formulated into a fixed ground plane and a moving cask and transporter subject to three components of imposed inertia forces, applied at the mass centers of the overpack and the transporter, respectively. The vertical acceleration component of the motion is applied in a direction that causes the vault to end up at a higher elevation than its starting position. Figure 3 shows the equations for the three components of inertia force applied to the HI-STAR for the Set 2 DBE event. Dividing by the negative of the loaded cask weight recovers the input acceleration components for Set 2. Similar inertia forces are applied to the cask transporter, differing only by the multiplying component weight. The equations shown in Figure 3 reflect the seismic orientation while the transporter is on the 8.5% grade. Input[34] is the fault normal event (containing fault fling) and is oriented along the global x axis (parallel to the transporter track); input[35] in the fault parallel seismic component; and, input[36] is the vertical seismic component (oriented so the free field position is higher after the seismic event). For simulations on level ground, the x and y seismic inputs are interchanged so that the fault normal event is oriented perpendicular to the transporter track. Figure 3 shows the complete DBE2 inertia force time history applied to the HI-STAR.

6.3 Transporter/Ground Interface

Proprietary Information Deleted

Coefficient of Friction = 0.4, 0.8 [11]

7.0 ANALYSES

Proprietary Information Deleted

Figures 4-19 include the collected data on transporter/cask maximum excursions.

Proprietary Information Deleted

All results are archived and are listed in Appendix B. The interface coefficient of friction is maintained at 0.4 for all four DBE simulations for both flat and inclined roadway; an additional simulation for one of the seismic input sets (the DBE3 set) on flat ground is performed with an interface coefficient of friction of 0.8 to assess the propensity for transporter tipover. Results for maximum transporter excursions are also presented in tabular form.

Finally, a parametric evaluation using one of the earthquake sets applied to a flat ground configuration is performed to assess the effect of seismic strength on the maximum excursion of the transporter. Simulations are performed with the three components of the input seismic accelerations reduced to 0.5 and 0.25 of the maximum, respectively, and the maximum transporter excursions computed. The results from the parametric evaluation are reported in tabular form.

8.0 RESULTS

Figures 4-7 present results using the four DBE events, the transporter on level ground, the transporter/ground interface coefficient of friction equal to 0.4, and the fault normal seismic component oriented perpendicular to the transporter track. Figure 8 presents results for one seismic event with the interface coefficient of friction increased to 0.8 to maximize the propensity for a tipover. The result of the single simulation at higher ground coefficient of friction indicated no propensity for tipover (the horizontal excursions at the top and base of the transporter (Coordinates 22 and 8, respectively) are recorded over the event duration. The maximum horizontal excursion perpendicular to the transporter track at the top of the transporter was only 0.56 inch larger than the maximum excursion at the base of the transporter). Figures 9-12 present results using the four DBE events, the loaded transporter climbing an 8.5% grade, the transporter/ground interface coefficient of friction equal to 0.4, and the fault normal seismic component oriented parallel to the transporter track. Results for ground contact forces and for HI-STAR vertical lift members are also shown (for future input to transporter structural design calculations). All tabulated results below are obtained by reading of the digitized data produced by the VN simulations. Note that for the non-zero grade simulations, the displacement meters do not start at “zero”. This is because the original meter definition was for the flat ground simulations. Rotation of the bodies to produce the 8.5% grade models was accomplished without resetting the origin (re-zeroing the meters). For the cases where the transporter is sliding down the grade, the maximum excursion in the horizontal direction is reported in the table. Because of the small angle, the difference between this value and the actual movement parallel to the roadway is small. Finally, Figure 13 presents results for the case of 8.5% grade with the DBE3 seismic event applied with the FN component conservatively applied perpendicular to the roadway (even though the roadway would at most approximately see 33% of this seismic component). The results from this simulation are compared with the same case with 0% grade and the following amplifier developed.

Amplifier = 282”/258” = 1.093

Figures 14-18 present results for the two cases where the seismic strength is reduced by attenuating the three components of the DBE3 event by 0.5 and 0.25, respectively, over the entire duration of the event. Figure 14 summarizes the displacement-time behavior of the base of the HI-STAR and the top of the transporter, and shows the three components of the inertia force applied to the cask for the case of 0.5 x DBE. Figures 15-17 show the three inertia force components separately. Division by the weight of the HI-STAR (161,200 lb.) used in the simulation provides the acceleration in g’s. Figure 18 reports the same results as Figure 14, except for the case of 0.25 x DBE3. Finally, Figure 19 presents results for the inertia force applied to the MPC while in the RFB and subject to Set 3 of the RFBSSE event (see HI-2033046, which examines the behavior of the loaded HI-STAR on the Dolly while in and adjacent to the Reactor Fuel Building (RFB)).

Maximum excursions from all simulations are reported in the first of the two tables presented below.

Maximum Transporter Excursions

Seismic Event	Level Ground – Max. Excursion Perpendicular to Track (inch)	8.5% Grade – Max. Excursion Parallel to Track (inch)	8.5% Grade – Max. Excursion Perpendicular to Track (inch)	Remarks
DBE 1	108	289	81.	COF=0.4
DBE 2	175	297	20	COF=0.4
DBE 3	258	449	63	COF=0.4
DBE 4	213	341	42	COF=0.4
DBE 3	-	215	282	COF=0.4 with FN perpendicular to roadway
DBE3	136 (base of transporter) 136.40 (top of transporter)	-	-	COF=0.8
0.5 x DBE3	60.8	-	-	COF=0.4 (Fig. 14)
0.25 x DBE3	1.59	-	-	COF=0.4 (Fig. 18)

To estimate the maximum excursions from the attenuated .5 x DBE3 if the loaded transporter is on the 8.5% grade, we use the same amplifiers that are obtained for the full DBE3 event when the flat ground results are compared with the 8.5% grade results. That is, a conservative estimate of transporter movement under the .5 x DBE3 event on the 8.5% grade is obtained as:

Movement Parallel to Roadway = 60.8” x 449/258 = 105.8”

Movement Perpendicular to Roadway = 60.8” x 282/258 = 66.5”

Finally, a comparison of the peak g’ values for 0.5DBE and for Set 3 of the RFBSSE event is presented in the next table (divide values of peak inertia force by the appropriate weight). The 50% DBE3 gives maximum acceleration levels that are approximately 50% higher than the results from the RFBSSE3 event that is applicable inside the fuel building.

Maximum “g” Values

Seismic Component	***0.5 x DBE3***	***RFBSSE3***
AX	.713	.491
AY	.757	.458
AZ	.868	.525

9.0 SUMMARY

Seismic simulations have been performed for the transporter/cask assembly while on the roadway between the RFB and the ISFSI vault. Maximum excursions have been summarized for the various configurations analyzed. Significant sliding excursions are shown to occur, but tipover of the transporter is not a credible occurrence even if a high coefficient of friction is set at the transporter/ground interface. No significant vertical motion of the HI-STAR HB, relative to the transporter was observed in any of the simulations. The meter data for lateral movement for Coordinate 22 (at the top of the transporter) and for Coordinate 8 (at the base of the transporter) could be used to determine the rigid body rotation; however, visual examination of the meter data is sufficient to conclude that transporter rigid body rotation and consequent uplift is not a concern. Therefore, it is concluded that the results are insensitive to the exact value computed for the link stiffness.

The results can be used to assess the width of roadway required to ensure that the transporter remains on the roadway, and to assess the desirability of performing a Probability Risk Assessment (PRA).

Analysis results can be averaged for the four sets per SRP 3.7.1 guidelines for performing non-linear analyses subject to various time histories enveloping the same design spectra set. Therefore, we report here the results of such averaging. Note that a conservative estimate of the average movement perpendicular to the road, if the FN seismic event is conservatively oriented to be perpendicular to the road, is obtained by amplifying the average obtained for the level ground set by the amplifier obtained from the comparison of the two simulations using the DBE3 seismic event.

Maximum Transporter Excursions

Seismic Event	Level Ground – Max. Excursion Perpendicular to Track (inch)	8.5% Grade – Max. Excursion Parallel to Track (inch)	8.5% Grade – Max. Excursion Perpendicular to Track (inch)	Remarks
Average	189	344	52	FN parallel to road in 8.5% grade analyses
Average	-	-	189 x 1.093 = 206.6 **	FN perpendicular to road in 8.5% grade analysis

** Estimated by applying amplifier derived by comparison of simulations with DBE3 event to average result computed from four level ground simulations with FN applied perpendicular to vehicle track.

The results for 50% and 25% of DBE may be considered as upper bounds on the actual displacements under these conditions as they were obtained for DBE3, which produced the largest excursions on flat ground.

10. FIGURES

Proprietary Information Deleted

FIGURE 1 – VisualNastran Cask Model with Shim Clearances

FIGURE 2 Component Mass Values

Proprietary Information Deleted

FIGURE 3 Inertia Forces on Transporter – DBE2 – Cask on 8.5% Grade

Proprietary Information Deleted

FIGURE 4 Results – DBE Set 1 – Level Ground – COF = 0.4

Proprietary Information Deleted

FIGURE 5 Results DBE Set 2 – Level Ground – COF=0.4

Proprietary Information Deleted

FIGURE 6 Results DBE Set 3 – Level Ground – COF = 0.4

Proprietary Information Deleted

FIGURE 7 Results DBE Set 4 – Level Ground – COF=0.4

Proprietary Information Deleted

FIGURE 8 Results DBE 3 – Level Ground – COF=0.8

Proprietary Information Deleted

FIGURE 9 Results DBE 1 – 8.5% Grade – COF=0.4

Proprietary Information Deleted

FIGURE 10 Results DBE 2 – 8.5% Grade – COF=0.4

Proprietary Information Deleted

FIGURE 11 Results DBE 3 – 8.5% Grade – COF=0.4

Proprietary Information Deleted

FIGURE 12 Results DBE 4 – 8.5% Grade – COF=0.4

Proprietary Information Deleted

FIGURE 13 Results DBE 3 – 8.5% Grade – COF=0.4, FN Oriented Perpendicular to Roadway

Proprietary Information Deleted

FIGURE 14 Results for 0.5 x DBE 3 – 0% Grade – COF=0.4

Proprietary Information Deleted

FIGURE 15 HI-STAR INERTIA FORCE - FX – 0.5 x DBE3

Proprietary Information Deleted

FIGURE 16 HI-STAR INERTIA FORCE - FY – 0.5 x DBE3

Proprietary Information Deleted

FIGURE 17 HI-STAR INERTIA FORCE - FZ – 0.5 x DBE3

Proprietary Information Deleted

FIGURE 18 Results for 0.25 x DBE 3 – 0% Grade – COF=0.4

Proprietary Information Deleted

FIGURE 19 MPC Inertia Force – Set 3 of SSERFB Event (MPC Weight=59,000 lb.)

Proprietary Information Deleted

11. APPENDICES

Appendix A : Proprietary Information Deleted

Appendix A - Calculations Supporting VisualNastran Simulations

Appendix B - Computer Files

Appendix C - Approved Computer Code List

APPENDIX B – Listing of Computer Files

G:\PROJECTS\1125\AIS\GENERAL ANALYSES\HI STAR ON TRANSPORTER

DBE2-4 flat cof 04 5-22-03.zip	60,303 KB	WinZip File	5/23/2003 1:53 PM
DBE3-4 flat cof 04 reduce eq 5-27-03.zip	68,886 KB	WinZip File	5/27/2003 8:38 AM
DBE EQ Files.zip	836 KB	WinZip File	5/30/2003 7:50 AM
HBT-Flat DBE1 cof=4 6-01-03 final.zip	22,952 KB	WinZip File	6/1/2003 9:05 PM
HBT-Flat DBE2 cof=4 5-21-03.WM3	30,338 KB	visualNastran Desktop...	6/2/2003 11:07 AM
HBT-Flat DBE3 cof=4 5-21-03.WM3	44,335 KB	visualNastran Desktop...	6/2/2003 11:12 AM
HBT-Flat DBE3 cof=8 6-07-03.WM3	44,456 KB	visualNastran Desktop...	6/8/2003 8:54 AM
HBT-Flat DBE4 cof=4 5-22-03.WM3	35,332 KB	visualNastran Desktop...	6/2/2003 11:19 AM
HBT-Hill DBE1 cof=4 5-30-03 final.zip	29,214 KB	WinZip File	6/2/2003 11:42 AM
HBT-Hill DBE2 cof=4 5-30-03 final.zip	25,603 KB	WinZip File	6/2/2003 11:47 AM
HBT-Hill DBE3 cof=4 5-31-03 final.zip	27,190 KB	WinZip File	6/2/2003 11:52 AM
HBT-Hill DBE4 cof=4 5-31-03 final.zip	28,447 KB	WinZip File	6/2/2003 11:58 AM

G:\PROJECTS\1125\REPORTS\TRANSPORTER REPORT

Appendix A.mcd	.mcd	6,594	Mathcad D...	6/7/2003	8:06 PM	
APPENDIX B.doc	.doc	62,976	Microsoft ...	6/10/2003	10:34 AM	a
APPENDIX C.doc	.doc	63,488	Microsoft ...	6/8/2003	1:41 PM	
CoverPage.pdf	.pdf	9,373	Adobe Acr...	6/9/2003	9:10 AM	
HI2033036.DOC	.doc	1,336,832	Microsoft ...	6/10/2003	10:31 AM	a
HI2033036text.pdf	.pdf	1,813,577	Adobe Acr...	6/10/2003	10:29 AM	a

HOLTEC APPROVED COMPUTER PROGRAM LIST

(Total No. of Pages = 5)

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 62 October 2, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
ANSYS (A)	5.3, 5.4, 5.6,5.6.2,5.7,7.0	JZ, EBR, PKC, CWB, SPA, AIS, IR, SP, JRT,AK	Windows		
AC-XPERT	1.12		Windows		
AIRCOOL	5.2I, 6.1		Windows		
BACKFILL	2.0		DOS/ Windows		
BONAMI (Scale)	4.3, 4.4		Windows		
BULKTEM	3.0		DOS/ Windows		
CASMO-4 (A)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ELR, SPA, DMM, KC, ST,VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects. The user should refer to the error notice documented in c4ser.04-results.pdf located in \generic\library\ nuclear\error notices\ concerning the use of version 1.13.04. Library N should be used with version 2.05.03 for all new reports issued after June 1st, 2003. Revisions to reports issued prior to June 1st, 2003 may continue to use the old Library L.	
CASMO-3 (A)	4.4, 4.7	ELR, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		
CHANBP6 (A)	1.0	SJ, PKC, CWB, AIS, SP,JRT	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST REV. 62 October 2, 2003					
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
DÉCOR	1.0		DOS/Windows		
DR.BEAMPRO	1.0.5		Windows		
DR.FRAME	2.0		Windows		
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ, JRT	DOS/Windows	Personnel qualified to use MR216 are automatically qualified to use DYNAMO.	
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.48, 4.56, 5.1 (see error notice), 4.2.8 (UNS),5.5, 6.1.18	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST,VJB	Windows		
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950, 960, 970	JZ, AIS, SPA, SP, JRT	Windows		
MAXDIS16	1.0		DOS/Windows		
MCNP (A)	4A, 4B	ELR, SPA, KC,ST,DMM, VJB, MAP	Windows/ UNIX	CASMO-4 Lumped Fission Products (IDs 401 and 402) and Isotope Pm148M (ID 61248) can be modeled in MCNP 4A using the cross sections documented in HI-2033031. Use of these cross sections is restricted to MCNP 4A, and to material specifications in atom densities.	
MASSINV	1.4, 1.5, 2.1		DOS/Windows		
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PKC, SJ,JRT	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 62 October 2, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
MSREFINE	1.3, 2.1		DOS/Windows		
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4,2002, 2003		Windows		2002
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		
ORIGENS (Scale)	4.3, 4.4		Windows		
PD16	1.1, 1.0, 2.0		Windows		
PREDYNA1	1.5, 1.4		DOS/Windows		
PSD1	1.0		DOS/Windows		
QAD	CGGP		Windows		
SAS2H (Scale)	4.3, 4.4		Windows		
SFMR2A	1.0		DOS/Windows		
SHAPEBUILDER	3.0		DOS/Windows		
SIFATIG	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 62 October 2, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
SOLIDWORKS	2001		DOS/Windows	This program may be used to calculate Weight, Volume, Centroid and Moment of Inertia. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session. If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	X
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0, 1.4.0		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 62 October 2, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

NOTES:
1. XXXX = ALPHANUMERIC COMBINATION
2. GENERAL PURPOSES UTILITY CODES (MATHCAD, EXCEL, ETC.) MAYBE USED ANYTIME.

HOLTEC
INTERNATIONAL

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

EVALUATION OF EXPLOSIONS FOR THE HBPP ISFSI

FOR

PG&E

Holtec Report No: HI-2033041

Holtec Project No: 1125

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT ISSUANCE AND REVISION STATUS[1]

DOCUMENT NAME: Evaluation of Explosions for the HBPP ISFSI

DOCUMENT NO.:	HI-2033041	CATEGORY: ☐	GENERIC
PROJECT NO.:	1125	☒	PROJECT SPECIFIC

Rev. No. [2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	10/24/2003	KKN	623251	1.0	11/26/03	KKN	219443

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 ☐ TOP SECRET

Documents labeled TOP SECRET contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 in the N-drive of 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 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 "Table of Contents", this page and the "Revision Log".

TABLE OF CONTENTS

SUMMARY OF REVISIONS

Revision 0: Original Revision

Revision 1: Incorporated Client editorial comments in Sections 4.0 (Assumption 2) and 6.1 (last sentence).

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

Section 72.122 of the Code of Federal Regulations [1] defines the requirements for licensing basis evaluations of explosion events at a proposed independent spent fuel storage installation (ISFSI). Section 6.2.8 of the Pacific Gas and Electric (PG&E) specification [2] for an ISFSI at the Humboldt Bay Power Plant (HBPP) postulates a number of site explosion hazards that could possibly affect proposed ISFSI structures, systems and components (SSCs) that are important-to-safety. This report is issued to document the analyses performed to quantify the effects, if any, of the postulated explosion hazards on the storage and transfer casks that will be used at the HBPP ISFSI.

The following sections of this document present the computational methods and input data used to perform the explosion hazard evaluations (Sections 2.0, 4.0 and 5.0), the acceptance criteria applied to the computational results (Section 3.0), the evaluations themselves (Section 6.0), and the numeric calculation results and final conclusions (Section 7.0).

2.0 Methodology

2.1 Evaluation of Explosion Potential

Potential explosion hazards are listed in the PG&E specification [2]. Before performing calculations to evaluate the effects of these hazards, an engineering evaluation is performed to determine the actual potential for explosion posed by each hazard. If the potential for explosion for an individual hazard is negligible, no subsequent calculations of explosion effects are required.

The engineering evaluation performed for each postulated hazard consists of a review of the applicable physical and chemical properties of the materials involved. Each material detonation hazard is evaluated for explosion potential on the basis of its flash point and explosion hazard rating. The explosion hazard rating for a commercially available material is typically found on the manufacturer's material safety data sheet (MSDS).

2.2 Evaluation of Explosion Effects

The analysis methodology described in this subsection is in accordance with USNRC Regulatory Guide 1.91 [3], which states: "…for explosions of the magnitude considered in this guide and the structures, systems, and components that must be protected, overpressure effects are controlling." In accordance with this regulatory position, the effects of the postulated explosion hazards will be evaluated by determining the magnitude of the explosive overpressure at the location of the affected cask systems. Due to the extremely short duration of explosion events any heat input to the cask would be negligible, so no temperature calculations are performed. Note that a separate fire evaluation [9] has been performed with temperature effects that would bound the heat input from an explosion.

where: Proprietary Information Deleted

Proprietary Information Deleted

where:

Proprietary Information Deleted

/

where:

Proprietary Information Deleted

3.0 Acceptance Criteria

The following acceptance criteria satisfy the requirements of USNRC Regulatory Guide 1.91 [3].

3.1 Evaluation of Explosion Potential

These evaluations are performed to determine if a postulated explosion hazard poses a real hazard to the cask systems or ISFSI vault. The following acceptance criteria are applied in making these determinations.

1. For flammable vaporized liquids or gases mixed with air, a postulated hazard will be determined to pose a real hazard if the flash point of the material is less than or equal to the ambient temperature. The annual maximum site temperature is 87°F [2].

2. For flammable vaporized liquids or gases mixed with air, a postulated hazard will be determined to pose a real hazard if an MSDS sheet lists the explosion hazard rating as other than none.

If any one of these criteria is met for a postulated hazard, the hazard will be deemed a real hazard and evaluated further.

3.2 Evaluation of Explosion Effects

These evaluations are performed to determine the effects, on the casks systems and/or ISFSI vault, of all postulated explosion hazards identified as real hazards. The following acceptance criteria are applied in making these determinations.

1. For all real explosion hazards, stresses in cask system SSCs resulting from the incident explosive overpressure must not exceed allowable stress levels as defined in the cask system Final Safety Analysis Report (FSAR) [8]. Demonstration that a normal, off-normal or accident condition already evaluated satisfactorily in the FSAR bounds the explosive overpressure is an acceptable method of satisfying this criterion. Furthermore, if the calculated overpressure for an event is greater than 1 psi a probabilistic risk analysis (PRA) is of that event will be required.

2. The overpressures calculated must be used in the design of the vault.

4.0 Assumptions

1. Proprietary Information Deleted

2. All elevation differences between the explosion hazard and the casks are neglected for material detonations. Any elevation differences would serve to increase the ground distance between the explosion hazards and the cask systems, thereby decreasing the resulting incident overpressure, so it is conservative to neglect elevation differences.

3. No credit for partial shielding of casks systems by transport vehicles or intervening structures other than the reactor building or Unit 1 and 2 power blocks is credited. Any energy absorbed by vehicles or other structures would reduce the severity of the overpressure incident on the cask systems, so it is conservative to neglect them.

4. Gasoline-powered vehicles are prohibited from entering the ISFSI or approaching within fifty feet of a loaded cask system during storage. This restriction ensures that the separation distance between a gasoline explosion and the cask system SSCs is sufficient to prevent blast damage.

5. Storage of flammable materials is not permitted within the ISFSI. This assumption is in accordance with Section 6.2.7.4 of the PG&E specification [2].

Proprietary Information Deleted

5.0 Input Data

5.1 Evaluation of Explosion Potential

All input data necessary to perform these engineering evaluations are presented within the calculations themselves (Section 6.1) and are not repeated here.

5.2 Evaluation of Explosion Effects

All input data necessary to perform these calculations are presented within the calculations themselves (Appendix A) and are not repeated here.

6.0 Calculations

6.1 Evaluation of Explosion Potential

Upon completion of this evaluation, all hazards that are identified as having a meaningful potential for explosion will be evaluated for their explosion effects. The PG&E Specification [2] postulates a number of explosion hazards at the ISFSI site and along the transport route. The potential for explosion for the postulated hazards are:

Hazard ID	Hazard Description	Hazard Potential
F-1	Unit 1 Fuel Oil Storage Tank	N
F-2	Unit 1 Fuel Oil Service Tank	N
F-3	Unit 2 Fuel Oil Storage Tank	N
F-4	Unit 2 Fuel Oil Service Tank	N
F-5	Diesel Fuel Oil Tank	N
F-6	Diesel North Service Tank	N
F-7	Diesel South Service Tank	N
F-8	**Propane Storage Tank**	**Y**
F-9	Unit 3 Transformers	N
F-10	**Natural Gas Pipeline**	**Y**
F-11	Cask Transporter Fuel Tank	N
F-12	Site Vegetation	N
F-13	Fuel Oil Tanker	N
F-14	Diesel Fuel Tanker	N
F-15	**Propane Tanker**	**Y**
F-16	**Gasoline Tanker**	**Y**
F-17	**Other Site Vehicle Fuel Tanks**	**Y**
F-18	Aircraft Crash	N
F-19	**Unit 1 or 2 Boiler Explosion**	**Y**
F-20	Turbine Explosion	N
F-21	Missiles Generated by Unit 1 or 2 Boiler Explosion	N
F-22	Missiles Generated by Turbine Explosion	N

The above evaluation is based on the explosive properties as listed in the MSDSs and is discussed below.

Number 6 fuel oil has a flash point of 150°F. The explosive properties are listed as "Not Applicable" on the MSDS. As the flash point is greater than 87°F (Section 3.1, Criterion 1) and the explosion rating is, basically, none (Section 3.1, Criterion 2) a fuel oil explosion does not present a real explosion hazard. This eliminates the hazards F-1, F-2, F-3, F-4 and F-13 from further evaluation.

Diesel fuel has a flash point of 125°F. The explosive properties are listed as "Not Applicable" on the MSDS. As the flash point is greater than 87°F (Section 3.1, Criterion 1) and the explosion rating is, basically, none (Section 3.1, Criterion 2) a diesel fuel explosion does not present a real explosion hazard. This eliminates the hazards F-5, F-6, F-7, F-11 and F-14 from further evaluation.

Gasoline has a flash point of -40°F. The explosive properties are listed as "Not Applicable" on the MSDS. As the flash point is less than 87°F (Section 3.1, Criterion 1) a gasoline explosion does present a real explosion hazard and must be evaluated to determine its effects. Hazards F-16 and F-17 will be evaluated further.

The fluid in the transformers (DIALA Oil AX) serves as a coolant. As stated in the MSDS, this material has a flash point of 295°F. As the flash point is greater than 87°F (Section 3.1, Criterion 1) a transformer fluid explosion does not present a real explosion hazard. This eliminates hazard F-9 from further evaluation.

Propane is stored and transported as a liquefied compressed (~125 psia) gas. Liquefied propane rapidly vaporizes at atmospheric pressure (~15 psia), so the flash point can be taken approximately equal to the boiling point (-43.5°F). As stated on the MSDS, propane "poses an immediate … explosion hazard when mixed with air at concentrations exceeding 2.1%." The upper flammability limit is 9.5%. As the flash point is less than 87°F (Section 3.1, Criterion 1) and the explosion rating is positive for explosion (Section 3.1, Criterion 2), a propane explosion does present a real explosion hazard and must be evaluated to determine its effects. Hazards F-8 and F-15 will be further evaluated for effects as vapor cloud on the vault.

The natural gas pipeline rupture (hazard F-10) and boiler explosion (hazard F-19) may create a vapor cloud with the right proportion of gas and air for detonation. Please note that the natural gas pipe rupture is a "free gas" event; whereas, the boiler explosion is for a gas cloud in the boiler itself. The consequences will be evaluated.

No explosion potential is considered due to the site vegetation fire (hazard F-12) since vegetation would not explode.

Hazards F-18 and F-20 through F-22 have been addressed outside of this calculation [8].

6.2 Evaluation of Explosion Effects

Based on the discussion in the previous section the number of potential explosion hazard has been reduced to only six events.

Hazard ID	Hazard Description	Parameters	Distance from Cask (ft)	Distance from Vault (ft)
F-8	Propane Storage Tank Rupture	Capacity 2,098 gallons [8]	113 [8]	414 [2]
F-10	Natural Gas Distribution Pipeline Rupture	30 minutes for manual isolation [7]	Gas Line is not in service during transport	377 [8]
F-15	Propane Tanker Rupture	Capacity 2,900 gallons [8]	Not allowed during transport	394 [8]
F-16	Gasoline Tanker Rupture	Capacity 3,000 gallons [8]	Not allowed during transport	562 [8]
F-17	Other Site Vehicle Fuel Tanks	Capacity 20 gallons [10]	50 [10] Controlled parking during transport	50 [8]
F-19	Unit 1 or 2 Boiler Explosion	Natural Gas Supply	227 [8]	454 [8]

Appendix A contains the computations of the overpressures due to the explosion events presented above. Only the smaller distances have been used in the calculations for the bounding results.

7.0 Results and Conclusions

As described in Subsection 6.2, the incident explosive overpressures on cask system SSCs have been calculated in Appendix A. The following table presents a summary of the calculations and corresponding results.

Hazard ID	Equivalent Weight of TNT (lb)	Scaled Ground Distance from Cask ($ft/lb^{1/3}$)	Scaled Ground Distance from Vault ($ft/lb^{1/3}$)	Incident Overpressure at Cask (psi)	Incident Overpressure at Vault (psi)
F-8	3,109	7.74	28.37	15.97	1.83 (1)
F-10	27,300	-	12.52	-	6.34 (2)
F-15	4,298	-	24.23	-	2.27
F-16	11,730	-	24.73	-	2.21
F-17	78.2	11.69	11.69	7.16	7.16
F-19	27,120	7.56	15.11	16.81	4.61

Note (1):
Additional scenario analyzed for the propane storage tank rupture (Hazard F-8) for the potential effect of gas cloud over the vault with the volume equivalent to the area of the vault times a 40 foot height. The result shows that the overpressure could reach 82.02 psi at the vault.

Note (2)
Two additional scenarios have been analyzed for natural gas distribution line rupture. In the first scenario it has been demonstrated that center of explosion must be at least 62 feet in order to limit the overpressure below 300 psi. The second scenario is the explosion of a gas cloud over the vault with the volume equivalent to the area of the vault times a 40 foot height. This results in an overpressure of 199.1 psi at the vault.

The incident overpressure calculated conservatively for various explosion events are insignificant compared to the allowable pressure on the cask. The overpressures established in this report have been considered in the ISFSI design.

For explosion hazard F-10, the distance between the cask and the vapor cloud should be limited to 62 feet in order to limit the explosion pressure at the cask to 300 psi.

The HI-STAR is designed for spectrum 1 missiles at Region 1 wind speeds and it is judged that these missiles at Region 1 wind speeds would bound any potential missiles from potential explosions. In addition, the vault cover would provide additional protection from explosion missiles. Therefore, it is believed that the HI-STAR HB in a vault configuration is considered to be adequately protected from potential explosion missiles.

A PRA will be performed to demonstrate that the risks are acceptable in accordance with Regulatory Guide 1.91.

8.0 References[a]

[1] 10CFR72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-level Radioactive Waste," Subpart F, Section 122.

[2] PG&E Specification HBPP-2001-01.

[3] USNRC Regulatory Guide 1.91, "Evaluations of Explosions Postulated to Occur on Transportation Routes Near Nuclear Power Plants," Revision 1, February 1978.

[4] "Handbook of Chemical Hazards Analysis," Federal Emergency Management Agency (FEMA), 1989.

[5] "Structures to Resist the Effects of Accidental Explosions," Department of the Army Technical Manual TM 5-1300, November 1990.

[6] HI-STAR FSAR, Holtec Report HI-2012610, Revision 1.

[7] PG&E Letter from Lawrence Pulley, dated March 11, 2003.

[8] PG&E Letter from Lawrence Pulley, dated May 23, 2003.

[9] Holtec Report HI-2033006, Revision 0.

[10] PG&E E-Mail from Lawrence Pulley to Eric Lewis, received September 11, 2003.

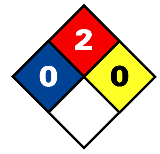
[a] The revision status of Holtec documents cited above is subject to updates as the project progresses. This document will be revised if a revision to any of the above-referenced Holtec work products materially affects the instructions, results, conclusions or analyses contained in this document. Otherwise, a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supersede the revision numbers cited above. The Holtec Project Manager bears the undivided responsibility to ensure that there is no inter-document conflict with respect to the information contained in all Holtec generated documents on a safety significant project.

Appendix A - Calculation of Incident Overpressures

Proprietary Information Deleted

Appendix B - MSDS Sheets for Flammable Materials

AMERADA HESS CORPORATION



NFPA 704 (Section 16)

MATERIAL SAFETY DATA SHEET

No. 6 Fuel Oil

MSDS No. 9907

1. CHEMICAL PRODUCT and COMPANY INFORMATION (rev. Jan-98)

Amerada Hess Corporation
1 Hess Plaza
Woodbridge, NJ 07095-0961

EMERGENCY TELEPHONE NUMBER (24 hrs): CHEMTREC (800) 424-9300
COMPANY CONTACT (business hours): Corporate Safety (732) 750-6000

SYNONYMS: #6 Fuel Oil; 6 Oil; Bunker C; Bunkers; High Sulfur Residual Fuel Oil; Low Sulfur Residual Fuel Oil; Residual Fuel Oil

See Section 16 for abbreviations and acronyms.

2. COMPOSITION and INFORMATION ON INGREDIENTS (rev. Jan-98)

INGREDIENT NAME	EXPOSURE LIMITS	CONCENTRATION PERCENT BY WEIGHT
Fuel Oil, Residual CAS NUMBER: 68476-33-5	OSHA PEL-TWA: 5 mg/m^3 as mineral oil mist ACGIH TLV-TWA: 5 mg/m^3 as mineral oil mist* *1997 NOIC: sum of 15 NTP-listed polynuclear aromatic hydrocarbons 0.005 mg/m^3, A1	100
Hydrogen Sulfide (H_2S) CAS NUMBER: 7783-06-4	OSHA PEL-Ceiling/Peak: 20 / 50 ppm ACGIH TLV-TWA/STEL: 10 / 15 ppm	< trace - see below >

A complex combination of heavy (high boiling point) petroleum hydrocarbons. The amount of sulfur varies with product specification and does not affect the health and safety properties as outlined in this Material Safety Data Sheet.

Hydrogen Sulfide (H_2S) may be present in trace quantities (by weight), but may accumulate to toxic concentrations such as in tank headspace. The presence of H_2S is highly variable, unpredictable and does not correlate with sulfur content. Studies with similar products have shown that 1 ppm H_2S by weight in liquid may produce 100 ppm or more H_2S in the vapor headspace of the storage tank .

3. HAZARDS IDENTIFICATION (rev. Jan-98; Tox-98)

EMERGENCY OVERVIEW
CAUTION!
COMBUSTIBLE LIQUID - SLIGHT TO MODERATE IRRITANT - EFFECTS CENTRAL NERVOUS SYSTEM - HARMFUL OR FATAL IF SWALLOWED

Moderate fire hazard. Avoid breathing vapors or mists. May cause dizziness and drowsiness. May cause moderate eye irritation and skin irritation. Long-term, repeated exposure may cause skin cancer. Hot liquid may cause thermal burns. If ingested, do NOT induce vomiting, as this may cause chemical pneumonia (fluid in the lungs).

HYDROGEN SULFIDE (toxic gas) may accumulate in tank vapor space. High concentration may cause immediate unconsciousness - death may result unless victim is promptly and successfully resuscitated. Hydrogen sulfide causes eye irritation.

EYES
Contact with eyes may cause mild to moderate irritation.

SKIN
May cause skin irritation with prolonged or repeated contact. Practically non-toxic if absorbed following acute (single) exposure. May cause dermal sensitization. Liquid may be hot (typically 110 - 120 ^{o}F) which could cause 1st, 2nd, or 3rd degree thermal burns.

INGESTION

This material has a low order of acute toxicity. If large quantities are ingested, nausea, vomiting and diarrhea may result. Ingestion may also cause effects similar to inhalation of the product. Aspiration may result in chemical pneumonia (fluid in the lungs), severe lung damage, respiratory failure and even death.

INHALATION

Because of its low vapor pressure, this product presents a minimal inhalation hazard at ambient temperature. Upon heating, fumes may be evolved. Inhalation of fumes or mist may result in respiratory tract irritation and central nervous system (brain) effects may include headache, dizziness, loss of balance and coordination, unconsciousness, coma, respiratory failure, and death.

WARNING: the burning of any hydrocarbon as a fuel in an area without adequate ventilation may result in hazardous levels of combustion products, including carbon monoxide, and inadequate oxygen levels, which may cause unconsciousness, suffocation, and death.

WARNING: Irritating and toxic hydrogen sulfide gas may be found in confined vapor spaces. Greater than 15 - 20 ppm continuous exposure can cause mucous membrane and respiratory tract irritation. 50 - 500 ppm can cause headache, nausea, and dizziness, loss of reasoning and balance, difficulty in breathing, fluid in the lungs, and possible loss of consciousness. Greater than 500 ppm can cause rapid or immediate unconsciousness due to respiratory paralysis and death by suffocation unless the victim is removed from exposure and successfully resuscitated.

The "rotten egg" odor of hydrogen sulfide is not a reliable indicator for warning of exposure, since olfactory fatigue (loss of smell) readily occurs, especially at concentrations above 50 ppm. At high concentrations, the victim may not even recognize the odor before becoming unconscious.

CHRONIC and CARCINOGENICITY

Similar products produced skin cancer and systemic toxicity in laboratory animals following repeated applications. The significance of these results to human exposures has not been determined - see Section 11, Toxicological Information.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE

Irritation from skin exposure may aggravate existing open wounds, skin disorders, and dermatitis (rash).

FUEL OIL COMBUSTION ASH

Trace amounts of nickel, vanadium, and other metals in slurry oil can become concentrated in the oxide form in combustion ash deposits. Vanadium is a toxic metal affecting a number of organ systems. Nickel is a suspect human carcinogen (lung, nasal, sinus), an eye, nose, and throat irritant, and can cause allergic skin reaction in some individuals. See Section 7 for appropriate work practices.

4. FIRST AID MEASURES (rev. Jan-98; Tox-98)

EYES

In case of contact with eyes, immediately flush with clean, low-pressure water for at least 15 min. Hold eyelids open to ensure adequate flushing. Seek medical attention.

SKIN

Remove contaminated clothing. Wash contaminated areas thoroughly with soap and water or waterless hand cleanser. Obtain medical attention if irritation or redness develops. Thermal burns require immediate medical attention depending on the severity and the area of the body burned.

INGESTION

DO NOT INDUCE VOMITING. Do not give liquids. Obtain immediate medical attention. If spontaneous vomiting occurs, lean victim forward to reduce the risk of aspiration. Monitor for breathing difficulties. Small amounts of material which enter the mouth should be rinsed out until the taste is dissipated.

INHALATION

Remove person to fresh air. If person is not breathing provide artificial respiration. If necessary, provide additional oxygen once breathing is restored if trained to do so. Seek medical attention immediately.

5. FIRE FIGHTING MEASURES (rev. Oct-96)

FLAMMABLE PROPERTIES:

FLASH POINT:	> 150 °F (>65.5 °C) (minimum) ASTM D-93
AUTOIGNITION TEMPERATURE:	> 765 °F (>407 °C)
OSHA/NFPA FLAMMABILITY CLASS:	3A (COMBUSTIBLE)
LOWER EXPLOSIVE LIMIT (%):	N/D
UPPER EXPLOSIVE LIMIT (%):	N/D

FIRE AND EXPLOSION HAZARDS

Vapors may be ignited rapidly when exposed to heat, spark, open flame or other source of ignition. When mixed with air and exposed to an ignition source, flammable vapors can burn in the open or explode in confined spaces. Being heavier than air, vapors may travel long distances to an ignition source and flash back. Runoff to sewer may cause fire or explosion hazard.

CAUTION: flammable vapor production at ambient temperature in the open is expected to be minimal unless the oil is heated above its flash point. However, industry experience indicates that light hydrocarbon vapors can build up in the headspace of storage tanks at temperatures below the flash point of the oil, presenting a flammability and explosion hazard. Tank headspaces should be regarded a potentially flammable, since the oil's flash point can not be regarded as a reliable indicator of the potential flammability in tank headspaces.

EXTINGUISHING MEDIA

SMALL FIRES: Any extinguisher suitable for Class B fires, dry chemical, CO2, water spray, fire fighting foam, or Halon.

LARGE FIRES: Water spray, fog or fire fighting foam. Water may be ineffective for fighting the fire, but may be used to cool fire-exposed containers.

FIRE FIGHTING INSTRUCTIONS

Small fires in the incipient (beginning) stage may typically be extinguished using handheld portable fire extinguishers and other fire fighting equipment.

Firefighting activities that may result in potential exposure to high heat, smoke or toxic by-products of combustion should require NIOSH/MSHA- approved pressure-demand self-contained breathing apparatus with full facepiece and full protective clothing.

Isolate area around container involved in fire. Cool tanks, shells, and containers exposed to fire and excessive heat with water. For massive fires the use of unmanned hose holders or monitor nozzles may be advantageous to further minimize personnel exposure. Major fires may require withdrawal, allowing the tank to burn. Large storage tank fires typically require specially trained personnel and equipment to extinguish the fire, often including the need for properly applied fire fighting foam.

See Section 16 for the NFPA 704 Hazard Rating.

6. ACCIDENTAL RELEASE MEASURES (rev. Jan-98)

ACTIVATE FACILITY'S SPILL CONTINGENCY OR EMERGENCY RESPONSE PLAN.

Evacuate nonessential personnel and remove or secure all ignition sources. Consider wind direction; stay upwind and uphill, if possible. Evaluate the direction of product travel, diking, sewers, etc. to confirm spill areas.

Carefully contain and stop the source of the spill, if safe to do so. Protect bodies of water by diking, absorbents, or absorbent boom, if possible. Do not flush down sewer or drainage systems, unless system is designed and permitted to handle such material. The use of fire fighting foam may be useful in certain situations to reduce vapors.

Take up with sand or other oil absorbing materials. Carefully shovel, scoop or sweep up into a waste container for reclamation or disposal. Response and clean-up crews must be properly trained and must utilize proper protective equipment.

7. HANDLING and STORAGE (rev. Jan-98)

HANDLING PRECAUTIONS

Product is generally transported and stored hot (typical 110 - 120 ^{o}F). Handle as a combustible liquid. Keep away from heat, sparks, and open flame! Electrical equipment should be approved for classified area. Bond and ground containers during product transfer to reduce the possibility of static-initiated fire or explosion.

STORAGE PRECAUTIONS

Keep away from flame, sparks, excessive temperatures and open flame. Use approved vented containers. Keep containers closed and clearly labeled. Empty product containers or vessels may contain explosive vapors. Do not pressurize, cut, heat, weld or expose such containers to sources of ignition.

Store in a well-ventilated area. This storage area should comply with NFPA 30 "Flammable and Combustible Liquid Code". Avoid storage near incompatible materials. The cleaning of tanks previously containing this product should follow API Recommended Practice (RP) 2013 "Cleaning Mobile Tanks In Flammable and Combustible Liquid Service" and API RP 2015 "Cleaning Petroleum Storage Tanks".

Hydrogen sulfide may accumulate in tanks and bulk transport compartments. Consider appropriate respiratory protection (see Section 8). Stand upwind. Avoid vapors when opening hatches and dome covers. Confined spaces should be ventilated prior to entry.

WORK/HYGIENIC PRACTICES

Emergency eye wash capability should be available in the near proximity to operations presenting a potential splash exposure. Use good personal hygiene practices. Avoid repeated and/or prolonged skin exposure. Wash hands before eating, drinking, smoking, or using toilet facilities. Do not use as a cleaning solvent on the skin. Do not use gasoline or solvents (naphtha, kerosene, etc.) for washing this product from exposed skin areas. Waterless hand cleaners are effective. Promptly remove contaminated clothing and launder before reuse. Use care when laundering to prevent the formation of flammable vapors which could ignite via washer or dryer. Consider the need to discard contaminated leather shoes and gloves.

OTHER/GENERAL PROTECTION

Petroleum industry experience indicates that a program providing for good personal hygiene, proper use of personal protective equipment, and minimizing the repeated and prolonged exposure to liquids and fumes, as outlined in this MSDS, is effective in reducing or eliminating the carcinogenic risk of high boiling aromatic oils (polynuclear aromatic hydrocarbons) to humans.

FUEL OIL ASH PRODUCTS

Personnel exposed to ash should wear appropriate protective clothing (example, DuPont Tyvek ®), wash skin thoroughly, launder contaminated clothing separately, and wear respiratory protection approved for use against toxic metal dusts (such as HEPA filter cartridges). Wetted-down combustion ash may evolve toxic hydrogen sulfide (H_2S) - confined spaces should be tested for H_2S prior to entry if ash is wetted.

8. EXPOSURE CONTROLS and PERSONAL PROTECTION (rev. Jan-98)

ENGINEERING CONTROLS

Use adequate ventilation to keep vapor concentrations of this product below occupational exposure and flammability limits, particularly in confined spaces.

EYE/FACE PROTECTION

Safety glasses or goggles are recommended where there is a possibility of splashing or spraying

SKIN PROTECTION

Gloves constructed of nitrile, neoprene, or PVC are recommended. Chemical protective clothing such as of E.I. DuPont Tyvek QC®, Saranex®, TyChem® or equivalent recommended based on degree of exposure. Note: The resistance of specific material may vary from product to product as well as with degree of exposure. Consult manufacturer specifications for further information

RESPIRATORY PROTECTION

If a hydrogen sulfide hazard is present (that is, exposure potential above H_2S permissible exposure limit), use a positive-pressure SCBA or Type C supplied air respirator with escape bottle.

Where it has been determined that there is no hydrogen sulfide exposure hazard (that is, exposure potential below H_2S permissible exposure limit), a NIOSH/ MSHA-approved air-purifying respirator with organic vapor cartridges or canister may be permissible under certain circumstances where airborne concentrations are or may be expected to exceed exposure limits or for odor or irritation. Protection provided by air-purifying respirators is limited. Refer to OSHA 29 CFR 1910.134, ANSI Z88.2-1992, NIOSH Respirator Decision Logic, and the manufacturer for additional guidance on respiratory protection selection.

Use a positive pressure, air-supplied respirator if there is a potential for uncontrolled release, exposure levels are not known, in oxygen-deficient atmospheres, or any other circumstance where an air-purifying respirator may not provide adequate protection.

9. PHYSICAL and CHEMICAL PROPERTIES (rev. Jan-01)

APPEARANCE

Black, viscous liquid

ODOR

Heavy, petroleum/asphalt-type odor

Hydrogen sulfide (H_2S) has a rotten egg “sulfurous” odor. This odor should not be used as a warning property of toxic levels because H_2S can overwhelm and deaden the sense of smell. Also, the odor of H_2S in heavy oils can easily be masked by the petroleum-like odor of the oil. Therefore, the smell of H_2S should not be used as an indicator of a hazardous condition - a H_2S meter or colorimetric indicating tubes are typically used to determine the concentration of H_2S.

BASIC PHYSICAL PROPERTIES

BOILING RANGE:	> 500 ^{o}F (> 260 ^{o}C)
VAPOR PRESSURE:	<0.1 psia @ 70 ^{o}F (21 ^{o}C)
VAPOR DENSITY (air = 1):	NA
SPECIFIC GRAVITY (H_2O = 1):	0.876 – 1.000 (API 30.0 – 10.0)
PERCENT VOLATILES:	Negligible
EVAPORATION RATE:	negligible
SOLUBILITY (H_2O):	negligible

10. STABILITY and REACTIVITY (rev. Jan-94)

STABILITY: Stable. Hazardous polymerization will not occur.

CONDITIONS TO AVOID and INCOMPATIBLE MATERIALS

Avoid high temperatures, open flames, sparks, welding, smoking and other ignition sources. Keep away from strong oxidizers.

HAZARDOUS DECOMPOSITION PRODUCTS:

Carbon monoxide, carbon dioxide and non-combusted hydrocarbons (smoke).

11. TOXICOLOGICAL PROPERTIES (rev. Jan-98)

ACUTE TOXICITY

Acute dermal LD50 (rabbits): > 5 ml/kg
Acute oral LD50 (rats): 5.1 ml/kg
Primary dermal irritation: slightly irritating (rabbits)
Draize eye irritation: mildly irritating (rabbits)
Guinea pig sensitization: mildly sensitizing

CHRONIC EFFECTS AND CARCINOGENICITY

Carcinogenicity: **OSHA:** NO **IARC:** 2B (animal) **NTP:** YES **ACGIH:** 1997 NOIC: A1

This material contains polynuclear aromatic hydrocarbons (PNAs), some of which are animal carcinogens. Studies have shown that similar products produce skin tumors in laboratory animals following repeated applications without washing or removal. The significance of this finding to human exposure has not been determined. Other studies with active skin carcinogens have shown that washing the animal's skin with soap and water between applications reduced tumor formation.

The presence of carcinogenic PNAs indicates that precautions should be taken to minimize repeated and prolonged inhalation of fumes or mists.

MUTAGENICITY (genetic effects)

Materials of similar composition have been positive in mutagenicity studies.

12. ECOLOGICAL INFORMATION (rev. Jan-98)

Keep out of sewers, drainage and waterways. Report spills and releases, as applicable, under Federal and State regulations.

13. DISPOSAL CONSIDERATIONS (rev. Jan-98)

Consult federal, state and local waste regulations to determine appropriate disposal options. Combustion ash may be a characteristic hazardous waste.

14. TRANSPORTATION INFORMATION (rev. Jan-98)

PROPER SHIPPING NAME:	Combustible liquid, n.o.s. (No. 6 Fuel Oil)
HAZARD CLASS and PACKING GROUP:	Combustible Liquid , PG III
DOT IDENTIFICATION NUMBER:	NA 1993
DOT SHIPPING LABEL:	None

15. REGULATORY INFORMATION (rev. Feb-01)

U.S. FEDERAL, STATE and LOCAL REGULATORY INFORMATION

This product and its constituents listed herein are on the EPA TSCA Inventory. Any spill or uncontrolled release of this product, including any substantial threat of release, may be subject to federal, state and/or local reporting requirements. This product and/or its constituents may also be subject to other regulations at the state and/or local level. Consult those regulations applicable to your facility/operation.

CLEAN WATER ACT (OIL SPILLS)

Any spill or release of this product to "navigable waters" (essentially any surface water, including certain wetlands) or adjoining shorelines sufficient to cause a visible sheen or deposit of a sludge or emulsion must be reported immediately to the National Response Center (1-800-424-8802) or, if not practical, the U.S. Coast Guard with follow-up to the National Response Center, as required by U.S. Federal Law. Also contact appropriate state and local regulatory agencies as required.

CERCLA SECTION 103 and SARA SECTION 304 (RELEASE TO THE ENVIRONMENT)

The CERCLA definition of hazardous substances contains a “petroleum exclusion” clause which exempts crude oil, refined, and unrefined petroleum products and any indigenous components of such. However, other federal reporting requirements (e.g., SARA Section 304 as well as the Clean Water Act if the spill occurs on navigable waters) may still apply.

SARA SECTION 311/312 - HAZARD CLASSES

ACUTE HEALTH	CHRONIC HEALTH	FIRE	SUDDEN RELEASE OF PRESSURE	REACTIVE
X	X	X	--	--

SARA SECTION 313 - SUPPLIER NOTIFICATION

This product may contain listed chemicals below the *de minimis* levels which therefore are not subject to the supplier notification requirements of Section 313 of the Emergency Planning and Community Right-To-Know Act (EPCRA) of 1986 and of 40 CFR 372. If you may be required to report releases of chemicals listed in 40 CFR 372.28, you may contact Amerada Hess Corporate Safety if you require additional information regarding this product.

CANADIAN REGULATORY INFORMATION (WHMIS)

Class B, Division 3 (Combustible Liquid)

16. OTHER INFORMATION (rev. Feb-01)

NFPA® HAZARD RATING	HEALTH:	0	Negligible
	FIRE:	2	Moderate
	REACTIVITY:	0	Negligible
HMIS® HAZARD RATING	HEALTH:	1*	Slight
	FIRE:	2	Moderate
	REACTIVITY:	0	Negligible
			*Chronic

SPECIAL HAZARDS: Container vapor space may contain hydrogen sulfide (poison gas).

SUPERSEDES MSDS DATED: 01/05/01

ABBREVIATIONS:

AP = Approximately	< = Less than	> = Greater than
N/A = Not Applicable	N/D = Not Determined	ppm = parts per million

ACRONYMS:

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute (212)642-4900
API	American Petroleum Institute (202)682-8000
CERCLA	Comprehensive Emergency Response, Compensation, and Liability Act
DOT	U.S. Department of Transportation [General info: (800)467-4922]
EPA	U.S. Environmental Protection Agency
HMIS	Hazardous Materials Information System
IARC	International Agency For Research On Cancer
MSHA	Mine Safety and Health Administration
NFPA	National Fire Protection Association (617)770-3000
NIOSH	National Institute of Occupational Safety and Health
NOIC	Notice of Intended Change (proposed change to ACGIH TLV)
NTP	National Toxicology Program
OPA	Oil Pollution Act of 1990
OSHA	U.S. Occupational Safety & Health Administration
PEL	Permissible Exposure Limit (OSHA)
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit (NIOSH)
SARA	Superfund Amendments and Reauthorization Act of 1986 Title III
SCBA	Self-Contained Breathing Apparatus
SPCC	Spill Prevention, Control, and Countermeasures
STEL	Short-Term Exposure Limit (generally 15 minutes)
TLV	Threshold Limit Value (ACGIH)
TSCA	Toxic Substances Control Act
TWA	Time Weighted Average (8 hr.)

WEEL	Workplace Environmental Exposure Level (AIHA)	WHMIS	Canadian Workplace Hazardous Materials Information System

DISCLAIMER OF EXPRESSED AND IMPLIED WARRANTIES

Information presented herein has been compiled from sources considered to be dependable, and is accurate and reliable to the best of our knowledge and belief, but is not guaranteed to be so. Since conditions of use are beyond our control, we make no warranties, expressed or implied, except those that may be contained in our written contract of sale or acknowledgment.

Vendor assumes no responsibility for injury to vendee or third persons proximately caused by the material if reasonable safety procedures are not adhered to as stipulated in the data sheet. Additionally, vendor assumes no responsibility for injury to vendee or third persons proximately caused by abnormal use of the material, even if reasonable safety procedures are followed. Furthermore, vendee assumes the risk in their use of the material.

MATERIAL SAFETY DATA SHEET

MSDS Number: 60030E - 13

24 Hour Emergency Assistance: CHEMTEL (877) 276-7283
General Assistance Number: (877) 276-7285

SECTION 1 PRODUCT IDENTIFICATION

MATERIAL IDENTITY: DIALA® Oil AX

PRODUCT CODES: 68702, 69702
COMPANY ADDRESS: Equilon Enterprises LLC, P. O. Box 4453, Houston, TX. 77210-4453

SECTION 2 PRODUCT/INGREDIENTS

CAS#	CONCENTRATION	INGREDIENTS
Mixture	100 %volume	Dielectric Oil
64742-53-6	100 %volume	Hydrotreated light naphthenic distillate

---

SECTION 3 HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
Appearance & Odor: Bright and Clear Liquid. Oil Type Odor.
Health Hazards: May be harmful or fatal if swallowed. Do not induce vomiting. May cause aspiration pneumonitis.
Physical Hazards: No known physical hazards.
NFPA Rating (Health, Fire, Reactivity): 0, 1, 0
Hazard Rating:Least - 0 Slight - 1 Moderate - 2 High - 3 Extreme - 4

Inhalation:
Inhalation of vapors (generated at high temperatures only) or oil mist may cause mild irritation of the nose, throat, and respiratory tract.

Eye Irritation:
Lubricating oils are generally considered no more than minimally irritating to the eyes.

Skin Contact:
Lubricating oils are generally considered no more than minimally irritating to the skin. Prolonged and repeated contact may result in defatting and drying of the skin that may cause various skin disorders such as dermatitis, folliculitis or oil acne.

Ingestion:

This material may be harmful or fatal if swallowed. Ingestion may result in vomiting; aspiration (breathing) of vomitus into lungs must be avoided as even small quantities may result in aspiration pneumonitis.

Signs and Symptoms:
Irritation as noted above. Aspiration pneumonitis may be evidenced by coughing, labored breathing and cyanosis (bluish skin); in severe cases death may occur.

Aggravated Medical Conditions:
Pre-existing eye, skin and respiratory disorders may be aggravated by exposure to this product.

For additional health information, refer to section 11.

SECTION 4 FIRST AID MEASURES

Inhalation:
Remove victim to fresh air and provide oxygen if breathing is difficult. Get medical attention.

Skin:
Remove contaminated clothing and shoes and wipe excess from skin. Flush skin with water, then wash with soap and water. If irritation occurs, get medical attention. Do not reuse clothing until cleaned.

Eye:
Flush with water. If irritation occurs, get medical attention.

Ingestion:
Do NOT induce vomiting. If vomiting occurs spontaneously, keep head below hips to prevent aspiration of liquid into lungs. Get medical attention.

SECTION 5 FIRE FIGHTING MEASURES

Flash Point [Method]: 295 °F/146.11 °C [Cleveland Open Cup]

Extinguishing Media:
Material will float and can be re-ignited on surface of water. Use water fog, 'alcohol foam', dry chemical or carbon dioxide (CO_2) to extinguish flames. Do not use a direct stream of water.

Fire Fighting Instructions:
Material will not burn unless preheated. Clear fire area of all non-emergency personnel. Only enter confined fire space with full gear, including a positive pressure, NIOSH-approved, self-contained breathing apparatus. Cool surrounding equipment, fire-exposed containers and structures with water. Container areas exposed to direct flame contact should be cooled with large quantities of water (500 gallons water per minute flame impingement exposure) to prevent weakening of container structure.

SECTION 6 ACCIDENTAL RELEASE MEASURES

Protective Measures:
May burn although not readily ignitable.

Wear appropriate personal protective equipment when cleaning up spills. Refer to Section 8.

Spill Management:
FOR LARGE SPILLS: Remove with vacuum truck or pump to storage/salvage vessels.

FOR SMALL SPILLS: Soak up residue with an absorbent such as clay, sand or other suitable material. Place in non-leaking container and seal tightly for proper disposal.

Reporting:
CERCLA: Product is covered by EPA's Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) petroleum exclusion. Releases to air, land, or water are not reportable under CERCLA (Superfund).

CWA: This product is an oil as defined under Section 311 of EPA's Clean Water Act (CWA). Spills into or leading to surface waters that cause a sheen must be reported to the National Response Center, 1-800-424-8802.

SECTION 7 HANDLING AND STORAGE

Precautionary Measures:
Wash with soap and water before eating, drinking, smoking, applying cosmetics, or using toilet. Launder contaminated clothing before reuse. Properly dispose of contaminated leather articles such as shoes or belts that cannot be decontaminated. Avoid heat, open flames, including pilot lights, and strong oxidizing agents. Use explosion-proof ventilation to prevent vapor accumulation. Ground all handling equipment to prevent sparking.

Storage:
Store in a cool, dry place with adequate ventilation. Keep away from open flames and high temperatures.

Container Warnings:
Keep containers closed when not in use. Containers, even those that have been emptied, can contain explosive vapors. Do not cut, drill, grind, weld or perform similar operations on or near containers.

SECTION 8 EXPOSURE CONTROLS/PERSONAL PROTECTION

Oil mist, mineral	ACGIH TLV	TWA: 5 mg/m3 STEL: 10 mg/m3
Oil mist, mineral	OSHA PEL	TWA: 5 mg/m3

EXPOSURE CONTROLS
Adequate ventilation to control airborne concentrations below the exposure

guidelines/limits.

PERSONAL PROTECTION
Personal protective equipment (PPE) selections vary based on potential exposure conditions such as handling practices, concentration and ventilation. Information on the selection of eye, skin and respiratory protection for use with this material is provided below.

Eye Protection:
Chemical Goggles, or Safety glasses with side shields

Skin Protection:
Use protective clothing which is chemically resistant to this material. Selection of protective clothing depends on potential exposure conditions and may include gloves, boots, suits and other items. The selection(s) should take into account such factors as job task, type of exposure and durability requirements.

Published literature, test data and/or glove and clothing manufacturers indicate the best protection is provided by:
Neoprene, or Nitrile Rubber

Respiratory Protection:
If engineering controls do not maintain airborne concentrations to a level which is adequate to protect worker health, an approved respirator must be worn. Respirator selection, use and maintenance should be in accordance with the requirements of the OSHA Respiratory Protection Standard, 29 CFR 1910.134.

Types of respirator(s) to be considered in the selection process include:
For Mist: Air Purifying, R or P style NIOSH approved respirator. For Vapors: Air Purifying, R or P style prefilter & organic cartridge, NIOSH approved respirator. Self-contained breathing apparatus.

SECTION 9 PHYSICAL AND CHEMICAL PROPERTIES

Appearance & Odor: Bright and Clear Liquid. Oil Type Odor.
Substance Chemical Family: Petroleum Hydrocarbon
Boiling Point: > 400 °F

Dielectric Strength: 20 KV - 30 KV

Evaporation Rate: N/A

Flash Point: 295 °F [Cleveland Open Cup]

Pour Point: -40 °F

Solubility (in Water): Negligible

Specific Gravity: 0.8833

Viscosity: 10 cSt - 20 cSt @ 40 °C

SECTION 10 REACTIVITY AND STABILITY

Stability:
Material is stable under normal conditions.

Conditions to Avoid:
Avoid heat and open flames.

Materials to Avoid:
Avoid contact with strong oxidizing agents.

Hazardous Decomposition Products:
Thermal decomposition products are highly dependent on combustion conditions. A complex mixture of airborne solids, liquids and gases will evolve when this material undergoes pyrolysis or combustion. Carbon Monoxide, Carbon Dioxide and other unidentified organic compounds may be formed upon combustion.

SECTION 11 TOXICOLOGICAL INFORMATION

Acute Toxicity
- Dermal LD50 >2 g/kg(Rabbit) OSHA: Non-Toxic Based on components(s)
- Inhalation LC50 2.18 mg/l(Rat) OSHA: Non-Toxic Based on components(s)
- Oral LD50 >5 g/kg(Rat) OSHA: Non-Toxic Based on components(s)

Carcinogenicity Classification
Dielectric Oil
NTP: No IARC: Not Reviewed by IARC ACGIH: No OSHA: No

SECTION 12 ECOLOGICAL INFORMATION

Environmental Impact Summary:
There is no ecological data available for this product. However, this product is an oil. It is persistent and does not readily biodegrade. However, it does not bioaccumulate.

SECTION 13 DISPOSAL CONSIDERATIONS

RCRA Information:
Under RCRA, it is the responsibility of the user of the material to determine, at the time of the disposal, whether the material meets RCRA criteria for hazardous waste. This is because material uses, transformations, mixtures, processes, etc. may affect the classification. Refer to the latest EPA, state and local regulations regarding proper disposal.

SECTION 14 TRANSPORT INFORMATION

US Department of Transportation Classification
This material is not subject to DOT regulations under 49 CFR Parts 171-180.

Oil: This product is an oil under 49CFR (DOT) Part 130. If shipped by rail or highway in a tank with a capacity of 3500 gallons or more, it is subject to these requirements. Mixtures or solutions containing 10% or more of this product may also be subject to this rule.

International Air Transport Association
Not regulated under IATA rules.

International Maritime Organization Classification
Not regulated under International Maritime Organization rules.

SECTION 15 REGULATORY INFORMATION

FEDERAL REGULATORY STATUS

OSHA Classification:
Product is hazardous according to the OSHA Hazard Communication Standard, 29 CFR 19.10.1200, because it carries the occupational exposure limit for mineral oil mist.

Ozone Depleting Substances (40 CFR 82 Clean Air Act):
This material does not contain nor was it directly manufactured with any Class I or Class II ozone depleting substances.

Superfund Amendment & Reauthorization Act (SARA) Title III:

There are no components in this product on the SARA 302 list.

SARA Hazard Categories (311/312):
Immediate Health:NO Delayed Health:NO Fire:NO Pressure:NO Reactivity:NO

SARA Toxic Release Inventory (TRI) (313):
There are no components in this product on the SARA 313 list.

Toxic Substances Control Act (TSCA) Status:
All component(s) of this material is(are) listed on the EPA/TSCA Inventory of Chemical Substances.

Other Chemical Inventories:
Component(s) of this material is (are) listed on the Australian AICS, Canadian DSL, Chinese Inventory, European EINECS, Korean Inventory, Philippines PICCS

State Regulation
This material is not regulated by California Prop 65, New Jersey Right-to-Know Chemical List or Pennsylvania Right-To-Know Chemical List. However for details on your regulation requirements you should contact the appropriate agency in your state.

California Safe Drinking Water and Toxic Enforcement Act (Proposition 65).

WARNING: This product contains a chemical(s) known to the State of California to cause cancer.

SECTION 16   OTHER INFORMATION

HMIS Rating (Health, Fire, Reactivity): 0, 1, 0

Revision#: 13
Revision Date: 04/01/2002
Revisions since last change (discussion): This Material Safety Data Sheet (MSDS) has been newly reviewed to fully comply with the guidance contained in the ANSI MSDS standard (ANSI Z400.1-1998). We encourage you to take the opportunity to read the MSDS and review the information contained therein.

SECTION 17   LABEL INFORMATION

READ AND UNDERSTAND MATERIAL SAFETY DATA SHEET BEFORE HANDLING OR DISPOSING OF PRODUCT. THIS LABEL COMPLIES WITH THE REQUIREMENTS OF THE OSHA HAZARD COMMUNICATION STANDARD (29 CFR 1910.1200) FOR USE IN THE WORKPLACE. THIS LABEL IS NOT INTENDED TO BE USED WITH PACKAGING INTENDED FOR SALE TO CONSUMERS AND MAY NOT CONFORM WITH THE REQUIREMENTS OF THE CONSUMER PRODUCT SAFETY ACT OR OTHER RELATED REGULATORY REQUIREMENTS.

PRODUCT CODES: 68702, 69702

DIALA® Oil AX

CAUTION!

ASPIRATION HAZARD IF SWALLOWED - CAN ENTER LUNGS AND CAUSE DAMAGE. PROLONGED OR REPEATED SKIN CONTACT MAY CAUSE OIL ACNE OR DERMATITIS.

Precautionary Measures:
Avoid prolonged or repeated contact with eyes, skin and clothing. Do not take internally. Wash thoroughly after handling.

FIRST AID

Inhalation: Remove victim to fresh air and provide oxygen if breathing is difficult. Get medical attention.
Skin Contact: Remove contaminated clothing and shoes and wipe excess from skin. Flush skin with water, then wash with soap and water. If irritation occurs, get medical attention. Do not reuse clothing until cleaned.
Eye Contact: Flush with water. If irritation occurs, get medical attention.
Ingestion: Do NOT induce vomiting. If vomiting occurs spontaneously, keep head below hips to prevent aspiration of liquid into lungs. Get medical attention.

FIRE

In case of fire, Material will float and can be re-ignited on surface of water.

SPILL OR LEAK
Dike and contain spill.
FOR LARGE SPILLS: Remove with vacuum truck or pump to storage/salvage vessels.

FOR SMALL SPILLS: Soak up residue with an absorbent such as clay, sand or other suitable material. Place in non-leaking container and seal tightly for proper disposal.

CONTAINS: Hydrotreated light naphthenic distillate, 64742-53-6

NFPA Rating (Health, Fire, Reactivity): 0, 1, 0
HMIS Rating (Health, Fire, Reactivity): 0, 1, 0

TRANSPORTATION
US Department of Transportation Classification
This material is not subject to DOT regulations under 49 CFR Parts 171-180.

Oil: This product is an oil under 49CFR (DOT) Part 130. If shipped by rail or highway in a tank with a capacity of 3500 gallons or more, it is subject to these requirements. Mixtures or solutions containing 10% or more of this product may also be subject to this rule.

CAUTION: Misuse of empty containers can be hazardous. Empty containers can be hazardous if used to store toxic, flammable, or reactive materials. Cutting or welding of empty containers might cause fire, explosion or toxic fumes from residues. Do not pressurize or expose to open flames or heat. Keep container closed and drum bungs in place.

Name and Address
Equilon Enterprises LLC
P. O. Box 4453
Houston, TX 77210-4453

TRANSPORTATION EMERGENCY CHEMTEL (877) 276-7283

HEALTH EMERGENCY CHEMTEL (877) 276-7283

ADMINISTRATIVE INFORMATION
COMPANY ADDRESS: Equilon Enterprises LLC, P. O. Box 4453, Houston, TX. 77210-4453
Company Product Stewardship & Regulatory Compliance Contact: Timothy W Childs
Phone Number: (281) 874-7708
MSDS FAX-BACK Phone Number: (877) 276-7285

EXCHANGE WITHOUT THE EXPRESS WRITTEN CONSENT OF EQUIVA SERVICES LLC.

36250-10558-100R-04/01/2002

170019-31 DIESEL FUEL (MRDUS)
MATERIAL SAFETY DATA BULLETIN

---

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: DIESEL FUEL (MRDUS)
SUPPLIER: MOBIL OIL CORP.
NORTH AMERICA MARKETING AND REFINING
3225 GALLOWS RD.
FAIRFAX, VA 22037

24 - Hour Emergency (call collect):	609-737-4411	
Product and MSDS Information:	800-662-4525	609-224-4644
CHEMTREC:	800-424-9300	202-483-7616

2. COMPOSITION/INFORMATION ON INGREDIENTS

CHEMICAL NAMES AND SYNONYMS: HYDROCARBONS AND ADDITIVES
INGREDIENTS CONSIDERED HAZARDOUS TO HEALTH:

Substance Name	Wt%
DIESEL FUEL (68334-30-5)	100

See Section 15 for European Label Information.
See Section 8 for exposure limits (if applicable).

3. HAZARDS IDENTIFICATION

US OSHA HAZARD COMMUNICATION STANDARD: Product assessed in accordance with OSHA 29 CFR 1910.1200 and determined to be hazardous.
EFFECTS OF OVEREXPOSURE: Respiratory irritation, dizziness, nausea, loss of consciousness. Prolonged, repeated skin contact may result in skin irritation or more serious skin disorders. Low viscosity material-if swallowed may enter the lungs and cause lung damage.
Note: This product contains polycyclic aromatic hydrocarbons, some of which have been reported to cause skin cancer in humans under conditions of poor personal hygiene, prolonged repeated contact, and exposure to sunlight. Toxic effects are unlikely to occur if good personal hygiene is practiced.
EMERGENCY RESPONSE DATA: Clear (May Be Dyed) Liquid. Material is combustible. DOT ERG No. -128

4. FIRST AID MEASURES

EYE CONTACT: Flush thoroughly with water. If irritation occurs, call a physician.
SKIN CONTACT: Remove contaminated clothing. Dry wipe exposed skin and cleanse yourself with waterless hand cleaner and follow by washing thoroughly with soap and water. For those providing assistance, avoid further contact to yourself or others. Wear impervious gloves. Launder contaminated clothing separately before reuse. Discard contaminated articles that cannot be laundered.

INHALATION: Remove from further exposure. If respiratory irritation, dizziness, nausea, or unconsciousness occurs, seek immediate medical assistance. If breathing has stopped, assist ventilation with bag-valve-mask device or use mouth-to-mouth resuscitation.
INGESTION: Seek immediate medical attention. Do not induce vomiting.
NOTE TO PHYSICIANS: Material if aspirated into the lungs may cause chemical pneumonitis. Treat appropriately.

---

5. FIRE-FIGHTING MEASURES

EXTINGUISHING MEDIA: Carbon dioxide, foam, dry chemical and water fog.
SPECIAL FIRE FIGHTING PROCEDURES: Use water to keep fire exposed containers cool. If a leak or spill has not ignited, use water spray to disperse the vapors and to protect personnel attempting to stop leak. Water spray may be used to flush spills away from exposures. Prevent runoff from fire control or dilution from entering streams, sewers, or drinking water supply.
SPECIAL PROTECTIVE EQUIPMENT: For fires in enclosed areas, fire fighters must use self-contained breathing apparatus.
UNUSUAL FIRE AND EXPLOSION HAZARDS: Material is combustible. Flash Point C(F): > 52(125) (ASTM D-93). Flammable limits - LEL: 0.6%, UEL: 7.0%.
NFPA HAZARD ID: Health: 1, Flammability: 2, Reactivity: 0
HAZARDOUS DECOMPOSITION PRODUCTS: Carbon monoxide.

---

6. ACCIDENTAL RELEASE MEASURES

NOTIFICATION PROCEDURES: Report spills as required to appropriate authorities. U. S. Coast Guard regulations require immediate reporting of spills that could reach any waterway including intermittent dry creeks. Report spill to Coast Guard toll free number (800) 424-8802. In case of accident or road spill notify CHEMTREC (800) 424-9300.
PROCEDURES IF MATERIAL IS RELEASED OR SPILLED: Adsorb on fire retardant treated sawdust, diatomaceous earth, etc. Shovel up and dispose of at an appropriate waste disposal facility in accordance with current applicable laws and regulations, and product characteristics at time of disposal.
ENVIRONMENTAL PRECAUTIONS: Prevent spills from entering storm sewers or drains and contact with soil.
PERSONAL PRECAUTIONS: See Section 8

---

7. HANDLING AND STORAGE

HANDLING: Harmful in contact with or if absorbed through the skin. Avoid inhalation of vapors or mists. PORTABLE CONTAINERS approved for storing fuel must be placed on the ground and the nozzle must stay in contact with the container when filling to prevent build up and discharge of static electricity.
STORAGE: Store in a cool area. A flammable atmosphere can be produced in storage tank headspaces even when stored at a temperature below the flashpoint. Monitor and maintain headspace gas concentrations below flammable limits. Ensure that there are no ignition sources in the area immediately surrounding filling and venting operations. Avoid sparking conditions. Ground and bond all transfer equipment. Store in a cool area.

---

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

VENTILATION: Use in well ventilated area. Ventilation desirable and equipment should be explosion proof.
RESPIRATORY PROTECTION: No special requirements under ordinary conditions of use and with adequate ventilation.
EYE PROTECTION: If splash with liquid is possible, chemical type goggles should be worn.
SKIN PROTECTION: Impervious gloves must be worn. If contact is likely oil impervious clothing must be worn.
EXPOSURE LIMITS: This product does not contain any components which have recognized exposure limits.

---

9. PHYSICAL AND CHEMICAL PROPERTIES

Typical physical properties are given below. Consult Product Data Sheet for specific details.
APPEARANCE: Liquid
COLOR: Clear (May Be Dyed)
ODOR: Hydrocarbon
ODOR THRESHOLD-ppm: NE
pH: NA
BOILING POINT C(F): > 149(300)
MELTING POINT C(F): NA
FLASH POINT C(F): > 52(125) (ASTM D-93)
FLAMMABILITY: NE
AUTO FLAMMABILITY: NE
EXPLOSIVE PROPERTIES: NA
OXIDIZING PROPERTIES: NA
VAPOR PRESSURE-mmHg 20 C: 0.5
VAPOR DENSITY: > 2.0
EVAPORATION RATE: NE
RELATIVE DENSITY, 15/4 C: 0.82-0.87
SOLUBILITY IN WATER: Negligible
PARTITION COEFFICIENT: NE
VISCOSITY AT 40 C, cSt: > 1.0
VISCOSITY AT 100 C, cSt: NE
POUR POINT C(F): < -7(20)
FREEZING POINT C(F): NE
VOLATILE ORGANIC COMPOUND: NE
NA=NOT APPLICABLE NE=NOT ESTABLISHED D=DECOMPOSES
FOR FURTHER TECHNICAL INFORMATION, CONTACT YOUR MARKETING REPRESENTATIVE

---

10. STABILITY AND REACTIVITY

STABILITY (THERMAL, LIGHT, ETC.): Stable.
CONDITIONS TO AVOID: Heat, sparks, flame and build up of static electricity.
INCOMPATIBILITY (MATERIALS TO AVOID): Halogens, strong acids, alkalies, and oxidizers.
HAZARDOUS DECOMPOSITION PRODUCTS: Carbon monoxide.
HAZARDOUS POLYMERIZATION: Will not occur.

---

11. TOXICOLOGICAL DATA

---ACUTE TOXICOLOGY---

ORAL TOXICITY (RATS): Practically non-toxic (LD50: greater than 2000 mg/kg). ---Based on testing of similar products and/or the components.
DERMAL TOXICITY (RABBITS): Practically non-toxic (LD50: greater than 2000 mg/kg). ---Based on testing of similar products and/or the components.
INHALATION TOXICITY (RATS): Practically non-toxic (LC50: greater than 5 mg/l). ---Based on testing of similar products and/or the components.
EYE IRRITATION (RABBITS): Practically non-irritating. (Draize score: greater than 6 but 15 or less). ---Based on testing of similar products and/or the components.
SKIN IRRITATION (RABBITS): Practically non-irritating. (Primary Irritation Index: greater than 0.5 but less than 3). ---Based on testing of similar products and/or the components.

---SUBCHRONIC TOXICOLOGY (SUMMARY)---

Repeated dermal application to rats for 13 weeks was carried out with aromatic oils similar to some of the components of this product. Resulting effects included increased mortality and decreased body and thymus weights. Severe skin irritation was also observed at the site of application.

---REPRODUCTIVE TOXICOLOGY (SUMMARY)---

Repeated dermal application to pregnant rats was carried out using aromatic oils similar to some of the components used in this product. Results included maternal toxicity, decreased fetal body weights and decreased fetal survival in some cases. No fetal malformations were observed.

---CHRONIC TOXICOLOGY (SUMMARY)---

Expected to be carcinogenic in lifetime mouse skin painting bioassays.

---OTHER TOXICOLOGY DATA---

Skin cleansing studies with aromatic oils show that toxic effects are not likely to occur in humans if good personal hygiene practices are used. Overexposure to diesel exhaust fumes may result in eye irritation, headaches, nausea, and respiratory irritation. Animal studies involving lifetime exposure to high levels of diesel exhaust have produced variable results, with some studies indicating a potential for lung cancer. Limited evidence from epidemiological studies suggest an association between long-term occupational exposure to diesel engine emissions and lung cancer. Diesel engine exhaust typically consists of gases and particulates, including carbon dioxide, carbon monoxide, nitrogen compounds, oxides of sulfur, and hydrocarbons. Diesel exhaust composition will vary with fuel, engine type, load cycle, engine maintenance, tuning and exhaust gas treatment. Use of adequate ventilation and/or respiratory protection in the presence of diesel exhaust is recommended to minimize exposures.

----

12. ECOLOGICAL INFORMATION

ENVIRONMENTAL FATE AND EFFECTS: Not established.

----

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL: Product is suitable for burning for fuel value i compliance with applicable laws and regulations.
RCRA INFORMATION: Disposal of unused product may be subject to RCRA regulations (40 CFR 261) due to the characteristic(s)/chemical(s) listed below. Disposal of the used product may also be regulated due to ignitability, corrosivity, reactivity, or toxicity as

determined by the Toxicity Characteristic Leaching Procedure
(TCLP).
FLASH: > 52(125) C(F)

---

14. TRANSPORT INFORMATION

NOTE:The flash point of this material is > 125F. Regulatory
classifications vary as follows:
DOT: Flammable Liquid OR Combustible Liquid - (49CFR 173.120(b)(2))
OSHA: Combustible Liquid
IATA/IMO: Flammable Liquid
USA DOT:
SHIPPING NAME: Diesel Fuel
HAZARD CLASS & DIV: COMBUSTIBLE LIQUID
ID NUMBER: NA1993
ERG NUMBER: 128
PACKING GROUP: PG III
STCC: NE
DANGEROUS WHEN WET: No
POISON: No
LABEL(s): NA
PLACARD(s): Combustible
PRODUCT RQ: NA
MARPOL III STATUS: NA
In accordance with 49 CFR 173.150(f)(2), non-bulk quantities of this
material (<119 gallons per container) may be shipped as non regulated
for USA domestic shipments.
RID/ADR:
HAZARD CLASS: 3
HAZARD SUB-CLASS: 31(c)
LABEL: 3
DANGER NUMBER: 30
UN NUMBER: 1202
SHIPPING NAME: Gas Oil
REMARKS: NA
IMO:
HAZARD CLASS & DIV: 3.3
UN NUMBER: 1202
PACKING GROUP: PG III
SHIPPING NAME: Gas Oil
LABEL(s): Flammable Liquid
MARPOL III STATUS: NA
ICAO/IATA:
HAZARD CLASS & DIV: 3
ID/UN Number: 1202
PACKING GROUP: PG III
SHIPPING NAME: Gas Oil
SUBSIDIARY RISK: NA
LABEL(s): Flammable Liquid

---

15. REGULATORY INFORMATION

Governmental Inventory Status: All components comply with TSCA, and
EINECS/ELINCS.
EU Labeling:
Symbol: Xn Harmful.
Risk Phrase(s): R10-40-65.
Flammable. Possible risks of irreversible effects. Harmful: may
cause lung damage if swallowed.
Safety Phrase(s): S24-2-36/37-61-62.

Avoid contact with skin. Keep out of the reach of children. Wea suitable protective clothing and gloves. Avoid release to the environment. Refer to special instructions/Safety data sheets. If swallowed, do not induce vomiting: seek medical advice immediately and show this container or label.
Contains: Gas oil - unspecified.
U.S. Superfund Amendments and Reauthorization Act (SARA) Title III:
This product contains no "EXTREMELY HAZARDOUS SUBSTANCES".
SARA (311/312) REPORTABLE HAZARD CATEGORIES:
FIRE CHRONIC ACUTE
This product contains no chemicals reportable under SARA (313) toxic release program.
The following product ingredients are cited on the lists below:

CHEMICAL NAME	CAS NUMBER	LIST CITATIONS
DIESEL OIL..C9-20	68334-30-5	21, 26

--- REGULATORY LISTS SEARCHED ---

1=ACGIH ALL	6=IARC 1	11=TSCA 4	16=CA P65 CARC	21=LA RTK
2=ACGIH A1	7=IARC 2A	12=TSCA 5a2	17=CA P65 REPRO	22=MI 293
3=ACGIH A2	8=IARC 2B	13=TSCA 5e	18=CA RTK	23=MN RTK
4=NTP CARC	9=OSHA CARC	14=TSCA 6	19=FL RTK	24=NJ RTK
5=NTP SUS	10=OSHA Z	15=TSCA 12b	20=IL RTK	25=PA RTK
				26=RI RTK

Code key: CARC=Carcinogen; SUS=Suspected Carcinogen; REPRO=Reproductive

---

16. OTHER INFORMATION

Precautionary Label Text:
CONTAINS DIESEL OIL.. C9-20
WARNING!
COMBUSTIBLE LIQUID AND VAPOR. MAY CAUSE NOSE, THROAT AND LUNG IRRITATION, DIZZINESS, NAUSEA, LOSS OF CONSCIOUSNESS. LOW VISCOSITY MATERIAL-IF SWALLOWED, MAY BE ASPIRATED AND CAN CAUSE SERIOUS OR FATAL LUNG DAMAGE.
MAY CAUSE SKIN CANCER ON PROLONGED, REPEATED SKIN CONTACT. ANIMAL SKIN ABSORPTION STUDIES RESULTED IN INCREASED MORTALITY, EFFECTS ON BOD WEIGHT, THE IMMUNE SYSTEM AND THE UNBORN CHILD. PROLONGED, REPEATED SKI CONTACT MAY CAUSE IRRITATION. DIESEL EXHAUST IS SUSPECT OF CAUSING LUNG CANCER.
Keep away from heat and flame. Avoid prolonged or repeated overexposure by skin contact or inhalation. Use with adequate ventilation. Keep container closed. Keep out of reach of children. Approved portable containers must be properly grounded when transferring fuel.
FIRST AID: If inhaled, remove from further exposure. If respiratory irritation, dizziness, nausea, or unconsciousness occurs, seek immediate medical assistance. If breathing has stopped, assist ventilation with a bag-valve-mask device or use mouth-to-mouth resuscitation. In case of contact, remove contaminated clothing. Dry wipe the exposed skin and cleanse with waterless hand cleaner and follow by washing thoroughly with soap and water. For those providing assistance, avoid further skin contact to yourself and others. Wear impervious gloves. If swallowed, seek immediate medical attention. Do not induce vomiting. Only induce vomiting at the instruction of a physician.
Empty container may contain product residue, including flammable or explosive vapors. Do not cut, puncture, or weld on or near container. All label warnings and precautions must be observed until container ha been thoroughly cleaned or destroyed.
Chemicals known to the State of California to cause cancer, birth defects, or other reproductive harm are created by the combustion of this product. Refer to product Material Safety Data Bulletin for further safety and health information.

USE: DIESEL FUEL
NOTE: MOBIL PRODUCTS ARE NOT FORMULATED TO CONTAIN PCBS.

INGREDIENT DESCRIPTION	PERCENT	CAS NUMBER
DIESEL OIL..C9-20	100	68334-30-5

For Internal Use Only: MHC: 1* 1* 1* 1* 1*, MPPEC: C, TRN: 170019-31, REQ: US - MARKETING, SAFE USE: C
EHS Approval Date: 30JUN1998

15024-34 AUTOMOTIVE GASOLINE, UNLEADED (NAM&R)
MATERIAL SAFETY DATA BULLETIN

---

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: AUTOMOTIVE GASOLINE, UNLEADED (NAM&R)
SUPPLIER: MOBIL OIL CORP.
NORTH AMERICA MARKETING AND REFINING
3225 GALLOWS RD.
FAIRFAX, VA 22037

24 - Hour Emergency (call collect):	609-737-4411	
Product and MSDS Information:	800-662-4525	856-224-4644
CHEMTREC:	800-424-9300	202-483-7616

2. COMPOSITION/INFORMATION ON INGREDIENTS

CHEMICAL NAMES AND SYNONYMS: HYDROCARBONS AND ADDITIVES
INGREDIENTS CONSIDERED HAZARDOUS TO HEALTH:

Substance Name	Wt%
GASOLINE (8006-61-9)	100
COMPONENT(S) OF PRODUCT INGREDIENTS INCLUDE:	
METHYL T-BUTYL ETHER (1634-04-4)	15
ETHANOL (64-17-5)	11
XYLENE (1330-20-7)	10
ISOPENTANE (78-78-4)	9
TOLUENE (108-88-3)	5
PSEUDOCUMENE (95-63-6)	5
BUTANE (106-97-8)	4
2-METHYLPENTANE (107-83-5)	4
PENTANE (109-66-0)	4
TRIMETHYL BENZENE (25551-13-7)	3
3-METHYLPENTANE (96-14-0)	2
BENZENE (71-43-2)	2
2,3-DIMETHYLBUTANE (79-29-8)	2
N-HEXANE (110-54-3)	2
ETHYL BENZENE (100-41-4)	2
3- METHYLHEXANE (589-34-4)	2
2- METHYLHEXANE (591-76-4)	1
METHYLCYCLOHEXANE (108-87-2)	1

NOTE: THIS MSDB ALSO COVERS REFORMULATED AND CARB PHASE 2 GASOLINE. The concentration of the components shown above may vary substantially. Because of volatility considerations, gasoline vapor may have concentrations of components very different from those of liquid gasoline. The major components of gasoline vapor are: butane, isobutane, pentane and isopentane. Federal RFG (reformulated) and Carb Phase 2 gasoline will contain oxygenates such as MTBE or ethanol at a concentration to provide a minimum oxygen content of 1.5 Wt%. The reportable component percentages, shown in the Regulatory Information section, are based on API's evaluation of a typical gasoline mixture.
See Section 15 for European Label Information.
See Section 8 for exposure limits (if applicable).

3. HAZARDS IDENTIFICATION

US OSHA HAZARD COMMUNICATION STANDARD: Product assessed in accordance with OSHA 29 CFR 1910.1200 and determined to be hazardous.
EFFECTS OF OVEREXPOSURE: Eye irritation, respiratory irritation, dizziness, nausea, loss of consciousness. Skin irritation. Studies (sponsored by API) conducted in the U.S. examining the mortality experience (causes of death) of distribution workers with long-term exposure to gasoline have not found any gasoline-related health effects. Case reports of chronic gasoline abuse (such as gasoline sniffing) and chronic misuse of gasoline as a solvent or as a cleaning agent have reported a range of neurological effects (nervous system effects), sudden deaths from cardiac arrest (heart attacks), hematologic changes (blood effects) and leukemia. These effects are not expected to occur at exposure levels encountered in the distribution and use of gasoline as a motor fuel. Low viscosity material-if swallowed may enter the lungs and cause lung damage.
EMERGENCY RESPONSE DATA: Clear (May Be Dyed) Liquid. Extremely flammable. Vapor accumulation could flash and/or explode if in contact with open flame. DOT ERG No. -128

---

4. FIRST AID MEASURES

EYE CONTACT: Flush thoroughly with water. If irritation occurs, call a physician.
SKIN CONTACT: Wash contact areas with soap and water. Remove contaminated clothing. Launder contaminated clothing before reuse.
INHALATION: Remove from further exposure. If respiratory irritation, dizziness, nausea, or unconsciousness occurs, seek immediate medical assistance. If breathing has stopped, assist ventilation with bag-valve-mask device or use mouth-to-mouth resuscitation.
INGESTION: Seek immediate medical attention. Do not induce vomiting.
NOTE TO PHYSICIANS: Material if ingested may be aspirated into the lungs and can cause chemical pneumonitis. Treat appropriately.

---

5. FIRE-FIGHTING MEASURES

EXTINGUISHING MEDIA: Carbon Dioxide, Foam, Dry Chemical, Water Fog.
SPECIAL FIRE FIGHTING PROCEDURES: Evacuate area. For large spills, fire fighting foam is the preferred agent and should be applied in sufficient quantities to blanket the gasoline surface. Water spray may be used to flush spill away from exposures, but good judgement should be practiced to prevent spreading of the gasoline into sewers, streams or drinking water supplies. If a leak or spill has not ignited, apply a foam blanket to suppress the release of vapors. If foam is not available, a water spray curtain can be used to disperse vapors and to protect personnel attempting to stop the leak.
SPECIAL PROTECTIVE EQUIPMENT: For fires in enclosed areas, fire fighters must use self-contained breathing apparatus.
UNUSUAL FIRE AND EXPLOSION HAZARDS: Extremely flammable. Vapor accumulation could flash and/or explode if in contact with open flame. Flash Point C(F): < -40(-40) (ASTM D-56). Flammable limits - LEL: 1.4%, UEL: 7.6%.
NFPA HAZARD ID: Health: 1, Flammability: 3, Reactivity: 0
HAZARDOUS DECOMPOSITION PRODUCTS: Carbon monoxide.

---

6. ACCIDENTAL RELEASE MEASURES

NOTIFICATION PROCEDURES: Report spills as required to appropriate authorities. U. S. Coast Guard regulations require immediate reporting of spills that could reach any waterway including intermittent dry creeks. Report spill to Coast Guard toll free number (800) 424-8802. In case of accident or road spill notify CHEMTREC (800) 424-9300.
PROCEDURES IF MATERIAL IS RELEASED OR SPILLED: Eliminate all ignition sources. Runoff may create fire or explosion hazard in sewer system. Adsorb on fire retardant treated sawdust, diatomaceous earth, etc. Shovel up and dispose of at an appropriate waste disposal facility in accordance with current applicable laws and regulations, and product characteristics at time of disposal.
ENVIRONMENTAL PRECAUTIONS: Prevent spills from entering storm sewers or drains and contact with soil.
PERSONAL PRECAUTIONS: See Section 8

7. HANDLING AND STORAGE

HANDLING: NEVER SIPHON GASOLINE BY MOUTH. GASOLINE SHOULD NOT BE USED AS A SOLVENT OR AS A CLEANING AGENT. Use non-sparking tools an explosion-proof equipment. Avoid contact with skin. Avoid inhalation of vapors or mists. Use in well ventilated area away from all ignition sources. PORTABLE CONTAINERS approved for storing fuel must be placed on the ground and the nozzle must stay in contact with the container when filling to prevent build up and discharge of static electricity.
STORAGE: Drums must be grounded and bonded and equipped with self-closing valves, pressure vacuum bungs and flame arresters. Store away from all ignition sources in a cool area equipped with an automatic sprinkling system. Outside or detached storage preferred. Storage containers should be grounded and bonded.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

VENTILATION: Use in well ventilated area with local exhaust ventilation. Ventilation required and equipment must be explosion proof. Use away from all ignition sources.
RESPIRATORY PROTECTION: Approved respiratory equipment must be used when airborne concentrations are unknown or exceed the TLV.
EYE PROTECTION: If splash with liquid is possible, safety glasses with side shields or chemical goggles should be worn.
SKIN PROTECTION: Impervious gloves should be worn. Good personal hygiene practices should always be followed.

Substance Name (CAS-No.)	Source	TWA ppm	TWA mg/m3	STEL ppm	STEL mg/m3	NOTE
GASOLINE (8006-61-9)						
	OSHA	300	900	500	1500	
	ACGIH	300	890	500	1480	
METHYL T-BUTYL ETHER (1634-04-4)						
	ACGIH	40	144			
ETHANOL (64-17-5)						
	OSHA	1000	1900			
	ACGIH	1000	1880			
XYLENE (1330-20-7)						
O, M, P, -Isomers	OSHA	100	435	150	655	

O, M, P, -Isomers	ACGIH	100	434	150	651
ISOPENTANE (78-78-4)					
All Isomers	ACGIH	600	1770		
TOLUENE (108-88-3)					
	OSHA	100	375	150	560
Skin	ACGIH	50	188		
PSEUDOCUMENE (95-63-6)					
	OSHA	25	125		
	ACGIH	25	123		
BUTANE (106-97-8)					
	OSHA	800	1900		
	ACGIH	800	1900		
2-METHYLPENTANE (107-83-5)					
Isomer of N-Hexane	ACGIH	500	1760	1000	3500
PENTANE (109-66-0)					
	OSHA	600	1800	750	2250
All Isomers	ACGIH	600	1770		
TRIMETHYL BENZENE (25551-13-7)					
	OSHA	25	125		
	ACGIH	25	123		
3-METHYLPENTANE (96-14-0)					
Isomer of N-Hexane	ACGIH	500	1760	1000	3500
BENZENE (71-43-2)					
	OSHA	1		5	
Skin	ACGIH	0.5	1.6	2.5	8
2,3-DIMETHYLBUTANE (79-29-8)					
Isomer of N-Hexane	ACGIH	500	1760	1000	3500
N-HEXANE (110-54-3)					
	OSHA	50	180		
N-Hexane Skin	ACGIH	50	176		
Other Isomers	ACGIH	500	1760	1000	3500
ETHYL BENZENE (100-41-4)					
	OSHA	100	435	125	545
	ACGIH	100	434	125	543
3- METHYLHEXANE (589-34-4)					
	MOBIL	400	1640		
2- METHYLHEXANE (591-76-4)					
	MOBIL	400	1640		
METHYLCYCLOHEXANE (108-87-2)					
	OSHA	400	1600		
	ACGIH	400	1610		

NOTE: Limits shown for guidance only. Follow applicable regulations.

---

9. PHYSICAL AND CHEMICAL PROPERTIES

Typical physical properties are given below. Consult Product Data Sheet for specific details.

APPEARANCE: Liquid
COLOR: Clear (May Be Dyed)
ODOR: Gasoline
ODOR THRESHOLD-ppm: NE
pH: NA
BOILING POINT C(F): > 35(95)
MELTING POINT C(F): NA
FLASH POINT C(F): < -40(-40) (ASTM D-56)
FLAMMABILITY: NE
AUTO FLAMMABILITY: NE
EXPLOSIVE PROPERTIES: NA
OXIDIZING PROPERTIES: NA

VAPOR PRESSURE-mmHg 20 C: > 400.0
VAPOR DENSITY: 3.0
EVAPORATION RATE: NE
RELATIVE DENSITY, 15/4 C: 0.79
SOLUBILITY IN WATER: Negligible
PARTITION COEFFICIENT: NE
VISCOSITY AT 40 C, cSt: < 1.0
VISCOSITY AT 100 C, cSt: NA
POUR POINT C(F): NA
FREEZING POINT C(F): NE
VOLATILE ORGANIC COMPOUND: NE
NA=NOT APPLICABLE NE=NOT ESTABLISHED D=DECOMPOSES
FOR FURTHER TECHNICAL INFORMATION, CONTACT YOUR MARKETING REPRESENTATIVE

---

10. STABILITY AND REACTIVITY

STABILITY (THERMAL, LIGHT, ETC.): Stable.
CONDITIONS TO AVOID: Heat, sparks, flame and build up of static electricity.
INCOMPATIBILITY (MATERIALS TO AVOID): Halogens, strong acids, alkalies, and oxidizers.
HAZARDOUS DECOMPOSITION PRODUCTS: Carbon monoxide.
HAZARDOUS POLYMERIZATION: Will not occur.

---

11. TOXICOLOGICAL DATA

---ACUTE TOXICOLOGY---

ORAL TOXICITY (RATS): Practically non-toxic (LD50: greater than 2000 mg/kg). ---Based on testing of similar products and/or the components.
DERMAL TOXICITY (RABBITS): Practically non-toxic (LD50: greater than 2000 mg/kg). ---Based on testing of similar products and/or the components.
INHALATION TOXICITY (RATS): Practically non-toxic (LC50: greater than 5 mg/l). ---Based on testing of similar products and/or the components.
EYE IRRITATION (RABBITS): Practically non-irritating. (Draize score: greater than 6 but 15 or less). ---Based on testing of similar products and/or the components.
SKIN IRRITATION (RABBITS): Irritant. (Primary Irritation Index: 3 or greater but less than 5). ---Based on testing of similar products and/or the components.
OTHER ACUTE TOXICITY DATA: Inhalation of vapors/mists may cause respiratory system irritation. HAZARDS OF COMBUSTION PRODUCTS: Exposure to high concentrations of carbon monoxide can cause loss of consciousness, heart damage, brain damage and death. Exposure to high concentrations of carbon dioxide can cause simple asphyxiation by displacing oxygen. May be harmful or fatal if swallowed due to aspiration pneumonitis.

---OTHER TOXICOLOGY DATA---

Gasoline and Refinery Streams: Studies conducted by the American Petroleum Institute examined a reference unleaded gasoline for mutagenic, teratogenic and sensitization potential; no evidence of these hazards was found. However, isolated constituents of gasoline may display these or other potential hazards in laboratory tests. There were no significant adverse effects in three-month subchronic inhalation studies in rats or monkeys, or in a two-year skin cancer study in mice. Studies with laboratory animals have shown that gasoline vapors administered at high concentrations over a prolonged period of time caused kidney damage and kidney cancer in male rats and liver cancer in female mice. The kidney tumors resulted from formation of a compound unique to male rats and is not considered relevant to humans. The relationship of liver cancer in mice to humans is not known. Studies carried out by Mobil's Environmental and Health Sciences Laboratory on some of the major refinery streams from which gasoline is formulated support the results of the API studies. There was no evidence of significant adverse systemic or reproductive effects for light catalytic cracked naphthas and reformed naphthas. Components: Gasoline consists of a complex blend of petroleum/processing derived paraffinic, olefinic, naphthenic and aromatic hydrocarbons which include up to 5% benzene (with 1-2% typical in the U.S.), n-hexane, mixed xylenes, toluene, ethylbenzene and trimethyl benzene. Repeated exposures to low levels of benzene have been reported to result in blood abnormalities including anemia and, in rare cases, leukemia in both animals and humans. Prolonged exposure to n-hexane may result in nervous system damage, including numbness of the extremities and, in extreme cases, paralysis. The adverse effects associated with these components have not been observed in studies with gasoline or the refinery streams from which it is formulated. Generally, human exposures to gasoline vapors are considerably less than those used in the animal toxicity studies. As far as scientists know, low level or infrequent exposures to gasoline vapor are unlikely to be associated with cancer or other serious diseases in humans. Methyl Tertiary Butyl Ether (MTBE) was tested for carcinogenicity, neurotoxicity, chronic, reproductive, and developmental toxicity. The NOAEL for all end points evaluated in three animal species was 400 ppm or greater. An increase in kidney tumors/damage and liver tumors was observed in animals exposed to high concentrations of MTBE. Some embryo/fetal toxicity and birth defects were observed in the offspring of pregnant mice exposed to maternally toxic doses of MTBE, however the offspring of exposed pregnant rabbits were unaffected. The significance of the animal findings at high exposures are not believed to be directly related to potential human health hazards in the workplace.

---

12. ECOLOGICAL INFORMATION

ENVIRONMENTAL FATE AND EFFECTS: Not established.

---

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL: Product is suitable for burning for fuel value i compliance with applicable laws and regulations.
RCRA INFORMATION: Disposal of unused product may be subject to RCRA regulations (40 CFR 261). Disposal of the used product may also be regulated due to ignitability, corrosivity, reactivity, or toxicity as determined by the Toxicity Characteristic Leaching Procedure (TCLP).

BENZENE: 2.3200 PCT (TCLP)
FLASH: < -40(-40) C(F)

---

14. TRANSPORT INFORMATION

USA DOT:

SHIPPING NAME:	Gasoline
HAZARD CLASS & DIV:	3
ID NUMBER:	UN1203

ERG NUMBER:	128
PACKING GROUP:	PG II
STCC:	NE
DANGEROUS WHEN WET:	No
POISON:	No
LABEL(s):	Flammable Liquid
PLACARD(s):	Flammable
PRODUCT RQ:	NA
MARPOL III STATUS:	NA
RID/ADR:	
HAZARD CLASS:	3
HAZARD SUB-CLASS:	3(b)
LABEL:	3
DANGER NUMBER:	33
UN NUMBER:	1203
SHIPPING NAME:	Hydrocarbons, liquid having a flash point below 21deg C
REMARKS:	NA
IMO:	
HAZARD CLASS & DIV:	3.1
UN NUMBER:	1203
PACKING GROUP:	PG II
SHIPPING NAME:	Gasoline
LABEL(s):	Flammable Liquid
MARPOL III STATUS:	NA
ICAO/IATA:	
HAZARD CLASS & DIV:	3
ID/UN Number:	1203
PACKING GROUP:	PG II
SHIPPING NAME:	Gasoline
SUBSIDIARY RISK:	NA
LABEL(s):	Flammable Liquid

---

15. REGULATORY INFORMATION

Governmental Inventory Status: All components comply with TSCA, and EINECS/ELINCS.
EU Labeling:
Symbol: F+ T Extremely flammable, Toxic.
Risk Phrase(s): R12-45-38-65.
Extremely flammable. May cause cancer. Irritating to skin.
Harmful: may cause lung damage if swallowed.
Safety Phrase(s): S53-45-2-23-24-29-43-62.
Avoid exposure - obtain special instructions before use. In case o accident or if you feel unwell, seek medical advice immediately (show the label where possible). Keep out of the reach of children. Do not breathe vapor. Avoid contact with skin. Do not empty into drains. In case of fire use carbon dioxide, foam, dry chemical or water fog. If swallowed, do not induce vomiting: seek medical advice immediately and show this container or label.
Contains: Low Boiling Point Naphtha.
U.S. Superfund Amendments and Reauthorization Act (SARA) Title III:
This product contains no "EXTREMELY HAZARDOUS SUBSTANCES".
SARA (311/312) REPORTABLE HAZARD CATEGORIES:
FIRE CHRONIC ACUTE
This product contains the following SARA (313) Toxic Release Chemicals:

CHEMICAL NAME	CAS NUMBER	CONC.
BENZENE(COMPONENT ANALYSIS)	71-43-2	2.32%
PSEUDOCUMENE(COMPONENT ANALYSIS)	95-63-6	4.55%
ETHYL BENZENE(COMPONENT	100-41-4	1.6%

ANALYSIS)		
TOLUENE(COMPONENT ANALYSIS)	108-88-3	4.65%
N-HEXANE(COMPONENT ANALYSIS)	110-54-3	1.69%
XYLENES(COMPONENT ANALYSIS)	1330-20-7	9.9%
METHYL-TERT-BUTYL ETHER(COMPONENT ANALYSIS)	1634-04-4	15.1%

The following product ingredients are cited on the lists below:

CHEMICAL NAME	CAS NUMBER	LIST CITATIONS
ETHYL ALCOHOL (COMPONENT ANALYSIS)	64-17-5	1, 6, 10, 18, 19, 20, 21, 23, 25, 26
BENZENE (COMPONENT ANALYSIS) (2.32%)	71-43-2	1, 2, 4, 6, 9, 10, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26
ISOPENTANE (COMPONENT ANALYSIS)	78-78-4	1, 19, 24, 25
2,3-DIMETHYLBUTANE (COMPONENT ANALYSIS)	79-29-8	1, 19, 25
PSEUDOCUMENE (COMPONENT ANALYSIS)	95-63-6	1, 20, 24, 25
PENTANE, 3-METHYL- (COMPONENT ANALYSIS)	96-14-0	1, 19, 25
METHYL CYCLOPENTANE (COMPONENT ANALYSIS)	96-37-7	19, 25, 26
ETHYL BENZENE (COMPONENT ANALYSIS)	100-41-4	1, 8, 10, 18, 19, 20, 21, 23, 24, 25, 26
BUTANE (COMPONENT ANALYSIS)	106-97-8	1, 10, 18, 19, 20, 21, 23, 24, 25, 26
PENTANE, 2-METHYL- (COMPONENT ANALYSIS)	107-83-5	1, 19, 23, 25
METHYLCYCLOHEXANE (COMPONENT ANALYSIS)	108-87-2	1, 10, 18, 19, 20, 21, 23, 25, 2
TOLUENE (COMPONENT ANALYSIS) (4.65%)	108-88-3	1, 10, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26
PENTANE (COMPONENT ANALYSIS)	109-66-0	1, 10, 18, 19, 20, 21, 23, 24, 25, 26
N-HEXANE (COMPONENT ANALYSIS)	110-54-3	1, 10, 18, 19, 20, 21, 23, 24, 25, 26
2-METHYL 2-BUTENE (COMPONENT ANALYSIS)	513-35-9	19, 25
3-METHYLHEXANE (COMPONENT ANALYSIS)	589-34-4	19, 25
HEXANE, 2-METHYL- (COMPONENT ANALYSIS)	591-76-4	19, 25
1-HEXENE (COMPONENT ANALYSIS)	592-41-6	1, 19, 25
XYLENES (COMPONENT ANALYSIS) (9.90%)	1330-20-7	1, 10, 18, 19, 20, 21, 22, 23, 24, 25, 26
METHYL-TERT-BUTYL ETHER (COMPONENT ANALYSIS)	1634-04-4	1, 11, 15, 21, 24, 25
GASOLINE	8006-61-9	1, 8, 10, 18, 19, 20, 21, 23, 26
TRIMETHYL BENZENE (COMPONENT ANALYSIS)	25551-13-7	1, 10, 18, 19, 20, 21, 23, 25, 2

--- REGULATORY LISTS SEARCHED ---

1=ACGIH ALL	6=IARC 1	11=TSCA 4	16=CA P65 CARC	21=LA RTK
2=ACGIH A1	7=IARC 2A	12=TSCA 5a2	17=CA P65 REPRO	22=MI 293
3=ACGIH A2	8=IARC 2B	13=TSCA 5e	18=CA RTK	23=MN RTK
4=NTP CARC	9=OSHA CARC	14=TSCA 6	19=FL RTK	24=NJ RTK
5=NTP SUS	10=OSHA Z	15=TSCA 12b	20=IL RTK	25=PA RTK
				26=RI RTK

Code key: CARC=Carcinogen; SUS=Suspected Carcinogen; REPRO=Reproductive

---

16. OTHER INFORMATION

Precautionary Label Text:
CONTAINS GASOLINE
DANGER!
EXTREMELY FLAMMABLE LIQUID AND VAPOR. VAPOR MAY CAUSE FLASH FIRE. MAY CAUSE SKIN, NOSE, THROAT, AND LUNG IRRITATION, DIZZINESS, NAUSEA, AND LOSS OF CONSCIOUSNESS. LOW VISCOSITY MATERIAL-IF SWALLOWED, MAY BE ASPIRATED AND CAN CAUSE SERIOUS OR FATAL LUNG DAMAGE
LONG-TERM EXPOSURE TO GASOLINE VAPOR HAS CAUSED KIDNEY AND LIVER CANCER IN LABORATORY ANIMIALS.
Keep away from heat, sparks, and flame. Avoid all personal contact. Avoid prolonged breathing of vapor. Use with adequate ventilation. Kee container closed. Approved portable containers must be properly grounded when transferring fuel. For use as a motor fuel only. Misuse of gasoline may cause serious injury or illness. Never siphon by mouth. Not to be used as a solvent or skin cleaning agent.
FIRST AID: In case of contact, wash skin with soap and water. Remove contaminated clothing. Destroy or wash clothing before reuse. If swallowed, seek immediate medical attention. Do not induce vomiting. Only induce vomiting at the instruction of a physician.
Empty container may contain product residue, including flammable or explosive vapors. Do not cut, puncture, or weld on or near container. All label warnings and precautions must be observed until container ha been thoroughly cleaned or destroyed.
This warning is given to comply with California Health and Safety Code 25249.6 and does not constitute an admission or a waiver of rights. This product contains a chemical known to the State of California to cause cancer, birth defects, or other reproductive harm. Chemicals known to the State of California to cause cancer, birth defects, or other reproductive harm are created by the combustion of this product. Refer to product Material Safety Data Bulletin for further safety and health information.

USE: UNLEADED MOTOR FUEL
NOTE: MOBIL PRODUCTS ARE NOT FORMULATED TO CONTAIN PCBS.

INGREDIENT	PERCENT	CAS NUMBER
GASOLINE	100.00	8006-61-9

***

For Internal Use Only: MHC: 1* 1* 1* 1* 2*, MPPEC: CF, TRN: 15024-34, REQ: US - MARKETING, SAFE USE: S
EHS Approval Date: 12MAY2000

***

***

Legally required information is given in accordance with applicable Information given herein is offered in good faith as accurate, but without guarantee. Conditions of use and suitability of the product for particular uses are beyond our control; all risks of use of the product are therefore assumed by the user and WE EXPRESSLY DISCLAIM ALL WARRANTIES OF EVERY KIND AND NATURE, INCLUDING WARRANTIES O MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE IN RESPECT TO THE USE OR SUITABILITY OF THE PRODUCT. Nothing is intended as a recommendation for uses which infringe valid patents or as extending any license under valid patents. Appropiate warnings and safe handling procedures should be providedto handlers and users. Use or re-transmission of the information contained herein in any other format than the format as presented is strictly prohibited. Mobil neither represents nor warrants that the format, content or product formulas contained in this document comply with the laws of any other country except the United States of America.

BCG #526

BC GAS - Material Safety Data Sheet (MSDS)

PRODUCT NAME(S) : Natural Gas (Pipeline Quality)
PREPARATION DATE : January 31, 2002

SECTION 1 PRODUCT INFORMATION

Manufacturer

WESTCOAST ENERGY INC
1333 West Georgia Street
Vancouver, BC
V6E 3K9

EMERGENCY #: (604) 691-5566

Supplier

BC GAS INC.
16705 Fraser Highway
Surrey, BC
V3S 2X7

EMERGENCY #: 1-800-663-9911

Material Use	: Fuel
TDG Shipping Name	: N/A
TDG Class	: 2.1
Chemical Family	: Simple Hydro Carbon
Chemical Formula	: CH4 (Methane)
Molecular Weight	: 16.04 (Methane)
CAS Number	: 74-82-8
Trade Names and Synonyms	: Marsh Gas , Methane
Hazard Ratings	
Health	:
Flammability	: 4
Reactivity	:
Personal Protection	:
UN/PIN Number 1971	:
WHMIS Class	: A B1

SECTION II HAZARDOUS INGREDIENTS

Hazardous Ingredients	Approx. Conc %	CAS Number	Exposure Limits	LD50 / LC50 Species and Route
Methane	95%	74-82-8	Simple Asphyxiant	N/A
Ethane	3%	74-84-0	Simple Asphyxiant	N/A
Propane	1%	74-98-6	Simple Asphyxiant	N/A
Inert Gas	<1%	N/AV	N/AV	N/AV
Sulphur Compounds	Trace	N/AV	N/AV	N/AV
Mercaptan Odourant	3 ppm	Mixture	0.5 ppm TWA	N/AV

SECTION III PHYSICAL DATA

Physical State	:	Gas
Odour/Appearance	:	Gassy odour, colourless
Specific Gravity (Water = 1)	:	N/A
Odour Threshold (ppm)	:	2500
Vapour Pressure (mm Hg)	:	N/A
Vapour Density (Air =1)	:	0.59
Evaporation Rate	:	N/A (Gas at room temperature)
Boiling Point (C)	:	-160 deg C
Freezing Point (C)	:	N/A
Solubility in Water (20 C)	:	Slight
% Volatile (by volume)	:	N/AV
pH	:	N/AV
Density (g/ml)	:	N/AV
Coefficient of Water/Oil Distribution	:	N/AV

SECTION IV FIRE AND EXPLOSION DATA

Flammable	:	YES Can be ignited by flame or spark
Means of Extinction	:	Dry Chemical, carbon dioxide, water spray, fog,
Special Procedures	:	Shut off flow of gas from a safe location. Use full protective equipment and SCBA. DO not extinguish flame until gas flow is shut off. Use gas detectors in confined spaces. Evaporate area if cooling of containers is not possible.
Hazardous Combust Products	:	Carbon Monoxide, Carbon Dioxide
Flash Pt. (C) & Method	:	Flammable Gas
Upper Explosion Limit (% by Volume)	:	15%
Lower Explosion Limit (% by Volume)	:	5 %
Auto Ignition Temp	:	537 C
Sensitivity to Static Discharge	:	Flammable
Sensitivity to Mechanical Impact	:	None
Explosive Power	:	N/AV
Rate of Burning	:	N/AV
TDG Flammability Class	:	2.1

SECTION V REACTIVITY DATA

Chemical Stability	:	Yes
Incompatibility with other Substances	:	No
Reactivity and under what conditions	:	Strong Oxidizing agents increase risk of fire (peroxides, perchlorates, chlorine, liquid oxygen)
Hazardous Decomposition Products	:	COx, luminous clean flame on combustion.

SECTION VI REACTIVITY DATA

Route of Entry

Skin Contact	[ ]	Skin Absorption	[ ]
Eye Contact	[ ]	Inhalation Acute	[X]
Inhalation Chronic	[ ]	Ingestion	[ ]

Effects of Acute Exposure to Product : Non Toxic. At high concentrations, natural gas can displace oxygen and cause asphyxiation.

Effects of Chronic Exposure to Product: None reported

LD50	: N/A	LC50	: N/A
Exposure Limits	: N/AV	Synergistic Effects	: N/AV

Carcinogen	[ ]	Reproductive Effects	[ ]	Teratogen	[ ]
Mutagen	[ ]	Irritant	[ ]	Sensitizer	[ ]

SECTION VII PREVENTIVE MEASURES

Personal Protective Equipment

Gloves : No specific Requirement
Respiratory : If engineering controls and work practices are not effective in controlling exposure to natural gas, then wear suitable respiratory protection. Supplied air or SCBA
Eye : No specific requirement
Footwear : No specific requirement
Clothing : No specific requirement
Other : none
Engineering Controls: All installations must conform to code requirements
Leak and Spill Procedure : Evacuate area. Call emergency services and gas supplier
Waste Disposal : Vent to outside atmosphere
Handling Procedures and Equipment : Observe handling regulations for compressed gases and flammable materials.
Storage Requirements: No smoking or open flames in storage area. Comply with storage regulations for compressed gases and flammable materials
Special Shipping Information : Handle as extremely flammable gas. Electronically ground/bond during transfer to avoid static accumulation. Precaution should be taken to minimize inhalation of natural gas.

SECTION VIII FIRST AID MEASURES

Skin : N/AV
Eye : N/AV
Inhalation : Ensure your own safety before attempting to rescue. Move victim to fresh air. If breathing has stopped administer oxygen. If heart beat can not be detected begin CPR. If person is overcome or been adversely affected by the emergency, obtain medical attention immediately.

Ingestion   : N/AV
General Advice : N/AV

SECTION IX   PREPARATION OF M.S.D.S.

Prepared by	Phone Number	Preparation Date
Safety and Occupational Health Services	1-800-66309911	02/01/31

Sources   : CCINFO
Additional Information and Comments

While BC Gas believes that the data contained herein is accurate and derived from qualified sources, BC Gas does not in any way warrant or represent the accuracy of the data and assumes no responsibility to determine safe conditions and any use of the data be determined by you to be in accordance with applicable laws and regs.

N/AV not available
N/A   not applicable

NFPA 704 (Section 16)

AMERADA HESS CORPORATION

MATERIAL SAFETY DATA SHEET

Propane **MSDS No. 6182**

1. CHEMICAL PRODUCT and COMPANY INFORMATION (rev. Mar-98)

Amerada Hess Corporation
1 Hess Plaza
Woodbridge, NJ 07095-0961

EMERGENCY TELEPHONE NUMBER (24 hrs): CHEMTREC (800)424-9300
COMPANY CONTACT (business hours): Corporate Safety (732)750-6000

SYNONYMS: Dimethylmethane; Liquefied Petroleum Gas (LPG); Sales Propane
See Section 16 for abbreviations and acronyms.

2. COMPOSITION and INFORMATION ON INGREDIENTS (rev. Mar-00)

INGREDIENT NAME	EXPOSURE LIMITS		CONCENTRATION PERCENT BY VOLUME
Propane CAS NUMBER: 74-98-6	OSHA PEL-TWA: ACGIH TLV-TWA:	1000 ppm NOIC: 2500 ppm	70 min.
Propylene CAS NUMBER: 115-07-1	None established by OSHA or ACGIH Simple asphyxiant		30 max.
Ethane CAS NUMBER: 74-84-0	None established by OSHA or ACGIH Simple asphyxiant		< 2
Mixed hydrocarbons [butane (C4) and higher]	N/A - Limits above will predominate		< 2.5

Light gases from distilled and catalytically-cracked petroleum oil consisting of hydrocarbons having carbon numbers in the range of C3 through C4, predominantly propane and propylene. This MSDS describes Propane, C_3H_8; other constituents exhibit similar hazards - significant differences are noted as appropriate. Odorized with trace amounts of odorant (typically well below 0.1% ethyl mercaptan).

3. HAZARDS IDENTIFICATION (rev. Mar-98; Tox-98)

EMERGENCY OVERVIEW
DANGER!
EXTREMELY FLAMMABLE GAS - MAY CAUSE FLASH FIRE OR EXPLOSION! - COMPRESSED GAS

High concentrations may exclude oxygen and cause dizziness and suffocation . Contact with liquid or cold vapor may cause frostbite or freeze burn .

EYES
Vapors are not irritating. However, contact with liquid or cold vapor may cause frostbite, freeze burns, and permanent eye damage

SKIN
Vapors are not irritating. Direct contact to skin or mucous membranes with liquefied product or cold vapor may cause freeze burns and frostbite. Ingestion is unlikely. Contact to mucous membranes with liquefied product may cause frostbite and freeze burns. Signs of frostbite include a change in the color of the skin to gray or white, possibly followed by blistering. Skin may become inflamed and painful.

INGESTION
Ingestion is unlikely. Contact with mucous membranes with liquefied product may cause frostbite and freeze burns.

INHALATION
This product is considered to be non-toxic by inhalation. Inhalation of high concentrations may cause central nervous system depression such as dizziness, drowsiness, headache, and similar narcotic symptoms, but no long-term effects. Numbness, a "chilly" feeling, and vomiting have been reported from accidental exposures to high concentrations.

This product is a simple asphyxiant. In high concentrations it will displace oxygen from the breathing atmosphere, particularly in confined spaces. Signs of asphyxiation will be noticed when oxygen is reduced to below 16%, and may occur in several stages. Symptoms may include rapid breathing and pulse rate, headache, dizziness, visual disturbances, mental confusion, incoordination, mood changes, muscular weakness, tremors, cyanosis, narcosis and numbness of the extremities. Unconsciousness leading to central nervous system injury and possibly death will occur when the atmospheric oxygen concentration is reduced to about 6% to 8% or less.

WARNING: The burning of any hydrocarbon as a fuel in an area without adequate ventilation may result in hazardous levels of combustion products, including carbon monoxide, and inadequate oxygen levels, which may cause unconsciousness, suffocation, and death.

CHRONIC and CARCINOGENICITY
None expected - see Section 11.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE
Individuals with pre-existing conditions of the heart, lungs, and blood may have increased susceptibility to symptoms of asphxia.

4. FIRST AID MEASURES (rev. Mar-98; Tox-98)

EYES
In case of liquid contact with the eyes, open eyelids wide to allow liquid to evaporate. Cover eyes to protect from light. Seek immediate medical attention.

SKIN
In case of blistering, frostbite or freeze burns seek immediate medical attention.

INGESTION
Risk of ingestion is extremely low. However, in cases of ingestion or oral exposure, seek immediate medical attention.

INHALATION
Remove person to fresh air. If person is not breathing, ensure an open airway and administer CPR. If necessary, provide additional oxygen once breathing is restored if trained to do so. Seek medical attention immediately.

5. FIRE FIGHTING MEASURES (rev. Nov-95)

FLAMMABLE PROPERTIES:

FLASH POINT:	-156 ^oF (-104 ^oC)
AUTOIGNITION POINT:	842 ^oF (450 ^oC)
OSHA/NFPA FLAMMABILITY CLASS:	FLAMMABLE GAS
LOWER EXPLOSIVE LIMIT (%):	2.1
UPPER EXPLOSIVE LIMIT (%):	9.5

FIRE AND EXPLOSION HAZARDS
Liquid releases flammable vapors at well below ambient temperatures and readily forms a flammable mixture with air. Dangerous fire and explosion hazard when exposed to heat, sparks or flame. Vapors are heavier than air and may travel long distances to a point of ignition and flash back. Container may explode in heat or fire. Runoff to sewer may cause fire or explosion hazard.

EXTINGUISHING MEDIA

Dry chemical, carbon dioxide, Halon or water. However, fire should not be extinguished unless flow of gas can be immediately stopped.

FIRE FIGHTING INSTRUCTIONS

Gas fires should not be extinguished unless flow of gas can be immediately stopped. Shut off gas source and allow gas to burn out. If spill or leak has not ignited, determine if water spray may assist in dispersing gas or vapor to protect personnel attempting to stop leak.

Use water to cool equipment, surfaces and containers exposed to fire and excessive heat. For large fire the use of unmanned hose holders or monitor nozzles may be advantageous to further minimize personnel exposure.

Isolate area, particularly around ends of storage vessels. Let vessel, tank car or container burn unless leak can be stopped. Withdraw immediately in the event of a rising sound from a venting safety device. Large fires typically require specially trained personnel and equipment to isolate and extinguish the fire.

Firefighting activities that may result in potential exposure to high heat, smoke or toxic by-products of combustion should require NIOSH/MSHA- approved pressure-demand self-contained breathing apparatus with full facepiece and full protective clothing.

See Section 16 for the NFPA Hazard Rating.

6. ACCIDENTAL RELEASE MEASURES (rev. Mar-98)

ACTIVATE FACILITY'S SPILL CONTINGENCY or EMERGENCY RESPONSE PLAN

Evacuate nonessential personnel and secure all ignition sources. No road flares, smoking or flames in hazard area. Consider wind direction, stay upwind and uphill, if possible. Evaluate the direction of product travel. Vapor cloud may be white, but color will dissipate as cloud disperses - fire and explosion hazard is still present!

Stop the source of the release, if safe to do so. Do not flush down sewer or drainage systems. Do not touch spilled liquid (frostbite/freeze burn hazard!). Consider the use of water spray to disperse vapors. Isolate the area until gas has dispersed. Ventilate and gas test area before entering.

7. HANDLING and STORAGE (rev. Mar-98)

HANDLING and STORAGE PRECAUTIONS

Keep away from flame, sparks and excessive temperatures. Store only in approved containers. Bond and ground containers. Use only in well ventilated areas. See also applicable OSHA regulations for the handling and storage of this product, including, but not limited to, 29 CFR 1910.110 Storage and Handling of Liquefied Petroleum Gases.

8. EXPOSURE CONTROLS and PERSONAL PROTECTION (rev. Nov-95)

ENGINEERING CONTROLS

Use adequate ventilation to keep gas and vapor concentrations of this product below occupational exposure and flammability limits, particularly in confined spaces. Use explosion-proof equipment and lighting in classified/controlled areas.

EYE/FACE PROTECTION

Where there is a possibility of liquid contact, wear splash-proof safety goggles and faceshield.

SKIN PROTECTION

Where contact with liquid may occur, wear apron, faceshield, and cold-impervious, insulating gloves.

RESPIRATORY PROTECTION

Use a NIOSH/MSHA approved positive-pressure, supplied air respirator with escape bottle or self-contained breathing apparatus (SCBA) for gas concentrations above occupational exposure limits, for potential for uncontrolled release, if exposure levels are not known, or in an oxygen-deficient atmosphere.

CAUTION: Flammability limits (i.e., explosion hazard) should be considered when assessing the need to expose personnel to concentrations requiring respiratory protection.

Refer to OSHA 29 CFR 1910.134, ANSI Z88.2-1992, NIOSH Respirator Decision Logic, and the manufacturer for additional guidance on respiratory protection selection.

9. PHYSICAL and CHEMICAL PROPERTIES (rev. Apr-96)

APPEARANCE

Colorless gas. Cold vapor cloud may be white but the lack of visible gas cloud does not indicate absence of gas. A colorless liquid under pressure.

ODOR

Odorless when pure, but may have a “natural gas” type odor when treated with odorizing agent (usually ethyl mercaptan).

BASIC PHYSICAL PROPERTIES

BOILING POINT:	-43.8 ^oF (-42.1 ^oC)
VAPOR PRESSURE:	109.73 psig @ 70 ^oF (21.1 ^oC)
VAPOR DENSITY (air = 1):	1.56 @ 32 ^oF (0 ^oC)
SPECIFIC GRAVITY (H_2O = 1):	0.531 @ 32 ^oF (0 ^oC)
SOLUBILITY (H_2O):	slight (62.4 ppm) @ 77 ^oF (25 ^oC)

10. STABILITY and REACTIVITY (rev. Nov-95)

STABILITY: Stable. Hazardous polymerization will not occur.

CONDITIONS TO AVOID and INCOMPATIBLE MATERIALS

Keep away from strong oxidizers, ignition sources and heat. Explosion hazard when exposed to chlorine dioxide. Heating barium peroxide with propane causes violent exothermic reaction. Heated chlorine-propane mixtures are explosive under some conditions.

HAZARDOUS DECOMPOSITION PRODUCTS

Carbon monoxide, carbon dioxide and non-combusted hydrocarbons (smoke).

11. TOXICOLOGICAL PROPERTIES (rev. Mar-98; Tox-98)

ACUTE TOXICITY

Propane exhibits some degree of anesthetic action and is mildly irritating to the mucous membranes. At high concentrations propane acts as a simple asphyxiant without other significant physiological effects. High concentrations may cause death due to oxygen depletion.

CARCINOGENICITY

Carcinogenicity: **OSHA:** NO **IARC:** NO **NTP:** NO **ACGIH:** NO

12. ECOLOGICAL INFORMATION (rev. Nov-95)

Liquid release is only expected to cause localized, non-persistent environmental damage, such as freezing. Biodegradation of this product may occur in soil and water. Volatilization is expected to be the most important removal process in soil and water. This product is expected to exist entirely in the vapor phase in ambient air.

13. DISPOSAL CONSIDERATIONS (rev. Apr-96)

Consult federal, state and local waste regulations to determine appropriate waste characterization of material and allowable disposal methods.

14. TRANSPORTATION INFORMATION (rev. Apr-96)

PROPER SHIPPING NAME:	Propane
HAZARD CLASS:	2.1
DOT IDENTIFICATION NUMBER:	UN 1978
DOT SHIPPING LABEL:	FLAMMABLE GAS

PROPER SHIPPING NAME:	Petroleum Gas, Liquefied
HAZARD CLASS:	2.1
DOT IDENTIFICATION NUMBER:	UN 1075
DOT SHIPPING LABEL:	FLAMMABLE GAS

15. REGULATORY INFORMATION (rev. Mar-00)

U.S. FEDERAL, STATE, and LOCAL REGULATORY INFORMATION

This product and its constituents listed herein are on the EPA TSCA Inventory.

Any spill or uncontrolled release of this product, including any substantial threat of release, may be subject to federal, state, and/or local reporting requirements. Consult those regulations applicable to your facility/operation. This product and/or its constituents may also be subject to other regulations at the state and/or local level. Consult those regulations applicable to your facility/operation.

CERCLA SECTION 103 and SARA SECTION 304 (RELEASE TO THE ENVIRONMENT)

The CERCLA definition of hazardous substances contains a "petroleum exclusion" clause which exempts natural gas and synthetic gas usable for fuel and any indigenous components of such from the CERCLA Section 103 reporting requirements. However, other federal reporting requirements, including SARA Section 304, may still apply.

SARA SECTION 311/312 - HAZARD CLASSES

ACUTE HEALTH	CHRONIC HEALTH	FIRE	SUDDEN RELEASE OF PRESSURE	REACTIVE
--	--	X	X	--

SARA SECTION 313 - SUPPLIER NOTIFICATION

This product contains the following chemicals subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right-To-Know Act (EPCRA) of 1986 and of 40 CFR 372.

INGREDIENT NAME		CONCENTRATION PERCENT BY VOLUME
Propylene	CAS NUMBER: 115-07-1	30 max.

CANADIAN REGULATORY INFORMATION (WHMIS)

Class A (Compressed Gas) Class B, Division 1 (Flammable Gas)

16. OTHER INFORMATION (rev. Mar-00)

NFPA® HAZARD RATING	HEALTH:	1	Slight
	FIRE:	4	Extreme
	REACTIVITY:	0	Negligible
HMIS® HAZARD RATING	HEALTH:	1	Slight
	FIRE:	4	Extreme
	REACTIVITY:	0	Negligible

SUPERSEDES MSDS DATED: 02/25/99

ABBREVIATIONS:

AP = Approximately	< = Less than	> = Greater than
N/A = Not Applicable	N/D = Not Determined	ppm = parts per million

ACRONYMS:

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute (212)642-4900
API	American Petroleum Institute (202)682-8000
CERCLA	Comprehensive Emergency Response, Compensation, and Liability Act
DOT	U.S. Department of Transportation [General info: (800)467-4922]
EPA	U.S. Environmental Protection Agency
HMIS	Hazardous Materials Information System
IARC	International Agency For Research On Cancer
MSHA	Mine Safety and Health Administration
NFPA	National Fire Protection Association (617)770-3000
NIOSH	National Institute of Occupational Safety and Health
NOIC	ACGIH TLV Notice of Intended Change
NTP	National Toxicology Program
OPA	Oil Pollution Act of 1990
OSHA	U.S. Occupational Safety & Health Administration
PEL	Permissible Exposure Limit (OSHA)
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit (NIOSH)
SARA	Superfund Amendments and Reauthorization Act of 1986 Title III
SCBA	Self-Contained Breathing Apparatus
SPCC	Spill Prevention, Control, and Countermeasures
STEL	Short-Term Exposure Limit (generally 15 minutes)
TLV	Threshold Limit Value (ACGIH)
TSCA	Toxic Substances Control Act
TWA	Time Weighted Average (8 hr.)
WEEL	Workplace Environmental Exposure Level (AIHA)
WHMIS	Canadian Workplace Hazardous Materials Information System

DISCLAIMER OF EXPRESSED AND IMPLIED WARRANTIES

Information presented herein has been compiled from sources considered to be dependable, and is accurate and reliable to the best of our knowledge and belief, but is not guaranteed to be so. Since conditions of use are beyond our control, we make no warranties, expressed or implied, except those that may be contained in our written contract of sale or acknowledgment.

Vendor assumes no responsibility for injury to vendee or third persons proximately caused by the material if reasonable safety procedures are not adhered to as stipulated in the data sheet. Additionally, vendor assumes no responsibility for injury to vendee or third persons proximately caused by abnormal use of the material, even if reasonable safety procedures are followed. Furthermore, vendee assumes the risk in their use of the material.

HOLTEC INTERNATIONAL

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

MISCELLANEOUS CALCULATIONS FOR THE HI-STAR HB

FOR

PG&E

Holtec Report No: HI-2033042

Holtec Project No: 1125

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT ISSUANCE AND REVISION STATUS[1]

DOCUMENT NAME: MISCELLANEOUS CALCULATIONS FOR THE HI-STAR HB

DOCUMENT NO.:	HI-2033042	CATEGORY: ☐ GENERIC
PROJECT NO.:	1125	☒ PROJECT SPECIFIC

Rev. No. [2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	10/08/03	JRT	547268				

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)

Documents labeled "Privileged Intellectual Property" contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 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 "Table of Contents", this page and the "Revision Log".

REVISION LOG

Revision 0 – Original Issue

The original issue of this report contains Supplements 1 through 6.

PREFACE

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 narration smoothness of a Technical Report, and are not intended to serve as a Technical Report.

Because of the Calculation Package's function as a repository of all analyses performed on the subject of its scope, this document is typically revised only if an error is discovered in the computations or the equipment design is modified. Additional analyses in the future will 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.

1.0 INTRODUCTION AND SCOPE

This Calculation Package is compiled to provide archival information to supplement the material presented in the upcoming License Application for an Independent Spent Fuel Storage Installation (ISFSI) at Humboldt Bay. In particular, this Calculation Package contains calculations related to the Damaged Fuel Container, Cask Transfer Rail Dolly, Tornado Missile Impacts with the HI-STAR HB, MPC Lid Restraint System, HI-STAR Enclosure Shell, and Tornado Winds.

2.0 METHODOLOGY

Calculation specific supplements are attached to this report. In general, the problem descriptions are provided in the introductory section of each calculation. The problem descriptions, unique to each calculation, include the description of the component to be analyzed, the nature and source of the applied loading on the component, and the acceptance criteria. All structural calculations are based on classical strength of materials solutions. Each calculation contains detailed explanation of the analysis methods.

3.0 ACCEPTANCE CRITERIA

This calculation package contains one or more supplements that deal with specific calculation items. The acceptance criteria are different for the individual calculations. Therefore, the appropriate acceptance criteria associated with each individual calculation are stated within the specific supplement.

4.0 ASSUMPTIONS

In general, each calculation in this package contains a unique set of conservative analysis assumptions. In most cases these assumptions are listed under a separate section in each of the calculations; for some calculations that are similar to work already detailed in an FSAR or in another calculation, references are made to the originating document section for the assumptions.

5.0 INPUT DATA

Input data is provided in the calculation supplements as needed for the specific analysis**.** The sources for the input data that are specific to a calculation are provided within that calculation.

6.0 COMPUTER CODES

The main section of this report is written using Microsoft Word (Office 2000), while the calculation supplements are prepared using MathCad (Version 2000 unless otherwise noted below).

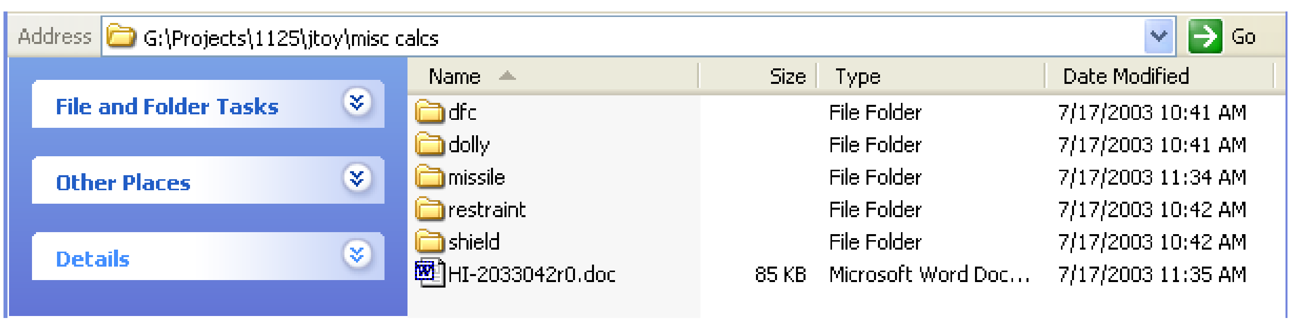
7.0 ANALYSES

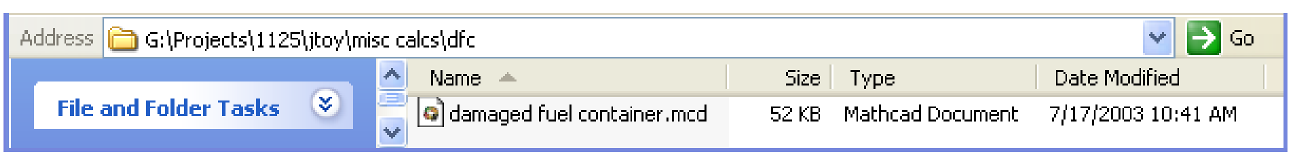
Analyses supporting the Damaged Fuel Container, Cask Transfer Rail Dolly, Tornado Missile Impacts with the HI-STAR HB, Lid Restraint System, HI-STAR HB Enclosure Shell, and Tornado Winds analyses are contained within this report as calculation supplements.

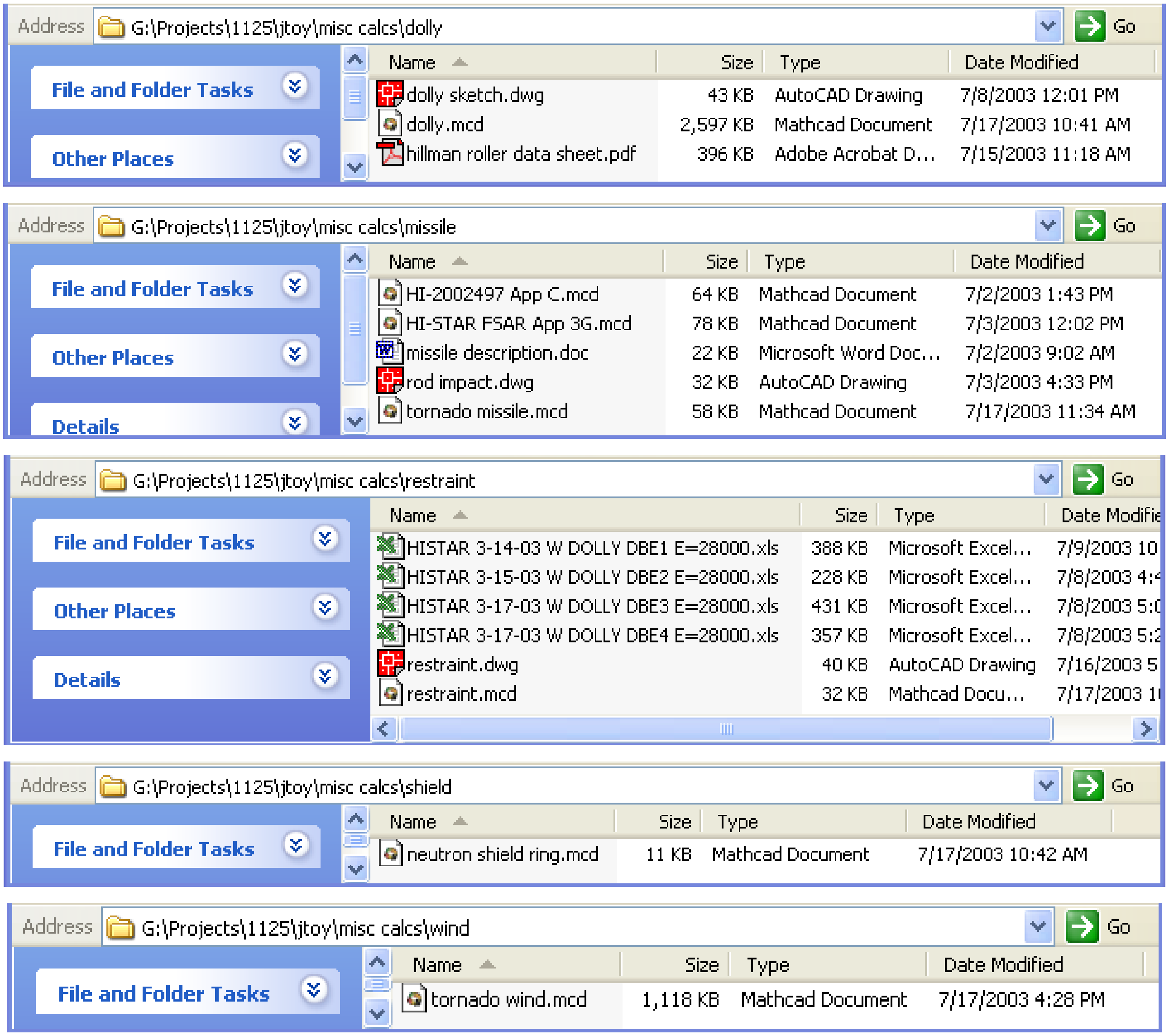
Supplement No.	Description
1	Damaged Fuel Container Evaluation
2	Cask Transfer Rail Dolly
3	Tornado Missile Impacts with the HI-STAR HB
4	Lid Restraint System
5	HI-STAR HB Enclosure Shell Evaluation
6	Response of Cask to Tornado Wind Load and Large Missile Impact

8.0 COMPUTER FILES

All relevant computer files associated with this calculation package are archived on the Holtec Server.






Address G:\Projects\1125\jtoy\misc calcs\dolly

Name	Size	Type	Date Modified
dolly sketch.dwg	43 KB	AutoCAD Drawing	7/8/2003 12:01 PM
dolly.mcd	2,597 KB	Mathcad Document	7/17/2003 10:41 AM
hillman roller data sheet.pdf	396 KB	Adobe Acrobat D...	7/15/2003 11:18 AM

Address G:\Projects\1125\jtoy\misc calcs\missile

Name	Size	Type	Date Modified
HI-2002497 App C.mcd	64 KB	Mathcad Document	7/2/2003 1:43 PM
HI-STAR FSAR App 3G.mcd	78 KB	Mathcad Document	7/3/2003 12:02 PM
missile description.doc	22 KB	Microsoft Word Doc...	7/2/2003 9:02 AM
rod impact.dwg	32 KB	AutoCAD Drawing	7/3/2003 4:33 PM
tornado missile.mcd	58 KB	Mathcad Document	7/17/2003 11:34 AM

Address G:\Projects\1125\jtoy\misc calcs\restraint

Name	Size	Type	Date Modifie
HISTAR 3-14-03 W DOLLY DBE1 E=28000.xls	388 KB	Microsoft Excel...	7/9/2003 10
HISTAR 3-15-03 W DOLLY DBE2 E=28000.xls	228 KB	Microsoft Excel...	7/8/2003 4:
HISTAR 3-17-03 W DOLLY DBE3 E=28000.xls	431 KB	Microsoft Excel...	7/8/2003 5:
HISTAR 3-17-03 W DOLLY DBE4 E=28000.xls	357 KB	Microsoft Excel...	7/8/2003 5:
restraint.dwg	40 KB	AutoCAD Drawing	7/16/2003 5
restraint.mcd	32 KB	Mathcad Docu...	7/17/2003 1

Address G:\Projects\1125\jtoy\misc calcs\shield

Name	Size	Type	Date Modified
neutron shield ring.mcd	11 KB	Mathcad Document	7/17/2003 10:42 AM

Address G:\Projects\1125\jtoy\misc calcs\wind

Name	Size	Type	Date Modified
tornado wind.mcd	1,118 KB	Mathcad Document	7/17/2003 4:28 PM

9.0 RESULTS OF ANALYSES

The results of each calculation are presented within the individual supplements. The adequacy of the designs is conclusively demonstrated by the computation of positive safety margins.

10.0 REFERENCES

The references required for each component analysis are listed within each supplement.

SUPPLEMENT 1, DAMAGED FUEL CONTAINER EVALUATION

Introduction

This report contains an analysis of the damaged fuel containers that are used for the Humbolt Bay MPCs. The objective of the analysis is to demonstrate that the storage container is structurally adequate to support the loads that develop during normal lifting operations and during an end drop.

The lifting bolt of the container is designed to meet the requirements set forth for Special Lifting Devices in Nuclear Plants [2]. The remaining components of the damaged fuel container are compared to ASME Code Section III, Subsection NG allowable stress levels.

Methodology

Two cases are considered:

normal handling of container
accident drop event.

Acceptance Criteria

Normal Handling -

a) Container governed by ASME NG [3] allowables:
shear stress allowable is 60% of membrane stress intensity

b) Welds are governed by NG Code allowables; stress limit =60% of tensile stress intensity (per Section III, Subsection NG-3227.2).

c) Lifting bolt is governed by ANSI N14-6 criteria

Drop Accident -

a) Container governed by ASME Section III, Appendix F allowables:
(allowable shear stress = 0.42 Su) [8]

Assumptions

Buckling is not a concern during an accident since during a drop the canister will be supported by the walls of the fuel basket.

The strength of the weld is assumed to decrease the same as the base metal as the temperature is increased.

Input Data for Humboldt Bay Damaged Fuel Container

The damaged fuel container is placed inside the MPC before submerging the MPC inside the spent fuel pool. As the fuel pool water temperature is still acting on the damage fuel container, its design temperature for lifting considerations is (150^o F). The design temperature for accident conditions is 725^o F. The basic input parameters used to perform the calculations are:

Design stress intensity of SA240-304 (150^{o}F)	$S_{m1} := 20000 \cdot psi$	[6]
Design stress intensity of SA240-304 (725^{o}F)	$S_{m2} := 15800 \cdot psi$	
Yield stress of SA240-304 (150^{o}F)	$S_{y1} := 27500 \cdot psi$	[6]
Yield stress of SA240-304 (725^{o}F)	$S_{y2} := 17500 \cdot psi$	
Ultimate strength of SA240-304 (150^{o}F)	$S_{u1} := 73000 \cdot psi$	[6]
Ultimate strength of SA240-304 (725^{o}F)	$S_{u2} := 63300 \cdot psi$	
Minimum Yield stress of SA193-B7 (200^{o}F)	$S_{by} := 98000 \cdot psi$	[6]
Minimum Ultimate strength of SA193-B7 (200^{o}F)	$S_{bu} := 125000 \cdot psi$	
Weight of a Humboldt Bay fuel assembly (allowable maximum value)	$W_{fuel} := 300 \cdot lbf$	[9]
Weight of the damaged fuel container	$W_{container} := 100 \cdot lbf$	[9]

All dimensional input about the damged fuel container is from [7].

Wall thickness of the container sleeve	$t_{sleeve} := 0.125 \cdot in$
Dimension of the square baseplate	$d_{bplate} := 4.93 \cdot in$
Thickness of the baseplate	$t_{bplate} := 0.75 \cdot in$

Diameter of baseplate through hole	$d_{bph} := 1 \cdot in$
Number of baseplate through holes	$N_{bph} := 4$
Diameter of the baseplate spot weld	$dw_{base} := 0.1875 \cdot in$
Inner dimension of the container sleeve	$id_{sleeve} := 4.93 \cdot in$
Wall thickness of container collar	$t_{collar} := 0.125 \cdot in$
Distance from end of sleeve to top of engagement slot	$d_{slot} := 0.125 \cdot in$
Thickness of the load tab	$t_{tab} := 0.125 \cdot in$
Width of the load tab	$w_{tab} := 0.75 \cdot in$
Thickness of the closure plate	$t_{cp} := 0.25 \cdot in$
Radius of the lifting bolt 3/8- 16 UNC	$r_{bolt} := 0.1875 \cdot in$ [5]
Weight density of the stainless steel	$\gamma_{ss} := 0.283 \cdot \frac{lbf}{in^3}$
Maximum thickness of the nut 3/8- 16 UNC	$t_{nut} := \frac{21}{64} \cdot in$ [5]
Length of the bolt	$L_{bolt} := 2in$
Thickness of the washer (assume)	$t_{washer} := 0.125 \cdot in$
Dynamic load factor for lifting [1]	$DLF := 1.15$

Computer Codes

This report, including all calculations, is written using MATHCAD 2000, a commercial electronic scratchpad code, developed by Mathsoft, Inc.Mathcad uses the symbol ':=' as an assignment operator, and the equals symbol '=' retrieves values for constants or variables.

Analysis

Lifting Operation (Normal Condition)

The critical load case under normal conditions is the lifting operation. The key areas of concern are the container sleeve, the weld between the sleeve and the base of the container, the container upper closure, and the lifting bolt. All calculations performed for the lifting operation assume a dynamic load factor of 1.15.

Container Sleeve

During a lift, the container sleeve is loaded axially, and the stress state is pure tensile membrane. For the subsequent stress calculation, it is assumed that the full weight of the damaged fuel container and the fuel assembly are supported by the sleeve. The magnitude of the load is

Proprietary Information Deleted

The cross sectional area of the sleeve is

Proprietary Information Deleted

Therefore, the tensile stress in the sleeve is

Proprietary Information Deleted

The allowable stress intensity for the primary membrane category is S_m per Subsection NG of the ASME Code. The corresponding safety factor is

$$SF := \frac{S_{m1}}{\sigma} \qquad SF = 109.9$$

Base Weld

The base of the container must support the amplified weight of the fuel assembly. This load is carried directly by 16 spot welds (4 on each side) which connect the base to the container sleeve. The weight of the baseplate is

Proprietary Information Deleted

The total load carried by the spot welds is

Proprietary Information Deleted

The area of the weld is

Proprietary Information Deleted

Therefore, the amplified shear stress in the weld is

Proprietary Information Deleted

From the ASME Code the allowable weld shear stress, under normal conditions (Level A), is 60% of the membrane strength of the base metal. The corresponding safety factor is

$$SF := \frac{0.6 \cdot S_{m1}}{\sigma} \qquad SF = 15.1$$

Container Collar

The load tabs of the upper lock device engage the container collar during a lift. The load transferred to the engagement slot, by a single tab, is

Proprietary Information Deleted

The shear area of the container collar is

The shear stress in the collar is

Proprietary Information Deleted

The allowable shear stress from Subsection NG, under normal conditions, is

$\sigma_{allowable} := 0.6 \cdot S_{m1}$ $\sigma_{allowable} = 12000\ psi$

Therefore, the safety factor is

$SF := \frac{\sigma_{allowable}}{\sigma}$ $SF = 6.5$

Load Tabs

The load tabs of the lock device engage the container collar during a lift. The shear area of each tab is

Proprietary Information Deleted

The shear stress in the tab is

Proprietary Information Deleted

Therefore, the safety factor is

$SF := \frac{0.6 \cdot S_{m1}}{\tau_{tab}}$ $SF = 9.783$

Upper Closure Plate

The damaged fuel container is lifted by a bolt at the center of the upper closure plate. Assuming that the square upper closure plate is simply supported at the boundary and loaded by a uniform concentric circle of radius of the bolt, we can use the formula given in Table 26, case 1b of Ref. [4] to calculate the maximum bending stress of the plate. For a square plate, the coefficient of the stress formula is:

$$\beta := 0.435$$

The maximum bending stress in the plate is

Proprietary Information Deleted

The allowable primary bending stress for the plate, per Subsection NG of ASME code, is

$\sigma_{allowable\_cp} := 1.5S_{m1}$ $\qquad$ $\sigma_{allowable\_cp} = 3 \times 10^4\,psi$

Safety factor $\qquad SF := \dfrac{\sigma_{allowable\_cp}}{\sigma_{max\_c}} \qquad SF = 2.083$

Lifting Bolt

The stress area of the 3/8- 16 UNC bolt is

The tensile stress in the bolt

The lifting bolt must meet the requirements set forth for Special Devices [2]. As such the allowable tensile stress for design is the lesser of one-third of the yield stress and one-fifth of the ultimate strength.

$$\sigma_1 := \frac{S_{by}}{3} \qquad \sigma_2 := \frac{S_{bu}}{5}$$

$$\sigma_1 = 32667\,psi \qquad \sigma_2 = 25000\,psi$$

For SA193-B7 bolt material the ultimate stress governs at the lifting temperature.

$$\sigma_{allowable} := \sigma_2$$

Safety factor $SF := \frac{\sigma_{allowable}}{\sigma_{bolt}}$ $SF = 4.185$

Now check the thread engagement of the bolt. The minimum required length of the bolt is

The length of the bolt is $L_{bolt} = 2 \text{ in}$

Therefore, the thread engagement requirement is satisfied.

60g End Drop (Accident Condition)

Upside down 60g end drop

The critical member of the damaged fuel container, during a postulated upside down end drop scenario is the 16 spot welds. The total load applied to the welds in a 60g end drop is

Weight on the welds due to upside down end drop

Proprietary Information Deleted

Force on weld due to upside down 60g end drop $F_{60gupsidedown} := 60 \cdot W_{upsidedown}$

Stress due to upsidedown 60g end drop

Proprietary Information Deleted

Allowable stress on the weld

$\sigma_{allowable} := 0.42 \cdot S_{u2}$

$\sigma_{allowable} = 26586 \text{ psi}$

Safety factor of the weld due to upside down60g end drop

$SF := \frac{\sigma_{allowable}}{\sigma_{upsidedown}}$ $SF = 43.6$

Upright 60g end drop

Once again the critical member of the damaged fuel container, during a postulated upright end drop scenario, is the 16 spot welds The total load applied to the welds in a 60g upright end drop is the weight of the container minus the weight of the base plate.

Weight on the welds due to upright end drop

Proprietary Information Deleted

Force on weld due to upright 60g end drop

$F_{60gupright} := 60 \cdot W_{upright}$

Stress due to upright 60g end drop

Proprietary Information Deleted

Allowable stress on the weld

$\sigma_{allowable} = 26586 \text{ psi}$

Safety factor on the weld due to the upright 60g end drop

$SF := \frac{\sigma_{allowable}}{\sigma_{upright}}$ $SF = 2$

Conclusion

The Humboldt Bay damaged fuel container is structurally adequate to withstand the specified normal and accident condition loads. All calculated safety factors are greater than one, which demonstrates that all acceptance criteria have been met or exceeded.

References

1 Crane Manufacture's of America Association, Specifications for Electric Overhead Traveling Cranes #70.

2 ANSI N14-6, Special Lifting Devices for Loads Greater than 10000 lbs. in Nuclear Plants.

3 ASME Boiler and Pressure Vessel Code, Section III Subsection NG, July 1995

4 Roark's Formulas for Stress & Strain, 6th Edition, 1989.

5 Mechanical Engineering Design 5th Edition, Shigley.

6 ASME, "Boiler & Pressure Vessel Code," Section II, Part D, Properties, 1995.

7 Humboldt Bay Damaged Fuel Container, Holtec International Dwg. 4113, revision 0.

8 ASME Section III, Subsection NF, 1995.

9 Dimensions and Weights for Humboldt ISFSI Project, Holtec International Report Number HI-2032999, revision 0.

Proprietary Information Deleted

SUPPLEMENT 2, CASK TRANSFER RAIL DOLLY

The most severe loading on the cask transfer dolly is the DBE. Eventhough HI-2033046 shows that the HI-STAR HB will tip over during this seismic event, a quasi-static analysis assuming the cask remains on the dolly is postulated. The peak acceleration at 4% critical damping is conservatively chosen for the vertical direction to maximize the loading on the rollers.

number of bolts per roller [1] $n_{b\_r} := 6$

nominal diameter of bolts (SA 193-B7) [1] $d_b := 1 \cdot in$

quantity of rollers [1] $n_r := 6$

total number of roller bolts [1] $n_b := n_r \cdot n_{b\_r}$ $n_b = 36$

weight of dolly and HI-STAR [1 and 6] Proprietary Information Deleted

vertical seismic acceleration bounding from excel spreadsheet [7]

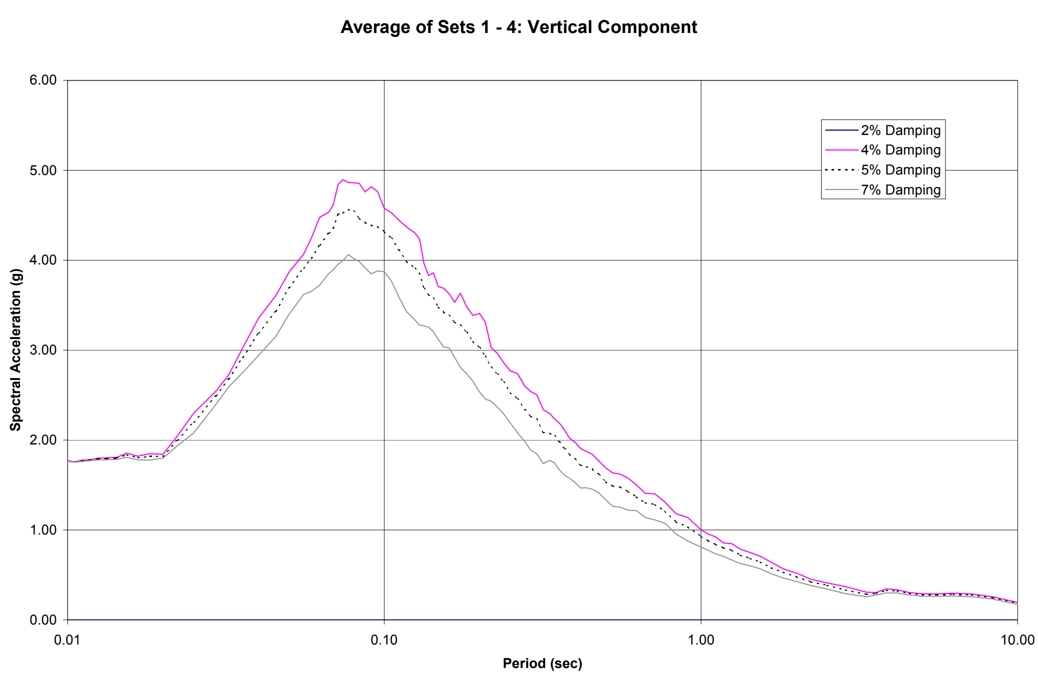


Figure 1. Vertical Response Spectra [7]

total vertical seismic load

roller capacity (each) [3]

Proprietary Information Deleted

dolly capacity (all rollers)

roller capacity safety factor $SF_r := \frac{P_d}{F_v}$ $SF_r = 1.197$

coefficient of friction (assume) $\mu := 0.8$

total bolt shear force

bolt shear area (assume equal to tensile area) [2]

Proprietary Information Deleted

bolt shear stress

bolt yield strength (SA 193-B7) [5] $\sigma_y := 105000 \cdot psi$

bolt ultimate strength [5] $\sigma_u := 125000 \cdot psi$

allowable shear stress [4, level D] $\tau_{all} := \min(0.42 \cdot \sigma_u, 0.6 \cdot \sigma_y)$ $\tau_{all} = 5.25 \times 10^4 \, psi$

bolt shear safety factor $SF_{bs} := \frac{\tau_{all}}{\tau_b}$ $SF_{bs} = 1.725$

PRODUCT NUMBERS OT / OTB	NT / NTB	T / TB	METRIC TONS	A	B	C	D	F	G	H	I	I (NTB)	J	J (NTB)	K	L	M	N	P	R	S	T	U	CONTACT ROLLS	WEIGHT LBS / KGS. OT	OTB	NT	NTB	T	TB
				DIMENSIONS INCHES (MM) CAPACITY																										
.75-OT	.75-NT	.75-T	.75	3/4 19	2-1/2 64	3/8 10	11/16 17	3-1/8 79	7 178	5-1/2 140	8 203	- -	7-1/4 184	- -	2 51	6-1/2 165	3-1/2 89	3-5/8 92	5/16 8	- -	2 51	- -	- -	6	12 5	- -	12 5	- -	11 5	- -
1-OT	1-NT	1-T	1	1 25	2-1/2 64	3/8 10	11/16 17	2-3/8 60	6 152	4-3/4 121	8 203	- -	7 178	- -	2 51	6 152	3-1/2 89	3-9/16 91	9/16 14	- -	1-7/8 48	- -	- -	6	13 6	- -	12 5.5	- -	11 5	- -
2.5-OT	2.5-NT	2.5-T	2.5	3/4 19	2-1/2 64	3/8 10	15/16 24	3-5/8 92	7 178	5-1/2 140	9-1/2 241	- -	8 203	- -	2-7/16 62	6-1/2 165	4 102	4-1/8 105	9/16 14	- -	2 51	- -	- -	4	21 10	- -	19 9	- -	17 8	- -
5-OT/OTB	5-NT/NTB	5-T/TB	5	3/4 19	3-1/4 83	3/8 10	15/16 24	3-1/8 79	8 203	6-3/4 171	11-3/4 298	14-1/4 362	10-1/8 257	12-5/8 321	2-7/16 62	8 203	4-1/2 114	4-7/16 113	9/16 14	9 229	3 76	M14x2	1/2 13	5	22 10	28 13	21 10	28 13	19 9	26 12
8-OT/OTB	8-NT/NTB	8-T/TB	8	3/4 19	3-1/4 83	3/8 10	15/16 24	3-1/8 79	8 203	6-3/4 171	11-3/4 298	14-1/4 362	10-1/8 257	12-5/8 321	3-5/16 84	8 203	5 127	5-5/16 135	9/16 14	9 229	3 76	M14x2	1/2 13	5	25 11	29 13	23 10	29 13	23 10	29 13
15-OT/OTB	15-NT/NTB	15-T/TB	15	1-5/8 41	3-11/16 94	5/8 16	1-3/16 30	3-7/8 98	10 254	8-1/2 216	14-3/4 375	17-1/4 438	12-11/16 322	16 406	2-3/4 70	10-5/8 270	5 127	5-3/16 132	11/16 17	12-1/8 308	2-5/16 59	M14x2	3/4 19	5	46 21	52 23	44 20	52 23	40 18	48 22
20-OT/OTB	20-NT/NTB	20-T/TB	20	1-5/8 41	3-11/16 94	5/8 16	1-3/16 30	3-7/8 98	10 254	8-1/2 216	14-3/4 375	17-1/4 438	12-11/16 322	16 406	4 102	10-5/8 270	6-1/2 165	6-7/16 164	11/16 17	12-1/8 308	3-1/2 89	M14x2	3/4 19	5	49 22	58 26	49 22	58 26	49 22	58 26
37.5-OT/OTB	37.5-NT/NTB	37.5-T/TB	37.5	2 51	5-1/2 140	3/4 19	1-5/8 41	5-1/2 140	12 305	10-1/2 267	21 533	24-1/2 622	18-3/4 476	22-1/4 565	3-1/2 89	15 381	7 178	7-1/4 184	13/16 21	17 432	4-1/4 108	M20x2,5	1 25	6	121 55	138 63	114 52	138 63	105 48	129 59
50-OT/OTB	50-NT/NTB	50-T/TB	50	3-3/4 95	5-1/2 140	3/4 19	1-5/8 41	5-1/2 140	12 305	10-1/2 267	22-1/2 572	28 711	20-1/4 514	25-3/4 654	3-1/2 89	18-1/2 470	7 178	7-1/4 184	13/16 21	20-1/2 521	4-1/4 108	M20x2,5	1 25	8	147 67	164 74	142 64	164 74	138 63	160 73
75-OT/OTB	75-NT/NTB	75-T/TB	75	1-1/4 32	9-1/4 235	1 25	1-15/16 49	6-3/4 171	14 356	11-1/2 292	27 686	31-1/2 800	24 610	28-1/2 724	3-5/8 92	21 533	7-1/2 191	7-3/8 187	1-1/16 27	23 584	5 127	M24x3	1 25	7	241 109	262 119	227 103	262 119	213 97	248 112

Special models can be created. Consult factory with requirements.

Figure 2. Hillman Roller Data Sheet [3]

References

[1] Cask Transfer Rail Dolly, Holtec International Drawing 4106, revision 0.
[2] Kent's Mechanical Engineers' Handbook, Design and Production Volume, 12th Edition.
[3] Hillman Roller Catalog.
[4] ASME Section III, Appendix F, 1995.
[5] ASME Section II, Properties, 1995.
[6] Dimensions and Weights for the Humboldt Bay ISFSI Project, Holtec International Report HI-2032999, revision 0.
[7] Vertical Fling Response Spectra and Time History, file: G:\Projects\1125\Time Histories\ISFSI Time Histories\Final Spectra\Vert_Fling_Spectra.xls, created by Humboldt Bay.

SUPPLEMENT 3, TORNADO MISSILE IMPACTS WITH THE HI-STAR HB

The purpose of this supplement is to evaluate the effects of tornado missiles on the HI-STAR HB while it is in the yard and attached to the transporter in route to the cask storage vault. The HI-STAR HB is in its most vulnerable configuration while on the dolly. This is an unanalyzed condition of the HI-STAR in the FSAR [1]. The HI-STAR is analyzed for Spectrum I missiles in the FSAR.

References

[1] HI-STAR FSAR, revision 1.
[2] Standard Review Plan for Spent Fuel Dry Storage Facilities, Final Report, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, NUREG 1567.
[3] Technical Basis for Interim Regional Tornado Criteria, U.S. Atomic Energy Commission Office of Regulation, May 1974, WASH-1300.
[4] HBPP Specification HBPP-2001-01.
[5] Missiles Generated by Natural Phenomena, Standard Review Plan, U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, NUREG-0800, Section 3.5.1.4.
[6] HI-STAR HB Overpack, Holtec International Drawing 4082, revision 0.

Spectrum I Tornado-Generated Missiles [1, table 2.2.5]

missile description	*missile mass*	*missile velocity*
automobile	$m_{Ia} := 1800 \cdot kg$	$v_{Ia} := 126 \cdot mph$
8" artillery shell, $d_{Ib} := 8 \cdot in$	$m_{Ib} := 125 \cdot kg$	$v_{Ib} := 126 \cdot mph$
1" solid sphere, $d_{Ic} := 1 \cdot in$	$m_{Ic} := 0.22 \cdot kg$	$v_{Ic} := 126 \cdot mph$

Spectrum II, Region II, Tornado Generated Missiles [2, table 15.3 and 3, fig 8]

missile description	*missile mass*	*missile velocity*
wood plank, $w_{IIa} := 0.092 \cdot m$, $h_{IIa} := 0.289 \cdot m$	$m_{IIa} := 52 \cdot kg$	$v_{IIa} := 70 \cdot \frac{m}{s}$
6" schedule 40 pipe, $d_{IIb} := 0.168 \cdot m$	$m_{IIb} := 130 \cdot kg$	$v_{IIb} := 42 \frac{m}{s}$
1" steel rod, $d_{IIc} := 0.0254 \cdot m$	$m_{IIc} := 4 \cdot kg$	$v_{IIc} := 40 \frac{m}{s}$

utility pole, $d_{IId} := 0.343 \cdot m$	$m_{IId} := 510 \cdot kg$	$v_{IId} := 48 \cdot \frac{m}{s}$
12" schedule 40 pipe, $d_{IIe} := 0.32 \cdot m$	$m_{IIe} := 340 \cdot kg$	$v_{IIe} := 28 \cdot \frac{m}{s}$
automobile, $w_{IIf} := 2 \cdot m$, $h_{IIf} := 1.3 \cdot m$	$m_{IIf} := 1810 \cdot kg$	$v_{IIf} := 52 \frac{m}{s}$

Spectrum I and Spectrum II Missile Comparison

The HI-STAR has been designed to withstand Spectrum I missiles [1, sec 2.2.3.5 and table 2.2.5]. The HBPP specification requires the HI-STAR HB to withstand Spectrum II missiles [4, sec 6.2.2]. Some of the Spectrum II missiles are bounded by the Spectrum I missiles already analyzed. Therefore, a comparison of the missiles is performed to limit further analysis. The missiles are classified as small, medium, and large. The small missiles are the 1" diameter solid sphere and the 1" diameter steel rod. These missiles are used to evaluate barrier openings according to [5, pg 3.5.1.4-3]. However, the HI-STAR has no openings so the small missiles are used to evaluate dents in the cask. The medium missiles are the 8" diameter artillery shell, wood plank, 6" schedule 40 pipe, utility pole, and 12" schedule 40 pipe. Medium missiles are evaluated for penetration and fuel retrievability. The large missiles are both automobiles. Large missiles are evaluated for overall cask stability and fuel retrievability. The kinetic energy of each missile is used to determine the bounding small, medium, and large missiles. If the ratio of the kinetic energy of the Spectrum I missile (already analyzed in [1]) to the kinetic energy of the Spectrum II missile is greater than 1.0, the Spectrum II missile is bounded. Otherwise, further evaluation is necessary.

Spectrum I Missile Kinetic Energy

automobile	$KE_{Ia} := \frac{1}{2} \cdot m_{Ia} \cdot v_{Ia}^2$	$KE_{Ia} = 2.11 \times 10^6 \, ft \cdot lbf$
artillery shell	$KE_{Ib} := \frac{1}{2} \cdot m_{Ib} \cdot v_{Ib}^2$	$KE_{Ib} = 1.46 \times 10^5 \, ft \cdot lbf$
solid sphere	$KE_{Ic} := \frac{1}{2} \cdot m_{Ic} \cdot v_{Ic}^2$	$KE_{Ic} = 257 \, ft \cdot lbf$

Spectrum II Missile Kinetic Energy

wood plank	$KE_{IIa} := \frac{1}{2} \cdot m_{IIa} \cdot v_{IIa}^2$	$KE_{IIa} = 9.4 \times 10^4 \, ft \cdot lbf$
6" schedule 40 pipe	$KE_{IIb} := \frac{1}{2} \cdot m_{IIb} \cdot v_{IIb}^2$	$KE_{IIb} = 8.46 \times 10^4 \, ft \cdot lbf$
1" steel rod	$KE_{IIc} := \frac{1}{2} \cdot m_{IIc} \cdot v_{IIc}^2$	$KE_{IIc} = 2.36 \times 10^3 \, ft \cdot lbf$

utility pole $KE_{IId} := \frac{1}{2} \cdot m_{IId} \cdot v_{IId}^2$ $KE_{IId} = 4.33 \times 10^5 \, ft \cdot lbf$

12" schedule 40 pipe $KE_{IIe} := \frac{1}{2} \cdot m_{IIe} \cdot v_{IIe}^2$ $KE_{IIe} = 9.83 \times 10^4 \, ft \cdot lbf$

automobile $KE_{IIf} := \frac{1}{2} \cdot m_{IIf} \cdot v_{IIf}^2$ $KE_{IIf} = 1.8 \times 10^6 \, ft \cdot lbf$

Small Missile Comparison

1" steel rod vs. 1" solid sphere $bounded := if\left(\frac{KE_{Ic}}{KE_{IIc}} > 1.0, "yes", "no"\right)$ $bounded = "no"$

Medium Missile Comparison

8" artillery shell vs. wood plank $bounded := if\left(\frac{KE_{Ib}}{KE_{IIa}} > 1.0, "yes", "no"\right)$ $bounded = "yes"$

8" artillery shell vs. 6" pipe $bounded := if\left(\frac{KE_{Ib}}{KE_{IIb}} > 1.0, "yes", "no"\right)$ $bounded = "yes"$

8" artillery shell vs. 13. 5" utility pole $bounded := if\left(\frac{KE_{Ib}}{KE_{IId}} > 1.0, "yes", "no"\right)$ $bounded = "no"$

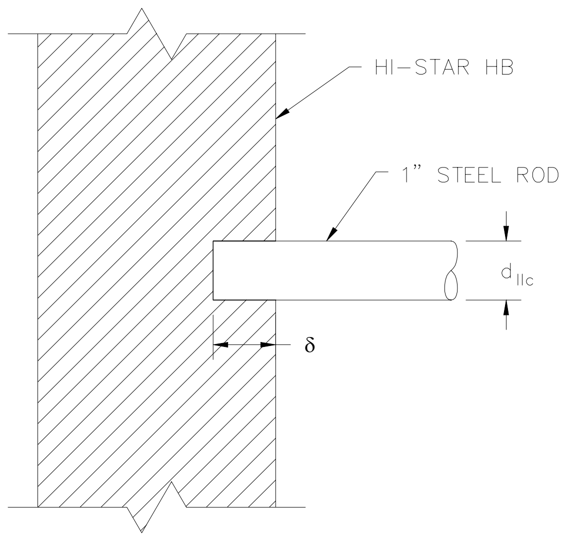
8" artillery shell vs. 12" pipe $bounded := if\left(\frac{KE_{Ib}}{KE_{IIe}} > 1.0, "yes", "no"\right)$ $bounded = "yes"$

Large Missile Comparison

automobile $bounded := if\left(\frac{KE_{Ia}}{KE_{IIf}} > 1.0, "yes", "no"\right)$ $bounded = "yes"$

1" Steel Rod Impact Evaluation

The main barrier of the HI-STAR HB protecting the MPC is an 8 1/2" thick layered steel shell and a 6" thick bottom plate, top flange, and lid. The most vulnerable location on the cask is any of the 6" boundaries. The 1/2" outer shell and the neutron shield are conservatively neglected in this analysis. For the small missile of [1, app 3.G], the energy absorbed during the elastic work is negligible, therefore, the elastic work will also be neglected in this analysis and only plastic work is considered. The kinetic energy of the missile is entirely balanced by the plastic work done in forming a circular shaped dent in the surface. Perfectly plastic behavior of the impacted material is assumed. To find the depth of penetration, start with an initial guess of $\delta_{IIc} := 0.1 \cdot in$. The figure below shows the impact configuration.



yield strength of SA 350-LF3 at 400ºF [1, table 3.3.4 and table 2.2.3] $S_y := 32200 \cdot psi$

impact contact area $A_{IIc} := \frac{\pi}{4} \cdot d_{IIc}^2$ $A_{IIc} = 0.785\ in^2$

energy balance (Given) Proprietary Information Deleted

the right-hand side of the energy balance equation represents the work done by the 1" steel rod

depth of penetration $\delta_{IIc} := Find(\delta_{IIc})$ $\delta_{IIc} = 1.12\ in$

The $\delta_{IIc} = 1.12\ in$ depth of penetration of the small missile, which is required to absorb all of the impact energy, is less than the thinnest section of material on the exterior surface of the cask. Therefore, the small missile will dent, but not penetrate, the cask. Global stresses in the overpack that arise from the 1" steel rod missile strike are assumed to be negligible. Also note that, the rod is assumed a rigid body and does not buckle, therefore, inflicting maximum damage to the cask.

Utility Pole Impact Evaluation

initial guess of depth of penetration $\delta_{IId} := 0.1 \cdot in$

impact contact area $A_{IId} := \frac{\pi}{4} \cdot d_{IId}^2$ $A_{IId} = 143\ in^2$

energy balance (Given) Proprietary Information Deleted

depth of penetration $\delta_{IId} := Find(\delta_{IId})$ $\delta_{IId} = 1.13\ in$

The $\delta_{IId} = 1.13\ in$ depth of penetration of the medium missile, which is required to absorb all of the impact energy, is less than the thinnest section of material on the exterior surface of the cask. Therefore, the medium missile will dent, but not penetrate, the cask. Global stresses in the overpack that arise from the utility pole missile strike are assumed to be negligible. Also note that, the utility pole is assumed a rigid body and does not buckle, therefore, inflicting maximum damage to the cask.

Wood Plank Impact Evaluation

initial guess of depth of penetration $\delta_{IIa} := 0.1 \cdot in$

impact contact area $A_{IIa} := w_{IIa} \cdot h_{IIa}$ $A_{IIa} = 41.2\ in^2$

energy balance (Given) Proprietary Information Deleted

depth of penetration $\delta_{IIa} := Find(\delta_{IIa})$ $\delta_{IIa} = 0.85\ in$

Artillery Shell Impact Evaluation

initial guess of depth of penetration $\delta_{Ib} := 0.1 \cdot in$

impact contact area $A_{Ib} := \frac{\pi}{4} \cdot d_{Ib}^2$ $A_{Ib} = 50\ in^2$

energy balance (Given) Proprietary Information Deleted

depth of penetration $\delta_{Ib} := Find(\delta_{Ib})$ $\delta_{Ib} = 1.08\ in$

6" Pipe Impact Evaluation

initial guess of depth of penetration $\delta_{IIb} := 0.1 \cdot in$

impact contact area $A_{IIb} := \frac{\pi}{4} \cdot d_{IIb}^2$ $A_{IIb} = 34\ in^2$

energy balance (Given) Proprietary Information Deleted

depth of penetration $\delta_{IIb} := Find(\delta_{IIb})$ $\delta_{IIb} = 0.92\ in$

12" Pipe Impact Evaluation

initial guess of depth of penetration $\delta_{IIe} := 0.1 \cdot in$

impact contact area $A_{IIe} := \frac{\pi}{4} \cdot d_{IIe}^2$ $A_{IIe} = 125\ in^2$

energy balance (Given) Proprietary Information Deleted

depth of penetration $\delta_{IIe} := Find(\delta_{IIe})$ $\delta_{IIe} = 0.29\ in$

SUPPLEMENT 4, LID RESTRAINT SYSTEM

The purpose of this supplement is to design and analyze a lid restraint system for the MPC lid prior to welding subjected to a DBE earthquake resulting in a tipover. The acceleration results of the cask are computed in VisualNastran and output in the form of an Excel spreadsheet from Holtec Report HI-2033046 (see Section 8.0 of the main report for the Excel file listing). In the VisualNastran model the horizontal plane is defined by the World X-Y plane. The vertical axis is defined by the Z-axis. The largest accelerations occur at the moment of impact of the top of the cask with the ground. Therefore, the square root of the sum of the squares of the horizontal acceleration components (Ax and Ay) is assumed to coincide with the axis of the cask, producing a tensile load on the lid restraint bolts. The acceptance criteria of the lid restraint system is that ultimate failure does not occur.

The accelerations listed below for the four earthquake sets are assumed to be bounding.

bounding acceleration $a_t := 10000 \cdot \frac{in}{s^2}$

bounding weight of lid [6] $W_{lid} := 10000 \cdot lbf$

maximum total tensile force Proprietary Information Deleted

Minimum Total Length of Weld Required Prior to Automatic Welding

This minimum weld length is required to ensure the MPC lid does not come off in the event of a tip over while the lid restraint system is being removed. This occurs just prior to the automatic welding of the MPC lid to the MPC canister. Normal operation allowable stresses based on the ASME or AISC codes are conservatively used for the tip over accident condition.

weld size (J-groove) [6] Proprietary Information Deleted

filler metal ultimate stress (assume) $\sigma_w := 70000 \cdot psi$

allowable weld stress (conservative) $\tau_{w\_all} := 0.3 \cdot \sigma_w$ $\tau_{w\_all} = 21000\,psi$

minimum weld area $A_{min\_weld} = 12.33\,in^2$

minimum J-groove weld length $l_{min\_weld} = 16.4\,in$

This minimum weld length should be divided into equal length segments equally spaced around the circumference of the lid to evenly distribute the load.

Lid Restraint Bolt Analysis

bolt ultimate strength SA-479 type 304 at 400ºF [7] $\sigma_{u\_bolt} := 64400 \cdot psi$

HI-STAR top flange ultimate strength at 400ºF [1, table 3.3.4 and table 2.2.3] $\sigma_{u\_tf} := 64600 \cdot psi$

quantity of lid restraint bolts $n_{bolt} := 4$

basic major diameter of bolt [5] $D := 1.625 \cdot in$

threads per inch of bolt [5] $n := \frac{8}{in}$

thread data, 1 5/8 - 8 UN - 2A [4, table 4, pg 1511]

minimum pitch diameter of external thread $E_{s\_min} := 1.5342 \cdot in$

maximum minor diameter of internal thread $K_{n\_max} := 1.515 \cdot in$

minimum major diameter of external thread $D_{s\_min} := 1.6078 \cdot in$

maximum pitch diameter of internal thread $E_{n\_max} := 1.5535 \cdot in$

tensile area of bolt [4, pg 1279] $A_t = 1.77\, in^2$

tensile force per bolt $T_{bolt} = 6.48 \times 10^4\, lbf$

bolt tensile stress $\sigma_{bolt} = 3.649 \times 10^4\, psi$

bolt tension safety factor $SF_{t\_bolt} = 1.77$

assumed length of thread engagement $L_e := 3.0 \cdot in$

shear area on external threads [4, pg 1279]

$A_s = 8.41\, in^2$

shear area on internal threads [4, pg 1279]

$A_n = 11.4\,in^2$

bolt thread shear stress $\tau_{s\_bolt} = 7.7 \times 10^3\,psi$

bolt stripping safety factor (von Mises) $SF_{s\_bolt} = 4.82$

flange thread shear stress $\tau_{s\_tf} = 5.69 \times 10^3\,psi$

flange stripping safety factor (von Mises) $SF_{s\_tf} = 6.55$

height of nut [4, table 6, pg 1287] $h_{nut} := 1.59375 \cdot in$

required nut lenght of engagement [4, pg 1278]

$L_{e\_nut} = 1.27\,in$

nut height O.K.

Since the projection of the shoulder of the nut is over the web stiffeners, the nut will not shear through the flange of the beam.

Lid Restraint Beam Bending Analysis

The lid restraint beam is assumed to be a simply supported beam with symmetric concentrated loads.

length of beam (between bolt centers) [8] $l_{beam} := 74.625 \cdot in$

load spacing (center of shim) [8] $s_{load} := 62 \cdot in$

load from support $a_{load} = 6.31\,in$

magnitude of load $F = 1.3 \times 10^5\,lbf$

section modulus of beam, W8x35 [3] $S_{W8} := 31.2 \cdot in^3$

maximum bending moment $M = 8.17 \times 10^5\ in \cdot lbf$

bending stress $\sigma_{bend} := \frac{M}{S_{W8}}$ $\sigma_{bend} = 2.62 \times 10^4\ psi$

beam ultimate strength, A36 steel at 400ºF [7] (reduced by ratio of yield strengths) $\sigma_{uA36} := \frac{30.9}{36.0} \cdot 58000 \cdot psi$ $\sigma_{uA36} = 4.98 \times 10^4\ psi$

bending safety factor against yield $SF_{beam\_y} = 1.9$

Lid Restraint Beam Shear Analysis

web shear plate thickness [8] $t_{sp} := 0.375 \cdot in$

web shear plate height [8] $h_{sp} := 5 \cdot in$

quantity of web shear plates per side [8] $n_{sp} := 2$

beam height [3] $h := 8.12 \cdot in$

beam flange thickness [3] $t_f := 0.495 \cdot in$

beam web height [3] $h_1 = 7.13\ in$

beam web thickness [3] $b_1 := 0.31 \cdot in$

approximate shear area [9, art. 28, pg 123] $A = 5.96\ in^2$

shear force $V = 1.295 \times 10^5\ lbf$

shear stress $\tau = 21728\ psi$

shear safety factor against yield $SF_{shear} = 1.32$

Gusset Buckling

modulus of elasticity of steel [3] $E := 29 \cdot 10^6 \cdot psi$

Poisson's ratio of steel [3] $\mu := 0.3$

gusset thickness [8] $h := 0.25 \cdot in$

gusset width [8] $b := 3.5 \cdot in$

gusset length [8] $a := 7.0625 \cdot in$

effective stress [10, art. 38, eq. 164] $\sigma_e := \dfrac{\pi^2 \cdot E \cdot h^2}{12 \cdot b^2 \cdot \left(1 - \mu^2\right)}$

aspect ratio $\dfrac{a}{b} = 2.02$

constant β [10, art. 38, table 11] (use $\dfrac{a}{b} = 2.0$) $\beta := 0.698$

critical compressive stress [10, art. 38, eq 163] $\sigma_{cr} = 93341\ psi$

critical compressive load per gusset $P_{cr} = 81674\ lbf$

quantity of active gussets per end [8] $n_g := 4$

reaction load per gusset $R = 32376\ lbf$

gusset buckling safety factor $SF_{buck} = 2.52$

References

[1] HI-STAR FSAR, rev 1.
[2] Report HI-2033046, revision 0.
[3] AISC Manual of Steel Construction, 8th Edition.
[4] Machinery's Handbook, 23rd Edition.
[5] HI-STAR Drawing 4082.
[6] MPC Drawing 4102.
[7] ASME Section II, Part D, Properties, 1995.
[8] Holtec Drawing 4148, revision 0.
[9] Strength of Materials, Part I, 3rd Edition, Timoshenko, Van Nostrand Reinhold, 1958.
[10] Strength of Materials, Part II, 3rd Edition, Timoshenko, Van Nostrand Reinhold, 1958.

SUPPLEMENT 5, HI-STAR HB ENCLOSURE SHELL EVALUATION

The HI-STAR HB enclosure shell is different from the HI-STAR detailed in the FSAR [2] in the enclosure shell construction. The original HI-STAR uses a segmented enclosure shell construction where the HI-STAR HB uses a single cylindrical shell. Therefore the "Enclosure Shell Flat Side Panels" section of the FSAR Appendix 3.AG is obsolete and the new cylindrical shell must be analyzed under the 30 psi internal loading and 60g end drop. All other sections of FSAR Appendix 3.AG remain valid.

Input Data

internal pressure [2] $p := 30\text{psi}$

Holtite density [1, sec 3.3.2.1] $\rho_h := 1.63 \frac{\text{gm}}{\text{cm}^3}$

carbon steel density [2, table 3.3.1.2] $\rho_s := 0.283 \frac{\text{lbf}}{\text{in}^3}$

outer shell outside diameter [1, sheet 6] $d_{os} := 96\text{in}$

outer shell thickness [1, sheet 6] $t_{os} := 0.5\text{in}$

outer shell inner diameter $d_{i\_os} = 95\,\text{in}$

inside diameter of HI-STAR [1, sheet 6] $d_i := 68.75\text{in}$

outer shell mean radius $r_{os} = 47.75\,\text{in}$

minimum built-up wall thickness [1, sheet 6] $t_{wall} := 8.5\text{in}$

Holtite maximum thickness $t_h = 4.625\,\text{in}$

Holtite inner diameter $d_h = 85.75\,\text{in}$

top and bottom annular ring thickness [1, sheet 2] $t_{ar} := 0.5\text{in}$

outer shell height [1, sheet 2] $h_{os} := 96.3125\text{in}$

maximum end drop acceleration (g's) [2, table 3.1.2] $a_{drop} := 60$

weld metal ultimate strength (use base metal at 300ºF) [2, sec 3.3.1.4, table 3.3.3 and 2.2.3] [1, sheet 6] $\sigma_u := 70000\text{psi}$

top and bottom annular ring weld size [1, sheet 2] $f_w := 0.5\text{in}$

Analysis

Internal Pressure

hoop stress

Proprietary Information Deleted

longitudinal stress

allowable stress [2, table 3.1.10] $S := 17.5 \times 10^3\text{psi}$

safety factor $SF_h := \frac{S}{\sigma_h}$ $SF_h = 6.11$

End Drop Shielding Weld Analysis

weight of outer shell $W_{os} = 4.09 \times 10^3\ \text{lbf}$

weight of Holtite $W_h = 7.45 \times 10^3\ \text{lbf}$

approximate weight of annular ring (single) $W_r = 207\ \text{lbf}$

total end drop force $P = 7.17 \times 10^5\ \text{lbf}$

annular ring weld area (single) $A_w = 135\ \text{in}^2$

shielding enclosure weld capacity
(ASME level D) [2, app 3.M, pg 3.M-2]

weld safety factor $SF_w := \frac{V_w}{P}$ $SF_w = 11$

References

[1] HI-STAR HB Overpack Drawing 4082.
[2] HI-STAR FSAR, rev 1.

SUPPLEMENT 6 - RESPONSE OF CASK TO TORNADO WIND LOAD AND LARGE MISSILE IMPACT

Introduction

The objective of this analysis is to determine the response of the cask to the combined load of the wind due to the design basis tornado and the large missile impact (automobile) specified in [2, sec 6.2.2]. It is demonstrated that under this loading condition, the cask will not tip over. The case of large missile impact plus the instantaneous pressure drop due to the tornado passing the cask is also considered. The two cases need not be combined.

Impacts from two types of smaller missiles are considered in Supplement 3

Method

In this analysis, the cask is simultaneously subjected to a missile impact at the top of the cask and either a constant wind force or an instantaneous pressure drop leading to an impulsive adder to the initial angular velocity imparted by a missile strike. The configuration of the system just prior to impact by the missile is shown in Figure 3.C.1.

The first step of the analysis is to determine the post-strike angular velocity of the cask, which is the relevant initial condition for the solution of the post-impact cask equation of motion. There are certain limiting assumptions that we can make to compute the post-impact angular velocity of the cask. There are three potential limiting options available.

a.

b.

Proprietary Information Deleted

c.

Missile impact tests conducted under the auspices of the Electric Power Research Institute (see EPRI NP-440, Full Scale Tornado Missile Impact Tests", 1977) have demonstrated that case c above matches the results of testing.

Determination of the force on the cask due to the steady tornado wind is the next step. The primary tornado load is assumed to be a constant force due to the wind, acting on the projected area of the cask and acting in the direction that tends to cause maximum propensity for overturning.

The equation of motion of the cask under the wind loading is developed, and using the initial angular velocity of the cask due to the missile strike, the time-dependent solution for the post-impact position of the cask centroid is obtained.

In the second scenario, the missile impact occurs at the same instant that the cask sees the pressure drop due to the passing of the tornado.

<u>Assumptions</u>

The assumptions for the analysis are stated here; further explanation is provided in the subsequent text.

1.

2.

3.

Proprietary Information Deleted

4. The cask is assumed to pivot about a point at the bottom of the baseplate opposite the location of missile impact and application of wind force in order to conservatively maximize the propensity for overturning.

5.

6.

Proprietary Information Deleted

7. Planar motion of the cask is assumed; any loads from out-of-plane wind forces are neglected.

8. Proprietary Information Deleted

9. The missile and wind loads are assumed to be perfectly aligned in direction.

10.

Proprietary Information Deleted

11.

It is recognized that the above assumptions taken together impose a large measure of conservatism in the dynamic model, but render the analysis highly simplified. In a similar spirit of simplification, the calculations are performed by neglecting the geometry changes which occur due to the dynamic motion of the cask. This linearity assumption is consistent with the spirit of the simplified model used herein.

Input Data

The following input data is used to perform the analysis and taken from [2, 3, and 4].

The weight of the cask plus contents, $W_c := 161200 \cdot lbf$

The cask total height, $L_c := 127.4375 \cdot in$

Dolly height with optional shim, $L_r := 8.125 \cdot in$

The cask on dolly total height, $L := L_c + L_r$ $L = 135.563\, in$

The diameter of the cask base in contact with the supporting surface, $a := 83.25 \cdot in$

Rail centerline spacing (conservatively used for tipping) $a := 59.25 \cdot in$

The maximum diameter of the overpack, $D := 96.0 \cdot in$

Gravitational acceleration, $g := 386.4 \cdot \frac{in}{sec^2}$

The weight of the large missile (see Supplement 3, 1810 kg) $W_m := 3990 \cdot lbf$

The maximum tornado wind speed [2, sec 6.2.2.3] (rotation plus translation, 240 mph and 60 mph, respectively), $v_t := 300 \cdot mph$

The pre-impact missile velocity (see Supplement 3, 52 m/s), $v_m := 116 \cdot mph$

The translation speed of the tornado [2, sec 6.2.2.3], $V_{tr} := 60 \cdot mph$

The drag coefficient for cylinder in turbulent crossflow, $Cd :=$

The density of air, $\rho_{air} := 0.075 \cdot \frac{lbf}{ft^3}$ ("lbf" indicates pounds "force")

The viscosity of air, $\mu_{air} := 4.18 \cdot 10^{-7} \cdot \frac{lbf}{ft \cdot sec}$

Maximum instantaneous pressure drop [2, sec. 6.2.2.3] $dp := 2.25 \cdot psi$

The total mass of the cask and its contents (M_c) can be calculated from the total weight and gravitational acceleration as:

$$M_c := \frac{W_c}{g}$$

Similarly, the mass of the large missile (M_m) can be calculated from its weight and gravitational acceleration as:

$$M_m := \frac{W_m}{g}$$

Solution for Post-Missile Strike Motion of Cask

The missile imparts the maximum angular momentum to the cask when the initial angle of the strike is defined by the relation:

Proprietary Information Deleted

Substituting the values of a and L defined above, the missile strike angle $\phi_0 = 23.609 \, deg$

The distance between the missile impact location and the cask pivot point, as shown on Figure 3.C.1, is calculated as:

Proprietary Information Deleted

The centroidal mass moment of inertia of a cylindrical object about an axis parallel to and intersecting its axial midplane (I_z), for rotation about z, is given by:

Using the parallel axis theorem, the moment of inertia of the cask after the missile strike about the rotation point can be determined as:

Proprietary Information Deleted

$$I_r = 1.221 \times 10^9 \, lb \cdot in^2$$ ("lb" indicates pounds "mass")

As stated in the Assumptions section, it is conservatively assumed that the missile does not remain attached to the cask after impact. Using balance of angular momentum, the post-impact initial angular velocity of the cask can be determined using:

Proprietary Information Deleted

Thus, the post-impact initial angular velocity, $\omega = 0.986 \frac{1}{sec}$

For subsequent dynamic analysis, this angular velocity is used as the initial condition on the equation for the angular rotation of the cask as a function of time.

Calculation of Pressure due to Tornado Wind

The drag coefficient of a cylinder in turbulent crossflow is a function of the Reynold's Number, which can be calculated using the relation:

$$Re := \frac{\rho_{air} \cdot v_t \cdot D}{\mu_{air}} \qquad Re = 6.316 \times 10^8$$

The drag coefficient (C_d) for a cylinder in crossflow for this Reynold's Number is less than 0.5 [1], so a conservatively higher value of 0.6 is used.

$Cd :=$ Proprietary Info Deleted

The pressure on the side of the cask (p_{max}), due to wind loading, is determined using:

Proprietary Information Deleted

and the resulting force on the projected area of the cask is therefore given by:

Proprietary Information Deleted

Thus, the force due to tornado wind, $F_{max} = 1.223 \times 10^4 \, lbf$

Post Impact Plus Steady Wind Solution

The solution of the post-impact dynamics problem for the period of time when the horizontal displacement of the cask mass center is greater than or equal to zero is obtained by solving the following equation of motion:

Proprietary Information Deleted

where I_r is the cask moment of inertia about the rotation point and α is the angular acceleration of the cask. The above equation arises from summation of dynamic moments about the cask pivot point. The steady wind enters into the above equation through F_{max}, and the impacting missile enters into the equation through the initial angular velocity.

The angular position of the cask is examined through 250 time steps of 0.005 sec duration.

Let $i := 1 .. 250$

$$t_i := \frac{i}{200} \cdot sec$$

Let θ = the angular rotation variable of the cask subsequent to the impact. The analytical solution of the above equation is therefore:

Proprietary Information Deleted

Results

Once the angular rotation with respect to time is known, the horizontal displacement of the cask center of gravity can be calculated as:

Proprietary Information Deleted

Figure 3.C.2 shows a plot of the motion of the cask center versus time.

Missile Impact Plus Pressure Drop

The case of instantaneous pressure drop plus impact by a missile is studied by finding the increment of initial angular speed imparted to the cask by the pressure wave. Using a balance of angular momentum relation, the increment of angular speed is determined and added to that of the missile strike.

Time of pressure wave to cross cask body $dt = 0.091\,\text{sec}$

Increment of angular velocity imparted to cask in time dt

$$d\omega = 0.057\,\text{sec}^{-1}$$

Therefore, for this case the initial angular speed is

$$\omega_1 = 1.043\,\text{sec}^{-1}$$

The angular position of the cask is examined through 250 time steps of 0.005 sec duration.

Let $i := 1 .. 250$

$$t_i := \frac{i}{200} \cdot \text{sec}$$

Let θ1 = the angular rotation variable of the cask subsequent to the impact. The analytical solution of the above equation is therefore:

Proprietary Information Deleted

Results

Once the angular rotation with respect to time is known, the horizontal displacement of the cask center of gravity can be calculated as:

Proprietary Information Deleted

Figure 3.C.3 shows a plot of the motion of the cask center versus time.

Conclusion

As is shown in Figure 3.C.2, the maximum horizontal excursion of the cask centroid under the given loading is less than 2.2 feet. In order for a cask tipover accident to occur, the centroid must undergo a horizontal displacement of 3.3 feet. Therefore, the combined tornado wind and missile strike events will not result in cask tipover. The case of missile strike plus tornado passing the cask is not a bounding case.

References

[1] E. Avallone and T. Baumeister, Marks' Standard Handbook for Mechanical Engineers, McGraw-Hill, Inc., Ninth Edition, 1987, p. 11-77.
[2] HBPP Specification HBPP-2001-01.
[3] HI-STAR HB Overpack, Holtec International Drawing 4082, revision 0.
[4] Cask Transfer Rail Dolly Drawing 4106, rev 0.

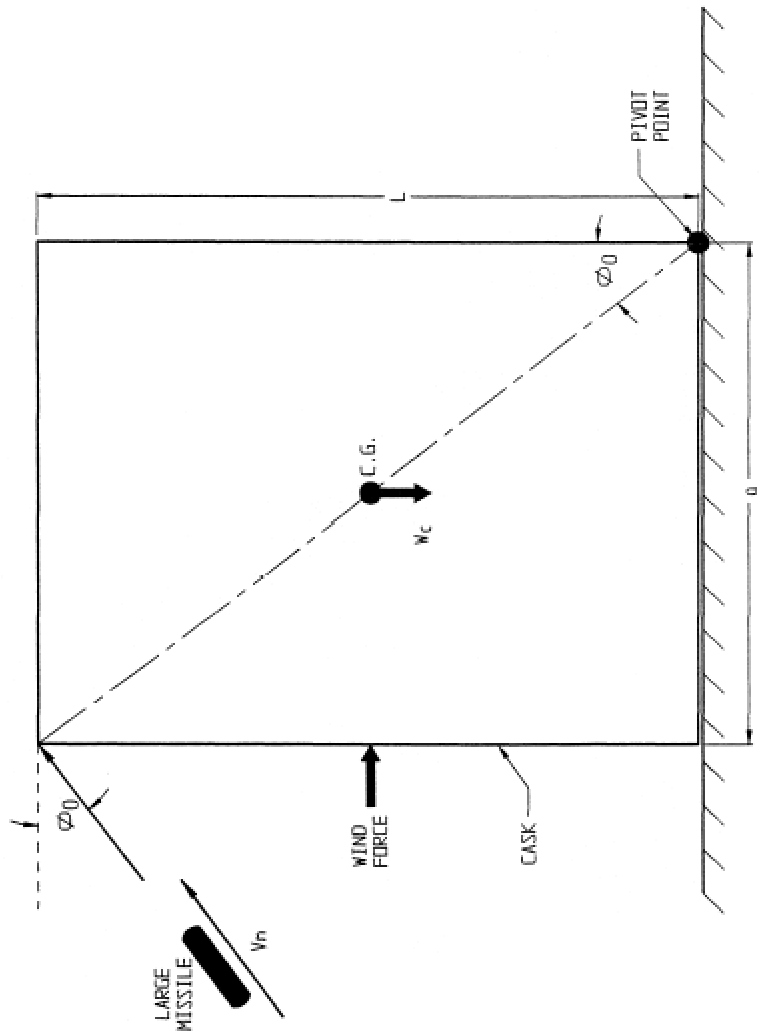


FIGURE 3.C.1; FREE BODY DIAGRAM OF CASK FOR LARGE MISSILE STRIKE/TORNADO EVENT

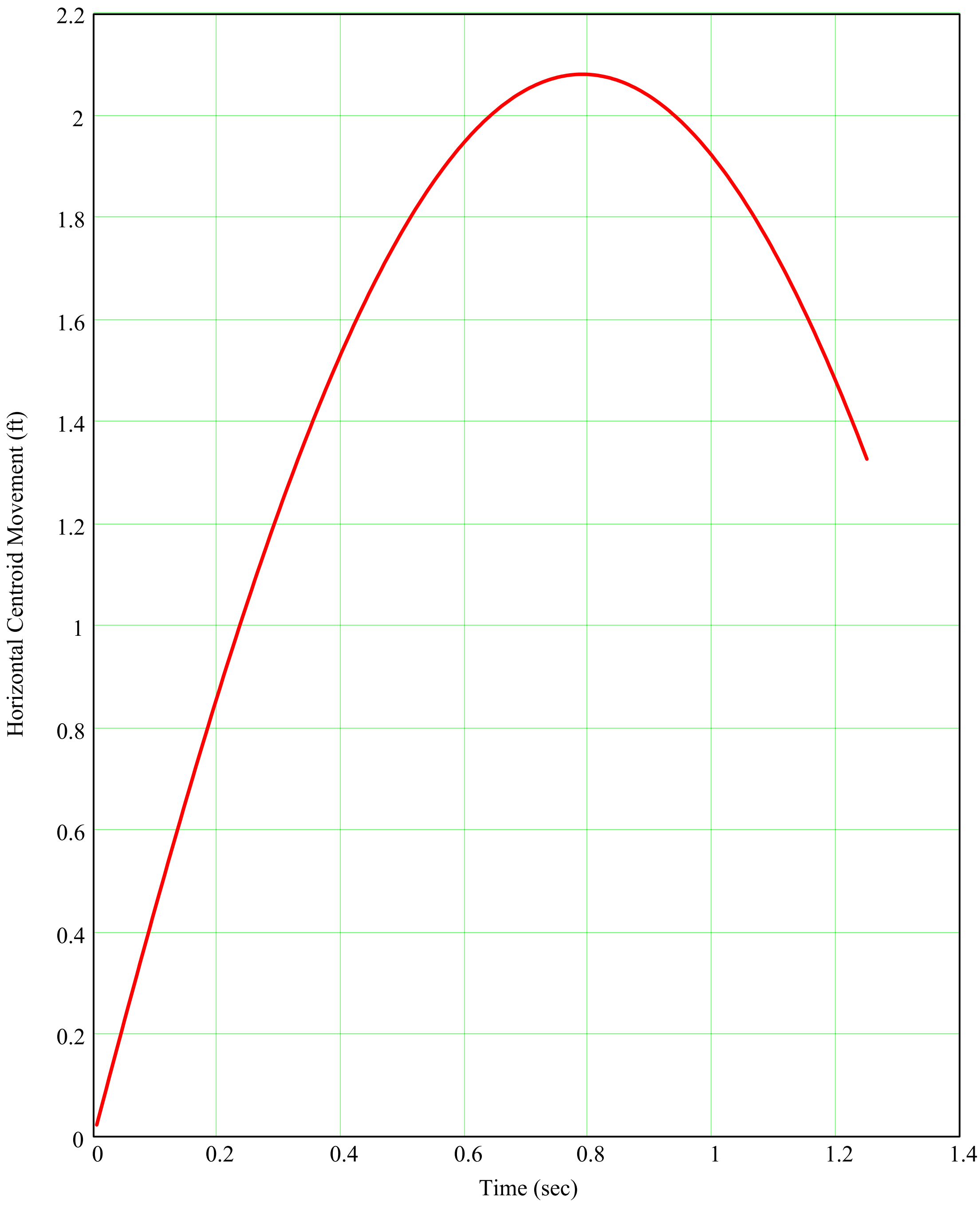


Fig. 3.C.2 Horizontal Motion of Centroid

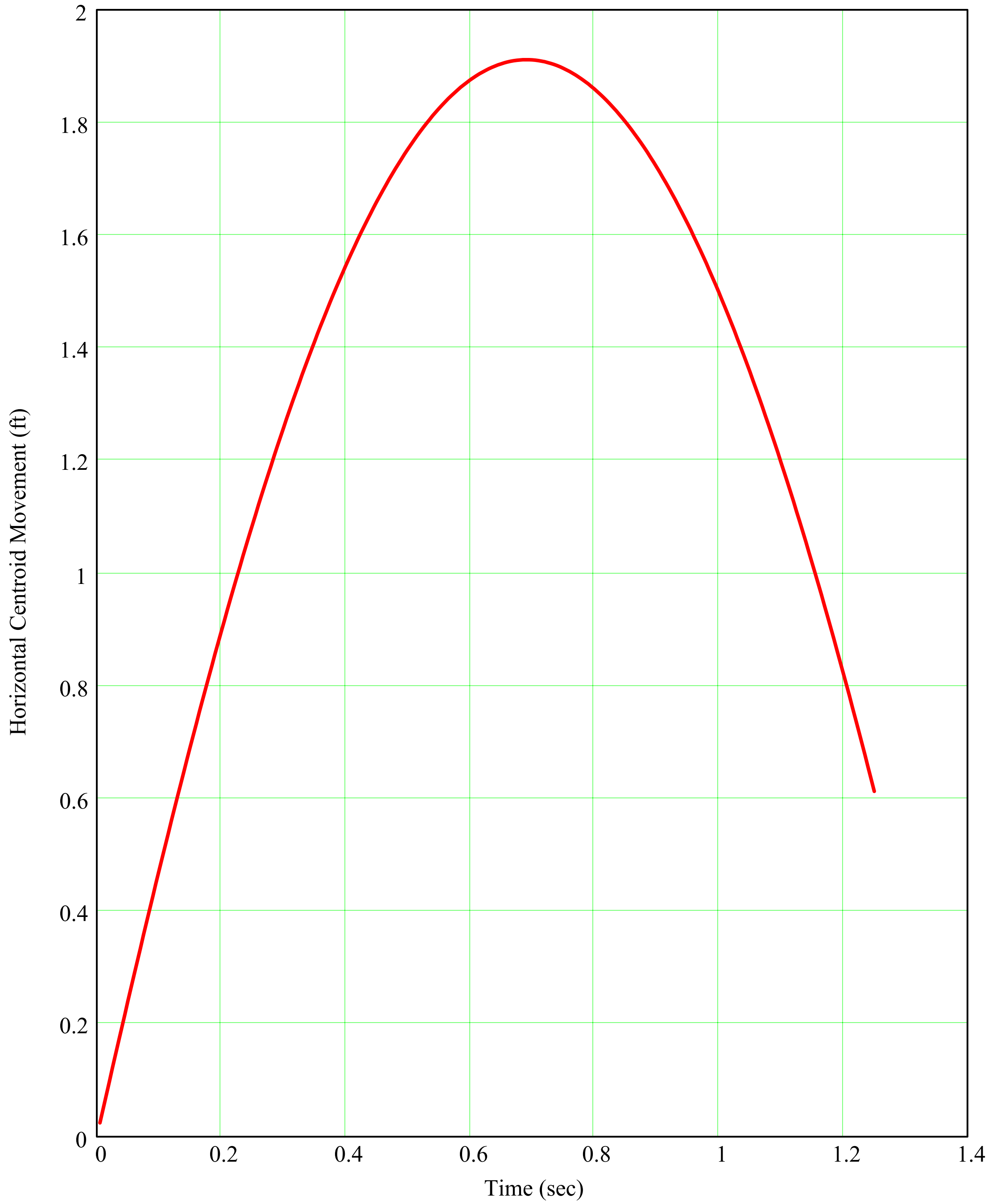


Fig. 3.C.3 Horizontal Motion of Centroid

HOLTEC INTERNATIONAL

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

SEISMIC RESPONSE OF HI-STAR HB IN RFB AND YARD

FOR

PG&E

Holtec Report No: HI-2033046

Holtec Project No: 1125

Report Class : SAFETY RELATED

DOCUMENT NAME: Seismic Response of HI-STAR HB in RFB and Yard							
DOCUMENT NO.:	2033046			CATEGORY: ☐ GENERIC X PROJECT SPECIFIC			
PROJECT NO.:	1125						
Rev. No.[2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	12/08/03	AIS	562938	3			
1							
2							

DOCUMENT CATEGORIZATION

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

X 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 does not follow HQP requirements but follows a format more suited for an ASME Code Calculation report.

DECLARATION OF PROPRIETARY STATUS

This document is labeled:

☒ Nonproprietary   Holtec Proprietary   ☐ TOP SECRET

Documents labeled TOP SECRET contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Top Secret document bears full and undivided responsibility to safeguard it against loss or duplication.

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 in the N-drive of 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 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 Calculation Packages may be made by adding supplements to the document and replacing the "Table of Contents", and the "Revision Log".

HOLTEC SAFETY SIGNIFICANT DOCUMENTS

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 this document must fulfill, as applicable, 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 is drawn from referencable sources. Any assumed input data is so identified.
- ❖ All significant assumptions are stated.
- ❖ The analysis methodology is consistent with the physics of the problem.
- ❖ Any computer code and its specific versions used in the work have 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 the report is understandable to a reader with the requisite academic training and experience in the underlying technical disciplines.

Once a safety significant document, such as this report, 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), editorial revisions to Holtec *safety significant* documents are not made unless such editorial changes are deemed necessary by the Holtec Project Manager to prevent erroneous conclusions from being inferred by the reader. In other words, the focus in the preparation of this document is to ensure correctness of the technical content rather than the cosmetics of presentation.

REVISION LOG

Revision 0: Original Issue

EXECUTIVE SUMMARY

Six Holtec International Storage, Transport, and Repository Cask System, Humboldt Bay (HI-STAR HB) casks will be stored in the Humboldt Bay Independent Spent Fuel Storage Installation (ISFSI) Vault. In accordance with the Humboldt Bay Specification for the dry storage system, the safe shutdown earthquake refueling building (SSEERFB) and design basis seismic events (DBE's) and are applied as an input 3-D motion to the HI-STAR HB while inside the refueling building and in the yard, respectively. Four separate SSEERFB and DBE events are considered as input data for dynamic simulation of the cask response to an earthquake. In this report, the response of the cask to each of the input seismic events is determined by performing a dynamic simulation. The results from the SSEERFB loading inside the refueling building show that the cask (while on the dolly) does not tip over and that stress levels meet American Society of Mechanical Engineers (ASME) code requirements as per Appendix H of Specification HBPP-2001-01. For conservatism, the results from the DBE loading while the cask is in the yard on the dolly in route to the transporter provide loadings for the design of a lid restraint system when in fact while in the yard the MPC lid is already welded closed and the HI-STAR HB lid is bolted in place.

TABLE OF CONTENTS

1.0 INTRODUCTION

Six Holtec International Storage, Transport, and Repository Cask System, Humboldt Bay (HI-STAR HB) casks will be stored in the Humboldt Bay Independent Spent Fuel Storage Installation (ISFSI) Vault. In accordance with the Specification [1], Section 6.2.5.1, the safe shutdown earthquake refueling building (SSEERFB) and design basis seismic events (DBE's) are applied as an input 3-D motion to the cask while in the refueling building and in the yard prior to hook-up to the transporter, respectively. In both scenarios, the limiting condition evaluated is when the HI-STAR HB is on the dolly. Four separate SSEERFB and DBE events are considered as input data for dynamic simulation of the cask response to an earthquake.

In this report, the response of the cask to each of the input seismic events is determined by performing a series of dynamic simulations.

The purposes of the analyses are threefold:

Demonstrate that subject to the design basis SSEERFB seismic event for the Reactor Fuel Building (RFB), the cask plus dolly does not become unstable and overturn and the stress levels remain below the applicable limits inside the Part 50 structure.
Demonstrate that once outside the RFB in the yard and subject to the DBE seismic event, the cask/dolly, while overturning, is not subject to deceleration levels that exceed the limits specified in the HI-STAR FSAR [7].
Determine the forces and moments that act to keep the lid in-place during a tipover event caused by the DBE seismic inputs, so that a lid restraint system may be conservatively engineered to ensure that the fuel remains inside the cask while in the RFB prior to the final welding of the MPC and the attachment of the HI-STAR HB lid.

While in the refueling building, the stability of the cask against tip over is observed graphically in VisualNastran (VN) [2] and stress levels are compared to American Society of Mechanical Engineers (ASME) code requirements as per [1], Appendix H. Once outside the RFB, the simulation model is subject to the DBE events and the loads and accelerations that arise from the cask overturning are determined from the VN results.

2.0 METHODOLOGY

The dynamic simulations are performed using VisualNastran Desktop (VN) [2]. This code is capable of modeling large motions of rigid bodies that may contact each other during the event. The VN simulation code (previously denoted as "Working Model") has been employed elsewhere [3-5] and has been subject to NRC scrutiny. The various bodies making up a simulation can be constructed directly in the VN program, or may be imported from a Computer Aided Design (CAD) program. Herein, the HI-STAR HB overpack is modeled as a solid body using Solidworks [6]. This CAD system has been subject to appropriate QA validation and has been demonstrated to produce accurate mass, inertia properties and location of the center of gravity. Therefore, mass and inertia properties are preserved after input of the rigid body cask overpack model into the dynamic simulation code. The cask lid, loaded MPC, and dolly are modeled as separate rigid bodies and imported into the VN model. A fixed ground is modeled as a reference plane. The HI-STAR HB, loaded MPC, cask lid, and dolly are assumed driven by the seismic events. In each scenario, in the refueling building and in the yard, the same VN model is used. The only difference between the two scenarios is the seismic loading.

Finally, custom contact models are defined between the HI-STAR HB and ground, rollers and ground, and dolly and ground. Contact between the HI-STAR HB and dolly, MPC and HI-STAR HB, and lid and MPC are based on classical impulse/momentum methods. The contact force-time history, from these interface contact elements, is archived and provides input loads for all above mentioned contact pairs.

3.0 REFERENCES[1]

[1] HB Specification HB-2001-01

[2] VisualNastran, Version 2002, MSC Software, 2002 and Validation Manual for VisualNastran 2002, HI-2022896, Revision 0.

[3] HI-2002507, Seismic Analysis of Loaded HI-TRAC in Diablo Canyon Fuel Building, Project 1073, Revision 1.

[4] HI-STAR 100 SAR, HI-951251, Revision 9.

[5] HI-2022878, Supplemental Seismic Stability Analysis for PFS, Project 70651, 2002, Revision 0.

[6] Solidworks 2001 Plus, Solidworks, Inc.

[7] HI-STAR FSAR, HI-2012610, Revision 1

[8] HI-2032999, Dimensions and Weights for the Humboldt Bay ISFSI Project, Project 1125, 2003, Revision 0.

[9] Humboldt Bay DBE Time Histories (Fault Normal, Fault Parallel, and Vertical Response Spectra and Time Histories), 4 sets provided by PG&E (Letter of 1/21/03 citing Report GEO.HBIP.02.05).

[10] Fax from Larry Pulley (HBIP) to Alan Soler (Holtec) dated 5/12/2003 and attached as Appendix B to this report.

[11] Sheets 15-33 of Bechtel Corporation Calculation for the Reactor Building (RFB) dated 4/11/60 (no calculation number) provided by L. Pulley by 8/22/2003 letter transmittal.

---

[1] This revision status of Holtec documents cited above is subject to updates as the project progresses. This document will be revised if a revision to any of the above-referenced Holtec work products materially affects the instructions, results, conclusions or analyses contained in this document. Otherwise, a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supersede the revision numbers cited above. The Holtec Project Manager bears the undivided responsibility to insure that there is no intra-document conflict with respect to the information contained in all Holtec generated documents on a safety significant project".

Also, Sheets 5-15 of Bechtel Corporation Calculation for the East Caisson provided in the same letter transmittal.

[12] ANSYS, Version 5.7 and 7.0, Ansys, Inc.

4.0 ACCEPTANCE CRITERIA

Demonstrate that inside the refueling building the HI-STAR HB does not tip over and that its stress levels meet ASME code requirements.

When the HI-STAR HB is outside the refueling building in the yard, demonstrate that "g" levels shall not exceed 60g as per [7] in the event of a tipover.

Acceptable dynamic analyses must be performed for a duration exceeding the observed strong motion region of each seismic event to ensure that maximum impact loads are captured in the response.

5.0 ASSUMPTIONS

The cask and contents are modeled as multiple rigid bodies with known geometry and weight. This is conservative since all energy loss from cask structural deformation is neglected.

The cask lid, while initially modeled as a separate body, is rigidly attached to the overpack for the dynamic analyses. This is realistic and preserves the mass and inertia distribution of the real system.

The internally loaded Multi-Purpose Canister (MPC) is assumed to be free to rattle inside the overpack when a seismic event occurs. This is realistic.

Contact between the internal MPC and the inside cavity of the HI-STAR HB overpack is simulated by a classical impulse-momentum relationship with a specified coefficient of restitution and coefficient of friction. This assumption is realistic and accounts for energy losses during internal impacts. This assumption has been employed in previous dynamic simulations that have undergone review by the USNRC [3].

Appropriate values of coefficient of friction at contacting surfaces are chosen based on expected “average values”.

The dolly plate weight is conservatively assumed to be 10,000 lb. And is modeled with four 182 lb. rollers. Overturning moments from the overestimated dolly weight are far outweighed by the overturning moments from the HI-STAR. The conclusions remain unchanged if a lower weight were used. The dolly elevates the HI-STAR approximately 9” above the ground and two actual rollers are assumed 60” long on 60” centers.

6.0 INPUT DATA

6.1 HI-STAR HB

The cask is represented as a homogeneous, rigid cylinder containing a loaded MPC. The HI-STAR lid mass is input separately and the lid rigidly attached at the top of the overpack. The mass and geometry data input used for the analyses in the fuel building and in the yard are obtained from [8] and from [4].

HI-STAR Overpack	93,860 lb.
Loaded MPC	59,000 lb.
HI-STAR Lid	8,363 lb.
Dolly Plate	10,000 lb.
Dolly Rollers	182 lb. each

The total cask mass is 161,223 lb., which is in essential agreement with the total value given in [8]. Figure 3 shows the VN input screens where the mass data is entered.

6.2 Target Surface (Ground)

The input data required is a force-deformation relation characterizing the response of the target surface to a vertical surface load over the interface area. The input is in the form of an interface stiffness value (lb/inch, for example). Values are determined in Appendix A for the interface between the HI-STAR, dolly plate, and dolly rollers and ground. Figure 4 shows the data input screens to the VN model for the ground and rollers, which are assumed to have stiffness values to ensure response in the rigid range. Figure 4 also shows the custom friction input.

6.3 Target Surfaces (Cask/MPC)

The cask/MPC contact interface is simulated using a classical impulse-momentum algorithm built into the VN simulation code. The coefficient of restitution and the coefficient of friction between the bodies are set as:

Proprietary Information Deleted

These input values are consistent with the values employed in similar analyses supporting the Diablo Canyon ISFSI license submittal.

6.4 Input Loading

Input time histories of different durations have been provided by PG&E [9] for four (4) sets of seismic events each, denoted as the "DBE" event (Sets 1-4) and "SSEERFB" event also with (Sets 1-4). Each data set is in the form of acceleration vs. time. For each set of data consisting of three orthogonal acceleration time histories (fault normal, fault parallel, and vertical for DBE and horizontal 1, horizontal 2, and vertical for SSEERFB), the problem is re-formulated into a fixed ground and a moving cask/dolly configuration subject to three components of imposed inertia forces, applied at the mass centers of the overpack, the lid, the loaded MPC, the dolly plate, and dolly rollers. Figures 5 and 6 show the equations for the three components of inertia force applied to the HI-STAR HB for the Set 1 DBE and Set 1 SSEERFB events, respectively. Dividing by the negative of the HI-STAR weight recovers the input acceleration components. Similar inertia forces are applied to the lid, MPC, dolly plate, and dolly rollers differing only by the multiplying component weight, which is shown in Figure 3.

Proprietary Information Deleted

Appendix C shows a sketch of the fault line, plant north, and true north orientations. The earthquake component directions for the DBE event in the yard are arbitrary since the dolly will change its orientation as it is maneuvered about the yard.

6.5 Rail Bay Slab Configuration

The properties of the rail bay slab are provided in [11] and are summarized here.

Slab thickness - 24” under dolly path [11, including sketch reproduced here and in Appendix E]

Proprietary Information Deleted

Subgrade Modulus of Soil Foundation – 100 psi/in (sheet 29 of [11])

Compressive strength of concrete - 3000 psi

Reinforcement yield strength – 40,000 psi (confirmed by e-mail from L. Pulley)

Subject: RE: Rebar strength

Date: Thu, 23 Oct 2003 13:59:28 -0700

X-MS-Has-Attach:

X-MS-TNEF-Correlator:

Thread-Topic: Reports and Drawings

Thread-Index: AcNosK/E5X2zp4WrQWWiS2I/HRoFsww96eYg

From: "Pulley, Lawrence" <LBP1@pge.com>

To: "Eric" <eric_lewis@holtec.com>,

"Alan Soler (E-mail)" <alan_soler@holtec.com>

Cc: "Pulley, Lawrence" <LBP1@pge.com>

X-OriginalArrivalTime: 23 Oct 2003 20:59:28.0946 (UTC) FILETIME=[8CA19120:01C399A8]

Eric:

The rebar strength for the refueling building is 40ksi yield material per Bechtel calc SRC-46 pg 25.

Hope this helps.

Larry

7.0 ANALYSES

The simulation model described above is subject to the four DBE and four SSEERFB events. The duration of the simulation for each event was continued to a point well past the time at which fault fling occurred to ensure that the maximum force response of the system was captured.

The same VN model in used in both analyses. The difference between the analyses is the applied seismic load.

Figures 7-22 summarize the collected data on HI-STAR HB, MPC, and lid maximum accelerations, constraint forces, and impact force-time histories during the SSEERFB and DBE events. Figure 23 gives a listing of the available output monitored during each simulation. All results can be archived in Excel spreadsheet form. The maximum acceleration in any direction is used to qualify the HI-STAR HB and MPC.

Stiffness values of impacts of the HI-STAR HB with the ground and impact of the dolly rollers with the ground are calculated in Appendix A. All other stiffnesses are based on classical impulse-momentum methods built into VN.

Based on results from the VN simulations using the SSEERFB events, the RFB floor slab in the truck bay is evaluated for continued structural integrity using a finite element model. The evaluation is performed for two load conditions, corresponding to the conditions required in [1, Appendix H].

8.0 RESULTS

8.1 Discussion of Results

Figures 7-22 present summaries of the key results from the seismic simulations using the input values assigned in the previous sections of this report. Summarized in the tables are the maximum and minimum values of acceleration at the top and bottom of the MPC, the bottom of the HI-STAR HB, and the lid restraint, which is representative of the acceleration of the top of the HI-STAR HB. Also, the force and moment (or torque) on the lid is monitored for input to the design of a lid restraint system.

When the HI-STAR HB is on the dolly in the yard subject to a DBE event, the HI-STAR HB overturns under each of the imposed seismic events. The lid restraint system is subject to the maximum forces and torques listed in the table below. These forces and torques are reported in the World (or global) coordinate system and do not coincide with the local lid restraint local coordinate system. Therefore, the application of this force and moment system should be oriented with respect to the lid restraint giving the worst-case loading scenario. Also, this is a conservative force and moment system since the maximum of each component is taken at different times during the analyses. The loads and moments in the following table are inputs to the design analysis for the lid restraint system performed in HI-2033042.

Effective Loads for Lid Restraint Design due to DBE Event

Lid Constraint Load	Max. Magnitude	Set
Force, F_x	155,000 lb	4
Force, F_y	139,000 lb	2
Force, F_z	373,000 lb	3
Torque, T_x	2,240,000 in-lb	2
Torque, T_y	1,770,000 in-lb	4
Torque, T_z	635,000 in-lb	4

Results for peak accelerations (in “g’s”) at the top and bottom of the HI-STAR and the internal MPC are reported below for both the SSEERFB and DBE events. These results are obtained by defining points fixed at the top restraint (coincident with the top of the HI-STAR HB cask), and at the base of the HI-STAR HB and defining acceleration "meters" at each location. Even without any filtering operation, the peak "g" values for the cask and top restraint are well below the design basis limiting value (60 g's) for the cask and contents. Therefore, no additional stress analyses are required to confirm that the cask and its contents meets CFR Part 72 structural integrity requirements for transportation out of the refueling building and through the yard to the cask transporter and it is concluded that the contents of the MPC remain enclosed. This is further explained in Section 8.2. For the SSERFB case, peak acceleration at the top and base of the MPC are also reported; the deceleration peaks are generally lower for the MPC than for the cask, which is attributed to the energy dissipated at the cask/MPC contact interface.

Peak Acceleration "g" Levels in HI-STAR, MPC, and Restraint for SSEERFB Event

SSEERFB Set	Top of Restraint	Base of HI-STAR	Top of MPC	Base of MPC
Set 1	3.86	3.91	1.28	1.40
Set 2	0.311	1.78	1.04	1.04
Set 3	1.09	2.10	1.32	1.31
Set 4	1.52	2.16	1.39	1.10

Note: values reported for MPC are the maximum achieved for lateral or longitudinal direction.

Peak Acceleration "g" Levels in HI-STAR and Restraint for DBE Event

DBE Set	Top of Restraint	Base of HI-STAR
Set 1	36.0	25.4
Set 2	38.6	15.1
Set 3	43.5	18.3
Set 4	38.1	13.0

In all instances, the accelerations of the HI-STAR HB are larger for the DBE event due to tip over of the HI-STAR HB and its contents.

8.2 Comparison of 10CFR72 and 10CFR50 Structural Requirements

The Part 72 stress/stress intensity requirements are presented in Tables 2.2.10-2.2.12 of [7]. The HBPP Part 50 requirements are given in Appendix H of the HBPP specification [1]. For Part 50 considerations, the cask should be considered as an "inactive" mechanical equipment support component. The Part 72 requirements invoke ASME NG for the fuel basket, ASME NB for the MPC shell, and ASME NF for the structural components of the HI-STAR HB cask. The fuel basket is confined by the canister shell, which is itself confined by the HI-STAR HB. The limiting load case for the fuel basket and for the MPC confinement boundary is the lateral or longitudinal deceleration load due to a handling accident or a non-mechanistic tipover together with internal pressure, as applicable. When confined in the HI-STAR HB, the limiting deceleration is 60g's. It has been demonstrated that the fuel basket and the MPC confinement structure meet Level D stress intensity limits when subject to the design basis limiting deceleration loads. A comparison of the stress limits applicable in a Part 50 analysis to the fuel basket, MPC confinement boundary, and HI-STAR HB to the corresponding Part 72 limits is presented below in order to highlight potential differences.

1. Comparison of Equipment Stress Allowables - MPC Design - ASME Section III, NB and NG FSAR Table 2.2.10 bounds that of Table 2.2.11

Loads	HBPP 10CFR50	Holtec FSAR Table2.2.10
Design (Normal)	$P_m \leq S_m$ (NG only) $(P_m$ or $P_L) + P_b \leq 1.5S_m$ (NG only) $P_m + P_b + Q \leq 3.0S_m$	$P_m \leq S_m$ $P_L \leq 1.5S_m$, $P_m + P_b \leq 1.5S_m$ Ave. Shear Stress $\leq 0.6S_m$
Abnormal and DBE (Level D)	$P_m \leq$ Smaller of $2.4S_m$ and $.70\ S_u$ $P_L \leq$ Smaller of $3.6S_m$ and $1.05S_u$ $(P_m$ or $P_L) + P_b \leq$ Smaller of $3.6S_m$ and $1.05S_u$	$P_m \leq$ Smaller of $2.4S_m$ and $.70\ S_u$, $P_L \leq$ Smaller of $3.6S_m$ and $1.05S_u$ $P_m + P_b \leq$ Smaller of $3.6S_m$ and $1.05S_u$ Ave. Shear Stress $\leq 0.42S_u$

Where:

Q = secondary stress, ksi.

P_m = general primary membrane stress, ksi, excludes discontinuities and concentrations

P_L = local primary membrane stress, ksi, considers discontinuities but not concentrations

P_b = primary bending stress, ksi

S_m= design stress intensity listed in ASME Code Section II, Part D, Table 2A, 2B, and 4, latest version approved by NRC. The allowable stress shall correspond to the highest metal temperature at the section during the condition under consideration.

S_u= Minimum ultimate stress listed in ASME Code Section II, Part D, Table U, latest version approved by NRC. The stress shall correspond to the highest metal temperature at the section during the condition under consideration.

2. Comparison of Equipment Stress Allowables – HI-STAR Design - ASME Section III, NF

   a. The σ_L load is not considered in the Part 72 criteria.

For SA516, Grade 70 material, the allowable stresses in Equations (1) and (2) of Holtec Level D criteria are generally higher than the corresponding HBPP Part 50 allowables.

The limitation of average shear stress to 0.72 S_y (per ASME Section III, Appendix F-1334.2) is not considered in Equation (3) of the Part 72 Level D criteria.

Loads	HBPP 10CFR50	Holtec FSAR Table 2.2.12
Design (Normal)	$\sigma_m \le 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.5S$	$P_m \le 1.0S$ $P_m + P_b \le 1.5S$ Ave. Shear Stress ≤ 0.6S
Abnormal and DBE (Level D)	(1) $\sigma_m \le 2.0S$ (2) $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 2.4S$	(1) $P_m \le$ Max. of ($1.2S_y$ or 1.5 S_m), But < 0.7 S_u (2) $P_m + P_b \le$ Max. of ($1.8S_y$ or 2.25 S_m), But < 1.05 S_u (3) Ave. Shear Stress ≤ $0.42S_u$

In the above table,

σ_m = general (or primary) membrane stress, ksi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

σ_L = local membrane stress, ksi. This stress is the same as σ_m except that it includes the effect of discontinuities.

σ_b = bending stress, ksi. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by mechanical loads.

S = allowable stress, ksi. Material allowable stresses listed in ASME Code Section II, Part D, Table 1A, 1B, and 3, latest version approved by NRC. The allowable stress shall correspond to the highest metal temperature at the section during the condition under consideration (for the fuel basket, at 373 degrees F (see HI-2033033, Humboldt Bay Thermal Analysis, Section 9.1), Table 1A of the ASME Code lists S=17.04 psi for 316LN (a representative material for the Alloy X listed in the HI-STAR FSAR)).

With the comparisons set down in tabular form, we may address potential issues for each of the three structural components. We first consider the fuel basket and the MPC and address the issue of the SSEERFB seismic event. We have demonstrated that the maximum deceleration of the MPC, under this event in the RFB, is below 2g's. In the HI-STAR FSAR [7], these components have been demonstrated to meet Level D allowable limits for 60g decelerations. The fuel basket is confined within the MPC and the loaded MPC is confined within the HI-STAR cask after leaving the spent fuel pool. In the Part 72 submittal, decelerations due to postulated handling and non-mechanistic tipover far outweigh other loads. If we consider Table 3.1.17 of the HI-STAR FSAR, the allowable stress intensity limits for the fuel basket under a Level D event are 36.9 ksi and 55.4 ksi for primary local membrane and primary local membrane plus primary bending stress intensity, respectively. Safety factors in excess of 1.0 were demonstrated to exist when compared to these limits. Therefore, if we consider the SSERFB event applied decelerations and use these tipover decelerations inside the Part 50 structure, then, the expected maximum stress levels in the fuel basket are certainly bounded by 1.23 ksi and 1.85 ksi, respectively (i.e., ratio the allowables from the FSAR). These conservative stress levels estimated for the fuel basket are below the limits set by the Part 50 requirements for a Level D event (2x17.04 =34.08 ksi and 2.4 x 17.04 = 40.9 ksi). Therefore, it is concluded, using very conservative bounding stress values, that the fuel basket, by virtue of its robust construction to meet the handling accident and tipover decelerations imposed by 10CFR72, also meets all stress limits set forth by 10CFR50 for the SSEERFB seismic event input load.

The same conclusions generally apply to the MPC confinement structure as the same reduction in computed stress intensities may be applied. However, since the design temperature for the structure is lower, the allowable stress intensities for the Level D condition are higher; namely, from Table 3.1.17 of the FSAR, 43.4 ksi and 65.2 ksi for primary local membrane and primary local membrane plus primary bending stress intensity, respectively. Using the same reduction factor (from the FSAR design basis to the calculated limiting acceleration for the SSEERFB) results in estimated bounding increments of 1.45 ksi and 2.17 ksi, respectively. Table 3.4.7 of the HI-STAR FSAR presents results for the pressure stresses inside the confinement boundary and gives the safety factors for the Level A condition. The addition of the estimated stress increments from the SSEERFB event to the values in the table does not cause any safety factor to fall below 1.0. Therefore, we again conclude that the addition of a SSEERFB event to the loading evaluation inside the RFB will not result in the violation of any Part 50 stress limit.

The robust construction of the HI-STAR overpack has been shown in the HI-STAR FSAR (and in the companion transport SAR) to resist Level D conditions that far exceed the conditions experienced at Humboldt Bay (maximum "g" limit is 43.5/60 = 72.5% of the FSAR design basis limit). A comparison of allowable stresses from HBPP Part 50 conditions with comparable Level D limits from Part 72 demonstrates that the HI-STAR overpack meets Part 50 limits.

8.3 Evaluation of the Effect of Roller-Ground Coefficient of Friction

The previous simulations have been performed using a coefficient of friction between ground and rollers equal to 0.5. For the DBE events, there is no need to assess the effect of varying the coefficient of friction since the cask overturns. For the SSEERFB events, however, the effect of coefficient of friction at the ground-dolly roller interface needs to be assessed to ensure that the cask will not overturn if the coefficient of friction has an upper bound value of 0.8, and to determine the likely extent of dolly movement if the coefficient of friction has a lower bound value of 0.05 (to simulate rolling contact). The nature of the simulation code precludes assigning coefficients of friction that are directional dependent at an interface; therefore, the sensitivity study is performed assuming that the upper bound or lower bound value is active in all directions at the interface. Figures 24 and 25 show the results for coefficients of friction of 0.05 and 0.8, respectively, applied at the ground-dolly roller interface. The input seismic event is Set 1 of the SSEERFB as this resulted in the maximum acceleration of the HI-STAR HB. Figure 24, which presents results for the lower bound coefficient of friction representing rolling friction, demonstrates that the maximum excursion along the roller track does not exceed 19” in either direction along the rail if the dolly is left unrestrained. Figure 25 shows, for the upper bound coefficient of friction that the maximum angular excursion range is 1.6 degrees, thus confirming that the cask does not overturn under this SSEERFB event.

8.4 Structural Analysis of Rail Bay Floor

The results from the analyses discussed in Subsection 8.3 (using the bounding Set 1 seismic event) are used to extract floor loads suitable for assessing the continued structural integrity of the floor slab under the loads from the loaded dolly. As Set 1 of the SSEERFB event is the more severe of the four events (based on maximum cask acceleration), it is conservative to assess the slab integrity using the dolly loads from this case (especially for the case of friction coefficient equal to 0.8 so that rocking shifts more than 50% of the load to one rail.). Figure 26 shows the time history of the vertical floor loadings from each of the four rollers modeled in the simulation, while Figure 27 shows the roller/ground forces on each roller line and the sum for both roller lines. An analysis of the time history results (Figure 27) in an Excel spreadsheet indicates that there is a point in time (9.85 sec.) where most of the load is carried on one roller line during the seismic event. The following table summarizes the peak results at that instant corresponding to the D+SSERFB load condition in [1, Appendix H]:

Item	Roller Line 1	Roller Line 2	Total Slab Load
Maximum Load (kip)	240.5	11.273	251.773

For the case of dead load only, the input data in Section 6 provides a total load of 172,000 lb. (50% on each roller line) that represents the dead load condition.

Figure 28 shows the finite element grid used to simulate the portion of the rail bay floor slab modeled. The plate elements include the effect of the uniform subgrade modulus supporting the floating slab. Figure 28 also shows the seven node points where concentrated loads are applied to simulate the total load of 240.5 kips on one of the roller lines. The slab configuration (thickness, width, reinforcement) is provided in Section 6. Appendix E provides calculation of the ultimate moment and shear capacities for both directions of the slab. Appendix F contains the input listing for the finite element model [12] (the included file is for a load applied equally to each roller line over a total length of 7'). Figures 29-31 show plate displacement and plate outer surface stresses obtained from the analysis of the dead (D) plus seismic (SSERFB) load condition. As expected, the largest deformation and the highest stresses are found in the vicinity of the highest loaded roller line. Figures 32-34 provide corresponding results for the dead (D) load condition where a total load of 125,888 lb. is applied to each roller line (concentrated loads at 7 node points along each line). This applied load is 5% larger than 1.4 x (.5 x total weight of loaded cask + dolly).

The following table summarizes the outer surface stresses computed from the finite element solutions:

Loading	SX(psi)(12" slab)	SY(psi)(12"slab)	SX(psi)(24"slab)	SY(psi)(24" slab)
Dead+Seismic	442.345	335.935	442.345	431.916
1.4 x Dead	255.549	265.484	255.549	341.337

The cross-section bending moments are computed from the equation M=(stress x thickness^2)/6 and are summarized below together with the moment capacities computed in Appendix E (units of moments are lb-inch/inch.

Loading	MX/MX_u (12" slab)	MY/MY_u (12" slab)	MX/MX_u (24" slab)	MY/MY_u (24" slab)
Dead+Seismic	10616/21170	8062/18820	42465/49450	41464/47090
1.4 x Dead	6133/21170	6372/18820	24533/49450	32768/47090

The lowest computed safety factor, defined as ultimate moment capacity/calculated moment is 1.14 > 1.0 so the slab structural integrity is maintained under the most severe seismic condition applicable to the rail bay slab inside the RFB. Calculations in Appendix E show that the safety factor in shear (shear capacity/calculated shear) for the slab is 1.39 under the maximum load applied on one roller line.

8.5 Structural Analysis of Cask Pit Slab

The cask pit in the RFB is a 12” thick slab on grade that is reinforced only on the waterside and supported on a gravel subgrade. The original design basis calculations of the East Caisson consisted of an evaluation of the effect of the dead weight of equipment on the limiting members [11, sheets 5-14 of East Caisson calculation]. Included in the evaluation was a 75-ton storage cask, whose submerged weight was estimated as 51,300 lb. [11,sheet 13 of Caisson calculation]. The submerged weight of the HI-STAR HB is 131,000 lb. For analysis purposes, the Bechtel calculation was revisited with the HI-STAR HB submerged weight replacing the original submerged weight. This marked-up calculation is provided in Appendix G and demonstrates that the wall support member stress increases by only 2.6%. Further, calculations in Appendix E demonstrate that the bearing stress on the cask pit slab surface (from the cask) is approximately 24 psi, which is much less than the compressive strength of the concrete. Finally, the safety factor of the slab in direct shear from the submerged weight of the cask, is computed in Appendix E as 2.22.

9.0 SUMMARY

Seismic analyses have been performed to evaluate the loads applied to the HI-STAR HB, MPC and lid restraint system. Four sets of seismic events for the DBE and SSEERFB conditions have been considered and impact load-time histories have been developed.

Reported are peak accelerations at the top and bottom of the HI-STAR HB and the MPC. The results demonstrate that the peak accelerations of the cask and its contents remain below the design basis limit for the cask and its contents while in the RFB (SSERFB seismic event) and on the path immediately outside the RFB (DBE seismic event).

The key lid restraint loads that are developed when the cask overturns under the DBE event are reported for use in subsequent design and analysis.

The rail bay floor slab is evaluated for dead load and for dead + seismic load combinations and shown to meet the Part 50 structural integrity requirements.

The original design basis calculation for the East Caisson limiting wall is revisited and it is shown that only a slight increase in limiting stress is observed.

10.0 FIGURES

Proprietary Information Deleted

FIGURE 1 – HI-STAR HB Dynamic Model (dolly not shown)

Proprietary Information Deleted

FIGURE 2 – Humboldt Bay Dolly Model (cask not shown)

Proprietary Information Deleted

FIGURE 3 - Component Mass Values

Proprietary Information Deleted

FIGURE 4 - Contact Stiffness/Damping and Friction for Ground and Roller

Proprietary Information Deleted

FIGURE 5 - Input Inertia Force for HI STAR HB – Set 1 DBE

Proprietary Information Deleted

FIGURE 6 – Input Inertia Force for HI-STAR HB – Set 1 SSEERFB

Proprietary Information Deleted

FIGURE 7 – SSEERFB. Set 1 Acceleration results

Proprietary Information Deleted

FIGURE 8 – SSEERFB, Set 2, Acceleration Results

Proprietary Information Deleted

FIGURE 9 – SSEERFB, Set 3, Acceleration Results

Proprietary Information Deleted

FIGURE 10 – SSEERFB, Set 4, Acceleration Results

Proprietary Information Deleted

FIGURE 11 – SSEERFB, Set 1, Force Results

Proprietary Information Deleted

FIGURE 12 – SSEERFB, Set 2, Force Results

Proprietary Information Deleted

FIGURE 13 – SSEERFB, Set 3, Force Results

Proprietary Information Deleted

FIGURE 14 – SSEERFB, Set 4, Force Results

Proprietary Information Deleted

FIGURE 15 – DBE, Set 1, Acceleration Results

Proprietary Information Deleted

FIGURE 16 – DBE, Set 2, Acceleration Results

Proprietary Information Deleted

FIGURE 17 – DBE, Set 3, Acceleration Results

Proprietary Information Deleted

FIGURE 18 – DBE, Set 4, Acceleration Results

Proprietary Information Deleted

FIGURE 19 – DBE, Set 1, Force Results

Proprietary Information Deleted

FIGURE 20 – DBE, Set 2, Force Results

Proprietary Information Deleted

FIGURE 21 – DBE, Set 3, Force Results

Proprietary Information Deleted

FIGURE 22 – DBE, Set 4, Force Results

Proprietary Information Deleted

FIGURE 23 – Available Output for SSEERFB and DBE Events

Proprietary Information Deleted

FIGURE 24 – SSEERFB Set 1 – Displacement Results for Interface Coefficient = 0.05

Proprietary Information Deleted

FIGURE 25 – SSEERFB Set 1 –Angular Rotation Results for Interface Coefficient = 0.8

Proprietary Information Deleted

FIGURE 26 – Individual Roller – Ground Forces for SET 1 SSEERFB, COF = 0.8

Proprietary Information Deleted

FIGURE 27 – Roller –Ground Forces Per Rail and Total for Two Rails SET 1 SSEERFB COF=0.8

Proprietary Information Deleted

FIGURE 28 - Dead + Seismic Loading – Slab Mesh

Proprietary Information Deleted

FIGURE 29 - Dead + Seismic Deformation Pattern

Proprietary Information Deleted

FIGURE 30 Dead + Seismic Stress SX

Proprietary Information Deleted

FIGURE 31 Dead + Seismic Stress SY

Proprietary Information Deleted

FIGURE 32 Dead Load – Deformation Profile

Proprietary Information Deleted

FIGURE 33 Dead Load Bending Stress SX

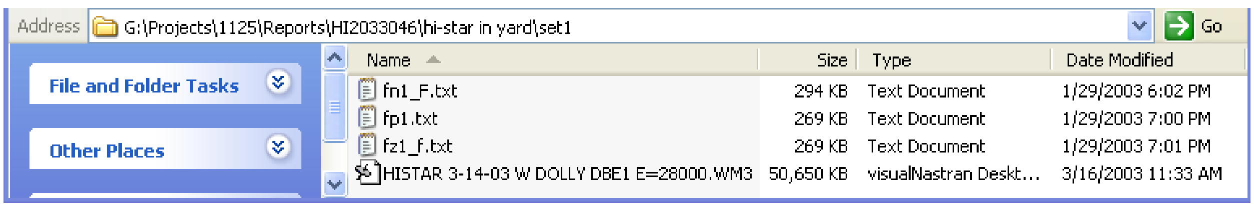
Proprietary Information Deleted

FIGURE 34 Dead Load Stress SY

11.0 COMPUTER FILES AND PROGRAMS

G:\projects\1125\reports\HI2033046\report

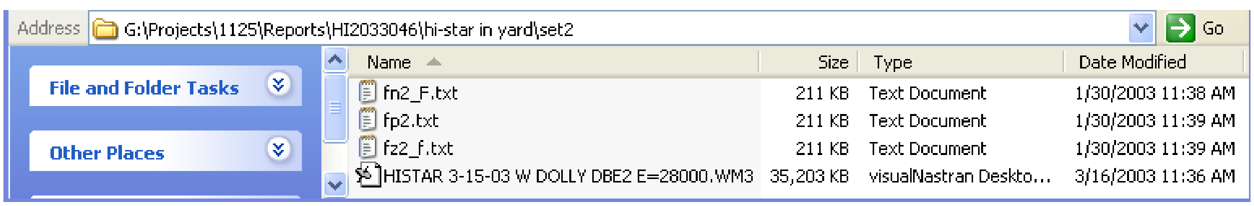
app A.mcd	6,050 KB	Mathcad Document	7/9/2003 8:26 AM
app A.pdf	321 KB	Adobe Acrobat Docu...	7/9/2003 8:29 AM
app B.pdf	134 KB	Adobe Acrobat Docu...	6/27/2003 1:03 PM
app C.doc	19 KB	Microsoft Word Docu...	6/26/2003 2:46 PM
app C.pdf	181 KB	Adobe Acrobat Docu...	6/26/2003 2:51 PM
app D.doc	89 KB	Microsoft Word Docu...	10/26/2003 11:08 PM
Appendix E.mcd	787 KB	Mathcad Document	10/26/2003 10:33 PM
cover.pdf	86 KB	Adobe Acrobat Docu...	6/27/2003 3:35 PM
hbtextdead.rtf	80 KB	Rich Text Format	10/26/2003 8:47 AM
HI-2033046r0 draft 07-09-03.pdf	4,091 KB	Adobe Acrobat Docu...	7/9/2003 8:31 AM
HI-2033046r0.doc	4,293 KB	Microsoft Word Docu...	10/26/2003 11:05 PM
results.doc	1,074 KB	Microsoft Word Docu...	6/26/2003 3:55 PM
~WRL3111.tmp	4,295 KB	TMP File	10/26/2003 9:37 AM
app D.pdf	110 KB	Adobe Acrobat Docu...	10/26/2003 11:08 PM


Address G:\Projects\1125\Reports\HI2033046\hi-star in yard\set1

File and Folder Tasks

Other Places

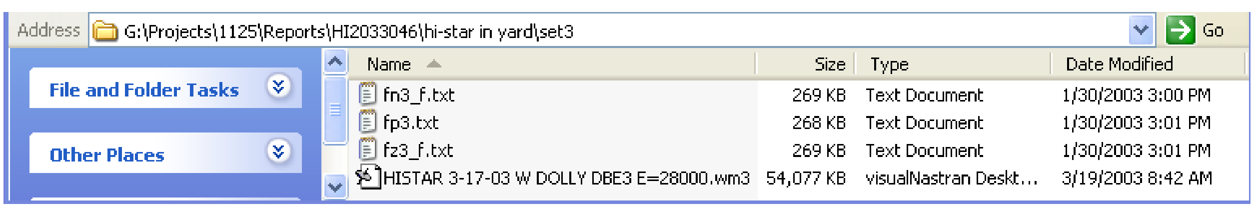
Name	Size	Type	Date Modified
fn1_F.txt	294 KB	Text Document	1/29/2003 6:02 PM
fp1.txt	269 KB	Text Document	1/29/2003 7:00 PM
fz1_f.txt	269 KB	Text Document	1/29/2003 7:01 PM
HISTAR 3-14-03 W DOLLY DBE1 E=28000.WM3	50,650 KB	visualNastran Deskt...	3/16/2003 11:33 AM


Address G:\Projects\1125\Reports\HI2033046\hi-star in yard\set2

File and Folder Tasks

Other Places

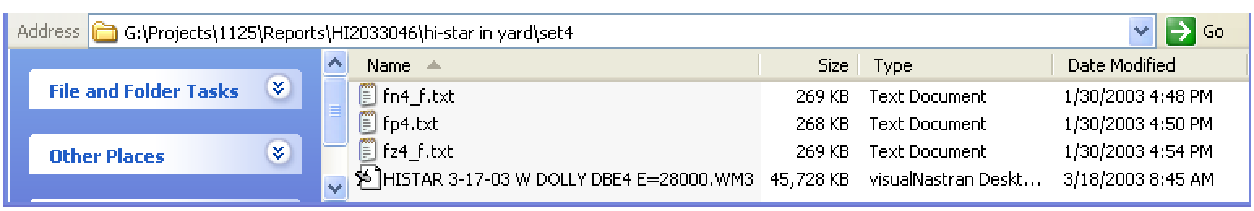
Name	Size	Type	Date Modified
fn2_F.txt	211 KB	Text Document	1/30/2003 11:38 AM
fp2.txt	211 KB	Text Document	1/30/2003 11:39 AM
fz2_f.txt	211 KB	Text Document	1/30/2003 11:39 AM
HISTAR 3-15-03 W DOLLY DBE2 E=28000.WM3	35,203 KB	visualNastran Deskto...	3/16/2003 11:36 AM


Address G:\Projects\1125\Reports\HI2033046\hi-star in yard\set3

File and Folder Tasks

Other Places

Name	Size	Type	Date Modified
fn3_f.txt	269 KB	Text Document	1/30/2003 3:00 PM
fp3.txt	268 KB	Text Document	1/30/2003 3:01 PM
fz3_f.txt	269 KB	Text Document	1/30/2003 3:01 PM
HISTAR 3-17-03 W DOLLY DBE3 E=28000.wm3	54,077 KB	visualNastran Deskt...	3/19/2003 8:42 AM


Address G:\Projects\1125\Reports\HI2033046\hi-star in yard\set4

File and Folder Tasks

Other Places

Name	Size	Type	Date Modified
fn4_f.txt	269 KB	Text Document	1/30/2003 4:48 PM
fp4.txt	268 KB	Text Document	1/30/2003 4:50 PM
fz4_f.txt	269 KB	Text Document	1/30/2003 4:54 PM
HISTAR 3-17-03 W DOLLY DBE4 E=28000.WM3	45,728 KB	visualNastran Deskt...	3/18/2003 8:45 AM

Address G:\Projects\1125\Reports\HI2033046\rfb seismic analysis\set1

File and Folder Tasks

Other Places

Name	Size	Type	Date Modified
HISTAR 3-16-03 W DOLLY RFB1 E=28000.WM3	67,935 KB	visualNastran Deskt...	3/20/2003 8:34 AM
Set1 AccelH1.txt	168 KB	Text Document	2/21/2003 5:02 PM
Set1 AccelH2.txt	168 KB	Text Document	2/21/2003 5:03 PM
Set1 AccelUP.txt	168 KB	Text Document	2/21/2003 5:05 PM

Address G:\Projects\1125\Reports\HI2033046\rfb seismic analysis\set2

File and Folder Tasks

Other Places

Name	Size	Type	Date Modified
HISTAR 3-18-03 W DOLLY RFB2 E=28000.WM3	17,514 KB	visualNastran Deskt...	3/18/2003 6:20 AM

Address G:\Projects\1125\Reports\HI2033046\rfb seismic analysis\set3

File and Folder Tasks

Other Places

Name	Size	Type	Date Modified
HISTAR 3-19-03 W DOLLY RFB3 E=28000.WM3	66,946 KB	visualNastran Deskt...	6/26/2003 9:49 AM
Set 3 RFBH1.txt	150 KB	Text Document	3/18/2003 7:48 PM
Set 3 RFBH2.txt	149 KB	Text Document	3/18/2003 7:50 PM
Set 3 RFBVT.txt	150 KB	Text Document	3/18/2003 7:51 PM

Address G:\Projects\1125\Reports\HI2033046\rfb seismic analysis\set4

File and Folder Tasks

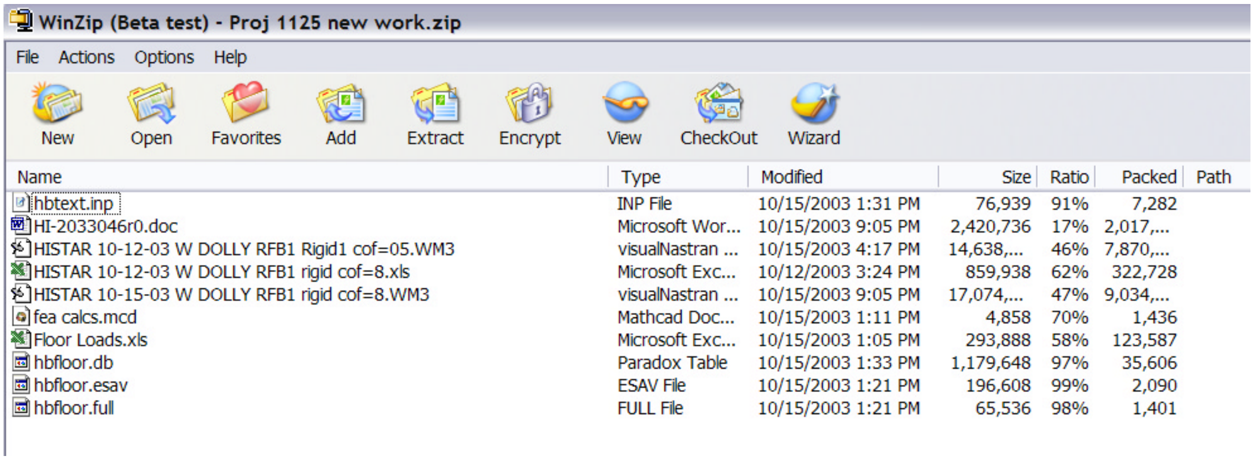
Other Places

Name	Size	Type	Date Modified
HISTAR 3-19-03 W DOLLY RFB4 E=28000.WM3	43,113 KB	visualNastran Deskt...	3/21/2003 4:28 PM
Set 4 AccelH1.txt	252 KB	Text Document	3/19/2003 8:59 AM
Set 4 AccelH2.txt	252 KB	Text Document	3/19/2003 9:00 AM
Set 4 AccelUP.txt	252 KB	Text Document	3/19/2003 9:01 AM

g:\projects\1125\reports\hi2033046\rfb seismic analysis

set1		File Folder	10/5/2003 9:11 PM
set2		File Folder	10/5/2003 9:10 PM
set3		File Folder	10/5/2003 9:10 PM
set4		File Folder	10/5/2003 9:10 PM
fea calcs.mcd	5 KB	Mathcad Document	10/15/2003 12:11 PM
file000.bmp	2,869 KB	Bitmap Image	10/23/2003 12:55 PM
file001.bmp	2,869 KB	Bitmap Image	10/23/2003 12:56 PM
file002.bmp	2,869 KB	Bitmap Image	10/23/2003 12:57 PM
file.db	2,752 KB	Paradox Table	10/23/2003 12:57 PM
file.err	1 KB	ERR File	10/23/2003 12:53 PM
file.esav	768 KB	ESAV File	10/23/2003 12:54 PM
file.full	448 KB	FULL File	10/23/2003 12:54 PM
file.log	3 KB	Text Document	10/23/2003 12:57 PM
file.mntr	1 KB	MNTR File	10/23/2003 12:54 PM
file.page	0 KB	PAGE File	10/23/2003 12:41 PM
file.rst	1,024 KB	RST File	10/23/2003 12:54 PM
floor load under dead.zip	747 KB	WinZip File	10/23/2003 12:58 PM
floor load under seismic.zip	2,427 KB	WinZip File	10/23/2003 12:37 PM
Floor Loads.xls	287 KB	Microsoft Excel Works...	10/15/2003 12:05 PM
hbtextdead.inp	76 KB	INP File	10/23/2003 12:52 PM
HISTAR 10-12-03 W DOLLY RFB1 Rigid1 cof=05.WM3	14,296 KB	visualNastran Desktop...	10/15/2003 3:17 PM
HISTAR 10-12-03 W DOLLY RFB1 rigid cof=8.xls	840 KB	Microsoft Excel Works...	10/12/2003 2:24 PM
HISTAR 10-15-03 W DOLLY RFB1 rigid cof=8.WM3	16,675 KB	visualNastran Desktop...	10/15/2003 8:05 PM
scratch.hlp	1 KB	Help File	10/23/2003 12:57 PM

G:\projects\1125\ais\general analysis\rfb seismic analysis (project 1125 new work.zip)



Name	Type	Modified	Size	Ratio	Packed	Path
hbtext.inp	INP File	10/15/2003 1:31 PM	76,939	91%	7,282	
HI-2033046r0.doc	Microsoft Wor...	10/15/2003 9:05 PM	2,420,736	17%	2,017,...	
HISTAR 10-12-03 W DOLLY RFB1 Rigid1 cof=05.WM3	visualNastran ...	10/15/2003 4:17 PM	14,638,...	46%	7,870,...	
HISTAR 10-12-03 W DOLLY RFB1 rigid cof=8.xls	Microsoft Exc...	10/12/2003 3:24 PM	859,938	62%	322,728	
HISTAR 10-15-03 W DOLLY RFB1 rigid cof=8.WM3	visualNastran ...	10/15/2003 9:05 PM	17,074,...	47%	9,034,...	
fea calcs.mcd	Mathcad Doc...	10/15/2003 1:11 PM	4,858	70%	1,436	
Floor Loads.xls	Microsoft Exc...	10/15/2003 1:05 PM	293,888	58%	123,587	
hbfloor.db	Paradox Table	10/15/2003 1:33 PM	1,179,648	97%	35,606	
hbfloor.esav	ESAV File	10/15/2003 1:21 PM	196,608	99%	2,090	
hbfloor.full	FULL File	10/15/2003 1:21 PM	65,536	98%	1,401	

The QA validated computer programs used to create this report are listed in Appendix D.

12.0 APPENDICES

Appendix A - Calculations Supporting VisualNastran Simulations

Appendix B - QA Validation for Direction of DBE Vertical Earthquakes

Appendix C – Fault Line, Plant North, and True North Orientation

Appendix D – Approved Computer Program List

Appendix E - Floor Slab Structural Integrity Calculations

Appendix F - ANSYS Input File (Dead Load Case)

Appendix G – Revised Bechtel Calculation Pages

Appendices A, E, F and G Contain Proprietary Information and have been Deleted

Facsimile Cover Sheet

To: Alan Soler
Department: Holtec
Phone: 856-797-0900
Fax: 856-797-0909

From: Larry Pulley
Department: HBIP
Phone: 707-444-0859
Fax: 707-444-0736

Date: 5/12/2003
Pages including this cover page: 5

Alan:

I have enclosed the 4 sets of vertical time history plots from calculation GEO.HBIP.02.05, Rev 0. Per this calculation, the time histories are to be run in the direction they are provided. This shows that the final permanent displacement is "up" at the location of the ISFSI.

The use of this calculation is QA validation for only running vertical time histories in one direction.

Please call me if you have any questions.

Thanks;

Larry Pulley

PROJ 1125

HI-2033046

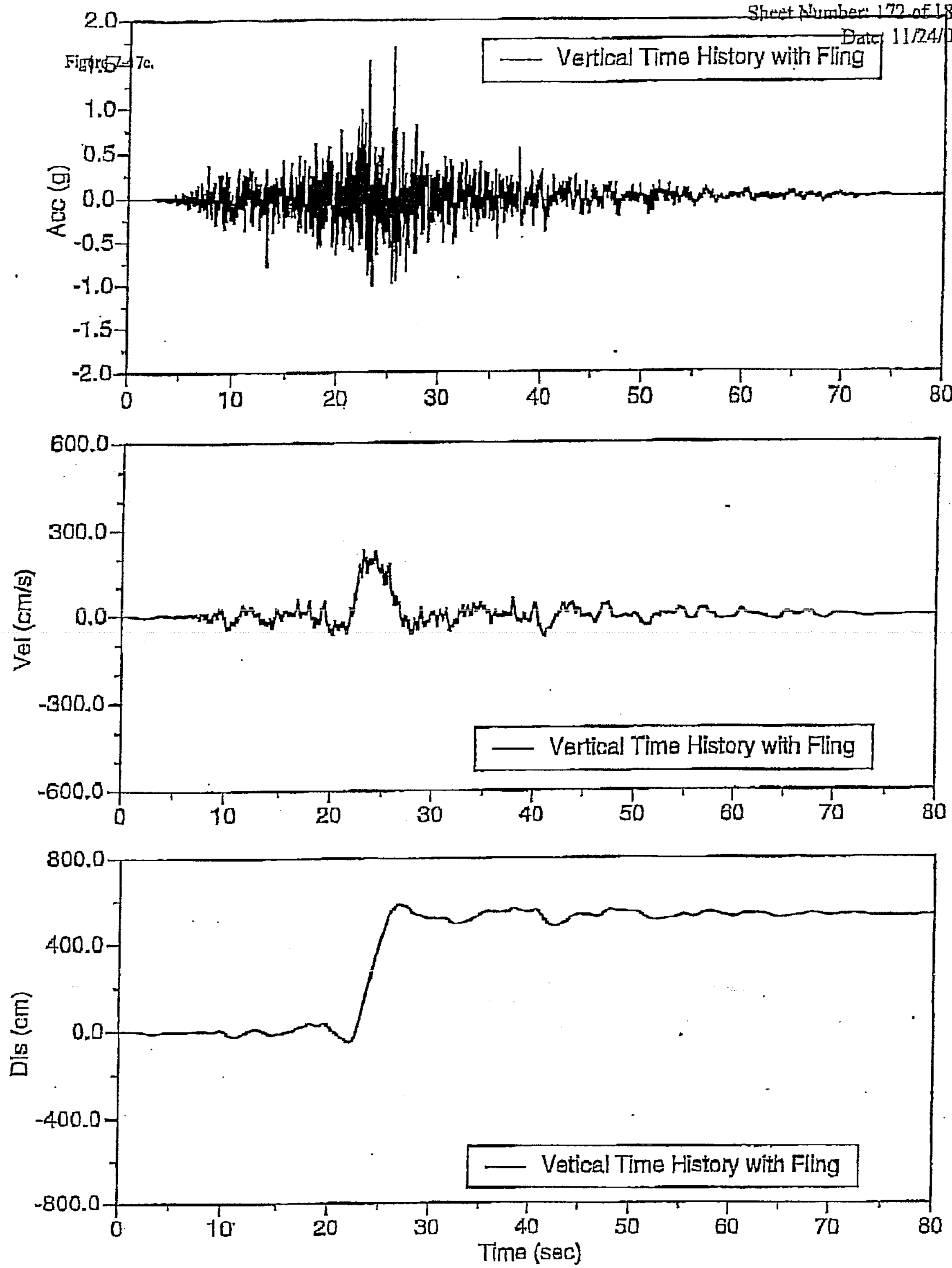


Figure 7-47c. Synchronous Set1 vertical modified acceleration, velocity, and displacement time histories with fling.

Proj. 1125

B-2 of 5

HI-2033046

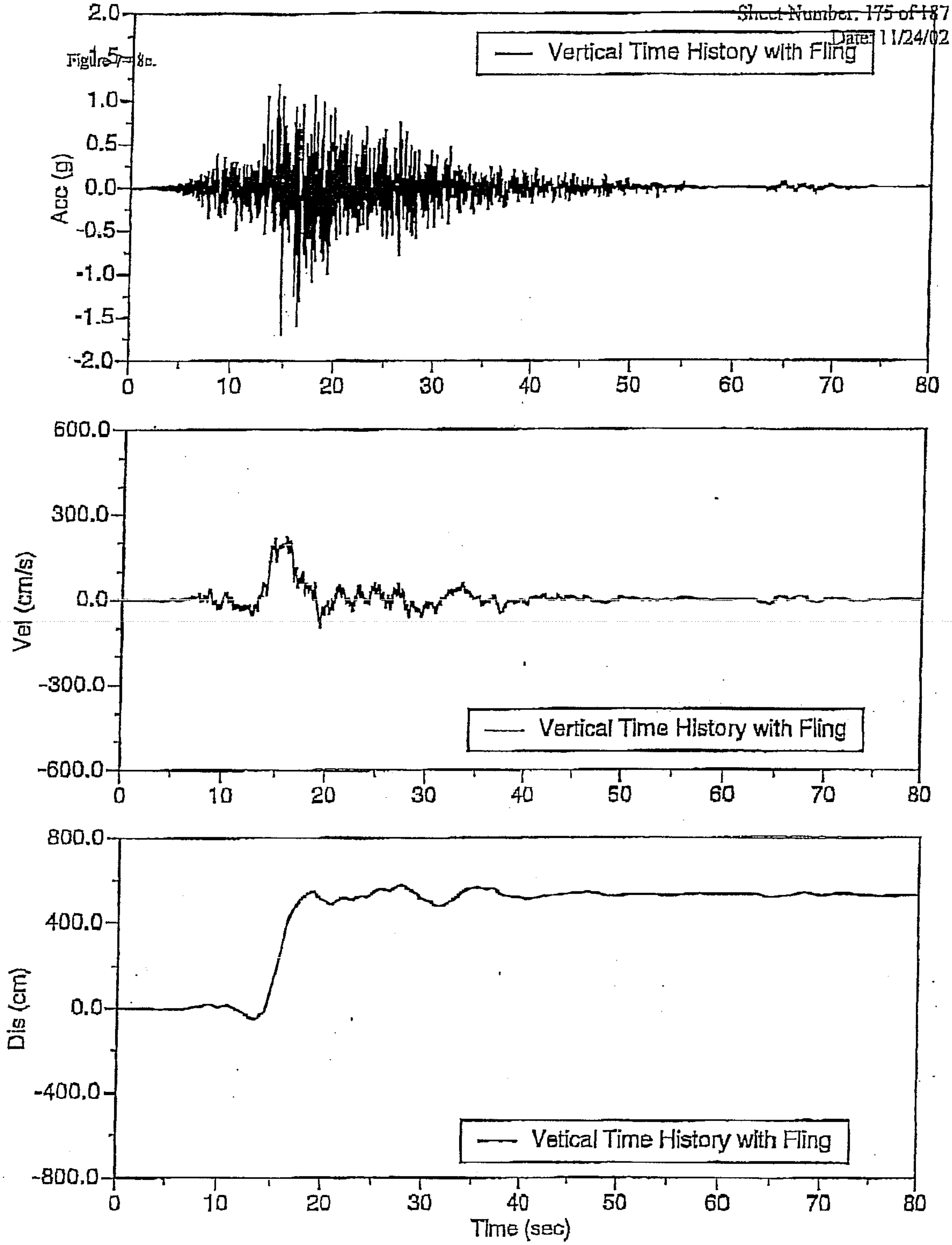


Figure 7-48c. Synchronous Set2 vertical modified acceleration, velocity, and displacement time histories with fling.

Proj. 1125

B-3 of

HI-2033046

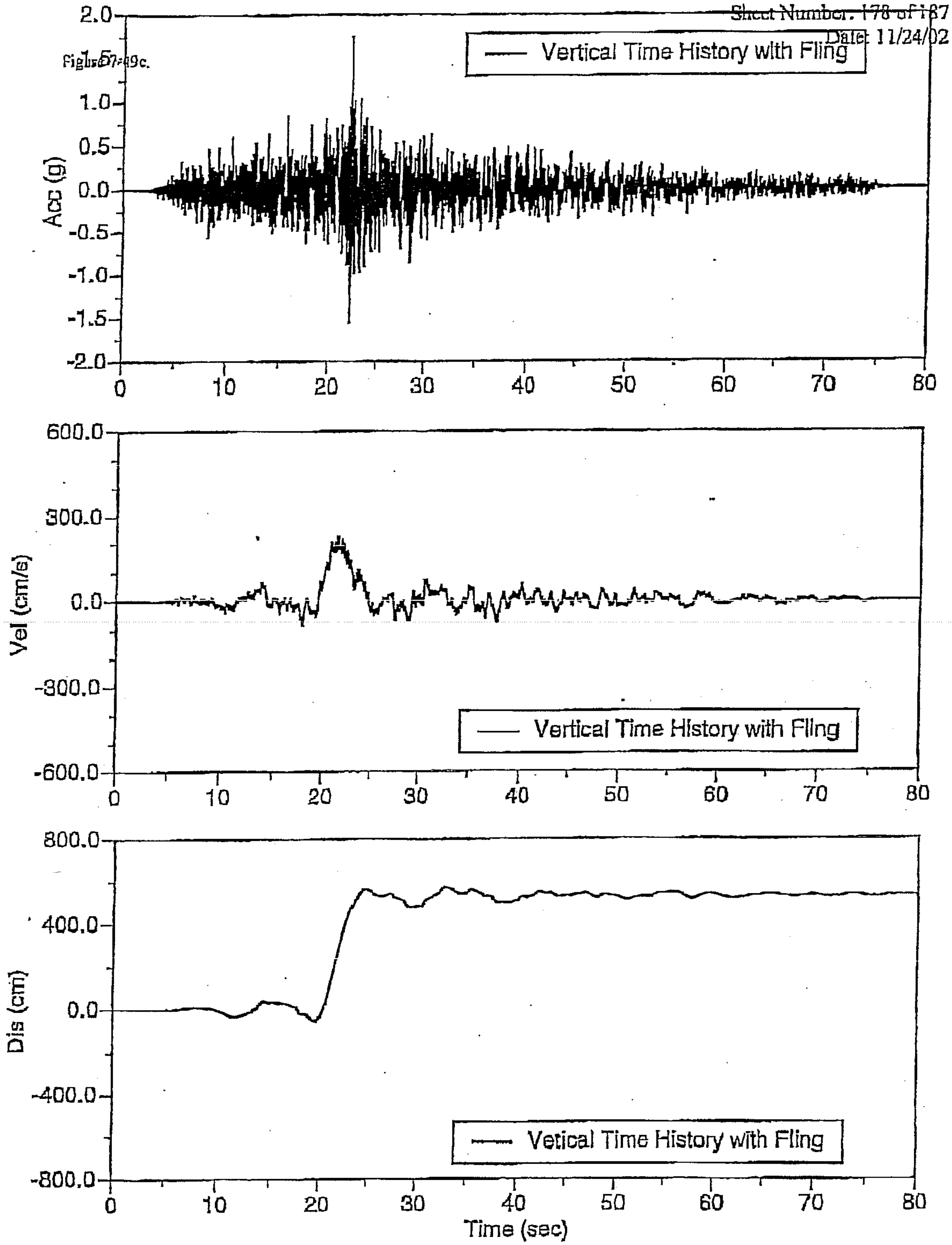


Figure 7-49c. Synchronous Set3 vertical modified acceleration, velocity, and displacement time histories with fling.

Proj. 1125

B-4 of 5.

HI-2033046

Figure 7-50c.

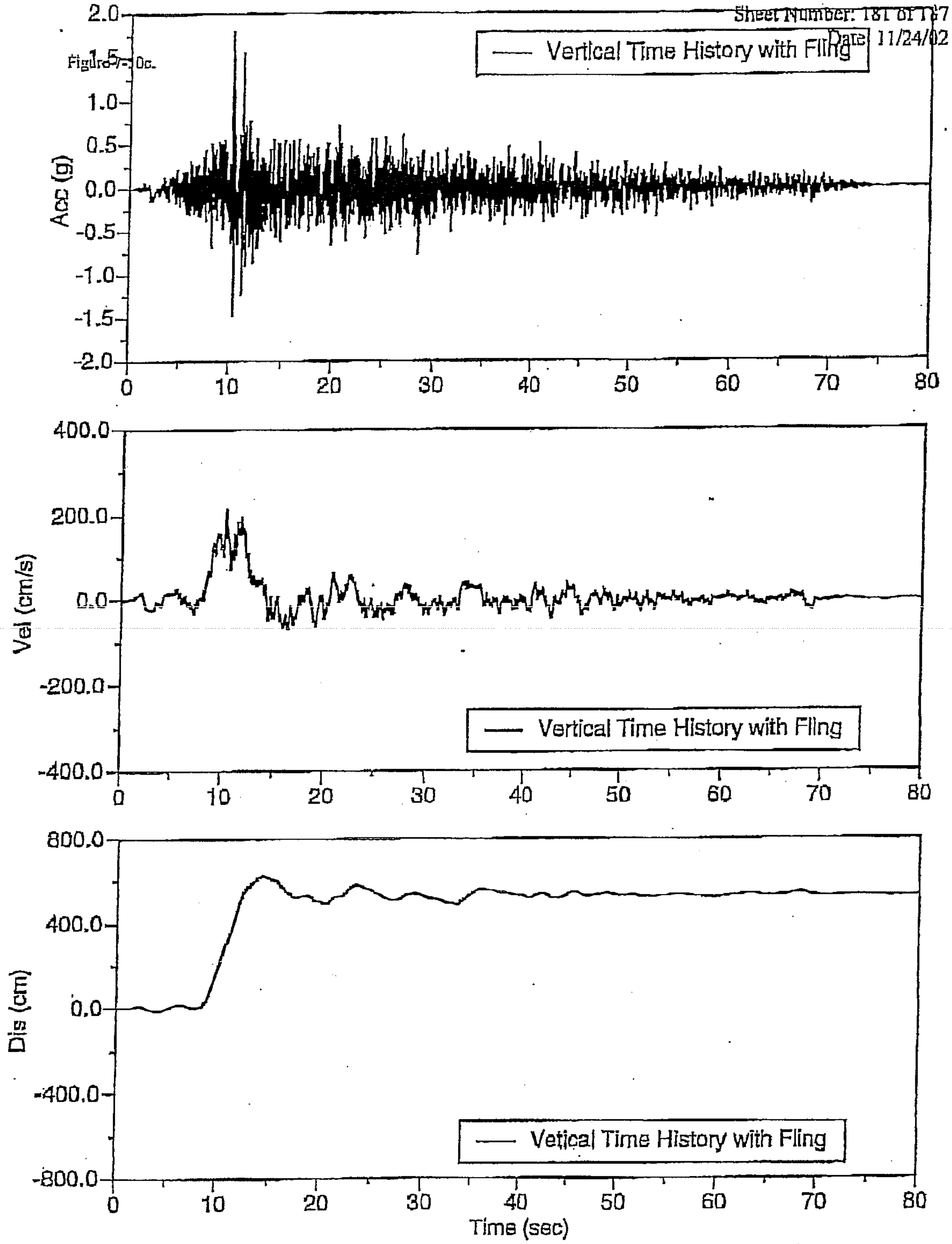


Figure 7-50c. Synchronous Set4 vertical modified acceleration, velocity, and displacement time histories with fling.

Proj. 1125

B5 of 5

HI-2033046

HUMBOLDT BAY CASK STORAGE VAULT, FAULT LINE, AND TRUE NORTH ORIENTATION

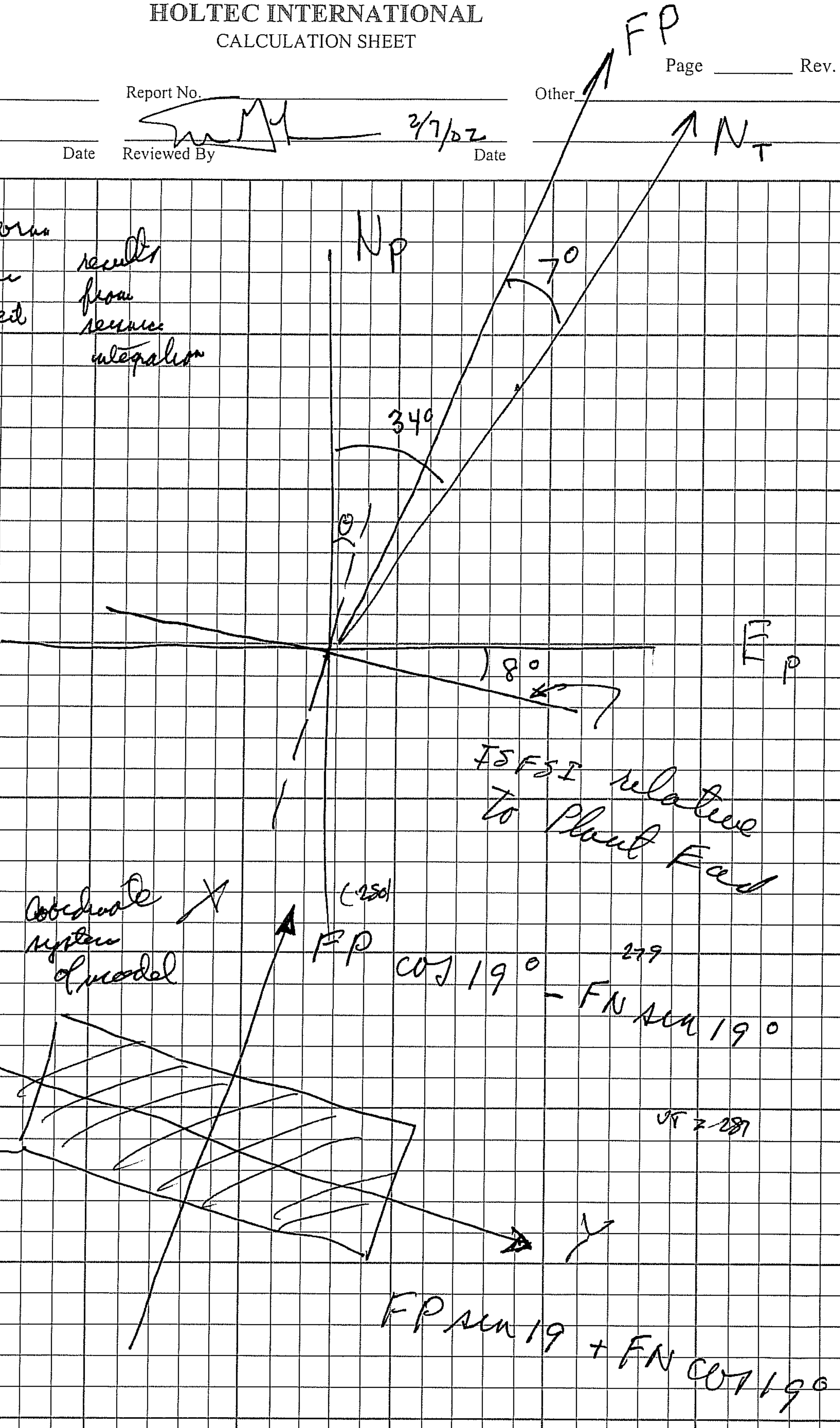
Page ________ Rev. ________

Project No. 1125 | Report No. ________ | Other ________

Prepared By ________ Date ________ | Reviewed By ________ Date 2/7/02

x = fault normal
y = fault par
z = fault vert

results from seismic integration



8000

HOLTEC APPROVED COMPUTER PROGRAM LIST

(Total No. of Pages = 5)

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 59 June 25th, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
ANSYS (A)	5.3, 5.4, 5.6,5.6.2,5.7,7.0	JZ, EBR, PKC, CWB, SPA, AIS, IR, SP, JRT,AK	Windows		7.0 and 5.7
AC-XPERT	1.12		Windows		
AIRCOOL	5.2I, 6.1		Windows		
BACKFILL	2.0		DOS/ Windows		
BONAMI (Scale)	4.3, 4.4		Windows		
BULKTEM	3.0		DOS/ Windows		
CASMO-4 (A)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ELR, SPA, DMM, KC, ST,VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects. The user should refer to the error notice documented in c4ser.04-results.pdf located in \generic\library\ nuclear\error notices\ concerning the use of version 1.13.04. Library N should be used with version 2.05.03 for all new reports issued after June 1st, 2003. Revisions to reports issued prior to June 1st, 2003 may continue to use the old Library L.	
CASMO-3 (A)	4.4, 4.7	ELR, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		
CHANBP6 (A)	1.0	SJ, PKC, CWB, AIS, SP,JRT	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 59 June 25th, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
DÉCOR	1.0		DOS/Windows		
DR.BEAMPRO	1.0.5		Windows		
DR.FRAME	2.0		Windows		
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ, JRT	DOS/Windows	Personnel qualified to use MR216 are automatically qualified to use DYNAMO.	
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.48, 4.56, 5.1 (see error notice), 4.2.8 (UNS),5.5, 6.1.18	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST,VJB	Windows		
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950, 960, 970	JZ, AIS, SPA, SP	Windows		
MAXDIS16	1.0		DOS/Windows		
MCNP (A)	4A, 4B	ELR, SPA, KC,ST,DMM, VJB, MAP	Windows/ UNIX	CASMO-4 Lumped Fission Products (IDs 401 and 402) and Isotope Pm148M (ID 61248) can be modeled in MCNP 4A using the cross sections documented in HI-2033031. Use of these cross sections is restricted to MCNP 4A, and to material specifications in atom densities.	
MASSINV	1.4, 1.5, 2.1		DOS/Windows		
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PKC, SJ,JRT	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 59 June 25th, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
MSREFINE	1.3, 2.1		DOS/Windows		
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4,2002		Windows		2002
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		
ORIGENS (Scale)	4.3, 4.4		Windows		
PD16	1.1, 1.0, 2.0		Windows		
PREDYNA1	1.5, 1.4		DOS/Windows		
PSD1	1.0		DOS/Windows		
QAD	CGGP		Windows		
SAS2H (Scale)	4.3, 4.4		Windows		
SFMR2A	1.0		DOS/Windows		
SHAPEBUILDER	3.0		DOS/Windows		
SIFATIG	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 59 June 25th, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
SOLIDWORKS	2001		DOS/Windows	This program may be used to calculate Weight, Volume, Centroid and Moment of Inertia. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session. If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	2001
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 59 June 25th, 2003	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

NOTES:
1. XXXX = ALPHANUMERIC COMBINATION
2. GENERAL PURPOSES UTILITY CODES (MATHCAD, EXCEL, ETC.) MAYBE USED ANYTIME.

HOLTEC INTERNATIONAL

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

ISFSI DOSE ASSESSMENT FOR HUMBOLDT BAY

FOR

PG&E

Holtec Report No: HI-2033047

Holtec Project No: 1125

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT ISSUANCE AND REVISION STATUS[1]

DOCUMENT NAME: ISFSI Dose Assessment for Humboldt Bay

DOCUMENT NO.:	2033047	CATEGORY: ☐	GENERIC
PROJECT NO.:	1125	☒	PROJECT SPECIFIC

Rev. No.[2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	12/16/03	VJB	775981				

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)

Documents labeled "Privileged Intellectual Property" contain extremely valuable intellectual/commercial property of Holtec International. They cannot be released to external organizations or entities without explicit approval of a company corporate officer. The recipient of Holtec's proprietary or Privileged Intellectual Property document bears full and undivided responsibility to safeguard it against loss or duplication.

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 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 "Table of Contents", this page and the "Revision Log".

Summary of Revisions

Revision 0

Original Issue

Table of Contents

1. Introduction

1.1 Statement of Purpose

This report documents the radiation shielding analysis that was performed for the Independent Spent Fuel Storage Installation (ISFSI) at Humboldt Bay Power Plant (HBPP). This shielding analysis includes calculation of the dose rates from the HI-STAR HB Vault System at the controlled area boundary. Occupational exposures during loading and unloading operations of a HI-STAR HB overpack and maintenance and surveillance operations around the ISFSI are estimated in this report. This report also addresses the radiation consequences of loss of neutron shielding as a result of a fire accident during transfer of a loaded HI-STAR HB to the storage vault.

In its fully implemented final configuration, this facility will consist of an underground concrete vault containing 6 HI-STAR HB casks in a 1 x 6 configuration, each loaded with an MPC-HB. One of the casks will contain GTTC waste and five will contain fuel, however, all six casks are assumed to be fuel in this analysis and HBPP will demonstrate that the GGTC cask is bounded by a fuel cask. The MPC-HB stores 80 Humboldt Bay BWR fuel assemblies. The center to center pitch between each vault storage cell is 10 feet 9 inches. Dose rates from the storage vault array are calculated along the top lid of the vault and at the site boundary. It is assumed that the canisters will not leak, so only dose from direct radiation is considered in this report.

1.2 About This Document

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.

2. General Methodology

The analysis of the Humboldt Bay ISFSI can be separated into two distinct parts. The first is the generation of the radiation source terms to represent the spent nuclear fuel at the appropriate burnup and cooling time. The second part is the radiation transport simulation to calculate the dose rates near and far from the vault array and a single HI-STAR HB cask.

The radiation source terms were calculated using the SAS2H and ORIGEN-S modules from the SCALE 4.4 [1,2] code system from Oak Ridge National Laboratory. This is a widely accepted means of generating radiation source terms from spent nuclear fuel.

The radiation transport simulation was performed with MCNP 4A [3] from Los Alamos National Laboratory. This is a state of the art Monte Carlo code that offers coupled neutron-gamma transport using continuous energy cross sections in a full three-dimensional geometry.

The specifics of the radiation source term calculations and radiation transport simulation are discussed below.

3. Acceptance Criteria

The acceptance criteria for offsite dose rates are dictated by 10CFR72.104 and 10CFR72.106 and are summarized below.

Normal condition requirements from 10CFR72.104.

1. During normal operations and anticipated occurrences, the annual dose equivalent to any real individual who is located beyond the controlled area, must not exceed 25 mrem to the whole body, 75 mrem to the thyroid and 25 mrem to any other critical organ.
2. Operational restrictions must be established to meet as low as reasonably achievable (ALARA) objectives for radioactive materials in effluents and direct radiation.

Accident condition requirements from 10CFR72.106

> Any individual located on or beyond the nearest boundary of the controlled area may not receive from any design basis accident the more limiting of a total effective dose equivalent of 5 Rem, or the sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue (other than the lens of the eye) of 50 Rem. The lens dose equivalent shall not exceed 15 Rem and the shallow dose equivalent to skin or to any extremity shall not exceed 50 rem. The minimum distance from the spent fuel or high level radioactive waste handling and storage facilities to the nearest boundary of the controlled area shall be at least 100 meters.

This report demonstrates that the ISFSI meets the above stated acceptance criteria for dose at distances less than 100 meters.

For onsite dose rates, the following dose rate limits are used which are consistent with the requirements specified in 10CFR20:

5 rem/year for personnel with dose rate monitors (10CFR20.1201)

0.5 rem/year for personnel without dose rate monitors (10CFR20.1201 and 1502)

2 mrem in any one hour and 100 mrem/year for individual members of the public (10CFR20.1301)

This report demonstrates that the ISFSI is capable of meeting the above stated acceptance criteria. Compliance with 10CFR20 will be demonstrated by personnel dose monitoring in accordance with the Humboldt Bay Health Physics Program.

4. Assumptions

The following assumptions are used in this analysis:

1. It is assumed that the occupancy factor for the closest resident beyond the site boundary is 8760 hr, which is full occupancy for the entire year.
2. In compliance with the applicable portions of [8], it is assumed that the occupancy factor for the nearest site boundary is 2080 hr. This assumption is based on the approach to identify individuals within the geographic location of the ISFSI, and estimate their maximum radiological exposure. The area directly outside the unrestricted area boundary is uninhabited. As a bounding approach, it is estimated that the individual with the maximum exposure would be an individual working outside the boundary for the entire year. The occupancy is then calculated based on a working week of 40 hours and 52 weeks/year.
3. It is assumed that the occupancy factor for the occupational dose rate is 2080 hr, which is based on a working week of 40 hours and 52 weeks/year.
4. The dose rate limitation of 100 mrem/year specified by 10CFR20 is met based on a 2080 hr/yr occupancy at the security fence, which is assumed to be at greater then 25 feet from the edge of the ISFSI.
5. For generating source terms, all BWR fuel assemblies are assumed to be GE Type III 6x6. This is the most abundant assembly type in the Humboldt Bay inventory and has the highest Uranium mass, which yields the highest source term. The design basis assembly is further discussed in Section 7.1.1.
6. It is assumed that the facility is filled to its maximum capacity in each phase, and that all 6 HI-STAR casks are loaded with fuel of 23,000 MWD/MTU burnup, 2.09 wt% initial average enrichment, and 29 year cooling time at the time of loading. This burnup, cooling time, and initial enrichment bounds all fuel in the Humboldt Bay spent fuel inventory as discussed in Section 7.1.
7. The cobalt-59 impurity level was assumed to be 1.0 gm/kg for the steel hardware, and 4.7 gm/kg in the inconel above and below the active fuel region and for the grid spacers as discussed in Section 7.1.4.
8. It is conservatively assumed that all in-core grid spacers are non-zircaloy, therefore a Cobalt impurity activation source term is calculated and added to the fuel gamma source.

9. The air density was assumed to be 1.17E-03 gm/cc and the air was assumed to be composed of only Nitrogen and Oxygen.
10. The site boundary and nearest resident are assumed to be 50 and 800 feet from the center of the ISFSI. These bound the values in [7,12].
11. Assumed the same operating parameters for generating the source terms as [13].

Other assumptions are stated in the text as necessary.

5. Input Data

The input data for generating the radiation source terms was taken from [7, 10] and is provided in Table A1 in Appendix A. The input data for the MCNP models of the overpack and the MPC dimensions are provided in the drawings listed in Section 10 of this report, and the material compositions are the same as used in [4] with the exception of the neutron poison material and steal, which is taken from [9]. The fuel assemblies are not modeled explicitly in MCNP, instead the pellet and cladding material is homogenized within the basket cell using a width of 6 times the fuel rod pitch. This has been shown to be acceptable as discussed in [4]. The homogenized fuel composition and density is provided in Appendix A.

5.1 ISFSI Geometry

The Humboldt Bay ISFSI vault houses 6 storage casks. The ISFSI configuration is specified in [7]. The ISFSI will be a 1x 6 array of cask vault cells. The center to center pitch for the vaults is 10 feet 9 inches. Dose rates are calculated along the top lid of the vault and at a distance of 50 feet away from the array center line. The array is conservatively modeled as an infinite line of loaded vault cells.

6. Computer Codes

The computer codes used for these calculations were the following.

1. SAS2H module from SCALE 4.4 - reference [1]
2. ORIGEN-S module from SCALE 4.4 - reference [2]
3. MCNP 4A - reference [3]

7. Analysis and Results

This section of the report describes the calculations that were performed to determine the dose rates for various distances and locations. The basic development of the MCNP models for a generic HI-STAR loaded with an MPC, including source terms and tally normalization, had already been accomplished during the HI-STAR 100 project. This information is appropriately referenced as needed.

7.1 Source Terms

Shielding analyses for dose rates from direct radiation were performed assuming that the overpacks contain MPC-HBs completely loaded with fuel assemblies having identical burnup and cooling times. The burnup was assumed to be 23,000 MWD/MTU with a cooling time of 29 years.

Humboldt Bay Power Plant (HBPP) ceased operations in July of 1976. Based on a cask loading date of July 2005, the minimum cooling time is 29 years. However, the vast majority of the fuel assemblies will have considerably longer cooling time. The burnup of 23,000 MWD/MTU was chosen because it is a bounding burnup for all fuel assemblies in the inventory. An enrichment of 2.09 wt.% ^{235}U was used for the shielding analysis. This enrichment is the lowest nominal initial assembly planar average enrichment and is conservative since lower enrichments result in slightly higher neutron source terms.

The principal sources of direct radiation in the HI-STAR HB System are:

- Gamma radiation originating from the following sources
  - Decay of radioactive fission products
  - Secondary photons from neutron capture in fissile and nonfissile nuclides
  - Hardware activation products generated during power operations

- Neutron radiation originating from the following sources
  - Spontaneous fission
  - Alpha, neutron (α, n) reactions in fuel materials
  - Secondary neutrons produced by fission from subcritical multiplication
  - Gamma, n (γ, n) reactions (this source is negligible)

The foregoing can be grouped into three distinct sources, each of which is discussed in the sub-sections below: fuel-gamma source, fuel-neutron source, and non-fuel activation source. The source terms for the analyses presented in this report were calculated using the same methods described in [4]. The neutron and gamma source terms, along with the quantities of radionuclides available for release, were calculated with the SAS2H and ORIGEN-S modules of the SCALE 4.4 system [1,2]. Note that [4] used the SCALE 4.3 version.

7.1.1 Design Basis Assembly

The fuel assembly chosen as the design basis fuel assembly for the shielding analysis was the GE Type III fuel assembly because it has the highest uranium mass loading and therefore will have a higher source term for the same burnup and cooling time than the other HBPP fuel designs. In addition, this fuel assembly comprises the largest fraction of the Humboldt Bay spent fuel inventory. Table A1 in Appendix A provides a physical description of the design basis fuel assembly and Table A2 describes the axial configuration of this fuel assembly as it was modeled in the shielding analysis. The shielding model of the fuel is based on the design basis GE Type III assemblies with the exception that the pellet and clad dimensions were based on the Exxon IV fuel with a 2.8% enrichment, which conservatively yielded a lower homogenized density. The axial burnup profile used in these analyses is identical to that described in Chapter 2 of [4] for BWR fuel. Table A3 presents the axial burnup profile used in this analysis.

The HI-STORM 100 System FSAR [5] describes the shielding analysis to qualify generic damaged fuel assemblies. The discussion in Section 5.4.2 of [5] describes the effect of damaged fuel assemblies on the external dose rates. This discussion indicates that the change in dose rate associated with the storage of damaged fuel assemblies is not significant. Based on that analysis, a specific evaluation of HBPP damaged fuel assemblies was not performed. Rather, all assemblies in all casks were assumed to be intact at the design basis burnup and cooling times.

Five of the storage casks are HI-STAR HB Systems containing spent fuel from HBPP and the sixth cask contains greater-than-class-C (GTCC) waste from HBPP. For the purposes of the shielding analysis, all six vault storage cells were assumed to contain spent fuel in HI-STAR HB overpacks.

7.1.2 Fuel-Gamma Source

Table A4 in Appendix A presents the gamma source terms that were used for the active fuel portion of the design basis assembly. The source is presented in both MeV/sec and photons/sec for an energy range of 0.45 MeV to 11.0 MeV. The lower bound of 0.45 MeV is consistent with the HI-STORM 100 System FSAR (the HI-STAR 100 System FSAR used a lower bound of 0.7 MeV) and was chosen because gammas with energies below 0.45 MeV are too weak to penetrate the HI-STAR HB overpack.

7.1.3 Fuel-Neutron Source

Table A6 in Appendix A presents the neutron source term used for the active fuel portion of the design-basis fuel assembly. The neutron source is presented in neutrons/sec. Section 5.2.2 of [4] provides additional discussion on the calculation of the neutron source.

The neutron source term increases as the ^{235}U enrichment decreases for the same burnup and cooling time. Therefore, as discussed earlier in this section, a bounding low enrichment was chosen for the source term calculations. The neutron source strength also varies with burnup, by the power of 4.2 [4]. Since this relationship is nonlinear and since burnup in the axial center of a fuel assembly is greater than the average burnup, the neutron source strength in the axial center of the assembly is greater than the relative burnup multiplied by the average neutron source strength.

In order to account for this effect, the neutron source strength in each of the 10 axial nodes listed in Table A3 was determined by multiplying the average source strength by the relative burnup level raised to the power of 4.2. The peak relative burnup listed in Table A3 is 1.195. Using the power of 4.2 relationship results in a 76.8 percent ($1.195^{4.2}/1.195$) increase in the neutron source strength in the peak nodes and the total neutron source strength listed in Table A6 increases by 36.9 percent. This increase in neutron source term is not reflected in the data presented in Table A6, but is accounted for in the shielding analysis.

7.1.4 Non-Fuel Sources

The non-fuel portions of a fuel assembly (e.g., steel and Inconel in the end fittings) activate during in-core operations to produce a radiation source. The primary radiation from these portions of the fuel assembly is ^{60}Co activity. Radiation from other isotopes within the steel and Inconel has a negligible impact on the radiation dose rate compared with the ^{60}Co activity. Therefore, ^{60}Co was the only isotope considered in the analysis. A SAS2H/ORIGEN-S run is used to determine the activation inventory. The method used to calculate the activity in the specific non-fuel hardware regions of the assembly is the same as that described in Section 5.2.1 of [4] and the equation is provided in Appendix C.

These values, which are
consistent with [11], are more conservative than those used in the HI-STAR 100 System FSAR. Although several of the HBPP assemblies contain Zircaloy grid spacers, it was conservatively assumed that grid spacers for all assemblies were steel/inconel as shown in Table A1 of Appendix A.

Table A5 in Appendix A lists the ^{60}Co source that was used in the non-fuel portions of the fuel assemblies. Table A2 in Appendix A describes the densities and dimensions of these non-fuel portions of the fuel assembly.

The HBPP fuel may be stored in the HI-STAR HB System with or without channels. The channels are made of Zircaloy material and have no significant activation source. Therefore, the channels are not modeled in the shielding analysis, which also conservatively neglects any shielding of the fuel source that they would provide. This approach is consistent with the approach used to address Zircaloy channels in the HI-STAR 100 generic shielding analysis.

7.2 MCNP Modeling of the MPC HB, The HI-STAR HB, and the Vault System

MCNP calculations are performed to determine dose rates along the top of a cask vault containing a HI-STAR HB loaded with an 80 assembly MPC HB. Calculations are also performed to determine the total dose contribution from the ISFSI at the site boundary. For this case, a single loaded vault was modeled with reflective boundary conditions on two sides of the storage cell in order to conservatively represent an infinite line of storage cells. Dose rates are calculated within the site boundary at approximately 50 feet from the center of the line of casks.

The MPC and the overpack were modeled in full three-dimensional detail using MCNP. The description of the modeling process can be found in [4,5,6].

Section 10.1 provides a listing of the drawings that were used to generate the MCNP models used in this report.

Proprietary Information Deleted

Proprietary Information Deleted

Lower energy fuel
gamma and gammas from the bottom fitting location would obviously be negligible through the vault. The dose from the bottom fittings and low energy fuel gammas are included in the HI-STAR HB calculations.

7.3 Method of Tallying

In MCNP, the calculation of a user requested quantity (e.g. dose rate) is referred to as tallying. The tally results calculated in MCNP are normalized per starting particle.

7.4 **Dose Calculations for the Humboldt Bay ISFSI**

7.4.1 Dose Rates Along the Top of the Storage Vault

MCNP calculations were performed to determine the dose rate at the surface of the vault lid. The computer input files used for the calculations are listed in Section 8.

Area tallies were taken along the vault lid surface using ring segments separated by approximately 1 foot. The peak dose of less than 0.15 mr/hr was seen at the center of the vault lid. A dose rate of less than 0.12 mrem/hr was calculated in radial segments across and just beyond the edge of the lid surface. The comprehensive results are provided in Appendix D, and summarized in Section 9 of this report.

7.4.2 Cask Configuration for Dose Versus Distance Calculations

It is practical to model the cask cell array as a single cask cell with reflective boundary conditions on two sides and calculate dose rates at a distance from the single cask. Although this is conservative because it represents an infinite line of cask cells, it is not overly conservative at distances that correspond to the close proximity of the site boundary. In reality, the peak dose will be seen in the center of the 1x 6 cask cell array, and casks that are further away from the center will contribute less to the total dose. Therefore, the infinite model dose rates will be reasonably close to those of a line of 6 casks at distances appropriate to the ISFSI.

Doses were calculated at approximately 50 feet from the infinite line of casks from the ground elevation to approximately 15 feet high in segments of approximately 4 feet. The exact elevations of the dose locations and the results are provided in Table 2. Assuming a 2080 hr/yr occupancy, these values meet the 25 mr/yr requirement of 10CFR72.104.

7.5 Dose Rates from the HI-STAR HB: Operations, Normal, and Accident Conditions

The loading of the MPC HB into the HI-STAR HB will produce a radiation field to workers performing the operations, as will the transfer operations of the HI-STAR HB from the Part 50 structure to the vault cell system. The dose contribution to the site boundary will also have to be considered during the HI-STAR HB transfer. To estimate the dose exposure during normal operations, dose rates were calculated at the surface, one meter, and 45 feet from the side of the cask. Dose rates were also calculated at the surface and one meter from the top of the cask with and without a lid.

It is also necessary to estimate the dose rates for a HI-STAR HB that has undergone a fire accident. For this calculation, it is assumed that all neutron shielding material (Holtite) and outer shell is burned off completely. Side dose rates are calculated at the surface, one meter, and 45 feet from the HI-STAR HB without Holtite present.

The results for the normal and accident dose rates for the HI-STAR HB are provided in Appendix D, and summarized in Section 9 of this report. Based on these normal condition results and assuming an 8 hour transfer per cask, and conservatively assuming that the cask is 45 feet from the site boundary for the entire 8 hours, all 6 casks may be loaded in a single year and meet the requirements of 10 CFR 72.104. Based on the accident condition results, the dose requirements for 10 CFR 72.106 are also met for the HI-STAR HB system.

8. Computer Files

All computer runs listed here were made on PCs at Holtec's main office. All files are stored on the Holtec computer server in directory \projects\1125\vjb.

The following is a list of all computer runs that were used in this report. See Section 7 for details of the calculations.

Input File	**Description**
MCNP HB Vault Calculations for the ISFSI	
hbvtcb	MPC-HB cobalt run for vault lid surface and site boundary.
hbvtgu	MPC-HB 3.0 – 11.0 MeV fuel gamma run for vault lid surface and site boundary.
hbvtgh	MPC-HB 1.0 – 3.0 MeV fuel gamma run for vault lid surface and site boundary.
hbvtgl	MPC-HB 0.45 – 1.0 MeV fuel gamma run for vault lid surface and site boundary. (Not used)
hbvtnp	MPC-HB neutron run for vault lid surface and site boundary.
MCNP HB HI-STAR Calculations for Normal Transfer	
hbstcb	Cobalt run side surface and 1 meter, and top lid surface and 1 meter. Site boundary.
hbstgj	3.0 – 11.0 MeV fuel gamma run side surface and 1 meter, and top lid surface and 1 meter. Site boundary.
hbstgi	1.0 – 3.0 MeV fuel gamma run side surface and 1 meter, and top lid surface and 1 meter. Site boundary.
hbstgk	0.45 – 1.0 MeV fuel gamma run side surface and 1 meter, and top lid surface and 1 meter. Site boundary
hbstnc	Neutron run side surface and 1 meter, and top lid surface and 1 meter. Site boundary
MCNP HB HI-STAR Calculations for Operations without STAR lid.	
hbstcy	Cobalt run on MPC lid surface
hbstgy	0.7 – 11.0 MeV fuel gamma run on MPC lid surface
hbstny	Neutron run on MPC lid surface
MCNP HB HI-STAR Calculations for accident conditions (loss of Holtite)	
hbstcx	Cobalt run side surface, 1 meter, and site boundary.
hbstgx	0.7 – 11.0 MeV fuel gamma run side surface, 1 meter, and site boundary.
hbstgq	0.45 – 0.7 MeV fuel gamma run side surface, 1 meter, and site boundary.
hbstnx	Neutron run side surface, 1 meter, and site boundary.
GE Type III 6x6 (23GWD/MTU, 29 years) ORIGEN-S and SAS2H input files	
hbs1	SAS2H run to generate library for ORIGEN-S.
hbso1	ORIGEN-S run for fuel gamma and neutron source terms.
hbso2	ORIGEN-S run for non-fuel hardware activation source terms.

9. Summary

The shielding analysis of the Independent Spent Fuel Storage Installation (ISFSI) at Humboldt Bay Power Plant (HBPP) is presented in this report. The evaluation uses reasonable and valid assumptions, as provided in Section 4, and meets all of the acceptance criterion stated in Section 3. The facility consists of up to 6 HI-STAR HB casks loaded into the HB Storage Vault and is assumed to be filled with fuel of 23,000 MWD/MTU and a minimum cooling time of 29 years. Dose rates were calculated at the surface, 1 meter, and 45 feet from the side of the HI-STAR HB overpack, as it will be used to transfer fuel from the Part 50 structure to the storage vault. The dose rates were also calculated above the MPC lid surface for a loaded HI-STAR HB without the overpack lid installed. The results and are given in Table 1 below, which also references the general locations on Figure 1. These values, along with the comprehensive results, are used in estimating the dose exposure during loading, unloading, and transfer operations as shown in detail in Appendix B.

Table 1
Maximum Calculated Dose Rates For HI-STAR HB
(23,000 MWD/MTU Burnup Fuel, 29 Years Cooling Time)

Dose Location Description	Location on Figure 1	Maximum Dose (mrem/hr)
Side Surface – On Holtite shell	2	8.3
Cutout region below Holtite	1	28.3
Cutout region above Holtite	3	11.7
1 meter from main body shell surface	2	5.1
45 feet from radial center of cask	2	0.145
HI-STAR HB Top lid surface	4	9.9
1 meter from top lid	4	2.8
Above MPC lid without HI-STAR HB lid	5	33.8

Each loaded HI-STAR HB is placed into one of the 6 underground concrete vault cells. The vault system provides very good shielding, such that the maximum dose rate calculated at the surface of the vault lid is less than 0.15 mrem/hr. Compliance with the 100 mrem/year dose limit in 10CFR20 is met at approximately 25 feet where a maximum dose of 38.56 mrem/yr was calculated.

The site boundary is located slightly greater than 50 feet from the ISFSI. The dose contribution at the site boundary from a fully loaded ISFSI was calculated and the results are provided in Table 2 below:

Table 2
Maximum Calculated Dose Rates For the Loaded
Humboldt Bay ISFSI at the Site Boundary

Elevation (cm)	Maximum Dose (mrem/yr)*
0 to 120	15.0
120 to 240	15.1
240 to 360	17.0
360 to 480	16.4

* Based on 2080 hr/yr occupancy

In order to demonstrate compliance with 10 CFR 72.104, it is necessary to consider the radiation contribution from the transfer of the HI-STAR HB casks from the Part 50 structure to its designated vault cell. Based on an 8 hour transfer operation duration per cask, and conservatively assuming that for the entire 8 hours the cask is located 50 feet from the site boundary, the total contribution from 6 cask transfers in one year can be calculated by the following:

(6 casks/yr) x (8 hr/cask) x (0.145 mrem/hr*) = 6.96 mrem/yr
*from Table 1

Adding the above to the total site boundary dose contribution from the ISFSI yields 23.96 mrem if all casks are placed in the vault system within a single year. This is acceptable per the requirements of 10 CFR 72.104.

It was also necessary to calculate dose rates for the accident condition during transfer where a fire causes all of the Holtite to melt away. The results are shown in Table 3 below:

Table 3
Maximum Calculated Accident Dose Rates For HI-STAR HB
(23,000 MWD/MTU Burnup Fuel, 29 Years Cooling Time)

Dose Location	Maximum Dose (mrem/hr)
Side Surface – outer shell location	123.0
1 meter from main body shell surface	44.9
45 feet from center of cask	1.0

Assuming a recovery duration of 30 days, this accident would yield a total dose of 720 mrem at full occupancy over the 30 day period, meeting the requirements of 10 CFR 72.106.

It is necessary to meet a 25 mrem/yr dose limit for the nearest resident at full occupancy (8760 hr/yr). The nearest resident is just over 800 feet from the ISFSI [12]. As shown in Appendix D, doses for the vault system were calculated at approximately 25 and 100 feet, in addition to the 50 foot site boundary. The results across this range show good agreement with an inverse decrease in dose rate as a function of distance. This gives a conservative dose estimate as a function of distance since an infinite line of storage cells was modeled, and is therefore an appropriate method to calculate the dose at the nearest resident. The calculation, which is provided in Appendix C, yields a dose rate of 6.31 mrem/yr, assuming full occupancy (8760 hr/yr) and the loading of all 6 casks.

Dose exposure was estimated for loading and unloading operations to be 0.57 and 0.33 total Man-Rem respectively. The details of that estimation are provided in Appendix B.

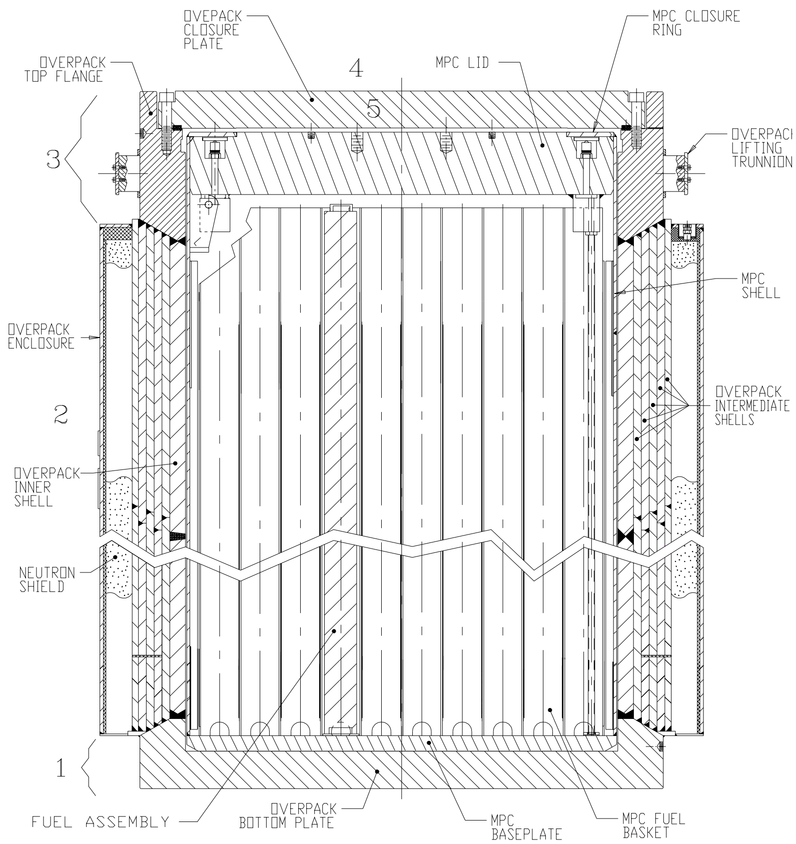


Figure 1: Loaded HI-STAR HB With Dose Loactions

10. References†

[1] O.W. Hermann, C.V. Parks, *SAS2H: A Coupled One-Dimensional Depletion and Shielding Analysis Module*, NUREG/CR-0200, Revision 6, (ORNL/NUREG/CSD-2/V2/R6), Oak Ridge National Laboratory, September 1998.

[2] O.W. Hermann, R.M. Westfall, *ORIGEN-S: SCALE System Module to Calculate Fuel Depletion, Actinide Transmutation, Fission Product Buildup and Decay, and Associated Radiation Source Terms*, NUREG/CR-0200, Revision 6, (ORNL/NUREG/CSD-2/V2/R6), Oak Ridge National Laboratory, September 1998.

[3] J. F. Briesmeister, editor, *MCNP - A General Monte Carlo N-Particle Transport Code,* LA-12625-M, Los Alamos National Laboratory, November 1993.

[4] *Final Safety Analysis Report for the HI-STAR 100 Cask System*, Holtec International Report No. HI-2012610, Revision 1, December 2002.

[5] *Final Safety Analysis Report for the HI-STORM 100 System*, Holtec International Report No. HI-2002444, Revision 1, September 2002

[6] *HI-STORM Shielding Design and Analysis for Storage,* HI-971608, Rev. 13, Holtec International.

[7] Humboldt Bay Specification HBPP-2001-01, Contract No. 3500120394.

[8] *Real Individual*, USNRC Interim Staff Guidance (ISG) No. 13, Rev. 0, May 2000.

[9] *Criticality Evaluation for the Humboldt Bay ISFSI Project*, HI-2033010, Rev 1, Holtec International.

[10] Letter from Lawrence Pulley to Eric Lewis dated May 5, 2003. Subject: Humboldt Bay ISFSI Project Transmittal of Engineering Documents and Information.

[11] A.G. Croff, M.A. Bjerke, G.W. Morrison, L.M. Petrie, *Revised Uranium-Plutonium Cycle PWR and BWR Models for the ORIGEN Computer Code*, ORNL/TM-6051, Oak Ridge National Laboratory, September 1978.

† Note: This revision status of Holtec documents cited above is subject to updates as the project progresses. This document will be revised if a revision to any of the above-referenced Holtec work products materially affects the instructions, results, conclusions or analyses contained in this document. Otherwise, a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supersede the revision numbers cited above. The Holtec Project Manager bears the undivided responsibility to ensure that there is no intra-document conflict with respect to the information contained in all Holtec-generated documents on a *safety-significant* project. The latest revision number of all documents produced by Holtec International in a *safety-significant* project is readily available from the company's Document Transmittal Form (DTF) database.

[12] PG&E Drawing 4025276 Rev 2, *Humboldt Bay ISFSI Conceptual Plan.*

[13] *Spent Nuclear Fuel Source Terms,* HI-2022847 Rev 3, Holtec International.

10.1 Drawings

The following is a list of the applicable drawings that were used to generate the MCNP models used in this analysis.

Drawing Number	**Revision Number**
MPC-HB	
4103	0
4102	0
HI-STAR HB Overpack	
4082	0
HB Vault	
4110	0
4105	0

Appendices A, B, C and D Contain Proprietary Information and have been Deleted