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TRANSPORTER STABILITY ON DIABLO CANYON DRY STORAGE TRAVEL PATHS

FOR

PG&E-DIABLO CANYON

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REVISION LOG

Revision 0 – Original issue.

Revision 1 – Incorporated client comments per Task 36 report. Introduction revised, miscellaneous comments incorporated per clients e-mail submitting Task 36. Appendix A footer revised (no calculation changes). All revisions reflect editorial changes only.

Revision 2 – Clarified initial offset of unit and retitled tables as necessary. Also included initial offset in tables.

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1.0 INTRODUCTION

This report presents the seismic stability evaluation of the cask transporter at the Diablo Canyon Power Plant (DCPP).

The HI-TRAC transfer cask loaded with an MPC exits the Fuel Handling Building (FHB) on a cask transport frame in a horizontal orientation. The DCPP Transporter lifts the HI-TRAC and the frame and moves along the road to the Cask Transfer Facility and then the Independent Spent Fuel Storage Installation (ISFSI), in the process descending a 8.5% nominal grade and then climbing a 6% nominal grade. At the CTF upending site, the transporter is used to rotate the HI-TRAC cask to a vertical orientation. The transporter then moves the HI-TRAC to the CTF where the loaded MPC canister is transferred to a waiting HI-STORM storage cask. During the MPC transfer operation, four restraints are attached to the top of the HI-TRAC and to connections at the top of the CTF concrete structure to prevent overturning of the HI-TRAC/HI-STORM stack. Also, there are four restraints attached to the transporter and to connections at the top of the CTF concrete structure to prevent sliding of the transporter. After the MPC transfer operation is executed, the transporter carries the loaded HI-STORM up a 5% nominal grade in a vertical orientation to its final position on the ISFSI pad for storage.

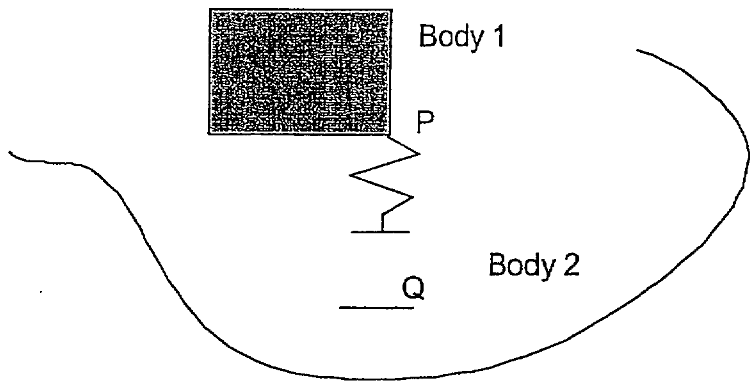
A design basis seismic event can occur during the various operations of the DCPP Transporter. The seismic stability analyses in this report demonstrate that the transporter, while moving together with the carried casks, does not overturn, and does not leave the roadway by sliding. Calculations to demonstrate the adequacy of transporter seismic restraints to prevent excessive relative motion of the HI-TRAC at the CTF are not included herein.

2.0 METHODOLOGY AND ACCEPTANCE CRITERIA

2.1 *Methodology*

Five design basis seismic events containing low frequency content have been specified for evaluating transporter stability on various loading paths for the Diablo Canyon ISFSI.

The QA validated computer code "VisualNastran 4D" [5.10] serves as the simulation engine to obtain the response to the 3-D seismic events. The program includes a dynamics algorithm that provides automatic collision and contact handling, including detection, response, coefficient of restitution, and friction. The ability to implement custom contact models to simulate complex non-linear behavior is also a feature of the code. The numerical integration is performed using the Kutta-Merson integrator with variable time-step. The interaction between two rigid bodies is modeled through a finite number of contact points named facets. The program automatically simulates impact, contact, lift-off, and sliding between bodies. These effects can be simulated using classical impulse-momentum relations where the user supplies a coefficient of restitution and a coefficient of friction for each potential set of contacting surfaces, or by using a more complex set of contact springs to represent the details of the contact stiffness. In this more detailed representation, at any contact point, a compression-only spring and damper is automatically located and activated between the two contacting bodies at every location where contact is indicated from the results at the previous time step. The spring rate and damping constant are user defined for every facet point; the computer algorithm automatically tracks all potential contact locations, computes the penetration and penetration rate and determines the instantaneous normal force at the location. The net lateral force at the contact point is limited by the instantaneous force multiplied by the coefficient of friction (assumed constant throughout the simulation). The following sketch demonstrates the custom contact model at a particular point where contact occurs involving Point "P" on Body 1 and Point "Q" on Body 2.



The associated damper, in parallel with the compression spring, is omitted in the sketch. When the facet point P is computed to have contacted Body 2 at location Q, subsequent penetration is computed and the spring compressed. The contact force at that location continues to act until the motion of the two bodies is such that separation occurs. Two components of horizontal force (not shown in the sketch) develop at the point of contact with the net horizontal force limited by the product of the instantaneous normal force and the friction coefficient. The accuracy of the contact algorithm is user specified. Once separation is indicated, no force is generated in either the compression spring or the associated damper until such time as the simulation again predicts that contact occurs at that location. For the simulations encompassed in this report, the impulse-momentum contact algorithm is used for the scenarios that involve primarily sliding on an inclined roadway; for the analyses on a level roadway that are attuned to evaluating the propensity for tipover, appropriate local contact springs are defined to represent the transporter tread interface with the roadway.

The motion of the rigid body model is defined by three translations (displacements) of the origin of the body coordinate system and three rotations. Assuming that the rigid bodies are of uniform mass density, the program automatically determines the mass center location and mass moments of inertia based on the geometry and the mass.

The time-domain dynamic simulations model the Transporter, the HI-STORM overpack, the HI-TRAC 125 transfer cask, the MPC, and the cask lids as rigid bodies. The lids are rigidly attached to the casks. The mass of the MPC and the containing spent fuel is lumped in a free standing rigid cylinder that during the earthquake is free to rattle in the cask cavity. The classical impulse-momentum algorithm simulates the contact of the MPC with the inner sides of the HI-TRAC transfer cask. While the VN algorithm has the capability to model coefficient of friction behavior that is a function of interface relative velocity, in the simulations herein, we use a constant value for the coefficient of friction. To study the propensity for transporter overturning, a track/ground interface coefficient of friction equal to 0.8 is assumed; similarly, to study sliding behavior, a lower bound coefficient of friction equal to 0.4 is assumed. For the transporter on inclined grade evaluations, the lower bound coefficient of friction is used to maximize transporter sliding displacements.

The analysis model has the cask rigidly attached to the body of the transporter. The transporter is supported by a rigid plate, representing the roadway, that is subjected to a ground displacement or ground acceleration time history. The simulations in this report use a generic model of the cask transporter that has a track width identical to that planned for the Diablo Canyon transporter but has a reduced track length. This ensures, as shown by the quasi-static stability analyses, that the results from the dynamic simulations performed herein bound the response of the real system. The weight of the transporter used in the analysis is based on estimates for the Diablo Canyon transporter.

2.2 Acceptance Criteria

Per the Specification for Dry Storage Casks for Diablo Canyon [5.7], the requirement that the transporter plus its carried load must remain stable (not overturn) and remain on the travel path under all postulated seismic events applicable to the Diablo Canyon ISFSI defines the acceptance criteria for the stability analyses of the transporter. The minimum roadway width is 26 feet, which sets the allowable transporter lateral sliding distance. The maximum acceptable sliding movement along the roadway is limited to the cask transporter track length to ensure that the transporter will remain on the roadway after exiting a turn in the roadway.

3.0 ASSUMPTIONS

3.1 The time domain dynamic analyses of the transporter seismic stability simulate the modeled components (transporter, cask, and MPC) as rigid bodies with specified geometry and bounding mass. The connection between the cask body and the lids is assumed to be rigid. This is a realistic assumption for the study of system stability. These are conservative assumptions for the seismic analysis since the energy dissipation in the dynamic system is neglected by the virtue of the rigid body modeling.

3.2 The time domain dynamic simulations model the MPC and the contained fuel by a solid cylinder with total mass equal to that of a bounding loaded MPC. This is conservative since all energy dissipation due to fuel assembly rattling inside the MPC is neglected and any reduction in amplitude due to chaotic fuel assembly motion over time is ignored.

3.3 The analyses in time domain are simplified by assuming the rigid bodies to be with uniform mass density when calculating their mass moments of inertia and mass center locations. Any shift in the centroid due to this assumption has negligible effect on the results of the analysis.

3.4 The coefficient of restitution for the contact surfaces (MPC-to-HI-STORM) is set to 0. 0. The coefficient of restitution between the transporter treads and the ground is set to 0.-0.25 (the exact value has no influence on the solution when sliding motions predominate). For the coefficient of friction at the transporter tread/ground interface, an upper bound value of 0.8 is assumed to emphasize tipping action. A lower bound on the tread/roadway surface is 0.4 [5.8]. Simulations are made herein using both upper and the lower bound. The lower bound value is used to determine maximum sliding excursions while the upper bound value is used to determine the rocking behavior of the transporter. The coefficient of friction values are assumed to be dynamic coefficients of friction. The coefficient of friction between the MPC and the HI-TRAC cavity side surfaces is set at

0.5 as a representative of steel-on-steel friction in a dry environment. Any value used at this interface is conservative since the actual connection precludes relative motions to within an assembly tolerance.

3.5 The time domain dynamic simulations use a generic model of the transporter with length of the transporter tracks that are shorter than the length of the DCPP Transporter tracks. The analyses consider the stability of this transporter when supported by a horizontal ground surface.

3.6 As all bodies are assumed as rigid for the global analysis, the transporter design specification, HI-2002501, includes a requirement that the transporter be designed such that its lowest global natural frequency be in the rigid range (>33 Hz) as defined by the input response spectra for the events considered herein. Once the transporter is designed it is our intent to perform an analysis to verify that it meets the rigidity requirement.

4.0 INPUT DATA

4.1 Input Geometry and Inertia Properties

4.1.1 DCPP Transporter

Section 4.7 in [5.2] specifies the following input for the DCPP Transporter:

- Min. Length of Tracks 294 in.
- Width of Tracks 29.5 in.
- Inner Distance between Tracks 152.5 in.
- Max. Height of Center of Gravity from Ground 87 in.
- Min. Height of Center of Gravity from Ground 75 in.
- Distance of Center of Gravity from Rear of Track 132 in.
- Position of Towers Centerline from Track Rear 173.74 in.
- Nominal Weight (Empty) 170 kips.

4.1.2 Spent Fuel Casks

Transport Mode	Nominal Lifted Weight (2)	Nominal Slope Grade (3)	Nominal Carry Height (2)	Center of Gravity Height
Vertical HI-STORM	360,000 lb	5 %	10 in.	118.5 in. (1)
Vertical HI-TRAC	250,000 lb.	5 %	42 in.	95 in. (1)
HorizontalHI-TRAC	260,000 lb.	8.5 %	6 in.	65 in. (2)

(1) per Table 3.2.3 in [5.3]
(2) estimated for information only – CAD precisely locates HI-TRAC
(3) per Section 4.7 in [5.2], bounding grade is 10%; actual maximum grade is 8.5% [5.7] while HI-TRAC is horizontal

The listed nominal lifting weights includes the bounding weight of 90 kips (per Table 3.2.2 in [5.3]) for a loaded MPC in the cask cavity. For the horizontal orientation, 10,000 lb. is included to approximate the weight of the upending frame.

4.1.3 Generic Model of Cask Transporter

The time domain dynamic stability simulations use a generic model of the cask transporter with the following input geometry and inertia properties:

- Length of Tracks 234 in.
- Width of Tracks 30 in.
- Inner Distance between Tracks 152 in.
- Height of Center of Gravity from Ground 77.41 in.
- Distance of Center of Gravity from Rear of Track 122 in.
- Position of Towers Centerline from Rear of Track 118 in.
- Weight (Empty) 170 kips.

The data above represents the proposed DCPP transporter except that the track length is conservatively assumed shorter.

The analyses use the following input contact interface parameters:

- MPC Restitution Coefficient 0.0
- Overpack/MPC Steel/Steel Friction Coefficient 0.5
- Transporter/Ground Min. Friction Coefficient 0.4
- Transporter/Ground Max. Friction Coefficient 0.8
- Transporter/Ground Coefficient of Restitution 0.0 (in simple box sliding models)

- Transporter/Ground Damping Coefficient equivalent to 0.25 COR (in level ground analyses using local contact spring, damper model)

The analyses of the sliding stability conservatively use the minimum value of the friction coefficient to provide conservative estimate of the sliding excursions. The dynamic simulations use a maximum value of the friction coefficient in order to investigate the stability of a system that is prone to overturning. For simulations that considered realistic values for coefficient of friction, a value of 0.4 was used (Reference [5.8] lists a friction factor of .45 for crawler tracks on concrete; conservatively, we choose 0.4.).

4.2 Input Earthquake Excitation

Pacific Gas & Electric has identified five time histories [5.5]. The low frequency content of these strong motion seismic events ensures that sliding displacements are maximized for the low coefficient of friction cases analyzed. These seismic events are identified below with their duration:

1. Lucerne Valley (48 sec.)

2a. Yarimca (40 sec.)

3. LGPC (22 sec.)

5. El Centro (40 sec)

6. Saratoga (40 sec.)

The number identifier is consistent with the PG&E designation. Each seismic set consists of a vertical acceleration time history, and two horizontal time histories, designated as "Fault Normal" or "Fault Parallel with fling".

5.0 REFERENCE DOCUMENTS AND COMPUTER FILES

5.1 References

[5.1] Holtec Report HI-2002501, Functional Specification for the Diablo Canyon Cask Transporter, Revision 0, 2001

[5.2] Holtec Report HI-2002511, Design Criteria Document for the ISFSI Pad for Anchored HI-STORM 11 Deployment at Diablo Canyon Power Plant, Section 4.7, Revision 1, 2001

[5.3] Holtec Report HI-2002444, HI-STORM FSAR, Chapter 3, Revision 1.

[5.4] Holtec Report HI-2012618, Seismic Analysis of Anchored HI-STORM 100 Casks at Diablo Canyon ISFSI. Revision 4, 2001.

[5.5] PG&E Transmittal Letter dated 11-01-2001 from R. Klimczak (PG&E) to E. Lewis (Holtec) with Excel Spreadsheets of the ISFSI Time Histories..

[5.6] Rothbart, H., Mechanical Design and Systems Handbook, 2nd Edition, McGraw-Hill, Section 6.

[5.7] DCPP Specification 100120 N-NPG for Dry Cask Storage System, Subsection 6.2.5.

[5.8] "Construction Planning, Equipment, and Methods", Second Edition, R.L. Peurifoy. McGraw-Hill Book Company

[5.9] Deliberately Blank

[5.10] VisualNastran Desktop, Version 2001, MSC Software, 2001.

[5.11] MATHCAD 2000, Mathsoft, Inc., 1999.

5.2 *Computer Files*

This document is written using MSWORD 2000. MATHCAD 2000 electronic calculation code [5.11] is used for the calculations and the preparation of Appendix A. The dynamic simulations are performed using the commercial simulation code VisualNastran Desktop 2001 [5.10]. This code has been subject to independent validation at Holtec International in accordance with the approved QA program.

All relevant computer files associated with this calculation package are archived on the Holtec Server. The following are the applicable directory listings:

For Revision 0, the analyses on flat road and missile impact are located in g:\projects\1073\ais\analysis\approved seismic runs 12-16-2000\transporter stability\8-2001 simulations.

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phase 5 set 5 9-3-01.zip	.zip	5,155,740	W	9/4/2001	12:18 PM
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For Revision 0, the analyses on inclined grade are located in g:\projects\1073\ais\analysis\approved seismic runs 12-16-2000\transporter stability\10-2001 simulations.

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The contents of the ZIP files contain the appropriate VN files as well as the spreadsheets containing generated meter data.

The report and its appendices are located in g:\projects\1073\ais\reports\hi-2012768\rev0

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HI-2012768r0.doc	.doc	2,493,9...	10/26/2001	9:03 AM

For revision 1, text and appendix A are located in a rev 1 subdirectory

- HI2012654
- HI-2012675
- HI-2012768
  - REV 0
  - REV 1

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Mathcad - Appen-A.pdf	.pdf	11,813	Adobe Acrob...	11/7/2001	9:58 AM	a
Review Comments on HI-201...	.doc	339,968	Microsoft Wor...	11/6/2001	5:22 PM	

For revision 2, the modified text is located in a new Rev 2 subdirectory under HI-2012768.

6.0 ANALYSES AND RESULTS

6.1 *Contact Interface Parameters*

The time domain dynamic analyses of the cask transporter seismic stability require simulation of the interaction at the contacts between the rigid bodies. Three parameters, a friction coefficient, a vertical stiffness constant, and vertical damping constant are used to model the contact of the transporter with the ground surface. In the rigid body model, a series of peripheral springs simulate the contact between the two large flat surfaces undergoing low velocity impacts. Appendix A calculates the vertical spring rate and damping coefficient. Sixteen (16) facet points represent the contact between the two transporter tracks of the Cask Transporter and the ground at any location on the travel path. The calculations determine the spring and damper, per facet, that are used as input into the "custom contact" VN model at the transporter/ground interface.

The premise for establishing the spring rate is that the responses of interest when considering system behavior to seismic ground motions should focus on the predominate modes below 33 Hz and avoid modeling assumptions that introduce spurious mathematical artifacts that serve only to interject high frequency effects into the simulation. It is noted that the predominate energy in earthquakes is concentrated in the frequency range below 33Hz. Therefore, the contact spring representation employed in the simulation is based on the mass of the unloaded cask transporter, and is developed so that the 33Hz frequency is based on a direct drop of the mass onto a rigid foundation. This renders the custom contact model independent of the local material and geometric shape of the contact surfaces.

Calculations in Appendix A yield the following input values for the contact parameters at the tread/ground interface

- Vertical linear spring coefficient 1,183 kips/in.

- Vertical viscous damping coefficient 4.565 kips sec/in.

6.2 Time Domain Dynamic Simulations-General

A series of non-linear dynamic simulations are performed using the "VisualNastran 4D" (VN) computer code [5.10] to assess the seismic stability of the transporter during the bounding earthquakes. The simulations analyze the operational modes that include transport of HI-TRAC and HI-STORM casks in vertical orientation. The models used for analyses of the HI-STORM and HI-TRAC configurations are shown on Figure 8.1 and 8.2, respectively. The dynamic simulations are performed with a variable time step. The maximum integration time step is set at 0.002 sec, a value that ensures an appropriate resolution of the input motion and adequate accuracy of the integration. The friction coefficient has a crucial effect on the overall dynamic behavior of the system. The sliding of the transporter is proportional to the value of the friction coefficient with lower values of friction coefficient resulting in larger sliding displacements. The high values of the friction coefficient restrict the transporter sliding making it prone to overturning. Although the simulation algorithm permits the use of a velocity dependent friction coefficient, herein, the coefficient of friction is held constant (at either 0.4 or 0.8) through the entire duration of the simulation.

A series of dynamic simulations have been performed to evaluate transporter stability. The combinations of grade, coefficient of friction, and seismic events have been chosen to be representative of bounding conditions at the site.

TABLE 1- SIMULATIONS DEFINED BY PG&E

Phase	Transporter Configuration	Grade and Friction Factors	Time Histories
1	Transporter with horizontal HI-TRAC rigidly connected to Transporter	Flat surface .4 friction factor	5 time history sets. Time history sets are designated as Sets 1, 2a, 3, 5, and 6
2	Transporter with horizontal HI-TRAC rigidly connected to Transporter	6% grade .4 friction factor	Sets 1P, 5N, 6N, 6P
3	Transporter with horizontal HI-TRAC rigidly connected to Transporter	8.5% grade .4 friction factor	Set 5N
4	Transporter with vertical HI-STORM rigidly connected to Transporter	6% grade .4 friction factor	Sets 5N and 6N
5	Transporter with vertical HI-STORM rigidly connected to Transporter	Flat surface .8 friction factor	Set 6

Note: For all simulations in Phase 1, and for Phase 5, the longitudinal axis of the transporter is aligned with the Fault Parallel time history. For simulations in Phases 2-4, the designator of N or P means that the component (N for Fault Normal and P for Fault Parallel) is aligned down-slope. The specific cases run are defined in e-mail transmittal of 8/31/01 from PG&E (R. Klimczak) to Holtec.

For each case considered, the loaded transporter is assumed to be on a flat or inclined surface with specified coefficients of friction. The simulations performed under Phase 1 serve to identify potentially bounding events from among the five candidate time histories. The choice of simulations for the remaining phases is based on the results from the simulations in Phase 1. The combination of grade and coefficient of friction are such as to induce sliding as opposed to tipping. Therefore, in the simulations on a non-zero grade (Phases 2-4), the transporter and the load are not modeled in detail per Figure 8.1 and 8.2, but are simulated as a simple rigid block with an appropriate bounding centroid location and having interface dimensions with the roadway equal to the length and width of the proposed Diablo Canyon transporter. Simulations on flat surfaces (Phases 1 and 5), however, use the detailed model in Figure 8.2 and 8.1, respectively. In the analyses, we use

- The transporter weight is 170,000 lb.
- The HI-TRAC weight is 250,000 lb. (tie-down rigging neglected as it should lower the c.g)
- The HI-STORM weight is 360,000 lb.

The width of the roadway is 26'= 312". The width of the transporter (outside of track-to-outside of track) is approximately 212"; therefore, there is just over 4' of span to the edge of the roadway.

6.3 Time Domain Simulations on Level Ground – Phases 1 and 5

Five seismic events are considered on level ground with the HI-TRAC in a horizontal orientation. Peak displacements of the transporter relative to the road are given in Table 2, below: For all cases in Phase 1, the Fault Parallel time history is aligned along the road, and the Fault Normal time history is aligned transverse to the road. All simulations are assumed to occur on a level roadway. Figure 8.2 is the simulation model for all events in Phase 1.

TABLE 2 PHASE 1 RESULTS

TRANSPORTER STABILITY DISPLACEMENT RESULTS (Relative to Road) – PHASE 1 - 0% Grade – HI-TRAC (horizontal) with cof=0.4		
Seismic Time History Set	Peak Longitudinal Displacement (inch)	Peak Transverse Displacement (inch)
1. Lucerne Valley (48s)	7.427	5.482
2a. Yarimca (40s)	3.928	5.587
3. LGPC (22s)	3.501	5.871
5. El Centro (40s)	3.491	7.371
6. Saratoga (40s)	8.912	8.907

Figures 8.3 through 8.7, below summarize the results from each of the simulations. The complete time history of the responses is archived in Excel spreadsheet form.

From the above results, we choose seismic event 6 to form the input for a bounding evaluation of the transporter carrying a loaded HI-STORM. The results from this simulation will demonstrate whether there is any credible overturning scenario from a seismic event. Table 3 summarizes the results of this evaluation; the results are presented in graphical form in Figure 8.8. The graphs give the time history of the displacement of the lid center and a point on the transporter relative to an origin of coordinates on the road (x=y=z=0.0 inch). It is clear from the results that overturning of a loaded transporter during a seismic event is not credible. Table 3 summarizes the results. In each direction, the starting position, the maximum position, and the minimum position, relative to the origin of coordinates is listed. The final position, relative to the origin of coordinates, can be read from the graphs

TABLE 3 – PHASE 5 RESULTS

TRANSPORTER STABILITY DISPLACEMENT RESULTS (Relative to Origin of Coordinates) – PHASE 5 - 0% Grade – HI-STORM with cof=0.8			
Time History Set	Longitudinal (inch)	Transverse (inch)	Vertical (inch)
6P. Saratoga (FP)	Start/Max./Min.	Start/Max./Min.	Start/Max./Min.
Top Lid of HI-STORM	-.086/.0095/-.3329	.0/.4261/-.0339	.025/.025/.025
Transporter	.0/.0987/-.2437	.0/.4331/-.0269	.01/.01/.01

6.4 Time Domain Simulations on Non-Zero Grade – Phases 2-4

During the period of time when the transporter is carrying a HI-TRAC horizontally, some portions of the travel path require movement on an incline. The previous simulations have clearly demonstrated that transporter overturning is not credible; however, because of the grade, the demand on frictional resistance is increased since the net download has a component parallel to the roadway. Therefore, we next examine the consequences of a ratcheting behavior where the loaded transporter exhibits a propensity to slide down the path under the action of the imposed seismic loading. The location of the system center of gravity is unimportant for this study; therefore, an evaluation of longitudinal sliding while on an inclined grade is undertaken using a simple box to represent the transporter plus load sliding down the incline on a fixed ground. The centroid of the box representing the transporter plus load is set higher than the actual system; the weight of the box are the bounding weights of 420 kips (HI-TRAC + transporter) or 530 kips

(HI-STORM+transporter), the coefficient of friction is 0.4, and 6% and 8.5% grades are considered. The seismic driving mechanism for these simulations is a 3-D inertia force, proportional to the three components of seismic acceleration, applied at the mass center of the box. The results for maximum transporter displacements are shown in the tables below and summarized in graphical form in Figures 8.9-8.15. The graphical results of interest are the position of a point on the transporter relative to the origin of coordinates set in the road. The displacement along (parallel) to the roadway can be obtained from the horizontal (x) component by dividing by the cosine of the incline angle corresponding to the incline. Note that the figures show a slight offset in each of the displacement coordinates. This is simply due to not "zeroing" the initial position between the measuring point on the transporter and the origin of coordinates. In the summary tables given below, we show the starting location of the tracked point, and the maximum and minimum excursions, relative to the origin of coordinates on the road (x = y = z = 0.0 inch). Only the results in the plane of the road are listed

Incline 8.5% corresponds to incline angle A = 4.858 degrees from horizontal (cosA=0.9964)

Incline 6.0% corresponds to incline angle A = 3.434 degrees from horizontal (cosA=0.9982)
(see Figure 8.19 for a screen capture of the data input verifying input for 6% grade)

TABLE 4 – PHASE 2 RESULTS

TRANSPORTER STABILITY DISPLACEMENT RESULTS (Relative to Coordinate Origin) – PHASE 2 6% grade, cof=0.4, HI-TRAC "BOX"		
Seismic Time History Set	Longitudinal Displacements (Parallel to Roadway) (inch)	Peak Transverse Displacements (inch)
	Start/Max./Min.	Start/Max./Min.
1P. Lucerne Valley	.225/13.997/.225	.191/.5783/-5.672
5N. El Centro	.354/21.871/-.01	.222/4.318/-1.316
6N. Saratoga	.350/16.351/.350	.227/10.871/.227
6P. Saratoga	.347/15.873/.347	.228/10.894/.228

TABLE -5 – PHASE 3 RESULTS

TRANSPORTER STABILITY DISPLACEMENT RESULTS (Relative to Origin) – PHASE 3 8.5% grade, cof=0.4, HI-TRAC "BOX"		
Seismic Time History Set	Peak Longitudinal Displacement (Parallel to Roadway)(inch)	Peak Transverse Displacements (inch)
	Start/Max./Min.	Start/Max./Min.
5N. El Centro	.210/30.431/.210	.157/4.774/-1.142

TABLE 6 – PHASE 4 RESULTS

TRANSPORTER STABILITY DISPLACEMENT RESULTS (Relative to Road) – PHASE 4 - 6% Grade, cof=0.4, HI-STORM "BOX"		
Time History Set	Longitudinal (inch)	Transverse (inch)
	Start/Max./Min.	Start/Max./Min.
5N. El Centro	.355/21.672/.355	.222/4.319/-1.316
6N. Saratoga	.350/16.350/.350	.228/10.870/.216

6.5 *Stability of Transporter/Cask With Large Tornado Missile Impact*

The HI-STORM FSAR contains analyses that demonstrate stability against overturning and sliding when the cask is subject to a large tornado missile strike plus tornado wind. Although the impact height is increased, the transporter width over the outside of the tracks is approximately double the diameter of the HI-STORM. Therefore, it is expected that tornado missile strikes will not lead to an overturning or excessive sliding scenario. To conclusively demonstrate this, the VN model of the transporter on level ground, carrying a HI-STORM in the vertical orientation, was modified to include a horizontal large tornado missile striking at the top of the transporter. The large tornado missile used was the same as the FSAR large missile; namely, a rigid cylinder with a 20 sq. ft. frontal area simulated a 4000 lb. car traveling at 126 mph The car was conservatively assumed to be a rigid body even though it would be expected to locally crush during transporter impact and absorb a good portion of the kinetic energy. The missile strike was assumed in the transverse direction to maximize the propensity for overturning. Tornado wind effects were ignored since if the wind cannot overturn a freestanding HI-STORM on a pad, it cannot overturn a loaded or empty transporter with its much larger contact width. The following table summarizes the results obtained from the analyses performed; Figures 8.16 through 8.18 provide a graphical summary of each simulation. Each figure shows the configuration at a single instant of time and the location of the strike. We note that the empty transporter shows the most propensity for overturning since it has the smallest weight and inertia compared to the impacting missile and therefore offers less resistance to overturning than does the loaded system.

TABLE 7

SUMMARY OF RESULTS FROM TORNADO MISSILE STRIKE ANALYSES		
CASE	MAX. LATERAL DISPLACEMENT – Top of HI-STORM (inch)	MAX. LATERAL DISPLACEMENT – Centroid of Transporter (inch)
1. LOADED HI-STORM plus TRANSPORTER – COF=0.8, STRIKE AT TOP	2.216	0.6515
2. LOADED HI-STORM plus TRANSPORTER – COF=0.4, STRIKE AT BASE	0.938	0.947
4. EMPTY TRANSPORTER – COF=0.8, STRIKE AT TOP	NA	8.699

7.0 CONCLUSIONS

Time domain dynamic simulations presented in this report demonstrate that the transporter, loaded with spent fuel casks in a vertical or horizontal orientation, maintains its seismic overturning stability and is secure from sliding off the road while moving on the Diablo Canyon ISFSI pad. If the transporter is on level ground, the maximum excursion is below 10" in any direction, a value that is less than the distance to the edge of the roadway. If the design basis seismic event occurs while the transporter is on an incline, the maximum movement down the incline is approximately 10% of the length of the transporter and the transporter stays on the road.

Tornado missile impacts are evaluated and dynamic analyses demonstrates that there is no dynamic instability or excessive sliding for either a loaded system or the transporter alone.

8.0 FIGURES

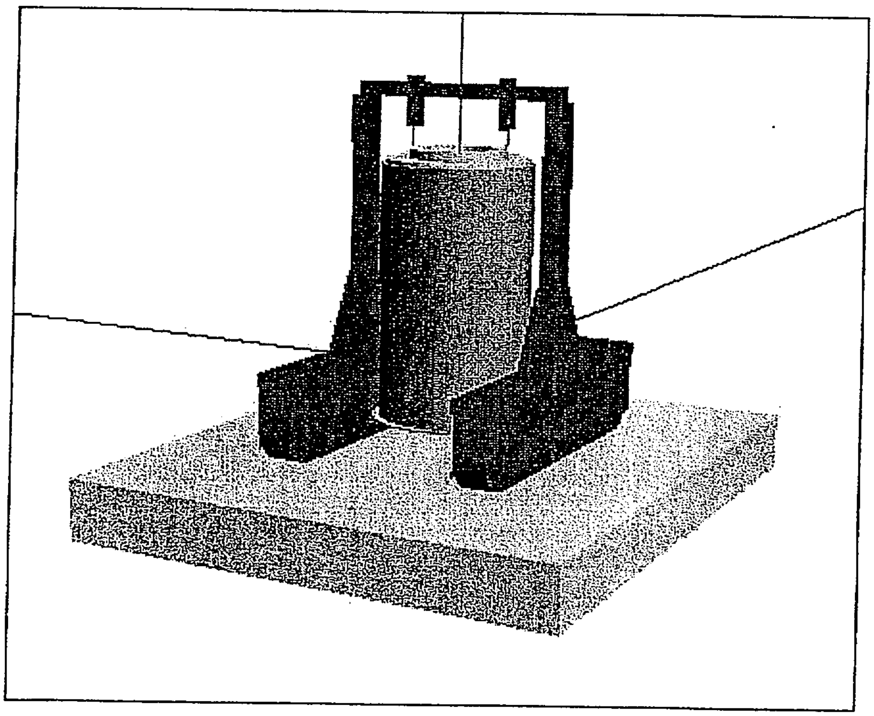

Figure 8.1: VN Model - Transporter with HI-STORM Vertical (Phase 5 Simulation)

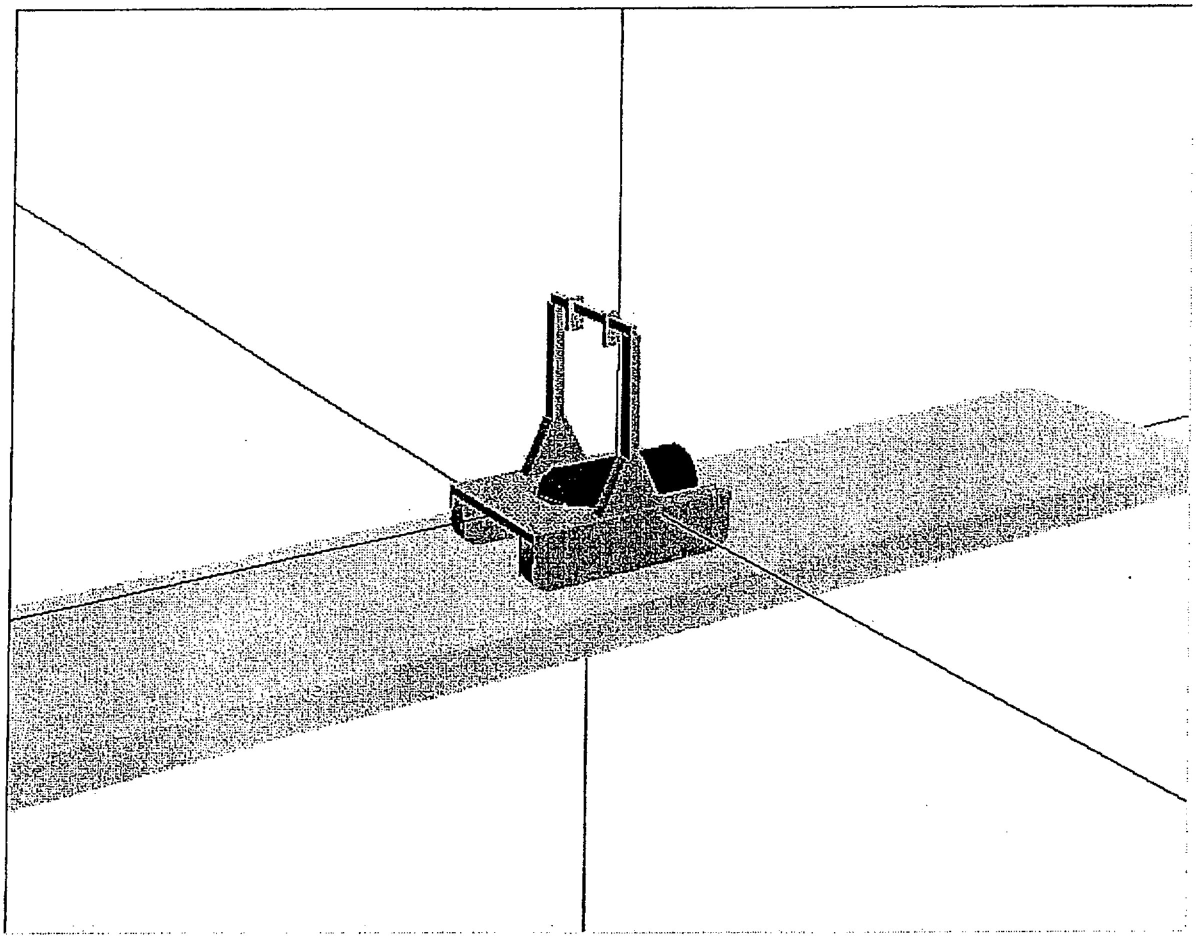

Figure 8.2: VN Model -Transporter with HI-TRAC Horizontal (Phase 1 Simulations)

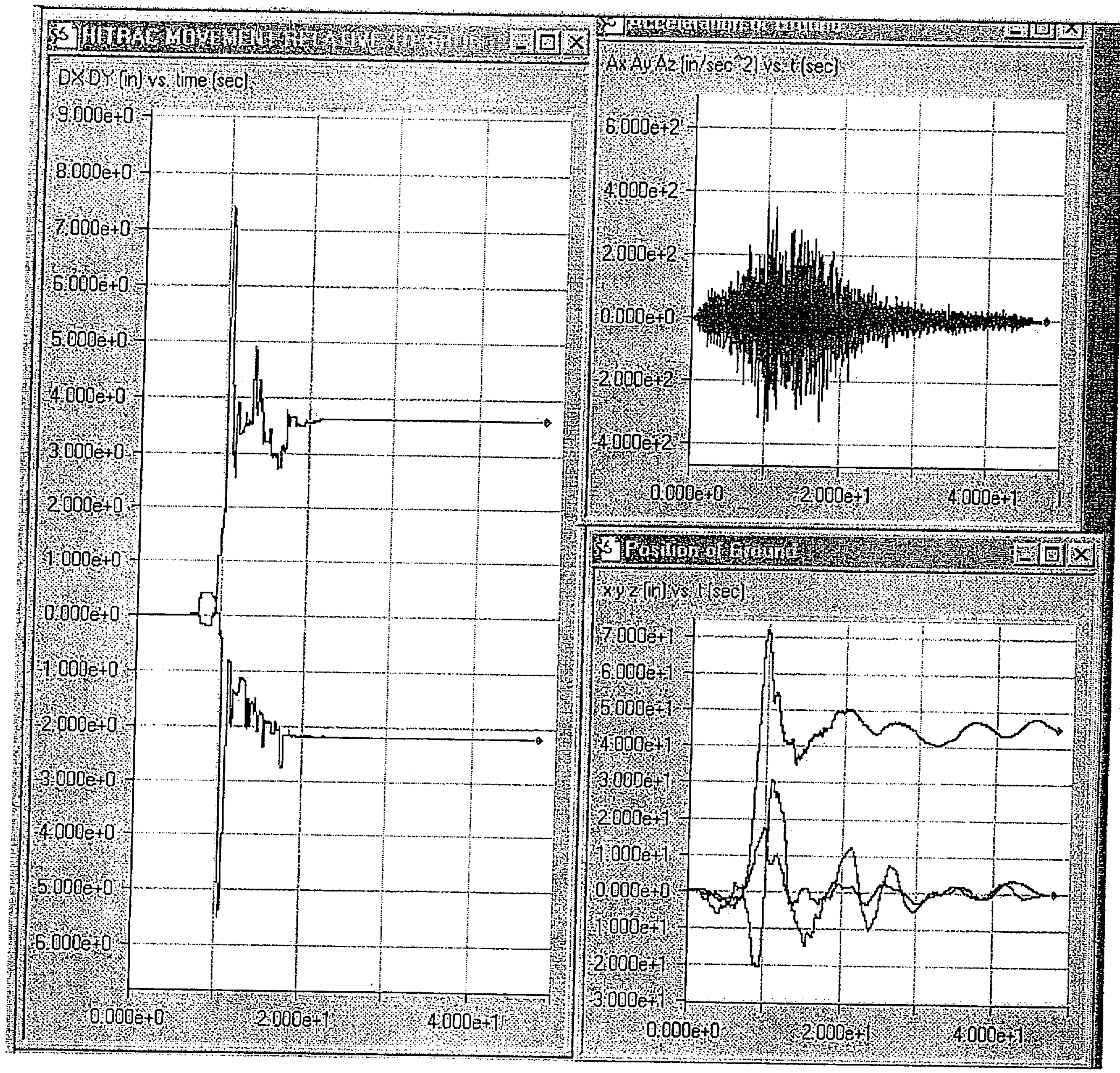

Figure 8.3: Phase 1, Set 1 Results

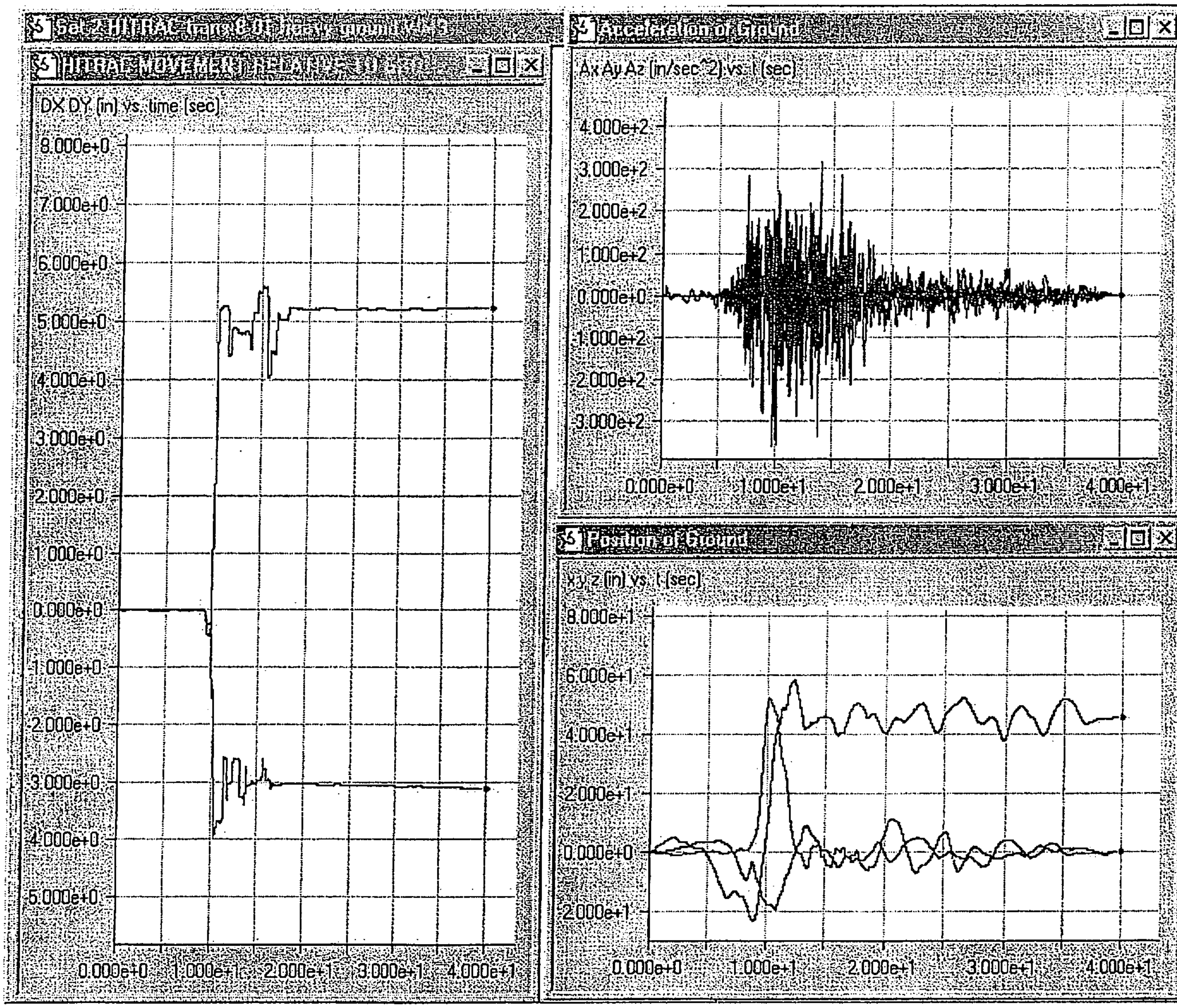

Figure 8.4: **Phase 1 Set 2a Results**

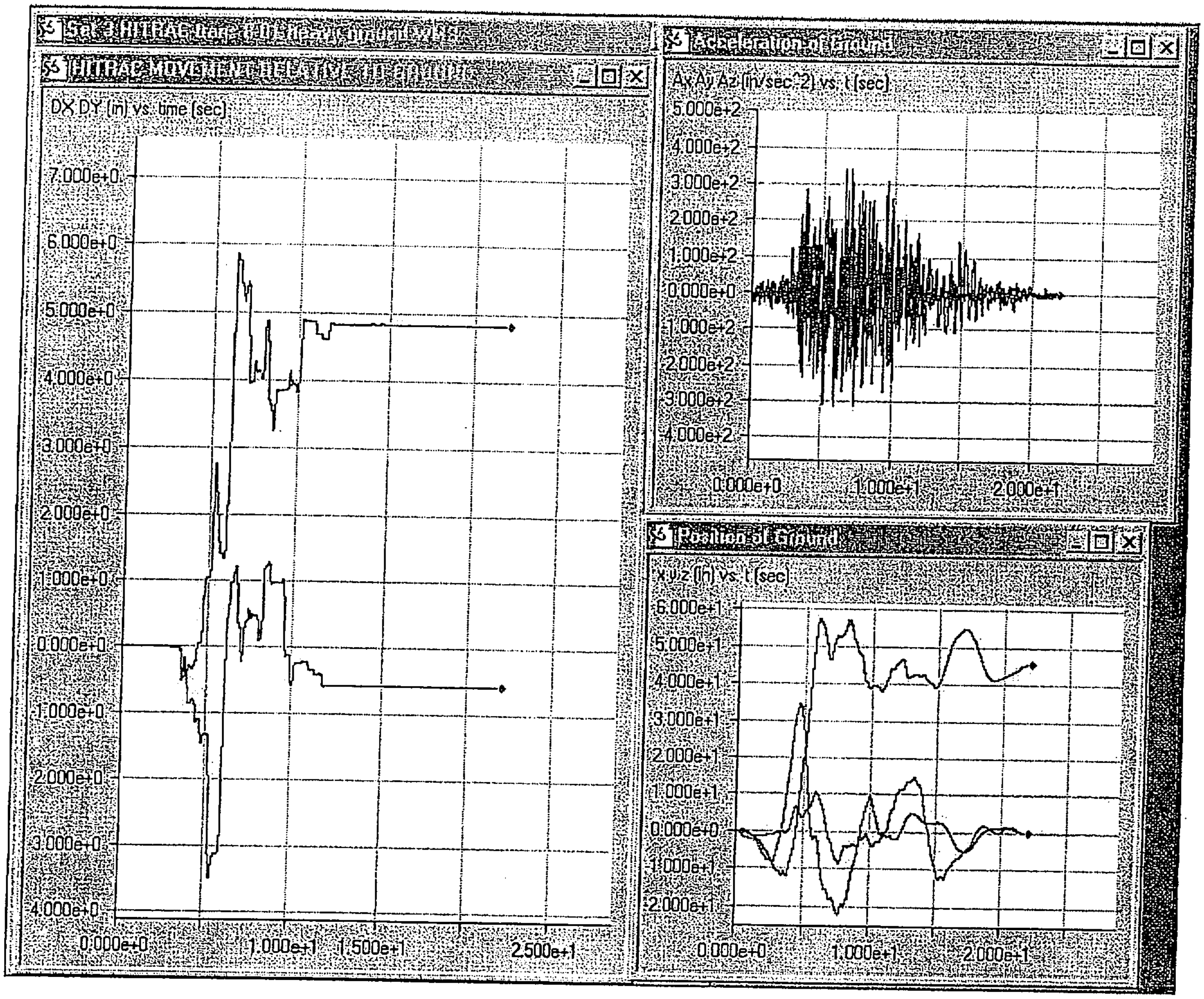

Figure 8.5: Phase 1, Set 3 Results

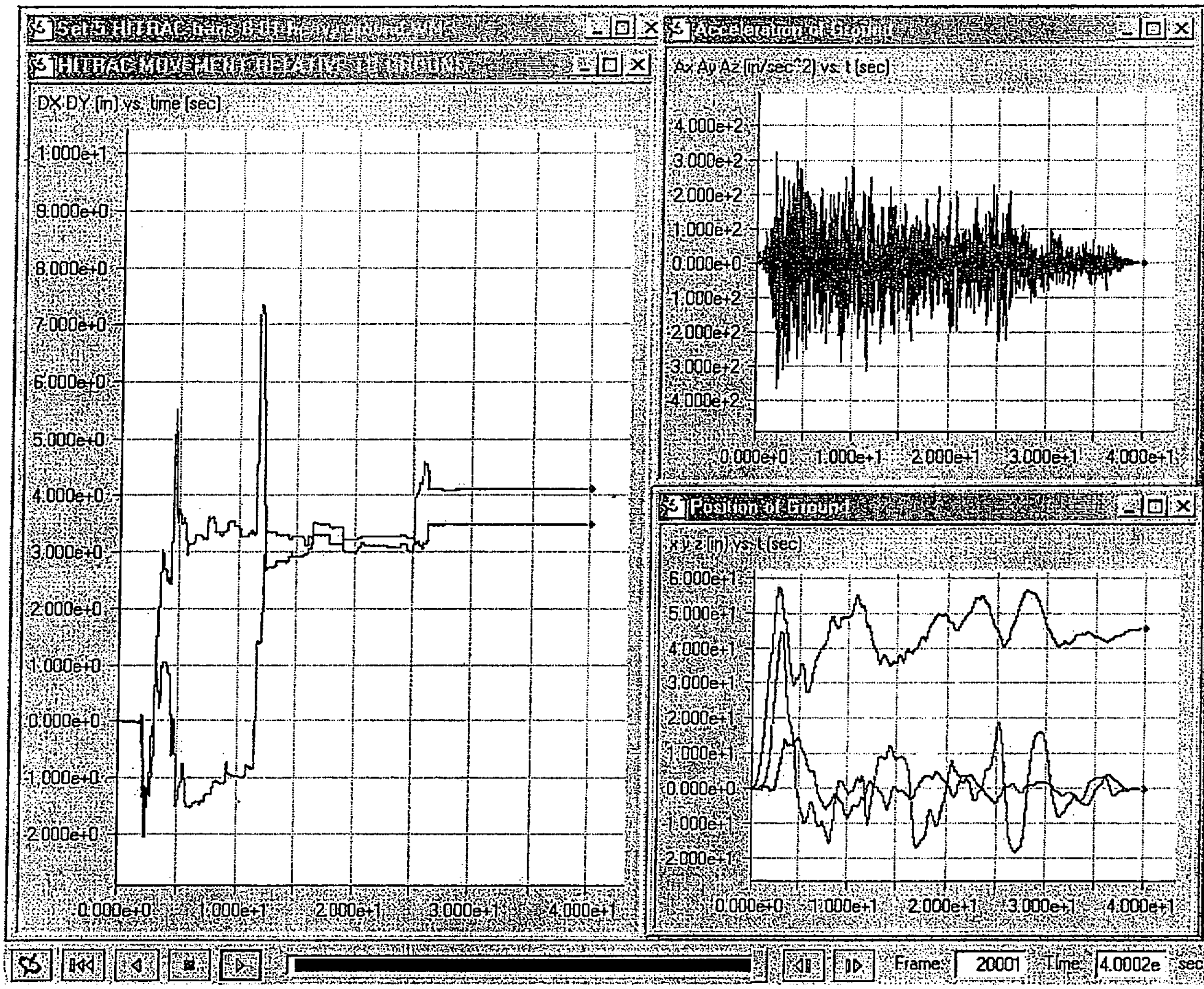

Figure 8.6: Phase 1, Set 5 Results

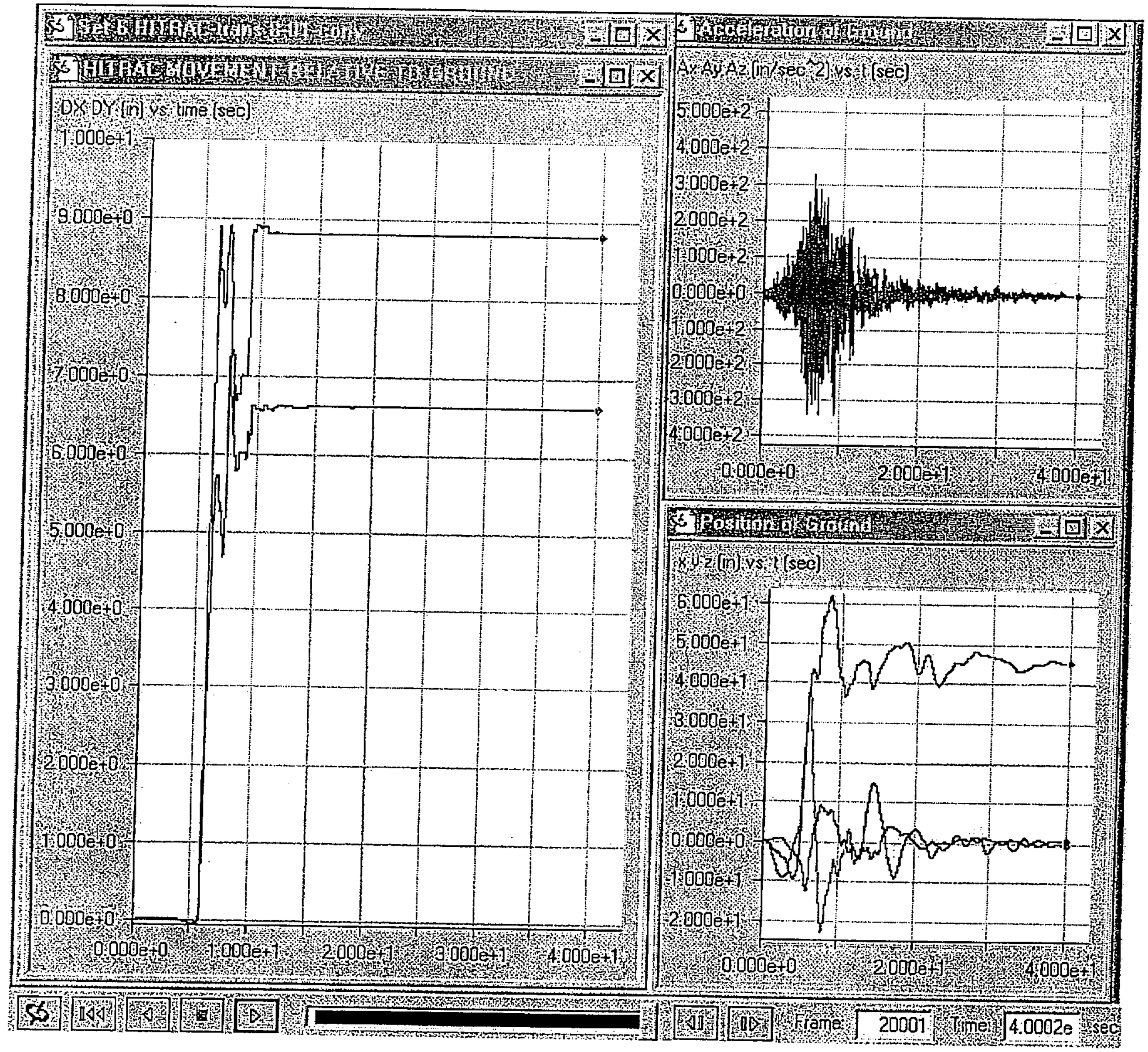

Figure 8.7: Phase 1, Set 6 Results

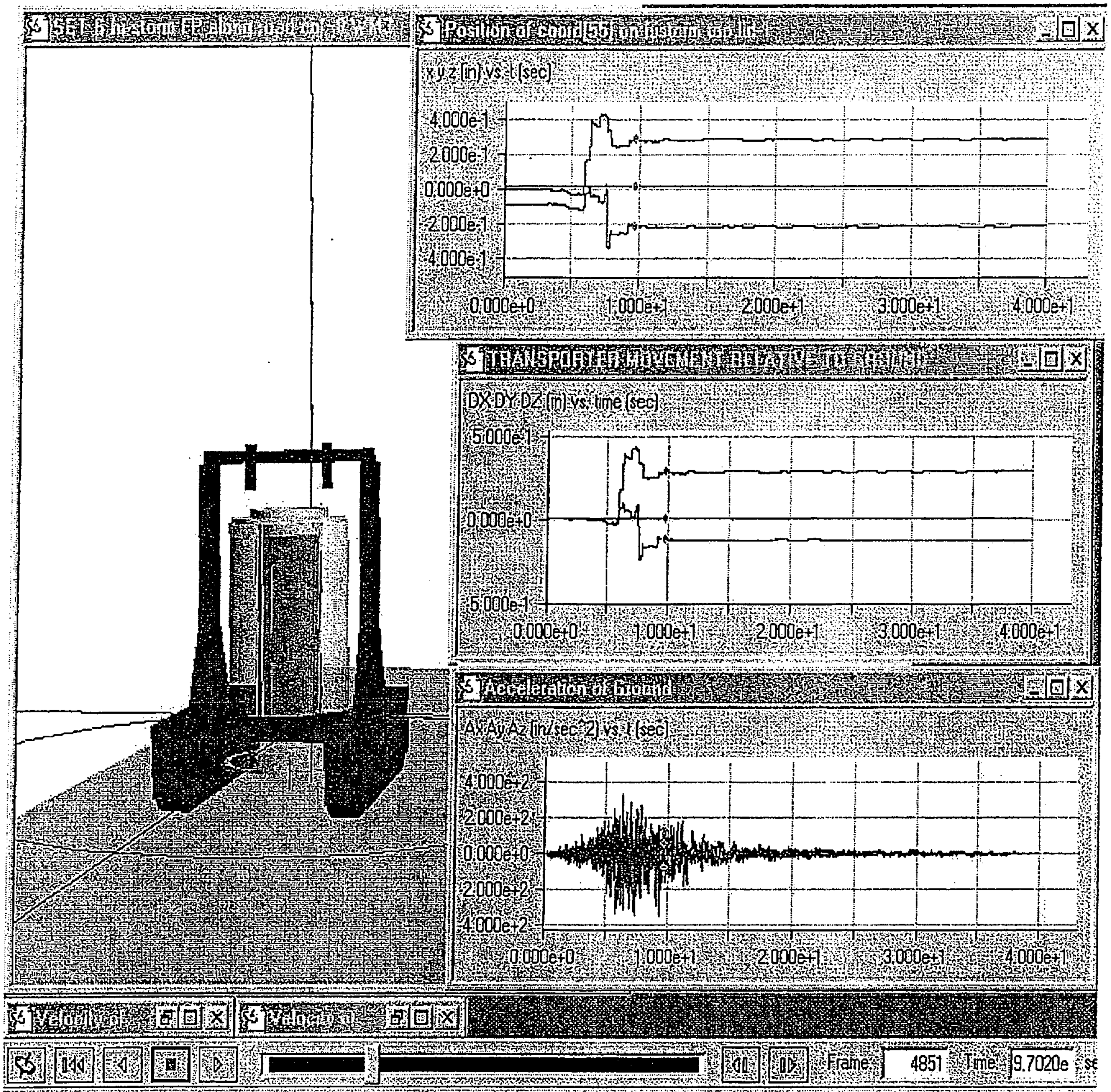

Figure 8.8: Phase 5, Set 6 Results - HI-STORM with cof=0.8

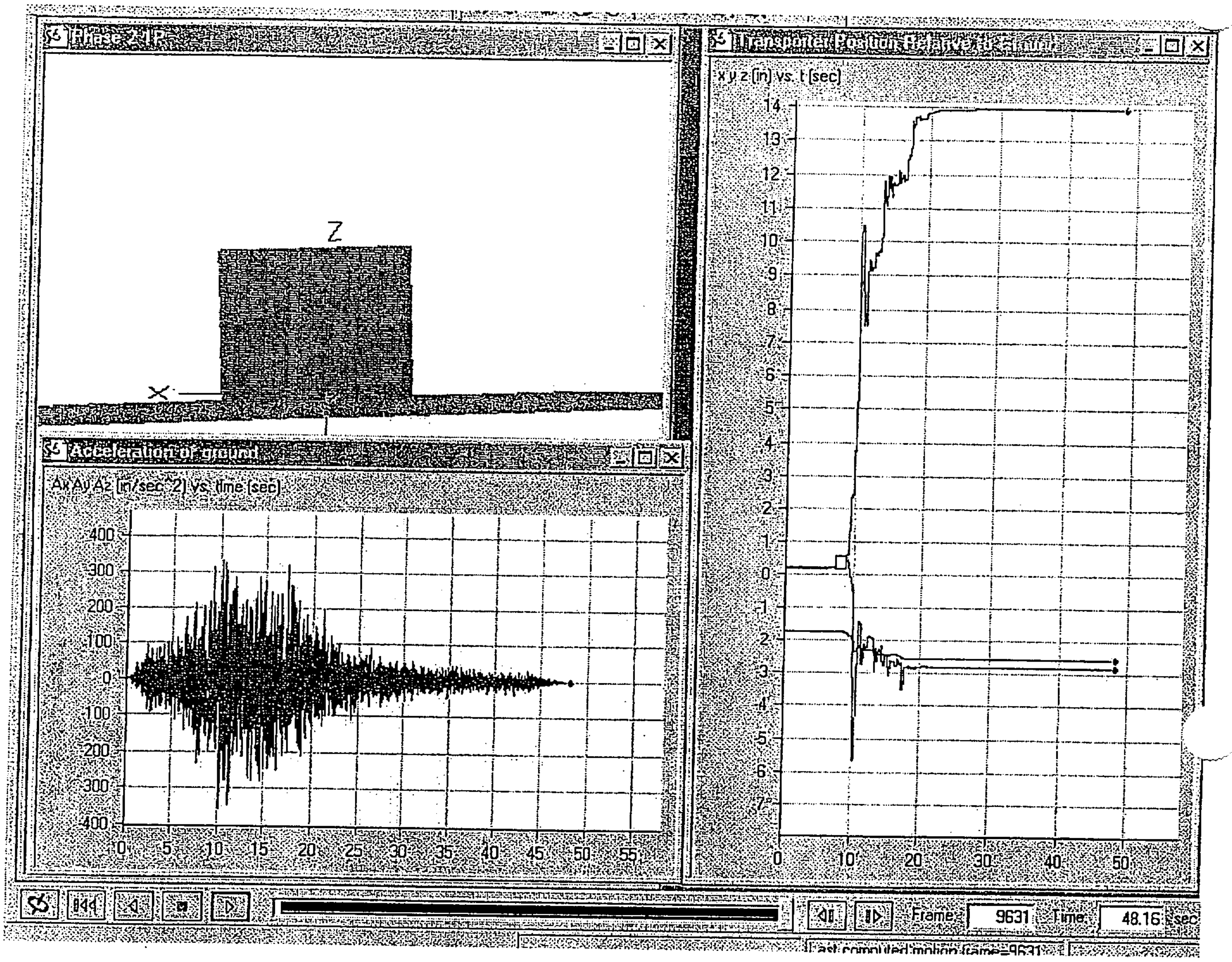

Figure 8.9: Phase 2, Set 1P – HI-TRAC

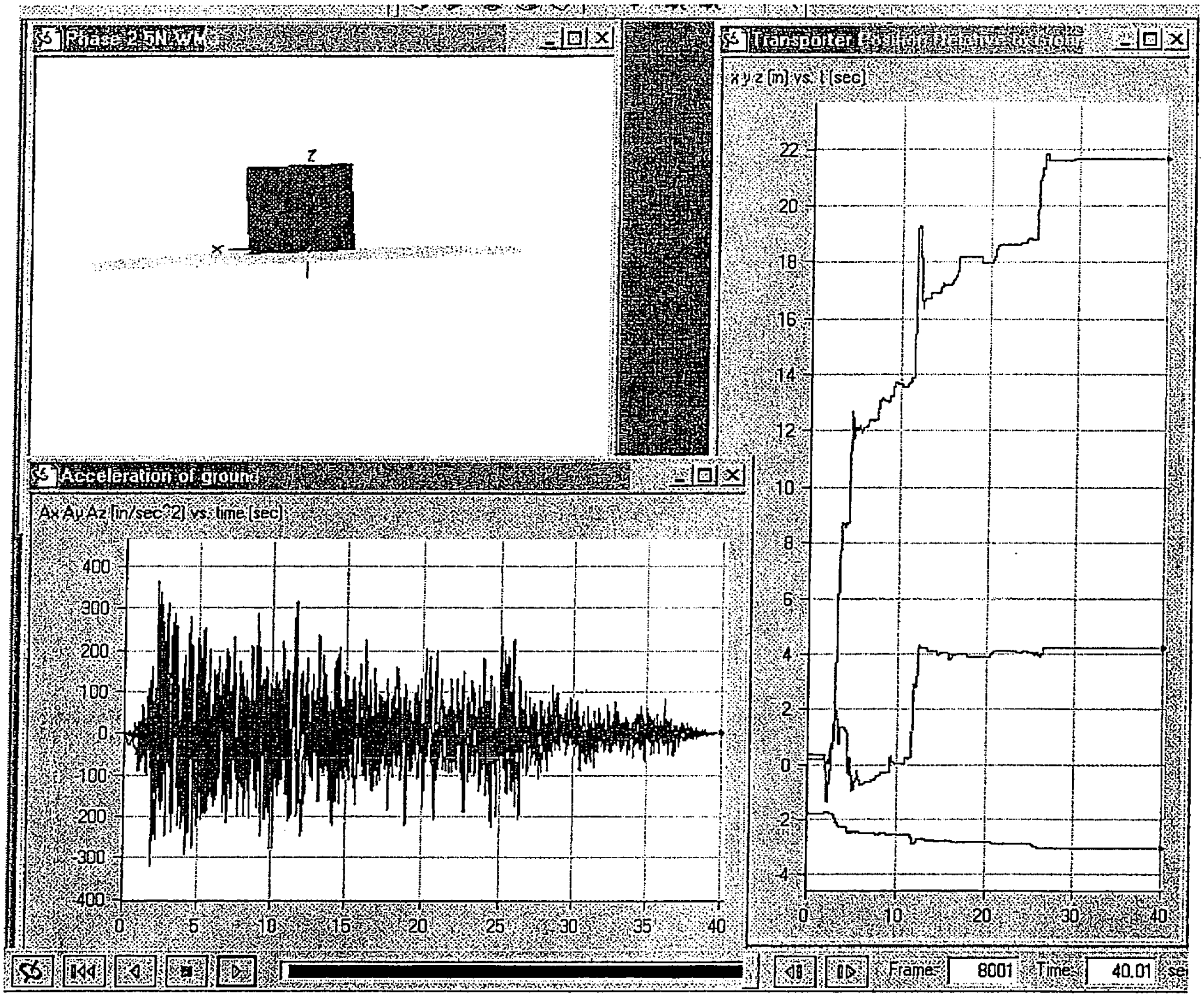

Figure 8.10: Phase 2, Set 5N – HI-TRAC

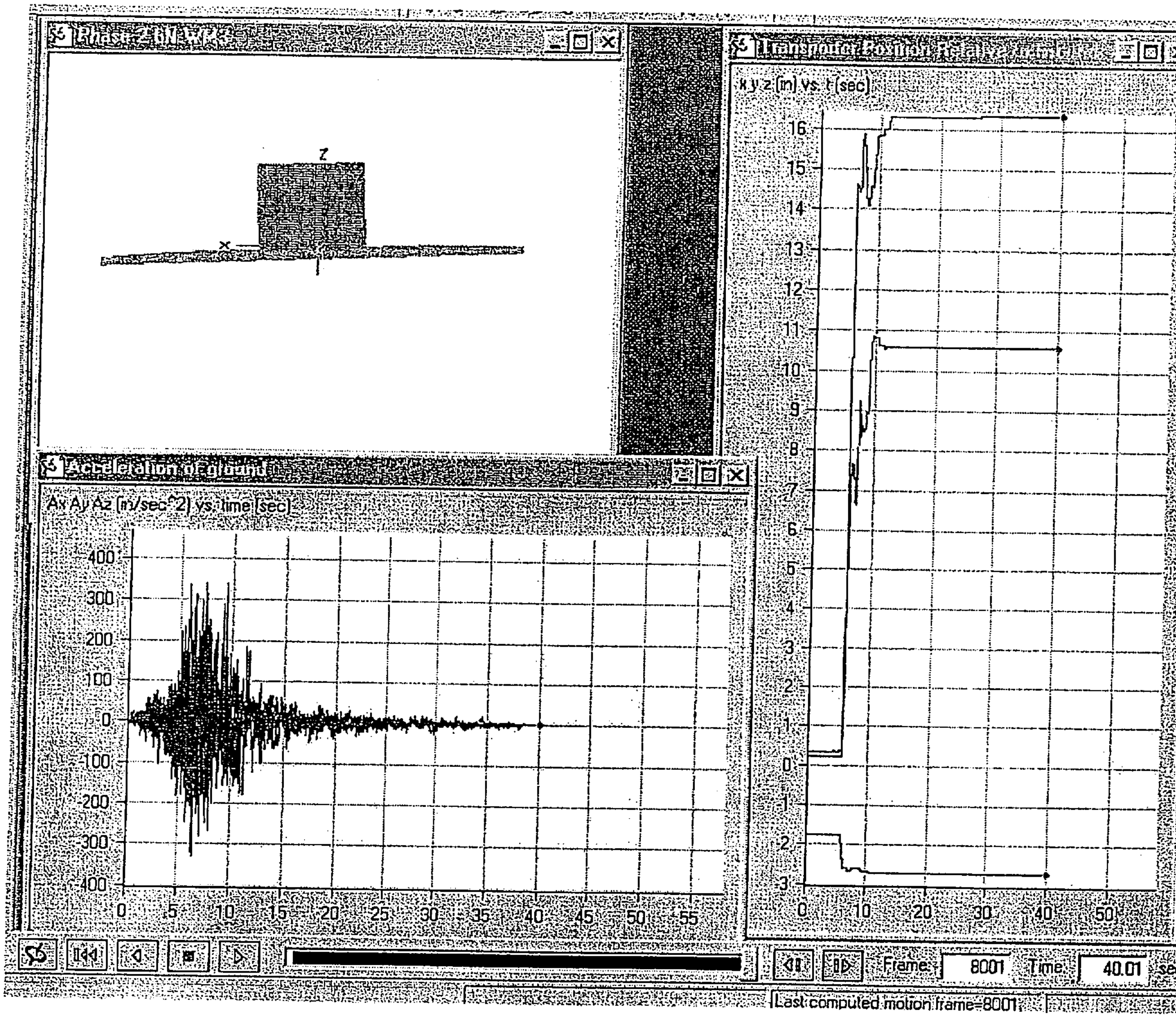

Figure 8.11: Phase 2, Set 6N – HI-TRAC

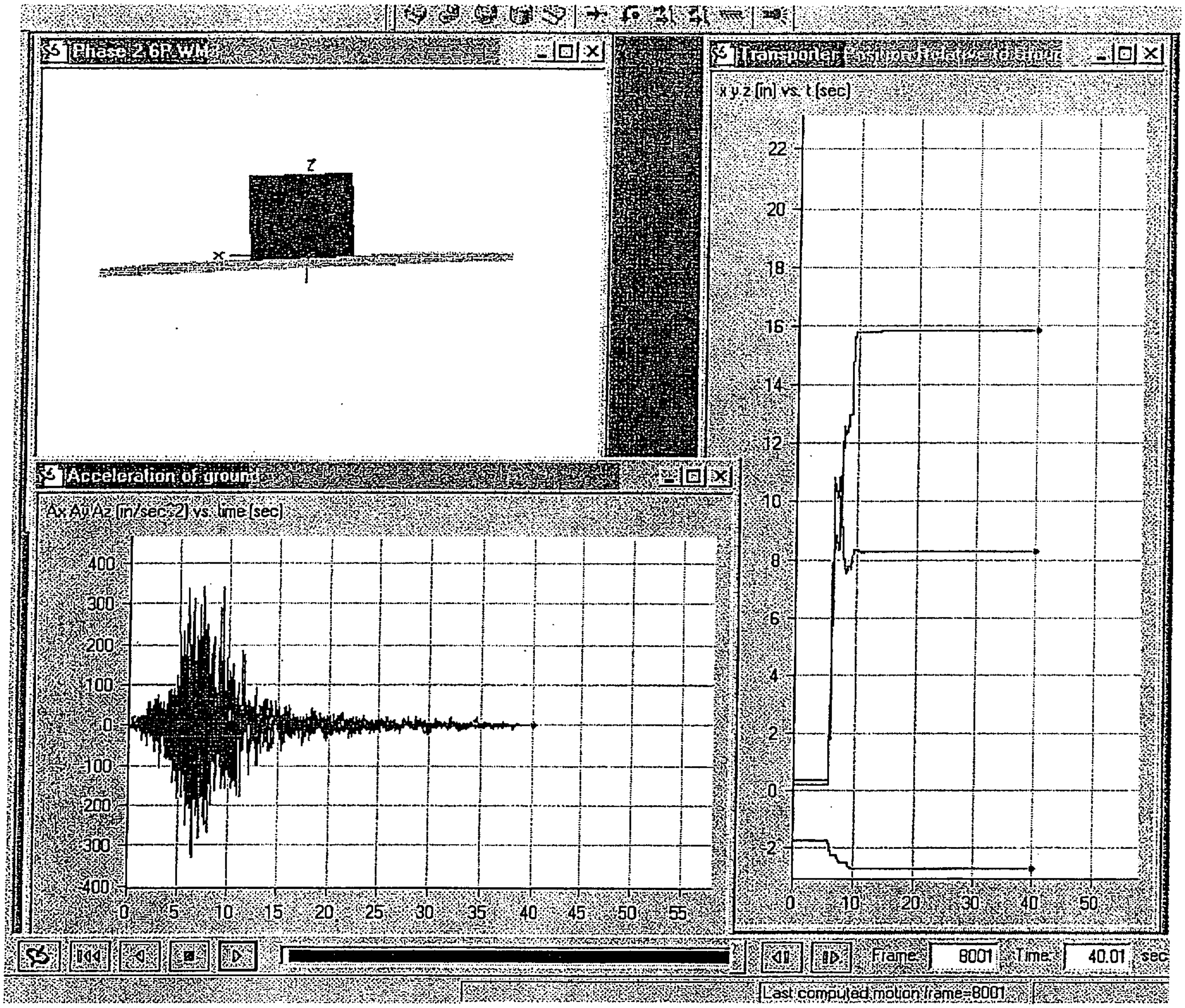

Figure 8.12: Phase 2, Set 6P – HI-TRAC

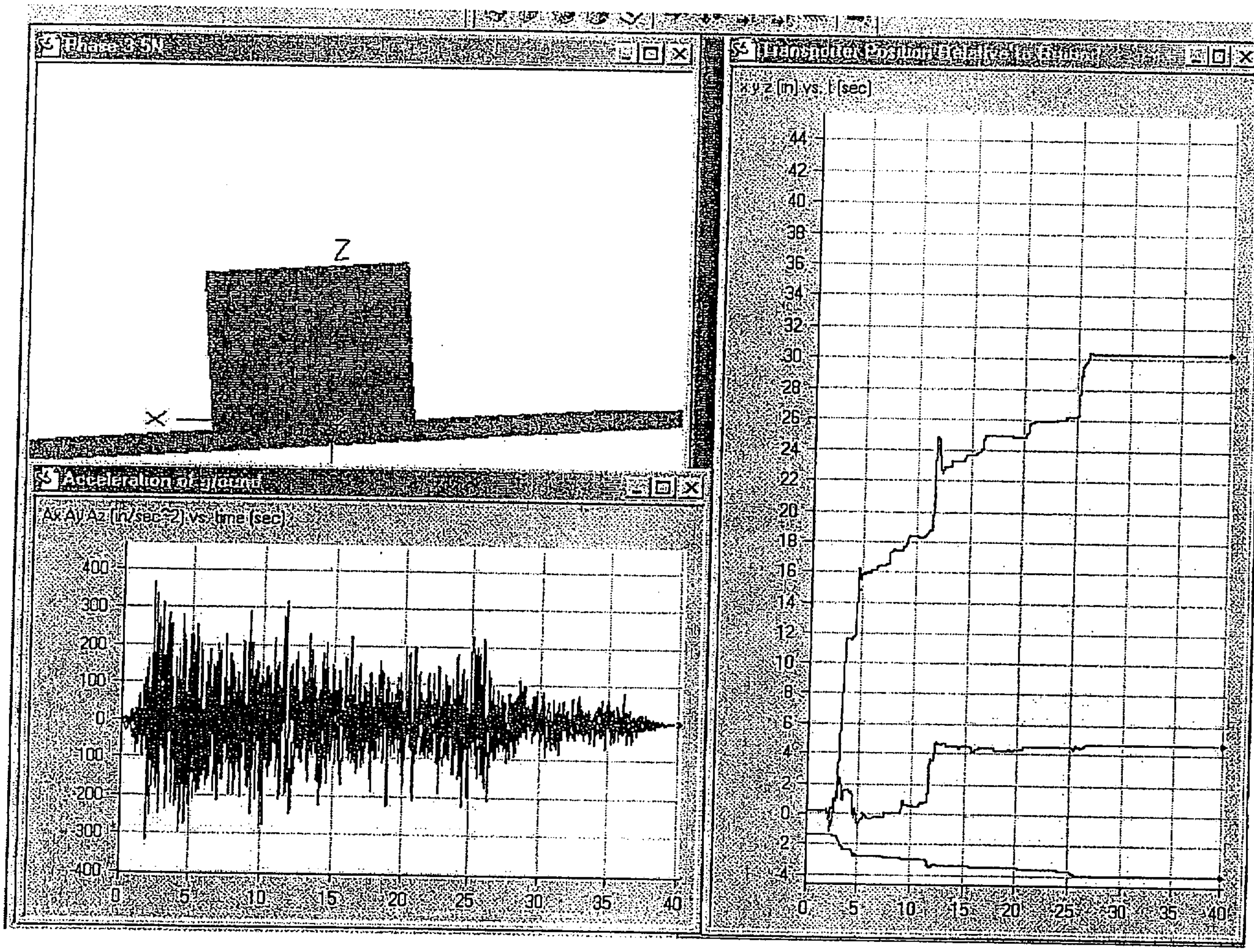

Figure 8.13: Phase 3, Set 5N – HI-TRAC

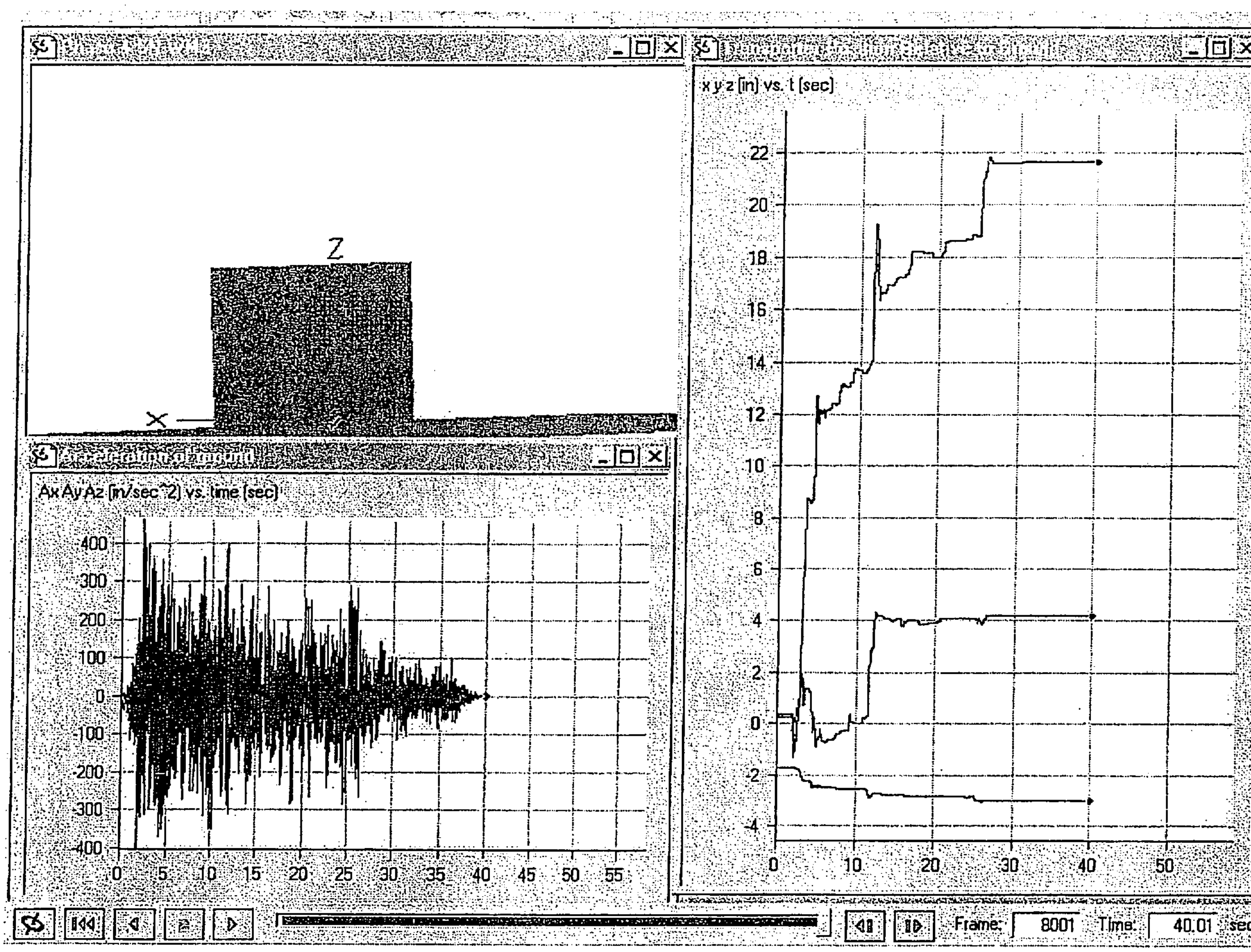

Figure 8.14: Phase 4, Set 5N – HI-STORM

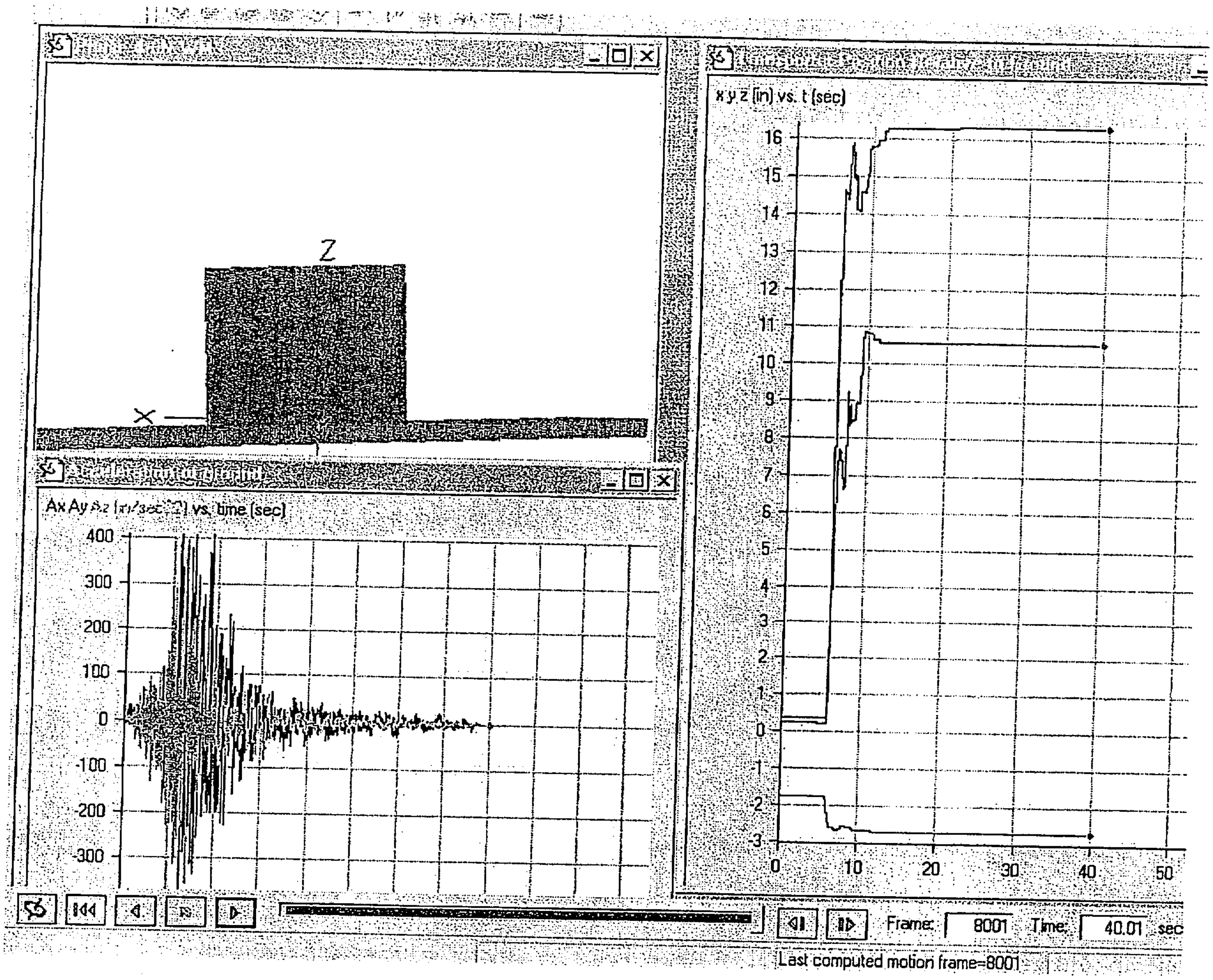

Figure 8.15: Phase 4, Set 6N – HI-STORM

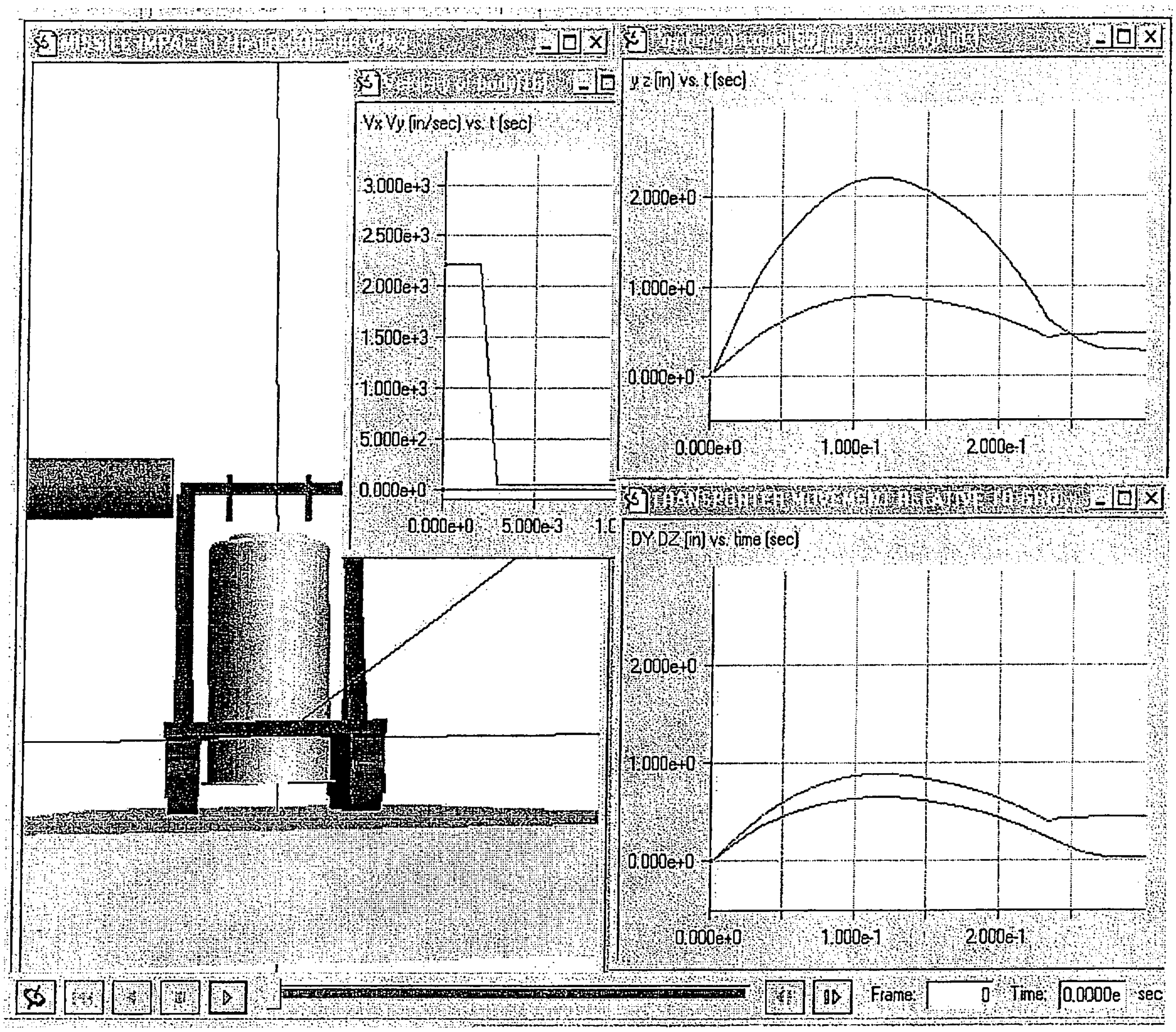

Figure 8.16: Transporter with HI-STORM – Missile Strike at Top, V=126 mph, Ground COF=0.8

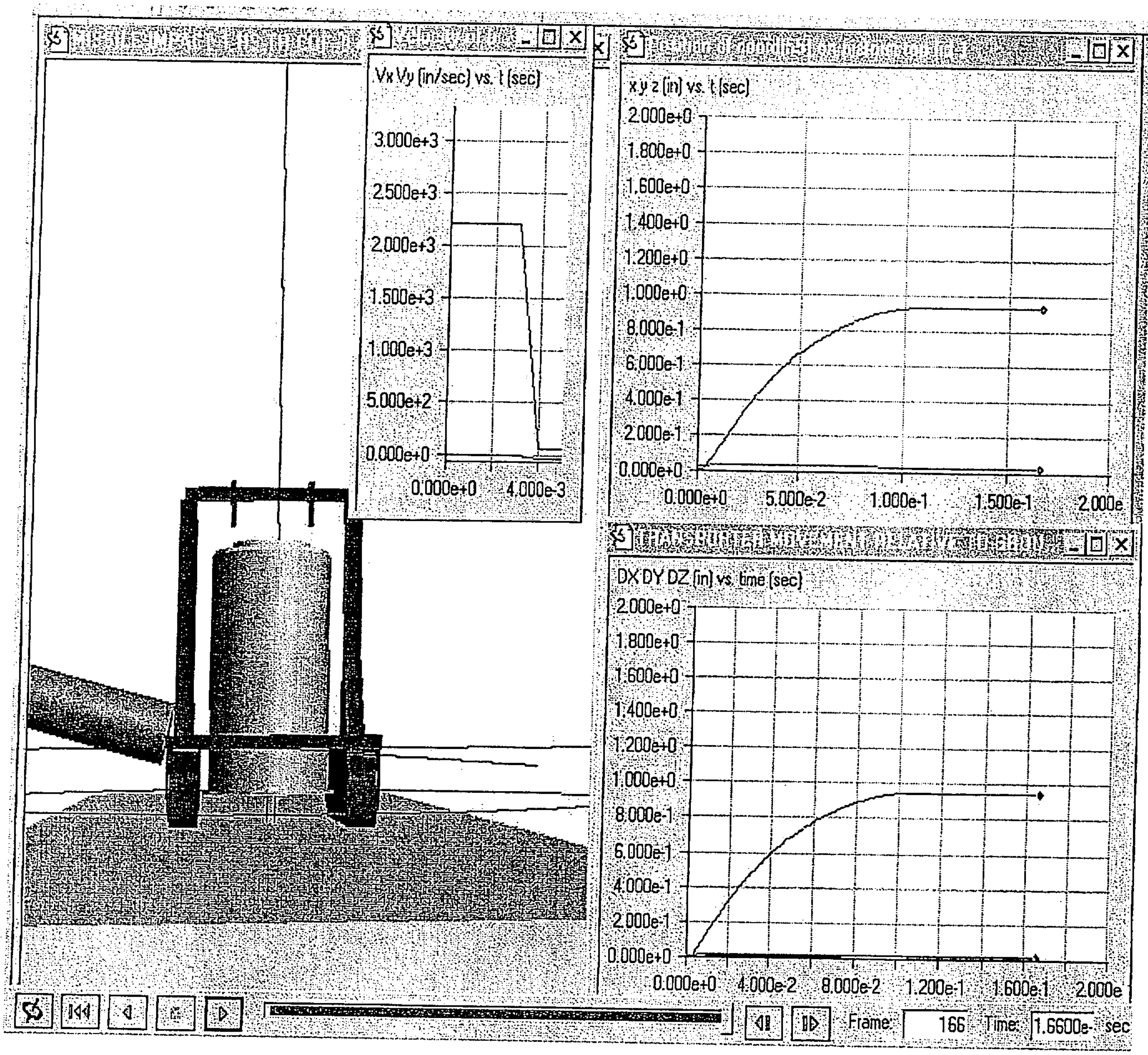

Figure 8.17: Transporter with HI-STORM – Missile Strike at Base, V=126 mph, Ground COF=0.4

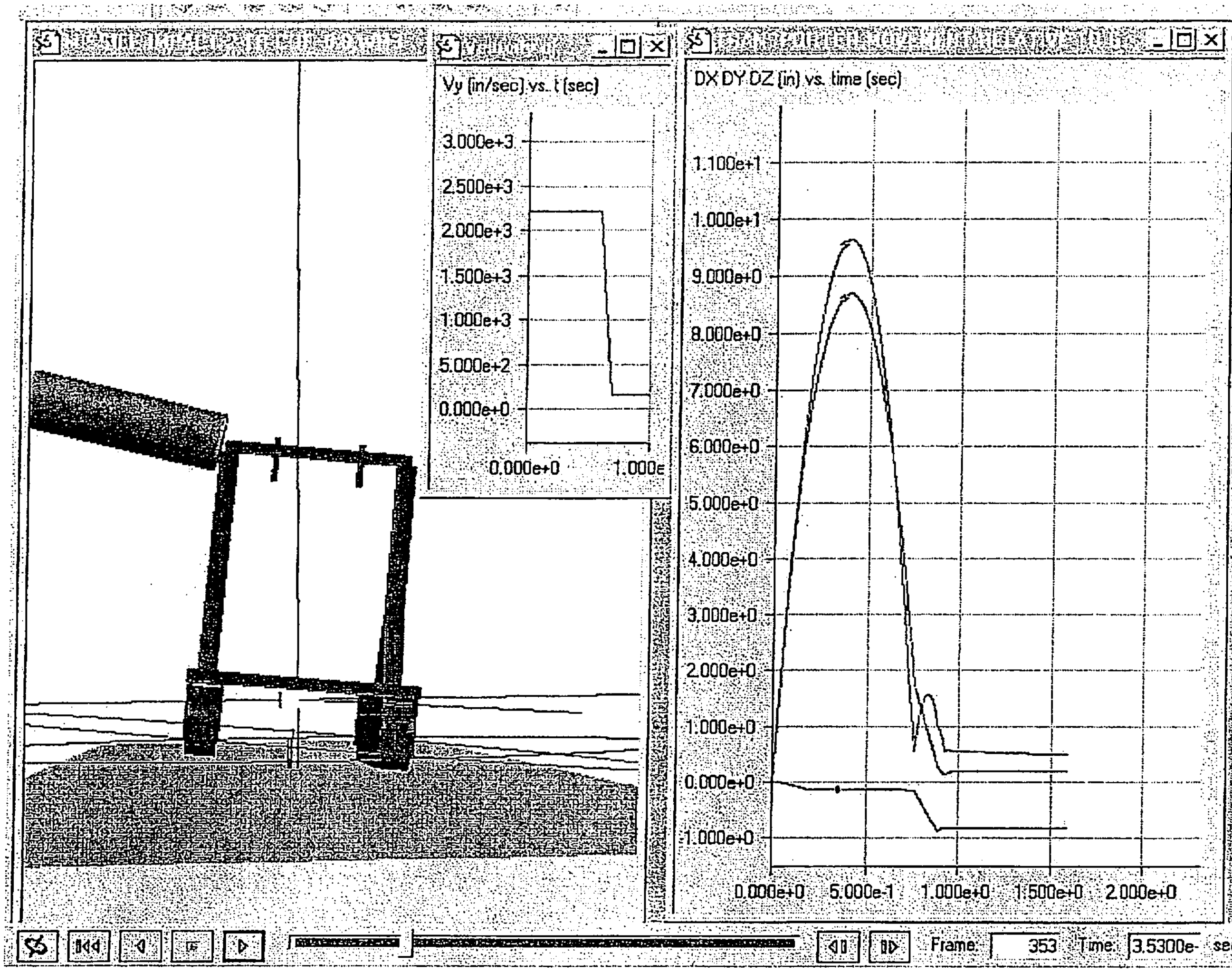

Figure 8.18: Empty Transporter – Missile Strike at Top, V=126 mph, Ground COF=0.8

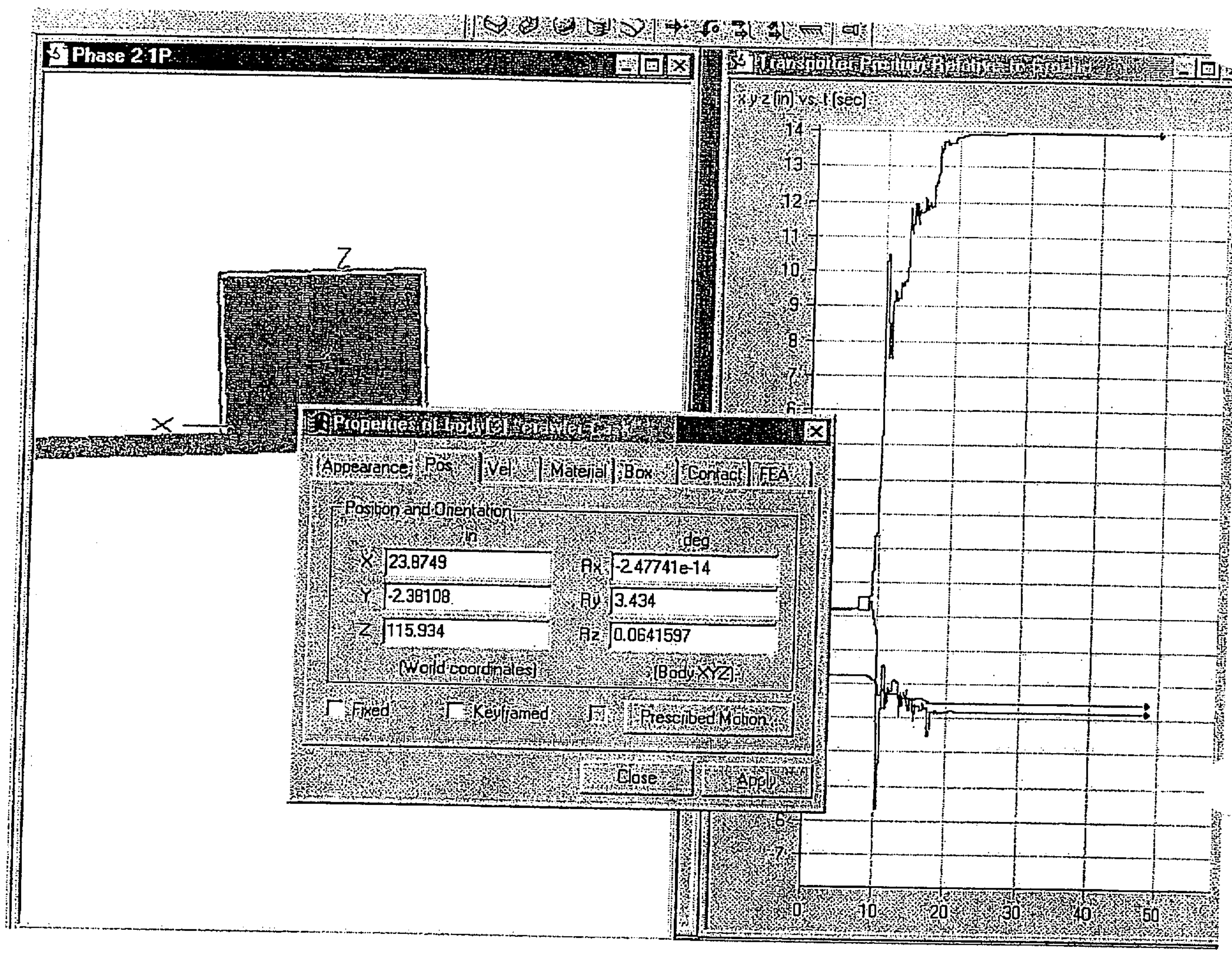

Figure 8.19: Screen Capture Verification of 6% grade input

APPENDIX A

(HOLTEC PROPRIETARY)

APPENDIX B
HOLTEC APPROVED COMPUTER LIST

October 24, 2001

PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
ANSYS (A)	5.3, 5.4, 5.6,5.6.2,5.7	JZ, EBR, PKC, CWB, SPA, AIS, IR, SP, JRT	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)	I.13.04	ELR, SPA, DMM, KC, ST,VJB	UNIX		
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	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		
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ	DOS/Windows		
DYNAPOST	1.0, 2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.48, 5.1 (see error notice), 4.2.8 (UNS),5.5	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	
GENEQ	1.3		DOS		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST,VJB	Windows		

October 24, 2001

PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950	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, 2.4	AIS, SP, CWB, PKC, SJ	DOS/Windows	Version 2.4 for dry storage only. Use DYNAMO for liquefaction problems.	
MSREFINE	1.3, 2.1		DOS/Windows		
MULPOOLD	2.0, 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		Windows		X,2001
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		
ORIGEN	2.1		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		

PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
SIFATIG	1.0		DOS/Windows		
SOLIDWORKS	2001		DOS/Windows	Only Weight and Volume calculated using this program can be used as input to other evaluations.	
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE91	1.1		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows		
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.

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DESIGN BASIS WIND AND TORNADO EVALUATION FOR DCPP

FOR

PG&E

Holtec Report No: HI-2002497 NP Rev. 1

Holtec Project No: 1073

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Rev. No. [2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	12/19/01	CWB	562471				
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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".

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REVIEW AND CERTIFICATION LOG

DOCUMENT NAME :	DESIGN BASIS WIND AND TORNADO EVALUATION FOR DCPP
HOLTEC DOCUMENT I.D. NUMBER :	2002497
HOLTEC PROJECT NUMBER :	1073
CUSTOMER/CLIENT:	PG&E

REVISION BLOCK

REVISION NUMBER *	AUTHOR & DATE !!	REVIEWER & DATE !!	QA & DATE !!	APPROVED & DATE !	DIST. x
ORIGINAL	C. Bullard II C.B. 12/?/00	John Zhai JZ. 12/18/00	N/A	EGL 12/19/00	
REVISION 1					
REVISION 2					
REVISION 3					
REVISION 4					
REVISION 5					
REVISION 6					

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REVISION LOG

Revision 0 – Original Issue

Revision 1 – Item h) in Section 7.0 was revised to include the calculation of the moment at the base of the anchored cask due to the site-specific tornado loads. The changes to the text are marked with revision bars in the left hand margin.

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 which are intended to create a document which 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.

Accordingly, this Calculation Package is compiled to provide archival information to supplement the material presented in Diablo Canyon Safety Analysis Report. The material presented in this Calculation Package is *not* needed to comprehend the material presented in the above-mentioned Technical Report (which is a self-contained document in full compliance with the USNRC regulations), unless the reader wishes to examine the computational details.

The purpose of each discrete calculation is explicitly stated in this compendium of calculations and the specific location in the above-mentioned technical report, which it is intended to supplement, is clearly indicated.

Because of its function as a repository of all 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 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).

EXECUTIVE SUMMARY†

A central objective of a storage overpack is to maintain the integrity of the "confinement boundary", namely, the multi-purpose canister (MPC) stored inside. This operational imperative requires that the mechanical loadings associated with a tornado do not jeopardize the physical integrity of the loaded MPC. Potential consequences of a tornado on the cask system are:

- Instability (tip-over) due to tornado wind load combined with either tornado missile impact or impulse from tornado pressure drop.
- Stress in the cask induced by the lateral force caused by the steady wind or missile impact.
- Loadings applied on the MPC transmitted to the inside of the cask through its openings or as a secondary effect of loading on the enveloping overpack structure.
- Excessive cask deformation which may prevent ready retrievability of the MPC.
- Excessive cask deformation which may significantly reduce the shielding effectiveness of the storage overpack.

At DCPP, the following missiles are postulated to impact the HI-TRAC transfer cask inside the Fuel Handling Building (FHB).

- 108 pound, 4-inch × 12-inch × 10-foot board traveling at 150 mph
- 76 pound, 3-inch × 10-foot schedule 40 pipe traveling at 50 mph

† The Executive Summary is a self-contained write-up of the wind load and tornado generated missile evaluation for DCPP, which is intended for direct insertion in the DCPP Safety Analysis Report (SAR).

Of particular interest is the case of a missile impact on the transfer cask and lift yoke after the loaded cask, with its lid unwelded, is lifted out of and above the SFP. Although the MPC is unsealed during this operation, this condition is no more critical than the conditions outside of the FHB since a MPC retention lid will be bolted to the HI-TRAC transfer cask for added protection.

Based on comparisons of the quantity $(MV^2)/D$, where M is the mass of the missile, V is the velocity of the missile, and D is the equivalent diameter of the missile, the 8-inch diameter steel cylinder (125 kg, 126 mph) analyzed in the HI-STORM FSAR bounds the two missiles listed above. Therefore, the results and conclusions from the FSAR are valid for the DCPP missiles inside the FHB and the Aux. Bldg.. The only scenario that is not analyzed in the FSAR is a direct missile strike on the cask lift yoke, which may potentially cause a loss of load.

The most vulnerable location on the cask lift yoke is the lift arm. The cross section of the lift arm is weaker (i.e., has a lower section modulus) in the direction parallel to its plane of rotation. Thus, the evaluation considers three bounding missile impacts in this direction. An impact on the inside surface produces a moment that tends to rotate the lift arm outward, away from the HI-TRAC, possibly disconnecting the lift arm from the trunnion. If the impact occurs on the outside surface, the lift arm may collapse due to the lateral force of the impact. Finally, if the impact occurs near the top of the lift arm, a shear failure may occur. These three scenarios are analyzed using classical methods. The following results are obtained.

i. The maximum moment produced by a missile impact on the inside surface of the lift arm is 1.003×10^6 lbf-in. By comparison, friction between the lift arm and the HI-TRAC trunnion is capable of producing a resisting moment up to 2.995×10^6 lbf-in. Since the frictional resistance is greater than the impact moment, the lift arm will not rotate.

ii. The maximum combined stress (i.e., axial plus bending) in the lift arm due to a missile impact on the outside surface is 47,191 psi, which is less than the ASME Subsection NF stress limit of 109,200 psi for Level D conditions. Thus, the lift arm will not collapse due to a missile impact.

iii. The maximum shear stress in the lift arm due to a missile impact near the top of the arm is 1,302 psi, which is far less than the ASME Subsection NF stress limit of 72,800 psi for Level D conditions. Thus, the lift arm will not experience a shear failure due to a missile impact.

The above results demonstrate that there will be no loss of load due to a missile impact while handling the transfer cask inside the FHB or the Aux. Bldg.. Furthermore, the 125-ton HI-TRAC cask satisfies all functional requirements under the postulated impact scenarios.

Outside the FHB, there are a host of missiles to consider, which can be divided into three categories (i.e., small, intermediate, and large) based on their size and weight. In the small missile category, the bounding missile (based on kinetic energy comparisons) is a 1-inch diameter steel rod traveling at 40 m/sec (89.5 mph). This missile is analyzed only for the loaded HI-STORM because, unlike the transfer cask, it has cooling vents that allow the missile to enter inside the cask. For the HI-TRAC transfer cask, the small missile is ignored because the intermediate missile, a 760 lb insulator string traveling at 157 mph, causes more damage. Finally, the two automobile missiles postulated at DCPP are bounded by the large missile analyzed in the HI-STORM FSAR.

The missile impacts are analyzed using formulas from Topical Report BC-TOP-9A, "Design of Structures for Missile Impact," and energy balance methods. The following results are obtained for the small and intermediate missiles.

i. The 1-inch diameter steel rod (i.e, small missile) is postulated to enter an inlet duct and impact the pedestal shell, which is the most vulnerable location on the HI-STORM cask. The analysis shows that the rod will pierce the shell and penetrate the concrete to a depth of 6.179 inches, which is significantly less than the radius of the pedestal shield. The damage to the concrete pedestal shield does not affect the confinement boundary nor does it affect the retrievability of the MPC. The net effect on the cask's shielding ability is negligible.

ii. The intermediate missile will not penetrate the 1-¼" inner shell of the HI-STORM cask. The minimum required thickness to withstand the missile impact is 0.619 inches.

iii. The intermediate missile will not penetrate the 2" top lid of the HI-STORM cask. The minimum required thickness to withstand the missile impact is 1.089 inches.

iv. The intermediate missile will not penetrate the ¾" inner shell of the HI-TRAC cask. The minimum required thickness to withstand the missile impact is 0.266 inches.

v. When the HI-TRAC is transferred horizontally outside of the FHB, the potential exists for a missile strike on the bottom transfer lid door. The analysis shows that the intermediate missile will not penetrate the 2-¼" top plate of the transfer lid door. The minimum required thickness to withstand the missile impact is 0.619 inches.

vi. The top lid of the HI-TRAC has a central hole for rigging the MPC, which is normally protected by the cask transporter (i.e., crawler). However, if the intermediate missile directly impacts the MPC top lid, the safety factor against failure of the peripheral weld is 7.103.

vii. Away from the impact locations, stresses in the overpack are below ASME Code Level D stress limits.

viii. The maximum moment at the base of the anchored cask, due to the wind and missile loads, is 2,448 kip-ft. This is below the moment induced by the seismic loads.

The above calculations demonstrate that the HI-STORM 100 Overpack and the 125-ton HI-TRAC transfer cask provide effective missile barriers for the MPC. No missile strike compromises the integrity of the confinement boundary. In addition, global stresses intensities arising from the missile strikes satisfy ASME Code Level D limits for an ASME Section III Subsection NF structure.

TABLE OF CONTENTS

1.0 PURPOSE AND SCOPE

The purpose of this report is to evaluate the postulated wind and tornado loads at Diablo Canyon Power Plant (DCPP) as specified in Sections 6.2.1 and 6.2.2 of the Client Specification [1.1]. The wind and tornado loads are considered for a sequence of events, which follow the fuel from the initial loading in the SFP to final storage on the ISFSI pad.

2.0 METHODOLOGY

The first step in the analysis is to compare the postulated wind and tornado loads at DCPP with the design basis loads in the HI-STORM 100 TSAR [2.1]. The bounding missile in each category[1] (i.e., small, intermediate, large) is the missile with the highest kinetic energy. Initial comparisons of the missiles were carried out in Holtec report HI-2002478 [2.2, Appendix A].

If the TSAR missiles are determined to bound all of the DCPP missiles, then the evaluation is complete. If not, impact analyses must be performed for the bounding DCPP missiles. The missile impacts are analyzed in a manner that is consistent with Appendices 3.C, 3.G, and 3.H of the HI-STROM 100 TSAR [2.1].

A separate analysis is performed in Appendix D of this report to determine the consequences of a missile impact between a 3-inch diameter pipe and the cask lift yoke. This analysis uses basic strength of material formulas to measure the damage.

[1] The missiles are characterized as small, intermediate, or large based on their size and weight.

3.0 ACCEPTANCE CRITERIA

In this section, the word "cask" refers to both the HI-STORM and HI-TRAC casks.

The acceptance criteria for the wind and tornado load evaluation are:

a) The loaded cask does not become kinematically unstable (i.e., tip-over) as a result of the postulated wind loads and/or a tornado missile impact.

b) The stresses in the cask do not exceed Level D stress limits away from the immediate impact location.

c) The missiles do not breach the MPC enclosure vessel ("confinement boundary").

d) The cask does not deform plastically such that the retrievability of the stored MPC is threatened.

e) The cask does not deform plastically such that the shielding effectiveness of the cask is significantly affected.

4.0 ASSUMPTIONS

The assumptions used in the analyses are listed in the appendices.

5.0 INPUT DATA

The dimensions of the 125-ton HI-TRAC and the HI-STORM 100 are obtained from the HI-STORM TSAR [2.1]. The wind and missile data, which is obtained from the Client Specification [1.1], is summarized in Sections 5.1 through 5.3.

5.1 Design Basis Wind

The design basis wind velocity is 80 mph with a gust factor of 1.1. The design basis wind load applies to rigging and lifting operations outside the Aux. Building and the Fuel Handling Building (FHB), during transport of the Transfer Cask on plant roadways, and at the ISFSI site.

5.2 Tornado Wind

The design tornado wind parameters are:

Maximum wind speed	200 mph
Rotational speed	157 mph
Maximum translational speed	43 mph
Pressure drop	0.86 psi
Rate of pressure drop	0.36 psi/sec
Radius of maximum rotational speed	150 ft

5.3 Tornado Generated Missiles

The postulated tornado-induced missiles acting on the Storage System include Spectrum I or Spectrum II missiles as specified and applied in Section 3.5.1.4 of NUREG-0800 and the following three missiles applied horizontally, except as specified in paragraphs a) through c) below:

- 108 pound, 4-inch × 12-inch × 10 feet board at tornado wind velocity
- 76 pound, 3-inch × 10 feet schedule 40 pipe at one-third tornado wind velocity
- 4000 pound auto (w/ 20 ft^2 frontal area) up to 25 feet above ground at one-sixth tornado wind velocity

a) Tornado missiles act on the Storage System at locations in the yard outside the Aux. Building and FHB, while on the transport roadway, and at the ISFSI site. Only one missile is considered to act at a given time.

b) Inside the FHB and the Aux. Bldg., the two missiles postulated below act on the Transfer Cask, with the lid unwelded, after the Cask is loaded and lifted out of the SFP. Impact loads are based on the entry of the missiles into the FHB at a 150 mph tornado wind velocity and assumed to act horizontally on the Cask or yoke.

- 108 pound, 4-inch × 12-inch × 10 feet board at tornado wind velocity
- 76 pound, 3-inch × 10 feet schedule 40 pipe at one-third tornado wind velocity

c) The following tornado missiles from the 500kV towers act on the Transfer Cask and the Storage Cask. The missiles travel at 157 mph in the horizontal and vertical directions.

- 2-inch × 2-inch × 1/8-inch angle, 5 feet long, weighing 8.5 lb
- insulator string weighing 760 lb, and segments weighing 15 lb
- yoke plate weighing 15 lb
- spacer weighing 5.2 lb
- damper weighing 32 lb

6.0 COMPUTER CODES

The commercial software program Mathcad [6.1] is used to complete this analysis.

7.0 ANALYSIS

The postulated wind loads and tornado generated missiles are analyzed for a sequence of events, which follow the fuel from the initial loading in the SFP to final storage on the ISFSI pad. The events are defined by the following time periods.

a) During fuel loading operations in the SFP
b) During handling of the HI-TRAC by the FHB crane
c) During activities in the cask washdown area
d) During staging activities in the Shipping and Receiving area and in the Yard outside the FHB
e) During transport to the Cask Transfer Facility (CTF)
f) During MPC transfer at the CTF
g) During transport to the ISFSI site
h) During long term storage on the ISFSI pad

These events are subject to different wind loads and different missiles depending on their location inside or outside of the FHB. The type of analysis performed for each event is described in the following paragraphs.

a) During fuel loading operations in the SFP

During fuel loading operations, the MPC is submerged in the SFP. Although tornado missiles can still enter the pool, the SFP water will dissipate the missile velocities. Therefore, due to the protection of the water, the wind and tornado loads while the MPC is in the pool are bounded by the loads outside of the pool. No analysis is required for this event.

b) During handling of the HI-TRAC by the FHB crane

Inside the FHB and the Aux. Bldg., there are only two postulated missiles (refer to paragraph 5.3.b), a 76 pound, 3-inch × 10 feet schedule 40 pipe and a 108 pound 4-inch × 12-inch × 10 feet board. Both of these missiles are bounded (i.e., lower kinetic energy) by the intermediate missile analyzed in the HI-STORM TSAR [2.1, Appendix 3.H]. Therefore, the results and conclusions from the TSAR can be applied to missile impacts during this event.

A new analysis is required to demonstrate that a direct missile impact on the cask lift yoke will not cause a loss of load. Appendix D evaluates the consequences of a missile impact at the most vulnerable locations on the cask lift yoke.

The wind loads analyzed in the HI-STORM TSAR bound any probable wind loads inside the FHB and the Aux. Bldg.. Therefore, the results and conclusions from the TSAR can be applied to wind loads during this event.

c) During activities in the cask washdown area

The postulated missiles inside the FHB are bounded (i.e., lower kinetic energy) by the intermediate missile analyzed in the HI-STORM TSAR [2.1, Appendix 3.H]. Therefore, the results and conclusions from the TSAR can also be applied to missile impacts in the cask washdown area.

The wind loads analyzed in the HI-STORM TSAR bound any probable wind loads inside the FHB and the Aux. Bldg.. Therefore, the results and conclusions from the TSAR can be applied to wind loads during this event.

d) During staging activities in the Shipping and Receiving Area and in the Yard outside the FHB

There are a host of missiles to consider in the Yard outside the FHB. These missiles can be divided into three categories (small, intermediate, and large) based on their size and weight. The small missiles have no significant effect on the loaded HI-TRAC because the transfer cask has no vents or openings that permit a direct impact on the MPC. In the intermediate category, the bounding missile is the 760 lb insulator string traveling at 157 mph (refer to paragraph 5.3.c). Three different impact locations on the transfer cask are analyzed in Appendix B. This appendix also considers a direct impact on the MPC lid through the center hole on the HI-TRAC top lid. Finally, the two automobile missiles postulated for DCPP are bounded by the large missile analyzed in the HI-STORM TSAR [2.1, Appendix 3.AN].

The design basis wind load and the tornado wind load at DCPP are also bounded by the tornado wind characteristics analyzed in the HI-STORM TSAR [2.1, Table 2.2.4].

e) During transport to the Cask Transfer Facility (CTF)

The wind loads and missiles for this event are identical to those described in paragraph d). The bounding intermediate missile, a 760 lb insulator string, is analyzed in Appendix B. The remaining missiles are bounded by the results from the HI-STORM TSAR [2.1]. The cask transporter has redundant drop protection; therefore, a loss of load due to a direct missile strike on the transporter is not plausible.

The design basis wind load and the tornado wind load at DCPP are bounded by the tornado wind characteristics analyzed in the HI-STORM TSAR [2.1, Table 2.2.4].

f) During MPC transfer at the CTF

At the CTF, the MPC is transferred from the 125-ton HI-TRAC to the HI-STORM 100. As a result, the HI-STORM 100 must be analyzed for the postulated missile impacts. Unlike the transfer cask, the HI-STORM 100 has several cooling vents, which allow small missiles to enter inside. In this category, the bounding missile is the 1-inch diameter steel rod traveling at 40 m/sec (Spectrum II missile). This missile, as well as the 760 lb intermediate missile, is analyzed in Appendix C. Appendix C also computes the global stresses in the HI-STORM overpack due to missile impact. As before, the large missiles are bounded by the results from the HI-STORM TSAR [2.1, Appendix 3.C].

The design basis wind load and the tornado wind load at DCPP are bounded by the tornado wind characteristics analyzed in the HI-STORM TSAR [2.1, Table 2.2.4].

Since the CTF structure at DCPP is underground, it is not exposed to missile impacts.

g) During transport to the ISFSI site

The wind loads and missiles for this event are identical to those described in paragraph f). The small and intermediate missiles are both analyzed in Appendix C. The large missiles are bounded by the results from the HI-STORM TSAR [2.1, Appendix 3.C].

The design basis wind load and the tornado wind load at DCPP are bounded by the tornado wind characteristics analyzed in the HI-STORM TSAR [2.1, Table 2.2.4].

h) During long term storage on the ISFSI pad

The wind loads and missiles for this event are identical to those described in paragraph f). The small and intermediate missiles are both analyzed in Appendix C. The large missiles are bounded by the results from the HI-STORM TSAR [2.1, Appendix 3.C].

At DCPP, the storage casks will be anchored to the ISFSI pad. Therefore, the wind and missile loads will produce a moment (M) at the base of the cask, whose magnitude is given by the following equation:

$$M = 0.5WH + Fh$$

where:

W equals the resultant force on the cask due to tornado wind;
H equals the height of the cask (231.25 in);
F equals the lateral force on the cask due to missile impact;
h equals the height of the missile impact above the base (231.25 in).

From the HI-STORM TSAR [2.1], the resultant force on the cask due a 360 mph tornado wind is 3.273×10^4 lb (Appendix 3.C), and the maximum force due to a large missile impact is 4.569×10^5 lb (Appendix 3.AN). The corresponding tornado wind force and missile impact force at DCPP are computed as follows:

$$W = 3.273 \times 10^4 lb \cdot \left(\frac{200mph}{360mph}\right)^2 = 1.010 \times 10^4 lb$$

$$M = 4.569 \times 10^5 lb \cdot \left(\frac{4000lb}{3960lb}\right) \cdot \left(\frac{33.3mph}{126mph}\right) = 1.220 \times 10^5 lb$$

When these values are substituted into the above equation, the moment at the base of the cask equals 2,448 kip-ft. As shown in Holtec report HI-2012618 [7.1], this moment is bounded by the seismic induced moment.

8.0 COMPUTER FILES

All computer files related to the DCPP missile evaluation are located under the network directory labeled **f:\projects\1073\cbullard**. A hardcopy of the directory listing is provided in Appendix A. The entire contents of the directory are permanently saved on a backup tape.

9.0 RESULTS

At DCPP, the bounding missiles in the small and intermediate categories are the 1-inch diameter steel rod and the 760 lb insulator string, respectively. The deformations and stresses in HI-STORM 100 Overpack due to these two missiles are reported in Appendix C. Similar results are reported in Appendix B for two postulated impacts between the 760 lb insulator string and the 125-ton HI-TRAC. Appendix D shows that a direct missile impact on the cask lift yoke will not cause loss of load. The results are summarized below.

i. The 1-inch diameter steel rod (i.e, small missile) is postulated to enter an inlet duct and impact the pedestal shell, which is the most vulnerable location on the HI-STORM cask. The analysis shows that the rod will pierce the shell and penetrate the concrete to a depth of 6.179 inches, which is significantly less than the radius of the pedestal shield. The damage to the concrete pedestal shield does not affect the confinement boundary nor does it affect the retrievability of the MPC.

ii. The intermediate missile will not penetrate the 1-¼" inner shell of the HI-STORM cask. The minimum required thickness to withstand the missile impact is 0.619 inches.

iii. The intermediate missile will not penetrate the 2" top lid of the HI-STORM cask. The minimum required thickness to withstand the missile impact is 1.089 inches.

iv. The intermediate missile will not penetrate the ¾" inner shell of the HI-TRAC cask. The minimum required thickness to withstand the missile impact is 0.266 inches.

v. When the HI-TRAC is transferred horizontally outside of the FHB, the potential exists for a missile strike on the bottom transfer lid door. The analysis shows that the intermediate missile will not penetrate the 2-¼" top plate of the transfer lid door. The minimum required thickness to withstand the missile impact is 0.619 inches.

vi. The top lid of the HI-TRAC has a central hole for rigging the MPC, which is normally protected by a missile shield plate. However, if the intermediate missile directly impacts the MPC top lid, the safety factor against failure of the peripheral weld is 7.103.

vii. The maximum moment produced by a missile impact on the inside surface of the lift arm is 1.003×10^6 lbf-in. By comparison, friction between the lift arm and the HI-TRAC trunnion is capable of producing a resisting moment up to 2.995×10^6 lbf-in. Since the frictional resistance is greater than the impact moment, the lift arm will not rotate.

viii. The maximum combined stress (i.e., axial plus bending) in the lift arm due to a missile impact on the outside surface is 47,191 psi, which is less than the ASME Subsection NF stress limit of 109,200 psi for Level D conditions. The maximum shear stress in the lift arm due to a missile impact near the top of the arm is 1,302 psi, which is far less than the ASME Subsection NF stress limit of 72,800 psi for Level D conditions. Thus, the lift arm will not fail due to a missile impact.

ix. Stresses in the overpack are below Level D stress limits away from the immediate impact locations.

x. The maximum moment at the base of the anchored cask, due to the wind and missile loads, is 2,448 kip-ft. This is below the moment induced by the seismic loads.

The transfer cask is not analyzed for a small missile impact, since HI-TRAC does not have any vents or openings that allow a missile to enter inside. With respect to the HI-TRAC transfer cask, the intermediate missile clearly bounds the small missile. The large missile analyzed in the HI-STORM TSAR bounds the automobile missiles at DCPP.

In addition, the design basis wind and the tornado wind at DCPP are bounded by the tornado wind characteristics analyzed in the HI-STORM TSAR.

In addition, the design basis wind and the tornado wind at DCPP are bounded by the tornado wind characteristics analyzed in the HI-STORM TSAR.

10.0 CONCLUSION

This report demonstrates that the HI-STORM 100 Overpack and the 125-ton HI-TRAC transfer cask provide effective missile barriers for the MPC. No missile strike compromises the integrity of the confinement boundary. In addition, global stresses intensities arising from the missile strikes satisfy ASME Code Level D limits for an ASME Section III Subsection NF structure.

11.0 REFERENCES

[1.1] PG&E Specification 10012-N-NPG, "Dry Cask Storage System," dated September 1, 2000.

[2.1] Holtec Report HI-951312, HI-STORM 100 TSAR, Proposed Revision 11, August 2000.

[2.2] Holtec Report HI-2002478, "Design Criteria Document for Cask Seismic/Structural Analyses for DCPP," Latest Revision.

[6.1] Mathcad 2000 Professional, Mathsoft Inc., 1999.

[7.1] Holtec Report HI-2012618, "Analysis of Anchored HI-STORM Casks at Diablo Canyon ISFSI," Revision 1.

APPENDIX A

[HOLTEC PROPRIETARY]

APPENDIX B

[HOLTEC PROPRIETARY]

APPENDIX C

[HOLTEC PROPRIETARY]

APPENDIX D

[HOLTEC PROPRIETARY]

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EVALUATION OF SITE-SPECIFIC BLASTS AND EXPLOSIONS FOR THE DIABLO CANYON ISFSI

FOR

PACIFIC GAS AND ELECTRIC

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DOCUMENT CATEGORIZATION

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

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☐ Technical Report (Per HQP 3.2) (Such as a Licensing Report)

☐ Design Criterion Document (Per HQP 3.4)

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☐ Other (Specify):

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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:

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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 - Corrected cylinder valve penetration calculations in Appendix B (pages B-6, B-11, B-16, B-21, B-26, B-31 and B-36) and updated results summary table in Section 7.2.2 (page 18).

Revision 2 – Incorporated several minor Client editorial comments. Modified discussions of compressed gas cylinder impacts to clarify that these events may affect a HI-STORM storage cask as well as the HI-TRAC transfer cask.

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 format 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 Diablo Canyon Power Plant (DCPP) 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 DCPP 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.

2.0 Methodology

2.1 Evaluation of Explosion Potential

A total of six 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 postulated explosion hazards fall into two categories. The first category, which comprises the majority of the postulated hazards, is the detonation of a fuel-air mixture. The methodology for evaluating these hazards is described in Subsection 2.2.1. The methodology for evaluating the hazards in the second category, an impact from a ruptured compressed gas cylinder, is described in Subsection 2.2.2.

2.2.1 Material Detonations

USNRC Regulatory Guide 1.91 [3] 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.

The magnitude of the overpressure that acts on a cask system is a function of the calorific energy released and the distance between the cask and the explosion. The first step in these evaluations is, therefore, computation of the total calorific energy released during detonation. This computation is performed using the following formula:

$$E = m \times HV \times Y \tag{2-1}$$

where:

E is the detonation energy
m is the mass of material
HV is the material heating value
Y is an explosive yield factor

The use of the explosive yield factor recognizes that only a relatively small percentage of the total heat energy in a material is released by detonation. The remaining heat energy is released during normal combustion subsequent to detonation and does not contribute to the detonation overpressure. Explosive yield factors for hydrocarbon vapor clouds in air are typically between 0.03 and 0.06 (i.e., 3% - 6% yield) [4].

It is common practice in evaluating explosion overpressures to convert all detonation energy quantities into equivalent weights of trinitrotoluene (TNT). This is accomplished by dividing the given detonation energy by the detonation energy of TNT [5], as:

$$W_{TNT} = \frac{E}{E_{TNT}} \tag{2-2}$$

where:

W_{TNT} is the equivalent weight of TNT
E_{TNT} is the detonation energy of TNT

An exhaustive investigation into the effects of explosions on structures, including the development of data for overpressure magnitude versus explosion size and distance, has been performed by the U.S. Army [5]. Using the published U.S. Army methodology of for ground-burst explosions, the equivalent weight of TNT and the separation distance between the explosion and the casks systems are used to determine a scaled ground distance, defined as:

$$Z_G = \frac{X}{W_{TNT}^{\;1/3}} \tag{2-3}$$

where:

Z_G is the scaled ground distance
X is the separation distance

Typical units for the scaled ground distance are ft per lb $^{1/3}$ of TNT. Curves that relate incident overpressure and scaled ground distance [5] are utilized to determine the overpressure that will act on the cask systems at the DCPP ISFSI.

2.2.2 Compressed Gas Cylinder Impacts

The internal pressures of compressed gas cylinders are frequently in excess of two thousand pounds per square inch. The potential energy at such high pressures is significant and any cylinder ruptures can be catastrophic. The large energy release that can accompany conversion of this potential energy into kinetic energy could potentially damage SSCs important to safety and must be evaluated.

To determine the effects of catastrophic cylinder ruptures on the DCPP ISFSI cask systems, it is postulated that high-pressure compressed gas cylinders fail such that the valve assemblies break off. This failure mode would create an approximately 2-inch diameter hole in one end of the cylinder, and the escaping compressed gas would impart a large acceleration on the cylinder body.

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Newton' s third law of motion requires that the thrust force must act to accelerate the gas cylinder in the opposite direction of the expanding gas motion. Thus, knowing the mass of the gas cylinder, including the mass of any contained gas, the instantaneous acceleration of the cylinder can be determined from Newton' s second law of motion as:

$$a = \frac{F}{M_{cyl} + M_{cg}} \tag{2-9}$$

where:

a is the acceleration of the gas cylinder
M_{cyl} is the mass of the empty cylinder
M_{cg} is the mass of contained gas

It should be noted that Equation 2-9 conservatively neglects the effects of drag, which would oppose the thrust force and reduce the acceleration of the cylinder. It should also be noted that the mass of contained gas (M_{cg}) reduces over time as gas escapes through the opening in the cylinder.

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The postulated high-pressure compressed gas cylinder failure mode (i.e., separation of the valve assembly) will also result in the valve assembly being accelerated by the escaping compressed gas. Thus, the velocity of the valve assembly must also be evaluated. An experimentally developed correlation for the velocity of an end cap or a single, large fragment (i.e., the valve assembly) ejected from a cylindrical vessel pressurized with an ideal gas is [10]:

$$V_f = 2 \times F^{0.5} \times a_e$$
$$F = \frac{P_e \times A \times R}{M \times a_e^{\ 2}} \qquad (2\text{-}10)$$

where:

- V_f is the end cap or fragment velocity
- a_e is the sonic velocity in the compressed gas prior to rupture
- P_e is the compressed gas pressure prior to rupture
- A is the projected area of the fragment
- R is the radius of the cylindrical vessel
- M is the mass of the fragment

It should be noted that, in Equation 2-10, the sonic velocity (a_e) cancels out when the two parts of the correlation are combined. As the sonic velocity is the only term in Equation 2-10 that is gas dependent, this means that the velocity of the ejected valve assembly will be the same for all compressed gases.

Once accelerated by the expanding contained gases, a cylinder or valve assembly presents a missile hazard to the HI-TRAC transfer cask or a HI-STORM storage cask. One function of the HI-TRAC transfer and HI-STORM storage casks is to provide physical protection for the contained multipurpose canister (MPC), which forms the confinement boundary for the radioactive materials within. The HI-TRAC and HI-STORM must, therefore, be capable of preventing any missiles that result from high-pressure gas cylinder failures from damaging the MPC.

A method for predicting the penetration of structures by missile impacts [11] has been previously accepted by the USNRC and has been used in the HI-STORM FSAR [8] for evaluating tornado missile impacts. The penetration of a missile into steel is given by the following equation:

$$T = \frac{\left[\frac{1}{2} \times M \times V^2\right]^{2/3}}{F_P \times D} \qquad (2\text{-}11)$$

where:

T is the thickness of penetration
M is the mass of the missile
V is the velocity of the missile
F_P is a constant, equal to 672 $[(\text{ft-lb}_f)^{2/3}]/\text{in}^2$
D is the diameter of the missile impact area

It is observed that, in Equation 2-11, the missile penetration is proportional to the missile kinetic energy and inversely proportional to the missile impact area diameter.

3.0 Acceptance Criteria

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. 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 85 °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

3.2.1 Material Detonations

These evaluations are performed to determine the effects, on the casks systems, of all postulated explosion hazards identified as real hazards. The following acceptance criterion is 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, 9]. 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.

3.2.2 Compressed Gas Cylinder Impacts

1. The impact of the cylinder or cylinder valve assembly with the cask systems must not damage the cask confinement (i.e., MPC) boundary and must not prevent removal of the MPC from the HI-TRAC transfer cask or the HI-STORM storage cask.

4.0 Assumptions

Material Detonations

1. All evaluations of the effects of flammable liquid explosions are performed assuming that 100% of the liquid has been vaporized and mixed with air between its upper and lower flammability limits. The largest possible fuel amount will result in the largest incident overpressure, so it is conservative to assume 100% vaporization conditions.

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 the neglect elevation differences.

3. No credit for partial shielding of casks systems by transport vehicles or other intervening structures 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 or onsite transport and handling. This restriction ensures that the separation distance between a gasoline explosion and the cask system SSCs is sufficient to prevent blast damage.

5. Combustible materials are not permitted within the ISFSI. This assumption is in accordance with Section 6.2.7.2 of the PG&E specification [2].

Compressed Gas Cylinder Impacts

6. To determine the effects of catastrophic cylinder ruptures on the DCPP ISFSI cask systems, it is postulated that high-pressure compressed gas cylinders fail such that the valve assemblies break off. This failure mode would create an approximately 2-inch diameter hole in one end of the cylinder, and the escaping compressed gas would impart a large acceleration to the cylinder body and the valve assembly. This scenario represents the most likely failure mode and, therefore, represents the highest actual risk.

7. The maximum velocity of all damaged gas cylinders and valve assemblies is calculated in the absence of aerodynamic drag forces. Any aerodynamic drag would only resist the acceleration of the cylinder or valve assembly, so it is conservative to neglect aerodynamic drag.

8. The maximum velocity of all damaged gas cylinders and valve assemblies is calculated in the absence of atmospheric wind. Normal atmospheric wind velocities would be negligible in comparison with the expected cylinder and valve assembly velocities, so it is acceptable to neglect atmospheric wind.

9. The maximum velocity of all damaged gas cylinders and valve assemblies is calculated without including any elevation differences between the cylinders and the casks. Due to the expected short duration required for the venting compressed gas to accelerate a cylinder or valve assembly to high velocity and the relatively low gravitational acceleration, any elevation differences would result in negligible velocity differences.

10. The maximum velocity of all damaged gas cylinders is calculated using bounding (1.0) discharge coefficients. Maximizing the discharge coefficient will maximize the thrust force and resultant acceleration, so it is conservative to use bounding discharge coefficients.

11. The maximum velocity of all damaged gas cylinders is calculated assuming the cylinder motion is aligned with the longitudinal axis of the cylinder. Any skew of the thrust vector away from the cylinder axis would result in an arcing or tumbling cylinder trajectory that would consume a portion of the available compressed gas potential energy. Any reduction of the available potential energy that is converted into linear velocity would reduce the eventual maximum velocity, so it is conservative to align the thrust vector with the cylinder axis.

12. Impact of the compressed gas cylinders and valve assemblies with the cask system SSCs occurs coincident with the maximum cylinder or valve assembly velocity. Maximizing the impact velocity will maximize the momentum and kinetic energy of the cylinder or valve assembly, so it is conservative to use the maximum velocity.

5.0 <u>Input Data</u>

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 for these calculations are presented within the calculations themselves (Appendices A and B) 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 three explosion hazards at the ISFSI site and three along the transport route. The postulated hazards are:

Hazard ID	Hazard Description	Potentially Affected Cask(s)
IE1	Fuel tank for the transporter or other vehicle during a fire.	HI-STORM or HI-TRAC
IE2	7-gallon propane bottle being transported past the ISFSI.	HI-STORM or HI-TRAC
IE3	Standard acetylene bottle being transported past the ISFSI.	HI-STORM or HI-TRAC
TE1	Three fuel tanks (250 gal. of propane, 2000 gal. of #2 diesel fuel and 3000 gal. of gasoline), approximately 1200 feet from the transport route to the ISFSI.	HI-TRAC
TE2	Unit 2 main bank transformers (13,000 gal. of mineral oil each), approximately 160 feet from the transport route to the ISFSI.	HI-TRAC
TE3	Compressed gas cylinders inside the reactor controlled area (RCA) and near the RCA south gate.	HI-STORM or HI-TRAC

Each of these postulated hazards is evaluated, using the methodology presented in Section 2.1, to determine its actual explosive potential in the following subsections.

6.1.1 Evaluation of Hazard IE1

The motor fuels that may be encountered in these vehicles include diesel fuel and gasoline. MSDS sheets for these two materials are included in Appendix C.

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 85 °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.

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 85 °F (Section 3.1, criterion 1) a gasoline explosion does present a real explosion hazard and must be evaluated to determine its effects.

6.1.2 Evaluation of Hazard IE2

Propane is stored and transported as a liquefied compressed (~125 psia) gas. An MSDS sheet for this material is included in Appendix C.

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%." As the flash point is less than 85 °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.

The impact of a propane bottle on a cask resulting from explosive decompression of the contents of the bottle is bounded by hazard TE3, discussed below.

6.1.3 Evaluation of Hazard IE3

Acetylene is stored and transported as a gas dissolved in acetone under pressure. An MSDS sheet for this material is included in Appendix C.

Acetylene rapidly vaporizes at atmospheric pressure, so the flash point can be taken approximately equal to the boiling point (-103.4 °F). As stated on the MSDS, acetylene "poses an immediate ..explosive hazard when concentrations exceed 2.5%." As the flash point is less than 85°F (Section 3.1, criterion 1) and the explosion rating is positive for explosion (Section 3.1, criterion 2), an acetylene explosion does present a real explosion hazard and must be evaluated to determine its effects.

The impact of an acetylene bottle on a cask resulting from explosive decompression of the contents of the bottle is bounded by hazard TE3, discussed below.

6.1.4 Evaluation of Hazard TE1

The three fuel tanks are close enough to each other that the explosion of one tank could result in the rupture of the other two. As such, all three tanks are postulated as a single explosion hazard. MSDS sheets for the three materials are included in Appendix C.

As described in Subsections 6.1.1 and 6.1.2, propane and gasoline present a real explosion hazards but diesel fuel, as a result of its high flash point, does not. While the rupture and subsequent detonation of the propane or gasoline tank could rupture the diesel fuel tank, the resulting spilled diesel fuel could burn but not detonate. As detonation of the diesel fuel would not occur, the diesel will not contribute to any incident explosive overpressure.

Based on this evaluation, the near-simultaneous explosion of the propane and gasoline tanks presents a real explosion hazard and must be evaluated. The explosion of the diesel fuel tank does not, however, represent a real explosion hazard and is therefore not evaluated further.

6.1.5 Evaluation of Hazard TE2

The mineral oil in the transformers serves as a transformer coolant. An MSDS sheet for this material is included in Appendix C.

Mineral oil has a flash point of 275 °F. As stated on the MSDS, mineral oil is "not considered to be an explosion hazard." As the flash point is greater than 85 °F (Section 3.1, criterion 1) and the explosion rating is, basically, none (Section 3.1, criterion 2) a mineral oil explosion does not present a real explosion hazard.

6.1.6 Evaluation of Hazard TE3

This postulated hazard does not involve the detonation of any material, but rather the explosive decompression of a confined, high-pressure gas. The postulated effect of this sudden, uncontrolled decompression is the acceleration of the cylinder, which could then impact cask system SSCs. As a consequence of the nature of this postulated hazard, this event is deemed to present a real explosion hazard and must be evaluated.

6.2 Evaluation of Explosion Effects

The screening evaluation presented in the previous section identified postulated hazards IE1, IE2, IE3, TE1 and TE3 as real explosion hazards that must be evaluated to determine their effects on cask system SSCs. Hazards IE1, IE2, IE3 and TE1 involve the detonation of spilled hydrocarbon vapor clouds and are evaluated in Subsection 6.2.1. Hazard TE3 involves the explosive decompression of ruptured gas cylinders and is evaluated in Subsection 6.2.2.

6.2.1 Material Detonations

Applying the methodology presented in Subsection 2.2.1, the incident explosive overpressure is calculated for each of the identified real explosion hazards. The evaluated scenarios are summarized here:

1. IE1 - The fuel tank of an onsite, gas-powered vehicle is ruptured, spilling the entire contents. All the spilled gasoline vaporizes and mixes with air and the resulting vapor cloud subsequently detonates. Gasoline-powered vehicles are excluded from actually entering the ISFSI, so the minimum distance between the explosion and the cask system SSCs is the distance between the ISFSI pads and the security fence.

2. IE2 - A propane bottle being transported past the ISFSI is ruptured, releasing the confined gas. The released propane mixes with air and the resulting vapor cloud subsequently detonates. Combustible materials are not permitted within the ISFSI, so the minimum distance between the explosion and the cask system SSCs is the distance between the ISFSI pads and the security fence.

3. IE3 - An acetylene bottle being transported past the ISFSI is ruptured, releasing the confined gas. The released acetylene mixes with air and the resulting vapor cloud

subsequently detonates. Combustible materials are not permitted within the ISFSI, so the minimum distance between the explosion and the cask system SSCs is the distance between the ISFSI pads and the security fence.

4. TE1 - The propane and gasoline tanks along the main plant road are ruptured, releasing all the confined propane and gasoline. All the spilled gasoline vaporizes and both the propane and vaporized gasoline mix with air and the resulting vapor cloud subsequently detonates. The minimum distance between the explosion and the transport path to the ISFSI is approximately 1,200 feet [2].

These calculations are included in Appendix A.

6.2.2 Compressed Gas Cylinder Impacts

Applying the methodology presented in Subsection 2.2.2, the maximum cylinder and valve assembly velocities are calculated for this real explosion hazard. The evaluated scenario is:

1. TE3 - Cylinders containing gas under high-pressure are damaged such that the valve assembly located at the top of the cylinder breaks off. Expansion of the high-pressure gases out of the holes in the cylinders accelerates the cylinders or the valve assemblies toward the cask systems, resulting in eventual impacts.

These calculations are included in Appendix B.

7.0 Results and Conclusions

7.1 Evaluation of Explosion Potential

As described previously (Section 6.1), this screening evaluation identified postulated hazards IE1, IE2, IE3, TE1 and TE3 as real explosion hazards that must be evaluated to determine their effects on cask system SSCs. The following table presents a summary of the screening evaluation results for all six postulated hazards.

Hazard ID	Hazard Classification	Basis for Classification
IE1	Diesel Fuel - No Real Hazard Gasoline - Real Hazard	Flash Point
IE2	Real Hazard	Flash Point and Explosion Rating
IE3	Real Hazard	Flash Point and Explosion Rating
TE1	Propane - Real Hazard Diesel Fuel - No Real Hazard Gasoline - Real Hazard	Flash Point and Explosion Rating
TE2	No Real Hazard	Flash Point and Explosion Rating
TE3	Real Hazard	Nature of Postulated Hazard

Subsequent evaluations are performed to determine the effects of all identified real explosion hazards on cask system SSCs.

7.2 Evaluation of Explosion Effects

7.2.1 Material Detonations

As described in Subsection 6.2.1, the incident explosive overpressure 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 (ft/lb$^{1/3}$)	Incident Overpressure (psi)
IE1	117.33	10.21	9.19
IE2	10.37	22.93	2.45
IE3	2.02	39.59	1.19
TE1	12103.71	52.27	0.84

As presented in Section 6.1, hazards IE1, IE2 and IE3 could all affect the HI-STORM storage casks proposed for use at the DCPP ISFSI. In Section 3.4.7.2 of the HI-STORM FSAR [8, 9], the HI-STORM is evaluated under a postulated 10 psi overpressure for a duration of one second and is shown to perform satisfactorily. As the already evaluated overpressure exceeds those calculated in Appendix A, it is concluded that the HI-STORM FSAR bounds the DCPP ISFSI explosion hazards, which subsequently do not adversely affect the HI-STORM system.

As presented in Section 6.1, hazards IE1, IE2, IE3 and TE1 could all affect the HI-TRAC transfer casks proposed for use at the DCPP ISFSI. The most severe accident involving the HI-TRAC that already evaluated in the HI-STORM FSAR [8, 9] is the HI-TRAC handling accident, which consists of a 45-g deceleration during a postulated cask side drop. During this event and crediting HI-TRAC self-weight only (i.e., neglecting MPC weight), the HI-TRAC shell is exposed to a lateral force of at least 7.2×10^{6} pounds. Applied evenly over the projected area of the side of the HI-TRAC, this load corresponds to a minimum pressure of approximately 384 psi. As the HI-TRAC has already been evaluated under a loading condition that far exceeds the overpressures calculated in Appendix A, and shown to perform satisfactorily, it is concluded that these DCPP ISFSI and transport route explosion hazards do not adversely affect the HI-TRAC transfer cask.

7.2.2 Compressed Gas Cylinder Impacts

As described in Subsection 6.2.2, the maximum velocities of postulated bounding high-pressure gas cylinders and cylinder valve assemblies, following catastrophic valve assembly failures, have been calculated in Appendix B. The following table presents a summary of the calculations and corresponding results.

Compressed Gas	**Gas Cylinder**		**Valve Assembly**	
	Velocity (mph)	**Steel Plate Penetration (in)**	**Velocity (mph)**	**Steel Plate Penetration (in)**
Acetylene	86.218	0.171	341.489	0.241
Air	89.281	0.179	341.489	0.241
Argon	98.999	0.205	341.489	0.241
Helium	34.879	0.051	341.489	0.241
Nitrogen	88.041	0.175	341.489	0.241
Oxygen	93.163	0.189	341.489	0.241
Propane	108.634	0.232	341.489	0.241

Conservatively neglecting the presence of water in the HI-TRAC water jacket and the presence of all radial and axial Holtite and lead, a missile impacting the 125-ton HI-TRAC transfer cask in any orientation must penetrate a minimum of 1.5 inches of steel [12] before it could impact the MPC confinement boundary. While the center portion of the HI-TRAC top lid is open, allowing direct access to the MPC lid inside, this opening is always protected from a missile impact by the body of the transporter. Even if the presence of the transporter is neglected, the 10-inch thickness of the MPC lid [13] precludes significant damage from the cylinder and valve assembly missiles. The maximum calculated penetrations for all cylinders and valve assemblies is less than the minimum steel thickness of the HI-TRAC transfer cask, so it is concluded that the MPC will not be damaged and that this DCPP explosion hazard does not adversely affect the HI-TRAC transfer cask.

The protective body of a HI-STORM 100S storage cask is composed of a 0.75-inch outer shell, a 27.25-inch concrete radial shield and a 1.25-inch inner shell [14]. Even if the concrete were completely neglected, a cylinder or valve assembly missile would have to penetrate over 2 inches of steel before it could impact the MPC. The air inlet and outlet ducts are located axially below and above the MPC, respectively, so a missile could not pass through a duct and impact the MPC. The maximum calculated penetrations for all cylinders and valve assemblies is less than the steel thickness of a HI-STORM 100S storage cask inner and outer shells, so it is concluded that the MPC will not be damaged and that this DCPP explosion hazard does not adversely affect the HI-STORM storage cask.

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] "Dry Cask Storage System," PG&E Specification 10012-N-NPG, 28 September 2000.

[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] Avallone and Baumeister, "Marks' Standard Handbook for Mechanical Engineers," Eighth Edition, 1978.

[7] Lindeburg, "Mechanical Engineering Reference Manual," Tenth Edition, 1997.

[8] "HI-STORM 100 System Final Safety Analysis Report," Holtec Report HI-2002444, Revision 0, July 2000.

[9] Holtec International License Amendment Request No. 1014-1, Revision 1, August 2000.

[10] Baum, "Disruptive Failure of Pressure Vessels: Preliminary Design Guidelines for Fragment Velocity and the Extent of the Hazard Zone," Journal of Pressure Vessel Technology, Transactions of the ASME, vol. 110, May 1988, pp. 168-176.

[11] "Design of Structures for Missile Impact," Bechtel Topical Report BC-TOP-9A, Revision 2, September 1974 (accepted by the USNRC by letter dated 25 November 1974).

[12] Holtec Drawings 1880 (Sheet 2, Revision 9; Sheet 5, Revision 9; Sheet 7, Revision 8) and 1928 (Sheet 2, Revision 9) and Bills-of-Materials BM-1880 (Sheet 1, Revision 8; Sheet 2, Revision 6) and BM-1928 (Revision 9).

[13] Holtec Drawings 1393 (Sheet 1, Revision 11) and 1396 (Sheet 1, Revision 15).

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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.

[14] Holtec Drawing 3443 (Sheet 2, Revision 0 and Sheet 3, Revision 0).

Appendix A - Calculation of Incident Overpressures

PROPRIETARY APPENDIX DELETED

Appendix B - Calculation of Maximum Gas Cylinder and Valve Assembly Velocities

PROPRIETARY APPENDIX DELETED

Appendix C - MSDS Sheets for Flammable Materials

AIR PRODUCTS

MATERIAL SAFETY DATA SHEET

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: **Acetylene, dissolved**
CHEMICAL NAME: Acetylene **FORMULA:** C_2H_2
SYNONYMS: Ethyne, welding gas
MANUFACTURER: **Air Products and Chemicals, Inc.**
7201 Hamilton Boulevard
Allentown, PA 18195-1501
PRODUCT INFORMATION: 1-800-752-1597
MSDS NUMBER: 1001 **REVISION:** 5
REVISION DATE: March 1998 **REVIEW DATE:** March 1998

SECTION 2. COMPOSITION / INFORMATION ON INGREDIENTS

Acetylene is sold as pure product >99%
CAS NUMBER: 74-86-2
EXPOSURE LIMITS:
OSHA: None **ACGIH:** Simple asphyxiant **NIOSH:** None

SECTION 3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW

Acetylene is a flammable, colorless, dissolved gas packaged in cylinders under pressure. It poses an immediate fire and explosive hazard when concentrations exceed 2.5%. It will decompose violently in its free state under pressure in excess of 15 psig. High concentrations that will cause suffocation are within the flammable range and must not be entered.

EMERGENCY TELEPHONE NUMBERS
(800) 523-9374 Continental U.S., Canada, and Puerto Rico
(610) 481-7711 other locations

ACUTE POTENTIAL HEALTH EFFECTS:
ROUTES OF EXPOSURE:

INHALATION: Acetylene is a simple asphyxiant. It should be noted that before suffocation could occur, the lower flammability limit of acetylene in air would be exceeded; possibly causing both an oxygen deficient and an explosive atmosphere. Exposure to moderate concentrations may cause dizziness, headache, and unconsciousness.

EYE CONTACT: None

SKIN CONTACT: None

REPEATED (CHRONIC) POTENTIAL HEALTH EFFECTS:

ROUTE OF ENTRY: Inhalation

SYMPTOMS: Acetylene is a non-toxic gas that has no chronic harmful effects even in high concentrations. Acetylene has been used as an anesthetic.

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: None

CARCINOGENICITY: Acetylene is not listed by NTP, OSHA or IARC.

SECTION 4. FIRST AID MEASURES

INHALATION: Remove person to fresh air. If not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.

EYE CONTACT: Not applicable

SKIN CONTACT: Not applicable

INGESTION: Not applicable

NOTES TO PHYSICIAN: None

SECTION 5. FIRE FIGHTING MEASURES

FLASH POINT:	AUTOIGNITION:	FLAMMABLE RANGE:
Not applicable	581°F (305°C)	2.5% - 81%

EXTINGUISHING MEDIA: Carbon Dioxide, Dry Chemical, Water.

SPECIAL FIRE FIGHTING INSTRUCTIONS: Shut off source of acetylene if possible. Extinguish fire only if flow can be stopped. Keep adjacent cylinders cool by spraying large amounts of water until the fire burns itself out and the cylinders are cool. If a flame is extinguished and acetylene continues to escape, an explosive re-ignition could occur.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Excessive heat or fire will cause fusible metal pressure relief device to melt allowing acetylene to escape. Cylinders may rupture violently if sidewalls are exposed to direct flame impingement.

HAZARDOUS COMBUSTION PRODUCTS: Carbon monoxide, carbon dioxide.

SECTION 6. ACCIDENTAL RELEASE MEASURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED: Evacuate immediate area. Eliminate any possible sources of ignition, and provide maximum explosion-proof ventilation. Shut off source of acetylene, if possible. Isolate any leaking cylinder. If leaking from cylinder, valve, or fusible metal pressure relief device, contact your supplier.

SECTION 7. HANDLING AND STORAGE

STORAGE: Store and use with adequate ventilation. Cylinders should be separated from oxygen and other oxidizers by a minimum distance of 20 ft. or by a barricade of non-combustible material at least 5 ft. high having a fire resistance rating of at least ½ hour. Storage in excess of 2,500 cubic feet. is prohibited in buildings with other occupancies. Cylinders should be stored upright with valve protection cap in place and firmly secured to prevent falling or being knocked over. Post "No Smoking Or Open Flames" signs in the storage or use areas. There should be no sources of ignition. All electrical equipment should be explosion-proof in the storage areas. Storage areas must meet National Electric Codes for class 1 hazardous areas. Do not allow storage temperature to exceed 125 °F(52 °C). Full and empty cylinders should be segregated. Use a first-in, first-out inventory system to prevent full containers from being stored for a long periods of time.

HANDLING: Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement. All acetylene piped systems and associated equipment must be grounded. Electrical equipment should be non-sparking or explosion-proof. Never use copper piping for acetylene service, only steel or wrought iron pipe should be used. An acetylene cylinder valve should be opened the minimum amount required to deliver acceptable flow so that it can be closed as quickly as possible in an emergency situation. Do not open acetylene cylinder valves more than one and one-half turns. Never use acetylene in excess of 15 psig pressure. Acetylene cylinders are heavier than other cylinders because they are packed with a porous filler material and acetone. Leak check with soapy water; never use a flame. Never insert an object (e.g., wrench, screwdriver, pry bar, etc.) into valve cap openings. Doing so may damage valve, causing a leak to occur. Use an adjustable strap wrench to remove over-tight or rusted caps. Never strike an arc on a compressed gas cylinder or make a cylinder a part of an electrical circuit. Use the proper CGA connections, DO NOT USE ADAPTERS.

SPECIAL PRECAUTIONS: Use piping and equipment adequately designed to withstand pressures to be encountered. Use a check valve or other protective apparatus in any line or piping from the cylinder to prevent reverse flow.

SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

ENGINEERING CONTROLS:

VENTILATION: Provide adequate natural or explosion-proof ventilation to ensure acetylene does not reach its lower flammable limit of 2.5%.

RESPIRATORY PROTECTION:

Emergency Use: Air supplied respirators are required in oxygen-deficient atmospheres (air purifying respirators will not function). Before entering area you must check for flammable or oxygen deficient atmospheres.

SKIN PROTECTION: Work gloves are recommended when handling cylinders.

EYE PROTECTION: Safety glasses are recommended when handling cylinders.

OTHER PROTECTIVE EQUIPMENT: Safety shoes recommended when handling containers.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE, ODOR AND STATE: Colorless gas. Acetylene of 100% purity is odorless but commercial purity has a distinctive garlic-like odor.

MOLECULAR WEIGHT: 26.04

BOILING POINT (10 psig): -103.4 °F (-75 °C)

SPECIFIC GRAVITY (Air = 1): 0.906

FREEZING POINT / MELTING POINT: -116 °F (-82.2 °C)

VAPOR PRESSURE (At 70°F (21.1°C)): 635 psig

GAS DENSITY (At 32°F (0°C) and 1 atm): 0.07314 lb./cu ft

EVAPORATION RATE (Butyl Acetate = 1): Not applicable (Gas)

SOLUBILITY IN WATER (Vol./Vol. at 32° F (0°C) and 1 atm): 1.7

SECTION 10. STABILITY AND REACTIVITY

CHEMICAL STABILITY: Unstable. Stable as shipped. Do not use at pressure above 15 psig.

CONDITIONS TO AVOID: Cylinders should not be exposed to sudden shock or sources of heat.

INCOMPATIBILITY (Materials to Avoid): Under certain conditions, acetylene can react with copper, silver, and mercury to form acetylides, compounds which can act as ignition sources. Brasses containing less than 65% copper in the alloy and certain nickel alloys are suitable for acetylene service under normal conditions. Acetylene can react explosively when combined with oxygen and other oxidizers including all halogens and halogen compounds. The presence of moisture, certain acids, or alkaline materials tends to enhance the formation of copper acetylides.

REACTIVITY:

A) **HAZARDOUS DECOMPOSITION PRODUCTS:** Hydrogen, carbon.
B) **HAZARDOUS POLYMERIZATION:** Will not occur.

SECTION 11. TOXICOLOGICAL INFORMATION

LC_{50} (Inhalation): Acetylene is a simple asphyxiant.

LD_{50} (Oral): None reported

LD_{50} (Dermal): None reported

SKIN CORROSIVITY: Acetylene is not corrosive.

ADDITIONAL NOTES TO PHYSICIAN: None

SECTION 12. ECOLOGICAL INFORMATION

No adverse ecological effects are expected. Acetylene does not contain any Class I or Class II ozone depleting chemicals (40 CFR Part 82). Acetylene is not listed as a marine pollutant by DOT (49 CFR Part 171).

SECTION 13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD: Do not attempt to dispose of residual or unused quantities. Return cylinder to supplier. Unserviceable cylinders should be returned to the supplier for safe and proper disposal.

SECTION 14. TRANSPORT INFORMATION

DOT SHIPPING NAME: Acetylene, dissolved.

HAZARD CLASS: 2.1 (Flammable gas.)

IDENTIFICATION NUMBER: UN1001

SHIPPING LABEL(s): Flammable gas.

PLACARD (When required): Flammable gas.

SPECIAL SHIPPING INFORMATION: Transport secured upright in a well ventilated truck. Never transport in passenger compartment or trunk of a vehicle. Shipment of compressed gas cylinders which have not been filled with the owners consent is a violation of Federal law (49 CFR Part 173.301(b)).

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:

EPA - ENVIRONMENTAL PROTECTION AGENCY

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980. (40 CFR Parts 117 and 302)

Reportable Quantity (RQ): None

SARA TITLE III: Superfund Amendment and Reauthorization Act

SECTIONS 302/304: Emergency Planning and Notification (40 CFR Part 355)

Extremely Hazardous Substances: None

Threshold Planning Quantity (TPQ): None

SECTIONS 311/312: Hazardous Chemical Reporting (40 CFR Part 370)

IMMEDIATE HEALTH:	No	PRESSURE:	Yes
DELAYED HEALTH:	No	REACTIVITY:	Yes
		FIRE:	Yes

SECTION 313: Toxic Chemical Release Reporting (40 CFR Part 372)

Acetylene does not require reporting under Section 313

40 CFR PART 68: Risk Management Programs for Chemical Accidental Release.

Acetylene is a regulated substance in quantities of 10,000 pounds (4,553 kg) or greater.

TSCA: Toxic Substance Control Act

Acetylene is listed on the TSCA inventory.

OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:

29 CFR Part 1910.119: Process Safety Management of Highly Hazardous Chemicals.

Acetylene is not listed in Appendix A as a highly hazardous chemical. However, any process that involves a flammable gas on site in one location, in quantities of 10,000 pounds (4,553 kg) or greater is covered under this regulation unless it is used as fuel.

STATE REGULATIONS:

CALIFORNIA:

Proposition 65: This product does NOT contain any listed substances which the State of California requires warning under this statute.

SECTION 16. OTHER INFORMATION

OTHER INFORMATION:

NFPA RATINGS:

HEALTH: = 0
FLAMMABILITY: = 4
REACTIVITY: = 3
SPECIAL: = None

HMIS RATINGS:

HEALTH: = 1
FLAMMABILITY: = 4
REACTIVITY: = 3

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

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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.

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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.

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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

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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.

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12. ECOLOGICAL INFORMATION

ENVIRONMENTAL FATE AND EFFECTS: Not established.

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13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL: Product is suitable for burning for fuel value in 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. Wear 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

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

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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).

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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 and 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.

		---TWA---		----STEL---		NOTE
Substance Name (CAS-No.)	Source	ppm	mg/m3	ppm	mg/m3	
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.

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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

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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.

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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.

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12. ECOLOGICAL INFORMATION

ENVIRONMENTAL FATE AND EFFECTS: Not established.

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13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL: Product is suitable for burning for fuel value in 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)

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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

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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 of 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, 26
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, 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

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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

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Please reduce your browser font size for better viewing and printing.

MSDS *Material Safety Data Sheet*

From: Mallinckrodt Baker, Inc.
222 Red School Lane
Phillipsburg, NJ 08865

MALLINCKRODT J.T.Baker

24 Hour Emergency Telephone: 908-859-2151
CHEMTREC: 1-800-424-9300

National Response in Canada
CANUTEC: 613-996-6666

Outside U.S. and Canada
Chemtrec: 202-483-7616

NOTE: CHEMTREC, CANUTEC and National Response Center emergency numbers to be used only in the event of chemical emergencies involving a spill, leak, fire, exposure or accident involving chemicals.

All non-emergency questions should be directed to Customer Service (1-800-582-2537) for assistance.

MINERAL OIL

MSDS Number: M7700 --- *Effective Date: 02/25/99*

1. Product Identification

Synonyms: Paraffin oil; liquid petrolatum; White Mineral Oil; Nujol
CAS No.: 8012-95-1
Molecular Weight: Not applicable.
Chemical Formula: Not applicable.
Product Codes:
J.T. Baker: 2705
Mallinckrodt: 6357, 6358

2. Composition/Information on Ingredients

Ingredient	CAS No	Percent	Hazardous
Oil, Mineral	8012-95-1	90 - 100%	Yes

3. Hazards Identification

Emergency Overview

WARNING! HARMFUL IF SWALLOWED OR INHALED. CAUSES IRRITATION TO SKIN, EYES AND RESPIRATORY TRACT. COMBUSTIBLE LIQUID AND VAPOR.

J.T. Baker SAF-T-DATA(tm) Ratings (Provided here for your convenience)

Health Rating: 1 - Slight
Flammability Rating: 1 - Slight
Reactivity Rating: 0 - None
Contact Rating: 1 - Slight
Lab Protective Equip: GOGGLES; LAB COAT
Storage Color Code: Orange (General Storage)

Potential Health Effects

Inhalation:
Causes irritation to the respiratory tract. Symptoms may include coughing, shortness of breath. Inhalation of mist or vapor may produce aspiration pneumonia.
Ingestion:
Material is a cathartic and can cause serious diarrhea. Nausea and vomiting may also occur and possibly abdominal cramping. Aspiration of mineral oil into the lungs can cause chemical pneumonia.
Skin Contact:
Prolonged contact may cause irritation; occasionally dermatitis due to hypersensitivity occurs.

Eye Contact:
Mists or fumes can irritate the eyes. Can cause discomfort similar to motor oil.
Chronic Exposure:
Prolonged or repeated skin exposure may cause dermatitis. Highly refined mineral oils are not classified as human carcinogens. However, related forms (untreated and mildly-treated oils) are listed as human carcinogens by both NTP and IARC.
Aggravation of Pre-existing Conditions:
Persons with pre-existing skin disorders or impaired respiratory function may be more susceptible to the effects of the substance.

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4. First Aid Measures

Inhalation:
Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.
Ingestion:
If swallowed, DO NOT INDUCE VOMITING. Give large quantities of water. Never give anything by mouth to an unconscious person. Get medical attention immediately. Aspiration hazard.
Skin Contact:
Immediately flush skin with plenty of water for at least 15 minutes. Remove contaminated clothing and shoes. Get medical attention. Wash clothing before reuse. Thoroughly clean shoes before reuse.

Eye Contact:
Immediately flush eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately.

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5. Fire Fighting Measures

Fire:
Flash point: 135C (275F) CC
Autoignition temperature: 260 - 370C (500 - 698F)
Combustible Liquid and Vapor!
Explosion:
Not considered to be an explosion hazard.
Fire Extinguishing Media:
Water spray, dry chemical, alcohol foam, or carbon dioxide. Water or foam may cause frothing. Do not allow water runoff to enter sewers or waterways.
Special Information:
In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode.

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6. Accidental Release Measures

Ventilate area of leak or spill. Remove all sources of ignition. Wear appropriate personal protective equipment as specified in Section 8. Isolate hazard area. Keep unnecessary and unprotected personnel from entering. Contain and recover liquid when possible. Use non-sparking tools and equipment. Collect liquid in an appropriate container or absorb with an inert material (e. g., vermiculite, dry sand, earth), and place in a chemical waste container. Do not use combustible materials, such as saw dust. Do not flush to sewer!

---

7. Handling and Storage

Keep in a tightly closed container. Store in a cool, dry, ventilated area away from sources of heat or ignition. Protect against physical damage. Store separately from reactive or combustible materials, and out of direct sunlight. Containers of this material may be hazardous when empty since they retain product residues (vapors, liquid); observe all warnings and precautions listed for the product.

---

8. Exposure Controls/Personal Protection

Airborne Exposure Limits:

For Mineral Oil; Misted1:
-OSHA Permissible Exposure Limit (PEL): 5 mg/m3
-ACGIH Threshold Limit Value (TLV):
5 mg/m3 (TWA) 10 mg/m3 (STEL)
(1as sampled by method that does not collect vapor)

(1Refers to airborne mist of mineral oil)

Ventilation System:

A system of local and/or general exhaust is recommended to keep employee exposures below the Airborne Exposure Limits. Local exhaust ventilation is generally preferred because it can control the emissions of the contaminant at its source, preventing dispersion of it into the general work area. Please refer to the ACGIH document, *Industrial Ventilation, A Manual of Recommended Practices*, most recent edition, for details.

Personal Respirators (NIOSH Approved):

If the exposure limit is exceeded and engineering controls are not feasible, a half facepiece particulate respirator (NIOSH type P95 or R95 filters) may be worn for up to ten times the exposure limit or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest.. A full-face piece particulate respirator (NIOSH type P100 or R100 filters) may be worn up to 50 times the exposure limit, or the maximum use concentration specified by the appropriate regulatory agency, or respirator supplier, whichever is lowest. Please note that N filters are not recommended for this material. For emergencies or instances where the exposure levels are not known, use a full-facepiece positive-pressure, air-supplied respirator. WARNING: Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.

Skin Protection:

Wear impervious protective clothing, including boots, gloves, lab coat, apron or coveralls, as appropriate, to prevent skin contact.

Eye Protection:

Use chemical safety goggles and/or a full face shield where splashing is possible. Maintain eye wash fountain and quick-drench facilities in work area.

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9. Physical and Chemical Properties

Appearance:
Clear oily liquid.
Odor:
Odorless.
Solubility:
Insoluble in water.
Specific Gravity:
Heavy: 0.845 to 0.905 Light: 0.818 to 0.880
pH:
No information found.
% Volatiles by volume @ 21C (70F):
0
Boiling Point:
260 - 330C (500 - 626F)
Melting Point:

No information found.
Vapor Density (Air=1):
ca. 9
Vapor Pressure (mm Hg):
< 0.5
Evaporation Rate (BuAc=1):
No information found.

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10. Stability and Reactivity

Stability:
Stable under ordinary conditions of use and storage. May solidify at room temperature.
Hazardous Decomposition Products:
Carbon dioxide and carbon monoxide may form when heated to decomposition.
Hazardous Polymerization:
Will not occur.
Incompatibilities:
Strong oxidizers.
Conditions to Avoid:
Heat, flames, ignition sources and incompatibles.

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11. Toxicological Information

No LD50/LC50 information found relating to normal routes of occupational exposure.
Irritation Data, rabbit (Std Draize): skin= 100 mg/24H, mild; eye= 500 mg, moderate.
Investigated as a tumorigen.

--------\Cancer Lists\--

Ingredient	---NTP Carcinogen--- Known	Anticipated	IARC Category
Oil, Mineral (8012-95-1)	No	No	None

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12. Ecological Information

Environmental Fate:
No information found.
Environmental Toxicity:
No information found.

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13. Disposal Considerations

Whatever cannot be saved for recovery or recycling should be managed in an appropriate and approved waste disposal facility. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.

14. Transport Information

Not regulated.

15. Regulatory Information

--------\Chemical Inventory Status - Part 1\--------------------------------

Ingredient	TSCA	EC	Japan	Australia
Oil, Mineral (8012-95-1)	Yes	Yes	No	Yes

--------\Chemical Inventory Status - Part 2\--------------------------------

Ingredient	Korea	--Canada-- DSL	--Canada-- NDSL	Phil.
Oil, Mineral (8012-95-1)	Yes	Yes	No	Yes

--------\Federal, State & International Regulations - Part 1\----------------

Ingredient	-SARA 302- RQ	-SARA 302- TPQ	------SARA 313------ List	------SARA 313------ Chemical Catg.
Oil, Mineral (8012-95-1)	No	No	No	No

--------\Federal, State & International Regulations - Part 2\----------------

Ingredient	CERCLA	-RCRA- 261.33	-TSCA- 8(d)
Oil, Mineral (8012-95-1)	No	No	No

Chemical Weapons Convention: No TSCA 12(b): No CDTA: No
SARA 311/312: Acute: Yes Chronic: No Fire: Yes Pressure: No
Reactivity: No (Pure / Liquid)

Australian Hazchem Code: No information found.
Poison Schedule: S5
WHMIS:
This MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

16. Other Information

NFPA Ratings: Health: **0** Flammability: **1** Reactivity: **0**
Label Hazard Warning:
WARNING! HARMFUL IF SWALLOWED OR INHALED. CAUSES IRRITATION TO SKIN, EYES AND RESPIRATORY TRACT. COMBUSTIBLE LIQUID AND VAPOR.
Label Precautions:
Avoid breathing mist.
Keep container closed.
Use only with adequate ventilation.
Avoid contact with eyes, skin and clothing.
Wash thoroughly after handling.
Keep away from heat, sparks and flame.
Label First Aid:
If swallowed, DO NOT INDUCE VOMITING. Give large quantities of water. Never give anything by mouth to an unconscious person. Get medical attention immediately. In case of contact, immediately flush eyes or skin with plenty of water for at least 15 minutes. Remove contaminated clothing and shoes. Wash clothing before reuse. If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. In all cases, get medical attention.
Product Use:
Laboratory Reagent.
Revision Information:
MSDS Section(s) changed since last revision of document include: 8, 11.
Disclaimer:
****

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Prepared by: Strategic Services Division
Phone Number: (314) 539-1600 (U.S.A.)

AIR PRODUCTS

MATERIAL SAFETY DATA SHEET

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: **Propane**
CHEMICAL NAME: Propane, Alkane, Saturated Aliphatic hydrocarbon, Liquefied Petroleum Gas (LPG), LP-Gas
FORMULA: C_3H_8
SYNONYMS: Dimethylmethane, Propyl Hydride

MANUFACTURER: **Air Products and Chemicals, Inc.**
7201 Hamilton Boulevard
Allentown, PA 18195 - 1501

PRODUCT INFORMATION: (800) 752-1597
MSDS NUMBER: 1061
REVIEW DATE: July 1999
REVISION: 5
REVISION DATE: July 1999

SECTION 2. COMPOSITION / INFORMATION ON INGREDIENTS

Propane is packaged as a pure material (>99%).

CAS NUMBER: 74-98-6
EXPOSURE LIMITS:
OSHA: PEL-TWA = 1000 ppm **ACGIH:** TWA/TLV = 2500 ppm **NIOSH:** IDLH = 2100 ppm (10%LEL)

SECTION 3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW

Propane is a flammable, odorless, colorless liquefied compressed gas packaged in cylinders under its own vapor pressure of 124.9 psia at 70 °F. It poses an immediate fire and explosion hazard when mixed with air at concentrations exceeding 2.1%. High concentrations that can cause rapid suffocation are above the lower flammable limit and must not be entered. Propane is heavier then air and may collect in low areas or travel along the ground where there may be an ignition source present. Direct contact with liquid can cause frostbite.

EMERGENCY TELEPHONE NUMBERS
(800) 523 - 9374 Continental U.S., Canada and Puerto Rico
(610) 481 - 7711 Other locations

ACUTE POTENTIAL HEALTH EFFECTS:
ROUTES OF EXPOSURE:
EYE CONTACT: Contact with liquid (or rapidly expanding gas) may cause irritation and frostbite.
INGESTION: Ingestion of Propane is not a likely route of industrial exposure.
INHALATION: Propane is nontoxic, but high concentrations may have an anesthetic effect. It can also reduce the amount of oxygen in the air necessary to support life. Exposure to oxygen-deficient atmospheres (less than 19.5%) may produce dizziness, nausea, vomiting, loss of consciousness, and death. At very low oxygen concentrations (less than 12%) unconsciousness and death may rapidly occur without warning. It should be noted that before suffocation could occur, the lower flammable limit for Propane in air will be exceeded; causing both an oxygen deficient and an explosive atmosphere.
SKIN CONTACT: Contact with liquid (or rapidly expanding gas) can cause irritation and frostbite.

POTENTIAL HEALTH EFFECTS OF REPEATED EXPOSURE:
ROUTE OF ENTRY: Skin contact
SYMPTOMS: Repeated or prolonged contact may cause dermatitis.

TARGET ORGANS: Skin
MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: May aggravate dermatitis.
CARCINOGENICITY: Propane is not listed as a carcinogen or potential carcinogen by NTP, IARC, or OSHA Subpart Z.

SECTION 4. FIRST AID MEASURES

EYE CONTACT: If liquid propane comes in contact with eyes, flush eyes with plenty of lukewarm water for several minutes. Seek medical attention immediately.
INGESTION: Ingestion of Propane is not a likely route of industrial exposure.
INHALATION: Remove person to fresh air. If not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.
SKIN CONTACT: If liquid Propane comes in contact with skin, remove contaminated clothing and flush with plenty of lukewarm water for several minutes. Seek medical attention immediately.

NOTES TO PHYSICIAN: Treatment of overexposure should be directed at the control of symptoms and the clinical condition.

SECTION 5. FIRE FIGHTING MEASURES

FLASH POINT:	AUTOIGNITION:	FLAMMABLE RANGE:
Not applicable	842 °F (450 °C)	2.1% - 9.5%

EXTINGUISHING MEDIA: Carbon dioxide, dry chemical, water.
SPECIAL FIRE FIGHTING INSTRUCTIONS: Evacuate all personnel from area. If possible, without risk, shut off source of Propane, then fight fire according to types of materials burning. Extinguish fire only if gas flow can be stopped. This will avoid possible accumulation and re-ignition of a flammable gas mixture. Keep adjacent cylinders cool by spraying with large amounts of water until the fire burns itself out. Self-contained breathing apparatus (SCBA) may be required.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Most cylinders are designed to vent contents when exposed to elevated temperatures. Pressure in a cylinder can build up due to heat and it may rupture if pressure relief devices should fail to function. Propane vapors are heavier than air and may travel to a source of ignition and flash back.
HAZARDOUS COMBUSTION PRODUCTS: Carbon monoxide

SECTION 6. ACCIDENTAL RELEASE MEASURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED: Evacuate immediate area. Eliminate any possible sources of ignition, and provide maximum explosion-proof ventilation. Use a flammable gas meter (explosimeter) calibrated for Propane to monitor concentration. Never enter an area where the Propane concentration is greater than 0.42% (which is 20% of the lower flammable limit). Am immediate fire and explosion hazard exists when atmospheric Propane concentration exceeds 2.1%. Use appropriate protective equipment (SCBA and fire resistant suit). Shut off source of leak if possible. Isolate any leaking cylinder. If leak is from container, pressure relief device or its valve, contact your supplier. If the leak is in the user's system, close the cylinder valve, safely vent the pressure, and purge with an inert gas before attempting repairs.

SECTION 7. HANDLING AND STORAGE

STORAGE: Store cylinders in a well-ventilated, secure area, protected from the weather. Cylinders should be stored upright with valve outlet seals and valve protection caps in place. There should be no sources of ignition. All electrical equipment should be explosion-proof in the storage areas. Storage areas must meet National Electrical Codes for class 1 hazardous areas. Flammable storage areas must be separated from oxygen and other oxidizers by a minimum distance of 20 ft. or by a barrier of non-combustible material at least 5 ft. high having a fire resistance rating of at least ½ hour. Post "No Smoking or Open Flames" signs in the storage or use areas. Do not allow storage temperature to exceed 125 °F (52 °C). Storage should be away from heavily traveled areas and emergency exits. Full and empty cylinders should be segregated. Use a first-in first-out inventory system to prevent full containers from being stored for long periods of time.

HANDLING: Do not drag, roll, slide or drop cylinder. Use a suitable hand truck designed for cylinder movement. Never attempt to lift a cylinder by its cap. Secure cylinders at all times while in use. Use a pressure reducing regulator or separate control valve to safely discharge gas from cylinder. Use a check valve to prevent reverse flow into cylinder. Never apply flame or localized heat directly to any part of the cylinder. Do not allow any part of the cylinder to exceed 125 °F (52 °C). Once cylinder has been connected to properly purged and inerted process, open cylinder valve slowly and carefully. If user experiences any difficulty operating cylinder valve, discontinue use and contact supplier. Never insert an object (e.g., wrench, screwdriver, etc.) into valve cap openings. Doing so may damage valve causing a leak to occur. Use an adjustable strap-wrench to remove over-tight or rusted caps. All piped systems and associated equipment must be grounded. Electrical equipment should be non-sparking or explosion-proof.

SPECIAL PRECAUTIONS: Always store and handle compressed gas cylinders in accordance with Compressed Gas Association, Inc. (telephone 703-412-0900) pamphlet CGA P-1, *Safe Handling of Compressed Gases in Containers*. Local regulations may require specific equipment for storage or use.

SECTION 8. EXPOSURE CONTROL / PERSONAL PROTECTION

ENGINEERING CONTROLS:

VENTILATION: Provide adequate ventilation and / or local exhaust to prevent accumulation of gas concentrations above the TWA of 1000 ppm.

RESPIRATORY PROTECTION:

Emergency Use: SCBA or positive pressure air line with mask should be used in areas where concentration is above the TWA, however do not enter areas where concentration is greater than 0.42% (20% of the LEL).

EYE PROTECTION: Safety glasses for handling cylinders. Chemical goggles with full faceshield for connecting or disconnecting cylinders.
SKIN PROTECTION: Leather gloves for handling cylinders. Neoprene gloves during use of product. Fire resistant suit and gloves in emergency situations.
OTHER PROTECTIVE EQUIPMENT: Safety shoes are recommended when handling cylinders.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE, ODOR AND STATE: At room temperature and atmospheric pressure, Propane is a colorless, odorless, flammable gas. It is shipped as a liquefied gas under its own vapor pressure.
MOLECULAR WEIGHT: 44.1
BOILING POINT (1 atm): -43.7 °F (-42.1 °C)
SPECIFIC GRAVITY (Air = 1): 1.522
FREEZING POINT / MELTING POINT: -305.8 °F (-187.7 °C)
VAPOR PRESSURE (At 70 °F (21.1 °C)): 124.9 psia
GAS DENSITY (At 70 °F (21.1 °C) and 1 atm): 0.116 lb/ft^3
SOLUBILITY IN WATER (vol./vol.): 6.5 / 100
LIQUID DENSITY (At 70 °F (21.1 °C), Sat.): 31.12 lb/ft^3

SECTION 10. STABILITY AND REACTIVITY

CHEMICAL STABILITY: Stable
CONDITIONS TO AVOID: Cylinders should not be exposed to temperatures in excess of 125 °F (52 °C).
INCOMPATIBILITY (Materials to Avoid): Oxygen, Halogens and Oxidizers
REACTIVITY:

A) **HAZARDOUS DECOMPOSITION PRODUCTS:** None
B) **HAZARDOUS POLYMERIZATION:** Will not occur

SECTION 11. TOXICOLOGICAL INFORMATION

LC_{50} (Inhalation): Not applicable. Simple asphyxiant.
LD_{50} (Oral): Not applicable
LD_{50} (Dermal): Not applicable

SKIN CORROSIVITY: Propane is not corrosive to the skin.
ADDITIONAL NOTES: Propane is nontoxic and acts as a simple asphyxiant and mild anesthetic. At concentrations of 10-15%, propane is also a weak cardiac sensitizer in animals.

SECTION 12. ECOLOGICAL INFORMATION

AQUATIC TOXICITY: Not determined
MOBILITY: Not determined
PERSISTENCE AND BIODEGRADABILITY: Not determined
POTENTIAL TO BIOACCUMULATE: Not determined
REMARKS: This product does not contain any Class I or Class II ozone depleting chemicals.

SECTION 13. DISPOSAL CONSIDERATIONS

UNUSED PRODUCT / EMPTY CYLINDER: Return cylinder and unused product to supplier. Do not attempt to dispose of residual or unused quantities.

DISPOSAL INFORMATION: Residual product in the system may be burned if a suitable burning unit (flair incinerator) is available on site. This shall be done in accordance with federal, state, and local regulations. Wastes containing this material may be classified by EPA as hazardous waste by characteristic (i.e., Ignitability, Corrosivity, Toxicity, Reactivity). Waste streams must be characterized by the user to meet federal, state, and local requirements.

SECTION 14. TRANSPORTATION INFORMATION

DOT SHIPPING NAME: Propane
HAZARD CLASS: 2.1
IDENTIFICATION NUMBER: UN1978
SHIPPING LABEL(s): Flammable gas
PLACARD (When required): Flammable gas

SPECIAL SHIPPING INFORMATION: Cylinders should be transported in a secure upright position in a well-ventilated truck. Never transport in passenger compartment of a vehicle. Ensure cylinder valve is properly closed, valve outlet cap has been reinstalled, and valve protection cap is secured before shipping cylinder.

CAUTION: Compressed gas cylinders shall not be refilled except by qualified producers of compressed gases. Shipment of a compressed gas cylinder which has not been filled by the owner or with the owner's written consent is a violation of Federal law (49 CFR 173.301).

NORTH AMERICAN EMERGENCY RESPONSE GUIDEBOOK NUMBER (NAERG #): 115

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:

EPA - ENVIRONMENTAL PROTECTION AGENCY

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (40 CFR Parts 117 and 302)
Reportable Quantity (RQ): None

SARA TITLE III: Superfund Amendment and Reauthorization Act
SECTIONS 302/304: Emergency Planning and Notification (40 CFR Part 355)
Extremely Hazardous Substances: Propane is not listed.
Threshold Planning Quantity (TPQ): None
Reportable Quantity (RQ): None

SECTIONS 311/312: Hazardous Chemical Reporting (40 CFR Part 370)

IMMEDIATE HEALTH:	Yes	PRESSURE:	Yes
DELAYED HEALTH:	No	REACTIVITY:	No
		FIRE:	Yes

SECTION 313: Toxic Chemical Release Reporting (40 CFR Part 372)
Propane does not require reporting under Section 313.

CLEAN AIR ACT:
SECTION 112 (r): Risk Management Programs for Chemical Accidental Release (40 CFR PART 68)
Propane is listed as a regulated substance.
Threshold Planning Quantity (TPQ): 10,000 lbs

TSCA: Toxic Substance Control Act
Propane is listed on the TSCA inventory.

OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:
29 CFR Part 1910.119: Process Safety Management of Highly Hazardous Chemicals
Propane is not listed in Appendix A as a highly hazardous chemical. However, any process that involves a flammable gas on site in one location, in quantities of 10,000 pounds (4,553 kg) or greater is covered under this regulation unless it is used as fuel.

STATE REGULATIONS:
CALIFORNIA:
Proposition 65: This product is not a listed substance which the State of California requires warning under this statute.

SECTION 16. OTHER INFORMATION

NFPA RATINGS:		HMIS RATINGS:	
HEALTH:	= 1	HEALTH:	= 0
FLAMMABILITY:	= 4	FLAMMABILITY:	= 4
REACTIVITY:	= 0	REACTIVITY:	= 0
SPECIAL:			

HOLTEC INTERNATIONAL

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EVALUATION OF THE EFFECTS OF LIGHTNING AND A 500 KV LINE BREAK ON HOLTEC CASKS

FOR

PACIFIC GAS AND ELECTRIC

Holtec Report No: HI-2002559 -NP Rev. 1

Holtec Project No: 1073

Report Class : SAFETY RELATED

HOLTEC INTERNATIONAL

DOCUMENT ISSUANCE AND REVISION STATUS[1]

DOCUMENT NAME: Evaluation of the Effects of Lightning & 500kV Line Break on Holtec Casks

DOCUMENT NO.:	HI-2002559	CATEGORY: ☐	GENERIC
PROJECT NO.:	1073	☒	PROJECT SPECIFIC

Rev. No. [2]	Date Approved	Author's Initials	VIR #	Rev. No.	Date Approved	Author's Initials	VIR #
0	1/17/2001	ER	778266				
1	2/26/01	ER	935306				

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:

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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 - This is a general revision. The methodology used for evaluating the transmission line break event is modified in accordance with Client comments on Revision 0. The calculations to determine the effects of a lightning strike on a HI-TRAC are modified to have conduction through the enclosure shell instead of the outer shell, to provide consistency with the updated transmission line break calculations. The acceptance criteria are deleted from the report and replaced by a reference to the DCPP ISFSI SAR. The preface and references sections are updated to reflect the latest Holtec administrative requirements.

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 referenced 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.

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 format 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 environmental conditions and natural phenomena at a proposed independent spent fuel storage installation (ISFSI). Sections 6.2.6 and 6.2.9.1 of the Pacific Gas and Electric (PG&E) specification [2] for the ISFSI at the Diablo Canyon Power Plant (DCPP) postulates two severe electrical hazards (a lightning strike and 500kV transmission line breaks) 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 potential effects, if any, of the postulated electrical hazards on the storage and transfer casks that will be used at the DCPP 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.

2.0 Methodology

The postulated lightning strike presents as a short duration, high current electric flow. The current will flow through the impacted cask SSC and dissipate to the ground. All Holtec casks are encased in painted carbon steel, so the current will flow through the outer conductive shell. Localized paint damage will likely occur where the current enters and exits the outer shell, and the resistance to current flow in the material will cause a heat generation within the shell that must be dissipated.

The power of a direct current flow through a resistive material (P_{dc}) can be calculated using the following, familiar formula [3]:

$$P_{dc} = I^2 R \quad (2\text{-}1)$$

where I is the current and R is the resistance of the conduction path. The resistance is calculated from the conductor length, cross-sectional area and resistivity, which is a property of the conducting material. The resistance is calculated as [4]:

$$R = \frac{\rho \times L}{A} \quad (2\text{-}2)$$

where ρ is the resistivity, L is the conductor length and A is the conductor cross-sectional area.

To obtain the electrical energy generated during a current flow of finite duration, the power is multiplied by the duration. The energy of a direct current flow through a resistive material (E_{dc}) can be calculated using the following formula:

$$E_{dc} = I^2 \Delta t \, R \quad (2\text{-}3)$$

where Δt is the duration of the current flow.

The lightning strike results in a finite-duration current flow. Recognizing that the resistance is independent of the current magnitude, Equation 2-3 can be modified to encompass events involving step changes of the current at discrete time points. The resulting equation, shown here for a two-part current flow event with a single step change of the current, is:

$$E_{dc} = (I_1^{\,2} \Delta t_1 + I_2^2 \Delta t_2) R \quad (2\text{-}4)$$

Once the energy is determined using Equation 2-4, the thermal effects (i.e., the temperature rise due to resistance heating) can be calculated from an energy balance using:

$$E_{dc} = m \times Cp \times \Delta T \quad (2\text{-}5)$$

where m is the mass of the conductor, Cp is the specific heat capacity of the conductor material and ΔT is the temperature rise of the conductor. Equation 2-5 can be rearranged to solve for the temperature rise, yielding:

$$\Delta T = \frac{E_{dc}}{m \times Cp} \tag{2-6}$$

It should be noted that this methodology has been used to evaluate the effects of lightning strikes on Holtec' s approved HI-STAR 100 System (NRC Docket 72-1008).

The postulated 500kV transmission line break presents as a time-varying, high-voltage and high-current electric flow. As the falling transmission line approaches the cask, a high-voltage arc will form from the line to the cask. The voltage of this arc will fall rapidly as the arc current rises. Once the line contacts the cask, the fault voltage will be relatively low and the fault current relatively high, compared with the beginning of the arc. As with the lightning strike event, the current will flow through the cask outer conductive shell and dissipate to the ground, resulting in heat generation.

Because of the time-varying voltage during the arc and the relatively long (compared to the lightning strike) duration of this event, the power of the arc and subsequent current flows is calculated using a modified formulation of Equation 2-1. Recognizing that voltage (V) is equal to current multiplied by resistance [3] and the time-varying nature of the voltage and current during the arc, the power equation can be recast as:

$$P(t) = V(t) \times I(t) \tag{2-7}$$

where P(t) is the time-varying power, V(t) is the time-varying voltage and I(t) is the time-varying current. This equation can be integrated over the duration of the event to obtain the energy generated (E_{gen}) as:

PROPRIETARY INFORMATION DELETED

3.0 Acceptance Criteria

No acceptance criteria are applied in this report. A discussion of the acceptability of the calculated results is provided in Section 8.2.8 of the DCPP ISFSI SAR.

4.0 Assumptions

1. All evaluations of the effects of electric resistance heating are performed assuming that all current flows through the outermost shell of the affected cask. Limiting the current flow to a single conduction path will maximize the heat generation, conservatively maximizing the resultant thermal effects.

2. Current penetration into only the outer 0.01-inch depth of the cask outer shell is credited in the resistance heat calculations. This will conservatively decrease the conductor cross sectional area, increasing the resistance and resulting heat generation, and the conductor thermal inertia, increasing the resultant temperature rise.

3. The resistivity of the carbon steel cask outer shells is conservatively estimated by increasing the resistivity of iron by 20%, to account for the presence of small amounts of higher-resistivity elements in the alloy. This simplification is necessary because specific resistivity data is not available for structural steels, as they are not typically used in electrical components. A comparison of the estimated resistivity value with the limited available steel data demonstrates the conservatism of this assumption.

4. The heat of sublimation of carbon steel is assumed equal to that of elemental iron. The majority component of carbon steel is iron, so there should be little difference between the two materials.

5.0 Input Data

All input data necessary to perform these engineering evaluations are presented within the calculations themselves (Section 6.0) and are not repeated here.

6.0 Calculations

Applying the methodology presented in Subsection 2.0, the effects of each of the postulated electrical hazards are evaluated. The evaluated scenarios are summarized here:

1. A large, naturally occurring lightning strike directly on a HI-STORM storage cask.

2. A large, naturally occurring lightning strike directly on a HI-TRAC transfer cask.

3. The break of a 500kV transmission line, which falls onto a HI-STORM storage cask.

4. The break of a 500kV transmission line, which falls onto a HI-TRAC transfer cask.

These calculations are included in Appendix A.

7.0 Results

As described in Section 6.0, the effects of the postulated electrical events on the cask systems have been calculated in Appendix A. The following table presents a summary of the calculations and corresponding results.

Scenario Number	Resistance Heat Generated	Temperature Rise
1	6,523 watt-seconds	0.221°F
2	7,905 watt-seconds	0.450°F
3	6,612 watt-hours	11.440°F
4	6,612 watt-hours	31.053°F
	Mass of Material Sublimated	**Maximum Sublimated Hole Diameter**
3	1.46 pounds	2.960 inches
4	1.46 pounds	3.625 inches

As stated in Section 3.0, no acceptance criteria are applied to these results in this report. Please consult Section 8.2.8 of the DCPP ISFSI SAR for a discussion of the acceptability of these results.

8.0 <u>References</u>[a]

[1] 10CFR72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-level Radioactive Waste," Subpart F, Section 122.

[2] "Dry Cask Storage System," PG&E Specification 10012-N-NPG, 28 September 2000.

[3] Swain and Arrott, "Power Handbook," McGraw-Hill, March 1951.

[4] Avallone and Baumeister, "Marks' Standard Handbook for Mechanical Engineers," Tenth Edition, 1997.

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[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. The latest revision of all documents produced by Holtec International in a *safety-significant* project is readily available from the company's Document Transmittal Form (DTF) database.

Appendix A - Calculation of Electrical Event Effects

PROPRIETARY APPENDIX DELETED

HOLTEC INTERNATIONAL

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EVALUATION OF SITE-SPECIFIC WILD FIRES FOR THE DIABLO CANYON ISFSI

FOR

PACIFIC GAS AND ELECTRIC

Holtec Report No: HI-2012615 - NP Rev. Ø

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DOCUMENT ISSUANCE AND REVISION STATUS[1]

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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:

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Notes

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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

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 format 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 fire events at a proposed independent spent fuel storage installation (ISFSI). Section 6.2.7 of the Pacific Gas and Electric (PG&E) specification [2] for an ISFSI at the Diablo Canyon Power Plant (DCPP) postulates a wild fire in the vegetation surrounding the ISFSI 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 of the postulated wild fires on the storage casks that will be used at the DCPP ISFSI.

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

2.0 Methodology

2.1 Heat Input to Cask from Onsite Transporter Fuel Tank Fire

Previous analyses documented in the HI-STORM FSAR [3, 4] have been performed to evaluate the effects of an onsite transporter fuel tank fire on a HI-STORM storage cask. The amount of heat input to a cask during this design basis fire is determined by post-processing the existing transient finite-element thermal results to obtain the solution to the following equation:

$$Q_{in} = m \times Cp \times \Delta T \qquad (2\text{-}1)$$

where:

Q_{in} is the total heat input during the fire
m is the mass of the heated body
Cp is the specific heat of the body
ΔT is the bulk temperature change of the body

As presented, Equation 2-1 is applicable to a homogeneous material. Because the casks are not homogeneous and the bulk temperature of the cask is not directly available, Equation 2-1 must be discretized to accommodate the nature of the discretized numeric models, as:

$$Q_{in} = \sum_{n} V_n \times \rho_n \times Cp_n \times \Delta T_n \qquad (2\text{-}2)$$

where:

Q_{in} is the total heat input during the fire
n is an index, from 1 to the total number of elements
V_n is the volume of element n
ρ_n is the density of element n
Cp_n is the specific heat of element n
ΔT_n is the temperature change of element n

The temperature change (ΔT_n) is the difference in temperature between the initial condition and the end of the fire duration.

2.2 Heat Input to Cask from Site-Specific Wild Fires

For a fire that is not directly adjacent to a cask, the primary heat transfer mechanism will be thermal radiation. This is due to the high flame temperatures associated with fires and the fourth-power relationship between the flame temperature and the radiation heat flux. Heat transferred via thermal radiation will be emitted equally in all directions.

As described in the assumptions in Section 4.0, no flammable materials are stored within the ISFSI and all areas within the ISFSI nuisance fence will be covered with either concrete or gravel. The ISFSI nuisance fence will be at least 50-feet from the nearest storage casks, so the postulated wild fires are of the type described above. The amount of heat input to a cask during the postulated wild fires can, therefore, be very conservatively estimated by using the following relationship:

$$Q_{in} = Q_{fire} \times F_{view} \times \varepsilon_{cask} \tag{2-3}$$

where:

Q_{in} is the total heat input during the fire
Q_{fire} is the total heat energy released during the fire
F_{view} is the fire-to-cask geometric view factor
ε is the emissivity of the cask surfaces

The fire-to-cask geometric view factor (F_{view}) can be estimated by modeling the cask as a cylinder and the fire as a concentric outer cylindrical wall of flame. The following set of equations [5], for concentric cylinders of unequal height, can be used to calculate the cask -to-fire view factor:

$$X = \frac{x}{r_2},\quad Y = \frac{y}{r_2},\quad L = \frac{z}{r_2},\quad R = \frac{r_1}{r_2}$$

$$A_\xi = \xi^2 + R^2 - 1$$

$$B_\xi = \xi^2 - R^2 + 1 \tag{2-4}$$

$$F_\xi = \frac{B_\xi}{8R\xi} + \frac{1}{2\pi}\left\{\cos^{-1}\frac{A_\xi}{B_\xi} - \frac{1}{2\xi}\left[\frac{(A_\xi+2)^2}{R^2} - 4\right]^{\frac{1}{2}}\cos^{-1}\frac{A_\xi R}{B_\xi} - \frac{A_\xi}{2R\xi}\sin^{-1}R\right\}$$

$$F_{cask-to-fire} = \frac{X}{L}F_X + \frac{L-X}{L}(1-F_{L-X}) + \frac{Y+X-L}{L}F_{Y+X-L} - \frac{X+Y}{L}F_{X+Y}$$

where:

x is the cask height minus the flame height
y is the flame height
z is the cask height
r_1 is the radius of the outer surface of the cask
r_2 is the radius of the flame fireline

The cask-to-fire view factor can be easily converted to the desired fire -to-cask view factor by multiplying the latter by the ratio of the cask surface area (A_{cask}) to the fireline face area (A_{fire}), as shown in the following equation:

$$F_{view} = F_{cask-to-fire}\frac{A_{cask}}{A_{fire}} = F_{cask-to-fire}\frac{D_{cask} \times H_{cask}}{D_{fire} \times H_{fire}} \tag{2-5}$$

where:

D_{cask} is the diameter of the cask
H_{cask} is the height of the cask
D_{fire} is the diameter of the fireline
H_{fire} is the flame height

3.0 Acceptance Criteria

The total heat input to a cask from each postulated site-specific wild fire must be less than that input from the design basis onsite transporter fuel tank fire accident evaluated in the HI-STORM FSAR [3, 4].

4.0 Assumptions

1. The analyses of the heat input from a wild 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.

2. 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 [2], which states "casks will be separated from such fires by the distance between the casks and the ISFSI perimeter."

3. The minimum distance from the ISFSI nuisance fence to the edge of the ISFSI pad is assumed to be 50 feet. The actual distance, governed by shielding concerns, is expected to be greater than 50 feet. The use of the smaller separation distance will conservatively maximize the fire heat input to the casks.

4. It is assumed that any wild fire that is more than 200 yards from the ISFSI will have no effect on the casks. The view angle from such a distant fire is less than 2°, so the fire-to-cask view factor will be negligible.

5. The wild fire is modeled as a ring of fire completely surrounding a single cask. This conservatively neglects the blocking effect of any other casks or structures at the ISFSI. It is noted that, per the PG&E specification [2], "no flammable facilities are present near the north side of the ISFSI site." It is, therefore, impossible for any wild fire to completely surround the ISFSI.

6. It is assumed that the entire heat energy of the wild 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.

7. The fire-to-cask view factor is calculated assuming the fire-to-cask distance is the minimum separation distance throughout the wild fire duration. This conservatively maximizes the view factor and, consequently, the resulting heat input to the cask.

8. 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, to their neglect is conservative.

5.0 Input Data

5.1 Heat Input to Cask from Onsite Transporter Fuel Tank Fire

The heat input to a HI-STORM storage cask from the onsite transporter fuel tank fire is determined using Equation 2-2 and post-processing the results of the previously performed transient finite-element thermal evaluation. The following input data are required to determine the fire heat input:

Input Parameter	Parameter Value	Data Source
Density of Carbon Steel	0.283 lb/in^3	Reference 6
Heat Capacity of Carbon Steel	0.10 Btu/(lb×°F)	Reference 6
Density of Concrete	0.0822 lb/in^3	Reference 6
Heat Capacity of Concrete	0.156 Btu/(lb×°F)	Reference 6

5.2 Heat Input to Cask from Site-Specific Wild Fires

All input data necessary to perform these calculations are presented within the calculations themselves (Appendix B) and are not repeated here.

6.0 Calculations and Results

6.1 Heat Input to Cask from Onsite Transporter Fuel Tank Fire

The heat input to a HI-STORM cask is determined using Equation 2-2, as described above in Section 2.1. Version 5.6 of the ANSYS finite-element computer program, QA validated by Holtec, is used to post-process the existing transient thermal results. The ANSYS output file from this post-processing is presented in Attachment A to this document. The following Holtec server directory listing shows the locations of all computer files used for this calculation:

```
 Volume in drive F is VOL1

 Directory of F:\USER\EROSENBA\5014\HISTORM\FIRETRAN

01/04/99  11:23            1,441,792 FIRE8.DB
01/04/99  11:22           20,103,168 FIRE8.RTH

 Directory of G:\PROJECTS\1073\EBR\WILDFIRE

10/23/00  11:48                2,587 fsarfire.inp
10/23/00  11:48               16,222 fsarfire.out
```

Using the heat values extracted from the output file fsarfile.out, the heat input to the HI -STORM cask is calculated as:

$$Q_{in} = \left(16.303\times10^{6} + 5.54412\times10^{6}\right) - \left(15.9553\times10^{6} + 4.34325\times10^{6}\right) = 1{,}548{,}570\,Btu$$

The two values in the first set of parenthesis (16.303×10^6 and 5.54412×10^6) are the post-fire heat contents of the cask concrete and steel, respectively. The two values in the second set of parenthesis (15.9553×10^6 and 4.34325×10^6) are corresponding pre-fire heat contents.

6.2 Heat Input to Cask from Site-Specific Wild Fires

Two separate wild fire scenarios are postulated for the DCPP ISFSI site. The first scenario is a wild fire that occurs without wind and the second is a wild fire that occurs with a 15 mph up hill wind. These two scenarios have different fireline intensities and velocities and different flame heights. For each scenario, the heat input to a HI -STORM cask is determined using Equation 2-3, as described above in Section 2.2, in Appendix B. The calculated results are:

Wild Fire Scenario	Calculated Cask Heat Input
No Wind	395,892 Btu
15 mph Wind	321,284 Btu

7.0 Conclusions

The heat input to the HI-STORM cask from the onsite transporter fire, calculated in Section 6.1, is greater than the heat input to the HI-STORM cask from either postulated wild fire scenario. This result satisfies the acceptance criterion stipulated in Section 3.0, so it is concluded that the postulated site-specific wild fires will not adversely affect the HI-STORM storage casks at the DCPP ISFSI.

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] "Dry Cask Storage System," PG&E Specification 10012-N-NPG, 28 September 2000.

[3] "HI-STORM 100 System Final Safety Analysis Report," Holtec Report HI-2002444, Revision 0, July 2000.

[4] Holtec International License Amendment Request No. 1014 -1, Revision 1, August 2000.

[5] Rea, "Rapid Method for Determining Concentric Cylinder Radiation View Factors," AIAA Journal, vol. 13, no. 8, pp. 1122-1123, 1975.

[6] Avallone and Baumeister, "Marks' Standard Handbook for Mechanical Engineers," Eighth Edition, 1978.

[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 Onsite Transported Fuel Tank Fire Heat Input

PROPRIETARY APPENDIX DELETED

Appendix B - Calculation of Wild Fire Heat Input to a Cask

PROPRIETARY APPENDIX DELETED