HOLTEC INTERNATIONAL

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

PFS HI-STORM PAD-SOIL THERMAL ANALYSIS UNDER SUB-FREEZING AMBIENT TEMPERATURE

FOR

PRIVATE FUEL STORAGE

Holtec Report No: HI-2022880

Holtec Project No: 70651

Report Class : SAFETY RELATED

NUCLEAR REGULATORY COMMISSION

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Applicant ✓ RECEIVED ✓

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Contractor ______ DATE 6/17/02

Other ______ Witness ______

Reporter [signature]

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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):

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3. Revisions to this document may be made by adding supplements to the document and replacing the "Table of Contents", this page and the "Revision Log".

TABLE OF CONTENTS
(Holtec Report HI-2022880)

1.0 INTRODUCTION

In this report, the temperature of a storage pad at the PSFS and that of soil below the pad are computed under a sub-freezing ambient temperature. The physical configuration of a storage pad and the underlying soil is illustrated in Figure 1. In this configuration, the HI-STORM cask with a heat emitting metal canister is emplaced on a 3 ft. thick reinforced concrete pad. Between the soil and the pad and laterally along the sides of the pad layers of Soil Cement Mix (SCM) are interposed.[1] The space laterally (beyond pad and SCM fill along sides) and below the SCM bottom layer, is occupied by soil. A ten feet thick layer of soil is included in the thermal model. The space above the pad (outside of HI-STORM footprint) and soil is occupied by ambient air.

It is heuristically evident that some of the decay heat generated by the fuel stored within the HI-STORM System will be transmitted from the base of HI-STORM that warms the pad outside the HI-STORM footprint, the SCM and the soil below. The analysis documented herein obtains a lower bound to (i) the pad surface temperature (T_{pad}) and (ii) SCM-Soil interface temperatures (T_{int}) under a sub-freezing ambient temperature. The thermal analysis is performed for two scenarios:

Scenario A: In this scenario, an upper bound MPC decay heat of $Q_o = 20$ kW is postulated[2] for a minimum Soil Cement Mix (SCM) thickness ($t_{min} = 1$ ft) underneath the pad. This scenario represents the maximum heat transfer conditions from cask to the pad, the SCM, and the underlying soil under the postulated condition.

Scenario B: In this scenario, a low decay heat ($Q_1 = 6$ kW) is postulated for a maximum SCM thickness ($t_{max} = 4.5$ ft). This scenario represents the minimum heat transfer conditions from the cask to the pad, the SCM, and the underlying soil under the postulated conditions.

For the sub-freezing ambient, the analysis postulates an air temperature equal to the minimum daily temperature $T_{min} = 19.7^{\circ}F$ (PFS FSAR [3]). In Scenario A the combination of upper bound heat load and minimum SCM thickness maximizes the heat transmission to soil below and in Scenario B the low decay heat and maximum SCM

[1] The SCM mixture under the pad has lower cement content than the mixture around the pad.
[2] This corresponds to the design maximum MPC heat load in transport. Because the MPCs must be transported prior to storage at the PFS site, this is the highest credible HI-STORM heat load at the PFS site.

thickness combination minimizes heat transmission to soil below. This analysis conservatively assumes steady state conditions, which means that the ambient temperature of 19.7°F has been constant and steady for a very long time (long winter).

2.0 METHODOLOGY

The thermal modeling methodology adopted in this work is the same as that which undergirds the HI-STORM thermal analysis [1]. For conservatively minimizing heat dissipation from HI-STORM to the pad the following assumptions are used:

a) Convection heat transfer in the MPC space is neglected.

b) Contact between the heat generating elements (fuel assemblies) and metal structures (MPC) in which they are housed is neglected.

For addressing the pad and soil heating, the generic HI-STORM model geometry is expanded to explicitly include the pad, SCM and soil regions. This is illustrated in Figure 2 showing the model grid for Scenario A. The soil below the SCM is modeled as a finite layer 10 ft in depth and an appropriate temperature, T_{BC}, as discussed below, applied to the model boundary.

The soil temperature at a substantial depth (tens of feet below surface) approaches a far field soil temperature[3] (T_∞). The numerical value of T_∞ is well approximated by the annual average temperature for the PFS site (49°F to 51°F [3]). At a finite depth (several feet below surface), the soil temperature is influenced somewhat by ambient temperature variations. On a cold winter day the temperature of soil at a finite depth (≈ 10 ft depth) is bounded by T_∞ and T_{min} with a leaning towards T_∞. In the HI-STORM analysis, a T_{BC} of 40°F is applied to the thermal model.

[3] Defined as the asymptotic temperature limit to a plane conduction problem in a semi-infinite solid with cyclic ambient temperature variations.

3.0 ACCEPTANCE CRITERIA

The goal of the analysis is to determine whether, under subfreezing ambient temperature conditions: :

1) The pad surface temperature remains above freezing (> 32°F).
2) The soil layer immediately under the SCM is warmer than the surrounding soil.

The analysis goals are adopted herein as the principal criteria by which the acceptability of the results are determined.

4.0 ASSUMPTIONS

To obtain a lower bound to the pad and soil temperatures, the following assumptions are included in the thermal modeling:

i) Convection heat transfer in the MPC space is omitted.

The MPC design features an internal natural circulatory flow of Helium in a pressurized canister. The circulating gas removes heat from the stored fuel and deposits it to the lid, the cylindrical shell and the base of the MPC. By omitting this feature in the thermal modeling, the heat transmission from the base of the MPC is minimized, thus understating the heating of pad, SCM and that of the underlying soil below.

ii) Contact between the heat generating elements (fuel assemblies) and metal structures (MPC) in which they are housed is neglected.

The MPC houses heat emitting structures (spent nuclear fuel) at substantially elevated temperatures in a close fitting, all-welded honeycomb basket structure. Because of this configuration, at locations of physical contact between fuel and MPC, a direct communicative path for transport of decay heat in the axial and in-plane directions in the MPC metal structure occurs. Neglecting this heat transport minimizes heating of the MPC base, thus understating the heating of pad, SCM and underlying soil.

iii) Solar energy input to pad and soil is understated.

iv) Thermal conductivity of pad, SCM and soil are understated.

The concrete pad is a reinforced structure consisting of a high heat dissipating steel cage filled with a low heat dissipating medium (concrete). In the analyses provided herein, a conservative low value for concrete is postulated and the effect of reinforcing steel conservatively omitted. For the underlying soil and SCM at the PFS site, SWEC Geotechnical Engineering[4] has evaluated the conductivity to be in the range of 0.95 to 1.05 W/m-°K. Relative to the evaluation, the conductivity of soil and SCM (reported in Section 5.0) is understated approximately 10%.

[4] E-mail from Trudeau (SWEC) to Rampall (Holtec),"Soil-Cement mix", May 21, 2002.

5.0 INPUT DATA

The necessary inputs for expanding the HI-STORM thermal model to include the pad SCM and soil are tabulated below:

PARAMETER	VALUE	REFERENCE
SCM thickness	1 ft. (min.) 4.5 ft (max)	[4]
Insolation	684.6 W/m^2 (max.)	[3]
Pad Dimensions	Array Size: 2 by 4 Width: 30 ft Length: 67 ft	[3]
Tributary Area[5]	520 ft^2	[2]
Concrete Conductivity	1.05 Btu/ft-hr-°F	[1]

For the soil and SCM conductivity, a conservative low value of 0.5 Btu/ft-hr-°F is employed in the thermal models. The solar energy input to the exposed pad and soil surfaces is set to a conservative low value (10% of the site insolation). The solar energy input is modeled as a volumetric heat source (S) in a thin horizontal slice of the pad or soil (0.005 m thick) from the top. The value computes to $S = (10\%/100\%)*684.6\ W/m^2 / 0.005\ m = 13692\ W/m^3$.

[5] Defined as the planar area per cask at the PFS cask array.

6.0 COMPUTER CODES

The Holtec QA validated FLUENT Code version 4.32 is employed in the analyses provided herein. (See Appendix A for the Holtec Approved Computer Programs List). The FLUENT code is commercially available from the code developer, FLUENT Inc. situated in Lebanon, New Hampshire. FLUENT is a widely used computer program for solving a variety of problems involving fluid flow, heat and mass transfer. FLUENT is a general purpose code which effects solutions of the classical Navier-Stokes equations of fluid motion by numerical means. FLUENT's ability to provide reliable results is confirmed by its successful use in a variety of industrial applications including the power generation, environment, automotive and chemical process industries.

7.0 ANALYSIS AND RESULTS

Employing the inputs provided in Section 5.0, an axi-symmetric rendering of a HI-STORM Overpack on a pad was modeled on the FLUENT computer code. The lateral extent of the pad and soil in the model was computed from the pad dimensions and tributary area inputs for the PFS site. The calculations are provided below:

i) Radius of Pad (R1)

Pad Area = Width x Length

= 30 x 67 = 2010 ft^2

HI-STORMs per Pad = 2 x 4

= 8

Pad Area per HI-STORM = 2010 / 8

= 251.25 ft^2

$$R1 = \sqrt{\frac{251.25}{\pi}} = 8.94 \text{ ft}$$

ii) Radius of Enveloping Cylinder (R2)

Tributary Area = 520 ft^2

The tributary area is defined as the planar area per HI-STORM cask at the PFS cask array. For an axi-symmetric rendering of the physical configuration of a HI-STORM overpack on a pad with surrounding soil, an enveloping cylinder is constructed having an area equal to the tributary area.

$$R1 = \sqrt{\frac{520}{\pi}} = 12.86 \text{ ft}$$

The analysis scenarios (Scenario A and Scenario B) were separately modeled and individual thermal solutions obtained. The thermal solutions were examined and numerical results for the exposed pad surface and SCM-Soil interface extracted. The results are summarized below:

Scenario A

Exposed Pad Surface Temperature (T_{pad}): 53.2°F (min.), 56.3°F (max.)

SCM-Soil Interface Temperature (T_{int}): 48.5°F (min.), 52.1°F (max.)

Soil Temperature Gradient ($T_{int} - T_{BC}$): 8.5°F to 12.1°F

Scenario B

Exposed Pad Surface Temperature (T_{pad}): 50.0°F (min.), 53.7°F (max.)

SCM-Soil Interface Temperature (T_{int}): 46.9°F (min.), 47.8°F (max.)

Soil Temperature Gradient ($T_{int} - T_{BC}$): 6.9°F to 7.8°F

From the results of the thermal solutions, the following conclusions are drawn:

a) The pad surface temperature is above freezing by a comfortable margin (> 10°F).

b) The soil directly underneath the pad/SCM is approximately 7°F warmer that the surrounding soil.

In other words, the results of the thermal analysis show that even during very cold winter days at Skull Valley, the warmth from the HI-STORMs keeps the pad above freezing and raises the temperature of soil beneath the pad/SCM to several degrees above that of the soil that surrounds it.

8.0 COMPUTER FILES

The list of FLUENT computer files for the thermal analyses (Scenarios A and B) is provided hereunder:

```
Directory of G:\Users\IRAMPALL\IRP\CASK\JAN99\FL\68B\PFS\cold
05/21/02  04:58p                    580 B20KW.LOG
05/22/02  05:15p                    572 b6kw.log
05/24/02  04:17p                256,604 pfs_A.cas
05/24/02  04:17p                907,153 pfs_A.dat
05/24/02  04:27p                256,604 pfs_B.cas
05/24/02  04:27p                907,153 pfs_B.dat
```

9.0 REFERENCES

[1] HI-STORM Storage FSAR, Holtec Report HI-2002444, Rev. 0.

[2] "Additional Thermal Evaluation of the HI-STORM 100 System for Deployment at Skull Valley", Appendix C, Holtec Report HI2002413, Rev. 1.

[3] "Private Fuel Storage Facility Safety Analysis Report", Rev. 22.

[4] E-mail from Paul Trudeau (SWEC) to Alan Soler (Holtec), "Subject: Profile & Moduli of Elasticities for Holtec's Tipover Analysis Including Soil Cement", (3/2/2001).

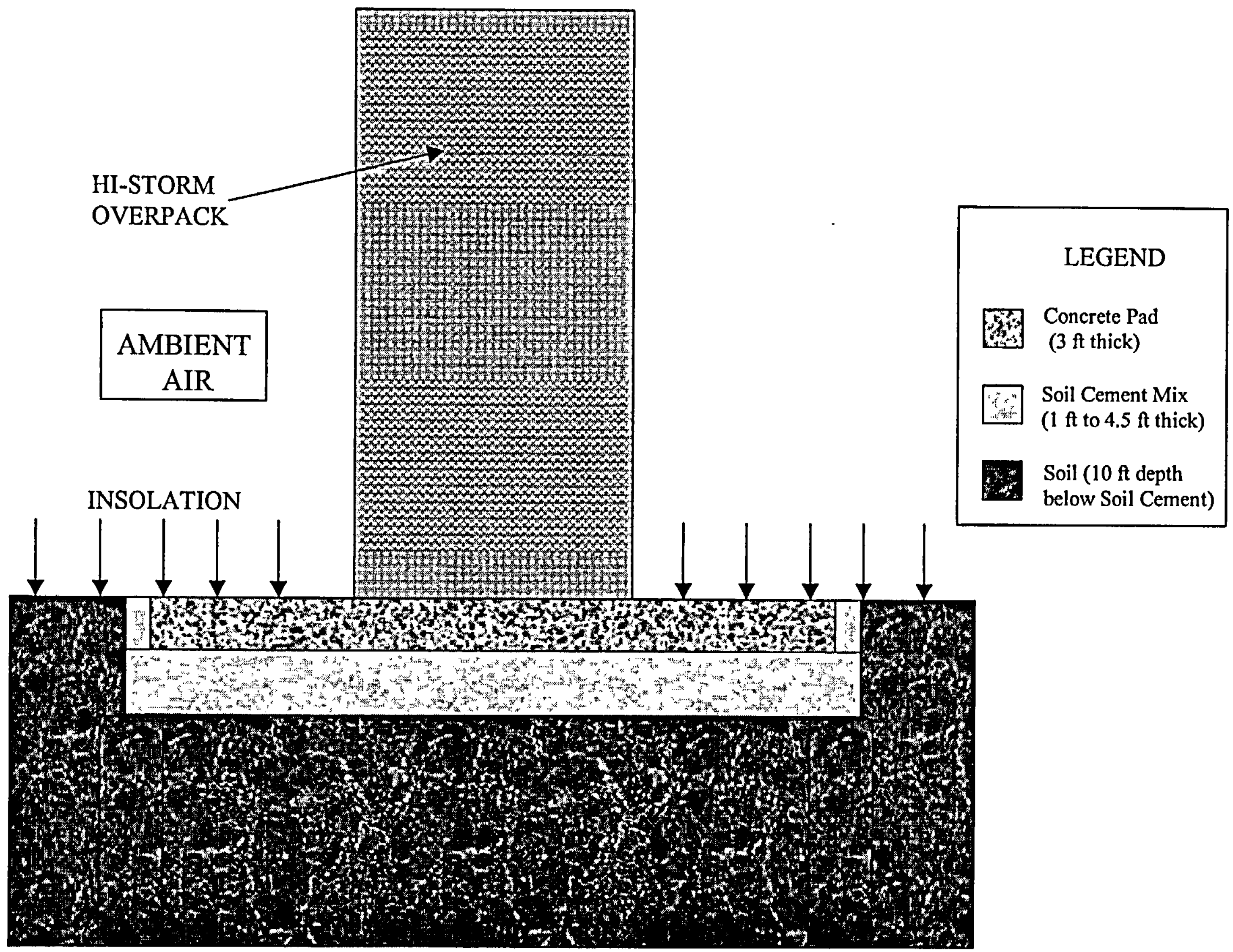

FIGURE 1: PHYSICAL CONFIGURATION OF THE HI-STORM PAD AND SOIL

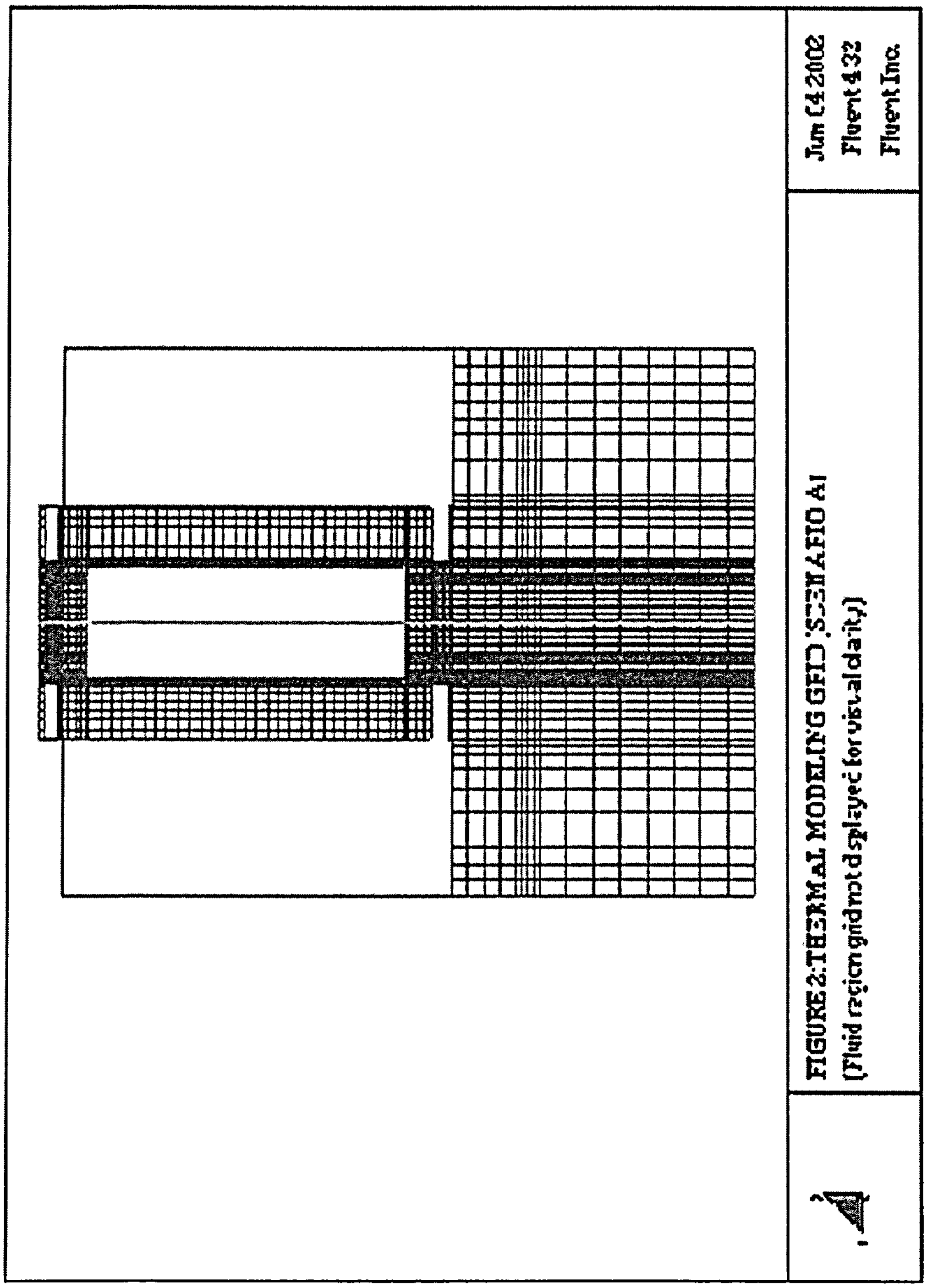

FIGURE 2: THERMAL MODELING GRID (SCENARIO A)
(Fluid region grid not displayed for visual clarity)

APPENDIX A
HOLTEC APPROVED COMPUTER PROGRAM LIST
(Total No. Of Pages = 4)

HOLTEC APPROVED COMPUTER PROGRAM LIST			REV. 47 May 30, 2002		
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)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ELR, SPA, DMM, KC, ST,VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects. The user should refer to the error notice documented in c4ser.04-results pdf located in \generic\library\ nuclear\error notices\ concerning the use of version 1.13 04.	
CASMO-3 (A)	4.4, 4.7	ELR, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		
CHANBP6 (A)	1.0	SJ, PKC, CWB, AIS, SP,JRT	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		
DÉCOR	1.0		DOS/Windows		
DR.BEAMPRO	1.0.5		Windows		
DR.FRAME	2.0		Windows		
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ, JRT	DOS/Windows	Personnel qualified to use MR216 are automatically qualified to use DYNAMO.	

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 47 May 30, 2002	
PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.48, 4.56, 5.1 (see error notice), 4.2.8 (UNS),5.5	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	4 32
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST,VJB	Windows		
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950	JZ, AIS, SPA, SP	Windows		
MAXDIS16	1.0		DOS/Windows		
MCNP (A)	4A, 4B	ELR, SPA, KC, ST, DMM,VJB	Windows/ UNIX		
MASSINV	1 4, 1.5, 2.1		DOS/Windows		
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PKC, SJ,JRT	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	
MSREFINE	1.3, 2.1		DOS/Windows		
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4		Windows		
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		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 47 May 30, 2002	
PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
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		
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. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session. If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 47 May 30, 2002	
PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

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

ATTACHMENT I: E-Mail From P. Trudeau (SWEC) to A. Soler (Holtec)

>From: Paul Trudeau on 03/02/2001 04:19 PM
>
>To: alan_soler@holtec.com
>cc: brian_gutherman@holtec.com, max.m.delong@nspco.com, Jerry
> Cooper/Mechanical/SWEC@SWEC, John Donnell/Power/SWEC@SWEC,
> pjtrudeau@adelphia.net
>
>Subject: PFSF: Profile & Moduli of Elasticities for Holtec's Tipover
>Analyses
> Including Soil Cement
>
>Alan,
>
>Our best-estimate of the static modulus of elasticity (E(subscript: s)) of
>the
>soil cement is 350,000 psi, the density is assumed to be 105 pcf, and
>Poisson's
>ratio is assumed to be ~0.2. We expect to have a minimum of 1 ft of soil
>cement
>under each of the pads and as much as 4.5 ft under some of the pads. To
>account
>for potential variations in the field, we feel it is prudent to perform
>these
>analyses using at least 5 ft of soil cement under the pads. Also note,
>that
>this maximum amount can be reduced by any increase in the thickness of the
>pads
>above the present 3 ft thickness. In this case, however, we still need to
>provide at least 1 ft of soil cement under all of the pads because of
>statements
>we made to that effect in the SAR.
>
>The underlying silty clay/clayey silt layers have a cumulative thickness of
>~23
>ft and are expected to have E(subscript: s) values that do not exceed 6,000
>psi,
>based on values reported for similar soils in Table 13 of NUREG/CR-6608.
>The
>average density for these soils is ~91 pcf. Similarly, the underlying
>silty
>sand/sandy silt layer has a thickness of ~ 7 ft, an estimated E(subscript:
>s) of
>~12,000 psi, an assumed density of 115 pcf, and Poisson's ratio is assumed
>to be

>~0.3. The underlying soils are comprised of sands that are very dense (SPT
>N-values typically exceed 100 blows/ft); therefore, we have labeled this an
>incompressible base for the cask tipover analyses.
>
>I do not believe that your analysis is very sensitive to density values.
>We do
>not have a good value for the density of the soil cement yet. Therefore,
>if you
>will be specifying the value used as a not-to-exceed-value, please use
>densities
>of 125 pcf for the soil cement and the in situ soils.
>
>Note: If this value of E(subscript: s) for the soil cement works out OK,
>please
>also increase the E(subscript: s) value for the underlying soils to
>determine
>how sensitive your analysis is to E(subscript: s). If we can demonstrate
>that E
>(subscript: s) can exceed these values by a wide margin, then we will have
>less
>need to test these soils in the field to demonstrate that we do not exceed
>the
>specified limit(s).
>
>You can reach me at home this weekend: 508-747-0394 or email to:
>pjtrudeau@adelphia.net.
>
>Generalized profile: (See attached file: Holtec-1.PDF)
>Thanks,
>Paul J. Trudeau
>Lead Geotechncial Engineer - PFSF