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TranStor™ Concrete Cask Tornado, Flood, Earthquake, and Explosion Analysis

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DESIGN CALCULATION

TRANSTOR™ CONCRETE CASK TORNADO, FLOOD, EARTHQUAKE, AND EXPLOSION ANALYSIS

PORTLAND GENERAL ELECTRIC COMPANY

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1.0 PURPOSE AND DESCRIPTION OF EVALUATIONS

This calculation provides the analyses of several generic and Trojan site-specific hypothetical accidents and bounding phenomena that could occur over the life of the TranStor™ Concrete Cask. Specific accidents addressed include the following:

- Tornado
- Flood
- Earthquake
- Explosion

2.0 RESULTS/CONCLUSIONS

Results of these analyses show that the TranStor™ storage system has substantial safety margin to provide more than adequate protection to both the public and occupational personnel. Specifically:

2.1 Tornado

2.1.1 Analyses for penetration resistance of the cask body and closure elements to the armor piercing shell missile indicate that sufficient thickness of concrete and steel is available to prevent perforation, spalling or scabbing of the various cask boundary elements.

2.1.2 Overall response of the cask has been evaluated for impacts associated with the high energy deformable missile (automobile). Such analyses indicate that the cask will remain upright following the event, and that loads associated with this impact do not compromise the integrity of the cask.

2.1.3 Various calculated parameters are indicated below:

Wind velocity pressure:	331.8 psf
Wind overturning moment acting on the Concrete Cask:	3.6×10^6 in-lbs
Depth of missile penetration:	5.69 in
Minimum concrete thickness to prevent spalling and scabbing:	17.1 in
Minimum cask lid perforation thickness:	0.52 in
Cask kinetic energy following missile impact:	7.47×10^5 in-lbs
Energy required to overturn the cask:	4.88×10^6 in-lbs
Maximum force due to impact:	457.4 kips
Section shear capacity:	1,106 kips
Maximum moment due to impact:	87,820 kips-in
Section moment capacity:	94,170 kips-in
Maximum cask rotation due to impact:	2.6 degrees
Cask restoring moment:	1.54×10^7 in-lbs

2.2 Flood

The Concrete Cask can withstand a flood which results in full submergence (211.5 in) and a stream velocity of 26.5 ft/sec. Therefore, no overturning of the cask will occur due to flooding.

2.3 Earthquake

2.3.1 The cask provides the required safety margins during both the Design Basis Earthquake (DBE) and Seismic Margin Earthquake (SME). The cask will not overturn during a seismic event at Trojan ISFSI site.

2.3.2 The cask concrete can withstand seismic loads as indicated below:

Concrete cask shear:	118.1 kips < 1,106 kips
Concrete cask moment:	22,675 kip-in < 94,170 kip-in

2.4 Explosion

The concrete cask can wit! :tand the Trojan design basis pressure force due to explosion without sliding or overturning.

3.0 DESIGN INPU` `ND ASSUMPTIONS

3.1 General

3.1.1 Concrete Cask dimensional information is provided by Reference 3. the cask height is 211.5 inches and the diameter is 136 inches. However, the bottom diameter is only 130 inches due to the 3" chamfer. Also, considering the air inlet channels provided at the base of the cask, the shortest footprint dimension is calculated in Attachment A. The shortest footprint dimension provides the least resistance, and used for analysis against overturning due to tornado, flood, earthquake and explosion.

3.1.2 Concrete Cask weight and center of gravity information is provided by Reference 4. The weight of the loaded cask was taken as 289,000 lbs with a center of gravity of 109.5 in . These values bound all loading conditions at the Trojan site since using these lower weight and higher c.g. values are conservative for the analysis presented herein.

3.2 Tornado

3.2.1 A tornado event is considered to occur during the life of the Trojan ISFSI site. The effects of a tornado on the Concrete Cask include the possibility of damage due to wind loading, wind generated pressure differentials, and tornado generated missiles. Possible damage

3.2.2 The design basis tornado characteristics are consistent with Regulatory Guide 1.76 and presented in Table 3.1-1 [Ref. 2].

Table 3.1-1
Wind and Tornado Specification

Environmental Condition	Limits
Rotational Wind Speed, mph	290
Translational Wind Speed, mph	70
Maximum Wind Speed, mph	360
Radium of Max. Wind Speed, ft.	150
Pressure Drop, psi	3.0
Rate of Pressure Drop, psi/sec	2.0

3.2.3 Postulated tornado missiles are as identified in NUREG-0800 [Ref. 1], Section 3.5.1.4 III.4. Spectrum I missiles are used and assumed to impact in a manner that produces the maximum damage to the cask. The design values shown in Table 3.1-2 are generic for TranStor™ Storage System design and bound the wind and tornado specifications for the Trojan ISFSI [Ref. 2]. These missiles consist of a massive high kinetic energy missile which deforms on impact, a rigid missile to test penetration resistance, and a small rigid missile of a size sufficient to just pass through any openings in protective barriers.

Table 3.1-2
Tornado Generated Missiles

Missile Description	Weight (lbs)	Velocity (mph)
Automobile	3960	126
Armor Piercing Shell (8 in. diameter)	275	126
Steel Sphere (1 in. diameter)	0.22	126

3.2.4 The wind velocity pressure is assumed constant with height and uniform over the projected area of the cask. Gust factors are taken as unity in evaluating effects of velocity pressures on cask surfaces.

3.2.5 Since the cask is a freestanding structure, the principal consideration in overall damage response is the likelihood of upsetting or overturning of the cask as a result of high energy missile impacts.

3.3 Flood

3.3.1 The worst case flood is assumed to fully submerge the Concrete Cask. This bounds the worst case flood at Trojan [Ref. 2].

3.3.2 Full immersion of the cask and steady state flow conditions for an infinite cylinder are assumed for the cask drag force calculation.

3.4 Earthquake

3.4.1 The Design Basis Earthquake (DBE) has a peak horizontal ground acceleration of 0.25g and a peak vertical ground acceleration of 0.17g. The Seismic Margin Earthquake (SME) has a peak horizontal ground acceleration of 0.38g and a peak vertical ground acceleration of 0.25g. The minimum overturning factors of safety for the DBE and SME analyses are 1.50 and 1.10 respectively. [Ref. 2]

3.4.2 The concrete cask is a very stiff structure. Although free-standing, the cask is assumed to be a cantilever fixed at the base (Ref. 7, Table 36, Case 3b). For the purpose of calculating seismic loads, the cask can be treated as a rigid body attached to the ground and equivalent static analysis methods can be applied to calculate loads, stresses, and overturning moments.

3.4.3 The concrete cask can be evaluated statically for overturning by conservatively applying equivalent static loads to the cask in two orthogonal horizontal directions simultaneously with an upward vertical component. Combination of the three components is performed in accordance with Reference 8. Reference 8 recognizes that maximum accelerations from three directions can not occur at the same time and suggests when one of the components is at its maximum value, the other two can be taken as 40% of their corresponding peaks. Although the DBE and SME peak accelerations were determined from the geometric mean of two horizontal accelerations [Ref. 17], the cask design conservatively utilizes a 100-40-40 distribution.

3.5 Explosion

3.5.1 Trojan site design pressure is 4.4 psi [Ref. 6].

3.5.2 Friction coefficient between the Concrete Cask and Pad is 0.3 [Ref. 5].

4.0 METHODOLOGY

4.1 Tornado

4.1.1 The methods used to convert the tornado and wind loadings into forces on the cask are based on NUREG-0800, Section 3.3.1 - Wind Loadings, and Section 3.3.2 - Tornado Loadings. Loads due to tornado generated missiles are based on NUREG-0800, Section 3.5.3 - Barrier Design Procedures.

4.1.2 The tornado wind velocity is transformed into an effective pressure load applied to the cask using procedures delineated in Reference 10.

4.1.3 Total wind loading is utilized to determine the overturning moment.

4.1.4 Wind force and moment are compared to values required to tipover or slide the cask.

4.1.5 Critical shear and bending stress due to the wind loading are calculated.

4.1.6 Local damage of the cask body is assessed using the National Defense Research Committee (NDRC) formula [Ref. 13]. This formula has been selected as the basis for predicting depth of penetration and minimum thickness of concrete to prevent spalling and scabbing. Penetration depths computed by this method have been shown to provide reasonable correlation with test results [Refs. 12 and 13].

4.1.7 The minimum depth of concrete necessary to preclude spalling and scabbing is calculated using the NDRC formula and compared to cask concrete thickness to determine acceptability.

4.1.8 The perforation thickness in the Concrete Cask cover plate is calculated using Reference 14.

4.1.9 The force developed by the missile is calculated using methodology presented in Reference 14.

4.1.10 The change in missile momentum is calculated during the deformation phase.

4.1.11 The change in angular momentum of the cask during the deformation phase is calculated about a point on the bottom rim.

4.1.12 Deformation phase final missile velocity and cask angular velocity are calculated by conservation of momentum.

4.1.13 Restitution phase final missile velocity and cask angular velocity are calculated by equating impulse forces on the missile and cask.

4.1.14 Cask final kinetic energy is calculated and compared to the energy required to overturn the cask.

4.1.15 Shear capacity of the cask at the air outlet level is calculated using the shear friction formula (Ref. 15, Section 11.7).

4.1.16 The maximum moment due to impact is calculated.

4.1.17 Section capacity of the uncracked concrete section is calculated per Section 9.5.2.3 of Reference 15.

4.1.18 The effects of tornado winds and missiles are combined in accordance with NUREG-0800, Section 3.3.2.II.3.d [Ref. 1]. The stability of the cask is assessed by calculating the cask rotation from the missile impact and applying the wind tipover moment to the cask in this configuration.

4.2 Flood

4.2.1 The buoyancy force on the cask is calculated from the weight of displaced water.

4.2.2 The cask drag force due to stream flow conditions is calculated [Ref. 16].

4.2.3 The stream velocity is calculated by equating the moment from drag with the required cask overturning moment.

4.3 Earthquake

4.3.1 Concrete Cask natural frequency is calculated.

4.3.2 The DBE and SME loads are calculated and utilized to determine the restoring moment safety factor which is compared to a corresponding allowable.

4.3.3 Maximum ground displacement necessary to cause tipover is evaluated.

4.3.4 Cask shear stress and moment are calculated and compared to capacities.

4.4 Explosion

4.4.1 The force required to slide the cask is calculated.

4.4.2 The moment required to overturn the cask is calculated. Using this value, the resulting force required to tip the cask is calculated.

4.4.3 The minimum pressure required to produce the smaller of the sliding or overturning force is calculated.

4.4.4 The minimum pressure is compared to Trojan design basis pressure.

5.0 CALCULATIONS

5.1 Tornado

5.1.1 Wind Loads

The tornado wind velocity is transformed into an effective pressure applied to the cask using procedures delineated in Reference 10. The maximum velocity pressure, p, is determined from the maximum tornado wind velocity as follows:

$p = (0.00256)\ V^2$ psf = 331.8 psf

where:

V = Maximum tornado wind speed
= 360 mph (bounds Trojan wind speed of 240 mph)

The total tornado wind loading on the projected area of the cask, W_w, is then computed as follows:

$W_w = p(C_f)(A_p)$ = 34,464 lbs

where:

p = Effective velocity pressure (psf) = 331.8 psf
C_f = Net pressure coefficient = 0.52 (Ref. 10, Table 12)
A_p = Projected area of cask normal to wind
= 136"·211.5" = 28,764 in^2 = 199.75 ft^2

The overturning moment acting on the cask is:

$M_w = (34,464)(211.5/2) = 3.6 \cdot 10^6$ lbs-in

This force and moment are clearly insufficient to tipover or slide a 289,000 lbs cask since the resisting moment of the cask is (289,000) 58.5 = $1.69 \cdot 10^7$ lbs-in and the sliding coefficient of friction (for steel on concrete) is typically used as 0.3 [Ref. 5]. Note that the shortest base dimension of 58.5", considering the air inlet channels at the base, is used; see Attachment A for details.

The critical section for the cask is at the bottom of the cavity. The shear stress, conservatively ignoring the cask liner, is:

$W_w/A_x = 3.5$ psi

where :

$A_x = (136^2 - 78^2)(\pi/4) = 9,748\ in^2$

The Concrete Cask is assumed cantilevered at the base of the liner bottom. The moment due to the wind loading is:

$M = (W_w)(211.5-19.5)/2 = 3.31 \cdot 10^6$ in-lb

The bending stress for the same section is:

$M/(I_y/C_x) = 15.0$ psi

where:

$I_y = (136^4 - 78^4)(\pi/64) = 1.5 \cdot 10^7\ in^4$

$C_x = 68$ in

5.1.2 Tornado Missiles

5.1.2.1 Local Damage Prediction - Cask Body

Local damage of the cask body is assessed using the National Defense Research Committee (NDRC) formula [Ref. 13]. The depth of penetration, X , as predicted using this approach may be expressed as follows:

For $X/2d \leq 2.0$:

$$X = [4KNWd^{-0.8}(V/1000)^{1.8}]^{0.5} = 5.69 \text{ in}$$

where:

d = Diameter of missile (8 in)

K = Coefficient depending on the concrete strength
  $= 180/(f_c)^{0.5}$
  = 2.85 assuming 4000 psi concrete

N = Missile shape factor
  = 1.14 for sharp nosed-missiles [Ref. 13]

W = Missile Weight (275 lbs)

V = Velocity (184.8 ft/sec)

The minimum depth of concrete necessary to preclude spalling and scabbing is three (3) times the depth of penetration predicted, or

3 (5.69) = 17.1 inches.

Since the minimum thickness of concrete in the cask body (29 inches) is well in excess of this value, it is concluded that adequate protection is provided for local damage due to tornado missiles.

5.1.2.2 Local Damage Prediction - Cask Closure Plate

The Concrete Cask is closed with a 0.75 inch thick steel plate bolted in place. By calculating the perforation thickness of a 126 mph, 275 lbs, 8 inch diameter artillery shell impacting a steel plate, the ability of the closure plate to adequately withstand tornado generated missiles is established.

The perforation thickness, T, in a steel plate is given in Reference 14 as:

$$T = [(0.5)(M_m)(V_s)^2]^{2/3}/672d_m = 0.52 \text{ in}$$

where:

M_m = Missile mass (slugs) = W/g = 275/32.2 = 8.54 slugs

W = Missile weight = 275 lbs

g = Acceleration due to gravity = 32.2 ft/sec^2

V_s = Missile striking velocity (ft/sec) = 184.8 ft/sec

d_m = Missile diameter (in) = 8 in.

Since the cask lid is thicker than the perforation thickness, the lid is adequate to withstand local impingement damage due to tornado generated missiles.

5.1.2.3 Overall Damage Prediction

The force developed by the missile (automobile) is calculated using methodology presented in Reference 14. The maximum force, F, is:

F =(0.625)(v)(W) = (0.625)(184.8)(3,960) = 457.4 kips

From the principles of conservation of momentum, the impulse of the force from the missile impact on the cask must equal the change in angular momentum of the cask. Likewise, the impulse force due to the impact of the missile must equal the change in linear momentum of the missile. With reference to Figure 5.1-1, these relationships may be expressed as follows:

During the deformation phase, the change in momentum of the missile becomes:

$$\int_{t1}^{t2} F dt = M(v_2 - v_1)$$

where:

F = Impact impulse force on missile

M= Mass of missile
= 3960 lbs/g
= 123 slugs

t_1 = Time at impact

t_1 = Time at impact

t_2 = Time at conclusion of deformation phase

v_1 = Velocity of missile at impact
= 184.8 ft/sec (126 mph)

v_2 = Velocity of missile at t_2

The change in angular momentum of the cask about a point on the bottom rim becomes :

$$\int_{t1}^{t2} M_c dt = \int_{t1}^{t2} (211.5 \cdot F) dt = I_c (w_1 - w_2)$$

where,

M_c	= Moment of the impact impulse force on the cask
I_c	= Cask mass moment of inertia about a point on the bottom edge
	= $(W_{cask}/g)(R^2/4+r^2+H^2/3) = 1.75 \cdot 10^8$ slug-in^2
w_1	= Angular velocity at time t_1
w_2	= Angular velocity at time t_2
R	= overall radius of cask, 68 inches
r	= shortest base dimension, 58.5 inches
H	= height of cask, 211.5 inches

Equating the impulse of the impact force on the missile to the impulse of the force on the cask yields:
$-(123 \text{ sl})[v_2 - (184.8 \text{ ft/sec})(12 \text{ in/ft})] = (1.75 \times 10^8 \text{ sl-in}^2/211.5 \text{ in})(w_2)$

where:
$v_2 = \sqrt{(58.5+68)^2 + 211.5^2}\ w_2 = 246.4\ w_2$ (see Figure 5.1-1)

then,
w_2 = 0.32 rad/sec, and
v_2 = 78.8 in/sec

During the restitution phase, the final velocity of the missile will depend upon the coefficient of restitution of the missile, the geometry of the missile and target, the angle of incidence, and upon the amount of energy dissipated in deforming the missile and target. Based upon tests conducted by EPRI (Ref: EPRI Repct NP-440, Tests 6 and 7), it is assumed that the final velocity of the missile, v_f, following the impact is zero.

Equating the impulse of the force on the missile during restitution to the impulse of the force on the cask yields:

$$-[m(v_f - v_2)] = I_c/211.5(w_f - w_2)$$

Then:

$$w_f = 0.32 \text{ rad/sec}$$

The final kinetic energy of the cask following the impact, Ek, is then determined as:

$$E_k = (I_c)(w_f)^2/2$$
$$= [(1.75 \times 10^8)(0.32)^2/2]\,(1/12)$$
$$= 7.47 \times 10^5 \text{ in-lb}_f$$

And the energy required to overturn the cask, Ep, is (see Attachment A):

$$E_p = (W_c)(h) = 4.88 \times 10^6 \text{ in-lb}_f$$

Comparison of E_k and E_p shows that overturning of the cask will not occur as a result of impact from tornado generated missiles. The above analysis is conservative since it assumes direct in line impact of the missile with the cask.

The shear capacity of the Concrete Cask location at air outlet level has also been calculated to evaluate resistance of the cask to tornado generated missiles. The capacity of the concrete section is calculated using shear-friction formula (Ref. 15, Section 8.7):

U_s = $V_n = 0.85\, A_{vf} f_y \mu$ = 1,10[illegible] kips,

where,

A_{vf} = (32)(0.44) = 14.1 in^2 - total area of reinforcement perpendicular to the shear plane

f_y = (1.1)(60,000) = 66,000 psi - reinforcement yield strength increased by 10% for dynamic loading (Ref. 15, Appendix C)

μ = 1.4 - for monolithically placed concrete.

The maximum moment due to the impact exists in the cask section adjacent to the bottom:

M $= FL = (457.4)(211.5-19.5) = 87{,}820$ kips•in

Section capacity of the uncracked concrete section has been conservatively calculated per Section 9.5.2.3 of Ref. 15 code.

$U_m = \phi\,(f_r I_g / y_t) = 94{,}170$ kips in

where:

f_r $= 7.5\,(f'_c)^{0.5} = 474.34$ (concrete modulus of rupture)
f'_c = 4000 psi (concrete compressive strength)
I_g $= 1/4\,\pi\,(R^4 - r^4) = 1.5 \times 10^7$ in^4 (gross moment of inertia of concrete section)
R = 68 in
r = 39 in
y_t = 68 in (distance from centroidal axis of gross section, neglecting reinforcement, to extreme fiber in tension.
ϕ = 0.9 (strength reduction factor - Section 9.3.2, Ref. 15)

5.1.2.4 Combined Tornado Wind and Missile Loading

The effects of tornado winds and missiles have been considered both separately and combined in accordance with Reference 1, Section 3.3.2.II.3.d. The stability of the cask has been assessed by calculating the cask rotation from the missile impact and applying the wind tipover moment to the cask in this configuration.

Equating the kinetic energy of the cask following missile impact to the potential energy yields a maximum postulated rotation of the cask as a result of the impact of 2.6 degrees.

Applying the total tornado wind load to the cask in this condition results in a tipping moment of $3.8 \cdot 10^6$ in-lbs with the restoring moment calculated to be $1.54 \cdot 10^7$ in-lbs. Hence, overturning of the cask under the combined effects of tornado winds plus tornado-generated missiles will not occur.

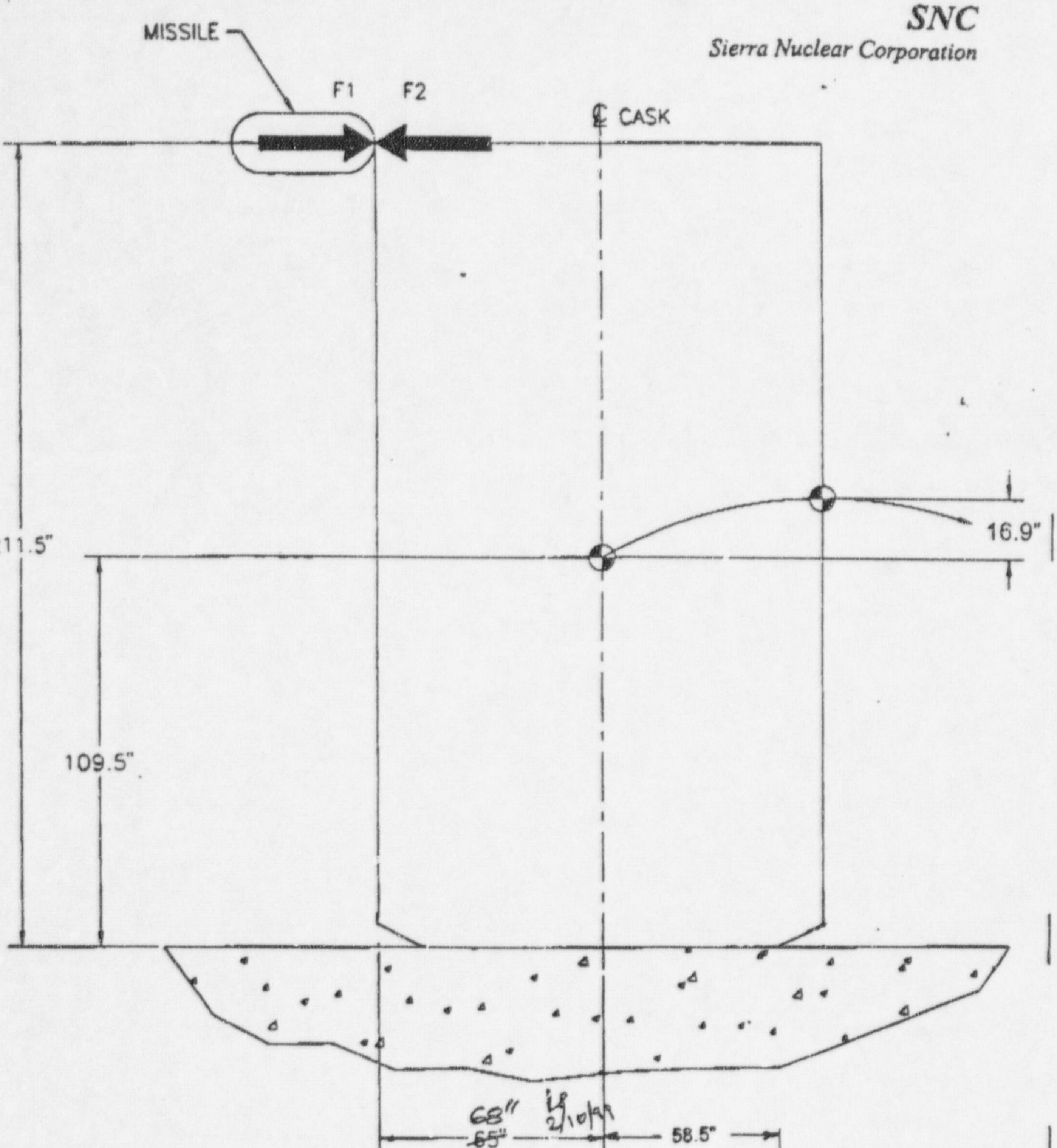

Figure 5.1-1

Sketch of Missile/Cask Impact Geometry

5.2 Flood

5.2.1 Immersing Flood Analysis

The buc ancy force on the cask, assuming full immersion of the cask is computed from the weight of the displaced water:

$F_b = (\rho_w)(V) = 110{,}950$ lbs

where:

ρ_w = Weight density of water = 62.4 lb/ft^3 = 1.94 slugs/ft^3 [Ref. 5]

V = Displaced volume of cask = $[\frac{\pi}{4} \cdot 136^2 \cdot 211.5] \cdot \frac{1}{1728} = 1778$ ft^3

Assuming full immersion of the cask and steady state flow conditions for an infinite cylinder, the total force due to drag, F_d, is

$F_d = (C_d)(\rho)(v^2)(A)/2 = 155.0\ v^2$

where:

C_d = Drag coefficient which depends on the Reynolds Number (Re)
= 0.8 for Re > 10^7 (which implies v = 16.56 ft/sec for water) (Ref. 16, Figure 5-7)

ρ = Mass density of water = 1.94 slugs/ft^3

u = Absolute viscosity of water = 0.0000273 lb-sec/ft^2

D = Cask outside diameter = 136 in = 11.33 ft

v = Velocity of stream flow

A = Projected area of cask normal to flow = 199.8 ft^2

The stream velocity required to overturn the cask is then determined by summing the moments of the submerged weight of the cask and the drag force about a point on the bottom edge:

$F_d = (W - F_b)(D/2) / (\text{half of cask height}) = 155.0\ v^2$

$= (289{,}000 - 110{,}950)(58.5) / (211.5/2) = 155.0\ v^2$

Solving:

v = 25.2 ft/sec (which is greater than 16.56 ft/sec and, hence, Re is greater than 10^7, and the use of $C_d = 0.8$ is justified).

Any reasonable flood at the Trojan ISFSI site will be bounded by these 25.2 ft/sec velocity and 211.5 inch depth [Ref. 2]. Therefore, no overturning of the cask will occur.

5.3 Earthquake

5.3.1 Concrete Cask Natural Frequency

The fundamental natural frequency of vibration for the cask was determined as shown below:

$f_n = [(K_n)/2\pi]\,[(E)(I)(g)/(w)(L^4)]^{0.5}$ [Ref. 7]

Where:

f_n = Frequency of the n-th mode

K_n = 3.52 for first mode of vibration

E = Modulus of Elasticity
= $57{,}000\ (fc)^{0.5}$
= $57{,}000\ (4{,}000\ \text{psi})^{0.5}$
= 3,604,996 psi

$I = I_g = 1.49 \cdot 10^7\ \text{in}^4$

g = 386.4 in/sec/sec

L = Height of cask
= 211.5 in

w = Uniform weight density of cantilever
= 289,000/211.5
= 1366.4 lb/in

Then:

$f_n = [3.52/2\pi]\ \{(3.6 \times 10^6)(1.49 \times 10^7)(386.4)/(1366.4)(211.5)^4\}^{0.5}$
$= 48.8$ cycles per second

It can be seen from both Reg. Guide 1.60 [Ref.18] and Trojan spectra [Ref. 2] that this frequency is well beyond the ZPA cut-off. Therefore, the dynamic amplification factor for this frequency is 1 and the seismic loads can be treated as static.

5.3.2 Design Basis Earthquake Loads

Horizontal seismic load $= (W_c)[(0.25)^2 + (0.4 \cdot 0.25)^2]^{0.5}$
$= 0.27W_c$
Vertical seismic load $= (0.4 \cdot 0.17)W_c = 0.07\ W_c$

W_c =289,000 lbs

Then:

S.F. = (Restoring Moment/Overturning Moment)
$= [(W_c)(1 - 0.07)58.5/(W_c)(0.27)(109.5)] = 1.84 > 1.50$

Therefore, the DBE criteria are satisfied.

5.3.3 Seismic Margin Earthquake Loads

Horizontal seismic load $= (W_c)[(0.38)^2 + (0.4 \cdot 0.38)^2]^{0.5}$
$= 0.41W_c$
Vertical seismic load $= (0.4 \cdot 0.25)W_c = 0.1\ W_c$

W_c =289,000 lbs

Then:

S.F. = (Restoring Moment/Overturning Moment)
$= [(W_c)(1 - 0.1)58.5/(0.41W_c)(109.5)] = 1.17 > 1.10$

Therefore, the SME criteria are satisfied and the cask is stable under seismic loads of the SME.

5.3.4 Ground Displacement

Furthermore, as Figure 5.3-1 shows(see Attachment A for details), a vertical ground displacement of approximately 5.3 ft would be required to move the center of gravity over the edge of the cask in order to cause overturning. This type of ground displacement and/or failure of the foundation is considered to be unrealistic and, hence, it is concluded that in addition to not overturning due to the earthquake inertia loads, the cask will also not overturn due to failure or vertical movement of the foundation. Therefore, based on this analysis it can be concluded that the Concrete Cask will not tipover or fall during a worst-case earthquake at the Trojan site.

5.3.5 Seismic Stresses

The Basket and Concrete Cask are very rugged and, since the tipover is precluded, their stresses due to design basis or seismic margin earthquake are negligible. The Basket stresses are bounded by the much higher drop accelerations, while the Concrete Cask seismic demands can be calculated as follows:

Shear: $V = 0.41 W_c = 0.41\ (289) = 118.5$ kips

Moment: $M = V\,l = (118.5)\ (211.5-19.5) = 22{,}750$ kip-in

By comparison of these values with capacities calculated in Section 5.1.2.3, it can be seen that the cask seismic stresses are small.

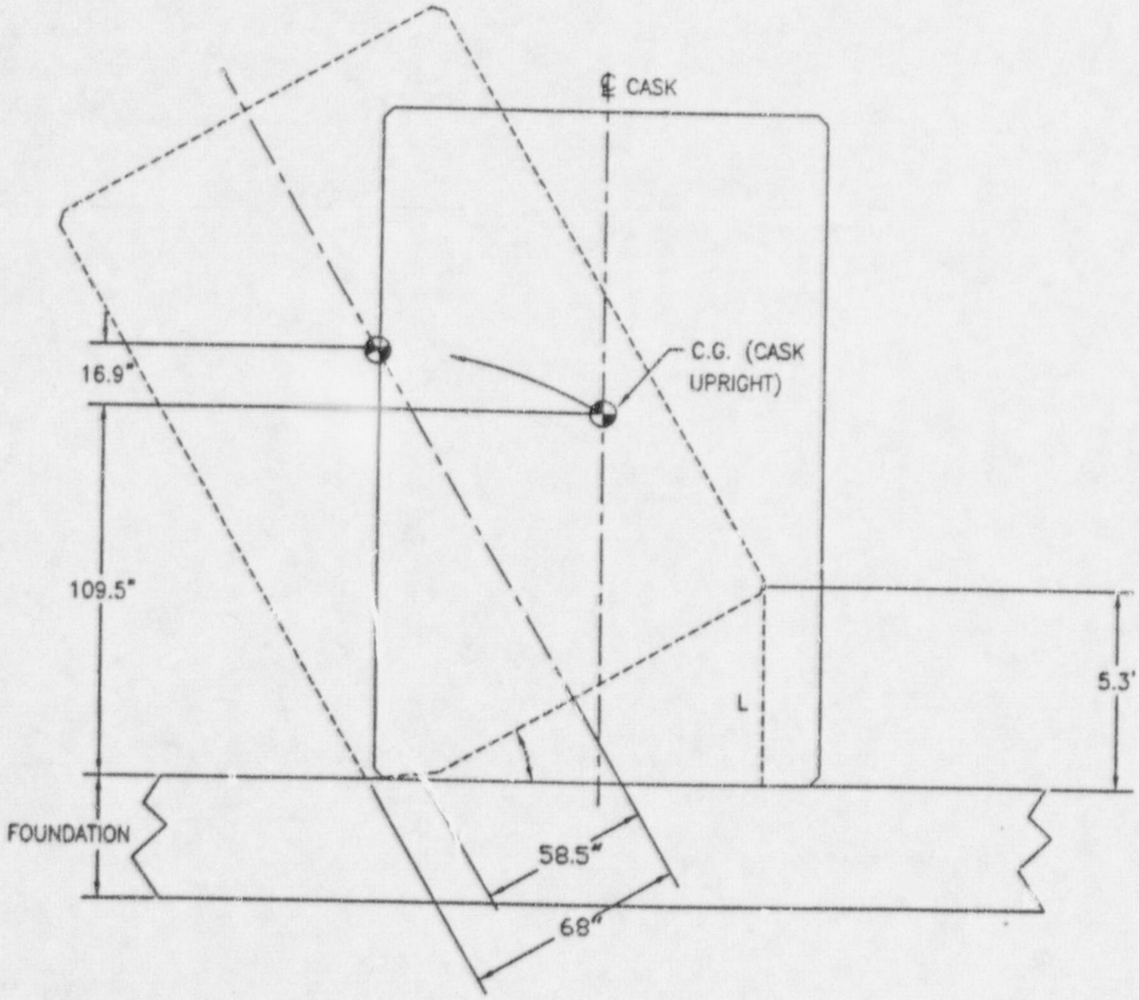

Figure 5.3-1

Cask Tip-Over Geometry

5.4 Explosion

The design criterion is that the explosion cannot slide or overturn the cask.

Force required to slide the cask:

$F_{slide} = 289{,}000 \text{ lbs} \cdot 0.3 = 86{,}700 \text{ lbs}$

Moment required to uplift the cask:

$M = 289{,}000 \text{ lbs} \cdot 58.5 = 1.69 \times 10^7 \text{ lbs-in}$

or the force required to create this moment:

$F_{topple} = M / (L/2) = 1.69 \times 10^7 / (211.5/2) = 159{,}811 \text{ lbs}$

The force required to slide the cask is smaller, thus, sliding controls. The minimum pressure that would move the cask can be back-calculated using the equation from Section 5.1.1:

$p = F_{slide} / (C_f A_p) = 86{,}700 / (0.52 \cdot 199.75) = 834.7 \text{ psf} = 5.8 \text{ psi}$

This pressure is higher than the Trojan DSAR design basis pressure of 4.4 psi. Therefore, the cask will not slide or tipover as a result of explosion. Safety factor of 5.8 /4.4 = 1.32 is provided.

6.0 REFERENCES

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ATTACHMENT A

CALCULATION OF CASK TIPOVER PARAMETERS

A1.0 Introduction

R3

This attachment provides the calculation of the TranStor™ cask tipover geometric parameters.

A2.0 Calculations

A2.1 Shortest Base Dimension

The shortest base dimension for hypothetical cask tipover corresponds to the section at the ends of the air inlet channels. Referring to Figure A1, the following angles and dimensions are derived:

$$\alpha = a\sin\left(\frac{6"}{65"}\right) = 5.3° \qquad \beta = a\cos\left(\frac{6"+48.5"}{65"}\right) = 33.0°$$

$$\gamma = 90° - \alpha - \beta = 51.7° \qquad R = R_b \cdot \cos\left(\frac{\gamma}{2}\right) = 65 \cdot \cos\left(\frac{51.7}{2}\right) = 58.5\ in$$

The cask tips about the plane 58.5" from the centerline.

For c.g. at cask centerline and 109.5" above the base, check rotation to place c.g. over the plane:

$$\alpha_1 = \tan^{-1}\left(\frac{58.5}{109.5}\right) = 28.1°$$

Check rotation about 58.5" plane to contact upper edge of chamfer:

$$\alpha_2 = \tan^{-1}\left(\frac{3}{68-58.5}\right) = 17.5°$$

Therefore, the cask rotates about upper edge before overturning; check rotation at stability limit for upper edge:

$$\alpha' = \tan^{-1}\left(\frac{68}{109.5-3}\right) = 32.6°$$

Cask Tipover – lower edge of chamfer above pad at point of stability: R3

$$L = 2 \times 58.5 \times \sin 32.6° = 63\text{"}$$ or 5.3' (the contribution of the chamfer is not included; conservative assumption)

Vertical height of c.g. :

$$h = \left(\frac{68}{\sin 32.6°}\right) = 126.4\text{"}$$

Vertical displacement:

$$\Delta h = 126.4\text{"} - 109.5\text{"} = 16.9\text{"}$$

Energy required to overturn the cask:

$$E_p = 289{,}000 \times 16.9$$

$$= 4.88 \times 10^6 \text{ in-lb.}$$

Figure A1 – Base of TranStor™ Storage Cask