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CHAPTER 2

PRINCIPAL DESIGN CRITERIA

This chapter provides the principal design criteria for the TN-68 casks. Section 2.1 presents a general description of the spent fuel to be stored. Section 2.2 provides the design criteria for environmental conditions and natural phenomena. This section presents the analysis which shows that the casks will not tip over or move significant distances under the design basis seismic, tornado, wind and missile loadings, design basis earthquake or extreme floods. This section also contains an assessment of the local damage due to the design basis environmental conditions and natural phenomena and the general loadings and design parameters used for analysis in subsequent chapters. Section 2.3 provides a description of the systems which have been designated as important to safety. Section 2.4 provides a general discussion regarding decommissioning considerations. This is further elaborated on in Chapter 14. Section 2.5 summarizes the cask design criteria.

2.1 Spent Fuel To Be Stored

The TN-68 cask is designed to store 68 General Electric (GE) Boiling Water Reactor (BWR) spent fuel assemblies with or without fuel channels. The maximum allowable lattice-average initial enrichment varies from 3.7 to 4.7 wt% U235 depending on the B10 areal density in the basket neutron absorber plates. The maximum bundle average burnup, maximum decay heat, and minimum cooling time are 40 GWd/MTU, 0.312 kW/assembly, and 10 years for 7x7 fuel, 60 GWd/MTU, 0.441 kW/assembly, and 7 years for all other fuel. The cask is designed for a maximum heat load of 30 kW. Damaged fuel that can be handled by normal means may be stored in eight peripheral compartments fitted with damaged fuel end caps designed to retain gross fragments of fuel within the compartment.

Damaged fuel is defined as fuel with known or suspected cladding defects greater than pinholes or hairline cracks, or no more than one grid spacer damaged or mislocated in a way that would affect its ability to support the fuel rods. Damaged fuel to be stored in the TN-68 must be capable of being handled by normal means. There must be no missing fuel pins or fuel pin segments. Fuel with missing pins that have been replaced with dummy rods that displace a volume equal to or greater than that of the original rods is not regarded as damaged. This definition is based on analysis in Appendix 6B which shows that damaged fuel so limited would be retrievable under normal and off-normal conditions. Thermal and criticality analyses assume that such fuel undergoes further damage under accident conditions.

Scoping calculations were performed to determine the fuel assembly type which was most limiting for each of the analyses including shielding, criticality, heat load and confinement. The fuel assemblies considered are listed in Table 2.1-1. The design basis fuel for decay heat, shielding and confinement is an 8x8 lattice with 63 fuel rods and with burnup, bundle average enrichment, and cooling time of 48 GWd/MTU, 2.6 wt% U235, and 7 years, respectively. The fuel qualification screening which is developed based on this fuel is conservative when applied to other fuel types with lower mass of uranium. Of the acceptable contents, only 7x7 fuel has a greater mass of uranium, but it is not bounding because it is restricted to lower burnup, longer cooling time, and lower decay heat. It has a separate fuel qualification table. For the criticality analysis, all fuel assembly types are analyzed with 3.7% lattice average enrichment. The 10x10 assembly is most reactive and is evaluated for configurations which bound all normal, off-normal and accident conditions at various enrichments with the corresponding B10 areal density in the basket neutron absorber. The thermal and radiological characteristics for the BWR spent fuel were generated using the SAS2H/ORIGEN S modules of SCALE[16]. These characteristics for the design basis 8x8 fuel assembly are shown in Table 2.1-2. The thermal analysis uses the 10x10 fuel assembly model with the 8x8 design basis decay heat. Justification for the selection of the most limiting fuel assembly is presented in Chapters 4, 5, 6 and 7 for the thermal, shielding, criticality and confinement analyses, respectively.

Fuel with various combinations of burnup, specific power, enrichment and cooling time can be stored in the TN-68 cask as long as the combination results in decay heat, surface dose rates, and radioactive sources for confinement that are bounded by the design basis fuel. For reference, Figure 2.1-1 shows the relationship between cooling time and decay heat for a typical BWR fuel assembly. As discussed in Chapter 5, an evaluation was performed to determine various combinations of burnup, enrichment and cool time that would be acceptable for the TN-68. Table 2.1-4 provides the minimum cooling time required for various combinations of minimum initial enrichment and maximum burnup for 7x7 fuel. Figure 2.1-4 presents a fuel screening flow chart and a decay heat formula for all other fuel. The 8x8 design basis fuel is evaluated in Chapter 7 to ensure that the off-site airborne dose limits of 10 CFR 72.104 and 72.106 are met. Figures 2.1-2 and 2.1-3 show the relationship between the gamma and neutron source terms and decay time for 7x7 fuel.

Specific gamma and neutron source spectra for the design basis 8x8 fuel are given in Table 5.2-7 and 5.2-9, respectively, and the fission product gas inventory is given in Table 5.2-11.

2.2 Design Criteria for Environmental Conditions and Natural Phenomena

The storage cask design ensures that fuel criticality is prevented, cask integrity is maintained, and fuel is not damaged so as to preclude its ultimate removal from the cask. The conditions under which these objectives are met are described below.

The casks are self-contained, independent, passive systems, which do not rely on any other systems or components for their operation. The criteria used in the design of the casks ensure that their exposure to credible site hazards do not impair their safety functions.
The design criteria satisfy the requirements of 10 CFR Part 72(3). They include the effects of normal operation, natural phenomena and postulated man-made accidents. The criteria are defined in terms of loading conditions imposed on the storage cask. The loading conditions are evaluated to determine the type and magnitude of loads induced on the storage cask. The combinations of these loads are then established based on the number of conditions that can be superimposed. The load combinations are then classified as Service Conditions consistent with Section III of the ASME Boiler and Pressure Vessel Code(4). The stresses resulting from the application of these loads are then evaluated based on the rules of the ASME Code as defined herein.

2.2.1 Tornado Wind and Tornado Missiles

The TN-68 storage cask is designed to resist tornado loadings resulting from those in the most tornado prone regions of the United States as defined in NRC Regulatory Guide 1.76(5). An analysis of impact on the cask by tornado missiles in accordance with NUREG-0800(6) Section 3.5.1.4, is presented in this Safety Analysis Report. Non-tornado wind loading is not significant in comparison to that due to tornadoes; therefore, the wind loading is conservatively taken to be the same as the tornado loading.

2.2.1.1 Applicable Design Parameters

The design basis tornado wind velocity and external pressure drop based on NRC Regulatory Guide 1.76 are 360 mph and 3 psi respectively. The external pressure drop of 3 psi associated with passing of the tornado is small and, when combined with the other internal pressure loads is far exceeded by the design internal pressure (100 psig) for the cask.

2.2.1.2 Determination of Forces on Structures

The 360 mph tornado wind loading is converted to a dynamic pressure (psf) acting on the cask by multiplying the square of the wind velocity (in mph) by a coefficient (0.002558 at ambient sea level condition) dependent on the air density, based on data presented in a paper by T.W. Singell.(7). The result is a pressure of 332 psf (Figure 2.2-1a). The net force acting on the cask is obtained by multiplying this pressure by the product of the area of the cask projected onto a plane normal to the direction of wind times a drag coefficient. A drag coefficient of 1 is used based on the geometric proportions of the cask (i.e. length to diameter ratio of approximately 2) and the conservative assumption that the cask surface is rough.

An additional type of load on the structure is that created by the impact of tornado missiles on the cask. These impacts are analyzed for 4 types of missiles:

- Missile A: high energy deformable type missile (4000 lb. automobile) impacting the cask

  a) horizontally at normal incidence at 35% of the design basis tornado horizontal wind speed.

  b) vertically at normal incidence at 70% of the horizontal component (24.5% of the design basis tornado horizontal wind speed).

- Missile B: rigid missile (276 lb., 8 inch diameter armor piercing artillery shell) impacting the cask:

  a) horizontally at normal incidence at 35% of the design basis tornado horizontal wind speed.

  b) vertically at normal incidence at 70% of the horizontal component (24.5% of the design basis tornado horizontal wind speed).

- Missile C: small rigid steel sphere 1 inch in diameter impinging upon the barrier openings in the most damaging direction at 35% of the design basis tornado horizontal wind speed.

- Missile D: a 4 inch thick by 12 inch wide by 12 foot long wood plank, travelling at 300 mph.

The tornado missiles are summarized in the following table.

Missiles		Mass (lbs)	Horizontal Velocity (mph)	Vertical Velocity (mph)
A	Automobile	4,000	126	88.2
B	8" Dia. Armor Piercing Artillery Shell	276	126	88.2
C	1" Dia. Steel Sphere	< 1	126	126
D	4" Thick. Wood Plank 12" Wide × 12' Long	200	300	300

2.2.1.2.1 Stability of the Cask in the Vertical Position Under Wind Loading

Cask stability evaluations are performed using a conservatively low cask weight of 227,000 lbs. The cask rests in an upright position on a concrete pad. To determine an appropriate coefficient of friction between steel and concrete, the following references are cited:

Coefficient of Static Friction	References
Metal on stone: 0.30 – 0.70	Beer and Johnston, Vector Mechanics for Engineers: Static and Dynamic[23]
Metal on Concrete: 0.30 – 0.40	Walmer, M.E., Manual of Structural Design and Engineering Solutions[24]
Concrete to Steel: 0.40	PCI Design Handbook, 2nd Edition[25]

The coefficient of static friction is used to calculate the maximum amount of frictional force available to prevent sliding. Once sliding begins, there is lower frictional force available, and the coefficient of kinetic friction should be used. According to the textbook[23], Vector Mechanics for Engineers: Static and Dynamic by F.P. Beer and E.R. Johnston, the coefficient of kinetic friction is approximately 25% smaller than the coefficient of static friction.

A broom finish will be specified for the top surface of the concrete pad. This will result in a coarser texture than a smooth, troweled finish. It is therefore concluded that a coefficient of static friction value of 0.35 is appropriate for the determination of the factor of safety against cask sliding, the kinetic coefficient of friction between the steel cask and the concrete pad is taken as 0.2625.

Cask Sliding

The wind loading on the cask body is:

$$q = 0.002558\ V^2 = 0.002558\ (360)^2 = 332\ \text{lb/ft}^2$$

and the projected area is

$$A = (160 \times 98 + 22.75 \times 81.25 + 32.25 \times 84.5)/144 = 140.65\ \text{ft}^2$$

Therefore, the total wind force is

$$F_{wind} = 332 \times 140.65 \approx 46{,}700\ \text{lbs.}$$

The friction force under the cask is

$F_{friction} = W_{cask} \text{ x } \mu = 227{,}000 \text{ x } 0.35 = 79{,}450$ lbs.

A conservatively low weight of 227,000 lbs. is used for the stability analyses.

$F_{friction} > F_{wind}$, thus, the wind will not slide the cask.

<u>Cask Tipping</u>

The cask has an outer diameter of 84.5 inches at its base. The constant wind velocity to tip the cask is calculated by equating the tipping moment to the restoring moment:

The tipping moment due to the 360 mph wind about the bottom edge of the cask is:

$M_{tipping} = F_{wind} \times B = 46{,}700 \times 97.26 = 4.54 \times 10^6$ in-lb (B = 97.26", CG of the Cask)

And the restoring moment due to the weight of the cask is:

$M_{restoring} = W_{cask} \times r = 227{,}000 \times 42.25 = 9.59 \times 10^6$ in-lb (r = 42.25", Radius of the Cask)

$M_{restoring} > M_{tipping}$

Therefore the design basis tornado wind velocity of 360 mph will neither slide nor tip the cask.

2.2.1.2.2 <u>Stability of the Cask in the Vertical Position Under Missile Impact</u>

It is assumed that Missiles A, B and D impact inelastically on the cask as shown in Figure 2.2-2. Missile A (the automobile) and Missile D (the wood plank) are assumed to crush and Missile B (the rigid shell) is assumed to partially penetrate the cask wall. The cask will tend to slide if the missile strikes it below the CG (unless it is blocked in position) or tilt if the missile strikes it above the CG. Conservation of momentum is assumed for both sliding and tipping with a coefficient of restitution of zero. The energy transferred to the cask is dissipated by friction in the sliding case or transformed into potential energy as the cask CG lifts in the tipping case. When a missile strikes the side of the cask at an elevation near the CG:

In the sliding case: $$V = \frac{mv_o}{M + m}$$

Where:

V = cask translational velocity after impact

v_0 = missile initial velocity
m = mass of Missile, lbf/386.4
M = cask mass, 227,000 lbf/386.4

When the appropriate substitutions are performed for Missile impact, the cask velocity after impact in the sliding case, V, is summarized as follows:

Missile		Mass (lbs)	Missile Initial Velocity v_0 (mph)	Cask Translational Velocity After Impact V (mph)
A	Automobile	4,000	126	2.182
B	8" Dia. Armor Piercing Artillery Shell	276	126	0.153
C	1" Dia. Steel Sphere	< 1	126	0
D	4" Thick. Wood Plank 12" Wide × 12' Long	204	300	0.264

Missile A therefore has a greater effect on the stability of the cask than do missiles B or D producing a velocity after impact of 2.182 mph or 38.4 in/sec.

Cask Sliding

The cask may tend to slide if the missile strikes it below the CG. Assuming no rotation and ignoring friction, the cask velocity could reach 2.182 mph or 38.4 in/sec after the impact. Therefore, the final kinetic energy is:

$$KE = 1/2(W_{cask} \times V^2)/g = 1/2\ (227{,}000 \times 38.4^2)/386.4 = 4.33 \times 10^5 \text{ in-lb}$$

If the cask slides on the concrete pad, the cask kinetic energy after impact is absorbed by friction. The friction work can be equated to the kinetic energy. Assuming a coefficient of friction of 0.2625:

$$F_{friction} = \mu\ W_{cask} = 0.2625 \times 227{,}000 = 0.596 \times 10^5 \text{ lbs}$$

Where:

$F_{friction}$ = friction force

μ = coefficient of friction

The sliding distance is determined by:

Sliding Distance $L = KE/ F_{friction} = 4.33 \times 10^5/0.596 \times 10^5 \approx 7.3$ in.

The cask may tend to slide 7.3 in. if the missile strikes it below the CG of the cask.

Cask Tipping

If the entire momentum of the missile is applied to the cask, the impulse momentum would be:

$$\begin{aligned}\text{Impulse Momentum} &= (W_{missile}/g) \times (v_o) \\ &= (4000/386.4) \times (126\times5280\times12/3600) = 2.296 \times 10^4 \text{ lb-sec}\end{aligned}$$

If the impulse is applied near the top and cask pivots about a bottom corner (not sliding), therefore,

Cask angular momentum after impact = Moment of impulse

The rotational kinetic energy about corner A is (see Figure 2.2-2):

$$KE_{rotation} = 0.5\ (I_{cask\ about\ A} \times \omega^2)$$

$$I_{cask\ about\ A} = I_{cg} + (W_{cask}/g)\ (x)^2$$

$$I_{cg} = (W_{cask}/g)(r^2 + A^2/3)/4 = (227{,}000/386.4)(42.25^2 + (197.25)^2/3)/4 = 2.17\times10^6 \text{ lb-in-sec}^2$$

$$I_{cask\ about\ A} = 2.17 \times 10^6 + (227{,}000/386.4)(106.04)^2 = 8.78 \times10^6 \text{ lb-in-sec}^2$$

Therefore, $(I_{cask\ about\ A})(\omega) = \text{Impulse} \times 215 = 2.296 \times 10^4 \times 215 = 4.94 \times 10^6$ in-lb-sec

$$\omega = 4.94 \times 10^6 / I_{cask\ about\ A} = 4.94 \times 10^6/8.78\times 10^6 = 0.56 \text{ sec}^{-1}$$

and rotational kinetic energy is

$$KE_{rotation} = 1/2(I_{cask\ about\ A} \times \omega^2) = 1/2(8.78 \times 10^6 \times 0.56^2) = 1.38 \times 10^6 \text{ in-lb}$$

The cask tilts through a small angle before it stops. When the cask tips or pivots about point A after impact, the kinetic energy is transformed into potential energy as CG rises (Figure 2.2-2):

$E_{tipping}$ = Increase in Potential Energy = Kinetic Energy = 1.38×10^6 in-lb

$$E_{tipping} = W_{cask} \times (x)\ (\sin \alpha - \sin \theta)$$

Therefore, $\alpha = \sin^{-1} [E_{tipping}/ (W_{cask} \times x) + \sin \theta]$

$\theta = \sin^{-1}(B/x) = \sin^{-1}(97.26/106.04) = 66.5^o$

$\alpha = \sin^{-1} [1.38 \times 10^6 /(227,000 \times 106.04) + \sin 66.5] \approx 77.0^o$

So the cask tilts an angle equals to $(\alpha - \theta) = 77.0^o - 66.5^o = 10.5^o$

The cask is still stable since it will right itself until the CG lifts over the corner when α reaches 90^o.

$\alpha = 90^o$ $\qquad \alpha - \theta = 90^o - 66.45^o = 23.5^o$

Therefore, the cask will not tipover.

2.2.1.2.3 Forces Applied to the Cask Due to Missile Impact

The impact forces applied to the cask as it is struck by the missiles are determined as follows:

- Missile A - (automobile) is assumed to crush 3 feet under a constant force during the impact. The loss of kinetic energy is assumed to be dissipated by crushing of the missile. The frontal area of the automobile is assumed to be 20 sq. ft.

$$F_a \; x \; 3ft. = \frac{1}{2} [m_a v_o^2 - (M + m_a)V^2]$$

$$p_a = F_a / 20 \; ft^2$$

  where:

  F_a = Impact force on cask by Missile A
  p_a = Impact pressure on cask by Missile A

  The impact force, F_a, is determined to be 706,950 lb, and the crush pressure on the frontal area of the automobile, p_a, is 246 psi.

- Missile B - (rigid missile) does not deform under impact. The loss in kinetic energy is assumed to be dissipated as the missile partially penetrates the cask wall. The penetration force is assumed to be equal to the yield strength of the cask body material multiplied by the frontal area of the 8 in. diameter missile.

$$F_b = S_y \left(\frac{\pi}{4}\right)(8)^2$$

The impact force, F_b, is determined to be 1.558 x 10^6 lbs. assuming a cask body yield stress, S_y, of 31,000 psi. This force is higher than that developed by Missile A, but the impact time duration is much smaller so that a smaller impulse is applied to the cask producing less cask movement than Missile A

- Missile C - (small rigid steel sphere) Due to its small mass, Missile C has no significant effect on the stability of the cask and is bounded by Missiles A and B.

- Missile D - Wood plank deforms and is crushed under impact. The wood is much softer than the cask material. From Reference 8, the wood with the highest density and modulus of elasticity is selected. This is hickory with a density of 51 lbs/ft^3, a modulus of elasticity of 2.18 x 10^6 psi and a compressive strength of 8,970 psi. The wood crushing force, F_d is therefore (8970)(4)(12) = 430,560 lbs.

The above forces, F_a , F_b and F_d are used in the stress analysis of the cask body.

2.2.1.3 Tornado Missiles

The TN-68 cask has been evaluated for potential damage due to the four tornado missiles identified in 2.2.1.2. The effect of the missiles on the cask is summarized below and described in the following subsections.

Missile	Compressive Stress	Bending Stress	Penetration Distance, in.	Impact Force (lbs.)
A	246 psi	30,670 psi	0	706,950
B	31,000 psi	32,280 psi	1.13	1.558×10^6
C	31,000 psi	1,640 psi	0.146	12,100
D	8,970 psi	< B	0	430,560

2.2.1.3.1 Missile A

Missile A (automobile) deforms and is crushed during the impact. The local pressure on the cask structure is less than 1% of the body yield strength. Therefore, no local penetration occurs. The shear stress in the cask wall is conservatively calculated below. It is assumed that the impact force is concentrated on a small curved section of the cask wall having dimensions w x L. It is also assumed that only two edges are tending to shear (above and below the curved section). It is assumed that only 3 foot sections are shearing. Then

Shear Area = 2 x 36 x the thickness of the gamma shielding

= 2 x 36 x 6.0 = 432 in^2

The shear stress, τ = Force/area = 706,950/432 = 1,637 psi.

The level D allowable shear stress for the gamma shielding is 0.42 S_u = 0.42 x 70,000 = 29,400 psi. The shear stress is well below the allowable shear stress.

Assuming that the impact on the side of the cask is reacted by a 3 foot high section of shielding, case 18 from Table VIII of Reference 20 is used to model the impact as shown below.

$|M_{max}| = 3/2(wR^2)$

The $2\pi Rw$ from Table VIII, case 18 is the side impact force = 706,950 lbs.

R = 39.25 inches (mean radius of gamma shield)

Therefore, w = F/2πR = 2,867 lbs/in.

And, $|M_{max}| = 3/2(wR^2) = 6.63 \times 10^6$ in lbs.

The bending stress on the section is:

$\sigma_b = M \times c/I = 6.63 \times 10^6 \times (6/2)/(36 \times 6^3/12) = 30,670$ psi

The Level D allowable for membrane plus bending stress is 3.6S or S_u . For SA-266 Cl. 2 shielding material, S = 17,500 psi at 300°F and S_u = 70,000 psi. Thus the allowable stress is 3.6 x 17,500 = 63,000 psi. Therefore the membrane plus bending stress is acceptable.

If the automobile were to strike the top of the cask in the vertical orientation, the velocity would be 88.2 mph (70% of the horizontal impact velocity. The kinetic energy would be 12.47 x 10^6 in-lbs. For a crush depth of 36 inches, the impact force would be

F_{av} = Kinetic Energy /crush distance = 346,340 lbs.

This force is less than for Missile B and is spread out over a larger area. Therefore the stresses will be lower for missile A impact than for missile B impact. The stresses from missile B impact are bounding.

2.2.1.3.2 Missile B

Missile B (rigid) partially penetrates the cask wall. The loss in kinetic energy is dissipated as strain energy in the cask wall. The force developed as the 8 in. diameter missile penetrates the cask body is calculated below. A yield strength of 31,000 psi is used for the gamma shield material at 300°F.

$$F_b = S_y\left(\frac{\pi}{4}\right)(8)^2 = 1.558 \times 10^6 \text{ lbs.}$$

From conservation of energy:

$$F_b x = \frac{1}{2} m_b v_o^2$$

Or for constant puncture force:

$$x = \frac{m_b v_o^2}{2 F_b}$$

Where x is the penetration distance.

The penetration distance is found to be 1.13 in. for perpendicular impact of the missile.

When the impact angle is not 90 degrees, the missile will rotate during impact (conservatively neglected), limiting the energy available for penetration since part of the energy will be transformed into rotational kinetic energy.

When hitting the weather protective cover, Missile B deforms the dished head before penetration begins (see Figure 2.2-2c). This will decrease the penetration distance from the above value.

If the missile were to impact the top of the cask in the vertical orientation, the missile velocity would be 88.2 mph (70% of the horizontal impact velocity of 126 mph). The kinetic energy would be:

$$KE = 0.5 \text{ x } (276 \text{ lbs}/32.2\text{ft/sec}^2) \text{ x } (88.2 \text{ mph x } 5280\text{ft/mi}/3600 \text{ sec/hr})^2 \text{ x } 12 \text{ in/ft}$$
$$= 860{,}440 \text{ in lbs.}$$

Ignoring the effect of the protective cover and the top neutron shield, the lid bending stresses under a top impact are evaluated. Reference 20 is used to evaluate the stresses for two boundary conditions:

1. Modeling the lid as a simply supported plate.
2. Modeling the lid as a plate with the edges fixed.

For edges simply supported, Table X, Case 2 of Reference 20 is used. The maximum stresses occur at the center, where the plate thickness is t = 9.5 in. The impact force, $F_b = 1.558 \text{ x } 10^6$ lbs.

The maximum stress at the center is calculated below:

$$S_r = S_t = 3W/(2\pi mt^2) \text{ x } [m + (m+1)\ln(a/r_o) - (m-1)r_o^2/4a^2]$$

Where r_o = uniform load radius = missile radius = 4 inches
m = 3.33
t = 9.5 inches
a = 37.94 inches(effective radius for a simply supported lid at the bolt circle)
$W = F_b = 1.558 \text{ x } 10^6$ lbs.

Therefore, $S_r = S_t$ = 32,280 psi

This is well below the Level D allowable stress of 63,000 psi.

For the second case, with the lid edges fixed, Table X, case 7 of Reference 20 is used.

The maximum stress occurs at the edge, where the plate thickness, t = 5 inches.

$$S_r = 3W/(2\pi t^2)\ (1 - r_o^2/2a^2)$$

Where $W = F_b = 1.558 \times 10^6$ lbs.

r_o = uniform load radius = missile radius = 4 inches
t = 5 inches
a = 37.94 inches

S_r = 29,590 psi.

This is also well below the allowable Level D stress of 63,000 psi.

2.2.1.3.3 Missile C (steel sphere 1" diameter)

The impact of the steel sphere can result in a local dent by penetrating into the cask surface at the yield strength, S_y, for a penetration depth, d. The contact area on the cask surface is:

$$A = \pi(2Rd - d^2)$$

Where:

R is the radius of the sphere, 0.5 inches
d is the penetration depth

The kinetic energy of the steel sphere is dissipated by displacing the cask surface material:

$$KE = ½(m_c v_o^2) = S_y \int_o^d \pi(2Rd-d^2)dd$$

Where m_c = sphere mass

$KE = 0.5(4/3)(\pi)(0.5)^3(0.28)(1/32.2)(126 \times 5280/3600)^2 = 933$ in-lbs

$S_y \int_o^d \pi(2Rd-d^2)dd = S_y\pi(Rd^2 - d^3/3) = KE = 933$ in-lbs

For a yield strength of 31,000 psi, by trial and error:

d = 0.146 in.

The area, A, is therefore 0.39 sq. inches. A maximum impact force of 12.1×10^3 lb. ($A \times S_y$) will be developed. It can be concluded that only local denting of the cask will result.

If the impact is at the top of the cask (ignoring the protective cover and the neutron shielding), Ref. 20, Table X, Case 4 is used to determine the stresses. The impact force is assumed to act at the center of the lid, where p = 0, r_o = 0.353 in. and a = 37.94 inches.

The maximum stress is:

$$S_r = S_t = 3W/(2\pi m t^2) \times [m + (m+1)\ln(a/r_o) - (m-1)r_o^2/4a^2] = 1,640 \text{ psi}$$

Since all penetrations are covered, the steel sphere will have a negligible effect on the cask.

2.2.1.3.4 Missile D (wood plank)

The weight of the plank is 204 lbs. The kinetic energy of the plank is:

KE $= 0.5mv^2$
$= (0.5) \times (204)/(32.2) \times [(300)(5280)/3600]^2 = 6.13 \times 10^5$ ft - lbs $= 7.359 \times 10^6$ in - lbs.

The wood is much softer than the cask material, and most of the kinetic energy will be absorbed by the wood crushing.

The wood crush force = 8,970 psi x 4 in x 12 in = 430,560 lbs.

The wood would need to crush 7.359×10^6 in-lbs/430,560 lbs = 17.1 inch to absorb 100% of the impact energy.

The wood crush force is much less than the impact force developed in the Missile B impact (1.558×10^6 lbs.), while the impact area is nearly the same. The cask stresses for the wood plank impact will therefore be lower than for the Missile B impact.

2.2.1.3.5 Ability of Structures to Perform Despite Failure of Structures not Designed for Tornado Loads

The TN-68 cask itself can withstand the tornado loading. Generally, the casks will be stored outside on a flat concrete slab. Therefore, there will be no structures that could collapse about the storage cask. If such structures were present at an ISFSI, further analysis would be required.

2.2.2 Water Level (Flood) Design

The cask has been evaluated for a water level of 57 ft (measured from the base of the cask) and a water drag force of 45,290 lbs. due to floods. It is demonstrated that the cask is acceptable for these conditions. If a specific site has requirements to evaluate conditions exceeding these values, further analysis is required.

2.2.2.1 Flood Elevations

It is anticipated that the storage casks will be located on flood-dry sites. However, the storage cask is designed for an external pressure of 25 psi which is equivalent to a static head of water of approximately 57 ft. This is greater than would be anticipated due to floods, regardless of the site.

2.2.2.2 Phenomena Considered in Design Load Calculations

The casks are designed to withstand loads from forces developed by the probable maximum flood including hydrostatic effects and dynamic phenomena such as momentum and drag.

2.2.2.3 Flood Force Application

Using a friction coefficient of 0.2625, a drag force greater than 45,290 lb. is required to move the cask when the cask is in an upright position (after taking into account the buoyant force on the cask). This force is equivalent to a stream of water flowing past the cask at 22.1 ft/sec.

The water velocity was calculated using the following formula:

$$F = C_D A \rho \frac{V^2}{2g}$$

where F = Drag force, 45,290 lbs.
C_D = Drag coefficient ≈0.7
A = Projected area, 136.1 ft^2
ρ = 62.4 lb/ft^3
V = water velocity, ft/sec
g = 32.2 ft/sec^2

Therefore

$$V = \sqrt{\frac{2Fg}{C_D A \rho}}$$

V = 22.1 ft/sec

For a lower friction coefficient, the drag force is less and the water velocity to move the cask is less.

2.2.2.4 Flood Protection

The storage cask is designed for an internal pressure of 100 psig. The metallic seals in the cask are designed to maintain helium inside of the confinement. They are also effective in preventing water in-leakage into the cask. In addition, the interspace between the confinement seals and the confinement vessel cavity are pressurized to approximately 6 atm abs and 2 atm abs, respectively, to preclude any possibility of water in-leakage.

2.2.3 Seismic Design

Seismic design criteria are dependent on the specific site location. These criteria are established based on the general requirements stated in 10CFR Part 72.102. The design earthquake for use in the design of the casks must be equivalent to the safe shutdown earthquake (SSE) for a collocated nuclear power plant, the site of which has been evaluated under the criteria of 10CFR100, Appendix A[9].

2.2.3.1 Input Criteria

The TN-68 cask is a very stiff structure. For the purpose of calculating seismic load, the cask is treated as a rigid body attached to the ground and equivalent static analysis methods are used to calculate loads and overturning moments. This assumption is valid as long as the cask does not slide due to the seismic loads.

The fundamental natural frequency of vibration for the cask is determined as shown below (Formulas for Stress and Strain[20], 4th Edition, Page 369, Case #3):

$$f = 3.89/\ (WL^3/8EI)^{1/2}$$

Where:

W = Weight of Cask (227,000 lbs)
L = Height of Cask = 197.25 in.
E = Modulus of Elasticity = 28.3×10^6 psi
$I = (\pi/64)(D_o^4 - D_i^4) = (\pi/64)(84.5^4 - 69.5^4) = 1.36 \times 10^6\ in^4$

Substituting the values given above,

$$f = 52\ Hz$$

The vertical structural frequency of cask will be still higher since the cask has higher axial stiffness than the lateral stiffness. Thus the cask standing vertically on its pad has dominant lateral and vertical frequencies higher than 33 Hz (corresponding to the maximum ground acceleration, reference NUREG 1.60[22]). Therefore, the cask can be treated as a rigid body and the maximum seismic load on the cask is the peak ground acceleration times the mass of the cask. The cask is, therefore, evaluated using an equivalent static seismic loading method, and there is no need to specify a design response spectrum or its associated time history. The factor of 1.5 (reference to NUREG 0800[6], Para. 3.7.2) to account for multimode behavior need not be included in the seismic accelerations for this analysis, as the potential for sliding/uplift is due to rigid body motion, and no frequency content effects are associated with this action.

2.2.3.2 Seismic-System Analysis

Cask Sliding

If the cask is to slide due to seismic loading, the horizontal component of the seismic load must overcome the friction force between the cask base and concrete pad. The friction force is equal to the normal force due to gravity acting at the cask/ground interface multiplied by the coefficient of friction.

The vertical seismic force is applied upward so as to decrease the normal force and hence the sliding resistance force. The equivalent static horizontal acceleration load required to initiate sliding is calculated as follows:

$$g_h \times W = \mu W (1 - 2/3\, g_h)$$

where:

g_h = Fraction of horizontal acceleration value necessary to initiate sliding
W = Weight of cask on pad
μ = Coefficient of friction

For a coefficient of friction of 0.35, the equivalent static horizontal load required to initiate sliding is 0.284g.

Using a safety factor of 1.1 as recommended by ANSI/ANS-57.9[26], Section 6.17.4.1, the cask will not slide for a horizontal g loading of 0.284/1.1 = 0.26g. The maximum vertical g loading is 2/3 (0.26) or 0.17g.

The two horizontal components of seismic load are combined as indicated in Section 3.7.2 of NUREG-0800. At 45^o to either horizontal component, the response due to a N-S earthquake is $\sin 45^o$ x N-S response and likewise for an E-W earthquake is
$\sin 45^o$ x E-W response. If both components are equal, the combined response is:

$(\sin^2 45^o + \sin^2 45^o)^{1/2}$ x response = response in either axis.

Therefore, we only need to consider a single horizontal axis for the maximum seismic response.

<u>Cask Tipping</u>

The cask will not tipover due to a seismic event if the stabilizing moment due to cask weight is higher than the seismic tipping moment. The vertical acceleration is assumed to be 2/3 the horizontal acceleration in accordance with NUREG-0800. For a cylindrical cask, the horizontal g value necessary to tip the cask is calculated below:

$$M_{tip} = g_h W L_v + (2/3)\, g_h\, W L_r$$

Where:

M_{tip} = Moment necessary to tip the cask, in-lbs
g_h = Fraction of horizontal acceleration value necessary to tip the cask
W = Weight of cask on pad
L_v = Vertical distance to C.G. = 97.26 in.
L_r = Radial distance to C.G. = 42.25 in.

$$M_{stab} = W L_r$$

Where:

M_{stab} = Stabilizing moment of the cask, in-lbs.
W = Weight of cask on pad
L_r = Radial distance to CG = 42.25 in

Therefore, the g value necessary to tip the cask is found by equating M_{tip} to M_{stab}:

$g_h W L_v + (2/3) g_h W L_r = W L_r$

$g_h = 42.25/(97.26 + 0.667 \times 42.25) = 0.34$

Using a safety factor of 1.1 as recommended by ANSI/ANS-57.9, Section 6.17.4.1, the cask will not tipover for a horizontal g loading of 0.34/1.1 = 0.31g. The maximum vertical g loading is 2/3 (0.31) or 0.21g.

Conclusion

As demonstrated by the above calculations, an applied horizontal acceleration of 0.26g (and vertical acceleration of 0.17g) or less will neither slide nor tip the cask. The load distribution is shown in Figure 2.2-1b.

For evaluation of the stresses of the cask body, a 1g lateral and 2g downward acceleration were conservatively used for seismic loads on the cask. These loads are applied while the cask is standing in a vertical position on the concrete pad and bound the specified seismic load limits.

2.2.4 Snow and Ice Loading

The decay heat of the contained fuel will maintain the storage cask outer surface temperature above 32°F throughout its service life, including the end of life, assuming an ambient temperature of -20°F. Therefore, snow or ice would melt when it comes in contact with the cask so that snow and ice loading need not be considered for the storage cask.

The temperature of the protective cover attached to the top of the cask above the lid under certain conditions could fall below 32°F and a layer of snow or ice might build up. A 50 psf (0.35 psi) snow or ice load corresponds to approximately 6 ft of snow or 1 ft of ice. However, this load is insignificant on the TN-68 since the cover is a 0.25 in. thick torispherical steel head which can withstand an external pressure over 13 psi. Therefore, the cover will maintain its intended protective function under snow or ice loading conditions.

2.2.5 Combined Load Criteria

2.2.5.1 Introduction

Sections 2.2.1 through 2.2.4, above, describe the most severe natural phenomena considered in the design of the TN-68. These phenomena have been analyzed to show that the cask is stable. It will not tip over under any condition or slide on its pad more than about 7.3 inches. In addition, the forces and pressures applied to the cask due to these phenomena have been determined.

It should be noted that all of the above phenomena are upper bound, low probability events. In most cases, however, there is a more regular or frequent similar phenomena of lower magnitude. For instance, some small wind loading occurs often, but tornado winds are unlikely. The forces and pressures determined for the severe phenomena can therefore be used as upper bound values for all similar events.

It has been assumed that these bounding forces and pressures, with a single exception, can occur at any time and their effects are combined with those due to normal operations. The sole exception is the loading(s) due to the tornado missiles as described in Section 2.2.1.3. The missile case is evaluated in combination with others as a low probability event which is postulated only because the consequences of cask penetration might result in severe impact on the immediate environs.

2.2.5.2 TN-68 Cask Loading

A brief explanation of the cask loads due to events that will occur or can be expected to occur in the course of normal operation follows. The cask loads due to the severe natural phenomena and accidents are compared with those for similar but less severe normal events. Then loads equal to or higher than the upper bound values selected for design and analysis of the TN-68, defined as Service Loads, are described. Finally, the Service Loads are separated into two levels and superposition of simultaneous loading (combined loads) is discussed.

2.2.5.2.1 Normal Operation

During normal storage on the ISFSI pad, the cask is subjected to loading due to its own dead weight and that of its contents (fuel and basket), assembly stresses due to the bolt preload required to seat the double metallic seals and react to the internal pressure, and internal pressure due to initial pressurization and any fuel clad failure resulting in fission gas release.

Additional normal loads include wind loading which produces a distributed lateral load on one side of the cask and can also result in slight external pressure drop on other portions of the cask.

Lifting loads are applied to the cask through the trunnions and the cask dead weight is reacted through the trunnions during lifting operations.

Finally, an increased external pressure is applied to all surfaces of the cask during fuel loading when the cask is at the bottom of the spent fuel pool. Snow and ice loads apply local external pressure loading to the top of the protective cover. The cask will, of course, be subjected to the full range of thermal conditions produced by ambient variations (including insolation) and decay heat.

2.2.5.2.2 Loading Due to Severe Natural Phenomena and Accidents

The cask is subjected to dead weight loading and assembly stresses due to bolt preload and seal compression under all conditions. If it becomes necessary to unload a recently loaded hot cask, water would be slowly pumped into the cask to reduce the temperature prior to unloading. If proper controls are not maintained, an internal pressure corresponding to saturated steam pressure at the cavity wall temperature could occur which would be higher than the normal internal pressure. An evaluation of the unloading process is provided in Section 4.5.

The tornado wind loading described in Section 2.2.1 could produce higher lateral loading than any normal wind loading or flood water drag force. The external pressure drop due to the tornado wind is also more severe than due to any normal condition. Tornado missile impact described in Section 2.2.1.3 could apply a high local loading to the cask unlike any normal condition.

External pressure loading of the cask could occur due to flooding (see Section 2.2.2), or nearby explosion. The full range of thermal conditions due to ambient variations, decay heat and minor fires in the vicinity of the cask apply.

2.2.5.2.3 Thermal Conditions

The TN-68 component temperatures and thermal gradients are affected by the following thermal conditions:

- Fuel loading
- Decay heat
- Insolation
- Beginning of life unloading
- Ambient variations
- Lightning
- Minor fire
- Cask Burial

The thermal conditions which are of concern structurally are the temperature distributions in the cask and the differential thermal expansions of interfacing cask components.

2.2.5.2.4 Fuel Loading

The cask is loaded in a spent fuel pool under water. The cask is cooled by pool water; therefore, the thermal gradients established during fuel loading are negligible.

2.2.5.2.5 Decay Heat/Insolation

After the cask is loaded and removed from the pool, the cask body will gradually reach steady state conditions. Since the mass of the cask is large, the time to reach equilibrium will be approximately 1 to 2 days. The temperature gradients in the cask body have an insignificant effect on the structural integrity of the body.

Thermal analysis has been performed to determine the temperatures within the cask for different normal and accident conditions. The methods used to obtain these results are discussed in Chapter 4. The cask temperature distribution for the short-term normal condition (See Chapter 4) was used for the structural analysis.

2.2.5.2.6 Beginning of Life Unloading

This condition would occur if it were necessary to place the cask back in the pool at the beginning of life after it had been loaded and reached thermal equilibrium. Prior to placing the cask in the pool, the cask and fuel would have to be cooled by circulating water through the cask. Therefore, cold water would contact the hotter cask inside surfaces and fuel pins. This condition has been evaluated and it has been shown that the thermal gradients in the cask body are small and would have an insignificant effect on the cask body and the fuel cladding.

2.2.5.2.7 Ambient Temperature Variations

Because the cask thermal inertia is large, the cask thermal response to changes in atmospheric conditions will be relatively slow. Ambient temperature variations due to changes in atmospheric conditions i.e., sun, ice, snow, rain and wind will not affect the performance of the cask. Snow or ice will melt as it contacts the cask because the outer surface will be above 32°F for ambient temperatures as low as -20°F. The cyclical variation of insolation during a day will also create insignificant thermal gradients.

The thermal analysis is discussed in further detail in Chapter 4.

2.2.5.2.8 Lightning

Lightning will not cause a significant thermal effect. If struck by lightning on the lid, the electrical charge will be conducted by paths provided by the lid bolts to the body.

The lid metallic O-ring seals can withstand temperatures of up to 536°F without loss of sealing capability. It is not anticipated that lightning could result in the seals reaching temperatures above these values.

2.2.5.2.9 Fire

The only real source of fuel for a fire in the vicinity of the cask is the fuel tank of the tow vehicle which transports the cask to the storage pad. An evaluation was made to determine the thermal response of the cask assuming this minor fire is an engulfing fire. The details of this analysis are provided in Section 4.4. The cask will maintain its confinement integrity during and after this bounding hypothetical fire accident.

2.2.5.2.10 Buried Cask

An evaluation is made to determine the increase in cask temperature with time assuming that the cask is completely buried by dirt and debris with very low thermal conductivity. The details of this analysis are given in Section 4.4. The analysis shows that the cask will maintain its confinement integrity for a maximum burial period of 76 hours.

2.2.5.3 Bounding Loads for Design and Service Conditions

2.2.5.3.1 Dead (Weight) Loads

The only dead loads (hereafter referred to as weights) on the cask are the cask weight including the contents. The calculated weights of the individual components of the cask and the total weights are given in Table 3.2-1. The weight of the cask assembly is reacted as a contact force between cask and storage pad except when the cask is supported (lifted) by the pair of trunnions at the top of the cask during handling prior to fuel loading.

2.2.5.3.2 Lifting Loads

The cask is provided with two trunnions at the top spaced 180 degrees apart for lifting. The trunnions at the bottom of the cask are for rotation of the cask, if necessary.

The upper trunnions are single failure proof lifting devices and are evaluated for lifting for g levels equivalent to 6 times and 10 times the upper bound weight of the cask. A dynamic load factor of 1.15 is assumed in the analysis. These values are based on ANSI N14.6 [(11)], which requires that special lifting devices for critical loads be either designed with a dual load path or capable of lifting 6 times and 10 times the cask weight without exceeding the yield and ultimate strengths of the material, respectively (twice the normal stress design factor for handling a critical load). The trunnion loads for the ANSI N14.6 analysis are shown in Figure 2.2-3 and listed in Table 2.2-2. The weight of the cask used for these analyses is a conservatively assumed maximum loaded weight of 240,000 lbs.

The local region of the cask body is conservatively evaluated for a vertical load of 6 g (i.e., 6 times the weight of the cask) which is reacted at the trunnions involved in the handling operation. The factor of 6 provides ample allowance for sudden load application during lifting.

2.2.5.3.3 Internal Pressure

The pressure inside the cavity of the storage cask results from several sources. Initially, the cavity is pressurized with helium such that the cavity pressure is about 2.2 atm abs at thermal equilibrium. The purpose of pressurizing the cavity above atmospheric pressure is to prevent in-leakage of air. The initial pressure is determined on the basis that, at minimum, a 1 atm abs pressure must exist in the cavity on the coldest day at the end of life. Pressure variations due to daily and seasonal changes in ambient temperature conditions will be small due to the large thermal capacity of the cask. Fuel clad failure results in the release of fission gas which increases cavity pressure. Chapter 7 evaluates the increases in pressure due to off-normal and accident scenarios.

Another condition when internal pressure could increase is the cool down prior to unloading. This could occur at the beginning or end of life. Unloading of fuel at the beginning of life would only be necessary due to excessive leakage past the lid seals or a severe accident, e.g. cask drop. Water will be gradually added to the cask during refilling. The inlet flow of water is controlled to ensure that the cask pressure does not exceed 90 psia (75.3 psig).

Table 2.2-1 presents a summary of internal pressures for the conditions identified. A pressure of 100 psig was chosen as the design internal pressure, since this value exceeds that of all conditions producing an internal pressure.

2.2.5.3.4 External Pressure

There are several conditions which could result in external pressure on the cask, such as a nearby explosion, debris falling on the cask and snow and ice buildup on the cask. The external pressure due to flood level is assumed to be equal to or less than 25 psi which is equivalent to a 57 ft. head of water as discussed in Section 2.2.2. This is the limiting condition for external pressure. The various external pressures are summarized in Table 2.2-1.

2.2.5.3.5 Cask Body Loads

Globally distributed loads may be applied to the cask by wind (tornado is upper bound case), flood water and seismic excitation. These loads are explained in detail and calculated in Sections 2.2.1 through 2.2.3. Table 2.2-3 lists the numerical values of these forces as calculated in the various sections. Note that bounding loads equal to the weight of the cask (1g load) in each direction (lateral and vertical) applied as inertial loads for stress analysis purposes envelope all of these distributed loads with a substantial margin. The local loads due to the tornado missile impact are unique. The calculated values from Section 2.2.1 are directly used in the cask analysis.

2.2.5.4 Design Loads

The various cask loading conditions are listed in Table 2.2-4. These loading conditions include those described in 10CFR Part 72[3], which are categorized as normal, man-made and natural phenomena. The applied loads acting on the different cask components due to these loading conditions have been determined and are discussed in the preceding sections and are listed in Tables 2.2-1 through 2.2-3. This section describes the bases used to combine the loads for each cask component. The specific stress criteria against which each load combination will be evaluated are described in Section 3.4.

The bounding pressures and loads described above are used in the load combinations. Certain combinations are evaluations of several events (e.g. one load combination represents stresses due to tornado wind, hurricane wind, normal wind, flood water, etc.). Several loads are always present and are included in all evaluations. These are the assembly stresses due to bolt preload and metallic seal compression. Lifting loads are always reacted by the cask weight (supported on trunnions - not the storage pad). Lifting loads are not combined with those due to extreme natural phenomena since cask operations would be halted during a flood, hurricane, etc. Dead weight loads are reacted at the bottom of the cask by the storage pad for all cases except the lifting cases.

2.2.5.4.1 Cask Body

The loading conditions for the cask body including the confinement vessel and gamma shielding are categorized based on the rules of the ASME Boiler and Pressure Vessel Code Section III, Subsection NB, for a Class 1 nuclear component. The ASME code categorizes component loadings into five service loading conditions. They include Design Conditions (same as the Primary Service) and Levels A, B, C and D Service Loadings. The code provides different stress limits for each of these service loadings.

For each of these service loading conditions, there are several applied loads acting on the cask. The Design Loads are listed in Table 2.2-5. They include internal and external pressure; lid bolt preload including the effect of the gasket reactions; distributed loads due to weight, wind, and handling, and attachment loads applied through the trunnion to the cask body.

The inertia g loads are quasistatically applied loads which are multiples of the weight of the cask and/or contents. The magnitude of the Design Loads envelop the maximum Level A Service Loads. Thermal effects are excluded, except for their influence on the preload of the lid bolts (if any) because the ASME Code does not consider them Design (i.e. primary) Loads.

The Level A Service loads are listed in Table 2.2-6 and are basically the same as the Design Loadings except that the thermal effects on the confinement vessel are included. The thermal effects consist of secondary (thermal) stresses caused by differential thermal expansion due to temperature differences caused by decay heat, solar insolation, ambient temperature variations and ambient conditions, e.g. ice, snow, wind, sun.

There are no Level B or C Service Loading Conditions. Events which occur infrequently which could be considered Level B or Level C Service Loadings are conservatively considered Level A loadings.

The loads due to Level D Service Loading Conditions, which are extremely unlikely conditions, are listed in Table 2.2-7.

Loading combinations for Normal Conditions (Design Conditions and Levels A) are given in Table 2.2-8. Loading combinations for Accident Conditions (Level D) are provided in Table 2.2-9. The loads are listed across the top of the table and the Load Combinations are designated in the first column of the table. There are six normal (Design and Level A) load combinations listed, and six accident condition (Level D) combinations. The loads which are acting simultaneously for each of these combinations are denoted by an "X" under the load column heading. For example, for Normal Condition Load Combination N1, internal pressure due to cavity pressurization, fission gas release, distributed weight, heat due to maximum normal temperatures and lid bolt preload are acting simultaneously.

2.2.5.4.2 Basket

Cask body internal and external pressures have no effect on the basket. External loads applied to the TN-68 cask do not result in basket loads unless the cask actually moves. Therefore, tornado wind and flooding produce no basket loads. The tornado missile will cause the cask to slide, however, because of the low velocity, the inertial load applied to the basket will be very small and is much less than the tipover accident impact load. Seismic loading, however, is an inertial loading as discussed in Section 2.2.3, and is applied to the basket. The seismic acceleration loading (much less than lg acceleration) is combined with dead weight loading since the two effects occur simultaneously.

Temperature effects due to snow, minor fire and ambient temperature variations which can cause thermal transients on the outside of the cask body will not cause similar transients in the basket. The high heat capacity of the body slows the temperature response and effectively eliminates transients at the wall of the cask cavity. The steady state temperature and temperature differences throughout the basket are, however, affected by decay heat, solar insolation and ambient temperature variations.

The basket is important for control of criticality of the fuel assemblies stored in the cask. The bounding lateral and vertical inertial loadings on the basket are equal to 1g (in each direction) and have been shown to envelope the basket loadings. For the basket evaluation, an even more conservative 3g loading in the vertical direction is analyzed.

The stresses in the 304 stainless steel portions of the basket due to the primary loading, 1g in any lateral direction combined with 3g vertical (including dead weight), are determined by conservatively neglecting the tensile and bending strength of the poison plates between fuel compartment boxes. The through thickness strength of the poison plates which separate the boxes is considered. Thus the poison material is conservatively neglected in the primary load analysis where it can react some of the load. These primary stresses in the steel are evaluated at the maximum metal temperature occurring under extreme ambient conditions.

Clearance is provided between the poison and stainless steel plates to provide for differential thermal expansion. The basket design criteria described in Chapter 3 is based on Section III Subsection NG and Appendix F of the ASME Code for stress and buckling limits. The basket evaluation is provided in Chapter 3.

2.2.5.4.3 Upper Trunnions

The upper trunnions are considered to be lifting devices and are evaluated to the ANSI N14.6 requirements for lifting operations. During lifting, the trunnions are evaluated for vertical lifting reactions applied at the lifting shoulders required to support six times or ten times the maximum weight of a fully loaded cask. A dynamic amplification factor of 1.15 is also applied to the loads. When the load is equal to six times the weight, the maximum tensile stresses shall not exceed the minimum yield strength of the trunnion material. For the load equal to ten times the weight, the maximum tensile stresses shall not exceed the minimum ultimate tensile strength of the trunnion material.

In addition to the trunnions themselves, the bolts that attach the trunnions to the gamma shielding and the local region of the gamma shielding are analyzed under the same 6W and 10W reactions. The stresses in the trunnions, trunnion bolts or shielding shall not exceed the minimum yield strength of these components under the 6W loading or the minimum ultimate strength under the 10W loading.

The loads acting on the trunnions are shown in Table 2.2-2. The structural analysis of the trunnions is presented in Section 3.4.3.1.

2.2.5.4.4 Outer Shell

The outer shell is evaluated for the combined effects of inertia g loads due to lifting and internal pressure.

Outgassing from the resin between the cask body and outer shell may cause a slight pressure on the inside of the outer shell. A pressure relief valve is provided in the outer shell to assure any pressure buildup is small. The outer shell is completely supported by the resin when subjected to an external pressure. An internal pressure of 3 psi will occur due to the reduced external pressure during a tornado. An internal pressure of 25 psi is conservatively used to evaluate the outer shell.
The structural analysis of the outer shell is presented in Appendix 3A.4. A summary of results and comparison with design criteria are given in Section 3.4.4.

The combined stress due to the inertial 3g load and pressure is less than the minimum yield strength of the outer shell material.

2.3 Safety Protection Systems

2.3.1 General

The TN-68 dry storage cask is designed to provide storage of spent fuel for at least 40 years. The cask cavity pressure is always above ambient during the storage period as a precaution against the in-leakage of air which could be harmful to the fuel. Since the confinement vessel consists of a steel cylinder with an integrally-welded bottom closure, the cavity gas can escape only through the lid closure system. In order to ensure cask leak tightness, two systems are employed. A double barrier system for all potential lid leakage paths consisting of covers with multiple seals is utilized. Additionally, pressurization of monitored seal interspaces provides a continuous positive pressure gradient which guards against a release of the cavity gas to the environment and the admission of air to the cavity.

The components of the cask are classified as "Important to Safety" and "Not Important to Safety." A tabulation of the components and their classification is shown in Table 2.3-1.

The following items are considered not important to safety:

- Drain tube with all associated hardware including drain tube clamp, drain tube adapter, attachment screws, and o-ring seals. The drain tube is for operational convenience only and does not perform any safety function. The drain tube can be removed and replaced with a lance which can perform the same function.

- Quick disconnect couplings and associated o-ring seals. The couplings are for operational purposes only. These couplings do not form part of the confinement boundary.

- Pressure Monitoring equipment including pressure switches or transducers and electrical cables. If the monitoring system were not to function, no safety function of the cask would be impaired. There would be no leakage in or out of the cask.

- The top neutron shield and its attachments. The top neutron shield is used for supplemental shielding, but the accident condition dose limits are met without installing the top neutron shield.

- The key used to position the basket during normal operation. This key is for operational convenience only. No structural credit is taken for the key during normal or accident conditions.

- Paint for exterior of cask. This coating is used to prevent the cask from rusting. As part of the surveillance activities, the paint coverage is surveyed periodically. The paint is also inspected prior to shipment at the Fabricator to ensure proper thickness and adhesion.

- Lid alignment pin. The lid alignment pin is used for ease of operation and provides no safety related function. No structural credit is taken for the pin.

- Basket rail shims. The shims are used to ensure proper spacing between the cask and the basket rails to ensure that the assumptions used in the thermal analysis are met. They provide no structural function.

- Fuel spacers. Spacers are used to support shorter fuel assemblies during normal conditions to make it easy to attach the fuel grappling tools. They provide no safety related function.

- Security wires and seals. These are used to provide evidence that the cask has not been tampered with. They provide no safety related function.

- Protective cover with bolts and o-ring seal. This cover protects the overpressure tank, top neutron shield and lid from debris and wildlife nesting and allows rain water to drain more easily from the top of the cask. It has no structural function.

- Shield ring. The shield ring is used for supplemental shielding. The accident dose rates are calculated without the shield ring. No structural credit is taken for the shield ring.

2.3.2 Protection By Multiple Confinement Barriers and Systems

2.3.2.1 Confinement Barriers and Systems

Double metallic seals are provided which guarantee tight, permanent confinement. A pressure monitoring system is used to verify the integrity of the metallic seals. There are two lid penetrations, one for draining and one for venting and pressurization. When the cask is placed in storage, a pressure greater than that of the cavity is set up in the gaps (interspaces) between the double metallic seals of the lid and the lid penetrations. A decrease in the pressure of the monitoring system is signaled by a pressure transducer/switch wired to a monitoring/alarm panel (Figure 2.3-1).

Connections to the overpressure tank are welded fittings. A quick connect coupling with a diaphragm valve is used to fill the tank.

The Helicoflex metallic face seals of the lid and lid penetrations possess long-term stability and have high corrosion resistance over the entire storage period. These high performance seals are comprised of two metal linings formed around a helically-wound spring. The sealing principle is based on plastically deforming the seal's outer lining. Permanent contact of the lining against the sealing surface is ensured by the outward force exerted by the helically-wound spring. Additionally, all metallic seal seating areas are stainless steel overlayed for improved surface control. The overlay technique has been used for Transnuclear's storage and transport casks.

The metallic seals consist of an inner spring, a lining, and a jacket. The spring is Nimonic 90 or an equivalent material. The lining and jacket are stainless steel or nickel alloy and aluminum respectively.

The review of corrosion and galvanic reactions in Section 3.4.1 demonstrates the corrosion resistance of aluminum and stainless 304. The exposure to the pool environment is short term.

The long term environment of the seals is helium, except for the outside of the outer seal. That is exposed to the air under the protective cover, but it is not exposed to rain or snow. If corrosion were to occur at the crevice formed where the outer metallic lid seal contacts the sealing surface, it would be detected by the overpressure monitoring system. However, the moisture necessary for this crevice corrosion to occur is not likely to be present because of the weather cover and the decay heat from the stored fuel.

The maximum seal temperature is 212°F (Chapter 4). The neutron flux is 2.34×10^5 n/cm^{2}s (Chapter 14) which is equivalent to less than 1.5×10^{14} n/cm^2 after 20 years. The temperature and neutron fluence are low enough such that for these materials, the environment is no more challenging than a non-radiation, ambient air environment.

Cefilac has conducted twice yearly leak testing of Helicoflex seals that were installed in 1973. The test fixture has been indoors, and has never been disassembled. The spring, lining, and jacket on the test seals are music wire, soft steel, and aluminum, respectively. The seal dimensions are 13 mm minor diameter x 3620 mm major diameter and 9.6 mm x 1935 mm. From 1973 to 1984, the seals were cycled 700 times between 20 and 150°C. From 1984 to present, the seals have been maintained at 20°C. The leak rates have remained below 10^{-7} Pa m^3/m s for the entire test duration. Plots showing test data are attached as Figures 2.3-2 through 2.3-4.

Additionally, all metallic seal seating areas are stainless steel overlay for improved surface control. The overlay technique has been used for Transnuclear's transport casks and storage casks including the TN-24, TN-40 and TN-32 designs.

For protection against the environment, a torispherical protective cover equipped with an elastomer seal is provided above the lid. This seal is not important to safety. While the seal may harden with time due to irradiation or air exposure, this will have little effect on its ability to keep out rain and snow, because the seal is not subject to compression/decompression cycling; it is a static seal. There is no requirement for periodic inspection or replacement of the elastomer o-ring seal on the protective cover. However, if any maintenance operation requires removal of the cover, the o-ring should be inspected at that time. If there are any signs of deterioration (hardening, cracking, permanent set) it should be replaced.

The lid and cover seals described above are contained in grooves. A high level of sealing over the storage period is assured by utilizing seals in a deformation-controlled design. The deformation of the seals is constant since bolt loads assure that the mating surfaces remain in contact. The seal deformation is set by its original diameter and the depth of the groove.

Metal gasket face seal fittings, diaphragm valves and Helicoflex metallic seals are all capable of limiting leak rates to less than 1×10^{-7} ref cm^3/sec.

The initial operating pressure of the monitoring system's overpressure tank is set at 6.0 atm abs minimum. Over the storage period, the pressure decreases as a result of leakage from the system and as a result of temperature reduction of the gas in the system. Since the level of permeation through the confinement vessel is negligible and leakage past the higher pressure of the monitoring system is physically impossible, a decrease in cavity pressure during the storage period occurs only as a result of a reduction in the cavity gas temperature with time. As long as the cavity pressure is greater than ambient pressure and the pressure in the monitoring system is greater than that of the cavity, no in-leakage of air nor out-leakage of cavity gas is possible.

The calculations provided in Chapter 7 define the monitoring system helium test leakage rate which ensures that no cavity gas can be released to the environment nor air admitted to the casks for the 40 year storage period. All seals are considered collectively in the analysis as the monitoring system pressure boundary. This analysis is performed in accordance with ANSI N14.5 [12].

As shown in Chapter 7, the monitoring system pressure is always greater than the cask cavity or atmospheric pressure. Thus, no leakage can occur from the cask cavity during the storage period. The pressure monitoring system will be set to 3.0 atm abs minimum. This is greater than the maximum cavity pressure during storage and provides sufficient time to investigate low pressure conditions. At this interseal pressure, no in leakage to the cask cavity nor out leakage from the cask cavity will occur.

2.3.2.2 Cask Cooling

To establish the heat removal capability of the TN-68 cask, several thermal design criteria are established for the normal conditions. These are:

- Confinement of radioactive material and gases must be maintained. Seal temperatures must be maintained within specified limits to satisfy the leak tight confinement function during normal and accident conditions. A maximum temperature limit of 536°F (280°C) is set for the Helicoflex seals (double metallic O-rings) in the confinement vessel closure lid.

- To maintain the stability of the neutron shield resin during normal storage conditions, a maximum temperature limit of 300°F (149°C) is set for the neutron shield.

- Maximum temperatures of the confinement structural components must not adversely affect the confinement function.

- Maintaining fuel cladding integrity during storage is another design consideration. Fuel cladding temperature limits reported in Section 3.5 are based on NRC Interim Staff Guidance memorandum ISG-11 rev 3[13].

The thermal evaluation for normal conditions and hypothetical accident conditions is presented in Chapter 4.

2.3.3 Protection by Equipment and Instrumentation Selection

2.3.3.1 Equipment

Design criteria for the casks are described in Section 2.2 and summarized in Table 2.5-1.

2.3.3.2 Instrumentation

Due to the totally passive and inherently safe nature of the storage system, Important to Safety instrumentation is not necessary. Instrumentation to monitor seal interspace pressure is furnished. The pressure monitoring system is further described in Section 2.3.2.1.

2.3.4 Nuclear Criticality Safety

2.3.4.1 Control Methods for Prevention of Criticality

The design criterion for criticality is that an upper subcritical limit (USL) of 0.95 minus benchmarking bias and modeling bias will be maintained for all postulated arrangements of fuel within the cask. The fuel assemblies are assumed to stay within their basket compartment based on the cask and basket geometry.

The control method used to prevent criticality is incorporation of neutron absorbing material (boron) in the basket material.

The basket has been designed to assure an ample margin of safety against criticality under the conditions of fresh fuel in a cask flooded with fresh water. The method of criticality control is in keeping with the requirements of 10CFR72.124.

Criticality analysis is performed using the KENO-V.a Monte Carlo code(14) along with data prepared using the NITAWL code(15) and the SCALE 44-group cross section library. These codes and cross-section library are part of the SCALE system prepared by Oak Ridge National Laboratory for the U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research(16). They are widely used for criticality analysis of shipping casks, fuel storage pools and storage casks. Benchmark problems are run to verify the codes, methodology and cross section library. Examples of computer input used for criticality evaluation are included in Section 6.6.

In the criticality calculation, fuel assembly, basket, and cask geometries are modeled explicitly. Within each assembly, each fuel pin and each water rod is represented.

Reactivity analyses were performed for GE 7x7, 8x8 9x9 and 10x10 assemblies at initial lattice-average enrichment of 3.7 wt% U235. Analyses at higher enrichment and corresponding B10 areal density of the basket neutron absorber, and analyses of damaged fuel were performed on the most reactive fuel lattice, the 10x10.

The analyses assume fresh fuel composition with fresh water in the cavity, and the cask surrounded by a water reflector.

The criticality analyses are described in Chapter 6.0.

2.3.4.2 Error Contingency Criteria

Provision for error contingency is built into the criterion used in Section 2.3.4.1 above. The criterion, used in conjunction with the KENO-V.a and NITAWL codes, is common practice for licensing submittals. Because conservative assumptions are made in modeling, it is not necessary to introduce additional contingency for error.

2.3.4.3 Verification Analysis-Benchmarking

Eighty-three criticality experiments were taken from Oak Ridge National Laboratory[(21)]. The experiments which featured characteristics applicable to the TN-68 design (e.g. simple arrays, separator plates, steel reflector walls, water holes, and borated poison plates) were selected for the benchmark analyses. The methodology of Reference 21 is used which is discussed further in Section 6.5. This analysis found that there is minimal correlation between bias and any of the experimental values and therefore, no discernable trend. An upper subcritical limit (USL) of 0.95 minus benchmarking bias and modeling bias is used in the TN-68 criticality analysis.

2.3.5 Radiological Protection

Provisions for radiological protection by confinement barriers and systems are described in Section 2.3.2.1.

2.3.5.1 Access Control

The storage casks will be located in a restricted area on a site to which access is controlled. In keeping with the terminology of 10CFR72, the term restricted area refers only to an area within the controlled area. The controlled area and the site are taken to be the same. The term restricted area is defined in 10CFR20.1003[(17)]. The specific procedures for controlling access to the controlled area and to the restricted area are to be addressed by the license applicant's Safety Analysis Report or 10CFR72.212 analyses. The cask will not require the continuous presence of operators or maintenance personnel.

2.3.5.2 Shielding

Shielding has the objective of assuring that radiation dose rates at key locations are at acceptable levels for those locations. Three locations are of particular interest:

(1) Immediate Vicinity of the Cask
(2) Restricted Area Boundary
(3) Controlled Area Boundary

Dose rates in the immediate vicinity of the cask are important in consideration of occupational exposure. Because of the passive nature of storage with this cask, occupational tasks related to the cask are infrequent and short. Personnel exposures due to operational and maintenance activities are discussed in Section 10.3.

Dose rates at the restricted area boundary should be such that people outside the restricted area need not have their radiation exposure monitored. Dose rates at the controlled area boundary should be in accordance with 10 CFR 20 Subpart D. The estimated occupational doses for personnel comply with the requirements of 10 CFR 20 Subpart C.

2.3.5.3 Radiological Alarm System

There are no credible events which result in releases of radioactive products or unacceptable increases in direct radiation. In addition, the releases postulated as the result of the hypothetical accidents described in Chapter 11 are of a very small magnitude. Therefore, radiological alarm systems are not necessary. However, as described in Section 2.3.3.1, nonsafety related pressure monitors are provided. Procedures to be followed when these alarms are activated will be specified in the ISFSI operating procedures.

2.3.6 Fire and Explosion Protection

There are no combustible or explosive materials associated with the TN-68 dry storage cask. In general, no such materials would be stored within an ISFSI controlled area. An evaluation of the cask engulfed in a fuel fire is discussed in Chapter 4.

To bound an external explosion, which might involve explosive materials which are stored or transported near the site, the cask is evaluated for an external pressure of 25 psi.

2.4 Decommissioning Considerations

The dry cask system to be utilized at the ISFSI features inherent ease and simplicity of decommissioning. At the end of its service lifetime, cask decommissioning could be accomplished by one of several options described below.

The casks, including the spent fuel stored inside, could be shipped to a suitable fuel repository for permanent storage.

The spent fuel could be removed from the ISFSI cask and shipped in a licensed shipping container to a suitable fuel repository. If desirable, cask decontamination could be accomplished through the use of conventional high pressure water sprays to further reduce contamination on the cask interior. The sources of contamination on the interior of the cask would be crud from the outside of the fuel pins and the crud left by the spent fuel pool water. The expected low levels of contamination from these sources could be easily removed with a high pressure water spray. After decontamination, the ISFSI cask could either be cut-up for scrap or partially scrapped and any remaining contaminated portions shipped as low level radioactive waste to a disposal facility.

For surface decontamination of the ISFSI cask, chemical etching using hydrochloric acid or nitric acid can be applied to remove the contaminated surface of the cask. Alternatively, electropolishing can also be used to achieve the same result.

Cask activation analyses have been performed to quantify specific activity levels of cask materials after years of storage. The following assumptions were made:

- The cask contains 68 design basis BWR assemblies.
- The neutron flux is assumed constant for 40 years, based on 7x7, 40GWd/MTU, 10 year cooled fuel.

The cask activation analyses are presented in Chapter 14. The results of these calculations show that the TN-68 cask will be far below the specific activity limits for both long and short lived nuclides for Class A waste. Consequently, it is expected that after application of the surface decontamination process as described above, the radiation level due to activation products will be negligible and the cask could be disposed of as Class A waste. A detailed evaluation will be performed at the time of decommissioning to determine the appropriate mode of disposal.

Due to the leak tight design of the storage casks, no residual contamination is expected to be left behind on the concrete base pad. The base pad, fence, and peripheral utility structures will require no decontamination or special handling after the last cask is removed.

If the spent fuel pool is to remain functional until the ISFSI is decommissioned, it will allow the pool to be utilized to transfer fuel from the storage casks to licensed shipping containers for shipment off site if this decommissioning option is chosen.

The volume of waste material produced incidental to ISFSI decommissioning will be limited to that necessary to accomplish surface decontamination of the casks once the spent fuel elements are removed. Furthermore, it is estimated that the cask materials will be only very slightly activated as a result of their long-term exposure to the relatively small neutron flux emanating from the spent fuel, and that the resultant activation level will be well below allowable limits for general release of the casks as noncontrolled material. Hence, it is anticipated that the casks may be decommissioned from nuclear service by surface decontamination alone.

The costs of decommissioning the ISFSI are expected to represent a small and negligible fraction of the cost of the decommissioning a Nuclear Generating Plant.

2.5 Summary of Cask Design Criteria

The principal design criteria for the TN-68 cask are presented in Table 2.5-1. The TN-68 dry storage cask is designed to store 68 BWR spent fuel assemblies with or without channel**s.** The maximum allowable initial lattice-average enrichment varies from 3.7 to 4.7 wt% U235 depending on the B10 areal density in the basket neutron absorber plates. The maximum bundle average burnup, maximum decay heat, and minimum cooling time are 40 GWd/MTU, 0.312 kW/assembly, and 10 years for 7x7 fuel, 60 GWd/MTU, 0.441 kW/assembly, and 7 years for all other fuel.

The maximum total heat generation rate of the stored fuel is limited to 30 kW in order to keep the maximum fuel cladding temperature below the limit necessary to ensure cladding integrity for 40 years storage(13). The fuel cladding integrity is assured by the cask and basket design which limits fuel cladding temperature and maintains a nonoxidizing environment in the cask cavity(19) .

Damaged fuel that can be handled by normal means may be stored in eight peripheral compartments fitted with damaged fuel end caps designed to retain gross fragments of fuel within the compartment.

The confinement vessel (body and lid) is designed and fabricated to the maximum practicable extent as a Class I component in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, Article NB-3200. The cask design, fabrication and testing are covered by Transnuclear's Quality Assurance Program which conforms to the criteria in Subpart G of 10CFR72.

The cask is designed to maintain a subcritical configuration during loading, handling, storage and accident conditions. Poison materials in the fuel basket are employed to maintain the upper subcritical limit of 0.9423. The TN-68 basket is designed and fabricated to the maximum practicable extent in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, Article NG-3200.

The TN-68 cask is designed to withstand the effects of severe environmental conditions and natural phenomena such as earthquakes, tornadoes, lightning and floods. Chapter 11 describes the cask behavior under these accident conditions.

2.6 References

1. (Deleted)

2. (Deleted)

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7. T. W. Singell, Wind Forces on Structures: Forces on Enclosed Structures. ASCE Structural Journal, July 1958.

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11. American National Standards Institute, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More for Nuclear Materials", ANSI N14.6, New York.

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21. NUREG/CR-6361, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages," 1997.

22. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.60, Rev. 1, Design Response Spectra for Seismic Design of Nuclear Plants, December, 1973.

23. Beer and Johnston, “Vector Mechanics for Engineer: Static and Dynamic”, Mcgraw-Hill Book Co., 1962.

24. Walmer, M.E., “Manual of Structural Design and Engineering Solutions”, Prentic-Hall, Inc., 1972.

25. PCI Design Handbook, 2nd Edition, Precast Concrete Institute, 1978.

26. ANSI/ANS-57.9-1984, “Design Criteria for an Independent Spent Fuel Storage Installation (Dry Type)”.

TABLE 2.1-1

FUEL ASSEMBLY TYPES

Fuel Assembly GE Series Designation
GE 7 x 7 Series GE2
GE 7 x 7 Series GE3
GE 8 x 8 Series GE4
GE 8 x 8 Series GE5
GE 8 x 8 Series GE-Prepres
GE 8 x 8 Series GE-Barrier
GE 8 x 8 Series GE8
GE 8 x 8 Series GE9
GE 8 x 8 Series GE10
GE 9 x 9 Series GE11
GE 10 x 10 Series GE12
GE 9 x 9 Series GE13

TABLE 2.1-2

DESIGN BASIS FUEL ASSEMBLY PARAMETERS[1]

Parameter	7 x 7
Number of Fueled Rods	49
Number of Water Rods	0
Fuel Assembly Cross Section (in)[2]	5.44 x 5.44
Fuel Assembly Length (in)[2]	176.2
Fuel Rod Pitch (in)	0.738
Fuel Rod O.D. (in)	0.563
Clad Material	Zircaloy
Clad Thickness (in)	0.032
Fuel Pellet O.D. (in)	0.487
U^{235} Bundle Average/Initial Enrichment (% wt)	3.3
U^{235} Maximum Lattice Average Enrichment (% wt)	3.7
Active Fuel Length (in)	144
U Content (kg)	197.7
Assembly Weight with channel (lbs)	705

Parameter	8 x 8
Number of Fueled Rods	63
Number of Water Rods	1
Fuel Assembly Cross Section (in)[2]	5.44 x 5.44
Fuel Assembly Length (in)[2]	176.2
Fuel Rod Pitch (in)	0.640
Fuel Rod O.D. (in)	0.493
Clad Material	Zircaloy
Clad Thickness (in)	0.034
Fuel Pellet O.D. (in)	0.416
U^{235} Bundle Average/Initial Enrichment (% wt)	2.6
U^{235} Maximum Lattice Average Enrichment (% wt)	Varies with basket type
Active Fuel Length (in)	146
U Content (kg)	188
Assembly Weight with channel (lbs)	705

[1] The 8x8 is the design basis fuel for thermal, shielding, and confinement analysis. Although the 7x7 has more fuel mass, it is limited to lower burnup and longer cooling times. This analysis is further detailed in Section 5.0.

[2] Unirradiated fuel width and length.

TABLE 2.1-3

THERMAL, GAMMA AND NEUTRON SOURCES FOR
THE DESIGN BASIS 8x8 GENERAL ELECTRIC FUEL ASSEMBLY

U^{235} Bundle Average Initial Enrichment (% wt)	2.6
Burnup (MWD/MTU)	48,000
Specific Power (MW/assembly)	6
Cooling Time (years)	7
Decay Heat (kW/assembly)	0.441
Gamma Source (photon/sec/assembly)[1]	1.99E+15
Neutron Source (neutrons/sec/assembly)	3.17E+08

[1] This is based on the SCALE 4.4 18 group gamma library, including bremsstrahlung & gamma radiation from alpha-n reactions in a UO_2 matrix.

TABLE 2.1-4
Cooling Time as a Function of Maximum Burnup and Minimum Initial Enrichment
7x7 Fuel

REQUIRED BWR COOLING TIMES (YEARS)

Initial Enrichment (bundle ave %w)	Burnup (GWd/MTU)											
	15	20	30	32	33	34	35	36	37	38	39	40
1.0	10	10										
1.1	10	***10***										
1.2	10	10										
1.3	10	10										
1.4	10	10										
1.5	10	10	***10***	10	***11***	11	***11***					
1.6	10	10	10	10	10	11	11	11				
1.7	10	10	10	10	***10***	11	11	11	***12***			
1.8	10	10	10	10	10	11	11	11	***11***	***12***		
1.9	10	10	10	10	10	11	11	11	11	12		
2.0	10	10	10	10	10	***10***	11	11	***11***	12	***12***	
2.1	10	10	10	10	10	10	11	11	11	12	12	***12***
2.2	10	10	10	10	10	10	11	11	11	12	12	12
2.3	10	10	10	10	10	10	11	11	11	***11***	12	12
2.4	10	10	10	10	10	10	***10***	11	11	11	12	12
2.5	10	10	10	10	10	10	10	11	11	11	12	12
2.6	10	10	10	10	10	10	10	11	11	11	12	12
2.7	10	10	10	10	10	10	10	***10***	11	11	***11***	12
2.8	10	10	10	10	10	10	10	10	10	11	11	12
2.9	10	10	10	10	10	10	10	10	10	11	11	12
3.0	10	10	10	10	10	10	10	10	***10***	10	11	12
3.1	10	10	10	10	10	10	10	10	10	10	11	12
3.2	10	10	10	10	10	10	10	10	10	10	***10***	***11***
3.3	10	10	10	10	10	10	10	10	10	10	10	10
3.4	10	10	10	10	10	10	10	10	10	10	10	10
3.5	10	10	10	10	10	10	10	10	10	10	10	10
3.6	10	10	10	10	10	10	10	10	10	10	10	10
3.7	10	10	10	10	10	10	10	10	10	10	10	10

- not evaluated

Notes:

1. Total dose from gamma and neutron considered.
2. Cooling Times entered in bold and italics are cases actually run. Other values interpolated.

TABLE 2.2-1

SUMMARY OF INTERNAL AND EXTERNAL PRESSURES
ACTING ON TN-68 CASK

Individual Load Conditions	Maximum Pressure, psig
Internal Pressure:	
(a) Initial Cavity Pressurization	18 (2.2 atm abs)
(b) With 10% Fuel Failure	21.6 (2.5 atm abs)
(c) With 100% Fuel Failure	See condition (d)
(d) In a Minor Fire (assumed 100% fuel failure)	71.7 (5.88 atm abs)
(e) Beginning of Life Unloading	75.3 (6.1 atm abs)
(f) Cask Burial (assumes 100% fuel failure)	96.7 (6.6 atm abs)
(g) Tornado	3*
(h) Selected Bounding Pressure	100
External Pressure	
(a) Flood	25
(b) Snow and Ice Loading	0.35
(c) Explosion	<25
(d) Selected bounding Pressure	25

*This is due to a reduced external pressure.

TABLE 2.2-2

SUMMARY OF LIFTING LOADS USED IN UPPER TRUNNION
ANSI N14.6 ANALYSIS

Handling Condition	Load at Cask CG (1) Vertical
Lifting - Cask Vertical	
Yield Evaluation	1.656×10^6 lbs.
Ultimate Evaluation	$2.76\,0 \times 10^6$ lbs.
	Load at each Trunnion (2)
Yield Evaluation	0.828×10^6 lbs.
Ultimate Evaluation	1.380×10^6 lbs.

NOTES:

1. Based on a cask weight of 240,000 lbs with 1.15 dynamic load factor.
2. Load evenly divided between one pair of upper trunnions.

TABLE 2.2-3

SUMMARY OF LOADS ACTING ON TN-68 CASK DUE
TO ENVIRONMENTAL AND NATURAL PHENOMENA

Distributed Loads

Lateral Loading:

(a)	Wind (external force on cask body)	332 psf
(b)	Seismic (inertial force throughout system) 0.26W	59,020 lb.[2]
	Selected Bounding Load W x 1G	227,000 lb.[2]

Vertical Loading[1]:

(a)	Seismic (inertial force throughout system) 0.17W	38,590 lb.[2]
	Selected Bounding Load W x 1G	227,000 lb.[2]

Local Loads

Tornado Missile Loading (external force on local area of body):

(a)	Lateral Load	1.558×10^6 lb.
(b)	Vertical Load	$<1.558 \times 10^6$ lb.

NOTE:

1. Does not include dead weight or lifting loads
2. A conservatively low weight is used for stability analysis. The actual weight of the cask is used for stress analysis.

TABLE 2.2-4

TN-68 CASK LOADING CONDITIONS

Normal

Assembly Loads (bolt preload and seal compression)
Pressure (internal and external)
Weight
Lifting Loads
Handling
Wind
Thermal variations (e.g. insolation, decay heat, rain, snow, ice, ambient)

Man-Made (Accident)

Fuel cladding failure (due to loading or unloading error)
Minor Fire
Explosion

Natural Phenomena (Accident)

Earthquakes
Tornadoes
Cask Burial
Flood
Lightning

TABLE 2.2-5

TN-68 CASK DESIGN LOADS
(Normal Conditions)

Applied Load	Loading Condition
Internal Pressure	(1) and (2)
External Pressure	(3)
Distributed Loads	Weight Cask Body Contents
	Snow
	Ice
	Wind (Tornado)
	Lifting
Attachment Loads	Lifting
Bolt Loads	Preload for 100 psi and metallic seal compression

(1) Cask designed for 100 psi internal pressure which envelopes all internal pressure effects.

(2) For normal conditions, the fission gas release is assumed to be 10%.

(3) Cask designed for 25 psi external pressure which envelopes all external pressure effects.

TABLE 2.2-6

LEVEL A SERVICE LOADS
(Normal Conditions)

Applied Load	Loading Condition
Internal Pressure	(1) and (2)
External Pressure	(3)
Distributed Loads	Weight Cask Body Contents
	Snow
	Ice
	Wind (Tornado)
	Lifting
Attachment Loads	Lifting
Bolt Loads	Preload for 100 psi and metallic seal compression
Thermal Effects	Decay Heat
	Insolation
	Cold Rain on Hot Cask

(1) Cask designed for 100 psi internal pressure which envelopes all internal pressure effects.

(2) For normal conditions, the fission gas release is assumed to be 10%.

(3) Cask designed for 25 psi external pressure which envelopes all external pressure effects.

TABLE 2.2-7

LEVEL D SERVICE LOADS
(Accident Conditions)

Load	Cause
Internal Pressure	(1) and (2)
External Pressure	(3)
Distributed Loads	Weight Cask body Contents
	Tornado Wind
	Flood Water
	Seismic
Local Loads	Tornado Wind Driven Missiles
Bolt Loads	Preload for 100 psi, metallic seal compression and drop impact
60 G Bottom Impact	18" Vertical Drop (Handling Accident)
65 G Side Impact	Tipover

(1) Cask design for 100 psi internal pressure which envelopes all internal pressure effects.

(2) Fission gas release of 100% is assumed for accident conditions.

(3) Cask designed for 25 psi external pressure which envelopes all external pressure effects including flood water level, cask burial and explosion.

TABLE 2.2-8

NORMAL CONDITION LOAD COMBINATIONS

Individual Load Combined Load	Bolt Preload	1g Down	Internal Pressure 100 Psi	External Pressure 25 Psi	Thermal	6 G on Trunnion	Trunnion Local Stress
N1	X	X	X				
N2	X	X	X		X		
N3	X		X		X	X	X
N4	X	X		X			
N5	X	X		X	X		
N6	X			X	X	X	X

TABLE 2.2-9

ACCIDENT CONDITION LOAD COMBINATIONS

Individual Load Combined Load	Bolt Preload	Internal Pressure 100 Psi	External Pressure 25 Psi	18" BOTTOM END DROP 60 G	Tip Over Side Drop 65 G	Seismic, Tornado, Or Flood 1g-Lateral + 2g-Down
A1	X	X		X		
A2	X		X	X		
A3	X	X			X	
A4	X		X		X	
A5	X	X				X
A6	X		X			X

TABLE 2.3-1

CLASSIFICATION OF COMPONENTS

IMPORTANT TO SAFETY	NOT IMPORTANT TO SAFETY
Confinement Vessel including Lid, Flange, Inner Confinement Shell and Bottom Confinement Plate Cask Body Shell Cask Body Bottom Lid Shield Plate Lid Bolts and Threaded Inserts Lid Seals Lid Vent, Drain, and Overpressure Covers, Bolts, and Gaskets Basket Assembly including fuel compartments, poison plates, and structural plates Trunnions, Trunnion Bolts, and Trunnion Cover Screws Radial Neutron Shield Outer Shell Shim (between shield shell and flange) Basket Holddown Basket Rails	Drain Tube Hansen Couplings Pressure Monitoring System Protective Cover, Bolts, Seal, and Threaded Inserts Basket Shear Key Fuel Spacers Basket Rail Shims Security Wire & Seals Lid Alignment Pins Top Neutron Shield including Bolts and Washers Shield Ring Pressure Relief Valve (on outer shell) Basket rail studs, nuts, & washers

TABLE 2.5-1

DESIGN CRITERIA FOR TN-68 CASKS

Maximum gross weight on crane (with lift beams, without water)	120 tons
Cask height with lid removed	192.25 in.
Minimum design life	40 years
Upper subcritical limit	< 0.95- Normal < 0.95- Accident
Payload Capacity	68 BWR assemblies Including 8 damaged (acceptable assemblies listed in Table 2.1-1)
Spent Fuel Characteristics	
a) Design Basis Bundle Average Initial Enrichment	2.6%
b) Maximum Lattice Average Initial Enrichment	3.7 -4.7% depending on basket type
c) Burnup (max)	40 GWD/MTU 7x7 fuel, 60 GWD/MTU all other fuel
d) Cooling time (min)	10 years 7x7 fuel, 7 years all other
e) Decay Heat	30 kW (total)
Max Clad Temperature	400°C (752°F) - Normal 570°C (1058°F) - Accident
Cask Cavity Atmosphere	Helium gas
Maximum Internal Pressure	100 psig
Daily Averaged Ambient Temperature (Min-Max) Over 24 hr. period (min-max)	-20 to 100^{o}F
Maximum Solar Heat Load	1475 BTU/ft^2 (Curved Surfaces)
Tornado Wind	360 mph (rotational and translational)
Tornado Missiles	4000 lb. auto 276 lb. (125 kg) 8 in. armor piercing shell 1 in. solid steel sphere 4" x 12" x 12' wood plank at 300 mph
Cask Drop	18" Drop onto concrete pad or equivalent end drop resulting in 60 G’s
Cask Tip	Tip onto ISFSI pad equivalent side drop of 65 G’s
Seismic Design Earthquake	0.26 g horizontal 0.17 g vertical
Snow and Ice	50 psf load

FIGURE 2.1-1

DECAY HEAT 7 x 7 GE FUEL ASSEMBLY
3.3 WT% U-235 MAXIMUM INITIAL BUNDLE AVERAGE ENRICHMENT,
40,000 MWD/MTU, 10 YEAR COOLED

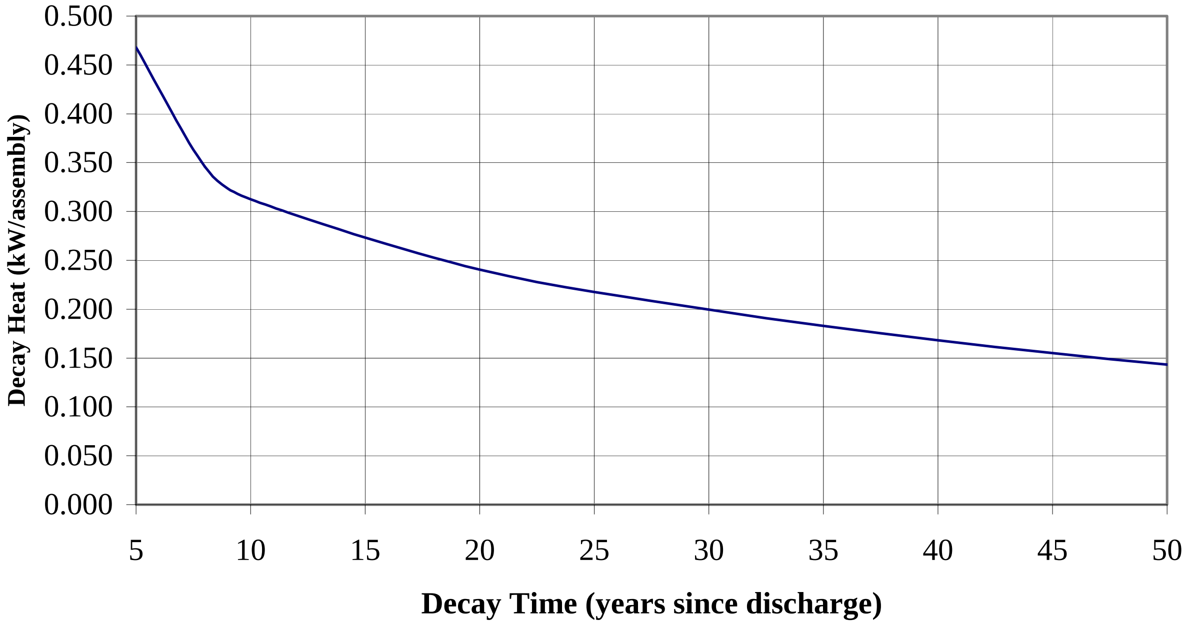


FIGURE 2.1-2

GAMMA SOURCE 7 x 7 BWR FUEL ASSEMBLY
3.3 WT% U-235 MAXIMUM INITIAL BUNDLE AVERAGE ENRICHMENT,
40,000 MWD/MTU, 10 YEAR COOLED

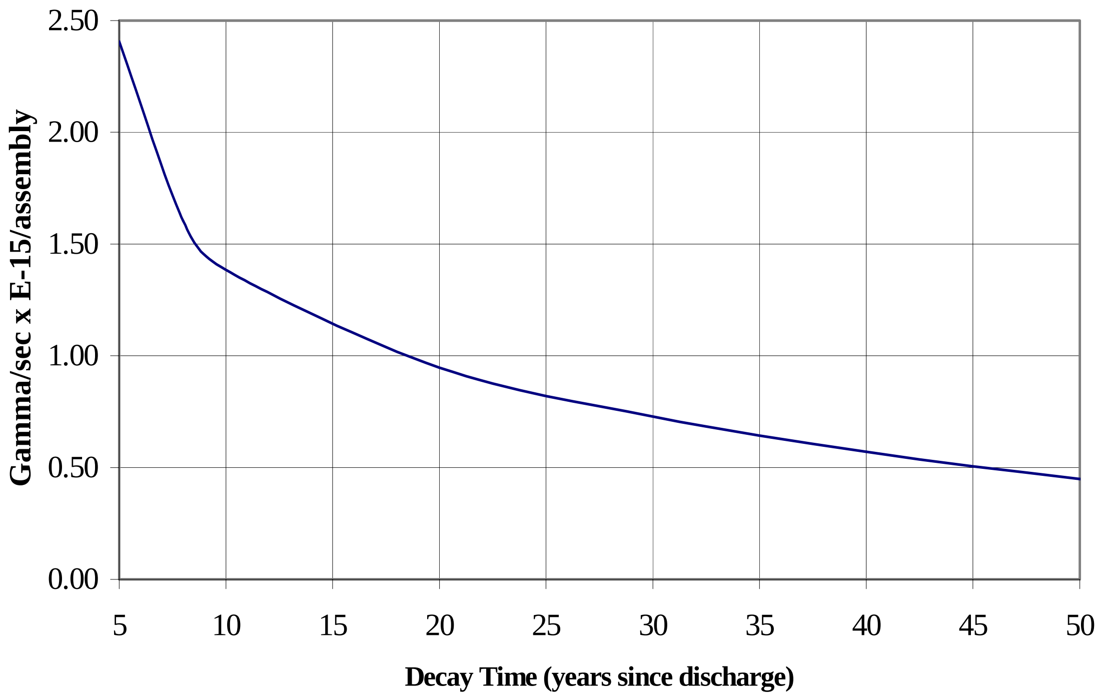


FIGURE 2.1-3

NEUTRON SOURCE 7 x 7 BWR FUEL ASSEMBLY
3.3 WT% U-235 MAXIMUM INITIAL BUNDLE AVERAGE ENRICHMENT,
40,000 MWD/MTU, 10 YEAR COOLED

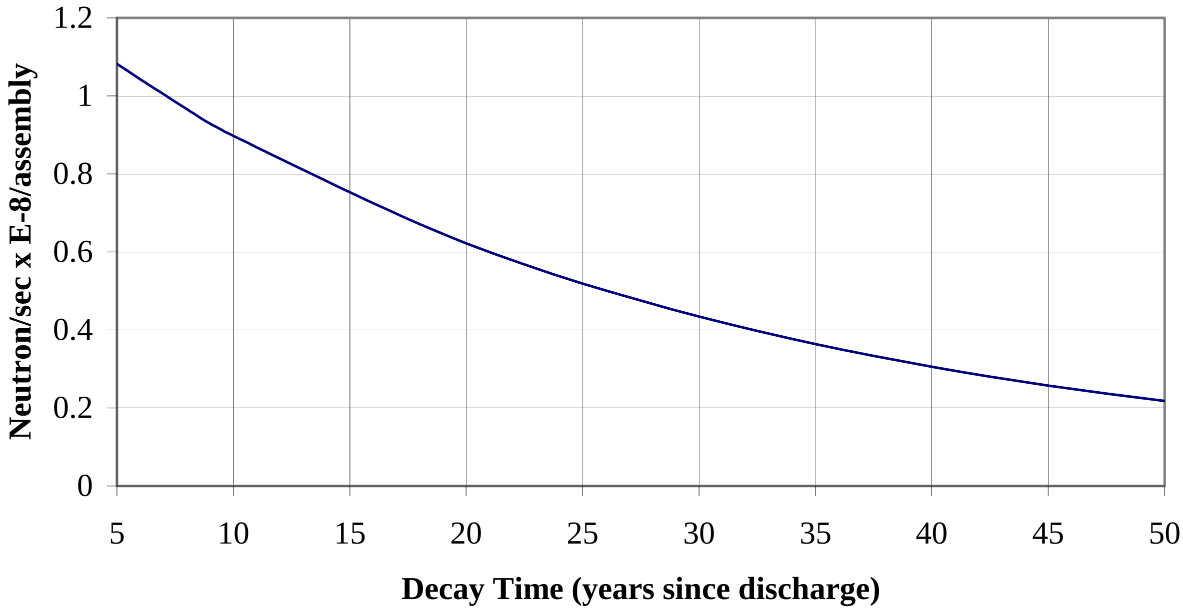
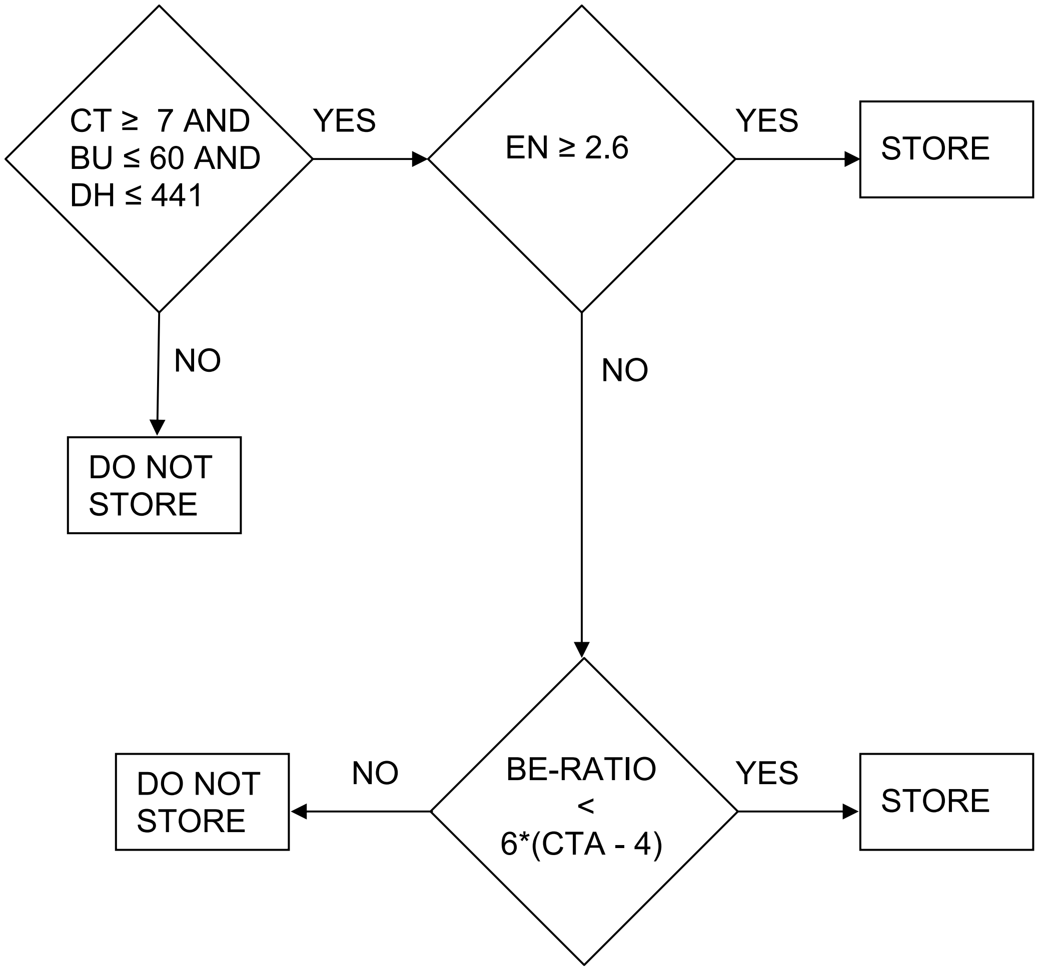


FIGURE 2.1-4

Fuel Qualification Flowchart for 8x8, 9x9, and 10x10 Fuel



CT = Cooling Time in years
CTA = CT rounded down to the nearest Integer
BU = Burnup in GWd/MTU
EN = Enrichment in wt % U235
DH = Decay Heat in Watts
BE-RATIO = Burnup to Enrichment ratio

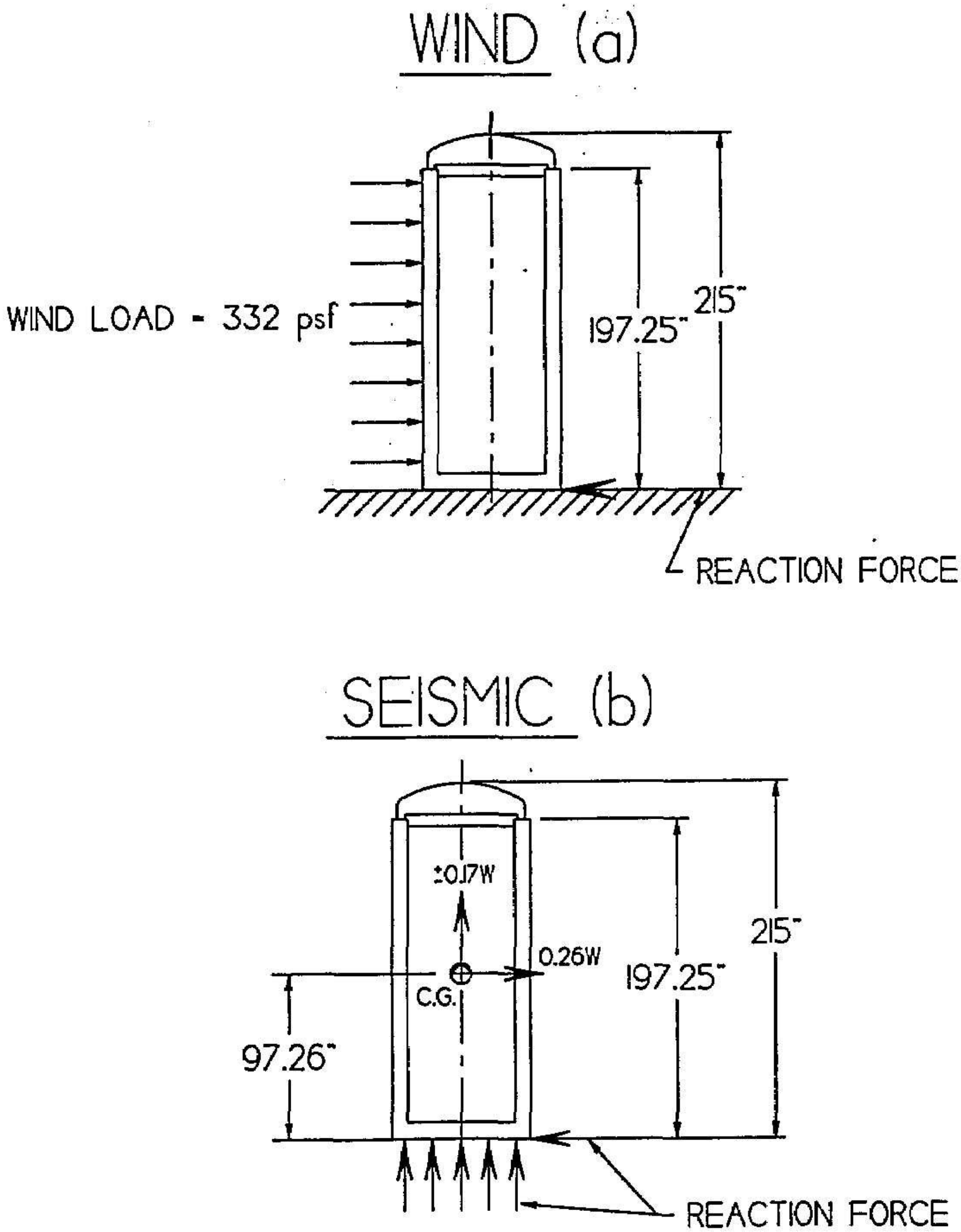


FIGURE 2.2-1
EARTHQUAKE AND WIND LOADS

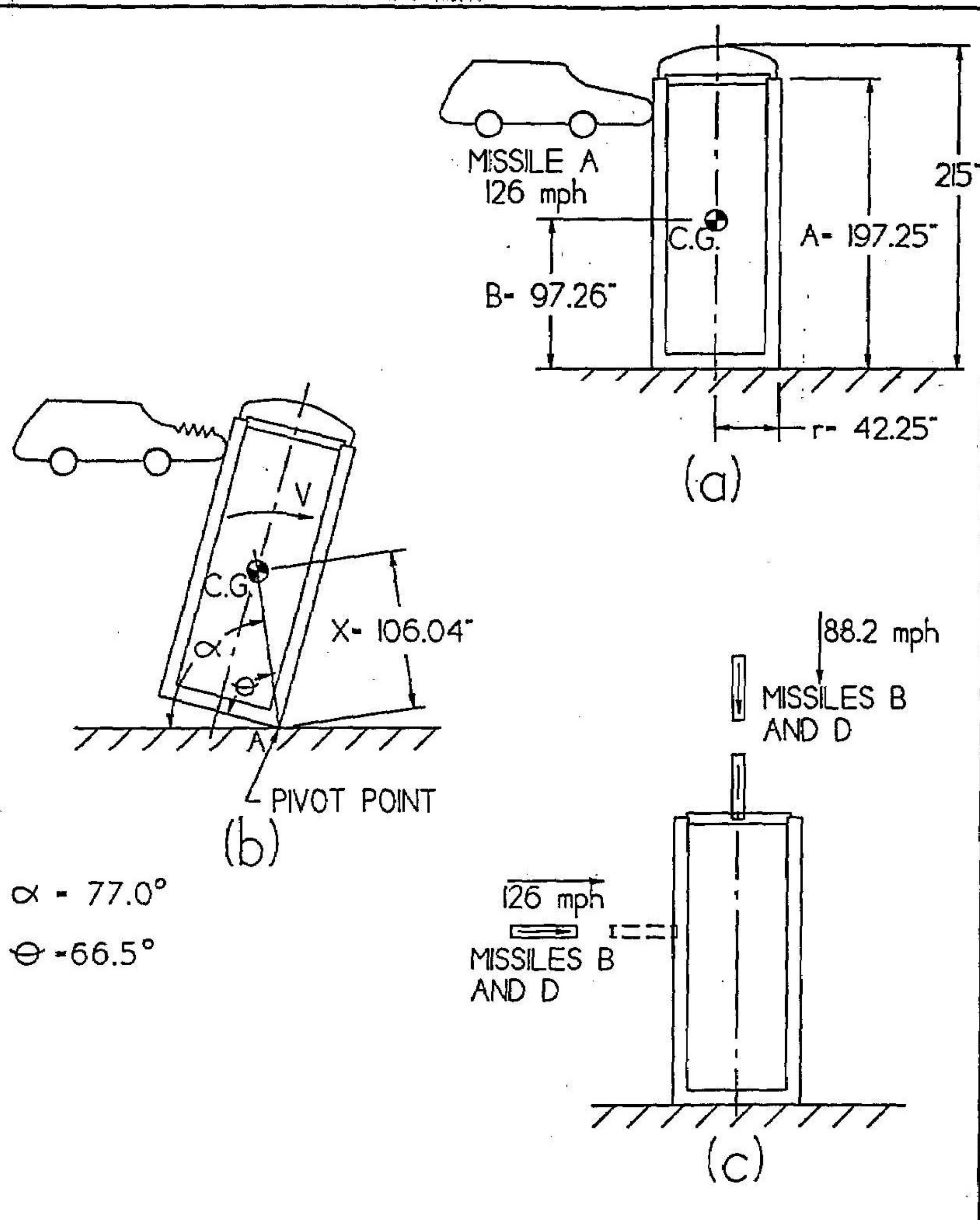


FIGURE 2.2-2
TORNADO MISSILE IMPACT LOADS

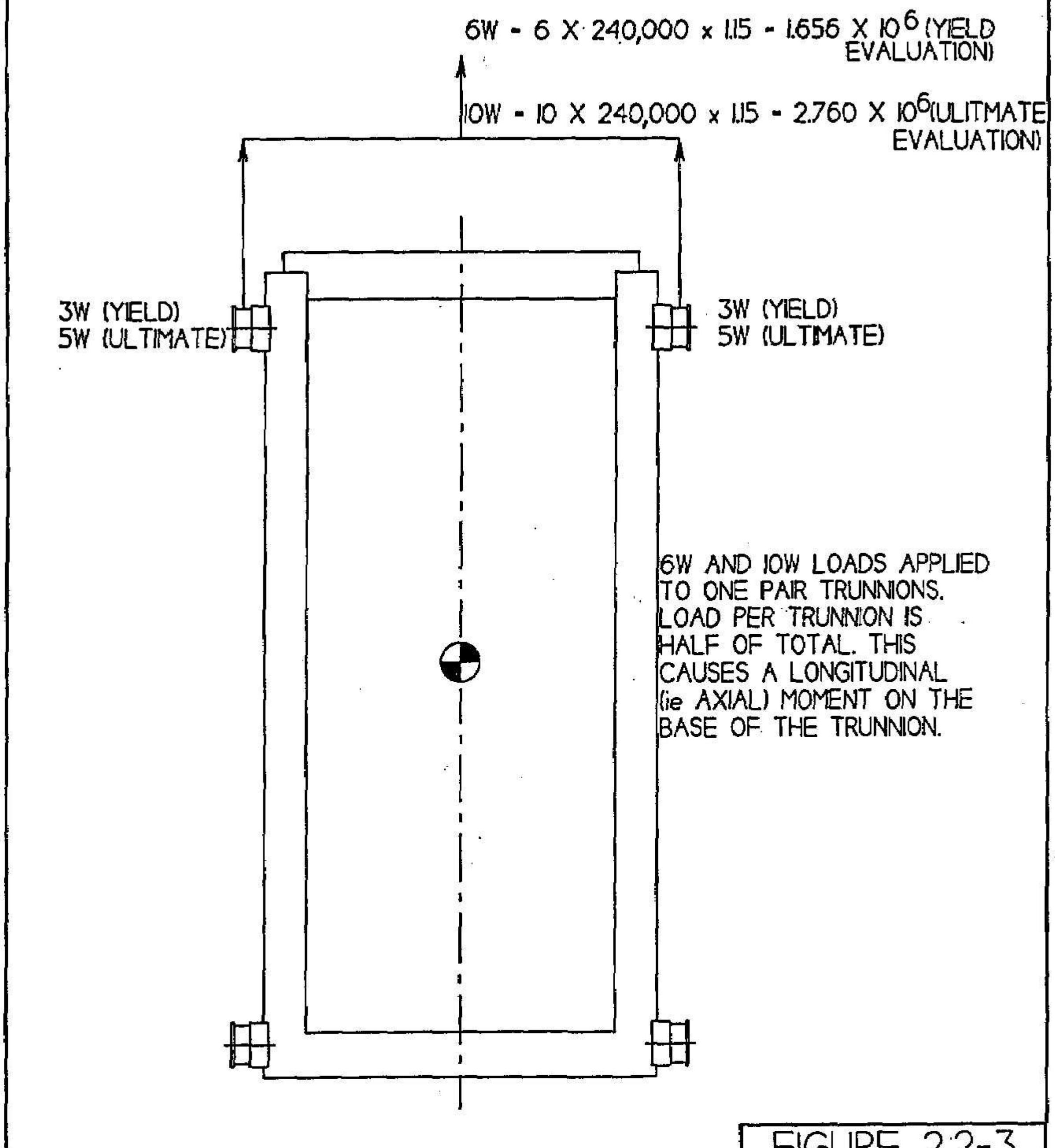


FIGURE 2.2-3
LIFTING LOADS

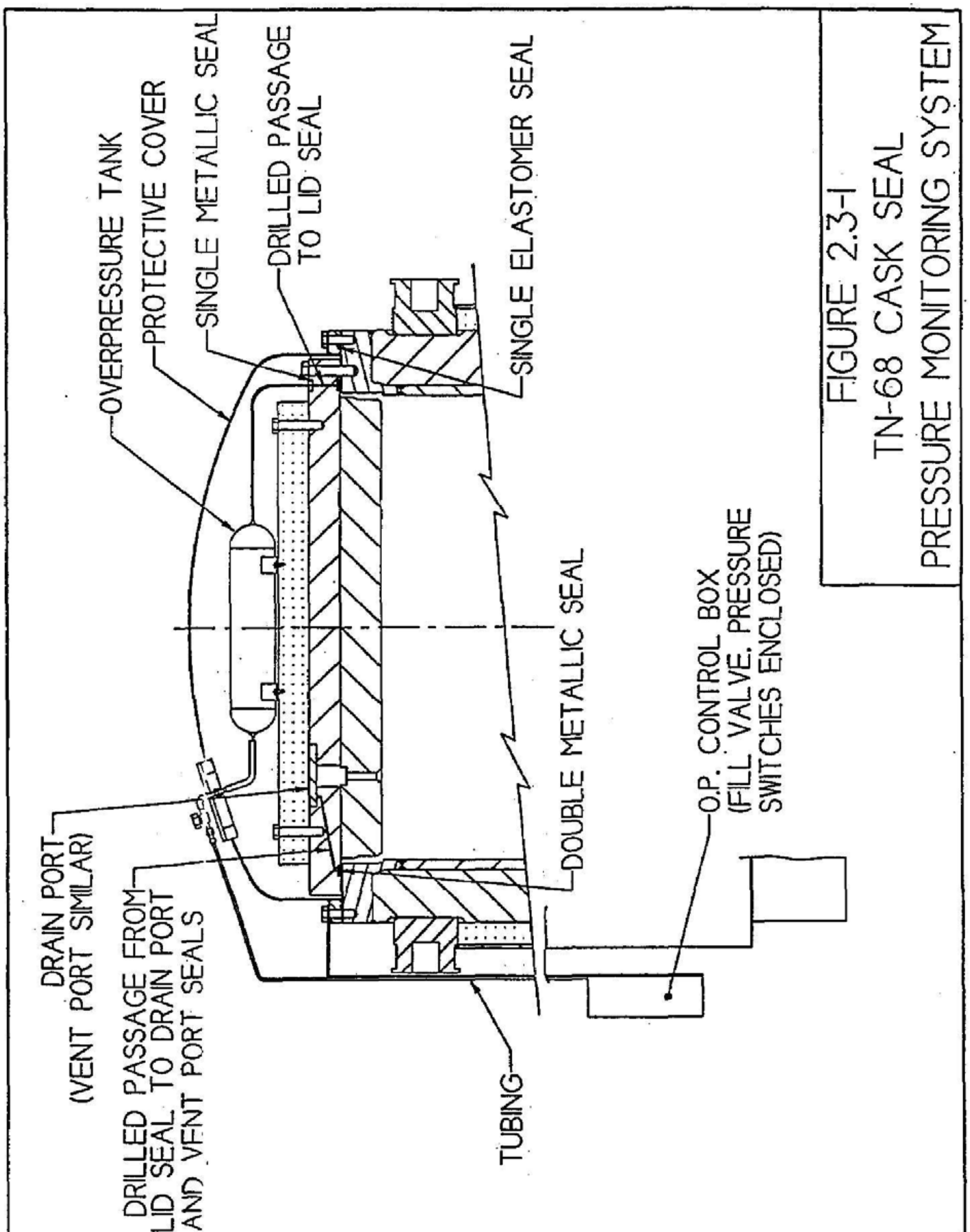


FIGURE 2.3-1
TN-68 CASK SEAL
PRESSURE MONITORING SYSTEM

FIGURE 2.3-2
Long Term Leak Test Results on Metallic Seals

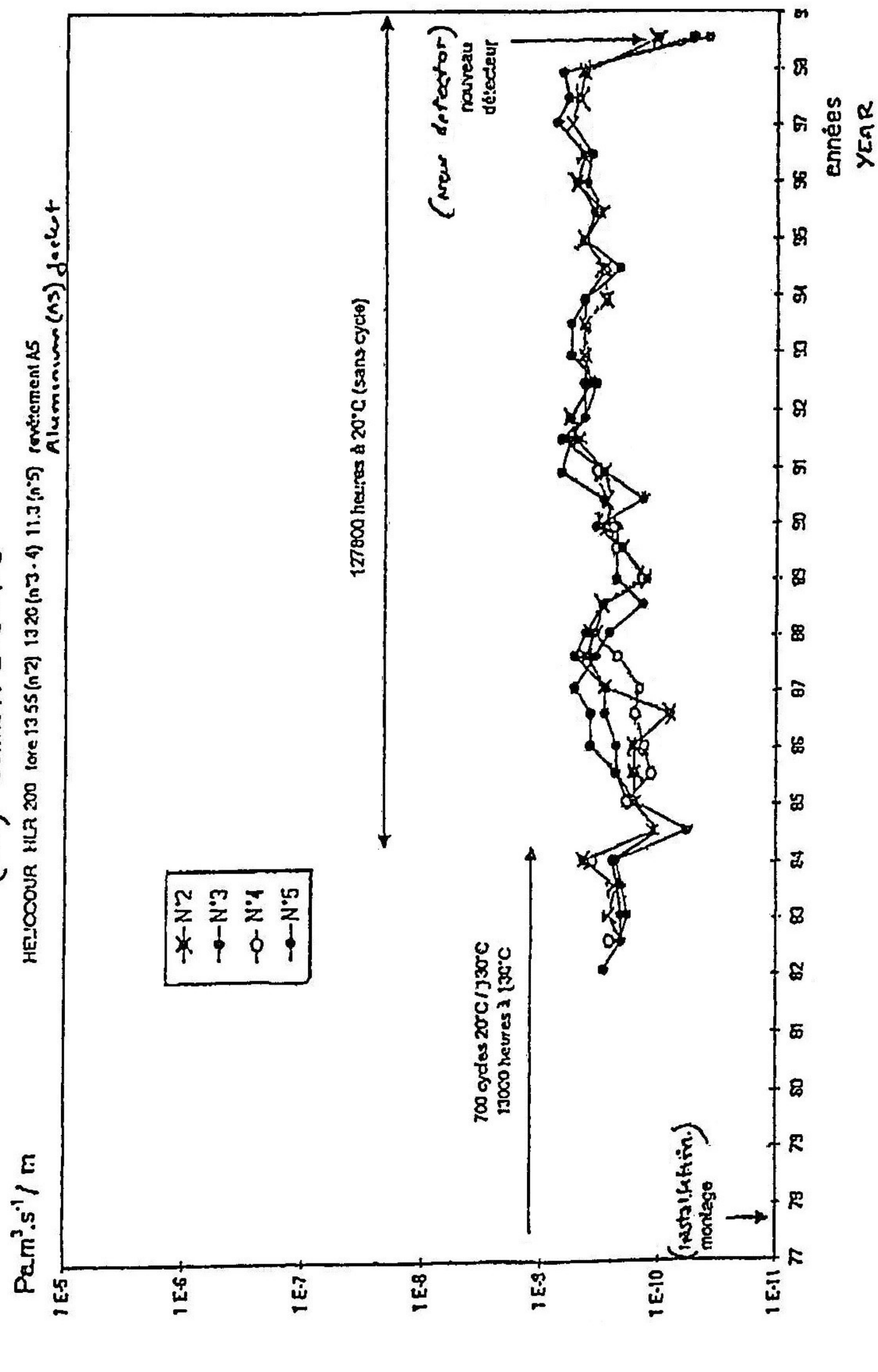


FIGURE 2.3-3
Long Term Leak Test Results on Metallic Seals

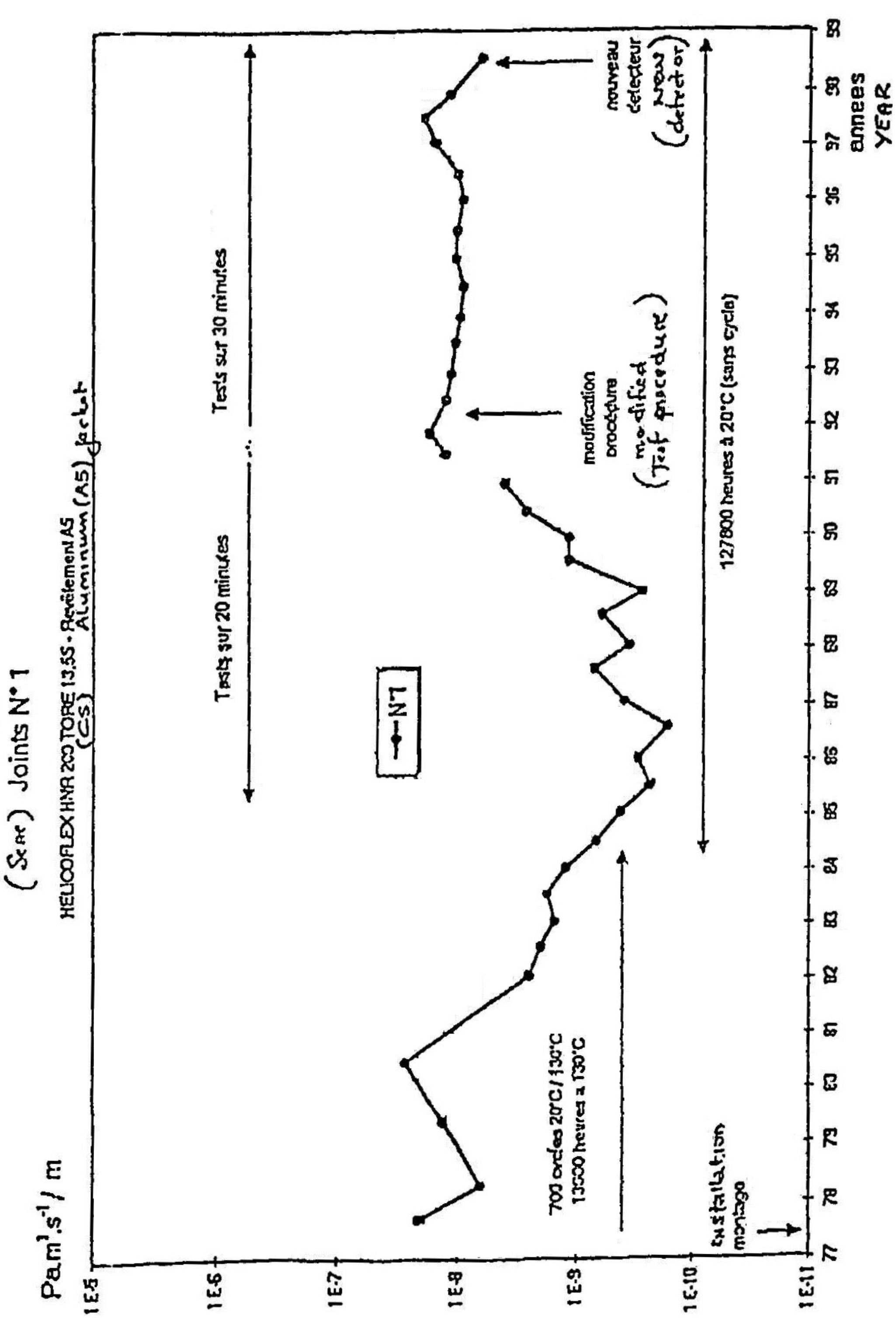


FIGURE 2.3-4
Long Term Leak Test Results on Metallic Seals