REVIEW OF SAFETY ANALYSIS REPORT FOR THE FFTF PIN SHIPPING CASK MODEL T-3, REV. 3, JANUARY 25, 1980, NUCLEAR PACKAGING, INC.

Z. Zudans

1. INTRODUCTION

1.1 METHOD REVIEW

First, a valid SAR copy was assembled in accordance with instruction provided by the Applicant. No pages were missing. Next, a preliminary review of the Table of Contents of the SAR was compared to the Reg. Guide 7.9, Standard Format and Contents. Except for a shift by a unit for Chapter numbers (i.e., Reg. Guide 7.9 Chapter numbers start with one (1), in the SAR with zero (0)), the SAR Chapter Topics are essentially identical to those of the Reg. Guide 7.9. This indicates that the SAR is reasonably complete in terms of the information needed for establishing T-3 qualifications.

Subsequently, the text of the SAR was reviewed and areas requiring detail review noted. General review followed the requirements outlined in Subpart C - Package Standards and the Appendices A and B to 10 CFR Part 71. Emphasis was placed on structural and thermal evaluation of the package.

2. GENERAL DESCRIPTION

Model T-3 cask is constructed in accordance with the Westinghouse Hanford Company Drawing Nos. H4-61289, Sheets 1 through 3, Revision No. 3 (see Figures 1-3). This is a stainless steel double wall cylindrical container, space between the two cylinders being filled with lead. Maximum package design capacity is for 600 W heat dissipation rate of the payload. Dimensions and Materials specifications are given in Figures 1 to 3. Drawings indicate that inner and other cylinders form closed welded structure (see shaded cross section).

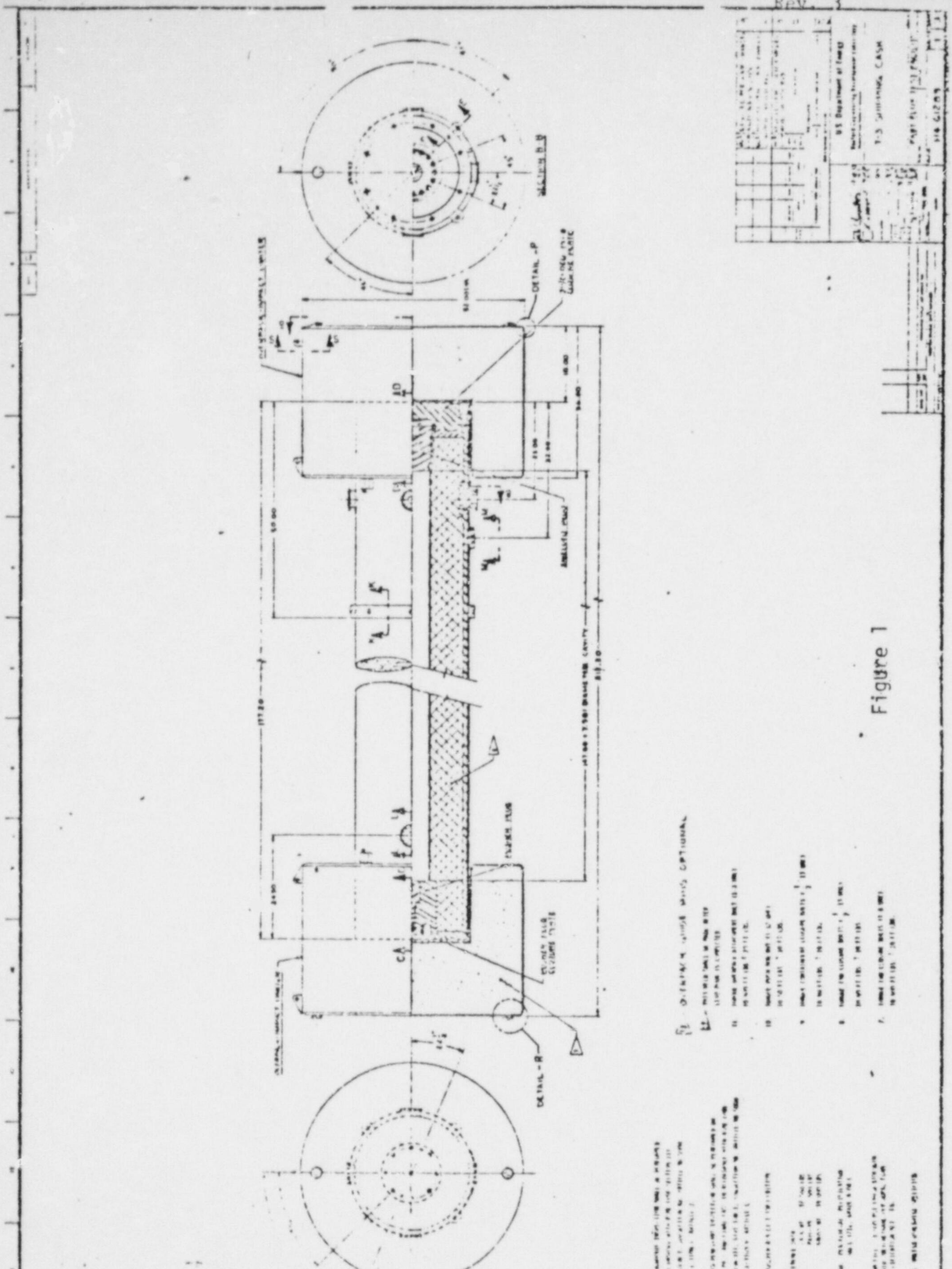


Figure 1

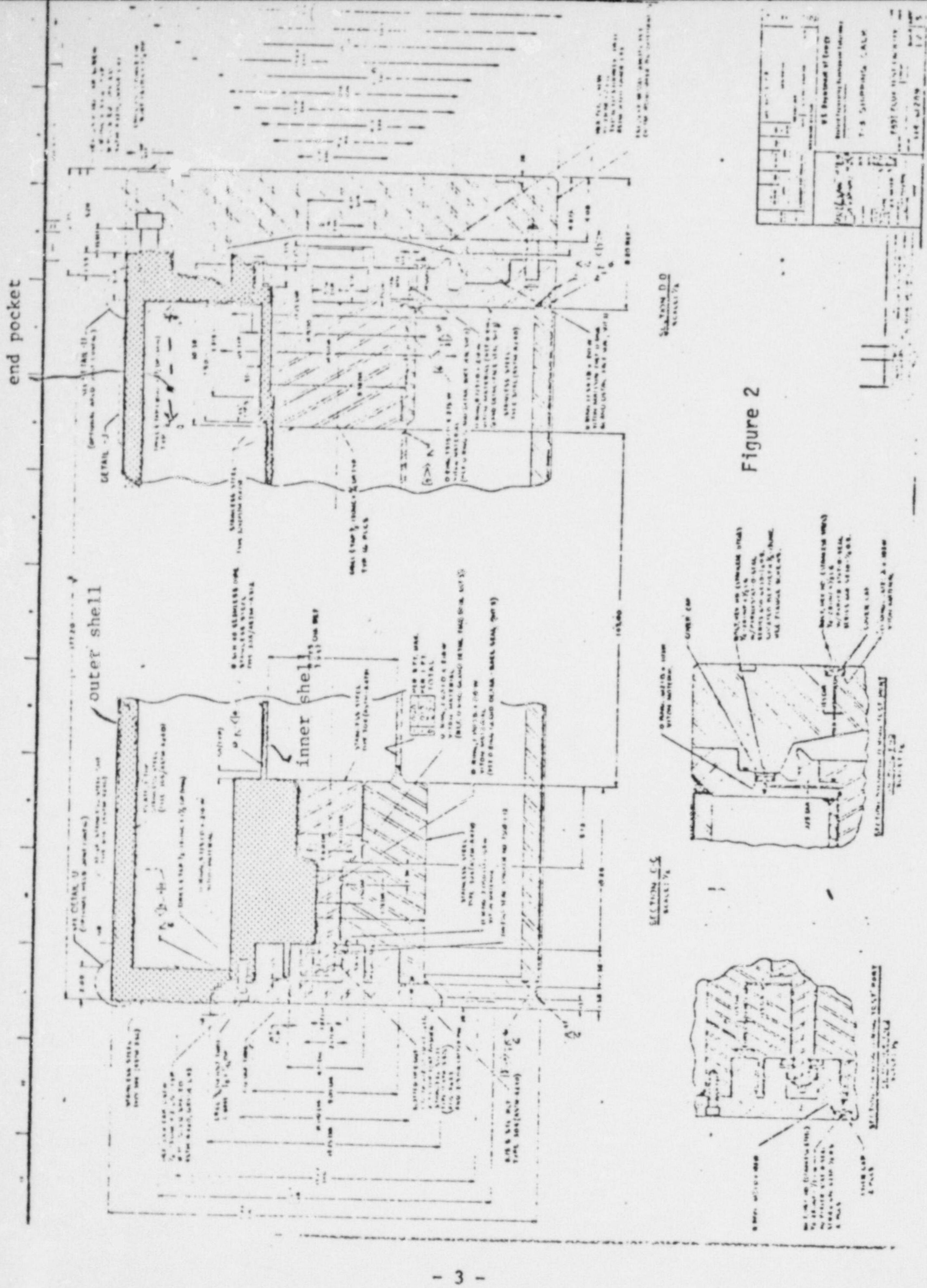
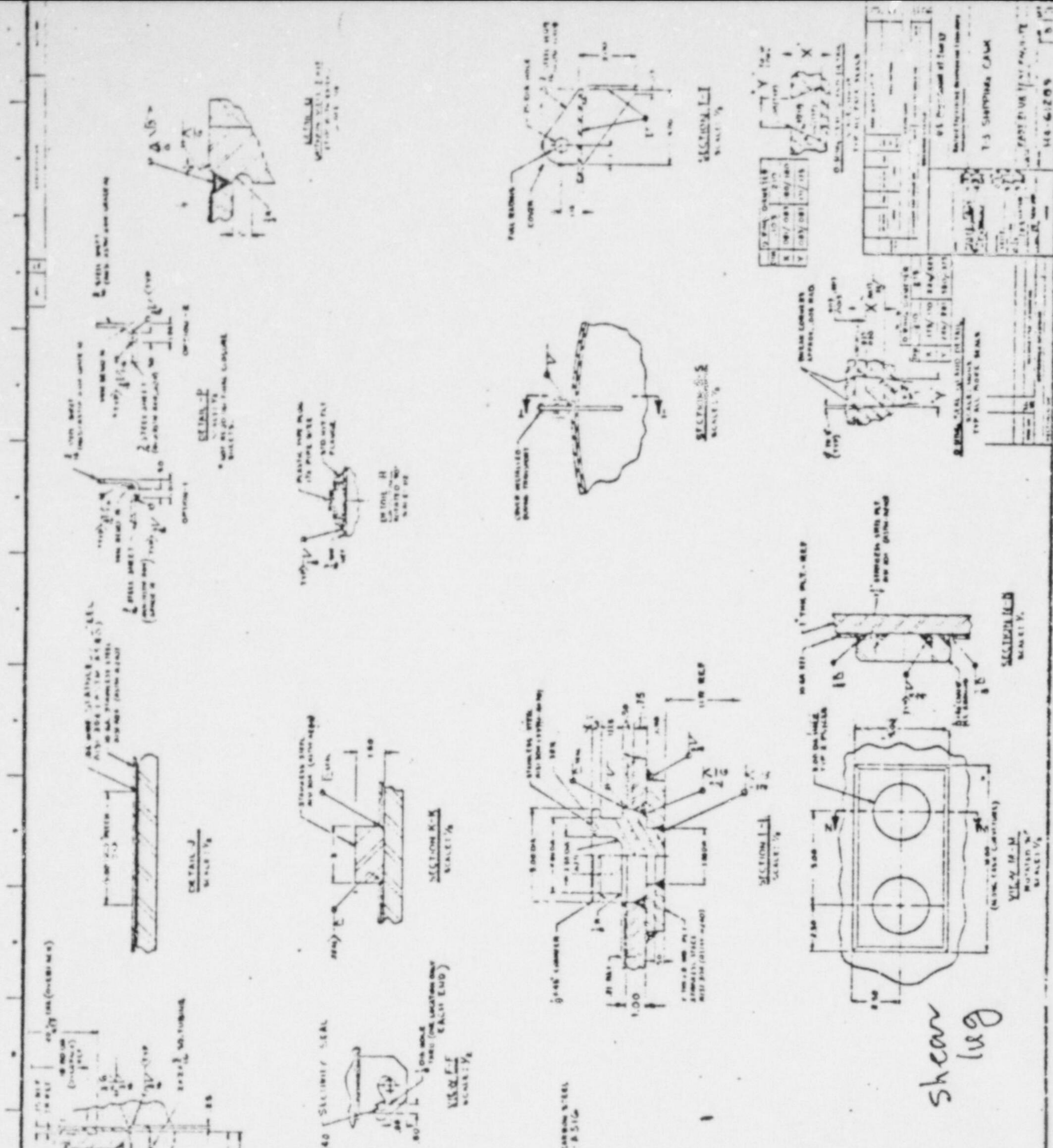


Figure 2



Shear lug

Figure 3

This feature is important when evaluating the thermal stress response due to differential heating of inner and outer cylinders. Since the inner cylinder (containment) metal cross section is much smaller than that of the outer cylinder, the inner cylinder will experience higher stresses due to temperature differences.

No drains and/or vents penetrate the inner containment vessel. A drain vent line opens into the area between the two (2) O-ring seals at each end of the case. Drainage/venting can be accomplished at either end of the cask by backing out the plugs past the first seal, thereby introducing a drain port to the containment volume. Six (6) trunnions are provided for handling: four (4) at one end and two (2) at the other. The cask is equipped with rigid polyurethane foam impact limiters. These are cylindrical in the form and cover both ends of the cask. Foam is encased in 3/16 in. thick mild carbon steel sheet. Overall dimensions of the cask with impact limiters (overpack) are 213.2 in. in length and 52 in. in diameter. Without the impact limiter the cask measures 177.2 in. in length and 26.44 inches in diameter. The gross weight of the cask and contents is 38,000 pounds of which 500 pounds, approximately, is the payload.

T-3 cask is intended for dry shipment. The outside of the cask is wrapped with 0.08 in. diameter wire which is further overlayed with gage ten (10) stainless steel cover for added thermal protection (fire exposure).

3. FINDINGS

3.1 PACKAGE DESIGN CRITERIA

The T-3 cask design requirements are given in 10 CFR Part 71. Specifically, Subpart C provides general, structural, criticality, normal transport conditions, hypothetical accident conditions and various specific standards for various classes of fisile material. Subpart D establishes operation procedure. Appendix A defines normal conditions of transport, Appendix B defines hypothetical conditions of transport. This review will concentrate on

the package design evaluation with respect to the loads derived from the Appendices A and B. In general, the procedure specified in Reg. Guide 7.9 will be followed. A convenient guide is found in the Checklist for Subpart C of the 10 CFR Part 71.

3.2 THERMAL ANALYSIS

Thermal analysis is performed in Section 2.0. This is reviewed prior to structural analysis because thermal results are required for stress computation.

Thermal analysis is performed by use of a lumped parameter model using Lockheed program THAN. Heat transfer by conduction, convection and radiation is considered. Due to the polyurethane in overpack, package ends are assumed adiabatic (during the Normal Transport Conditions). Isothermal materials properties are used for stainless steel, lead and polyurethane foam. Ambient thermal input specified in Appendix A, 10 CFR Part 71 is used.

Nodalization used to computed lumped parameters is adequate. However, one potentially significant modelling shortcoming was identified: during the fabrication lead is poured between the two cylindrical shells. The end is left open until lead solidifies, which is at approximately T = 621°F. At this time the space between the shells is still solidly filled with the lead. During the cooling down period lead will shrink more than stainless steel. Assuming that temperature reduces from 621°F to 100°F, i.e.,

$$\Delta T = 521°F$$

the inside radius of lead will shrink to an interference fit with the outside radius of the containment by

$$\Delta w_i = (\alpha_\ell - \alpha_s)\ \Delta T r_i = (18.6\text{-}11.0)\ (10^{-6})\ 521\ (5.4) = 0.021 \text{ in}$$

while the outside radius of the lead will move away from the outside stainless steel (lead does not bond to SS) shell by

$$\Delta w_o = (\alpha_\ell - \alpha_s)\ \Delta T r_i = (18.6\text{-}11.0) \times 10^{-6}\ (521)(12) = 0.047 \text{ in}$$

This means that the lead and inside cylinder will be in a compressive contact for all of the environments analyzed, while the outside cylinder will be separated by an air gap. This air gap will increase the heat flow resistance and hence will cause larger ΔT (and hence larger stresses) in the containment. Quantitative effect of the above is, however, not anticipated to be significant in terms of T-3 capability. The interference due to cooldown shrinkage, however, will put containment under a small compressive hoop prestress and the gap between the outer cylinder and the lead will case inner cylinder to carry lead weight during impact.

3.3 STRUCTURAL ANALYSIS

The list of structural elements analyzed is rather complete. Statement that T-3 is designed for 850 psig, but operated only at less than 50 psig (Page 1-3) is unsubstantiated in that the only element able to take such pressure is the inside shell away from the end closures. It is noted that T-3 cask is designed for three thousand (3000) operating cycles. Due to the preload requirement, the end closure bolts (1" diameter, pretorqued at 410 ± 20 ft-lb) can only support 800 cycles. Although on Page I-6c it is stated that Operational Procedures will specify replacement of these bolts every five years, no such specification was found in Sections 6, 7 or 8.

Buckling analysis indicates no collapse in this mode under all operating conditions.

Lifting devices are analyzed for strength, however, lifting device local effects on outside shell have not been evaluated (due to 1" thickness of the shell and local reinforcing, shell stresses are not expected to be significant). Similarly, the effect of tiedown shear lug on the shell was not analyzed. The shear lug is 1-1/2 in. thick with rounded corners. The required 10g longitudinal capability (§§71.31, 10 CFR 71) is satisfied if this shear lug remains engaged to the support structure. There is no evaluation of strapdown devices and local shell deformations to demonstrate that the shear lug will remain engaged. Also there is no evaluation of 5g transverse forces on tiedown devices (§§71.31 requirement).

The simplified differential thermal expansion analysis (Pages 1-23 to 1-23a) assumes rigid ends moving axially. Lead is assumed to interact with these rigid ends, although due to differential thermal expansion there should be adequate clearance between the lead and the rigid ends. Because of that a better model for simplified analysis would be that shown in Figure 4. This model, however would also neglect interference between the lead and the inside shell. Differential expansion stresses for Figure 4 configuration are found from equating the axial displacements at the moving shell end.

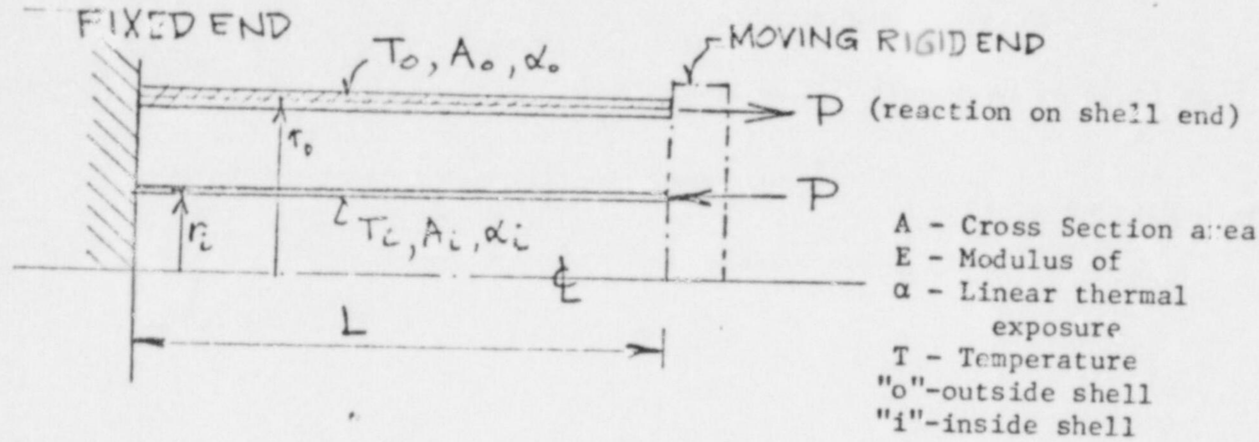


Figure 4. Simplified Differential Thermal Expansion Model

$$\alpha_o T_o L + \frac{PL}{A_o E_o} = \alpha_i T_i L - \frac{PL}{A_i E_i} \qquad \text{with } \alpha_o = \alpha_i = \alpha$$

$$P = \frac{\alpha(T_i - T_o)}{\frac{1}{A_o E_o} + \frac{1}{A_i E_i}}$$

Using $\alpha = 9.7 \times 10^{-6}$ in/in°F

$E = 28 \times 10^{-6}$ psi

$A_o = 78.5$ in^8

$A_i = 8.4$ in

we have

$P = 2061\ (T_i - T_o)$ lb

Stresses are found dividing P by the corresponding cross section area

Inside shell

$$\sigma_i = -245\ (T_i - T_o)$$

Outside shell

$$\sigma_o = 26.25\ (T_i - T_o)$$

For the worst case during normal transport (Page 1-23)

$$T_i = 170.1°F - 70°F \text{ (assembly temperature)} = 100.1°F$$
$$T_o = 165.7°F - 70°F = 95.7°F$$

and

$$\sigma_i = -1102 \text{ psi}$$
$$\sigma_o = 119 \text{ psi}$$

This indicates that the values on Page 1-23a are conservative.
No analysis has been performed for thermal discontinuity stresses.

For hypothetical thermal accident case $T_i - T_o = -105°F$ at 0.5 seconds.
Stresses in shells

$$\sigma_i = -245\ (-105) = 25725 \text{ psi}$$
$$\sigma_o = -2782 \text{ psi}$$

These stresses have not been added to pressure stresses (Page 1-119).

Analytical models used for pressure stress calculations, Pages 1-24 to 1-27 ignore the fact that inner and outer shells form closed-double-connected body (see shaded cross section on Figure 2). For doubly-connected shells, it is not possible apriori to tell how axial load will be shared between the two shells. Therefore, the models used will not predict the axial stress and the discontinuity stresses at the end closures correctly. Furthermore, the finite element models of shell, Pages 1-32 and 1-43, have only two (2) elements through the thickness. Such model is adequate for the sections of the shell about five (5) in. from the end closure, however, at the discontinuities the computed bending stresses will not be correct.

Vibration model used is not representative of the configuration during the shipment. Natural frequencies and modes shapes based on configuration during shipping should be computed to calculate the vibratory response. Table on Page 1-58 represents the vibratory load input at the vehicle platform upon which T-3 is mounted not the T-3 response during the transport. For these reasons the SAR calculations (Pages 1-56 to 1-59) are not representative of the vibrations normally incident to the transport.

Free drop kinetic energy at the impact is correctly computed (Page 1-60). Corner drop internal force computation (Pages 1-60d to 1-60i) is incorrect: Equations of motion of the form given on Page 1-60e are only valid in a Newtonian reference frame (a reference frame at rest or at most at a uniform velocity). The local coordinates, X, Y, Page 1-60e, are tied to the body and are subject to acceleration, hence non-Newtonian coordinates.

Proper equations of rigid body motion would have the following vector form (refer to Figure 5 for notation):

$$- M\ddot{\underset{\sim}{d}} + \underset{\sim}{F} + M\underset{\sim}{g} = 0$$

$$- I\ddot{\underset{\sim}{\theta}} + \underset{\sim}{p} \times \underset{\sim}{F} = 0 \qquad (1)$$

where

$$\underset{\sim}{p} = - \ell\sin\alpha \, \underset{\sim}{a}_1 - \ell\cos\alpha \, \underset{\sim}{a}_2$$

$$\underset{\sim}{d} = x\underset{\sim}{a}_1 + y\underset{\sim}{a}_2 \qquad \text{mass center position}$$

$$\underset{\sim}{\theta} = \theta_3\underset{\sim}{a}_3$$

$$F = F_1 a_1 + F_2 a_2 \qquad (2)$$

and

$$x = \ell\sin\alpha + X\sin\alpha - Y\cos\alpha$$

$$y = \ell\cos\alpha + X\cos\alpha + Y\cos\alpha \qquad (3)$$

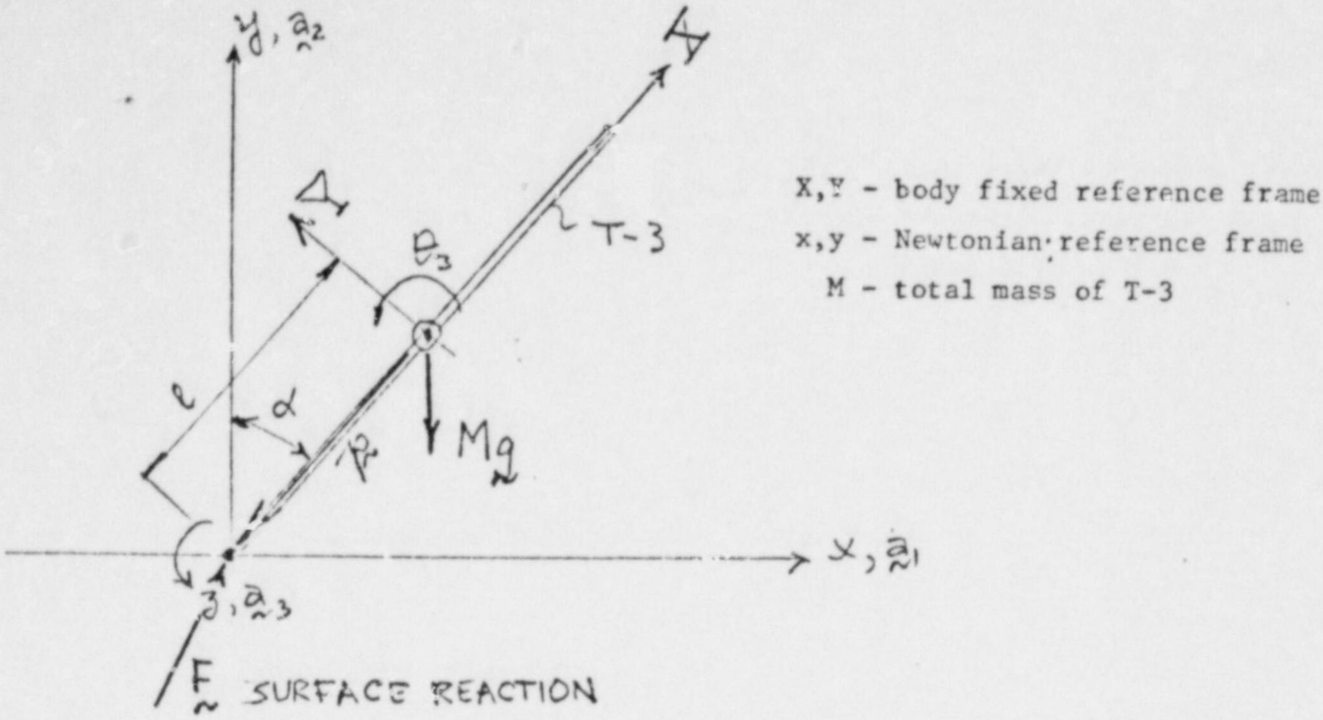


Figure 5. Rigid Body Motion

Substitution of (2), (3) into (1) would introduce X,Y coordinates into equations, but the form would be quite different from that shown on Page 1-60e. Additional problems with Page 1-60e are: neglect of gravity force and assumption that $\tilde{F}$ will always be vertical (frictionless contact). Neglect of gravity force $M\tilde{g}$ may not significant since the main contributor to stress will be the initial impact velocity.

It is noted further that the equations for the impact force calculation on Pages 1-60p to 1-60t are correct. The gravity load is included in these equations, but no horizontal reaction at the impact surface is considered. The assumption that $\tilde{F}$ will always go through T-3 corner is hard to justify. However, if Page 1-60 to 1-60i methodology is used for computation of internal forces, the results on Pages 1-60t to 1-60y are incorrect.*

*In fairness to the analyst, the OBLIQUE computer program may have correct algorithm for computation of internal forces and moments: a correct body fixed accelerations can be easily computed from absolute accelerations generated by the method of Pages 1-60p to 1-60t.

SAR does not consider impact of the trailing end of T-3 on the unyielding surface after the package has rotated. In the case of a shallow impact angle this secondary impact may produce higher T-3 bending stress, in particular since a significant fraction of the kinetic energy is initially transformed into rotational kinetic energy (Page 1-60t). Friction between overpack and the unyielding surface may wipe the overpack off the end of T-3 rather than crash it as is assumed in the analysis.

The second side drop analysis by use of the ANSYS computer program is reasonable. The agreement of g-loads and crash depth with the energy balance analysis is to be epxected since the same overpack crash load characteristics were used for both analyses.

Hypothetical Accident Analysis Methodology is the same as for normal transport, hence the same comments apply.

4. RECOMMENDATIONS

The certification process defined in 10 CFR 71 and the associated Regulatory Guides (7.1, 7.2, 7.3, 7.4, 7.6, 7.7, 7.8, 7.9) were utilized in this review and were found to be quite adequate. In particular, Reg. Guide 7.9 was found to be very useful in evaluating the SAR submitted for shipping container qualification.

Although several real (or perceived, due to erroneous reporting) shortcomings in the analysis were identified in Section 3 of this report, this reviewer believes T-3 is a well engineered package, adequate for safe transport of large quantities of radioactive material.