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SAFETY ANALYSIS REPORT FOR PACKAGING: THE ORNL LITHIUM HYDROXIDE FIRE AND IMPACT SHIELD

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

The ORNL Lithium Hydroxide Fire and Impact Shield and its packaging were designed and fabricated at Oak Ridge National Laboratory to permit the transport of Type B quantities of radioactive material and limited quantities of fissionable material. The shield and its packaging were evaluated analytically and experimentally to determine its compliance with the applicable regulations governing containers in which radioactive and fissile materials are transported, and that evaluation is the subject of this report. Computational and test procedures were used to determine the structural integrity and thermal behavior of the shield relative to the general standards for normal conditions of transport and the standards for the hypothetical accident conditions. The results of the evaluation demonstrate that the shield and its packaging are in compliance with the applicable regulations.

0. GENERAL INFORMATION

0.1 Introduction

The ORNL lithium hydroxide (LiOH) fire and impact shield was designed by ORNL in 1969. The original design was revised in 1973 to incorporate improvements and to upgrade the shields. Six shields were built in 1970. One shield was filled with lithium hydroxide monohydrate ($LiOH \cdot H_2O$) and was then impact and fire tested as described in Sects. 1.5.1 and 2.4.1 of this report. The shields were inspected and examined, and the shields were filled with $LiOH \cdot H_2O$ in accordance with the drawings and specifications in Appendix A.

The primary use of the shield is to provide impact and thermal resistance for a Type A shielded cask (Fig. A.4) containing special form[3,4] packages to permit the transport of Type B quantities of radioactive material and limited quantities of fissionable material for both normal and accident conditions by rail, highway, and water modes. The contents for which the design is evaluated are outlined in Sect. 0.2.3. The LiOH shield and its packaging complies with the regulations of the International Atomic Energy Agency (IAEA), 1973,[4] the Nuclear Regulatory Commission, Title 10 CFR Part 71,[2] DOE Order 5480.1, Chapter III,[1] and the Immediate Action Directives (IAD) in effect as of this report date. The shields also comply with U.S. Department of Transportation (DOT) regulations, Title 49 CFR Part 173.[3] Calculations, engineering logic, test results, and documents demonstrating compliance are presented in succeeding sections of this report. Copies of the approval documents are included in Appendix B.

0.2 Package Description

0.2.1 Container description

The features of the shield are illustrated in Fig. 0.1. As-built fabrication drawings are in Appendix A. The shield consists of two right circular cylinders 36 and 27-1/4 in. in diameter, each 1/8 in. thick, forming the outer and inner cladding. The body or vessel is 30-3/4 in. high, and the lid or plug is 4-5/8 in. high. These form a cavity 27 in. in diameter by 26 in. high. The 4-1/4-in. nominal space between outer and inner cladding is filled with $LiOH \cdot H_2O$ crystals. After pouring, the crystals form a solid mass by absorption of water. The outer surface of the vessel has 92 vertical cooling fins 1/8 in. thick by 1 in. wide welded to the wall to improve heat dissipation to the atmosphere.

The closure consists of a pair of 44-in.-diam reinforced flanges. Twenty seal-wired 1-in. alloy steel bolts secure the closure. There is no gasket, since beta/gamma shielding is provided by the Type A radioisotope shipping cask and the special form capsule provides containment as discussed below. At the base of the vessel, the inner and the outer cladding are separated by a cross structure of pine lumber. The inner and the outer cladding of the lid are spaced apart and supported by a structural member. The material of construction, with the exceptions noted above, is type 304L stainless steel sheet, plate, and special shapes. The fire and impact shield weighs 1450 lb, and the total package weight will not exceed 4000 lb.

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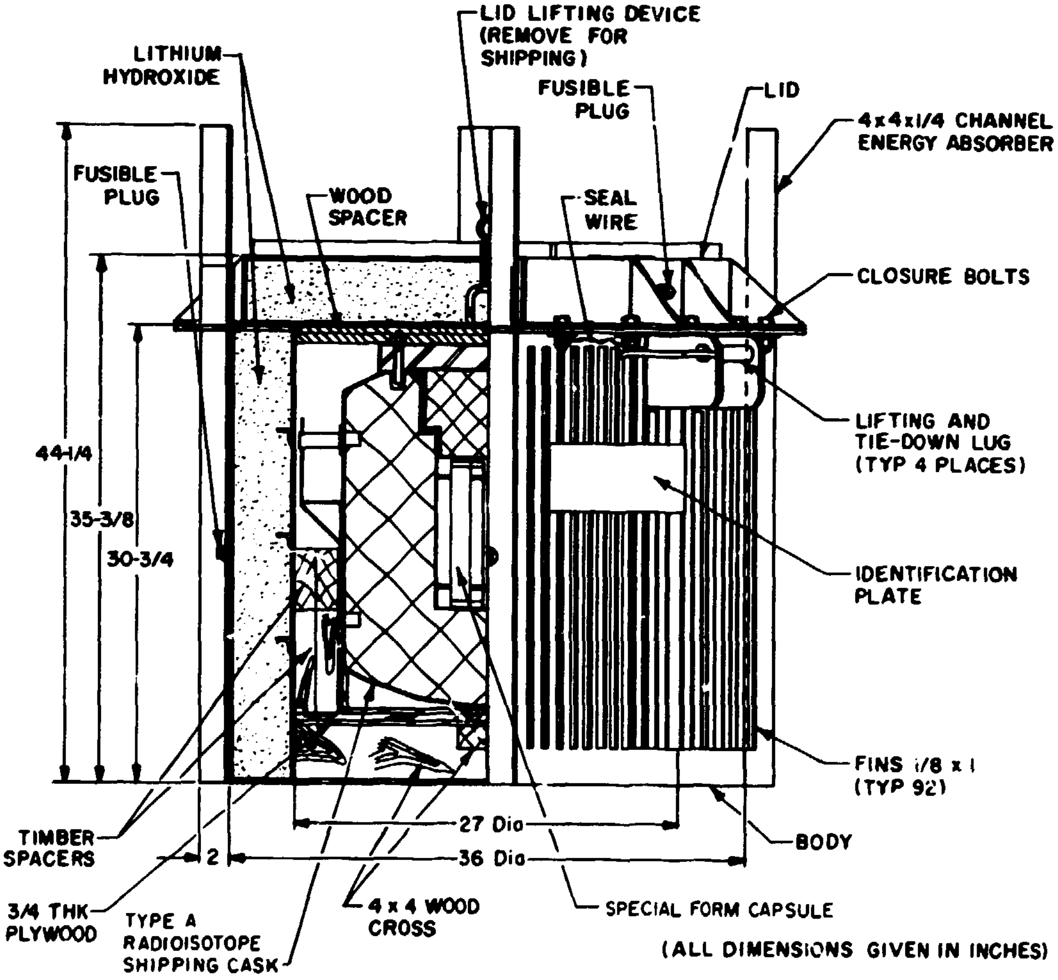

Fig. 0.1. LiOH Fire and Impact Shield Package

0.2.2 Operational features

The shield is designed to be lifted and tied down by lugs (see Sect. 1.2.2, Fig. 1.1). The four channels extending above the top offer impact protection.

The $LiOH \cdot H_2O$ forms neutron shielding in addition to offering thermal and impact protection. The beta/gamma shielding is provided by a shielded cask which meets the test requirements outlined in DOT and IAEA regulations[3,4] for Type A containers (see Appendix B). This cask weighs 2500 lb for a total package weight of 4000 lb.

The radioactive material is contained in a special form capsule which has been tested and certified to meet the test requirements for special form found in the DOT and IAEA regulations.[3,4]

The radioisotope shipping container (Fig. 0.2) will be blocked in the LiOH shield with lumber such that movement in any radial or axial direction is limited to 1/4 in. or less.

0.2.3 Contents

The contents of the special form container within the LiOH packaging will be any solid radioactive material whose decay heat load does not exceed 300 W and whose gamma and/or neutron activity does not exceed dose rate limits specified in DOT and IAEA regulations.[3,4] The maximum quantity of ^{242}Am, ^{244}Cm, ^{245}Cm, ^{247}Cm, ^{249}Cf, and ^{251}Cf will be limited to a combined total of 5 g. The LiOH shield package will also be used to transport up to 100 g of fissionable materials including ^{235}U and ^{233}U, in solid form. The above materials will be packaged internally to meet special form requirements.

The LiOH package will carry irradiated metal specimens such as tensile, impact, and weld specimens including, but not limited to, stainless steel, mild steel, INOR-8, nickel, high-nickel alloys such as Inconel and Monel, and tungsten. All such specimens will meet special form requirements of the DOT and IAEA.

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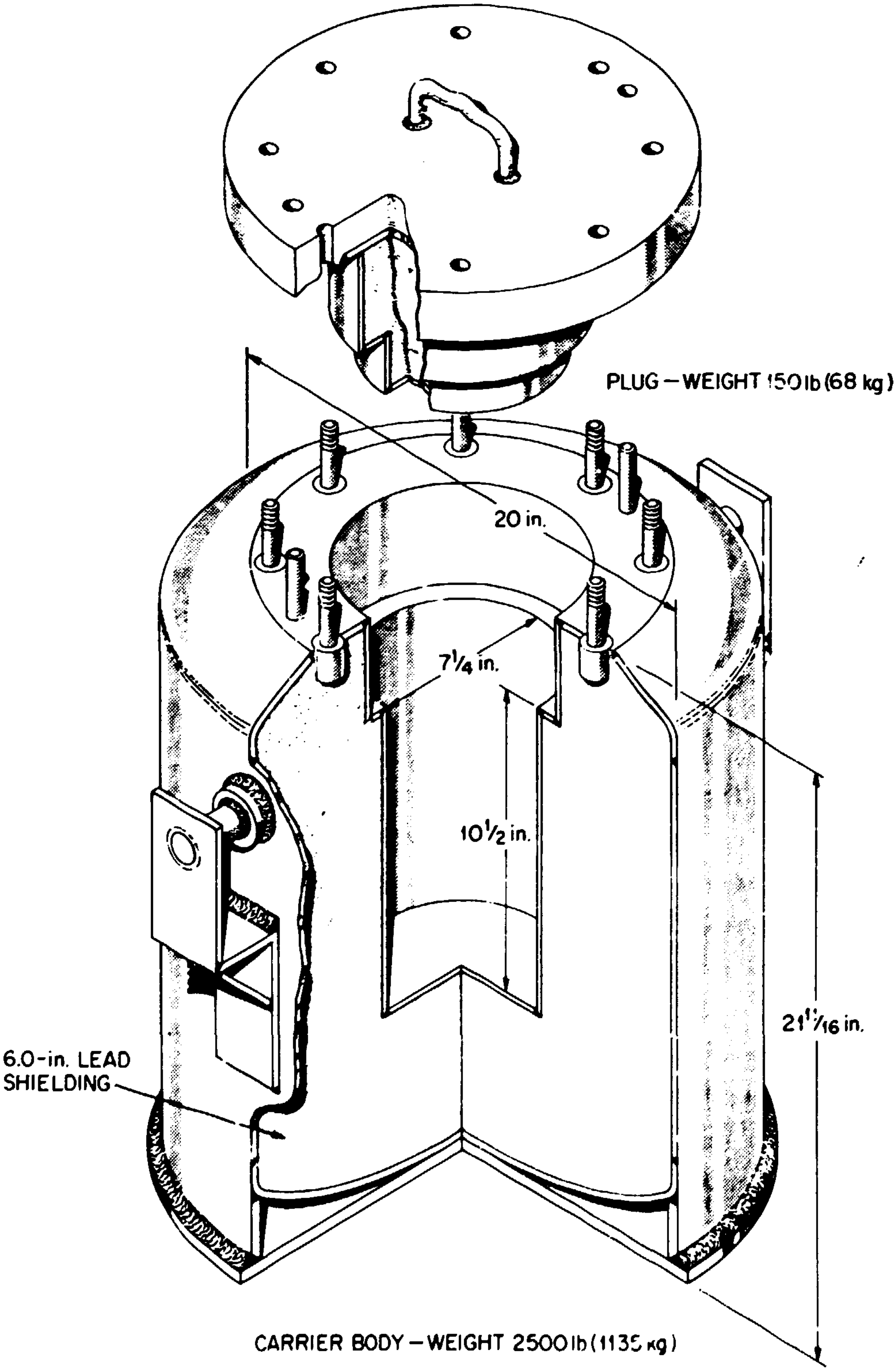

Fig. 0.2. Radioisotope shipping cask _ Type A

0.2.4 LiOH cavities

Cavities in the vessel and lid are filled with $LiOH \cdot H_2O$, which provides neutron shielding and thermal protection. Lithium hydroxide monohydrate is a corrosive material as defined by DOT regulations[4] (see 173.240) even though not specifically listed (see Part 172). Since the material is contained in a stainless steel shell, the shields comply with the DOT requirements for corrosive materials containers (see 173.21 and 173.245b) and will be labeled as required (see 172.442).

1. STRUCTURAL EVALUATION

1.1 Mechanical Properties of Materials

The properties of the materials used in the LiOH shield are listed in Table 1.1. For some materials, dynamic properties are not available. In these instances, static properties are used, but care is exercised to ensure that their use results in a conservative evaluation.

1.2 General Standards for All Packages

The general standards for all packaging cover the chemical and galvanic reactions of the materials of the package, closure of the package, and the lifting and tie-down devices for the package. The shields are constructed of 300-series stainless steel filled with $LiOH \cdot H_2O$ salt. There has been no evidence of any corrosive or galvanic action between these materials.

1.2.1 Closure

The standards specify that the package be equipped with a positive closure that will prevent inadvertent opening. The lid and body are secured with seal-wired bolts that qualify as a positive closure.

Table 1.1. Mechanical properties of cask materials

Static and dynamic properties[a]	Symbol	304L stainless steel	Closure bolts ASTM A320
Yield stress, psi	σ_y	30,000[b]	105,000[c]
Ultimate tensile stress, psi	σ_u	75,000[b]	125,000[c]
Modulus of elasticity, psi	E	29×10^6[b]	
Ultimate elongation, in./in.	ϵ	0.5	0.16[c]
Poisson's ratio	ν	0.3[b]	
Density, lb/in.^{3}	ρ	0.283[b]	
Allowable shear stress, psi	τ	15,000[d]	52,500[d]
Design stress, psi		14,400[e]	

[a] Dynamic properties are taken equal to static properties.

[b] Materials in Design Engineering, Reinhold, New York, 1961.

[c] Specification for Alloy Steel Bolting Materials for Low Temperature Service, ASME SA-320, ASME Boiler and Pressure Vessel Code, Section II, "Materials," American Society of Mechanical Engineers, New York, 1971.

[d] One-half yield stress.

[e] At 500°F, design stress is applicable to pressure calculations only. Taken from ref. 5.

1.2.2 Cask lifting device

If there is a system of lifting devices that is a structural part of the package, the regulations require that this system be capable of supporting three times the weight of the loaded package without generating stress in any material of the package in excess of its yield strength.

The shields are designed to be lifted by four lugs (see Fig. 0.1) spaced symmetrically around the shield using conventional slings. It is reasonable to assume that on occasion only two lugs will be used; hence the lugs will be evaluated on this basis. The lugs are of type 304L stainless steel, which has a yield stress of 30,000 psi. The force on the lugs is applied as shown in Fig. 1.1.

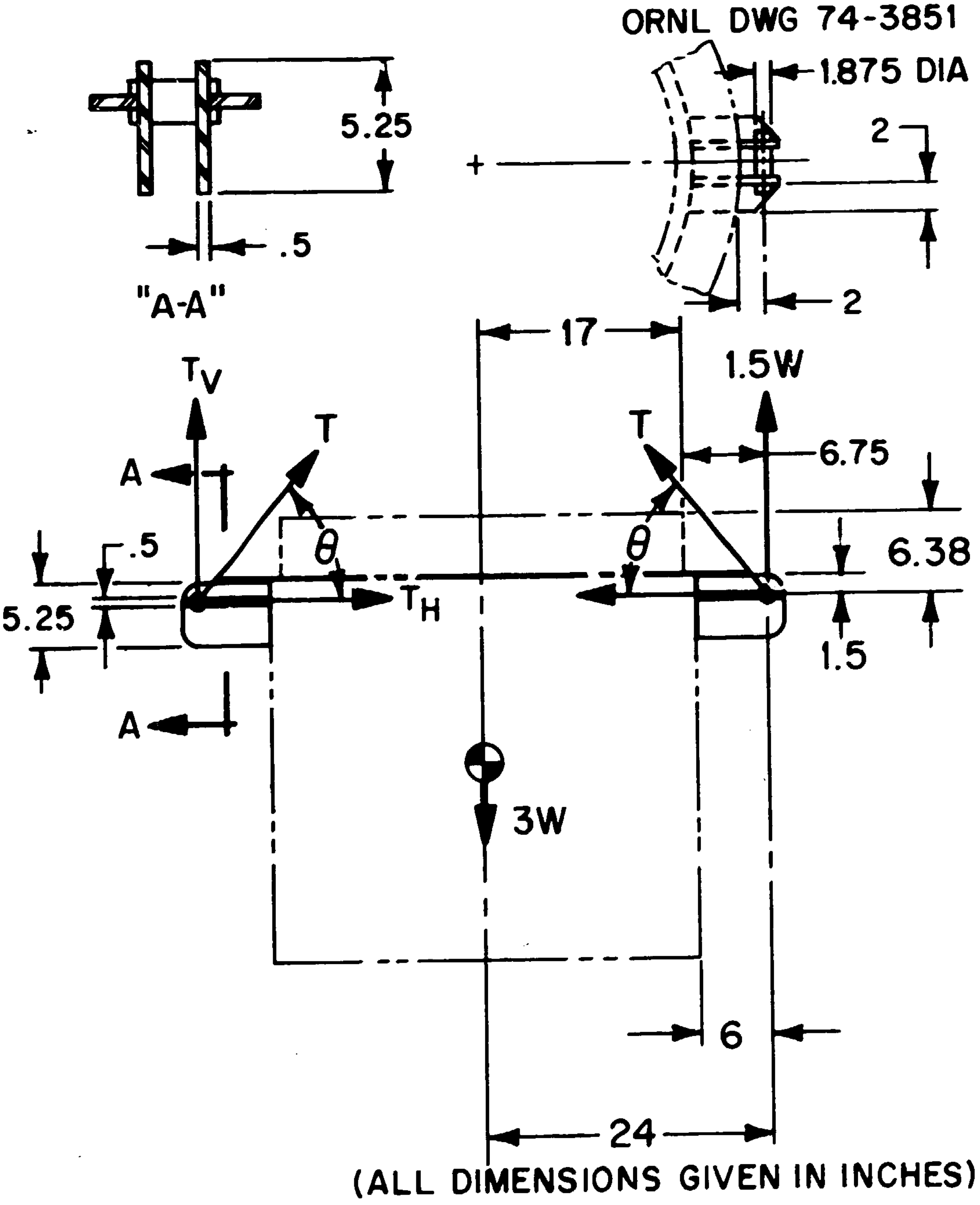

Fig. 1.1. Lifting load diagram.

The angle θ is limited by shield geometry to

$$\theta = \tan^{-1} (6.38/6.75) = 43.38° .$$

The force, T, is found from

$$T = 1.5W/\sin \theta = (1.5)(4000)/\sin\ 43.38° = 8736 \text{ lb} .$$

The shearing stress, τ, on the 1.875-in. rod is

$$\tau = T/(2A) = 8740/[(2)(\pi)(1.875)^2/4] = 1600 \text{ psi} ,$$

where A is cross-sectional area of the rod.

The bending stress in the rod, σ, assuming a concentrated load at the center, is

$$\begin{aligned}\sigma &= M/Z = [(T/2)(L/2)]/[(\pi)(D)^3/32] \\ &= [(8740)(2.5)(8)]/[(\pi)(1.875)^3] \approx 8450 \text{ psi} ,\end{aligned}$$

where

L = length of rod (in.),
D = diameter (in.),
M = moment around center of mass (in.·lb),
Z = I/c,

in which

c = height of center of mass above the base (in.),
I = moment of inertia.

With reference to Fig. 1.1,

$$T_v = 1.5W = 1.5(4000) = 6000 \text{ lb} ,$$

$$T_h = T \cos \theta = 8740(\cos 43.38°) = 6350 \text{ lb} .$$

The centroid of Sect. A-A is found by the area moment proposition

$$\begin{aligned}\bar{y} &= (A_1y_1 + A_2y_2)/(A_1 + A_2)\\ &= [(5.25)(0.5)(2.625) + (2)(0.5)(3.875)]/[(5.25)(0.5) + (2)(0.5)]\\ &= 2.97 \text{ in.} \ ,\end{aligned}$$

where

A_1 = cross-sectional area of support plates (in.^{2}),

A_2 = cross-sectional area of flange (in.^{2}).

The moment of inertia about the centroidal axis is found by the transfer axis theorem

$$\begin{aligned}I &= \Sigma I_0 + Ad^2 = I_1 + A_1(\bar{y} - y_1)^2 + I_2 + A_2(\bar{y} - y_2)^2\\ &= 2[1/12(0.5)(5.25)^3 + (5.25)(0.5)(2.97 - 2.625)^2 + 1/12(2)(0.5)^3\\ &\quad + 2(0.5)(2.97 - 3.875)^2] = 14.34.^4 \ .\end{aligned}$$

The maximum bending stress, σ_b, in the support plates resulting from T_v is at C-C and is found from

$$\begin{aligned}\sigma_b &= mc/l = \pm[F_v a(b/2)]/I\\ &= \pm 6000(2)(5.25)/2(14.34) = \pm 2200 \text{ psi} \ .\end{aligned}$$

The compressive stress, σ_c, in the plates resulting from T_H is

$$\sigma_c = T_H/A = 6350/2[(5.25)(0.5) + (2)(0.5)] = 880 \text{ psi} \ .$$

The maximum stress, σ, is

$$\sigma = \sigma_b + \sigma_c = 2200 + 880 = 3080 \text{ psi} \ .$$

The force, T_H, loads the shell in compression and the weld securing the support plates to the flange in shear. Assuming that the weld carries all the load, the maximum shearing stress, τ_H, in the weld is

$$\tau_H = T_H/(e)(\cos 45°)S = 6350/(0.25)(\cos 45°)(16) = 2250 \text{ psi} ,$$

where

e = weld size = 1/4 in.,
S = total length of weld (in.).

The force T_V loads the weld securing the support plates to the shell. As above, the shearing stress in the weld is

$$\tau_V = T_V/(e)(\cos 45°)S = 6000/(0.25)(\cos 45°)(4)(5.25) = 1620 \text{ psi} .$$

These stresses are less than the allowable stresses (see Table 1.1); hence the shield complies with the lifting requirements.

Failure of the lifting device under excessive load would probably be a bending failure of the 1.875-in.-diam rod, since it is the most highly stressed member. Failure of the rod or any other part of the lifting device would not impair the shielding and containment capabilities of the shield.

1.2.3 Lid-lifting device

The regulations require that if there is a system of lifting devices that is a structural part of the lid only, this system shall be capable of supporting three times the weight of the lid and any attachment without generating stress in any material of the lid in excess of its yield strength. It is further required that unless rendered useless for lifting during transport of the package, the lid-lifting or any other system of lifting devices shall conform to the requirements for the package lifting system.

The lid, which weighs approximately 310 lb, is lifted by a 1/2-in. eyebolt located at the center. The safe working load for the eyebolt is 2600 lb,[8] which is in excess of three times the weight of the lid. The eyebolt is removed for shipping; hence it is not available for lifting the entire cask during transport (see Appendix C).

Failure of the lid-lifting device under excessive load would be in the form of a tensile failure of the eyebolt which would not impair the shielding or containment capabilities of the shield.

1.2.4 Tie-down devices

If there is a system of tie-down devices that is a structural part of the package, the regulations require that this system be capable of withstanding a static force applied to the center of gravity of the package with a vertical component of two times the weight of the package (W) and its contents, a horizontal component along the direction of travel of ten times the weight of the package (W) and its contents, and a horizontal component in the transverse direction of five times the weight of the package (W) and its contents. This applied force shall not generate stresses in any material of the package in excess of the yield strength of that material. It is also required that any tie-down device that is a structural part of the package shall be so designed that failure of the device under excessive load will not impair the ability of the package to meet other requirements of the regulations.

The LiOH shield is designed to be secured to the transport vehicle as shown in Fig. 1.2 by four tension members attached to the four lifting and tie-down lugs. For the general case, the notation I, J, K, H, and L of Fig. 1.2 represents the dimensions of the tie-down system. Of these, only the value of H is fixed by the container geometry.

It cannot be determined by inspection if the forward members C and D are under load. If they are under load, the normal force, F_n, will be located on the outer radius of the shield. To determine whether C and D are loaded, it will be assumed that they are not, and the location of F_n will be calculated. If the calculated location is within the confines of the shield base, these members are not loaded. However, if the calculated location is not within the boundary of the base, the members C and D must be under load to achieve equilibrium.

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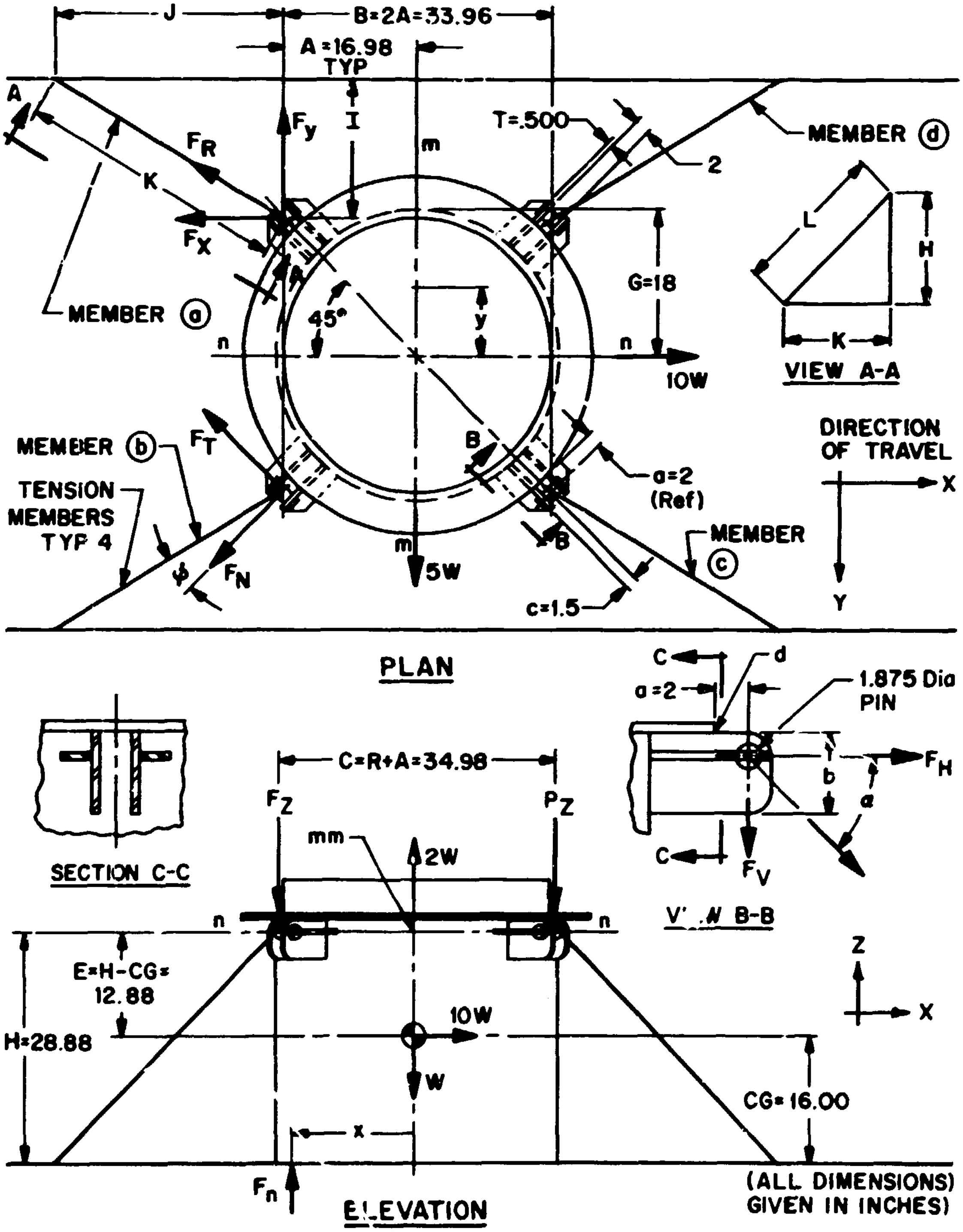


Fig. 1.2. Typical tie-down.

For the 10W load, by summation of horizontal forces (see Fig. 1.2), F_x is equal to 5W. It follows that the horizontal resultant in the direction of the tie-down member is $F_R = 5W(K/J)$. The tension in each of the two rear tie-down members is $T_{10} = 5W(L/J)$. For the 5W transverse load, the tension in member a and in member d is $T_5 = 2.5W(L/I)$. The 2W vertical load has a net resultant of W upward and is equally distributed between the four tie-down members. The tension in each member as a result of the upward load is $T_2 = (W/4)(L/H)$. The tension, T, in the most loaded member is $T_a = T_{10} + T_5 + T_2 = 5W(L/J) + 2.5W(L/I) + (W/4)(L/H) = WL(5/J + 2.5/I + 0.25/H)$. The values of the dimensions I and J will vary over a considerable range in practice. Ratios of I to J will be in the range 1/1 to 1/2. For highway trailers, the most likely mode of transport for the shields, an I to H ratio of near 1/1 is likely. These ratios are selected to demonstrate compliance with the tie-down requirements. Taking H as the reference height of a tie-down, and letting $I/J = 1$, $K = 2^{1/2}$, $L = 3^{1/2}$, then T_a is equal to $W(d)^{1/2}(5 + 2.5 + 0.25)$ or 13.42W. Similarly, for the I/J ratio of 1/2 and H = reference height, $K = 5^{1/2}$, $L = 6^{1/2}$, then T_a is equal to $W(6)^{1/2}(5/2 + 2.5/1 + 0.25/1)$ or 12.86W.

The I to J ratio of 1/1 results in the larger of the loads considered in the tie-down lugs, and the evaluation will be made on this basis. The tensile forces and component loads in the members are

$$T_a = 13.42W ,$$
$$T_b = W(3)^{1/2}(5 + 0.25) = 9.09W ,$$
$$T_c = W(3)^{1/2}(0.25) = 0.43W ,$$
$$T_d = W(3)^{1/2}(2.5 + 0.25) = 4.76W ,$$
$$F_{za} = T_aH/L = 13.42W/3^{1/2} = 7.75W ,$$
$$F_{zb} = 9.09W/3^{1/2} = 5.25W ,$$
$$F_{zc} = 0.43W/3^{1/2} = 0.25W ,$$
$$F_{zd} = 4.76/3^{1/2} = 2.75W ,$$
$$F_n = \Sigma F_z - W = 15W .$$

Summation of moments about axis m-m yields $\Sigma M_{m-m} = 0$:

$$\Sigma M_{m-m} = F_nX - 10WE + (-F_{za} - F_{zb} + F_{zc} + F_{zd})A = 0 ,$$

$$X = [10WE + (7.75 + 5.25 - 0.25 - 2.75)\ WA]/15W$$

$$= (E + A)/1.5 = (12.88 + 16.98)/1.5 = 19.9 \text{ in.}$$

Summation of moments about axis n-n yields $\Sigma M_{n-n} = 0$:

$$\Sigma M_{n-n} = F_nY - 5WE + (-\text{[illegible]} + F_{zb} + F_{zc} - F_{zd})A = 0 ,$$

$$Y = [5WE + (7.75 - \text{[illegible]} - 0.25 + 2.75)\ WA]/15W$$

$$= (E + AK)/3 = (12.88 + 16.98)/3 = 9.95 \text{ in.}$$

The normal force F_n is located at a radius $r = (X^2 + Y^2)^{1/2} = (19.9^2 + 9.95^2)^{1/2} = 22.25$ in., which has a slope of $y/-x = 1/-2$. This coincides with the line of action of the resultant of the 10W and 5W forces. The calculated location of F_n is not on the container base. This demonstrates that there is additional tension in the members. The radius, r, cannot exceed 18 in., and the expression $r = [X^2 + (X/2)^2]^{1/2} + X(5)^{1/2}/2$. Solving for X, $X = 2(18)/5^{1/2} = 16.1$ in. and $Y = X/2 = 8.05$ in. Considering only the 10W load and again summing moments about axis m-m,

$$F_nX - 2F_zA + 2P_zA - 10WE = 0 ,$$

where F_z is the vertical component of the tension, T, in member a and in member b, and P_z is the vertical component of the tension, T', in member c and in member d. By summation of vertical forces, $F_n = 2(F_z + P_z)$. By summation of horizontal forces, $2T(J/L) - 10W - 2T'(J/L) = 0$, and $T = 5WL/J + T'$. The vertical components $F_z = T(H/L) = 5WH/J + T'(H/L)$ and $P_z = T'(H/L)$. Substituting in the moment equation yields

$$2F_zX + 2P_zX - 2F_zZ + 2P_zA - 10WE = 0 ,$$

$$F_z(X - A) + P_z(X + A) - 5WE = 0 ,$$

$$T(H/L)(X - A) + T'(H/L)(X + A) - 5WE = 0 ,$$

$$(5WL/J + T')(X - A) + T'(X + A) - 5WEL/H = 0 ,$$

$$5WLX/J + T'X - 5WLA/J - T'A + T'X + T'A - 5WEL/H = 0 ,$$

$$5WL(X/J - A/J - E/H)\ 2T'X = 0 .$$

Making the notation change $T' = T'_{10}$ and solving,

$$T'_{10} = 5WL/2X(A/J + E/H - X/J)$$

$$= 5(4000)\sqrt{37}/2(16.1)[16.98 + 12.88 - 16.1]$$

$$= 14,800 \text{ lb} = 3.7W ,$$

where P_z = vertical component of the tension in members b and c, and F_z = vertical component of the tension in members a and d; it can be seen by inspection that T'_5, the tension in members b and c, is zero, since the results at F_n are located within the base. The tension, T_a, in the most loaded member, member a, is

$$T_a = (T_{10} + T_5 + T_2 + T'_{10}) = 17.12W$$

$$= 68,500 \text{ lb} .$$

The shearing stress, τ, in the pin is

$$\tau = T_a/(2A) = 68,500/[(2)(\pi)(1.875)^2/4] = 12,400 \text{ psi} .$$

The bending stress, σ, in the rod, considering the rod as a beam with restrained ends, is

$$\sigma = M/Z = [T_aL/8]/[(\pi)(D)^3/32]$$
$$= [(68,500)(2)(4)]/[(\pi)(1.875)^3] = 26,500 \text{ psi} .$$

To determine the maximum stress in the tie-down lug (point d, Fig. 1.2, view B-B), the component stresses (σ_V and σ_H) are calculated and summed. The force (see Fig. 1.2) is

$$F_V = T_a(H/L) = 68,500(1)/3^{1/2} = 39,550 \text{ lb} .$$

The moment of inertia from Sect. 1.2.2 = 14.34.

As before, the bending stress

$$\sigma_V = Mc/I = F_Va(b/2)/I = (39,550)(2)(2.5)/14.34 = 13,800 \text{ psi} .$$

The force $F_H = T_a(K/L) = 68,500(2^{1/2}/3^{1/2}) = 55,900$ lb, so the direct tensile stress is

$$\sigma_H = F_H/A = 55,900/[(2)(0.500)(5.25) + 2(0.500)(2)] = 7700 \text{ psi} .$$

The maximum stress at point d (see Fig. 1.2, view A-A) is

$$\sigma = \sigma_V + \sigma_H = 13,800 + 7700 = 21,500 \text{ psi} .$$

The four vertical channels extending above the shield could be used to tie it down. The dimensional ratios previously used are valid; hence the maximum force in the most loaded tie-down member is 68,500 lb. The horizontal component of the force,

$$F_H = T_a(K/L) = 68,500(2^{1/2}/3^{1/2}) = 55,900 \text{ lb} ,$$

would place the built-up portion of the channel in shear. This shearing stress would be

$$\tau = F_H/A = 55,900/[(4 + 2 + 2)(1/2)] = 14,000 \text{ psi} .$$

The vertical component of this force, F_Z, would load the shield locally in compression in the area around the channel and would be of little consequence.

All normal stresses are less than the yield point, 30,000 psi for stainless steel, and shearing stresses are less than the allowable shear stress. Various tie-down geometries are possible when securing the shipping container to the transport vehicle. The most likely tie-down geometry was used in the analysis, which showed that normal stresses are less than the allowable shear stress. If under extreme load the tie-down device fails, damage will be localized to the area of the tie-down lug. This area of the container does not contribute to the function of the shipping container. Failure would not impair the containment or shielding properties of the overall package. Hence the package conforms to the tie-down requirements.

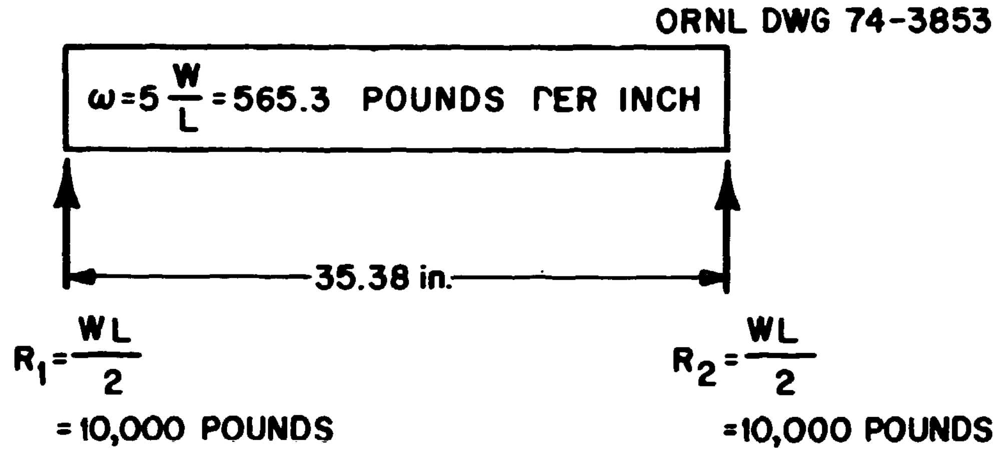
1.3 Standards for Type B Packaging

The structural standards for Type B packaging cover load resistance of the packaging and the external pressure which the package must withstand. The ORNL lithium hydroxide shield complies with these requirements as discussed in the following subsections.

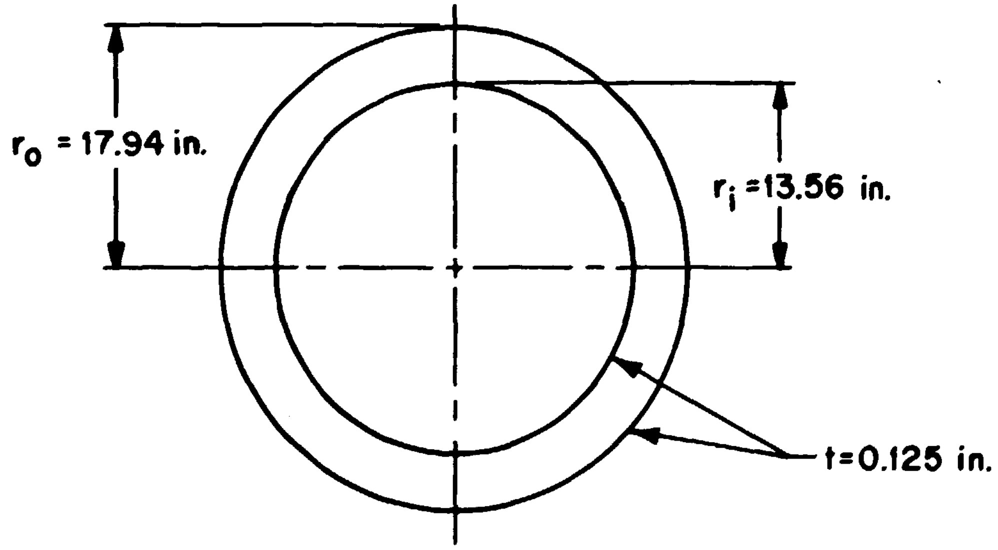
1.3.1 Load resistance

When regarded as a simple beam supported at its ends along any major axis, the shield must be capable of withstanding a static load normal to and uniformly distributed along its length that is equal to five times its fully loaded weight without generating stress in any material of the container in excess of the yield strength of that material. The equivalent cross section of the container analyzed in this study is illustrated in Fig. 1.3.

The cross section of the LiOH shield is composed of the outer stainless steel shell, the $LiOH \cdot H_2O$ salt, and the inner stainless steel shell as shown in Fig. 1.3. Since these components are symmetrical about the same axis, the moment of inertia for the section is the sum of the moments



(a) CONTAINER AS SIMPLE BEAM



(b) EQUIVALENT CROSS SECTION OF CONTAINER

Fig. 1.3. Simple beam model.

of inertia of the individual components. For a thin shell the moment of inertia about its center is

$$I_s = \int y^2 \, dA = \int_0^{\pi/2} (r_m^2 \sin^2\theta) t r_m \, d\theta = \pi r_m^3 t \ ,$$

where

r_m = mean radius (in.),

t = thickness (in.).

Neglecting the effect of the $LiOH \cdot H_2O$ and since $t_o = t_i = t$, the moment of inertia of the composite section is

$$I = \pi (r_o^3 + r_i^3) t = \pi [(17.94)^3 + (13.56)^3](1/8) = 3250 \text{ in.}^4 \ .$$

The maximum bending stress is

$$\sigma = Mc/I = \omega (L)^2 r_o/(8I) = [(565.3)(35.38)^2(17.94)]/[(8)(3250)]$$
$$= 490 \text{ psi} \ ,$$

where ω = weight per unit length (lb/in.), which is small compared with the yield strength of the material.

1.3.2 External pressure

The regulations require that the shipping package be adequate to assure that the vessel will suffer no loss of contents if subjected to an external pressure of 25 psig. For calculational purposes it will be assumed that the LiOH cavity is at atmospheric pressure.

A potential consequence of external pressure is buckling of the cylindrical shells. The outer shell of the vessel or body is probably the most vulnerable shell from a buckling standpoint. It is strengthened by the fins and four channels and supported by the $LiOH \cdot H_2O$; hence it is not readily analyzed. If the conservative approach is taken of neglecting these reinforcements and assuming the simplified model of a right circular cylinder 26 in. in outside diameter by 30.25 in. long by 0.125 in. in wall thickness with closed ends, the critical (buckling) pressure can be determined using equations published by Faupel.[6] For axisymmetric (bellows type) buckling, the critical pressure is found from

$$P_{cr} = [2E(t/r_m)^2]/[3(1 - \nu^2)]^{1/2}$$

$$= [2(20 \times 10^6)(0.125/18.0)^2]/[3(1 - 0.3^2)]^{1/2}$$

$$= 1693 \text{ psig} .$$

For lobar buckling,

$$P_{cr} = \frac{1.345E(t/r_m)^{5/2}}{(1 - \nu^2)^{3/4}[(1.57)(L/r_m) - (t/r_m)^{1/2}]}$$

$$= \frac{1.345(29 \times 10^6)(0.125/18.0)^{5/2}}{(1 - 0.3^2)^{3/4}[(1.57)(30.25/18.0) - (0.125/18.0)^{1/2}]}$$

$$= 66 \text{ psig} .$$

Since the critical buckling pressure of 66 psig is greater than 25 psi, the shells will not buckle.

External pressure would load the flat ends of both the base and lid. The plates forming the inner and outer heads are braced by the crossed 4 by 4 lumber and the lid plates by the lifting socket.

Both sets of plates are also supported over their entire area by the $LiOH \cdot H_2O$, which has a crushing strength in excess of 25 psig. It is therefore concluded that the heads will not fail when subjected to the 25-psig external pressure.

Primary containments formed by the special form container will withstand the 25-psig external pressure, since they are tested (see Sect. 1.7 and ref. 5) at 1.5 times the design pressure of 21 psig.

1.4 Compliance with Standards for Normal Conditions of Transport

The regulations for normal conditions of transport for a single package require that the effectiveness of the package will not be substantially reduced by the normal conditions of transport and that there will be no release of radioactive material from the containment vessel. The contents of the container are limited such that there will be no gases or vapors in the package that could reduce the effectiveness of the packaging. There is no circulating coolant other than atmospheric air, and there is no mechanical cooling device required or provided. The shield and the inner container(s) are so designed that the contents will not be vented to the atmosphere under normal conditions of transport. These normal conditions include the effects of heat, cold, pressure, free drop, and penetration.

1.4.1 Heat

The package must be able to withstand direct sunlight at an ambient temperature of 130°F in still air without reducing the effectiveness of the packaging. A computer program,[7] HEATING 3 (see Sect. 2.0), was used to compute the steady-state temperature distribution in the package and its contents under the specified conditions. The dimensional model is shown in Fig. 2.1 and the input constants in Table 2.1. The computed temperatures at locations of concern are outlined in Table 2.2. These temperatures will not adversely affect the shields. The materials of construction do not suffer significant loss of physical properties at these temperatures. The LiOH cavity temperature is below the level where water of hydration would be lost, and the maximum calculated surface temperature is below the minimum release temperature of the fusible plugs (208°F). The calculated pressures (see Sect. 2.3.4) will not adversely affect the shields.

The DOT regulations stipulate that the temperature of any accessible surface of the fully loaded shipping package shall not exceed 122°F when the package is in the shade in still air at an ambient temperature. For this evaluation, ambient temperatures were assumed to be 100°F, and the referenced computer program[7] was used to compute the maximum shield surface temperature with the shield loaded with a heat load of 300 W. The maximum accessible surface temperature was found to be 118°F, which occurred at the centerline on the bottom of the vessel.

1.4.2 Cold

The shipping package must be able to withstand an ambient temperature of -40°F (420°R) in still air and shade. Using the same methods of analysis used in Sect. 1.4.3 and assuming no internal heat load, the final or maximum pressure (P) in any cavity sealed at a pressure of 14.7 psia and a temperature of 70°F (530°R) is

$$P = P_1T_2/T_1 = (14.7)(420)/(530) = 11.65 \text{ psia} .$$

The resulting pressure differential is not significant by comparison with the 25-psig external pressure of Sect. 1.3.2. A temperature of -40°F is within the operating temperature range of the materials of the package. Brittle fracture of the shield under the stipulated cold condition is not credible because the temperatures of all the components of the shield will be above the ductile-to-brittle transition temperatures of the materials from which the shields are constructed. Therefore, the stipulated cold condition will not reduce the effectiveness of the packaging, and the package conforms to the requirements for the cold condition of normal transport.

1.4.3 Pressure

The regulations for normal conditions of transport specify that the package be able to withstand an atmospheric pressure of 0.5 times the standard atmospheric pressure, the resulting pressure being 7.35 psia. The shield is not equipped with a gasket; hence the cavity would also be at the reduced pressure. The LiOH cavities are sealed; therefore, the pressure would not drop. This reduced atmospheric pressure is additive to the internal pressures in the LiOH cavities attributable to the elevated temperatures resulting from decay heat of the contents and atmospheric conditions (see Sects. 1.3 and 2.0). The inner containers (secondary and/or primary containment) are designed to withstand this differential (see Sect. 1.7).

The pressure differential in the LiOH cavities of the body would be the sum of 7.35 and 3.3, or 10.65 psi, and for the cover cavity the sum of 7.35 and 2.41, or 9.76 psi (see Sects. 2.3.2 and 2.3.4). By comparison with the calculations of Sect. 1.3.2, the inner cylinders will not buckle. The hoop stress, σ_h, in the outer cylinder would be

$$\sigma_h = Pr/t = (10.65)(18)/(0.125) = 1540 \text{ psi} ,$$

where

P = pressure (psi),

r = radius (in.),

t = wall thickness (in.).

The flat heads of the base and the cover are connected at the center. The plates forming the base head are 1/4 in. thick, while the cover is formed by a 1/4-in.-thick lower plate and a braced 1/8-in.-thick upper plate. The plates in the lid represent a more stressed condition than do the plates in the body due to the center support (see Fig. 0.1).

Calculation techniques for determining the stress in the 1/8-in. reinforced plate were not evident in the literature; consequently, the lid was hydrostatically pressure tested to determine its ability to withstand the reduced pressure requirement. The lid was pressurized to 11 psig and the deflection measured at various pressures. The results of this test are presented in Appendix D.

The 1/4-in. lower plate could be analyzed, and the formulas for this calculation have been coded into a FORTRAN program. The derivation of this program is presented in Appendix D along with the compilation of the program.

The hydrostatic pressure test of the head indicates that there was no significant permanent deformation of the 1/8-in. reinforced plate;

therefore, yield stress was not exceeded. The calculation for the 1/4-in. lower plate revealed maximum point stresses at or near the yield point of the material; hence, significant deformations will not occur. It is, therefore, concluded that the package complies with the reduced atmosphere requirement.

1.4.4 Vibrations

The regulations require packages to withstand the vibrations normally incident to transport.

The shields are of welded construction, and all welds are complete penetration. Transport vibrations are not expected to affect the integrity of the shield weldment. The $LiOH \cdot H_2O$ forms a hard cake after filling. Vibrations are not expected to cause cracks or settling. Fasteners will be seal wired and will not loosen due to transport vibrations.

1.4.5 Water spray

The regulation specifies that package effectiveness not be reduced when subjected to a water spray sufficiently heavy to keep the entire surface of the package except the bottom continuously wet for a period of 3 min.

The specified water spray will not affect the integrity of the stainless steel LiOH shield.

1.4.6 Free drop

The regulations for normal conditions of transport require that a package weighing less than 10,000 lb be capable of withstanding a free drop through a distance of 4 ft onto a flat, essentially unyielding, horizontal surface, striking the surface in a position in which maximum damage is expected to result.

Only for the corner drop is impact directly on the container body. All other drop orientations result in impact on an extension of the body, for example, cooling fins, which acts as an energy absorber. Therefore, the maximum damage would result from a drop onto the top corner. There would be some local permanent deformation of the lid. The corner welds are of a design and quality that a rupture would not likely occur. Containment would be maintained, and the deformation would not affect the heat transfer capabilities of the package. These conclusions are based on the results of the 30-ft and 40-in. free-fall tests of the full-scale model discussed in Sect. 1.5 and the testing of a 3800-lb container employing gypsum plaster in lieu of the LiOH reported by Evans.[14] If a weld rupture did occur, routine inspections (see Appendix C) would result in detection and repair before further usage.

1.4.7 Penetration

The regulations for normal conditions of transport also stipulate that the package be capable of withstanding the impact of the hemispherical end of a vertical steel cylinder which weighs 13 lb, has a diameter of 1-1/4 in., and is dropped from a height of 40 in., normally onto the exposed surface of the package that is expected to be the most vulnerable to puncture. This test was conducted on an unfilled LiOH shield and did not reduce the effectiveness of the shield. The results were no more than a very superficial dent in the stainless steel surface of the LiOH shield.

1.4.8 Compression

It is required that packages weighing less than 10,000 lb be capable of withstanding a compression load of five times the container weight, or 2 lb/in.^{2}, distributed uniformly across the top or bottom, whichever is greater. Five times the weight of the container is greater than 2 psi for the LiOH shield. The maximum compressive stress occurs in the lid and is, neglecting the contribution of the $LiOH \cdot H_2O$,

$$\sigma = P/A = (5W)/(\pi D_o t) = [(5)(5000)]/[(\pi)(34.0)(0.125)] = 1500 \text{ psi} ,$$

where

W = weight of container = 4000 lb,
D_0 = mean diameter of outer wall (in.),
t = wall thickness (in.).

The shield adequately meets this requirement in that the stresses generated by the compression load are very much less than the allowable yield stress.

1.5 Compliance with Standards for Hypothetical Accident Conditions

The standards for the hypothetical accident conditions stipulate that a package used for the shipment of fissile or a large quantity of radioactive material shall be so designed and constructed and its contents so limited that if it is subjected to the specified free-drop, puncture, thermal, and water immersion conditions, the reduction in shielding would not be sufficient to increase the external radiation dose rate to more than 1000 millirems/hr at 3 ft from the outside surface of the package, no radioactive material would be released from the package except for gases and contaminated coolant not to exceed 0.1% of the total radioactivity of the contents of the package, or specific activity levels specified in the regulations by transport group, and the contents would remain subcritical.

The effects of the free drops are discussed below, and the effects of the thermal exposure are discussed in Sect. 2. The water immersion would result in the cavity being flooded and the LiOH cavities being partially filled with water. The degree of filling would depend on shield orientation. The flooding would not result in criticality (see Sect. 5). Little if any of the LiOH would go into solution and be lost.

1.5.1 Free drop

The first in the sequence of hypothetical accident conditions to which the cask must be subjected is a free drop through a distance of 30 ft onto a flat, essentially unyielding, horizontal surface, striking the surface in a position in which the maximum damage is expected to occur. A full-scale test model was designed and fabricated at ORNL. The model was fabricated in accordance with the ORNL drawings in Appendix E.

1.5.1.1 End drop (bottom). During July 1971, this full-sized model was drop tested at the ORNL Drop Test Facility. The shield was loaded with 2300 lb of lead bricks to simulate an inner Type A or Specification 55 gamma shield. An 8- by 8- by 1-in.-thick steel plate welded to the drop pad at its geometric center for other testing in progress at this time was not removed, since it would effect a more stringent test. The model was dropped from 30 ft, impacting on its bottom. The change in length of the package was less than 1/4 in. The area of the base that contacted the plate was deflected equivalent to the plate thickness of 1 in. There was one visible hairline crack about 1/4 in. long in a weld which impacted in the vicinity of the plate. There was no significant damage to the interior due to the bricks nor was there any breach of the outer shell through which any $LiOH \cdot H_2O$ could be lost. This test was witnessed by ORNL staff members.

1.5.1.2 End drop (top). If the shield impacted on the top, the four vertical channels would contact the pad (unyielding surface) and collapse. The primary concern in a top impact would be separation of the cover from the base. Note that the maximum allowable weight of 2500 lb of an inner shield and contents would place the twenty 1.0-in.-diam bolts in tension due to the inertial forces. Calculations to estimate the accelerations experienced in this impact would be suspect. Hence, five half-scale models of the channel section were tested at the ORNL drop tower on April 18, 1974. The test was conducted in accordance with the procedure in Appendix F. The report of this test and the data are also included in Appendix F. The model shown in Figs. 1.4 and 1.5 was bolted to the bottom of the guided, variable-weight drop hammer. A total weight of 121 lb represents a half-scale of one-fourth the total container weight, the portion applicable to one channel.

Five drops from 30 ft were made. Figure 1.6 indicates the typical damage to the models. Acceleration with respect to time was measured

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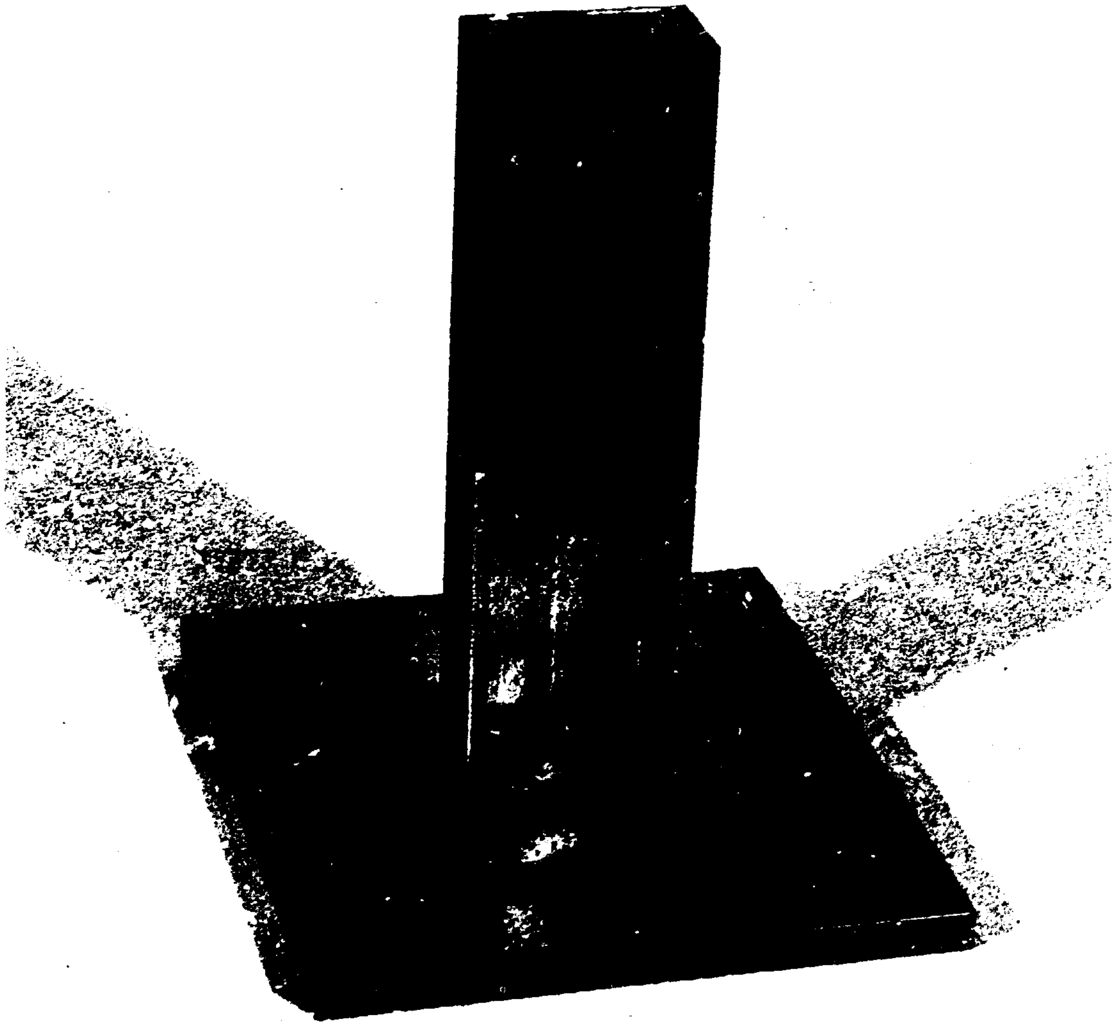

Fig. 1.4. Impact test model.

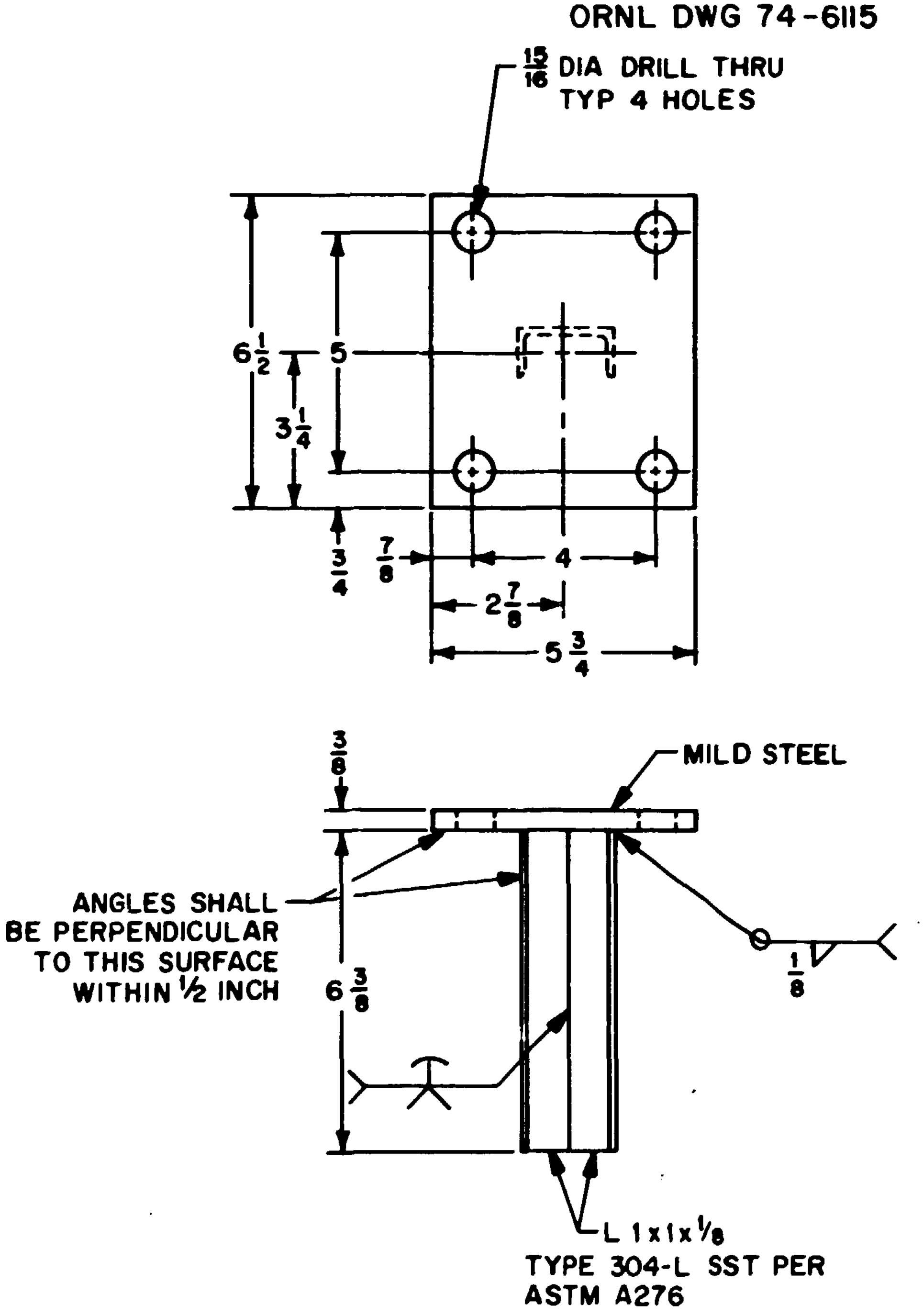

Fig. 1.5. Top impact test model.

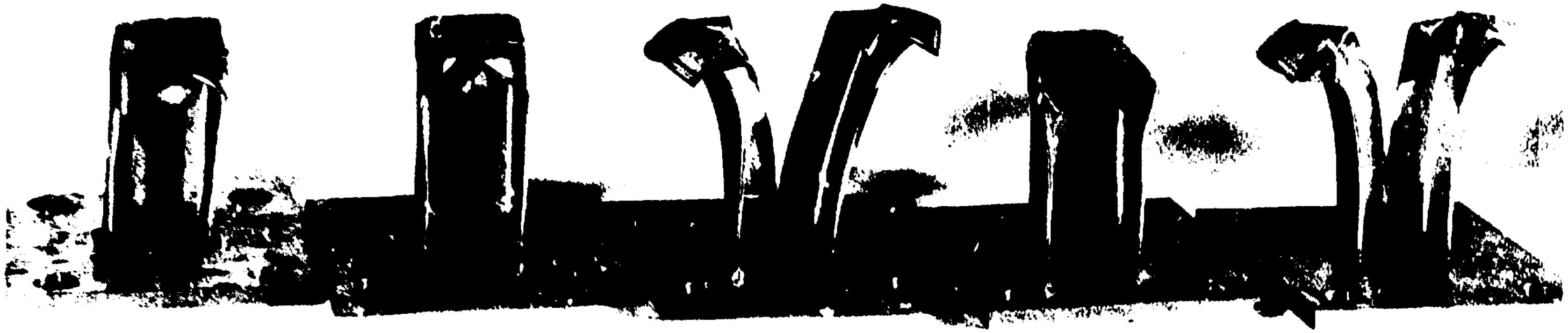

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Fig. 1.6. Models after testing.

using the instrumentation system shown in Fig. 1.7 and the peak recording accelerometer. From the data in Appendix F it can be seen that the acceleration of the half-scale model did not exceed 200 g's. From model theory it can be concluded that the maximum acceleration for the full-sized channel would not exceed one-half this value, or 100 g's, since model theory predicts that accelerations are inversely proportional to scale factor. Hence, for four channels, the shield acceleration would be 100 g's. From Newton's second law, the force, F, applied to the bolts can be found from

$$F = ma - Wa/g - (2730)(100)(32.2)/32.2 = 273{,}000\ \text{lb}\ ,$$

where

W = weight of the contents and lid = 2730 lb,

a = acceleration = 100 g's,

g = gravitational constant $(\text{ft}\cdot\text{lb}_m/\text{lb}_f\cdot\text{sec}^2)$.

Note that this is a conservative approach: it assumes that the lid and contents are rigid. It follows that the stress is

$$\sigma = F/(NA) = 273{,}000/[(20)(0.6051)] = 22{,}600\ \text{psi}\ ,$$

where

N = number of bolts = 20,

A = stress area of one bolt (see ref. 8).

Since this is below the yield stress of the bolts, which is 105,000 psi (see Table 1.1), it can be concluded that the lid will remain in place and that the shield meets the requirements of the regulations.

1.5.2 Impact on side

The highest level of acceleration would occur if the shield impacted normal to one of the channels. The two legs of the channel would collapse similarly to heat transfer fins with very small angles of inclination

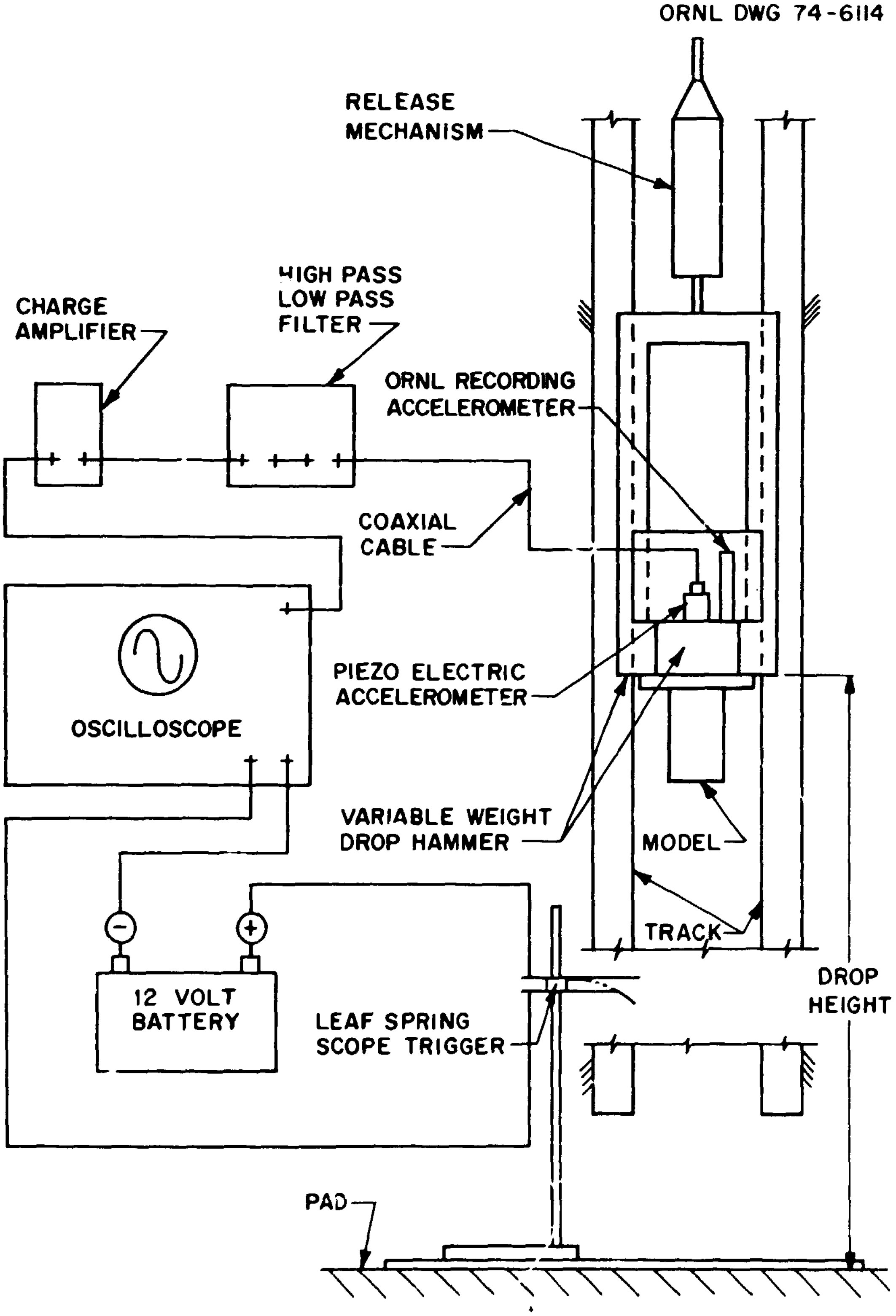

Fig. 1.7. Schematic model testing.

if the turning moment attributable to the closure flange, which strikes first, is neglected. If the data from Fig. 5.10 from Davis's report[9] on fins are extrapolated slightly, the peak force for a fin having a height-to-thickness ratio of 8 is found to be about 9.2×10^4 lb per inch of length. Note that Davis's fin models were 2 in. long. It is believed that there is little difference in the peak force for a stainless steel fin and for the ASTM A285 steel fins Davis tested. This conclusion is supported by static column theory and dynamic tensile stress-strain data by Clark,[10] and is modified to compressive data and presented by Evans.[11] Static column theory states that the critical collapse load for an intermediate column, $30 < L/K < 100$, is a function of material yield strength and L/K, where L = effective column length (in.), and K = least radius of gyration (in.). The dynamic yield point from data by Clark for both 18-8 stainless steel and mild steel is approximately 60,000 psi at an impact velocity of 40 fps.

If the effective length of the channel is taken as 44-1/4 in., the channel length for total fin length of 88-1/2 in., the peak force, F, is

$$F = (9.2 \times 10^4)(88.5) = 8.14 \times 10^6 \text{ lb} .$$

The peak acceleration, a, from Newton's second law is

$$a = Fg/W = (8.14 \times 10^6)(g)/4000 = 2040 \text{ g's} .$$

Again, from Newton's law the shearing force, F_s, on the bolts holding the lid to the base is

$$F_s = W_L a/g = (310)(2040)(g)/g = 632{,}000 \text{ lb} ,$$

where W_L is the weight of the lid = 310 lb.

The shearing stress in the twenty 1-in. closure bolts is

$$\tau = F_s/[(N)(A_B)] = 632{,}000/[(20)(\pi)(1)^2/4] = 40{,}200 \text{ psi} ,$$

which is less than the allowable shear stress of 53,500 psi (see Table 1.1).

The evaluation of Davis's data (see Appendix B of Davis's report[9]) for straight fins revealed that the ratio, K, of the peak or maximum force to the average force was between 1.3 and 3.2. Using this ratio, it can be written that

$$U = F_{avg}\Delta L = F_{max}L\Delta/K = WH \ ,$$

where

U = energy (in.·lb),

Δ = deformation of the fin (in.),

L = total active length of fin (in.),

W = shield weight (lb),

H = drop height (in.),

F_{avg} = average or mean force required to crush a fin per inch of length (lb),

F_{max} = maximum force, that is, force required to start collapse of fin per inch of length (lb).

Solving for Δ and taking K as 3.2 for conservatism,

$$\Delta = (KWH)/(F_{max}L) = [(3.2)(4000)(360)]/[(92,000)(61.5)] = 0.81 \text{ in.}$$

Since Δ is less than the 1.75 in. available for collapse, it is concluded that the channels have the capacity to absorb the kinetic energy possessed by the package; hence there will not be significant damage to the remainder of the package. Note that only the length of the fin rigidly backed by the shield was taken for L. Also, the stainless steel fin would have greater energy absorption capacity than a steel fin of the same geometry due to the strain hardening characteristics of stainless steel.

If the shield impacted on its side in another radial orientation, the closure flange would contact the surface first. There would be some plastic deformation of the flange, and the shield would rotate about the point of contact until the fins at the base contacted the impact surface. The shield's kinetic energy would be dissipated in plastic deformation of the closure flanges, the heat transfer fins, and the shield body. The response of the shield to this impact cannot be calculated by current techniques. However, it can be seen that the accelerations will be less than those calculated for the impact on the channels. Comparison of the structural rigidity of the channel legs and the closure flanges supports this. The previously referenced tests[14] of the 4000-lb plaster-filled container also support this and demonstrate that there will not be gross structural failure which would allow loss of LiOH and that the lid will remain in place.

1.5.3 Puncture

The second in the sequence of hypothetical accident conditions to which the package must be subjected is a free drop through a distance of 40 in. to strike, in a position in which maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding, horizontal surface. The mild steel bar shall have a diameter of 6 in., with the top horizontal and its edge rounded to a radius of not more than 1/4 in., and the bar shall be of such length that it will cause maximum damage to the package but not less than 8 in. long. The long axis of this bar shall be normal to the surface of the package upon impact.

The full-scale test model described in Sect. 1.5.1.1 and Appendix E was dropped from 40 in. onto the bar as described above. The package impacted on the flat bottom. There was no puncture of the outer shell. The permanent deflection in the piston contact area was minimal, less than 1/4 in. The flat bottom was a more vulnerable orientation than the fin-protected circumference and essentially equivalent to the flat top. Based on the observed damage, it is concluded that the shield conforms to the requirements of the regulations.

1.6 Special Form

The ORNL Operations Division is authorized by Laboratory management to certify that a material conforms to the special form requirements of IAEA, Safety Series No. 6, 1973 Revised edition,[4] Section VII. The tests prescribed by the IAEA have been performed on a significant quantity of capsule designs, and Certificates of Competent Authority, meeting the 1973 IAEA requirements, have been issued by the DOT. Typical examples of special form capsules are illustrated in Figs. 1.8 and 1.9. The ORNL special form capsule also meets the leak rate requirements of IAEA Safety Series No. 6 (1973 Revision), Section II for Type B(U) packages.

ORNL DWG 74-3855

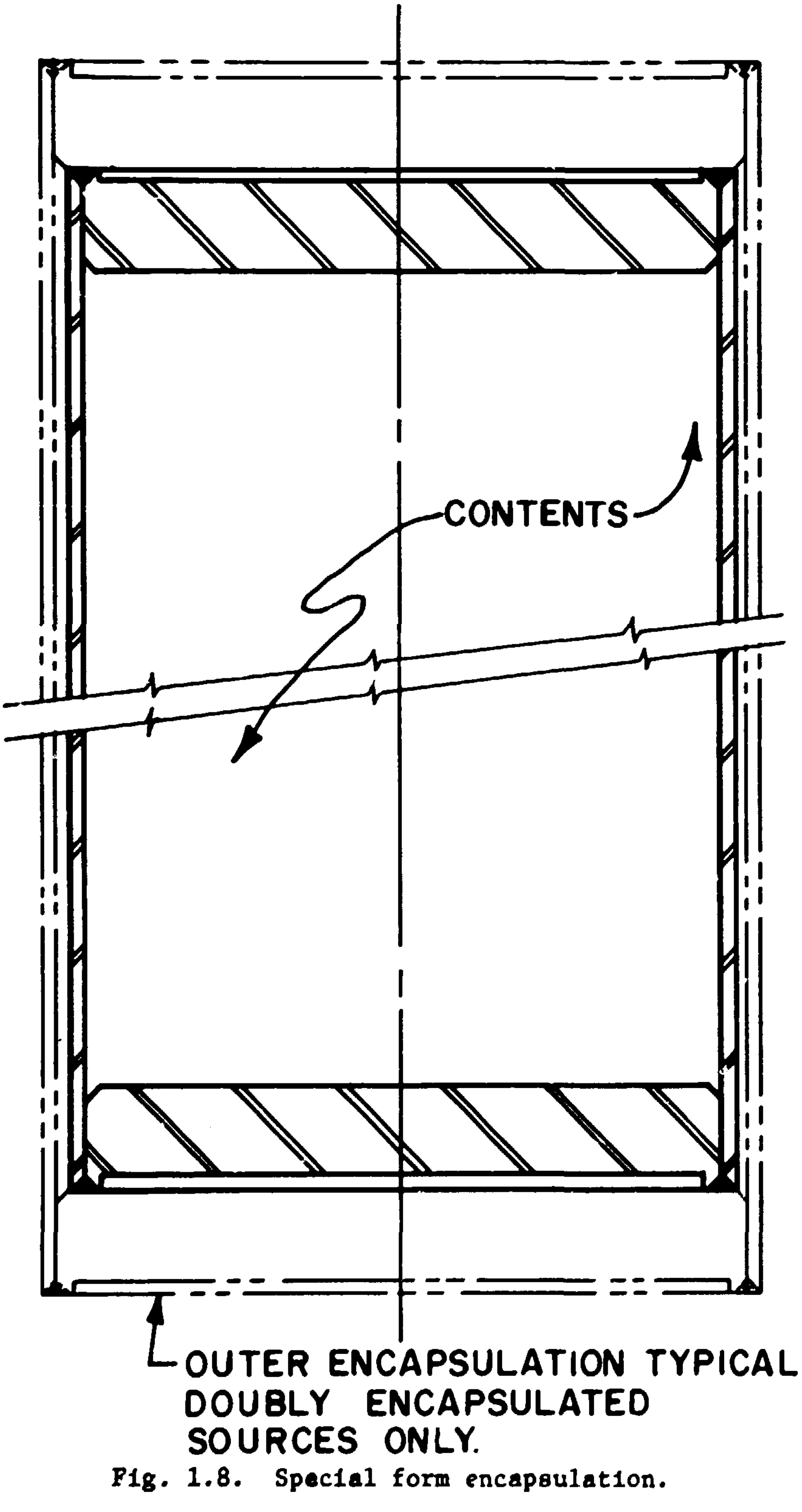

Fig. 1.8. Special form encapsulation.

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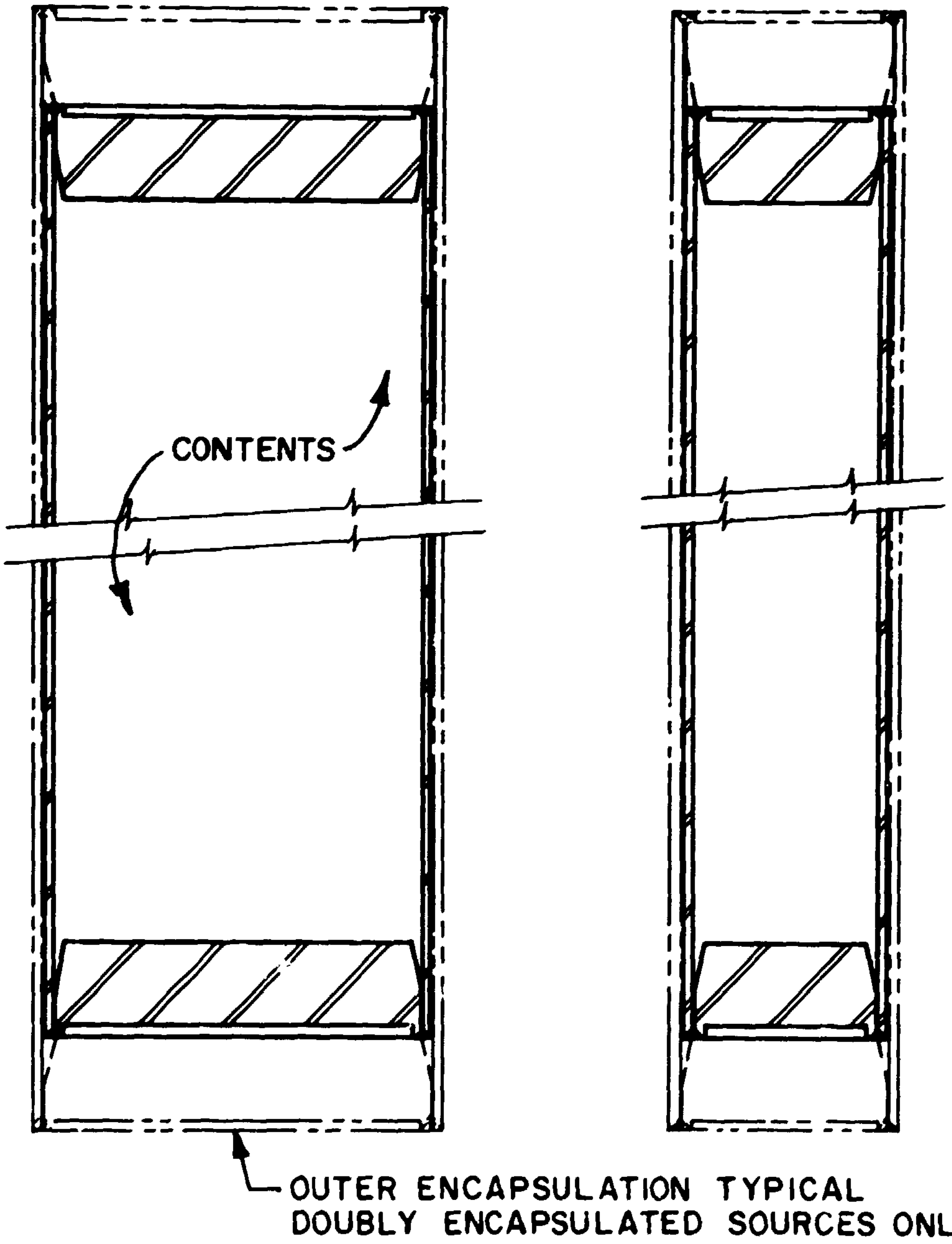

Fig. 1.9. Special form encapsulation.

2. THERMAL EVALUATION

2.1 Discussion

The package must be able to withstand direct sunlight at an ambient temperature of 130°F in still air without reducing the effectiveness of the packaging. The DOT regulations[3] further stipulate that the temperature of any accessible surface of the fully loaded shipping package shall not exceed 122°F when the package is in the shade in still air at an ambient temperature; for this evaulation, ambient temperature was assumed to be 100°F.

The third in the sequence of hypothetical accident conditions to which the cask must be subjected, as specified by the regulations, is exposure for 30 min within a source of radiant heat having a temperature of 1475°F and an emissivity coefficient of 0.9 or equivalent. For calculational purposes, it shall be assumed that the package has an absorption coefficient of 0.8. The package shall not be cooled artificially until after the 30-min test period has expired and the temperature at the center of the package has begun to fall.

A computer program, HEATING-3,[7] was used to determine the temperature distribution and the quantity and location of material which changes phase when the cask is exposed to these thermal environments.

It was assumed that the container was loaded with the maximum permissible decay heat load of 300 W. The temperature distribution from 100°F ambient condition was input as starting temperatures for the accident (fire) calculation.

2.2 Thermal Properties of Materials

The thermal properties of materials used to compute the temperature distribution and material phase change are listed in Table 2.1.

2.3 Thermal Evaluation for Normal Conditions of Transport

2.3.1 Thermal model

The computational model representing the LiOH shield and its intended contents is illustrated in Fig. 2.1. The contents are modeled as a

Table 2.1. Material properties used in thermal analysis

	Temperature (°F)	Thermal conductivity (Btu/hr·ft·°F)	Density (lb/in.^{3})	Heat capacity (Btu/lb·°F)	Latent heat (Btu/lb)
Hydrated lithium hydroxide[a,b,c]	212	0.316	0.031	0.661	560
Dehydrated lithium hydroxide[a,b]		0.2576	0.0243	0.356	
Stainless steel[d]	32	7.73-8.51	0.2861	0.120	
	212	9.43			
	752			0.135	
	932	12.57			
	1292	14.99			
Lead[e,f]	32	20.3	0.41088	0.0305	
	572	17.2			
	621			0.03282	
Plywood[g]		0.1	0.0347	0.1	

[a] The thermal conductivity and density of lithium hydroxide were obtained from a memo from R. J. Lauer to R. D. Seagren, "Monthly Report for June 1969," dated June 27, 1969 (see Appendix J).

[b] The heat capacity of lithium hydroxide was calculated from data taken from J. A. Dean, Lange's Handbook of Chemistry, McGraw-Hill, New York, 1973.

[c] The latent heat of hydrated lithium hydroxide ($LiOH \cdot H_2O$) was based upon the weight fraction of water.

[d] The properties of stainless steel were obtained from A Compilation of Thermal Property Data for Computer Heat-Conduction Calculations, UCRL-50589.

[e] The thermal conduction and density of lead were taken from J. P. Holman, Heat Transfer, McGraw Hill, New York, 1972.

[f] The specific heat of lead was obtained from R. H. Perry, Chemical Engineer's Handbook, McGraw-Hill, New York, 1973.

[g] The thermal properties of plywood were based upon an engineering estimation.

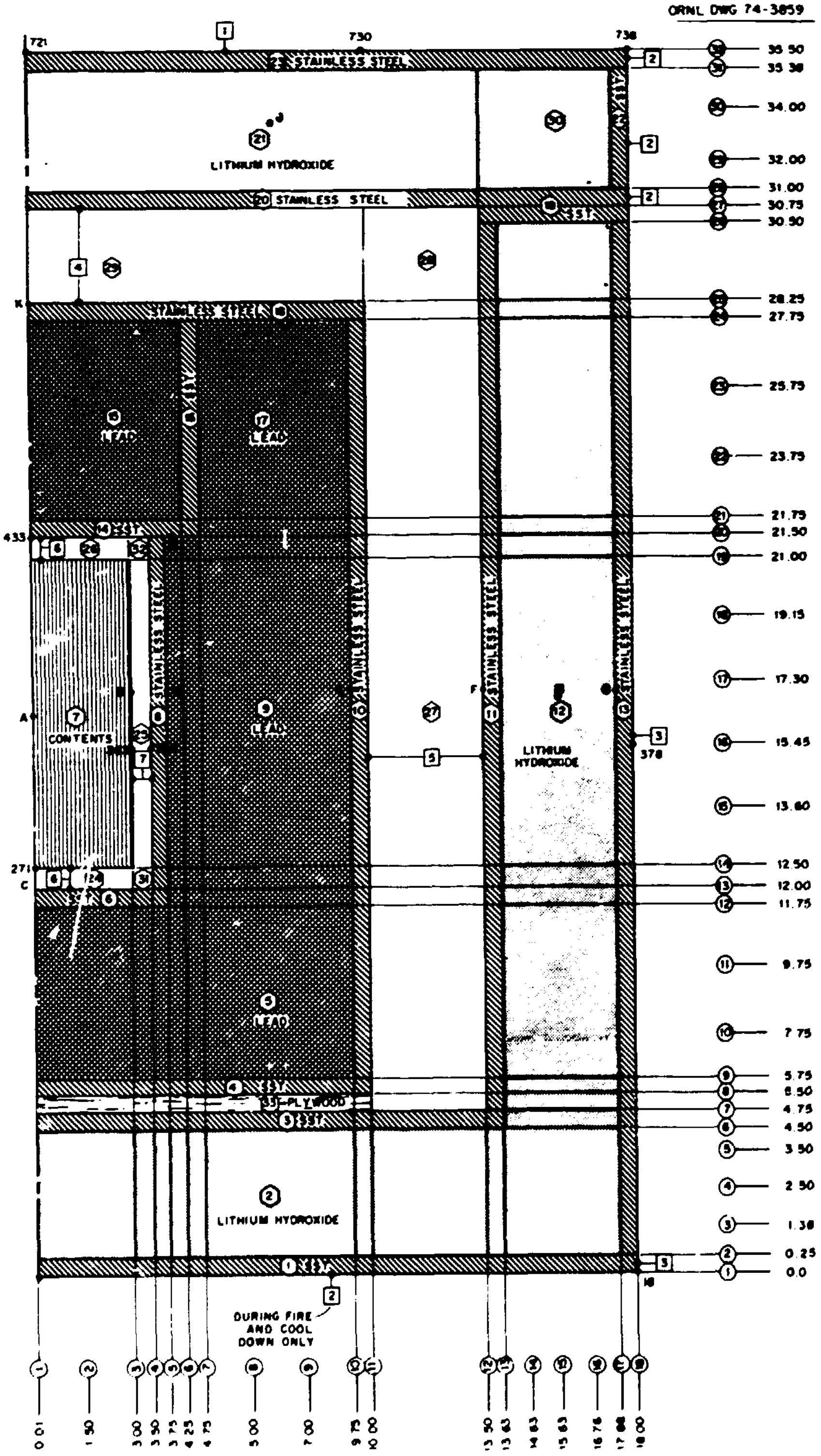

Fig. 2.1. Thermal model.

homogeneous body. The decay heat generation was modeled as being uniformly distributed in the contents. The heat generation rate is assumed to be constant with no decay with time. The contents are separated from the inner container by an air gap as shown. This was done, since the contents will be supported in a rack which has minimum contact. The dimensions of the model of the inner container are typical of the containers used. The base of the cask was assumed to be insulated during normal conditions. The size of the inner shield has very little effect on contents temperature during the specified thermal exposure (fire) due to evaporative cooling from the loss of water from the lithium hydroxide. The efficiency of the fins was calculated, and the heat transfer coefficient for the outer surface was raised to compensate for the exclusion of the fins from the model. These calculations, using equations from Kreith,[13] are shown below:

$$E = [\tanh(mL)]/mL ,$$

where

E = fin effectiveness,
L = fin height = 1 in. = 0.0833 ft,
$m = (hc/KA)^{1/2}$,

in which

h = prevailing convective heat transfer coefficient ($\mathrm{Btu/hr \cdot ft^2 \cdot {}^\circ F}$),
c = fin perimeter = 2 in. = 0.167 ft,
K = fitted thermal conductivity of stainless steel (see Table 2.1)
$= 7.350 + 1.23 \times 10^{-2}T - 1.3 \times 10^{-5}T^2 + 6.22 \times 10^{-9}T^3$ $\mathrm{Btu/hr \cdot ft \cdot {}^\circ F}$,
A - profile area = 1/8 $\mathrm{in.}^2$ = 0.00087 ft^2.

The convective heat transfer coefficient, h, was based upon a laminar natural convection correlation for vertical cylinders. A least-squares fit was made to incorporate the temperature dependence of h and K at an ambient temperature of 100°F, $h = 0.25\Delta T^{0.23}$ Btu/hr·ft^2·°F.

The factor, F, by which h is increased to obtain the effect of the fins is

$$F = (A_b + A_F E)/A_b ,$$

where

A_b = base area = $\pi DH = \pi(36)(30.5) = 3450$ in.^{2},
A_F = fin area = $HN(2L + t) = 92(30.5)[2(1) + 0.125] = 5960$ in.^{2},

in which

N = number of fins = 92,
H = fin length = 30.5 in.,
t = fin thickness = 0.125.

Thus, the effective heat transfer coefficient can be calculated from

$$h_e = (0.25\Delta T^{0.23})F \text{ Btu/hr·ft}^2\text{·°F} .$$

The effective surface emissivity for the finned area of the cask was calculated using the equations in the Cask Designer's Guide[16] for a cavity-type radiator. The surface emissivity was assumed to be 0.6. The effective emissivity was found to be 0.81.

After the above results (Table 2.2) were calculated, region 24 (Fig. 2.1) was changed from air to stainless steel to simulate an inner container which would always contact the bottom of the shielded container. This also simulates the effect of a concentrated heat source. Results indicated there were only minor differences in temperature distribution.

Table 2.2. Package temperature during normal conditions of transport

Location[a]	Temperature (°F)		
	130°F air in sunlight	100°F air in shade	100°F air in shade (suspended container)
A. Contents at centerline	530	500	680
B. Contents at midpoint and outer radius	520	490	670
C. Inner container at bottom on centerline	280	220	
D. Mid-elevation inner container inner radius	280	220	
E. Mid-elevation inner container outer radius	270	220	
F. Mid-elevation LiOH shield at inside radius	220	160	200
G. Mid-elevation LiOH shield at outside radius	170	115	120
H. Air temperature LiOH cavity	180	150	160
I. Inner container seal	270	220	
J. Cavity LiOH cap	220	140	120
K. Inner container at top on centerline	200	150	130
L. Air in container	400	350	600

[a] See Fig. 2.1 for location.

2.3.2 Maximum temperatures

The maximum temperatures for the model illustrated in Fig. 2.1 for the environment of 130°F in direct sunlight, with a 300-W load, are presented in Table 2.2. It is assumed that a solar heat flux of 144 Btu/hr·ft^2 was incident on the cask. This value of solar heat flux is the value suggested in the Cask Designer's Guide.[16] For the 100°F in the shade environment, the maximum accessible surface temperatures were 115°F at the midpoint and 110°F near the end on the cylindrical portion of the shield. Since this is less than 122°F, the package complies with the DOT and IAEA surface temperature regulation cited in Sect. 2.1.

2.3.3 Minimum temperatures

Reduced (less than 300 W) or zero heat loads would lower temperatures throughout the container. This situation would not affect the safe operation of the container nor the margin of safety (see Sect. 1.4.2).

2.3.4 Maximum internal pressure

A sealing temperature of 70°F is assumed. Thus, for the 130°F condition, there would be a rise in pressure in the encapsulated contents, the inner container, and the $LiOH \cdot H_2O$ cavities. The resulting pressures are calculated from the gas laws, assuming constant volume and a sealing temperature of T_1 of 70°F (530°R):

$$P_2 = P_1 T_2 / T_1 \;;$$

for the $LiOH \cdot H_2O$ cavity shield cap,

$$P_2 = (14.7)(680)/530 = 18.9 \text{ psia} = 4.2 \text{ psig.}$$

For the cask cavity,

$$P_2 = (14.7)(706)/530 = 19.6 \text{ psia} = 4.9 \text{ psig} ;$$

and for the $LiOH \cdot H_2O$ cavity,

$$P_2 = (14.7)(657)/530 = 18.2 \text{ psia} = 3.5 \text{ psig} .$$

2.3.5 Thermal stress

There are no thermal gradients sufficient to cause significant thermal stresses in metallic members.

2.4 Hypothetical Thermal Accident Evaluation

The damage from the free-drop and puncture portions of the hypothetical accident would not adversely affect the performance of the shield in the hypothetical thermal accident. Hence the undamaged configuration was assumed.

2.4.1 Fire testing

A full-sized model of the shield as detailed on the drawings (see Appendix E) was fire tested as described below. The lithium hydroxide cavities were vented via 1/2-in.-diam vent holes[15] for fire testing as shown on the drawings.

The fire test was carried out at the Oak Ridge Gaseous Diffusion Plant (ORGDP) fire test site. One hundred fifty gallons of diesel fuel were pumped into the outer tank, 100 gal into the middle tank, and 55 gal into the center tank. This was in accordance with normal fire test operating methods at the ORGDP fire test facility. Water was added to each tank to bring the oil level up to within 10 in. of the rails on which the shield rested.

The oil was ignited at 10:49 a.m. on July 23, 1971. Five minutes after oil ignition, cracking noises were heard. The cracking noises increased in frequency and continued until about 11.20 a.m. At 11.15 a.m.

it was possible to observe the package momentarily from time to time. Steam was issuing from the vents in the lid, and steam appeared to be venting from one side of the package.

There was complete flame coverage until 11:25 a.m. (30 min) and partial flame coverage for an additional 10 to 15 min before the fire self-extinguished. Steam was still issuing from the lid when the fire went out.

Examination of the shield showed that the cracking noise was the popping of the almost dry LiOH being forced out of the vents by the steam inside. Evidently, LiOH would build up over the vent holes and would be blown out. There was LiOH spattered over a radius of 10 ft around the shield. The shield itself was covered with spattered LiOH. It was estimated that no more than 2 to 3 lb of LiOH was lost. The loss was not considered significant.

Examination of the inside of the shield showed no apparent damage. The stainless steel was still shiny, with no evidence of heat tinting. The stenciled heat number and ASTM specification number on the inner cladding were intact and showed no evidence of being heated. The lead bricks, loaded into the shield to simulate a shielded container and contents, were also intact.

2.4.2 Thermal accident analysis

The computational model previously used (see Sect. 2.3.1 and Fig. 2.1) to represent the package was assumed for the thermal analysis. The HEATING-3 computer program[7] was used to determine the temperature distribution in the package that would result from the prescribed 30-min thermal exposure, and the material constants given in Table 2.1 were used as computer input. The thermal conductivity of hydrated lithium hydroxide was used in the thermal analysis throughout the 30-min thermal exposure, with the water of hydration being driven off at 212°F. This is a conservative assumption, since the thermal conductivity of hydrated lithium hydroxide is greater than the thermal conductivity of unhydrated lithium hydroxide. During the subsequent cooldown, the thermal conductivity of unhydrated lithium hydroxide was used in the thermal analysis.

The steady-state temperature distribution computed for the heat condition of 100°F ambience for normal transport and a heat load of 300 W was taken as the starting point; internal heat generation was also included in the transient analysis. During the 30-min thermal exposure and subsequent cooldown, the base of the cask was exposed to the ambient environment.

2.4.3 Container temperatures

The temperature distribution within the shield with respect to time is illustrated in Figs. 2.2 and 2.3. The interior surface of the fire shield does not exceed 240°F at any time; hence the contents would not exceed the special form test temperature of the IAEA Safety Series No. 6 (1973 Revision).

2.4.4 Maximum pressures

The resulting pressure for the cask cavity is

$$P_2 = P_1T_2/T_1 = (14.7)(700)/530 = 19.4 \text{ psia} \simeq 4.7 \text{ psig} ,$$

and for the special form container

$$P_2 = P_1T_2/T_1 = (14.7)(825)/530 = 22.9 \text{ psia} = 8.2 \text{ psig} ;$$

these pressures are negligible.

The $LiOH{\cdot}H_2O$ cavities are equipped with fusible plugs so that they will be vented during a fire.

2.4.5 Evaluation of package performance

The temperatures and pressures resulting from the specified thermal exposure will not result in the release of radioactive material, increase in radiation dose beyond permissible limits, or nuclear criticality. The special form encapsulation will maintain containment of contents. No lead will melt within the inner container. The $LiOH{\cdot}H_2O$ will lose moisture (hydrogen content) as illustrated in Fig. 2.4. The resulting increase in neutron dose will not exceed the specified limits (Sect. 4).

ORNL DWG 77-3115

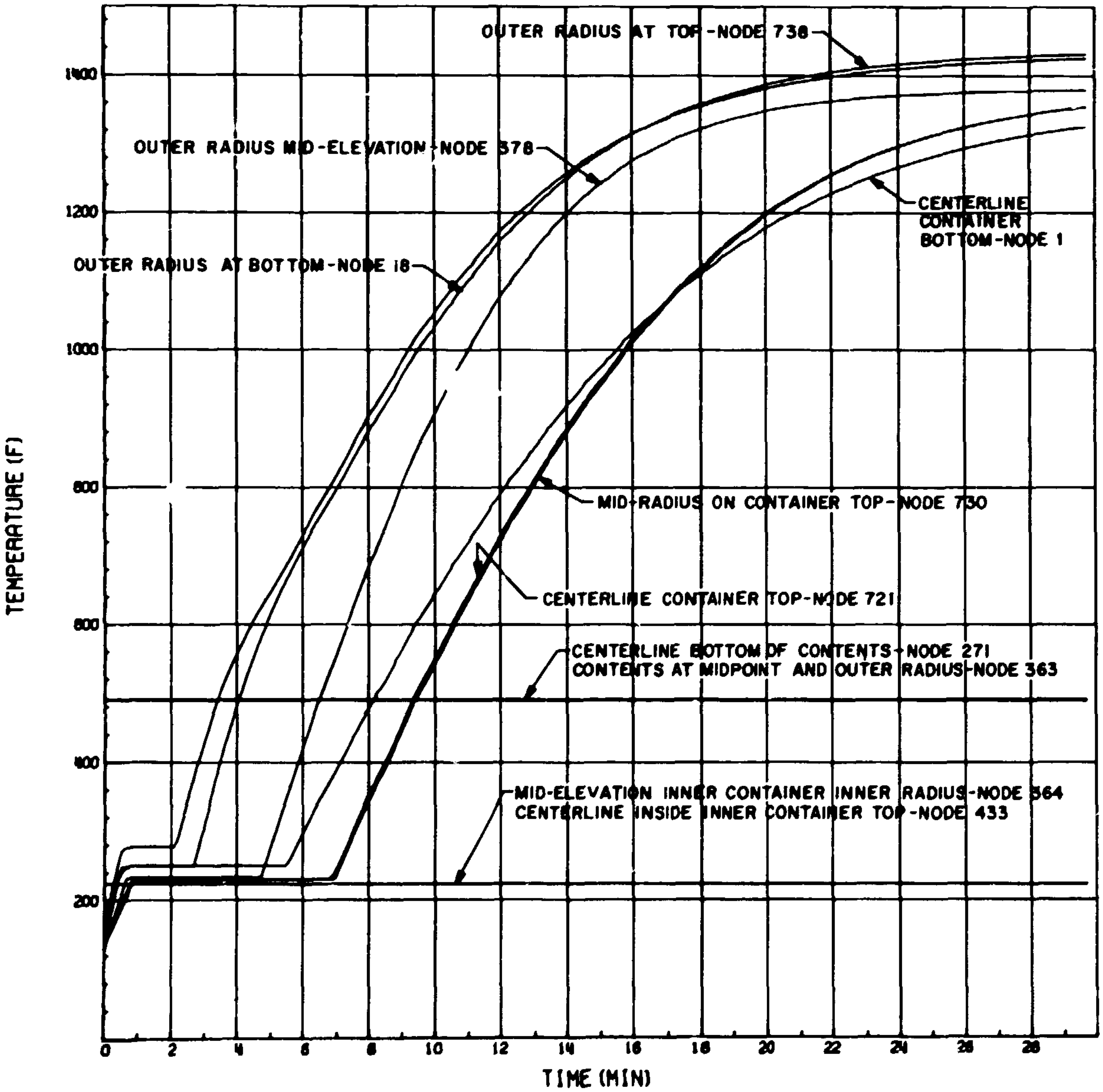

Fig. 2.2. Temperature-time history for cask fire test.

ORNL DWG 77-3116

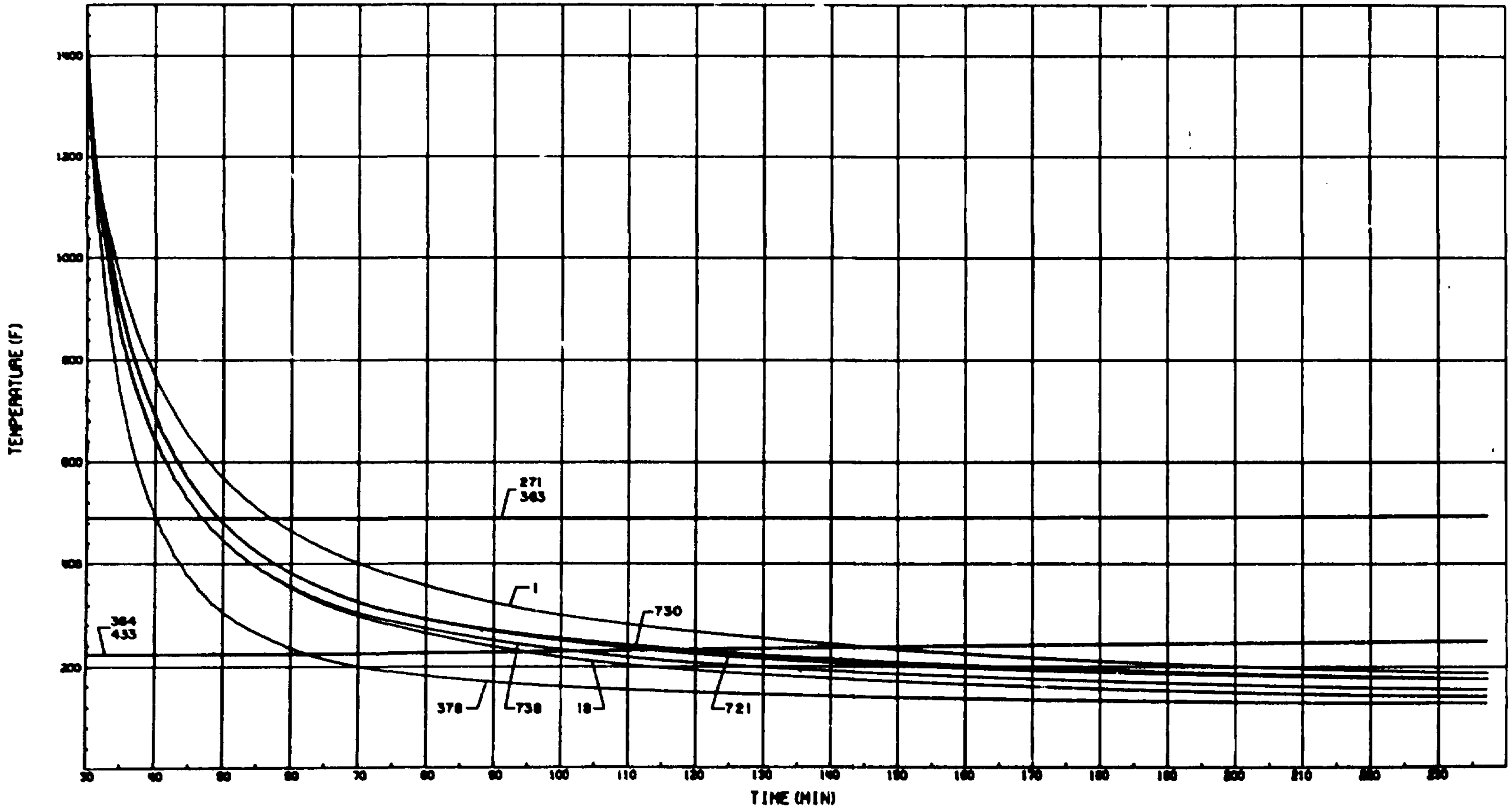

Fig. 2.3. Temperature-time history for cask cooldown (see Fig. 2.2 for node identification).

ORNL DWG 74-3860

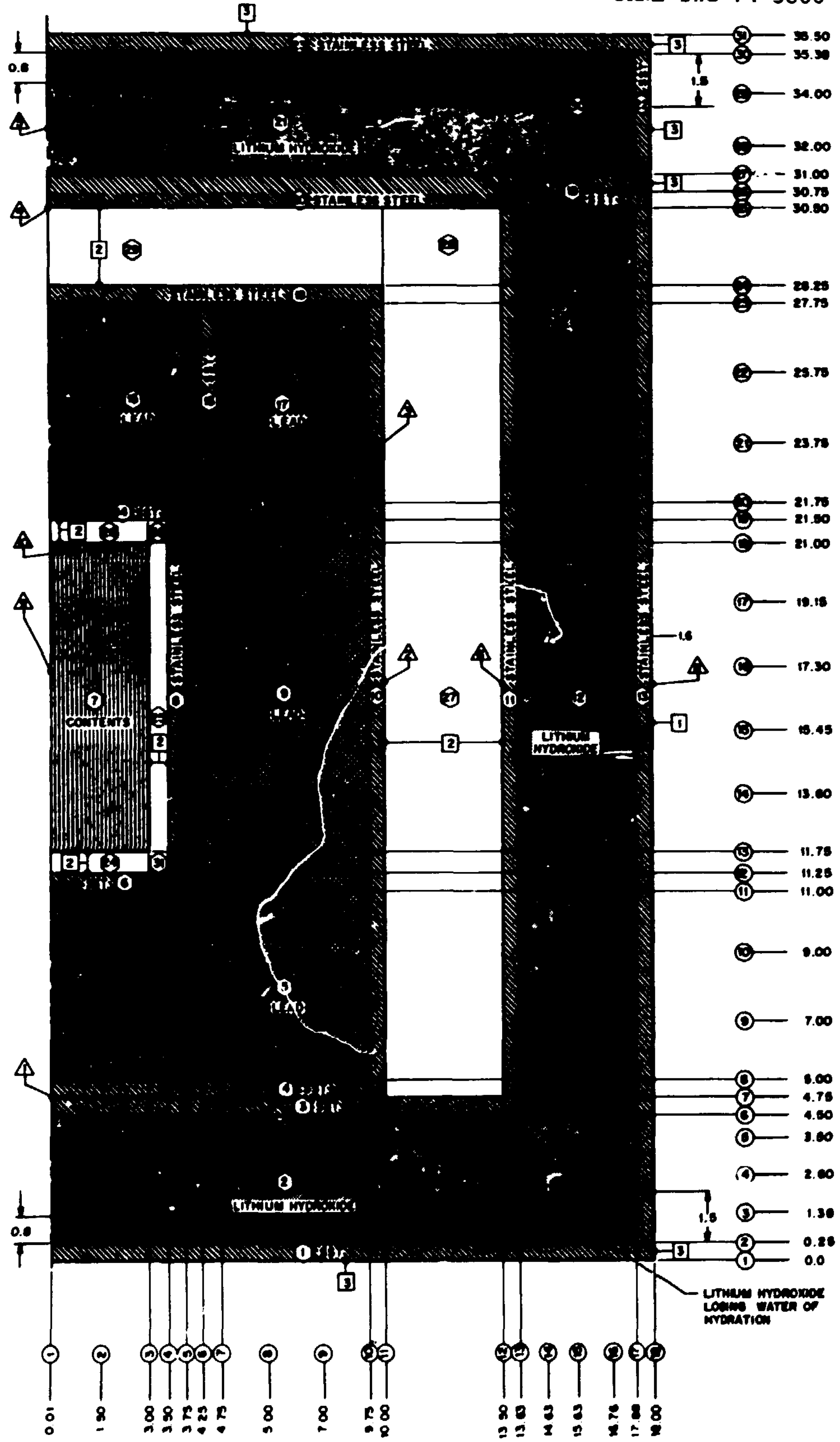

Fig. 2.4. Thermal model — LiOH losing water of hydration.

3. CONTAINMENT

3.1 Containment Boundaries

Containment boundaries for the shipping options available with this package are described below.

3.1.1 Special form shipments

For all special form shipments, the welded encapsulation forms primary containment which meets the IAEA Safety Series No. 6 (1973 Revision) for Type B(U) packaging. See Figs. 1.8 and 1.9 for examples of special form encapsulations and Sect. 1.6 for description of ORNL special form certification. If the material is doubly encapsulated, the outer welded capsule forms secondary containment. These lines of containment are routinely leak checked using vacuum-bubble[12] leak detection techniques (Appendix C). The radioisotope shipping cask supplies gamma shielding and also forms an additional line of containment. These containers are equipped with gasketed closures which are periodically leak checked.

3.1.2 Other shipments

Solids such as metal specimens, etc., meeting the definition of special form may be shipped in containers which are not designed for leak checking. The required gamma shielding is supplied by the Type A shipping cask and forms secondary containment. The fire test performed on the LiOH shield showed that the lead shielding would not melt under accident conditions and the packaging would meet the shielding requirements for IAEA Safety Series No. 6 (1973 Revision), Section II, for Type B(U) packages.

3.2 Requirements for Normal Conditions of Transport

The test sequence for special form is more severe than the requirements for normal conditions of transport; hence, there will be no release of radioactive material from the containment vessel(s). The pressure rises encountered will be less than those experienced in the special form thermal test. There will be essentially no contamination of primary coolant (air).

3.3 Requirements for the Hypothetical Accident Conditions

The test series for special form demonstrates that special form encapsulation will not fail nor leak contents as the result of the free falls. The special form thermal test results in temperatures in excess of those applicable to the contents during the specified thermal exposure (see Sect. 2); hence there will be no release during the thermal exposure. The water immersion test for special form is identical to the hypothetical accident.

4. SHIELDING

Shielding from neutrons is effected by the $LiOH \cdot H_2O$ in the fire and impact shield. The gamma shielding is provided by the DOT Type A inner container. The user is required (see Sect. 6) by the operating procedures and checklist to monitor each package to ensure that the external radiation dose rate does not exceed that allowed by the regulations.

The hypothetical accident will not reduce the shielding effectiveness of an inner container. There will be no significant redistribution of lead shielding, and no lead will melt (see Sects. 1.5 and 2.4). The specified temperature excursion will result in a reduction in the effectiveness of shielding from neutrons. The water of hydration will be evaporated, and the $LiOH \cdot H_2O$ will become LiOH in the region indicated in Fig. 2.4. The effect of this shielding loss was evaluated. A copy of the results of these calculations is presented in Appendix G. In summary, this evaluation demonstrates that if the neutron dose rate level is equal to the maximum allowable for shipment, it will not exceed the allowable after the accident.

5. CRITICALITY

The regulations require that packages used for the transport of fissile material shall be so designed and constructed, and the contents so limited, that they would be subcritical if it is assumed that water leaks into the containment vessel; that water moderation of the contents occurs to the most reactive credible extent consistent with the chemical and physical form of the contents; and that the containment vessel is fully reflected on all sides by water.

There are additional requirements for packages containing liquids which do not apply to the LiOH shield. It is also required that a package used for the shipment of fissile material shall be designed and constructed, and its contents so limited, that under normal conditions of transport specified in the regulation, considered individually, the package will be subcritical and the geometric form of the package contents will not be substantially altered. There will be no leakage of water into the containment vessel. This requirement need not be met if, in the evaluation of undamaged packages for compliance with Fissile Class I requirements below, it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material.

It is also required that when subjected to the specified normal conditions of transport, there will be no substantial reduction in the effectiveness of the packaging, including the specific requirements below: (1) a reduction by more than 5% in the total effective volume of the packaging of which nuclear safety is assessed; (2) a reduction by more than 5% to the effective spacing on which nuclear safety is assessed between the center of the containment vessel and the outer surface of the packaging; (3) the occurrence of any aperture in the outer surface of the packaging large enough to permit the entry of a 4-in. cube.

The regulations specify that a package used for the shipment of fissile material shall be so designed and constructed, and its contents so limited that, if subjected to the sequence of the hypothetical accident conditions specified in Annex 2 of the regulations, the package would be subcritical. In determining whether this standard is satisfied, the conditions outlined below shall be assumed.

The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents.

Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.

There is reflection by water on all sides and as close as is consistent with the damaged condition of the package.

A Fissile Class I package shall be so designed and constructed, and its contents so limited, that compliance with the requirements below are ensured.

Any number of such undamaged packages would be subcritical in any arrangement, and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered. Two hundred fifty such packages would be subcritical in any arrangement, if each package were subjected to the sequence of the hypothetical accident conditions specified in Annex 2, with close reflection by water on all sides of the array and with optimum interspersed moderation unless there is a greater amount of interspersed moderation in packaging, in which case that greater amount may be considered. The condition of the package shall be assumed to be as described below.

It shall be assumed that the fissile material is in the most reactive credible configuration consistent with the damaged condition of the package, the chemical and physical form of the contents, and controls exercised over the number of packages to be transported together. It shall also be assumed that water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.

The ORNL Criticality Committee has evaluated the package and its contents as described in Sect. 0.2 and the as-built drawings in Appendix A. This evaluation, presented in Appendix H, demonstrates compliance with the regulations for Fissile Class I shipments.

6. QUALITY ASSURANCE

6.1 Fabrication, Inspection, and Acceptance Tests

The majority of the fabrication work on these shields was performed prior to the requirements for a formal quality assurance program. The fabrication was performed in ORNL Shops in accordance with normal shop fabrication procedures. Material was specified on the original drawings as "304L SST." Material was withdrawn from ORNL Stores stock. The material used conforms to the requirements of note I of as-built drawing M-11566-EM-001-D, since ORNL Stores stock is purchased by these specifications. The existing weldments were inspected by ORNL personnel for conformance to the as-built drawings and quality of workmanship required by the drawings. In the opinion of the inspecting personnel, the weldments were built in accordance with the drawings and specifications. The ORNL report is presented in Appendix I.

The modifications to the weldments were performed in accordance with the drawings, notes, and the applicable ORNL Quality Assurance Procedures. The welds were made in accordance with the WPS procedures and inspected as specified by note II.2 of the drawings. The material used in modifications was withdrawn from ORNL Stores stock which was purchased in accordance with the specifications in note I. The lithium hydroxide monohydrate was poured in accordance with the procedure on the drawing (note VI). The leak tests required by note III of the drawing were performed to verify the integrity and leak-tightness of the weldment. Dimensional inspections of the completed containers were performed. Weld and dimensional inspection reports and leak tests reports are presented in Appendix I. Each container was tested for homogeneity of the $LiOH \cdot H_2O$ pour (neutron shielding) per note VI of the drawing.

6.2 Operating Procedures and Routine Inspection

The ORNL Operations Division has established packing and routine inspection procedures to ensure that all shipments are safe and comply with the regulations.[1-3] Copies of the procedures and checklists are presented in Appendix C.

6.3 Periodic Maintenance and Inspection

The design of the shield is such that a dye penetration inspection report, no older than six months, must be maintained in the container's QA file. In addition, the gaskets are replaced every six months. Additional maintenance will be required only when routine inspections indicate damage. There are no time-degradable materials used in the construction of the shields. All inspection and maintenance reports are to be included in the OA files. These files must be auditable and maintained for the life of the container.

REFERENCES

1. U.S. Department of Energy, "Safety Requirements for the Packaging of Fissile and Other Radioactive Materials," in DOE 5480.1A Chapter III.

2. *Code of Federal Regulations*, Title 10, Part 71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions."

3. *Code of Federal Regulations*, Title 49, Part 173, "Transportation."

4. International Atomic Energy Agency, Safety Series No. 6, *Regulations for the Safe Transport of Radioactive Material*, 1973 Revised Edition.

5. *ASME Boiler and Pressure Vessel Code*, Section VIII, "Pressure Vessels," Division I, American Society of Mechanical Engineers, New York, July 1, 1974.

6. Joseph H. Faupel, *Engineering Design, a Synthesis of Stress Analysis and Materials Engineering*, Wiley, New York, 1964.

7. W. D. Turner and M. Siman-Tov, *HEATING-3, an IBM 360 Heat Conduction Program*, ORNL/TM-3208 (February 1972).

8. E. Oberg and F. O. Jones, *Machinery's Handbook*, Industrial Press, 17th Ed. (1964).

9. F. C. Davis, *Structural Analysis of Shipping Casks, Vol. 9, Energy Absorption Capabilities of Plastically Deformed Struts under Specified Impact Loading Conditions*, ORNL/TM-1312 (February 1971).

10. D. S. Clark, *The Influence of Impact Velocity on the Tensile Characteristics of Some Aircraft Metals and Alloys*, National Advisory Committee for Aeronautics, Technical Note No. 868 (October 1942).

11. J. H. Evans, *Design and Analysis of the New Brunswick Laboratory High Level Waste Cask*, ORNL/TM-4242 (June 1973).

12. American National Standards Institute, "Leakage Tests on Packages of Radioactive Materials," ANSI N 14.5, 1977.

13. F. Kreith, *Principles of Heat Transfer*, International Textbook Company, Scranton, Pa., 1966.

14. J. H. Evans, *Safety Analysis Report for Packaging Lawrence Livermore Laboratories Shipping Containers*, ORNL/TM-4905 (in publication).

15. R. D. Seagren, personal communication (unpublished data).

16. L. B. Shappert, *Cask Designer's Guide*, ORNL/NSIC-68 (February 1970).

Appendix A

AS-BUILT DRAWINGS

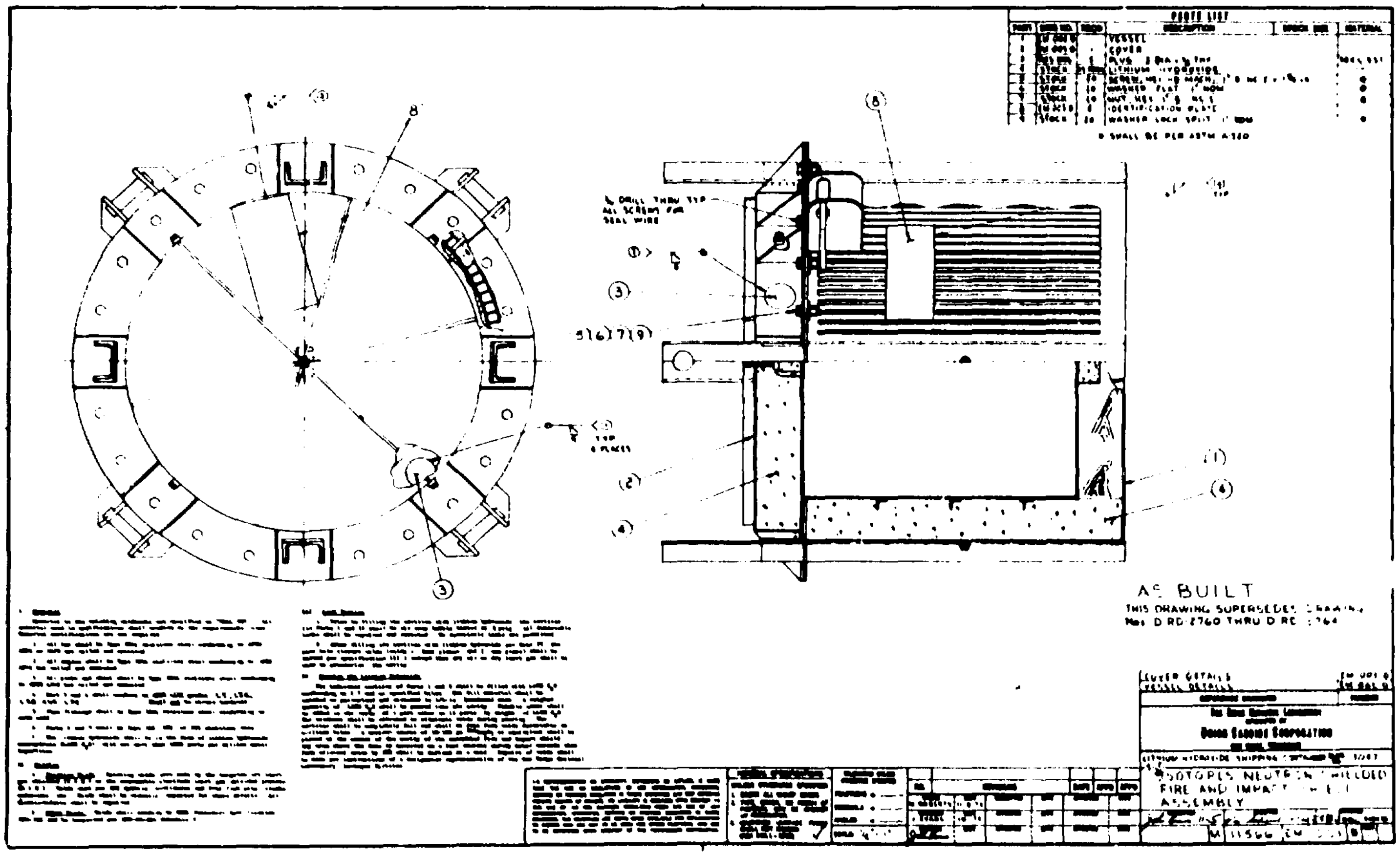

Fig. A.1. As-built drawing no. M-11566-EM-001-D.

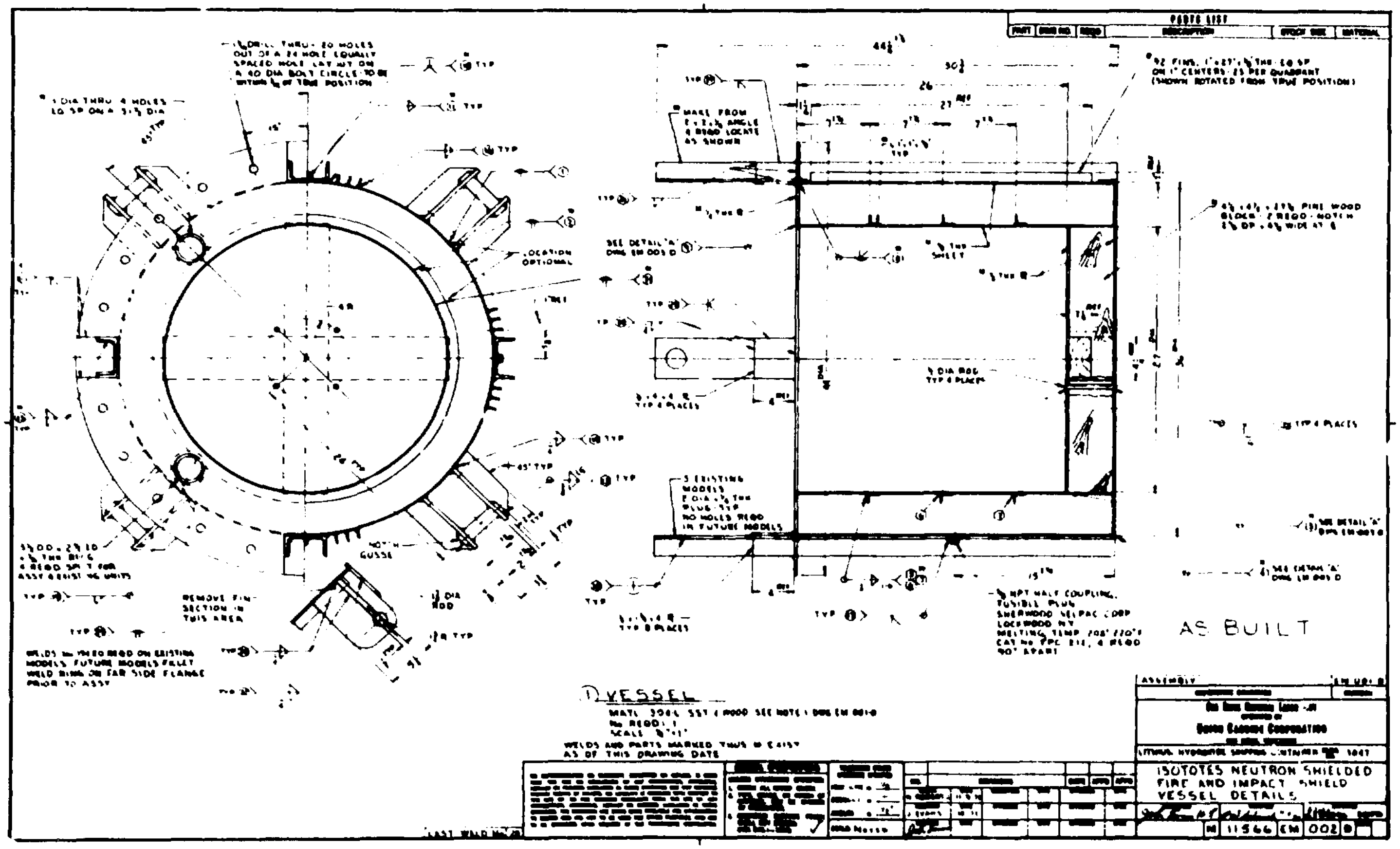

Fig. A.2. As-built drawing no. M-11566-EM-002-D.

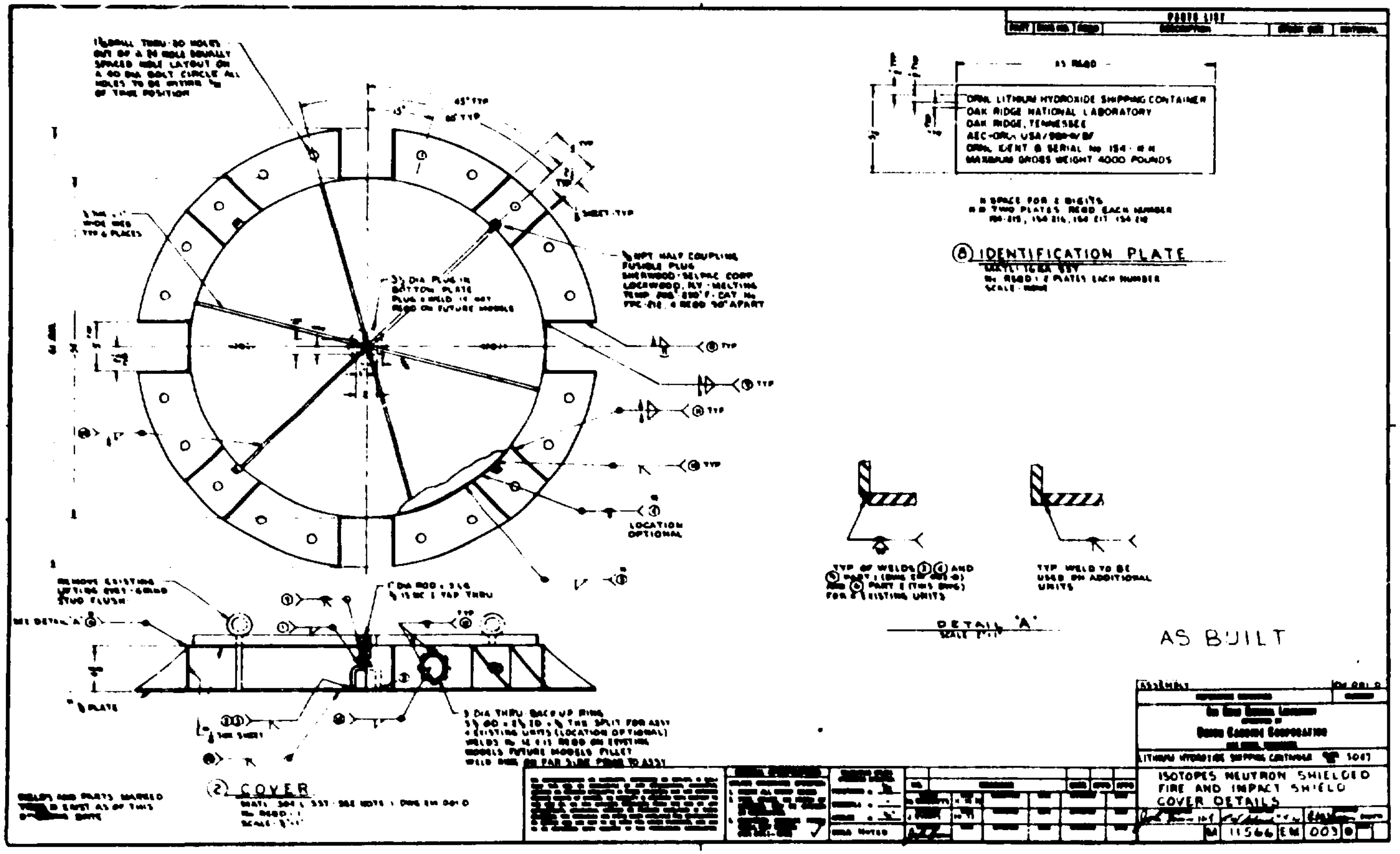

Fig. A.3. As-built drawing no. M-11566-EM-003-D.

Appendix B

APPROVAL DOCUMENTS

INTRA-LABORATORY CORRESPONDENCE
OAK RIDGE NATIONAL LABORATORY

December 16, 1974 TC 74-8

To: J. H. Evans, R. W. Schaich ✓

From: Transportation Committee

Subject: Approval of SARP for the ORNL Lithium Hydroxide Fire and Impact Shield

The ORNL Transportation Committee has reviewed your submission of the subject SARP to fulfill the requirements (internal review) of paragraph B of AEC Immediate Action Directive 5201-3. Particular attention was given the five areas of structural integrity, thermal resistance, radiation shielding, nuclear criticality safety, and quality assurance.

The results of the evaluation show that the shield meets the requirements of AECM 0529 and the SARP is approved for submission to the AEC for request of a Certificate of Compliance for approval of the shield for use as described for offsite shipments of fissile and radioactive materials.

E. M. King

E. M. King, Chairman
Transportation Committee

EMK:bb

cc: Transportation Committee

DOE Form EV-618
(11-77)
10 CFR 71

U.S. DEPARTMENT OF ENERGY

CERTIFICATE OF COMPLIANCE

For Radioactive Materials Packages

1a. Certificate Number 9851	1b. Revision No. 2	1c. Package Identification No. USA/9851/B(U)(DOE-OR)	1d. Page No. 1	1e. Total No. Pages. 2

2. PREAMBLE

2a. This certificate is issued to satisfy Sections 173.393a, 173.394, 173.395, and 173.396 of the Department of Transportation Hazardous Materials Regulations (49 CFR 170-189).

2b. The packaging and contents described in item 5 below, meets the safety standards set forth in Subpart C of Title 10, Code of Federal Regulations, Part 71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions."

2c. This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

3. This certificate is issued on the basis of a safety analysis report of the package design or application—

(1) Prepared by (Name and address):	(2) Title and Identification of report or application:	(3) Date:
Oak Ridge National Laboratory Post Office Box X Oak Ridge, TN 37830	Safety Analysis Report for Packaging for the ORNL Lithium Hydroxide Fire and Impact Shield Report No.: ORNL/ENG/TM-8/R1	November 1983

4. CONDITIONS

This certificate is conditional upon the fulfilling of the requirements of Subpart D of 10 CFR 71, as applicable, and the conditions specified in item 5 below

5. Description of Packaging and Authorized Contents, Model Number, Fissile Class, Other Conditions, and References:

(a) Packaging:

(1) Model: Lithium Hydroxide Fire and Impact Shield

(2) Description:

Packaging for inner Type A packages to permit transport of Type B quantities of radioactive materials and limited quantities of fissile materials, which are contained within inner special form encapsulation. The inner vessels will be blocked to minimize movement during transport.

The inner cavity of the shield is a cylinder 27 inches diameter x 26 inches high (68.6 cm. dia. x 66 cm. high). The outer shell is 36 inches diameter x 30-3/4 inches high (91.4 cm. dia. x 78.1 cm. high).

The lid is 4-5/8 inches (11.7 cm.) thick. The shield is fabricated from 1/8 inches (0.3 cm.) thick 304-L stainless steel with the 4-1/4 inches (10.8 cm.) nominal space between inner and outer cladding being filled with $LiOH \cdot H_2O$ crystals. The outer surface of the shield has 92 vertical cooling fins. The flanged closure is held in position by twenty 1-inch (2.5 cm.) alloy steel bolts.

6a. Date of Issuance: November 30, 1983	6b. Expiration Date: November 30, 1988

FOR THE U.S. DEPARTMENT OF ENERGY

7a. Address (of DOE Issuing Office) U.S. Department of Energy P.O. Box E Oak Ridge, Tennessee 37830	7b. Signature, Name, and Title (of DOE Approving Official) William H Travis William H. Travis, Director Safety & Environmental Control Division

The inner Type A package is a top loading, cylindrical lead shield clad with 3/8 inch (1 cm.) thick Series 300 stainless steel. Outside dimensions are 20 inches OD x 21-11/16 inches high (51 cm. OD x 55 cm. high). Cavity dimensions are 7-1/4 inches ID x 10-1/2 inches high (18.4 cm. ID x 26.7 cm high). The cavity plug is closed with eight 1/2-inch (1.3 cm.) diameter bolts and nuts.

The gross weight of the package is 4,000 lbs. (1814 kg.).

(3) Drawings:

The overpack and the inner Type A Cask are described and fabricated in accordance with Union Carbide Corp., Nuclear Division, Oak Ridge National Laboratory drawings:

D-RD-2760-D through D-RD-2764-D, X3D-1091-109, and X3D-10191-109.

(b) Contents:

(1) Type and form of material:

Any solid, large quantity of radioactive materials, fissile and nonfissile, meeting special form and whose decay heat load does not exceed 300 watts.

(2) External radiation levels will be within the levels prescribed in DOT Regulations, Title 49.

(3) Specific limits of contents:

(i) 5 g of:

^{242}Am, ^{244}Cm, ^{245}Cm, ^{247}Cm, ^{249}Cf, or ^{251}Cf

(ii) 100 g of:

^{235}U or ^{233}U.

(iii) Irradiated metal such as tensile, impact, and weld specimens (including but not limited to stainless steel, mild steel, INOR-89, nickel, high-nickel alloys such as Inconel, Monel, and tungsten).

(c) Fissile Class: I

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

June 24, 1982

To: E. Lamb

KWH BPP

From: K. W. Haff and B. P. Phillips

Subject: Type A Testing of ORNL Radioisotope Shipping Cask (ORNL Drawing X3D-10191 109)

Tests prescribed for Type A Radioactive Materials Packaging in Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition, International Atomic Energy Agency, Vienna, 1973, pp. 79-82 and Title 49, Code of Federal Regulations, paragraph 173.398(b) have been performed on the shipping container described in ORNL drawing X3D-10191 109. The cask suffered minimal damage as a result of the tests, and showed that no damage serious enough to impair shielding or containment of radioactive material occurred as a result of the tests.

The cask has demonstrated its ability to withstand the rigors of transportation and the other tests required by 49CFR 173.398(b) through greater than 15 years of actual service. I, therefore, conclude that the ORNL Radioisotope Shipping Cask meets the requirements for Type A packaging.

KWH:drw

Attachments

cc: F. N. Case
C. L. Ottinger
J. E. Ratledge
R. W. Schaich

Appendix C

ROUTINE PACKAGING AND INSPECTION PROCEDURES

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

PROC. NO. 1
PAGE 1 OF 3
DATE 6/30/80

BUILDING 3038
RADIOISOTOPE PACKING AND SHIPPING
OAK RIDGE NATIONAL LABORATORY

RADIOISOTOPE PACKAGING AND SHIPPING PROCEDURE
OPERATIONS DIVISION

PROCEDURE FOR APPROVAL TO SHIP RADIOACTIVE MATERIAL

1. All requests to ship radioactive material are first referred to the SS Materials Management Department or to the Isotopes Sales Office for approval [reference: *Isotopes Sales Operating Manual* and the *Nuclear Materials Management Manual*, ORNL-2800 (Revised)].

2. Radioactive Materials Packaging Form (UCN-12301) is completed by the requester and attached to the Special Works data sheet (UCN-1784) or the SS Accountability document (UCN-2681). The supervisor of the Radioisotope Packing and Shipping operation reviews the information provided and flags all shipping documents for shipments requiring Type "B" shipping containers.

3. Documentation of requests for shipping radioactive materials with half-lives >14 days is submitted two full working days before the scheduled shipping date to give adequate time for review of package documentation and approval of the shipment.

4. Documentation of requests for shipment of radioactive material with a half-life of <14 days must be submitted by 1:00 p.m. on the day before the scheduled shipping date.

5. The review of packaging documentation follows the procedure established in *ORNL Guide for the Packaging of Radioactive Materials for Transport*, and *Nuclear Materials Management Manual*, ORNL-2800 (Revised).

6. A Radioactive Materials Packaging Form (UCN-12301) is required for all returnable container shipments (empty or full) and for all shipments containing >1 mCi alpha or >3 Ci beta/gamma.

PACKING AND SHIPPING PROCEDURE

1. The supervisor of the Radioisotope Packing and Shipping Operation (RPSO) receives approved shipping documents UCN-2775 (3 3-79) from the SS Materials Management and Isotopes Sales Group by 1:00 p.m. on the day before the shipment is scheduled to leave ORNL.

2. The RPSO supervisor reviews each shipping document and the Radioactive Materials Packaging Form and reports any discrepancies to the Process Group Leader for action. In the absence of the Group Leader, discrepancies in the documentation are reported to the Radioisotope Department Superintendent for action.

APPROVED

SUPERVISOR R D Johnston

PROCESS GROUP LEADER

DATE 6/30/80

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

PROC. NO 1
PAGE 2 OF 3
DATE 6/30/80

BUILDING 3038
RADIOISOTOPE PACKING AND SHIPPING
OAK RIDGE NATIONAL LABORATORY
RADIOISOTOPE PACKAGING AND SHIPPING PROCEDURE
OPERATIONS DIVISION

3. All shipping documents flagged as Type "B" are separated by the RPSO supervisor and handled on a personal basis until the unit is properly loaded on the transporting vehicle. He then signs the Radioactive Materials Packaging Form (UCN-12301) and immediately returns all completed documents to the Process Group Leader for a final review.

4. In the absence of the RPSO supervisor, the relief supervisor brings all shipping documents to the Process Group Leader for review and identification of shipments that require special attention of the relief supervisor.

GENERAL REGULATIONS

1. Short half-life materials (<14 days) are shipped on Tuesday and Friday of each week. Special schedules can be arranged for holiday weeks. Medical isotopes are shipped when required.

2. Long half-life materials (>14 days) are shipped on Wednesday and Thursday of each week. Shipments weighing greater than 300 lb are shipped on Friday unless special arrangements are made.

3. All packages received at Building 3038 Packing and Shipping Room must meet ORNL *Health Physics Manual* Chapter 4.2 requirements concerning internal transfers of radioactive materials and must meet DOT shipping regulations for external radiation (<200 mrem/hr at the surface and 10 mrem/hr at 3 feet). The RPSO supervisor must be notified by the originator of the shipment when he delivers his package to Building 3038.

4. For each package, bottle of product, source, target, or other form of radioactive material taken to Radioisotope Packing and Shipping, a copy of the Special Work Order or a note must be attached to the container with the following information:

   A. Quantity of radioactivity actually being shipped.[1]

   B. Chemical form.

   C. Concentration of radionuclide in solution, mCi/ml.

   D. Volume or product weight.

   E. Specific activity[1] (list as "C.F." for carrier free where applicable).

   F. Assay date and time.[1]

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		6/30/80

G. Normality of solutions of acids and bases.

H. Radiochemical purity.[2]

---

[1] Unprocessed reactor and cyclotron targets are not assayed; therefore, quantity of radioactivity is calculated in these cases. Cyclotron target strip solutions should be analyzed for quantity of product radioisotope prior to shipment.

[2] In the case of short-lived radioisotopes, radiochemical purity assay results may be furnished after the shipment is made.

In the case of partial shipments of products listed on the Special Work Order a copy of the Special Work Order must be furnished with each partial shipment, and the items on the Special Work Order not being shipped must be marked out.

An Isotope Product Card (UCN-6216) must be filled out for every radioisotope product solution. In the case of product solutions loaded in shipping containers outside of Radioisotope Packing and Shipping, a completed copy of this form must be submitted with the product container to the Packing Supervisor with a copy to the Isotopes Sales Office.

5. The packaging and shipment of radioisotopes shall follow the *Procedures for Packaging and Shipment of Radioactive Materials Building 3038* and *ORNL Guide for the Packaging of Radioactive Materials for Transport.*

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OAK RIDGE NATIONAL LABORATORY RADIOACTIVE MATERIALS PACKAGING CERTIFICATION

THIS FORM IS REQUIRED FOR ALL RADIOACTIVE SHIPMENTS AND ALL EMPTY RETURNABLE CONTAINERS

(Routine Type A Shipments Packaged by Process Group Personnel are Exempt)

GENERAL INFORMATION

1. Origin (Division) | 2. Destination
3. Method of Transport | 4. Weight
5. Special Instructions

Special Instructions Complied by

RADIOACTIVE CONTENTS

1. All major activities in curies and/or grams
2. ☐ Analyzed? ☐ Calculated?
3. Specify (a) ☐ Normal Form (b) ☐ Special Form (c) ☐ Fissile (d) ☐ Non-Fissile
4. Radioactive Material Form: ☐ Solid ☐ Liquid ☐ Gas
5. Heat Load (watts) : Calculated ________ Estimated ________ By ________

INTERNAL CONTAINER

1. Internal Containment: ☐ Glass Bottle ☐ Plastic Bottle ☐ "2R" ☐ Conoseal ☐ Welded Capsule
   (specify capsule material) ________
   ☐ Other (explain) ________
2. Contamination level on internal container: Estimated ________ Smeared ________
3. Radiation level from internal container: Measured ________ Calculated ________
4. Gaskets or seals (valves) properly installed ________ By ________
5. Leak tests of internal container ________ By ________
6. Packaging schematic attached ________ By ________

EXTERNAL CONTAINER

1. Moderator and neutron absorber present for fissile materials? ☐ Yes By ________
2. External container examination ________ ☐ Yes By ________
3. Gaskets or seals properly installed ________ ☐ Yes By ________
4. Leak test ________ ☐ Yes By ________
5. Bolts torqued to ________ ft. lbs. By ________
6. Tie down to skid checked ________ ☐ Yes By ________
7. Tamper seal installed ________ ☐ Yes By ________
8. Lid eye bolt removed and wire to the outside of the carrier ☐ Yes By ________
9. Packaging schematic attached ________ ☐ Yes By ________

SHIPPING CONTAINER

1. Certificate of Compliance No. USA–
2. DOT Specification No.

RADIATION SURVEY

1. Surface contamination level: Alpha ________ dpm; Beta/Gamma ________ dpm
2. External radiation level ________ mrem/hr @ contact
3. Domestic shipments ________ mrem/hr @ 3 ft. from surface
4. Foreign shipments ________ mrem/hr @ 1 meter from center
5. Health Physics Surveyor ________ Date ________

TRUCK TIE-DOWN AND SHORING

1. Tie-down in accordance with SARP and Designed Layout checked by
   (Inspection Engineering) ________
2. Shoring check by (if required) ________

Certifies Packaging Data is Correct for Shipment | Date

UCN-12301
(3 4-81)

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

PROC. NO. 24
PAGE 1 OF 7
DATE 2/26/82

BUILDING 3029
SOURCE DEVELOPMENT LABORATORY

QUALITY ASSURANCE PROCEDURE FOR TYPE B SHIPPING CONTAINERS

Incoming Type B Containers

1. Container is opened under the supervision of the Packing Foreman and a representative of the Health Physics Division. Radiation readings and smear levels on the external and internal surfaces are recorded. These records are stored in the auditable Quality Assurance (QA) file in Buildings 3029.

2. If container is contaminated externally or internally, it is cleaned to ORNL smear tolerance of 500 dis/min beta-gamma or 30 dis/min alpha. The final smear level is recorded by Health Physics and placed in the container's QA file.

3. If the radiation level internally or externally is greater than 1 mr/hr beta-gamma or 500 dis/min alpha, the container is to be decontaminated to the above tolerance. If decontamination efforts fail, the container is tagged out of service and the Department Head is notified in writing of the status. A copy of the notification is placed in the container's QA file. EXCEPTION: Uranium carriers may read up to 10 mrem/hr internally or externally.

4. Fire Shields

   The RSPO Foreman will visually inspect all fire shields for cracks in the wood, protective coatings, foam glass, and/or steel covers. Defects in these items are to be recorded in the container's QA file and a blanket work order issued immediately to repair same. A copy of the blanket work order and the copy of the completed work order are to be placed in the container's QA file. An inspection of the repair work is to be made by the RSPO Foreman and a record of acceptance placed in the container's QA file.

Outgoing Type B Containers

1. Shielded Containers

   a. Vacuum leak test will be performed by operating personnel and recorded in the container's QA file in Building 3029 before the container can be used for loading encapsulated radioactive material.

   b. An Inspection Engineering report on the internal weld dye penetrant inspection is valid for 6 months prior to shipment. If inspection is over 6 months old, a new dye penetrant inspection of the internal welds must be made and the results recorded in the QA file. All repairs will be inspected and approved by Inspection Engineering and recorded in the QA file.

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OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT
BUILDING 3029
SOURCE DEVELOPMENT LABORATORY
QUALITY ASSURANCE PROCEDURE FOR TYPE B SHIPPING CONTAINERS

PROC. NO. 24
PAGE 2 OF 7
DATE 2/26/82

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c. Gaskets will be changed every 6 months and recorded in the container's QA file. Gasket material from stores stock must be verified by the store stock number.

2. Fire Shields

Fire shield lids and bolting devices will be inspected before shipment by the Packing Foreman to insure proper fit of the locking mechanism to hold the lid securely in place during transit. A record of this inspection is to be placed in the container's QA file. All repairs are to be made before shipment and the blanket work order with its completed form is to be filed in the container's QA file.

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SUPERVISOR	PROCESS GROUP LEADER	DATE
		2/26/82

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

PROC. NO. 24
PAGE 5 OF 7
DATE 2/26/82

BUILDING 3029
SOURCE DEVELOPMENT LABORATORY
QUALITY ASSURANCE PROCEDURE FOR TYPE B SHIPPING CONTAINERS

SUGARMAN CASK PACKING PROCEDURE

Pre-Loading Check

1. Chokers for cask handling and lid removal checked for proper loading value and certification by Inspection Engineering ____ By ____
2. Vacuum leak test ____ By ____
3. Inspection Engineering report date (If over 6 months since last report, re-inspect) ____ By ____
4. Planned radioactive heat load ____ ____ watts
5. Cavity and lid smear level ____ β-γ ____ dpm
   ____ α ____ dpm
   By ____
6. Outside cask surface smear level ____ β-γ ____ dpm
   ____ α ____ dpm
   By ____
7. Lid closure cap screws, lockwashers, and nuts checked for burrs and proper operation ____ By ____

Post Loading Check

1. Outside cask surface smear level (clean to ORNL smear tolerance for shipping ____ β-γ ____ dpm
   ____ α ____ dpm
   By ____
2. Lid closure cap screws free of burrs or damage from in-cell loading ____ By ____
3. Lid cap screws torqued to 150 ft.-lb ____ By ____
4. Tamper seal installed ____ By ____
5. Loaded into Fire & Impact Shield ____ By ____
6. Packaging Information Form (UCN-12301) completed ____ By ____
7. Notification to Packing and Shipping Foreman ____ By ____

Supervisor Approval by ____

Date ____

APPROVED:

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UCN-12530A (3 4-77)

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

PROC. NO. 24
PAGE 6 OF 7
DATE 2/26/82

BUILDING 3029
SOURCE DEVELOPMENT LABORATORY

QUALITY ASSURANCE PROCEDURE FOR TYPE B SHIPPING CONTAINERS

CONTAINER INSPECTION SHEET

Date ____________ Container Number ____________

EXTERNAL INSPECTION

By ____________

Smeared ____________ dpm βγ; ____________ dpm alpha

Condition Good Fair Poor

Repairs Needed ____________

Action Taken ____________

INTERNAL INSPECTION

By ____________

Smeared ____________ dpm βγ; ____________ dpm alpha

Decontaminated: Yes No By ____________

CONTAINER TESTING

Vacuum Test ____________ Gaskets ____________

Weld Dye Check ____________ Bolts & Lock Washers ____________

Repairs Made ____________

RE-TESTING

Vacuum Test ____________

Weld Dye Check ____________

CONTAINER CERTIFIED FOR SHIPMENT - Date ____________

By ____________

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UCN-12510A (3 6 77)

PROC. NO. 31
PAGE 1 OF 3
DATE 2/26/82

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

BUILDING 3029
SOURCE DEVELOPMENT LABORATORY

LEAK TESTING PROCEDURE FOR RADIOACTIVE MATERIALS CONTAINED IN SPECIAL FORM CAPSULES

I. Leak Testing

A. General

All radioactive materials contained in Special Form or DOT 2R capsules are leak tested before shipment. The method used is the air bubble, vacuum, and glycol as described in ANSI Standard N14.5 A3.6.

B. Equipment

1. The leak test equipment consists of a glass test chamber with a removable sealable top. A line penetrates the top and is connected to an in-cell vacuum pump. The size and shape of the test chamber may vary with the design of the piece being tested; and must be large enough that the piece can be completely immersed in the test liquid, leaving at least one inch of test liquid above the weld area.

2. Racks, suspension assemblies, or similar positioning devices may be required for some radioactive sources. These will be designed so as not to interfere with observation of the weld area during testing.

3. Unless otherwise specified, the test liquid for liners is distilled water. The final test liquid for radioactive sources is ethylene glycol. The final leak test has a sensitivity greater than 1×10^{-6} at.cm^3/sec.

C. Procedure

1. The test chamber is filled with test liquid to a depth sufficient to cover the piece being tested and leave at least one inch, but not more than three inches, of test liquid above the weld area when the piece is in the test position.

2. The top is placed on the test chamber and a vacuum of at least 20 inches Hg is imposed.

3. The piece, and especially the weld area, is observed for 30 seconds while the vacuum is maintained. A leak is indicated by a steady stream of air bubbles coming from a fixed point on the source.

4. After the 30-second observation the vacuum is relieved; then the piece is removed from the test chamber.

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		2/26/82

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BUILDING 3029
SOURCE DEVELOPMENT LABORATORY
LEAK TESTING PROCEDURE FOR RADIOACTIVE MATERIALS CONTAINED IN SPECIAL FORM CAPSULES

PROC. NO. 31
PAGE 2 OF 3
DATE 2/26/82

a. Leaking pieces are rejected and defueled.

b. Non-leaking pieces are transferred to the furnace testing area.

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UCN-12530A (3 4-77)

85/86

PROC. NO. 31
PAGE 3 OF 3
DATE 2/26/82

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

BUILDING 3029
SOURCE DEVELOPMENT LABORATORY

LEAK TESTING PROCEDURE FOR RADIOACTIVE MATERIALS CONTAINED IN SPECIAL FORM CAPSULES

RADIOACTIVE SOURCE DATA SHEET

Customer ____________________ Capsule No. ____________________
S.W. No. ______________ Fuel Form ______________ Curies ______________
Fuel Batch No. ____________________ Assay ____________________
Nom. Dim.-O.D. ____________ I.D. ________ Length ________ Cap. Thk. ______
Capsule Comp. ____________________ Spec. Sheet ____________________

	Accepted	Reject		Date	Supvr.
Capsule & Cap Degreased					
Liner No. ____________					
Liner Cleaned					
Liner Dried ( )					
Welding Procedure					
Test Weld No. ____________					
Capsule Welded ____________					
Go-no-go Test					
Leak Test					
Oven Test ( )					
Go-no-go Test					
Leak Test					
Decontaminated	Max.Smear	Avg.			
Shelf Test Started					
Shelf Test Completed					
Re-smear	Max.Smear	Avg.			

Go-no-go Test

Source Disposition

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DATE 2/26/82

UCN-12530A (3 4-77)

Appendix D

HYDROSTATIC PRESSURE TEST AND COMPUTER LISTING FOR COMPOSITE HEADS

Derivation of Equations for Computer Calculations

Fig. D.1 illustrates the model on which the calculations are based. Two circular plates built in at the edges are connected at their geometric center, forming a sealed cavity. The connection, at b, is assumed to be rigid; hence there is no deflection at the center of either plate. The plates are loaded by a pressure differential as shown. Note that the analysis is valid if the pressure differential is reversed and the higher pressure is within the cavity. Since at b the deflection must equal 0, then by superposition,

$$\Delta p = \Delta f \ ,$$

where

Δp = deflection due to pressure P,

Δf = deflection due to force F.

Using Roark's notation[1] (from <u>Formulas for Stress and Strain</u>, Table X, Cases 6 and 7), and since r_0 is very small compared with a and the term r_0^2/a^2 can be ignored, we may write

$$[(3W)(m^2 - 1)(a^2)]/(16\pi Em^2t^3) = [(3F)(m^2 - 1)(a^2)]/(4\pi Em^2t^3) \ ,$$

where

t = thickness of plate,
$W = \pi a^2 P$,
$F = W/4 = \pi a^2 P/4$,
m = reciprocal of Poisson's ratio,
E = modulus of elasticity.

The radial stress, σ_r, at any radius, r, is

$$\sigma_r = \sigma_{rP} - \sigma_{rF} \ ,$$

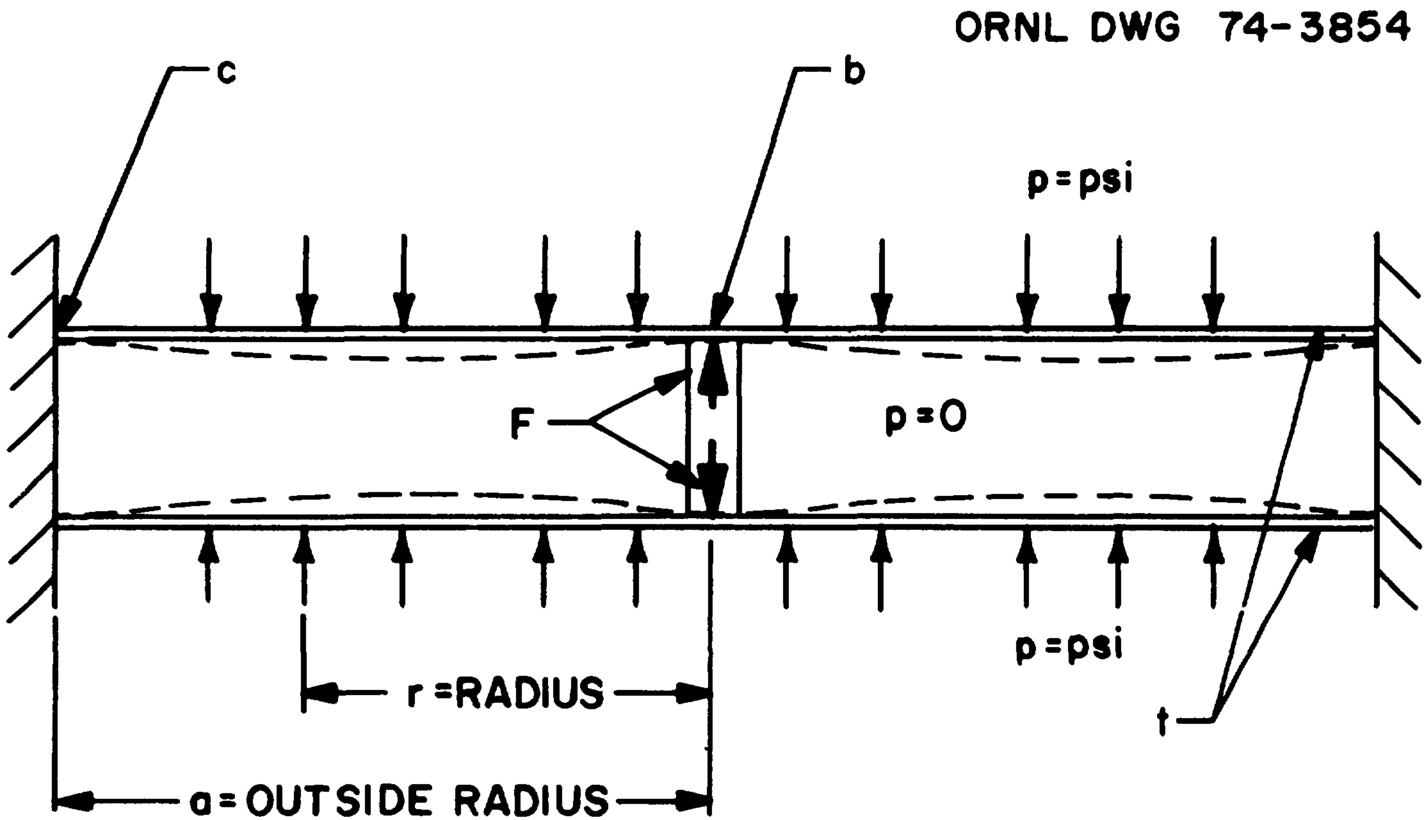


Fig. D.1. Calculatory model shield lid.

where

$$\sigma_{rP} = [(3W)/(8\pi mt^2)]\{[3m + 1)(r^2/a^2)] - (m + 1)\} ,$$

$$\sigma_{rF} = [(3W)/(8\pi mt^2)]\{[(m + 1)\ell n(a/r)] - m\} .$$

Thus

$$\sigma_r = [(3a^2P)/(8mt^2)]\{[(3m + 1)(r^2/a^2)] - (2m + 1) + [(m + 1)\ell n(a/r)]\} .$$

In a similar fashion, the tangential stress, σ_T, is

$$\sigma_T = [(3a^2P)/(8mt^2)]\{[(m + 3)(r^2/a^2)] - (m + 2) + [(m + 1)\ell n(a/r)\} .$$

REFERENCE

1. R. J. Roark, Formulas for Stress and Strain, 4th ed., McGraw-Hill, New York, 1965.

```
**FTN,L,M,R,G,A.
C
C    ***************************************************************
C    ***************************************************************
C
C
C              THIS PROGRAM CALCULATES STRESSES IN  A COMPOSITE CIRCULAR
C              FLAT PLATE  HEAD COUPLED AT THE CENTER LOADED WITH PRESSURE
C              ON THE EXTERIOR SURFACES
C              CODED BY JOHN EVANS P.E., OAK RIDGE NATIONAL  LAB.,AUG 1973
C
C
C    ***************************************************************
C    ***************************************************************
C
C                O R N L LITHIUM HYDROXIDE SHIPPING CONTAINER
C
C    ***************************************************************
C    ***************************************************************
C
C
      DIMENSION R(100),B(100),E(100),SR(100),ST(100)
     1 ,W(100), XP(100),YP(100)
      DO 2 I=1,100
      R(I)=0.0
      B(I)=0.0
      E(I)=0.0
      SR(I)=0.0
      ST(I)=0.0
      W(I)=0.0
    2 CONTINUE
      A=17.
      T=.25
      P=10.55
      CN=(1./.3)
      AN=2.*CN + 1.
      CN=CN + 2.
      G=0.0
      H=0.0
      SUMR=.75
      WRITE(51,1006)
      WRITE(51,1006)
      WRITE (51,1002)
      WRITE(51,1005)
      WRITE (51,1002)
      WRITE(51,1006)
      WRITE(51,1006)
      WRITE (51,1002)
      WRITE(51,1007)
      WRITE(51,1008)
      WRITE (51,1002)
      WRITE(51,1006)
      WRITE(51,1006)
      WRITE (51,1002)
      WRITE(51, 1003)
      WRITE (51,1002)
      WRITE(51,1006)
```

```
      WRITE(51,1006)
      WRITE (51,1002)
      WRITE (51,1001)A,T,P,
      WRITE (51,1002)
      WRITE(51,1006)
      WRITE(51,1005)
      WRITE(51,1006)
      WRITE(51,1006)
      WRITE (51,1002)
      WRITE(51,1004)
      WRITE (51,1002)
      C=((3.*A*A)/(8.*CM*T*T))*P
      G   =((3.*CM)+1.)
      DO 1 I=1,69
      N(I)=I
      SUMR=(FLOAT(I) + 3.)*.25
      R(I)=SUMR
   10 B(I)=((R(I)*R(I))/(A*A))
    5 E(I)=((CM+1.)*(ALOG(A/R(I))))
    8 ST(I)=(C*((((CM+3.)*E(I))-CM+E(I)))
    7 SR(I)=  (C*((G*B(I))-AU+E(I)))
      WRITE(51,1000)R(I)          ,ST(I),SR(I)
      WRITE (51,1002)
 1000 FORMAT(F20.3,2F20.1)
 1001 FORMAT(2F20.3,F20.1)
 1002 FORMAT(1H0)
 1003 FORMAT(1H ,9X,14HOUTSIDE RADIUS, 9X, 9HTHICKNESS,12X, 8HPRESSURE)
 1004 FORMAT(1H ,14X,6HRADIUS,8X,17HTANGENTIAL STRESS,3X,6HRADIAL,
    1      X,6HSTRESS)
 1005 FORMAT(1H,10X,48HC P H L LITHIUM HYDROXIDE FIRE AND IMPACT SHIELD)
 1006 FORMAT(1H, X,49H*************************************************,
    1        55H*******************************************************,
    2        14H**************)
 1007 FORMAT(1H ,8X,45HSTRESSES IN A FLAT PLATE BUILT IN AT THE EDGE,
    1   X,3HAND)
 1008 FORMAT(1H ,8X,42HSUPPORTED AT THE CENTER, LOADED BY UNIFORM,
    1          X,8HPRESSURE)
      IF(R(I).EQ.A) GO TO 90
    1 CONTINUE
   90 CONTINUE
      WRITE(51,1006)
      WRITE(51,1006)
      STOP
      END
```

```
**********************************************************************
**********************************************************************


        O R N L LITHIUM HYDROXIDE PIPE AND IMPACT SHIELD

**********************************************************************
**********************************************************************


      STRESSES IN A FLAT PLATE BUILT IN AT THE EDGE AND
      SUPPORTED AT THE CENTER  LOADED BY UNIFORM PRESSURE

**********************************************************************
**********************************************************************

       OUTSIDE RADIUS          THICKNESS            PRESSURE

**********************************************************************
**********************************************************************

           17.000                0.250                10.5

**********************************************************************
**********************************************************************
**********************************************************************
**********************************************************************

             RADIUS         TANGENTIAL STRESS   RADIAL STRESS

             1.000              38229.3            25512.3

             1.250              32990.2            20323.0

             1.500              28736.9            16130.7

             1.750              25168.6            12634.5

             2.000              22105.8             9654.7

             2.250              19432.5             7075.5

             2.500              17069.6             4817.9

             2.750              14960.9             2825.5
```

3.000	13064.5	1056.5
3.250	11338.8	-520.7
3.500	9785.3	-1930.6
3.750	8366.6	-3192.8
4.000	7064.7	-4322.9
4.250	5871.0	-5333.8
4.500	4774.8	-6236.2
4.750	3767.1	-7039.0
5.000	2640.4	-7749.7
5.250	1988.3	-8374.7
5.500	1205.2	-8919.7
5.750	486.3	-9389.3
6.000	-172.6	-9787.8
6.250	-775.1	-10118.9
6.500	-1324.4	-10385.8
6.750	-1823.6	-10591.4
7.000	-2275.0	-10738.2
7.250	-2681.1	-10828.6
7.500	-3043.8	-10864.6
7.750	-3365.1	-10848.0
8.000	-3646.6	-10780.5
8.250	-3889.8	-10663.7

	[illegible]	[illegible]
8.750	-4266.8	-10287.5
9.000	-4403.1	-10030.5
9.250	-4506.0	-9729.0
9.500	-4576.4	-9384.0
9.750	-4615.4	-8996.5
10.000	-4623.6	-8567.2
10.250	-4602.0	-8096.9
10.500	-4551.2	-7586.4
10.750	-4471.8	-7036.3
11.000	-4364.6	-6447.2
11.250	-4230.1	-5819.7
11.500	-4068.7	-5154.3
11.750	-3881.1	-4451.6
12.000	-3667.7	-3712.0
12.250	-3428.9	-2936.0
12.500	-3165.2	-2123.9
12.750	-2876.9	-1276.2
13.000	-2564.5	-393.3
13.250	-2228.2	524.5
13.500	-1868.4	1477.0
13.750	-1485.5	2463.6

```
        14.000               -1079.6                3484.3

        14.250                -651.2                4538.6

        14.500                -200.3                5626.4

        14.750                 272.6                6747.4

        15.000                 767.4                7901.3

        15.250                1283.9                9088.0

        15.500                1821.7               10307.1

        15.750                2380.8               11558.5

        16.000                2961.0               12842.1

        16.250                3561.9               14157.5

        16.500                4183.5               15504.7

        16.750                4825.6               16883.5

        17.000                5488.1               18293.7

************************************************************************************************
************************************************************************************************
```

Hydrostatic Pressure Test of Composite Head

Test description

On July 15, 1975, the lid of an ORNL lithium hydroxide fire and impact shield was hydrostatically pressure tested in Building 3020 at ORNL. This particular lid had not been filled with the lithium hydroxide material. The lid was placed on its edge and tied to supports as shown in Fig. D.2 (a). Dial indicators were positioned at several points on the reinforced side of the lid. Pressure was indicated by a gage on the inlet. The results of this test are tabulated below.

Test results

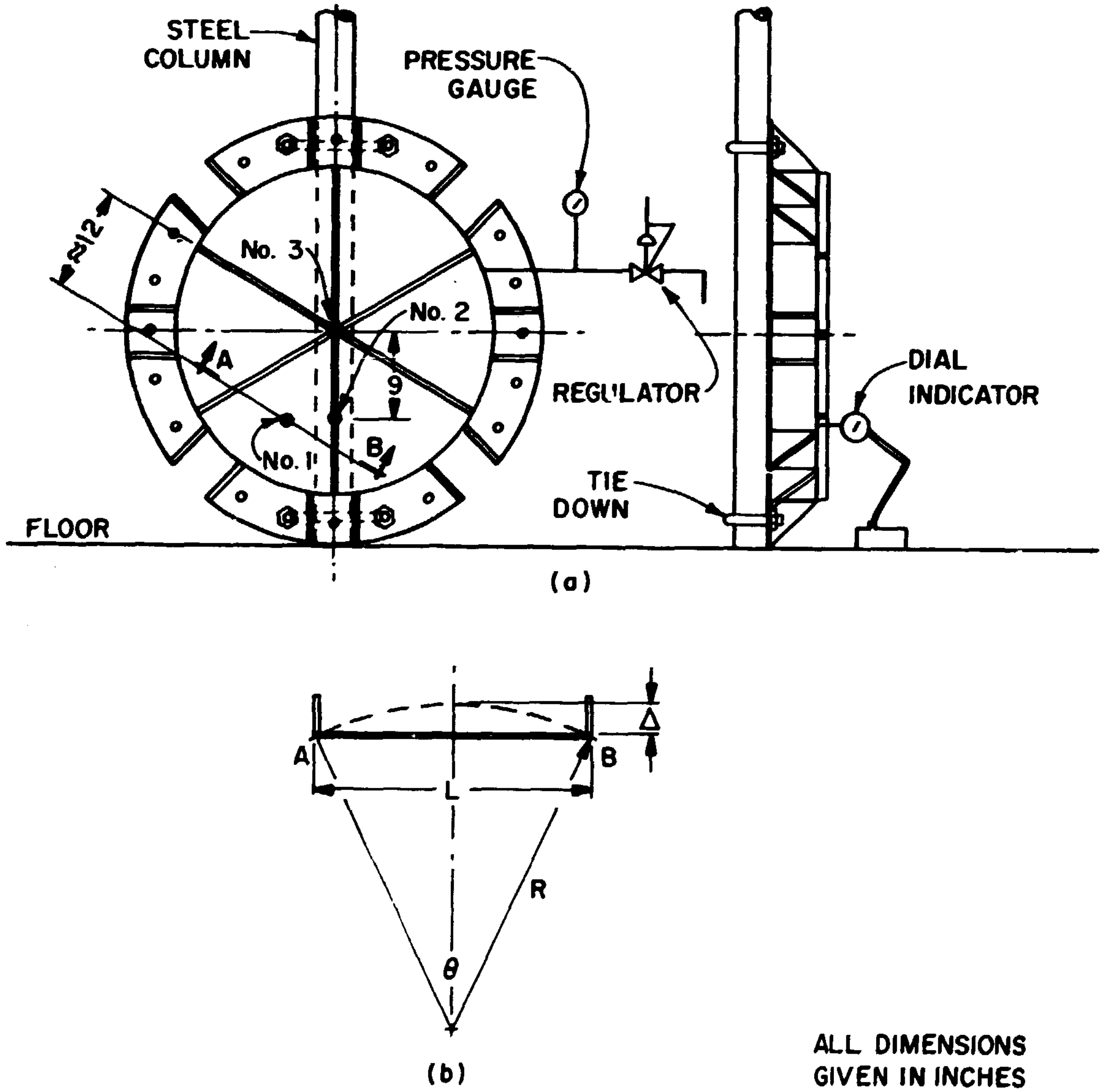
Test No. 1

		Deflection at indicator location		
		No. 1	No. 2	No. 3
Pretest	0 psig	0.0000	No	No
	5 psig	0.0375		
	11 psig	0.1332	data	data
Posttest	0 psig	0.0081		

Test No. 2

		Deflection at indicator location		
		No. 1	No. 2	No. 3
Pretest	0 psig	0.000	0.0000	No
	5 psig	0.042	0.0155	
	11 psig	0.144	0.0362	data
Posttest	0 psig	0.004	0.0000	

ORNL DWG 75-12967



ALL DIMENSIONS GIVEN IN INCHES

Fig. D.2. Hydrostatic pressure test.

Test No. 3

		Deflection at indicator location		
		No. 1	No. 2	No. 3
Pretest	0 psig	No data	No data	0.0000
	5 psig			0.0018
	11 psig			0.0039
Posttest	0 psig			0.0006

<u>Data reduction and calculations</u>

From the test results for test No. 2 at location 1, it can be seen that there was a #0.004-in. permanent deflection. The permanent strain or set can be calculated by calculating the length of the element before and after pressurization.

The length of the element as shown in Fig. D.2 (b) before pressurization is

$$L = 2\ (12/3^{1/2}) = 13.85640646 \text{ in.}$$

Assuming the deflected curve is a portion of a circle, the deflected element will have a length equal to the arc length $\overset{\frown}{AB}$. From the equations of a circle presented in the CRC Standard Math Tables, the arc is

$$\overset{\frown}{AB} = R\theta \ ,$$

where

$$\theta = 2 \sin^{-1} \frac{L}{2R} \ ,$$

$$R = \frac{L^2}{8\Delta} + \frac{\Delta}{2} \ ;$$

therefore

$$\overset{\frown}{AB} = 13.85640925 \text{ in.}$$

The permanent elongation of this element is

$$e = \overset{\frown}{AB} - L = 0.00000279 \text{ in.}$$

The permanent strain is

$$e = e/L = 2.01 \times 10^{-7} \text{ in./in.}$$

This permanent strain is very small and indicates that the commonly accepted 0.2% offset yield point for stainless steel has not been exceeded.

Appendix E

FABRICATION DRAWINGS OF FULL-SCALE TEST MODEL

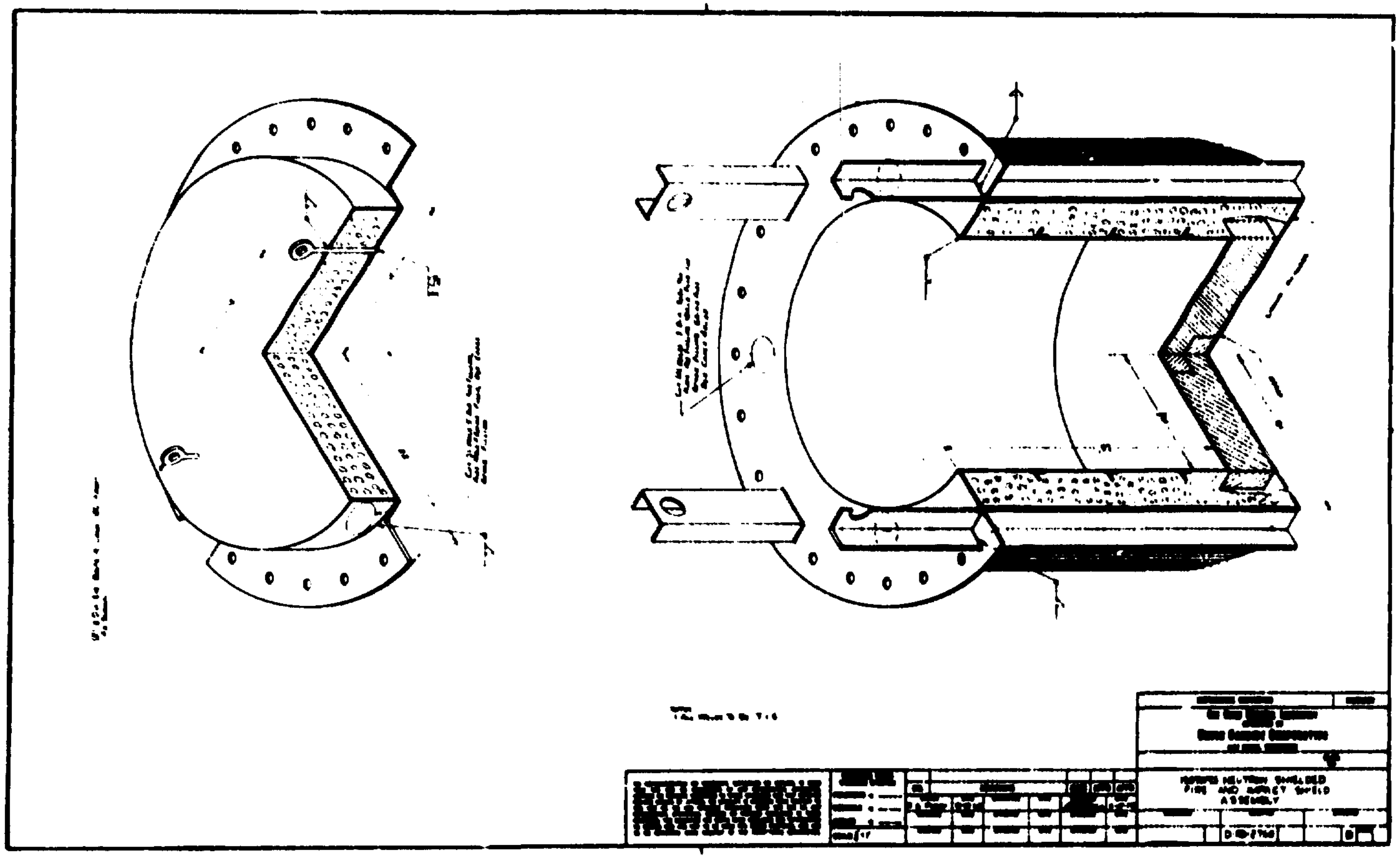


Fig. E.1. Fabrication Drawing no. D-RD-2760.

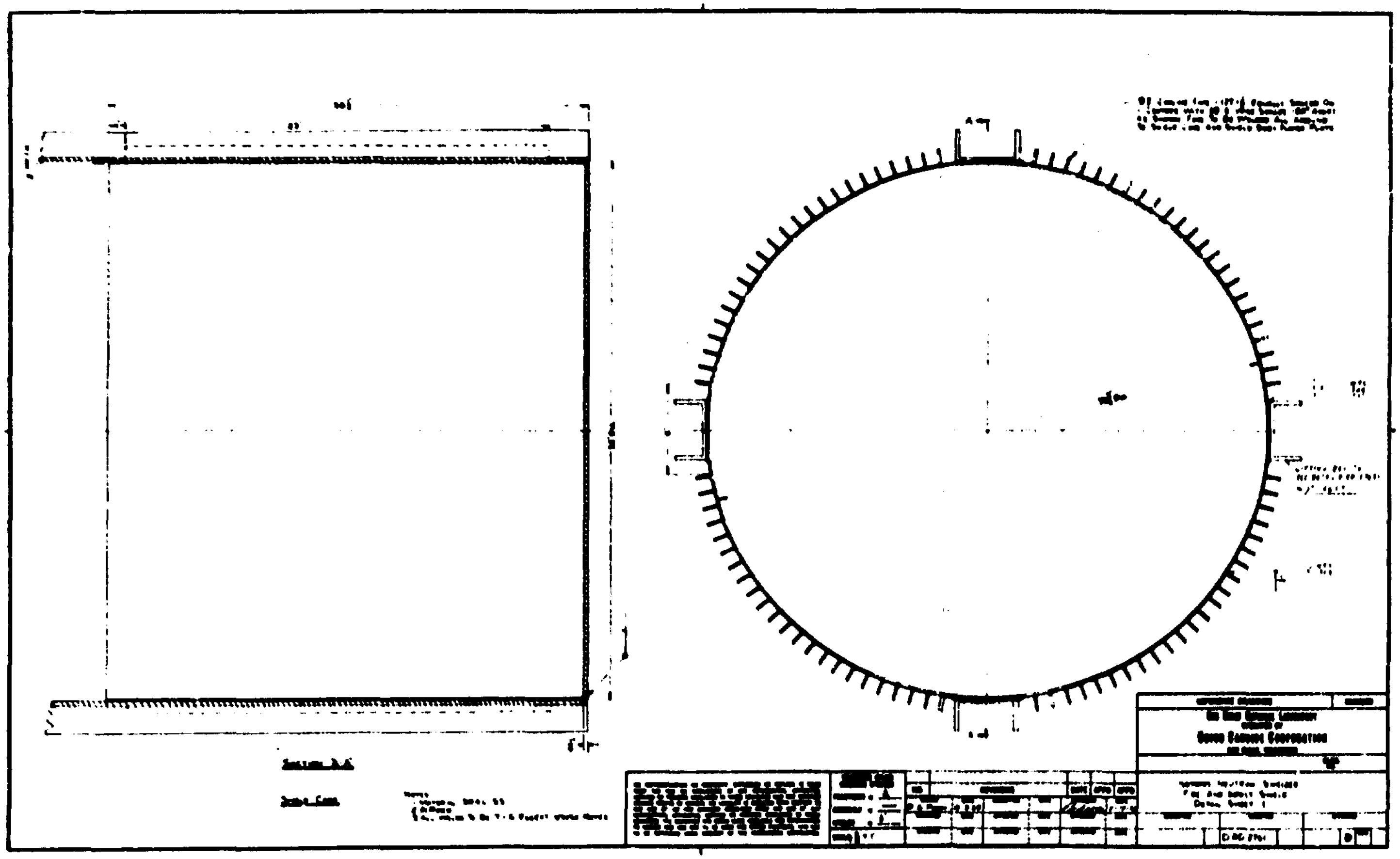


Fig. E.2. Fabrication drawing no. D-RD-2761.

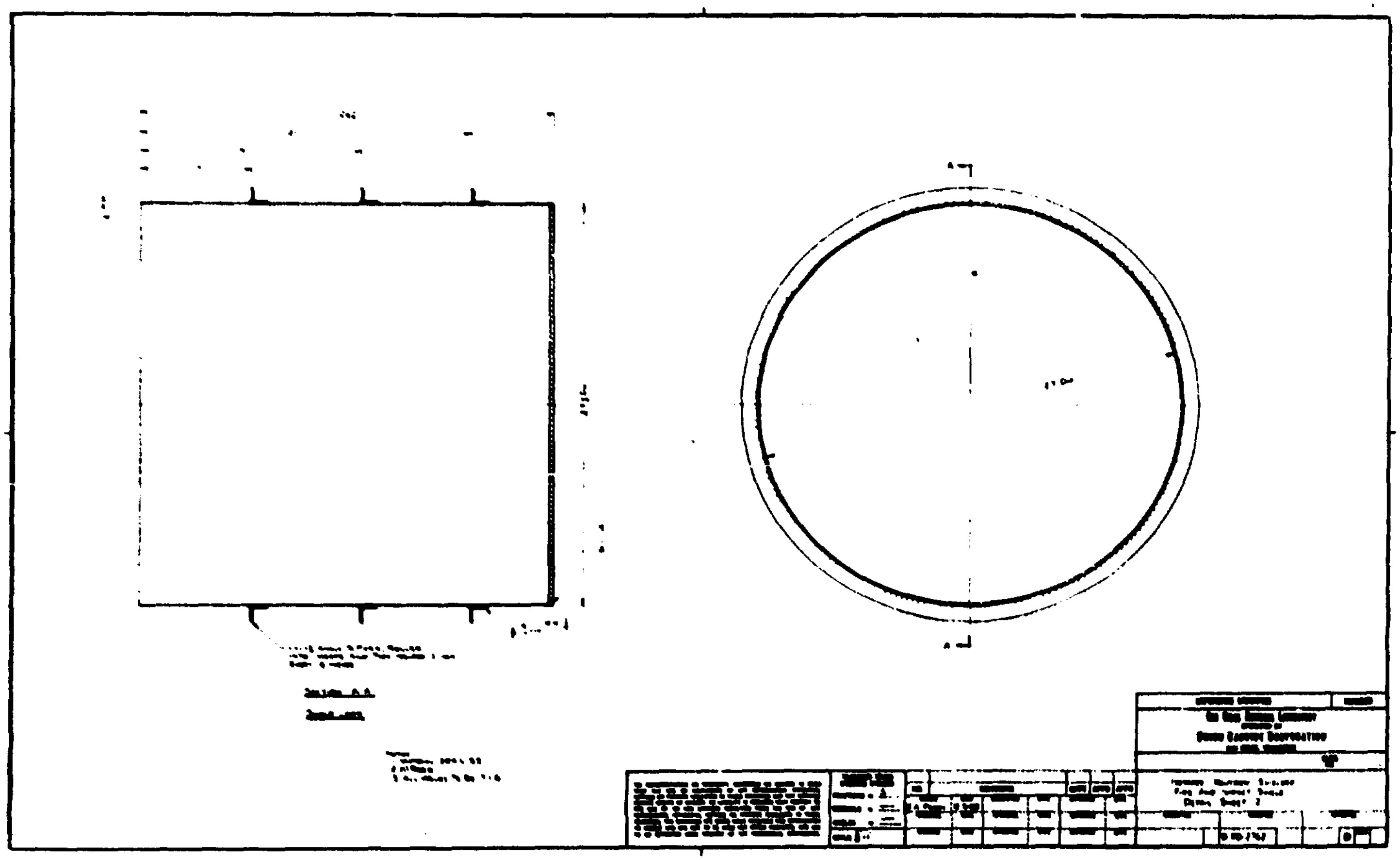


Fig. E.3. Fabrication drawing no. D-RD-2762.

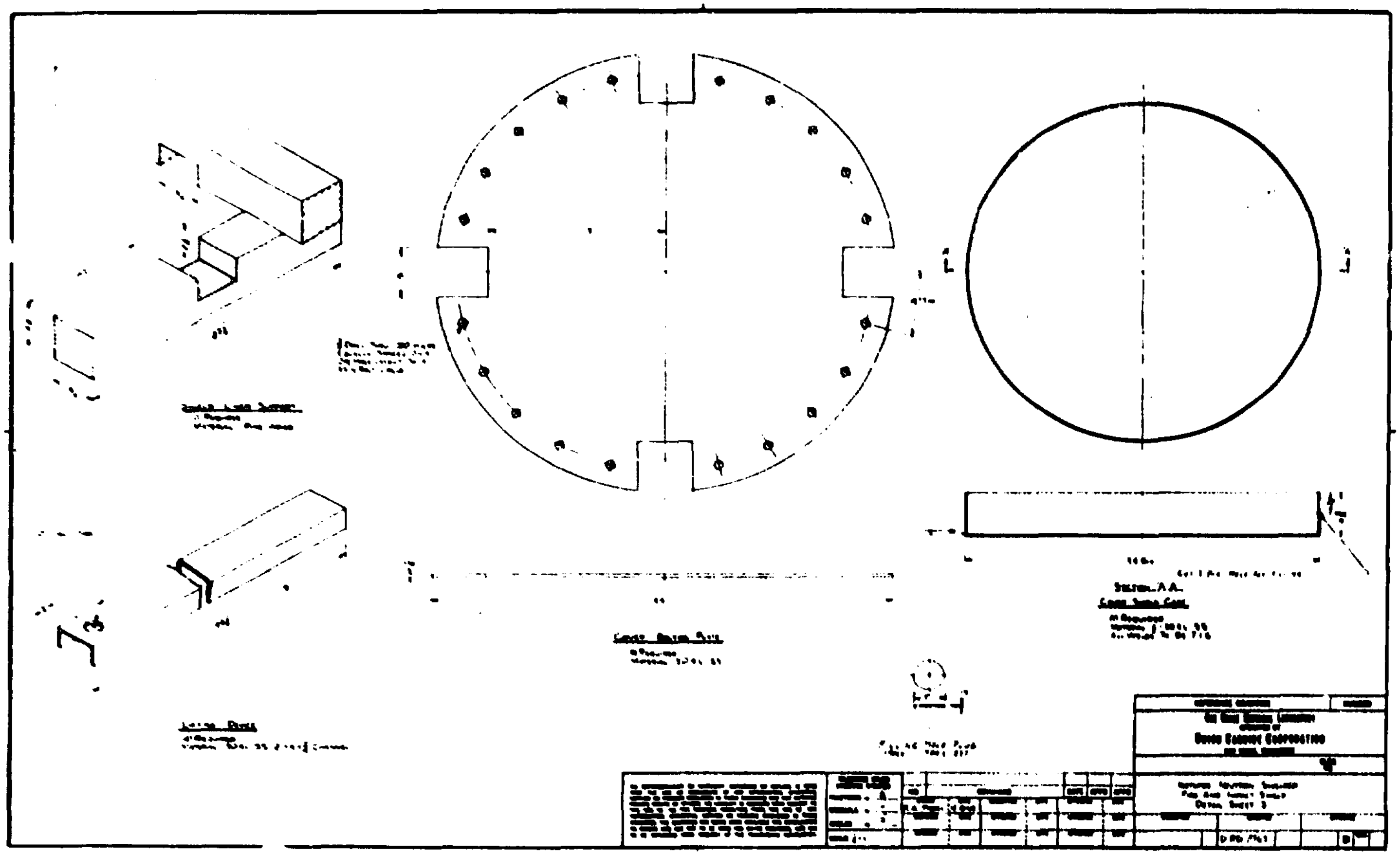


Fig. E.4. Fabrication drawing no. D-RD-2763.

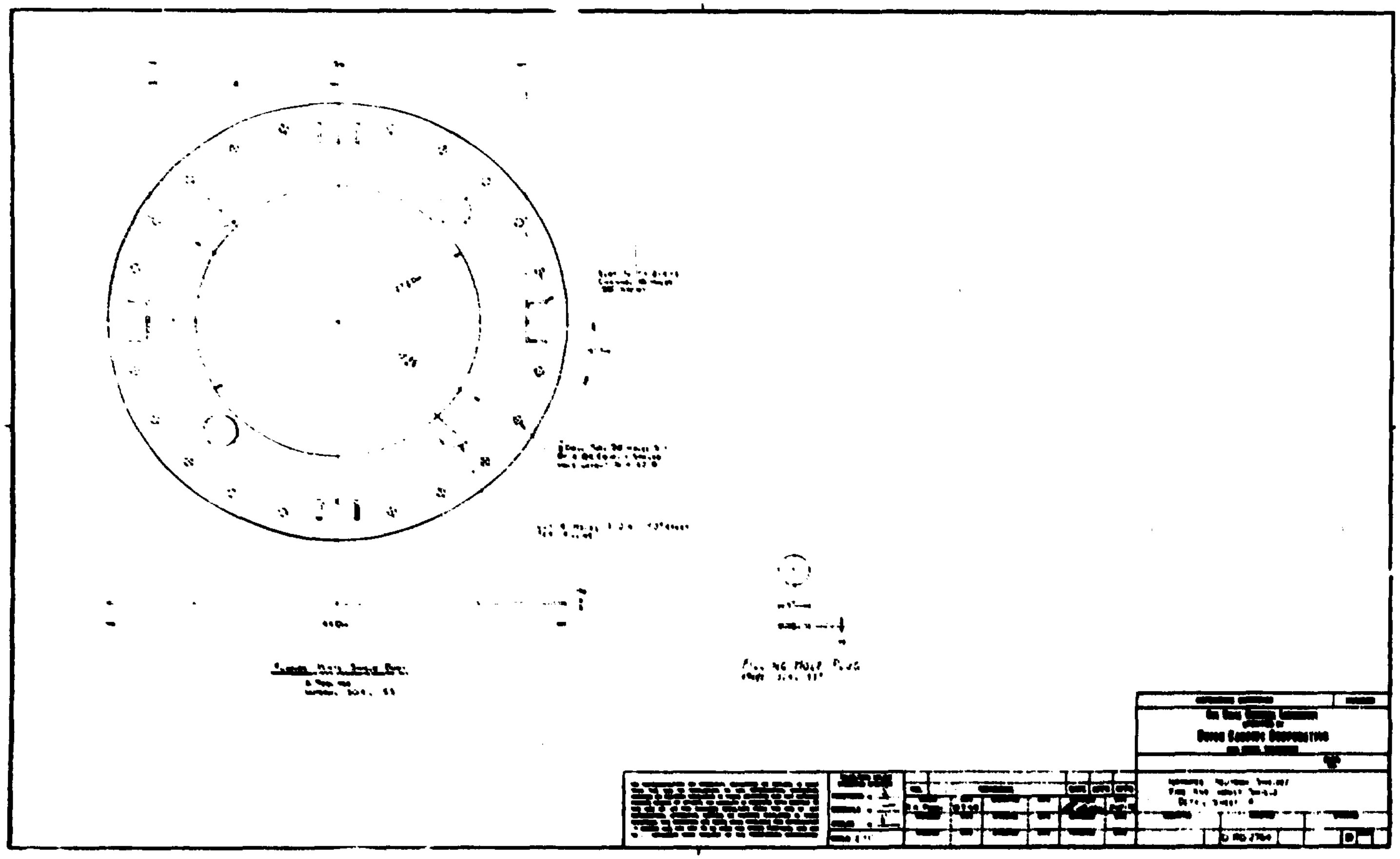


Fig. C.5. Fabrication drawing no. D-RD-2764.

Appendix F

MODEL TESTING PROCEDURE AND REPORT

Impact Testing of the LiOH Shield Top Energy Absorber Models

Introduction

The tests described below were conducted to develop data from which the response of the ORNL lithium hydroxide shield in a top (with the axis of the shield vertical) impact of the shield on the unyielding surface could be calculated. The shield is detailed on ORNL drawings M-11566-EM-001-D through -003-D. The data taken were used to demonstrate that the cap (Part 2) remains secured to the body (vessel) (Part 1). The tests were performed by J. H. Evans and N. D. Bradley of ORNL and witnessed by R. E. Harris of DOE-ORO. The tests were conducted at the ORNL drop tower on April 18, 1974.

The test model was a one-half scale model of one of the four channel sections extending above the container. It was intended that the channels would buckle and protect the shield in a top impact. The model fabrication drawing is shown in Fig. F.1. Five models were fabricated in ORNL Shops in accordance with this drawing.

Test procedure

The variable-weight drop hammer was loaded to 121 lb. This is the half-scale equivalent of one-fourth the weight of the container. The test models were mounted one at a time on the lower surface of the variable-weight drop hammer, using four bolts. The length of each specimen was measured and recorded prior to dropping. A piezoelectric accelerometer was mounted on the hammer extension as described in ORNL/TM-1312, vol. 9. The data acquisition system shown in Fig. F.2 was utilized to measure and record an acceleration with respect to time of each impact. The scope was set to make contact approximately 3/4 in. prior to the model contacting the impact surface. The specimens were dropped from 30 ft onto the unyielding surface, and the acceleration was measured, with respect to time, and recorded. The deformed length of the specimens was measured for all tests.

ORNL DWG 74-6115

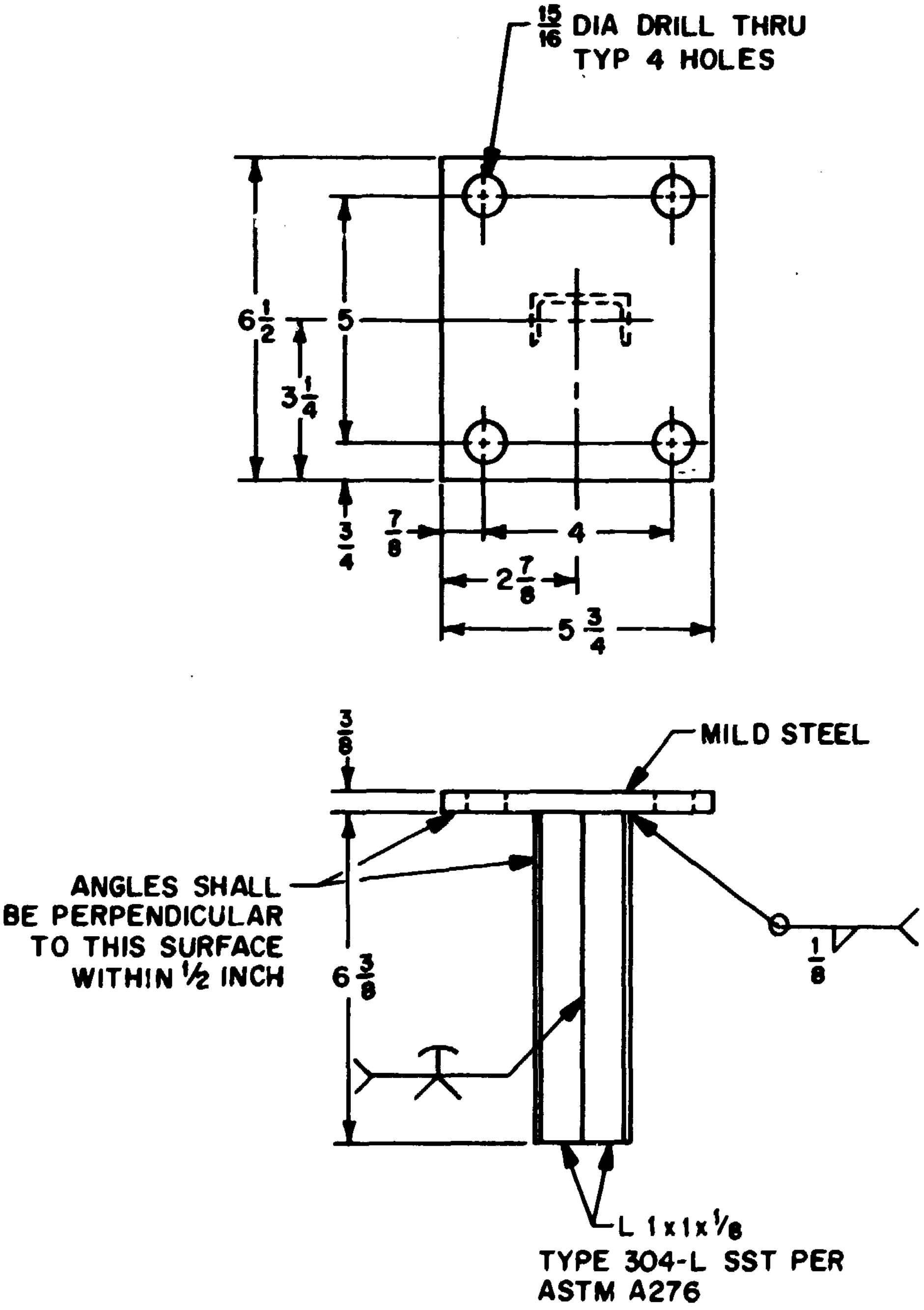


Fig. F.1. Impact test model.

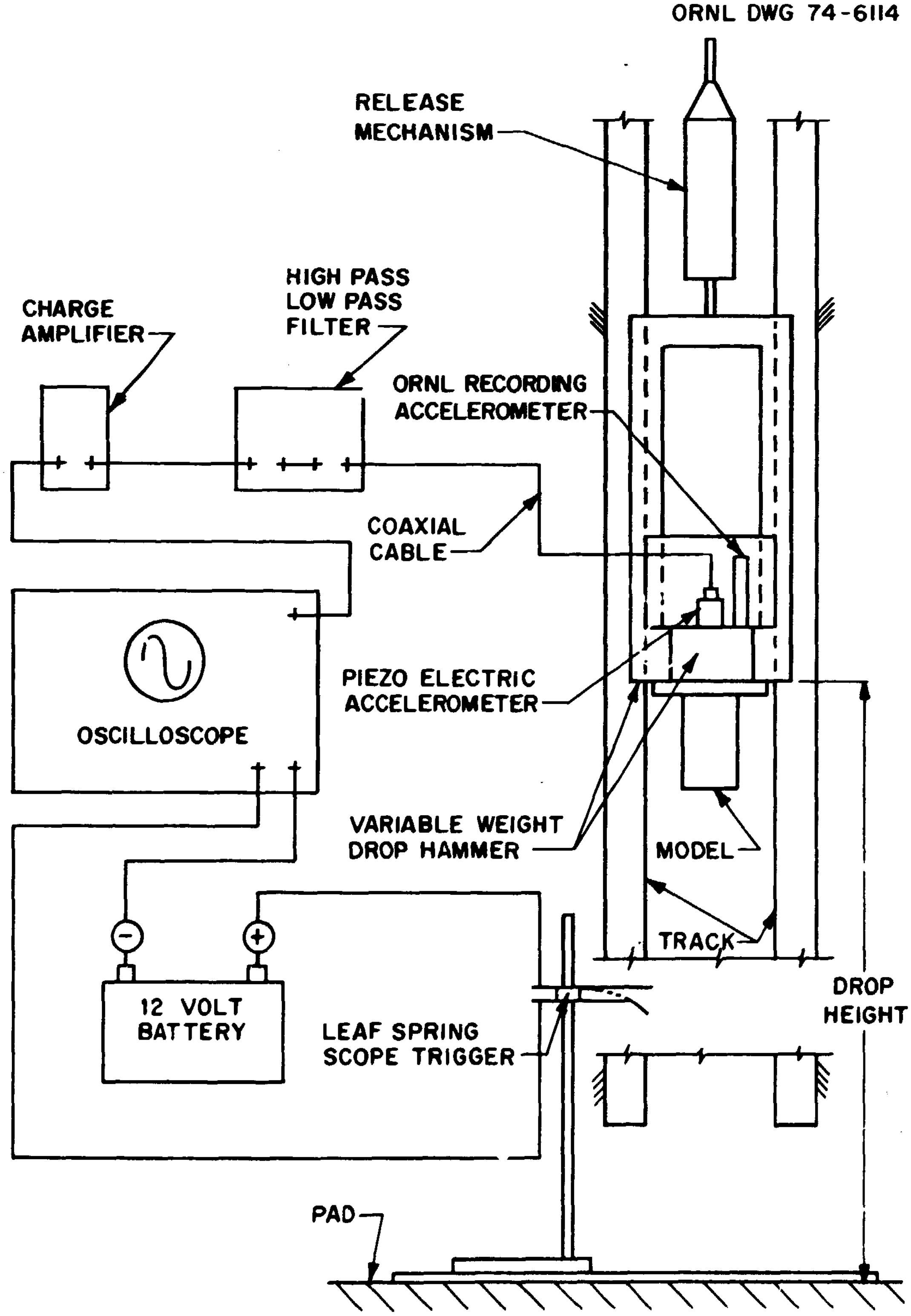


Fig. F.2. Data acquisition system.

Summary of results and conclusion

The specimens performed as expected and are adequate to absorb all the shield's energy. The results are summarized in Table F.1. The specimens after testing are shown in Fig. F.3. Three of the specimens (74-1-1, 74-1-2, and 74-1-4) buckled and absorbed energy as expected. The remaining two absorbed energy by a combination of buckling and rupture of the weld joining the two angle sections forming the channel. It can be seen from Table F.1 that the difference in the response between specimens is not significant. It is therefore of little consequence which mode of deformation the specimen follows.

Table F.1. Impact data and results

Specimen	Drop[a] height (in.)	Weight[b] dropped (lb)	Final deformation (in.)	Maximum Acceleration (x g)
74-1-1	360	125	2.53	190
74-1-2	360	125	2.36	200
74-1-3	360	125	2.26	200
74-1-4	360	125	2.53	200
74-1-5	360	125	2.12	210

[a] Drop height ± 1/2 in.

[b] Includes weight of specimen-mounting hardware.

ORNL-PHOTO 1005-74

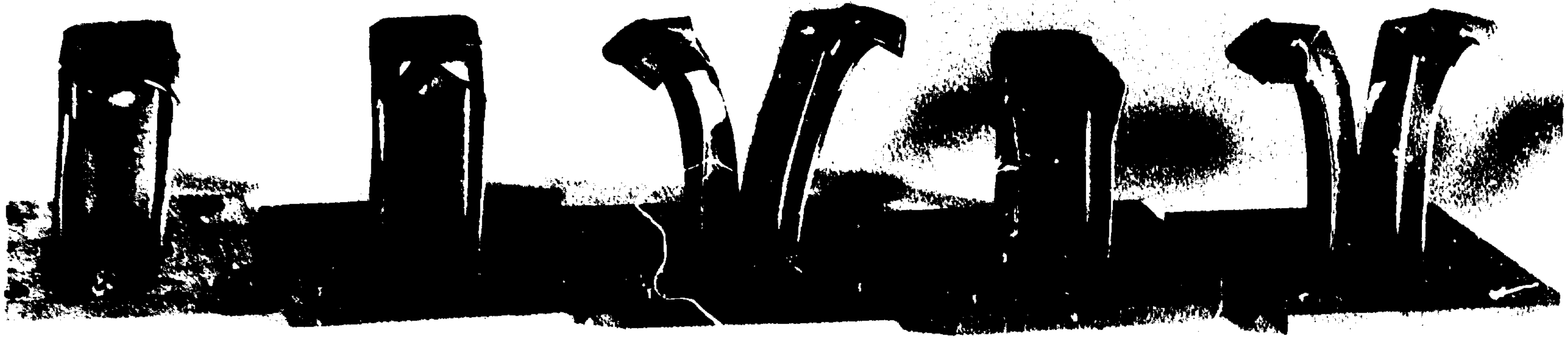


Fig. F.3. Models after testing.

Appendix G

SHIELDING ANALYSIS

Radiation Safety Evaluation of the ORNL Lithium Hydroxide Fire and Impact Shield

A study of the radiation safety of the ORNL lithium hydroxide fire and impact shield was made using the ANISN[1] discrete ordinates transport code and the 22-group neutron-18-group gamma-coupled cross-section set. For purposes of this study, a source consisting of neutrons having an energy distribution of spontaneous fission neutrons from ^{252}Cf was used. No primary gamma source was included, but secondary gamma rays resulting from neutron capture were included in the total dose rates obtained. A one-dimensional spherical annuli mock-up, using the radii of the cylindrical cask, was assumed, since such a representation should give doses as great or greater than those from the real cylindrical container.

The $LiOH \cdot H_2O$ was assumed to be made of 100% ^{7}Li isotope. The undamaged shield contained a 4-1/4-in.-thick layer of $LiOH \cdot H_2O$ at a density of 0.031 lb/in.^{3}. The damaged shield, for which fire damage was assumed, contained dry LiOH with the same lithium density instead of the $LiOH \cdot H_2O$ for the outer 1.6 in. of the 4-1/4-in. layer. Type 304L stainless steel was used for all metal parts. Damage other than fire damage was not considered in this study.

The same strength neutron source was used for both the undamaged and damaged containers. The dose rates at the surface and at 3 ft from the surface of the shield were scaled to that source, yielding 200 millirems/hr at the surface of the undamaged shield. The results are given in Table G.1.

Table G.1. Dose rates from LiOH shield

Condition	At surface		3 ft from surface	
	Total millirems/hr	% gamma	Total millirems/hr	% gamma
Undamaged	200	7.9	16.8	11.5
Damaged	273	4.6	23.1	4.0

The maximum contribution from secondary gamma rays is 12.7% of the total dose rate, and the increase in the total dose rate due to fire damage both at the surface and at 3 ft from the surface for the damaged shield is about 50%. Since the allowable dose rate for a damaged shield at 3 ft from the surface is 1000 millirems/hr as compared with the calculated value of 23.1 millirems/hr, the shield satisfies the requirements for safety with a considerable margin for any uncertainties in the calculations.

REFERENCE

1. W. W. Engle, A User's Manual for ANISN, K-1693 (Mar. 30, 1967).

Appendix H

CRITICALITY REVIEW

REQUEST FOR NUCLEAR SAFETY REVIEW

ORNL
CRITICALITY COMMITTEE

NSR 7371

EXPIRATION DATE
March, 1979

This request covers operations with fissile material in a control area and/or fissile material transfers that originate within the control area. The control area supervisor shall complete the blocks below and describe the process and/or operations to be performed, emphasizing the provisions for nuclear criticality safety on the reverse side of this page. This request shall be approved by the Radiation Control Officers of the originating Division and the Division(s) to which fissile material will be transferred.

TITLE, CONTROL AREA, AND SUMMARY OF BASIC CONTROL PARAMETERS

(To be completed by the Control Area Supervisor)

TITLE (FOR REFERENCE PURPOSES) ORNL – LiOH H_2O Fire and Impact Shield		DATE OF REQUEST 2/13/76	DATE PLANT REQUIRED
CONTROL AREA	CODE NO.	BUILDING ROOM	DIVISION Operations

TYPE AND FORM OF MATERIAL		Solid U, Pu, Am, Cm, Cf, Es, and Bk (fissionable isotopes)
ISOTOPIC ENRICHMENT (Wt. %)		
QUANTITY OF FISSILE ISOTOPES	PER ISOLATED BATCH OR UNIT	See provisions for Nuclear Criticality Safety
	TOTAL IN CONTROL AREA	
	TOTAL TO BE PROCESSED	
Concentration or Density of Fissile Material		
Spacing of Fissile Units		
Proximity and Type of Neutron Reflectors or Adjacent Fissile Material		
Limit on Moderation		
Limit on Neutron Absorbers		
Limit on Volume or Dimensions of Containers		

THIS REQUEST (MODIFIES, REPLACES) NSR(S) NO.
NSR-737 – Rev. 1

RECOMMENDATIONS

(To be completed by the Criticality Committee)

This endorsement is based on our present understanding of the operation (whether acquired verbally or in writing) and is subject to review and cancellation.

This request is approved subject to the requirement that the sum of the even isotopes of Am, Bk, Es and the odd isotopes of Cm, Cf, and Fm in the package not exceed 5 grams.

In addition, the maximum quantity of ^{233}U, ^{235}U, ^{239}Pu plus ^{241}Pu shall not exceed 100 gm total. This is considered a safe mass assuming reflection outside the package and water moderation inside the cavity.

Other factors that help account for nuclear safety are the configuration of the cask and cavity and normal dilution of the source with other neutron absorbing species

All shipments will be Fissile Class I.

R.C. Affel

R. C. Affel for ORNL CRITICALITY COMMITTEE

3/4/76
DATE

UCN-5917
(3 9-70)

PROVISIONS FOR NUCLEAR CRITICALITY SAFETY

(To be completed by the Control Area Supervisor)

Provisions for nuclear criticality safety shall be described below in accordance with Appendices II and III of the Manual Chapter 0530. This shall include brief descriptions of the process and/or all operations to be performed, plan procedures for the operations for nuclear criticality safety, and the basic control parameters. Please attach 11 cop referenced drawings and documents.

The ORNL Lithium Hydroxide Fire and Impact Shield forms neutron shielding; however, when gamma shielding is required any Type A container, or equivalent, is carried inside.

The contents of the container will be any solid, large quantity radioactive material whose decay heat load does not exceed 300 watts and gamma and/or neutron activity that does not exceed allowable dose rate levels. The maximum quantity of ^{242}Am, ^{244}Cm, ^{245}Cm, ^{247}Cm, ^{249}Cf, and ^{251}Cf will be limited to a combined total of 5 grams. The container will also be used to transport up to 150 grams of PuO_2 heat sources containing greater than 80% ^{238}Pu and less than 16% ^{239}Pu, 3% ^{240}Pu and 1% ^{241}Pu and having a decay heat load of 200 watts or less. The above materials will meet "special form" requirements.

The cask is intended for shipments of up to 100 grams of fissionable materials including ^{235}U, ^{233}U, and ^{239}Pu in solid form.

ORNL
CRITICALITY COMMITT
NSR 7371

EXPIRATION DATE
March, 1979

RADIATION CONTROL OFFICER	DIVISION	CONTROL AREA SUPERVISOR R. W. Schaich	BUILDING 3037
RADIATION CONTROL OFFICER	DIVISION	RADIATION CONTROL OFFICER	DIVISION Operations

INTERNAL CORRESPONDENCE

NUCLEAR DIVISION

POST OFFICE BOX X, OAK RIDGE, TENNESSEE 37830

To (Name) J. W. Wachter

Division

Location 4500N

Copy to File - RC

Date July 24, 1975

Originating Dept. Computing Applications

Answering letter date

Subject LiOH Cask

As per your request, I have examined the LiOH cask for loadings furnished by you to establish validity of CLASS I designation.

In an effort to maximize the calculated k_∞ with the KENO Monte Carlo code, the steel external fire LiOH shield was ignored as was any internal container configurations that may be used. The cask was described in the code as having a central cylindrical cavity with a radius of 34.3 cm and a height of 78 cm. The cavity was lined with a 0.5 cm-thick layer of 304SS. A 11.43 cm-thickness of LiOH covered the top and lateral surfaces of the stainless steel while the bottom surface had a 1.9 cm-thickness of plywood. The fissionable materials were considered as spheres centered in the cavity. The calculated k_∞ values are summarized in the following table.

Fissionable Material	Density g/cc	Mass g	Calculated k_∞
^{235}U	18.7	100	0.14
^{233}U	18.4	100	0.20
^{239}Pu	19.7	100	0.23
$^{238}PuO_2$	10.6	150	0.21
^{244}Cm	13.5	5	0.03

It would appear that these mass limits would comprise satisfactory values to permit use of the cask as a Class I container.

J. T. Thomas

JTT/kb

Appendix I

INSPECTION REPORTS

6/2/75

DEPLETED LITHIUM-6 HYDROXIDE, MONOHYDRATE

FOR HML LiOH FIRE AND IMPACT SHIELD

Laboratory analyses are on a material basis.

Laboratory Requisition No. 821044 -

Atom % ^{7}Li	97.52
Atom % ^{6}Li	2.48
Wt. % ^{7}Li	97.87
Wt. % ^{6}Li	2.13
Gms. Li/Gms of Material	0.166039
% LiOH	56.965
% H_2O	42.11
% CO_3	0.17
% Cl	0.0053

PPM		PPM	
Ag	0.17	Mn	<0.17
Al	49.81	Mo	<0.66
Ba	3.32	Na	13.95
Ca	13.95	Nb	<3.32
Cd	<1.00	Ni	<1.66
Co	<3.32	Pb	<0.66
Cr	<0.17	Si	<3.32
Cu	<1.66	Sn	<3.32
Fe	9.96	Sr	<1.66
Hg	0.02	V	<1.66
K	13.95	W	<16.60
Mg	<3.32	Zn	0.19

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

To: R. W. Schaich Date: February 26, 1975

cc: R. E. Sizemore

Subject: X-111507 LiOH SUGARMAN FIRE SHIELD

The pressure test was completed on this Fire Shield and Lid on this date.

Pressure - 2 psig

Soap Solution - Sherlock Gas and Air Leak Detector Type I

No visible leaks were detected on Fire Shield body or Lid.

S. E. Gheesling
P&E Field Engineer

SEG:RES:drw

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

To: R. W. Schaich Date: June 17, 1975

Subject: LiOH FIRE SHIELD LID VOLUME

Filled an empty LiOH Fire Shield lid with water.

Void space in the lid took 61.150 liters.

61.150 ÷ 3.785 = 16.156 gallons

16.156 × 231 = 3732.036 cu. in.

Used 107 pounds of LiOH to fill a similar lid.

Used 8.92 pounds of water to give the 1:10 ratio.

115.92 ÷ 3732 = 0.031 pounds/cu.in.

R.E. Sizemore

R. E. Sizemore

RES:drw

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

To: R. W. Schaich   Date: June 12, 1975

From: R. E. Sizemore

cc: S. E. Cheesling

Subject: LiOH FIRE SHIELD FUSIBLE PLUGS

Heat tests were conducted on two of the LiOH fire shield fusible plugs.

The first plug was subjected to 100°C for 2-1/2 hr with the following results:

> Starting length of fusible section - 0.782 in.
> At the end of the heating cycle there was 0.287 in. of the fusible material still in the plug.

The second plug was subjected to 110°C for 2-1/2 hr with the following results:

> Starting length of fusible section - 0.782 in.
> At the end of the heating cycle there was 0.130 in. of the fusible material still in the plug.

Both tests were conducted in our drying oven. The plugs were suspended in a glass beaker. No pressure was applied to the plugs.

R. E. Sizemore

RES:drw

UCN-430
(3 5-67)

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

May 9, 1974

TO: John H. Evans

SUBJECT: Inspection of ORNL Isotopes Fire and Impact
Shield Weldments.
ORNL Drawings: M11566-EM-001; -002 & -003

Five weldments (Property No., X-111506, X-111507, X-111508, X-111509 and X-111510) were visually inspected for quality workmanship and general conformance to the referenced drawings. All welds appear to be of good quality and seem to be of the type joints as specified on the drawings. The support channels and some of the sheet metal used in fabrication bore identification markings as being 304L Stainless Steel.

Identification Plates have not been attached to these fabrications. Property numbers have been attached to the bottom of each weldment.

This inspection indicates good quality workmanship and, in our opinion, no reason to question the integrity of the weldment.

INSPECTION ENGINEERING DEPT.

O.J. Smith

O. J. Smith

OJS:bc

cc: J. R. McGuffey
J. N. Robinson
C. R. Starlin

Appendix J

THERMAL STUDY OF LiOH

(Memo from R. J. Lauer to R. D. Seagren)

INTRA-LABORATORY CORRESPONDENCE
OAK RIDGE NATIONAL LABORATORY

The specimen was iso-statically compres. with 30,500psi into a block 1ft. high, 1ft. in dia. with a 1" hole in the center.

June 27, 1969

To: R. D. Seagren

Subject: Monthly Report for June, 1969

Thermal Study of LiOH

The thermal study continued with the collection of data while the heater power was increased in 10-watt increments from 50 watts to a maximum of 100 watts. As reported in May, 1969, the LiOH block lost weight at a rate of 3 lbs./day as the water was driven off. This was the maximum rate until ~17% of the weight had been lost. The rate gradually decreased until all the water, which comprised 42.77% of the total weight, had been lost. The water driven off is attributed to ~2% free moisture and the rest is water of hydration. Some refluxing of the water was apparent i.e. water was being driven from the center of the LiOH block to the outer surface, which was wrapped in a polyethylene bag, where the lower temperature induced condensation. The condensate was then absorbed by the LiOH thus completing the reflux cycle. This reflux cycle was apparent until ~40% of the weight was lost.

One objective of this study was to calculate a value of the thermal conductivity (K) for LiOH at various rates of heat flow (q_k) by conduction through the LiOH. Data collected for the range of 50 to 90 watts did not give satisfactory results i.e. is consistent values for K and ΔT. The probable reason is the refluxing of the water through the LiOH. The data collected will be checked again, and a different approach in use of the data to calculate K will be attempted. A more satisfactory result was achieved however for data collected with the heater power set at 100 watts. In calculating the thermal conductivity K the rate of heat flow is defined by the equation

$$q_k = \frac{(W-35.1335\%W)\,Kw}{2.93 \times 10^{-4}\ Kw\text{-}hr/B}$$

where ~35% of the heat was lost through paths other than the instrumented path over which the data was being collected, and W is the heater power in Kilowatts. The value of K was defined by the equation

$$K= \frac{q_k (r_o - r_i)}{\Delta T \bar{A}} = Btu/hr-°F-ft$$

where $(r_o - r_i)$ is the difference of the LiOH cylinder radii, ΔT is the temperature drop across the radial difference, and $\bar{A}$ is the logarithmic mean of the surface area where $A=2\pi rl$. Table I lists some of the pertinent data with the heater at 100 watts, and K vs. % water by wt in LiOH is plotted in graph No. 1. A second study is now under way to collect data to determine a value of K for the dry cylinger of LiOH. The data collected for the heater set at 80 through 100 watts in 10 watt increments is listed in table II. This study will continue through July, 1969.

X-Ray Unit

The Faxitron x-ray and fluoroscope unit purchased by the Isotopes Engineering Group has been delivered and is being installed in Bldg. 3026-C.

Capsule Puncturing Apparatus

The parts of the puncturing apparatus, which were being machined, have been finish and final assembly of the apparatus should be completed within the next two weeks. As soon as the assembly and testing of the apparatus has been done, cell space and time will be scheduled, and an attempt will be made to get a gas sample and other required data concerning the bulged source capsules.

Kr-85 Leak Test

The 3 capsules to be used in determining a leak rate correlation between He and Kr-85 have been checked with He. Two of the capsules still have leaks too large to be accurately rated on the He leak tester. An attempt will again be to peen the leak holes to decrease the leak size.

Table I. Data used to determine value of K with heater power at 100 watts and to plot K vs. % water lost.

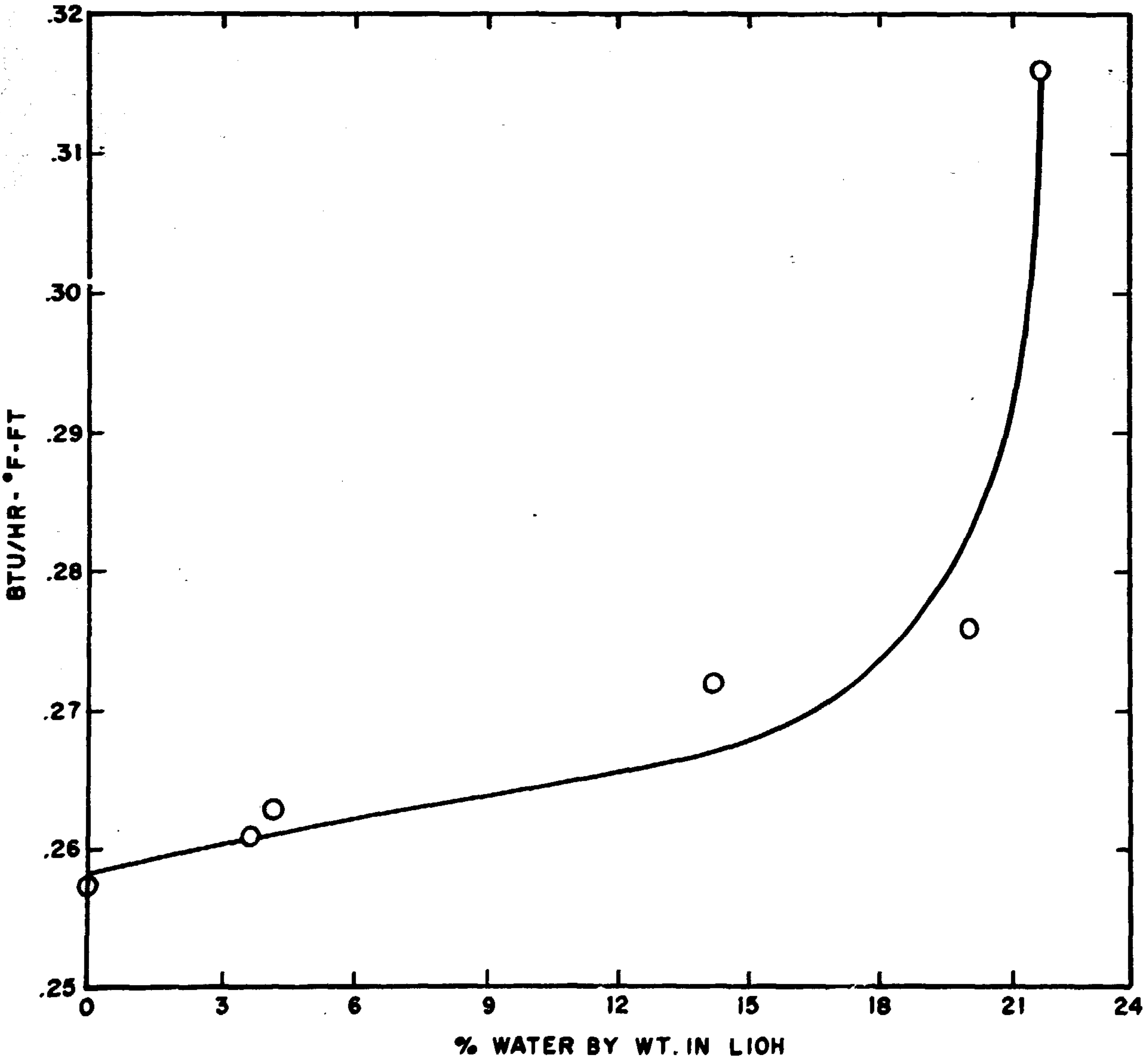
ΔT °F	Δwt. lbs.	% water by wt. in LiOH	K Btu/hr-°F-ft
285.8	23.0	21.77	0.316
327.2	25.7	20.01	0.276
332.6	32.4	14.20	0.272
343.4	33.3	4.23	0.263
347.0	44.3	3.70	0.261
350.6	48.5	0.00	0.2576

Table II. Data used to determine value of K for dry LiOH while varying heater power i.e. q_k.

Heater Power kw	ΔT °F	K Btu/hr-°F-ft
80×10^{-3}	296.6	0.24383
90×10^{-3}	334.7	0.24310
100×10^{-3}	350.6	0.25760

R. J. Lauer

ORNL DWG 77-9681



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