Safety Analysis Report for Packaging: The ORNL Lithium Hydroxide Fire and Impact Shield

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OAK RIDGE NATIONAL LABORATORY

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LITHIUM HYDROXIDE FIRE AND IMPACT SHIELD**

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CONTENTS

	<u>Page</u>
ACKNOWLEDGMENTS	ix
ABSTRACT	1
0. GENERAL INFORMATION	1
0.1 Introduction	1
0.2 Package Description	2
0.2.1 Container Description	2
0.2.2 Operational Features	4
0.2.3 Contents	4
0.2.4 LIGH Cavities	5
1. STRUCTURAL EVALUATION	5
1.1 Mechanical Properties of Materials	5
1.2 General Standards for All Packages	5
1.2.1 Closure	5
1.2.2 Cask-Lifting Device	6
1.2.3 Lid-Lifting Device	10
1.2.4 Tie-Down Devices	11
1.3 Standards for Type B and Large-Quantity Packaging	17
1.3.1 Load Resistance	17
1.3.2 External Pressure	19
1.4 Compliance with Standards for Normal Conditions of Transport	21
1.4.1 Heat	21
1.4.2 Cold	22
1.4.3 Pressure	22
1.4.4 Vibrations	24
1.4.5 Water Spray	24
1.4.6 Free Drop	24
1.4.7 Penetration	25
1.4.8 Compression	25
1.5 Compliance with Standards for Hypothetical Accident Conditions	26
1.5.1 Free Drop	26
1.5.2 Impact on Side	31
1.5.3 Puncture	35
1.6 Special Form	35
1.7 Inner Container Design	36
2. THERMAL EVALUATION	42
2.1 Discussion	42
2.2 Thermal Properties of Materials	42
2.3 Thermal Evaluation for Normal Conditions of Transport	42
2.3.1 Thermal Model	42
2.3.2 Maximum Temperatures	49

	<u>Page</u>
2.3.3 Minimum Temperatures	49
2.3.4 Maximum Internal Pressure	49
2.3.5 Thermal Stress	50
2.4 Hypothetical Thermal Accident Evaluation	50
2.4.1 Fire Testing	56
2.4.2 Thermal Accident Analysis	51
2.4.3 Container Temperatures	52
2.4.4 Maximum Pressures	52
2.4.5 Evaluation of Package Performance	52
3. CONTAINMENT	56
3.1 Containment Boundaries	56
3.1.1 Special Form Shipments	56
3.1.2 Other Shipments	56
3.2 Requirements for Normal Conditions of Transport	57
3.3 Requirements for the Hypothetical Accident Conditions	57
4. SHIELDING	61
5. CRITICALITY	61
6. QUALITY ASSURANCE	63
6.1 Fabrication, Inspection, and Acceptance Tests	63
6.2 Operating Procedures and Routine Inspection	64
6.3 Periodic Maintenance and Inspection	64
REFERENCES	65
APPENDIX A - As-Built Drawings	67
APPENDIX B - Approval Documents	73
APPENDIX C - Routine Packaging and Inspection Procedures	79
APPENDIX D - Hydrostatic Pressure Test and Computer Listing for Composite Heads	89
APPENDIX E - Fabrication Drawings of Full-Scale Test Model	105
APPENDIX F - Model Testing Procedure and Report	113
APPENDIX G - Shielding Analysis	121
APPENDIX H - Criticality Review	125
APPENDIX I - Inspection Reports	131
APPENDIX J - Thermal Study of LiOH (Memo from R. J. Lauer to R. D. Seagren)	139

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
0.1	LiOH shield	3
1.1	Lifting load diagram	7
1.2	Typical tie down	12
1.3	Simple beam model	18
1.4	Impact test model	28
1.5	Top impact test model	29
1.6	Models after testing	30
1.7	Schematic model testing	32
1.8	Special form encapsulation	37
1.9	Special form encapsulation	38
1.10	2R container	39
1.11	Typical 2R containers	40
2.1	Thermal model	44
2.2	Thermal model -- suspended 2R container	48
2.3	Temperature-time history for cask fire test	53
2.4	Temperature-time history for cask cooldown	54
2.5	Thermal model -- LiOH losing water of hydration	55
3.1	2R test models	58
3.2	2R test model	59
A.1	As-built drawing no. M-11566-EM-001-D	69
A.2	As-built drawing no. M-11566-EM-002-D	70
A.3	As-built drawing no. M-11566-EM-003-D	71
D.1	Calculatory model shield lid	92
D.2	Hydrostatic pressure test	103

<u>Figure</u>	<u>Page</u>
E.1 Fabrication drawing no. D-RD-2760	107
E.2 Fabrication drawing no. D-RD-2761	108
E.3 Fabrication drawing no. D-RD-2762	109
E.4 Fabrication drawing no. D-RD-2763	110
E.5 Fabrication drawing no. D-RD-2764	111
F.1 Impact test model	116
F.2 Data acquisition system	117
F.3 Models after testing	119

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1.1 Mechanical properties of cask materials	6
1.2 Dimensions schedule for 2R specification containers . . .	41
2.1 Material properties used in thermal analysis	43
2.2 Package temperatures during normal conditions of transport	47
F.1 Impact data and results	118
G.1 Dose rates from LiOH shield	123

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

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ABSTRACT

The ORNL lithium hydroxide fire and impact shield was designed and fabricated at Oak Ridge National Laboratory to permit the transport of Type B and large quantities of radioactive material and limited quantities of fissionable material. The shield was 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 is in compliance with the applicable regulations.

0. GENERAL INFORMATION

0.1 Introduction

The ORNL lithium hydroxide (LiOH) fire and impact shield was designed by the ORNL Isotopes Division 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 ($\text{LiOH}\cdot\text{H}_2\text{O}$) 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 one shield was filled with $\text{LiOH}\cdot\text{H}_2\text{O}$ in accordance with the drawings and specifications in Appendix A.

The primary use of the shields is to provide impact and thermal resistance to Type A and Specification 55 packages³ to permit the transport of Type B and large 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 shield complies with Energy Research and Development Administration (ERDA) regulations,

Title 10 CFR Part 71,² ERDA Manual Chapter 0529,¹ and all 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 reproduced 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 $\text{LiOH}\cdot\text{H}_2\text{O}$ 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 containment is provided by the Type A or Specification 55 package containing the special form encapsulation or an inner 2R container⁴ 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.

ORNL DWG 74-3850

Fig. 0.1. LiOH shield.

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 $\text{LiOH} \cdot \text{H}_2\text{O}$ forms neutron shielding in addition to offering thermal protection. When required, gamma shielding is provided by a shielded cask equivalent to or exceeding containment and construction criteria outlined in DOT regulations.⁴ This cask would weigh 2500 lb or less for a total package weight of 4000 lb.

When radioactive material other than special form^{1,2} is shipped, it is packaged in an inner container which meets or exceeds the requirements of DOT Specification 2R,⁴ conforms to the allowable stress and design philosophies of Sect. VIII of the *ASME Boiler and Pressure Vessel Code*,⁵ has a high integrity seal, and has provisions for leak checking of vessel and seal.

All inner containers 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. Movement of the inner vessel relative either to the gamma shield or the LiOH shield as applicable will be restricted to 1/4 in. or less in a like manner.

0.2.3 Contents

The contents of the inner container within the LiOH shield will be any solid, large quantity of radioactive materials 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 regulations.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 150 g of $^{238}\text{PuO}_2$ and up to 100 g of fissionable materials including ^{235}U , ^{233}U , and ^{239}Pu in solid form. The above materials will be packaged internally to meet special form requirements or DOT Specification 2R.

The LiOH package will carry irradiated metal specimens such as tensile, impact, and weld specimens including, but not limited to,

stainless steel, mild steel, aluminum, INOR-8, nickel, high-nickel alloys such as Inconel and Monel, and tungsten. All such specimens will meet special form requirements or be contained in a DOT Specification 2R container.

0.2.4 LiOH cavities

Cavities in the vessel and lid are filled with $\text{LiOH} \cdot \text{H}_2\text{O}$, which provides neutron shielding and thermal protection. Lithium hydroxide monohydrate is a corrosive material as defined by DOT regulations⁴ (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 173.417).

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 $\text{LiOH} \cdot \text{H}_2\text{O}$ 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	

^aDynamic properties are taken equal to static properties.

^b*Materials in Design Engineering*, Reinhold, New York, 1961.

^cSpecification 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.

^dOne-half yield stress.

^eAt 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

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

The force, T , is found from

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

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

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

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,

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

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

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

$$\begin{aligned}\bar{y} &= (A_1 y_1 + A_2 y_2) / (A_1 + A_2) \\ &= [(5.25)(0.5)(2.625) + (2)(0.5)(3.875)] / [(5.25)(0.5) + (2)(0.5)] \\ &= 2.97 \text{ in. ,}\end{aligned}$$

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

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

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

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

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, T_H , in the weld is

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

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

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

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 and its contents, a horizontal component along the direction of travel of ten times the weight of the package and its contents, and a horizontal component in the transverse direction of five times the weight of the package 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.

ORNL DWG 74-3852

Fig. 1.2. Typical tie down.

For the $10W$ load, by summation of horizontal forces (see Fig. 1.2), $F_x = 5W$. 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. Take H as the reference height of a tie-down, and letting $I/J = 1$, $K = 2^{1/2}$, $L = 3^{1/2}$, and $T_a = W(3)^{1/2}(5 + 2.5 + 0.25) = 13.42W$. Similarly, for the I/J ratio of $1/2$ and $H =$ reference height, $K = 5^{1/2}$, $L = 6^{1/2}$, and $T_a = W(6)^{1/2}(5/2 + 2.5/1 + 0.25/1) = 12.86W$.

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

$$T_a = 13.42 W ,$$

$$T_b = W(3)^{1/2}(5 + 0.25) = 9.09W ,$$

$$T_c = W(3)^{1/2}(0.25) = 0.43W ,$$

$$T_d = W(3)^{1/2}(2.5 + 0.25) = 4.76W ,$$

$$F_{za} = T_a H/L = 13.42W/3^{1/2} = 7.75W ,$$

$$F_{zb} = 9.09W/3^{1/2} = 5.25W ,$$

$$F_{zc} = 0.43W/3^{1/2} = 0.25W ,$$

$$F_{zd} = 4.76/3^{1/2} = 2.75W ,$$

$$F_n = \Sigma F_z - W = 15W .$$

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

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

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

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

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

$$\Sigma M_{n-n} = F_n Y - 5WE + (-F_{za} + F_{zb} + F_{zc} - F_{zd})A = 0 ,$$

$$Y = [5WE + (7.75 - 5.25 - 0.25 + 2.75) WA]/15W$$

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

The normal force F_n is located at a radius $r = (X^2 + Y^2)^{1/2} = (19.9^2 + 9.95^2)^{1/2} = 22.25 \text{ in.}$, 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 , $X = 2(18)/5^{1/2} = 16.1 \text{ in.}$ and $Y = X/2 = 8.05 \text{ in.}$ Considering only the 10W load and again summing moments about axis m-m,

$$F_n X - 2F_z A + 2P_z A - 10WE = 0 ,$$

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

$$2F_z X + 2P_z X - 2F_z A + 2P_z A - 10WE = 0 ,$$

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

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

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

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

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

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

$$\begin{aligned} T'_{10} &= 5WL/2X(A/J + E/H - X/J) \\ &= 5(4000)\sqrt{3}/2(16.1)[16.98 + 12.88 - 16.1] \\ &= 14,800 \text{ lb} = 3.7W , \end{aligned}$$

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

$$\begin{aligned} T_a &= (T_{10} + T_5 + T_2 + T'_{10}) = 17.12W \\ &= 68,500 \text{ lb} . \end{aligned}$$

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

$$\sigma = M/Z = [T_a L/8]/[(\pi)(D)^3/32]$$

$$= [(68,500)(2)(4)]/[(\pi)(1.875)^3] = 26,500 \text{ psi}.$$

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

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

The force $F_H = T_a (K/L) = 68,500(2^{1/2}/3^{1/2}) = 55,900 \text{ lb}$, 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 and Large-Quantity Packaging

The structural standards for large-quantity 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 $\text{LiOH}\cdot\text{H}_2\text{O}$ 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 moment

ORNL DWG 74-3853

(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 $\text{LiOH} \cdot \text{H}_2\text{O}$ 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

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

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 $\text{LiOH} \cdot \text{H}_2\text{O}$; hence it is

not readily analyzed. If we take the conservative approach 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

$$\begin{aligned} P_{cr} &= [2E(t/r_m)^2]/[3(1 - \nu^2)]^{1/2} \\ &= [2(29 \times 10^6)(0.125/18.0)^2]/[3(1 - 0.3^2)]^{1/2} \\ &= 1693 \text{ psig} . \end{aligned}$$

For lobar buckling,

$$\begin{aligned} P_{cr} &= \frac{1.345E(t/r_m)^{5/2}}{(1 - \nu^2)^{3/4}[(1.57)(L/r_m) - (t/r_m)^{1/2}]} \\ &= \frac{1.345(29 \times 10^6)(0.125/18.0)^{5/2}}{(1 - 0.3^2)^{3/4}[(1.57)(30.25/18.0) - (0.125/18.0)^{1/2}]} \\ &= 66 \text{ psig} . \end{aligned}$$

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 $\text{LiOH} \cdot \text{H}_2\text{O}$, 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 or 2R 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 continuous operating temperature limit of the silicone rubber O-rings in the 2R container is 500°F, which is above the calculated seal temperature. 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 temperature was assumed to be 100°F, and the referenced computer program⁷ 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

$$P = P_1 T_2 / T_1 = (14.7)(420) / (530) = 11.65 \text{ psia} .$$

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 $\text{LiOH}\cdot\text{H}_2\text{O}$ 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 and 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·H₂O,

$$\sigma = P/A = (5W)/(\pi D_o t) = [(5)(4000)]/[(\pi)(34.0)(0.125)] = 1500 \text{ psi} ,$$

where

W = weight of container = 4000 lb,

D_o = 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 in ORNL Shops. The model was fabricated in accordance with the ORNL Isotopes Division 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 $\text{LiOH}\cdot\text{H}_2\text{O}$ 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

PHOTO 0765-74

Fig. 1.4. Impact test model.

Fig. 1.5. Top impact test model.

PHOTO 1005-74

Fig. 1.6. Models after te ting.

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 report⁹ on fins is 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 52,500 psi (see Table 1.1).

The evaluation of Davis's data (see Appendix B of Davis's report³) 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

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

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,

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

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 tests¹⁴ 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 Annex 4 of MC0529.¹ The tests prescribed by Annex 4 have been performed

on a significant quantity of capsule designs. When a design is similar in size, mass wall thicknesses, materials, weld design, etc., to a capsule previously tested, the design is certified as special form based on previous test results. If this similarity does not exist, it is required that a prototype be tested as prescribed. Typical examples of special form capsules are illustrated in Figs. 1.5 and 1.9.

1.7 Inner Container Design

Typical inner 2R containers used at ORNL are shown in Figs. 1.10 and 1.11. For use with the LHM fire and impact shield, the containers will have the minimum head and wall thicknesses given in Table 1.2. These dimensions are based on the requirements of INE Specification 2B and of Sect. VIII of the ASME Boiler and Pressure Vessel Code,² which is ever to greater. The design pressure is established as 21 psig, which is the sum of the pressure rise due to internal heat generation (see Sect. 2) and the reduced atmospheric pressure (see Sect. 1.4.3). Design temperature is taken as 700°F (see Sect. 2). Materials and milling are limited to that given in Tables UCS-23 and UCS-24 of the ASME Boiler and Pressure Vessel Code.² Design stress is taken as 9700 psi, which is the minimum listed in these tables for 700°F. The applicable equations from the code for sizing shells and heads are:

For the shell, Eq. (1), paragraph UC-27,

$$t = PR/(SE - 0.5P) ;$$

For the top and bottom heads, Eq. (1), paragraph UC-34,

$$t = 3(PR/Q)^{1/2} ;$$

The milling is increased beyond that required for pressure to ensure leak-tightness in an accident. Some dimensions are increased beyond the calculated values for fabricability.

ORNL DWG 74-3855

Fig. 1.8. Special form encapsulation

Fig. 1.9. Special form encapsulation.

ORNL DWG 74-3857

Fig. 1.10. 2R container.

Fig. 1.11. Typical 2R containers.

Table 1.2. Dimension schedule for 2R specification containers
(Fig. 1.11)

d	t_s	t_f	t_h	t_s	Bolts	
					No.	Size
2	3/32	3/16	3/16	3/8	4	1/4 - 20
3	1/8	1/4	1/4	3/8	6	1/4 - 20
4	1/8	1/4	1/4	3/8	8	1/4 - 20
5	1/8	1/4	1/4	3/8	8	5/16 - 18
6	1/8	3/8	1/4	3/8	8	5/16 - 18
8	1/4	3/8	3/8	3/8	8	3/8 - 16
10	1/4	1/2	3/8	1/2	12	3/8 - 16
12	1/4	1/2	1/2	1/2	16	3/8 - 16

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 regulations³ 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 evaluation, 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

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	

^aThe 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).

^bThe heat capacity of lithium hydroxide was calculated from data taken from J. A. Dean, *Lange's Handbook of Chemistry*, McGraw-Hill, New York, 1973.

^cThe latent heat of hydrated lithium hydroxide (LiOH·H₂O) was based upon the weight fraction of water.

^dThe properties of stainless steel were obtained from *A Compilation of Thermal Property Data for Computer Heat-Conduction Calculations*, UCRL-50589.

^eThe thermal conduction and density of lead were taken from J. P. Holman, *Heat Transfer*, McGraw Hill, New York, 1972.

^fThe specific heat of lead was obtained from R. H. Perry, *Chemical Engineer's Handbook*, McGraw-Hill, New York, 1973.

^gThe thermal properties of plywood were based upon an engineering estimation.

Fig. 2.1. Thermal model.

as a 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 largest containers used. The base of the cask was assumed to be insulated during normal conditions. In actual practice the contents will vary considerably. An inner shielded container will not always be used. If an inner container is not used, there will be less resistance to heat flow during normal conditions than for the case considered due to increased transfer by convection and removal of the radiation baffles and air gaps associated with the inner shielded container. The configuration or 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 Krith,¹³ are shown below:

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

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 (Btu/hr·ft²·°F),

c = fin perimeter = 2 in. = 0.167 ft,

K = fitted thermal conductivity of stainless steel (see Table 2.1)

$$= 7.350 + 1.23 \times 10^{-2}T - 1.3 \times 10^{-5}T^2 + 6.22 \times 10^{-9}T^3$$

(Btu/hr·ft·°F),

A = profile area = 1/8 in.² = 0.00087 ft².

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·ft²·°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

$$A_b = \text{base area} = \pi DH = \pi(36)(30.5) = 3450 \text{ in.}^2,$$

$$A_F = \text{fin area} = HN(2i + t) = 92(30.5)[2(1) + 0.125] = 5960 \text{ in.}^2,$$

in which

$$N = \text{number of fins} = 92,$$

$$H = \text{fin length} = 30.5 \text{ in.},$$

$$t = \text{fin thickness} = 0.125 \text{ in.}$$

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* 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.

Finally, the 2R container was assumed to be suspended in the fire shield cavity (see Fig. 2.2). Although this is not a realistic possibility, it serves as a conservative case. Results indicated a higher temperature (Table 2.2) for the contents, with a minor change in surface temperatures.

Table 2.2. Package temperatures 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 2R 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 2R container	400	350	600

^aSee Fig. 2.1 for location.

ORNL DWG 75-12968

Fig. 2.2. Thermal model - suspended 2R container.

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·ft² 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 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, the LiOH·H₂O cavities, and, if used, the 2R container. The resulting pressures are calculated from the gas laws, assuming constant volume and a sealing temperature of T₁ of 70°F (530°R):

$$P_2 = P_1 T_2 / T_1 ;$$

for the LiOH·H₂O cavity shield cap,

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

and for the 2R container,

$$P_2 = (14.7)(860)/530 = 23.9 \text{ psia} = 9.2 \text{ psig} .$$

For the cask cavity,

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

and for the $\text{LiOH} \cdot \text{H}_2\text{O}$ 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 metal 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 holes¹⁵ 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 was 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 AM on July 23, 1971. Five minutes after oil ignition, cracking noises were heard. The cracking noise increased in frequency and continued until about 11:20 AM. At 11:15 AM

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 AM (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 program⁷ 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 for 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. 2.3 and 2.4. The interior of the fire shield does not exceed 240°F at any time; hence the contents would not exceed the special form test temperature of Annex 4 of MC0529, Part IV.

2.4.4 Maximum pressures

The resulting pressure for the cask cavity is

$$P_2 = P_1 T_2 / T_1 = (14.7)(700)/530 = 19.4 \text{ psia} = 4.7 \text{ psig} ,$$

and for the 2R container

$$P_2 = P_1 T_2 / T_1 = (14.7)(825)/530 = 22.9 \text{ psia} = 8.2 \text{ psig} ;$$

these pressures are negligible.

The $\text{LiOH} \cdot \text{H}_2\text{O}$ 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. Both the special form encapsulation and the 2R container will maintain containment of contents. No lead will melt within the inner container. The $\text{LiOH} \cdot \text{H}_2\text{O}$ will lose moisture (hydrogen content) as illustrated in Fig. 2.5. The resulting increase in neutron dose will not exceed the specified limits (Sect. 4).

LION SHIPPING CASK FIRE TEST

ORNL DWG 77-3115

Fig. 2.3. Temperature-time history for cask fire test.

Fig. 2.4. Temperature-time history for cask cooldown (see Fig. 2.3 for node identification).

Fig. 2.5. 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. 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 mass spectrometer or vacuum-bubble¹² leak detection techniques. If required for gamma shielding, the inner container forms an additional line of containment. These containers are equipped with gasketed closures but are not generally designed to be leak checked.

3.1.2 Other shipments

All materials shipped which do not conform to special form are contained in a Specification 2R container (see Sect. 1.7) which forms primary containment. Typical examples of ORNL 2R containers are illustrated in Figs. 1.10 and 1.11. These containers are designed to be leak-tight to the extent that water will not leak from the container at the anticipated pressure and room temperature. The container shown in Fig. 1.11(d) is designed for leak checking and will be leak-tight to the extent that leaks are not detectable by appropriate techniques. All powders and other dispersibles will be shipped in 2R containers which are leak checked. Solids such as metal specimens, etc., may be shipped in containers which are not designed for leak checking.

If required for gamma shielding, an inner container forms secondary containment.

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), nor will there be a loss of coolant.

The 2R containers are designed (see Sect. 1.7) for pressures and temperatures in excess of those encountered in normal transport; hence, there should be no release of radioactive material, loss of coolant (air), nor contamination of coolant.

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 as long as the shield(s) remains intact. The test and calculations in Sect. 1.5 demonstrate this. 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.

Likewise, the design pressure and temperature (see Sect. 1.7) for the 2R containers are not exceeded during the accident. The silicone rubber gaskets, maximum service temperature of 300°F will not be exceeded. The impact will not overstress the container. Hence, there will be no detectable loss of contents from the 2R container. The tests outlined below were conducted to establish ability of 2R containers to maintain containment after a 30-ft drop impact.

On August 21, 1974, two each of the Specification 2R containers as illustrated in Figs. 3.1 and 3.2 were drop tested at ORNL to establish the adequacy of this type of container as the primary containment vessel for radioactive materials. This type of container is extensively used at ORNL in conjunction with various shielded casks. Normally, the containers are assembled using forged caps for both end closures.

PHOTO 2468-74

Fig. 3.1. 2R test models.

Fig. 3.2. 2R test model.

Frequently, one cap is welded to the pipe nipple, enhancing its structural integrity. Both steel and stainless steel pipe and caps have been used. For this test the cast steel (malleable) caps were used at one end due to a temporary shortage of forged caps. In all the tests conducted, the forged cap was the point nearest the point of impact. The cast cap is not considered a part of the test except to facilitate leak testing.

Both containers were air-soap-bubble leak tested at 10 psig prior to testing. There were no detectable leaks. The first container was filled with tap water, placed in an existing steel casing (see Fig. 3.2), and dropped from a height of 30 ft onto the ORNL pad, impacting at an angle of $\sim 17.3^\circ$. The angle of impact was calculated from the deformation dimensions of the casing. The casing was used to simulate the protection afforded by the cask. The second container was also filled with tap water, then placed in the casing and dropped as above on its end. The containers were drained using the pipe plug in the top and soap-bubble tested at 10 psig. There were no detectable leaks.

Both containers were then refilled with water. The first container was dropped from a height of 30 ft onto the pad without any outer protection. It impacted at a very flat, oblique angle. No leakage of water was observed. There were significant leaks at both threaded joints when the containers were air-soap-bubble tested at 10 psig. The second container was dropped as above such that the plane containing the point of impact and the center of gravity was essentially vertical. Again, there was no visible loss of water. A 10-psig air-soap-bubble test revealed significant leakage around the lower (nearest to the point of impact) threaded joint.

It is concluded that a 2R container made of threaded stainless or carbon steel pipe and forged steel or stainless steel caps is adequate to provide primary containment when inside the L10H container. It is also concluded that such a container is not adequate without some external protection. It is obvious that the accelerations experienced by the test containers in the steel casing were of greater magnitude than would be experienced in a shipping cask.

4. SHIELDING

Shielding from neutrons is effected by the $\text{LiOH}\cdot\text{H}_2\text{O}$ in the fire and impact shield. When required, gamma shielding is provided by an inner container meeting DOT requirements. 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 $\text{LiOH}\cdot\text{H}_2\text{O}$ will become LiOH in the region indicated in Fig. 2.5. 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 Inspection Engineering Department 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 Inspection Engineering report is presented in Appendix I.

The modifications to the weldments were performed in accordance with the drawings, notes, and the ORNL Quality Assurance Procedures applicable to Quality Level III fabrication. 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 $\text{LiOH} \cdot \text{H}_2\text{O}$ 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 QA files. These files must be auditable and maintained for the life of the container.

REFERENCES

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Appendix A
AS-BUILT DRAWINGS

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 74-5

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

ENK:bb

cc: Transportation Committee

Form AEC418
(17-73)
18 CFR 71
AECM 5281

U.S. ATOMIC ENERGY COMMISSION
CERTIFICATE OF COMPLIANCE
For Radioactive Materials Packages

1a. Certificate Number USA/9852/BLF (ERDA-ORO)	1b. Revision No. 0	1c. Package Identification No. USA/9852/BLF (ERDA-ORO)	1d. Page No. 1	1e. Total No. Pages 2
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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 and 14 CFR 103) and Sections 146-19-10a and 146-19-100 of the Department of Transportation Dangerous Cargo Regulations (46 CFR 146-149), as amended.
- 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):

Oak Ridge National Laboratory
Post Office Box X
Oak Ridge, TN 37830

(2) Title and Identification of report or application:

Safety Analysis Report for
Packaging for the ORNL Lithium Hydroxide Fire
and Impact Shield

Report No.: ORNL/ENG/TM-8

(3) Date:

November 1977

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 and DOT Specification 55 packages to permit transport of Type B and large quantities of radioactive materials and limited quantities of fissile materials, which are contained within inner special form encapsulation or DOT Specification 2R containers. The inner vessels will be blocked to minimize movement during transport.

The inner cavity of the shield is a cylinder 27 in. diameter x 26 in. high. The outer shell is 36 in. diameter x 30 3/4 in. high.

The lid is 4 5/8 in. thick. The shield is fabricated from 1/8 in. thick 304-L stainless steel with the 4 1/4 in. nominal space between inner and outer cladding being filled with LiOH.H₂O crystals. The outer surface of the shield has 92 vertical cooling fins. The flanged closure is held in position by twenty one-inch alloy steel bolts.

The gross weight of the package is 4,000 lbs.

6a. Date of Issuance September 2, 1977	6b. Expiration Date FOR THE U.S. ATOMIC ENERGY COMMISSION
7a. Address of Issuing Office: U. S. Energy Research & Development Adm. Post Office Box E Oak Ridge, Tennessee 37830	7b. Signature, Name, and Title of Approving Official: <i>William H. Travis</i> William H. Travis, Director Safety and Environmental Control Div.

(3) Drawings:

The overpack is described and fabricated in accordance with Union Carbide Corporation, Nuclear Division, Oak Ridge National Laboratory drawings:

D-RD-2760-D through D-RD-2764-D

(b) Contents:

(1) Type and form of material:

Any solid, large quantity of radioactive materials, fissile and non-fissile, meeting special form or packaged in DOT Specification 2R inner container 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) 150 g. of:

$^{238}\text{PuO}_2$

(iii) 100 g. of:

^{235}U , ^{233}U or ^{239}Pu

(c) Fissile Class:

I

Appendix C

ROUTINE PACKAGING AND INSPECTION PROCEDURES

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

Proc. No. 1
Page 1 of 3
Date 2/17/77

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 PM on the day before the scheduled shipping date.
5. The review of packaging documentation follows the procedure established in ORNL-TM-2769, *ORNL Isotopes Division 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) from the SS Materials Management and Isotopes Sales Group by 1:00 PM 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

Process Group Leader

FEB 18 1977
Date

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENTProc. No. 1
Page 2 of 3
Date 2/17/77

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 lbs 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 activity¹ (list as "C.F." for carrier free where applicable).
 - F. Assay date and time.¹

Approved: Johnston

Supervisor

R. W. Schuch
Process Group Leader

FEB 28 1977

Date

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

Proc. No. 1
Page 3 of 3
Date 2/17/77

G. Normality of solutions of acids and bases.

H. Radiochemical purity.²

¹Unprocessed 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.

²In 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 (attached Form 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-TM-2769, ORNL Isotopes Division Guide for the Packaging of Radioactive Materials for Transport.*

Approved:

Supervisor

Process Group Leader

Date

FEB 28 1977

OAK RIDGE NATIONAL LABORATORY RADIOACTIVE MATERIALS PACKAGING INFORMATION

THIS FORM IS REQUIRED FOR ALL SHIPMENTS GREATER THAN 1 MILLICURIE ALPHA OR 3 CURIES BETA/GAMMA SOLID, LIQUID, OR GAS AND ALL EMPTY RETURNABLE CONTAINERS

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. Specify (a) ☐ Normal Form (b) ☐ Special Form Special Form No. _____	
(c) ☐ Fissile (d) ☐ Non-Fissile	
3. Radioactive Material Form: ☐ Solid ☐ Liquid ☐ Gas	
4. Heat Load (watts): Calculated _____ Estimated _____ By _____	

SHIPPING CONTAINER

1. Certificate of Compliance No. USA-	3. Nuclear Safety Review No.
2. DOT Specification No.	Date
4. Container determined proper for contents by	

INTERNAL CONTAINER

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

EXTERNAL CONTAINER

1. Moderator and neutron absorber present for fissile material?	☐ 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 welded to the outside of the carrier	☐ Yes	☐ By _____

RADIATION SURVEY

1. Surface contamination level: Alpha _____ dpm, Beta _____ 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 and shoring in accordance with SARP and Designed Layout checked by _____	
(Inspection Engineering) _____	
Shipment Approved By _____	Date _____

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

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

PROC. NO. 26
PAGE 1 OF 4
DATE 8/17/77

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) files in Buildings 3029 and 3037 by container number.
2. If container is contaminated externally or internally, it is cleaned to ORNL smear tolerances 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 files.
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 files. 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 files 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 files. 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 files.

Outgoing Type B Containers

1. Shielded Containers
 - a. Vacuum leak test will be performed by operating personnel and recorded in the container's QA files in Buildings 3029 and 3037 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 files. All repairs will be inspected and approved by Inspection Engineering and recorded in the QA files.

APPROVED

SUPERVISOR

[Signature]

PROJECT LEADER

[Signature]

DATE

AUG 1 1977

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT

PROC. NO. 26
PAGE 2 OF 4
DATE 8/1/77

-
- c. Gaskets will be changed every 6 months and recorded in the container's QA files. 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 files. 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 files.

APPROVED

SUPERVISOR

DATE

PROCESS GROUP LEADER

DATE

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OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT
BUILDING 3029
SOURCE DEVELOPMENT LABORATORY
URANIUM CASK PACKING PROCEDURE

PROC. NO. 26
PAGE 3 OF 4
DATE 8/1/77

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
 - a. Neoprene gasket for <1400 W installed _____ by _____
 - b. Silicone rubber gasket for >1400 W installed _____ by _____
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 (16 required), checked for burrs and proper operation _____ by _____
8. Skid studs and nuts checked for burrs and proper alignment _____ by _____

Post Loading Checks

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 onto skid _____ by _____
6. Skid nut torqued to 300 ft.-lb _____ by _____
7. Personnel heat shield installed _____ by _____
8. Packaging Information Form (UCN-12301) completed _____ by _____
9. Notification to Packing and Shipping Foreman _____ by _____

Supervisor Approval by _____

Date _____

APPROVED

SUPERVISOR
[Signature]

PROJECT LEADER

[Signature]

DATE AUG 1 1977

OPERATIONS DIVISION
RADIOISOTOPE DEPARTMENT
BUILDING 3029
SOURCE DEVELOPMENT LABORATORY
CONTAINER INSPECTION SHEET

PROC. NO. 26
PAGE 4 OF 4
DATE 3/1/77

Date _____ Container Number _____

EXTERNAL INSPECTION

By _____

Smear _____ dpm Bq; _____ dpm alpha

Condition Good ☐ Fair ☐ Poor ☐

Repairs Needed _____

Action Taken _____

INTERNAL INSPECTION

By _____

Smear _____ dpm Bq; _____ 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 _____

APPROVED

SUPERVISOR

PROCESS GROUP LEADER

DATE

AUG 1 1977

U.S. GOVERNMENT PRINTING OFFICE: 1974-4-771

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 Δ 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 notation¹ (from *Formulas for Stress and Strain*, 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

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

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

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

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ORNL DWG 74-3854

Fig. D.1. Calculatory model shield lid.

where

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

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

Thus

$$\sigma_r = [(3a^2P)/(8\pi t^2)]\{[(3m + 1)(r^2/a^2)] - (2m + 1) + [(m + 1)\ln(a/r)]\} .$$

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

$$\sigma_T = [(3a^2P)/(8\pi t^2)]\{[(m + 3)(r^2/a^2)] - (m + 2) + [(m + 1)\ln(a/r)]\} .$$

REFERENCE

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

 

THIS PROGRAM CALCULATES STRESSES IN A COMPOSITE CIRCULAR
FLAT PLATE HEAD COUPLED AT THE CENTER LOADED WITH PRESSURE
ON THE EXTERIOR SURFACES
CODED BY JOHN EVANS P.E., CAN RIDGE NATIONAL LAB., AUG 1973

O R N L LITHIUM HYDROXIDE SHIPPING CONTAINER.

```

DIMENSION R(100), B(100), Z(100), SR(100), ST(100)
1  ,N(100), XP(100), YP(100)
DO 2 I=1, 100
  R(I)=0.0
  B(I)=0.0
  Z(I)=0.0
  SR(I)=0.0
  ST(I)=0.0
  N(I)=0.0
2 CONTINUE
A=17.
T=-.25
P=10.55
CH=(1./-.3)
AH=2.*CH + 1.
CH=CH + 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, 1006)
WRITE (51, 1006)
WRITE (51, 1006)
WRITE (51, 1002)
WRITE (51, 1004)
WRITE (51, 1002)
C = ((3. * A * A) / (9. * C * T * T)) * P
G = ((3. * C * H) + 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) = ((C * H + 1.) * (ALOG (A / R(I))))
8 ST(I) = (C * (((C * H + 3.) * E(I)) - O * E(I)))
7 SR(I) = (C * ((G * B(I)) - A * 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, 48H C R N L LITHIUM HYDROXIDE FIRE AND IMPACT SHIELD)
1006 FORMAT (1H, X, 49H*****
1      55H*****
2      14H*****
1007 FORMAT (1H, 8X, 45HSTRESSES IN A PLAT 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 M L LITHIUM HYDROXIDE PIPE AND IMPACT SHIELD

STRESSES IN A PLAT 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	11348.8	-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	2840.4	-7749.7
5.250	1989.3	-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	-10667.7

		-10458.2
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	-1079.8	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 gauge on the inlet. The results of this test are tabulated below.

Test results

Test No. 1

		<u>Deflection at indicator location</u>		
		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

		<u>Deflection at indicator location</u>		
		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	No	0.0000
	5 psig			0.0018
	11 psig	data	data	0.0039
Posttest	0 psig			0.0006

Data reduction and calculations

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 $\widehat{AB}$. From the equations of a circle presented in the CRC Standard Math Tables, the arc is

$$\widehat{AB} = R\theta ,$$

where

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

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

therefore

$$\widehat{AB} = 13.85640925 \text{ in.}$$

The permanent elongation of this element is

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

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.

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 AEC-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

 $\frac{15}{16}$ DIA DRILL THRU
TYP 4 HOLES

Fig. F.1. Impact test model.

ORNL DWG 74-6114

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

^aDrop height $\pm 1/2$ in.

^bIncludes weight of specimen-mounting hardware.

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 ANISN¹ 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 ²⁵²Cf 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·H₂O was assumed to be made up of 100% ⁷Li isotope. The undamaged shield contained a 4-1/4-in.-thick layer of LiOH·H₂O 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·H₂O 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

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.

ORNL
CRITICALITY COMMITTEE

NSR 7371

EXPIRATION DATE
March, 1979

TITLE, CONTROL AREA, AND SUMMARY OF BASIC CONTROL PARAMETERS

(To be completed by the Control Area Supervisor)

TITLE (for REFERENCE PURPOSES)		DATE OF REQUEST	DATE REVIEW REQUIRED
ORNL - LiOH H ₂ O Fire and Impact Shield		2/13/76	
CONTROL AREA	CODE NO.	BUILDING ROOM	DIVISION
			Operations
TYPE AND FORM OF MATERIAL	Solid U, Pu, Am, Cm, Cf, Es, and Bk (fissionable isotopes)		
ISOTOPE 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 ²³³U, ²³⁵U, ²³⁹Pu plus ²⁴¹Pu 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. G. Affel for CHAIRMAN, CRITICALITY COMMITTEE

3/4/76

DATE

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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 copies of 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 COMMITTEE

MSR 7371

EXPIRATION DATE
March, 1979

RADIATION CONTROL OFFICER	DIVISION	CONTROL AREA SUPERVISOR <i>R. W. Schaich</i>	BUILDING 3037
RADIATION CONTROL OFFICER	DIVISION	RADIATION CONTROL OFFICER <i>G. C. Hall</i>	DIVISION Operations

INTERNAL CORRESPONDENCE

NUCLEAR DIVISION

POST OFFICE BOX X, OAK RIDGE, TENNESSEE 37830

To (Name) J. W. Wachter
 Division
 Location 4500N

Date July 24, 1975
 Originating Dept. Computing Applications

Answering Letter date

Copy to File - RC

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
$^{238}\text{PuO}_2$	10.6	150	0.21
^{240}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.

Joe
 J. T. Thomas

JTT/kb

Appendix I
INSPECTION REPORTS

6/2/75

DEPLETED LITHIUM-6 HYDROXIDE, MONOHYDRATE

FOR NNL LiOH FIRE AND IMPACT SHIELD

Laboratory analyses are on a material basis.

Laboratory Requisition No. 821044 -

Atom % ^7Li	97.52
Atom % ^6Li	2.48
Wt. % ^7Li	97.87
Wt. % ^6Li	2.13
Gos. Li/Gos of Material	0.166039
% LiOH	56.965
% H_2O	42.11
% CO_2	0.17
% Cl	0.0053

<u>PPM</u>		<u>PPM</u>	
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.

$$61.150 \div 3.785 = 16.156 \text{ gallons}$$

$$16.156 \times 231 = 3732.036 \text{ cu. in.}$$

Used 107 pounds of LiOH to fill a similar lid.

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

$$115.92 \div 3732 = 0.031 \text{ pounds/cu.in.}$$

R. E. Sizemore

RES:drw

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

To: E. W. Schaich

Date: June 12, 1975

From: R. E. Sizemore

cc: S. E. Gheesling

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

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: HL1566-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

OJS:bc

cc: J. R. McGuffey
J. H. 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

June 27, 1969

To: R. D. Seagren

Subject: Monthly Report for June, 1969

The specimen
was isostatically compressed
with 30,500 psi into a
block 1 1/2" high, 1 1/2" in
dia. with a 1/2" hole in the
center.

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. inconsistent 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

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

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

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

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 $A = 2\pi r l$. 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 cylinder 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 finished 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	$\Delta wt.$ 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