neutron products inc

22301 Mt. Ephraim Road, P.O. Box 68
Dickerson, Maryland 20842 USA
301/349-5001 TWX: 710-828-0542
FAX: 349-2433

October 29, 1992

Mr. Charles E. MacDonald, Chief
Transportation Branch
Division of Safeguards and Transportation, NMSS
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Subj: Certificate of Compliance No. 9215, Docket No. 71-9215

Dear Mr. MacDonald:

Transmitted herewith is a consolidated application for renewal of Certificate of Compliance No. 9215 for the Model NPI-20WC-6 MkII shipping package. This supplements our initial application for renewal, dated September 14, 1992, and provides information in the form requested by your letter of October 9, 1992.

Should it be desired, pages and drawings in the consolidated application can be identified to our several submittals as follows:

No revision number	Initial submittal, August 5, 1986
Revision 1	Submittal dated December 31, 1986
Revision 2	Submittal dated May 18, 1987
Revision 3	Submittal dated August 28, 1987
Revision 4	This submittal
NPI drawing N-240116, Rev D	Submittal dated May 18, 1987
NPI drawing N-240122, Rev F	Submittal dated August 5, 1992

We hereby give authorization for you to file copies of drawings N-240116, Rev D and N-240122, Rev F in the Public Document Room.

Please contact the undersigned if you require additional information.

Very truly yours,

NEUTRON PRODUCTS, INC.

Frank Schwoerer

Frank Schwoerer, Vice President

FS:mvc:12

Attachment 290034

NTO1 1/6

CONSOLIDATED APPLICATION FOR RENEWAL OF

CERTIFICATE OF COMPLIANCE NO. 9215 FOR A TYPE B(U)

RADIOACTIVE MATERIAL TRANSPORTATION PACKAGING

MODEL NUMBER NPI-20WC-6 MkII

neutron products inc

22301 Mt. Ephraim Road • P.O. Box 68 • Dickerson, Maryland 20842 USA • 301/349-5001
TWX: 710-828-0542 • FAX: 301/349-2433

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1. GENERAL INFORMATION

1.1 Introduction

This application is in support of renewing Certificate of Compliance No. 9215 for a B(U) rated radioactive material transportation package, NPI-20WC-6 MkII. The package is essentially identical in dimensions and configuration to another shipping package, Model No. NPI-20WC-6, presently in use under Certificate of Compliance No. 9102, with package identification number USA/9102/B( ). Both packages are for shipment of encapsulated cobalt-60 sources and comprise a shielded inner container which fits snugly within an overpack meeting DOT Specification 20WC-6 requirements. The overpack is made up of a Wooden Protective Jacket and a Steel Shell which encloses the Wooden Protective Jacket.

The package design is service proven; the existing containers having been in use for over 17 years. During this period, 3 containers of this design have been used to make more than 100 shipments per year without an adverse incident.

Model No. NPI-20WC-6 MkII differs from Model No. NPI-20WC-6 principally in the materials used for construction of the shielded inner container. The structure of the shielded inner container is fabricated of either a normalized high strength carbon steel made to fine grain practice, or an austenitic stainless steel. Both have superior fracture roughness properties at low temperatures.

The original package, Model No. NPI-20WC-6, is authorized for tranaport of a maximum activity of 9,500 curies and a maximum internal decay heat of 150 thermal watts. The new package, Model No. NPI-20WC-6 MkII, was initially licensed for use under Certificate No. 9102 at the same ratings as the original package. However, Model No. NPI-20WC-6 MkII is capable of meeting applicable regulatory requirements at a maximum activity of 15,000 curies of cobalt-60 and the associated decay heat of 240 watts and it was subsequently licensed for these ratings by Certificate of Compliance No. 9215. The higher capability results from increased lead shielding and reduced gamma streaming, which in turn results from the combination of a reduced drum liner diameter and shell liner wall thickness as compared with the original package.

All references to the new package in this document are to the Model No. NPI-20WC-6 MkII package at the 15,000 curie rating. Results of development and operational experience with the existing transportation package are used, as appropriate, in support of this application for renewal of certification, and where used are so identified.

1.2 Package Description

1.2.1 Packaging

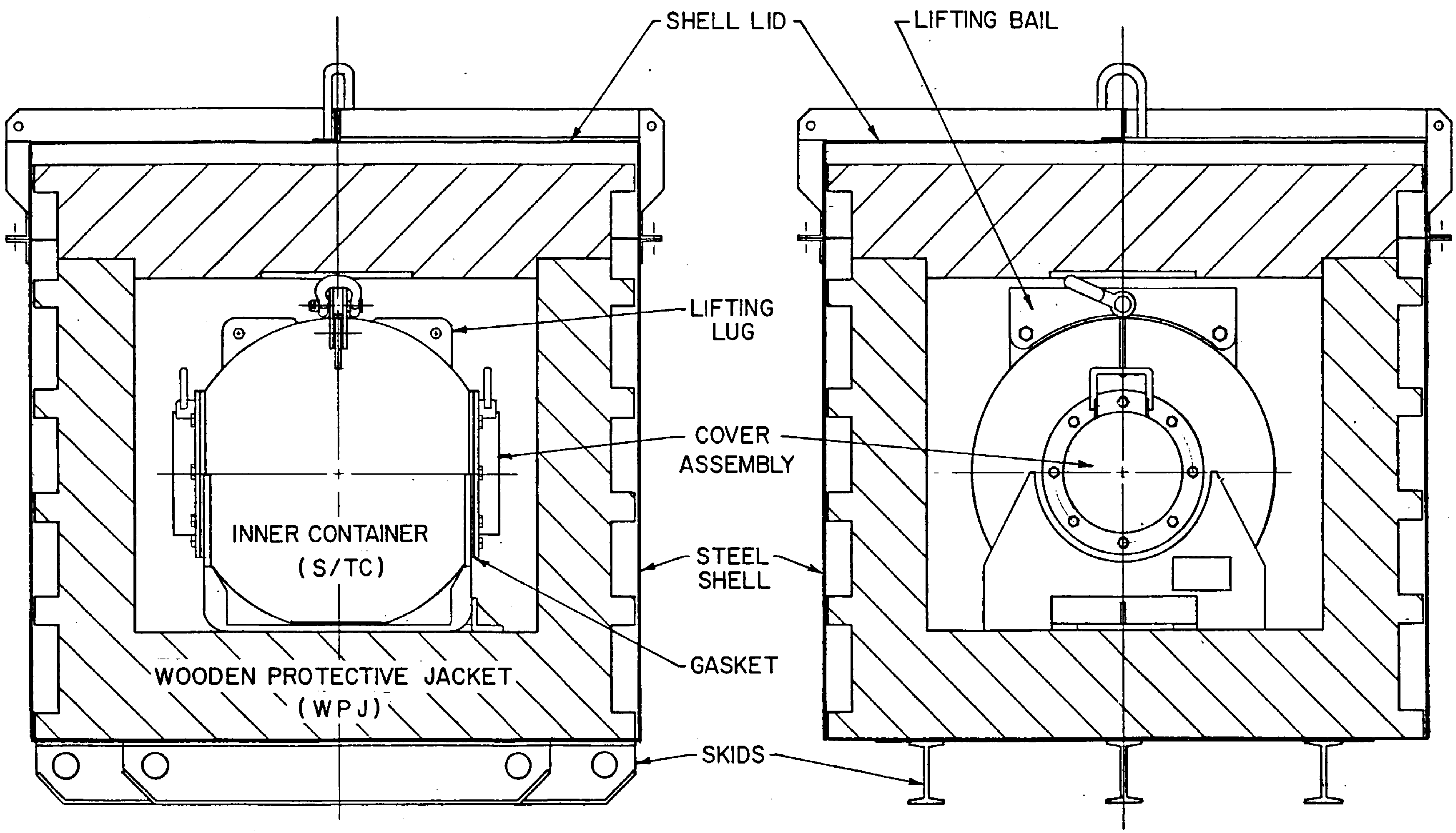
The inner container serves as a transfer cask to mate with and exchange cobalt-60 sources with teletherapy devices, as well as providing a shielding and containment function during shipment. As a shipping/transfer cask, it is designated Model S/TC MkII. Each cask is numbered serially as TC-X. The overpack, consisting of both the Wooden Protective Jacket and the surrounding Steel Shell, is designated OP-Y, again numbered serially. Overpacks and inner containers are interchangeable and are used in any combination.

Figure 1.2.1 is a vertical section drawing of the Model NPI-20WC-6 MkII shipping packaging. Figure 1.2.2 is a horizontal section drawing. A vertical section of the S/TC inner container is shown in Figure 1.2.3. The principal components of the packaging are identified in the drawings. Drawings of the S/TC inner container (NPI N-240122, Rev. F) and the overpack (NPI N-240116, Rev. D) are included as attachments to this application and are referenced in Appendix 1.3.

The S/TC shielded inner container consists of a 3/8 inch thick spherical shell, 24 inches inside diameter, containing a chambered, shielded Drum Assembly held in place by two Cover Assemblies. The Drum Assembly fits into an 8-1/4 inch inside diameter by 3/16 inch thick horizontally oriented cylinder, which forms a weldment with the shell through a steel flange. The toroidal cavity formed by the horizontal cylinder penetrating the sphere is filled with lead. The cavity within the cylinder houses the chambered source positioning Drum Assembly.

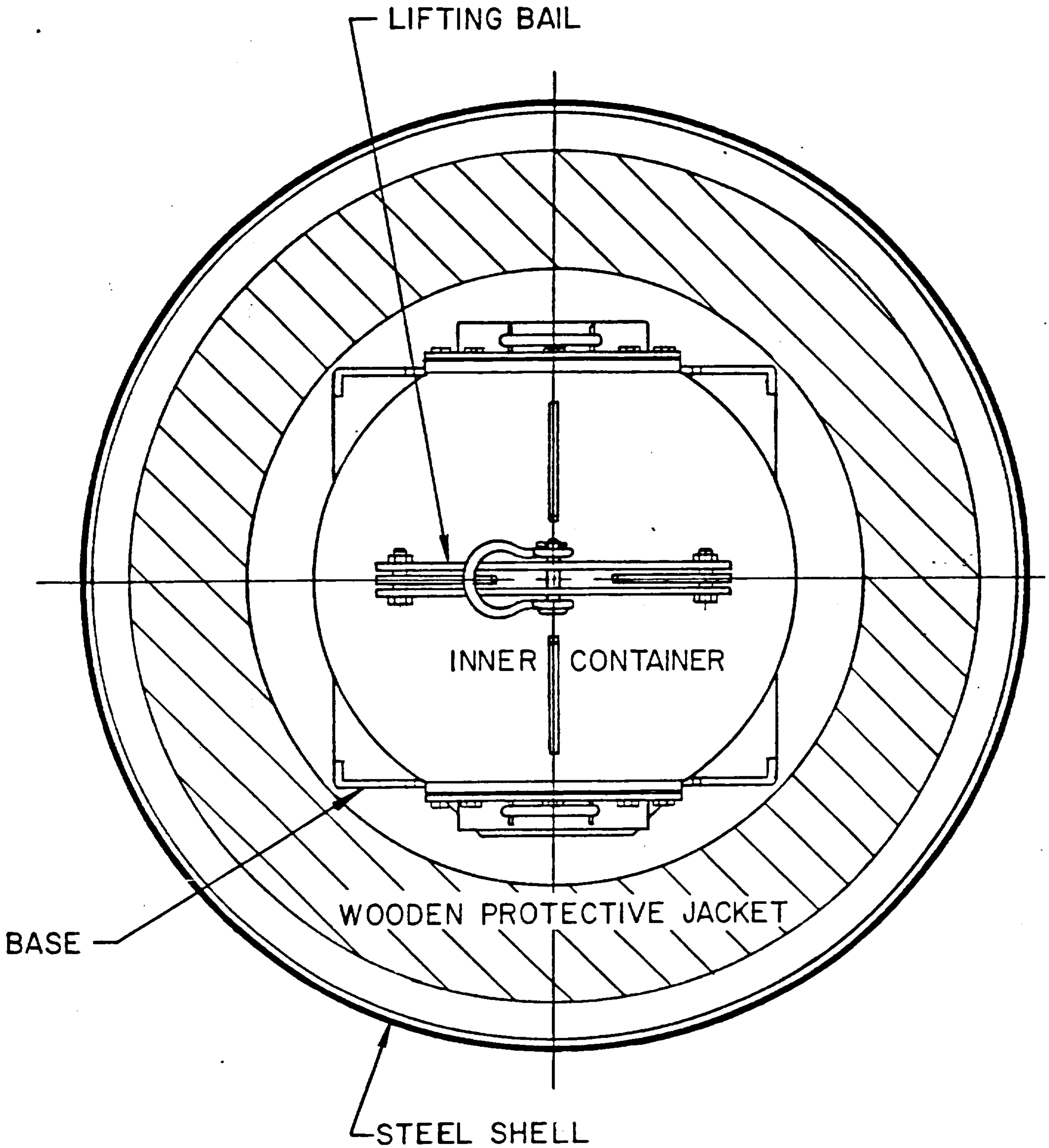
The Drum Assembly chambers carry the source holders, which may vary from one model of teletherapy machine to another. The Drum Assembly is removable and can be interchanged with another to provide for the different design of source holders. During shipment, the chambers, or section of chambers, that are not filled with source holders, are fitted with full diameter, steel encased lead or tungsten plugs and spacers, which restrict movement to less than 0.25 inches laterally and 0.1 inches radially. The Drum Assembly, source holders, and plugs are secured in the container by shielded Cover Assemblies bolted to the Shell Assembly at both ends of the Drum Assembly containing cylinder. The bolted Cover Assemblies are sealed using silicone rubber gaskets.

The shielded inner container is enclosed within the overpack, consisting of a Wooden Protective Jacket (WPJ) surrounded by a Steel Shell. The overpack meets the requirement of DOT Specification 20WC-6 Wooden Protective Jacket. The WPJ is a right circular cylinder consisting of 3/4 inch thick exterior grade, Douglas Fir plywood discs glued together with a resorcinal resin adhesive and nailed. In addition, the WPJ is reinforced with 16 axial, 5/8 inch diameter, full length steel rods. The WPJ has a plywood sidewall of six inch minimum thickness and a plywood top and bottom, each of 8-1/4 inch thickness. The WPJ is surrounded by the 12 gage Steel Shell. The Steel Shell has a flanged, bolted closure and 12 or more 1/2 inch vent holes; these are covered with durable, weatherproof tape, or fitted with plugs which relieve under pressure.



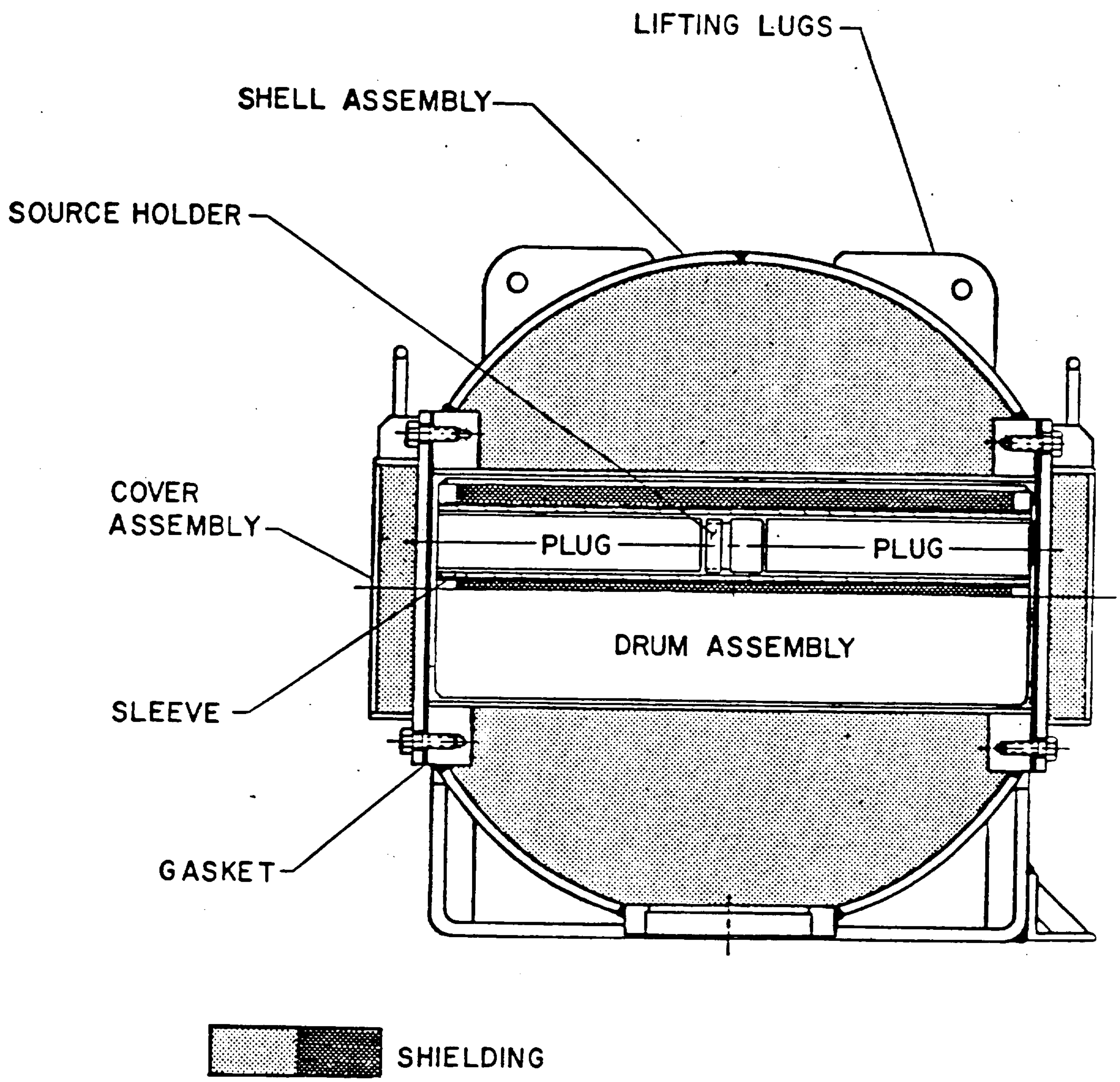
MODEL NPI-20WC-6MK II SHIPPING PACKAGE VERTICAL SECTION

FIGURE 1.2.1



MODEL NPI-20WC-6/MK II SHIPPING PACKAGE
HORIZONTAL SECTION

FIGURE 1.2.2



S/TC INNER CONTAINER - VERTICAL SECTION

FIGURE 1.2.3

Welded to the bottom of the 12 gage Steel Shell is an additional 8 gage steel plate to which, in turn, are welded three skids fabricated from five inch, ten pound I beams. The I beams provide the support for the package which can be lashed down and secured by blocking in a transport vehicle. Normal handling for loading and unloading the package is from beneath; for example, with a forklift truck. There are four tie down brackets attached to the Steel Shell. These are not intended as lifting devices, but meet lifting device requirements. The lifting eye used for handling the Steel Shell lid is provided with a cover and seal to prevent its use to lift the package during regular transport.

The structural components of the inner container Shell Assembly are constructed of ASTM A-516 Gr 70 and ASTM A-333 Gr 60 specification carbon steel made to fine grade practice. The removable drum is fabricated of austenitic stainless steel. The lead shielding employed in all components is pig lead, chemical grade.

The S/TC inner container has a gross weight of approximately 3,400 pounds. The packaging gross weight is limited to 6,000 pounds, although the typical gross shipping weight is expected to be about 5,200 pounds. The packaging has no inner protrusions. The only protrusions beyond three inches from the surface of the Steel Shell are the lid lifting eye (six inches) and the skids (five inches).

1.2.2 Operational Features

The cooling arrangement of the packaging is completely passive; no special hardware for cooling is required. The source heat is dissipated by a combination of conduction, convection, and radiation to the outer surface of the Steel Shell and thence to the surroundings. The maximum internal energy generation is 240 watts deposited almost completely within the inner cask.

The cobalt-60 sources are encapsulated in stainless steel containers with welded closures. The encapsulation provides the principal containment. In addition, however, the Drum Assembly chambers of the inner cask are sealed during transport, using silicone rubber gaskets, which provide an additional containment barrier for normal transport and hypothetical accident conditions.

The entire shipping package is free of liquids and no special gases are required.

1.2.3 Contents of Packaging

The packaging is for shipment of cobalt-60, as sealed sources, which meet the requirements of special form as defined in 10 CFR 71. The maximum activity shall not exceed 15,000 curies per package. The maximum internal decay heat generation shall not exceed 240 watts. Normal operating pressure is nominally atmospheric and, in any case, substantially below one atmosphere gage.

1.3 Appendix

1.3.1 Shipping/Transfer Cask, Model S/TC MkII
NPI Drawing Number N-240122, Rev. F (attached)

1.3.2 Lifting Bail
NPI Drawing Number A-240012 (page 1-8)

1.3.3 Overpack
DOT Specification 20WC-6
NPI Drawing Number 240116, Rev. D (attached)

FIGURE WITHHELD UNDER 10 CFR 2.390

2. STRUCTURAL EVALUATION

2.1 Structural Design

2.1.1 Discussion

The principal function of the packaging is to provide a secondary containment barrier and shielding under the normal transport and accident conditions imposed. The primary containment is provided by the source capsule, which meets special form requirements, and is usually doubly encapsulated. For containment, the source capsule design has been proven for conditions more stringent than those required of the packaging.

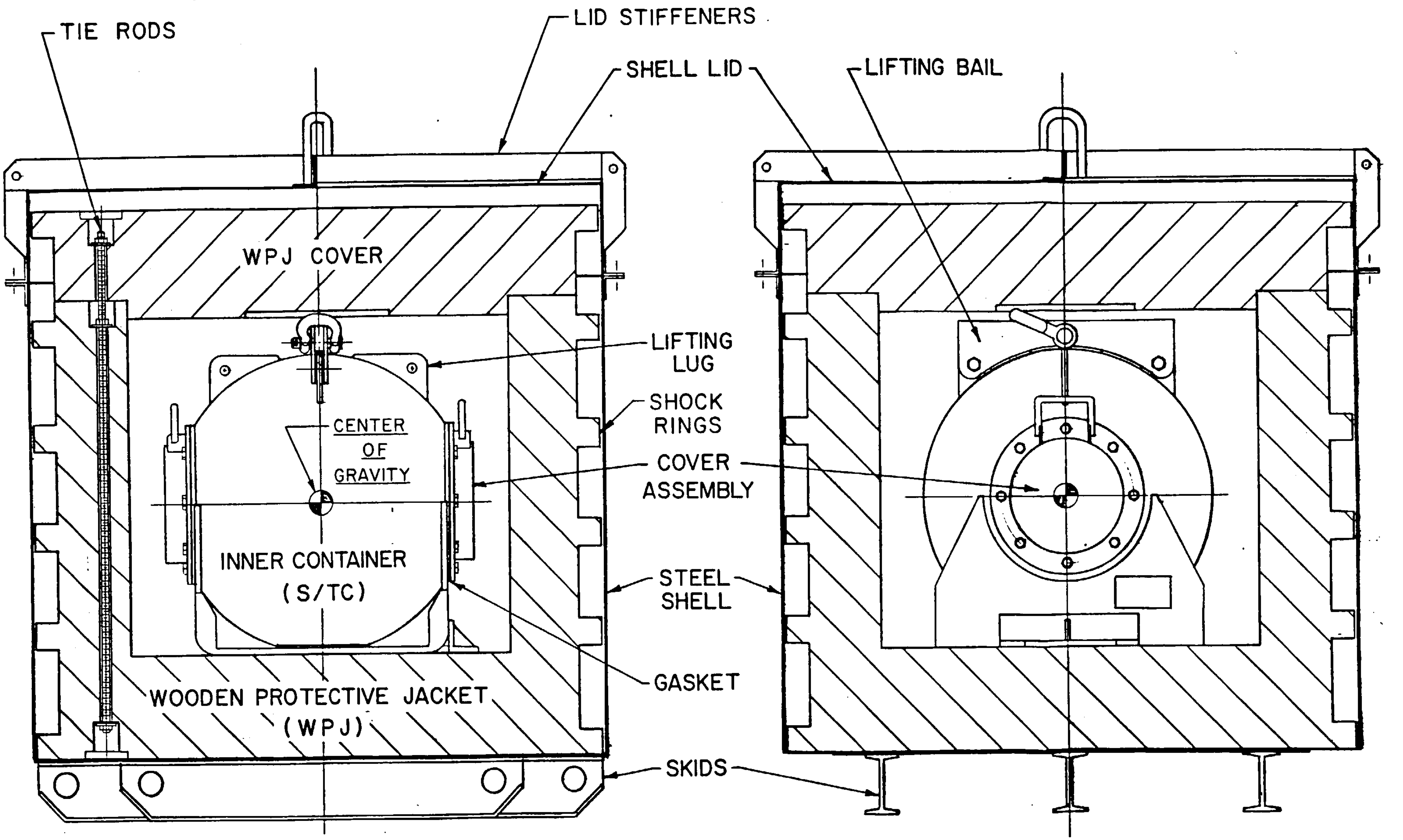
Figure 2.1.1 is a section drawing of the package showing the S/TC inner container in place and the principal structural components.

Figure 2.1.2 is a vertical section of the S/TC inner container with the structural components identified. Depending upon the type of teletherapy machine for which the source is being supplied, the source holder either fills an entire Drum Assembly chamber or is centered by the shield plugs as shown in Figure 2.1.2. Drum Assembly chambers not carrying a source are loaded with full length shield plugs. The Drum Assembly, as well as the source holder/shield plugs, are held in place by the Cover Assemblies, which bolt to a flange that is an integral part of the Shell Assembly. Silicone rubber gaskets seal the cavity which houses the Drum Assembly. The bolts are tightened to firmly compress the gasket. The bolting load is light because the cavity pressure remains essentially atmospheric and the gasketing does not require a significant preload for sealing. The cover bolts are tightened to a torque of about 100 inch pounds.

The base supports the Shell Assembly from beneath the flange. Four lifting lugs are welded to the upper side of the Shell Assembly, which are used in pairs along with the lifting bail in moving the inner container when out of the overpack. The Shell Assembly and Cover Assemblies are fabricated of ASTM A-516 steel and the Drum Assembly is of austenitic stainless steel. Both materials have superior fracture toughness properties to a temperature of -40°F and below.

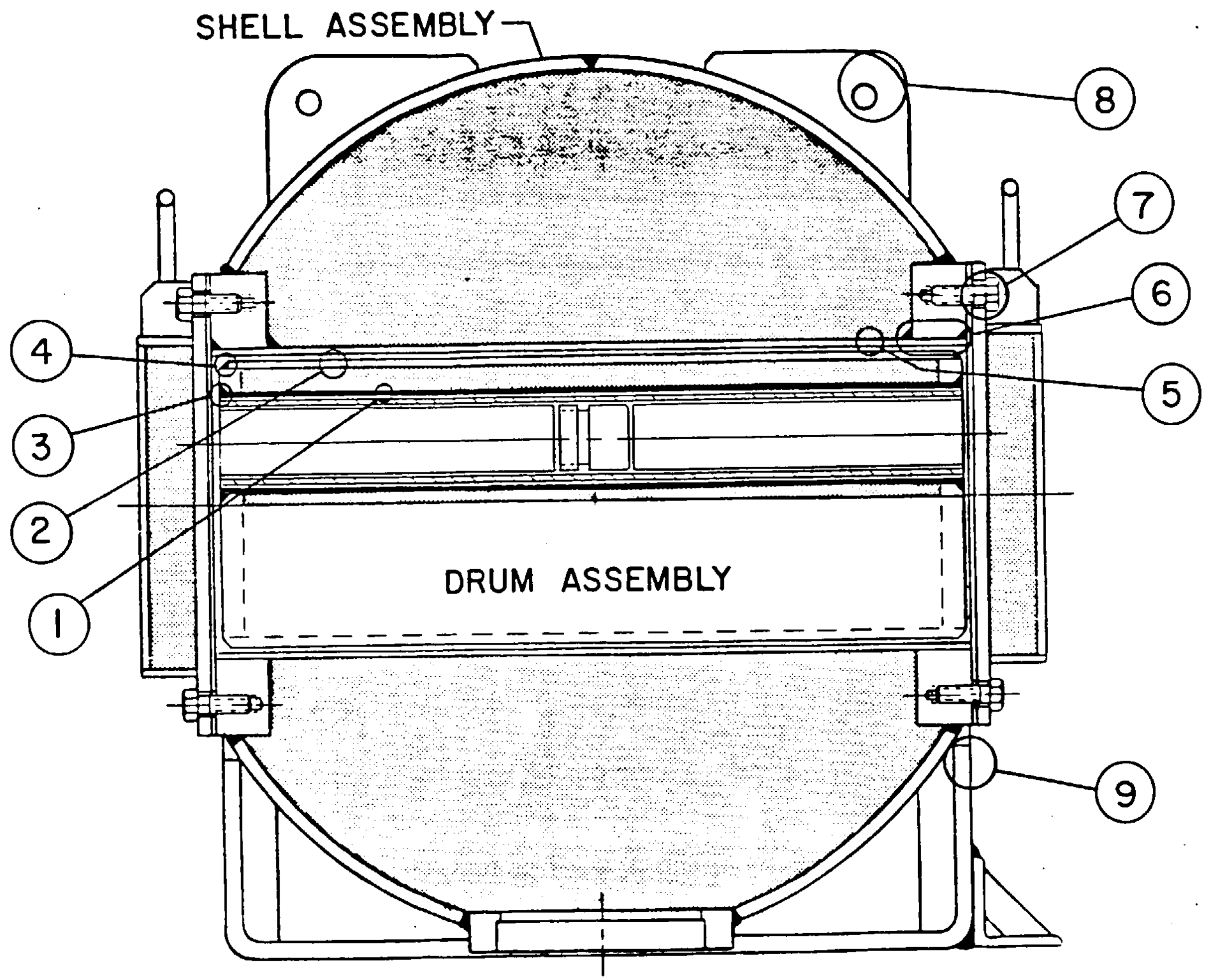
The base of the inner container fits into the Wooden Protective Jacket (WPJ) of the overpack with a nominal radial clearance of about 3/8 of an inch. With the WPJ cover in place, the nominal vertical clearance is also 3/8 of an inch, with the bail installed. The inner container is transported with the bail in place.

The Wooden Protective Jacket fits into the Steel Shell with nominal clearances of 1/4 inch radially and 1 inch vertically. The latter clearance, however, also serves as storage space for the WPJ Cover lifting chain. The WPJ



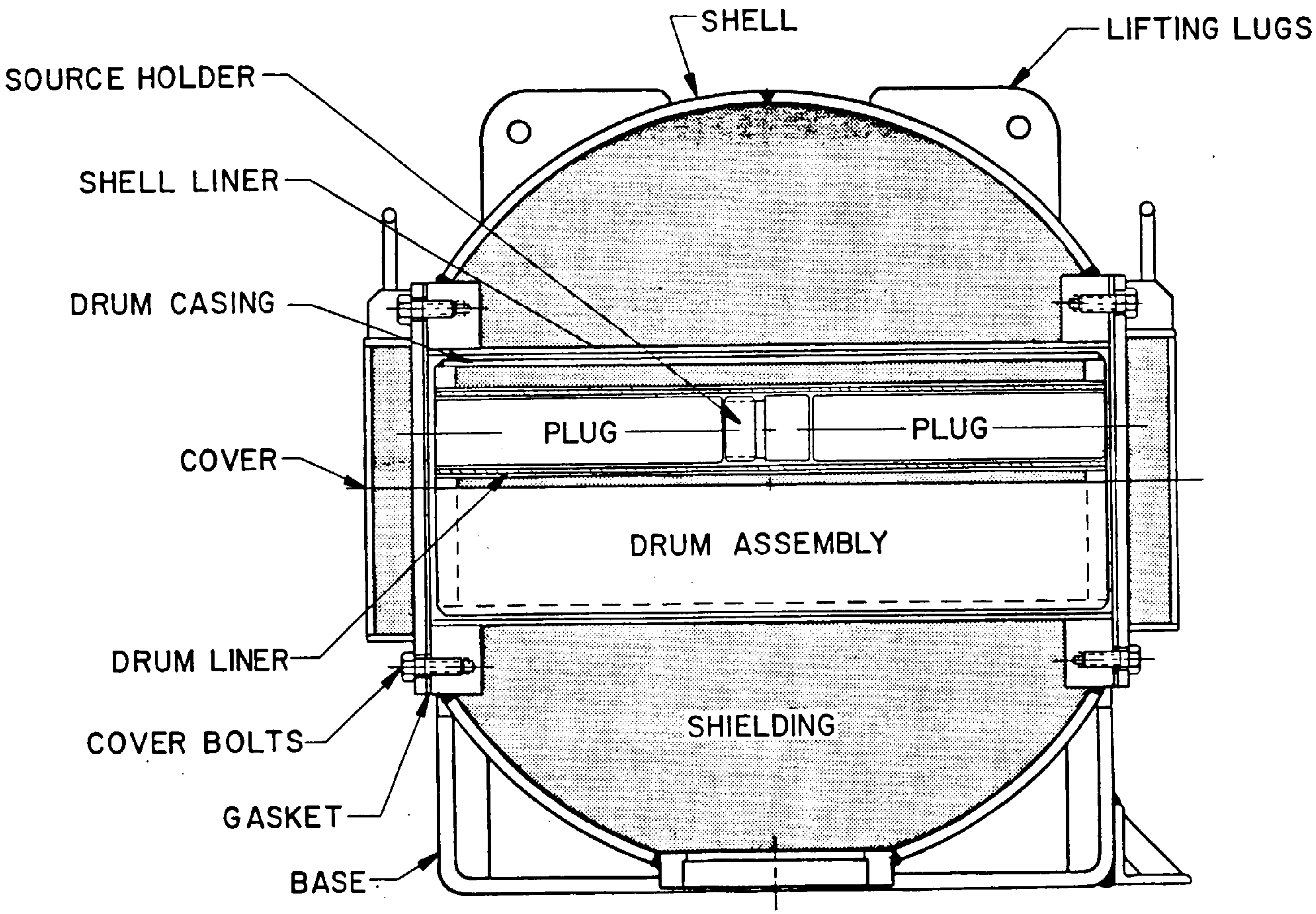
MODEL NPI-20WC-6MK II SHIPPING PACKAGE VERTICAL SECTION

FIGURE 2.1.1



LOCATION OF STRESSES LISTED IN TABLE 2.6.1.4

FIGURE 2.6.1.4



S/TC INNER CONTAINER STRUCTURAL COMPONENTS

FIGURE 2.1.2

Cover is secured by bolting to the extension of the 16 5/8 inch diameter tie rods running the full axial height of the WPJ. The outer Steel Shell flanged closure is secured with a minimum of 32, 1/2 inch bolts with locknuts.

While the overpack serves principally as fire protection, under accident and some normal transport conditions, the overpack is expected to provide energy absorption. Permanent deformation of noncritical components and damage to the overpack is acceptable under accident conditions if the packaging function remains unimpaired. For example, a one meter free drop under normal transport might permanently deform the Steel Shell skids or lid, but this would not impair the containment nor shielding function of the package.

2.1.2 Design Criteria

The guiding design criteria for ferrous material are those of the ASME Boiler and Pressure Vessel Code, Section 3, Division 1, and the NRC Regulatory Guide 7.6 (March 1978), which are in essential agreement. However, the package structural simplicity and the absence of any significant primary stresses in normal transport permit using simple criteria which fit into the envelope of the more encompassing formulation cited and are as follows:

	Stress Limits for Critical Components (2)	
	Normal Transport	Hypothetical Accident Conditions
Primary Stresses		
Sustained loads independent of displacement, i.e., weight or a separately pressurized cavity		
Normal	S_m	S_y
Shear (1)	$.55\ S_m$	$.55\ S_y$
Impact loads		
Normal	S_y	S_u
Shear (1)	$.55\ S_y$	$.55\ S_u$
Secondary Stress		
Strain relieved stress; i.e., thermal or local bending		
Normal	S_y	S_u
Shear (1)	$.55\ S_y$	$.55\ S_u$

(1) S. Timoshenko, Strength of Materials, Volume I, Page 58

(2) S_m = Design Stress Intensity; S_y = Yield Strength; S_u = Tensile Strength

For evaluating impact energy absorption and associated deflections, the following rules were used:

- o Critical Components - Calculated elastically up to the appropriate stress limit (S_y for normal transport and S_u for the hypothetical accident conditions).

- o Noncritical Components - Calculated elastically to $S \leq S_y$ or to the elastic limit (wood). In compression only, energy absorption beyond yield or the elastic limit is taken as:

  $E = \delta \cdot (S_y + S_u)/2$ for ferritic materials; and,

  $E = \delta \cdot$ (Dynamic Crushing Pressure) for plywood composite (see Appendix 2.10.6)

  where δ is the deflection or deformation

- o Post buckling energy absorption is taken as compression or bending, as appropriate.

The factor of safety is defined as the allowable stress, divided by the actual stress, or the limiting load divided by the actual load.

Brittle fracture of metal is avoided by selecting materials of construction that exhibit ductile fracture under impact testing within the design temperature range (to $-40^{\circ}F$).

2.2 Weights and Center of Gravity

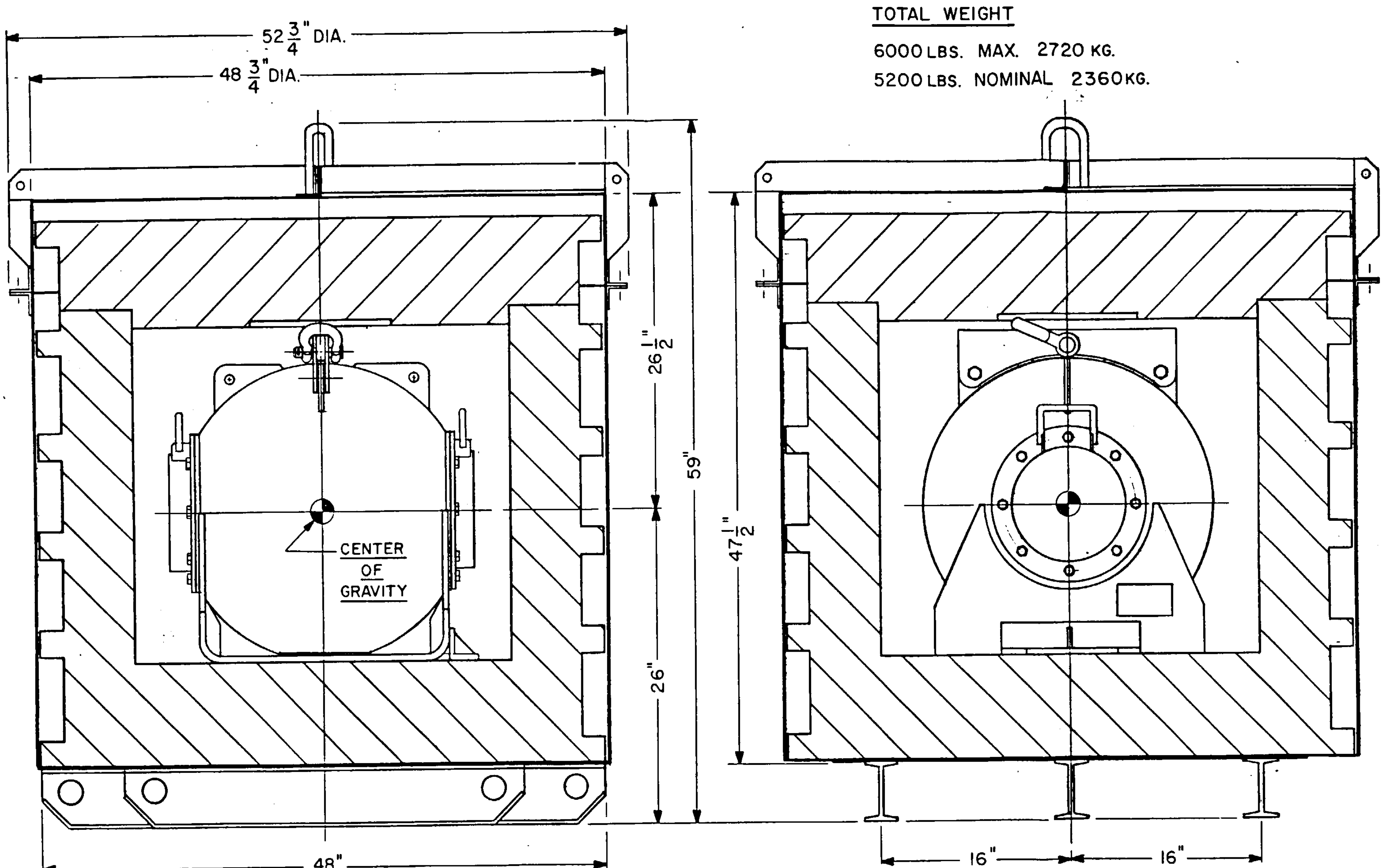
The packaging component and total weights are provided in Table 2.2.1. The overall dimensions, along with the weight and location of the center of gravity of the packaging, is shown in Figure 2.2.1. The center of gravity coincides very closely with the geometric center of the spherical portion of the inner cask. For a particular shipment, the weight may differ slightly because that particular combination of drawers, plugs, and sleeves may not add up to the same weight. The differences are not significant in evaluating the package. Where total weight was central to an evaluation, the maximum value of 6,000 pounds was used for the total package.

TABLE 2.2.1

COMPONENT AND TOTAL PACKAGING WEIGHTS

MODEL NPI-20WC-6 Mk II/SHIPPING PACKAGE

Component	Weight, Pounds
Inner Cask, S/TC	
Shell Assembly	2,754
Drum Assembly	310 max.
Covers (2)	148 max.
Drawers, Plugs, & Sleeves	133 max.
Lifting Bail	30
Subtotal	3,375
Wooden Protective Jacket	
Body	890
Lid	310
Subtotal	1,200
Steel Shell	
Body	450
Lid	165
Subtotal	615
Total Package Weight, Nominal	5,150
Total Package Weight, Maximum	6,000



MODEL NPI-20WC-6 MK II SHIPPING PACKAGE
OVERALL DIMENSIONS, WEIGHT AND CENTER OF GRAVITY

FIGURE 2.2.1

2.3 Mechanical Properties of Materials

Mechanical properties of the ferritic steels used in the package are listed in Table 2.3.1 over the temperature range of interest. Properties of the austenitic steels are listed in Table 2.3.2 and those for the low alloy steel bolts in Table 2.3.3. Coefficients of thermal expansion for steels were lumped as either ferritic or austenitic materials and are listed in Table 2.3.4. All of the above properties, as well as the thermal conductivity of steels used in Chapter 3, were obtained from the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, 1983 Edition, with addenda, Section III, Division 1, Appendix I.

The physical properties of lead are listed in Table 2.3.4 and most were obtained from the Cask Designers Guide, ORNL-NSIC-68.

Pertinent mechanical properties for the Wooden Protective Jacket material, a coast type Douglas fir marine plywood, were developed from the U.S.D.A. Forest Product Laboratory's Wood handbook and are listed in Table 2.3.6.

In addition to the above, Poisson's ratio for steel was taken as 0.3 and the density of package materials listed in Table 3.2 was that used in calculation.

TABLE 2.3.1

MECHANICAL PROPERTIES - FERRITIC STEELS

ASTM A-516 Gr70 Plate (2)

Temperature, ^{o}F	100	200	300	400	500	600	Ref. (1)
Su, ksi	70	70	70	70	70	70	(3)
Sy, ksi	38	34.6	33.7	32.6	30.7	28.1	(4)
Sm, ksi	23.3	23.1	22.5	21.7	20.5	18.7	(5)
E X 10^{-6} (2) psi	(12)	28.8	28.3	27.7	27.3	26.7	(6)
ASTM A-333 Gr 6 Pipe (2)							
Su, ksi	60	60	60	60	60	60	(7)
Sy, ksi	35	31.9	31	30	28.3	25.9	(8)
Sm, ksi	20	20	20	20	18.9	17.3	(9)
E X 10^{-6} psi			same as A-516				
ASTM 1-36 Structural Steel (2)							
Su, ksi	58	58	58	58	58	58	(10)
Sy, ksi	36	32.8	31.9	30.8	29.1	26.6	(11)
Sm, ksi	19.3	19.3	19.3	19.3	19.3	17.7	(10)
E X 10^{-6} psi			same as A-516				

(1) ASME B & PV Code, 1983 Edition, Section III, Division 1, Appendix I, all references
(2) Su = Tensile Strength; Sy = Yield Strength; Sm = Design Stress Intensity; E = Elastic Modulus
(3) Table I - 3.1, Page 69
(4) Table I - 2.1, Pages 44, 45
(5) Table I - 1.1, Pages 8, 9
(6) Table I - 6.0, Page 99
(7) Table I - 3.1, Page 67
(8) Table I - 2.1, Pages 42, 43
(9) Table I - 1.1, Pages 6, 7
(10) Table I - 11.1, Page 196
(11) Table I - 13.1, Page 200
(12) 30.2 at $-100^{o}F$, 29.5 at $70^{o}F$

TABLE 2.3.2

MECHANICAL PROPERTIES - AUSTENITIC STEEL

Type 304 Stainless Steel (2)

ASTM A-213 Seamless Tube
ASTM A-240 Plate
ASTM A-312 Welded and Seamless Pipe

Temperature, °F	100	200	300	400	500	600	Ref. (1)
Su, ksi	75.0	71.0	66.0	64.4	63.5	63.5	(3)
Sy, ksi	30.0	25.0	22.5	20.7	19.4	18.2	(4)
Sm, ksi	20.0	20.0	20.0	18.7	17.5	16.4	(5)
E X 10^{-6} psi	(6)	27.6	27.0	26.5	25.8	25.3	(7)

(1) ASME B & PV Code, 1983 Edition, Section III, Division 1, Appendix I, all references
(2) Su = Tensile Strength; Sy = Yield Strength; Sm = Design Stress Intensity; E = Elastic Modulus
(3) Table I - 3.2, Page 76
(4) Table I - 2.2, Pages 56, 57
(5) Table I - 1.2, Pages 23.1, 23.2
(6) 29.1 at -100°F, 28.3 at 70°F
(7) Table I - 6.0, Page 99

TABLE 2.3.3

BOLTING MATERIAL

SAE Grade 8 Steel Bolts (1)

Temperature, °F	100	200	300	400	500	600	Reference
Su, ksi	150	150	150	150	150	150	(2,3,4,5)
Sy, ksi	130	124	120	116	112	107	(2,3,4,5)
Sm, ksi	43.3	41.4	40.0	38.8	37.6	35.8	(3,4)

(1) Su = Tensile Strength; Sy = Yield Strength; Sm = Design Stress Intensity

(2) Metals Handbook, ASM Committee on Carbon and Alloy Steels, 9th Edition (See 2.10.11 Part B)

(3) ASME B & PV Code, 1983 Edition, Section III, Division 1, Appendix I, Table I - 1.3 and Table I-3.1

(4) Tensile Strength, Yield Strength, and Design Stress Intensity at 200°F and above taken proportional to ASTM A540 B22 values which material is encompassed in Grade 8 standard. (See 2.10.11)

(5) SAE Standard SAE J429 AUG83. (See 2.10.11 Part A)

TABLE 2.3.4

COEFFICIENTS OF THERMAL EXPANSION, in./in. °F X 10^6

Temperature, °F	100	200	300	400	500	600	Ref. (1)
Ferritic Steels							
Instantaneous	5.65	6.39	7.04	7.60	8.07	8.46	(2)
Mean from 70°F	5.53	5.89	6.26	6.61	6.91	7.17	(2)
Austenitic Steels							
Instantaneous	8.63	9.08	9.46	9.80	10.10	10.38	(2)
Mean from 70°F	8.55	8.79	9.00	9.19	9.37	9.53	(3)

(1) ASME B & PV Code, 1983 Edition, Section III, Division 1, Appendix I
(2) Table I - 5.0, Page 94
(3) Table I - 5.0, Page 95

TABLE 2.3.5

PHYSICAL PROPERTIES OF LEAD (CHEMICAL GRADE)

		Source
Tensile Strength	2,300 to 2,800 psi	(1)
Yield Strength	1,180 to 1,380 psi	(1)
Modulus of Elasticity	2 X 10^6 psi	(1)
Poisson's Ratio	0.40 to 0.45	(1)
Melting Point	618°F (3)	(1)
Thermal Expansion	16.1 X 10^{-6} in./in. °F	(1)
Thermal Conductivity	20 to 18 B/hr. ft. °F from R.T. to 600°F	(2)

(1) Cask Designers Guide, ORNL-NSIC-68, Pages 56, 84
(2) W. H. McAdams, Heat Transmission, 2nd Edition, Page 380
(3) M. P. of lead is frequently given as 621°F and reference is sometimes made to this value

TABLE 2.3.6

MECHANICAL PROPERTIES OF COAST TYPE DOUGLAS FIR PLYWOOD BASE[1]

Proportional Limit, parallel to grain	6,000 psi
Proportional Limit, perpendicular to grain	900 psi
Elastic Modulus:	
Parallel to grain	2 X 10^6 psi
Perpendicular to grain, tangential	10^5 psi

(1) Wood Handbook (Agriculture Handbook No. 72)
U. S. Department of Agriculture, Forest Products Laboratory

2.4 General Standards for All Packages

2.4.1 Chemical and Galvanic Reactions

The materials specified for the construction of this package system and its contents form no significant chemical on galvanic couples under any normal wet or dry condition. Loading, unloading, and normal transport are all dry operations. The shielded inner cask is sealed with a gasket of silicone rubber. The only portion of the package subject to moisture, which would be atmospheric condensation, is the Steel Shell, and possibly the outside surface of the Wooden Protective Jacket. Chemical or galvanic reaction problems have not been experienced in over 12 years of service with the existing packages.

2.4.2 Positive Closure

All of the package closures are bolted. The shielded inner cask has two covers, each of which is fastened to the cask body by eight one half inch diameter bolts. The inner cask fits into the Wooden Protective Jacket so that the cover bolts are inaccessible during transport. The Wooden Protective Jacket lid is secured by 16, 5/8 inch nuts. The Wooden Protective Jacket, in turn, fits into the Steel Shell, which has a flange closure using 36, 1/2 inch bolts. This closure is also seal wired. The package cannot be opened inadvertently, and deliberate opening requires extensive effort, utilizing a variety of equipment, some of which is not normally available during transit.

2.4.3 Lifting Devices

The inner cask has four lifting lugs which are a structural part of the Shell Assembly. Only two of these are used at any one time, along with a metal lifting bail to handle the inner container. The minimum factor of safety to yield, when the cask is being lifted in the intended manner, is over ten, which exceeds the regulation required factor of three. Since the lifting lugs are part of the inner container, they are not accessible during normal transport.

No specific lifting devices are provided for handling the package during general transport. The normal method of moving the package is by lifting from the bottom, as with a forklift truck. The bottom of the Steel Shell is reinforced with an additional eight gage plate (0.169 inches thick) to accommodate such handling.

The Steel Shell is provided with four tie down brackets which are discussed in Section 2.4.4 following. While not intended as lifting devices, if used as such they would provide a safety factor of greater than nine against yielding if the load were distributed between at least two of the four brackets. This meets the minimum safety factor of three, required in 10 CFR 71.45(a), for any lifting attachment that is a structural part of the package.

A lifting eye for handling the shell lid during loading and unloading is provided, but is rendered inoperative during general transport with the addition of a lifting eye cover.

2.4.4 Tie Down Devices

Four brackets are provided for tie down of the package, should it be convenient to use them. Their use is not mandatory for safe transport of the package.

The brackets are fabricated from 3 X 3 X 3/8 inch structural steel angle, placed back-to-back, and welded to a 6 inch wide, 3/16 inch thick reinforcing support band, which encircles the body of the Steel Shell just below the lower closure flange. They are spaced at 90° intervals around the periphery of the shell and oriented 45° from the direction of the support rails. The tie down brackets are shown in Drawing N 240116 (see Appendix 1.3.3). The brackets and package meet the specific tie down requirements of 10 CFR 71.45(b). The supporting calculations are provided in Appendix 2.10.1.

While not designed to be used regularly in this manner, the brackets can be used as lifting devices. The total load would be uniformly shared between the four brackets. When used as lifting devices, the brackets and attachments meet the structural requirements of 10 CFR 71.45(a); specifically, a minimum safety factor of three against yielding. The supporting calculations are provided in Appendix 2.10.10.

If the brackets are not used, lines placed across the top or around the Steel Shell fastened to the transport vehicle will adequately secure the package under the required loads. The support rails can also be clamped and shored for hold down. The package can be secured by any method acceptable for the intended mode of transport.

2.5 Standards for Type B Packaging

The application package meets the standards for Type B packaging, as specified in the following paragraphs of 10 CFR 71:

71.43 General standards for all packages
71.45 Lifting and tie down standards for all packages
71.47 External radiation standards for all packages
71.51 Additional requirements for Type B packages

2.5.1 Load Resistance

Not applicable

2.5.2 External Pressure

Demonstration that the containment vessel would suffer no loss of contents if the package were subjected to an external pressure of 25 psig is no longer a regulatory requirement. However, both the inner container, which is the secondary barrier, and the contained special form source capsule substantially exceed this requirement. Both are internally supported and can withstand high hydrostatic pressures. The spherical shell of the inner container is suitable for a sustained working pressure of over 500 psi, even without support.

2.6 Normal Conditions of Transport

2.6.1 Heat

The thermal evaluation is based on heating tests conducted with a representative shipping package, along with calculations used to obtain design evaluation conditions. The description of the tests, calculations, and results of the thermal evaluations are presented in Section 3.4. Summary results are provided here, as needed for the structural evaluation.

2.6.1.1 Summary of Pressures and Temperatures. The maximum normal operating pressure in the sealed cavity of the inner container is expected to be essentially atmospheric for all conditions. For the purpose of establishing a pressure loading for the structural analysis, it was postulated that the cavity could be sealed immediately after loading the source, thus enclosing room temperature air, which would subsequently heat up to surrounding maximum metal temperature or, alternatively, to maximum source surface temperature. Under these circumstances, the maximum internal pressures were estimated to be 7 and 13 psig, respectively (see Section 3.4.4). A value of 15 psig has been used for structural evaluation.

Maximum package temperatures, under normal transport conditions, are given in Table 2.6.1.1, which is identical to Table 3.1.1. The principal thermal loadings have been developed from these temperatures.

2.6.1.2 Differential Thermal Expansion. A differential thermal expansion occurs in both the Drum and Shell Assembly under normal transport conditions. It is caused by differential heating of the components and is a steady state load. In the case of the Drum, the liners of the source chambers remain at a higher average temperature than the Drum casing, as long as a source is loaded. This results in a compression loading of the liner and a tension loading in the casing. A similar, but less severe, situation is obtained in the Shell Assembly.

A thermal stress evaluation of the Drum and Shell Assemblies is detailed in Appendix 2.10.2. It is based on the maximum space average temperature differences anticipated under fully loaded decay heating conditions. The temperature calculations are detailed in Appendix 3.6.5.

In summary, for the Drum the maximum normal stress is calculated to be an axial compression of 5,620 psi in the liner, as compared with an allowable stress of 22,500 psi, providing a factor of safety of four. The maximum shear stress occurs in the end plate to liner weld joint and is calculated to be 5,430 psi, as compared with an allowable stress of 12,400 psi, providing a factor of safety of 2.3.

In the Shell Assembly, both the liner compressive stress and the face plate to liner weld joint shear stress are below 3,000 psi. The allowable stresses are 31,200 psi in compression and 17,200 psi in shear and the safety factors are greater than ten and six, respectively.

TABLE 2.6.1.1

MAXIMUM PACKAGE TEMPERATURES
UNDER NORMAL TRANSPORT CONDITIONS(1)

Outside Shell Surface	135°F	(57°C)
Outside Wooden Protective Jacket Surface	130°F	(54°C)
Inside Wooden Protective Jacket Surface	250°F	(121°C)
S/TC Surface	265°F	(129°C)
S/TC Shell Liner and Drum O.D. (Local Max.)	330°F	(165°C)
S/TC Drum Liner (Local Max.)	425°F	(218°C)
Source Capsule Surface	550°F	(288°C)

(1) 240 watts corresponding to 15,000 curies of cobalt-60, and the insolation heat load prescribed in 71.71(c)(1) normalized to a reference ambient temperature of 100°F (38°C).

It is not anticipated that any transient conditions would significantly exceed the steady state loads considered above for normal transport conditions. However, margin is available for increased thermal loads without exceeding the design criteria. In any case, no loading is perceived that would compromise the package integrity.

2.6.1.3 Stress Calculations. In the following, stresses due to the combined effects of thermal gradients, pressure, and mechanical loads are considered. The need for fatigue analysis is reviewed.

Under normal transport conditions, the principal loadings are determined by the thermal conditions, as discussed above.

The pressure loadings are essentially zero. In practice, the source heats the cask internals to some extent before closure is made, or, as in a source transfer, the cask is already heated. As a consequence, the cause of any pressure increase, trapping of room temperature air in the source chamber upon closure, is mitigated. However, even at the evaluation basis, 15 psig internal pressure, the stress levels associated with the combined pressure and thermal loadings are less than one and one half percent greater than the thermal stresses alone. The calculation is addressed in Appendix 2.10.2 for the Drum Assembly.

The mechanical loads are associated with the lifting lugs, cover bolt up, and structural support. None of the stresses resulting from these loads combine with those impacting the shielding or containment boundary. Steady load stresses associated with the lifting lugs are all less than ten percent of the minimum yield strength of the material. At a torque of 100 pound inch, the bolt up preload results in a bolt stress of 8,500 psi. This compares to an allowable working stress of 31,400 psi (working stress factor of safety, 3.7) and a minimum yield strength of 94,200 psi at the maximum operating temperature for the bolts. The steady state structural support stresses are negligible.

All of the stresses produced by the loadings described can be considered as steady state for evaluation purposes. The thermal loadings could be considered cyclical; however, the frequency is very low, perhaps 1,000 to 2,000 cycles in 20 years of service. Along with the consideration that the resulting maximum stress is less than one half the yield strength, a steady state assessment should prove adequate.

2.6.1.4 Comparison With Allowable Stresses. A comparison of normal transport load stresses with allowable stresses is provided in Table 2.6.1.4 for the most severe loading conditions on the inner cask assemblies and assembly components. The location of the stresses are shown in Figure 2.6.1.4. The tension and compression stress locations are representative. Items 1 through 6 are combined thermal and pressure stresses. The pressure stresses provide so low a contribution to the total (as discussed above) that the secondary allowable stresses are used for the comparison.

TABLE 2.6.1.4

NORMAL TRANSIENT LOAD STRESSES
COMPARISON WITH ALLOWABLE STRESSES

Member and Location (1)	Stress, psi	Allowable Stress, psi (Type) (2)	Factor of Safety
Drum Assembly			
1. Liner	5,700 (compression)	22,500 (S)	3.9
2. Casing	2,760 (tension)	22,500 (S)	8.2
3. End Plate to Liner Weld Joint	5,510 (shear)	12,400 (S)	2.3
4. End Plate to Casing Weld Joint	2,860 (shear)	12,400 (S)	4.3
Shell Assembly			
5. Liner	2,860 (compression)	31,200 (S)	10.9
6. Face Plate to Liner Weld Joint	2,800 (shear)	17,200 (S)	6.1
7. Bolts	8,500 (tension)	31,400 (P)	3.7
8. Lifting Lugs	1,705 (shear)	12,500 (P)	7.1
9. Support	7,300 (compression)	22,700 (P)	3.1

(1) See Figure 2.6.1.4
(2) P = Primary; S = Secondary; all allowable stresses at maximum operating temperature

There are no combined loadings on the overpack components that require a structural analysis. Loads associated with tie down are discussed in Section 2.4.4.

2.6.2 Cold

Paragraph 71.71 of 10 CFR 71 requires an evaluation of the package design at an ambient temperature of -40°C (-40°F) in still air and shade.

All of the materials from which the package is fabricated are suitable for service at -40°F. The ferritic steel from which the inner cask Shell Assembly is fabricated is ASTM A-516 Grade 70 or ASTM A-333 Grade 6 which has superior fracture toughness properties and is not susceptible to brittle fracture at these temperatures. The Drum Assembly steel is austenitic stainless which remains ductile at low temperatures. The Steel Shell of the overpack is thin material and, in addition, does not constitute a containment boundary.

The sources are loaded and transported dry. No coolant is used. The exterior surface of the Drum Assembly and the plugs are occasionally cleaned with a penetrating oil. The residual film is left on the surface. This practice has not presented any operational or maintenance problems.

If the fully loaded package were at the low ambient temperature, a most unlikely circumstance, the stress conditions would not be substantially different than those reported in the previous section.

2.6.3 Pressure

Paragraph 71.71 of 10 CFR 71 requires an evaluation of the package design at a reduced external pressure of 24.5 kilopascal (3.5 psi) absolute and also an increased external pressure of 140 kilopascal (20 psi) absolute.

An external pressure of 3.5 psia to 20 psia would have little effect on the package. The overpack is not pressure tight and would adjust to the change in external pressure. The inner cask, which is pressure tight, would not see any substantial difference in structural loading or gasket sealing. See also the discussion under Section 2.5.2.

2.6.4 Vibration

This package system has been used to make over 1,500 shipments, most of them by road vehicles, without any indication of problems, such as fretting, arising from forced vibration incident to transport. The weight, configuration, and materials of the package all contribute to the natural damping of the system. No problems due to vibration have been experienced.

2.6.5 Water Spray

The water spray tests, as outlined in 10 CFR 71.71 (c)(6), will have no adverse influence on the package. Neither the outer Steel Shell nor the

Wooden Protective Jacket it surrounds would be adversely affected by a spray that simulates exposure to a rainfall of two inches per hour for a one hour period. The inner container would not be influenced.

2.6.6 Free Drop

The free drop for this package was analyzed initially under the 30 foot hypothetical accident conditions. The results for the HAC drop are presented in Section 2.7. The loadings for each of the drop orientations (end, side, and edge) are developed in Appendix 2.10.5. The results are summarized in Table 2.7.1.1.

In evaluating the normal transport four foot drop, the same methodology was used. Calculations for the end drop, both top and bottom, side drop, and oblique drop for normal transport are detailed in Appendix 2.10.3. The g loadings and minimum factors of safety are summarized in Table 2.6.6.1. The normal transport factors of safety are based on the yield strength as a limit as compared with the HAC factors, which are based on the tensile strength.

The results indicate that the package will withstand a four foot drop without compromising containment or shielding integrity. The minimum containment factor of safety is 25 and for shielding is 4.8.

2.6.7 Corner Drop

Not applicable

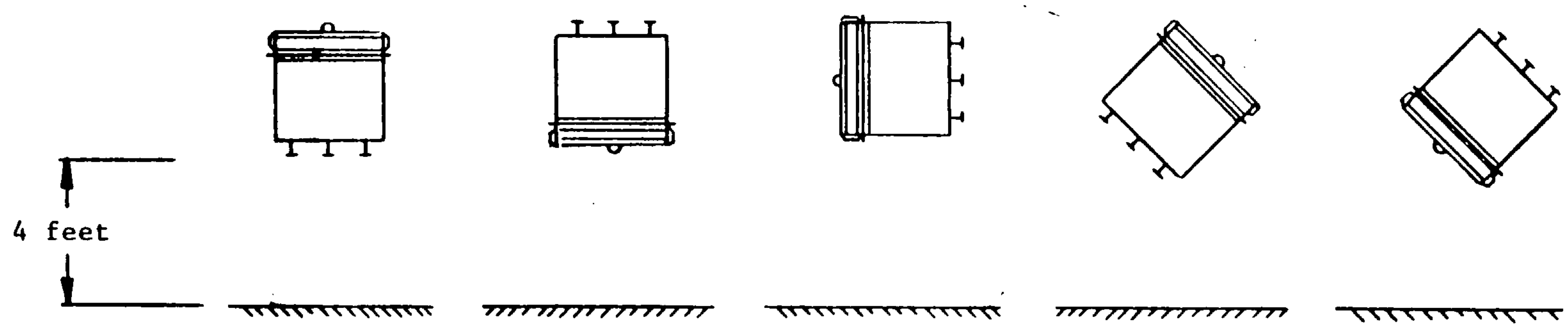
2.6.8 Penetration

Impact of the hemispherical end of a vertical steel cylinder 1-1/4 inches in diameter and weighing 13 pounds, dropped from a height of one meter on the outer 12 gage Steel Shell of the package, is discussed in Appendix 2.10.4. The results indicate that the cylinder will not penetrate the shell nor otherwise impair the integrity of the package.

2.6.9 Compression

The governing load for the compression requirement is equal to five times the maximum weight of the package. Using the maximum allowable package weight of 6,000 pounds as a reference, the compression load applied uniformly to the top and bottom of the package while in the normal transport position amounts to 30,000 pounds, or 15 tons. The minimum cross section of the Wooden Protective Jacket will support over 150 tons before crushing of the plywood commences. The I beam skids will support over 400 tons before yielding. The required compression load can be sustained for over 24 hours without difficulty.

TABLE 2.6.6.1 FREE DROP G LOADINGS AND MINIMUM FACTORS OF SAFETY - NORMAL TRANSPORT



DROP ORIENTATION	End Drop		Side Drop	Oblique Drop	
	Bottom	Top		Bottom Edge	Top Edge
g Loadings	140	100	87	43	43
Containment Factor of Safety (1)	25	35	40	80	80
Shielding Factor of Safety (2)	4.8	6.8	7.8	16	16

(1) g loading to shear yield strength in source encapsulation steel ÷ imposed g loading

(2) g loading to shear yield strength in cover bolts ÷ imposed g loading

2.7 Hypothetical Accident Conditions

Evaluation of the behavior of the NPI package under the hypothetical accident conditions is based upon the extensive series of tests performed by the Sandia Corporation and reported by Sisler(1). The tests were performed in the mid-1960's and were directed towards developing an overpack which would meet the 30 foot drop requirement and the subsequent fire test when used in conjunction with a typical shielded inner container. The design developed and tested was the hollow cylindrical wooden shell, which became the DOT Specification 20WC type protective jacket. The NPI package meets the DOT requirements and compares with the configuration which was tested at Sandia.

While tests at Sandia included packages of various sizes, the package that compared directly with the present NPI unit comprised a 3,275 pound lead shielded inner container surrounded by the Wooden Protective Jacket to make a total weight of approximately 4,000 pounds. The NPI unit inner container weight is 3,400 pounds and the total package weight is approximately 5,200 pounds, but this includes a 600 pound Steel Shell surrounding the Wooden Protective Jacket not included in the Sandia tests.

The results of 10, 30 foot drop tests were reported for the 4,000 pound containers(1). A total of eight units were dropped. One unit was dropped three times; one drop each on one end, on the side, and at 45 degrees on the opposite end. All containers survived in suitable condition to withstand a one hour, 1,800°F petroleum fire without repair(2). One container was drop tested following the one hour petroleum fire. It also survived the drop without damage to the inner container.

A comparison of the present NPI package with the units tested at Sandia is made in Table 2.7.1. The NPI unit has a Steel Shell surrounding the Wooden Protective Jacket that serves to mitigate the severity of both the drop and fire tests. The Sandia tests were done without such a shell.

The total weight of the 4,000 pound units tested by Sandia was approximately 13% less than that of the present NPI package without the Steel Shell. The inner container was 4% lighter. Overall, the units tested at Sandia compare closely with the NPI package, which was built to the specifications developed from the test results.

(1) J. A. Sisler, "New Developments in Accident Resistant Shipping Containers for Radioactive Materials," Proceedings of the International Symposium for Packaging and Transportation of Radioactive Materials, January 12-15, 1965, SC-RR-65-98, Pages 141-185. This paper is reproduced in Appendix 2.10.9.

(2) Ibid, Page 149

TABLE 2.7.1

COMPARISON OF NPI 20WC-6 MKII WITH SANDIA TEST PACKAGE

		Sandia	NPI
Inner Container:	Weight, pounds	3,275	3,415
	Diameter, inches	18 (cyl.)	25 (sph.)
	Height, inches	38	28
Wooden Protective Jacket:	Weight, pounds	725	1,200
	Diameter, inches	30 + rings	44 + rings
	Height, inches	58[2]	45
	Number of rings	5[2]	6
	Wall thickness, inches	6	6
	End cap thickness, inches	8	8-1/4 min.
	Bonding	[3]	Resorcinol resin with nails
Steel Shell:	Weight, pounds	none	615
	Diameter, inches		55
	Height, inches		56
	Shell thickness, inches		0.11
Total package weight, pounds		4,000	5,230

(1) By subtraction
(2) One container was 54-1/2 inches high with no end rings (three rings only)
(3) Resorcinol-formaldehyde, both with and without nails; white glue, with nails

2.7.1 Free Drop

Package adequacy under the 30 foot free drop condition can be evaluated by considering the function and response, and limiting loading of each of the three principal components of the package: the source capsule, the inner container, and the overpack.

The approach employed has been to calculate the range of the most severe loadings for the various drop orientations and compare them with the limit loadings that, if imposed on critical components, might result in an increase in ex-package radiation levels, either directly from reduced shielding or from potential escape of radioactive materials.

The source capsule provides the primary containment. In meeting the special form requirement, it has already met more stringent containment requirements than those of the total package, including a 30 foot free drop without the benefit of any additional shock absorption. Nevertheless, there is some inertial load that could breech the encapsulation. The most restrictive failure mode from the standpoint of energy absorption is of the capsule "window." This is the limiting loading for containment and was calculated to exceed 10,000 g. Detail is provided in Appendix 2.10.7.A.

The shielding function is provided by the inner container. While it also serves as secondary containment and functions as a transfer cask, under accident conditions its principal function is to insure that the source shielding geometry does not change significantly. The assembled inner container is essentially solid metal. The cumulative internal clearances are typically less than one tenth of an inch radially and one quarter of an inch transversely. The structure is a ductile high strength steel casing filled with lead. It is not likely that the shielding configuration will change very much as a consequence of a strike on the Shell Assembly, no matter how severe. On the other hand, should the cover bolts shear as a consequence of the strike, the covers could fall away and the drum, shield plugs, and source capsules could shift, causing a significant change in shielding configuration. The limiting load on the inner container is that required to shear the cover bolts. Calculations, detailed in Appendix 2.10.7.B, indicate that this loading is approximately 900 g.

The principal function of the overpack is to protect the inner container against excessive temperatures in the event of a fire. To do so it must sustain the 30 foot drop without a breach (the Sandia tests showed that some plywood delamination could occur without adversely influencing the fire protection). The overpack also cushions the inner container.

The limiting loading for the overpack is not known; however, all that is required is assurance that the overpack will protect the inner container from excessive temperatures under fire conditions and provide some shock absorption. The Sandia tests showed that when the overpack was built to the specifications developed, it was capable of sustaining a 30 foot drop and a subsequent fire more severe than the present regulation requires. One test showed that the overpack could experience the fire first and then the 30 foot drop with satisfactory results. The test results are discussed further in Section 3.5 and the paper summarizing the Sandia test results is included in Appendix 2.10.9.

The limiting loadings based on the capsule and inner container have been compared to the calculated loadings resulting from the 30 foot free drop. The calculated drop loadings are developed in Appendix 2.10.5. They are summarized in Table 2.7.1.1 as g loadings for each of the drop orientations of interest. Comparison is also presented as factors of safety associated with containment and shielding. The factors of safety are the ratio of the limiting loadings as expressed in g's divided by the maximum g loadings calculated for each of the 30 foot drop orientations. The containment factors of safety exceed about 60 and the shielding factors of safety exceed 4.2.

A qualitative appraisal of the effects of each of the drop orientations is provided in the following paragraphs:

2.7.1.1 End Drop

1. Bottom Strike

   For the end drop in the upright position, the principal energy absorption is taken by the package skids. The skids will crush, or possibly buckle, the unit energy absorption being about the same. The Wooden Protective Jacket will absorb some of the energy elastically, but this effect is small. The average loading for this drop is calculated to be approximately 180 g. Load calculations are shown in Appendix 2.10.5.A.

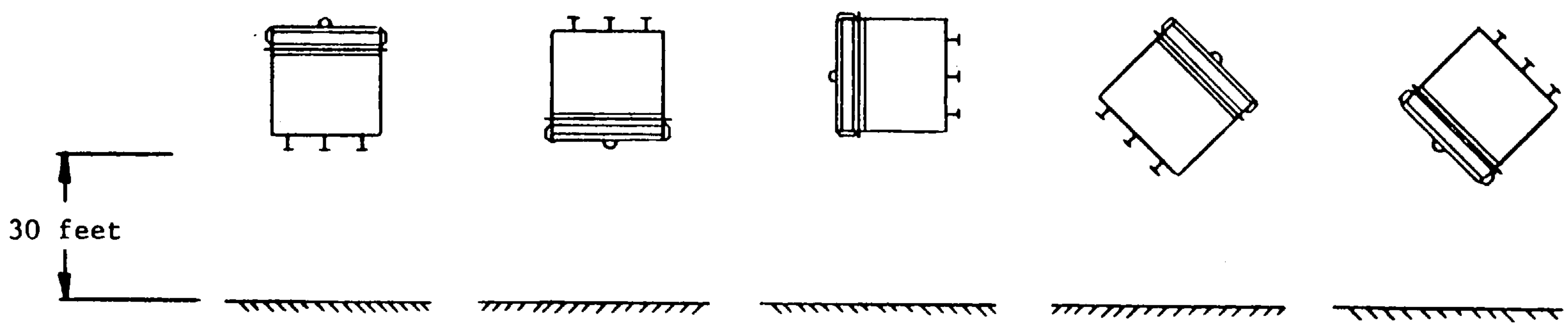
   Little effect on the inner container and on the source capsule is expected. The load on the inner container would be taken by the normal cask support arrangement, as well as by a bearing load against the lead filled plug and flange of the Shell Assembly. Loads on the totally enclosed capsule would be in combined bearing and shear and of a magnitude well below any permanent deformation.

   The principal package damage would be to the Steel Shell of the overpack. Integrity of the shielding and containment would be maintained.

2. Top Strike

   For the direct, inverted drop, the strike would take place on the cross shaped steel angles, reinforcing the cover of the Steel Shell. The energy absorption would be taken by crushing of either the steel angle or the wood of the protective jacket, with the latter being more likely. Any buckling of the steel angle would present equivalent resistance. If the energy absorption is taken essentially by the wooden jacket, calculations indicate that the loading would be approximately 215 g. The load calculations are shown in Appendix 2.10.5.B.

TABLE 2.7.1.1 FREE DROP G LOADINGS AND MINIMUM FACTORS OF SAFETY - HYPOTHETICAL ACCIDENT CONDITIONS



DROP ORIENTATION	End Drop		Side Drop	Oblique Drop	
	Bottom	Top		Bottom Edge	Top Edge
g Loadings	180	215	180	65	65
Containment Factor of Safety (1)	70	59	70	194	194
Shielding Factor of Safety (2)	5	4.2	5	14	14

(1) g loading to shear ultimate strength in source encapsulation steel ÷ imposed g loading

(2) g loading to shear ultimate strength in cover botls ÷ imposed g loading.

There is an additional energy absorbing mechanism for the inner container in the inverted position. The inner cask lifting bail could crush the wood of the protective jacket from the inside under the inertial loading of the inner container. This effect was not included in calculating the inertial loading, although it would serve to reduce the loading.

As in the case of the upright end drop, the inverted end drop does not result in adverse effects on either the shielding or containment capability of the capsule or inner container. The heaviest loads on the inner container are distributed bearing loads and the capsule stresses are well within the elastic limit.

The principal package damage would be to the Steel Shell and locally to the Wooden Protective Jacket. Local penetration to the Wooden Protective Jacket would be less than two inches of the total top thickness of nine inches. The integrity of the shielding and containment would be maintained.

2.7.1.2 Side Drop

In the side drop most of the energy absorption is taken by crushing of the shock rings on the Wooden Protective Jacket. The remaining energy is dissipated in deflecting the body of the protective jacket. A small contribution to energy absorption is provided by the crushing of the enclosing Steel Shell. Crushing of the shock rings is calculated to impose a 180 g loading. Calculations are shown in Appendix 2.10.5.C.

The capsule loads will not result in stresses exceeding the elastic limit. The containment capability of the capsule will not be impaired.

One loading on the inner container is cover bolt shear. The maximum loading on the bolts occurs if the plane of the cover face is perpendicular to the striking surface. The maximum load can be calculated as the product of the cover weight and the g loading, or 74 pounds X 180 = 13,300 pounds. The eight 1/2-13 UNC bolts have a minimum root diameter of 0.400 inches for a total shear area of 1.008 in.^{2}. The associated shear stress is 13,300/1.008 = 13,200 psi. For the SAE Grade 8 Steel bolt material at the maximum temperature of 300°F, a shear stress of 0.55 (120,100) = 66,000 psi would have to be exceeded to reach yield conditions (see Appendix 2.10.7, B3). The safety factor to yield is 5.

Another loading on the inner container results in cover bolt tension. The maximum loading on the bolts occurs when the plane of the cover face is parallel to the striking surface. The maximum load can be calculated as the product of the g loading and the combined weight of the drum (310 pounds), the maximum weight of the source capsules and shield plugs (133 pounds), and one cover (74 pounds) or 180 g X 517 = 93,060 pounds. The corresponding tensile stress produced in the bolts would be 93,060/1.008 = 92,320 psi. The minimum yield strength of the bolt material at 300°F is 120,100 psi. The resulting factor if safety to yield is 1.30.

No change in shielding configuration results from the side drop.

Damage to the package from this drop would be crushing of the shock rings of the Wooden Protective Jacket and crushing of the external Steel Shell. Integrity of the shielding and containment would be maintained.

2.7.1.3 Corner Drop

Not applicable

2.7.1.4 Oblique Drop

The oblique drop results in a strike on the cylindrical edge of the package. While in some orientations crushing of the Steel Shell appurtenances provide some energy absorption, the principal energy dissipation mechanism is crushing of the edge of the Wooden Protective Jacket. With the package center of gravity directly over the strike, the calculated loading of the inner container is approximately 65 g. The results are the same for the top edge or bottom edge drop. The calculations are provided in Appendix 2.10.5.D.

Loads on the capsule will not result in stresses exceeding the elastic limit and the containment capability of the capsule will not be impaired.

The limiting load on the inner container taken as shear on the cover bolts is below the failure limit by a factor of 14.

Damage to the package from this drop would be crushing the end shock rings of the Wooden Protective Jacket and also crushing sections of the external Steel Shell. Integrity of the shielding and containment would be maintained.

2.7.1.5 Summary of Results

Discussion of the condition of the package is provided under each of the preceding drop configurations. Summary of the loadings and factors of safety are provided in Table 2.7.1.1.

2.7.2 Puncture

Free drop of the package through a distance of one meter (40 inches) onto the standard, six inch diameter cylindrical bar was examined analytically for all of the principal drop configurations and damage sensitive parts of the package. The local package deflection and g loadings were estimated for each of the drop configurations. In all cases the strike was considered as being located directly under the center of gravity of the package. The calculations are presented in Appendix 2.10.8. Results are summarized in Table 2.7.2.1.

The local deflections range from about 0.6 inches for a strike against the bottom plate of the package (the bar missing the skids) to about 1.4 inches for several of the orientations in which it was postulated that all of the energy was absorbed in crushing the wood of the protective jacket. The associated loadings range from 70 g for the smaller deflections to 25 g for the larger ones.

In all cases the overpack Steel Shell would experience some permanent deformation and when the strike is directly on the 12 gage shell material, some perforation and tearing might occur. Since the shell is neither lead containing or essential to fire protection, a shell tear does not measurably reduce the effectiveness of the package. The loadings are not high and there would be no damage to the inner container or its contents.

2.7.3 Thermal

2.7.3.1 Summary of Temperature and Pressures. Maximum package temperatures under HAC are summarized in Table 2.7.3.1 which is identical to Table 3.5.1. The upper limit pressure is calculated to be 16.6 psig (see Appendix 3.6.4), although even under maximum internal heating and post fire temperature conditions the pressure would likely be very little above atmospheric pressure.

TABLE 2.7.2.1

PUNCTURE SUMMARY

	Deformation or Deflection (in.)	Loading, g	Steel Shell Penetration	S/TC Damage
Bottom				
Plate strike	0.58	70	Not likely	None
Skid strike	1.6	25	Not likely	None
Top	0.9	45	Possibly	None
Side	$0.9 < \delta < 1.4$	45	Possibly	None
Oblique (edge)	$0.9 < \delta < 1.4$	45	Possibly	None

TABLE 2.7.3.1

MAXIMUM PACKAGE TEMPERATURES UNDER HYPOTHETICAL ACCIDENT CONDITIONS[1]

Inside W P J Surface	370°F	(188°C)
S/TC Surface	385°F	(196°C)
S/TC Shell Liner and Drum O.D. (Local Max)	450oF	(232oC)
S/TC Drum Liner (Local Max)	545°F	(285°C)
Source Capsule Surface	670°F	(355°C)

(1)240 watt source corresponding to 1,500 curies of cobalt-60 and a 1,475°F one half hour duration thermally radioactive fire.

2.7.3.2 Differential Thermal Expansion. The differential thermal expansion of the inner container components are essentially the same as those presented in 2.6.1.2 associated with the maximum normal transport condition. While the peak post fire temperatures are about 120°F higher than the corresponding normal transport peak temperatures, the temperature differences that determine the deformations and stresses remain the same.

2.7.3.3 Stress Calculation. As discussed above, the stress calculations presented in 2.6.1.3 for the maximum normal transport conditions also apply to the maximum hypothetical accident conditions.

2.7.4 Water Immersion

Not applicable, no fissionable material involved.

2.7.5 Summary of Damage

The principal safety systems can be characterized as containment and radiological shielding. Their identity is functional and their operation is passive. Many of the pieces of hardware serve both functions. No active hardware, such as valves or coolant system components, are used.

The primary containment system is the special form source capsule. The inner container covers hold the source capsule in place within the drum and confine the latter in a fixed position within the inner container. The covers are gasketed and seal the drum cavity, principally from external contaminants. Satisfactory operation of the shielding system depends upon the lead and tungsten alloys remaining in place under both normal transport and accident conditions. Shielding within the drum cavity is held in place by the covers and the lead shielding within the Shell Assembly will remain in place under the design basis accident conditions.

Under the drop and fire accident sequence, the inner container sustains no significant damage and remains functionally unimpaired. In the drop, anticipated loadings are significantly less than limiting (potentially damaging) loadings and in the fire the peak calculated surface temperature of the source capsule is 670°F. The localized peak lead temperature remains 73°F below the melting point.

Under the drop and fire sequence it is not anticipated that the overpack would be reusable, although it would have properly served its principal function.

2.8 Special Form

The radioactive sources intended for transport in the present package meet the requirements of special form material as specified in 10 CFR 71.75, as well as corresponding U. S. Department of Transportation and International Atomic

Energy Agency documents, as applicable, and are appropriately certified. A typical teletherapy source capsule is described in Chapter 4 on containment and shown in Figures 4.1 and 4.2.

2.9 Fuel Rods

Not applicable

2.10 APPENDIX

2.10.1 Tie Down Analysis

Requirement: "If there is a system of tie down devices which is a structural part of the package, the system must be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of two times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of ten times the weight of the package with its contents, and a horizontal component in the traverse direction of five times the weight of the package with its contents." -10 CFR 71.45(b)(1)

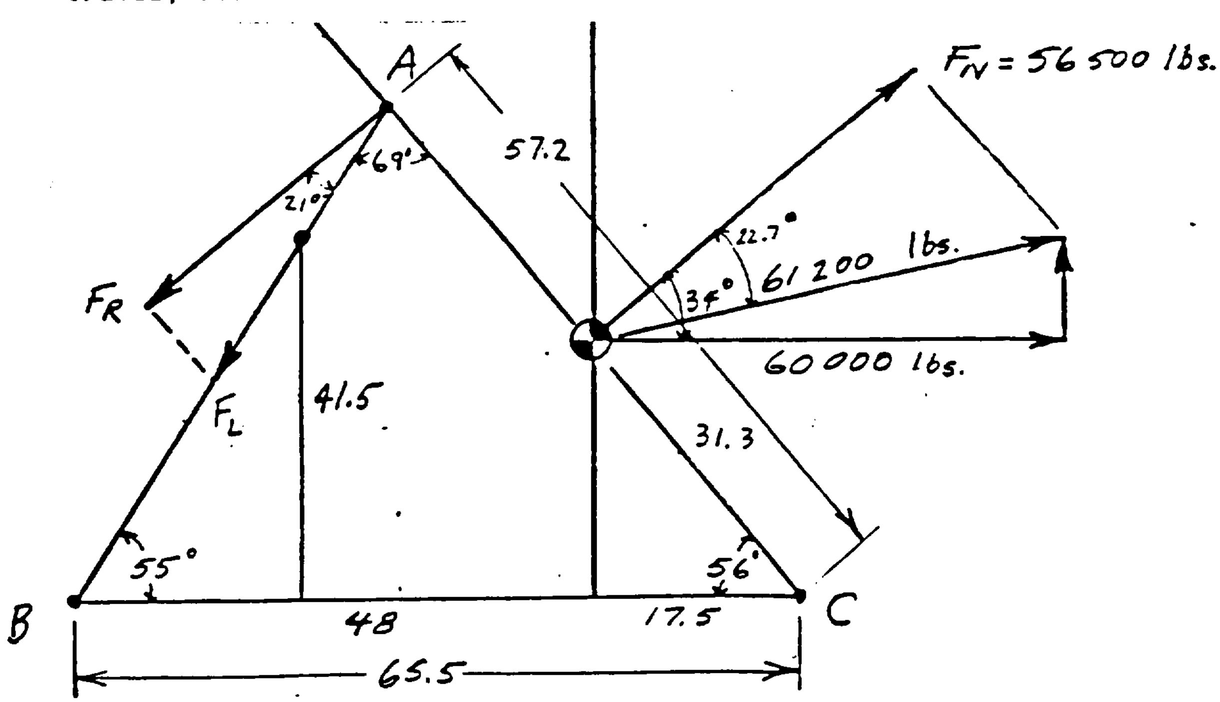
Loads: The loads are diagramed at the top of Figure 2.10.1.1. Based on a maximum package weight, W, of 6,000 pounds, the loads are:

o Horizontal, direction of travel, 10W	=	60,000 lbs.
o Horizontal, transverse, 5W	=	30,000 lbs.
o Vertical, 2W	=	12,000 lbs.

The weight is considered included in the vertical component.

Arrangement: A representative shipping arrangement is shown in Figure 2.10.1.1. The attachment can be made to the frame of a truck or to a cargo container, for example. The rails are aligned transversely to the direction of motion. The largest load (60,000 pounds in the direction of travel) is the one analyzed.

Forces: A force diagram, projected in a vertical plane passing through the center of gravity (c of g) and aligned with the direction of travel, follows:



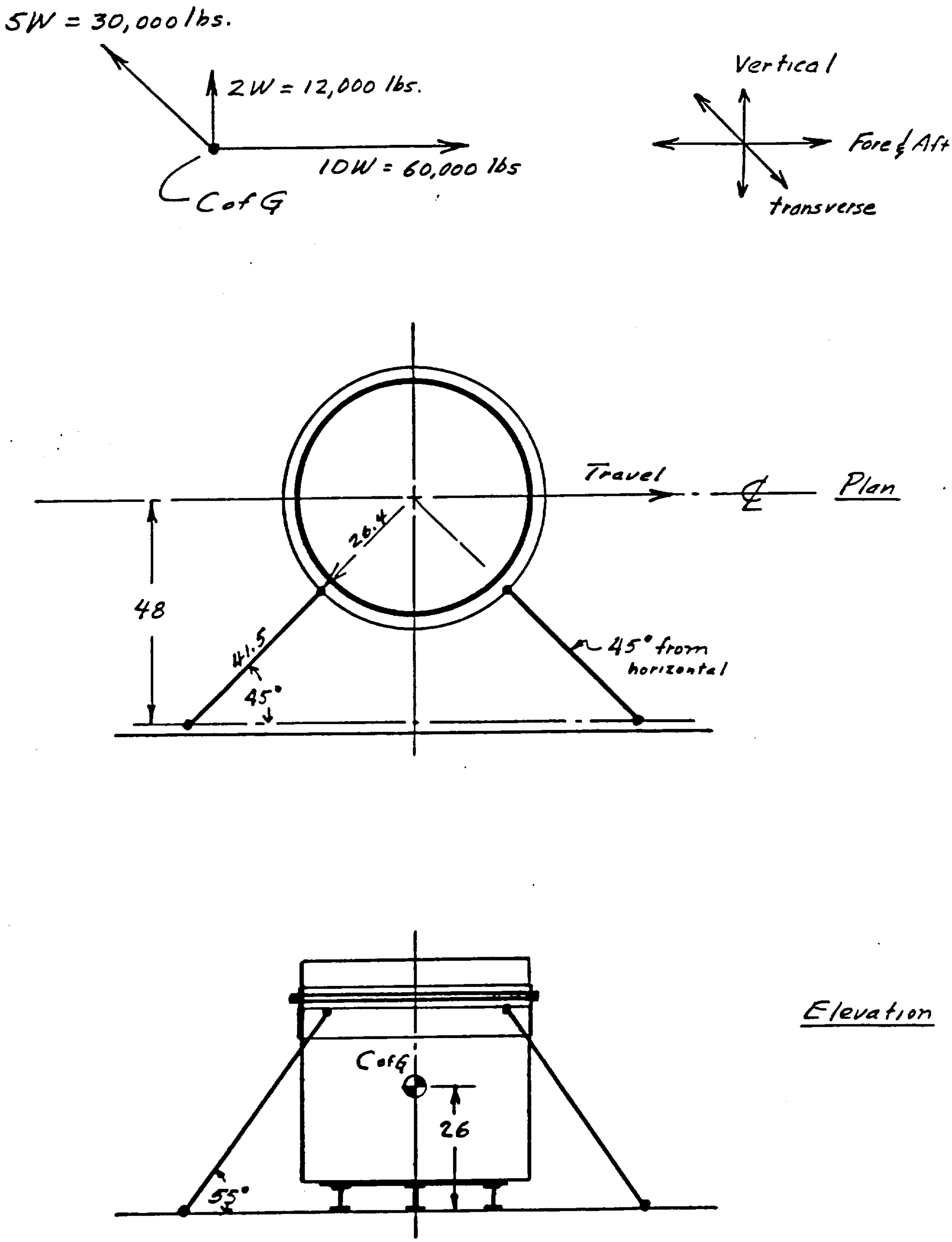


Figure 2.10.1.1 Loads and Tiedown Arrangement

A moment balance about point C, which corresponds to the outermost edge of the support rail, provides the reaction force, F_R:

$$56,500\ (31.3) - F_R\ (57.2) = 0$$
$$F_R = 30,900 \text{ pounds}$$

and the component of the tie down force in the central vertical plane, F_L:

$$F_L = F_R/\cos 21^o = 30,900/.934 = 33,100 \text{ pounds}$$

from which the tension, T, in each of the two tie down lines opposing the applied force can be determined from the geometry, recognizing that the tie down lines are angled 45° to the horizontal, as well as to the direction of travel:

$$T = F_L \cos 55^o/2 \cos^2 45^o$$
$$= 33,100\ (.574) = 19,000 \text{ pounds}$$

This result is representative and not very sensitive to reasonable changes in the angles of the tie down lines.

Component Adequacy: Reference Drawing N 240116

1. Bracket eye - shear
   Shear area = 1.45 in.^{2}
   Load capability = ys (.55) (area)
   = 36,000 (.55) 1.45
   = 28,700 pounds
   Maximum load = 19,000 pounds - no yielding
   Safety factor - 1.5

2. Bracket - tension/compression
   For a vertical load, each bracket
   Section area of two 3 X 3 X 3/8 inch angles = 3.18 in.^{2}
   Load capability = ys (area)
   = 36,000 (3.18) = 114,000 pounds
   Maximum load = 19,000 sin 45° = 13,500 pounds - no yielding
   Safety factor - 8.4

3. Support band and body flange - shear
   Downward force on bracket to reach shear yield limit in support ring and body flange cross section only.
   Section area = 3.68 in.^{2}
   Load capability = 36,000 (.55)(3.68) = 72,800 pounds
   Maximum load = 13,500 pounds - no yielding
   Safety factor - 5.4

4. Bracket attachment weld - shear
   Weld length = 8 in. (sides only considered)
   Minimum weld section = (1/4)(.707)(8) = 1.41 $in.^2$
   Weld efficiency = 75%
   Load capability = 2 (36,000)(.55)(1.41)(.75)
   = 41,900 pounds
   Maximum load = 13,500 pounds - no yielding
   Safety factor - 3.1

5. Shell - Tension/Compression
   Tension in shell cover:
   Area = 48.5 (.1072) = 16.3 $in.^2$
   Load capability = 36,000 (16.3) = 587,000 pounds
   Upper limit load = 13,500 (4) = 54,000 pounds - no yielding
   Safety factor - 10.9

   Compression in shell:
   Load capability same as above
   Load - none from prescribed load conditions

6. Support Band and Shell Flange - Hoop Stress

   The Wooden Protective Jacket loads the shell sideways with restraint from two of the four brackets. It is postulated that the principal WPJ restraint is transmitted by the hoop tension through the support band and shell closure flanges. A bracket covers three inches of the total periphery of the Steel Shell, which can be represented as a central angle, θ. For the 48.5 inch diameter Steel Shell:

   $$0 = 3 \text{ X } 360^{\circ}/\pi \; 48.5 = 7^{\circ}$$

   From a horizontal force balance on the bracket, the relationship between the hoop tension load, T, and the horizontal component of the restraining load, R, is:

   $$2 \text{ T } \sin \theta = \text{R}$$

   The tension load to yield is the support band and shell flange cross sectional area multiplied by the yield strength of the A-36 material. The cross sectional area is 3.62 $in.^2$. The hoop tension load to yield is:

   $$\sigma \text{ ys (area)} = 36,000 \; (3.62) = 130,000 \text{ pounds}$$

   from which the limiting, restraining load is:

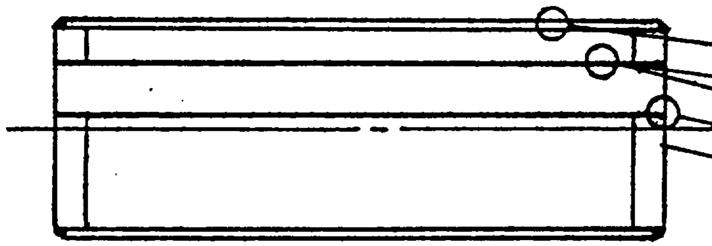
   $$\text{R} = 2 \; (130,000) \sin 7^{\circ} = 31,760 \text{ pounds}$$

   The maximum horizontal component of the tie down load is 13,500 pounds - there is no yielding.

Other Loads: The 10W + 2W load governs the design. The transverse 5W + 2W load results in similar but lesser loadings.

2.10.2 Thermal Stress in Drum and Shell Assemblies

A. The Drum Assembly



The drum liner and casing are at different average temperatures when the drum contains a source capsule. This results in tension/compression stresses in the liner and casing and shear stresses in the weld joints. In calculating the stresses, it is postulated that the 3/4 inch thick end plates do not bend and that there is not interaction with the lead or other encapsulated shielding material. The maximum temperature difference between liner and casing, averaged over the length, is calculated in Section 3.6.5 and was found to be 33°F at an average temperature level of 297°F. From a force balance on the drum (the subscripts refer to liner, casing, and end plate):

$$A_1\sigma_1 + A_2\sigma_2 = 0 \qquad (1)$$

Since the elongation of the liner is equal to that of the casing,

$$\delta_2 = \sigma_2 \ell_2/E_2 = \delta_1 = \sigma_1 \ell_1/E_1 + \ell\alpha\Delta T$$

and $\ell_1 = \ell_2$ and $E_1 = E_2$

$$\sigma_2 - \sigma_1 = E\alpha\Delta T \qquad (2)$$

combining (1) and (2)

$$\sigma_1 = - [A_2/(A_1 = A_2)]\ E\alpha\Delta T \qquad (3)$$

$$\sigma_2 = [A_1/(A_1 = A_2)]\ E\alpha\Delta T \qquad (4)$$

$A_1 = 2.38$ in.^{2}, $A_2 = 4.712$ in.^{2}, $E = 27.0 \times 10^6$ psi @ 300°F

Coefficient of thermal expansion, $\alpha = 9.5 \times 10^{-6}$ in./in. °F @ 300°F and

$$\sigma_1 = -[4.71/(2.38 + 4.71)]\ 27 \times 10^6\ (9.5 \times 10^{-6})\ 33 = -5{,}620 \text{ psi}$$

$$\sigma_2 = [2.38/(2.38 + 4.71)]\ 27 \times 10^6\ (9.5 \times 10^{-6})\ 33 = 2{,}840 \text{ psi}$$

The total load is :

$$-\sigma_1 A_1 = \sigma_2 A_2 = 2,840\ (4.712) = 13,380 \text{ pounds}$$

The shear load on the welds are:

$T = 13,380/.095\pi\ (2.75)\ 3 = 5,430$ psi   End plate to liner weld joint
$T = 13,380/.187\ (7.81)\pi = 2,900$ psi   End plate to casing weld joint

Comparison with allowable stresses:

Member	Stress, psi	Secondary Stress Allowable, psi
Liner	-5,620 (compression)	22,500 (min. Y.S.)
Casing	2,840 (tension)	22,500 (min. Y.S.)
End plate to liner weld joint	5,430 (shear)	12,400 (.55 min. Y.S.)
End plate to casing weld joint	2,900 (shear)	12,400 (.55 min. Y.S.)

If an internal pressure is added to the loading, equation (3) becomes:

$$\sigma_1 = -\ (A_2/(A_1 + A_2))E\alpha\Delta T - (A_3/(A_1 + A_2))p \quad (5)$$

where A_3 is the area over which the pressure, p, acts. An analogous term is added to equation (4). Using the evaluation basis 15 psi as the differential loading acting over the net drum end area, $A_3 = (\pi/4)\ (8.187)^2 - 3(\pi/4)\ (2.56)^2 = 37.2$ in.^{2}, the liner compressive stress becomes $5,620 = (37.2/2.38 + 4.71)\ 15 = 5,620 + 79 = 5,699$ psi, an increase of 1.4 percent. The other stresses change correspondingly.

B. The Shell Assembly

The relationships above also apply to the Shell Assembly. Subscript 1 now refers to the shell liner and subscript 2 to the shell. The spherical shell is postulated to behave as a coaxial cylinder of equivalent thickness and of great circle diameter. The spherical shell is more flexible than the postulated coaxial cylinder so that the calculation overestimates the shell liner stresses. The maximum temperature difference between the shell and the liner is calculated in Section 3.6.5 and was found to be 15°F at an average temperature level of 273°F.

$A_1 = \pi\ (8.44)\ 3/16 = 4.97\ in.^2$

$A_2 = \pi\ (24.38)\ 3/8 = 28.7\ in.^2$

$E = 28.4 \times 10^6$ psi at 273°F

$\alpha = 7.93 \times 10^{-6}$ in./in. °F at 273°F

$$\sigma_1 = -(28.7/4.97 + 28.7)\ 28.4 \times 106\ (7.93 \times 10\text{-}6)\ 15 = -\ (.852)\ 3,380 = -2,880 \text{ psi}$$

$$\sigma_2 = (4.97/4.97 + 28.7)\ 28.4 \times 106\ (7.93 \times 10\text{-}6)\ 15 = (.148)\ 3,380 = 500 \text{ psi}$$

The total load is:

$\sigma_2 A_2 = 500 \times 28.7 = 14,350$ pounds

The shear load on the shell liner welds:

$\tau = 14,350/2\ \pi\ 8.625\ (3/16)$ Face plate to liner weld joint

$= 2,825$ psi

Comparison with allowable stresses:

Member	Stress psi	Secondary Stress Allowable, psi	Factor of Safety
Shell liner	-2,880 (compression)	31,200 (min. Y.S.)	10.8
Face plate to liner weld joint	2,825 (shear)	17,200 (.55 min. Y.S.)	6.1

2.10.3 Free Drop - Normal Transport

The analysis of free drop under normal transport conditions follows that of the hypothetical accident conditions (HAC), except for the level of loading (see Appendix 2.10.5). The total energy to be absorbed in the normal transport drop is 6,000 pounds X 48 inches = 288,000 pound inches.

A. End Drop - Bottom Strike

The impact load is distributed between the support skids, the Wooden Protective Jacket bottom, and the support base of the inner container. Initially, the most compliant of the three is the Wooden Protective Jacket (WPJ) plywood bottom, which deflects elastically. However, before the plywood crushing stress is reached (taken at 6,000 psi) the load on the skids exceeds the buckling/crushing limit and the remainder of the impact load is absorbed by the skids. The average post yield compressive load resistance of the skids is 1,150,000 pounds (see Appendix 2.10.5.A). Until this load is reached, the energy absorbed in the WPJ is $U = \sigma^2 A \ell / 2 E_T$ where σ, the compressive stress in the plywood is 1,150,000/A = 1,150,000/489 = 2,350 psi, A = support base area = 489 in.^{2}, ℓ, the WPJ plywood thickness is 8.25 inches, and E_T, the elastic modulus of the wood perpendicular to the grain in the tangential direction, is 10^5 psi from which U = 111,000 pound inches. The remaining impact energy, 288,000 - 111,000 = 177,000 pound inches is absorbed by the skids. The total deflection is the sum of that of the wood plus the skids, 2,350 X 8.25/10^5 = .194 inches and 177,000/1,150,000 = .154 inches, respectively. The total deflection is .348 inches with an associated loading on the inner container of 140 g.

B. End Drop - Top Strike

As in the HAC drop, the strike would take place on the 2.5 X 2 X 5/16 inch cross shaped reinforcing angle iron that is welded to the top of the Steel Shell Lid. For the HAC drop (see Appendix 2.10.5.B), it was shown that a load of about 1,200,000 pounds needed to be developed before either the angle iron or the WPJ plywood would commence energy absorption by the crushing. Energy absorption by elastic response of the plywood was ignored. Under the normal transport drop, the elastic deflection of the wood beneath the cross shaped reinforcing angle iron absorbed almost all of the energy before very much crushing commences. Taking the limit of proportional response for the wood at 6,000 psi, as in the previous section, the absorbed energy is $U = \sigma^2 A \ell / 2 E_T$ = $(6000)^2$ X (192) X (8.25)/2 X 10^5 = 285,000 pound inches which is approximately the 288,000 pound inches that must be absorbed. The associated deflection is 6,000 X 8.25/10^5 = 0.495 inches, resulting in a loading of 100 g on the inner container.

C. Side Drop

Neglecting crushing of the Steel Shell, the total drop energy would be taken by crushing the rings of the WPJ. Using a value of 6,000 psi for the dynamic crushing pressure (see Appendix 2.10.6), the deflection can be calculated from the volume of the displaced wood. The following table is constructed in the same manner as described in the cited reference:

Deflection h in.	h - D	Segment Area $\div D^2$ (1)	Segment Area in.^{2}	Volume (13.5 X Area) in.^{3}	Energy Absorbed (Vol., in.^{3} 6,000 psi) lb. in.
0.25	.0052	.00066	1.52	20.52	123,120
0.50	.0104	.0014	3.23	43.6	261,630
1.0	.0208	.0040	9.216	124.4	746,500
2.0	.0417	.0012	25.8	348.3	2,089,800

(1) From Table, Page 35, Marks Handbook, Fourth Edition

Interpolating to obtain the deflection, h, corresponding to the energy absorption of the drop, 6,000 X 48 = 288,000 pound inches, yields 0.554 inches with a corresponding inner cask loading of 87.

D. Oblique Drop

Referring to the nomenclature, relationship, and table in HAC oblique drop analysis (see Appendix 2.10.5.D), the displaced volume of plywood resulting from the strike is 288,000 pound inches/6,000 psi (DCP) = 48 $in.^3$ for the normal transport drop. Interpolating in the table: $u = 21^o$; $c = r \cos u = 24 \cos 21 = 22.4$ in.; $h = r - c = 24 - 22.4 = 1.58$ in.; and the deflection is $1.58 \sqrt{2}/2 = 1.12$ inches. The resulting loading on the inner container is 43 g. The calculation is applicable to either a top or bottom edge drop.

2.10.4 Penetration

The potential for penetration of the Steel Shell by a 13 pound, 1-1/4 inch diameter vertical steel cylinder dropped from a one meter height can be estimated from the relationship developed from determining the outer shell thickness, t, of lead shielded casks to prevent penetration from a one meter free fall onto a six inch diameter punch:

$$t = (W/S)^{0.71}$$

Where W is the weight of the cask and S is the ultimate strength of the outer shell material (Cask Designers Guide, ORNL-NSIC-68, Page 17). Rearranging to determine the weight, W, that will withstand the punching action for a given thickness and material:

$$W = St^{1.41} = 58,000\ (.107)^{1.41} = 2,480 \text{ pounds}$$

The 13 pound weight might dent, but not penetrate, the 12 gage Steel Shell by a large margin.

2.10.5 Free Drop - Hypothetical Accident Conditions

A. Bottom End Drop - Direct Fall Onto Skids

Total energy = 30 X 12 in. (6,000 pounds) = 2,160,000 pound inches

Skids: Five inch by ten pound I beams

ASTM A-36 Steel $S_{ys} = 36,000$ psi
$S_{ts} = 58,000$ psi
Web thickness - .210 inches
Two outboard skids, 34 inches long
Center skid, 48 inches long
Web area - 2 (34)(.210) + 48 (.210) = 14.3 + 10.1 = 24.4 $in.^2$

The free drop energy absorption is most likely to be taken by one or more of the following package components:

- o Skids, by crushing or buckling;
- o WPJ bottom, by elastic deflection and crushing; and,
- o S/TC support plate by crushing or buckling.

The energy absorption distribution depends upon the load deflection characteristics of the members. The member having the lowest applied load at which significant deflection occurs will absorb the initial, and perhaps the total, energy. If, in the sequence of package arrest, the load resistance of the initial member increases to the extent that it exceeds that for another member or members, the energy absorption burden is shifted or shared. The load deflection characteristics for the members listed above are estimated in the following:

1. Skids

Load to yield = (36,000 psi) X (24.4 in.^{2}) = 878,000 pounds. Average post yield compressive load resistance, taken as constant with increasing deflection:

$(1/2)(S_{ys} + S_{ts})(\text{area}) = (1/2)(36{,}000 + 58{,}000)(24.4) =$
1,150,000 pounds

Load to Buckle Skids

Buckling Stress, S′

$S' = K[E/(1 - \mu^2)]\ (t/b)^2$

Roark, 4th Edition, Table IVA, Page 348, Case A1

where K = K (height/length)

<u>Center</u>

$(t/b)^2 = (.210/48)^2 = 19.1 \times 10^{-6}$
Height/length = 5/48
K = 43 (extrapolated)
$S' = 43\ (30 \times 10^6/.91)(19.1 \times 10^{-6}) = 27{,}100$ psi
Load = 27,100 (10.1) = 274,000 pounds
Total load = 813,000 pounds

<u>Outboard</u>

$(t/b)^2 = (.210/34)^2 = 38.1 \times 10^{-6}$
Height/length = 5/34
K = 30 (extrapolated)
$S' = 30\ (30 \times 10^6/.91)(38.1 \times 10^{-6}) = 37{,}700$ psi
Load = 37,700 (14.3) = 539,000 pounds

Either or both loadings could occur, since the threshold is about the same. Crushing is slightly higher and is used for deflection determination, since it yields the higher inertial loading.

2. Wooden Protective Jacket

The jacket bottom will respond to loading, elastically at first, with build up to the dynamic crushing pressure (see Appendix 2.10.6) of the plywood. Extending the elastic range until DCP is reached, the load deflection relation is $\delta = \sigma \ell / E_T$ and the energy absorbed is:

$$U = \sigma^2 \; A \ell / 2 \; E_T$$

where σ is the compressive stress on the plywood, psi; A is the loaded area which in this case is the S/TC support base area, (21.5 X 22.75) = 489 in.^{2}; ℓ is the thickness of the bottom, 8.25 inches; and, E_T is the elastic modulus of the wood perpendicular to the grain in the tangential direction, 10^5 psi. The DCP is a cap on the upper level of the stress, σ. Using 6,000 psi as the DCP for the plywood stock, the threshold crushing load becomes (DCP) X (support base area) = 6,000 X 489 = 2,930,000 pounds.

3. S/TC Support Plate

Cross sectional area = 2 (22.75 + 2)(1/2) = 24.8 in.^{2}
ASTM A-516 Gr 70 Steel S_{yp} = 38,000 psi
S_{ts} = 70,000 psi
Load to yield = 38,000 (24.8) = 942,000 pounds
Average post yield compressive load resistance - (1/2)(38,000 + 70,000)(24.8) = 1,340,000 pounds for the first 1/8 inch of deflection at which point the 7.5 inch diameter fill opening flange and plug make contact with the WPJ and the load is increased by:

$$6{,}000 \text{ psi X } (.7854)(7.5)^2 = 265{,}000 \text{ pounds}$$

4. Bottom Drop Summary

Of the three components in a position to absorb the impact load, crushing of the skids results in the lowest sustained load and most of the energy could be considered absorbed in this manner. The initial energy absorbed by deflection (compression) of the WPJ bottom, can be calculated if σ A is set equal to the post yield compressive load resistance of the skid (1,150,000 pounds) and the resulting stress = 1,150,000/489 = 2,350 psi used to calculate the absorbed energy U (see Section 2.10.3.A). This results in a value of U = 111,400 pound inches and a deflection of δ = .194. The remaining energy, 2,160,000 - 111,000 = 2,050,000 pound inches, is absorbed by the skids, resulting in a deflection of

2,050,000/1,150,000 = 1.78 inches. The average loading in arresting the drop is:

$$(30 \times 12)/(1.78 + .194) = 182\ g, \text{ say } 180\ g$$

B. Top End Drop

The strike would take place on the 2.5 X 2 X 5/16 inch cross shaped reinforcing angle iron that is welded to the top of the Steel Shell cover. The energy absorption would be by some combination of crushing wood (the WPJ), crushing the angle iron, or buckling the angle iron.

1. Crushing the WPJ

The principal crushing would take place at the position of the angle irons. Using the dynamic crushing pressure of wood as 6,000 psi and the projected area of the angle iron, the load is:

$$6{,}000 \times (48 \times 2 \times 2) = 1{,}150{,}000 \text{ pounds}$$

2. Crushing the Steel Angle

$$\text{Area} = (5/16) \times (48) \times 2 = 30 \text{ in.}^2$$

The post yielded compressive load resistance for the ASTM A-36 steel angle.

$$(1/2)(S_{ys} + S_{ts})(\text{area})$$
$$(1/2)(36{,}000 + 58{,}000)(30) = 1{,}410{,}000 \text{ pounds}$$

3. Buckling of the Steel Angle

Using previously cited relationship from Roark, Page 348:

$$S' = K\ (E/1 - \nu^2)(t/b)^2 \qquad K = K(a/b);\ a/b = 2.5/48 = .052$$
$$K = 60 \text{ (extrapolated)}$$
$$S' = 60\ (30 \times 10^6/.91)(.3125/24)^2 = 335{,}000 \text{ psi}$$

This exceeds the compressive crushing stresses; no buckling.

4. Top End Drop Summary

To account for the additional resistance of the 12 gage steel and some load spreading between shell and WPJ, the load resistance is taken as an average of Items (1) and (2), or 1,281,000 pounds, rather than the lowest value. The deflection becomes:

$$2{,}160{,}000/1{,}281{,}000 = 1.69 \text{ inches}$$

and the average loading:

$$30 \times 12/1.69 = 213 \text{ g, say } 215 \text{ g}$$

C. Side Drop

The strike in a side drop would crush the side of the Steel Shell and a corresponding portion of the Wooden Protective Jacket. Most of the drop energy would be dissipated in crushing the shock rings of the WPJ. Using a dynamic crushing pressure of 6,000 psi (see Appendix 2.10.6), the energy that can be absorbed by the six rings is:

$$6{,}000 \text{ psi} \times \text{volume of the wood displaced, in.}^3$$

The volume of the wood displaced is the area of a circular segment, h = 2 inches deep on a 48 inch diameter, D, multiplied by 2.25 X 6, the thickness of all six rings. For h/D = 2/48 = .0417, the segment area is $(48)^2 \times (.0112) = 25.8$ in.^{2} (from Marks Handbook, 4th Edition, Page 35, or see Appendix 2.10.6). The ring volume displaced is 25.8 X 2.25 X 6 = 348 in.^{2} and the total energy absorbed is 6,000 X 348 = 2,090,000 pound inches. This is close enough to the total drop energy of 6,000 pounds X (30 X 12) in. = 2,160,000 pounds, to amount to total absorption. The resulting loading is 30 X 12/2 = 180 g.

D. Oblique Drop

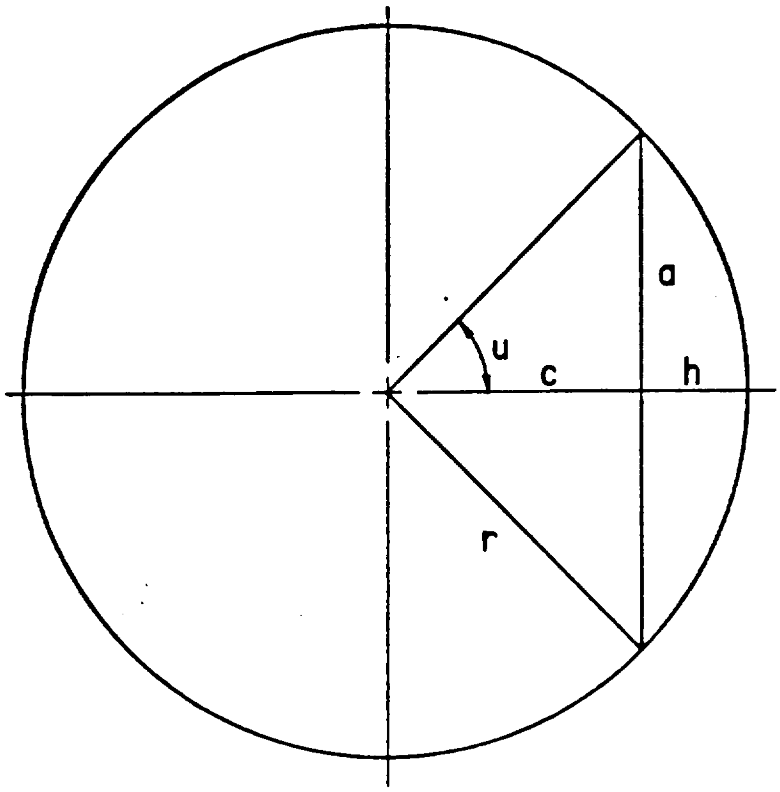
The most severe oblique or edge drop will be that for which the axis of the package is inclined approximately 45°, because this places the center of gravity over the point of impact. The Steel Shell with associated attachments and reinforcements can absorb impact energy in many orientations, but there are a few for which the principal impact absorber will be the Wooden Protective Jacket. Upon impact the crushed edge of the wooden jacket can be represented as an ungula of a right circular cylinder. To determine the deflection and loading using the DCP method, it is necessary to calculate the volume of the ungula, which is:

$$\text{Vol} = H[(2/3)a^2 - cB]/[r - c]$$ (Marks Handbook, 4th Edition, Page 108)

where the geometric parameters are defined in the accompanying sketch. The expression for the volume can be re-written as a function of r, θ, and u only.

$$\text{Vol} = r^3 \tan\theta\, [2/3 \sin^3 u - u \cos u + \sin u \cos u]$$

and tabulated as a function of u (θ = 45°).



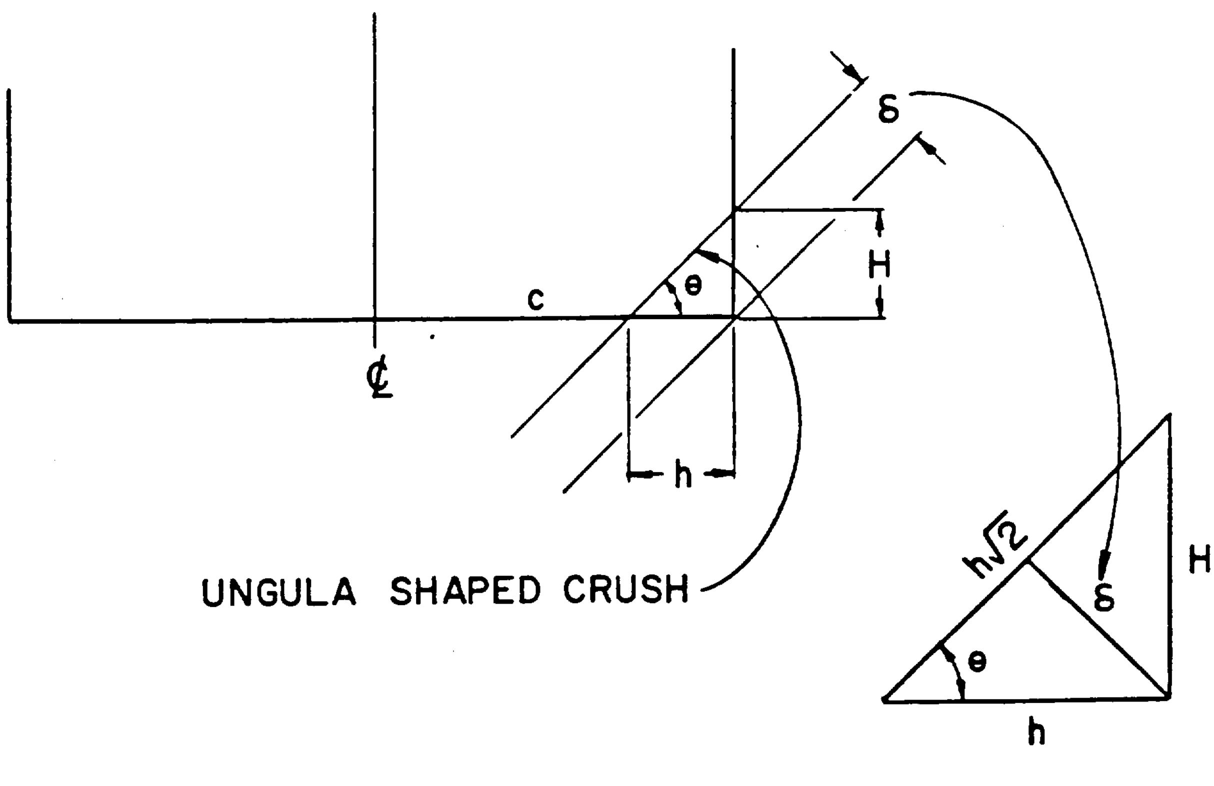
$$\tan\theta = \frac{H}{h}$$

$$c + h = r$$

$$\frac{a}{r} = \sin u$$

$$\frac{c}{r} = \cos u$$

$$B = \frac{1}{2} r^2 (2u - \sin 2u)$$



$$\delta = h\frac{\sqrt{2}}{2} \text{ @ } \theta = 45°$$

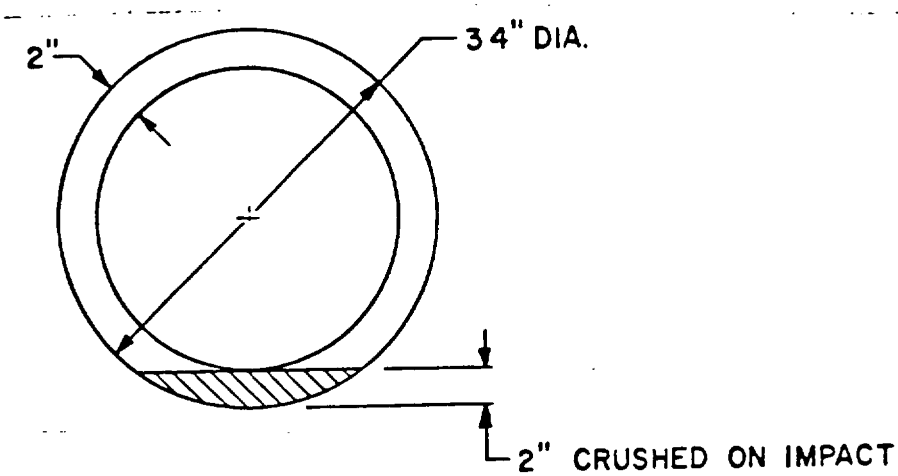
u, degrees	Volume @ $\theta = 45^{\circ}$, in.^{3}
5	0.467
10	4.303
15	14.8
20	34.0
30	109.4
45	312
60	592
75	845

The drop energy divided by the DCP yields the volume displaced in the strike: 2,160,000/6,000 = 360 in.^{3}. Interpolating from the table above gives u = 47.5°, from which the values of c = 16.2 in., h = 7.79 in., and δ = 5.5 in. can be calculated. The average loading is 30 X 12/5.5 = 65 g. The calculation is applicable to either a top or bottom edge drop.

2.10.6 Dynamic Crushing Pressure of Plywood

One of the principal functions of the wooden protective jacket is to serve as an impact absorber to protect the inner container under accident conditions. This function is fulfilled by crushing some of the overpack plywood. In evaluating various accident scenarios, convenience would be served by having an approximate relationship between the energy absorbed and the plywood crushed, much as the dynamic flow pressure concept is employed in evaluating a strike on a shielded container.

A. A reasonable estimate of the energy required to crush overpack plywood can be derived from information provided by the Sandia drop tests. Figure 2.10.6.1 (this is Figure 21 on Page 228 of SC-RR-65-98, Proceedings, International Symposium for Packaging and Transportation of Radioactive Materials), shows a 4,000 pound package, with a wooden protective jacket having five two inch thick and two inch wide shock rings. The package had been dropped 30 feet in the horizontal position (side drop). The rings were completely crushed on the side of the package that took the strike. As pointed out in the caption, the main body of the shell is almost untouched. Probably 90 percent of the drop energy was absorbed in crushing and displacing the shock ring plywood. Postulating that all of the drop energy was used in crushing and displacing a two inch high segment of the jacket rings (as represented by the cross hatching in the accompanying sketch) the capability of the plywood material to act as an impact absorber can be determined in a manner analogous to the dynamic flow pressure (DFP) determination for lead shielded casks (see Cask Designers Guide, ORNL-NSIC-68, Pages 57-64). The volume of the segment can be determined from tables (Marks Handbook, 4th Edition, Page 35) as a function of ring height to diameter:



$h/D = 2/34 = 0.0588$
From the table, segment area/D^2 = 0.0187
Segment area = $0.0187\ (34)^2 = 21.6$ in.^{2}
Total volume displaced = 21.6 X 2 (in.) X 5 (rings) = 216 in.^{3}

The total energy to be absorbed from the drop is:

4,000 pounds X 30 feet X 12 in./ft. = 1,440,000 pound inches

Calling the unit energy absorption the dynamic crushing pressure (DCP) in analogy to the DFP:

DCP = 1,440,000/216 = 6,700 psi

Recognizing that some of the drop energy was absorbed in gross deflection of the package, a reasonable upper limit value for DCP would be 6,000 psi.

B. Another method for determining the DCP of wood is provided by the standard hardness test (reference: Wood Handbook, U. S. Department of Agriculture, Handbook No. 72, Forest Products Laboratory, Forest Service, 1955, Page 69, and Table 12, Page 75). Hardness represents the resistance of wood to wear and marring. The hardness rating is given in pounds and is taken as the force needed to imbed a 0.444 inch diameter steel ball into the wood to a depth of one half of the ball diameter. Hardness numbers for Douglas fir (not plywood) taken from Table 12 of the reference are as follows:

Figure 2.10.6.1 (Figure 21 of reference cited)

Type of Douglas Fir	% Moisture	Hardness, lbs. End	Side
Coast	38	570	500
	12	900	710
Intermediate	48	510	450
	12	710	600
Rocky Mountain	38	450	400
	12	740	630

The hardness is the force required to push the ball into the wood the last few thousandths of an inch, δ, at the full diameter of the ball. The force X δ divided by the volume displaced, which is the ball projected area X δ is the DCP:

$$DCP = \text{Hardness} \times \delta / [\pi/4(.444)^2 \times \delta] = \text{Hardness}/.1548$$

Hardness lbs.	DCP psi	
400	2,600	
500	3,230	high moisture
600	3,875	
700	4,520	
800	5,170	low moisture
900	5,800	

Using the above DCP hardness correlation, the DCP for Douglas fir ranges from 2,600 to 6,000 psi.

C. There is another indication of the DCP for Douglas fir. The highest (parallel to the grain) values of the compressive fiber stress at the proportional limit and the maximum crushing strength falls in the range of 3,000 to 7,000 psi (Table 12, Wood Handbook).

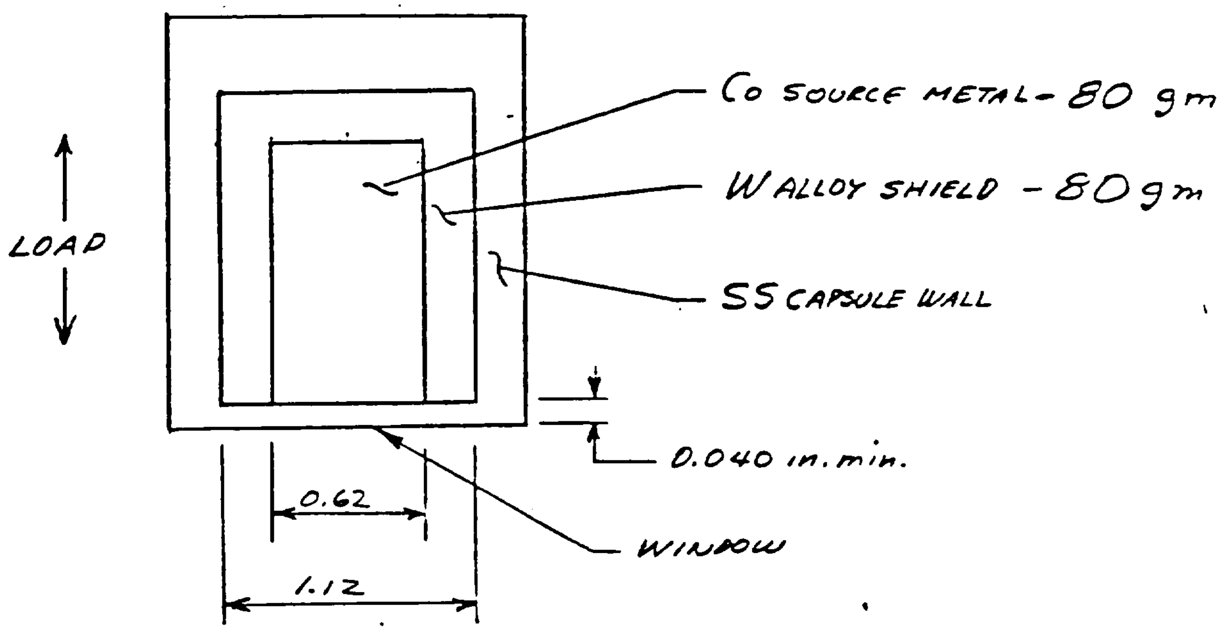
D. Summary

For estimating load deflection characteristics of plywood laminate composites as used in overpacks, the indication is that use of the dynamic crushing pressure (DCP) is as useful and probably about as accurate as the dynamic flow pressure (DFP) as applied to lead shielded casks. From limited data, the range of the DCP for plywood laminate construction is 3,000 to 6,000 psi. For calculation of impact loadings, the 6,000 psi value results in more conservative (higher) loadings.

2.10.7 Limiting Loadings

A. Source Capsule Loading

Teletherapy sources, while having generally similar configurations, are made to various component dimensions. Figure 4.1 in Chapter 4 shows the construction of a typical medical therapy source. The following sketch is a representation selected for calculation as developing a more severe inertial loading than most. The double wall has been combined into one to simplify calculations.



The most restrictive loading is axial, causing a shear load at the 1.12 inch diameter of the window. This shear area is π (1.12) 0.040 = 0.141 in.^{2}. The source metal plus shield weight is 160 gm. X 2.2046 X 10^{-3} lbs./gm. = .353 pounds.

1. The loading to reach the yield strength (Type 304L):

   Shear Stress = 0.55 S_{ys} (at T = 550°F) = 0.55 (15,900)
   = 8,750 psi
   Load = 8,750 (.141) = 1,234 pounds
   Equivalent g loading = 1,234/.353 = 3,500 g

2. The loading to reach the tensile strength (Type 304L):

   Shear Stress = 0.55 S_{ts} (at T = 550°F) = 0.55 (57,400)
   = 31,600 psi
   Load = 31,600 (.141) = 4,460 pounds
   Equivalent g loading = 4,460/.353 = 12,600 g

B. Cover Bolt Loading

1. Each cover closure employs eight bolts:

   Size 1/2 - 13 UNC by 1.25 inches long, hex head
   SAE Grade 8 steel bolt
   Minimum root diameter = .400 inches, minimum root area = 0.126 $in.^2$
   Total shear area = 8 (.126) = 1.008 $in.^2$

2. The limiting loading is shear along the face of the cover (normal to the horizontal axis of the Shell Assembly).

3. The loading to reach yield strength:

   Shear Stress = 0.55 S_{ys} (at T = 300°F) = 0.55 (120,100) = 66,800 psi
   Load = 66,800 (1.008) = 66,500 pounds
   Equivalent g loading for cover weight of 74 pounds: 66,500/74 = 899 g

4. The loading to reach tensile strength:

   Shear Stress = 0.55 S_{ts} (at T = 300°F) = 0.55 (150,000) = 82,500 psi
   Load = 82,550 (1.008) = 83,160 pounds
   Equivalent g loading for cover weight of 74 pounds: 83,160/74 = 1124 g

2.10.8 Puncture

Total energy to be dissipated in the one meter (40 inch) drop against the solid cylindrical bar is 6,000 X 40 = 240,000 pound inches.

A. Bottom Strike Against the Steel Shell

It is postulated that the cylindrical bar would: (1) stretch the metal of the shell bottom, acting much as the horn of a draw die; and, (2) crush the underlying plywood over an area corresponding to the bar tip cross section in absorbing the energy of the strike. The energy absorbed in the first effect is the work of drawing the bottom sheet metal over the cylindrical bar to the depth of the penetration, δ , or:

$$E_{ws} = \text{metal working force} \times \delta = \sigma_p \pi d t \delta$$

where σ_p is the stress in the shell metal under plastic flow conditions and taken as the average of the yield and tensile strength of the A-36 material, d is the diameter of the cylindrical bar, and t is the thickness of the shell metal (the double layer of 12 gage plus 8 gage sheet is taken as a single sheet .107 + .169 = .276 inches thick):

$$E_{ws} = 47,000 \pi\ 6(2.76)\delta = 245,000\ \delta \text{ pound inches}$$

The energy absorbed in the second effect, crushing the plywood, E_{ww}, can be estimated using the dynamic crushing pressure (Appendix 2.10.6) as:

$$E_{ww} = 6,000 \pi\ 3^2 \delta = 170,000\delta$$

The total energy is:

$$E_t = E_{ws} + E_w = 415,000\delta$$

and

$$= 240,000/415,000 = 0.58 \text{ inches}$$

with an associated g loading of 40/.58 = 69 g

B. Bottom Strike Against the Skids

A direct hit on the skid would either crush or buckle the skid. Assuming a one foot section of the skid would carry most of the reaction, calculations (similar to that in 2.10.5.A.1) indicate the buckling stress exceeds 100,000 psi. Since the compressive strength is approximately 60,000 psi for the A-36 material, the skid would crush. The energy required to crush a one foot section of the skid of web thickness 0.210 inches is:

$$E_s = 60,000\ (12)(.210)\delta = 151,000\delta \text{ pound inches}$$

For total strike energy absorption by the skid, the deflection would be:

$$= 240,000/151,000 = 1.6 \text{ inches}$$

and the associated g loading 40/1.6 = 25 g

C. Top Strike Against the Steel Shell

The analysis is the same as the bottom strike against the Steel Shell, except for the decreased metal thickness (12 gage) of the top:

$$E_{ws} = 47,000 \pi\ 6(1.07)\delta = 95,000\delta$$

and

$$E_T = E_{ws} = E_{ww} = 265,000\ \delta\ = 240,000/265,000 = 0.9 \text{ inches}$$

with the associated g loading of 45 g.

D. Side Strike

If the impact is on one of the WPJ shock rings, results similar to the top strike should be expected. The deflection may be a little greater and the g loading reduced because the shock ring would crush further, being only 2-1/4 inches wide. If the strike occurs between the WPJ shock rings, the metal shell will not likely provide very much resistance, the resistance now being provided by the plywood. This might result in a deflection, δ, of about 1.4 inches with an associated loading of 30. As an estimate:

$$0.9 < \delta < 1.4$$

$$45 > g > 30$$

E. Oblique (Edge) Strike

The edge strike would be expected to result in deflections and loadings generally similar to the side strike. At the bottom edge, in the region of the additional support plate and skids, the effects would be closer to the bottom strike.

F. Steel Shell Damage

In all cases the overpack Steel Shell would experience permanent deformation. The extent to which the metal might tear or become perforated is difficult to estimate. The relationship given in the Cask Designers Guide (ORNL-NSIC-68, Page 17; see also Appendix 2.10.4) yields a thickness of 0.19 inches to prevent penetration of the present package. This would indicate that the bottom strike would not result in penetration (t = .276 inches) whereas the other strikes might. Since the shell is neither lead containing nor essential for fire protection, any puncture resulting from the postulated drop will not likely reduce the effectiveness of the total package significantly.

2.10.9 References

A. Accident Resistant Shipping Containers

The report, "New Developments in Accident Resistant Containers for Radioactive Materials," by J. A. Sisler from the Proceedings of the International Symposium for Packaging and Transportation of Radioactive Materials, January 12-15, 1965, SC-RR-65-98, Pages 141-185, has been reproduced in the following because of the importance of the work in assessing the performance of the Wooden Protective Jacket. Both drop and fire tests are summarized in the report.

NEW DEVELOPMENTS IN ACCIDENT RESISTANT SHIPPING CONTAINERS FOR RADIOACTIVE MATERIALS

J. A. Sisler

Introduction

The production of radioactive isotopes has greatly increased since scientists have learned how to control the reaction of fissionable materials in numerous types of reactors. With the production of the various isotopes came their commercial utilization. When any product has a commercial application, it is introduced into interstate and international commerce and involves one or more modes of transportation. Because radioactive materials are hazardous in varying degrees, their shipment falls within the purview of certain agencies established by law to regulate shipment in interstate or international traffic.

Both the severe consequences that could result from an accidental release of the more dangerous radioactive materials and the public's fear of this silent, unseen hazard prompted regulatory agencies such as the Interstate Commerce Commission (ICC), the Air Transport Association (ATA), and the Bureau of Explosives (B of E) to meet with their counterparts in other nations to consider proposed regulations to control the shipment of radioactive materials. These proposed regulations impose more severe container requirements upon the user and shipper of radioactive materials. These proposals, establishing criteria for radioactive-material containers for national and international traffic, require that a container survive a series of conditions which might occur during an accident. The conditions for containers of certain classes of radioactive materials are simulated in the following sequence:

1. A 30-foot free fall to an unyielding surface.
2. A 40-inch drop onto a 6-inch-diameter by 8-inch-long carbon-steel spike. The container shall be positioned to cause the maximum damage in both drops.
3. An ASTM standard 1-hour fire.
4. A 24-hour submersion of the container in water to a depth of 3 feet over the uppermost portion of the container without leakage of the contents or loss of any shielding.

Since the 1-hour fire is considered the most severe obstacle to overcome in the above test sequence, the Atomic Energy Commission (AEC) requested Sandia Corporation, with their extensive environmental testing facilities and the knowledge gained in performing numerous open-pit fire tests and radiant heat tests, help in developing containers for shipping radioactive materials that would withstand the above test sequence and to assist in the subsequent formulation of appropriate regulations.

Program Feasibility

At the outset of the container development work, it was decided that existing containers must be retained because the national inventory of radioactive-material shipping containers is so great that it would be wasteful to dispose of this inventory. Consequently, it was decided to develop an outer shell which would enable existing containers to meet the test criteria and, simultaneously, to establish a concept which would permit simpler future container designs.

Since preliminary evaluation of the test parameters indicated that the fire environment presented the greatest design difficulties, maximum effort was concentrated upon controlling the fire environment by means of insulating and ablative materials, or a combination of the two. However, insulating materials were discarded early in the program because of either the difficulties of container fabrication or failure to meet the drop-test criteria. It should be noted, however, that a steel encased, gypsum-cement insulated container successfully passed the fire test.

In considering the use of ablative materials, several factors had to be evaluated: material cost, availability, structural integrity, and ease of fabrication. These factors unerringly pointed to wood as the most suitable material. The mechanics of wood combustion through destructive distillation, the formation of a low-density char with good insulation properties, and the reasonably good insulation characteristics of the wood itself indicated that a full-scale test and development program should be initiated using this material.

Test Program

Drop Tests

To meet the drop-test criterion of a 30-foot free fall to an unyielding surface, Sandia's 185-foot drop-tower complex, capable of handling containers up to 16,000 pounds, was utilized. The containers were dropped from 30 feet onto a reinforced concrete pad with the drop angle controlled. Although only one 30-foot drop is required, the small to medium-size containers usually were dropped three times, once each on an edge, a side, and the bottom. The smaller containers were so slightly damaged by only one drop that the data obtained might have resulted from minor variations in construction rather than from damage. This drop resistance results from the thick wall required for fire resistance. Large containers were generally dropped only once in the most damaging position. However, as a proof test, one 4000-pound container was dropped three times--once at 45 degrees, once on a side, and once on an end.

Because the drop-test criterion of a 40-inch fall onto a 6-inch-diameter spike is a recent addition to the regulation, tests against this requirement have not been performed to date. However, meeting this requirement is not considered to be a problem.

Fire Tests

To meet the test requirement of an ASTM standard 1-hour fire, an open-pit petroleum fire with JP-4 jet fuel (Figure 1) was used, although it must be recognized that this is a more extreme test than required by the ASTM standard curve. It has been found that a minimum fuel area of 400 square feet and a maximum of 2000 square feet[1] was optimum for maximum heat input to the container. The container array was adjusted so that a minimum of 2 to 3 feet of flame would completely surround each container. This is equivalent to an infinite wall of flame and maximizes heat input to the object under test. We have found that in a fire of this size, radiation is the dominant heat-transfer mode. Thus, for computer studies, an 1850°F black-body temperature can be used as the input figure and will give close correlation for a modeling study.[2]

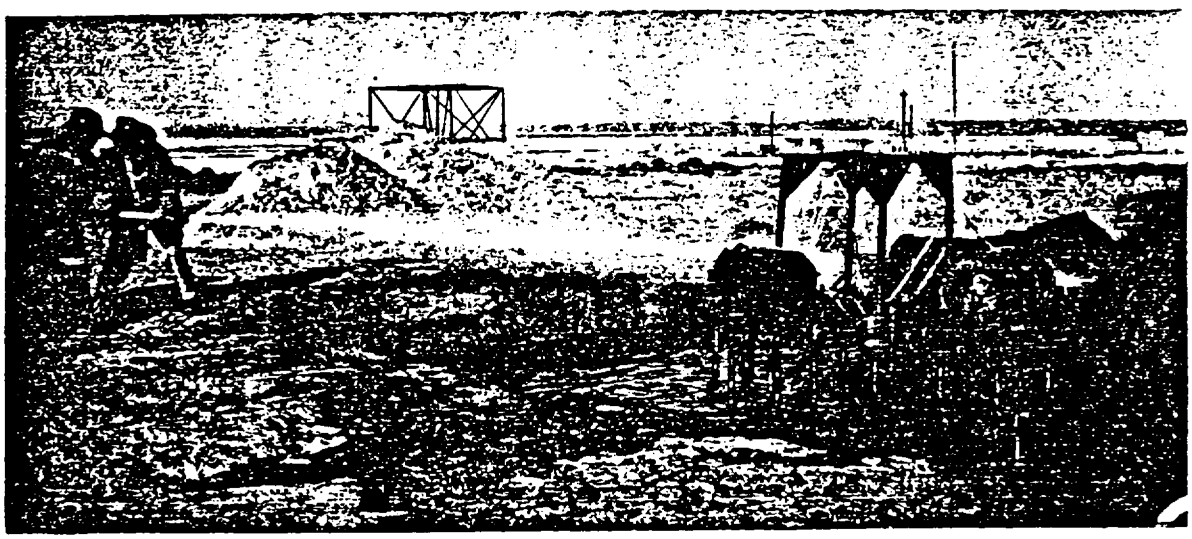


Figure 1. 20 x 20-foot fire test pit and containers immediately following Fire Test 1 (D63-13152)

Water-Submersion Tests

The water-submersion criterion has, with the exception of one test, been largely ignored, basically, because the development concept of this shipping container was an outer shell protecting an inner

[1] B. E. Bader, Heat Transfer in Liquid Hydrocarbon Fuel Fires, Sandia Corporation Report SC-DR-320-63, February 1964.

[2] Ibid.

container from essentially all effects of shock and fire. If this is done, a water-tight seal on the inner container is a simple matter to maintain.

Designs Tested

A number of designs have been examined and found lacking because of high cost, limited application, or other reasons. A few designs that were subjected to test were as follows:

1. Steel container with a special gypsum insulation. This material is a very good insulator, but was difficult to fabricate because of drying problems.

2. Steel container with a zonolite concrete insulation. This material was also difficult to fabricate and failed the fire test because of shrinking and cracking.

3. Wooden containers in cubical shapes. These containers were difficult to build strong enough to survive both the drop and fire tests.

A hollow cylindrical wooden shell was finally selected for encasing an ICC Type 55 or similar shielded container, thus protecting this inner container from the effects of shock and fire (Figures 2 and 3). The shell was constructed from rings of 3/4 inch plywood which were glued together with a strong shock-resistant adhesive and reinforced with cement-coated nails. A full-length bolt ring was also used to add rigidity and to hold the lid (Figure 4). Both the bolts and the nails serve to prevent complete failure of the container if it is cracked in the drop test. For containers of several tons, some cracking is acceptable during the drop test so long as no serious separation of the wood plies takes place. A wall thickness of 4 inches of bare insulating material is necessary to survive a 1-hour fire, although a 3-inch wall will survive a 1-hour fire if a protective sheet-steel outer covering (Figure 5) is used and internal temperatures of up to 500°F can be tolerated for the last 15 or 20 minutes of the fire. If the contents of the inner container are not to exceed 200° to 220°F (i.e., when shipping liquids), a minimum of 6 inches of wood insulation is required.

There are times when requirements other than the fire test affect features of shell construction. Heavy or very dense containers require a thicker wall to survive a 30-foot drop test. The large container in these development tests had 2 by 2 inch rings added (Figures 4 and 6). These rings have two purposes: to facilitate handling; and to absorb a significant portion of the energy of the drop, thus preventing the container wall from splitting (Figure 7). An important consideration in constructing all wooden-shell containers is to assure that the lid joints of the inner container and the outer shell are offset. Another construction feature worth consideration is the addition of a light sheet-metal shell (16 to 20 gage). This type of shell not only offers protection against routine shipping damage, but also protects against a fire environment by preventing the charred wood from sloughing off (Figure 8). However, when a steel shell is used, the shell must be vented to prevent pressure buildup by allowing combustion gases to escape.

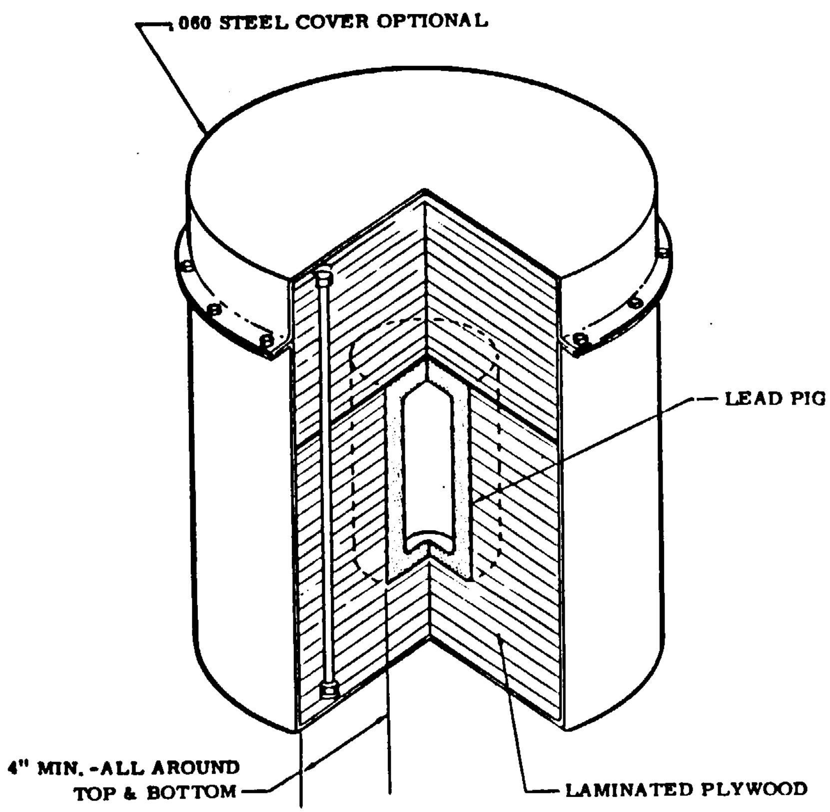


Figure 2. Cutaway view of the small wood insulated container with optional steel shell

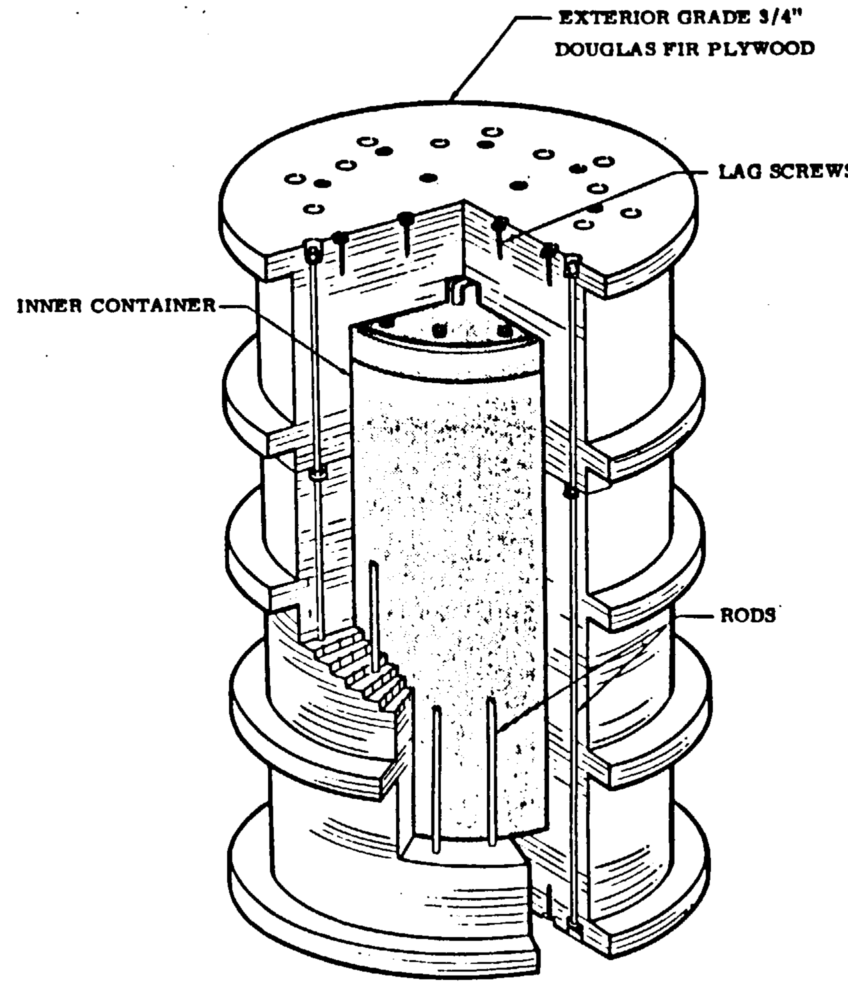


Figure 3. Cutaway view of the 4000-pound container used in SC test and development program; it is representative of large containers in general

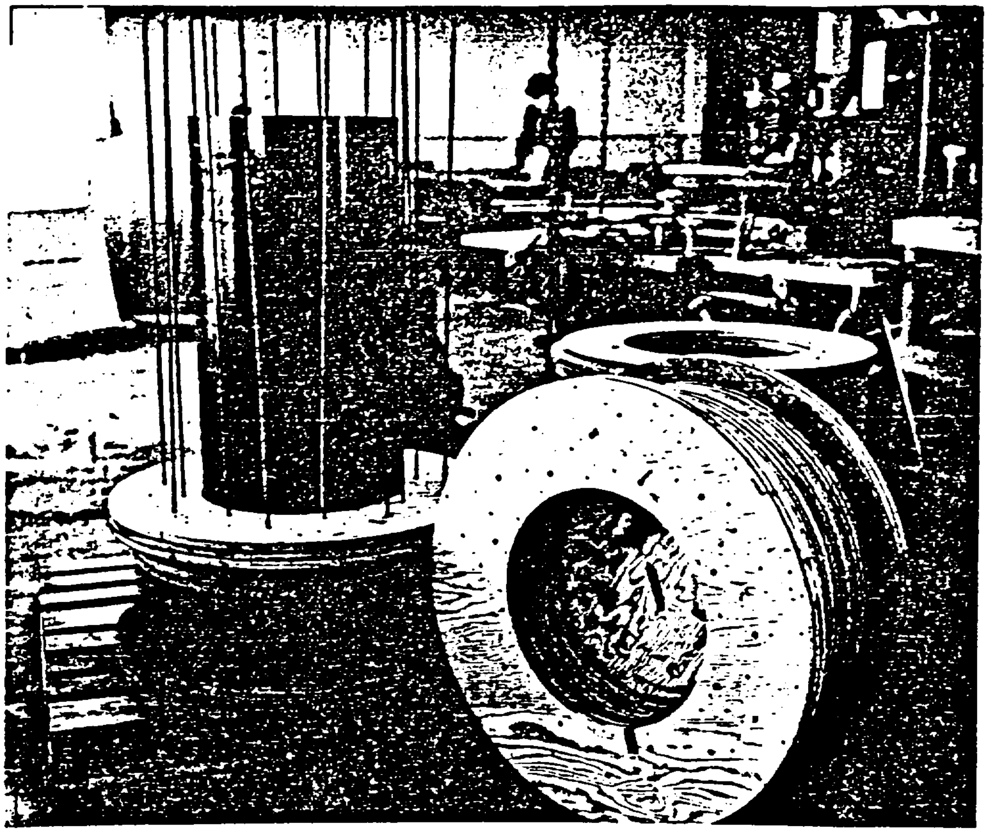


Figure 4. Construction of the 4000-lb container using an ICC-55 shielded inner container (D64-7921)

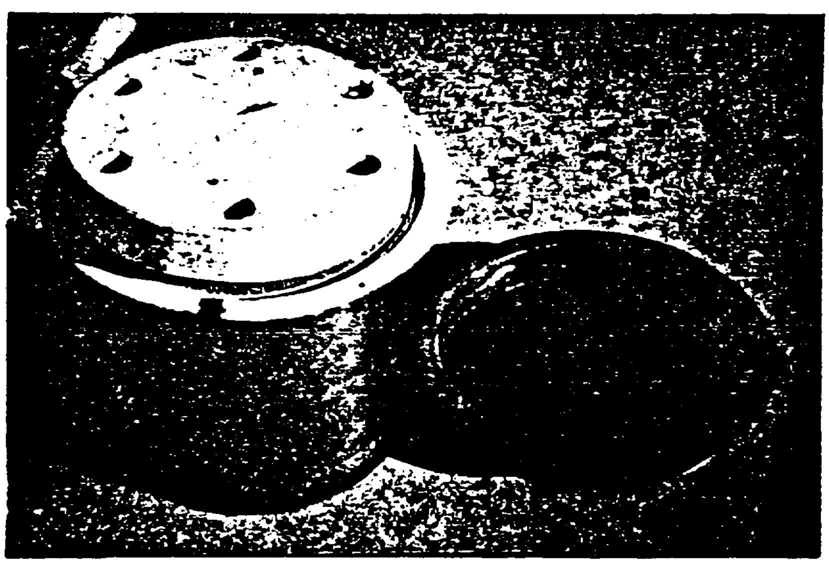


Figure 5. Small 3-inch wall container with steel shell (D63-13101)

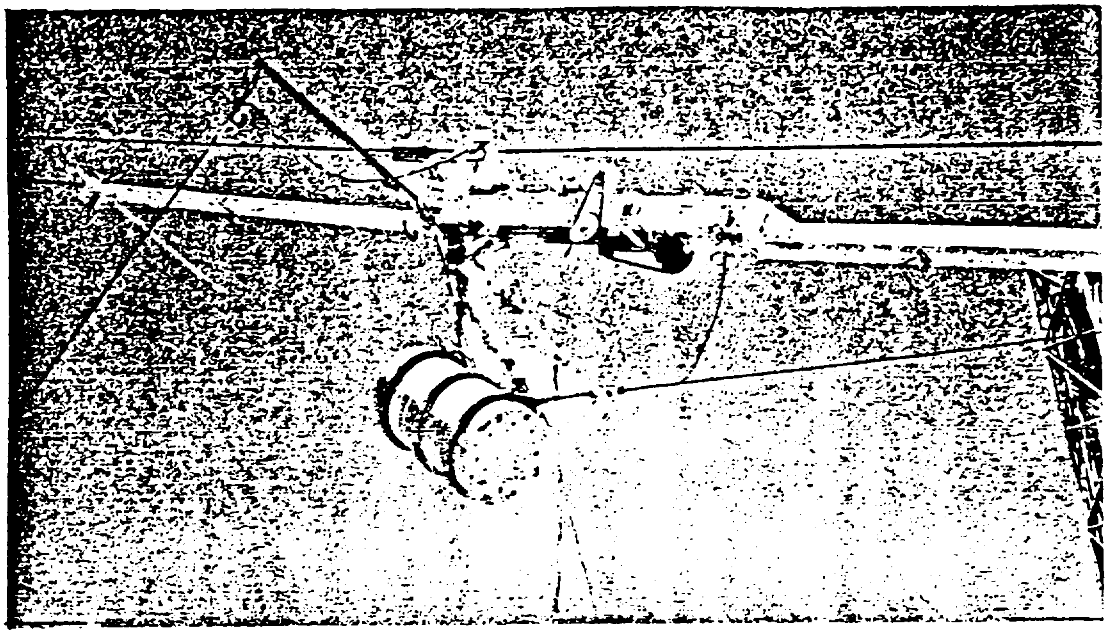


Figure 6. Drop test of second 4000-pound container (D64-9589)

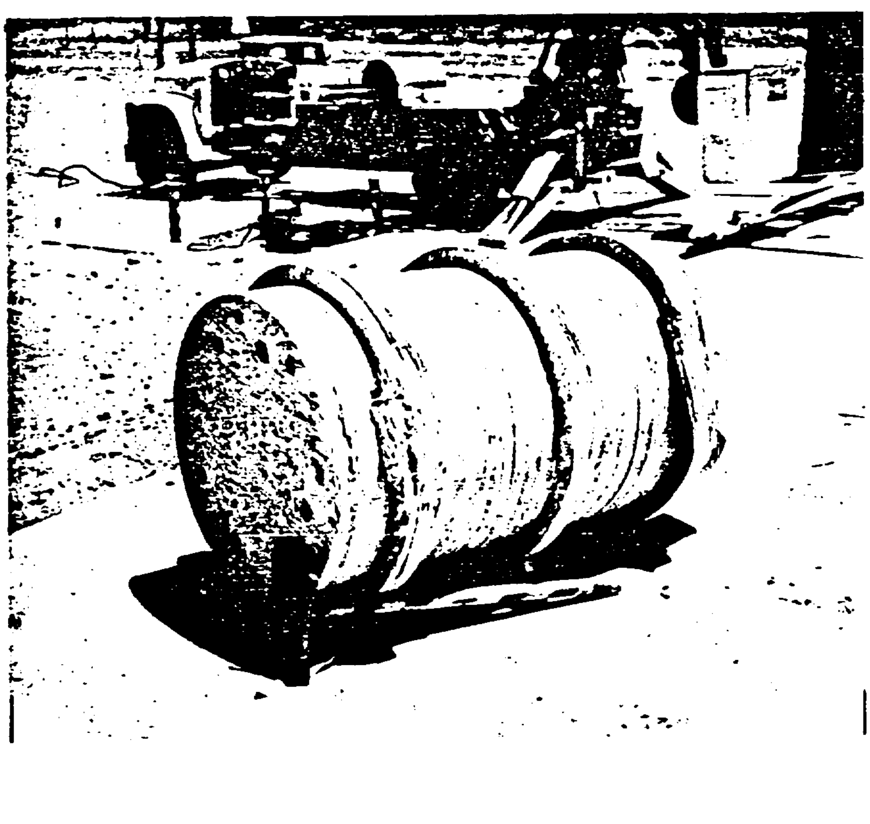


Figure 7. Effects of 45-degree angle drop test of 4000-pound container (D64-9588)

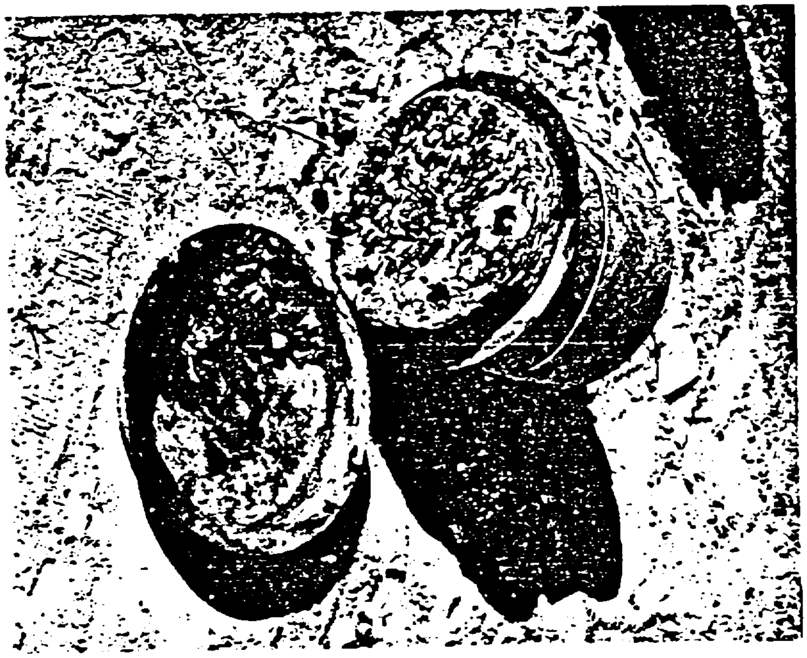


Figure 8. Small 3-inch wall container protected by steel shell showing char layer still intact after Fire Test 1--this container is constructed exactly as shown in Figure 2 (D63-13140)

Test Results

Drop Tests

A number of containers were built with various wall thicknesses and inner diameters. After consultation with several wood research laboratories, four types of materials were tried: Douglas-fir plywood and solid wood, and redwood plywood and solid wood. The Douglas-fir plywood proved to be the most satisfactory material. The solid woods have too great a tendency to split or crack.

The redwood plywood seems to exhibit this tendency to split or crack to a greater degree than the fir plywood, for larger high-density container designs. For containers of 200 pounds gross weight or smaller, it is felt that redwood plywood would be satisfactory. In addition, there are obviously many other types of plywood, and perhaps some pressed-wood-fiber board, that would be equally as effective as Douglas-fir plywood for use in a wooden-shell design. It was not intended to evaluate all possible materials, but only to find one or two good ones that were cheap and readily available.

A number of different adhesives were considered or tried. Resorcinol-formaldehyde, phenyl-formaldehyde, and polyvinyl acetate aqueous emulsion (white glue) appear to be some of the better ones. Each one has its limitations, however. Resorcinol-formaldehyde is a room-temperature curing, exterior grade glue that has high shear strength and strong bonding characteristics, but it must be cured under pressure (180-200 psi) to form a good bond. Phenyl-formaldehyde is an excellent exterior grade adhesive, but it must be cured under heat (200°-250°F) and is difficult to use in bonding very thick layers of wood. Polyvinyl-acetate aqueous emulsion (white "Elmers Glue" type) is the easiest to use, but it should be reinforced with cement-coated nails. It has very high shear strength under dynamic testing conditions but it is temperature and humidity sensitive to some extent and will "cold flow" if subjected to temperatures of 120°F or higher. These characteristics did not appear to be a problem for the Sandia wood-insulation designs because of the reinforcement provided by the cement-coated nails, the full length bolt ring, and the rigidity of the inner metal pig. This combination of adhesive and construction survived the testing program extremely well under the moderately warm and dry desert conditions prevalent in the Albuquerque area, but it would need close examination for use in very large and massive shells being designed for use in the tropics. The ideal construction techniques would utilize a resorcinol-formaldehyde adhesive bonded under pressure and reinforced with cement-coated nails. The use of a full length bolt ring to keep the lid in place is always assumed in this paper. This bolt ring contributes to the stiffness of the shell and helps, with the nails, to prevent a catastrophic failure if some delamination of the plywood takes place as a result of an impact.

The largest container built in this series consists of a 3275-pound ICC-55 steel-lead-steel cylinder encased in a 6-inch-thick plywood shell (Figure 4) with 2 by 2-inch cushioning rings added. The gross weight of this container is 4000 pounds.

Five or more cushioning rings are suggested for containers weighing over 2000 pounds, one cushioning ring layer at each end and three more evenly spaced between. This would make the end caps 8 inches instead of 6 inches thick. As a result of this added thickness, no harm is done if one of the end rings shears off entirely during a drop test.

Ten 30-foot drop tests have been made to date of the 4000-pound container. Eight units have been dropped; one was dropped three times (one end, on the side, and at 45 degrees on opposite end), accounting for the extra two drops. All containers survived in suitable condition to withstand a 1-hour petroleum fire without repair. The first test unit, utilizing resorcinol-formaldehyde glue, experienced some glue-joint failure, but this condition was corrected in subsequent drops. One 4000-pound container was drop tested following a 1-hour petroleum fire and survived without damage to the inner pig. Three drop tests were of resorcinol-formaldehyde-bonded (no nails used except in end rings), fir-plywood-shell designs. One of the drops took place during the International Symposium. Although there was slightly more delamination evident in this construction than in the nail-reinforced design, there was no damage that would affect the subsequent fire response of the container. It should be mentioned at this time that any wood-insulation design that utilizes an exterior metal shell should not require the use of reinforcing nails in the construction.

A number of smaller containers, ranging in size from 25 to 200 pounds, were dropped from 30 feet and were not noticeably damaged. Most of these were dropped three times (one end, side, and at 45 degrees) in an attempt to detect differences in response. Even with three drops, damage to this size range of container was only superficial.

A tabulation of the drops will be found in Appendix A.

Fire Tests

The results of the first fire test (see Appendix B) were most favorable for the wooden containers. Before the fire test, both the 3-inch and 6-inch wall models survived three drop tests each, while ballasted with a 61-pound steel billet simulating an inner container. The containers were then subjected to the 1-hour petroleum fire at 1850°F. Although there were difficulties with the thermocouple leads, other backup data indicate that the interior temperature in the 6-inch wall container could not have exceeded 300°F and probably was under 150°F (Figure 9). The 3-inch wall, steel jacketed, container had 1 inch of good wood left surrounding the inner billet and temperatures were in the 400° to 500°F range, according to the best estimates based on other test results.

Figure 9. 6-inch wall Douglas-fir plywood unprotected container after Fire Test 1 showing amount of undamaged wood (D63-13141)

Following the first fire test and the excellent performance of wood, an investigation was begun into the thermal insulation properties of several types that were of most interest due to cost and other considerations. The Sandia Corporation Radiant Heat Facility was utilized to supply a simulated fire environment that could be carefully controlled over small areas. Four 8 x 8 x 6-inch thick blocks were made up with small thermocouples imbedded at 1/2-inch intervals all the way through the 6-inch thickness (Figure 10). A quartz lamp radiant heat panel was programmed to provide an 1850°F black-body radiant heat source (a heat rate of 11 BTU/ft^2-sec was actually measured) for 1 hour for each of the four blocks. Sample blocks tested were:

1. Douglas-fir plywood exterior grade, 3/4 inch thick, laminated into a single 6-inch thick block.
2. Douglas-fir lumber, nominal 2 inches thick, laminated into a single 6-inch thick block.
3. Redwood plywood, exterior grade, 3/4 inch thick, laminated into a single 6-inch thick block.
4. Redwood lumber, nominal 2 inches thick, laminated into a single 6-inch thick block.

The plywood blocks were tested so that the heat source was exposed to the maximum end grain. In the solid-wood blocks end grain was 90 degrees to the heat source. For the actual curves obtained from this test series see Appendix C. As can be determined from the curves the solid-wood blocks performed best with plywood blocks close behind. The redwood plywood made the poorest showing. Figure 11 showing the blocks after the tests reveal two things; namely, the char rate in the radiant heat test was twice what it was in an actual fire (it jumped from 2 inches in a fire to 4 inches in the radiant heat test), and there was a definite tendency for the heat to travel down the glue joints. The adhesive used in laminating the blocks was polyvinyl-acetate aqueous emulsion (white glue) fabricated under "box shop" conditions. The resorcinol-formaldehyde used in the fabrication of the plywood did not exhibit such tendencies. It is rather unusual that excessive heat travel, down the glue joints, had not been detected in actual fire tests. It is believed both of the above anomalies can be explained by the strong air blast applied to the face of each block during the test. This air blast is necessary to cool the radiant panel quartz lamps and causes no problem on nonflammable materials. An effort is now underway to construct an analytical model of the heat flow through a wood block from an 1850°F black-body radiant source.

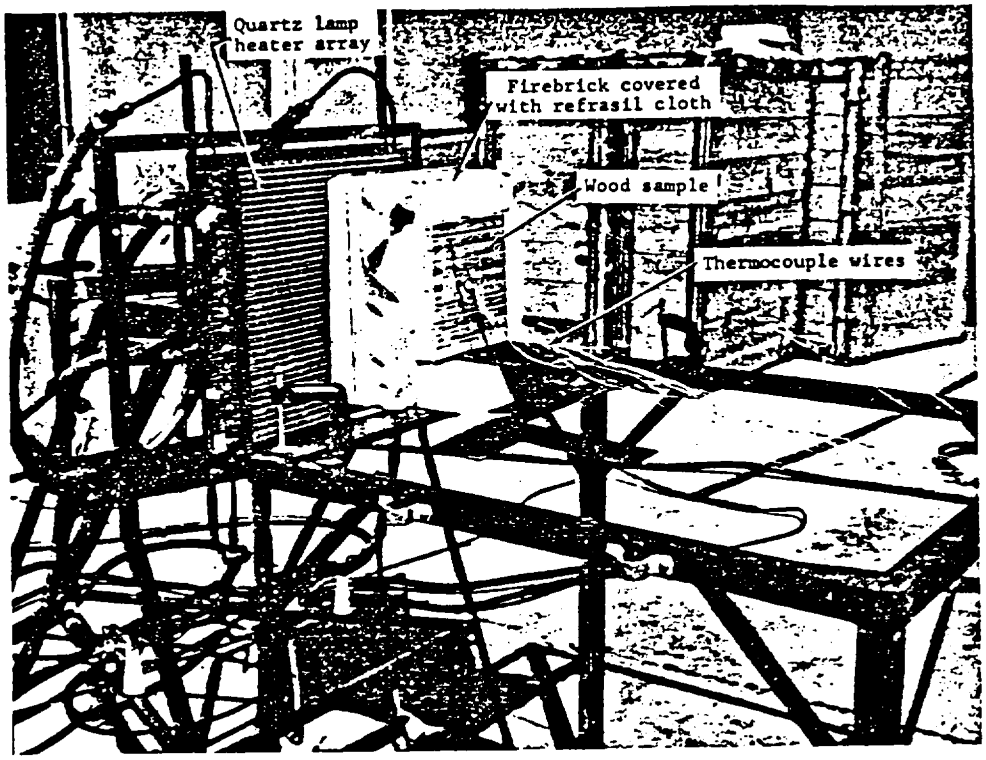


Figure 10. Test setup; radiant heat test of four wood panels (D64-2524)

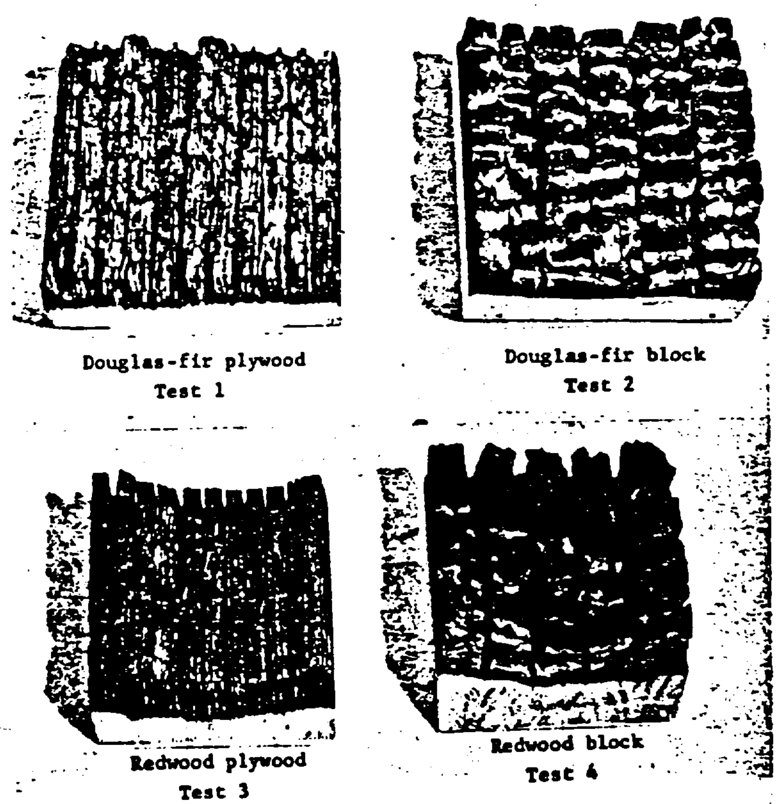


Figure 11.

Appearance of four wood panel after radiant heat test simulating a 1 hour fire (D64-2519)

The second open-pit fire test was similar to the first test, except a 30 x 30-foot pit was used instead of a 20 x 20-foot pit (Figure 12). Eleven instrumented containers were tested (see Appendix B) for 1 hour; 9880 gallons of JP-4 fuel were used, producing the hottest fire in the test series. Some of the high-temperature fiberglass insulation on the thermocouples disintegrated causing shorts. Carbon impregnation of the thermocouple insulation also caused shorts. With partial failure of the thermocouples (which had been successfully used in dozens of other Sandia fire tests) in two fire tests, it was decided to change to stainless-steel sheathed thermocouples in future tests for container instrumentation. Seven of the eleven test objects in Fire Test 2 survived. It had been anticipated that two of the containers would fail, since wall thickness was very minimal. The other two failures were the solid redwood containers which apparently split and burned quite rapidly. The solid Douglas fir also split and cracked, but still survived (Figure 13).

Fire Tests 3, 4, and 5 (see Appendix B) confirmed conclusions drawn earlier regarding the superior performance of fir plywood laminated shells in protecting an inner ICC-55 or similar container from the rigors of a severe accident.

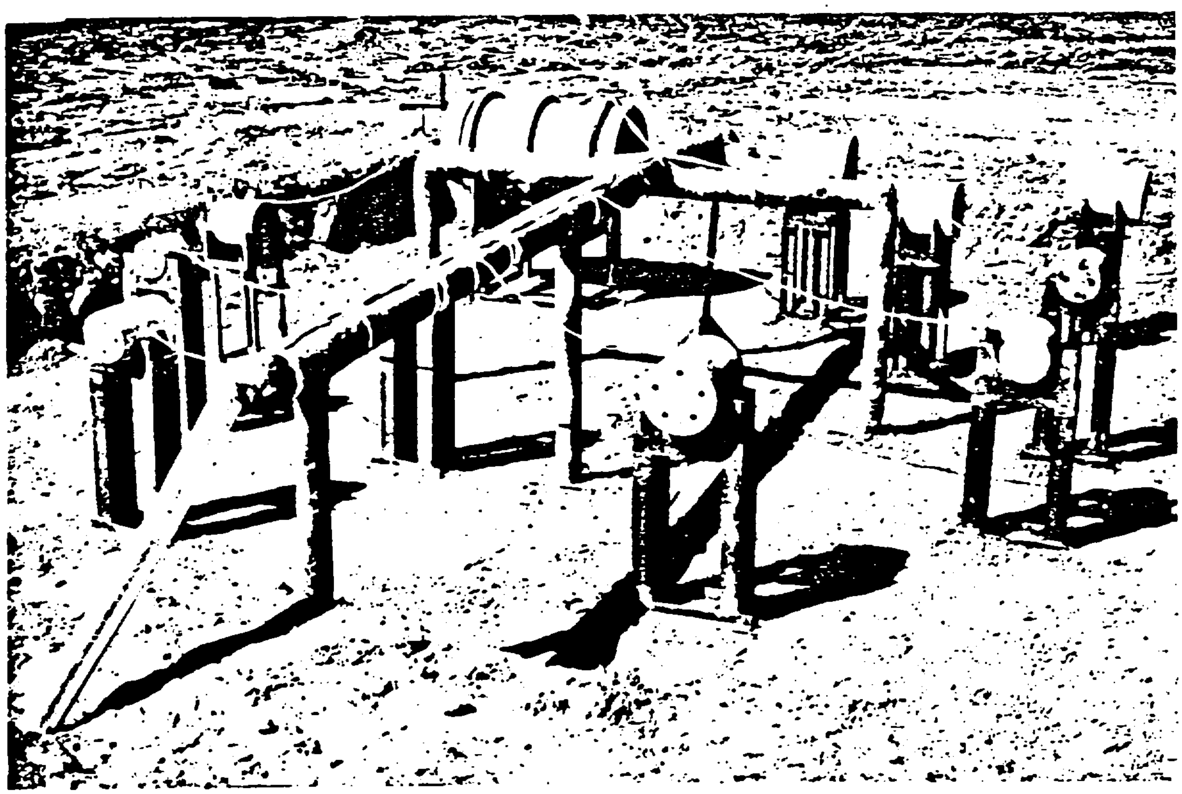


Figure 12. Test array in 30 x 30-foot pit for Fire Test 2 (D64-10016)

Figure 13. Solid Douglas fir, 4-inch thick wall cylinder showing splitting found to be characteristic of solid wood containers (D64-2616)

Conclusions

The purpose of this study and test effort was to develop a container, for shipping radioactive materials, capable of withstanding the fire and drop test outlined in the proposed regulations.

A laminated plywood shell with a 4-inch minimum wall thickness will provide the necessary protection for an approved ICC inner container against the 1-hour fire environment. However, thicker wood shells may be required for shipment of low-boiling-point liquids. The weight and structural features of the inner container may require a thicker wood shell to survive the drop-test requirements and to ensure that 4 inches of wood surround the container after the drop tests. However, in providing a protective shell for massive containers that contain no liquids or other pressure generating materials that might escape when exposed to temperatures under 500°F, it would not always be necessary for the protective shell to stay completely intact. At least 10 to 15 percent of the outer surface area of most large containers could be exposed to a fire environment for 1 hour and still not be in danger of loss of shielding. Therefore, for some shipping container designs the requirement that the outer protective shell remain 100-percent intact during the 30-foot drop could be relaxed to something more practical.

The early development work for the wooden-shell insulation concept has indicated that the following conditions appear to be true:

1. There is no significant difference in the burn rate between Douglas-fir and redwood plywood; however, redwood seems to incur a greater amount of splitting that could be detrimental in the fire environment.

2. There is no significant difference in the temperature gradient or char rate that can be verified for these two plywoods.

3. Plywood is superior to solid woods because of the tendency of the solid woods to split in the fire environment.

4. A glued and nailed laminate with through bolts for lid closure will produce a container that will survive the drop tests.

Although additional research must be done to refine existing data and establish concise design criteria, sufficient information is available to design an effective, economical container which will meet the rigorous requirements of the regulatory agencies.

APPENDIX A

Drop-Test Results

DROP TEST RESULTS

Construction Material	Bonding	Outside Diameter (inch)	Total Height (inch)	Wall Thickness (inch)	Gross Weight (lb)	Sandia Test No.	Completion Date	Data Obtained	Drop Height (ft)	No. Drops	Results
Douglas Fir Plywood Box	Nailed and glued	16 cube	16	3	98	19506	4/11/63	g's and damage	16	3	Box destroyed on third g loading ranged from 5 corner drop to 144 on f side.
Douglas Fir Plywood Cylinder	White glue and nails	20	19-5/8	6	188.5	19770	7/17/63	Damage	30	3	Only superficial damage drops.
Douglas Fir Plywood Cylinder	White glue and nails	14	14	3	~126	19879	9/17/63	g's and damage	30	3	Only superficial damage drops. Peak g loads we bottom drop, 1420 on si 350 on 45 degree drop. light, unyielding conta expect g loads to be ve
Douglas Fir Plywood Cylinder	Resorcinol-formaldehyde and nails	30 plus rings	58	6 inches plus 5 2-inch rings	4000	10336	6/12/64	Damage	30 (@ 45°)	1	End ring separated. De several glue joints.
Douglas Fir Plywood Cylinder	White glue and nails with no end rings	30 plus rings	54-1/2	6 inches plus 3 2-inch rings	4000	10336	6/12/64	Damage	30 (@ 45°)	1	Some damage to end cap pected. Container late 1-hour fire.
Douglas Fir Plywood Cylinder	White glue and nails	7	12-1/2	2-1/2	~ 25	10440	6/17/64	Damage	30	3	Only superficial damage drops.
Redwood Plywood Cylinder	White glue and nails	20	19	6	~ 175	10440	6/17/64	Damage	30	3	Container suffered minc of the plywood. Contai vived a 1-hour fire.

DROP TEST RESULTS

Construction Material	Bonding	Outside Diameter (inch)	Total Height (inch)	Wall Thickness (inch)	Gross Weight (lb)	Sandia Test No.	Completion Date	Data Obtained	Drop Height (ft)	No. Drops	Results
Redwood Plywood Cylinder	White glue and nails	30 plus rings	58	6 inches plus 5 2-inch rings	3900	10529	10/2/64	Damage	30	3	Damage to the container from each of three drops was more severe than experienced by the Douglas Fir shell. Even though badly battered the container would still have survived a 1-hour fire.
Douglas Fir Plywood Cylinder	Resorcinol-formaldehyde	30 plus rings	58	6 inches plus 5 2-inch rings	4000	10705	1/13/65	Damage	30 (@ 45°)	1	The symposium test. End cap separated. Delamination cracks appeared at approximately four places. Minor slippage of wood interfaces at two of these cracks. This low level of damage would not have effected the fire response of the container.
Douglas Fir Plywood Cylinder	White glue and nails	30 plus rings	58	6 inches plus 5 2-inch rings	4000 less burned wood	10705	1/19/65	Damage	30 (@ 45°)	1	This container was fire tested at the symposium prior to drop testing. The charred wooden shell was still strong enough to completely protect the inner "pig" from damage.
Douglas Fir Plywood Cylinder	Resorcinol-formaldehyde	30 plus rings	58	6 inches plus 5 2-inch rings	4000	10947	3/24/65	Damage	30 (on end)	1	Superficial damage.
Douglas Fir Plywood Cylinder	Resorcinol-formaldehyde	30 plus rings	58	6 inches plus 5 2-inch rings	4000	10947	3/24/65	Damage	30 (on side)	1	Crushing of rings only at impact point.
Douglas Fir Plywood Cylinder	Resorcinol-formaldehyde	30 plus rings	58	6 inches plus 5 2-inch rings	4000	10947	3/25/65	Damage	30 (@ 45°)	1	End ring separated. Some crushing of end cap as expected. Minor delaminatic at each end of inner "pig." Satisfactorily passed test.

APPENDIX B

Fire Tests

FIRE TEST 1
Completed 11/6/63

Sandia Test No. 1984

Construction Material	Bonding	Outside Diameter (inch)	Inside Diameter (inch)	Wall Thickness (inch)	Total Height (inch)	Gross Test Weight (lb)	Previously Drop Tested	Unburned Insulation Remaining (inch)	Maximum Temperature Reached	
Steel-Gypsum Mix		18-1/2	14	2	27-1/4	146-1/4	No	3/4	Under 300°F*	Container was de fire and not the passed fire test
Steel-Zonolite		18-1/2	14	2	27-1/4	153-1/2	No	None	Failed test	Insulation abrar direct heat path container. Enc
Douglas Fir Plywood Cylinder	White glue and nails	14	8	3	14	118-1/2	3 times	1	No data*	Container was ec steel shell vent container surviv temperature prot
Douglas Fir Plywood Cylinder	White glue and nails	20	8	6	19-1/2	127	3 times	3-1/2 to 4	Under 300°F*	Based on subseq of container in feel that maxim actually under proven.

*Difficulty with thermocouple leads caused loss of most of the temperature data.

Note: This test was a 1-hour test in a 20 x 20 foot open pit using JP-4 jet fuel. Average temperature in the area of the test containers was approximately 1850°F.

Sandia Test No. 10441

FIRE TEST 2
Completed 6/20/64

Construction Material	Bonding	Outside Diameter (inch)	Inside Diameter (inch)	Wall Thickness (inch)	Total Height (inch)	Gross Test Weight (lb)	Previously Drop Tested	Unburned Insulation Remaining (inch)	Maximum Temperature Reached	Remarks
Douglas Fir Plywood Cylinder	White glue and nails	30 plus rings	18	6 inches plus 3 2-inch rings	54-1/2	4000	Once	3-1/2 to 4	Under 150°F	One delamination crack at impact end burned through to the surface of the "pig." This did not seem to effect inside temperature.
Redwood Plywood Cylinder	White glue and nails	20	8	6	19	178	3 times	2-1/2 to 3-1/2	No data	Interior of container was in perfect condition at the completion of test.
Redwood Plywood Cylinder	White glue and nails	16	4	6	20-3/4	--	No	3 to 4	Under 150°F	Temperature indicated was inside lead pig.
Redwood Plywood Cylinder	White glue and nails	16	8	4	16-1/4	--	No	1-1/2	No data	Slight failure on one side of lid joint.
Solid Redwood Cylinder	White glue	14	6	4	14-1/2	--	No	None	--	Container destroyed in test.
Solid Douglas Fir Cylinder	White glue	14	6	4	17-3/4	--	No	1-1/2	200°F	Container was badly split and cracked after completion of fire test. It was also at the coolest spot in the fire.
Douglas Fir Plywood Cylinder	White glue and nails	10	2	4	15-1/2	--	No	1/2 to 3	Under 400°F	Near failure at lid joint. Container still successfully withstood the 1-hour fire.
Solid Redwood Cylinder	White glue	10	2	4	16-3/4	--	No	None	--	Container was destroyed apparently very early in test. It is suspected that the container split open due to heat.
Solid Douglas Fir Cylinder	White glue	10	2	4	14-1/2	--	No	1 to 1-1/2	No data	Container survived test but was in very marginal condition with a lot of splitting.
Douglas Fir Plywood Cylinder	White glue and nails	7	2	2 1/2	12-1/2	25	3 times	None	220°F @ 1/2 hr	Container did very well up to 0.6 hour. By 3/4 hour inside temperature had reached 1000°F and container had failed.
Douglas Fir Plywood Cylinder	White glue and nails	9	3-1/2	2-3/4	9		No	None	No data	Container was destroyed in test. This item with containers 1, 2, and 3 were the only ones with massive heat sinks inside.

Note: Fire Test 2 was a 1-hour test in a 30 x 30 foot open pit using approximately 10,000 gallons of JP-4 jet fuel. Fire temperatures in the area of the test containers ranged between 1600°F and 2150°F with an average around 1850° to 1900°F.

Sandia Test No. 10537

FIRE TEST 3
Completed 8/26/64

Construction Material	Bonding	Outside Diameter (inch)	Inside Diameter (inch)	Wall Thickness (inch)	Total Height (inch)	Gross Test Weight (lb)	Previously Drop Tested	Unburned Insulation Remaining (inch)	Maximum Temperature Reached	Remarks
Redwood Plywood Cylinder	White glue and nails	16	8	4	16-1/4	--	No	Up to 2	200°F @ 1.4 hr (see note)	Inside temperature rose gradually to 190°F at end of test. It continued to rise to 200°F and then leveled off. Temperature was only 75°F at 1/2 hour. Container successfully passed test although wood charre all the way through at one side of lid joint.
Douglas Fir Plywood Cylinder	White glue and nails	16	4	6	21	--	No	2 to 4	75°F @ 1.4 hr (see note)	Inside temperature was stable for the duration of the test. Container successfully passed the fire test.

Note: This test was intended to be a 1-hour test, but it actually burned out in 55 minutes due to fuel seepage into the ground. Test was conducted in a 20 x 20 foot open pit using 4960 gallons of JP-4 jet fuel. Containers were allowed to cool without benefit of any fire fighting procedures being used.

Sandia Test No. 90289

FIRE TEST 4
Completed 8/26/64

Construction Material	Bonding	Outside Diameter (inch)	Inside Diameter (inch)	Wall Thickness (inch)	Total Height (inch)	Gross Test Weight (lb)	Previously Drop Tested	Unburned Insulation Remaining (inch)	Maximum Temperature Reached	Remarks
ouglas Fir ywood ·linder	White glue and nails	16	8	4	16-1/2	--	No	1 to 2	265°F	Inside temperature of container rose steadily from the start of the test according to the thermocouples. This is a little unusual and probably indicates a leak around the thermocouples. Normally in wood shell designs of this type, there is a considerable delay between the time the heat is applied to the outside and the time the temperature starts to rise inside. Examination of the lid joint after the test revealed that such a leak was possible. The container still survived the test successfully.
uglas Fir ywood linder	White glue and nails	20	8	6	19-1/2	128	No	4	160°F @ 30 min and 73°F @ 1 hour	Again the thermocouples acted strangely. Temperature started a steady rise to 160°F by the end of 30 minutes. This is very unusual and indicates a heat leak probably assisted by the unprotected metal sheathed thermocouples. Other tests have indicated that there is at least a 30 minute delay before the interior of a 6-inch wall Douglas-fir plywood shell starts to heat up under these conditions. The container survived the 1-hour test with the interior still in perfect condition.

te: This test was conducted using a 30 x 30 foot open pit filled with 10,000 gallons of JP-4 jet fuel. At the end of 1 hour, experimental dry powder fire fighting procedures were started. Due to difficulties with the pumping equipment, it was 15 minutes before the fire was extinguished.

Sandia Test No. 10646

FIRE TEST 5
Completed 1/13/65

Construction Material	Bonding	Outside Diameter (inch)	Inside Diameter (inch)	Wall Thickness (inch)	Total Height (inch)	Gross Test Weight (lb)	Previously Drop Tested	Unburned Insulation Remaining (inch)	Maximum Temperature Reached	
Douglas Fir Plywood Cylinder	White glue and nails	30 plus cushion-ing rings	18	6	54-1/2	4000	No	4	160°F @ 20 min and 58°F @ 1 hour	Thermocouples s immediately aft minutes, a peak Then a decline was reached at ture stabilized mainder of the

Note: This test was conducted in a 30 x 30 foot open pit using 10,000 gallons of JP-4 jet fuel and was observed by the attendees at the In Symposium for Packaging and Transportation of Radioactive Materials. Duration of the test was 1-hour, plus 6 minutes for fire fighti put it out.

APPENDIX C

The following time-temperature curves were obtained by placing the 6-inch thick wood blocks, described earlier, in the radiant heat facility. One face of each block was subjected to a radiant heat rate of 11 BTU/ft^2-sec.

The thermocouples locations, embedded at 1/2-inch intervals through the 6-inch dimension, are identified as follows:

Thermocouple Number (same for all tests)	Distance from original surface exposed to heat source (inch)
51	5-1/2
52	5
53	4-1/2
54	4
55	3-1/2
56	3
57	2-1/2
58	2
59	1-1/2
60	1
61	1/2
62	6 (on back surface of block)

Information contained in Appendix C has been extracted from Sandia Report T-10317, May 27, 1964.

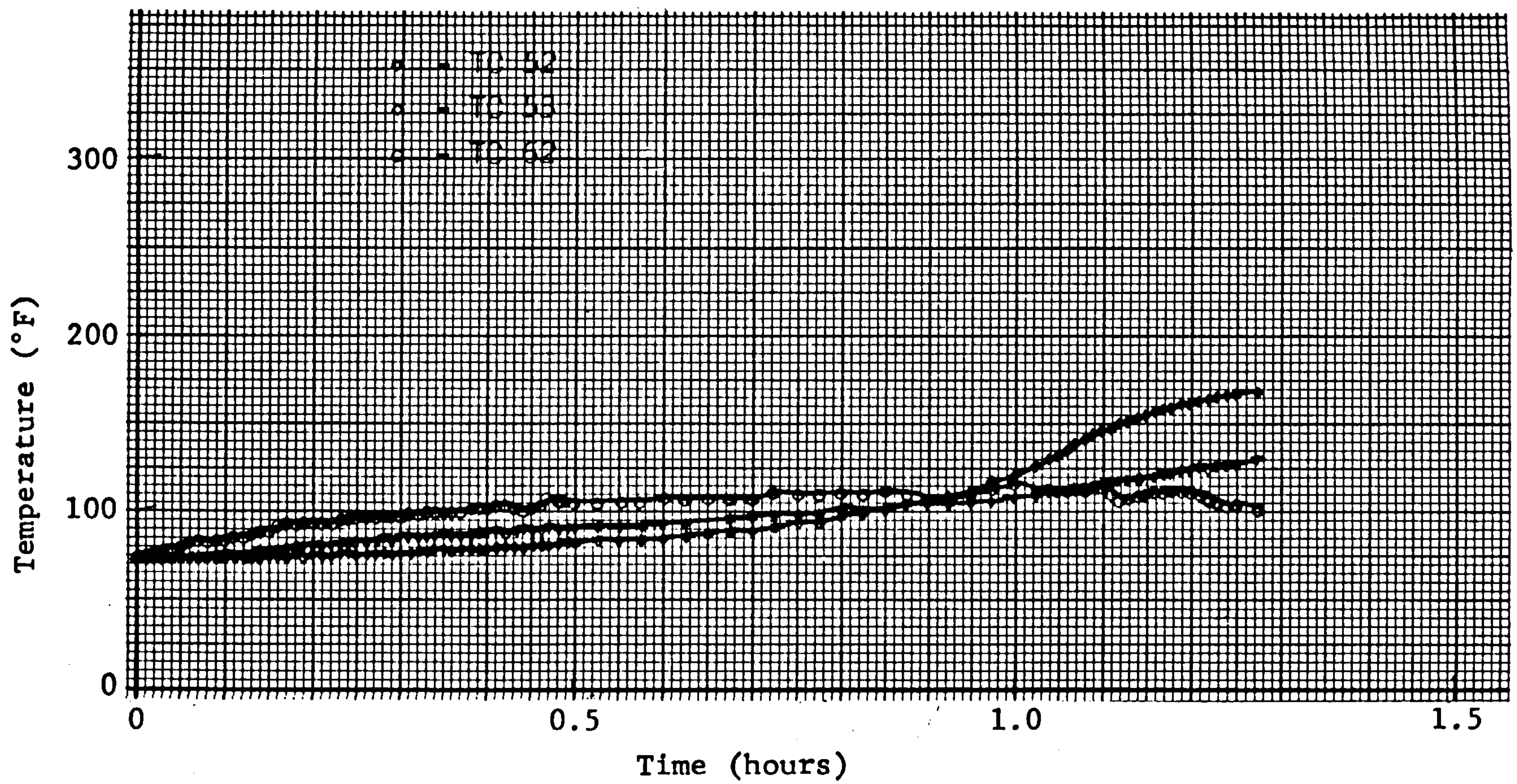


Figure C-1.a Douglas-fir block--simulated JP-4 fire on wood sample

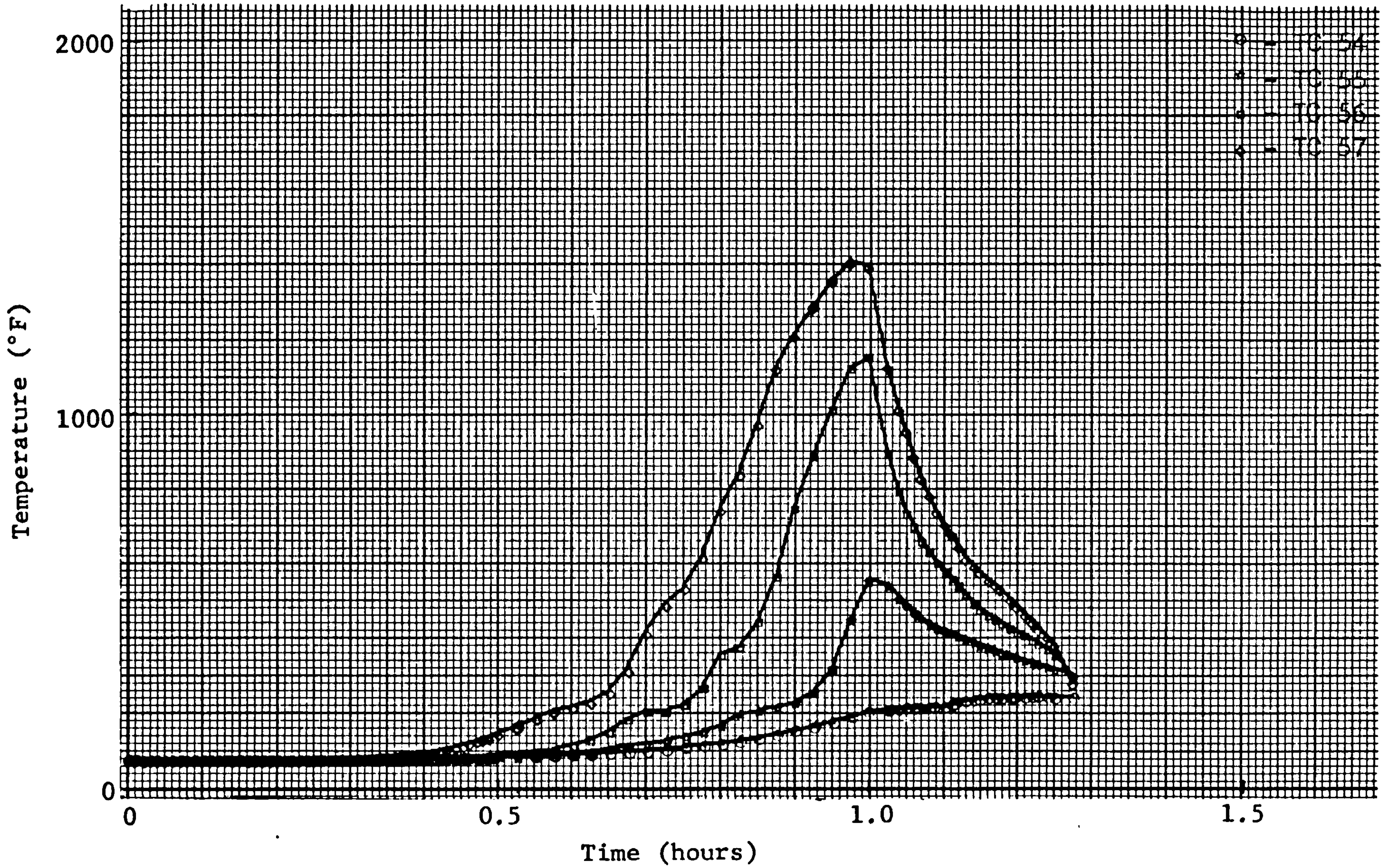


Figure C-1.b Douglas-fir block--simulated JP-4 fire on wood sample

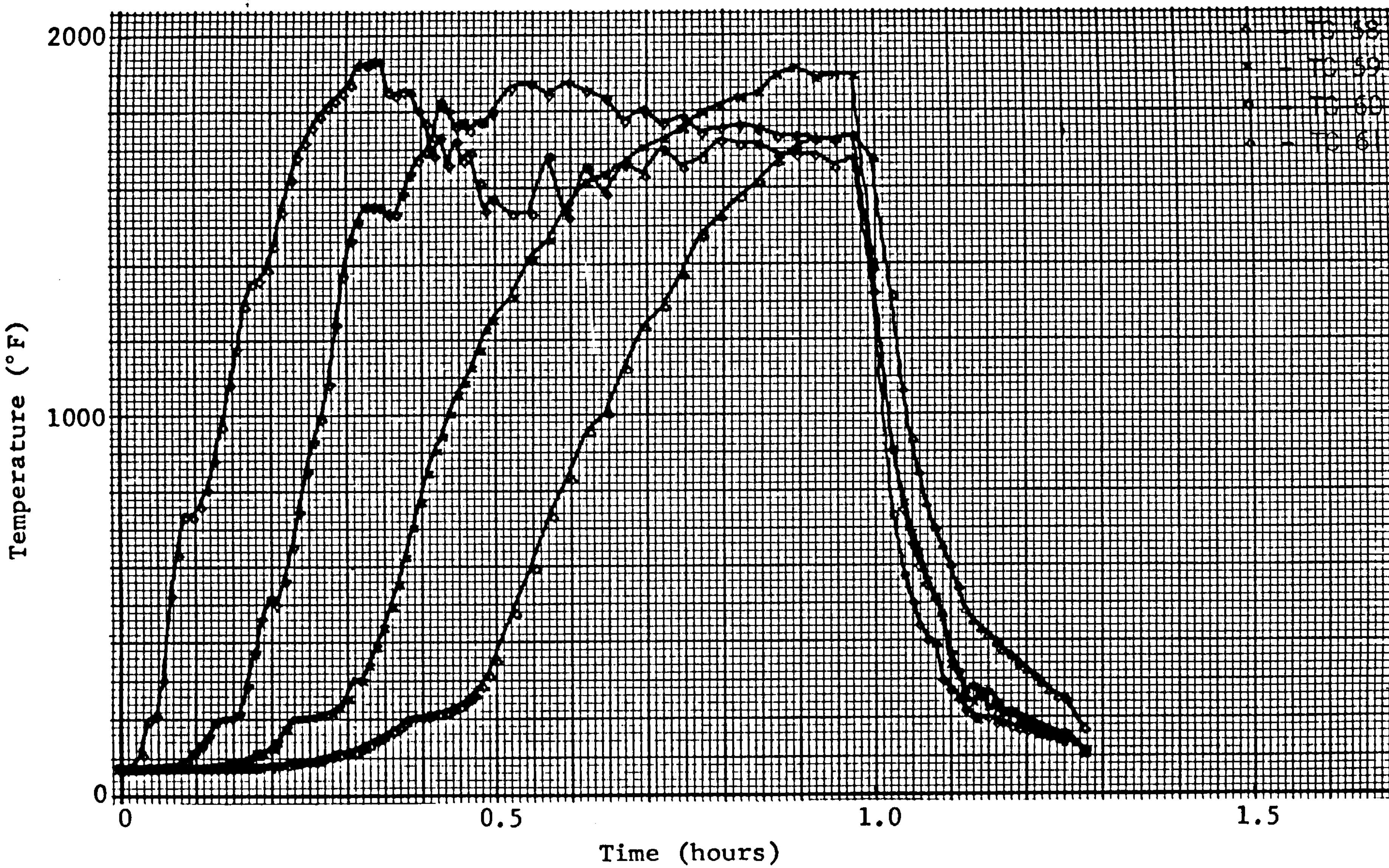


Figure C-1.c Douglas-fir block--simulated JP-4 fire on wood sample

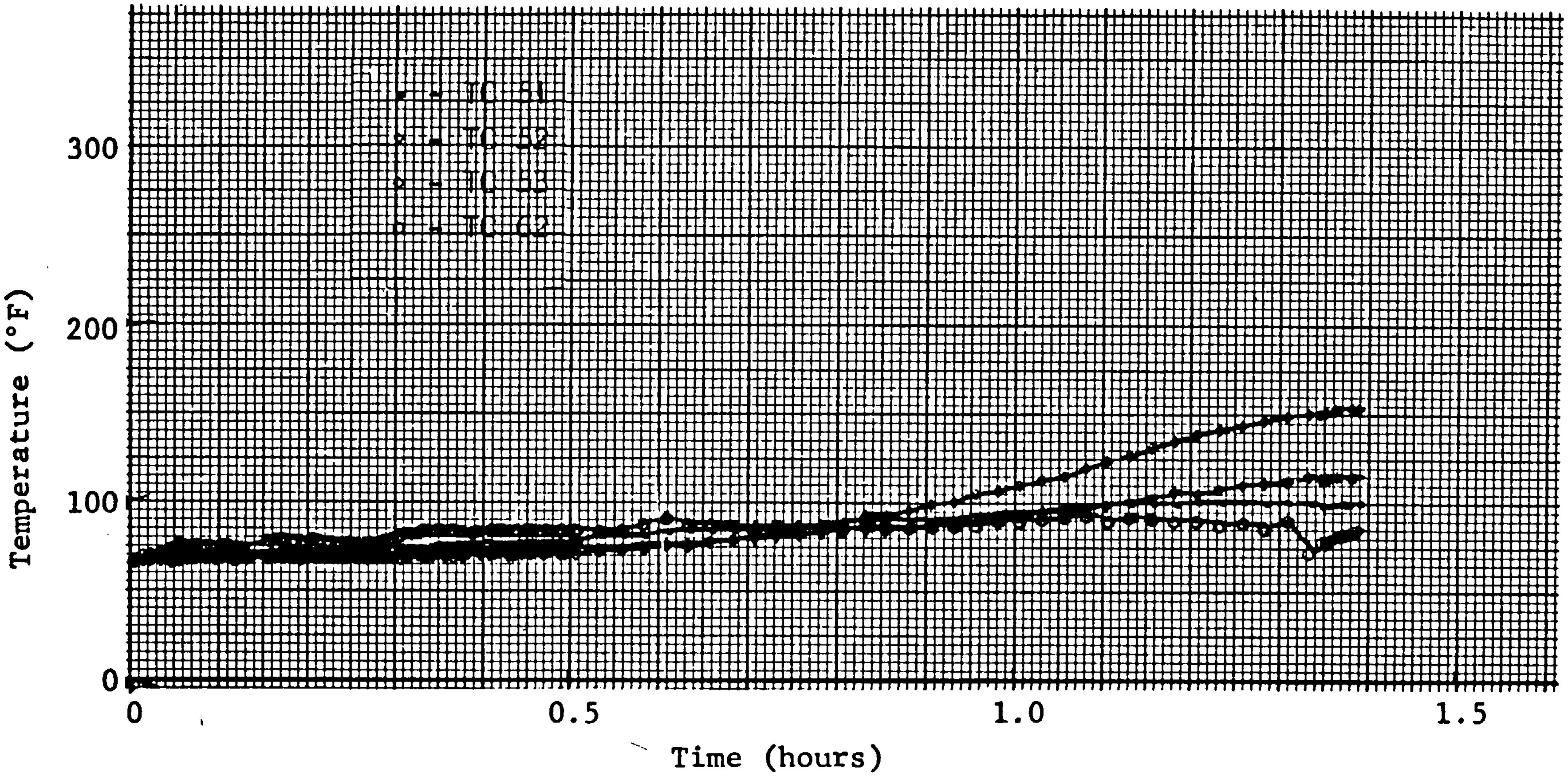


Figure C-2.a Redwood block--simulated JP-4 fire on wood sample

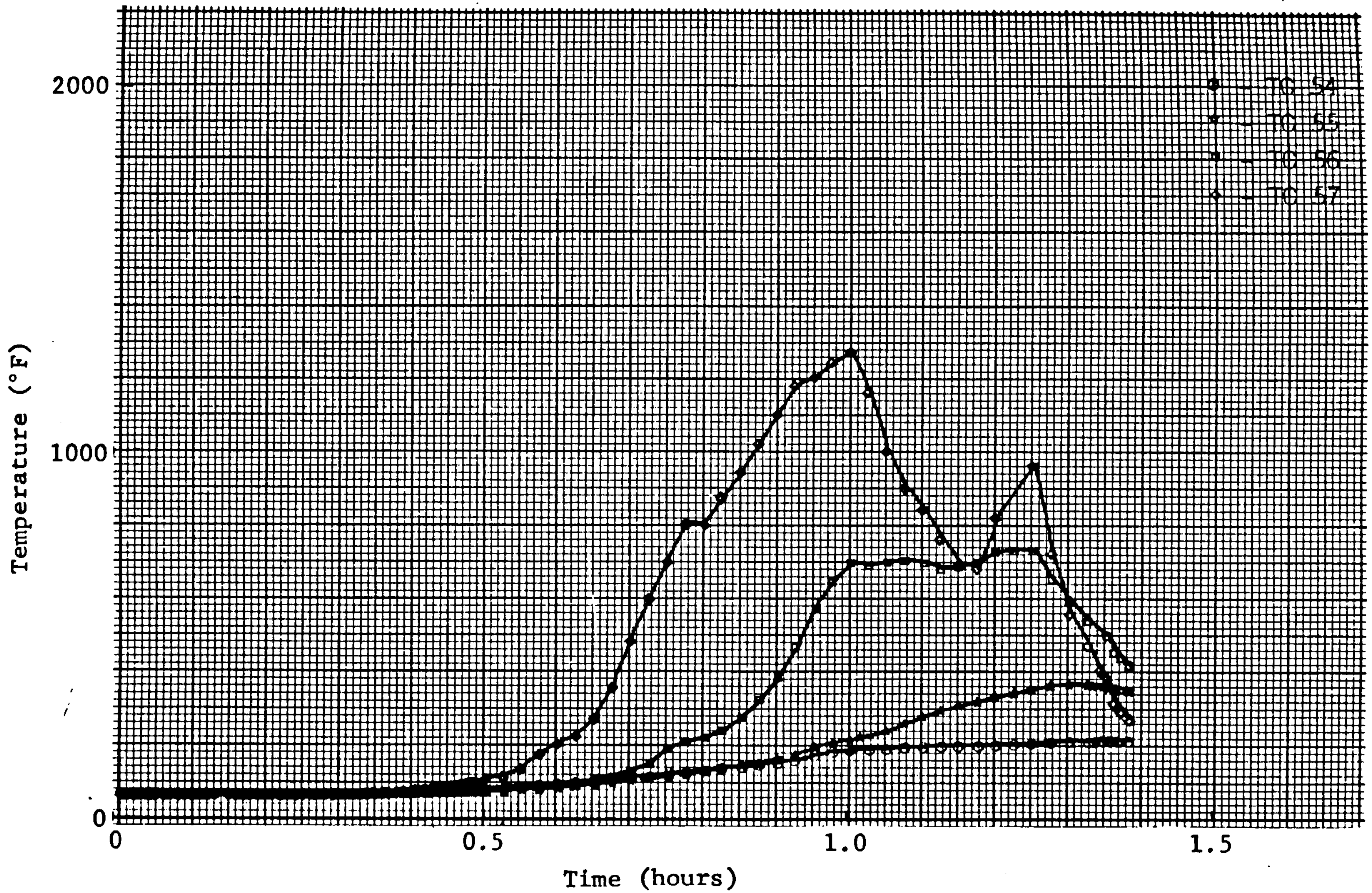


Figure C-2.b Redwood block--simulated JP-4 fire on wood sample

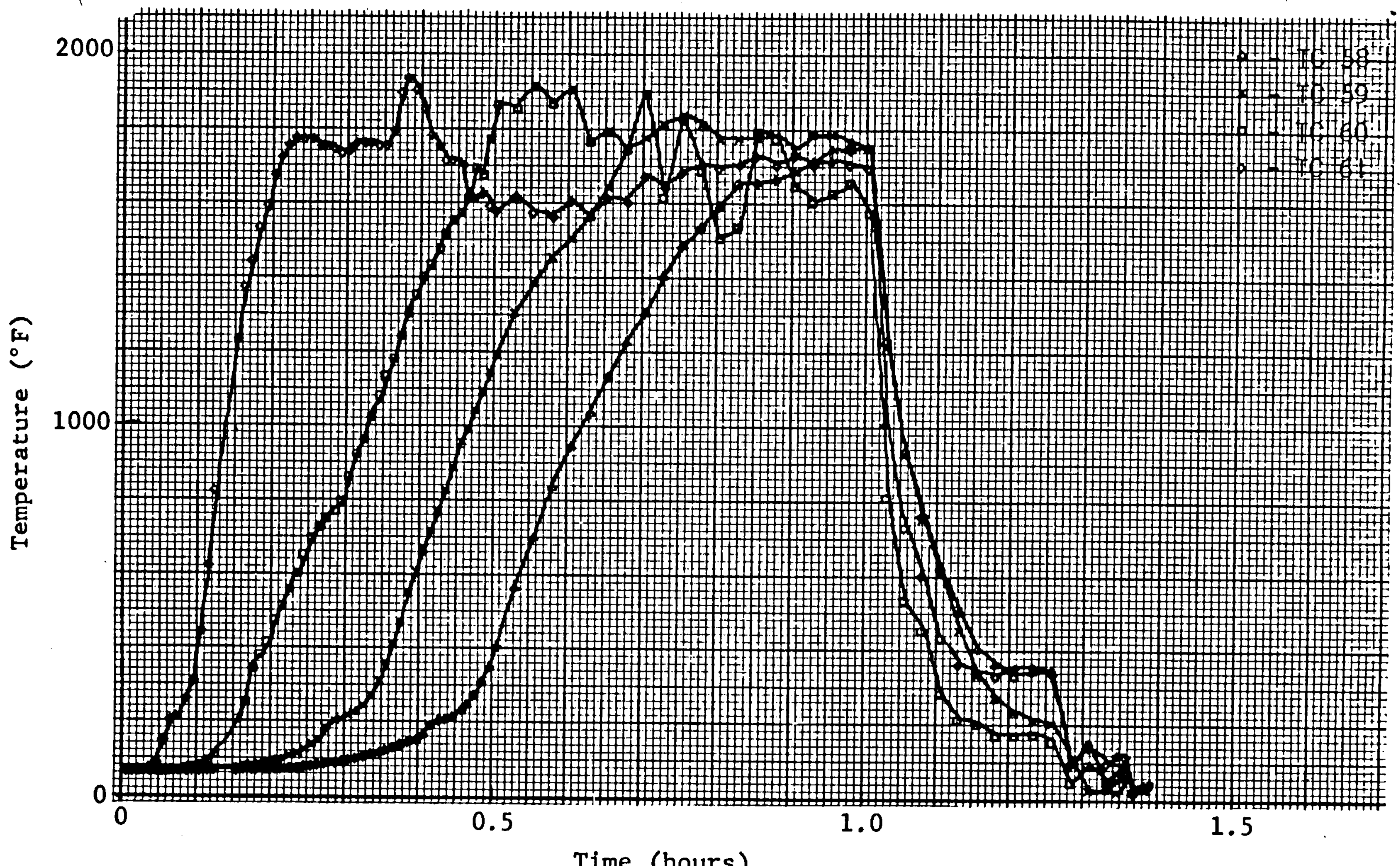


Figure C-2.c Redwood block--simulated JP-4 fire on wood sample

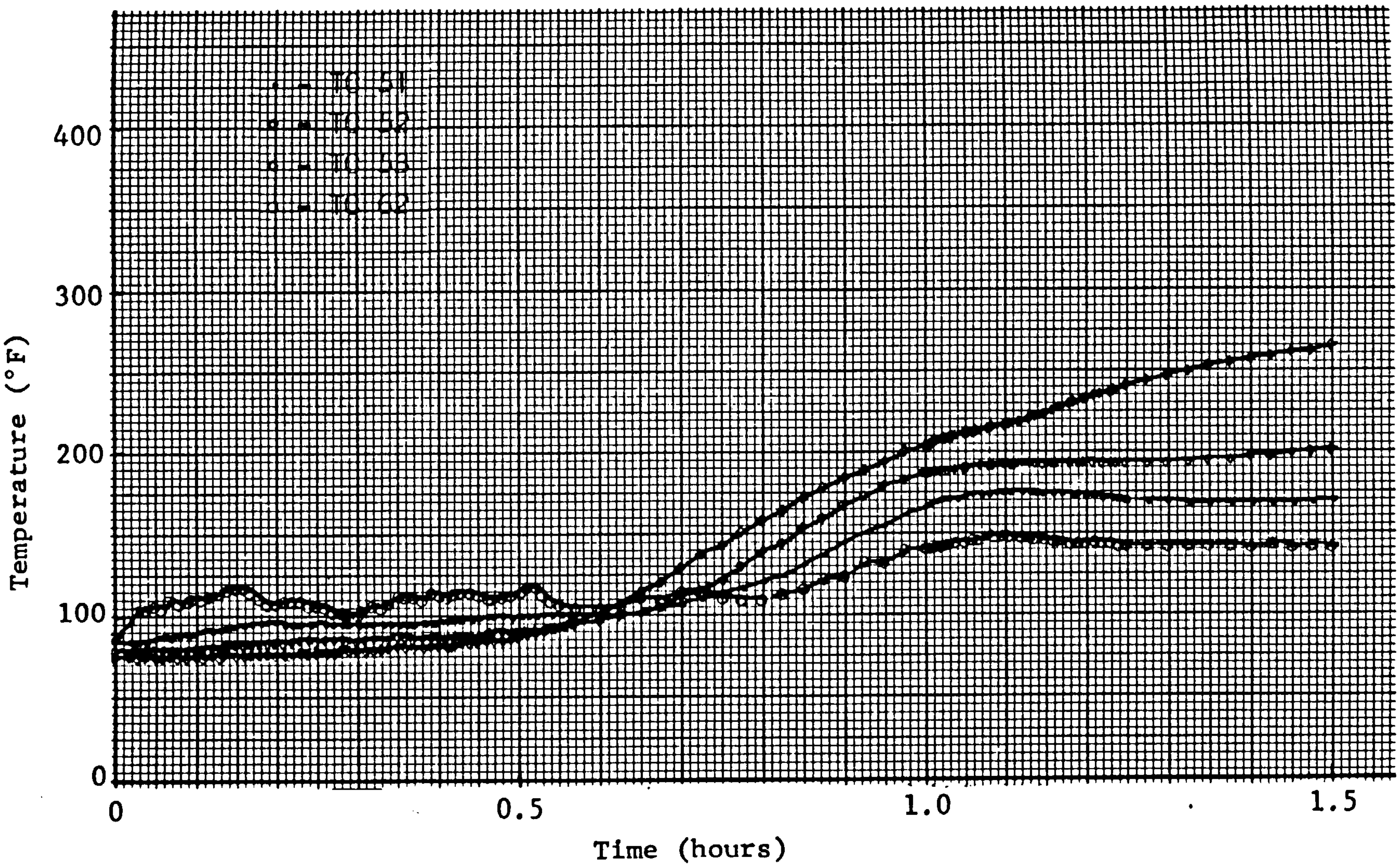


Figure C-3.a Douglas-fir plywood sample--simulated JP-4 fire on wood sample

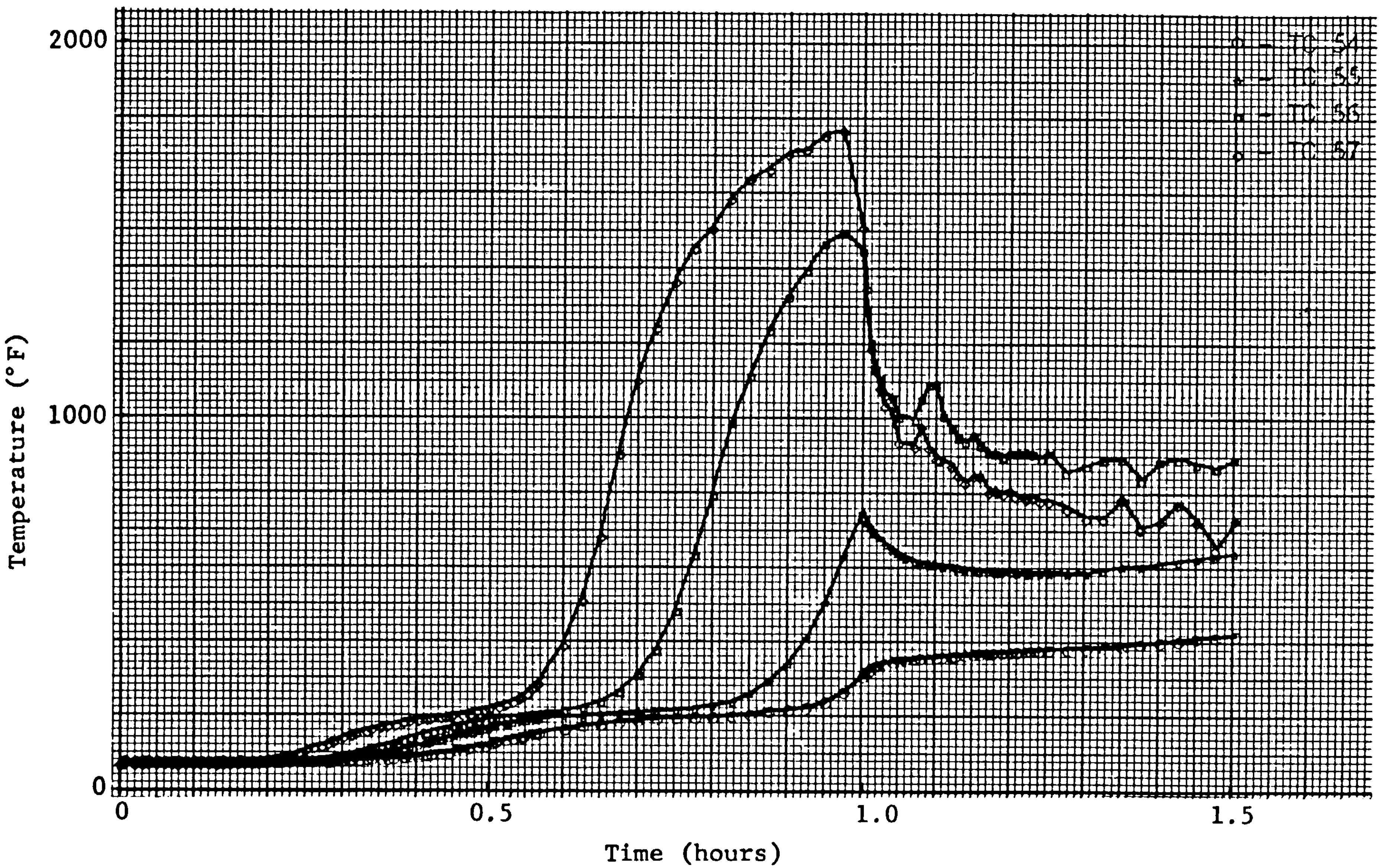


Figure C-3.b Douglas-fir plywood sample--simulated JP-4 fire on wood sample

Figure C-3.c Douglas-fir plywood sample--simulated JP-4 fire on wood sample

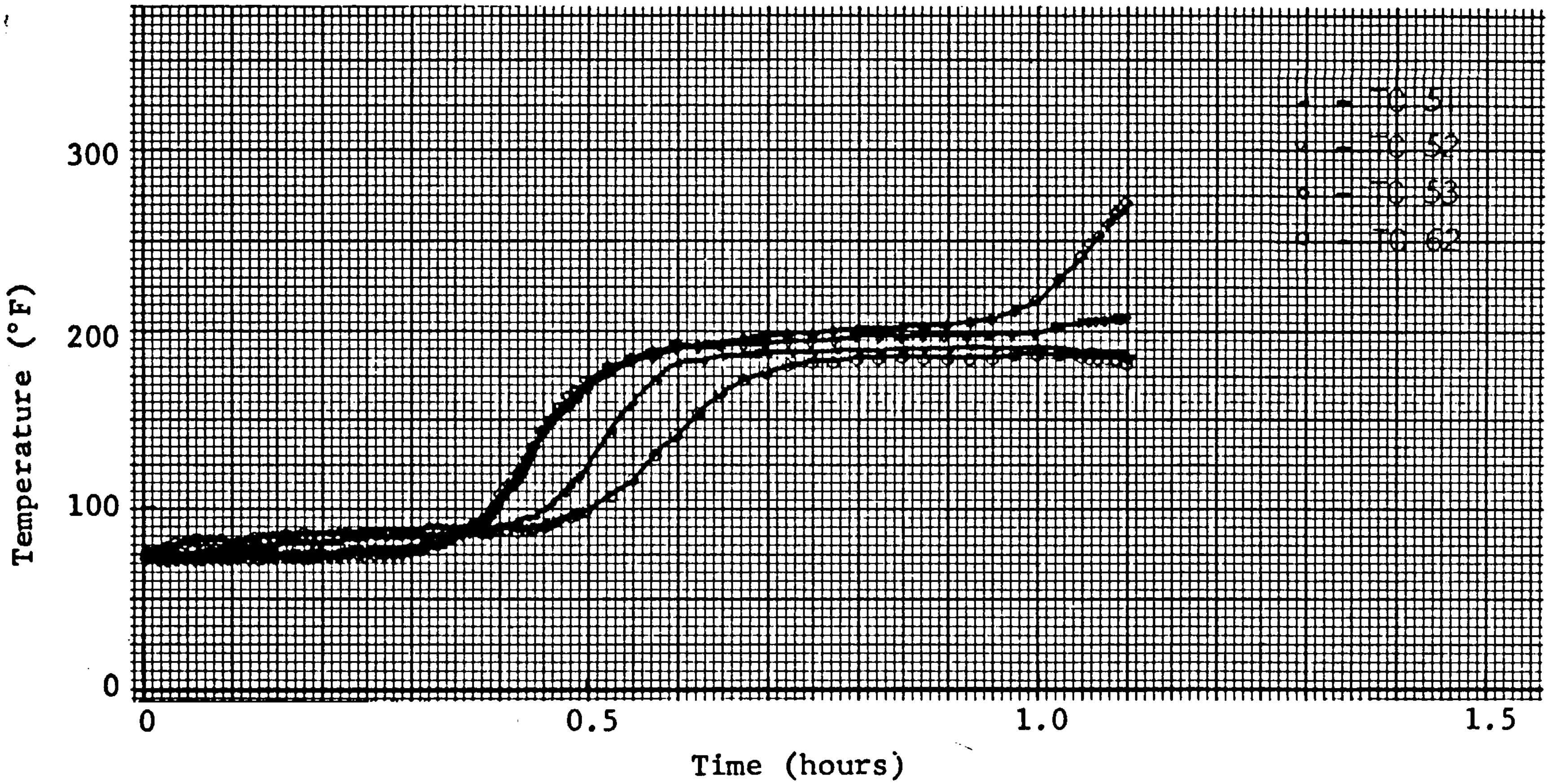


Figure C-4.a Redwood plywood sample--simulated JP-4 fire on wood sample

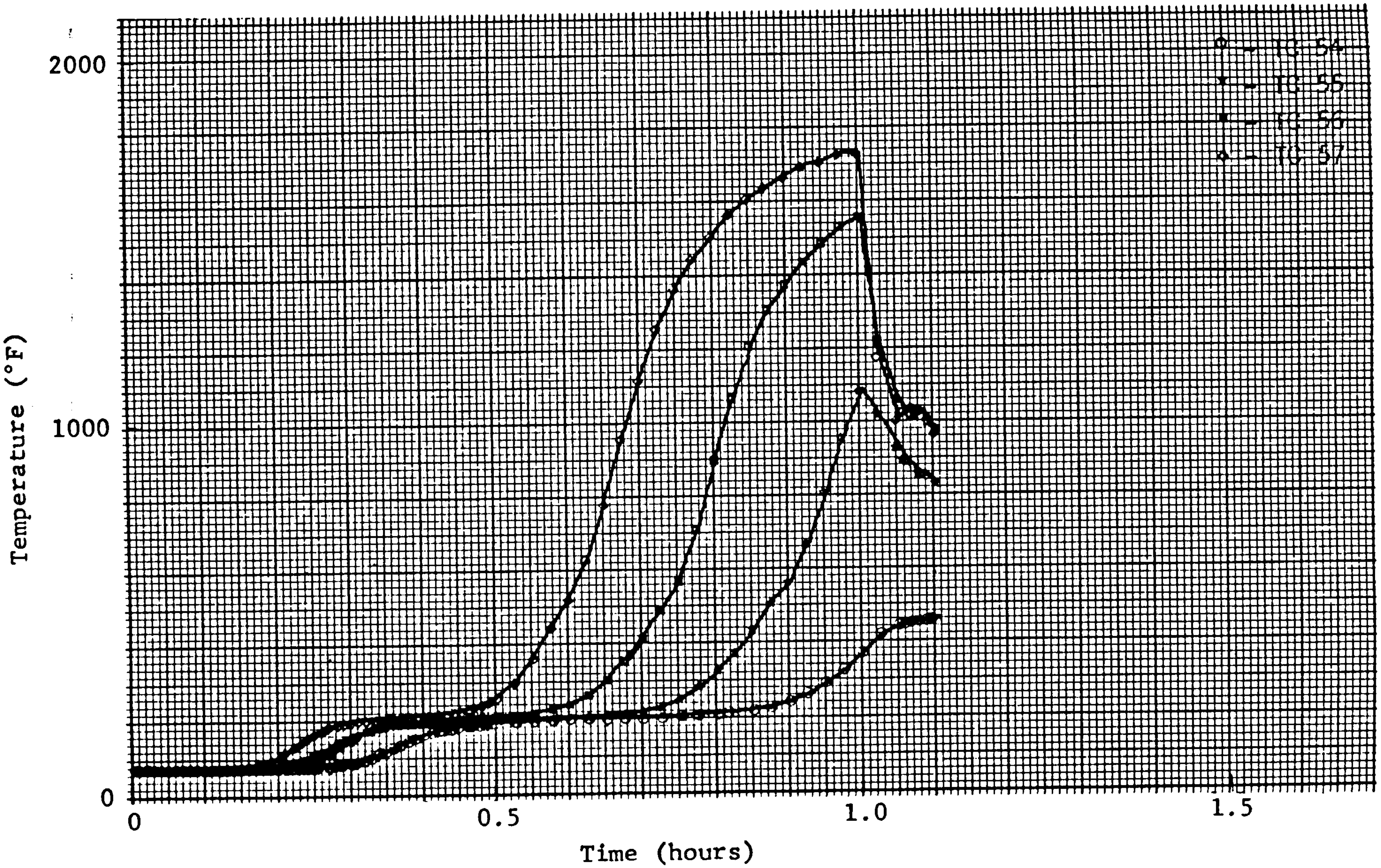


Figure C-4.b Redwood plywood sample--simulated JP-4 fire on wood sample

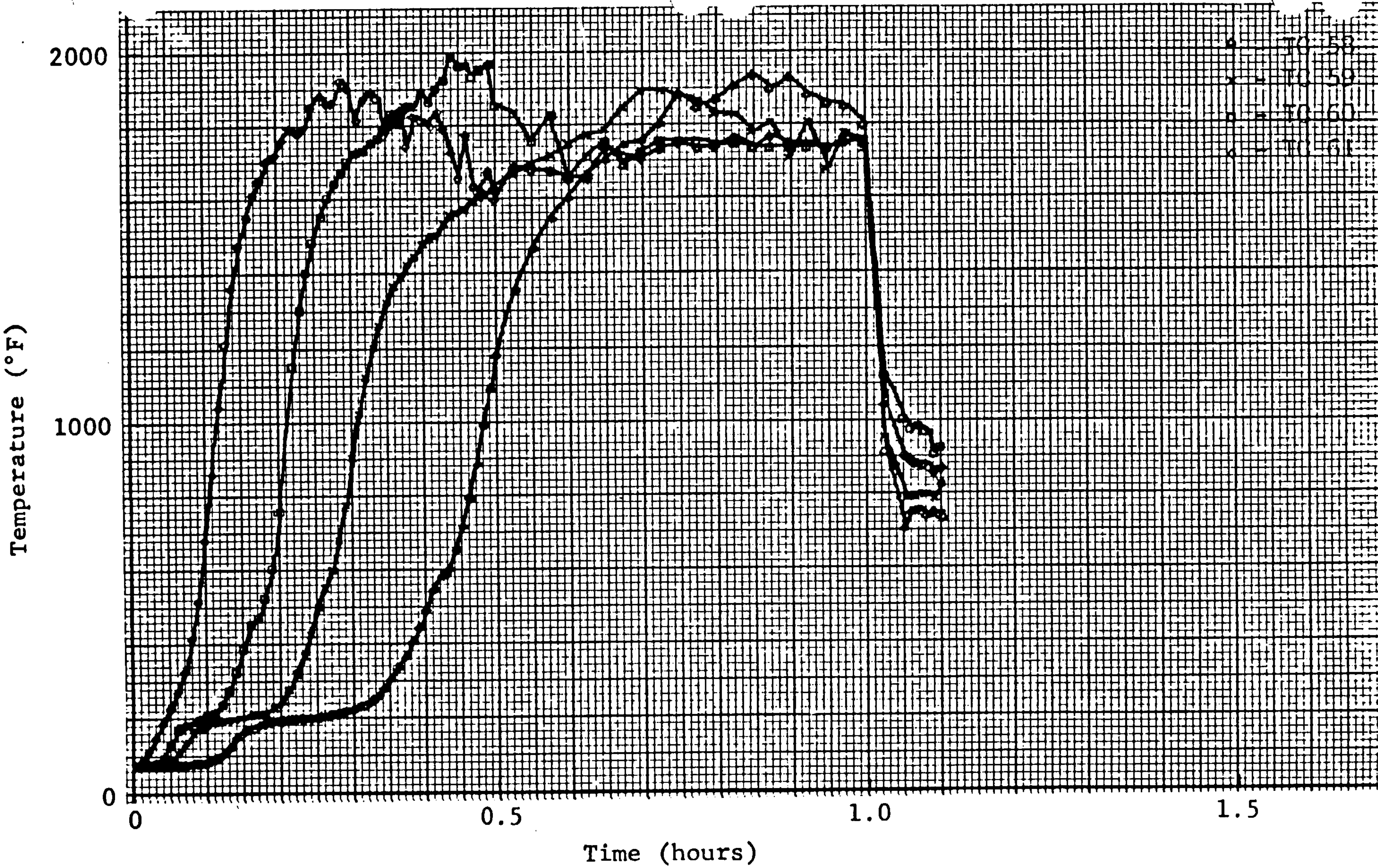


Figure C-4.c Redwood plywood sample--simulated JP-4 fire on wood sample

DISCUSSION

R. B. SMITH: Would you give some comments on the nature of the temperature on the inside of the container following the completion of the test? Does it continue to rise, or fall, or where does it go?

SISLER: Temperatures may continue to rise for a few minutes following the fire tests but we have observed no significant rises. The change from start to finish in a 6-inch wall test is so insignificant that it is hardly worth while. We get a maximum that starts somewhere like 75° or 80°F and ends up at 100°F so this is not really a very significant change. Now in a very thin wall container where it is just about to burn through at the time the fire stops then you would probably get a significant change.

ERNEST: Could you tell us what adhesives you are using?

SISLER: The adhesives used in our own containers was a material similar to Elmer's glue and the material used in the container out here in the lobby is the same as the adhesive as used in assembling the plywood, originally. It is a formaldehyde, I believe.

MOATS: Phenol formaldehyde is used.

SISLER: Good, I am glad that you corrected me, thank you.

BLATZ: In all of the references to the fire tests of wooden containers, these and the ones made by the Fire Underwriters Laboratory, no reference has been made to oxygen. The thought occurred to me that perhaps the presence of oxygen, or the absence of oxygen, might influence the extent to which the wood would stand the fire. Is this true or not?

SISLER: It very definitely would. An oxygen blast fed into the fire would increase damage.

BLATZ: The point is, would there be a difference between the test conditions and those that might exist in the field.

SISLER: This is one of the reasons why Sandia has adopted the petroleum fire test; because we are trying to approximate the conditions that might conceivably happen in some sort of rail car accident, or a tanker truck accident with a spillage of a large quantity of some sort of hydrocarbon fuel burning for an hour or so. We have not conducted any furnace tests. I think the best information on that subject would be Leonard Horn's paper; it looks like the responsive is not significantly different.

HORN: In answer to Mr. Blatz's question, in the UL furnace the gas is fed into each port, and the port is open so there is a very rich mixture of air and gas, it is not gas alone --- it is a very rich mixture of air and gas.

SISLER: If I remember the figures from the Forest Products Laboratory in Wisconsin, I think they have run some temperature points that indicate that about 1/2 inch ahead of the char layer, the char layer itself would be about 1800°F, 1/2 inch ahead of that the temperature is down to 500 degrees. So in a 1/2 inch of wood you have a temperature drop of approximately 1300 degrees.

FAIRBAIRN: I would like to express my sincere admiration for the work that has gone into the development of the packaging design as described. My question relates to future development. If I may put it this way, do you see any hope for developing your "wooden overcoat" into a "wooden tea cosy?" May I explain? I think you did say that, at this stage, you were not thinking of applying this method to the protection of an irradiated fuel flask emitting a lot of heat, for example a flask with some one million gamma curies in it. Well, suppose that someone has a lot of capital locked up in say, 15 to 30 ton flasks, and that when the competent authority examined these designs with the help of tests such as we shall see tomorrow, it was found that the lead melted and burst its way out so resulting in loss of shielding. Suppose that is the situation. Well, a possible way of protection might, as I see it, be the design and use of an insulated "tea cosy" which, of course, creates the problem that for purposes of normal transport the heat has to be got out of the overall packaging assembly which is the flask inside the "tea cosy." Now this can be done by off-setting the "cosy" from the flask, leaving say a 4 inch gap, providing air inlets and outlets and so forth. The question that I would like to ask Mr. Sisler - it may be an unfair one in relation to his present problem - has he given any thought to that kind of problem? At this stage, does he see any future in the value of what I have chosen to call "the wooden tea cosy?"

SISLER: If I understand your question correctly, you are talking about a wooden shell with a built-in heat exchanger? I didn't wish to imply that we hadn't given this some consideration, in fact Mr. Bader and I have talked it over at some length. Depending on what our work load is going to be in the next 6 months, we may give this some very serious consideration. I do believe that it can be done. I believe that a wooden shell can be utilized in design of a larger container to give protective fire protection and still be able to get heat transferred through the shell. I cannot say at the moment how we expect that this can be done, but I don't think that it would be an insurmountable problem. What I intended to imply by the movie was that this particular design could not be directly applied to containers which did have a large heat source inside them, because the wood is a very good insulating material.

HELGESON: A number of people today have talked about the fact that the safety record in the shipping and transportation of nuclear materials has been excellent--the movie commented on the same thing. This morning Mr. George said that there had been no serious accidents. I wonder if anyone has accumulated any actual statistical data in terms of accidents per million man miles or million truck miles, or something like that, with radioactive material and compared them with equally hazardous materials in other industries? If there has been such a compilation I would be interested to know what it is. Secondly, then, is there a reason that the regulatory agencies are putting such a tremendous effort into the shipping control of radioactive materials--should not the same effort be put into the shipping control of other hazardous materials, also?

SISLER: Professor Thompson, would you care to comment on that question?

THOMPSON: As far as I know there has been no such information collected. The truth of the matter is, that when you begin to look into volumnous records of truck accidents such as we did with the Interstate Commerce Commission, the contents of the truck are seldom identified. Even if the number of shipments of radioactive material is very small compared to common commodities it would therefore take an indeterminable length of time to collect such statistics. I don't believe there is much hope of doing so without a vast amount of effort.

B. Development Tests of Wooden Overpacks

The following photographs show testing conducted in connection with development of wooden overpacks at the Sandia Corporation. They are taken from a photographic summary of a special events demonstration conducted as part of the International Symposium for Packaging and Transportation of Radioactive Materials held in Albuquerque, New Mexico, January 12-15, 1965 and included in the proceedings, SC-RR-65-98, June 1965. The captions follow the photographs, which retain their figure numbers as recorded in the proceedings.

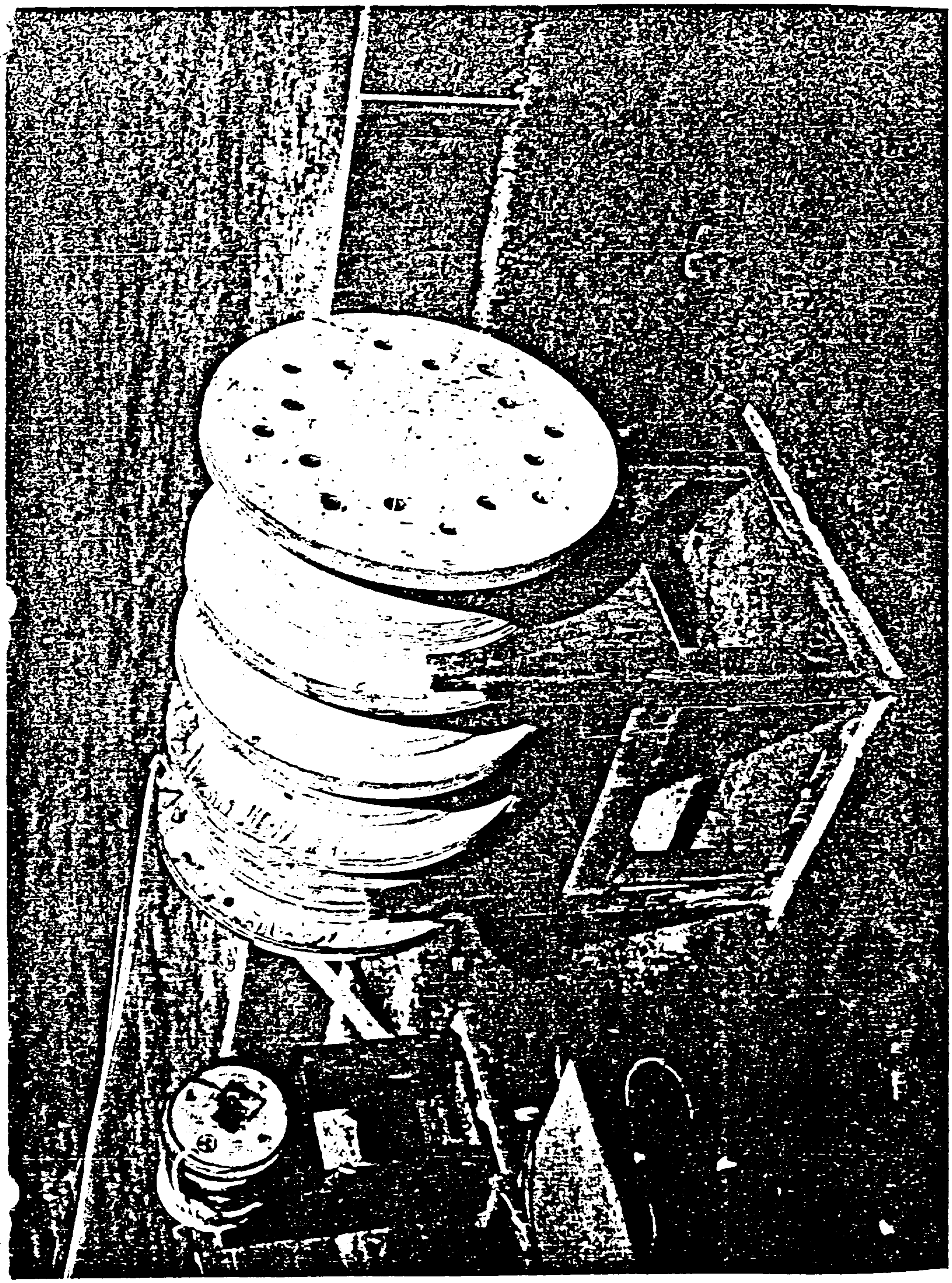


Figure 6.

This is the Sandia Corporation plywood insulated container which provides an impact- and fire-resistant shell that can be used to provide additional protection for standard ICC-55-type steel-lead-steel radioactive material shipping containers. Design details of the plywood shell are described elsewhere in this report. This particular plywood shell is built around an 18-inch diameter ICC-55 cylindrical container that is 38 inches long and weighs 3275 pounds. The 18-inch metal cylinder is fitted with a 6-inch-thick laminated plywood shell that has five 2-inch thick by 2-inch high rings added for impact resistance. Its gross weight is 4000 pounds. The two end rings make the end caps 8 inches thick and are designed so that the fire resistance of the container is unaffected even if an end ring shears off completely. Several identical containers have been drop-tested and then fire-tested with excellent results. Interior temperatures were all under 150°F after 1 hour of fire exposure at 1850°F or higher. This container was fire-tested and then dropped from 30 feet to determine its response to impact after a fire. Results are shown in Figure 19.

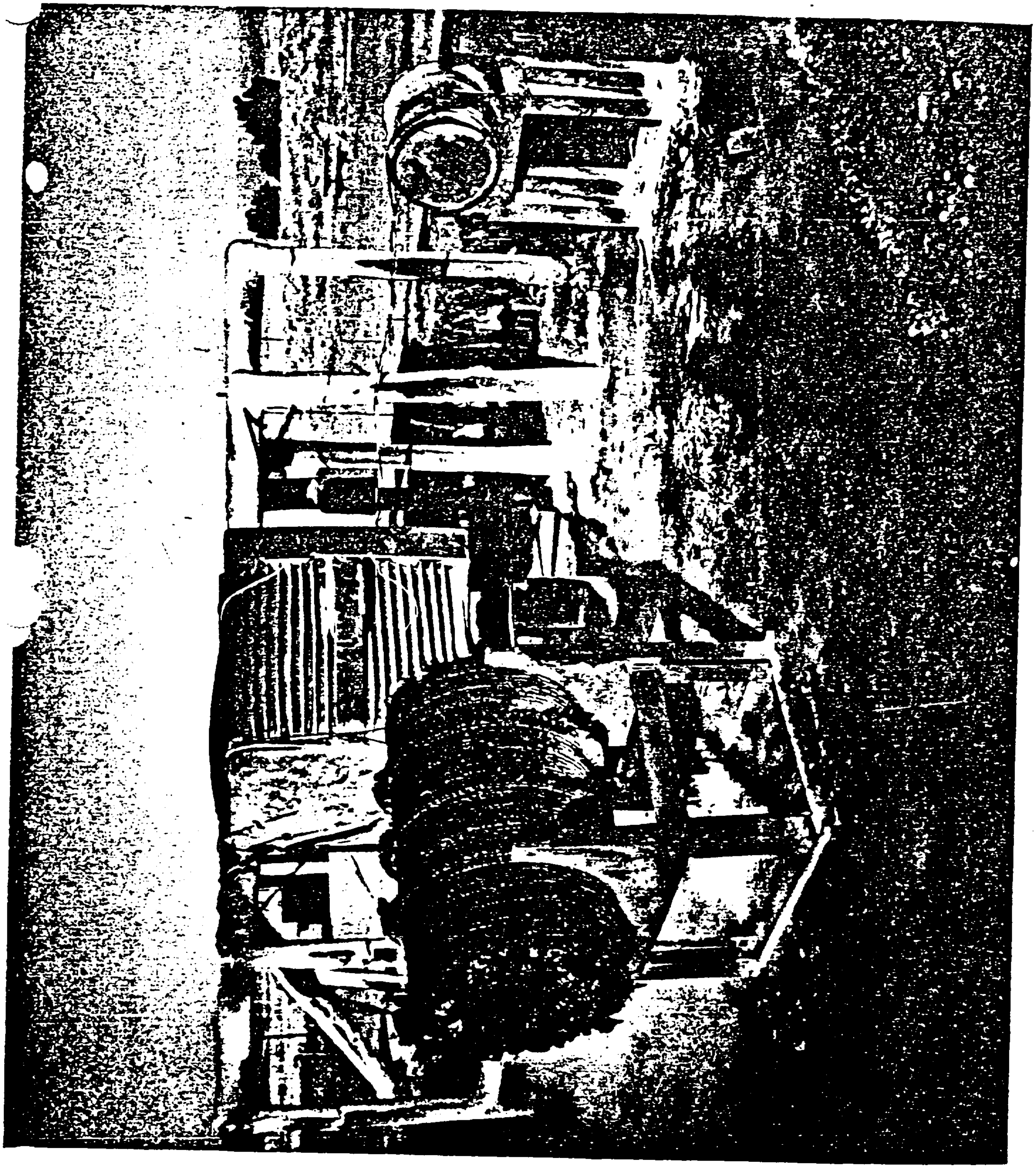


Figure 10.

The fire pit immediately after termination of the test. A considerable quantity of molten lead was still dripping from the cask. The interior temperature of the cask reached approximately 1200°F and all indications are that the lead shielding was completely molten for some time before the test ended. The interior temperature of the Sandia container had stabilized at approximately 60°F for the last 15 minutes of the fire. This was a winter test, and the interior was approximately 35° to 40°F at the start of the test. The United Kingdom cask appeared to have failed when the test was about three-fourths complete; inspection revealed that a thermocouple had broken, and the critical inner "pig" or "pot" survived the test. The container performed beyond design criteria.

Figure 11.

The Sandia plywood insulated container shortly after termination of the test. Although the outer 2 inches of the plywood shell was burned and charred, the inner 4 inches was still in perfect condition. This container was not opened during the Symposium because it was later to be subjected to a 30-foot drop test to evaluate the ability of the shell to protect the container from impact following a 1-hour fire. This container was laminated, using both adhesive and cement-coated nails. The container that was drop-tested during the Symposium was laminated without nails.

Notice the severe bulging of the upper side of the large cask. This condition developed during the fire test and is particularly evident in this photograph. The other three sides did not exhibit this condition to such a noticeable degree. The bottom of the cask (the finless area in this photo) was the only other surface that was obviously deformed.

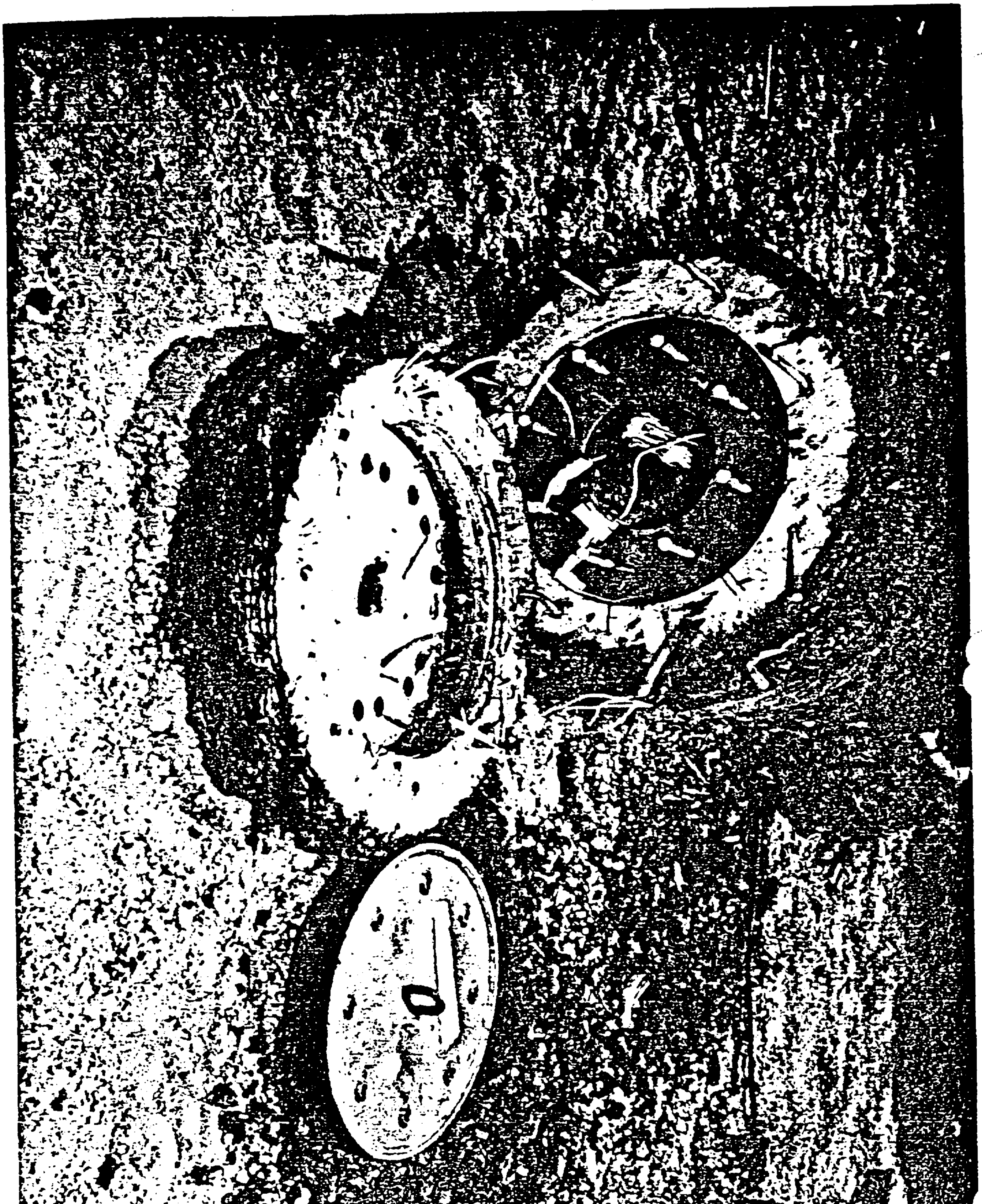


Figure 12.

A Sandia 4000-pound Douglas fir plywood insulated container following a 1-hour petroleum fire test; this container was identical to the one that was tested during the Symposium. The 4 inches of remaining good wood surrounding the inner shielded "pig" is quite evident in this photograph. The unburned wood is not discolored or damaged, and the red paint on the inner pig is normal color. Interior temperatures on this container were under 100°F for the full hour as measured both by thermocouples and temperature-sensitive paints. This particular container had been dropped once from 30 feet onto reinforced concrete prior to fire testing.

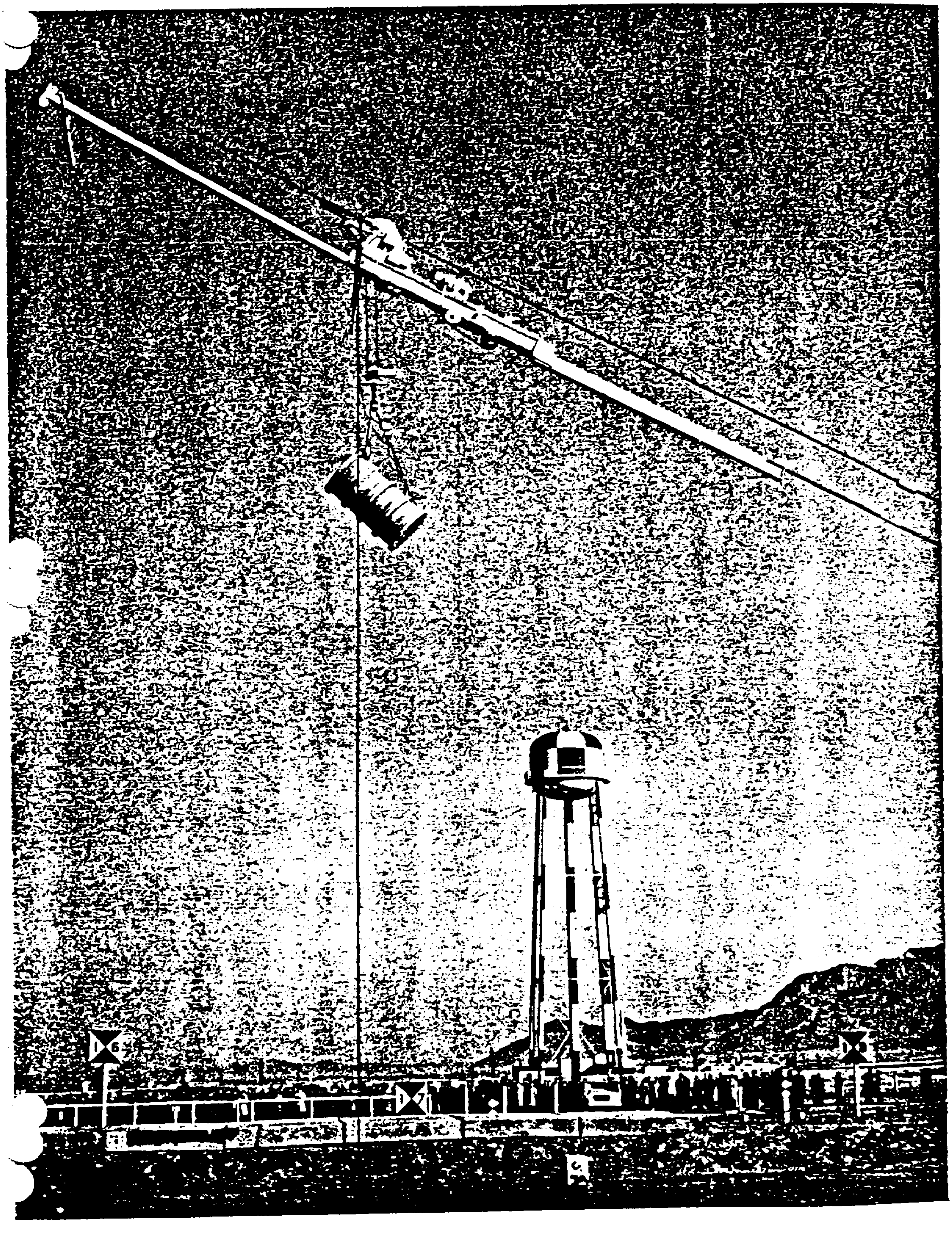


Figure 17.

The 4000-pound Sandia plywood insulated container suspended from the drop tower at the 30-foot level just before the drop test. This container shell was fabricated from Douglas fir plywood rings which were laminated by using adhesive only with no nails. The purpose of this test was to determine the effectiveness of the all-bonded construction versus the bonded-and-nailed construction. The drop angle was 45 degrees.

The Sympoisum attendees are observing in the background.

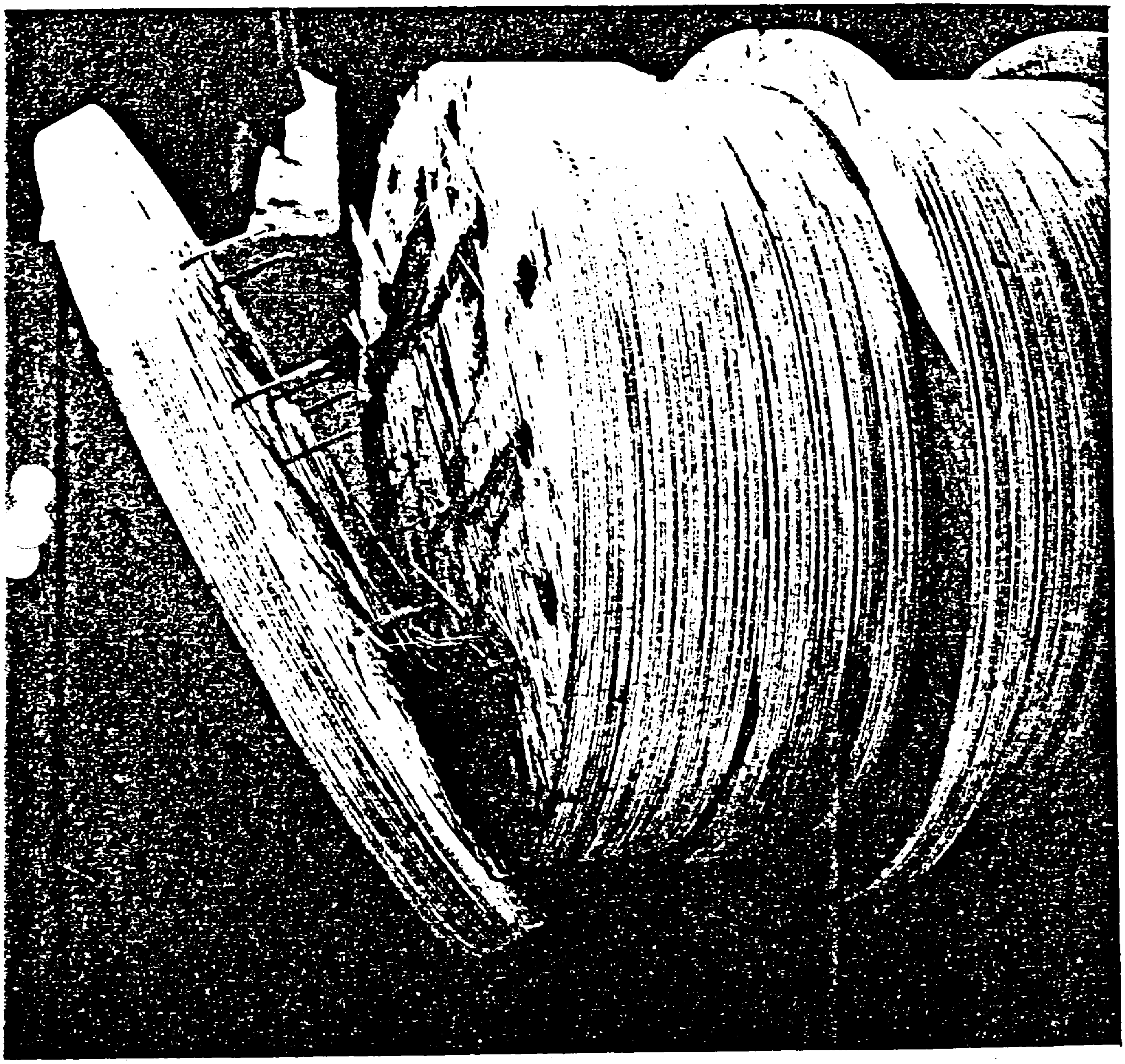


Figure 18.

Shown here is the effect of the 45-degree, 30-foot drop on the 4000-pound, adhesive-bonded Sandia container. The 2-inch end ring was almost completely sheared off, and some minor delamination of the shell had taken place in the area near the end of the inner, shielded pig. The nails seen in the end ring were used to reinforce the end ring only. No other nails were used. The full-length bolt ring is used in all containers and holds the lid in place and prevents catastrophic failure of the wood shell in the event delamination does take place as a result of an impact. The separation of the end ring is not considered serious in this container design as there is still 6 inches of solid plywood covering the end of the inner pig. The minor delamination seen here in the body of the shell has no detectable effect on fire resistance. This container design was not quite as strong as the bonded-and-nailed construction but is still a perfectly satisfactory construction technique for this size container, providing the bonding techniques used are of high quality. This particular container was manufactured at the Lebanon, Oregon laboratory of the U. S. Plywood Corporation using bonding techniques similar to those used in the manufacture of the plywood itself.

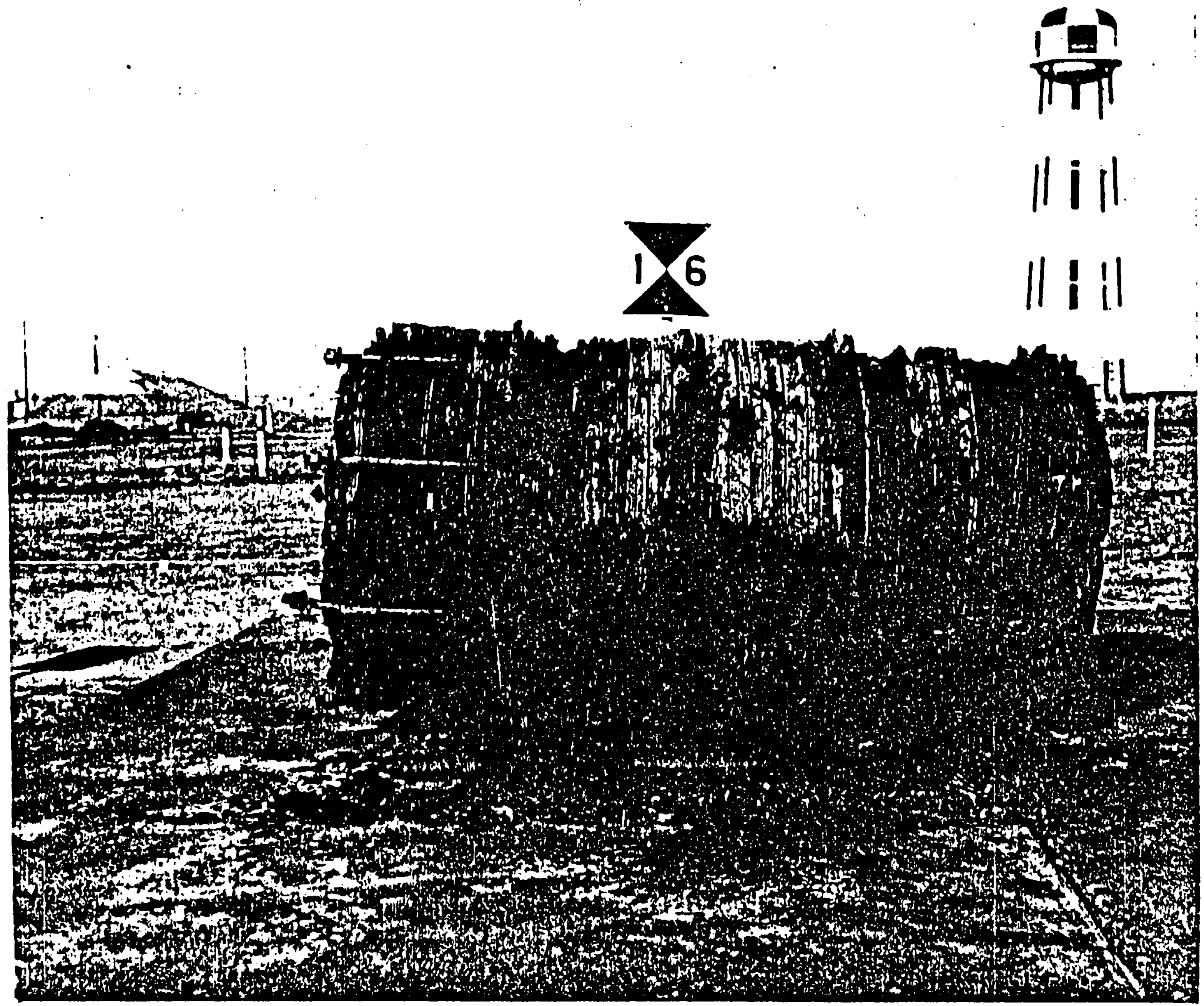

1 6

Figure 19.

This shows the effect of a 30-foot drop test on the 4000 pound Sandia container that was fire-tested during the Symposium. This drop test took place a few days following the Symposium. The drop angle was 45 degrees. As can be seen, there is some crushing of the container at the point of impact (on the right end), but examination of the inner, shielded pig revealed no damage to that critical item. The exposed bolts shown are used to hold the lid in place and stiffen the shell. Since the bolt ring is in a staggered pattern, only every other bolt can be seen.

This test proved that the Sandia-designed wooden insulated container should withstand the accident criteria of a 30-foot drop, 1-hour fire, and water submersion in any order. Based on test results and good engineering judgment, this design should not be affected by a 40-inch drop on a 6-inch diameter spike.

This container shell was laminated using both adhesive and cement-coated nails.

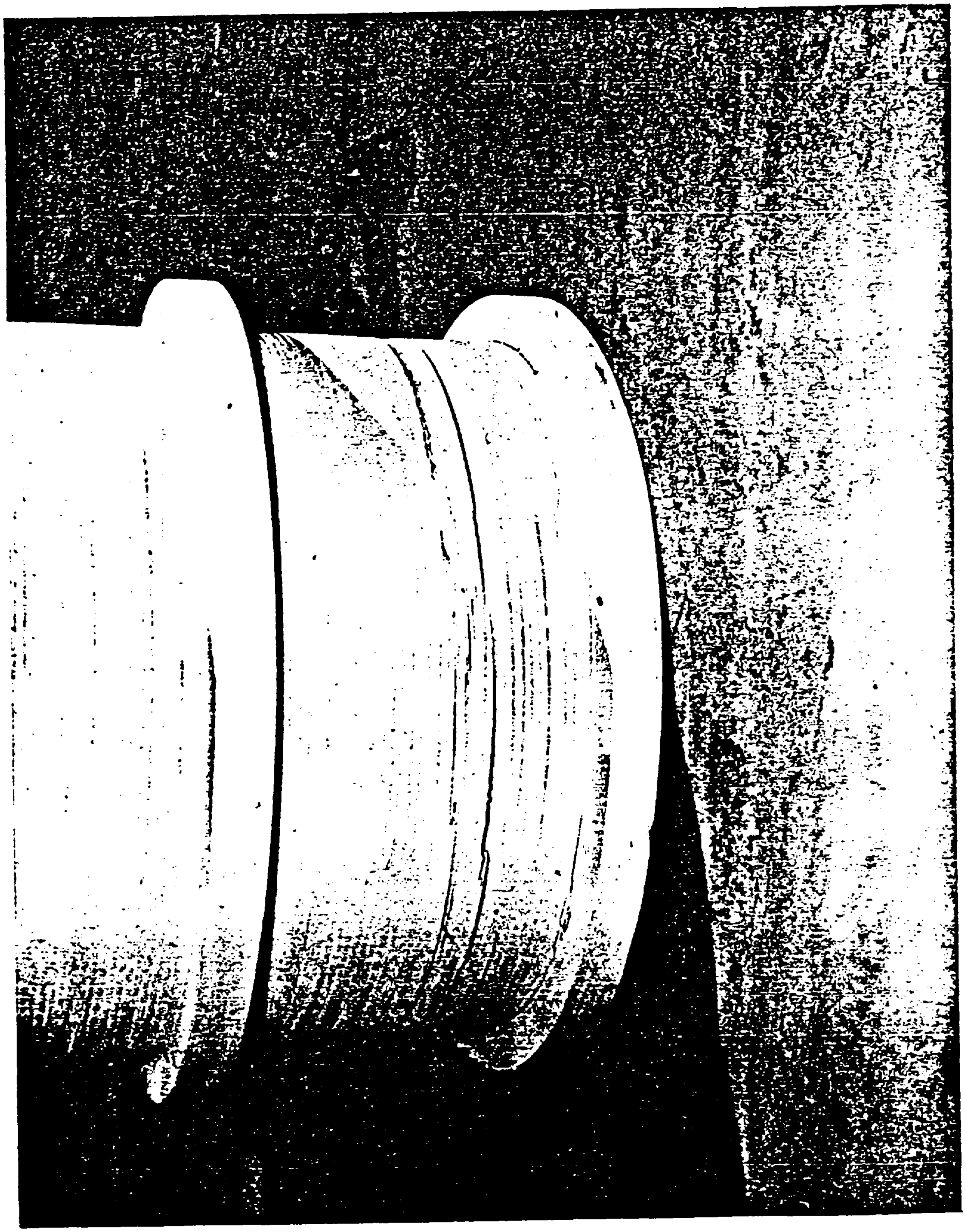


Figure 20.

Pictured here for comparison is the result of a 30-foot end drop on the Sandia 4000-pound container. Only very slight crushing of some plywood layers can be detected. The plywood is again Douglas fir.

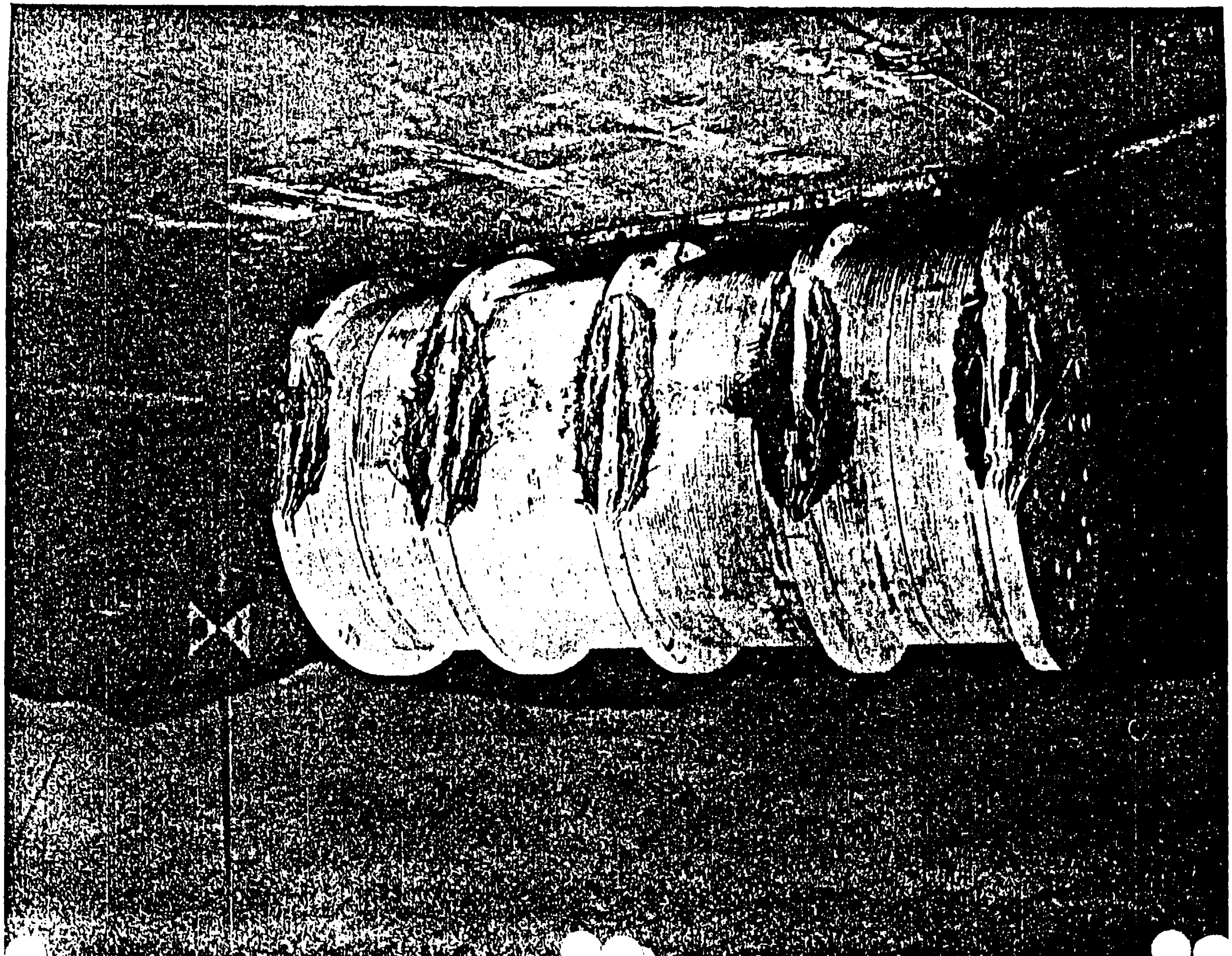


Figure 21.

Again, for comparison, the results of a 30-foot drop flat on one side are shown. Note the very effective shock mitigation by the five rings. The main body of the shell is almost untouched. All three of the unburned containers shown in this and preceding photographs are of identical construction.

2.10.10 Tiedown Bracket Used As Lifting Attachment

Requirement: "Any lifting attachment that is a structural part of a package must be designed with a minimum safety factor of three against yielding when used to lift the package in the intended manner, and must be designed so that failure of any lifting device under excessive load would not impair the ability of the package to meet other requirements of this subpart." (10 CFR 71.45(a))

Load: Maximum weight of package (6,000 pounds) acting vertically upward, uniformly distributed between the brackets. Maximum static load per bracket: 1,500 pounds.

Component Adequacy: Reference Drawing N240116

1. Bracket eye - shear
   Shear area = 31/32 X 3/8 X 2 X 2 = 1.45 in.^{2}
   Load capability = (y.s.)(.55)(area)
   = 36,000 (.55) 1.45
   = 28,700 pounds
   Three times maximum load = 3 X 1,500 = 4,500 pounds
   No yielding
   Safety factor$^{(1)}$ - 6.4

2. Bracket - tension
   For a vertical load - each bracket
   Section area = 2 X 3 X 3 X 3/8 = 3.2 in.^{2}
   Load capability = (y.s.)(area)
   = 36,000 (3.2) = 115,000 pounds
   Three times maximum load = 4,500 pounds - No yielding
   Safety factor$^{(1)}$ - 25

3. Support band and body flange - shear
   Upward force on bracket to reach shear limit in support ring and body flange cross section only
   Section area = 3.68 in.^{2}
   Load capability = 36,000 (.55)(3.68) = 72,800 pounds
   Three times maximum load = 4,500 pounds - No yielding
   Safety factor$^{(1)}$ - 16

4. Bracket attachment weld - shear
   Weld length = 8 inches (sides only considered)
   Minimum weld section = (1/4)(.707)(8) = 1.4 in.^{2}
   Weld efficiency = 75%
   Load capability = 2(36,000)(.55)(1.4)(.75) = 41,600 pounds
   Three times maximum load = 4,500 pounds - No yielding
   Safety factor$^{(1)}$ - 9.2

$^{(1)}$Safety factor to 3X yield strength

5. Shell - tension

Tension in shell

Area = 48.5(.1072) = 16.3 in.^{2}

Load capability = 36,000(16.3) = 587,000 pounds

Three times maximum load = 4 X 4,500 = 18,000 pounds

No yielding

Safety factor[1] - 33

[1] Safety factor to 3X yield strength

2.10.11 Inner Cask Bolting Material

The bolts used to fasten the covers to the shell assembly are purchased to SAE Standard J429. The Standard is included as part A of this appendix. The mechanical requirements and identification markings are listed in Table 1 and the chemical composition requirements are listed in Table 2 of the standard. The application temperature range is not specifically identified except to indicate that stress relaxation characteristics should be taken into consideration for service temperatures above 500°F.

The background for the Standard is provided in the first three sections of the chapter on Threaded Steel Fasteners in the Metals Handbook (Ninth Edition, pp. 273–75) included as part B of this appendix. The primary service temperature range is identified as -65°F to +400°F with guidelines for application up to +700°F. In the present application, the maximum temperature perceived under hypothetical accident conditions is within the primary service temperature range.

While the tensile strength and yield strength properties at elevated temperatures are not specifically called out in the standard, they can be derived with sufficient accuracy from room temperature properties in the standard and values provided for bolting material of generally the same composition in the ASME B & PV Code, Section III, Div. 1, Appendices. The tensile strength for ferritic steels changes very little, if at all, through temperatures up to 600°F and in most cases beyond (See ASME B & PV Code, Sec. III, Div 1 Appendices Table I-3.1). The decrease in yield strength from the room temperature value can be taken as proportional to the decrease in Sm for a bolting material such as ASTM A540 B22, which has about the same room temperature tensile and yield strength values and a composition falling within the specification of the Grade 8 standard (See ASME B & PV Code, Section III, Div. 1, Appendices Table I-1.3). The values for Su, Sy and Sm listed in Table 2.3.3 were developed in this manner.

Appendix 2.10.11 Part A

From: 1987 SAE Handbook
Volume 1, Materials

4 Steel Fasteners

MECHANICAL AND MATERIAL REQUIREMENTS FOR EXTERNALLY THREADED FASTENERS—SAE J429 AUG83

SAE Standard

Report of the Iron and Steel Technical Committee, approved January 1949, eleventh revision, ISTC Division 29, August 1983.

1. Scope—This SAE Standard covers the mechanical and material requirements for steel bolts, screws, studs, sems,[1] and U-bolts[2] used in automotive and related industries in sizes to 1½ in, inclusive.

[1] Sems: Screw and washer assemblies.

[2] U-bolts covered by this SAE Standard are those used primarily in the suspension and related areas of vehicles. For specification purposes, this standard treats U-bolts as studs. Thus, wherever the word "studs" appears, "U-bolts" is also implied. (Designers should recognize that the "U" configuration may not sustain a load equivalent to two bolts or studs of the same size and grade; thus, actual load carrying capacity of U-bolts should be determined by saddle load tests.)

NOTE: Previous issues of this standard also covered nuts, now covered separately in SAE J995 (August, 1967).

2. Designations

2.1 Designation System—Grades are designated by numbers where increasing numbers represent increasing tensile strength, and by decimals of whole numbers where decimals represent variations at the same strength level. The grade designations are given in Table 1.

2.2 Grades—Bolts and screws are normally available only in Grades 1, 2, 5, 5.2, 7, 8, and 8.2. Studs are normally available only in Grades 1, 2, 4, 5, 8, and 8.1. Grade 5.1 is applicable to sems which are heat

TABLE 1—MECHANICAL REQUIREMENTS AND IDENTIFICATION MARKING FOR BOLTS, SCREWS, STUDS, SEMS, AND U-BOLTS[i]

Grade Designation	Products	Nominal Size Dia, in	Full Size Bolts, Screws, Studs, Sems: Proof Load (Stress), psi	Full Size Bolts, Screws, Studs, Sems: Tensile Strength (Stress) Min, psi	Machine Test Specimens of Bolts, Screws, and Studs: Yield[a] Strength (Stress) Min, psi	Machine Test Specimens: Tensile Strength (Stress) Min, psi	Machine Test Specimens: Elongation[f] Min, %	Machine Test Specimens: Reduction of Area Min, %	Surface Hardness: Rockwell 30N Max	Core Hardness: Rockwell Min	Core Hardness: Rockwell Max	Grade Identification Marking[j]
1	Bolts, Screws, Studs	1/4 thru 1-1/2	33 000[k]	60 000	36 000[b]	60 000	18	35	—	B70	B100	None
2	Bolts, Screws, Studs	1/4 thru 3/4[c]	55 000[k]	74 000	57 000	74 000	18	35	—	B80	B100	
		Over 3/4 to 1-1/2	33 000	60 000	36 000[b]	60 000	18	35	—	B70	B100	None
4	Studs	1/4 thru 1-1/2	65 000	115 000	100 000	115 000	10	35	—	C22	C32	None
5	Bolts, Screws, Studs	1/4 thru 1	85 000	120 000	92 000	120 000	14	35	54	C25	C34	
		Over 1 to 1-1/2	74 000	105 000	81 000	105 000	14	35	50	C19	C30	
5.1[d]	Sems,[h]	No. 6 thru 5/8	85 000	120 000	—	—	—	—	59.5[g]	C25	C40[g]	
	Bolts, Screws	No. 6 thru 1/2										
5.2	Bolts Screws	1/4 thru 1	85 000	120 000	92 000	120 000	14	35	56	C26	C36	
7[e]	Bolts Screws	1/4 thru 1-1/2	105 000	133 000	115 000	133 000	12	35	54	C28	C34	
8	Bolts, Screws, Studs	1/4 thru 1-1/2	120 000	150 000	130 000	150 000	12	35	58.6	C33	C39	
8.1	Studs	1/4 thru 1-1/2	120 000	150 000	130 000	150 000	10	35	—	C32	C38	None
8.2	Bolts Screws	1/4 thru 1	120 000	150 000	130 000	150 000	10	35	58.6	C33	C39	

[a] Yield strength is stress at which a permanent set of 0.2% of gage length occurs.

[b] Yield point shall apply instead of yield strength at 0.2% offset.

[c] Grade 2 requirements for sizes 1/4 through 3/4 in apply only to bolts and screws 6 in and shorter in length, and to studs of all lengths. For bolts and screws longer than 6 in, Grade 1 requirements shall apply.

[d] Grade 5 material heat treated before assembly with a hardened washer is an acceptable substitute.

[e] Grade 7 bolts and screws are roll threaded after heat treatment.

[f] See Table 6 for gage length.

[g] Hex washer head and hex flange products without assembled washers shall have a core hardness not exceeding Rockwell C38 and a surface hardness not exceeding Rockwell 30N 57.5.

[h] Sems and similar products without washers.

[i] See footnote 2 of text.

[j] Not applicable to studs or slotted and cross recess head products.

[k] Proof load test: Requirements in these grades only apply to stress relieved products.

treated following assembly of the washer on the screw, and to products without assembled washer.

3. Materials and Processes

3.1 Steel Characteristics—Bolts, screws, studs, and sems shall be made of steel conforming to the description and chemical composition requirements specified in Table 2 for the applicable grade.

3.2 Heading Practice—Methods other than upsetting and/or extrusion are permitted only by special agreement between purchaser and supplier.

Grade 1 bolts and screws may be hot or cold headed, at option of the manufacturer.

Grades 2, 5, 5.2, 7, 8, and 8.2 bolts and screws in sizes up to ¾ in, inclusive, and in lengths up to 6 in, inclusive, shall be cold headed, except that by special agreement they may be hot headed. Larger sizes and longer lengths may be hot or cold headed, at option of the manufacturer.

Grade 5.1 bolts, screws, and sems shall be cold headed.

3.3 Threading Practice—Grades 2, 5, 5.2, 8, and 8.2 bolts and screws in sizes up to ¾ in, inclusive, and lengths up to 6 in, inclusive, shall be roll threaded, except by special agreement. Grade 7 bolts and screws shall be roll threaded after heat treatment. Grade 5.1 bolts, screws, and sems shall be roll threaded. Threads of all sizes of Grade 1 bolts and screws, and Grades 2, 5, 5.2, 8, and 8.2 bolts and screws in sizes over ¾ in and/or lengths longer than 6 in, may be rolled, cut, or ground, at option of the manufacturer. Threads of all grades and sizes of studs may be rolled, cut, or ground, at option of the manufacturer.

3.4 Heat Treatment Practice—Grade 1 bolts and screws and Grades 1 and 2 studs need not be heat treated. When specified by purchaser, Grade 2 cold headed bolts and screws shall be stress relieved at a minimum stress relief temperature of 875°F (468°C). Grades 4 and 8.1 studs are manufactured from pretreated material and the studs, as manufactured, need no further heat treatment. Grades 5 and 5.2 bolts, screws, and studs shall be heat treated, oil or water quenched, at option of manufacturer, and tempered at a minimum tempering temperature of 800°F (427°C). Grade 5.1 bolts, screws, and sems shall be heat treated, quenched, and tempered at a minimum tempering temperature of 650°F (343°C). For Grade 5.1 sems, quenchants whose principal constituent is water shall not be used, unless specifically approved by the user. Grades 7 and 8 bolts and screws and Grade 8 studs shall be heat treated, oil quenched, and tempered at a minimum tempering temperature of 800°F (427°C). Grade 8.2 bolts and screws shall be fully austenitized, quenched in oil or water, and tempered at a minimum temperature of 650°F (340°C).

3.5 Decarburization—Unless otherwise specified, Grades 5, 5.1, and 5.2 bolts, screws, and studs shall conform to Class C, and Grades 7, 8, 8.1, and 8.2 bolts, screws, and studs shall conform to Class B as described in SAE J121a.

3.6 Surface Discontinuities—Grades 5, 5.1, 5.2, 7, 8, 8.1, and 8.2 bolts, screws, and studs in sizes up to 1 in inclusive, and lengths up to 6 in inclusive shall be in conformity with the requirements of SAE J1061 (September, 1973).

When the engineering requirements of the application necessitate that surface discontinuities of bolts, screws, and studs should be more closely controlled, the purchaser shall specify the applicable limits in the original inquiry and purchase order. For certain fasteners, this may be done by reference to SAE J123 (September, 1973).

4. Mechanical Requirements—Bolts, screws, studs, and sems shall be tested in accordance with the mechanical testing requirements for the applicable type, grade, size, and length of product as specified in Table 3, and shall meet the mechanical requirements specified for that product in Table 1.

In the case of U-bolts having thread length equal to 3D or longer, cut stud-like specimens from either leg of the "U" (utilizing the maximum available thread length) and test as shown for studs. Where thread length is less than 3 D, test for hardness only as shown for "short studs." (Applicable mechanical tests are shown in Table 3 and requirements in Table 1.)

5. Methods of Test

5.1 Hardness—The hardness of bolts, screws, studs, and sems shall be determined at mid-radius of a transverse section through the threaded portion of the product taken at a distance of one diameter from the end of the product. The reported hardness shall be the average of four hardness readings located at 90 deg to one another. The preparation of test specimens and the performance of hardness tests shall be in conformity with the requirements of SAE J417 (January, 1946).

To meet the requirements of Section 4, the hardness shall not exceed the maximum hardness specified in Table 1 for the applicable grade. In addition, as required in Section 4 and Table 3, the hardness shall be not less than the minimum hardness specified in Table 1 for the applicable grade.

5.2 Surface Hardness—Tests to determine surface hardness conditions shall be conducted on the ends, hexagon flats, or unthreaded shanks which have been prepared by lightly grinding or polishing to insure accurate reproducible readings in accordance with SAE J417 (January, 1946). Proper correction factors shall be used when hardness tests are made on curved surfaces, per ASTM E 18.

Depending on the location and individual surface upon which the test is conducted, some increase in hardness above that specified in Table 1, when measured on the Rockwell 30N scale, may occur for reasons other than carburization. To insure that lots of products not considered acceptable for this cause are in fact carburized, the metallographic and hardness checking technique described in SAE J121 (September, 1969) shall be used.

In applying the J121 (September, 1969) procedure, a difference between Knoop and Rockwell 30N readings by conversion may occur. This difference is disregarded since the primary purpose of the Knoop traverse in J121 (September, 1969) is to establish the existence of carburization.

5.3 Proof Load—The proof load test consists of stressing the bolt, screw, stud, or sem with a specified load which the product must withstand without permanent set.

The overall length of the specimen shall be measured between conical or ball centers on the centerline of the specimen, using mating centers on the measuring anvils. The specimen shall be marked so that it can be placed in the measuring fixture in the same position for all measurements. The measurement instrument shall be capable of measurement to 0.0001 in. In the case of sems, the washer may be removed from the screw prior to assembly in the testing machine; however, for referee testing, the washer shall be removed. For bolts, screws, and sems, 3D or longer, the specimen shall be assembled in the fixture of the tensile machine so that six complete threads are exposed between the grips. This is obtained by freely running the nut or fixture to the thread runout of the specimen and then unscrewing the specimen six full turns. Short bolts,

ϕ **TABLE 2—CHEMICAL COMPOSITION REQUIREMENTS**[a]

Grade	Material and Treatment	Element, %					
		C		Mn	P	S	B
		Min	Max	Min	Max	Max	Min
1	Low or medium carbon steel	—	0.55	—	0.048	0.058	—
2	Low or medium carbon steel	—	0.55	—	0.048	0.058[b]	—
4	Medium carbon cold drawn steel	—	0.55	—	0.048	0.13	—
5	Medium carbon steel, quenched and tempered	0.28	0.55	—	0.048	0.058[c]	—
5.1	Low or medium carbon steel, quenched and tempered[e]	0.15	0.30	—	0.048	0.058	—
5.2	Low carbon martensite steel, fully killed, fine grain, quenched and tempered	0.15	0.25	0.74	0.048	0.058	0.0005
7	Medium carbon alloy steel, quenched and tempered[d]	0.28	0.55	—	0.040	0.045	—
8	Medium carbon alloy steel, quenched and tempered[d]	0.28	0.55	—	0.040	0.045	—
8.1	Elevated temperature drawn steel—medium carbon alloy or SAE 1541 (or 1541H steel)	0.28	0.55	—	0.048	0.058	—
8.2	Low carbon martensite steel, fully killed, fine grain, quenched and tempered[f]	0.15	0.25	0.74	0.048	0.058	0.0005

[a] All values are for product analysis (percent by weight). For cast or heat analysis, use standard permissible variations as shown in SAE J409 (January, 1942).

[b] For studs only, sulfur content may be 0.33% max.

[c] For studs only, sulfur content may be 0.13% max.

[d] Steel shall be fine grain, with hardenability that will produce a minimum hardness of Rockwell C47 at the center of a transverse section one diameter from the threaded end of the bolt, screw, or stud after oil quenching (see SAE J407 (August, 1947)). Carbon steel may be used by agreement between producer and consumer, for sizes 1/4–3/4 in diameter products. SAE 1541 (or 1541H) steel, oil quenched and tempered, may be used at the option of the producer for products 7/16 in nominal diameter and smaller.

[e] For sems only, sizes 7/16–5/8 in diameter, low carbon martensite steel (as specified for Grade 5.2) may be used.

[f] Steel with hardenability that will produce a minimum hardness of Rockwell C38 at the center of a transverse section one diameter from the threaded end of the bolt or screw after quenching.

ϕ TABLE 3—MECHANICAL TESTING REQUIREMENTS FOR BOLTS, SCREWS, STUDS, AND SEMS

Product	Grade	Specified Min Tensile Strength of Product, lb	Length of Product	Hardness[a]		Tests Conducted Using Full Size Products[a]			Tests Conducted Using Machine Test Specimens[a]				Surface Hardness max[e]	Decarburization in Threaded Section[e]
				Max	Min	Proof Load	Wedge Tensile Strength	Axial Tensile Strength	Yield Strength	Axial Tensile Strength	Elongation	Reduction of Area		
Short Bolts and Screws	1, 2, 5, 5.2, 7, 8, 8.2	All	Less than 2-1/4D[b]	*	*	—	—	—	—	—	—	—	*	Option C
Special Head Bolts and Screws	1, 2, 5, 5.2, 7, 8, 8.2	All	All	*	*	—	—	—	—	—	—	—	*	Option C
Square and Hex Bolts and Screws	1, 2, 5, 5.2, 7, 8, 8.2	100 000 and less	2-1/4D to 8D or 8 in, whichever is greater	*	—	*	*	—	—	—	—			
			Over 8D or 8 in, whichever is greater, thru and including 12 in	*	—	Option C	*	—	Option B	Option B	Option B	Option B	*	Option C
			Over 12 in	*	—	Option C	Option A	—	Option B	Option B	Option B	Option B	*	Option C
		Over 100 000	2-1/4D and longer	*	—	Option C	Option A	—	Option B	Option B	Option B	Option B	*	Option C
All Other Bolts and Screws	1, 2, 5, 5.2, 7, 8, 8.2	100 000 and less	2-1/4 to 8D or 8 in, whichever is greater	*	—	*	—	*	—	—	—	—	*	Option C
			Over 8D or 8 in, whichever is greater	*	—	Option C	—	Option A	Option B	Option B	Option B	Option B	*	Option C
		Over 100 000	2-1/4D and longer	*	—	Option C	—	Option A	Option B	Option B	Option B	Option B	*	Option C
Short Studs	1, 2, 4, 5, 8, 8.1	All	Less than 3D	*	*	—	—	—	—	—	—	—	*	Option C
All Other Studs	1, 2, 4, 5, 8, 8.1	100 000 and less	3D to 8D or 8 in, whichever is greater	*	—	*	*	—	—	—	—	—	*	Option C
			Over 8D or 8 in, whichever is greater	*	—	Option C	Option A	—	Option B	Option B	Option B	Option B	*	Option C
		Over 100 000	3D and longer	*	—	Option C	Option A	—	Option B	Option B	Option B	Option B	*	Option C
Short Bolts, Screws, and Sems	5.1	All	Less than 2-1/4D	*	*	—	—	—	—	—	—	—	*	Option C
Hex Head Bolts, Screws, and Sems	5.1	All	2-1/4D and longer	*	—	*	*	—	—	—	—	—	*	Option C
Other Bolts, Screws, and Sems	5.1	All	2-1/4D and longer	*	—	*	—	*	—	—	—	—	*	Option C
Tests to be performed in accordance with paragraph				5.1		5.3	5.5	5.4	5.6				5.2	3.5

[a] Asterisks (*) denote mandatory tests. Where options are indicated, all Option A tests (which apply to full size products) or all Option B tests (which apply to machined specimens) shall be performed. Option C tests (which apply to full size products) are not mandatory unless specified in the original inquiry and purchase order. Option A and Option C tests shall be performed in case arbitration is necessary. Dashes (—) denote tests which are not required.

[b] D equals nominal diameter of the product.

[c] Special head bolts and screws are those with special configurations or with drilled heads which are weaker than the threaded section.

[d] For purposes of Table 3 requirements, "length of product" is the nominal length including point chamfer as defined in SAE J105 (June, 1911), and all special point products shall be measured from the bearing surface to the crest of the last complete thread form.

[e] Surface hardness and decarburization requirements apply only to Grades 5, 5.1, 5.2, 7, 8, 8.1, and 8.2. ϕ

2¼-3D in length, threaded to within 2½ pitches of the bearing surface shall be assembled finger tight in the fixture and unscrewed two full turns. When proof load testing studs, one end of the stud shall be assembled in a threaded fixture to the thread runout. For studs having unlike threads, this shall be the end with the finer pitch thread. The other end of the stud shall likewise be assembled in a threaded fixture, as above for bolts. The bolt, screw, stud, or sem shall then be axially loaded to the proof load specified for the applicable size, thread series, and grade in Table 5, the load retained for a period of 10 s, the load removed, and the overall length again measured. The speed of testing, as determined with a free running cross head, shall not exceed 0.12 in/min.

To meet the requirements of Section 4, the length of the bolt, screw, stud, or sem after loading shall be the same as before loading within a tolerance of ±0.0005 in allowed for measurement error.

Variables, such as straightness and thread alignment (plus measurement error), may result in apparent elongation of the fasteners when the proof load is initially applied. In such cases, the fastener may be retested using a 3% greater load, and may be considered satisfactory if the length after this loading is the same as before this loading (within the 0.0005 in tolerance for measurement error).

5.4 Axial Tensile Strength—Following proof load testing, the same bolt, screw, stud, or sem shall be reassembled in the testing machine per paragraph 5.3 and axial loading applied until failure. Typical fixturing is illustrated in Fig. 1. The speed of testing, as determined with a free running cross head, shall not exceed 1 in/min.

To meet the requirements of Section 4, the bolt, screw, stud, or sems shall not fracture before having withstood the minimum tensile load specified for the applicable size, thread series, and grade in Table 5. In addition, for bolts, screws, and sems with regular style heads, the ultimate failure location shall occur in the body or threaded section and not at the junction of the head and shank. (See footnote c under Table 3.)

5.5 Wedge Tensile Strength

5.5.1 BOLTS AND SCREWS—Following proof load testing, the same bolt or screw shall be assembled with a wedge inserted under the head, as

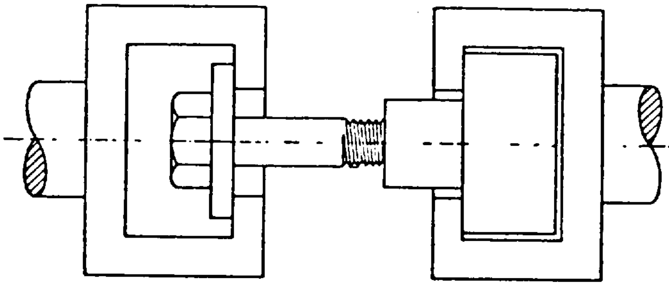


FIG. 1—TENSILE TESTING OF FULL SIZE BOLT OR SCREW

illustrated in Fig. 2, installed in the testing machine and tensile tested to failure, as described in paragraph 5.3. The angle of the wedge for the bolt or screw size and grade is specified in Table 4. The wedge shall be so placed that no corner of the square or hexagon bolt or screw head takes the bearing load; that is, a flat of the head shall be aligned with the direction of uniform thickness of the wedge. The wedge shall have a thickness of one-half the bolt or screw diameter measured at the thin side of the hole. The hole in the wedge shall have the following clearance over the nominal size of the bolt or screw, and its top and bottom edges shall be rounded or chamfered 45 deg to the following dimensions:

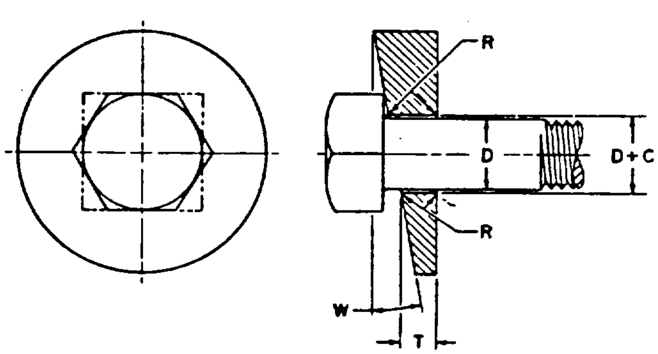
Nominal Bolt or Screw Size, in	Clearance in Hole, in	Radius or Depth of Chamfer, in
No. 6 thru 12	0.020	0.020
1/4 thru 1/2	0.030	0.030
9/16 thru 3/4	0.050	0.060
7/8 and 1	0.060	0.060
1-1/8 and 1-1/4	0.060	0.125
1-3/8 and 1-1/2	0.094	0.125

ϕ Wedge tensile testing shall be limited to product with hexagon, square, ex flange, or twelve point flange heads. Product with other head styles .d shaped shoulders or those with shoulders substantially larger in diameter than the nominal bolt body diameter, should be axial tensile tested.

To meet the requirement of Section 4, the bolt, screw, stud, or sems shall not fracture before having withstood the minimum tensile load specified for the applicable size, thread series, and grade in Table 5. In addition, the ultimate failure location shall occur in the body or threaded section and not at the junction of the head and shank. (See footnote c under Table 3.)

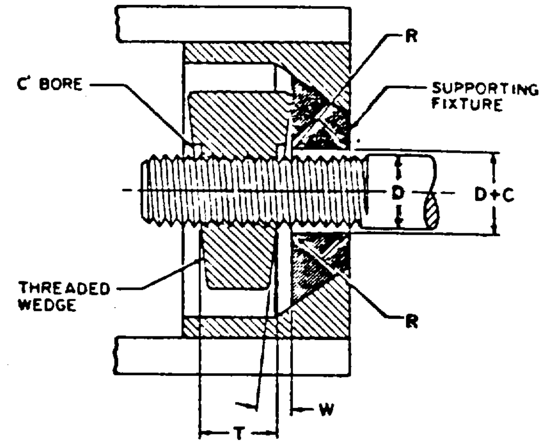
5.5.2 STUDS—Following proof load testing, the stud shall be assembled per paragraph 5.3 except with a threaded wedge, as illustrated in Fig. 3. The angle of the wedge for the stud size and grade shall be as specified in Table 4. The stud shall be assembled in the testing machine and tensile tested to failure, as described in paragraph 5.3.

The length of the threaded section of the wedge shall be equal to the diameter of the stud. To facilitate removal of the broken stud, the wedge shall be counterbored. The thickness of the wedge at the thin side of the hole shall equal the diameter of the stud plus the depth of



C = CLEARANCE OF HOLE (SEE PARA. 5.4.1)
D = DIAMETER OF BOLT OR SCREW
R = RADIUS OR CHAMFER (SEE PARA 5.4.1)
T = THICKNESS OF WEDGE AT THIN SIDE OF HOLE EQUALS ONE HALF DIAMETER OF BOLT OR SCREW
W = WEDGE ANGLE (SEE TABLE 4)

FIG. 2—WEDGE TEST DETAILS—BOLTS AND SCREWS



C = CLEARANCE OF HOLE (SEE PARA. 5.4.1)
D = DIAMETER OF STUD
R = RADIUS OR CHAMFER (SEE PARA 5.4.1)
T = D PLUS DEPTH OF COUNTERBORE
W = WEDGE ANGLE (SEE TABLE 4)

FIG. 3—WEDGE TEST DETAILS—STUDS

counterbore. The supporting fixture, as shown in Fig. 3, shall have a hole clearance over the nominal size of the stud, and shall have its top and bottom edges rounded or chamfered to the same limits specified for the hardened wedge in paragraph 5.5.1.

To meet the requirements of Section 4, the stud shall not fracture before having withstood the minimum tensile load specified for the applicable size, thread series, and grade in Table 5.

TABLE 4—TENSILE TEST WEDGE ANGLES

Product	Grade	Nominal Size of Product, in	Wedge Angle, deg
Bolts and Screws[b]	1, 2	1/4 thru 1	10
		Over 1 to 1-1/2	6
	5, 5.2, 7, 8, 8.2[a]	1/4 thru 1	10
	5, 7, 8[a]	Over 1 to 1-1/2	6
Hex Head Bolts[b] Screws and Sems	5.1	No. 6 thru 5/8	6
Studs	1, 2, 5, 8, 8.1	1/4 thru 3/4	6
		Over 3/4 to 1-1/2	4

[a] For Grades 5, 5.2, 7, 8, and 8.2 bolts and screws which are threaded 1 dia and closer to the underside of head, wedge angle shall be 6 deg for sizes 1/4 through 3/4 in, and 4 deg for sizes over 3/4 in.

[b] For hex flange and hex washer head product, the wedge angle shall be 6 deg.

5.6 Testing of Machined Test Specimens—Where bolts, screws, and studs cannot be tested in full size for proof load and tensile strength requirements, tests shall be conducted using test specimens machined from the bolt, screw, or stud.

For 1½ in diameter bolts, screws, and studs, a standard 0.500 in round 2 in gage length test specimen shall be turned from the bolt, screw, or stud with the axis of the specimen located midway between the center and outside surface of the bolt, screw, or stud shank, as shown in Fig. 4. Bolts, screws, and studs ¾ through 1⅜ in diameter shall have their shanks machined to the dimensions of a standard 0.500 in round 2 in gage length test specimen concentric with the axis of the bolt, screw, or stud, leaving the bolt or screw head and threaded sections intact, as shown in Fig. 5. Bolts, screws, and studs ¼ through ⅝ in diameter shall have their shanks machined to subsize specimens having dimensions shown in Fig. 5 and Table 6.

The test specimen shall be tensile tested as described in paragraph 5.3, and the yield strength, tensile strength, elongation, and reduction of area determined.

To meet the requirements of Section 4, the test specimen must have a yield strength, tensile strength, elongation, and reduction of area equal

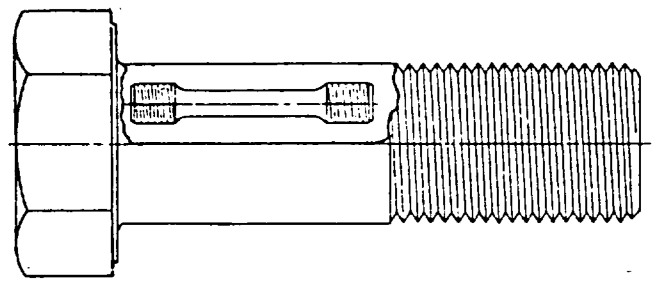


FIG. 4—LOCATION OF STANDARD ROUND 2 IN GAGE LENGTH TENSILE TEST SPECIMEN WHEN TURNED FROM LARGE SIZE BOLTS OR SCREWS

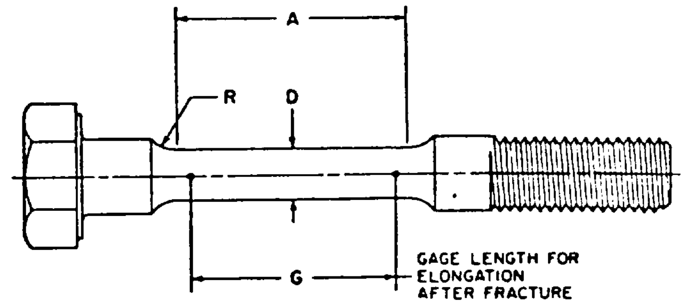


FIG. 5—TENSILE TEST SPECIMEN FOR BOLTS OR SCREWS WITH TURNED DOWN SHANK

to or greater than the values for these properties specified for the applicable product size and grade in Table 1.

5.7 Common Test Fixture Details—The grips of the tensile testing machine shall be self-aligning to avoid side thrust on the specimen.

The wedge shall have a minimum hardness of Rockwell C45.

The hole in the fixture or washer used under the head of bolts and screws during proof load and tensile testing shall have the same clearance as that specified for wedges (paragraph 5.5.1).

Wedges, nuts, and fixtures into which bolts, screws, and studs are threaded for proof load, tensile strength, and wedge tensile testing shall have threads which are of the same size, pitch, and tolerance class as the product being tested. (For *standard products*, Class 3B tolerances are normally applicable.) For studs having interference fit threads, wedges shall be threaded to provide a *finger-free fit.*

6. Marking—Unslotted bolts, screws, and hex head sems shall be marked with the grade identification symbol shown in Table 1. In addition, bolts and screws shall be marked with the manufacturer's identification symbol. Markings shall be located on the top of the head, and may be either raised or depressed, at option of the manufacturer.

Studs need not be marked.

TABLE 5—PROOF LOAD AND TENSILE STRENGTH REQUIREMENTS[a]

Nominal Dia of Product and Threads per in	Stress Area, in²	Grade 1		Grade 2		Grade 4		Grades 5 and 5.2[b]		Grade 5.1		Grade 7		Grades 8, 8.1, 8.2[b]	
		Proof Load, lb	Tensile Strength Min, lb	Proof Load, lb	Tensile Strength Min, lb	Proof Load, lb	Tensile Strength Min, lb	Proof Load, lb	Tensile Strength Min, lb	Proof Load, lb	Tensile Strength Min, lb	Proof Load, lb	Tensile Strength Min, lb	Proof Load, lb	Tensile Strength Min, lb
Coarse Thread Series—UNC															
No. 6–32	0.00909	—	—	—	—	—	—	—	—	750	1100	—	—	—	—
8–32	0.0140	—	—	—	—	—	—	—	—	1200	1700	—	—	—	—
10–24	0.0175	—	—	—	—	—	—	—	—	1500	2100	—	—	—	—
12–24	0.0242	—	—	—	—	—	—	—	—	2050	2900	—	—	—	—
1/4–20	0.0318	1050	1900	1750	2350	2050	3650	2700	3800	2700	3800	3350	4250	3800	4750
5/16–18	0.0524	1750	3150	2900	3900	3400	6000	4450	6300	4450	6300	5500	6950	6300	7850
3/8–16	0.0775	2550	4650	4250	5750	5050	8400	6600	9300	6600	9300	8150	10 300	9300	11 600
7/16–14	0.1063	3500	6400	5850	7850	6900	12 200	9050	12 800	9050	12 800	11 200	14 100	12 800	15 900
1/2–13	0.1419	4700	8500	7800	10 500	9200	16 300	12 100	17 000	12 100	17 000	14 900	18 900	17 000	21 300
9/16–12	0.182	6000	10 900	10 000	13 500	11 800	20 900	15 500	21 800	15 500	21 800	19 100	24 200	21 800	27 300
5/8–11	0.226	7450	13 600	12 400	16 700	14 700	25 400	19 200	27 100	19 200	27 100	23 700	30 100	27 100	33 900
3/4–10	0.334	11 000	20 000	18 400	24 700	21 700	38 400	28 400	40 100	—	—	35 100	44 400	40 100	50 100
7/8–9	0.462	15 200	27 700	15 200	27 700	30 000	53 100	39 300	55 400	—	—	48 500	61 400	55 400	69 300
1 –8	0.606	20 000	36 400	20 000	36 400	39 400	69 700	51 500	72 700	—	—	63 600	80 600	72 700	90 900
1-1/8–7	0.763	25 200	45 800	25 200	45 800	49 600	87 700	56 500	80 100	—	—	80 100	101 500	91 600	114 400
1-1/4–7	0.969	32 000	58 100	32 000	58 100	63 000	111 400	71 700	101 700	—	—	101 700	127 700	116 300	145 400
1-3/8–6	1.155	38 100	69 300	38 100	69 300	75 100	132 800	85 500	121 300	—	—	121 300	153 600	138 600	173 200
1-1/2–6	1.405	46 400	84 300	46 400	84 300	91 300	161 600	104 000	147 500	—	—	147 500	186 900	168 600	210 800
Fine Thread Series—UNF															
No. 6–40	0.01015	—	—	—	—	—	—	—	—	850	1200	—	—	—	—
8–36	0.01474	—	—	—	—	—	—	—	—	1250	1750	—	—	—	—
10–32	0.0200	—	—	—	—	—	—	—	—	1700	2400	—	—	—	—
12–28	0.0258	—	—	—	—	—	—	—	—	2200	3100	—	—	—	—
1/4–28	0.0364	1200	2200	2000	2700	2350	4200	3100	4350	3100	4350	3800	4850	4350	5450
5/16–24	0.0580	1900	3500	3200	4300	3750	6700	4900	6950	4900	6950	6100	7700	6950	8700
3/8–24	0.0878	2900	5250	4800	6500	5700	10 100	7450	10 500	7450	10 500	9200	11 700	10 500	13 200
7/16–20	0.1187	3900	7100	6550	8800	7700	13 650	10 100	14 200	10 100	14 200	12 500	15 800	14 200	17 800
1/2–20	0.1599	5300	9600	8800	11 800	10 400	18 400	13 600	19 200	13 600	19 200	16 800	21 300	19 200	24 000
9/16–18	0.203	6700	12 200	11 200	15 000	13 200	23 300	17 300	24 400	17 300	24 400	21 300	27 000	24 400	30 400
5/8–18	0.256	8450	15 400	14 100	18 900	16 600	29 400	21 800	30 700	21 800	30 700	26 900	34 000	30 700	38 400
3/4–16	0.373	12 300	22 400	20 500	27 600	24 200	42 900	31 700	44 800	—	—	39 200	49 600	44 800	56 000
7/8–14	0.509	16 800	30 500	16 800	30 500	33 100	58 500	43 300	61 100	—	—	53 400	67 700	61 100	76 400
1 –12	0.663	21 900	39 800	21 900	39 800	43 100	76 200	56 400	79 600	—	—	69 600	88 200	79 600	99 400
1 –14 uns	0.679	22 400	40 700	22 400	40 700	44 100	78 100	57 700	81 500	—	—	71 300	90 300	81 500	101 900
1-1/8–12	0.856	28 200	51 400	28 200	51 400	55 600	98 400	63 300	89 900	—	—	89 900	113 800	102 700	128 400
1-1/4–12	1.073	35 400	64 400	35 400	64 400	69 700	123 400	79 400	112 700	—	—	112 700	142 700	128 800	161 000
1-3/8–12	1.315	43 400	78 900	43 400	78 900	85 500	151 200	97 300	138 100	—	—	138 100	174 900	157 800	197 200
1-1/2–12	1.581	52 200	94 900	52 200	94 900	102 800	181 800	117 000	166 000	—	—	166 000	210 300	189 700	237 200

[a] Proof loads and tensile strengths are computed by multiplying the proof load stresses and tensile strength stresses given in Table 1 by the stress area of the thread.

The stress area of sizes and thread series not included in Table 5 may be computed from the formula: $A_s = 0.7854 \left[D - \frac{0.9743}{n}\right]^2$ where D equals nominal diameter in inch, and n equals threads per inch.

[b] Grades 5.2 and 8.2 applicable to sizes 1/4 through 1 in.

TABLE 6—DIMENSIONS OF MACHINED TEST SPECIMENS (SEE FIG. 5 AND PARAGRAPH 5.5)

Nominal Dia of Product	Gage Length G	Dia Parallel Section, D	Length Parallel Section, Min, A	Fillet Radius, Min, R
3/4 thru 1-1/2	2.000 ± 0.005	0.500 ± 0.010	2.25	0.38*
1/4 thru 5/8	1.400 ± 0.005	0.350 ± 0.007	1.75	0.25
	1.000 ± 0.005	0.250 ± 0.005	1.25	0.19

* Minimum radius recommended 0.38 in; 0.12 minimum permitted.

7. Testing Requirements

7.1 **Manufacturer's Responsibility**—During the manufacture of products to the requirements of this specification, the manufacturer shall make periodic tests to ensure that the properties of the product are being maintained within specified limits. Such tests shall be conducted in accordance with a sampling plan, preferably the sampling plan given in paragraph 7.3, and the test results shall be recorded in a test report. When requested in writing by the purchaser, the manufacturer shall furnish a copy of the test report certified to be a report of the results of the last completed set of tests for the specific type, size, length, and grade of product.

Additional tests of products in individual shipments are not normally contemplated. Unless otherwise agreed at time of original inquiry and purchase order, individual heats of steel need not be identified in the finished product.

7.2 **Purchaser's Options**—If the purchaser requires that additional tests be performed by the manufacturer to determine that the properties of products in an individual shipment are within specified limits, or if the purchaser requires that a sampling plan different from that given in paragraph 7.3 shall be used when determining the acceptability of a lot, or shipment, of products, the purchaser shall specify the complete testing requirements, including sampling plan and basis of acceptance, in the original inquiry and purchase order.

7.3 **General**—An acceptable sampling plan is outlined below:

Number of Pieces in Lot	Minimum Number of Specimens To Be Tested
50 and under	2
51 to 500	3
501 to 35 000	5
35 001 and over	8

A lot, for purposes of selecting test specimens, shall consist of all products offered for inspection and testing at one time that are of the same type, grade, size, length, and thread series and are manufactured essentially at one time and under the same process conditions.

The same test specimen may be used for different tests wherever practical.

When tested in accordance with this sampling plan, a lot shall be subject to rejection if any of the test specimens fail to meet the applicable test requirements. If the failure of a test specimen is due to improper preparation of the specimen or to incorrect testing technique, the specimen shall be discarded and another specimen substituted.

APPENDIX

(Relative to 150 000 psi tensile bolts and screws produced from low carbon martensite steels and designated as Grade 8.2)

Coverage for 150 000 psi tensile bolts and screws produced from low carbon martensite steels is included in SAE J429 (January, 1949) because several large steel and bolt producers and users have reported highly favorable results with such products over a period of more than three years. This coverage is designated by a separate grade number (Grade 8.2) to distinguish such fasteners from Grade 8 made of medium carbon and medium carbon alloy steels.

Limited data available concerning room temperature ductility and low temperature impact characteristics indicate that fasteners made to Grade 8.2 requirements may have advantages compared to alloy steels historically used for Grade 8 fasteners.

Heat treatment control for elements such as decarburization or carburization and quench medium heat transfer are more critical for Grade 8.2 than for Grade 8 steels. Thus, more attention should be given to verification of the use of proved practices. (It is suggested that users initially require details of heat treatment practices from the fastener producer until a broad spectrum of suppliers are familiar with the closer controls necessary.)

Users should recognize the difference in stress relaxation characteristics of various steels between the temperature range of 650°F, minimum, specified for Grade 8.2 and 800°F, minimum, specified for Grade 8, when considering bolts and screws that may be exposed to such temperature range. The data available on elevated temperature properties of Grade 8.2 indicates that performance testing is desirable in applications where the operating temperature exceeds 500°F (as may also be the case with Grade 8 fasteners).

The requirements stated, herein, limit the use of steels to those which have been used on a production basis with highly favorable results. There is much evidence that other steels are satisfactory also, but these are excluded from the standard until more widespread experience is had with them.

MECHANICAL AND MATERIAL REQUIREMENTS FOR METRIC EXTERNALLY THREADED STEEL FASTENERS—SAE J1199 SEP83

SAE Standard

Report of the Iron and Steel Technical Committee, approved February 1978, first revision, ISTC Division 29, September 1983.

1. Scope

1.1 This standard covers the mechanical and material requirements for eight property classes of steel, externally threaded metric fasteners in sizes M1.6 through M36, inclusive, and suitable for use in automotive and related applications.

1.2 Products included are bolts, screws, studs, U-bolts, pre-assembled screw and washer assemblies (sems), and products manufactured the same as sems except without washer.

1.3 Products not covered are tapping screws, thread rolling screws, and self-drilling screws. Mechanical and material requirements for these products are covered in other SAE documents.

1.4 The term *stud* as referred to herein applies to a cylindrical rod of moderate length, threaded on either one or both ends or throughout its entire length. It does not apply to headed, collared, or similar products which are more closely characterized by requirements shown herein for bolts.

1.5 For specification purposes, this standard treats U-bolts as studs. Thus, wherever the word *studs* appears, *U-bolts* is also implied. U-bolts covered by this standard are those used primarily in the suspension and related areas of vehicles. (Designers should recognize that the *U* configuration may not sustain a load equivalent to two bolts or studs of the same size and grade; thus actual load carrying capacity of U-bolts should be determined by saddle load tests.)

2. Designations

2.1 Property classes are designated by numbers where increasing numbers generally represent increasing tensile strengths. The designation symbol consists of two parts:

(a) The first numeral of a two-digit symbol or the first two numerals of a three-digit symbol approximates 1/100 of the minimum tensile strength in MPa.

(b) The last numeral approximates 1/10 of the ratio expressed as a percentage between minimum yield stress and minimum tensile stress.

Appendix 2.10.11 Part A

From: Metals Handbook, 9th Edition, Vol. I
American Society for Metals, 1978

Threaded Steel Fasteners

By the ASM Committee on
Carbon and Alloy Steels*

THREADED FASTENERS for service between −50 and +200 °C (−65 and +400 °F) may be made from several different grades of steel, as long as the finished fastener meets the specified strength requirements. This article discusses the properties of the carbon and alloy constructional steels containing a maximum of 0.55% carbon that are used to produce fasteners intended for use under these service conditions.

Guidelines for the selection of steels for bolts (including cap screws), studs (including U-bolts) and nuts for service at this temperature range and also for service between 200 and 370 °C (400 and 700 °F) are also discussed. Threaded fasteners for service above 370 °C (700 °F) and below −50 °C (−65 °F) will be discussed in subsequent volumes of the Metals Handbook.

The purchaser of steel bolts, studs and nuts usually selects the desired strength level by specifying a grade or class in the widely used SAE, ASTM, IFI or ISO specifications. The producer then selects a particular steel from the broad chemical composition ranges in these specifications. This allows the producers freedom to use the most economical material consistent with their equipment and production procedures to meet the specified mechanical properties. This situation has forced producers to adopt substantially the same manufacturing process for a given class of product, which has resulted in a certain degree of steel standardization.

*See page XVII for committee list

Strength Grades and Property Classes

The strength level of a bolt, stud or nut is designated by its strength grade or property class number—the greater the number, the higher the strength level. A second number, following a decimal point, is sometimes added to represent a variation of the product within the general strength level. SAE strength grade numbers are often used for mechanical fasteners made to the United States system of inch dimensions, while the property class numbers defined in ISO Recommendation R898 are used for metric fasteners. Strength and property designations of bolts and studs are based on tensile (breaking) strength, while those of nuts are based on proof stress.

The commonly used strength grades and property classes of steel threaded fasteners are shown in Tables 1 and 2, along with the mechanical properties associated with those grades and classes. As may be seen in these tables, the strength grade numbers cannot be directly converted to a specific strength level. The property class numbers, however, indicate the general level of tensile strength or proof stress in MPa; for example, ISO class 9 nuts have a proof stress ranging from 900 to 990 MPa. The number following the decimal point in a class number for a bolt or stud indicates the ratio of the yield strength to the tensile strength; for example, an ISO class 5.8 stud has a tensile strength of 520 MPa and a yield strength of 420 MPa. The mechanical properties of bolt and stud classes are compared in Table 3 to those of bolt and stud grades. The mechanical properties of these various grades and classes of steel are discussed in greater detail in a subsequent section of this article.

Steels for Threaded Fasteners

Many different low-carbon, medium-carbon and alloy constructional steels are used to make all of the various strength grades and property classes of threaded steel fasteners suitable for service between −50 and +200 °C (−65 and +400 °F). The chemical compositions of those steels used for the grades and classes of threaded steel fasteners listed in Tables 1 and 2 are given in Tables 4 and 5. The following sections discuss the selection and processing of these steels for each type of end product: bolt, stud or nut.

Bolt Steels. As previously noted, the producer of bolts is free to use any steel within the grade and class limitations of Table 4 to attain the properties of the specified grade or class in Table 1. As strength requirements and section size increase, hardenability becomes the most important factor.

Sometimes, specific applications require closer control, and the purchaser will consequently specify the steel composition. However, except where a particular steel is absolutely necessary, this practice is losing favor. A specific steel may not be well-suited to the fastener producer's processing facilities; specification of such a steel may result in unnecessarily high cost to the purchaser.

Table 1 Mechanical properties of steel bolts and studs (a)(b)

Strength grade or property class	Nominal diameter	Proof stress (c) MPa	Proof stress (c) ksi	Min tensile strength (d) MPa	Min tensile strength (d) ksi	Min yield strength (e) (f) MPa	Min yield strength (e) (f) ksi	Min elongation, %(e)	Rockwell hardness Surface 30N, min	Rockwell hardness Core min	Rockwell hardness Core max
SAE Strength Grades (g)											
1	¼-1½ in.	225	33	415	60	250(h)	36(h)	18	...	B70	B100
2	¼-¾ in. (j)	380	55	510	74	395	57	18	...	B80	B100
	>¾-1½ in.	225	33	415	60	250(h)	36(h)	18	...	B70	B100
4 (k)	¼-1½ in.	...	...	795	115	690	100	10	...	C22	C32
5	¼-1 in.	585	85	830	120	635	92	14	54	C25	C34
	>1-1½ in	510	74	725	105	560	81	14	50	C19	C30
5.2 (m)	¼-1 in.	585	85	830	120	635	92	14	56	C26	C36
7 (m) (n)	¼-1½ in.	725	105	915	133	795	115	12	54	C28	C34
8	¼-1½ in.	830	120	1035	150	895	130	12	58.6	C33	C39
8.1 (k)	¼-1½ in.	830	120	1035	150	895	130	10	...	C32	C38
8.2 (m)	¼-1 in.	830	120	1035	150	895	130	10	61	C35	C42
ISO Property Classes (p)											
4.6	5-36 mm	225	33	400	58	240(h)	35(h)	22	...	B67	B100
4.8	1.6-16 mm	310	45	420	61	340	49	14	...	B71	B100
5.8	5-24 mm(g)	380	55	520	75	420	61	10	...	B82	B100
8.8	16-36 mm	600	87	830	120	660	96	12	54	C24	C34
9.8	1.6-16 mm	650	94	900	131	720	104	10	56	C27	C36
10.9	5-36 mm	830	120	1040	151	940	136	9	59	C33	C39
12.9	1.6-36 mm	970	141	1220	177	1100	160	8	63	C39	C44

(a) Including cap screws and U-bolts. (b) The minimum reduction of area for specimens machined from all grades and classes of fasteners listed is 35%. (c) Determined on full size fasteners. (d) Determined on both full size fasteners and specimens machined from fasteners. (e) Determined on specimens machined from fasteners. (f) Yield strength is stress to produce a permanent set of 0.2%. (g) Data from SAE Standard J429. (h) Yield strength instead is stress at 0.2%. (j) For bolts and screws longer than 6 in., grade 1 requirements apply. (k) Studs only. (m) Bolts and screws only. (n) Roll threaded after heat treatment. (p) Data from IFI Standard 501. Values for fasteners with coarse threads. (q) Requirements apply to bolts 150 mm long and shorter, and to studs of all lengths.

Most bolts are made by cold or hot heading. Resulfurized steels are not suitable for heading because they will split. However, if splitting did not occur, their high cost could not be justified against the small amount of machining necessary to produce a headed bolt. Only a few bolts are machined from bars; these usually are of special design or the required quantities are extremely small. For such bolts, the extra cost for resulfurized grades of steel may be justified. For example, 1541 steel might be selected to make headed bolts of a specific size. If the same bolts were to be machined from bars, 1141 steel would be selected because of its superior machinability. Special bolts can usually be made more economically by machining from oversize upset blanks instead of from bars.

Stud Steels. The chemical compositions of studs (and U-bolts, which are basically studs formed into a U-shape) are given in Table 4; special modifications that apply to studs may be found in the footnotes. Because studs (and U-bolts) are not headed, it is not essential to restrict sulfur. It may be noted that grade 2 and class 5.8 permit 0.33% maximum sulfur, while grade 5 and classes 8.8 and 9.8 permit 0.13% maximum sulfur.

Table 2 Mechanical properties of steel nuts (a)

Strength grade or property class	Nominal diameter	Proof stress (b) MPa	Proof stress (b) ksi	Hardness, HRC min	Hardness, HRC max
SAE Strength Grades (c)					
2 (d)	¼-1½ in.	620	90	...	32
5	¼-1 in.	830	120(e)	...	32
		750	109(f)	...	32
	>1-1½ in.	725	105(e)	...	32
		650	94(f)	...	32
8	¼-⅝ in.	1035	150	24	32
	>⅝-1 in.	1035	150	26	34
	>1-1½ in.	1035	150	26	36
ISO Property Classes (g)					
5 (h)	5-36 mm	570	83	...	30
9 (h)	1.6-4 mm	900	131	...	30
	4-16 mm	990	144	...	30
	20-36 mm	910	132	...	30
10 (h)	5-36 mm	1040	151	26	36

(a) Not normally including jam, slotted, castle, heavy or thick nuts. (b) Determined on full size nuts. (c) Data from SAE Standard J995. (d) Normally applicable only to square nuts, which are normally available only in grade 2. (e) For UNC, 9 UN thread series. (f) For UNF, 12 UN threaded series and finer. (g) Data from IFI Standard 508. Values for fasteners with coarse threads. (h) For hex nuts only.

Stud (or U-bolt) threads, however, are not necessarily cut, but may be rolled for economy and good thread shape. A smaller diameter rod must be used to roll a specific thread size than to cut the same thread size from rod. For example, a ½–13 thread could be cut from a rod 0.500 in. in diameter; a smaller diameter rod would be used to roll the same size threads. Grades 4 and 8.1 are made from a medium-carbon steel and obtain their mechanical properties not from quenching and tempering, but from being drawn through a die with special processes. They are particularly suitable for studs, for these materials can-

Table 3 Corresponding property classes and strength grades of steel bolts and studs

ISO property class	Corresponding SAE strength grade	Tensile strength Nominal MPa	Tensile strength Min, MPa	Tensile strength Min, ksi(a)	Yield strength Min, MPa	Yield strength Min, ksi(a)
3.6	...	300	330	48	190	28
4.6	1	400	400	58	240	35
5.6	2	500	500	73	300	48
5.8	...	500	520	75	420	61
6.8	3	600	600	87	480	70
8.8	5	800	830	120	660	96
10.9	8	1000	1040	151	940	136
12.9	...	1200	1220	177	1100	160

(a) Converted values

Table 4 Chemical compositions of steel bolts and studs (a)

Strength grade or property class	Material and treatment	Composition, % (b) C	P	S	Others
SAE Strength Grades (c)					
1	Low- or medium-carbon steel	0.55	0.048	0.058	...
2	Low- or medium-carbon steel	0.28(d)	0.048	0.058(e)	...
4	Medium-carbon cold drawn steel	0.55	0.048	0.058	...
5	Medium-carbon steel, quenched and tempered	0.28-0.55	0.048	0.058(f)	...
5.2	Low-carbon martensitic steel, fully killed, fine grain, quenched and tempered	0.15-0.25	0.048	0.058	(g)
7	Medium-carbon alloy steel, quenched and tempered (h, j)	0.28-0.55	0.040	0.045	...
8	Medium-carbon alloy steel, quenched and tempered (h, j)	0.28-0.55	0.040	0.045	...
8.1	Drawn steel for elevated-temperature service: medium-carbon alloy steel or 1541 steel	0.28-0.55	0.048	0.058	...
8.2	Low-carbon martensitic steel, fully killed, fine grain, quenched and tempered (k)	0.15-0.25	0.048	0.058	(g)
ISO Property Classes (m)					
4.6	Low- or medium-carbon steel	0.55	0.048	0.058	...
4.8	Low- or medium-carbon steel, partially or fully annealed as required	0.55	0.048	0.058	...
5.8	Low- or medium-carbon steel, cold worked	0.13-0.55	0.048	0.058(e)	...
8.8	Medium-carbon steel, quenched and tempered(n) (p)	0.28-0.55	0.048	0.058(f)	...
9.8	Medium-carbon steel, quenched and tempered(n)	0.28-0.55	0.048	0.058(f)	...
10.9	Medium-carbon alloy steel, quenched and tempered(h,q) (k,n)	0.28-0.55	0.040	0.045	...
12.9	Alloy steel, quenched and tempered	0.31-0.65	0.045	0.045	(r)

(a) Including cap screws and U-bolts. (b) All values are for product analysis; where a single value is shown, it is a maximum. Unless otherwise noted, manganese contents of the steels in this table are not specified. (c) Data from SAE Standard J429. (d) Carbon may by 0.55% max for all sizes and lengths of studs and for bolts larger than ¾ in. diameter and/or longer than 6 in. (e) For studs only, sulfur may be 0.33% max. (f) For studs only, sulfur may be 0.13% max. (g) 0.74 min Mn and 0.0005 min B. (h) Fine grain steel with hardenability that will produce 47 HRC min at the center of a transverse section one diameter from the threaded end of the fastener after oil quenching (see SAE J407). (j) For diameters of ¼ through ¾ in., carbon steel may be used by agreement. At producer's option, 1541 steel, oil quenched and tempered, may be used for diameters through 7/16 in. (k) Steel with hardenability that will produce 38 HRC min at the center of a transverse section one diameter from the threaded end of the fastener after quenching. (m) Data from IFI Standard 501. (n) For diameters through 24 mm, unless otherwise specified by the customer, the producer may use a low-carbon martensitic steel with 0.15 to 0.40 C, 0.74 min Mn, 0.048 max P, 0.058 max S and 0.0005 min B. (p) At producer's option, medium-carbon alloy steel may be used for diameters over 24 mm. (q) For diameters through 20 mm, carbon steel may be used by agreement. At producer's option, 1541 steel, oil quenched and tempered, may be used for diameters through 12 mm. (r) One or more of the alloying elements chromium, nickel, molybdenum or vanadium shall be present in the steel in sufficient quantity to assure that the specified mechanical properties are met after oil quenching and tempering.

not readily be formed into bolts.

Selection of Steel for Bolts and Studs. The following guidelines should be consulted before selecting steel for bolts and studs (including cap screws and U-bolts):

1. Bolts over 150 mm (6 in.) long or over 19 mm. (¾ in.) in diameter are usually hot headed.
2. Strength requirements for steels for grade 1 bolts can be met with hot rolled low-carbon steels.
3. The strength requirements for steels for grade 2 bolts 19 mm (¾ in.) and less in diameter can be met with cold drawn low-carbon steels; sizes over 19 mm (¾ in.) in diameter require hot rolled low-carbon steel only, but may be made of cold finished material.
4. Grade 4 fasteners (studs only) require a cold finished medium-carbon steel, specially processed to obtain higher than normal strength. Resulfurized steels are acceptable.
5. Grade 5 bolts and studs require quenched and tempered steel. The choice among carbon, 1541 and alloy steel will vary with the hardenability of the material, the size of the fastener, and the quench employed. Cost dictates the use of carbon steel, including 1541; however, the threading practice (before or after hardening) determines the severity of quench that can be used if quench cracks in the threads are to be avoided. Figure 1 shows cost-hardenability relationships for both oil- and water-quenched steels. An increase in hardenability does not necessarily mean an increase in cost per pound. Figure 1 is not intended to prescribe or imply the use of water quenching for alloy steels that are normally oil quenched. These data are presented only to show the economic advantages of water quenching when it can be properly and successfully applied to the product being heat treated.
6. Fasteners made to grade 7 and 8 specifications normally require alloy steel. This steel is selected on a hardenability basis so a minimum of 90% martensite exists at the center after oil quenching. This requirement ensures fasteners of the highest quality. Grade 7 bolts must be roll threaded after heat treatment. This practice substantially increases the fatigue limit in the threaded section, as shown in Fig. 2. Other factors being equal, a bolt with threads properly rolled after heat treatment—that is, free from mechanical imper-

3. THERMAL EVALUATION

3.1 Discussion

The principal feature of the thermal design is that it is completely passive; that is, no operating hardware is needed to adequately cool the package due to the heat generated by the radioactive source. The heat generation design basis is 240 watts, which corresponds to the decay heat of approximately 15,000 curies of cobalt-60. Most of this energy is deposited within about a two inch radius sphere centered at the source capsule.

The heat generated is transferred to the surface of the shipping/transfer cask (S/TC), principally by conduction through the lead, steel, and tungsten alloy materials which, except for clearances, fill the two foot diameter container. From the surface of the cask, the decay heat is transferred by conduction, convection, and radiation through an air space, the Wooden Protective Jacket (WPJ), another air space, and through the Steel Shell to the surroundings.

The other normal transportation heat load is that imposed by insolation. The design basis solar load on the external surface of the package, as prescribed in 71.71 (c)(1), is greater than the decay heat generation by about a factor of 15. It is a cyclical load, 12 hours on and 12 off. The influence of the insolation heat load on the inner container is damped by the low thermal conductivity of the Wooden Protective Jacket. In insolation tests conducted at Neutron Products, Inc. over a seven day period, the net effect of the regulation design basis heat load was to raise the surface temperature of the inner container a maximum of 27° at the equilibrium condition. After the third day, the surface temperature variation of the inner cask remained within a band of 3°F, even though the heating lamps remained on the 12 hours on and off cycle, and the overpack Steel Shell temperature cycled over a range of about 30°F. This shows that the thermal behavior of the inner container and the overpack are not tightly coupled. As a result, the thermal behavior of the inner container and the overpack can be treated independently and then combined in a simple manner to assess the thermal behavior of the total package.

Using the results of the insolation tests and a simplified thermal model for the inner cask, the maximum surface temperature of the inner cask was calculated to be 265°F for a 240 watt source under normal transport conditions. The corresponding maximum source capsule surface temperature is estimated at less than 550°F.

Maximum package component temperatures used to evaluate thermal stresses under normal transport conditions are listed in Table 3.1.1.

The principal package protection under accidental fire conditions is provided by the overpack Wooden Protective Jacket. The jacket design is based on criteria established, in large part, on the Sandia test program results cited previously in connection with the drop tests. The minimum requirements developed are substantially those set forth in 49 CFR 178.194, specification 20WC Wooden Protective Jacket. The present package overpack meets or exceeds these requirements.

Internal temperatures of the S/TC inner container under hypothetical accident fire conditions were calculated. Using nominal values for the input parameter, the maximum overpack backface temperature (the protective jacket inner cavity surface) was 370^{o}F. This, in turn, resulted in inner cask maximum component temperatures 125^{o}F greater than those listed in Table 3.1.1. These accident temperature conditions do not result in structural loadings that are significantly different from those imposed under maximum normal transport conditions. Lead melting would not occur. Reasonable differences from nominal for the value of input variables do not alter these conclusions.

TABLE 3.1.1

MAXIMUM PACKAGE TEMPERATURES
UNDER NORMAL TRANSPORT CONDITIONS[(1)]

Outside Shell Surface	135°F	(57°C)
Outside Wooden Protective Jacket Surface	130°F	(54°C)
Inside Wooden Protective Jacket Surface	250°F	(121°C)
S/TC Surface	265°F	(129°C)
S/TC Shell Liner and Drum O.D. (Local Max.)	330°F	(165°C)
S/TC Drum Liner (Local Max.)	425°F	(218°C)
Source Capsule Surface	550°F	(288°C)

(1) 240 watts corresponding to 15,000 curies of cobalt-60, and the insolation heat load prescribed in 71.71(c)(1) normalized to a reference ambient temperature of 100°F (38°C).

3.2 Summary of Thermal Properties of Materials

The thermophysical properties of all of the materials used in the thermal evaluation are listed in Table 3.2. Also provided are the temperature range of application and source references.

TABLE 3.2

THERMAL PROPERTIES OF MATERIALS USED IN EVALUATION

Material/Property	Value	Temp. °F (Range)	Reference (Page)
Ferritic Steels			
Density, lbs./in.^{3}	0.284	RT-600	1.(312)
Thermal Conductivity, B/hr. ft. °F	25	RT-600	2. (83)
Specific Heat, B/lb. °F	0.125	RT-600	1.(313)
Austenitic Steels			
Density, lbs./in.^{3}	0.288	RT-600	1.(312)
Thermal Conductivity, B/hr. ft. °F	9.5	RT-300	2. (88)
	10.5	450	
Specific Heat, B/lb. °F	0.125	RT-600	1.(313)
Lead			
Density, lbs./in.^{3}	0.41	RT	1.(960)
Thermal Conductivity, B/hr. ft. °F	19	RT-600	3.(380)
Specific Heat, B/lb. °F	.032	100-500	1.(399)
Plywood			
Density, lbs./ft.^{3}	36	RT-400	6.
Thermal Conductivity, B/hr. ft. °F	.085	RT	5. (13)
Specific Heat, B/lb. °F	0.65	RT-200	4.(300)

<u>References for Table 3.2</u>

1. Metals Handbook, American Society for Metals (1948)

2. Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, Sec. III, Div. 1, Appendices (1983)

3. W. H. McAdams, Heat Transmission, Second Edition (1942)

4. L. S. Marks, Mechanical Engineers Handbook, Fourth Edition (1941)

5. Applications Summary, American Plywood Association (1981)

6. Measured (as plywood composite)

3.3 Technical Specification of Components

The principal package specifications are material specifications which are listed along with the mechanical properties in Section 2.3 and the thermal properties in Section 3.2. There are no valves or any other active components utilized in the package construction.

3.4 Thermal Evaluation for Normal Conditions of Transport

Evaluation of the package behavior under the extremes of normal transport is based on results from testing of a functional transportation package. Tests were conducted under four different internal heat loads while concurrent exterior insolation heat loads meeting or exceeding those prescribed in 10 CFR 71.71(c)(1) were imposed. The packages tested were instrumented with specially installed thermocouples. Detailed information for evaluation was obtained directly from test measurements or calculated using test calibrated simple analytical models. The package was evaluated for all of the thermal conditions identified in 10 CFR 71.71.

3.4.1 Thermal Model

3.4.1.1 Analytical Model. For most of the thermal evaluation an analytical model comprised of concentric, spherical shells was used. Representative thermal and physical properties were determined for each shell. Internal heating was taken as being uniformly generated in an innermost ball and the heat was postulated to flow radially outward through successive shells. For external thermal input such as insolation or, in the case of accident conditions, fire loads, heat flow was postulated radially inward. For such a one dimensional representation, the concentric sphere model best suited the source as well as the package geometry. Both overpack components are cylinders in which the height is comparable in dimension to the diameter.

Thermophysical properties were considered uniform within each shell and were established based on a weighted mass or volume basis. Where necessary, adjustments to physical constants were made based on measurements from the package insolation tests. The adjustments in thermal conductance, for example, permitted compensation for gaps and contact resistance without inordinately complicating the model.

The model and underlying assumptions, including determination of principal parameters, are described in Appendix 3.6.1.

3.4.1.2 Test Model. Tests were conducted using a functional transportation package which was instrumented with thermocouples to obtain inner cask and overpack temperatures under standard insolation conditions. Internal, as well as surface, temperatures were measured for the inner cask and overpack. The test geometry was identical to the application package.

A total of four tests were run. In two of the tests the internal heat generation was simulated by electrical resistance heaters of 110 watts and 235 watts corresponding to 7,000 curies and 15,000 curies, respectively. In the remaining two tests, cobalt-60 was employed. The source strengths were 6,750 curies (107 watts) and 9,250 curies (146 watts). For all tests insolation heating was provided by infrared heat lamps totaling 4.5 kw input.

A summary of the test results is provided in Appendix 3.6.2, along with diagrams showing the location of the temperature measurements.

3.4.2 Maximum Temperatures

The maximum temperature of principal package components under normal transport conditions are provided in Table 3.1.1. These include the regulatory insolation load as defined in 10 CFR 71.71(c)(1). At an ambient temperature of 100°F, the maximum component temperatures listed would each be approximately 30°F lower in the absence of the insolation thermal load.

The maximum gasket temperature is below 300°F and the maximum lead temperature is 425°F. The gasketing material can withstand service temperatures up to 550°F and the maximum lead temperature is well below the lead melting point of 621°F. The temperature considerations and calculations are shown in Appendix 3.6.3.

The maximum source capsule temperature of 550°F is well below any weld sensitization temperature for the austenitic steel encapsulating material.

3.4.3 Minimum Temperatures

The minimum design basis temperatures could occur only with an empty container, which is an infrequent mode of transport. Nevertheless, all of the package materials are suitable for use at the specification ambient temperature of -40°F.

When loaded with a source and otherwise being used within the design basis ambient conditions, no minimum heat load is required for safe transport of the package. A fully loaded (240 watts) package at an ambient temperature of -40°F in still air and shade would not experience significantly different component temperature differences and, hence, thermal stresses than those associated with the high limit ambient temperature. No limiting safety condition is seen at the fully loaded, low temperature operating condition.

3.4.4 Maximum Internal Pressure

The cask is loaded dry so that the only anticipated pressure loading results from heating of the air within the enclosed cavity. In loading sources, the container internals heat up in the interval, normally less than one hour, after the source is loaded and before the closure is made. The air in the gaps heats up along with the metal components, thereby reducing subsequent pressure build up when the container is closed. However, even assuming room temperature air were sealed in the cavity void space and that it was subsequently all heated to the maximum source surface temperature (550°F), the pressure build up would be only 13.3 psi. A more plausible maximum pressure build up would be about half this value, or 7 psig for an internal air temperature in equilibrium with its surrounding metal. Even this is a postulated temperature limit rather than one likely to be encountered. In either case, the stress levels developed are not significant in evaluating the integrity of the components. See Appendix 3.6.4.

3.4.5 Maximum Thermal Stresses

The only potentially significant thermal loading impacting the structural integrity of the inner container under normal transport conditions results from the differential heating of the shell liner and the drum liner. The considerations and calculations are given in Appendix 3.6.5 for temperature and in Appendix 2.10.2 for the stresses. The stress levels are modest.

For the shell, the highest average temperature difference between the shell and internal cylindrical liner is calculated to be 15°F, which results in an axial compressive stress in the liner of less than 3,000 psi. The minimum yield strength is 31,200 psi for the material. The minimum working margin exceeds ten in compression and six in shear. This is a very low cycle displacement stress, so that there is no problem of fatigue failure.

In the case of the stainless steel drum liner, the highest average temperature difference between the source chamber liner and the remainder of the drum structure is 33°F, which results in an axial compressive stress in the liner of less than 6,000 psi compared with a minimum yield strength of 22,500 psi for the type 304 stainless steel. The minimum working margin is 3.9 in compression and 2.3 in shear. Again, this is a very low cycle displacement stress.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

The package will satisfactorily serve its intended function under the normal transport conditions identified in 10 CFR Part 71 and will continue to do so even if many of the limiting conditions should be exceeded. The package performance is not sensitive to thermally imposed loads. For example, the maximum lead temperature in the inner cask would not exceed 600°F, even if the thermal rating of the source were exceeded by 50%.

In still air and shade, under an ambient temperature of 100°F, the accessible surface temperature of the package would not exceed approximately 105°F when carrying a 15,000 curie cobalt-60 source (240 watts) representative of the maximum package rating. The allowable limit in a nonexclusive use shipment is 122°F (10 CFR 71.43(g)).

Anticipated thermal and pressure loads result in stresses well below any structural limitations on the package. The principal results of the thermal evaluation are summarized in Table 3.1.1 and have been used in the Chapter 2 structural evaluation.

At the maximum 240 watt source rating under the most adverse normal transport conditions, the inner container gasket temperature would not exceed 280°F and the source capsule surface temperature would be less than 550°F. For typical normal transport conditions both of these temperatures would be about 100°F lower, even at maximum thermal rating.

3.5 Hypothetical Accident Thermal Evaluation

Under the hypothetical accident conditions, specifically the standard fire, package adequacy was demonstrated in the fire tests conducted by the Sandia Corporation in the early and middle 1960's. This work is summarized in the article by J. A. Sisler referred to previously in connection with the drop tests[1]. A total of 18 wooden wall overpack containers were subjected to one hour open pit petroleum (JP-4) fires in a series of five tests. The fires were characterized as 1,850°F black body temperature equivalents. This represents a more severe condition in both time and temperature than that specified in 10 CFR 71.73(c)(3), which calls for a one half hour 1,475°F fire. The test results bearing on the present application were as follows:

1. Seven of the packages passed the fire tests unconditionally, six were considered conditionally satisfactory, and five failed the fire test.

2. All containers with six inch thick walls passed the fire test unconditionally. (Six inches is the minimum Wooden Protective Jacket wall thickness of the present NPI package.)

3. Two 4,000 pound packages were tested. Both passed the fire test unconditionally. The minimum unburned wood insulation thickness was 3-1/2 inches for one package and 4 inches for the other. Neither package employed a Steel Shell.

4. Maximum internal cavity temperatures were 160°F, or less, for both 4,000 pound packages. Based on the appearances of the internal cavity, it was believed that maximum internal temperatures for all packages with 6 inch thick walls were below 150°F, although this could not be proven because of thermocouple failure. An upper limit to the internal temperature was considered to be 300°F. Ambient temperatures were not reported, but could not have had much influence because the results of tests conducted in August were similar to those conducted in January.

[1]The report, "New Developments in Accident Resistant Containers for Radioactive Materials" from the Proceedings of the International Symposium for Packaging and Transportation of Radioactive Materials, January 12-15, 1965, SC-RR-65-98, Pages 141-185, has been included in Appendix 2. Both drop and fire tests are summarized.

Pertinent conclusions concerning proper design and construction of the Wooden Protective Jacket and its behavior under the test fire conditions are as follows:

1. Overall, Douglas Fir plywood is the favored wooden construction material for fire resistance.

2. Laminated Douglas Fir plywood walls, six inches thick, are more than adequate to prevent damaging heat transfer from the fire from reaching the inner container.

3. In the absence of heat generation by radiation sources in the inner container, the overpack cavity will experience only a modest temperature rise, typically 25°F, through the course of the fire for an adequately sealed overpack.

4. A small amount of plywood delamination does not have an adverse effect on the internal temperature or the effectiveness of the overpack.

5. In the absence of internal heat generation, the temperature within the overpack cavity is likely to peak at less than 150°F and probably not exceed 300°F.

Results of these tests provide the basis for design of a satisfactory fire protection jacket for the inner lead shielded container of a shipping package. The NPI package under review more than meets the minimum requirements of overpack thickness and arrangement taught by these experiments. In addition, the NPI overpack includes an enclosing Steel Shell not employed in these experiments, which will further lag the package.

Results of the test program above notwithstanding, calculations using realistic, although simplified models, were made to provide an indication of the internal temperatures that might be expected in the course of the hypothetical accident as represented by the standard 1,475°F, one half hour fire. The calculations, along with the underlying assumptions, models, and input parameters, are provided in Appendix 3.5. The principal results of the calculation are the following:

1. At its maximum thermal rating of 240 watts (corresponding to a content of approximately 15,000 curies of cobalt-60), the adiabatic heating rate of the S/TC inner container is 5.4°F/hr. At this heating rate and no external cooling, it would take 36 hours, starting from the maximum normal transport conditions identified in Table 3.1.1, before any cask lead would reach the 621°F melting temperature.

2. Using the post fire adiabatic equilibrium temperature of the Wooden Protective Jacket following the standard 1,475°F, one half hour fire as an upper limit to the backface temperature, the maximum overpack inner surface (backface) temperature would be 370°F.

3. Postulating the internal heating rate and maximum backface temperature given above, the maximum S/TC inner temperatures in the course of the hypothetical accident fire were calculated to be 120°F higher than the maximum values for normal transport listed in Table 3.1.1. This does not result in exceeding any limiting condition for either inner cask or source capsule. For example, the maximum lead temperature (local) remains more than 70°F below the melting temperature of 621°F during the course of the accident.

Taken together with the results of the several test programs, these calculated results show that the hypothetical accident does not produce conditions which will cause melting of the lead shielding, compromise radioactive containment, nor significantly change the radiation protective configuration of the package.

3.5.1 Thermal Model

3.5.1.1 Analytical Model. The analytical model used for evaluation of the inner cask (S/TC) under hypothetical accident conditions was the same as that used for normal transport assessments. The range of application permitted substantially the same input parameters to be used. The overpack prevents excessively high temperatures under the standard fire conditions.

For quantitative evaluation of the overpack under the fire condition, calculations based on the Integral Method(1) were used. In the cited work, approximate solutions to the thermal conduction (Fourier) equations were presented for several common geometries and boundary conditions utilizing the heat penetration depth concept. The spherical representations were used in the evaluation. The almost square configuration of the overpack Wooden Protective Jacket (44 inches in outside diameter and 45 inches high) best suited spherical geometry simulation. This selection was also indicated from comparison of measured with calculated temperatures in the normal transport evaluation.

The relationships used are detailed in Appendix 3.6.6. The post-fire adiabatic equilibrium temperature was used as the upper limit of the overpack (WPJ) backface temperature. The temperature drop through the outer Steel Shell was not included in the calculation. The adiabatic temperature rise rate of the S/TC was calculated from weighted specific heats of the constituent materials and the maximum rated internal heat generation rate.

3.5.1.2 Test Model. No physical models specific to this application were tested under hypothetical accident conditions. The experimental behavior of Wooden Protective Jackets under fire conditions was well established in the Sandia tests. The pertinent findings are summarized in Section 3.5 and the

(1) William H. Lake, "Thermal Analysis of Packaging Using the Integral Method," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Materials, New Orleans, 1983 (PATRAM 83)

report is included in Appendix 2.10.9. Most of the Sandia fire tests were done using only the Wooden Protective Jackets as the overpack. In the present fire evaluation, no credit was taken for the Steel Shell surrounding the wooden jacket, which would further lag the packaging.

3.5.2 Package Conditions and Environment

Based on the drop analysis, no significant effect on the thermal properties of the package is expected. While the overpack outer Steel Shell would be bent and crushed as a result of the free drop and possibly the puncture test, and the outer portion of the Wooden Protective Jacket that took the principal impact would be shredded, the integrity of the unit as an effective fire seal would not be affected, based on the Sandia test results. In the Sandia tests it was also shown that a small amount of plywood delamination does not have an adverse influence on the internal temperature nor the effectiveness of the overpack.

The most adverse case was considered to be a fully loaded cask, at maximum temperature, normal transport, initial conditions subjected sequentially to the drop and fire, in either order. The conditions in Table 3.1.1 were postulated as the starting point for the hypothetical accident.

3.5.3 Package Temperature

The evaluation of peak temperature and temperature differences is simplified by taking advantage of the slow response of the Wooden Protective Jacket to imposed changes in temperature, i.e., the fire conditions. The intense heating of the fire is over before the temperature of the backface of the overpack starts to rise significantly. The backface temperature rises to a peak and then decreases. The timing of the peak is not important, but the magnitude is. The magnitude is less than the adiabatic equilibrium temperatures of the overpack calculated from the time that heating ceases. In the present instance, the peak backface temperature was taken as equal to the adiabatic equilibrium temperature and was calculated to be 370°F for the one half hour, 1,475°F fire. The calculation is detailed in Appendix 3.6.6.

While the overpack backface is rising in temperature, the inner cask is also heating up. The adiabatic heating rate of the inner cask is 5.4°F/hr. at the maximum cask rating of 240 watts. The peak inner container surface temperature will not exceed the overpack peak backface temperature plus the temperature drop needed to transfer the 240 watt heating load to the overpack under equilibrium steady state condition, in this case 370°F plus 15°F = 385°F. The inner cask internal temperature distribution does not vary significantly from that for the corresponding heating load under normal transport conditions.

The envelope of limiting conditions can be assigned as the peak temperature under the HAC for evaluation of the package. The temperatures are listed in Table 3.5.3.1.

TABLE 3.5.3.1

MAXIMUM PACKAGE TEMPERATURES UNDER HYPOTHETICAL ACCIDENT CONDITIONS[(1)]

Inside W P J Surface	370°F	(188°C)
S/TC Surface	385°F	(196°C)
S/TC Shell Liner and Drum O.D. (Local Max)	450°F	(232°C)
S/TC Drum Liner (Local Max)	545°F	(285°C)
Source Capsule Surface	670°F	(355°C)

[(1)] 240 watt source corresponding to 15,000 curies of cobalt-60 and a 1,475°F one half hour duration thermally radiative fire.

3.5.4 Maximum Internal Pressure

The maximum pressures developed under the hypothetical accident conditions (HAC) are only slightly higher than those reported in 3.4.4 for the normal transport case. The rationale and calculation is the same as that given in Appendix 3.6.4. For the two cases postulated, the HAC results in pressure of 16.6 psig and 10 psig, which would develop stress levels of 365 psi and 220 psi, respectively. As in the normal transport case, these stress levels are not significant in evaluating the integrity of the components.

3.5.5 Maximum Thermal Stresses

The potential temperature excursions of the S/TC components under hypothetical accident conditions result in temperature differences that fall within the bounds of those evaluated in connection with the maximum normal transport conditions. While the temperature levels are higher, the temperature differences which generate the loads are not exceeded under the accident conditions, because external heat addition tends toward lowering the temperature difference. The maximum thermal load remains on the shell and drum liners and the results of the analyses discussed in Section 3.4.5 apply to the accident conditions.

3.5.6 Evaluation of Package Performance for the Hypothetical Accident Thermal Conditions

The sacrificial element of the packaging under accident conditions is the Wooden Protective Jacket. Tests, analyses, and evaluations indicate that it will maintain integrity to the extent that it will protect the S/TC inner container from an excessive temperature rise under the sequential drop and fire exposure of the prescribed hypothetical accident. Calculations show that the temperature rise of the S/TC would be about 120°F as a result of package exposure to the fire. The Sandia tests support this range of temperature rise for a package with this configuration. This temperature rise does not threaten the integrity of the S/TC and source capsules with regard to both shielding and containment of radioactive material.

The pertinent quantitative information is summarized in Table 3.5.1 and used in Chapter 2 evaluations.

3.6 APPENDIX

3.6.1 Analytical Model

A. Calculations of Temperature Distribution

B. Determination of Principal Model Parameters

3.6.2 Summary of Insolation Tests

3.6.3 Peak Temperature Condition for Normal Transport

A. Initial Conditions

B. S/TC - Inner Container

C. Overpack

D. Summary - Values for Table 3.1.1

3.6.4 Maximum S/TC Internal Pressure

3.6.5 Maximum Thermal Stress Temperatures

A. Drum Sleeve Average

B. Drum Shell (O.D.) Average

C. Shell Liner Average

D. Summary

3.6.6 Hypothetical Accident - Fire Test

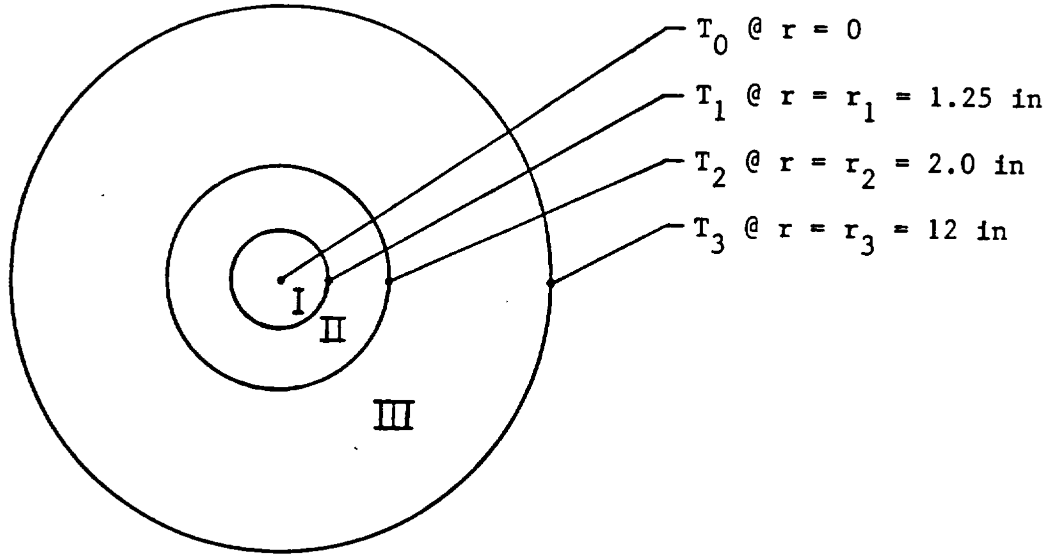
A. Adiabatic Temperature Rise of S/TC

B. Maximum Overpack Backface Temperature

C. Peak S/TC Temperatures

3.6.1 Analytical Model

A. Calculation of Temperature Distribution



- o The model for calculation is three concentric spheres in a steady state.
- o Each region has different characteristics which are determined by back calculation from the results of the insolation experiments.
- o Each region is postulated to have uniform thermal characteristics, i.e., thermal conductivity, K, specific heat, Cp, and density.
- o The physical boundaries of each region are as given above, except for evaluation of electrical heating tests where r_1 = 0.625 and r_2 = 4.25".
- o No compensation was made for eccentricity of the source and outer shell. However, an attempt was made to match region boundaries to actual distances between source center and thermocouples. A 12 inch radius was used for the outer shell.

Region I This is the region in which most of the heat is deposited and roughly corresponds in diameter to that of the drum sleeve. In the model it is postulated that all of the heat released is generated with a uniform volumetric heat generation equal to the total heat release divided by the volume of the region. Temperature difference across the region radially:

$$T_0 - T_1 = Wr_1^2/6K$$

W = Heat generated/unit volume, Btu/ft.^{3}

K = Thermal conductivity, Btu/hr. ft. ^oF

The temperature distribution:

$$T - T_1 = (W/6K)(r_1^2 - r^2) \qquad T_o \geqslant T(r) \geqslant T_1$$

Region II In this region all of the heat passes through the shell from the inside boundary. The outer boundary is approximately the distance from the source center to the drum surface to shell liner interface. The temperature difference across the region:

$$T_1 - T_2 = (q/4\pi K)\ (1/r_1 - 1/r_2)$$

q = Total heat passing through the boundary, Btu/hr.
K = Thermal conductivity

The temperature distribution:

$$T - T_2 = (q/r\pi K)\ (1/r - 1/r_2) \quad T_1 \geqslant T(r) \geqslant T_2$$

Region III Heat flow behaves as in Region II; it is postulated that all of the heat passes through the shell.

The temperature difference radially:

$$T_2 - T_3 = (q/4\pi K)\ (1/r_2 - 1/r_3)$$

q = Total heat passing through the boundary, Btu/hr.
K = Thermal conductivity

The temperature distribution:

$$T - T_3 = (q/4\ \ K)\ (1/r - 1/r_3) \quad T_2 \geqslant T_{(r)} \geqslant T_3$$

B. Determination of Principal Model Parameters

1. Where possible, the physical size of each region was selected based on the location of thermocouples in the insolation tests for simplicity of determining the effective thermal conductance (effective thermal conductivity), or approximately corresponding to physical regions of the S/TC. The boundary radii selected were those identified in the figure of the last section, namely:

   Region I $0 \leqslant r \leqslant r_1 = 1.25$ in. (0.625 in. for elec. heaters)
   Region II $r_1 \leqslant r \leqslant r_2 = 2.0$ in. (4.25 in. for elec. heaters)
   Region III $r_2 \leqslant r \leqslant r_3 = 12$ in.

   No attempt was made to improve test data fit by changing region boundaries.

2. Based only on the materials of construction, the conductances expected would fall in the range of the conductivities for the materials, as shown in Table 3.2. However, the air gaps and contact resistances result in much lower values. Therefore, representative values were developed from temperature

distribution data obtained during insolation testing reported in 3.6.2, following. Rounded values were selected based on matching the experimental data and are as follows:

Region I	K_e = 2.5 B/hr. ft. °F
Region II	K_e = 2.5 B/hr. ft. °F
Region III	K_e = 5.0 B/hr. ft. °F

The comparison of experimental measurements with the calculations, using the above values of conductance and region boundaries, are presented in Table 3.6.1.1. The heating rates used in the evaluation are listed in Table 3.6.1.2.

TABLE 3.6.1.1

COMPARISON OF MEASURED AND CALCULATED INNER CONTAINER (S/TC) TEMPERATURE DIFFERENCES

Test Series	T_0	ΔT_I	T_1	ΔT_{II}	T_2	ΔT_{III}	T_3	Conditions
	Temperature on Temperature Difference, °F							
Test A Radius, in.	0		0.625		4.25		12	7,000 curies
T Measured, °F			411		207		190	110 watts
Δ T Measured, °F				234		17		Electric
Δ T Calculated, °F				195		11		Heating
Test B Radius, in.	0		0.625		4.25		12	15,000 curies
T Measured, °F			711		290		251	251 watts
Δ T Measured, °F				421		39		Electric
Δ T Calculated, °F				417		24		Heating
Test C Radius, in.	0		1.25		2.00		12	6,750 curies
T Measured, °F			253		216		190	107 watts
Δ T Measured, °F				37		26		Cobalt-60
Δ T Calculated, °F		55		41		29		Heating
T Calculated(1), °F	315		260		219		190	
Test D Radius, in.	0		1.25		2.00		12	9,250 curies
T Measured, °F			2.67		206		191	146 watts
Δ T Measured, °F				61		15		Cobalt-60
Δ T Calculated, °F		>76		57		40		Heating
T Calculated(1), °F	364		288		231		191	

(1) Normalized, T_3 Measured = T_3 Calculated

TABLE 3.6.1.2

HEATING RATES USED IN INSOLATION TEST
EVALUATION CALCULATIONS

	Curies or Equivalent	Heating Watts	q Btu/hr.	W_1 Btu/hr. ft.^{3}
Test A	7,000(1)	110	376	NA
Test B	15,000(1)	235	802	NA
Test C	6,770	107	365	77,000(2)
Test D	9,250	146	499	106,000(2)

(1) Simulated by electric heaters, 63.3 ci/watt equivalent

(2) Uniform heat generation over Region I: r_1 = 1.25", vol = 0.00473 ft.^{3}

3.6.2 Summary of Insolation Tests

A series of four package insolation tests were conducted by Neutron Products in the spring and summer of 1977. In two of these tests, the internal heating was simulated by electric resistance heaters. In the other two tests, cobalt-60 sources were used.

All of the tests were done with an operational package, Model NPI 20WC-6, meeting requirements of Certificate of Compliance USA/9201/B( ). It was a lead shielded shipping/transfer cask with a 20WC-6 overpack and was essentially identical in configuration to the application package. Insolation heating was provided by incandescent lamps totaling 4.5 kilowatts which were cycled 12 hours on and 12 hours off. A test series typically lasted 7 to 9 days, during which a cyclical thermal equilibrium was established. The tests met the insolation heating requirements of what is presently prescribed under 10 CFR 71.71 (c)(1).

The test results are summarized in Table 3.6.2.1. Tests A and B employed electric heaters of 110 watts and 235 watts, respectively, to simulate source heating. The heaters were placed in the position normally occupied by a source capsule in the center of one of the drum sleeves with shield plugs on both sides. In Tests C and D the drum was loaded with cobalt-60 sources as in actual transport. In Test C, two sources were used, totaling 6,750 curies (107 watts). In Test D, two sources totaling 9,250 curies (146 watts) were used. The temperatures listed in the table are keyed to the diagram in Figure 3.6.2.1, which shows the location of the thermocouples.

The temperatures listed in Table 3.6.2.1 have all been normalized to an ambient temperature of 100°F by adding the difference between 100°F and the test ambient temperature to all values, so that comparison can be made between tests. Any bias from normalization is likely to result in temperatures slightly high, but in any case, is small.

A radial temperature plot of the test results is provided in Figure 3.6.2.2.

The Test D results (not normalized) have been previously reported in the NPI August 1977 submittal, under Docket No. 71-9102.

TABLE 3.6.2.1

SUMMARY OF NPI INSOLATION TEST RESULTS

	Local Package Temperatures, °F			
Test Series	A	B	C	D
Heating Source	Electric Heaters		Cobalt-60 Sources	
Heating Power, Watts	110	235	107	146
T.C. Location/curie	-	-	6,750	9,250
1. Source chamber or heater	441	711	253	267
2. Source chamber	-	-	245	200
3. Plug chamber	207	290	216	206
4. S/TC outside - top	190	251	191	193
5. S/TC outside - side	190	250	190	192
6. S/TC outside - bottom	190	253	184	185
7. WPJ inside - bottom	181	250	190	185
8. WPJ inside - side	176	224	175	171
9. WPJ inside - top	183	236	181	186
10. WPJ outside - bottom	106	124	119	110
11. WPJ outside - side	113	141	129	131
12. WPJ outside - top	126	126	-	143
13. Steel shell outside - side	102	114	110	131
14. Ambient (normalized)	100	100	100	100

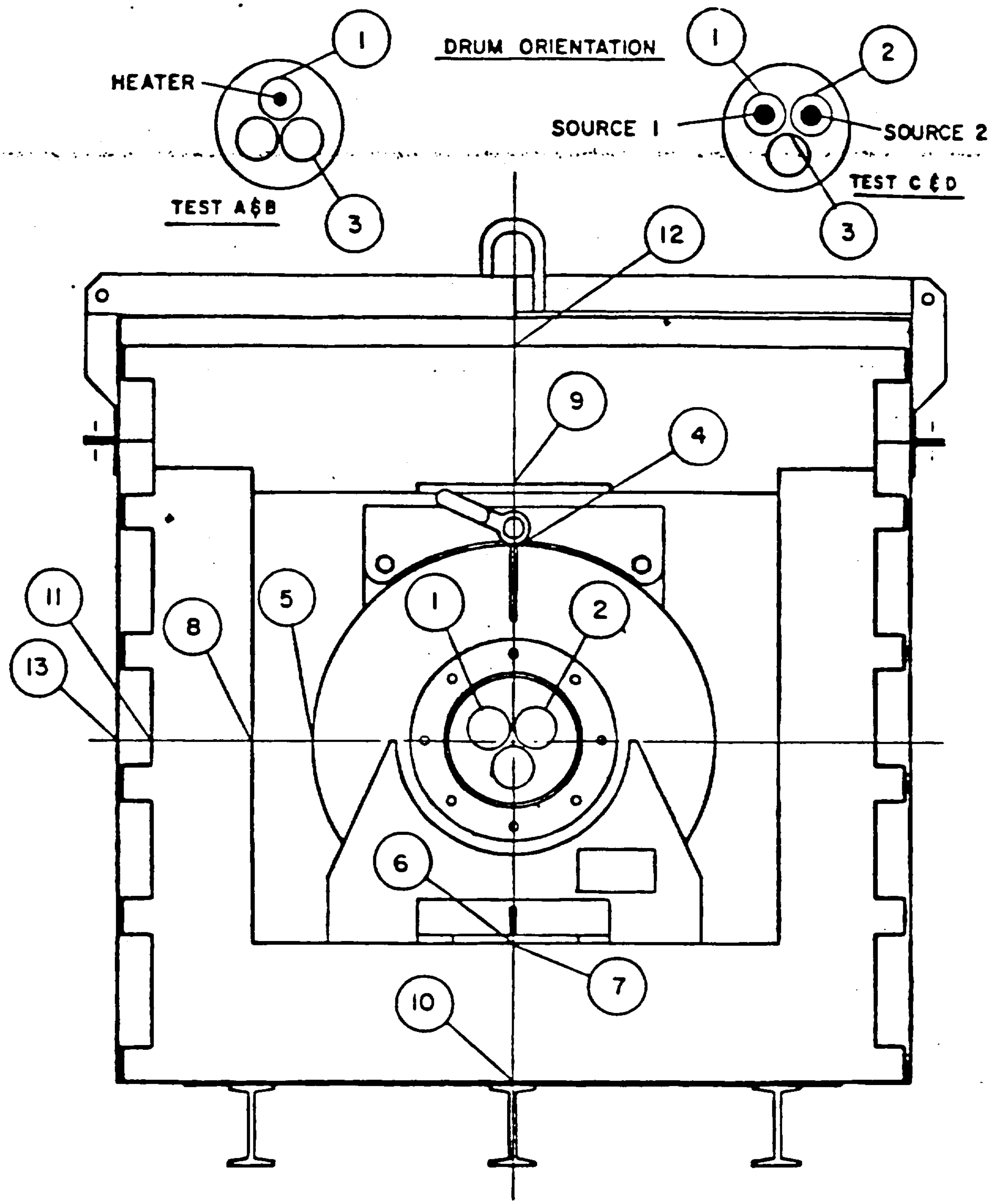


FIGURE 3.6.2.1

LOCATION OF THERMOCOUPLES IN INSOLATION TEST

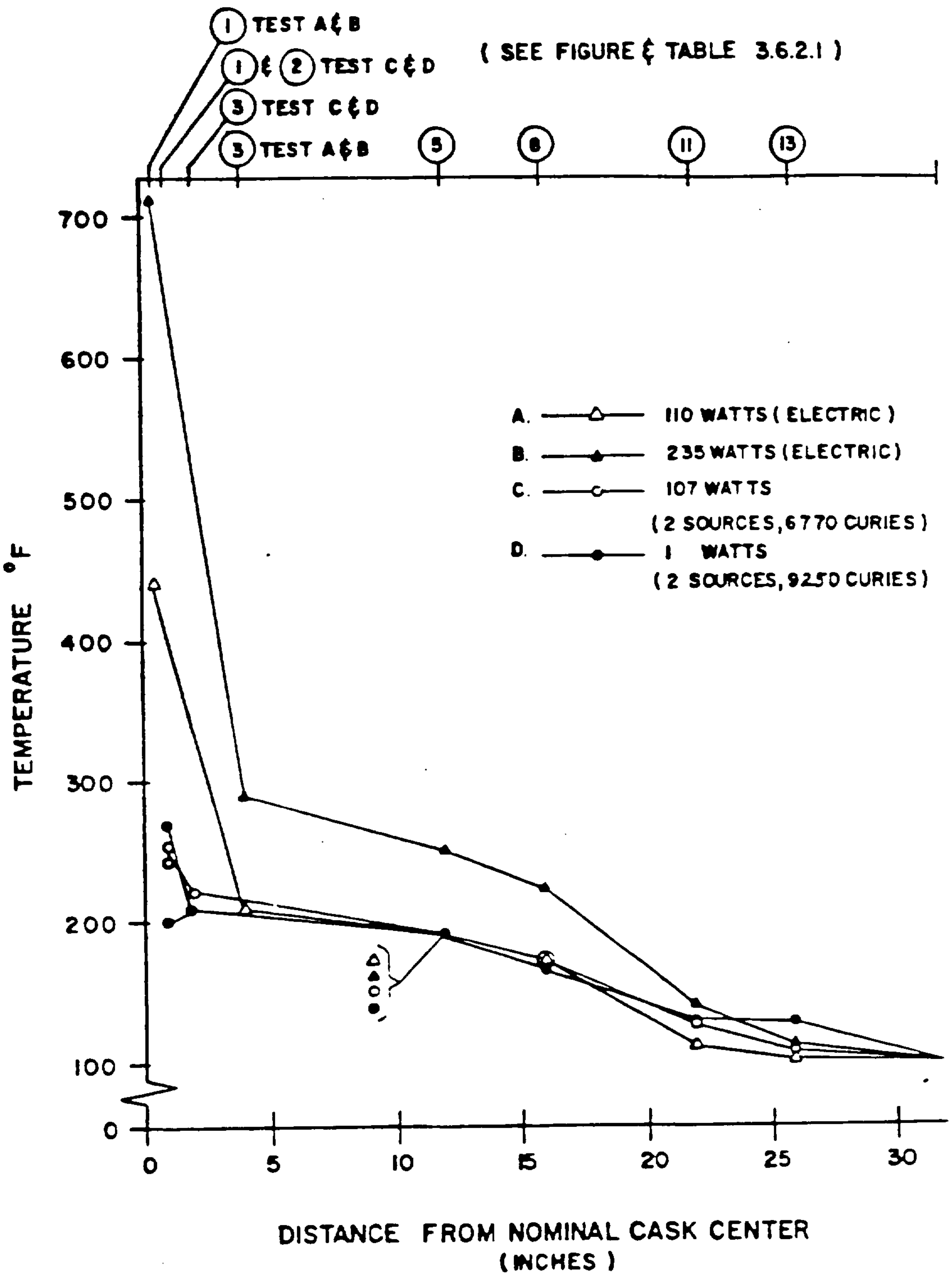


FIGURE 3.6.2.2

INSOLATION TEST RADIAL TEMPERATURE PROFILE

3.6.3 Calculation of Peak Temperature Conditions for Normal Transport

A. Initial Condition

1. S/TC with single 15,000 curie (240 watt) source
2. Ambient air, 100°F
3. Using Test B results for the overpack, the surface temperature of the S/TC for 235 watts was 250 to 253°F. This yields a ΔT from ambient to S/TC surface of 150°F. Increase this value by 10% as an allowance. Resulting base surface S/TC temperature = 265°F.

B. S/TC Inner Container

Using same ground rules as evaluation of experiments (3.6.1) and the following heat generation rate:

15,200 curies, 240 watts, 820 Btu/hr., 173,000 Btu/hr. ft.^{3}

Region I $\quad T_0 - T_1 = [173,000/6(2.5)][1.25/12]^2 = 125°F$

Region II $\quad T_1 - T_2 = [820/4\ (2.5)][(12/1.25) - (12/2)] = 94°F$

Region III $\quad T_2 - T_3 = [820/4\ (2.5)][(12/2 - 1)] = 65°F$

1. The 265°F S/TC temperature is high by the 10% overpack temperature drop allowance. If Test D were used as a base:

   (Test D ΔT) X (power corrections) = comparative value

   91 (15,000/9,250) = 148°F

   S/TC surface temperature @ 100°F ambient = 248°F, which is very close to the value obtained from the Test B results. Continue to use 265°F as maximum S/TC normal transport surface temperature, however.

2. Temperatures:

	r, in
T_3 = 265°F	12.0
T_2 = 265 + 65 = 330°F	2.0
T_1 = 330 + 94 = 424°F	1.25
T_0 = 424 + 125 = 549°F	0.0

3. T_0 is the centerline temperature; however, no structural member is at this temperature. As a conservative convenience, use T_0 as the capsule surface temperature. With this

modification, and rounding T_0 and T_1 to the nearest $5^{o}F$, the values above are the peak normal transport temperatures for the S/TC.

4. If 59.8 curies/watt were used, the heating would be:

   15,000 curies, 251 watts, 856 Btu/hr., 181,000 Btu/hr. $ft.^3$
   $T_3 = 100 + 173 = 273^{o}F$
   $T_2 = 273 + 68 = 341^{o}F$
   $T_1 = 341 + 98 = 439^{o}F$
   $T_0 = 424 + 131 = 570^{o}F$

   Sensitivity to deposited heat is low.

C. Overpack

1. Using Test B results, determine the maximum temperature drop from the S/TC surface to the inside surface of the WPJ:

   $\Delta T = 251 - 237 = 14^{o}F$ @ 235 watts

   The 251 and $237^{o}F$ values are each averages of top, side, and bottom. Use $15^{o}F$ for maximum value (@ 240 watts).

2. A good value for the outside surface (O.S.) temperature of the Wooden Protective Jacket (WPJ) and Steel Shell cannot be obtained directly from the insolation test measurements because of the back heating, i.e., a value for the purpose of determining conductivity or steady state temperature condition associated with the internal heating load. However, a value can be obtained by examining data from the early (nonequilibrium) part of Test D which is provided in the following table:

TEMPERATURES (NOT NORMALIZED), ^{o}F

INSOLATION HEATING		WOODEN PROTECTIVE JACKET ON AMBIENT	WOODEN PROTECTIVE JACKET ON O.S.(1)	WOODEN PROTECTIVE JACKET OFF AMBIENT	WOODEN PROTECTIVE JACKET OFF O.S.	STEEL SHELL ON O.S.	STEEL SHELL OFF O.S.
Day 2	Temp.	–	–	80	84	–	79
	ΔT		–		4		-1(0)
Day 3	Temp.	75	96	76	86.6	83	79
	ΔT		21		10.6	8	3
Day 4	Temp.	73	102	73	86	103	77
	ΔT		29		13	31	4
Day 5	Temp.(2)	71	101	74	87.5	103	79.5
	ΔT		30		13.5	32	5.5
Day 6	Temp.	73	102.6	–	–	106.5	–
	ΔT		29.7		–	33.5	–
Day 7	Temp.	69	101	–	–	101	–
	ΔT		32		–	32	–
Day 8	Temp.	71	100	–	–	102	–
	ΔT		29		–	31	–
Day 9	Temp.	72	102	–	–	104	–
	ΔT		30		–	32	–

(1) Outside surface

(2) Values following the fifth day did not change significantly

From the data above, the best reference estimate shell temperatures and differences from ambient are:

Power OFF	$\Delta T = 5^{o}$	$T = 105^{o}F$
Power ON	$\Delta T = 30^{o}$	$T = 130^{o}F$

The corresponding estimate for the outside surface of the WPJ is:

Power OFF	$\Delta T = 15^{o}$ (To ambient)	$T = 115^{o}F$
Power ON	$\Delta T = 30^{o}$ (To ambient)	$T = 130^{o}F$

To get a consistent set of maxima:

Ambient	100°F
Outside Shell Surface	135°F
Outside WPJ Surface	130°F

E. Summary values for Table 3.1.1, Maximum Package Temperature Under Normal Transport Conditions:

Outside Shell Surface	135°F	(57°C)
Outside WPJ Surface	130°F	(54°C)
Inside WPJ Surface	250°F	(121°C)
S/TC Surface	265°F	(129°C)
S/TC Shell Liner and Drum O.D. (Local Max.)	330°F	(165°C)
S/TC Drum Liner (Local Max.)	425°F	(218°C)
Source Capsule Surface	550°F	(288°C)

3.6.4 Maximum Internal Pressure

The maximum cavity pressure would result from heating air sealed in the gaps of the source chambers by closure of the covers. The cask is always loaded dry so that the only moisture would be vapor contained in air, which would also behave as a gas.

Several estimates of the maximum chamber pressure can be made:

Estimate 1 Upper Limit - The cask is sealed with source with the enclosed air at room (loading ambient) temperature of 70°F. Upon reaching equilibrium with the S/TC in the overpack, it is postulated that all of the air reached the maximum source surface temperature (550°F):

$$P = [(550 + 460)/(70 + 460)]\ 14.7 = 28 \text{ psia or } 13.3 \text{ psig}$$

The associated maximum stress would be a tangential (hoop) stress in the shell liner:

$$\sigma = PD/2t = 13.3(8.25)/2(.1875) = 293 \text{ psi, say } 300 \text{ psi}$$

Estimate 2 It is unlikely that all of the air enclosed within the S/TC could be heated to the source surface temperature. More plausible upper limit would be heating to the average temperature (maximum) of the drum sleeve based on the same type of calculation done for Estimate 1 above. Using the spacially averaged value of the maximum drum sleeve temperature determined in 3.6.5 of 312°F, the internal pressure maximum would be:

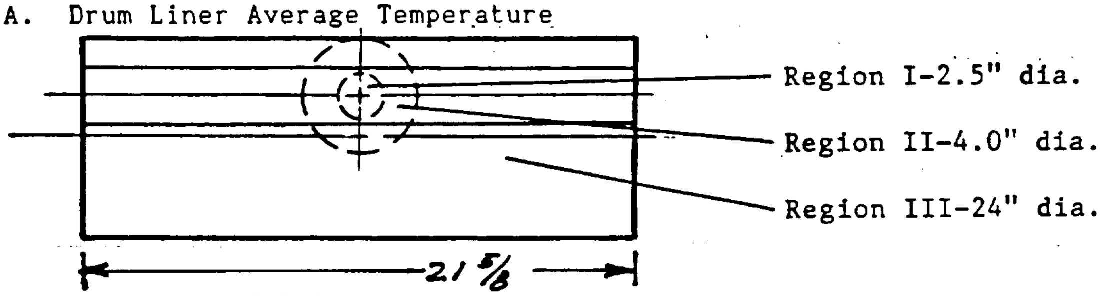
$$P = [(312 + 460)/(70 + 460)]14.7 = 21.4 \text{ psia or } 6.7 \text{ psig}$$

and corresponding hoop stress 150 psi.

In either case, the stress levels are not significant in evaluating the integrity of the components.

3.6.5 Maximum Thermal Stress Temperatures

A. Drum Liner Average Temperature



From Table 3.1.1:

Peak Liner (local)	$T_1 = 425^oF$
Drum Shell O.D. (local)	$T_2 = 330^oF$
Drum End	$T_3 = 265^oF$

The Space Weighted Average Temperature is taken as:

$$T_{av} = ({}_1T_2 \times {}_1W_2 + {}_2T_3 \times {}_2W_3)/({}_1W_2 + {}_2W_3)$$

where ${}_1T_2$ is the linear average of T_1 and T_2, and ${}_1W_2$ is the corresponding weighting factor, in this case the one half length portion of the liner that can be considered within Region II. ${}_2T_3$ and ${}_2W_3$ are the corresponding values for the remaining one half length of the liner.

$${}_1T_2 \times {}_1W_2 = (425 + 330)/2 \times 2 \text{ (in.)} = 756$$

$${}_2T_3 \times {}_2W_3 = (330 + 265)/2 \times 8.8 \text{ (in.)} = 2,622$$

$$= 3378/10.8 = 313^oF$$

B. Drum Shell (O.D.) Average Temperature

From Table 3.1.1:

Peak Temperature	$T_2 = 330^oF$
Drum End	$T_3 = 265^oF$

The mean temperature of the drum shells:

$$\Delta T = \bar{T} - \bar{T}_3 = \frac{1}{r_3 - r_2} \int_{r_2}^{r_3} T(r)dr$$

Where:

$$T(r) = T - T_3 = [q/4\pi K][1/r - 1/r_3] = K_o[1/r - 1/r_3]$$

Substituting and integrating:

$$\Delta T = [K_o/(r_3 - r_2)][\ln r_3/r_2 - 1 + r_2/r_3]$$

$$= [820/4\pi 5][12/(12-2)][\ln 12/2 - 1 + 2/12] = 15^oF$$

The maximum space averaged temperatures of drum shell = 265 + 15 = 280°F

C. Shell Liner Average Temperature

The space averaged maximum temperature of the shell assembly liner is essentially the same as that of the drum shell (OD) because they are concentric and in intimate contact.

$$T_{av} = 280^oF$$

Under the same conditions, the average shell temperature is 265°F. The important value from the thermal stress standpoint is the T between shell and liner. This T = 15°F and is not likely to vary much.

D. Summary of compatible maximum space average component temperatures for thermal stress calculations:

Drum Liner	313°F	$\Delta T = 33^oF$
Drum O.D.	280°F	
Shell Assembly Liner	280°F	$\Delta T = 15^oF$
Shell O.D.	265°F	

The above represents the most severe combination of thermal gradients anticipated under normal transport conditions.

3.6.6 Hypothetical Accident - Fire Test

A. Adiabatic Temperature Rise Rate of S/TC

	Weight, Pounds			
	Lead	Steel	Tung. Alloy	Total
Shell Assembly	2,340	414	-	2,754
Drum (lead)	242	56	-	298
Covers (2)	72	45	-	117
International Capsule (with plugs and sleeves)	-	10	38	48
AECL Drawer	29	8	neg.	37
Long Plug and Sleeve	-	8	42	50
	2,683	541	80	3,304
Cp, Btu/lb. °F	.0315	.118	.032	
Heat Capacity, Btu/°F	85	63	2.6	151 B/F

15,000 curies 240 watts = 820 Btu/hr.

Adiabatic Temperature Rise Rate = $\frac{820.3}{151}$ = 5.43°F/hr.

B. Maximum Overpack Backface Temperature

Ref: W. H. Lake, "Thermal Analysis of Packaging Using the Integral Method," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Materials, New Orleans, 1983 (PATRAM 83)

Calculate the adiabatic equilibrium temperature associated with the post fire cool down condition as representative of the upper limit of the backface overpack (WPJ) temperature. No credit taken for the steel shell.

The initial conditions and thermal properties:

t_f = fire duration = one half hour

T_o = fire temperature (outside temperature) = 1,475°F

T_i = initial overpack temperature, taken as the average WPJ temperature at the maximum package temperature conditions under normal transport (Table 3.1.1) = (1/2)(140 + 245) = 193°F

l = Wooden Protective Jacket (WPJ) wall thickness = 6 in. = 0.5 ft.

k = thermal conductivity of WPJ
  = 0.085 B/hr. ft. °F (from APA Applications Summary, Page 13)
  = WPJ density = 36 lbs./cu. ft. (measured value)

C_p = heat capacity = 0.65 B/LB°F (Marks IV, Page 300, Table 9)
  = thermal diffusivity = $K/_pC_p$ = 0.085/36(0.65) = 0.00363 ft.^{2}/hr.

To calculate the post fire adiabatic equilibrium temperature, T, when the radiation source temperature is specified, use is made of the different geometry and boundary condition cases worked out in Table 3 of the reference to obtain an equivalent heat flux. Only constant heat flux solutions are available for the cylindrical and spherical geometry cases. However, the semiinfinite slab geometry, for which both constant temperature and constant heat flux solutions are available, is used to develop a constant heat flux equivalent to the imposed constant temperature condition. The equivalent heat flux is used to obtain cylindrical and spherical geometry solutions. The adiabatic temperature rise, $T = T - T_i$, where the subscript designates the particular case, using the nomenclature of the reference.

1. Semi-Infinite Slab, Constant Surface Temperature

$\overline{T_{x2}} = (6/\ell)(\alpha t_f/24)^{1/2} (T_o - T_i)$ ref. equ. 27

$= (6/0.5)[(0.0036)(0.5)/24]^{1/2} \cdot (1282)$

$= 133^\circ F$

2. Semi-Infinite Slab, Constant Heat Input

The equivalent constant heat input is obtained from this case using the temperature rise calculated from the previous constant temperature case.

$\overline{\Delta T_{x3}} = (q_o \alpha t_f)/(k \ell)$ ref. equ. 28

$q_o = (\Delta T\ k \ell)/(\alpha\ t_f)$

$= (133) \times (0.085)(0.5)/(0.00353)(0.5) = 3114$ B/hr. ft.^{2}

3. Infinite Cylinder, Constant Heat Input

$\overline{\Delta T_c} = (2\ q_o R_o \alpha\ t_f)/[k(R_o^2 - R_1^2)$ ref. equ. 29

$= [2(3114)(1.833)(0.00363)(0.5)]/[0.085(1.833^2 - 1.333^2)]$

$= 154^\circ F$

4. Sphere, Constant Heat Input

$$\overline{\Delta T_s} = (3q_c R_o^2 \alpha t_f)/[k(R_o^3 - R_i^3)] \quad \text{ref. equ. 30}$$

$$= [3(3114)(1.883)^2(0.00363)0.5]/[0.085(1.883^3 - 1.333^3)]$$

$$= 177^{\circ}F$$

The Wooden Protective Jacket is 45 inches high and 44 inches in outside diameter and is probably better represented by a sphere than by an infinite cylinder. The spherical values are used for evaluating the temperature rise using the inside and outside diameters of the Wooden Protective Jacket as the inside and outside diameters of the equivalent sphere.

The peak backface temperature, T_{BF} = peak inside wall temperature of the Wooden Protective Jacket is less than, but for the present purpose, taken equal to the adiabatic equilibrium temperature, T_{AE}

$$T_{BF} = T_{AE} = 193 \text{ (initial)} + 177 \text{ (adiabatic rise)} = 370^{\circ}F$$

C. Peak S/TC Temperatures

The peak S/TC surface temperature is equal to the peak backface temperature plus the drop (15°F) needed to transfer internal heat generated through the space between overpack and S/TC.

T (S/TC surface, post fire maximum) = 370 + 15 = 385°F

The peak temperatures for the S/TC become:

o S/TC surface	385°F	(196°C)
o S/TC shell liner and drum O.D. (local max.)	450°F	(232°C)
o S/TC drum liner (local max.)	545°F	(285°C)
o Source capsule surface	670°F	(355°C)

These temperatures are unlikely to be reached because the inner container is unlikely to remain adiabatic for 22 hours (120°F/5.43°F/hr.) after the termination of the fire. Nevertheless, making the evaluation of the consequence of the hypothetical accident on this basis: (1) there would be no lead melting; the peak lead temperature is less than 545°F (the maximum local lead temperature is lower than the local maximum temperature of the drum liner) as compared with a melting point of 618°F; and, (2) the maximum source capsule surface temperature (355°C) remains well below the weld sensitization temperature (above 480°C).

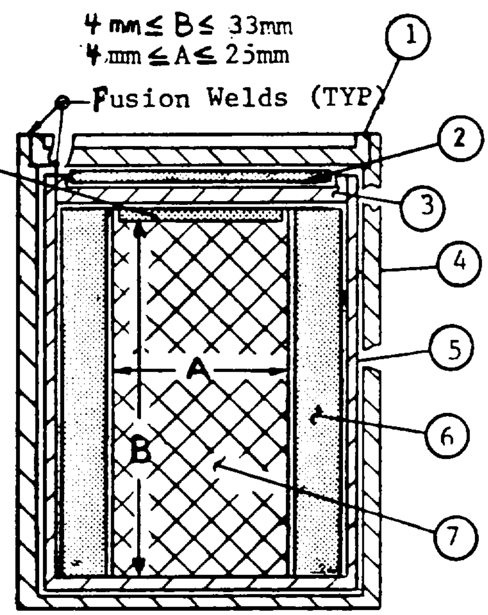
It is not crucial to the integrity of the packaging if either of the criteria employed above are exceeded. However, they provide a convenient and conservative measure for evaluation of maximum normal and upset conditions.

SEALED SOURCE TYPE: Medical Teletherapy Source

DIAGRAM:

1. Secondary End Cap*
2. Tungsten Shield (When Required)
3. Primary End Cap**
4. Secondary Capsule*
5. Primary Capsule**
6. Tungsten Shield (When Required)
7. Cobalt Source Consisting of:
   Single Casting, Multiple Casting, Rods, Wafers or Combinations
   No single active cobalt piece to have its largest dimension less than 4mm.

*304L or 316L Only
**Stainless Steel Only



NPT T-SERIES | neuTRon PRODUCTS inc
DWG. MLH | DATE 11-12-84

FIGURE 4.1
MEDICAL TELETHERAPY SOURCE

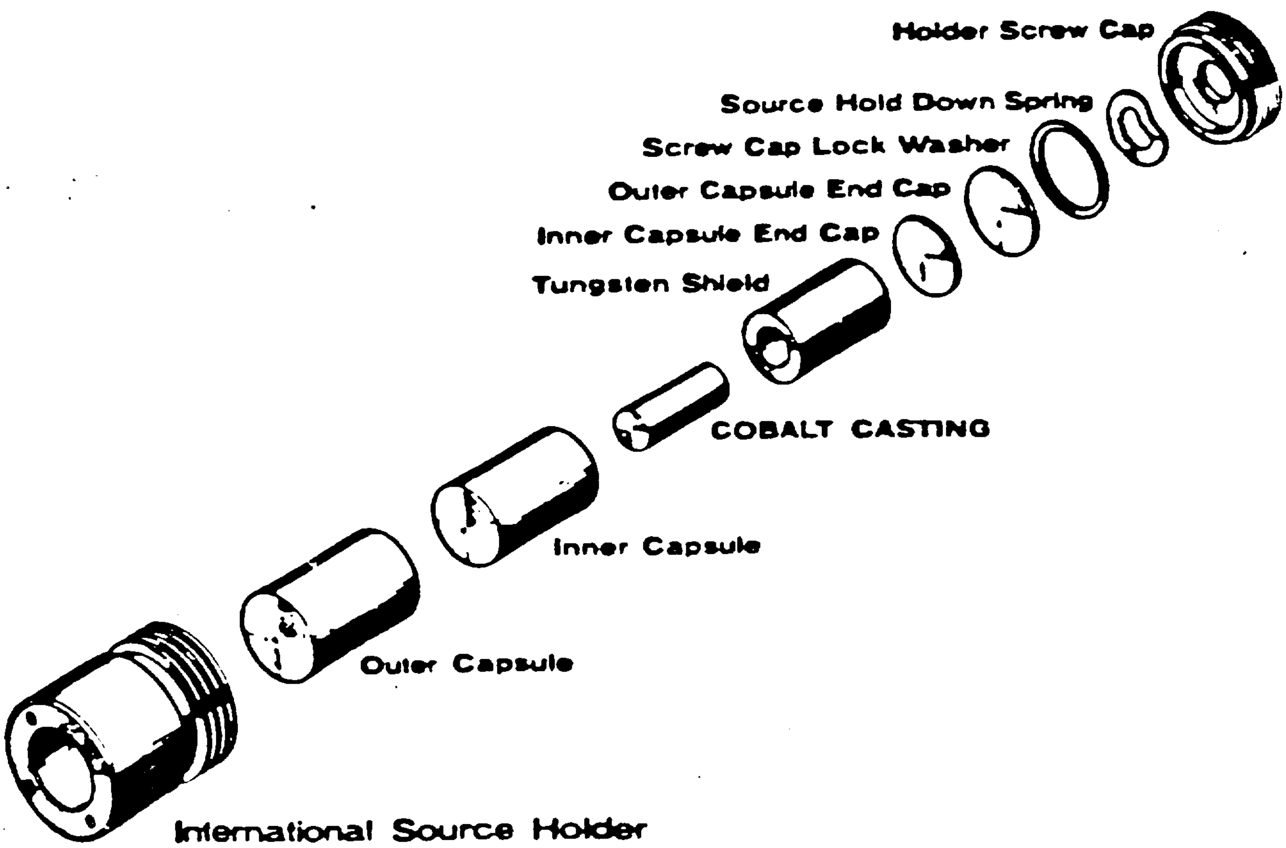


Figure 4.2

TELETHERAPY SOURCE

Fig 4.2

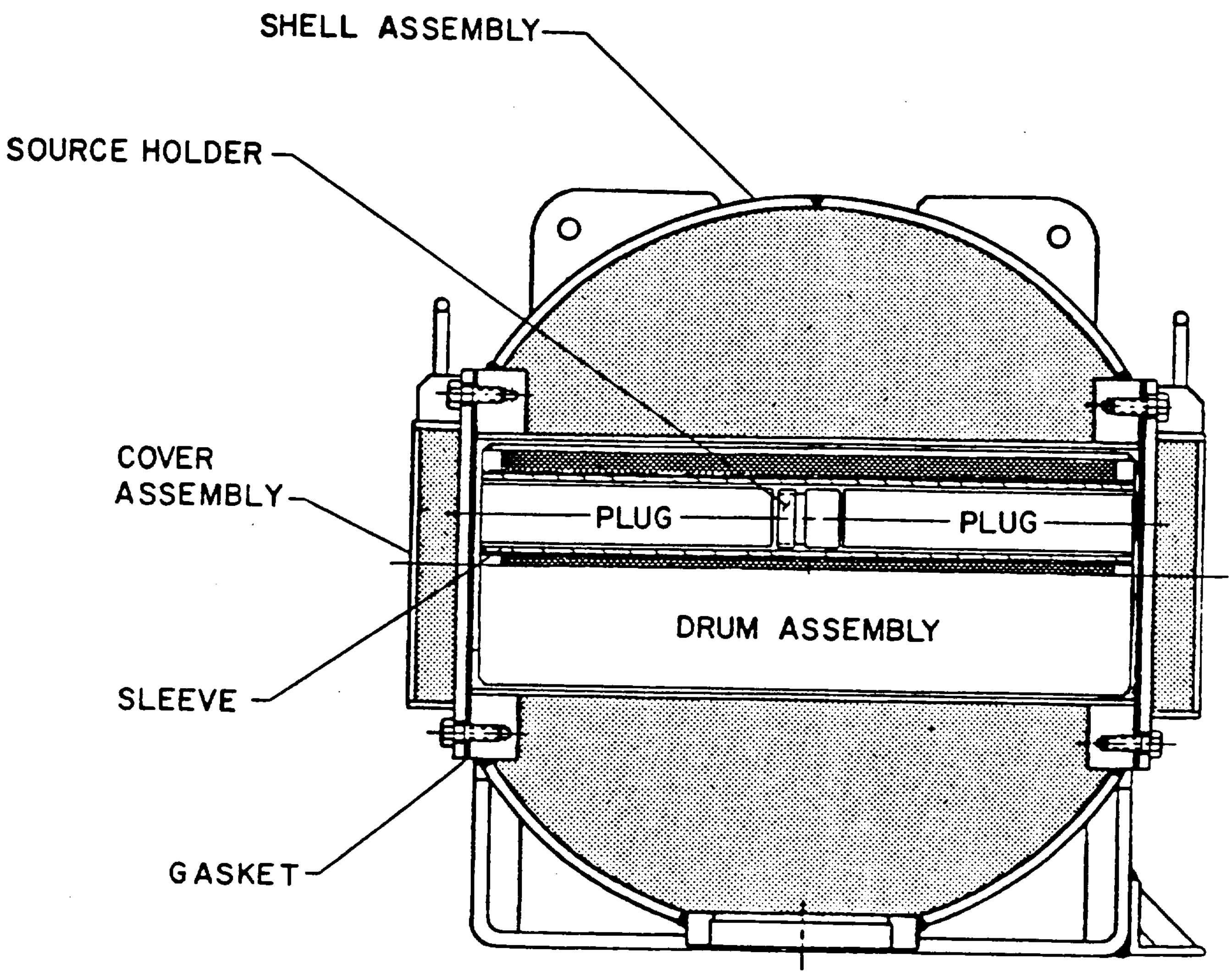


FIGURE 4.3

INTERNATIONAL SOURCE HOLDER
INSTALLED IN S/TC INNER CONTAINER

Specifications for welds and seals are included in the purchase documentation. As discussed in Chapters 2 and 3, the internal pressure under normal transport is essentially atmospheric. Postulating extreme circumstances under hypothetical accident conditions results in a calculated pressure of about one atmosphere gage.

4.1.4 Closure

The closure is mechanical, using 8 one half inch bolts on an 11-1/4 inch bolt circle. The cover is bolted to the Shell Assembly and the closure seal is provided by a flat, full diameter, 1/16 inch thick silicone rubber gasket. The bolts are tightened to firmly compress the gasket with a torque of approximately 100 inch-pounds.

The overpack provides two additional closures, but these are not gasketed and are not intended to provide a gas tight seal.

4.2 Requirements for Normal Conditions of Transport

The source capsule qualifies as special form material. The evaluation in Chapters 2 and 3 indicates that the shipping/transfer cask will provide a secondary seal under normal transport conditions. One of the principal functions of the seal is to prevent any external contaminants, such as liquids or particulates, from reaching the source chamber.

4.2.1 Release of Radioactive Material

None

4.2.2 Pressurization of Containment Vessel

There are no gases that can form and/or explode in the containment chamber. There has been no evidence of pressure build up in the sealed drum chamber in practice. Any foreseeable change in chamber pressure will not reduce package effectiveness.

4.2.3 Coolant Contamination

Not applicable

4.2.4 Coolant Loss

Not applicable

4.3 Containment Requirements for the Hypothetical Accident Conditions

The evaluation of test information and associated analysis presented in Chapters 2 and 3 show that the package could experience the sequence of conditions postulated in 10 CFR 71.73 without release of radioactive material or significant change in shielding capability. In addition, the encapsulated source meets special form requirements, which are at least as stringent as the accident conditions for the package.

4.3.1 <u>Fission Gas Products</u>

Not applicable

4.3.2 <u>Release of Contents</u>

In summary, from the standpoint of containment (as opposed to shielding), the source capsule by itself can meet all of the hypothetical accident conditions imposed on the package. In addition, evaluation of the shipping/transfer cask as a secondary containment, enclosed within the Wooden Protective Jacket and the Steel Shell overpack, will meet the requirements of the hypothetical accident sequence of conditions.

4.4 <u>Appendix</u>

Supporting evaluations and analysis for statements in this chapter are provided in the body and appendices of Chapters 2 and 3.

5. SHIELDING EVALUATION

5.1 Discussion and Results

The shielding arrangement for the new package is generally similar to that of the existing package. The principal shielding is provided by the inner container. The design is governed by the requirement to shield the 1.17 MeV and 1.33 MeV gamma rays resulting from each cobalt-60 disintegration.

The shielding can be considered comprising three parts: the source holder, the drum into which the source holder fits, and the lead filled, Steel Shell assembly and covers.

The cobalt-60 source is normally loaded into a holder or drawer, either horizontally or vertically, which is specifically designed to fit a particular model teletherapy unit. The holder or drawer is fabricated of one or more of the following shielding materials: steel, depleted uranium, tungsten, lead, or brass. The remaining space in the Drum Assembly chambers is filled with shielding fabricated of steel, tungsten, and/or lead of a dimension to provide the specified clearance tolerance during shipment. Thus, the Drum Assembly chambers are filled with shielding that is an inherent part of the source capsule or the shipping packaging. As expected, and verified in Table 5.1.1, the dose rate from the package depends upon the specific shielding arrangement and source orientation, as well as the total activity.

The drum in which the source holder or drawer is carried is the second shielding barrier. The drum is an 8-3/16 inch diameter cylinder, 21-5/8 inches long, penetrated by 3 tubes, each 2.560 inches in inside diameter, which form the source chambers. The tubes are parallel to the axis of the drum and extend through its entire length. The axes of the tubes are equally spaced circumferentially on a circle of 1-3/4 inch radius concentric with the axis of the drum. The source holder and the teletherapy drawer are slip fits into the source chambers. Frequently only one source is carried per container. The source chambers not containing sources are loaded with lead filled or tungsten shield plugs.

The drum fits into the Shell Assembly which, along with the two covers, provides the third shielding barrier. Both the Shell Assembly and covers are lead filled. The bolted covers hold the drum tightly in place during transport.

The overpack, into which the inner container fits, contributes to dose reduction, principally by the geometric factor. The six inch thickness of wood and 0.1 inch thickness of steel contribute little to the gamma shielding.

Because the new package is essentially identical geometrically to the existing package, the shielding evaluation can be made directly, and likely most accurately, by comparison. Table 5.1.1 presents dose rates for

TABLE 5.1.1

DOSE RATES FOR REPRESENTATIVE RECENT SHIPMENTS
EXISTING PACKAGE

Source Strength Curies	Distance From Package	Maximum Dose Rate, mR/Hr. FWD	Back	Left[1]	Right[1]	Above	Below
8,050	Surface	2	5	7	5	0.2	70E[2]
	1 meter	0.3E	0.6	0.5	0.5	0.1	12E
8,700[4]	Surface	10	14	20	13	0.6	60
	1 meter	2	3	3	2	0.4	8E
4,100	Surface	5	15	5	15	GB[3]	4.0
	1 meter	.2	1	.5	1	GB[3]	1.5
9,500[4]	Surface	4	5	18	30	0.8	70E
	1 meter	1.5	2	5	5	0.6	9E
7,950	Surface	9	11	25	25	0.1	70
	1 meter	1.5	1.5	8	5	0.3	9
7,300	Surface	4	9	20	18	0.7	46
	1 meter	0.9	1.5	3	3	0.4	8

(1) Facing forward
(2) E indicates estimate
(3) At gamma background
(4) Two source total

representative recent shipments with the existing package. These provide a base for comparison with the new package. The design guidelines for the new package are a maximum dose rate of 100 mr./hr. at the accessible surface of the package and 10 mr./hr. at a distance of one meter from the surface of the package for normal conditions of transport. These are the values listed in Table 5.1.2.

A comparison of the radial gamma ray attenuation between the new and existing inner container is detailed in Appendix 5.4.1. On a comparative basis, the new container will permit an increase of 54 percent in source strength for the same cask surface dose. This factor, along with the initial shielding design margin of the casks, as shown in Table 5.1.1, provides a satisfactory 15,000 curie operating limit for cobalt-60. This is further supported by a surface and one meter distant dose rate for the package calculated to be 10.4 mr./hr. and 1.4 mr./hr., respectively, for a contained 15,000 curie source. This calculation is also included in Appendix 5.4.1.

The principal physical change to the drum of the new package has been to decrease the drum liner tube inside diameter from 2.82 to 2.56 inches, while maintaining the 0.095 inch tube wall thickness. In the radial direction, the change amounts to replacing 1/8 to 3/16 inches of steel and clearance with an equal thickness of lead. The change also reduces gamma streaming in the axial direction by factors calculated to be 1.8 to 7.3, depending upon the source holder configuration. The supporting calculations are provided in Appendix 5.4.2.

The only other physical change to the new inner container that impacts shielding is the reduction in the outside diameter of the Shell Assembly Liner. The effect is to replace a 3/16 thickness of steel with an equivalent amount of lead. The principal influence is an increase in radial attenuation. This factor has been included in the calculations shown in Appendix 5.4.1.

Subsequent to the calculations and comparisons described above, a package incorporating the new inner container carrying a 6,650 curie source was radiation surveyed. The results are provided in Appendix 5.4.3. As extrapolated to 15,000 curies, the package maximum surface reading would be 34 mr./hr., as compared with the design basis value of 100 mr./hr. and the 10 CFR 71.47 limit of 200 mr./hr. for general transport. At one meter distant, the level would be about one-third of the 10 mr./hr. general transport limit.

The change in shielding effectiveness under hypothetical accident conditions is due to shifting of the inner container with reference to the outer surface of the package as a consequence of the 30 foot drop. With a maximum estimated inner container shift of seven inches, the surface dose increases by a factor of 2 and the dose at 1 meter by about 25 percent. Both values are below the 10 CFR 71 limit of 1,000 mR/hr. at 1 meter for the hypothetical accident condition. There is no opportunity for any measurable shift of source or shielding within the inner container under the most severe free drop condition. Greater detail is provided in Appendix 5.4.4.

5.2 Source Specification

The only source considered for radiation shielding design and evaluation was the 1.17 MeV and 1.33 MeV photons produced from each cobalt-60 decay. There is no neutron source.

TABLE 5.1.2

SUMMARY OF MAXIMUM DOSE RATES
(mR/hr.)

	Package Surface			One Meter From Surface of Package		
	Side	Top	Bottom	Side	Top	Bottom
Normal Conditions						
Gamma	<100	<100	<100	<10	<10	<10
Neutron	N/A	N/A	N/A	N/A	N/A	N/A
Total	<100	<100	<100	<10	<10	<10
Hypothetical Accident Conditions						
Gamma	<200	<200	<200	<20	<20	<20
Neutron	N/A	N/A	N/A	N/A	N/A	N/A
Total	<200	<200	<200	<20	<20	<20
10 CFR Part 71 Limit	---	---	---	1,000	1,000	1,000

5.3 Model Specification

The shielding evaluation is based on measurements made on generally similar packages and determining the changes in dose rate due to the comparatively small changes in geometry and materials. The changes were made by calculation employing a simple exponential attenuation model postulating an isotropic source. Buildup factors were obtained from the Radiological Health Handbook, Revised Edition (January 1970). Values of material densities and mass attenuation coefficients are shown in Table 5.3.1 and were obtained from the same source. Streaming was also considered. The calculational models employed are described in Appendices 5.4.1 and 5.4.2. Subsequently a radiation survey of a referenced shipping package provided results which compared favorably with the calculations.

TABLE 5.3.1

SHIELDING PARAMETERS

Material	Density gm/cc	Mass Absorption Coefficient cm^2/gm
Tungsten alloy	17	.0555
Lead	11.3	.058
Stainless steel	8.0	.054
Carbon steel	7.85	.054

5.4 APPENDIX

5.4.1 Radial Gamma Attenuation

The specific shielding arrangement within the drawer or holder placed in the drum chamber may vary. However, a comparison of radial (in the plane perpendicular to the axis of the drum) attenuation in the original with that of the new inner container can be made from the drum liner outward. This comparison, along with an overall calculation of dose rate for the new package in the radial direction, is presented in this appendix.

For both purposes a point source model was used. For the comparison, the attenuation from chamber wall to exterior of the inner container, $[I_o/I]_{S/TC}$ was taken as the product of the individual shielding components.

$[I_o/I]_{S/TC} = \prod^{n} B_n(\mu_n X_n, E) \exp(\mu_n X_n)$ where B_n is the buildup factor, μ_n the linear attenuation coefficient, X_n the thickness of the shield component under consideration, and n designates the particular shielding material component.

Table 5.4.1.1 lists the input parameters for the calculation, as well as the results. The configuration is shown schematically in Figure 5.4.1.1. The constituent material attenuations are shown for each of the shielding component materials, as well as the total for both the original and new inner containers. The ratio of the new to the original cask attenuation is 1.54. Looked at in another way, for the same surface dose, the new cask would have to contain a source strength 54 percent greater. The original inner container was not considered shielding limited at 9,500 curies, so that no absolute level of source strength can be determined by this means; however, when applied to actual package measurements, such as those shown in Table 5.1.1, the package dose rates with a 15,000 curie source could easily meet normal shipping requirements.

The dose rate at the package surface and at one meter distant were also calculated in the radial direction. The attenuation due to shielding inside of the source containing drum chamber and the small attenuation due to the overpack were combined with the SITC attenuation shown in Table 5.4.1.1 to provide the total material attenuation of the packaging. The additional constituents, as well as the overall result, are presented in Table 5.4.1.2. The overall shielding attenuation, I_o/I is 5.75×10^6. Combining this with the source dose rate relationship[1] in the absence of shielding

I_o = Dose rate at distance d,cm from C curie source
$= 5.2 \times 10^6$ C E/d^2 mr./hr.

where

C = 15,000 curies
E = Total gamma energy/disintegration = 2.5 Mev for cobalt-60
d (surface) = [(48.5/2) - 1.75] 2.54 = 57.2 cm
d (@ 1 meter) = 157.2 cm

(1) S. Glasstone, Principles of Nuclear Engineering, pg. 545

TABLE 5.4.1.1

CALCULATED RADIAL GAMMA ATTENUATION COMPARISON

Location(1) and New/Original Inner Container	Material and Thickness, in.	Linear Absorption Coefficient $cm.^{-1}$	Buildup Factor (2)	Attenuation I_o/I (2)
1. Drum Liner	S.S. (3)			
New	0.095	0.432	1.09	1.02
Original	Same as above			
2. Drum Shielding	Lead			
New	0.782	0.655	1.47	2.50
Original	0.625	0.655	1.40	2.02
3. Drum Casing	S.S.			
New	0.187	0.432	1.17	1.046
Original	0.219	0.432	1.20	1.056
4. Shell Liner	C.S. (3)			
New	0.187	0.424	1.17	1.044
Original	0.375	0.424	1.34	1.115
5. Shell Shielding	C.S.			
New	7.69	0.655	4.75	7.63×10^4
Original	7.50	0.655	4.65	5.68×10^4
6. Shell	C.S.			
New	0.375	0.424	1.34	1.115
Original	Same as above			
S/TC Attenuation, π (new)				2.37×10^5
S/TC Attenuation, π (original)				1.538×10^5
Ratio, π (new)/π (original)				1.54

(1) Numbers keyed to locations shown in Figure 5.4.1.1.
(2) Attenuation, $I_o/I = B(\mu x, E) \exp(\mu x)$. Buildup factor based on point isotopic source. (Radiological Health Handbook, pgs. 145-146.)
(3) S.S. = stainless steel, C.S. = carbon steel

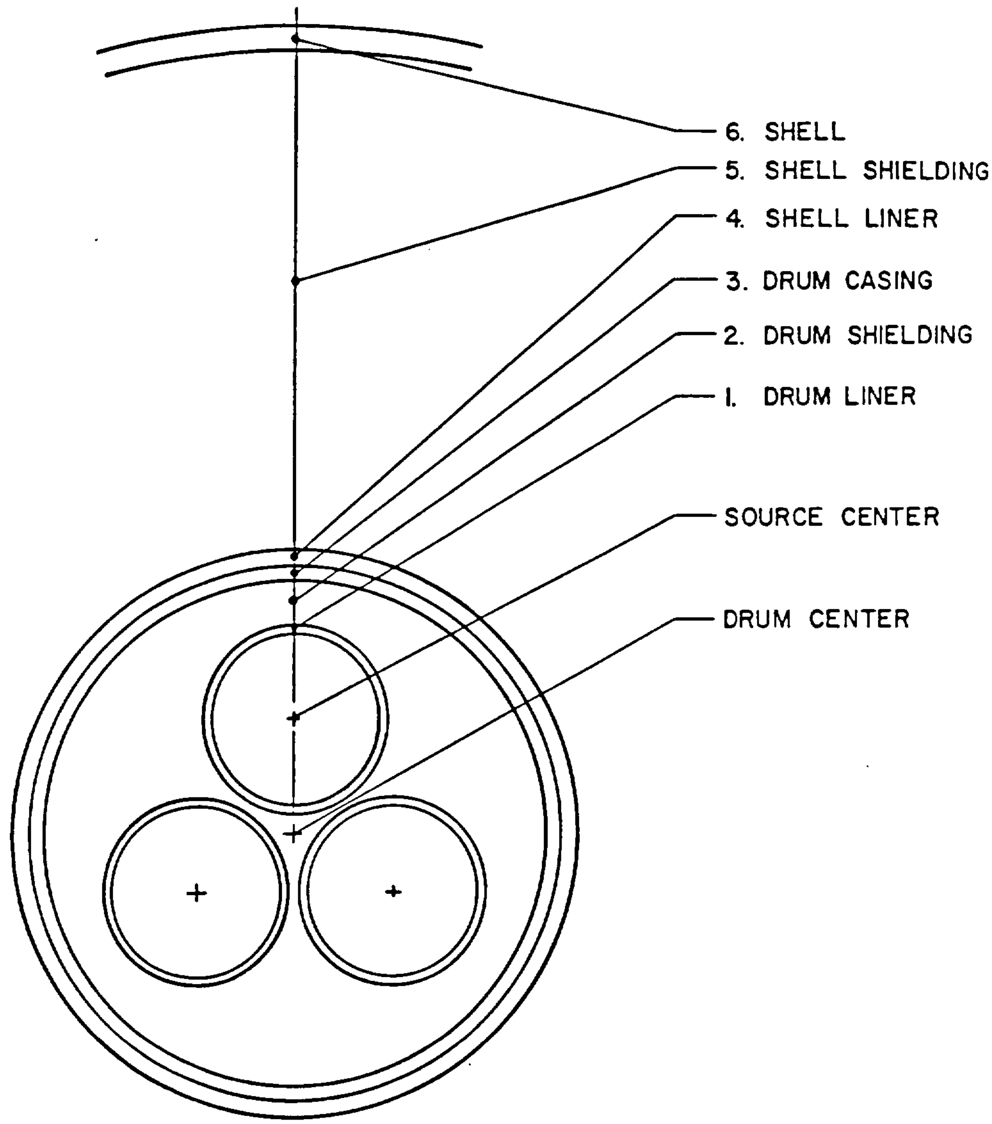


FIG. 5.4.1.1

STRUCTURE & SHIELDING ARRANGEMENT KEY FOR TABLE 5.4.1.1

TABLE 5.4.1.2

CALCULATED DOSE RATE FOR NEW PACKAGE

Location	Material and Thickness, in.	Linear Absorption Coefficient cm.-1	Buildup Factor	Attenuation I_o/I
Source capsule	Tungsten alloy 0.437	0.944	1.47	1.94
Source chamber steel	Stainless steel 0.314	0.432	1.29	1.092
Source chamber to inner container surface	From Table 5.4.1.1			2.37×10^6
Wooden protective jacket	Wood 6.0	0.0384	1.62	1.11
Steel shell	Carbon steel 0.107	0.424	1.10	1.032

Total material attenuation, source to package surface $(I_o/I) = 5.75 \times 10^6$

Yields the following surface dose:

$$(5.2 \times 10^6)(15{,}000)(2.5)/(5.75 \times 10^6)(57.2)^2 = 10.4 \text{ mr./hr.}$$

The dose at 1 meter is:

$$(5.2 \times 10^6 \times 15{,}000)(2.5)/(5.75 \times 10^6)(157.2)^2 = 1.4 \text{ mr./hr.}$$

These values compare with 200 mr./hr. and 10 mr./hr., respectively, for normal shipment. The margin provided appears adequate for slight changes in shielding, thickness, geometry, or calculational uncertainty.

5.4.2 Axial Gamma Attenuation

Evaluation of the shielding in the direction parallel to the axis of the new inner container drum involves the source loading arrangement. The loading arrangement of a source in an international capsule is shown in Figure 4.3. This is representative and one of the more frequent loading arrangements. The 2.56 inch diameter drum chamber is fitted with a stainless steel sleeve having an outside diameter of 2.50 inches and an inside diameter of 2.060 inches. The capsule is placed within the sleeve and held in the axially central region of the drum with two tungsten alloy plugs, one on each side. The covers hold the entire assembly in place.

The arrangement in the original inner container is similar, except the drum chamber is 2.81 inches in diameter and a second sleeve of 0.095 wall thickness, surrounding the first is used to fill the space and center the source.

For both configurations the shielding arrangement in the axial direction is a plug of tungsten alloy 9.8 inches long and 2.03 inches in diameter (about twice the diameter of the source face) surrounded by an annulus of steel with either two or three narrow air gaps. This assembly, in turn, is surrounded by a maxtrix of lead. The arrangement is shown for the new drum in Figure 5.4.2.1.

Based on a point source, a simple calculation shows that for a shield thickness of 9.8 inches (the length of the plug and approximate distance from the source to the face of the shell assembly), the attenuation in tungsten alloy is of order 10^{10}, that in lead of order 10^7, and in steel of order 10^4. With the highest leakage path being that through the annulus of steel, a comparative measure of attenuation between the new and the original arrangement can be made by treating the steel annulus as a streaming path. The annulus is thinner in the new arrangement. To determine the relative streaming, the following expression[1] for the ratio of entering to leaving gamma flux was used and taken as proportional to the corresponding dose rates:

(1) Source: T. Rockwell, Reactor Shielding Manual, pg. 293

FIGURE WITHHELD UNDER 10 CFR 2.390

FIG. 5.4.2.1

DETAIL OF INTERNATIONAL CAPSULE POSITIONING WITHIN INNER CONTAINER DRUM.

(REF. FIG. 4..3)

$$\phi / \phi_1 = 1/2 \pi L^2 [(\cos^{-1} r/R)(2R^2 - r^2) - r(R^2 - r^2)^{1/2}]$$

The definition of the symbols and the corresponding values for both the new and original inner containers used in the comparison are as follows:

Value	Original S/TC's	New S/TC's
ϕ, gamma flux (taken proportional to dose rate)	-	-
R, drum chamber radius, in.	1.405	1.280
r, shield plug radius, in.	1.02	1.02
L, comparative shield thickness, in.	9.81	9.81

For the original units:

$$\begin{aligned}\phi/\phi_o &= 1/2\pi(9.81)^2[(\cos^{-1} 1.02/1.405)(2(1.405)^2 - (1.02)^2) \\ &\quad - 102((1.405)^2 - (1.02)^2)^{1/2}] \\ &= 2.01 \times 10^{-3}\end{aligned}$$

For the new units:

$$\begin{aligned}\phi/\phi_o &= 1/2\pi(9.81)^2[(\cos^{-1} 1.02/1.28)(2(1.78)^2 - (1.02)^2) \\ &\quad - 1.02((1.28)^2 - (1.02)^2)^{1/2}] \\ &= 1.095 \times 10^{-3}\end{aligned}$$

The increase in attenuation is proportional to 2.01/1.095 or 1.84, which is close to a factor of two.

Another loading arrangement that occurs frequently is one in which the entire teletherapy machine drawer, with source loaded, is carried in the drum chamber. In the case of the AECL machine, for example, the shielded drawer, with center positioned source, is the full length of the drum chamber and 2.475 inches in diameter. The input values for the calculation are:

Value	Original S/TC's	New S/TC's
R	1.405	1.280
r	1.234	1.234
L	10.8	10.8

Substituting the new values:

For the original units $\phi/\phi_o = 5.187 \times 10^{-4}$
For the new units $\phi/\phi_o = 7.01 \times 10^{-5}$

The increase in attenuation for the new units is 5.187/.701 = 7.3 or a factor of about seven.

Other specific cases will vary, but the improvement is significant.

5.4.3 Package Radiation Measurements

The results of a radiation survey of a package incorporating the new inner container are provided in this appendix. The survey was made on December 4, 1986, on a package that had been prepared for shipment and sealed a few days before. The source strength was 6,650 curies (12/1/86). The source was fitted into an international capsule and held in the central region of the drum chamber between tungsten alloy end plugs. The remaining drum chambers were loaded with full length, lead filled plugs. Measurements were made with a calibrated G-M detector.

The package surface measurements are shown in Figure 5.4.3.1. All of the radiation entries are in mr./hr. The maximum reading was 15 mr./hr. at the center of the package bottom. The highest side readings were 14 mr./hr. and 6 mr./hr., located 180° from each other at a belt line height of 24 inches. The remaining surface readings were between 0.6 and 5 mr./hr. at locations as shown on Figure 5.4.3.1.

All readings taken at one meter distant from the package surface were 1 mr./hr. or less. No measurement was taken at one meter between the bottom of the package.

Based on these measurements, the design basis 15,000 curie source would result in a maximum surface reading of (15,000/6,650) X 15 = 34 mr./hr., as compared with the design basis value of 100 mr./hr. and the 10 CFR 71.47 limit of 200 mr./hr. At a one meter distance, the level would be one third of the limiting 10 mr./hr. These results also generally support the calculations provided in Appendix 5.4.1.

5.4.4 Hypothetical Accident Conditions

Any change in shielding effect resulting from the Hypothetical Accident Conditions is due to shifting of the inner container within the overpack. There is no opportunity for any measurable shift of source or shielding in the inner container under the most severe free drop and fire conditions. Except for some small clearances, the inner container is completely filled with metal.

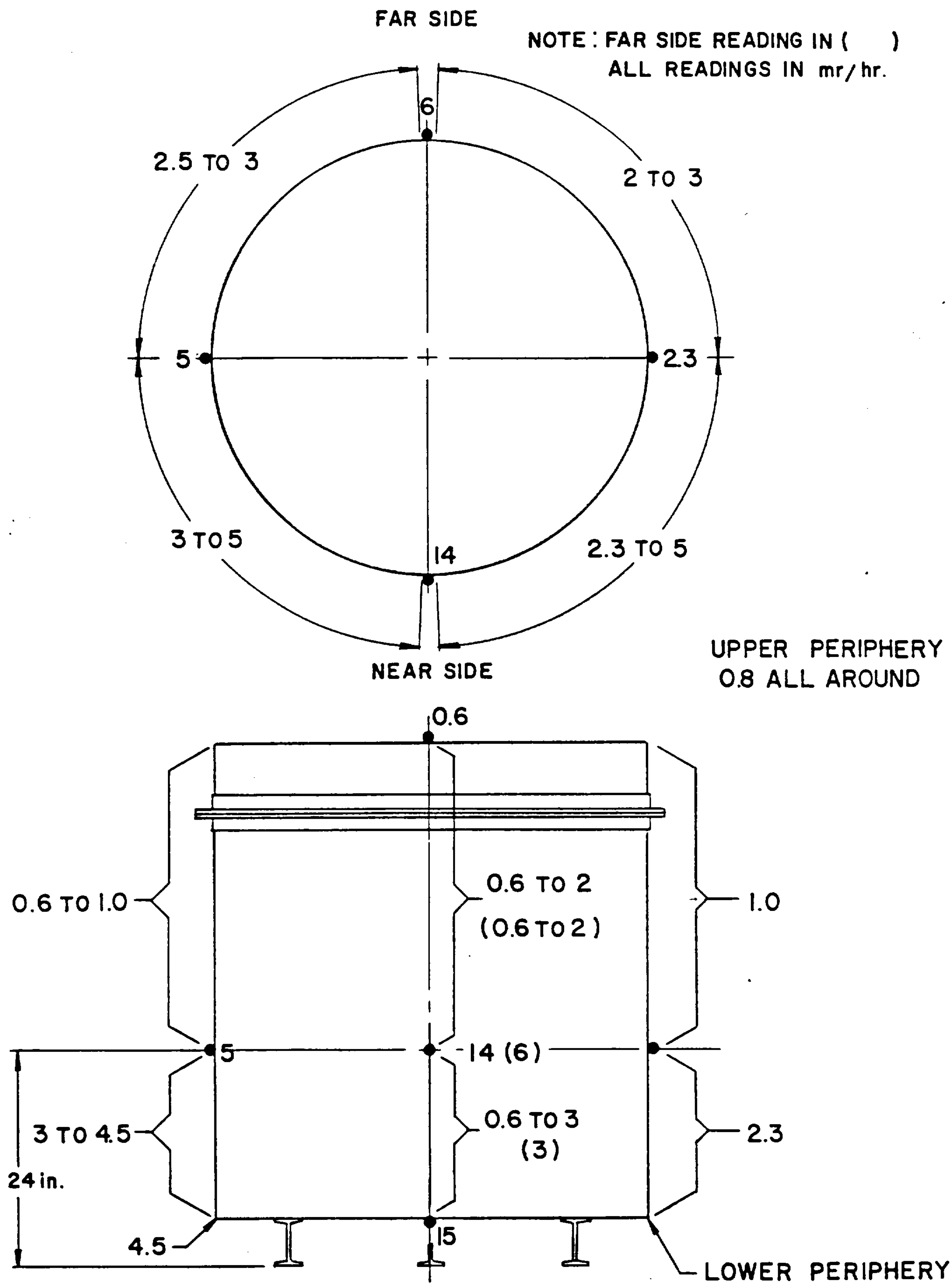


FIG. 5.4.3.1

MEASURED PACKAGE SURFACE RADIATION LEVELS FOR A CONTAINED SOURCE OF 6650 CURIES

The maximum shift of the inner container within the overpack can be obtained from the analysis of the several hypothetical accident drop conditions. The shift of the source relative to the outer surface of the package is due to the crushing, bending, or other distortion of the overpack wooden protective jacket (WPJ) and steel shell (SS). The results obtained from the accident analysis are summarized in the following table:

Component of Overpack Affected	Maximum Displacement of Source Relative to Normal Location in Packages, inches			
	Top Drop	Bottom Drop	Side Drop	Edge Drop(1)
Crush support beams (SS)	4	-	-	
Shred shock rings (WPJ)	-	-	2	
Inner container movement	-	1	2	
Inner container penetration of WPJ	-	4	1	
After fire drop, char allowance	2	2	2	-
Maximum Displacement, in.	6	7	7	-

(1)Not critical for shielding

The amount of shielding material will remain the same. The shielding change will result only from geometric factors. Postulating a point isotopic source, the increased transmission due to the seven inch maximum displacement is:

At the surface: $\left(\frac{24.4}{24.4-7}\right)^2 = 1.97$

At one meter: $\left(\frac{63.4}{63.8-7}\right)^2 = 1.26$

Assuming the surface radiation level under pre-accident conditions was at the 100 mr./hr. design basis condition, the hypothetical accident would result in a surface radiation level of less than 200 mr./hr. Similarly, postulating the permissible 10 mr./hr. pre-accident, the postaccident one meter dose rate increase would be less than 3 mr./hr. In any case, both levels are below the 10 CFR 71.51(a)(2) limit of 1 rem/hr. at one meter from the external surface of the package under hypothetical accident conditions.

6. CRITICALITY EVALUATION

NOT APPLICABLE

NO FISSIONABLE MATERIAL INVOLVED

7.0 OPERATING PROCEDURES

This chapter describes the operating procedures, inspections, tests, and special preparations used in loading and unloading the shipping package. These procedures are in place and utilized for handling the existing teletherapy package. In all cases, evaluation of the procedures, inspections, etc. have demonstrated the ability of the shipping package to comply with the applicable operating procedure requirements specified in 10 CFR 71, Subpart G. Based on these evaluations, occupational radiation exposures are maintained as low as reasonably achievable, as required by Paragraph 20.1(C) of 10 CFR 20.

7.1 Procedure for Loading the Shipping Package

The source is loaded into the shipping/transfer cask in the hot cell according to NPI routine loading procedure, R 2014, a copy of which is provided in Appendix 7.4.1. The loaded source is shielded by either the tungsten or lead in the center region of the drum, depending upon the type of drum being used, and the remaining lead shielding of the cask.

The cask is always handled dry and there is no liquid coolant. Special procedures to prevent moisture from being present in cavities designed to be dry are not necessary. Decontamination is performed, if necessary, before the source is placed in the cask. After removal from the hot cell, radiation measurements are taken at the outside surface of the shipping/transfer cask to assure that permissible levels are not exceeded.

After the radiation survey and any decontamination, if necessary, the cask is placed in the overpack. The Wooden Protective Jacket cover is bolted in place and then the cover of the Steel Shell is bolted in place.

The shipping package is then placed on the transport vehicle by use of a forklift, or suitable lifting arrangement, and secured with tie down devices.

The quality assurance checklist is included in the Radioactive Shipment Record (RSR). The RSR is prepared for each shipment and provides the record for applicable external radiation monitoring and surface contamination measurements that must be acceptable before shipment is permitted.

Field loading requires no additional special procedures, except those associated with assembly and servicing of the specific teletherapy unit.

7.2 Procedures for Unloading the Shipping Package

The cask and overpack are dry and the cask contains only encapsulated sources. These sources are monitored prior to being loaded for shipment. There is very little chance of contamination during transport. Procedure R 2014 also includes the unloading of the shipping container at Neutron Products. Procedures for the unloading of specific teletherapy sources at medical institutions are included in the field servicing and installation procedures for those units. In accordance with these procedures, the shipping package is visually inspected for damage and external radiation measurements and contamination measurements are made prior to unloading.

7.3 Preparation of an Empty Shipping Package for Transport

The shipping package is not normally transported empty. In the event such a shipment occurs, standard procedures, as described in preceding sections of this chapter, are followed to confirm that the packaging is not contaminated (or decontaminated, if necessary), the Cover Assembly gaskets are intact, and the Cover Assemblies are securely bolted. Procedure R 2014 includes handling of an empty cask.

The casks are shipped dry and the free volume within the cask is so small that any moisture that might be formed by condensation during transport would be negligible. Freezing temperatures will not cause damage to the cask cover gaskets.

7.4 Appendix

7.4.1 Teletherapy Shipping/Transfer Cask - Unloading and Loading Procedure: NPI Procedure R 2014, Revision 5

TELETHERAPY SHIPPING/TRANSFER CASK
UNLOADING AND LOADING PROCEDURE

PROCEDURE R 2014

REVISION 5

SEPTEMBER 15, 1992

Reviewed for Radiation Safety, and Approved

Marvin M. Turkanis
Date 9/15/92

Reviewed for Compliance and Approved

Frank Schwoerer
Date 9/15/92

Reviewed for Adequacy for Intended Purpose, and Approved

Jeffrey W. Corun
Date 9/15/92

Control Copy Number: ________

TELETHERAPY SHIPPING/TRANSFER CASK
UNLOADING AND LOADING PROCEDURE

PROCEDURE R 2014

REVISION 5

SCOPE

The teletherapy shipping package, NPI-20WC-6, consists of a specially designed inner lead shielded shipping/transfer cask contained within an overpack. This procedure covers hot cell unloading and loading of doubly encapsulated sources out of, and into, the approved shipping/transfer casks, and shall be used in conjunction with Procedure R 5001, General Procedure for Hot Cell Operations. Enclosure of the cask within the overpack and unloading and loading the shipping package is included in the procedure. For operations at other hot cells, this procedure will be modified as necessary.

BACKGROUND

Both unloading and loading is covered here in a single procedure because the most frequent circumstance in the shipping and transfer of teletherapy sources is receipt of a package containing a spent source which, after appropriate initial operations and surveys, is removed from the package in the hot cell and placed in interim storage; whereupon the cask is inspected, cleaned, resleeved, as necessary, and loaded with a new source in the hot cell for subsequent shipment off site. Loading an initially empty container and similarly, unloading a container to be placed into standby or serviced in an empty condition, are included as variations of the procedure.

1. REFERENCES

Procedure R 1002, Sampling Procedure
Procedure R 5001, General Procedure for Hot Cell Operations
Procedure R 5002, Opening Hot Cell Door After Processing Single and Double Encapsulated Cobalt-60
Procedure R 5015, Operation of the Hot Cell Interlock
Applicable Certificate of Compliance (for domestic destination) or Certificate of Competent Authority (for foreign destinations) for the shipping package
QA 1003, Package Loading Procedure for Radioactive Materials
QA 1004, Package Unloading Procedure for Radioactive Materials

2. GENERAL CONSIDERATIONS

Sources shall be loaded only upon written instruction, after it has been determined that the sources meet all specifications, including customer's, and cask loading specifications.

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The shipping packages usually contain radioactive material upon receipt and all procedures and precautions associated with handling radioactive materials must be followed.

3. PERSONNEL AND SUPERVISION REQUIREMENTS

Radioactive materials may be loaded or unloaded from transfer containers only by experienced hot cell operators, acting under the authority of the hot cell manager or the radiation safety officer (RSO), or his designee.

4. EQUIPMENT

Operating hot cell
Shipping/transfer cask
Shipping/transfer cask applicable inserts
Survey meter capable of reading up to 2 R/hour
All necessary tools

5. OPERATIONS

5.1 Preparations

5.1.1 Confirm with the hot cell manager, or other individual responsible for the shipment, the following:

a) source(s) identification;
b) activity of source(s);
c) applicable shipping/transfer cask and source holder; and,
d) applicable overpack (wooden protective jacket and steel shell).

5.1.2 For shipment received, unload the NPI-20WC-6 package from the truck in accordance with QA 1004.

5.1.3 Remove bolts and lids from the steel shell and wooden protective jacket, respectively. Store for reuse.

5.1.4 Remove shipping/transfer cask from the overpack. Do not leave wooden protective jacket open to weather. Inspect overpack for damage and repair, if necessary. Store overpack for next use with wooden lid and shell cover in place.

5.1.5 Measure radiation levels to confirm that handling of cask will be a low level operation.

5.1.6 Open hot cell door per Procedure R 5015.

5.1.7 Place the shipping/transfer cask on the dolly in the machine shop. Manually move dolly from the machine shop to the area behind the hot cell and under the crane trolly. Lift shipping/transfer cask to sufficient height and center it over the hot cell dolly. Lower cask onto the hot cell dolly. Disengage the crane trolly and remove it to its original position.

5.1.8 Remove bolts holding one of the shipping/transfer cask covers. Make certain end of cask faces shielded area when removing cover.

5.1.9 Confirm whether the cask contains a source by both measuring the radiation level near, and visually inspecting inserts at, the open face of the container. Any reading above background should be considered as indicating a loaded container.

5.1.10 If shipping/transfer cask is <u>loaded</u>, proceed to 5.1.12.

5.1.11 If shipping/transfer cask is <u>empty</u>, remove inserts, clean the inside of the container, check drum rotation (where applicable), wipe test the inside of the container and inserts, and reinstall applicable inserts.

5.1.12 Load shipping/transfer cask, appropriate insert or holder, and all necessary tools into cell.

5.1.13 Close hot cell door.

5.1.14 If shipping/transfer cask is <u>empty</u>, proceed to 5.3.

5.1.15 If shipping/transfer cask is <u>loaded</u>, proceed to 5.2.

5.2 <u>Unloading</u>

5.2.1 If container is loaded, remove source holder and remove source from holder.

5.2.2 Visually inspect source for damage and evidence of failure of source integrity.

5.2.3 Wipe test source.

5.2.4 Acceptability for source storage:

5.2.4.1 If the source passed the visual examination and if the removable contamination determined by the wipe test is less than 0.05 uCi, place the source in storage and note in the inventory record.

5.2.4.2 If the removable contamination, as determined by wipe test, is greater than 0.05 uCi, the source should be visually re-examined. If the examination reveals no sign of cladding failure, decontaminate and wipe test again. If the results of the wipe test after decontamination is less than 0.05 uCi, the source shall be considered acceptable and placed in storage.

5.2.4.3 If there is any sign of cladding failure, or if the wipe test after decontamination is greater than 0.05 uCi, notify the production manager and establish the corrective action to be taken to prevent significant contamination in storage. Note condition and action taken in the hot cell log.

5.2.5 Open hot cell door using referenced procedures and move <u>empty</u> cask into the hot cell access area.

5.2.6 If the <u>empty</u> cask is to be reloaded for outgoing shipment, proceed to Step 5.1.11.

5.2.7 If the <u>empty</u> cask is to be shipped empty or taken out of service, remove inserts, clean the inside of the container and wipe test both the inside of the container and the inserts.

The inside surface of the shipping/transfer cask and the inserts should not exceed a count rate of 500 dpm per 100 cm^2 on the wipe tests; clean and rewipe as necessary to meet this limit.

5.2.8 If the <u>empty</u> cask is to be shipped empty, install inserts (if appropriate), and bolt gasketed covers into place. Tighten bolts to firmly compress the gasket (approximately 100 inch-pounds torque). Insure requirements of 49 CFR 173.427 regarding shipment of empty radioactive packaging materials are met. Proceed to Step 5.3.10 or an alternative special procedure.

5.2.9 If the empty cask is to be taken out of service, install the covers along with any internals to be stored and place the cask into storage.

5.3 Loading

NOTE: Before loading, make certain that all applicable preparation steps, starting with 5.1, are completed.

5.3.1 Remove completed and inspected source from storage.

5.3.2 Visually inspect source for damage and evidence of failure of source integrity.

5.3.3 Wipe test source.

5.3.4 Acceptability for source shipment:

5.3.4.1 If the source passed the visual examination and the removable contamination, as determined by the wipe test, is less than 0.001 uCi, the source is acceptable for shipment.

5.3.4.2 Repeated decontamination and wipe testing is acceptable in meeting criteria.

5.3.5 Load source into appropriate holder and the holder into the designated position in the shipping/transfer cask.

5.3.6 Record the identification and location of each source in the cask.

5.3.7 Open the hot cell door using the referenced procedures.

5.3.8 Place cover on the shipping/transfer cask.

5.3.9 Remove shipping/transfer cask from hot cell and tighten bolts to firmly compress the gasket (approximately 100 inch-pounds torque).

5.3.10 Decontaminate the shipping/transfer cask.

5.3.11 Wipe test shipping/transfer cask and decontaminate as necessary.

5.3.12 Measure and record maximum radiation levels at surface and at 1 meter (3.3 feet).

5.3.13 Complete and place appropriate label on the shipping/transfer cask.

5.3.14 Load shipping/transfer cask into the overpack and install wooden protective jacket cover. Bolt cover firmly into place, making certain that all thread reinforcement rod ends remain recessed at least 1.5 inches below the surface of the wooden protective jacket.

5.3.15 Bolt overpack steel shell.

5.3.16 Fit steel shell cover and bolt into place.

5.3.17 Affix appropriate labels for the shipment and load the NPI-20WC-6 package onto the truck in accordance with QA 1003.

6. <u>RECORD REQUIREMENTS</u>

6.1 The hot cell logbook shall contain:

- identification of the cask that has been loaded;
- identification and in-cask location of sources that have been loaded;
- name of operator;
- results of all wipe tests and results of source inspections; and,
- dose received by operator as read on the dosimeter.

6.2 Make the appropriate entry into the inventory record.

6.3 The hot cell manager shall review the hot cell logbook for compliance with the procedure at least once a day and shall either indicate its adequacy by initialling at the end of each day's entry or shall note and initial any inadequacy. The radiation safety officer shall review the hot cell logbook at least weekly and shall make similar notations.

8.0 ACCEPTABLE TESTS AND MAINTENANCE PROGRAM

The sections presented in this chapter are in conformance with applicable items of 10 CFR 71, Subpart H, Quality Assurance. In addition, Neutron Products has a complete and approved Quality Assurance Program, which addresses all the numbered items of Subpart H.

The shipping package that is the subject of this application is practically identical to one that has been successfully in service at Neutron Products for 12 years. Consequently, it is not considered necessary that any extensive tests, other than those associated with acceptance of the proposed packaging, be conducted prior to putting it into service. To confirm the adequacy of the shipping packaging, a thorough series of inspections, measurements, and a set of as-built drawings will be made to determine that the manufacturer of the packaging is in accordance with the drawings and specifications. In addition, tests in fabrication to confirm leak tightness of lead containing cavities and the shielding integrity will be performed.

8.1 Acceptance Tests

The entire shipping packaging, i.e., the components of the shipping/transfer cask, the Wooden Protective Jacket, and the outer Steel Shell, will be inspected in accordance with the following quality assurance provisions:

- Inspection of all quality conformance activities is performed under the responsibility of the QA manager. Inspection personnel are independent of those performing the work. The inspections are performed by personnel qualified in accordance with the company's training program.

- Operating and QA procedures identify, where applicable, mandatory inspection hold points for witness by an inspector. Surveillance during fabrication, inspection, testing, and shipment of purchased materials, equipment, and components is maintained to assure conformance with specifications. Suppliers are required to furnish documentation that identifies the purchased material or equipment and the specific procedure requirements (e.g., codes, standards, and specifications) met by safety related items.

Receiving inspection of the supplier furnished material, equipment, and services will be performed to assure:

- The material, components, or equipment is properly identified and corresponds with the identification on receiving documentation.

- Material, components, equipment, and records are inspected and judged acceptable in accordance with the package specifications prior to installation or use.

- Inspection records or certificates of conformance attesting to the acceptance of material and components are available prior to equipment installation or use.

- Items accepted and released are identified as to their inspection status.

8.1.1 Visual Inspections

Visual inspections will be conducted to insure that the packaging is in conformance with the drawings and specifications.

Welds which are part of the boundary of the lead containing cavities of the inner container will be inspected using liquid penetrant in accordance with ASME B & PV Code, Section V. This includes the Drums, Covers, and the Shell Assembly. Any evidence of weld cracking will be repaired by removal of the metal in the indicated region and satisfactorily rewelding the joint. Acceptance criteria shall be in accordance with ASME B & PV Code, Section VIII, Division 1, Appendix 8.

In addition to dimensional checks, visual inspection of the Wooden Protective Jacket will include proper bonding of the plywood sheets and installation of the reinforcing rods. The outer Steel Shell will be visually inspected for weld quality. Any questionable areas will be rewelded or reinforced.

8.1.2 Structural and Pressure Tests

Not applicable

8.1.3 Leak Tests

In fabrication of the inner container, the chambers containing lead shielding will be leak tested before filling to assure containment integrity. Leak tests of the inner container closure are not required in normal service.

8.1.4 Component Tests

Not applicable

8.1.5 Tests for Shielding Integrity

Before delivery, the inner container will be tested and inspected by nondestructive means and evidence submitted to show that the required homogeneity of shielding is provided to meet the shielding specifications. The outer surface of the cask will be surveyed with a cobalt-60 radiation source in the central chamber. Normally this is done by surveying the entire accessible surface of the cask. In the case of the inner container, almost all of the outer surface is accessible. As a minimum, however, a 14 point survey will be made (on the surface face intersecting each of the principal axies, plus the central point on the face of each octant defined by the three principal planes containing the center of the spherical shell) and the values recorded. Any area showing surface radiation more than 15% above the average where lead shielding thickness is comparable will be repaired and retested.

8.1.6 Thermal Acceptance Tests

Not applicable

8.2 Maintenance Program

The shipping package does not contain liquid shielding, coolant, valves, pressure gages, rupture disks, etc., thereby simplifying regular maintenance. In addition to periodic routine visual inspections, the following routine maintenance is performed in accordance with NPI Procedure R 2019.

- Components of the package are checked for contamination when it is being loaded or unloaded and decontamination is effected as required.

- When the end covers are installed or removed, the condition of the silicone gasket is inspected and the gasket is replaced when checking, hardening, deterioration, or any damage is observed. The gaskets are replaced within a 12 to 18 month period in any event.

- Prior to each use, the Wooden Protective Jacket is inspected for defects, or conditions potentially leading to defects, such as loss of plywood bonding, cracking, waterlogging, excessive drying, corrosion of the steel rods, or any body or cover warping that would result in an inadequate cover seal. Should any of these conditions be observed, the situation shall be evaluated and a repair made, or the Wooden Protective Jacket taken out of service.

- The overpack Wooden Protective Jacket and Steel Shell are inspected for damage when being put into, or taken out of, service. Spare parts are kept in stock and replacement or repair is made as required.

8.3 Appendix

8.3.1 Teletherapy Shipping Package - Maintenance Procedure: NPI Procedure No. R 2019, Revision 0.

TELETHERAPY SHIPPING PACKAGE
MAINTENANCE PROCEDURE

PROCEDURE R 2019

REVISION 0

OCTOBER 27, 1992

Reviewed for Adequacy for Intended Purpose and Approved	Jeffrey W. Corun Date 10/27/92
Reviewed for Radiation Safety and Approved	Marvin M. Turkanis Date 10/27/92
Reviewed for Compliance and Approved	Frank Schwoerer Date 10/27/92
Quality Assurance Review	Catherine M. O'Brien Date 10-27-92

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TELETHERAPY SHIPPING PACKAGE
MAINTENANCE PROCEDURE

PROCEDURE R 2019

REVISION 0

SCOPE

Neutron Products' teletherapy source shipping packages, Model Nos. NPI-20WC-6, NPI-20WC-6 MkII, and U.S. DOT Type 20WC-6, consist of a DOT Specification 20WC wooden protective jacket with a single, snug-fitting inner container (a lead shielded shipping/transfer cask). The maintenance program for these shipping packages is the subject of this procedure.

1. REFERENCES

NPI Procedure R 2014, Teletherapy Shipping/Transfer Cask, Unloading and Loading Procedure
U.S. NRC Certificates of Compliance Nos. 9102 and 9215
U.S. DOT Certificates of Competent Authority Nos. USA/5800/B and USA/9215/B(U)
U.S. DOT Regulations, 49 CFR 173.416(f)
NPI Quality Assurance Program for Radioactive Material Packages, U.S. NRC Approval No. 0121

2. GENERAL CONSIDERATIONS

2.1 Inspections/tests are performed each time a shipping package is disassembled and assembled for shipment. If these inspections/tests reveal the need to replace parts or to repair the shipping package, the work is either done immediately or the package is taken out of service until repairs are accomplished.

2.2 A few components of the packages are replaced at intervals of at least 12 to 18 months, even though inspections/tests indicate that they are in a fully functional condition.

2.3 All maintenance work done on teletherapy shipping packages is performed under Neutron Products' NRC-approved Quality Assurance Program. Repairs are documented in a teletherapy shipping package log.

3. PERSONNEL AND SUPERVISION REQUIREMENTS

Inspection and maintenance of teletherapy shipping packages may be performed only by qualified individuals, acting under the authority of the hot cell manager or the radiation safety officer (RSO), or their designee(s).

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4. EQUIPMENT

General:
Forklift truck and lifting slings
Wipes and radiation counter to determine smearable, removable activity

Shipping/transfer cask:
Spare parts inventory
Applicable inserts for drum
Special tools

Overpack:
Spare parts inventory
Special hardware as necessary
Special tools

5. MAINTENANCE PROGRAM

5.1 Surface Contamination

The shipping/transfer cask and the overpack are to be wipe tested for surface contamination prior to shipment from Neutron Products and prior to unloading, when a package is received from a facility that has unsealed cobalt-60. Decontamination is to be effected as required to meet U.S. DOT criteria for shipment.

5.2 Shipping/Transfer Cask

5.2.1 The two gaskets on the shipping/transfer cask are to be inspected whenever the end covers are installed or removed. The gasket(s) shall be replaced if checking, hardening, or any damage is observed. Regardless of their condition, the gaskets shall be replaced after 12 to 18 months of use.

5.2.2 Each shipping/transfer cask is to be inspected annually.

5.3 Wooden Protective Jacket

5.3.1 Prior to each use, the wooden protective jacket is to be inspected for defects or conditions potentially leading to defects. The conditions of concern include loss of plywood bonding, cracking, waterlogging, excessive drying, corrosion of the steel rods, or warping that causes an inadequate cover seal. If any of these conditions is observed, the situation shall be evaluated and, if relevant to satisfactory performance of the package, immediate repairs shall be made or the wooden protective jacket taken out of service until repairs are accomplished.

5.3.2 Each wooden protective jacket shall be weighed annually.

5.4 Outer Shell

The steel outer shell of the overpack is to be examined visually after receipt of a shipment at Neutron Products and prior to the next use. Any defects shall be corrected or the shell taken out of service until repairs are accomplished.

5.5 Package Repairs

5.5.1 Minor repairs that can be effected by replacement of parts from the inventory of spares may be made in the course of package loading or unloading operations.

5.5.2 If major repairs are necessary, the package (or components thereof) shall be taken out of service until repairs are accomplished.

5.5.3 Repairs are to be made by qualified employees or vendors, working under and in compliance with Neutron Products' Quality Assurance Program.

5.6 Records

A documented record is to be maintained of all package repairs. This record may be in the form of a logbook for teletherapy shipping package maintenance.

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