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PLUTONIUM AIR TRANSPORTABLE PACKAGE MODEL PAT-1

Safety Analysis Report

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The document is a Safety Analysis Report for the Plutonium Air Transportable Package, Model PAT-1, which was developed by Sandia Laboratories under contract to the Nuclear Regulatory Commission (NRC). The document describes the engineering tests and evaluations that the NRC staff used as basis to determine that the package design meets the requirements specified in the NRC "Qualification Criteria to Certify a Package for Air Transport of Plutonium," (NUREG-0360). By virtue of its ability to meet the NRC Qualification Criteria, the package design is capable of safely withstanding severe aircraft accidents. The document also includes engineering drawings and specifications for the package.

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ABSTRACT

The document is a Safety Analysis Report for the Plutonium Air Transportable Package, Model PAT-1, which was developed by Sandia Laboratories under contract to the Nuclear Regulatory Commission (NRC). The document describes the engineering tests and evaluations that the NRC staff used as a basis to determine that the package design meets the requirements specified in the NRC "Qualification Criteria to Certify a Package for Air Transport of Plutonium" (NUREG-0360). By virtue of its ability to meet the NRC Qualification Criteria, the package design is capable of safely withstanding severe aircraft accidents. The document also includes engineering drawings and specifications for the package.

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PREFACE

The package described in this Safety Analysis Report was designed for air transport of plutonium. The package was developed and tested by Sandia Laboratories under contract to the Nuclear Regulatory Commission (NRC). The purpose of this document is to describe the engineering tests and analyses that the NRC staff used as a basis to determine that the package design meets the requirements specified in the NRC "Qualification Criteria to Certify a Package for Air Transport of Plutonium" (NUREG-0360). By virtue of its ability to meet the NRC Qualification Criteria, the package design is capable of safely withstanding severe aircraft accidents.

Prior to publication of this document, the NRC Qualification Criteria and the Model PAT-1 package design received an independent technical review and endorsement by both the NRC Advisory Committee on Reactor Safeguards and the Aeronautics and Space Engineering Board of the National Academy of Sciences.

1.0 GENERAL INFORMATION

1.1 Introduction

The Plutonium Air Transportable Package, Model PAT-1, is designed for shipment of plutonium by air. The package design was physically tested to demonstrate that it meets the criteria specified in NUREG-0360, "Qualification Criteria to Certify a Package for Air Transport of Plutonium" (Ref. 1) and the requirements of 10 CFR Part 71 (Ref. 2). The package has been assessed for transport of up to 2.0 kg of PuO_2 having a maximum decay heat of 25 watts. The package qualifies as Fissile Class I.

1.2 Package Description

1.2.1 General

The PAT-1 package has a gross weight of approximately 500-lbs. The exterior shape of the package is a right-circular cylinder, 24-1/2 inches diameter by 42-1/2 inches long (Figure 1.1).

1.2.2 Packaging

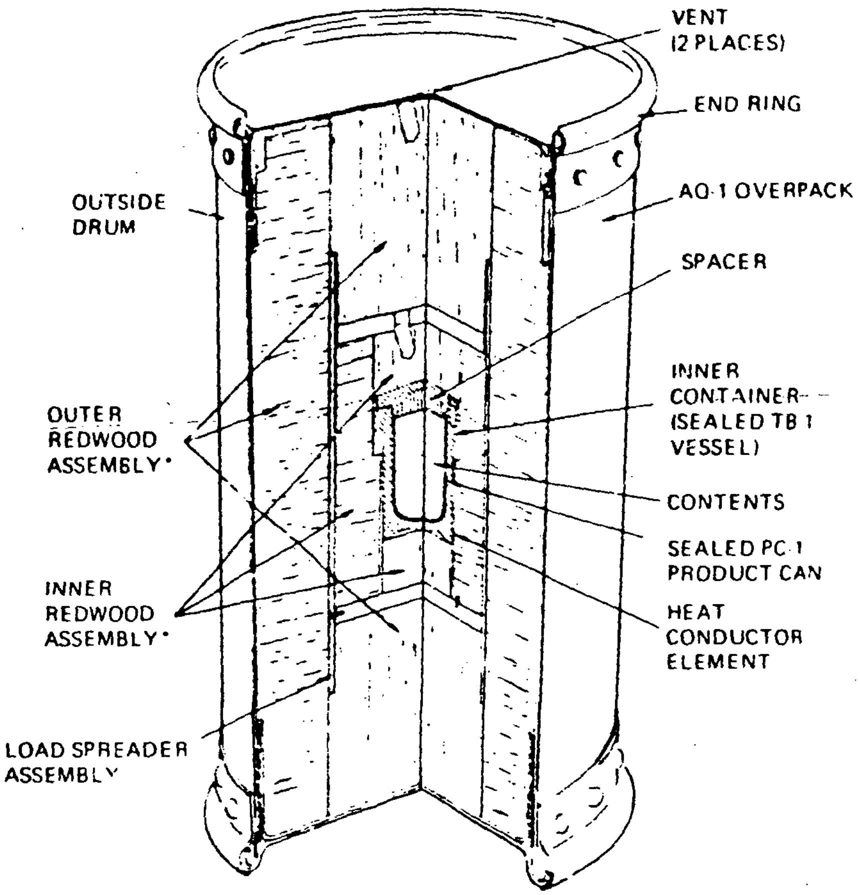
The PAT-1 packaging is composed of three basic parts: (1) a stainless steel containment vessel (designated the TB-1), (2) a protective overpack assembly (designated the AQ-1), and (3) a stainless steel product can (designated the PC-1) within the TB-1 containment vessel. The TB-1 serves as the containment vessel for the purpose of meeting the requirements of 10 CFR Part 71 and the NRC Qualification Criteria. The PC-1 serves as a separate inner container as required by 10 CFR §71.42.

Figure 1.2 shows the principal elements of the package. A set of engineering drawings and specifications for the packaging is included in Section 9.0.

The AQ-1 overpack (Figure 1.3) consists of a 65-gallon drum that is fully lined with an inner drum; both drums are made of 304 stainless steel. The inner drum has a cylindrical center section, and is bonded (fixed) to the outside drum. The end sections of the inner drum are separate and have rounded corners. The drum covers have integral skirt extensions which, upon assembly, fit between the center and end sections of the inner drum. The 12-gage C-ring cover clamp has a skirt extension that overlaps a region of the outside drum. Twenty-three 3/8-in. diameter bolts pass through these five layers of sheet metal (i.e., the C-clamp extension, the outside drum, the inner liner central section, the cover extension skirt, and the top or bottom end sections of the inner liner) and fasten into nut plates secured inside the inner end sections. The C-ring at the top end of the package can be removed by removing the draw bolt. The C-ring at the bottom end of the package is welded shut.

The outer redwood assembly is made of select, kiln-dried redwood to take advantage of redwood's high specific energy and fire resistant characteristics. The assembly is made of three elements:

Figure 1.1 Exterior View of PAT-1 Package



*Note Wood Grain Orientation (See Table 3.2)

Figure 1.2 Plutonium Air Transportable Package (PAT-1)

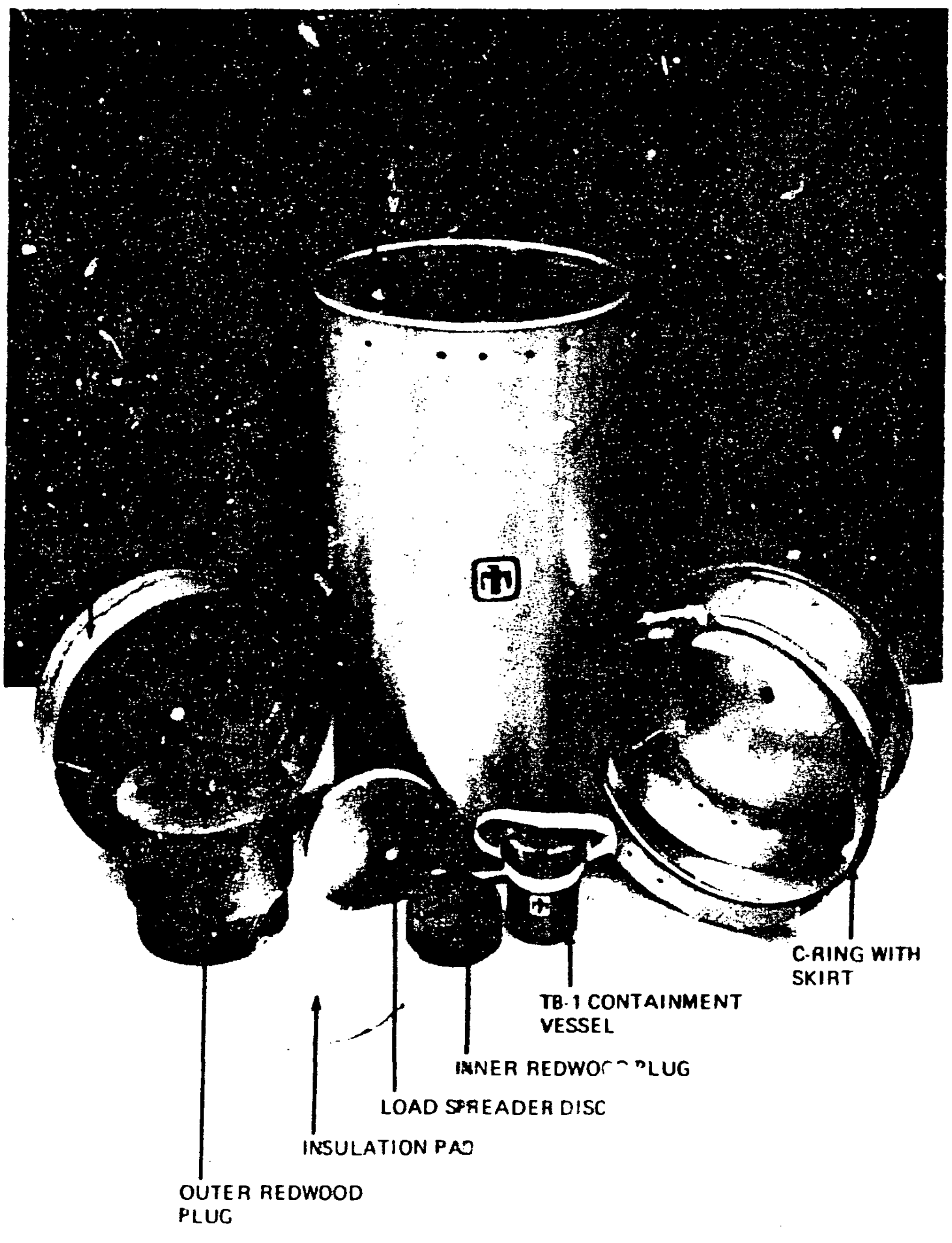


Figure 1.3 PAT-1 Outer Drum Assembly

(1) a removable plug with longitudinally oriented grain, (2) a cylindrical annulus with radial grain orientation (fabricated as a series of wedges arranged in a ring), and (3) a fixed plug with longitudinally oriented grain. The removable plug affords access to the TB-1 vessel. The redwood annulus is bonded to the inner drum The large fixed plug is bonded to the wooden annulus and to the inner drum; the large fixed plug is also bonded to adjacent load spreader members.

The bonding agent used to join the wooden elements together or to adjacent metal is a polyester flexibilized epoxy adhesive, which has resilience over a wide temperature range. When impact forces cause deformation, this bond causes the wooden elements and their adjacent metal members to act in unison.

The load spreader assembly is a 24-inch long aluminum tube, 0.5-inch thick by 12-inch outside diameter. One-inch thick by 11-inch diameter aluminum discs are located at each end of the tube. One disc is removable to access the TB-1 vessel. The other disc is bonded to adjacent members. The load spreader distributes inertial loads from the containment vessel over a relatively large area of shock-absorbing material (redwood). For side impacts, the tube is the principal load spreader. For end impacts, the discs are the principal load spreaders. For severe corner impacts, the extended region of the tube buckles or deforms inward, constricting outward movement of the discs.

The inner heat conductor tube is made of copper. The tube conducts internal decay heat from the TB-1 containment vessel. The conduction path leads from the contents to the product can, to the TB-1 containment vessel, to the copper tube, into the fixed disc, and into the aluminum load spreader tube. Heat is conducted from the load spreader tube through the outer redwood to the outer drum assembly, then to an exchange with ambient air. The inner conductor tube, the disc, and the load spreader tube are mechanically connected to insure an effective heat conductive path.

The TB-1 containment vessel, Figures 1.4, 1.5, and 1.6, is comprised of a body, a lid secured by bolts, a copper gasket, and an O-ring. The vessel body and lid are fabricated from PH13-8Mo precipitation hardened stainless steel. A H1075 temper enhances the ductility of the steel while preserving its strength from low to high temperatures. The lid is hermetically sealed to the body by a copper gasket with knife-edge sealing beads on both the body and lid. The sealing surfaces are arranged to protect the knife-edge sealing beads during handling. The lid has a pilot diameter region which fits closely into the mating internal diameter of the body. The TB-1 containment vessel is also equipped with an O-ring and groove which serve as a secondary seal.

The twelve 1/2-inch diameter closure bolts, Figure 1.6, are forged from A-286 stainless steel. This material exhibits excellent corrosion resistance and provides strength at high temperature to maintain the TB-1 seal. The bolts are silver plated to prevent galling with the stainless steel TB-1.

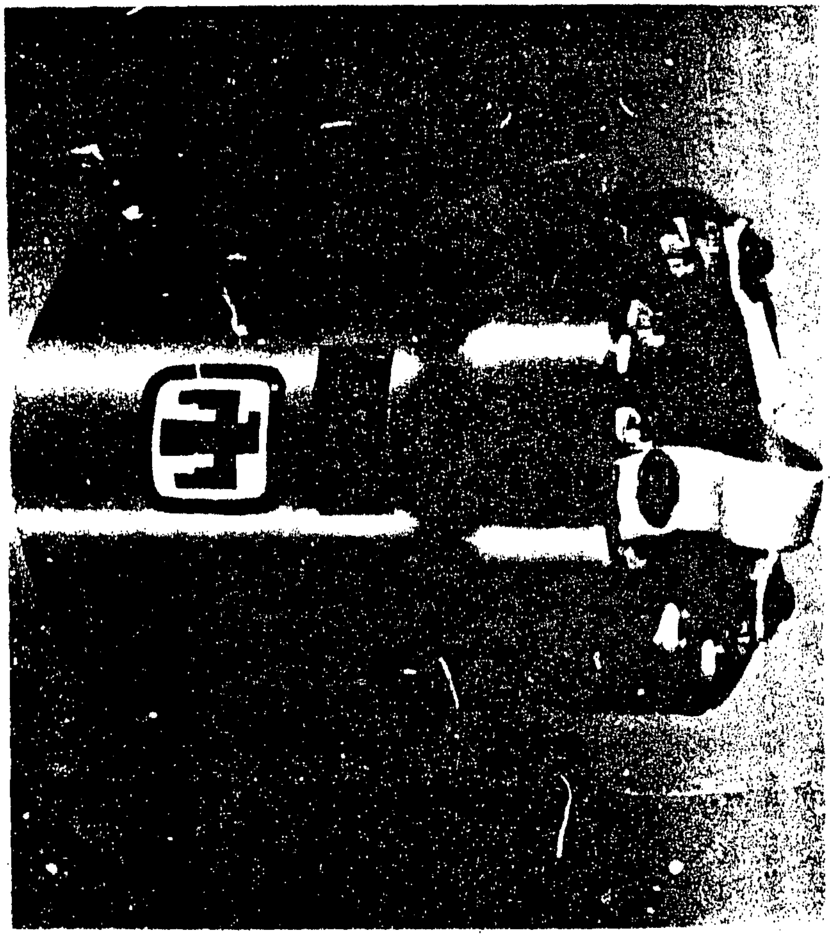


Figure 1.4 Assembled TB-1 Containment Vessel

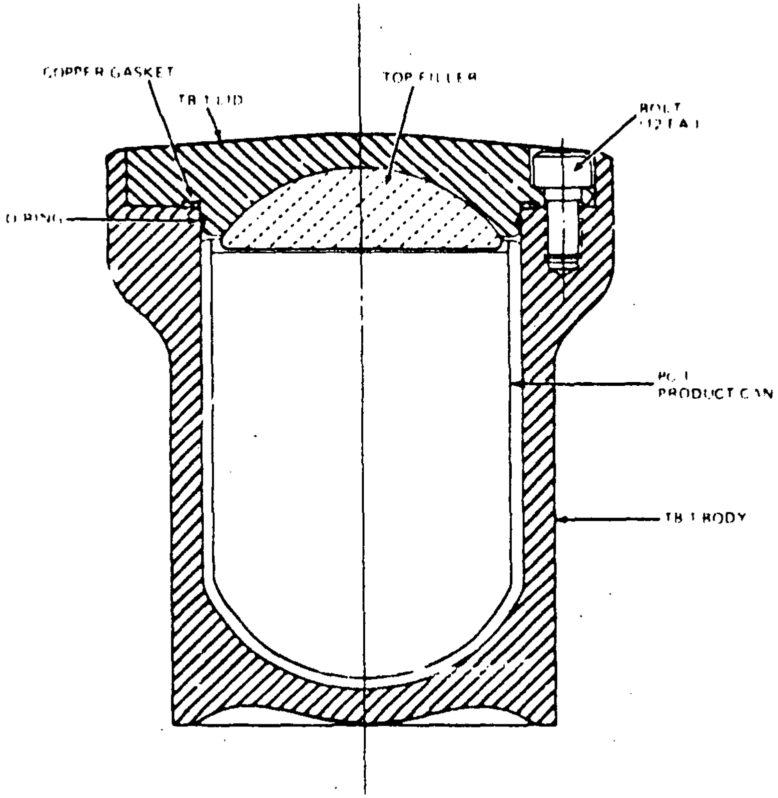


Figure 1.5 Cutaway Drawing of TB-1 Containment Vessel

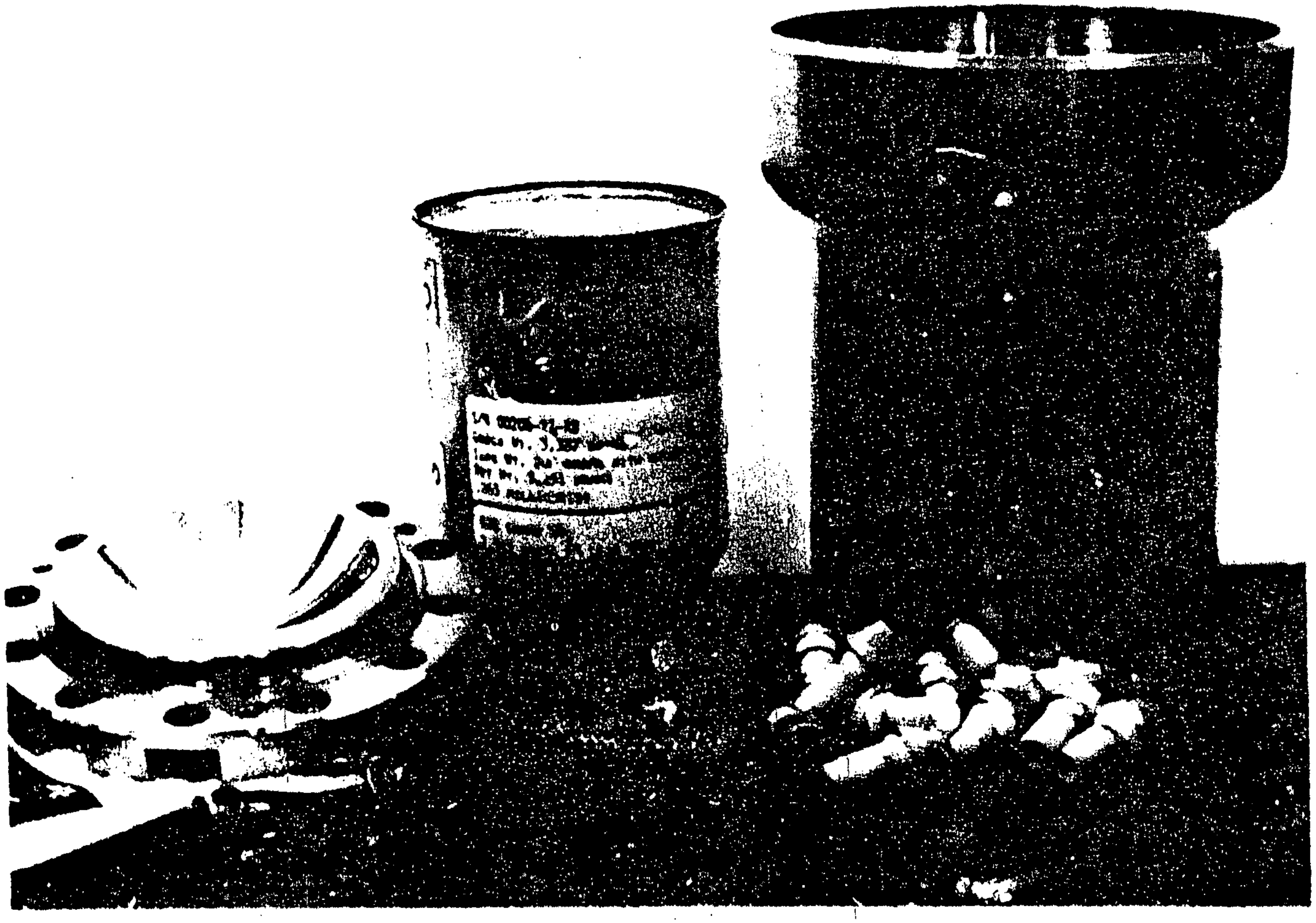


Figure 1.6 Component Parts of TB-1 Containment Vessel and PC-1 Product Can

A spacer within the TB-1 containment vessel is fabricated from aluminum honeycomb (see Figure 1.6). The spacer cushions the flat end of the PC-1 product can under impact loadings and serves as a thermal conductor for internal decay heat.

The PC-1 product can (Figure 1.6) is fabricated from 304 stainless steel and is closed by crimping in a canning machine. After crimping, the can is sealed by welding or silver soldering. The product can meets the separate inner container requirements specified in 10 CFR §71.42.

1.2.3 Allowable Contents

The authorized contents of the PAT-1 package are limited as follows:

Material Type and Form:

(i) Plutonium oxide and its daughter products, in any solid form.

(ii) Mixtures of natural or depleted uranium oxide and plutonium oxide and their daughter products, in any solid form.

Maximum Quantity: Maximum 2.0 kg total material

Maximum Internal Decay Heat: 25 watts

Additional Permissible Contents:

(i) Maximum 16 grams of water

(ii) Two single-layer polyethlene bags weighing no more than 9 grams. The bags may be taped closed or heat-sealed.

Fissile Class: Fissile Class I

REFERENCES

1. "Qualification Criteria to Certify a Package for Air Transport of Plutonium," U.S. Nuclear Regulatory Commission Report NUREG-0360, January 1978. Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

2. "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions," Title 10, *Code of Federal Regulations*, Part 71, Revised August 19, 1975. Available from the Government Printing Office.

2.0 STRUCTURAL EVALUATION

2.1 Discussion

Physical testing of specimen packages was the primary method used to demonstrate that the Model PAT-1 package design meets the structural integrity requirements of 10 CFR Part 71 and the NRC "Qualification Criteria to Certify a Package for Air Transport of Plutonium," (NUREG-0360).

Five specimen PAT-1 packages were subjected to the sequential tests prescribed by the qualification criteria. These tests are described in Section 2.8. In addition, a TB-1 containment vessel was subjected to the 600 psi deep submersion test. This test is described in Section 2.8.3.

Section 2.6 describes the response of the package design when subjected to the normal conditions of transport specified in Appendix A of 10 CFR Part 71. The response of the PAT-1 package design when subjected to the hypothetical accident conditions in Appendix B of 10 CFR Part 71 is described in Section 2.7.

2.2 Weights and Center of Gravity

The approximate weights of the three basic components of the PAT-1 package are as follows:

	Kg	Lbs.
AQ-1 Overpack	206*	454*
TB-1 Containment Vessel	16.8	37
PC-1 Product Can (including alum. spacer)	0.1	0.3
Contents (maximum)	2.0	4.4
Totals	225 Kg.	496 lbs.

The centroid of the Model PAT-1 package is located on its longitudinal centerline, approximately 20 inches from the bottom end.

2.3 Mechanical Properties of Materials

The following material properties are used in the structural analysis in this section.

Stainless Steel 304

Yield Stress $f_y = 30{,}00$ psi

Modulus of Elasticity $E = 29 \times 10^6$ psi

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*The weight of the AQ-1 overpack can vary, due to natural weight variation of kiln-dried redwood.

2.4 General Standards for All Packages (10 CFR §71.31)

2.4.1 Chemical and Galvanic Reactions

There is no potential for a significant chemical, galvanic or other reaction to occur either between the various PAT-1 package components or between the package and its contents.

Metal-to-metal contact on the exterior of the AQ-1 overpack is limited to the 304 stainless steel drum and cadmium plated steel bolts. The aluminum load spreader tube is joined to the bottom load spreader disc by cadmium-plated steel spring pins. The bottom disc of the load spreader is joined to the cadmium-plated copper heat-conducting tube by self-tapping cadmium-plated steel screws These two joints are coated with a moisture-resistant epoxy. The inside of the copper heat conducting tube is lined with epoxy-resin fiberglass cloth to prevent abrasion of the cadmium plating when loading and unloading the TB-1 vessel. In the TB-1 containment vessel, metal-to-metal contact is made between PH 13-8Mo martensitic stainless steel, silver-plated stainless steel bolts and the copper gasket. Within the vessel, contact is made between the aluminum honeycomb spacer and the stainless steel PC-1 product can. The plutonium contents, which may be double wrapped and taped (or heat-sealed) within polyethylene bags, are contained inside the PC-1 product can.

These interfaces have no significant potential for corrosion.

2.4.2 Positive Closure

Positive closure of the cover to the outer drum of the PAT-1 is provided by a skirted C-clamp ring and twenty-three 3/8-inch bolts. The bottom end of the PAT-1 is similarly secured, except that the clamp ring is welded closed. Positive closure of the TB-1 containment vessel is provided by twelve 1/2-inch diameter bolts. Positive closure of the PC-1 product can is provided by a crimped closure which is sealed by welding or silver soldering.

2.4.3 Lifting and Tiedown Devices

The PAT-1 package design has no lifting or tiedown features which are a structural part of the package. The package can be handled by sling, pallet, or other means.

2.5 Standards for Type B and Large Quantity Packaging (10 CFR §71.32)

2.5.1 Load Resistance

The PAT-1 package meets the requirement of 10 CFR §71.32(a), that when treated as a simply supported beam and subjected to a uniformly distributed load equal to five times the package weight, the stresses in the package materials do not exceed yield.

For the purpose of evaluation, the outer drum of the package is assumed to support the entire load* (see Figure 2.1). The maximum stress given by simple beam theory is then:

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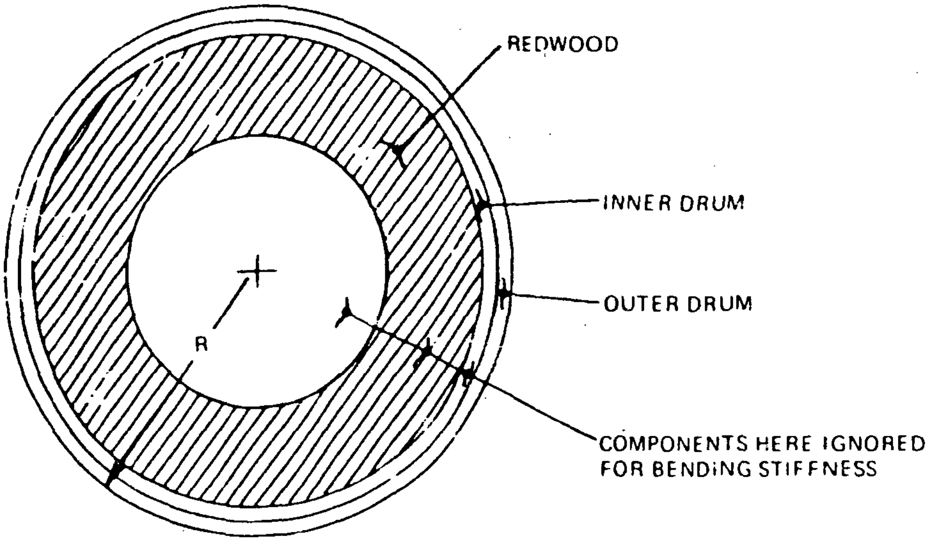
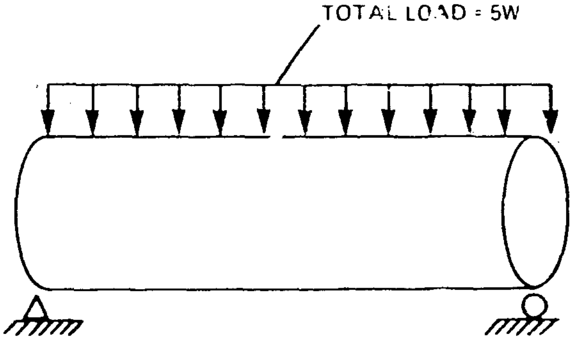
*Assumption is conservative, since inner assemblies will add additional bending resistance to the package.



a. PACKAGE CROSS SECTION AT MIDSPAN



b. ASSUMED LOADING AND BOUNDARY CONDITIONS

Figure 2.1 Model for Calculating Load Resistance

$$\sigma_m = \frac{M}{S} = \frac{5WL}{8} \times \frac{1}{\pi R^2 t}$$

where

$W = 500$ lbs.

$L = 42.5$ inches

$R = 11.27$ inches

$t = 0.059$ inches

$\sigma_m = 565$ psi

This stress is negligible in comparison to the yield stress of the outer drum material (Section 2.3).

2.5.2 External Pressure

As discussed in Section 2.8.3, the PAT-1 package design is capable of meeting the 600 psi test requirement specified in the qualification criteria (NUREG-0360). Therefore, it will also meet the 25 psig test requirement specified in 10 CFR Part 71.

2.6 Normal Conditions of Transport (10 CFR §71.35)

2.6.1 General

A PAT-1 package was subjected to the Normal Conditions of Transport specified in Appendix A of 10 CFR Part 71. Following these tests, the TB-1 containment vessel exhibited an air leak-rate of 10^{-10} atm cc/sec. A leak-rate of 10^{-7} atm cc/sec or less represents leak tightness (Ref. 1). The observed test results demonstrate that the PAT-1 package meets the 10 CFR Part 71 containment requirements for Normal Conditions of Transport.

Since the geometric shape and dimensions of the PAT-1 package and its TB-1 containment vessel were essentially unchanged after the tests, the following requirements in 10 CFR Part 71 for Normal Conditions of Transport are also satisfied: (1) no substantial reduction in the effectiveness of the package, (2) the total effective volume on which nuclear safety was assessed was not reduced by more than five percent, (3) the package dimensions upon which nuclear safety was assessed were not reduced by more than five percent, and (4) no aperture occurred in the outer surface of the package large enough to permit entry of a four-inch cube.

2.6.2 Heat

A PAT-1 package was subjected to a 215°F environment for 48 hours (Figure 2.2). As indicated by the thermal analysis, Table 3.1, this test environment will generate package temperatures that are greater than those which would occur if the package were to be exposed to direct sunlight at an ambient temperature of 130°F, in still air, with 25 watts of internal decay heat. Water was placed in the vessel to assure that the internal pressure during the test would exceed the maximum normal operating pressure of 34.3 psi (Section 4.2.3).

To assess the adequacy of the TB-1 containment vessel for prolonged service under high temperature environments, a TB-1 was progressively cycled between ambient temperature and

200°F, 400°F, 600°F, 700°F and 800°F. Each successive peak temperature was held for approximately 24 hours. At the conclusion of the tests, helium leakage from the TB-1 containment vessel was not detectable.

The internal decay heat limitation of 25 watts assures that, under the Normal Conditions of Transport specified in 10 CFR Part 71, the mean temperature of the redwood will not exceed 182°F and the peak temperature will not exceed 225°F. No significant redwood degradation would result from prolonged exposure to this range of temperatures (Refs. 2 and 3).

The properties of the polyester epoxy used as the bonding agent between redwood elements and between the redwood and metal surfaces is such that its adhesiveness may be slightly enhanced by exposure to a temperature of 225°F.

2.6.3 Cold

Following the heat test, the PAT-1 package was cold soaked at -40°F for 48 hours. No degradation of the package was observed.

2.6.4 Pressure

A TB-1 containment vessel was heated to 255°F for eight hours, with sufficient water inside the vessel to assure that the internal pressure would be at least 51 psia (1.5 times the maximum normal operating pressure of 34 psia). The unit was helium leak tested before being heated, while hot, and after cool down. The measured leak-rate was less than 10^{-10} atm cc/sec in each case. A leak-rate of 10^{-7} atm cc/sec or less represents leaktightness (Ref. 1). This result demonstrates that the package design is capable of withstanding 1.5 times the maximum normal operating pressure. (10 CFR §71.53(b) requires each package to be pressure tested to this value prior to first use.) The leak-rate measurements were conducted at a pressure less than 0.5 atmospheres. This demonstrates that the package design meets the reduced pressure test requirement of 10 CFR Part 71.

2.6.5 Vibration

The PAT-1 package was subjected to the following vibration environments (Figures 2.3 and 2.4), representative of vibration conditions in transport (Ref. 4).

0.2 g^2/Hz 30-150 Hz*
6 db/octave rolloff 150-2000 Hz
8 hours duration - longitudinal axis
8 hours duration - vertical axis.

The vibration tests had no effect upon the package.

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*Random vibration levels are specified in g^2/Hz units (which are analogous to power levels) versus frequency. The method to translate this level to an approximate equivalent sinusoidal vibration is to choose the bandwidth of interest and integrate and take the squart root. This provides an rms g-level that corresponds to sinusoidal motion in that bandwidth.

2.6.6 Water Spray

The PAT-1 package was subjected to the water spray test required by Appendix A of 10 CFR 71. The test, shown in Figure 2.5, used a three-inch diameter hose equipped with a fog nozzle to drench the package with more than 124 gallons of water per minute. The upper surfaces of the package were continuously sprayed for more than 30 minutes, followed by spraying onto the side surfaces. 10 CFR Part 71 does not require the effects of this test to be assessed individually. However, the free drop test is to be conducted within 1-1/2 to 2-1/2 hours following the spray test.

2.6.7 Free Drop

The PAT-1 package was subjected to a four-foot free drop onto an essentially unyielding surface in a side impact orientation. To provide assurance that the PAT-1 has a wide design margin to withstand the rigors of normal handling and transport, the package was also dropped four feet onto its top end, top-corner, bottom end, and bottom corner. Figure 2.6 shows that the effect of these tests was inconsequential. As described in Section 2.6.1, the PAT-1 package design meets all the acceptance standards specified in 10 CFR Part 71 for Normal Conditions of Transport.

2.6.8 Corner Drop

This requirement does not apply to packages weighing more than 210 pounds and is therefore not applicable to the 500-pound PAT-1 package.

2.6.9 Penetration

The PAT-1 package was subjected to the penetration test specified in Appendix A of 10 CFR 71. This test requires that a 13-pound, 1-1/4 inch diameter, steel cylinder having a hemispherical end be dropped onto the package from a height of 40 inches. The result was a slight dimple in the outer drum of the package as shown in Figure 2.7.

2.6.10 Compression

The PAT-1 package was subjected to the compression test specified in Appendix A of 10 CFR 71. This test requires that a compressive load equal to five times the package weight (5 x 500 lbs. = 2500 lbs.) be applied uniformly against the top and bottom of the package for 24 hours. A load of 3150 lbs., a conveniently available mass, was placed on top the PAT-1 package, which rested on a massive steel plate, which in turn rested on a massive concrete block (Figure 2.8). The load was maintained for a period exceeding 24 hours. There was no observable effect to the package. The package was then placed on its side on a concrete pad, and a concrete block weighing 5000 lbs was leaned on the package, on top of which a 3150-lb concrete block also was placed. The total load, amounting to more than 5600 lbs. (Figure 2.9), produced no effect to the package.

2.7 Hypothetical Accident Condition - 10 CFR §71.42

2.7.1 General

The ability of the PAT-1 package to meet the Hypothetical Accident Conditions specified in Appendix B of 10 CFR Part 71 can be inferred from its ability to meet the more stringent NRC

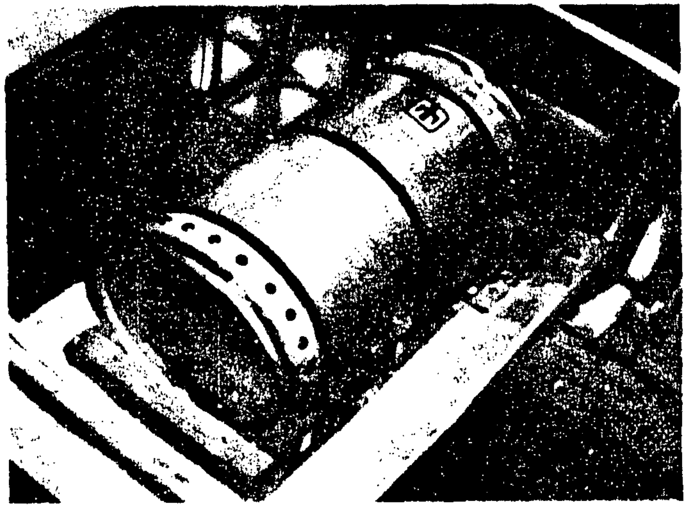

Figure 2.2 PAT-1 Package Following Heat Test

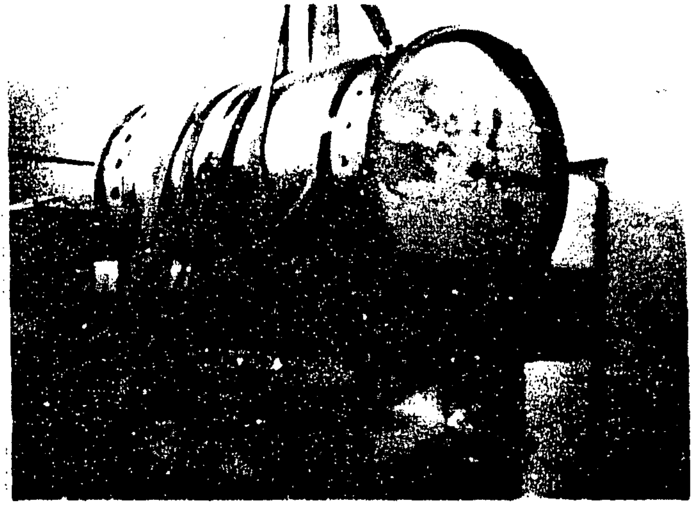

Figure 2.3 Lateral Vibration Test of the PAT-1 Package

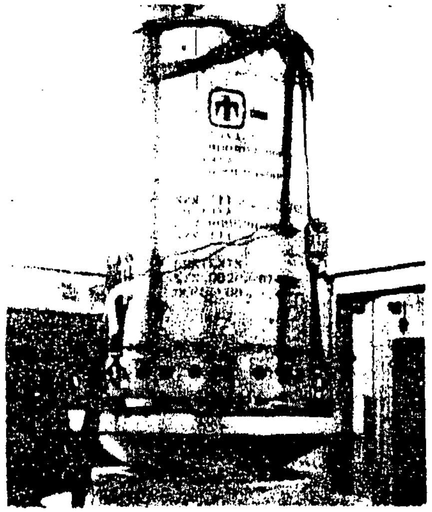

Figure 2.4 Longitudinal Vibration Test of the PAT-1 Package

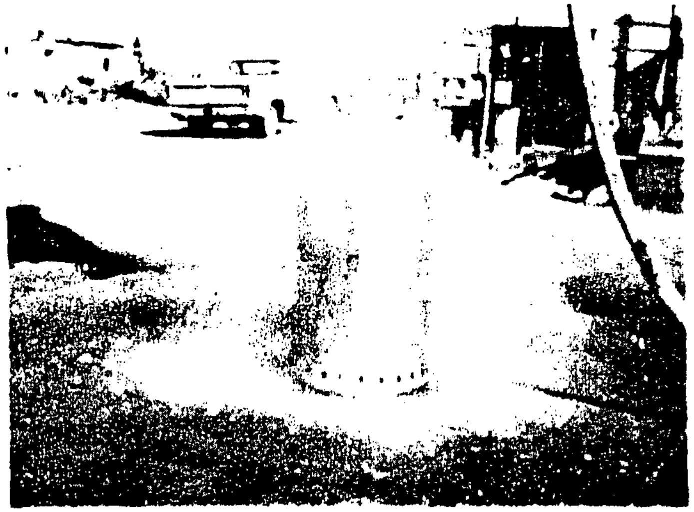

Figure 2.5 Water Spray Test

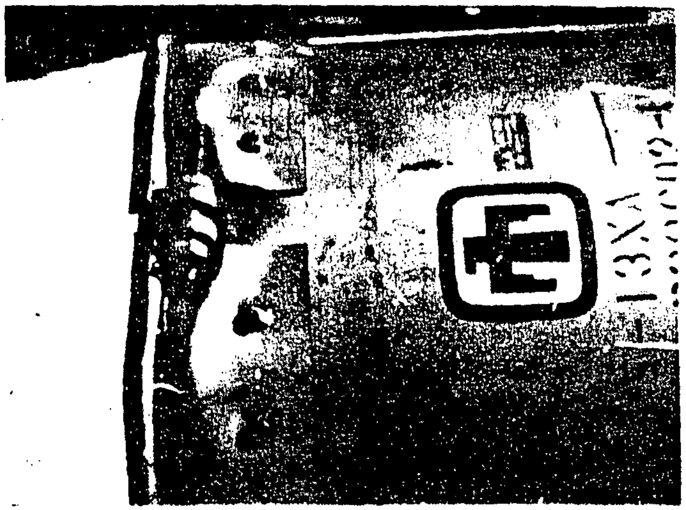

Figure 2.6 PAT-1 Package Following Four-Foot Drop Test

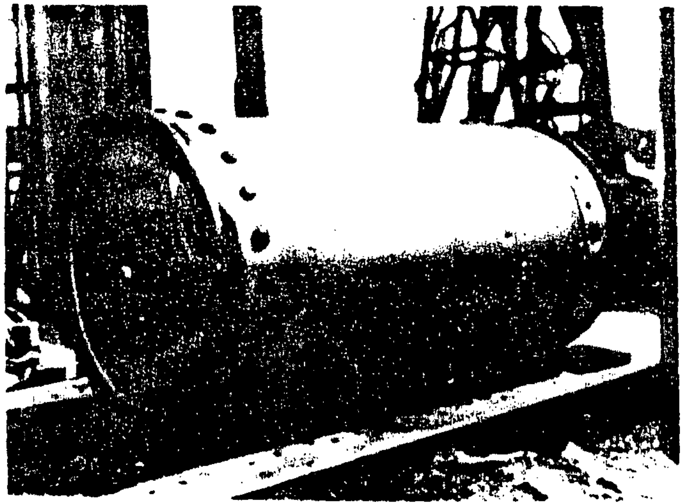

Figure 2.7 PAT-1 Package Following Penetration Test

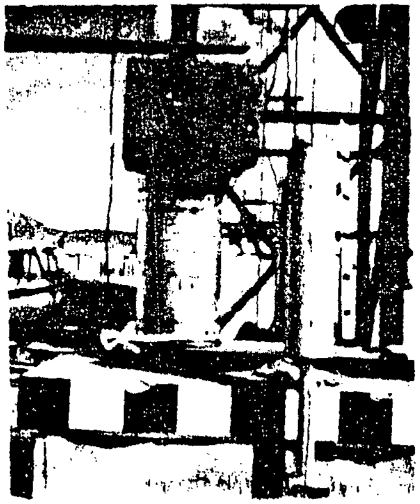

Figure 2.8 Compression Test – Longitudinal Axis

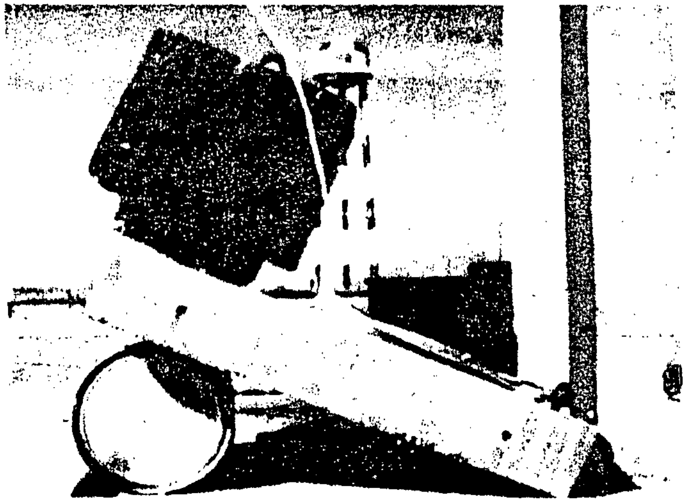

Figure 2.9 Compression Test - Lateral Axis

Qualification Criteria to Certify a Package for Air Transport of Plutonium. However, effective June 17, 1978, for shipments in excess of 20 curies per package, 10 CFR Part 71 requires certain forms of plutonium to be packaged within a separate inner container which will not release material when subjected to the normal and accident test conditions specified in Appendices A and B of 10 CFR Part 71.

A PAT-1 package, including a PC-1 product can loaded with UO_2 surrogate material, was subjected to the Hypothetical Accident Conditions in Appendix B of 10 CFR Part 71. The UO_2 surrogate material was not contained within polyethylene bags (i.e., the material was in direct contact with the inner surfaces of the PC-1 product can). Also, the PC-1 product can was sealed with epoxy rather than by welding or silver soldering.

Post-test examination of the PC-1 product can indicated that the crimped closure and the epoxy overbond had remained intact. The can itself had several minor dents (Figure 2.15). Helium leak testing indicated a leak rate beyond the provisions of Regulatory Guide 7.4, however, no uranium surrogate material was detected to have been released using a wipe test and fluorimeter assay technique on the interior of the TB-1 vessel and the exterior of the PC-1 product can. As discussed in Section 4.3.2, the PC-1 product can, within the PAT-1 package, will meet the provisions of 10 CFR §71.42 when closed by crimping and sealed by welding or silver soldering.

The TB-1 containment vessel was found to be leaktight.

2.7.2 30-Foot Free Drop

A PAT-1 package was subjected to a 30-foot drop onto an essentially unyielding surface in the side orientation. This orientation was estimated to be the most damaging to the PAT-1. Figure 2.10 illustrates the minor denting which resulted to the outer drum of the package.

2.7.3 Puncture

The PAT-1 package was then subjected to a free drop of 40 inches onto a six-inch diameter, ten-inch long, steel bar mounted on an essentially unyielding horizontal surface (Figure 2.11). The bar made contact at mid-length on the package because this is the point at which minimum redwood is provided between the TB-1 containment vessel and the outer drum. Damage to the PAT-1 consisted of a minor imprint on the outer drum.

2.7.4 Fire Test

The PAT-1 package was subjected to a fire test which exceeded the severity of the test required by 10 CFR Part 71. The facility used for this test was a ten-foot diameter pool of JP-4 aviation fuel pool surrounded by a chimney, 16 feet in diameter by ten feet high. Temperatures measured within the fire and on the package surface exceeded the 1475°F value specified in the regulations (Table 2.1). Following the fire, the package was permitted to cool naturally.

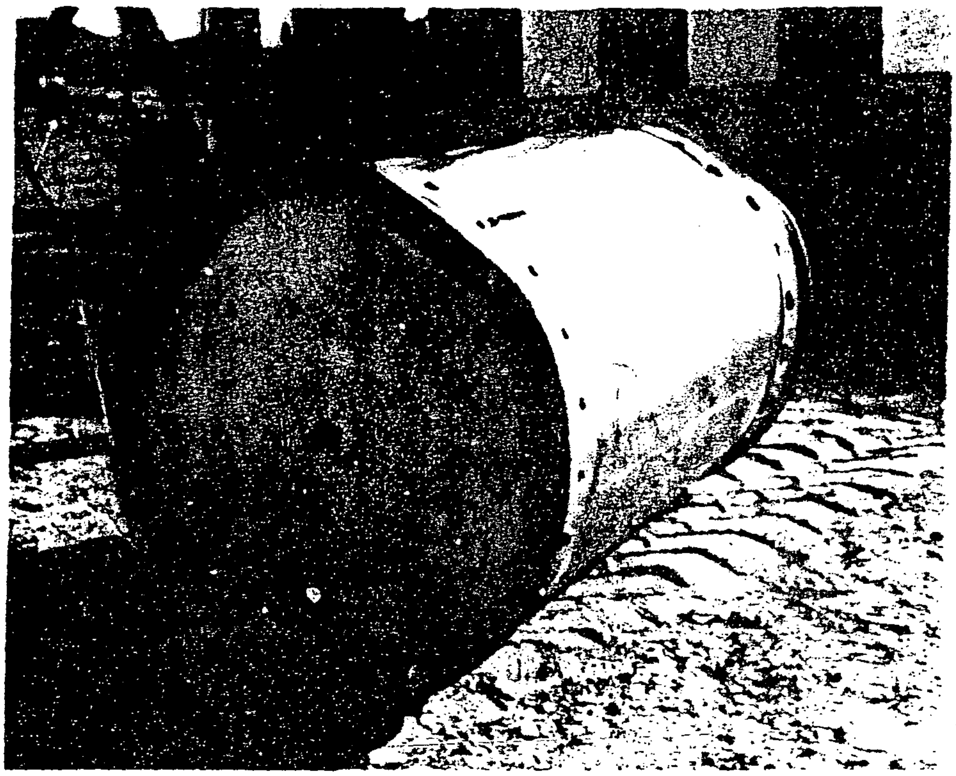

Figure 2.10 PAT-1 Package Following 30 Foot Drop Test

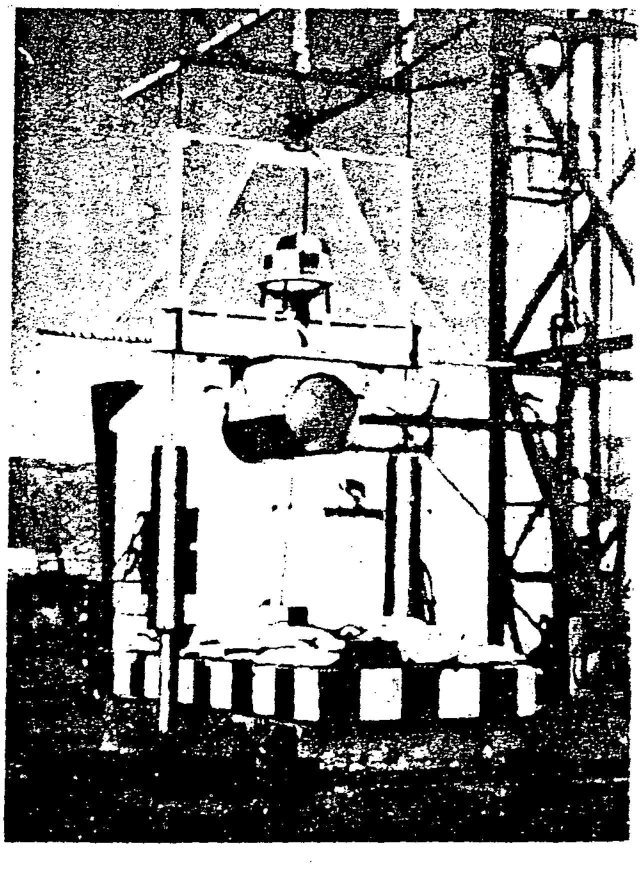

Figure 2.11 Set Up for Puncture Test

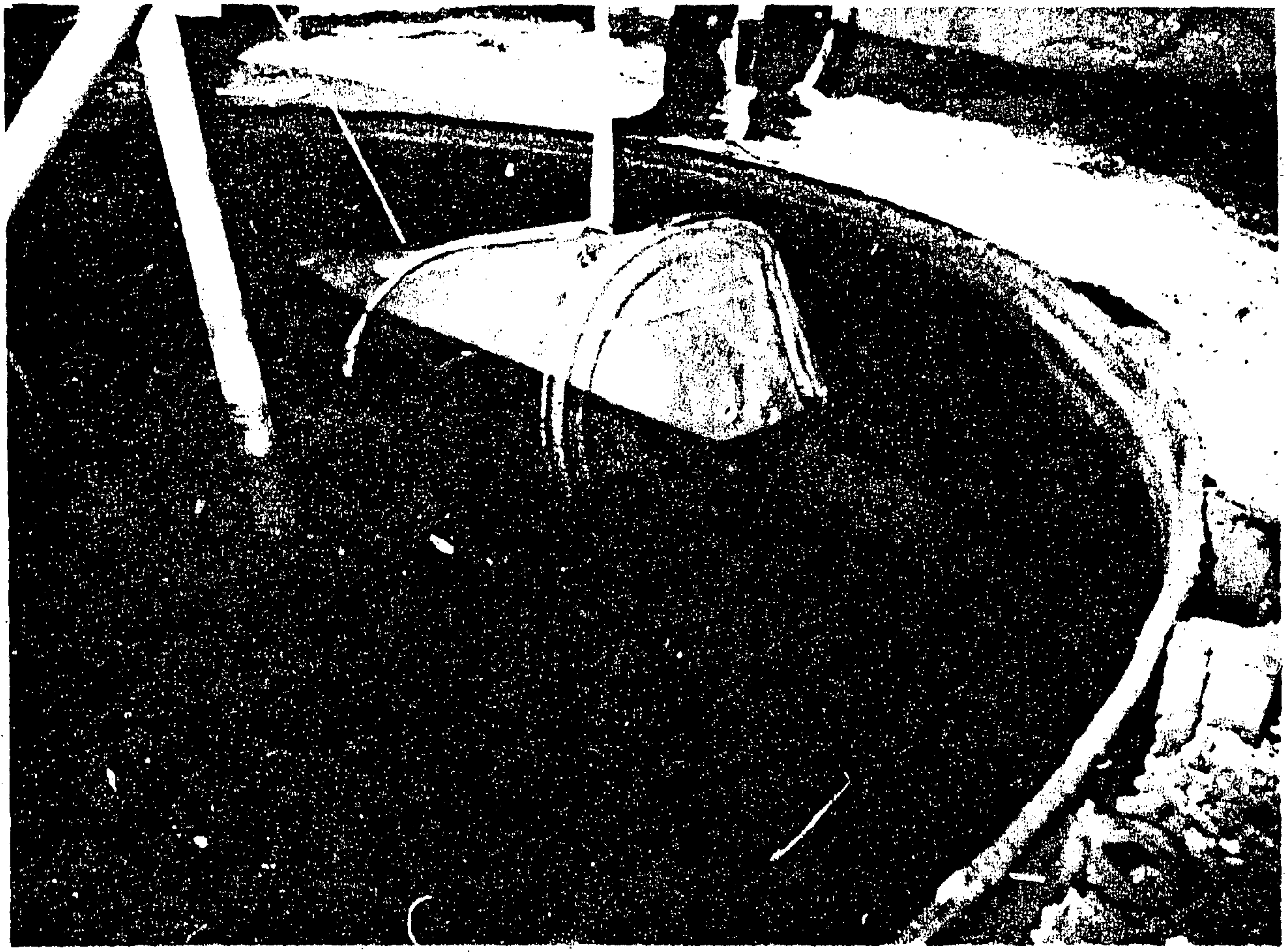

Figure 2.12 Water Immersion Test

Figure 2.13 Package Section Following 10 CFR Part 71
Appendix B Tests

Figure 2.14 Redwood Char Following 10 CFR Appendix B Tests

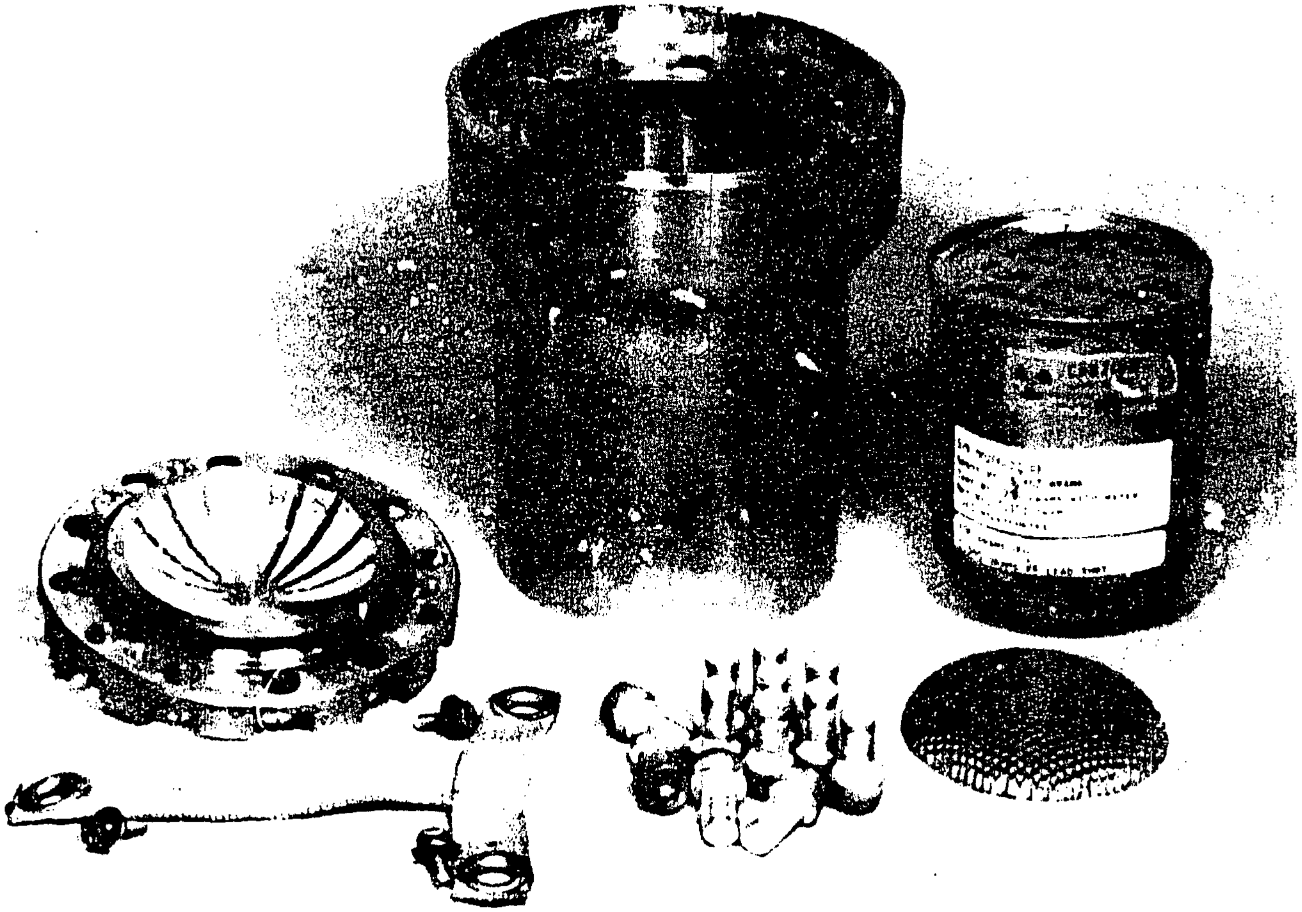

Figure 2.15 Disassembled TB-1 Containment Vessel Following 10 CFR Part 71 Appendix B Tests

Table 2.1

10 CFR PART 71 APPENDIX B FIRE TEST

Average temperature on AQ-1 drum:	Approx. 1800°F
Flame temperatures in vicinity package:	2200-2300°F
Duration of fire:	52 minutes
Char depth in outer redwood:	3.8 inches
TB-1 temperature:	Approx. 200°F

2.7.5 Water Immersion

The package was then submerged under three feet of water within the basin of the fire test facility for approximately 24 hours (Figure 2.12).

2.7.6 Post-Test Summary of Package Damage

The sequential impact, puncture, fire, and immersion tests produced only minor damage to the outer drum and its closure rings. The outer redwood annulus had charred to a depth of about three inches (Figure 2.13), while redwood inside the load spreader was essentially unaffected (Figure 2.14). As discussed in Section 2.7.1, the TB-1 containment vessel was leaktight following the tests and met 10 CFR Part 71 containment requirements. Since the tests did not significantly effect the geometry of the PAT-1 package, its shielding effectiveness following the Hypothetical Accident Conditions in Appendix B of 10 CFR Part 71 would be essentially the same as under Normal Conditions of Transport.

2.8 NRC Qualification Criteria Requirements

2.8.1 Discussion

The NRC Qualification Criteria to Certify a Package for Air Transport of Plutonium (NUREG-0360) specify that the structural integrity of the package be demonstrated by physical testing. The major requirement is for sequential testing to the following conditions:

1. Impact at a velocity of not less than 422 ft/sec at a right angle onto a flat, essentially unyielding surface, in the orientation (e.g., side, end, corner) expected to result in maximum damage at the conclusion of the test sequence.

2. A static compressive load of 70,000 pounds applied in the orientation expected to result in maximum damage at the conclusion of test sequence. The force on the package to be developed between a flat steel surface and a two-inch wide, straight, solid, steel bar. The length of the bar to be at least as long as the diameter of the package and the longitudinal axis of the bar to be parallel to the plane of the flat surface. The load to be applied to the bar in a manner that prevents any members or devices used to support the bar from contacting the package.

3. Packages weighing less than 500 pounds to be placed upon a flat, essentially unyielding, horizontal surface and subjected to a weight of 500 pounds falling from a height of ten feet, striking in the position expected to result in maximum damage at the conclusion of the test sequence. The end of the weight contacting the package to be a solid probe made of mild steel. The probe to be the shape of the frustum of a right circular cone, 12 inches long, eight inches in diameter at the base, and one inch in diameter at the end. The longitudinal axis of the probe shall be perpendicular to the horizontal surface. For packages weighing 500 pounds or more, the base of the probe to be placed on a flat, essentially unyielding surface and the package dropped from a height of ten feet onto the probe, striking in the position expected to result in maximum damage at the conclusion of the test sequence.

4. The package to be firmly restrained and supported such that its longitudinal axis is inclined approximately 45 degrees to the horizontal. The area of the package which made first contact with the impact surface in test 1, above, to be in the lowermost position. The package to be struck at approximately the center of its vertical projection by the end of a structural steel angle section falling from a height of at least 150 feet. The angle section to be at least six feet in length with equal legs at least five inches long and one-half inch thick. The angle section to be guided in such a way to fall end-on, without tumbling. The package to be rotated approximately 90 degrees about its longitudinal axis and struck by the steel angle section, falling as before.

5. The package to be exposed to luminous flames from a pool fire of JP-4 or JP-5 aviation fuel for at least 60 minutes. The luminous flames to extend an average of at least three feet and no more than ten feet beyond the package in all horizontal directions. The position and orientation of the package in relation to the fuel to be that which is expected to result in maximum damage at the conclusion of the test sequence. An alternate method of thermal testing may be substituted for the above fire test provided that the alternate test is not of shorter duration and would not result in a lower heating rate to the package. At the conclusion of the thermal test, the package shall be allowed to cool naturally or shall be cooled by water sprinkling, whichever is expected to result in maximum damage at the conclusion of the test sequence.

6. Immersion under at least three feet of water for at least eight hours.

The acceptance standards for the package following this series of tests are:

1. Containment - The containment vessel must not be ruptured in its post-tested condition and the package must provide a sufficient degree of containment to restrict accumulated loss of plutonium contents to not more than an A_2 quantity* in a period of one week.

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*An A_2 quantity of plutonium is defined in Table VII of the International Atomic Energy Agency Regulations for the Safe Transport of Radioactive Materials, IAEA Safety Series No. 6.

2. Shielding - Demonstration that the external radiation level would not exceed one Rem per hour at a distance of three feet from the surface of the package in its post-tested condition in air.

3. Sub-Criticality - A single package and an array of packages shall be demonstrated to be sub-critical in accordance with 10 CFR Part 71, except that the damaged condition of the package shall be considered to be that which results from the above qualification tests rather than the conditions specified in Appendix B of 10 CFR Part 71.

The NRC Qualification Criteria also require that the package withstand an external water pressure of at least 600 psi for not less than eight hours, without detectable water leakage into the containment vessel.

A further requirement of the NRC Qualification Criteria for impact testing at terminal free-fall velocity is not applicable to the PAT-1 package because the terminal free-fall velocity of the package at sea-level is less than 422 fps (Section 2.8.4).

To demonstrate that the PAT-1 package meets the structural integrity requirements of the NRC Qualification Criteria, five prototype PAT-1 packages were subjected to the described sequential tests. In these five tests, the impact orientation of the package was varied. Since the orientation which would produce maximum package damage at the conclusion of the test sequence could not be readily determined by analysis, impact tests were performed on the top end, top corner, side, bottom corner and bottom end of the packages.

To demonstrate that the package design meets the deep submersion requirement prescribed in the NRC Qualification Criteria, a TB-1 containment vessel was subjected to a 600 psi pressure in a hydrostatic test chamber.

Appendix 2.2 briefly describes the test facilities and outlines how the individual and sequential tests were performed. Section 2.8.2 assesses the results of the sequential tests. Section 2.8.3 describes the results of the hydrostatic test and Section 2.8.5 describes other tests and analytical assessments which are required by the NRC Qualification Criteria.

2.8.2 Sequential Tests

2.8.2.1 Impact Test at 422 fps

2.8.2.1.1 Top End Impact (0°)

A PAT-1 package was impact tested onto its top end (designated as the 0° orientation) at 442 fps. The impact compressed the original package from 42.5 inches to approximately 30 inches in length. No opening occurred in the outer drum and no redwood was exposed (Figures 2.16 and 2.18). Post-test radiographs indicated no discernable effect to the TB-1 containment vessel (Figure 2.17).

2.8.2.1.2 Top Corner (30°) Impact

A PAT-1 package was impact tested onto its top corner (designated the 30° orientation) at 451 fps with the clamp ring draw bolt oriented in the downward position. The test resulted in extensive deformation of the top end of the package. A small tear in the drum cover exposed some redwood (Figures 2.19 and 2.21), but no wood was lost. Post-test radiographs indicated no discernable effect to the TB-1 containment vessel (Figure 2.20).

2.8.2.1.3 Side Impact (90°)

A PAT-1 package was impact tested onto its side (designated the 90° orientation) at 445 fps. The impact flattened the package to approximately one-half of its original diameter and exposed the inner drum liner at the corners. However, no redwood was visible (Figures 2.22 and 2.24). Post-test radiographs indicate that this impact orientation was the most damaging to the redwood, but there was no discernable effect to the TB-1 containment vessel (Figure 2.23).

2.8.2.1.4 Bottom Corner Impact (150°)

A PAT-1 package was impact tested onto its bottom corner (designated the 150° orientation) at 443 fps with the welded joint in the bottom clamp ring oriented downward. The test resulted in extensive deformation of the bottom end of the package. A tear in the outside drum exposed the bonding material between the drum and the drum liner; however, neither the inner liner nor the redwood were exposed (Figures 2.25 and 2.27). The post-test radiographs indicated no discernable effect to the TB-1 containment vessel (Figure 2.26).

2.8.2.1.5 Bottom End Impact (180°)

A PAT-1 package was impact tested onto its bottom end (designated the 180° orientation) at 466 fps. The impact reduced the original package length from approximately 43 inches to approximately 30 inches. There was no opening through the drum or drum liner and no redwood was exposed (Figures 2.28 and 2.30). Post-test radiographs indicated no discernable effect to the TB-1 containment vessel (Figure 2.29).

2.8.2.2 Crush Test

A 70,000-lb crush force was applied through a two-inch wide steel beam to the most vulnerable point on the packages following impact testing. The effects of the crush test were negligible (Figures 2.31, 2.32 and 2.33).

2.8.2.3 Puncture Test

A 500-lb steel spike was dropped ten-feet onto the point on the package where the preceding crush force had been applied. The puncture test generally resulted in a two-inch diameter hole through the drum and drum liner and partial penetration into the redwood. For the side impact-tested package, penetration was not as great because of redwood compaction produced by the impact test (Figures 2.34, 2.35, 2.36, 2.37 and 2.38).

2.8.2.4 Slash Test

The slash test penetrated the outer stainless-steel drum and the drum liner to a depth of approximately four inches along the trajectory of the falling angle section. The angle section did not penetrate to the load spreader imbedded within the outer redwood components (Figures 2.39 and 2.40).

2.8.2.5 Fire Test

The 60-minute fire typically produced a flame temperature of approximately 2200 F at the height of the PAT-1 package. Because the outer drums and outer redwood annulus were penetrated by the slash test, the fire caused all redwood in the PAT-1 package to be charred. However, the aluminum load spreader elements did not reach the solidus temperature (approximately 1080 F and the copper heat conductor tube was integral. The redwood was reduced to ashes.

Arrangement of a package for the fire test is shown in Figure 2.41. A fire test in progress is shown in Figure 2.42. The results of the tests are discussed in Section 2.8.2.7, below.

2.8.2.6 Immersion

The immersion test washed away the redwood ash near the two slash holes in each PAT-1 package and caused black soot (suspended in the water) to spread onto the TB-1 containment vessel (Figures 2.43 and 2.44).

2.8.2.7 Summary of Post-Test Damage

Disassembly of the five packages after the tests required use of cutting torches, band saws, and hand tools (Figure 2.45).

The disassembled packages are shown in Figures 2.46 through 2.56.

A heat-responsive lacquer coating that had been applied to the base of the TB-1 containment vessel indicated that the vessel temperature had reached approximately 1000°F.

As the package were disassembled, the TB-1 containment vessels were surveyed for contamination from the uranium surrogate material. Using a wipe test and fluorimeter assay technique, no uranium surrogate material was detected on the exterior of the TB-1 vessels. Table 2.2 summarizes the post-test leak rates that were measured on each TB-1 containment vessel.

2.8.3 Hydrostatic Test

A TB-1 containment vessel was subjected to an external pressure of more than 600 psig for [illegible] hours in dyed green water (Figure 2.57). The helium leak-rate of the vessel was less than 10^{-10} atm cc/sec both before, and after, hydrostatic testing. After drying the exterior, the weight of the vessel was identical to its pre-test weight. Upon opening, there was no indication that green dye or water had leaked inside the vessel.

Table 2.2

SUMMARY OF THE NRC QUALIFICATION TESTS, PAT-1 PACKAGE

Impact Orientation	Impact Velocity (fps)	Crush	Puncture	Slash	Fire Duration (minutes)	Maximum Leak-Rate (atm cc/sec)
Top (0°)	442	X	X	X	66	4.5×10^{-6}
Top Corner (30°)	451	X	X	X	66	4.5×10^{-5}
Side (90°)	445	X	X	X	66	1.4×10^{-6}
Bottom Corner (150°)	443	X	X	X	63	5.5×10^{-6}
End (180°)	446	X	X	X	66	1.9×10^{-6}

2.8.4 Terminal Free-Fall Velocity

A computer program at Sandia Laboratories was used to calculate the free-fall velocity of the PAT-1 package at sea-level. The package was represented as a right-circular cylinder and was conservatively assumed to be aerodynamically unstable (i.e., it would tumble while falling). The package was considered to fall from an altitude of 35,000 feet. Appropriate coefficients were used to account for the effects of drag. When the package had fallen to sea-level, its velocity was calculated to be 350 ft/sec. Because of the convergent nature of the calculations, the sea-level velocity of the package would not be affected by releasing the package from an altitude higher than 35,000 ft. (i.e., 350 ft/sec is the terminal free-fall velocity of the package at sea-level). Since the terminal velocity at sea-level is less than 422 ft/sec, the NRC Qualification Criteria do not require the package to be subjected to an individual free-fall impact test.

2.8.5 Other Requirements of the NRC Qualification Criteria

2.8.5.1 Cold Ambient Temperature Tests

An early prototype of the PAT package was cold soaked at -50°F for more than 48 hours, wrapped with insulating materials, and 2 hours-15 minutes later, was impact-tested on a 40°F day. The bulk temperature of the package at the time of impact was calculated to be less than -40°F.

The package was impact-tested onto an essentially unyielding target at 433 fps in a side orientation. The package was slightly less crushed than similar packages impact-tested under ambient temperature conditions (Figure 2.58). Radiographic inspection (Figure 2.59) indicated slightly less crushing of the redwood between the outer drum and the TB-1 containment vessel then in similar tests at ambient temperature. No damage was observed to the TB-1 containment vessel. The package was then crushed, punctured, burned, and immersed. The post-test leak rate of the TB-1 containment vessel was measured to be 2.4×10^{-6} atm cc/sec air. This leak rate is comparable to those observed in similar tests at ambient temperature (Table 2.2).

This result supports a conclusion that testing at -40°F would have no significant adverse effect on the PAT-1 package.

2.8.5.2 High Ambient Temperature Tests

An early prototype of the PAT package was hot soaked at +200°F for more than 48 hours, wrapped in insulating materials, and quickly rigged for side impact onto the essentially unyielding target. The impact velocity was 424 fps. The bulk temperature of the package at the time of the impact test was approximately 200°F.

The package was crushed similar to packages tested at ambient temperature (Figure 2.60). Radiographic inspection indicated slightly more crushing of the redwood between the outer drum and the TB-1 containment vessel than in tests conducted at ambient temperature (Figure 2.6 . There was no damage observed to the TB-1 containment vessel. The package was then crushed, punctured, burned and immersed. The post-test leak rate of the TB-1 containment vessel was measured to be 7 x 10^{-8} atm cc/sec. This leak rate is comparable with those observed in similar tests at ambient temperature (Table 2.2).

This result supports a conclusion that testing the package with a full heat load (25 watts) in equilibrium with a 130°F-ambient temperature would have no significant adverse effect on the PAT-1 package.

2.8.5.3 Individual Application of Sequential Tests

The NRC Qualification Criteria require that the ability of a package to withstand the accident condition test sequence must not be adversely affected if one or more tests in the sequence were to be omitted. The purpose of this requirement is to assure that safety does not depend upon the necessary occurrence of a prior or subsequent accident condition (e.g., it may conceivably be possible to design a package so that adverse effects from impact could be corrected by melting material to form a seal during the fire test).

The PAT-1 package has no design features which would allow any of the tests prescribed in the sequence to correct damage done by another test in the sequence. For the PAT-1 design, damage produced by the individual tests is cumulative throughout the sequence and omission of one or more tests in the series would not affect the ability of the package to meet the prescribed acceptance standards.

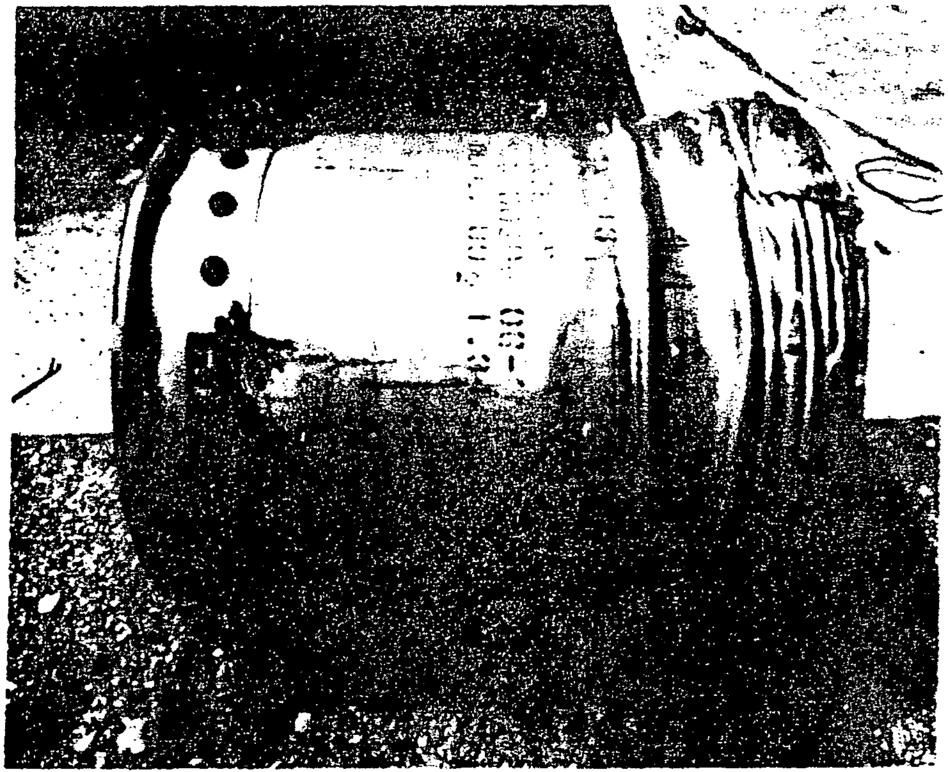


Figure 2.16 PAT-1 Package Following 442-FPS Top End Impact

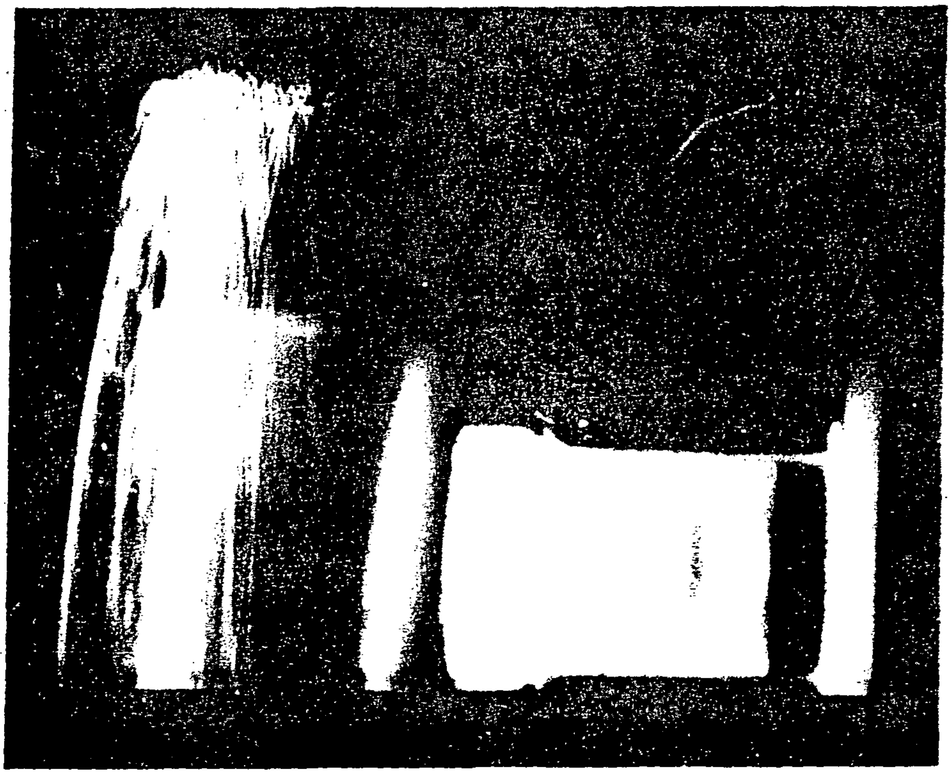


Figure 2.17 Radiograph of PAT-1 Package Following 442-FPS
Top End Impact

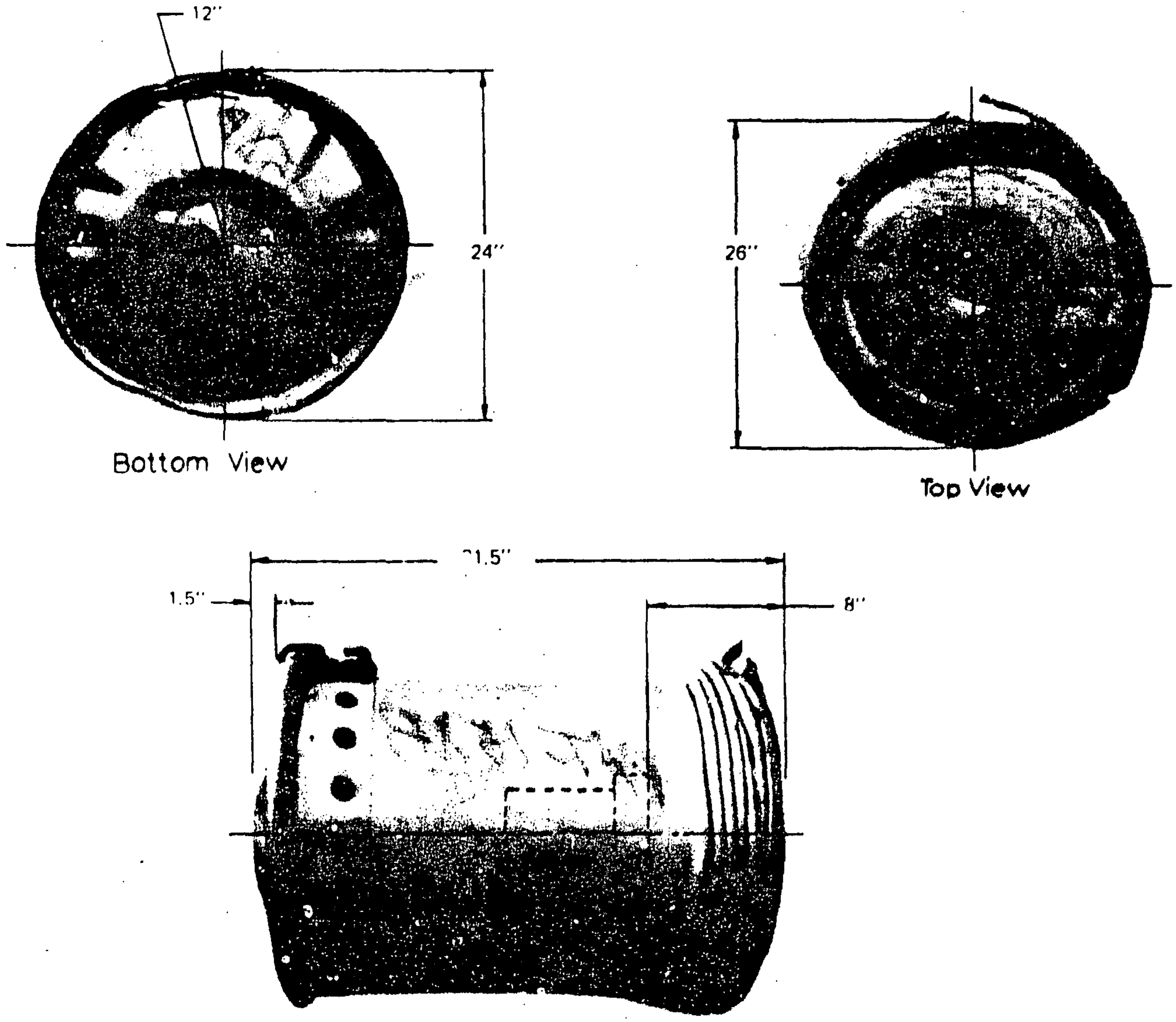


Figure 2.18 PAT-1 Dimensions Following 442-FPS Top End Impact

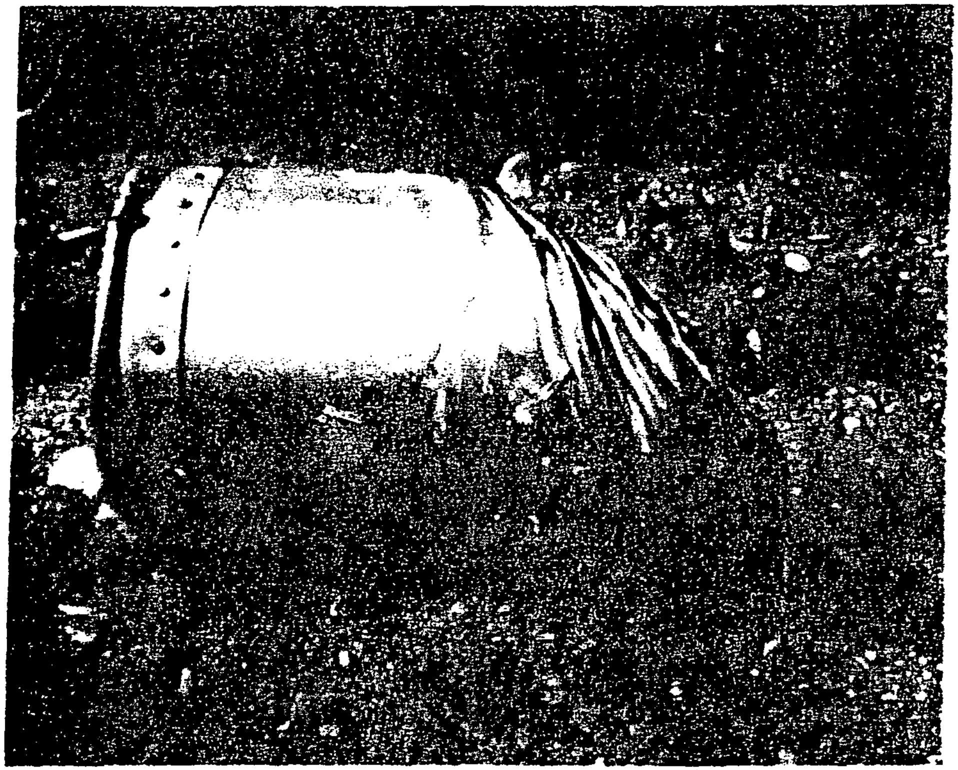


Figure 2.19 PAT-1 Package Following 451-FPS Corner Impact

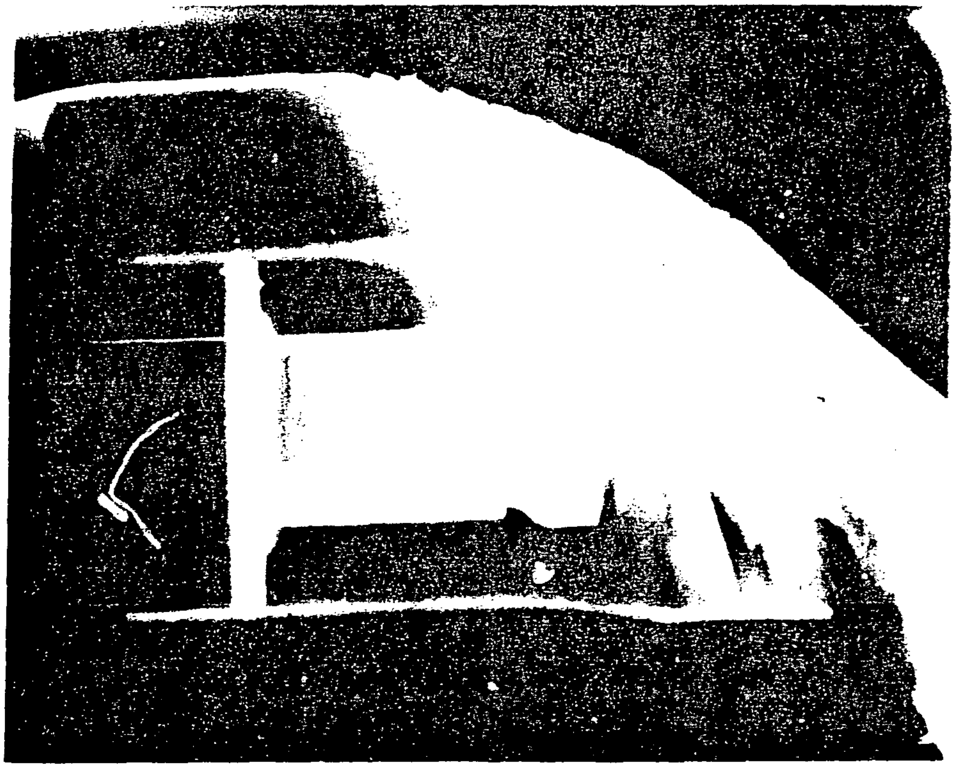


Figure 2.20 Radiograp of PAT-1 Package Following 451-FPS Top Corner Impact

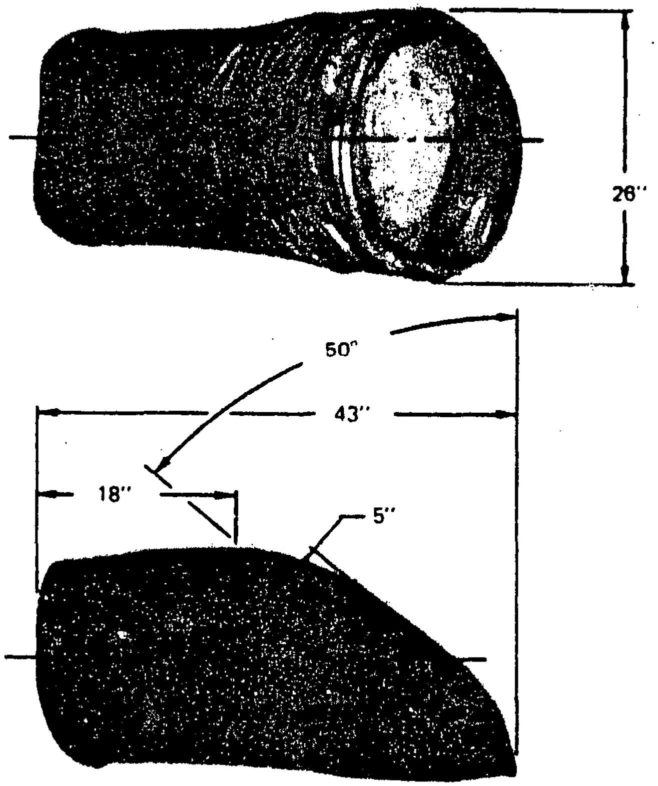


Figure 2.21 PAT-1 Dimensions Following 451-FPS Top Corner Impact

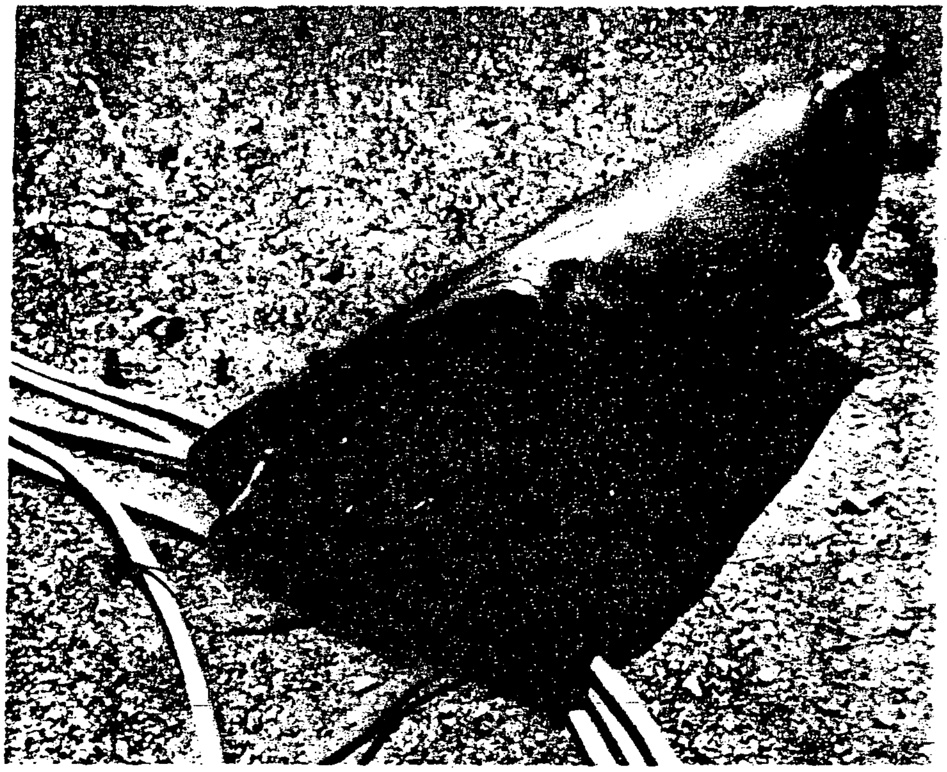


Figure 2.22 PAT-1 Package Following 445-FPS Side Impact

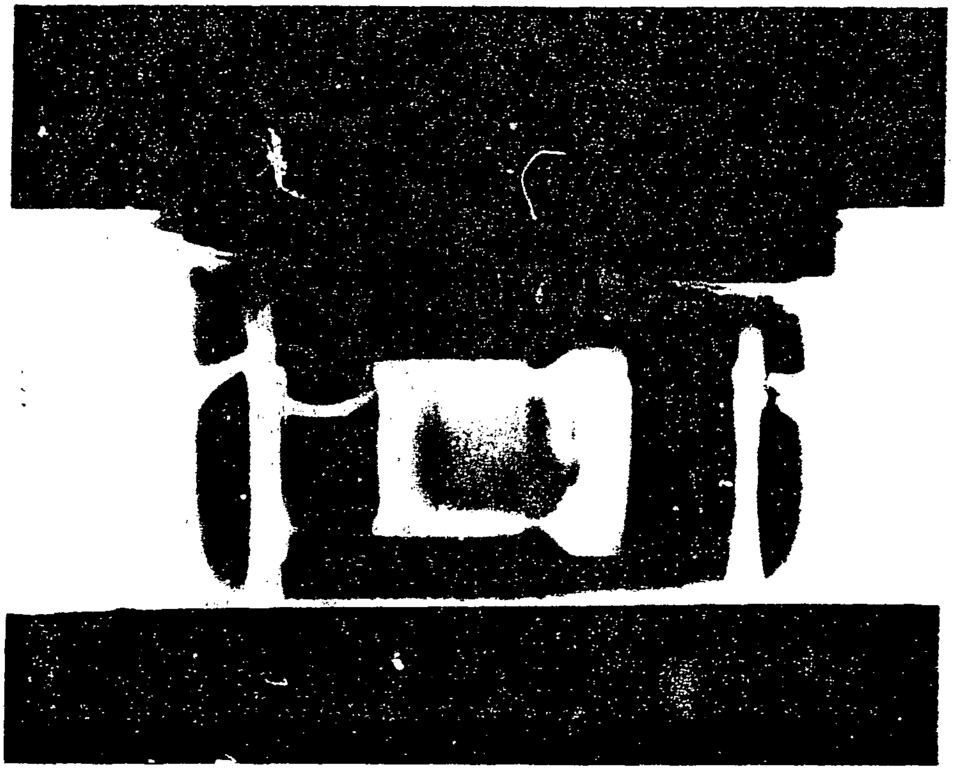


Figure 2.23 Radiograph of PAT-1 Package Following 445-FPS
Side Impact

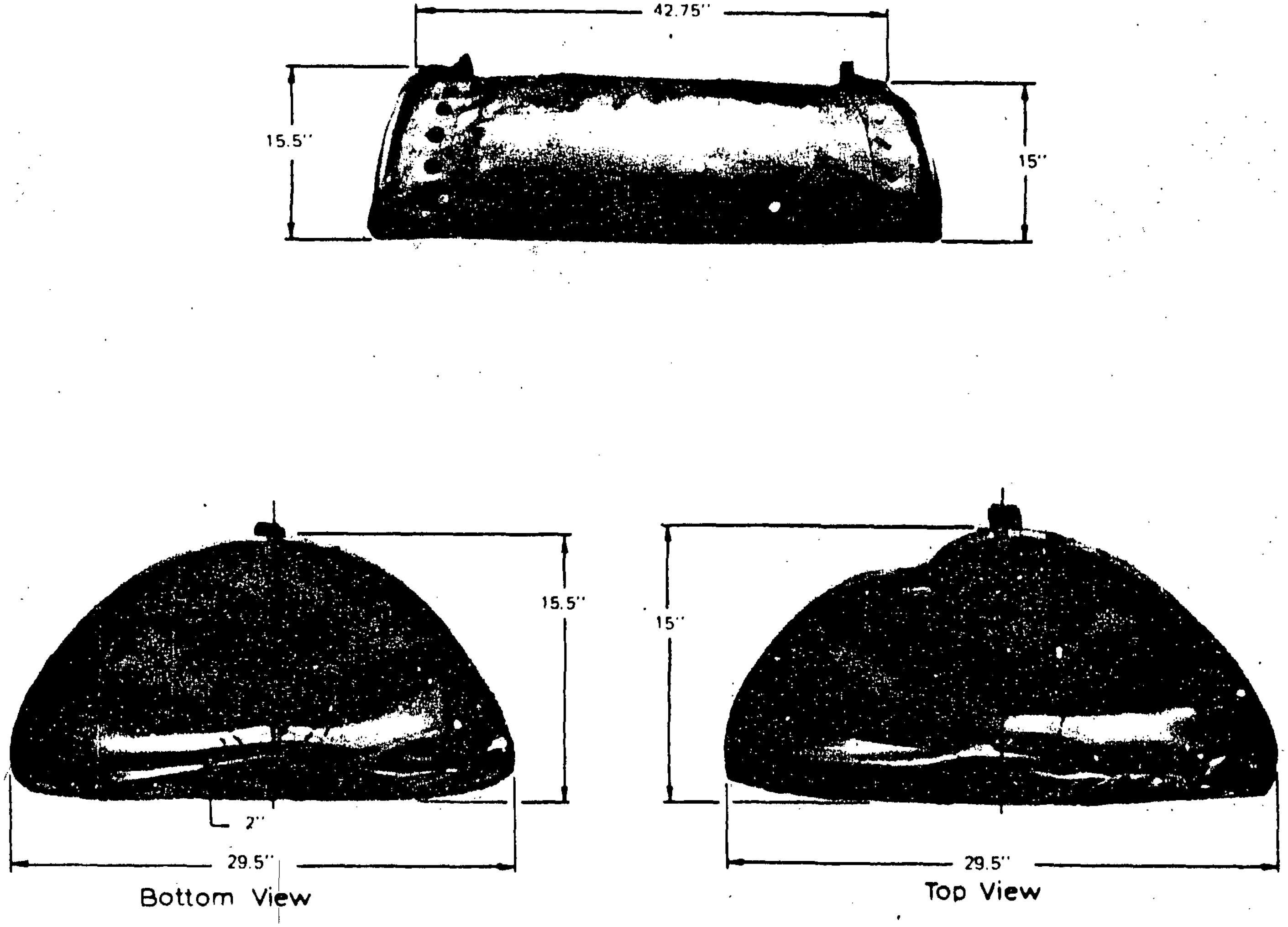


Figure 2.24 PAT-1 Dimensions Following 445-FPS Side Impact

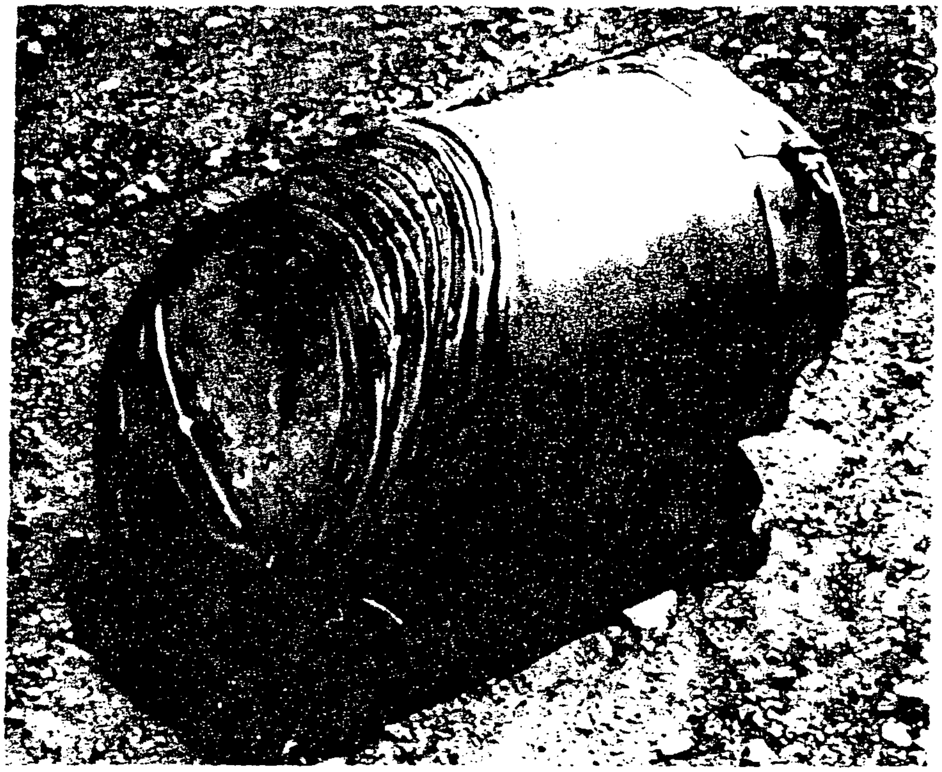


Figure 2.25 PAT-1 Package Following 443-FPS Bottom Corner Impact

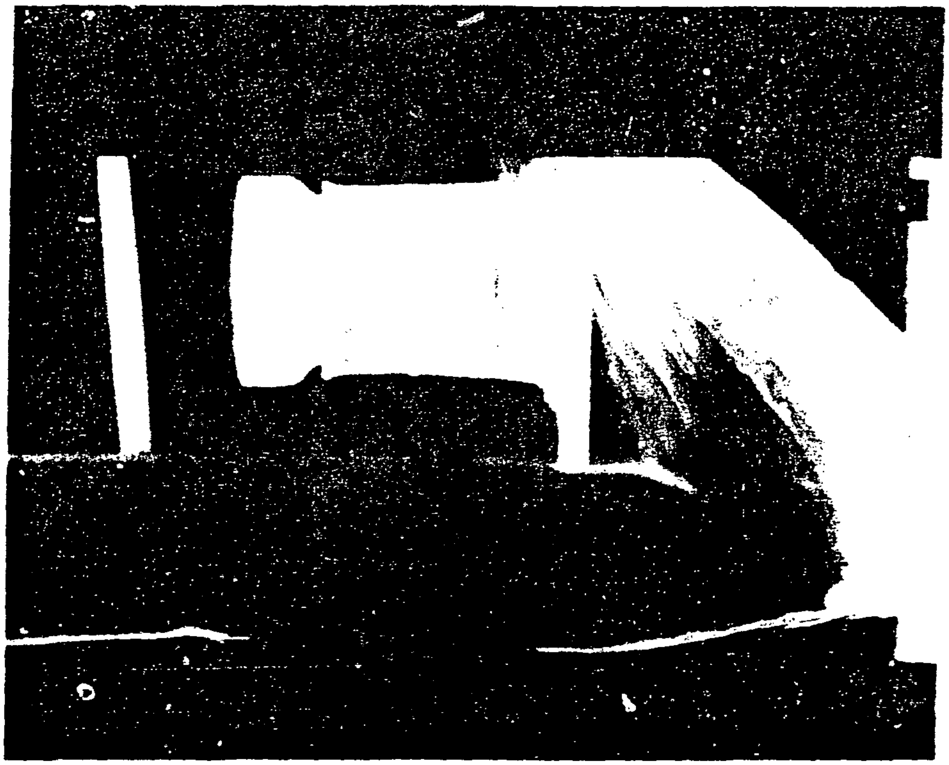


Figure 2.26 Radiograph of PAT-1 Package Following 443-FPS Bottom Corner Impact

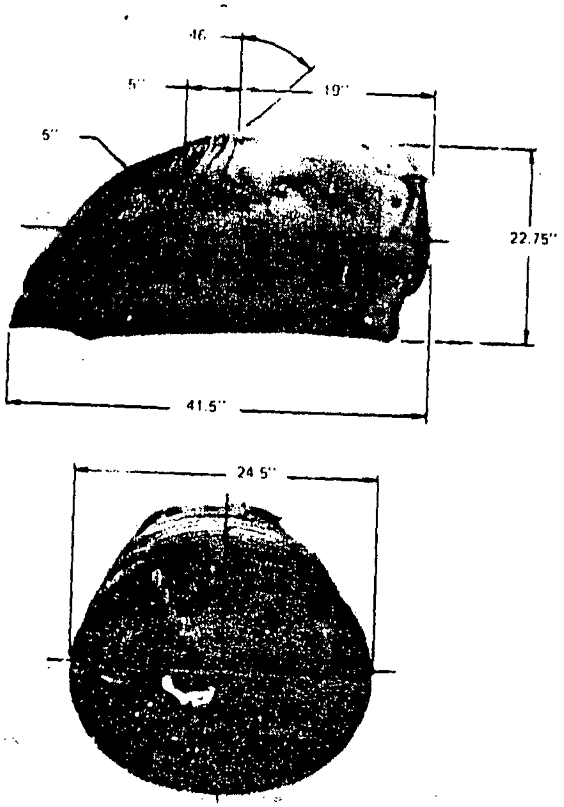


Figure 2.27 PAT-1 Dimensions Following 443-FPS Bottom Corner Impact

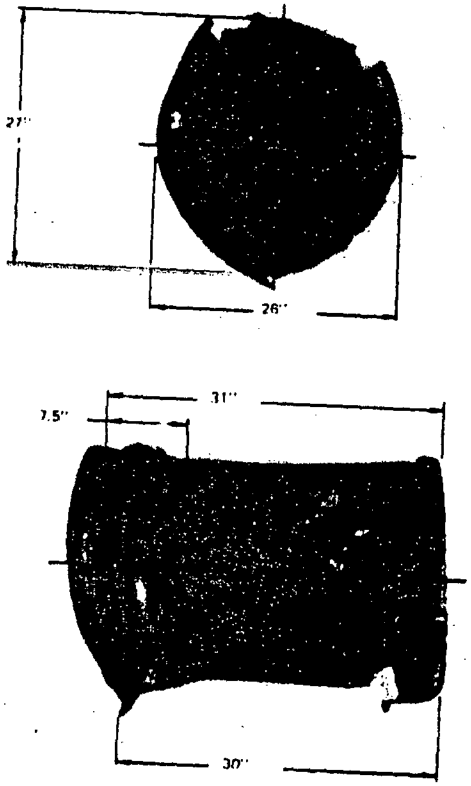


Figure - 30 PAT-1 Dimensions Following 466-FPS Bottom End Impact

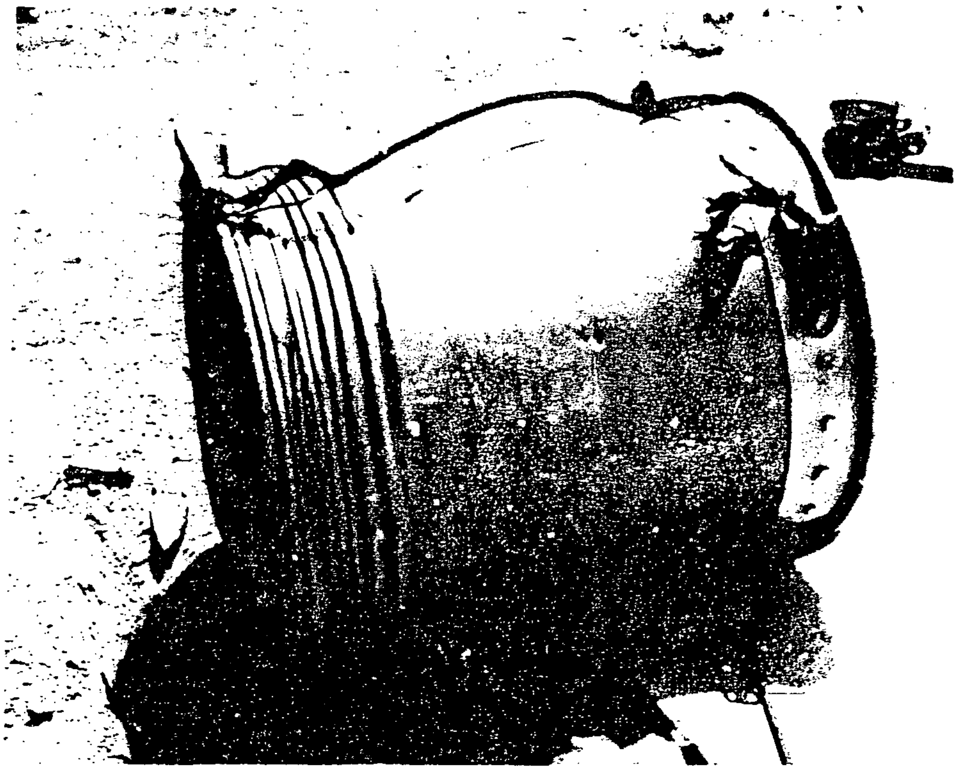


Figure 2.28 PAT-1 Package Following 466-FPS Bottom End Impact

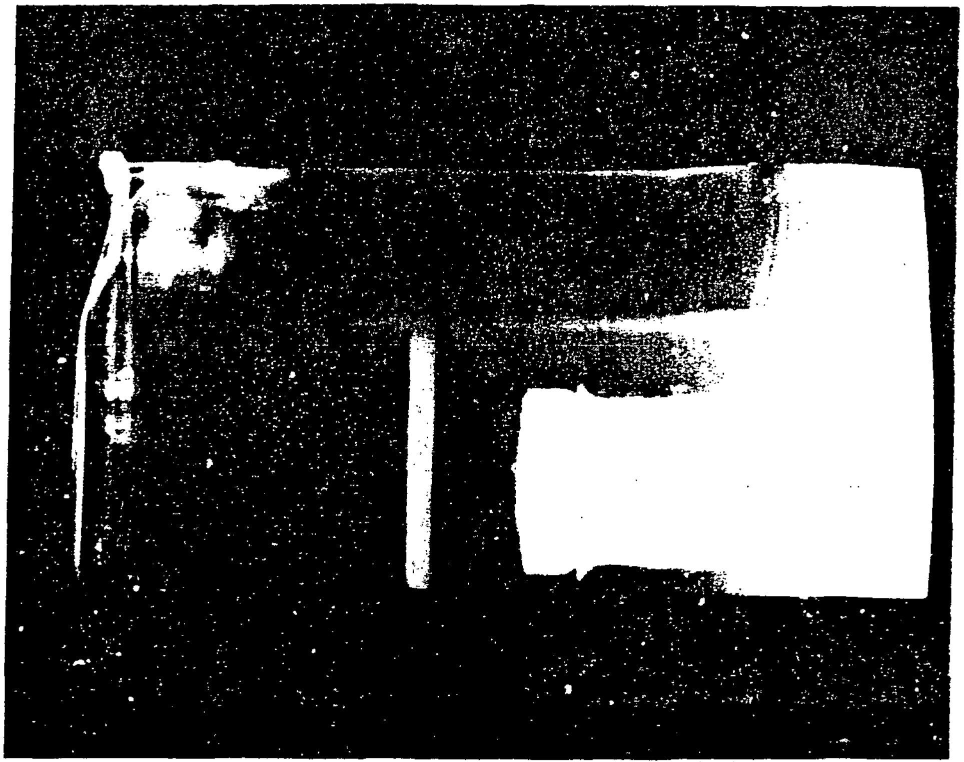


Figure 2.29 Radiograph of PAT-1 Package Following 466-FPS Bottom End Impact

Figure 2.31 Crush Test (Package Impact Tested on End)

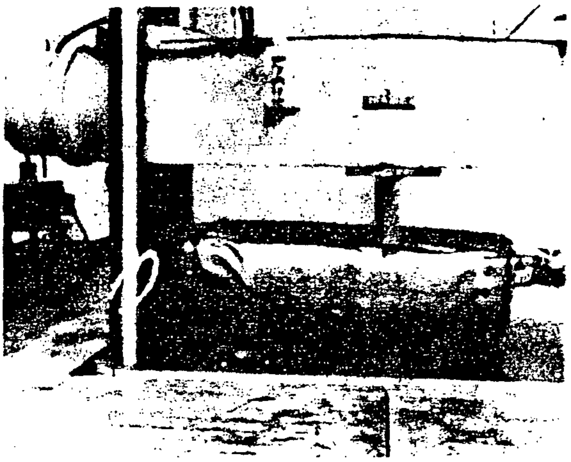


Figure 2.32 Crush Test (Package Impact-Tested on Side)

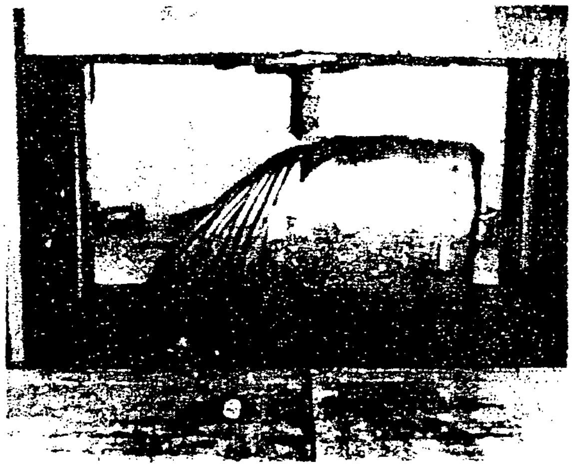


Figure 2.33 Crush Test (Package Impact-Tested on Corner)

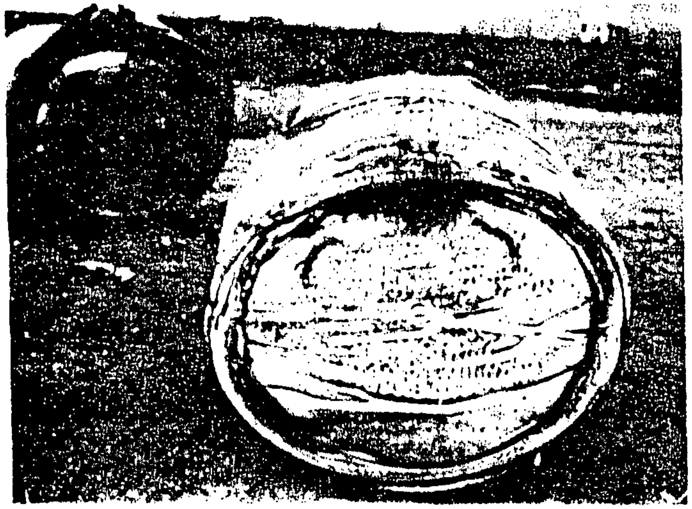


Figure 2.34 Puncture Test (Package on Top Corner)

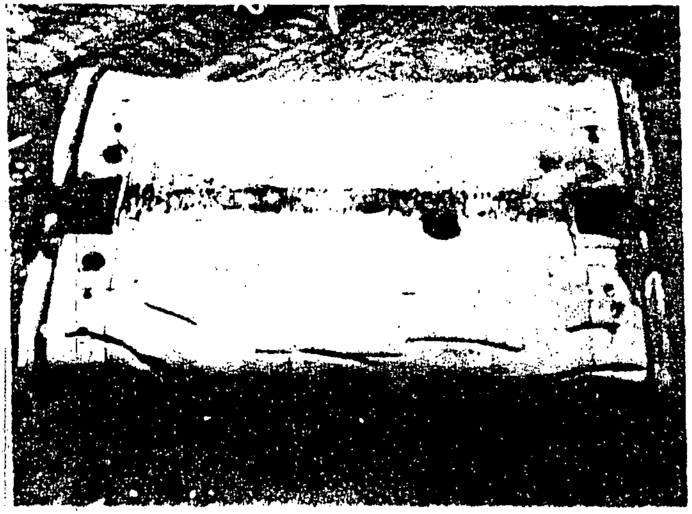


Figure 2.35 Puncture Test (Package Impact-Tested on Side)

Figure 2.36 Puncture Test (Package Impact Tested on Bottom Corner)

Figure 2.37 Puncture Test (Package Impact-Tested on Bottom Corner)

Figure 2.36 Puncture Test (Package Impact-Tested on Top End)

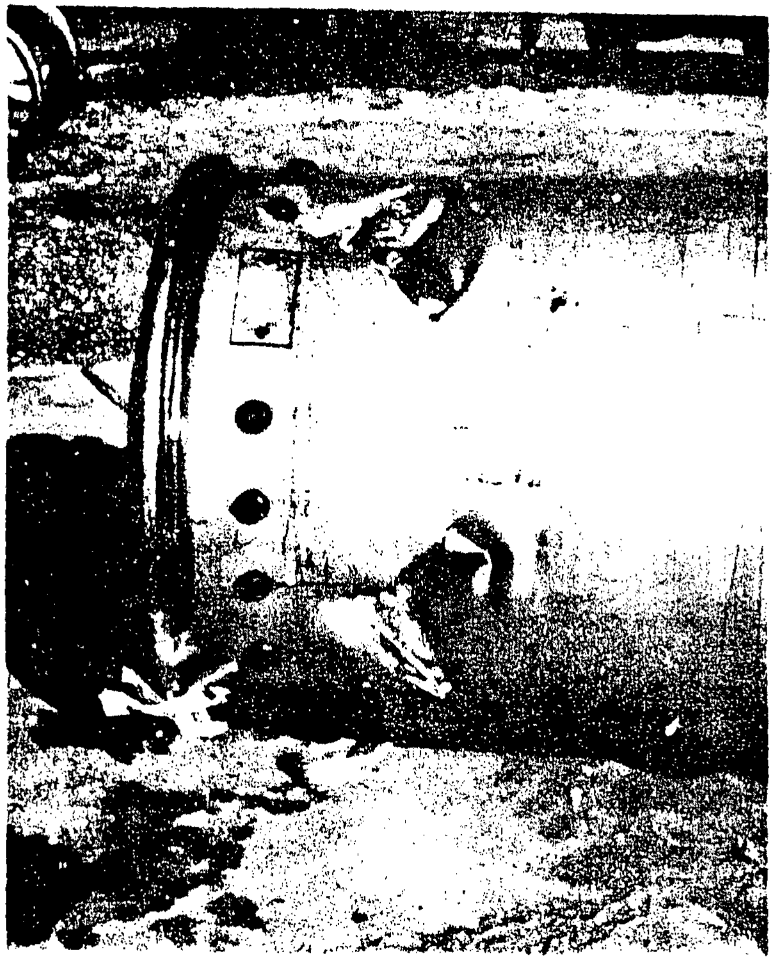


Figure 2.39 Slash Test Damage

Figure 2.40 Close Up of Slash Test Penetration

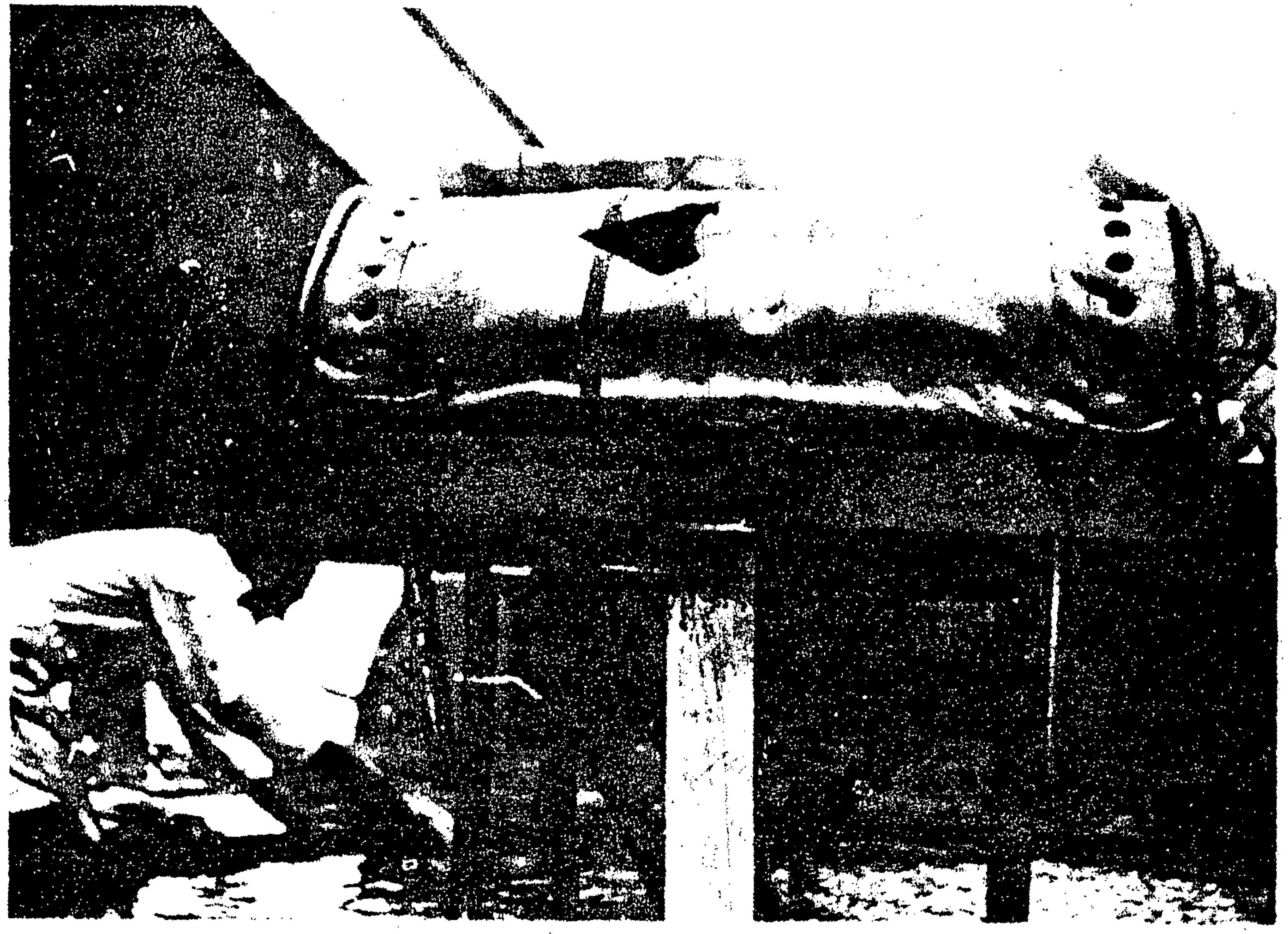


Figure 2.41 Arrangement of Package for Fire Test

Figure 2.42 Fire Test in Progress

Figure 2.43 PAT-1 Package Being Lifted From Immersion Test Pool

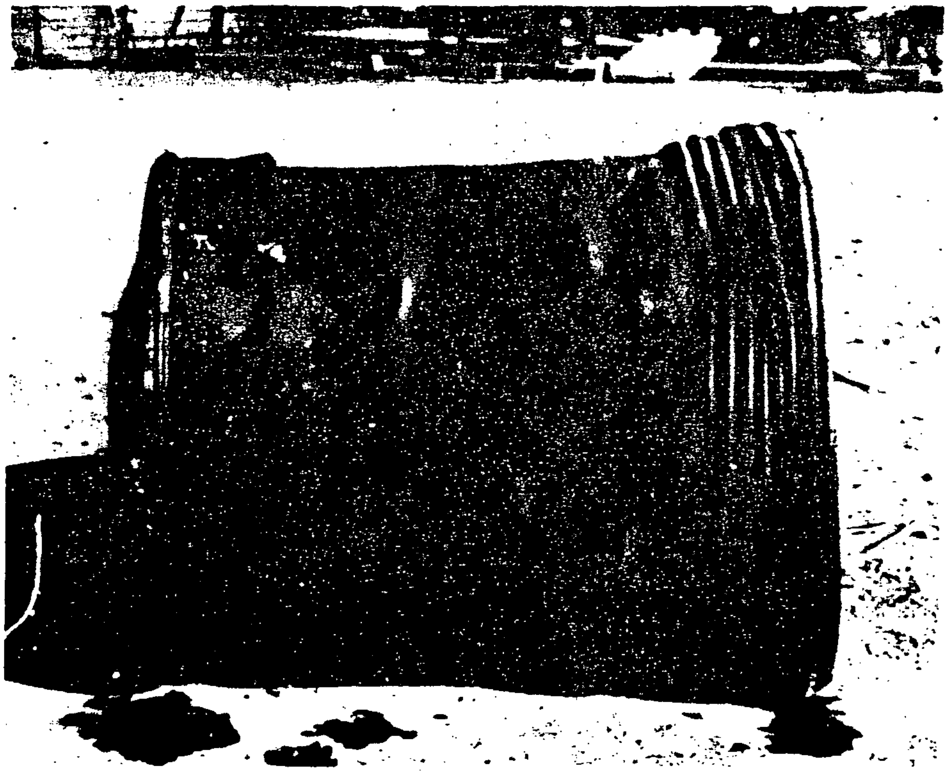


Figure 2.44 Appearance of PAT-1 Packages Following Testing

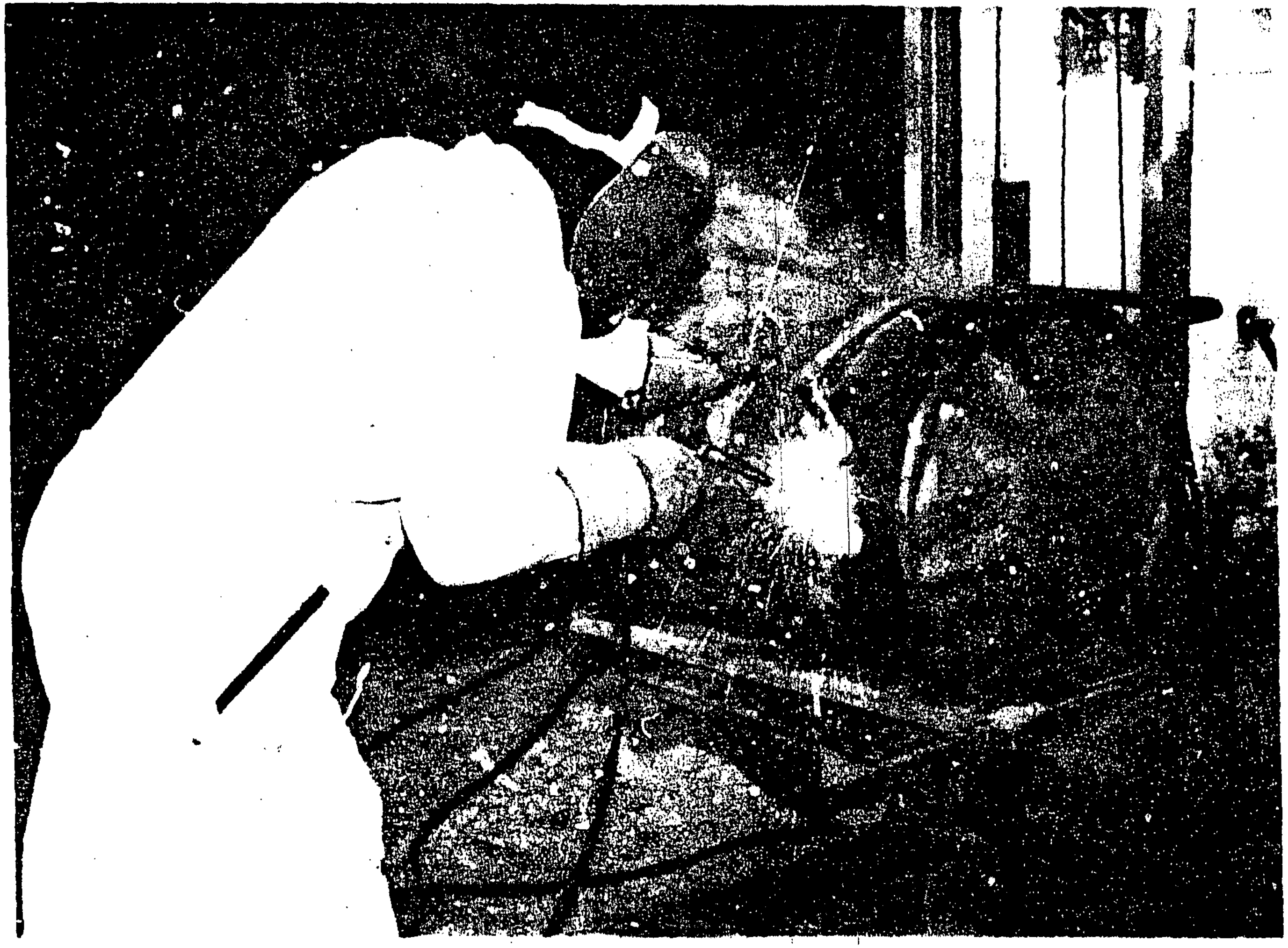


Figure 2.45 Post-Test Disassembly of a PAT-1 Package

Figure 2.45 Package Impact-Tested on Top-End

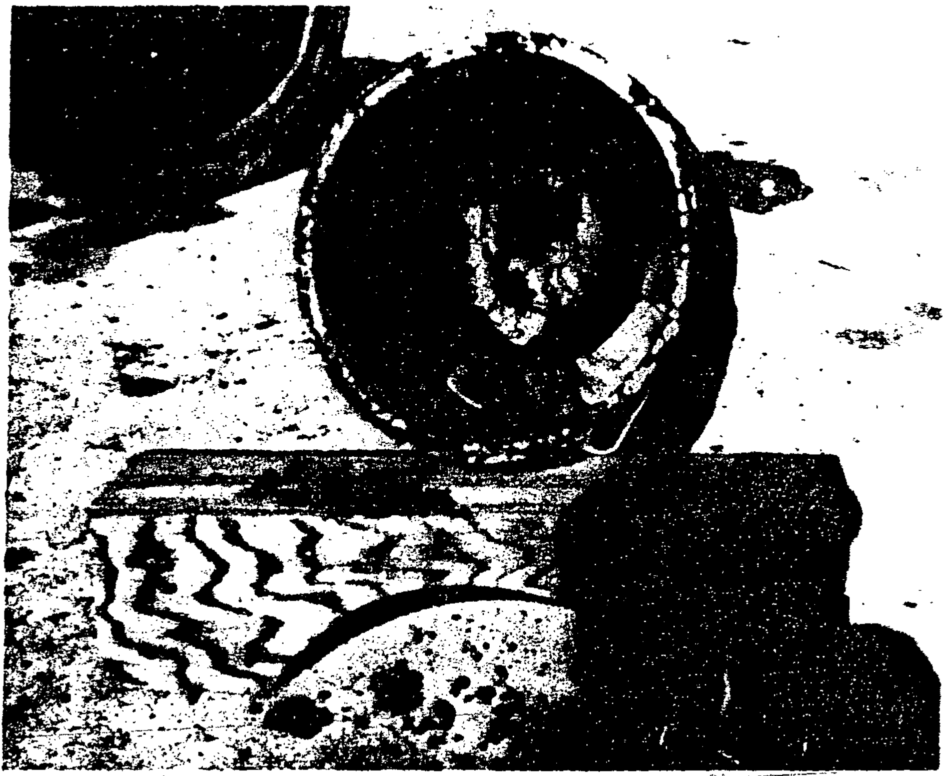


Figure 2.47 Redwood Inside of Load-Spreader Tube of PAT-1
(Package Impact-Tested on Top End)

Figure 2.48 TB-1 Containment Vessel Within Load-Spreader Tube
(Package Impact-Tested on Top End)

Figure 2.49 TB-1 Containment Vessel (Package Impact-Tested on Top End)

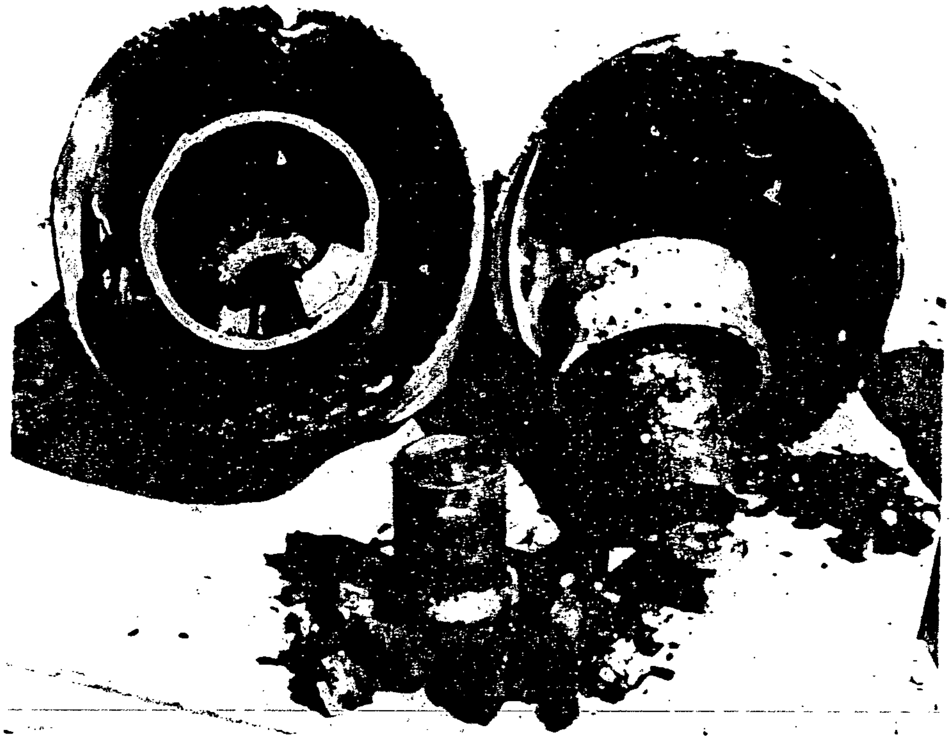


Figure 2.50 Disassembled PAT-1 (Package Top-Corner Impact Tested)

Figure 2.51 Disassembled PAT-1 (Package Side-Impact Tested)

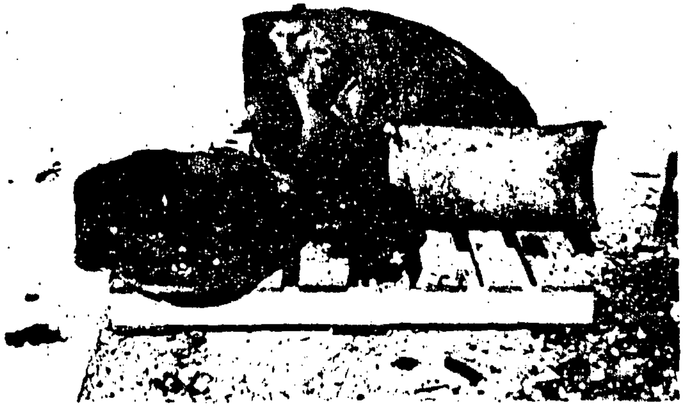


Figure 2.52 Disassembled PAT-1 (Package Bottom-Corner Impact Tested)

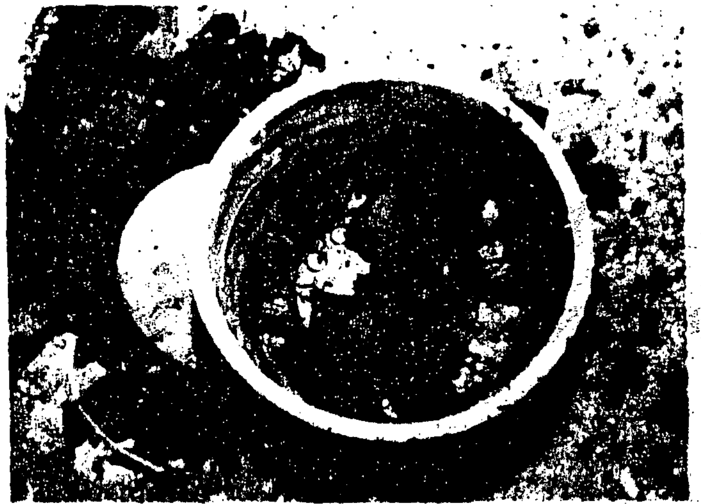


Figure 2.53 Charred Redwood and TB-1 Vessel Inside Load Spreaders (Package Bottom-Corner Impact Tested)

Figure 2.54 Disassembled PAT-1 (Package Bottom-Corner Impact Tested)

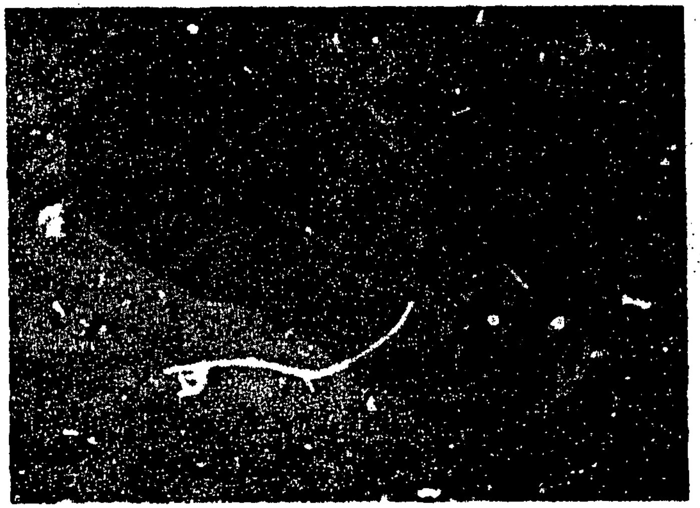


Figure 2.55 TB-1 Containment Vessel (Package Bottom-Corner Impact Tested)

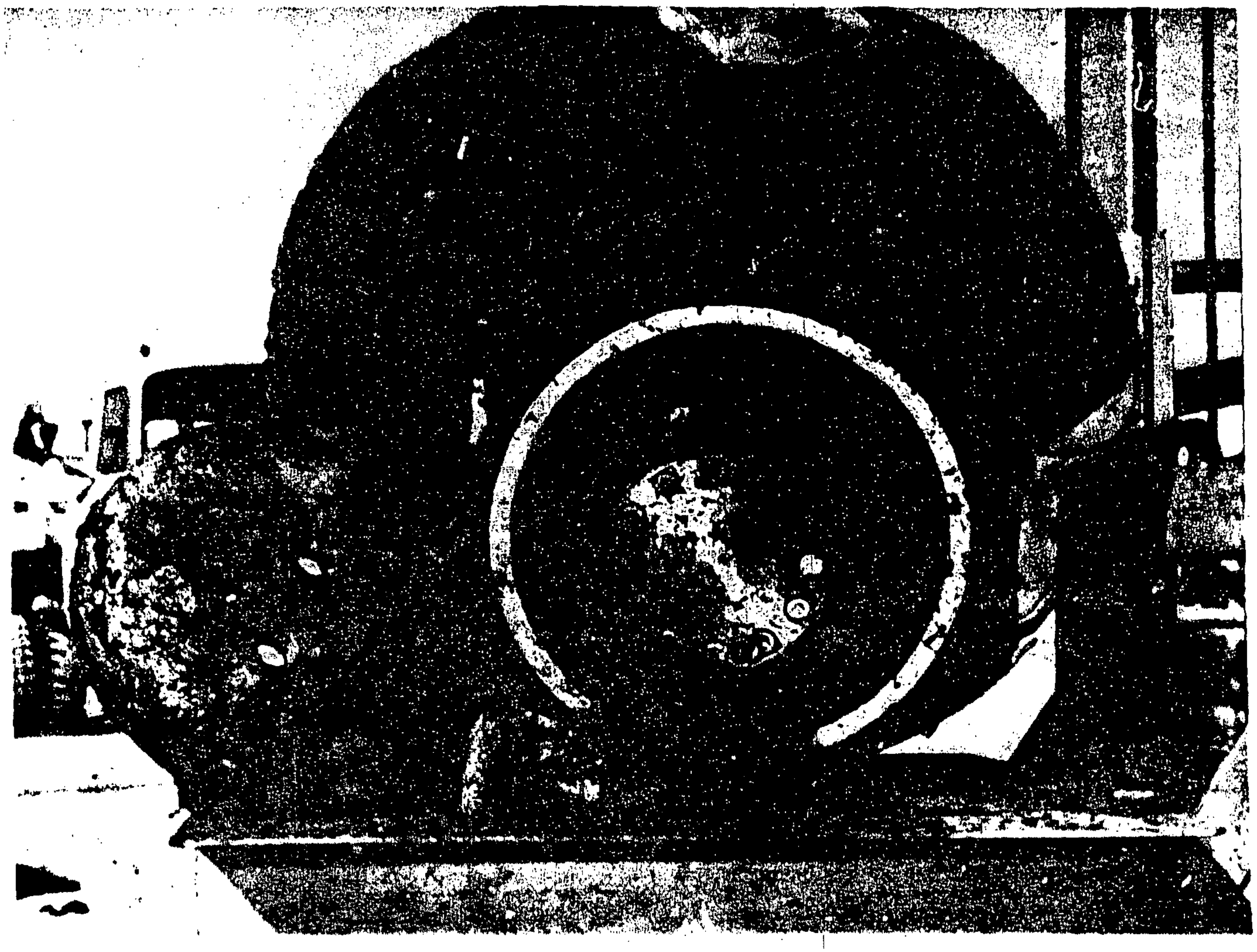


Figure 2.56 Disassembled PAT-1 (Package Bottom-End Impact Tested)

Figure 2.57 Hydostatic Test Chamber with TB-1 Containment Vessel

Figure 2.58 PAT-1 Package Following 433-FPS Side Impact at Approximately -40°F

Figure 2.59 Radiograph of PAT-1 Package Following 433-FPS Side Impact at Approximately -40 F

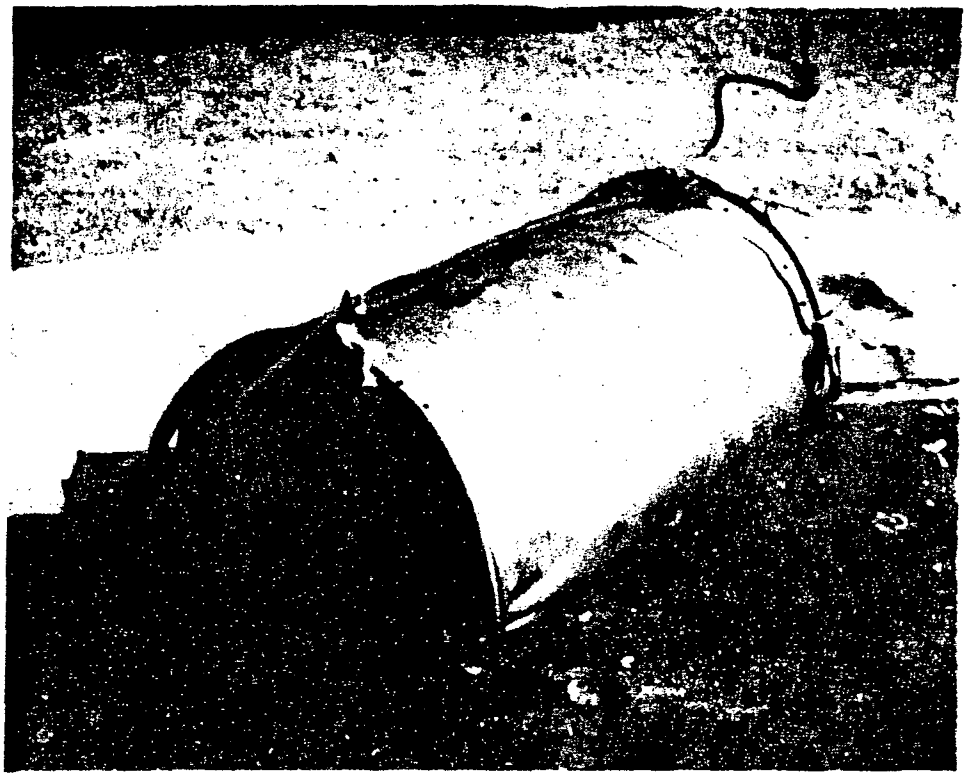


Figure 2.60 PAT-1 Package Following 424-FPS Side Impact at Approximately 200° F

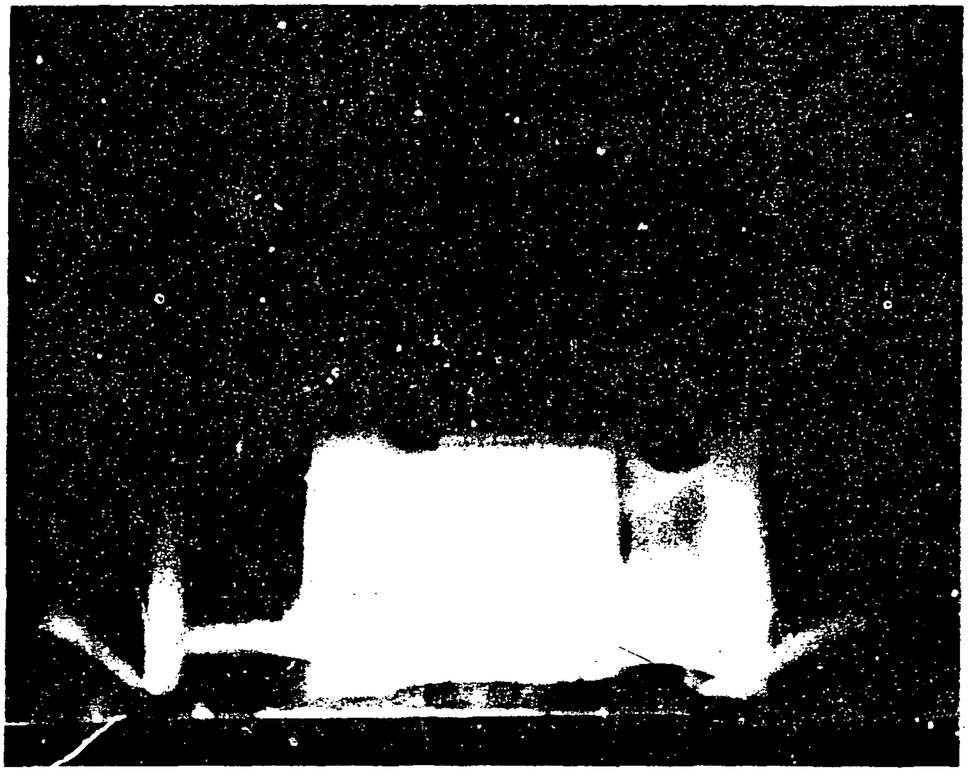


Figure 2.61 Radiograph of PAT-1 Package Following 424-FPS Side Impact at Approximately 200° F

REFERENCES

1. "Leakage Tests on Packages for Shipments of Radioactive Materials," USNRC Regulatory Guide 7.4, June 1975. Available from the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

2. W. A. Von Riesemann and T. R. Guess, "The Effects of Temperature on the Energy Absorbing Characteristics of Redwood," Sandia Laboratories Report SAND 77-1589, 1977. Available in source file for USNRC Report NUREG-0361, February 1978.

3. N. J. DeLollis, "Durability of Structural Adhesive Bonds (A Review)," Sandia Laboratories. Available in source file for USNRC Report NUREG-0361, February 1978.

4. "Transportation, Shock and Vibration Tests for PARC," Memorandum from L. T. Wilson to J. A. Andersen, Sandia Laboratories, January 26, 1977. Available in source file for USNRC Report NUREG-0361, February 1978.

APPENDIX 2-A

MAXIMUM WEIGHT OF CONTENTS

The NRC Qualification Criteria (NUREG-0360) require a demonstration or analytical assessment showing that the physical test results would not be adversely affected to a significant extent by the presence, during the tests, of the actual contents that will be transported.

During qualification testing of the PAT-1 package, UO_2 powder was used as a surrogate for the intended package contents (plutonium). However, the amount (weight) of plutonium oxide powder that could be accommodated within the PC-1 product can is larger than the amount (weight) of UO_2 powder used as a surrogate during the tests.

The maximum weight of radioactive material authorized for transport in the PAT-1 package is 4.4 pounds (2.0 kg). Since the combined weight of the PC-1 product can, the polyethylene bags, and the honeycomb spacer is approximately 0.3 pounds, the maximum total weight within the TB-1 containment vessel will be approximately 4.7 pounds. The maximum weight of the TB-1 containment vessel, when loaded for shipment, will be approximately 41.7 pounds.

As described in Section 2.8, five PAT-1 packages were subjected to the sequential tests specified in the NRC Qualification Criteria. The amount (weight) of UO_2 powder used in each package is shown in Table 2-A-1. Also shown is the velocity at which each package was impact tested. In each case, the kinetic energy of the TB-1 containment vessel and contents was at least 6 higher during the qualification tests than it would have been if the package had impacted at a velocity of 422 ft/sec with its maximum authorized weight of contents. This supports a conclusion that the physical test results would not have been adversely effected to a significant extent if 2.0 kg of plutonium had been present in the packages during the tests.

Table 2-A.1

KINETIC ENERGY OF TB-1 CONTAINMENT VESSEL

Impact Orientation	Velocity (ft/sec)	Wt. of UO_2 (lbs)	Wt. of Loaded TB-1 Containment Vessel (lbs)	Kinetic Energy of TB-1 Containment Vessel at Impact (ft-lb)
Top End	442	2.97	40.3	1.22 $(10)^5$
Top Corner	451	2.31	39.6	1.25 $(10)^5$
Side	445	2.66	40.0	1.23 $(10)^5$
Bottom Corner	443	2.37	39.7	1.21 $(10)^5$
Bottom End	466	2.38	39.7	1.34 $(10)^5$

If impact-tested at the specified test velocity of 422-ft/sec with maximum authorized content weight, the kinetic energy of the 41.7 lb (loaded weight) TB-1 containment vessel would be 1.15 $(10)^5$ ft-lbs.

APPENDIX 2-B

TEST FACILITY DESCRIPTION

The following facilities were used to perform the sequential tests: (1) a rocket pulldown facility for the high velocity impact tests, (2) a static test machine for the crush test, (3) two tower facilities for the puncture and slashing tests, (4) a fire test facility, and (5) an immersion pool.

Rocket Pulldown Facility

The rocket pulldown facility consists of a cable suspended between two ridges, a carriage which can be hoisted from the ground to the aerial cable, an essentially unyielding target, a monorail sled track, a rocket propelled sled, and control and instrumentation equipment (Figures 2-B.1 and 2-B.2). To conduct the high-velocity impact tests, packages are suspended at a height of approximately 185 feet above the essentially unyielding target. Rocket sled towlines are attached (Figure 2-B.3) in such a manner that the packages impact in the desired orientation. The towlines are routed vertically downward from the packages and pass through pulleys that straddle the target. The towlines are then routed horizontally to the rocket sled, where they are firmly attached to a rocket sled. The rocket sled can be propelled by a variable number of high-velocity aerial rocket motors. By adjusting the package height above the target and varying the number of rockets installed on the sled, the desired impact velocities can be attained.

The essentially unyielding target is an extensively reinforced 526,000-lb mass of concrete, approximately 20 feet in diameter by 11.5 feet deep and founded on prepared earth. The top surface of the concrete slab is faced with a ten-foot by ten foot plate of battleship armor, three to five inches thick. The steel facing is welded to the steel reinforcing members in the concrete and grouted in place.

High-speed photometrics were used to measure the impact velocity and orientation of the PAT-1 package.

Static Test Machine

The crush test was accomplished through use of a static test machine (Figure 2-B.4). Radiographs of the package were used to establish that the crush and puncture tests were performed with the package oriented in a manner to cause maximum damage.

Drop Tower Facilities

Two drop towers (185 and 300 feet) were used to conduct the puncture and slashing tests. Both towers provide for controlling the location and orientation of the test probes striking the package. The general arrangement of the puncture test is shown in Figures 2-B.5 and 2-B.6. The general arrangement of the slashing test is shown in Figure 2-B.7.

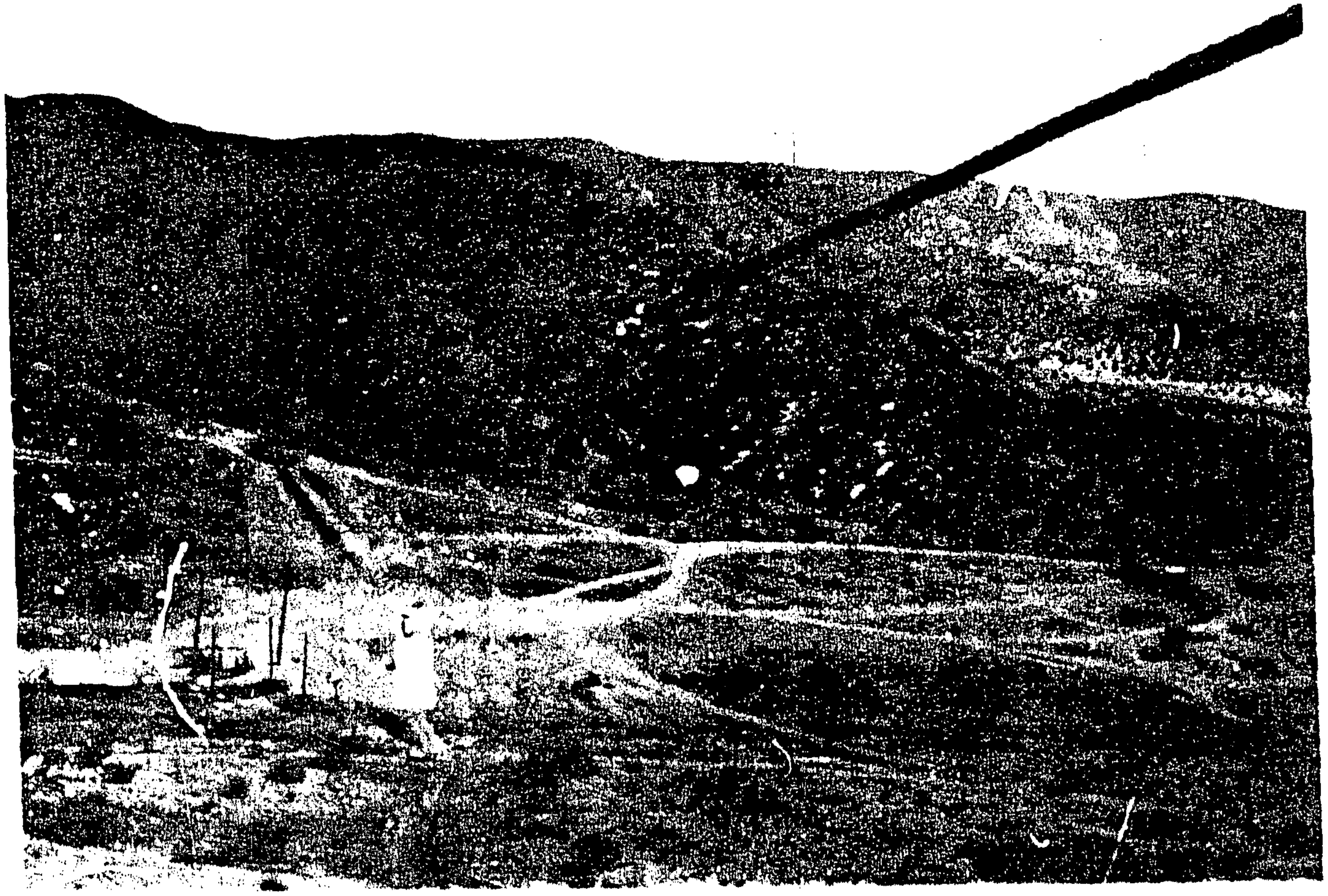


Figure 2-B.1 Rocket Pulldown Facility

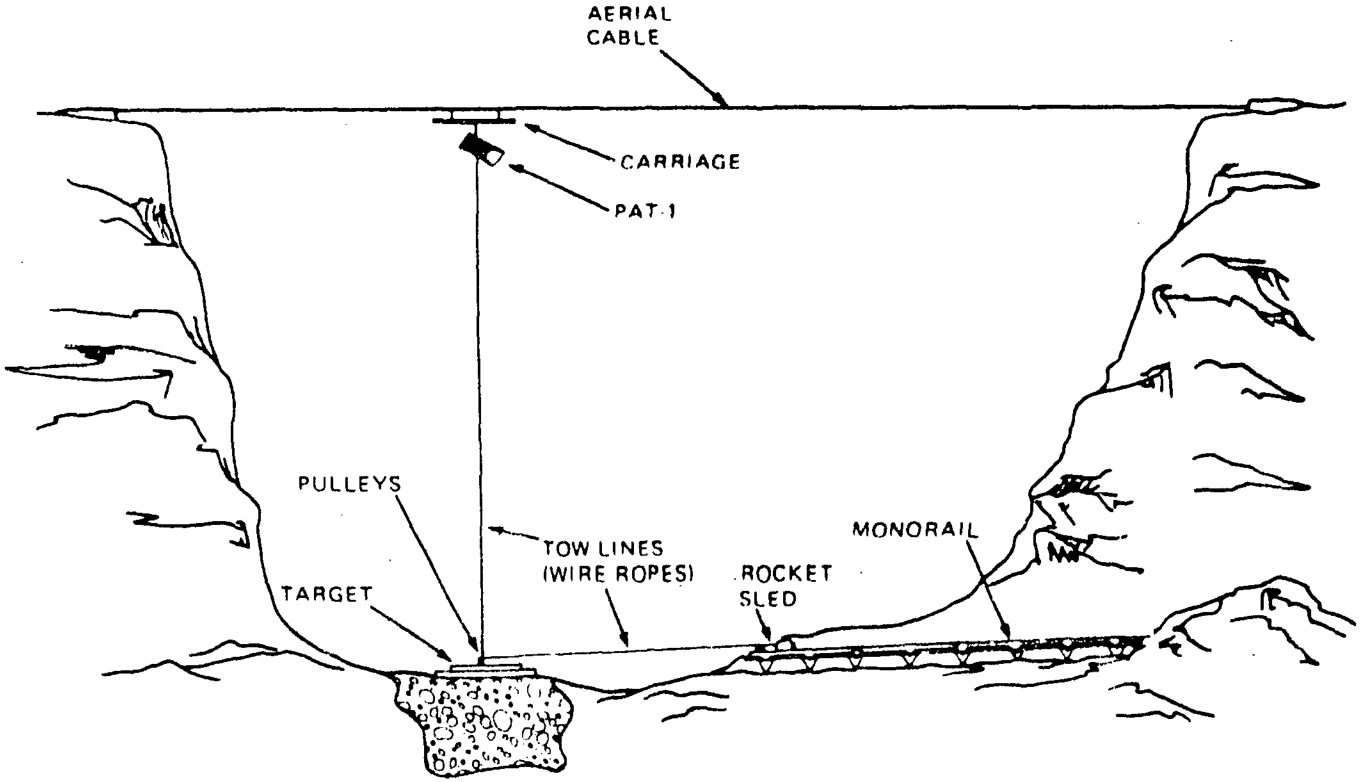


Figure 2-B.2 Rocket Pulldown Facility

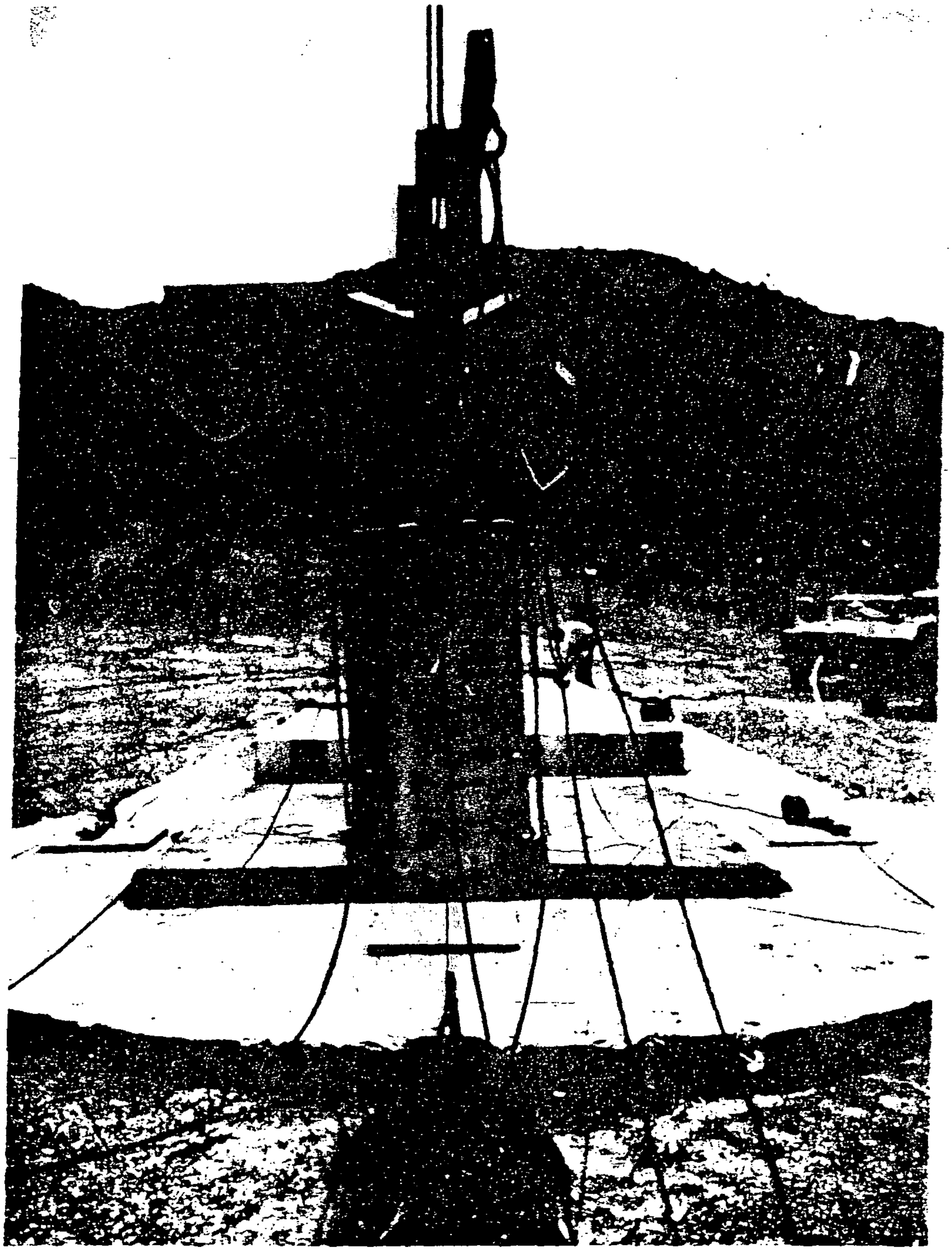


Figure 2-B.3 Towline Attachment to a PAT-1 Package

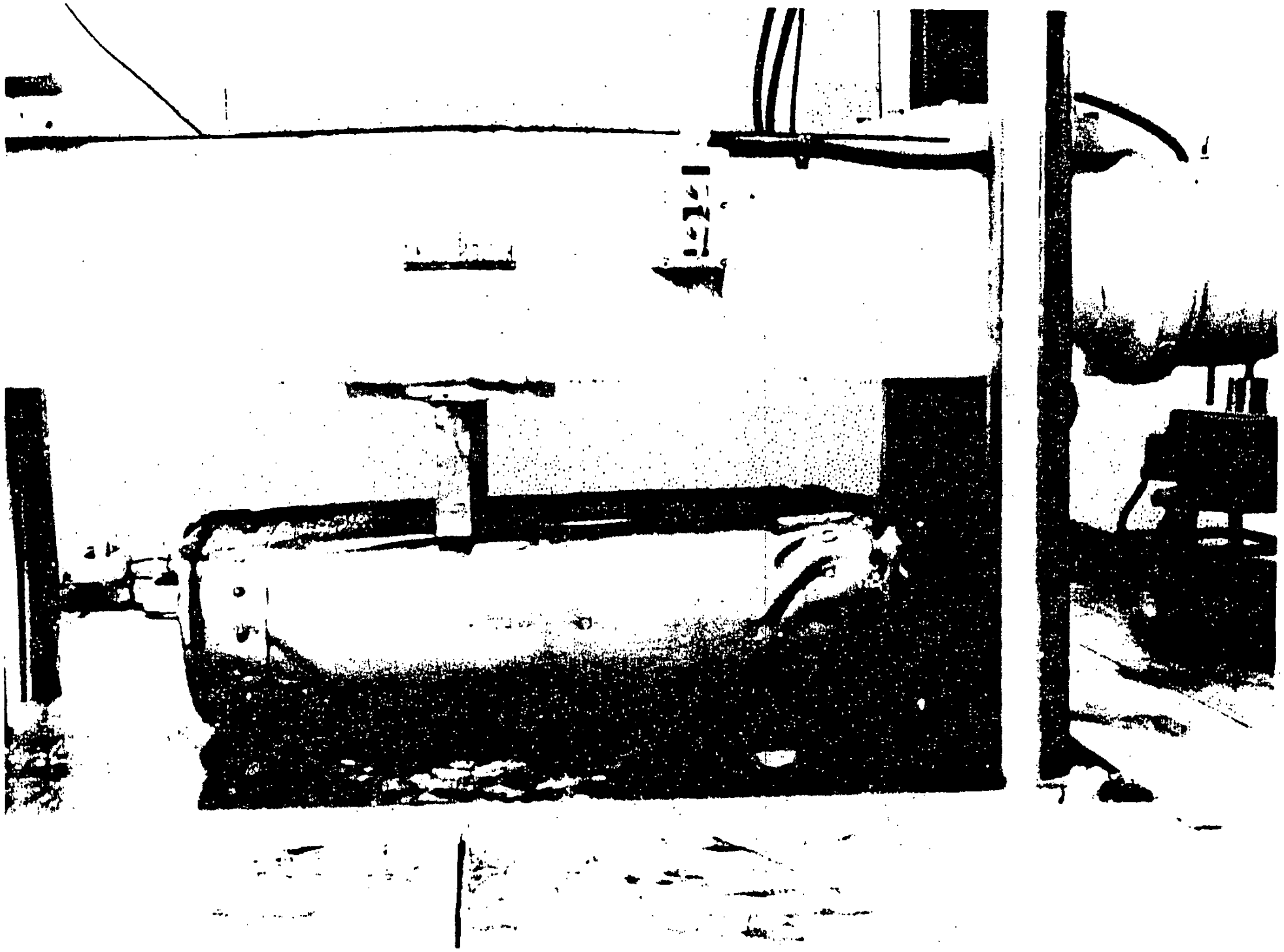


Figure 2-B.4 Static Test Machine

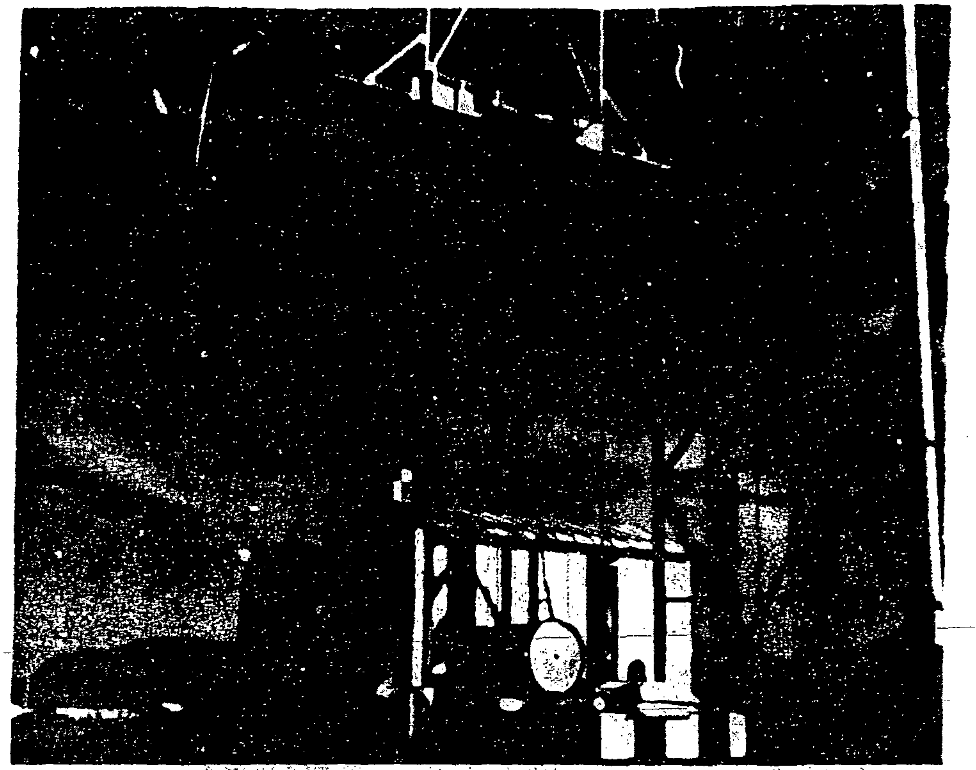


Figure 2-B.5 Set Up for Puncture Test

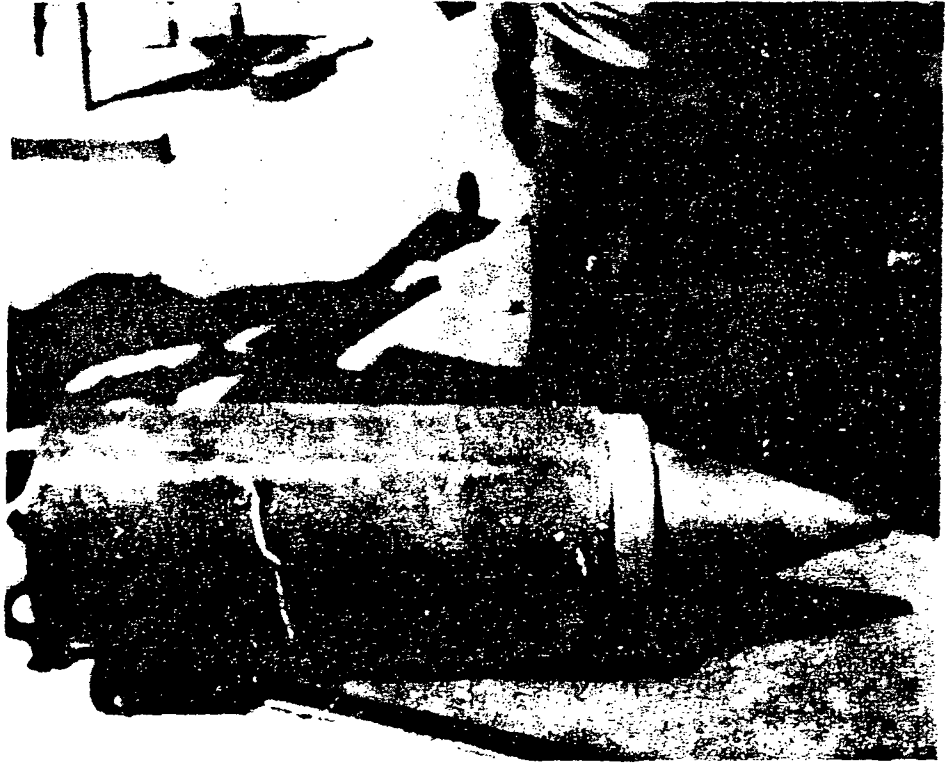


Figure 2-B.6 Conical Probe Used to Conduct Puncture Test

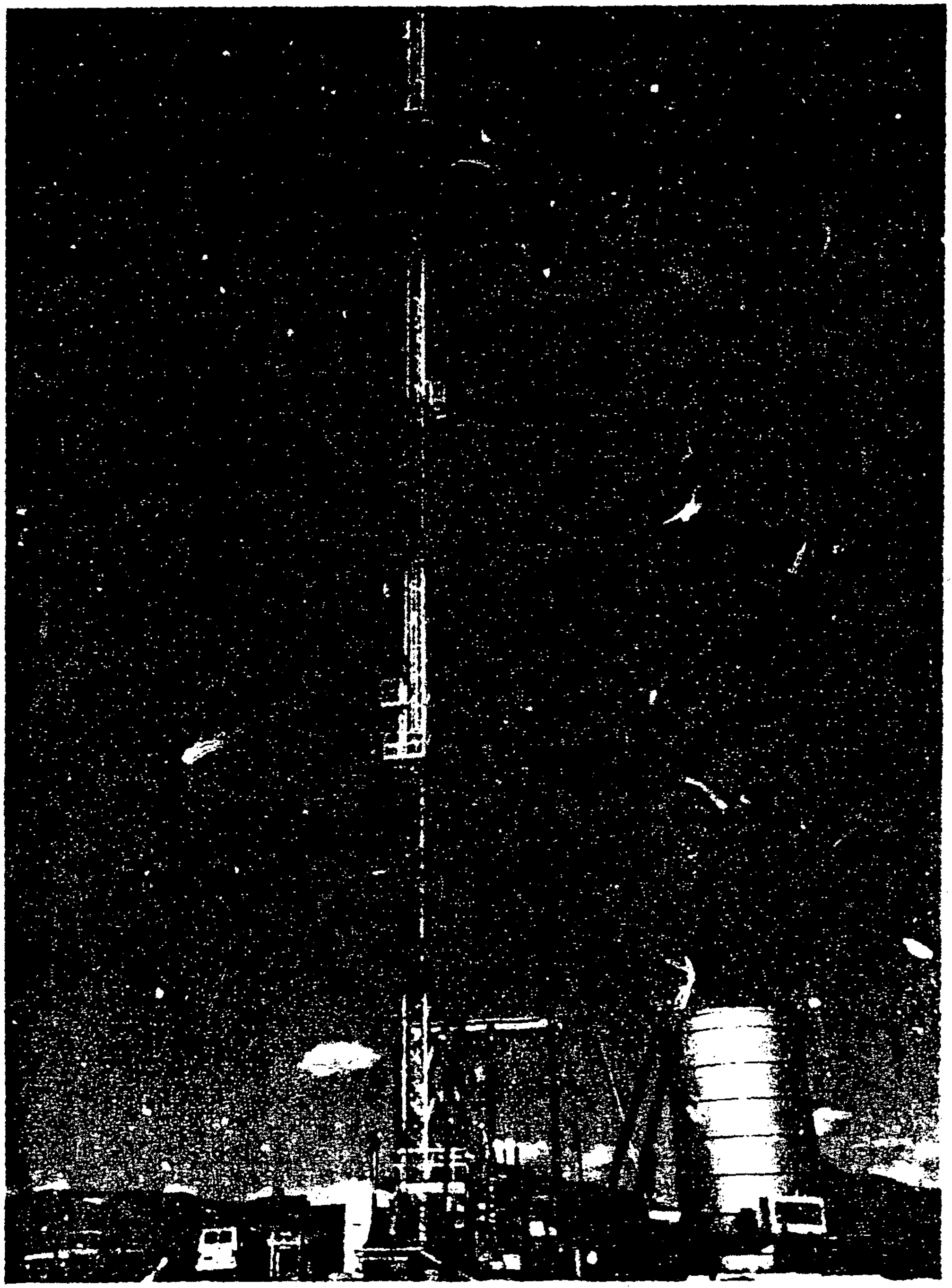


Figure 2-B.7 Set Up for Slash Test

Fire Test Facility

The fire test facility is basically a steel tub, approximately 10 feet in diameter. The tub is set into the ground with minimum freeboard above the surface. JP-4 aviation jet fuel is floated on water within the tub. A chimney, approximately 16 feet in diameter and 10 feet high, is centered over the tub (Figure 2-B.8). The chimney is suspended on wire ropes and can be lifted to provide draft for the fire. A four-foot high fence is situated about three feet away from the draft opening and surrounds the chimney to lessen the effects of wind.

The packages being tested are placed on a stand centered over the tub and located about three feet above the fuel. Flame temperatures were measured with thermocouples at various heights within the fire. In addition, thermocouples were mounted on the surface of the packages.

Water and JP-4 fuel were gravity-fed to the burner site from storage tanks.

Water Immersion Facility

The 10-foot diameter by 6-foot deep tub used for the burn test was also used for the water submersion test.

Figure 2-B.8 Fire Test Faculty

3.0 THERMAL EVALUATION

3.1 Discussion

The thermal performance of the PAT-1 package is adequate to ensure that its contents are safely contained under the test conditions specified in 10 CFR Part 71 and in the NRC Qualification Criteria, NUREG-0360 (Ref. 1). This section summarizes the thermal evaluations which complement the structural evaluation in Section 2.0 and the containment evaluation in Section 4.0.

The structural evaluation required package temperatures to be calculated under Normal Conditions of Transport. This information was used to: (1) establish the experimental test conditions for the heat test in Section 2.0, (2) assure that differential thermal expansion of package materials had been properly considered, (3) assure that the long-term performance of the package materials would not degrade significantly over the container's useful life, and (4) establish test conditions for the pressure test in Section 2.0.

The containment evaluation required that maximum temperatures and internal pressures be calculated for the TB-1 containment vessel. This information was used to assess the degree of leaktightness of the five PAT-1 packages tested to the NRC Qualification Criteria.

The results of the thermal evaluation of the package under the Normal Conditions of Ttransport specified in Appendix A of 10 CFR 71 are shown in Table 3.1.

The maximum normal operating pressure (MNOP) that will occur within the TB-1 containment vessel is 34.3 psia. For the accident tests specified in the NRC Qualification Criteria, the maximum TB-1 containment vessel temperature and pressure are 1080°F and 1110 psia, respectively.

3.2 Summary of Thermal Properties of Materials

The thermal conductivity and specific heat of the redwood will vary with moisture content and with variations in the assembly of the glued joints. The thermal property values stated in Table 3.2 are based on experimental data from an actual assembly (Appendix 3.1), and varied slightly from the values given in Reference 2.

The charring data shown in Figure 3.1 (Ref. 3) was used to assess the thermal protection provided by the redwood. Experimental evidence from the five packages subjected to the performance tests of the NRC Qualification Criteria indicates that this data is valid for predicting TB-1 temperatures.

3.3 Technical Specifications

Engineering specifications and drawings for the PAT-1 package are provided in Section 9.0.

Table 3.1

SUMMARY OF PAT-1 PACKAGE TEMPERATURES NORMAL CONDITIONS OF TRANSPORT*

Location		Maximum	Minimum
TB-1 Vessel and Seals		212°F	-40°F
Aluminum Load Spreader		188°F	-40°F
Redwood:	Mean	182°F	-40°F
	Maximum	225°F	-40°F
Stainless Steel Outer Drum:			
	Mean	176°F	-40°F
	Peak	225°F	-40°F

Note: Under ambient conditions in the absence of solar heating, the outer drum temperature will exceed ambient by 10°F.

---

*As specified by 10 CFR 71, assuming the maximum 25-watt content decay heat in establishing maximum temperatures.

Table 3.2

THERMAL PROPERTIES OF MATERIALS

Material	Thermal Conductivity (Ref. 2) (Btu/hr/ft°F)	Density (lbm/ft^3)	Specific Heat (Btu/lbm/°F)	Solar Absorptance/ Emittance
Aluminum Honeycomb	N.A.	8.1	0.21	N.A.
Aluminum	90.0	169.0	0.21	N.A.
ETP Copper	220.0	558.0	0.09	N.A.
Stainless Steel	10.0	500.0	0.11	0.45/0.2 @ 200°F
UO_2	N.A.	N.A.	0.08	N.A.
Redwood:				
Parallel to Grain	0.14(1+0.006T(°F))			
Prependicular to Grain	0.05(1+0.006T(°F))	22.0	0.19(1+0.01T(°F))	N.A.

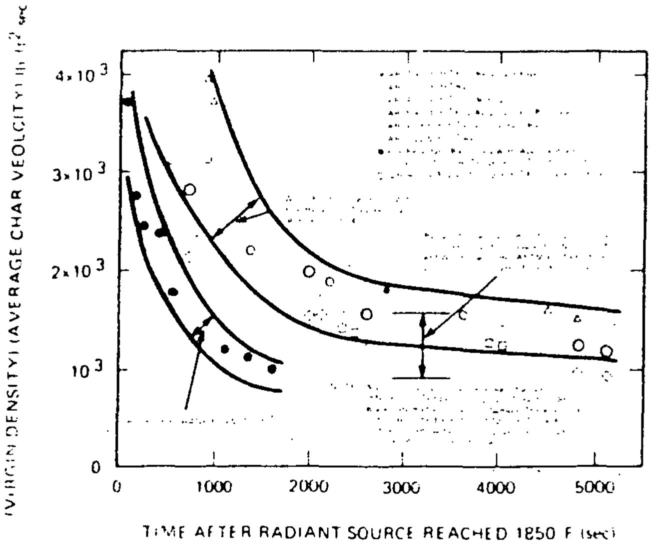


Figure 3.1.a Char Velocity for Various Materials

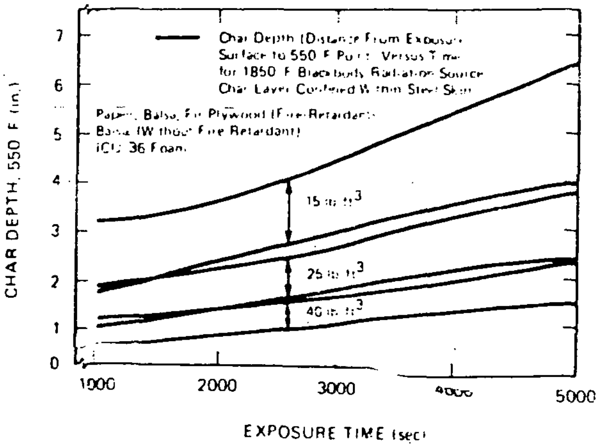


Figure 3.1.b Char Depth vs Time for Charring Materials

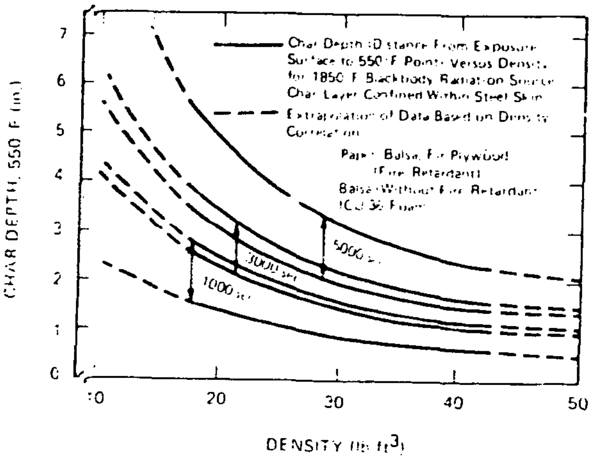


Figure 3.1.c Char Depth vs Density

Figure 3.1 Charring Data from Reference 3

3.4 Thermal Evaluation for Normal Conditions of Transport

Two models were used in the thermal evaluation: a simplified steady-state model and a finite difference numerical model. The steady-state model assumed a constant solar heating value while the finite difference numerical model (Figure 3.2) considered the daily thermal cycle (i.e., 130°F ambient temperature with 16-hour exposure to direct sunlight). To establish basic input data for both models, a thermal test reported in Appendix 3.1 was conducted to determine the thermal resistance of PAT-1 components along the heat path leading from the TB-1 containment vessel, through the copper heat conducting tube, aluminum load spreader tube and discs, the redwood, and to the outside stainless steel drum. A schematic diagram of this heat path is shown in Figure 3.3. The thermal resistance values determined through this experiment are shown in Table 3.3.

3.4.1 Thermal Models

3.4.1.1 Steady-State Model

The outer wall temperature of the PAT-1 depends upon the external environment. A steady-state heat balance on the stainless steel surface can be written as follows:

$$Q + q_s \quad \alpha_s A_s = \bar{h}\, A_c\, (T_s - T_\infty) \qquad (1)$$

where Q is the decay heat, q_s is the incident solar flux, α_s is solar absorptivity, A_s is the area of the container projected normal to the solar flux, A_c is the total surface area for convective and radiative exchange with the local surroundings, and T_s and T_∞ are the surface and ambient temperatures.

The surface heat transfer coefficient $\bar{h}$ includes both radiation and convection:

$$\bar{h} = h_c + h_r \qquad (2)$$

Data correlations for natural convection (Ref. 4) give the mean surface Nusselt number Nu as a function of Grashoff Gr and Prandtl Pr numbers:

$$Nu = 0.53\ [Gr(T)Pr(T)]^{0.25} \qquad (3)$$

where $Nu = h_c D/k$, D is a characteristic length (diameter), and k is the conductivity of air. The convection heat transfer coefficient h_c is obtained from Equation (3).

$$h_c = 0.53\ (k/D)[GrPr]^{0.25} \qquad (4)$$

The radiative heat transfer coefficient h_r is defined as:

$$h_r = s\ e\ (T_s^2 + T_\infty^2)(T_s + T_\infty) \qquad (5)$$

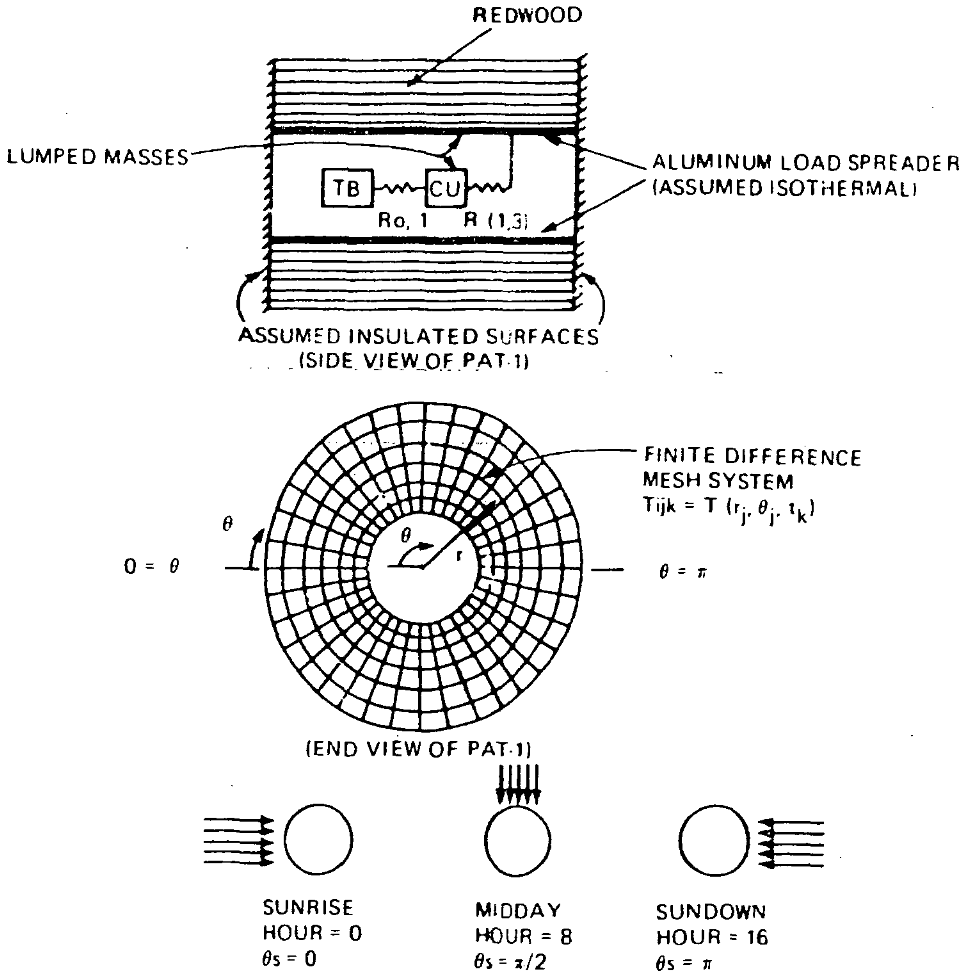
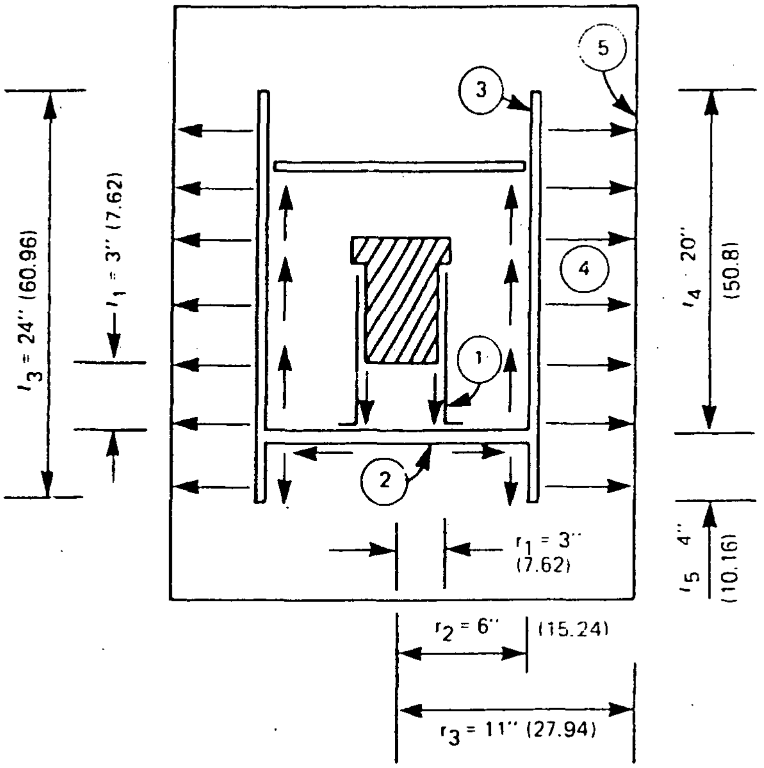


Figure 3.2 Schematic of Numerical Model Used to Assess Solar Heating



① COPPER CYLINDER: $k_c = 220\ (0.91)$ δ = THICKNESS INCHES (cm)
$\delta = 0.25\ (0.63)$ k = CONDUCTIVITY $\frac{\text{Btu}}{\text{hr. ft. °F}} \left(\frac{\text{cal}}{\text{cm. s. °C}}\right)$

② ALUMINUM PLATE: $k_A = 90\ (0.37)$
$\delta = 1''\ (2.54)$

③ ALUMINUM TUBE: $k_A = 90\ (0.37)$
$\delta = 0.5''\ (1.27)$

④ REDWOOD LINER: $k_w = 0.31$ @ 200°F (0.0013)

⑤ STAINLESS WALL: $k_s = 10\ (0.04)$

Figure 3.3 Schematic of Internal Heat-Flow Path

Table 3.3

EXPERIMENTALLY DETERMINED THERMAL RESISTANCES

Location	Thermal Resistance
TB-1 Vessel and copper heat tube $R_{0,1}$	0.56°F/watt
Copper heat tube and Al tube load spreader, $R_{1,3}$	0.36°F/watt
axial resistance in copper sleeve, R_1	0.1°F/watt
radial resistance in lower aluminum plate, R_2	0.05°F/watt
axial resistance in aluminum tube, R_3	0.19°F/watt
contact resistance Cu/Al and Al/Al joints, $R_{1,2} + R_{2,3}$	0.02°F/watt
Through Redwood Liner (varies slightly with T), R_4	0.5°F/watt
From TB-1 to outside surface, R_{Total}	1.4°F/watt (0.41 °F hr/Btu)

The net radiant heat flux q_r'' as given by:

$$q_r'' = \varepsilon\sigma(T_s^4 - T_\infty^4) \tag{6}$$

in which ε = 0.2 is the mean surface emissively (and absorptivity) in the long wavelength range and σ = 0.1714 x 10^{-8} (Btu/Hr/ft^2/°R^4) is the Steffan-Boltzman constant.

With solar heating, the local external surface temperature of the PAT-1 may deviate significantly from the isothermal condition implied in Equation (1). The most severe attitude occurs when the sun impinges directly on the cylindrical side of the package. An upper bound on $\bar{T}_s$ for these circumstances can be obtained by neglecting heat loss from the ends of the package, and using the heat transfer areas:

$$A_c = 2\pi\ell_3 r_3 \tag{7}$$

$$A_s = 2\pi\ell_3 r_3 \tag{8}$$

For ℓ_3 and r_3 of 24-inches and 11-inches, calculate 11.5 ft^2 and 3.7 ft^2 for areas Ac and A_s, respectively.

By appropriate substitution of equations (2), (4), (5), (7), and (8) into (1), the heat balance at the package surface is obtained.

$$Q + q_s \alpha_s A_s = \{0.53(k/D)[Gr\ Pr]^{0.25} + \sigma\varepsilon(T_s^2 + T_\infty^2)(T_s + T_\infty))(A_c)(T_s - T_\infty) \qquad (9)$$

Then, for Q = 25 watts (85 Btu/hr) q_s = 87 watts/ft^2 (295 Btu/hr/ft^2), α_s = 0.45, and T_∞ = 130°F (590°R), the average surface temperature $\bar{T}_s$ and the TB-1 temperature T_{TB} are obtained:

$$\bar{T}_s = 176°F \qquad (10)$$

and in terms of the internal heat Q and the total thermal resistance R_{Total} (Table 3.3).

$$T_{TB} = Q\ R_{Total} + \bar{T}_s = 211°F \qquad (11)$$

The maximum temperature on the surface was estimated by considering an elemental surface area normal to the impinging solar flux, for which the heat balance is:

$$Q/A_c\ dA + q_s\ \alpha_s\ dA = \bar{h}\ (T_s - T_\infty)\ dA \qquad (12)$$

Making the appropriate substitutions into equation (12), and solving for T_s, whi[illegible]s the maximum surface temperature $(T_s)_{MAX}$

$$(T_s)_{MAX} = 237°F \qquad (13)$$

However, it is expected that circumferential conduction in the PAT-1 would reduce the maximum surface temperature.

These analytical estimates are based on steady-state heat balance. It is likely that the heat capacity of the package will somewhat reduce the temperature rise caused by insolation, particularly since the sun is absent at night. The effect of these transients is addressed in the next section.

3.4.1.2 Mathematical Model

The transient temperature response of the PAT-1 was calculated using finite difference methods (Figure 3.2). Since the influence of solar flux is of primary interest, heat flow in the radial and circumferential directions was modeled, with temperature assumed uniform in the axial direction. This is equivalent to removing the ends of the package (at the ends of the aluminum tube) and replacing this material with insulated planes. Such a model overpredicts the PAT-1 temperatures because internal heat and absorbed solar radiation are not lost to the surroundings from the end surfaces.

To further simplify the model, a few assumptions were made concerning the internal metallic components. The TB-1, the copper tube, and the aluminum load spreader assembly were each treated as lumped masses of uniform temperature. The thermal resistances between these components, taken from the test results of Appendix 3.1 which are shown in Table 3.3, have a negligible influence on temperature distribution in the wood.

The energy equation applied to the redwood liner is the transient conduction equation:

$$\rho c \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r k_1 \frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \theta}\left(R k_2 \frac{\partial T}{\partial \theta}\right) \qquad (14)$$

in which c, k_1, and k_2 were taken as the specific heat and thermal conductivities parallel and perpendicular to the redwood grain direction given in Table 3.2; the other parameters are illustrated in Figure 3.3. The boundary conditions applied at the outer wall are as follows:

$$- k \frac{\partial T}{\partial \theta} = \bar{h}\,(T_\infty - T) + \alpha_s\, q_s\, F(\theta) \qquad (15)$$

$$F(\theta) = \begin{cases} \cos(\theta - \theta_s), & 0 < \theta - \theta_s < \frac{\pi}{2} \\ 0, & \frac{\pi}{2} < \theta - \theta_s < \pi \end{cases} \qquad (16)$$

where θ_s is the angular location of the sun which varies during the day and θ is the angular coordinate on the surface as noted in Figure 3.2. As the sun passes over the package, θ_s is gradually increased from $\theta_s = 0$ to $\theta_s = \pi$ during a 16-hour period, with q_s set to zero for the next eight hours. The daily cycle was repeated until a steady periodic behavior was established. Because of the cylindrical shape of the package, the area projected normal to the insolation remains the same throughout the 16-hour period of sunlight. This is in contrast to the case of a flat plate for which the energy absorption varies approximately as a half-sine wave due to geometric considerations (Ref. 5). Thus, the most severe orientation for the PAT-1 package is the one considered here with the sun moving in the (r,θ)-plane.

The finite difference equations derived from (14) and (15) comprise a standard, explicit scheme. The nodal equations for the outer boundary include the heat capacity and the circumferential conduction in the stainless steel wall as well as the convective and radioactive exchange with the surroundings. Stability and sufficient accuracy were obtained using nine radial divisions, 15 angular divisions, and a time step of one-half minute.

Before considering the effects of insolation, a test case was run corresponding to the conditions of the thermal test described in Appendix 3.1. A comparison of experimental and numerical results is shown in Figure 3.4. The steady-state temperatures are in precise agreement because the coded expressions for redwood conductivity and resistance between metallic components are based on the test data. The transient behavior is in reasonably good agreement. The thermocouples which measure wall temperature were located on the ends of the PAT-1 and are, therefore, not in intimate contact with the redwood. The calculated wall temperature refers to the side wall where the temperature rise due to environmental heating is slowed by conduction into the redwood. The predicted internal temperatures increase somewhat faster than the experimental data, particularly in the early period. This is partly because the resistance heater was not in direct contact with the TB-1, thus causing an initial time lag in the experimentally observed temperature rise. Also, the mathematical model neglects axial sinking of the internal heat from the TB-1. These factors would not have a significant effect on the calculations concerned with insolation.

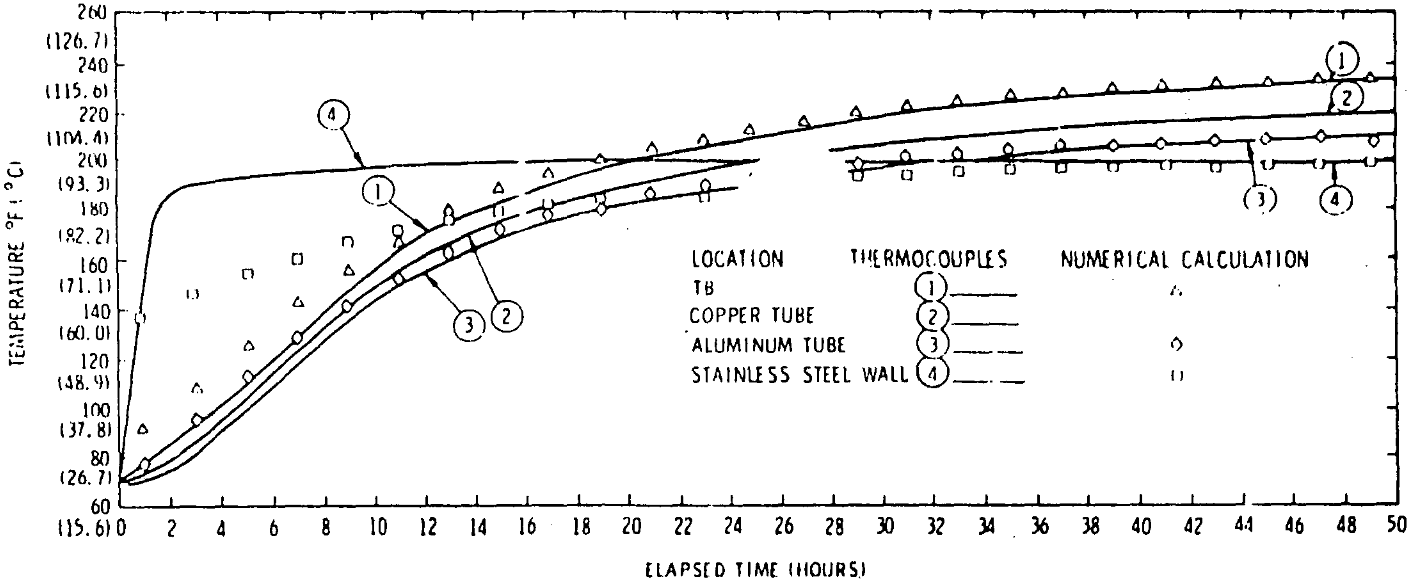


Figure 3.4 Results of Thermal Test (Solid Lines) and Comparison with Numerical Calculation (Symbols)

The response of the PAT-1 package was calculated for a solar flux of $q_s = 295$ Btu/hr/ft^2 passing over the cylindrical surface from $\theta_s = 0$ to $\theta_s = \pi$ in a 16-hour period followed by eight hours of darkness. The ambient temperature was held steady at 130°F throughout the day for five consecutive days. After the third day the thermal cycle shown in Figure 3.5 was well established. The representative temperatures increase steadily during insolation, reaching maximum values at sunset or shortly after. The maximum TB-1 temperature, the mean surface temperature $\bar{T}_s$, and the mean redwood temperature $\bar{T}_w$ are as follows:

$$
\begin{aligned}
&T_{TB} < 212°F \\
&\bar{T}_s < 176°F \qquad (17) \\
&\bar{T}_W < 182°F
\end{aligned}
$$

These values are essentially the same those obtained by the analytical estimates in equations (10) and (11) of the previous section, indicating that 16 hours of insolation has almost brought the package up to quasi-steady state.

The most severe temperature distribution in the redwood is shown in Figure 3.6. The peak temperature occurs at the surface near $\theta = \pi$ where the insolation impinges the surface.

$$(T\ )_{MAX} < 224°F \qquad (18)$$

This is about 14°F less than the analytical estimate in the previous section because circumferential conduction and transient effects are now included. Since the circumferential conductivity of the wood is small, the aluminum load spreader plays a significant role in carrying heat from the hot side to the cold side of the package. Also, the temperature distribution is skewed slightly to the left of $\theta = \pi$ because that side has been subjected to greater solar flux in the preceeding hours of the day.

Figure 3.7 shows the amount of the redwood overpack which is cooler relative to any given temperature. Ninety percent of the redwood is cooler than 200°F even at the end of the day. This is a conservative estimate because the ends of the package, which are significantly cooler, have not been included in the analysis.

3.4.2 Maximum Temperatures

The above analysis and testing of the PAT-1 package supports the estimates for maximum temperatures under normal conditions of transport as shown in Table 3.1. The conservative estimates that Table 3.1 is based upon are emphasized by a review of modeling assumptions:

a. An assumed geometric orientation that maximizes absorption of solar flux.

b. An exposure of solar flux for 16 hours (295 Btu/hr/ft^2).

c. A high ratio of solar absorptivity to surface emissivity.

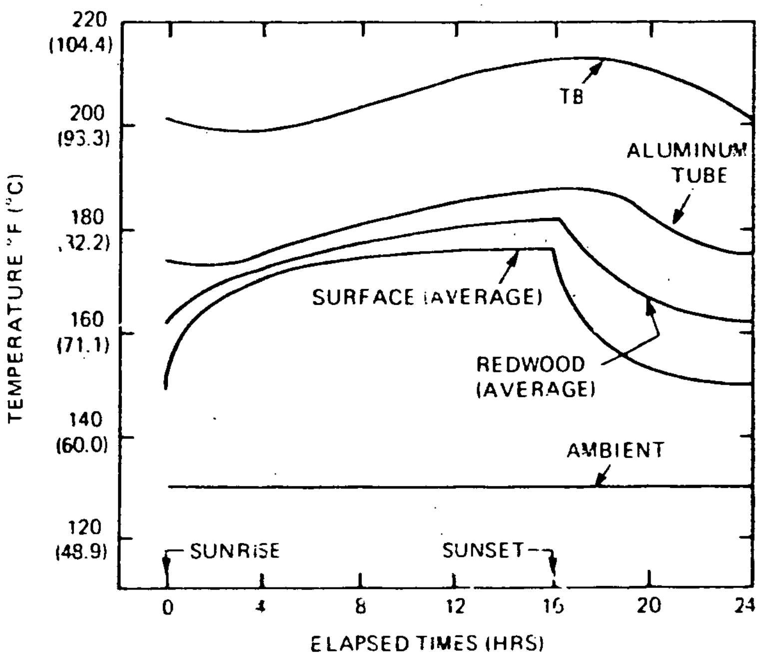


Figure 3.5 Daily Thermal Cycle of PAT-1 Subjected to Solar Radiation

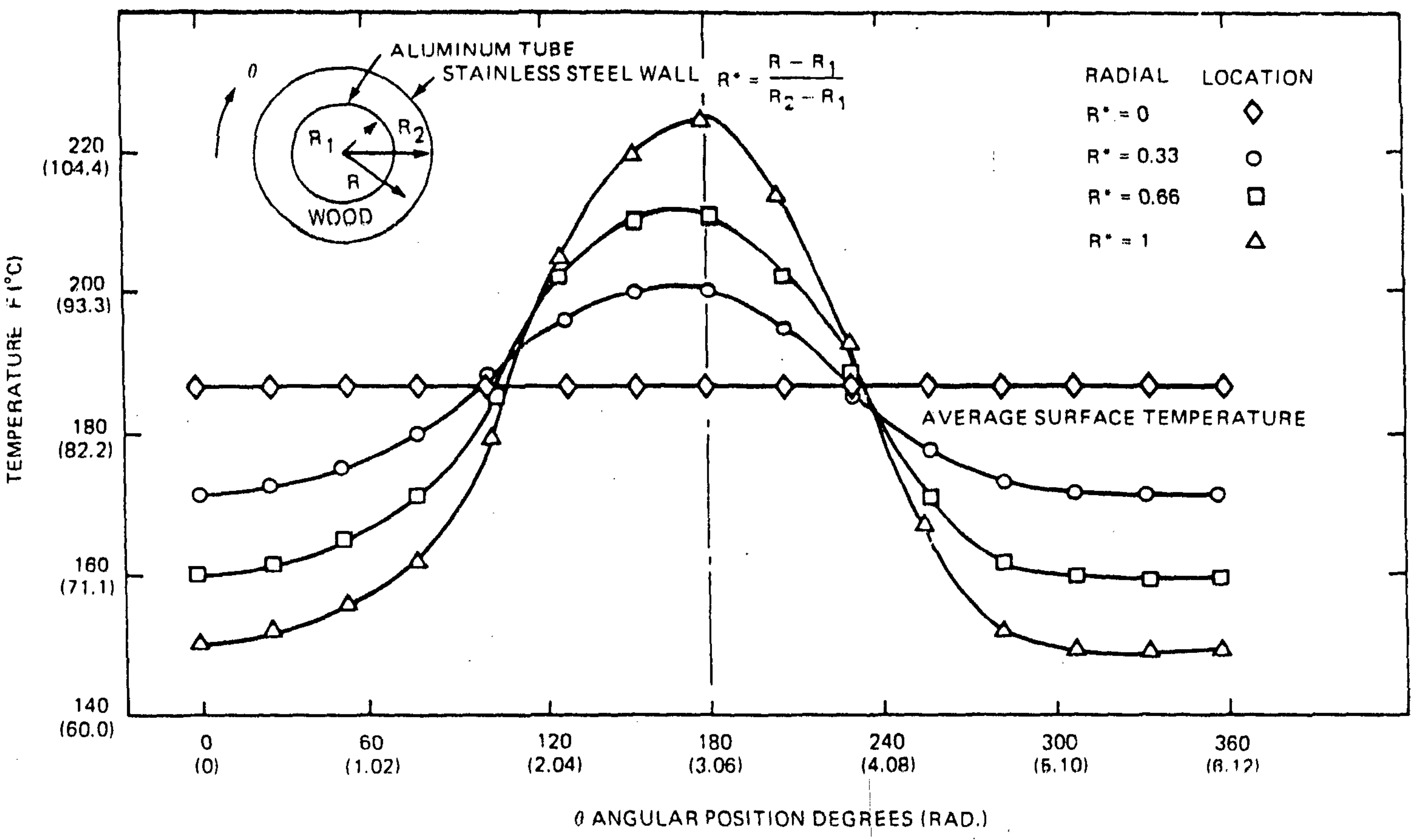


Figure 3.8 Temperature Distribution in Redwood Overpack Just Before Sundown (Most Severe Case)

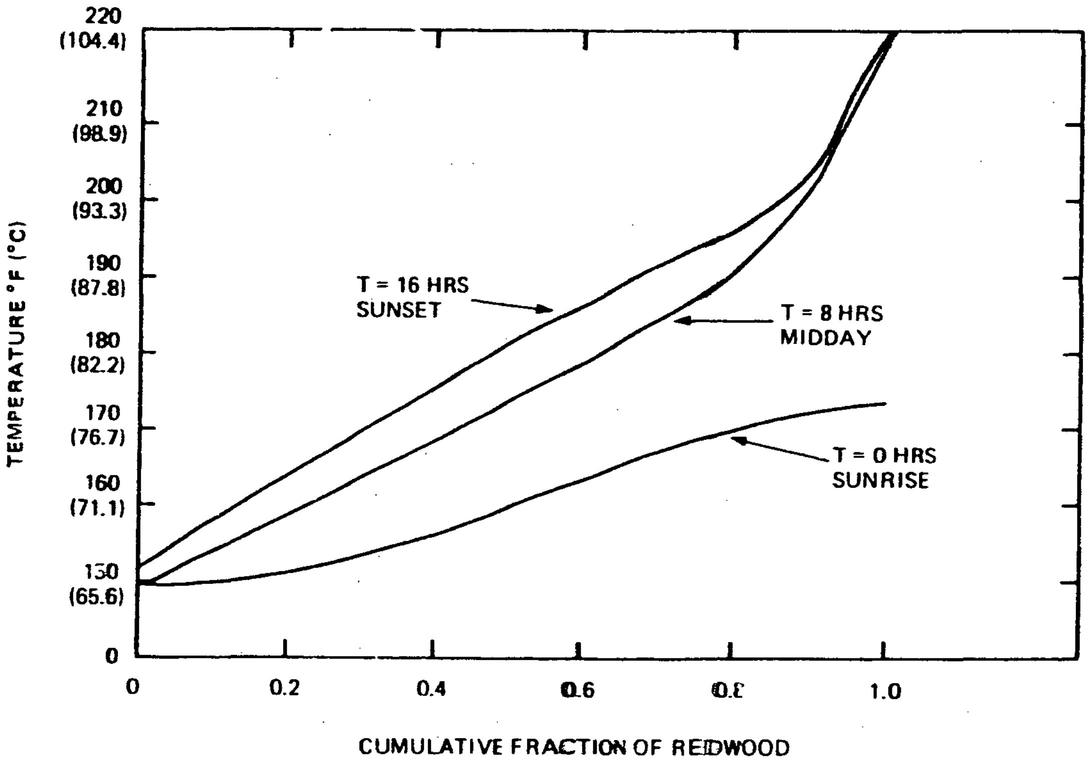


Figure 3.7 Temperature of PAT Redwood—Maximum Normal Environment

d. An ambient temperature of 130°F.

e. No heat loss from ends of PAT-1.

f. No wind to enhance convection.

The thermal stresses and internal pressures in the TB-1 are negligible at these temperatures. Also, the characteristics of the redwood are not significantly affected by a temperature of 200°F, as demonstrated in Reference 6.

3.4.3 Minimum Temperatures

In an external ambient of -40°F with no direct solar flux, the temperatures of the outer wall and the TB-1 are estimated as -30°F and +5°F, respectively, for an internal heat load of 25 watts. For a -40°F ambient without an internal heat load the entire package is a uniform -40°F. The associated thermal stresses and pressures at these temperatures are insignificant.

3.4.4 Maximum Internal Pressure

For a TB-1 containment vessel at a temperature of 215°F with a 25-watt decay heat load, the internal pressure is 34.3 psia (see Section 4.2.3).

3.4.5 Maximum Thermal Stresses

Temperature differences within the TB-1 are not excessive under normal conditions of transport, and corresponding stresses are insignificant. Differential thermal expansion within the PAT-1 package is not significant in terms of thermal contact resistance or secondary stresses which result.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

The evaluation of the ability of the PAT-1 package to safely contain its contents under normal conditions of transport (Section 2.0) is supported by information in this section.

The TB-1 containment vessel is leaktight over the range of its normal operating temperatures. The copper gasket and elastomeric O-ring are unaffected by this range of temperature, over their periods of intended use.

The PC-1 product can would not be affected by the normal condition performance tests and would not be degraded during its single shipment usage.

The metal components of the AQ-1 overpack are unaffected by the temperature range of normal transport (e.g., -40°F to 225°F for the outer stainless steel drum). Redwood material properties experience neither short nor long-term degradation from the mean temperature range of normal transport (-40°F to 182°F).

3.5 10 CFR 71 - Thermal Accident Evaluation

Physical tests were the primary method used to show that the PAT-1 package meets the test requirements specified in Appendix B of 10 CFR Part 71. However, one assessment was required to establish that the maximum TB-1 temperature assumed in Section 4.0 is reasonable.

3.5.1 Thermal Models

3.5.1.1 PAT-1 Package Response in a 10 CFR 71 Fire Environment Analytical Model

The response of the package to the fire test can be calculated utilizing data of charring rates in wood (Refs. 3, 7).

In Reference 3, an exposed surface of wood was sheathed in a steel skin similar to that covering the PAT-1 package following the 30-foot drop and puncture tests specified in Appendix B of 10 CFR 71. However, data was generated utilizing an external 1850°F black body radiation source rather than a 1475°F radiation environment. Figure 3.1 shows that after 30 minutes of fire exposure, a char depth in the range of 2.1 inches is predicted for the 22-lb/ft^3 density redwood typical of the PAT-1 package. After 30 minutes, approximately 2.6 inches of virgin redwood remains between the char front and the aluminum load spreader tube. The char front is shown to move at a velocity of about 0.28 ft/hour (see Figure 3.1-a).

Several tests of the PAT-1 and other prototype packages indicate that if the redwood remains in an integral condition following the fire, char front progression is curtailed (as demonstrated in Section 3.5.1.2, to follow). Since the PAT-1 package is essentially undamaged prior to the fire test, charring stops shortly after the fire is extinguished. The temperature in front of the char front can be estimated by equation (19).

$$(T - T_i)/(T_c - T_i) = \exp\,(-vx/\alpha_w) \qquad (19)$$

where T is the temperature at a distance x in front of the progressing char front (0.22 ft), T_i is the initial internal temperature at x, v is the char front velocity (0.28 ft/hr), and T_c is the char front temperature, ∿ 550°F. Based on the high thermal resistance of uncharred redwood, the value chosen for T_i would not be significantly higher than the temperature (∿ 200°F - Table 3.1) of the load spreader. The thermal diffusion coefficient ($\alpha_w = k/\rho c$) can be calculated as 0.024 ft^2/hr, Table 3.2. The temperature of the wood adjacent to the load spreader tube is calculated as:

$$T = \text{redwood @ load spreader} = 227°\text{F} \qquad (20)$$

Since the physical condition of the PAT-1 package throughout the accident tests assures that reasonable thermal contact between the TB-1 and the aluminum load spreader is maintained, the TB-1 temperature would also be at approximately the same.

3.5.1.2 Test Model - PAT-1 Performance During 10 CFR 71 Accident Condition Tests

The thermal test specified in Appendix B of 10 CFR 71 requires a heat input to the whole package not less than would result from radiation exposure of 1475°F for 30 minutes with an emissivity coefficient of 0.9 (assuming a surface absorption coefficient of 0.8). The ability of the fire test facility to produce this environment is discussed in Section 3.6.2.2. This fire test, which lasted 52 minutes, shows that the 10 CFR 71 requirements were exceeded (see Table 3.4). Figure 3.8 shows that the luminous flame zone extends essentially across the diameter at the top of the chimney. The internal condition of the package and char depth are shown in Figures 3.9 and 3.10). The maximum TB-1 temperature during the test was estimated at over 200°F by post-test examination of Tempilaque coating painted on the bottom and inside the cover of the vessel. This coating, which degrades at 200°F, indicated a temperature slightly in excess of 200°F.* The 200°F coating inside the TB-1 cover was discolored but still intact, confirming the estimated 200°F temperature, the 300°F coating was completely intact. Tempilabels placed on the surface of the PC-1 indicated temperatures of 170°F and 180°F.

Table 3.4

10 CFR 71 APPENDIX B FIRE TEST

Observed average temperature on AQ-1 drum:	1800°F
Observed flame temperatures in vicinity of PAT-1:	2200-2300°F
Curation of above temperatures:	52 minutes
Char depth in outer redwood:	3.825"
TB-1 temperature: average	200°F
range	(170°F to 210°F)
Cumulative char rate:*	0.37 ft/hr

---

*Total char depth observed was divided by 52 minutes; this is a conservative assumption because char would persist beyond the 52 minute duration of the JP-4 fire.

The TB-1 temperature achieved in the test and the corresponding temperature calculated by analysis (assuming maximum PAT-1 package normal operating temperatures, Table 3.1) were essentially the same.

3.5.2—Package Conditions and Environment

The minor dents and scratches caused by the 30-foot free drop and puncture tests would have no significant effect on the package during the thermal test.

3.5.3 Package Temperatures

The above analysis and testing of the PAT-1 package supports a conclusion that approximately 227°F would be the maximum TB-1 temperature during the thermal test specified in Appendix B of 10 CFR Part 71.

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*The 200°F coating on the exterior of the TB-1 vessel was degraded, possibly from the effects of the water immersion test, but the 300°F coating was completely intact.

Figure 3.8 10 CFR Part 71 Appendix B Fire Test

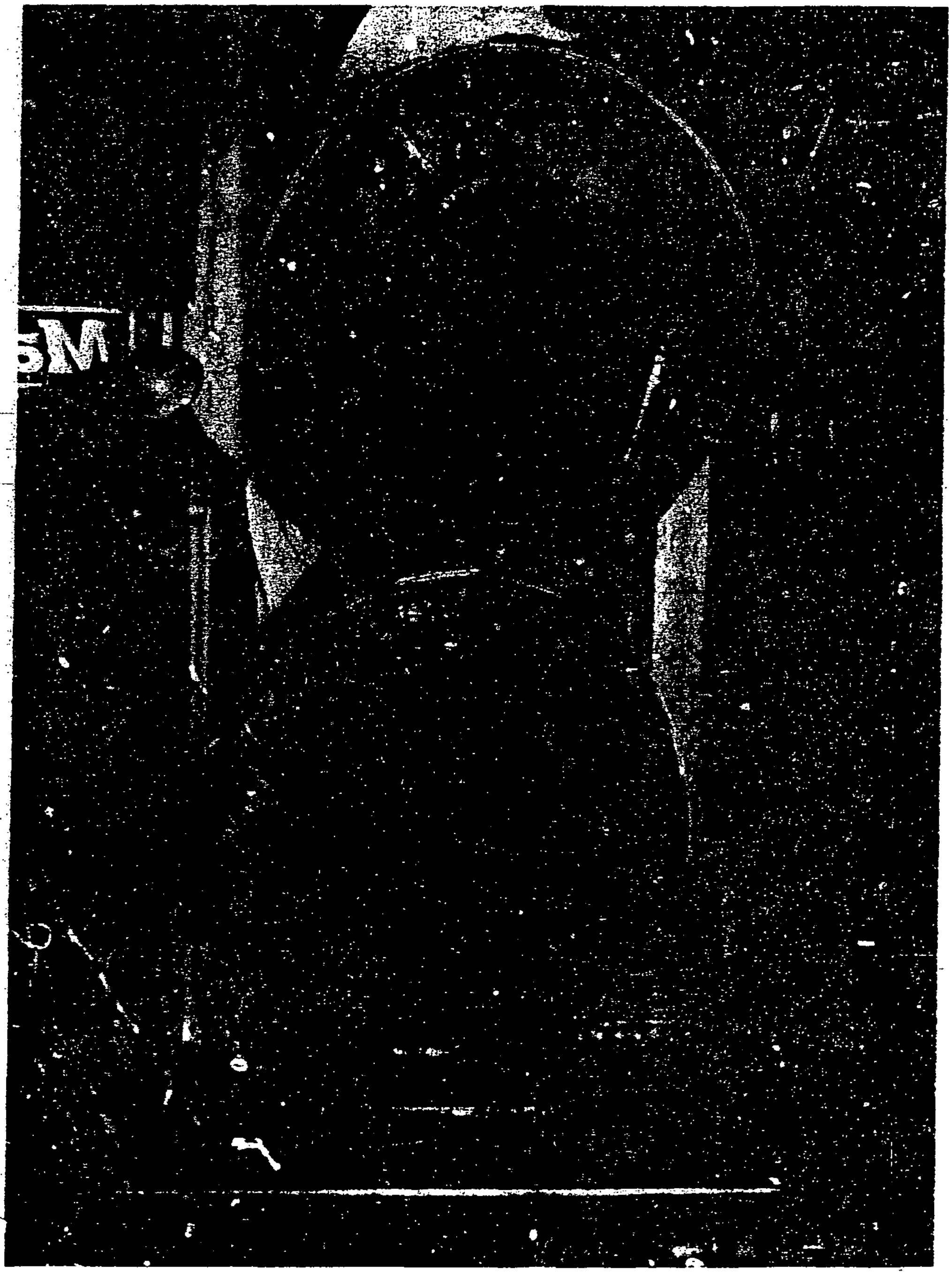

Figure 3.9 Depth of Redwood Char Following 10 CFR Part 71 Appendix B Fire Test

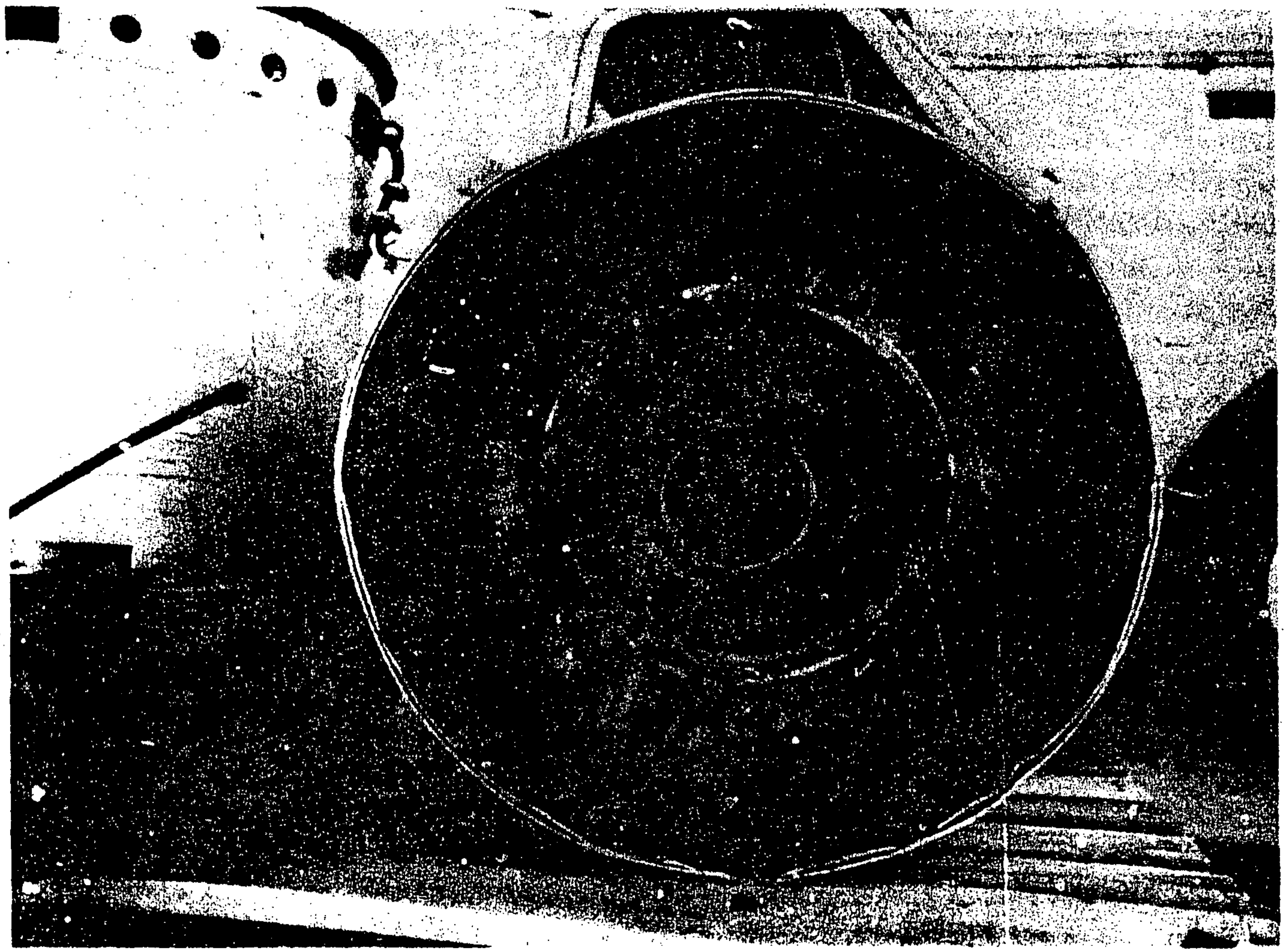

Figure 3.10 Post-Fire View of Redwood

3.5.4 Maximum Internal Pressure

For a TB-1 containment vessel at 227°F, the internal pressure is 38.7 psia (Section 4.3.3).

3.5.5 Maximum Thermal Stresses

Temperature differences and the resulting differential expansion and secondary thermal stresses within the TB-1 are not excessive under the tests specified in Appendix B of 10 CFR Part 71. The performance is verified by test.

3.5.6 Evaluation of Package Performance for the 10 CFR 71 Accident Conditions

Because the maximum temperature predicted for the TB-1 (227°F) exceeds the peak normal operating range by only 15°F, the containment vessel would not be degraded by the thermal environment in Appendix B of 10 CFR Part 71.

For 227°F the maximum internal pressure is 38.7 psia, 12 psia less than the internal pressures generated in the 1-1/2 x maximum normal operating pressure test. Testing the PAT-1 package to this pressure is routinely required in the verification tests for containment system fabrication specified in Section 8.0. The elastomeric O-ring and copper gasket were not degraded under these performance test conditions.

The PC-1 product can, when closed by crimping and sealed by welding or silver soldering, meets the requirements of 10 CFR §71.42.

The redwood within the AQ-1 overpack served its intended purpose. During the fire test, the redwood external to the aluminum load spreaders charred to a depth of about 3 inches (consistent with the analytical assessment described in Section 3.5.1.1). The redwood within the load spreader tube and discs was unaffected by the performance tests in Appendix B of 10 CFR Part 71.

3.6 NRC Qualification Criteria - Thermal Accident Evaluation

Physical tests were also the primary means used to show that the PAT-1 package meets the requirements specified in the NRC Qualification Criteria. The purpose of the assessment in this section is to show that the maximum TB-1 temperature assumed in Section 4.4.2 is a reasonable upper limit which would bound all test results.

3.6.1 Thermal Models

3.6.1.1 PAT-1 Package Response to the Fire Environment of the NRC Qualification Criteria - Analytical Assessment

The PAT-1 packages subjected to the fire test specified in the NRC Qualification Criteria had been damaged by being impacted, crushed, punctured, and slashed. Such distortions of package geometry and alterations in the packaging materials (e.g., compressed redwood,) limit any theoretical evaluation to conservative estimates.

The two ripping/slashing tests are especially significant because the resulting penetrations exposed a significant amount of redwood to the fire. As a result, the wood continued to char after the fire stopped.

During development testing, the burning and smoldering temperature of the redwood was observed to occur in two ranges. If the redwood was contained within an essentially integral stainless steel outer drum after the high velocity impact test, any continued combustion occurred through the progression of a char front, whose temperature would be expected to range between 550°F and 620°F (see Ref. 3). If, however, the breakup of the redwood was extensive and the damage to the outer stainless steel drum allowed "open" glowing combustion of the charcoal, temperatures of approximately 1100°F were recorded.

Although the PAT-1 package outer stainless steel drum remains integral following the high velocity impact test, it sustained two five-square inch penetrations as a result of the ripping/slashing tests. Therefore, the maximum temperature to which the TB-1 will be directly exposed (during the fire test) will be between the temperature of the redwood char front, 550°F to 620°F, and the glowing combustion temperature of charcoal of 1100°F. The TB-1 surface temperature would not be expected to vary significantly from these values (i.e., the temperature differential caused by the 25-watt internal heat source would be inconsequential).

3.6.1.2 PAT-1 Package Response to the Fire Environment of the NRC Qualification Criteria - Test Model

Five PAT-1 packages were subjected to the tests specified in the NRC Qualification Criteria. In each, the TB-1 contained from 1.05 to 1.25 kg of UO_2 surrogate contents. To simulate TB-1 containment vessel internal pressures (as described in Section 4.4.2), 19.3 grams of water were added to the surrogate contents.

The major variable in the sequential tests was the package orientation with respect to the target at impact. Side, top, top corner, bottom and bottom corner impacts were conducted followed by the crush, puncture and slashing tests, after which packages were subjected to the specified fire test. The fire test requires exposure to luminous flames from a pool of JP-4 fuel for at least 60 minutes. The luminous flames are to extend an average of at least three feet and no more than ten feet beyond the package in all horizontal directions. The ability of the fire test facility to produce this environment is discussed in Section 3.6.2.2. The time/temperature records for the three fires used to test the five packages were recorded. The estimated average flame temperature at package height, estimated average package skin (AQ-1 drum) temperature, duration of the fires, and maximum TB-1 temperature during each test are indicated in Table 3.5.

Thermocouple data plots from the tests are scattered over a fairly wide band (Table 3.5 shows maximum package temperatures). The estimates were made by post-test examination of Tempilaque coatings painted on the bottom and inside of the TB-1 vessel covers. Although the Tempilaque was affected by the adjacent redwood char, and by the mechanical effects from the impact test, a rough estimate indicated a response of about 1000°F (538°C) for each TB-1. Also, four of the five TB-1s tested was dark blue, a color roughly indicative of 1000°F (538°C) for PH13-8 Mo

Table 3.5

AVERAGED RESULTS - NRC QUALIFICATION CRITERIA FIRE TESTS

PAT-1 Package I.D.	Flame Temp. @ Pkg. Level for Time Reported	Duration of Fire Above 1850°F	Max. Temp. of AQ-1 Drum	Minimum Total Exposure Time to Engulfing JP-4 Flames	Approx. TB-1 Temp.
Top Impact	1850-2100°F (1)	63 minutes	> 2400°F	66 minutes	1000°F
Top Corner Impact	1850-2100°F (2)	58 minutes	2150°F	66 minutes	1000°F
Side Impact	1850-2200°F (2)	58 minutes	2200°F	66 minutes	1000°F
Bottom Corner Impact	1700-2100°F (2)	50 minutes (3)	> 2400°F	63 minutes	1000°F
Bottom Impact	1850-2100°F (1)	63 minutes	> 2400°F	66 minutes	1000°F

---

1. Flame temperature 6" below packages
2. Flame temperature at package median
3. Short time dip below 1850°F during fire; package temperature continued to rise.

stainless steel heated in an oxidizing atmosphere. The other TB-1 was colored medium yellow, indicative of a temperature of less than 1000°F (538°C).

3.6.2 Package Conditions and Environment

The damage to the PAT-1 packages resulting from the high-velocity impact, crush, puncture, and slashing tests (described in Section 2.0), significantly deforms and exposes specific areas of redwood in the outer overpack. This exposure (1) affords the fire direct access to the redwood, and (2) permits long-term charring of the redwood following the fire.

3.6.3 Package Temperatures

Based on the analysis and test results in Sections 3.6.1.1, and 3.6.1.2, the TB-1 is estimated to have attained a maximum temperature of approximately 1080°F during the thermal test specified in the NRC Qualification Criteria.

3.6.4 Maximum Internal Pressure

For a TB-1 containment vessel at 1080°F, the maximum internal pressure is 1110 psia (Section 4.4.2.).

3.6.5 Maximum Thermal Stresses

The fire tests support the conclusion that thermal stresses in the TB-1 do not affect its containment integrity. Temperatures of the TB-1 varied, depending on the progression of the redwood char front, but were equalized by the aluminum load spreader. The conductivity of the stainless steel used in the TB-1 is such that significant temperature differences would not be expected within a vessel.

3.6.6 Evaluation of Package Performance for NRC Qualification Criteria Thermal Conditions

The ability of the PAT-1 package to safely contain its contents throughout the tests specified in the NRC Qualification Criteria is demonstrated in Section 4.4.

Both analyses and testing show that maximum temperatures reached by the TB-1 containment vessels during the fire test range from 900°F to 1100°F.

Five tests confirm that the PAT-1 package offers sufficient thermal protection to limit TB-1 temperatures to below 1100°F, when subjected to the fire test specified in the NRC Qualification Criteria. Post test examination of the package indicated that all of the redwood had charred. The condition of the charred redwood indicated that the redwood external to the aluminum load spreader was subject to glowing combustion (characterized by 1100°F), while the redwood internal to the aluminum load speader was subject to smoldering (characterized by 550°F to 620°F). The different charring conditions are attributed to available oxygen during combustion. Further damage from ripping/tearing of the AQ-1 would not significantly effect the thermal performance of the TB-1 since the redwood glowing combustion temperature is limiting and the redwood internal to the aluminum load spreader is consumed at the lower (< 620°F) temperature. The maximum 1100°F TB-1 temperature is forced by the aluminum load spreader temperature. The aluminum load spreader has a direct thermal connection through the copper liner. A good safety margin is afforded by the fact that when the fuel fire has burned-out, a considerable amount of uncharred redwood remains around the containment vessel. Following the fuel fire, the remaining redwood undergoes smoldering and glowing combustion, with a corresponding maximum TB-1 vessel temperature of approximately 1100°F.

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Appendix 3-A

Test to Establish Thermal Resistance Values
of PAT-1 Components

A thermal test was conducted to determine the thermal resistance values for PAT-1 components. A resistance heater was placed inside the TB-1 of the PAT-1 package and thermocouples were attached at the locations noted in Table 3-A.1.

Table 3-A.1

STEADY-STATE TEMPERATURES ATTAINED DURING TEST TO ESTABLISH THERMAL RESISTANCES

TC #	Location	Designation on Fig. 3.4.	Steady-State Temperature
2, 3, 4	Lid of TB	1	235°F
5, 6	Cu Sleeve	2	221°F
7, 8	Al Tube	3	212°F
9	Al Plate (upper)	3	212°F
10, 11, 12	Outer SS Wall	4	200°F

The heat was run in a temperature-controlled chamber maintained at approximately 200°F. The internal heater was maintained at 25 watts using a variable resistance power supply. The transient response of the thermocouples is indicated by the solid lines in Figure 3.4. The symbols on this plot represent comparative numerical calculations which are discussed in Section 3.4.1.2.

The steady-state temperatures listed in Table 3-A.1 were used in conjuction with the known heat load of 25 watts to calculate thermal resistances along the heat flow path. The steady-state temperature difference between the TB-1 and the outer surface of the PAT-1 was written as follows:

$$T_{TB} - T_S = RQ \qquad (1)$$

where Q is the internal heating rate (25 watts) and R is the overall thermal resistance of the primary conduction path shown in Figure 3.3. The overall resistance R is the sum of the separate resistances along the path. The axial heat flow at the ends was neglected since it contributes less than 15% to the total conductance.

The temperature difference between the TB-1 and the copper sleeve was 14°F. Since thermocouples five and six were located near the top of the copper sleeve, this temperature drop was attributed to the resistance $R_{0,1}$ of the fiberglass protective layer at the slip-fit joint between the TB-1 containment vessel and the cadmium-plated copper sleeve.

$$R_{0,1} = \frac{T_{TB} - T_{Cu}}{Q} = .56°F/watt \tag{2}$$

The measured temperature difference between the copper sleeve and the aluminum tube was 9°F, corresponding to a thermal resistance of

$$R_{(1,3)} = \frac{T_{Al} - T_{Cu}}{Q} \approx 0.36°F/watt \tag{3}$$

Since thermocouples seven and eight were located near the top of the aluminum tube, this resistance includes the axial resistance in the tube as well as the axial resistance of the copper sleeve, the radial resistance in the lower aluminum plate, and the contact resistance at the two joints

$$R_{(1,3)} = R_1 + R_2 + R_3 + R_{1,2} + R_{2,3} \tag{4}$$

The axial resistance in the copper sleeve is

$$R_1 = \frac{1}{2\pi r_1 \delta_1 k_C} \approx 0.1°F/watt \tag{5}$$

where the parameters are defined in Figure 3.3, and the radial resistance in the lower aluminum plate is

$$R_2 = \frac{\ln (r_2/r_1)}{2\pi\delta_2 k_A} \approx 0.05°F/watt \tag{6}$$

As will be explained below, the axial resistance in the aluminum tube is on the order of

$$R_3 \approx 0.19°F/watt \tag{7}$$

This leaves a total contact resistance of approximately

$$R_{1,2} + R_{2,3} \approx 0.02°F/watt \tag{8}$$

for the copper/aluminum joint $R_{1,2}$ and the aluminum/aluminum joint $R_{2,3}$. Since these are jointed with metallic fasteners, a very small resistance was expected.

The measured temperature difference between the top of the aluminum tube and the outer wall was

$$\Delta T_{3,5} = 12°F \tag{9}$$

Since this temperature drop is related to the thermal resistance of the wood liner, it provided a means for checking the redwood conductivity. The axial conduction in the aluminum cylinder was coupled with outward radial conduction along the grain of the wood. Thus, the fin equation was applicable provided that the convection coefficient h and the outer wall (forcing) temperature are uniform. The usual convection coefficient h was redefined in terms of the radial conductance of the wood, as follows

$$h = \frac{k_w}{r_2 \ln(r_3/r_2)} \tag{10}$$

Then, from the textbook solution [4],

$$Q = \Delta T (hPk_A)^{1/2} \left\{ \tanh\left[\frac{hP\ell_5^2}{k_A A}\right]^{1/2} + \tanh\left[\frac{hP\ell_4^2}{k_A A}\right]^{1/2} \right\} \tag{11}$$

In which ΔT is the temperature difference between the lower end of the aluminum tube (base of the fin) and the outer wall. Equation (11) was rearranged as follows

$$\Delta T = Q \frac{\ln(r_3/r_2)}{2\pi \ell_3 k_w} \Psi \left\{ \tanh\left[\Psi \frac{\ell_5}{\ell_3}\right] + \tanh\left[\Psi \frac{\ell_4}{\ell_3}\right] \right\}^{-1} \tag{12}$$

in which

$$\Psi = \left[\frac{k_w}{k_A} \frac{\ell_3^2}{r_3 \delta_3} \frac{1}{\ln(r_3/r_2)}\right]^{1/2} \tag{13}$$

Also, the relationship between ΔT and $\Delta T_{3,5}$ was available from the solution of the fin equation [4]

$$\Delta T = \Delta T_{3,5} \cosh\left[\Psi \frac{\ell_4}{\ell_3}\right] \tag{14}$$

Then, by combining (12) and (14),

$$\Delta T_{3,5} = Q \frac{\ln(r_3/r_2)}{2\pi \ell_3 k_w} \Psi \left\{ \sinh\left(\frac{\ell_4}{\ell_3}\Psi\right) + \cosh\left(\frac{\ell_4}{\ell_3}\Psi\right) \tanh\left(\frac{\ell_5}{\ell_3}\Psi\right) \right\}^{-1} \tag{15}$$

Since Q, $\Delta T_{3,5}$, and the geometry were all known, the value of k_w is calculated from (13) and (15) as

$$k_w = 0.31 \text{ Btu/hr/ft/°F} \quad , \tag{16}$$

This is in good agreement with published empirical expressions noted in Table 3.2.

The temperature drop along the aluminum tube was estimated using (14)

$$\Delta T_3 = \Delta T - \Delta T_{3,5} = 4.8°F \qquad (17)$$

and the corresponding thermal resistance was

$$R_3 = \frac{\Delta T_3}{Q} = 0.19°F/watt \qquad (18)$$

as given previously in Equation (7).

The thermal resistance of the redwood liner was evaluated as

$$R_4 = \frac{\Delta T_{3,5}}{Q} = 0.5°F/watt \qquad (19)$$

but this resistance decreases as the temperature increases due to temperature dependence of the redwood conductivity.

Contact resistance was neglected in the analytical model (fin approximation) which describes the heat flow from the aluminum tube to the outer wall. Nevertheless, the inferred value for redwood conductivity, $k_w = 0.31$, already exceeds the expected value based on published correlations. If contact resistance had been included, the inferred value of k_w would be even greater. This assessment appears to confirm that contact resistance is negligible at the wood/metal glue joints.

In summary, the overall thermal resistance R between the TB-1 and the outer stainless steel drum wall consists of the three major contributions discussed separately above:

$$R = R_{0,1} + R_{1,3} + R_4 = 1.4°F/watt \qquad (20)$$

Although the redwood conductivity varies with temperature, the total R changes by only 5% with a temperature change of 50°F. Thus, the steady-state temperature difference between the TB-1 and the outer surface can be taken as

$$T_{TB} - T_s = QR = 35°F \qquad (21)$$

The experimental temperature measurements in the PAT-1 were found to be consistent with a simple analytical model of conduction heat flow. Contact resistance and redwood conductivity were estimated from these tests results.

4.0 CONTAINMENT

The PAT-1 package meets the containment acceptance standards specified in 10 CFR Part 71 and in the NRC Qualification Criteria set forth in NUREG-0360 (Ref. 1).

The ability of the TB-1 vessel to meet these standards was assessed by helium leak testing with a mass spectrometer. The assessment indicates that the PAT-1 package provides a greater degree of containment than is required by the acceptance standards. The results are summarized in Table 4.1.

4.1 Containment Boundary

The TB-1 containment vessel (Figure 1.4) provides the primary containment boundary for the PAT-1 package. Within it, the PC-1 product can (Figure 1.5) provides the separate inner container required by 10 CFR §71.42.

Table 4.1

PAT-1 PACKAGE POST-TEST CONTAINMENT

			Post Test Results	
Component	Test Condition	Regulatory Acceptance Standard	Helium Leak-Rate (atm-cc/sec)	Max. Mass of Powder Release (mg)
	Normal Conditions of transport (Appendix A of 10 CFR 71)	No Release	less than 1×10^{-10}	0
TB-1	Hypothetical Accident Conditions (Appendix B of 10 CFR 71)	No Release	less than 1×10^{-10}	0
	NRC Qualification Criteria	A_2/week*	less than 4.5×10^{-5}	0.17

4.2 Normal Conditions of Transport - 10 CFR §71.35

4.2.1 TB-1 Containment Vessel Leaktightness

During assembly of the PAT-1 package, the TB-1 containment vessel was filled with helium at ambient temperature and pressure and checked with a mass spectrometer for leaktightness. (The spectrometer is capable of detecting leakage as low as 10^{-10} atm cm^3/sec).**

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*For a typical mixture of plutonium oxide powder, an A_2 quantity is approximately 2.55 mg.

**Leaktightness is defined in USNRC Regulatory Guide 7.4 (Ref. 2) to be leakage less than 10^{-7} atm-cm^3/sec.

After completing the normal condition of transport tests, the TB-1 vessel was placed in the mass spectrometer. A near vacuum was drawn external to the TB-1 vessel and helium leakage was measured. No helium leakage was detected. The presence of helium in the TB-1 vessel was confirmed at disassembly.

These results verify that the TB-1 containment vessel remained leaktight throughout the normal condition of transport tests and meets the regulatory acceptance standards for containment.

4.2.2 PC-1 Product Can Integrity

Since the PC-1 product can is closed by crimping and sealed by welding or silver soldering, no material would be released from the product can if the package were to be subjected to the Normal Conditions of Transport in Appendix A of 10 CFR Part 71.

4.2.3 Pressurization of Containment Vessel and Product Can

The TB-1 vessel and the PC-1 product can are designed for a maximum of 2.0 kg of material with a maximum moisture content of 16 grams of water. The authorized contents can generate a maximum decay heat of 25 watts.

Under the heat test specified for normal conditions of transport in Appendix A of 10 CFR Part 71, the maximum temperature of the TB-1 vessel (with 25 watts internal decay heat) would be 215°F. The maximum internal pressure within the vessel would be 34.3 psia.*

4.3 Hypothetical Accident Conditions - 10 CFR §71.36

4.3.1 TB-1 Containment Vessel Leaktightness

Following testing of a PAT-1 package to the conditions specified in Appendix B of 10 CFR Part 71, the TB-1 vessel was subjected to a helium leak test similar to the test described in Section 4.2.1. No helium leakage was detected.

These results verify that the TB-1 containment vessel remained leaktight throughout the hypothetical accident conditions in Appendix B of 10 CFR Part 71 and meets the regulatory acceptance standards for containment.

4.3.2 PC-1 Product Can Integrity

After leak testing, the TB-1 vessel was disassembled and the PC-1 product can was examined (Section 2.7.1). The crimped closure and the epoxy overbond had remained intact. The can itself had several minor dents (Figure 2.15). During the tests, the PC-1 product can was loaded with 606 grams of the UO_2 surrogate material, 2545 grams of lead shot, and 19.3 grams of water. The two polyethylene bags, which normally hold the contents, were not used so that the powder

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*The vapor pressure of water at 215°F (15.6 psia) plus pressure from the original volume of heated air (18.7 psia).

retaining ability of the product can alone could be tested. Helium leak testing indicated a leak rate beyond the provisions of USNRC Regulatory Guide 7.4; however, no uranium surrogate material was detected to have been released using a wipe test and fluorimeter assay technique on the interior of the TB-1 vessel and the exterior of the PC-1 product can. Since the PC-1 product can maintained its basic structural integrity during the tests, and no uranium surrogate material was found to have been released with the can sealed by epoxy; the NRC staff concluded that with a welded or silver soldered seal, the PC-1 product can meets the requirements of 10 CFR §71.42.

4.3.3 Pressurization of Containment Vessel and Product Can

For the fire test specified in Appendix B of 10 CFR Part 71, the maximum temperature of the TB-1 vessel (with 25 watts internal decay heat) would be approximately 227°F. The maximum internal pressure within the vessel would be 38.7 psia.*

4.4 NRC Qualification Criteria

4.4.1 Release of Radioactive Contents

4.4.1.1 Summary

A helium leakage measurement was used to verify that the TB-1 vessel meets the acceptance standards for containment specified in the NRC Qualification Criteria (NUREG-0360). Specifically, containment was confirmed by measuring the post-test leak rate of helium across the seal of the TB-1 vessel. The results indicated, through correlation with experiments involving PuO_2 powder (Ref. 3), that the bounding magnitude of potential PuO_2 leakage from the TB-1 vessel would be less than 0.17 mg in one week.**

4.4.1.2 Gas Leak-Rate - Powder Loss Correlation

During assembly of the five PAT-1 packages, the TB-1 containment vessels were charged with helium at ambient temperature and pressure. Each TB-1 vessel was then leak tested. None of the vessels indicated a detectable leakage of helium (less than 10^{-10} atm cm^3/sec). After being tested to the conditions specified in the NRC qualification Criteria, the TB-1 vessels were again leak tested. The results, converted to air leakage, are indicated in Table 4.2.

Table 4.2

POST-TEST TB-1 AIR LEAKAGE RATES

Package Impact Orientation	Maximum Air Leakage Rate (atm cm^3/sec)
Top End (0°)	4.5×10^{-6}
Top Corner (30°)	4.5×10^{-5}
Side (90°)	1.4×10^{-6}
Bottom Corner (150°)	5.5×10^{-6}
Bottom End (180°)	1.9×10^{-6}

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*The vapor pressure of water at 227°F (19.6 psia) plus pressure from the original volume of heated air (19.1 psia).

**This assessment represents a conservative upper limit (i.e., conservatively high differential pressures were assumed to exist between the environment and the TB-1 vessel, and the vessel and its PuO_2 contents were assumed to be continuously vibrated for one week).

The potential PuO_2 powder release was determined using these air leakage measurements. The evaluation is based upon the following conservative assumptions.

(1) the seal of the TB-1 vessel (Figure 4.1) leaks gas through a single straight circular channel of constant diameter, rather than through the more probable distribution of smaller holes,

(2) the PuO_2 particles are entrained without affecting the fluid flow escaping through the leak (i.e., no settling, blockage or attenuation occurs, and particle diameters << hole diameter),

(3) the diameter of this channel can be calculated using the measured post-test air leakage rates (Table 4.2),

(4) the time-history of the pressure within the TB-1 vessel is bounded by the curve shown in Figure 4.2,

(5) the TB-1 and its contents are subjected to continuous agitation following the tests, and

(6) release of PuO_2 powder from the TB-1 vessel (through a channel) would be the same as observed in experimental measurements of PuO_2 leakage through an orifice having a diameter approximately the same as the effective diameter (see items 1, 2, and 3, above) of the TB-1 leak channel.

Using the equation below, a diameter, D, of 6.6 μm was calculated to correspond to a leak-rate of 5×10^{-5} atm-cm^3/sec* and a 0.716 cm channel length. The 0.716 cm length corresponds to the copper seal width. The equation below is based on Poiseuille laminar continuum flow and free molecular flow. The TB-1 internal pressure would typically be about 34.3 psia (Section 4.2.3) but would increase for a short time during the fire environment to 1110 psia** maximum (Section 4.4.2).

$$L = 3810 \frac{D^3}{a} \left[323 \frac{D}{\mu} (Pu^2 - Pd^2) + \sqrt{T/M}\,(Pu - Pd)\right]$$

where:

L = Gas leakage, atm-cm^3/sec
D = Effective diameter of leak, cm
a = Effective length of leak, cm
μ = Gas viscosity, centipoises
Pu = Upstream pressure, atm
P_d = Downstream pressure, atm
T = Gas stagnation temperature, °K
M = Gas molecular weight

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*The 5×10^{-5} atm cm^3/sec value bounds all values in Table 4.2.

**Above 30 psia pressure differential, gas flow is limited to sonic velocity.

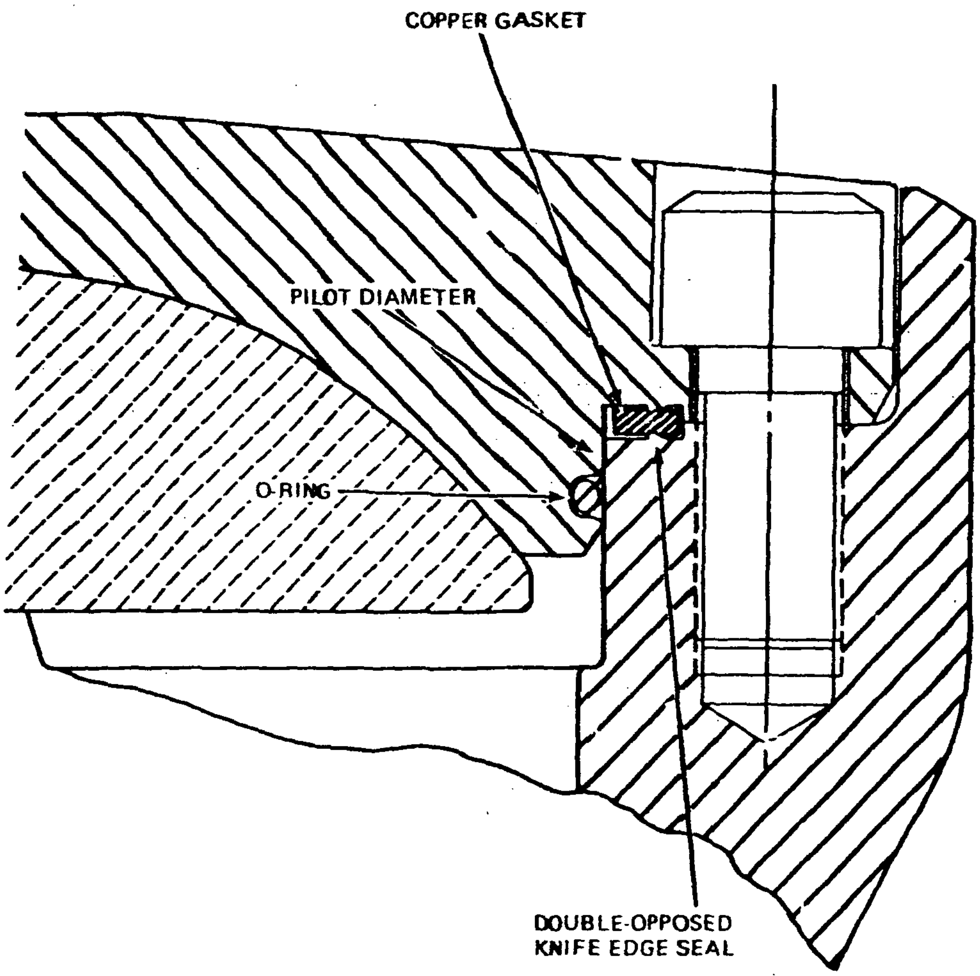

Figure 4.1 Cross Section of TB-1 Seals

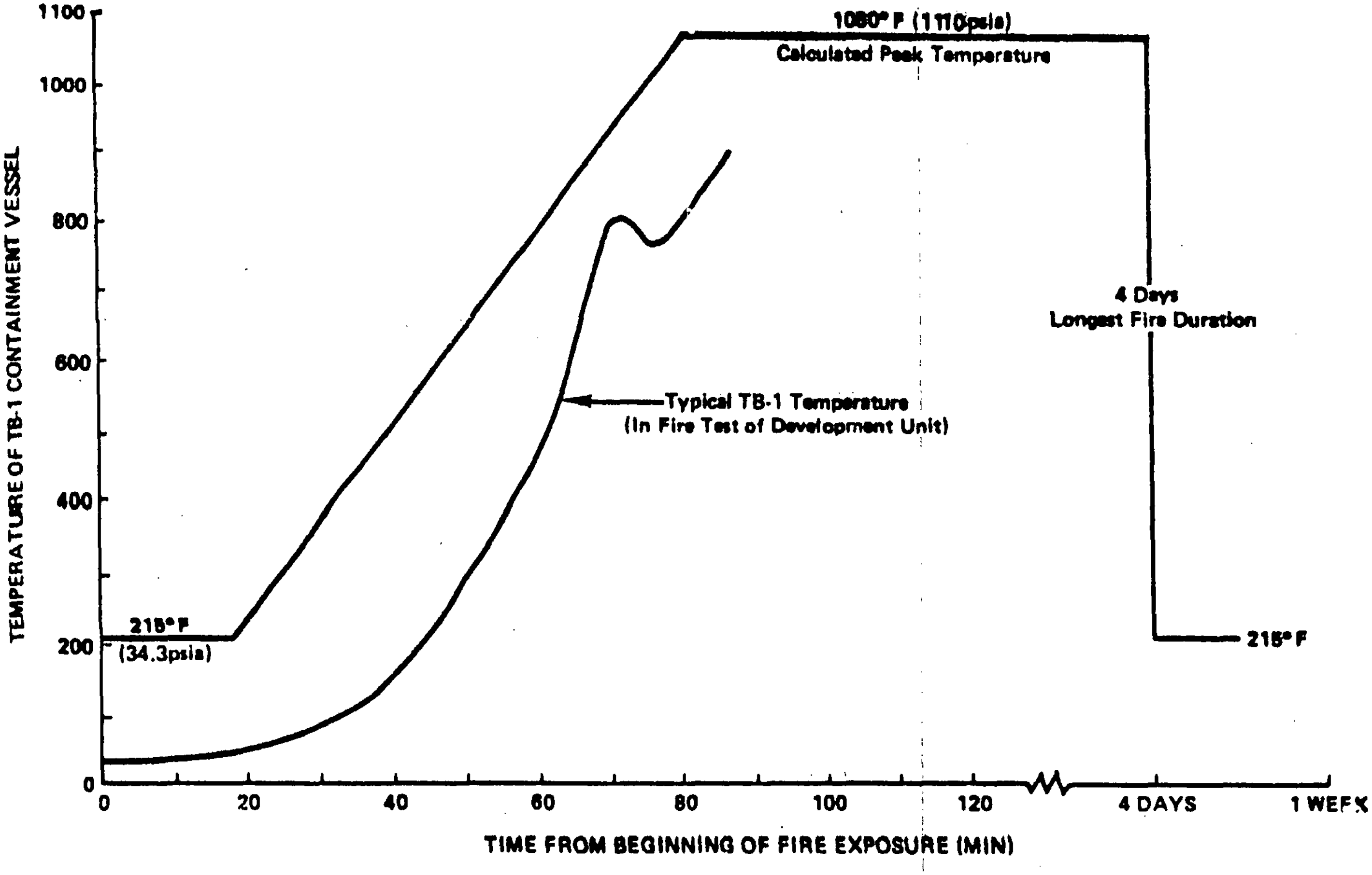

Figure 4.2 Maximum TB-1 Temperature and Pressure Profile During NRC Qualification Criteria Fire Test

Potential release from the TB-1 vessel was evaluated using data from experiments which measured the release of PuO_2 through 5 µm, 10 µm and 20 µm orifices with differential driving pressures of 500 psi and 1000 psi. In these experiments, the apparatus containing the PuO_2 powder and the orifice was subjected to continuous vibration. The maximum values of PuO_2 release that were measured in the tests, at pressures of 1000 psi and 500 psi and orifice diameters of 10 µm and 5 µm, were used to calculate an upper bound of PuO_2 release from the TB-1 vessel over a one week period. By interpolating the data for 10 µm and 5 µm hole diameters, release rates of 0.225 µg/10 min and 0.029 µg/10 min were obtained for 1000 psi and 500 psi pressures. The post-test pressure within the TB-1 vessel is bounded by four days at 1110 psia, followed by three days at 500 psia (Figure 4.2). The release rate data for 1000 psi was extrapolated to 0.270 µg/10 min at 1110 psia. By integration, the maximum release was determined to be 0.17 µg of PuO_2 within a one week period. This quantity of material is much less than typical A_2 quantities of mixed oxides and is also less than an A_2 quantity of any isotope of plutonium.

4.4.2 Pressurization of Containment Vessel

At the peak temperature attained from the fire test specified in the NRC Qualification Criteria (1080°F), the internal pressure within the TB-1 vessel would be less than 1110 psia. This total includes approximately 772 psia from superheated steam at 1080°F, 49 psia from heated air within the vessel, and 285 psia from the ethylene gas (the assumed decomposition product from the two polyethylene bags).

These pressures were based on an original free volume of 1156 cm^3.* The five PAT-1 packages tested to the NRC Qualification Criteria contained from 1048 to 1254 grams of UO_2, to which 19.3 grams of water were added. Four of the TB-1 vessels within these packages appeared to have reached temperatures approximating the estimated maximum of 1080°F. The total internal pressure attained in these tests was calculated to range between 1144 and 1183 psia, which exceeds the 1110 psia design pressure. The total pressure includes 833 to 867 psia from superheated steam, 49 psia from heated air, and 262 and 267 psia from decomposition of the polyethylene bags. These pressures were based on a calculated free volume ranging from 1235 to 1261 cm^3. The calculated pressure in the TB-1 vessel would be slightly less than the actual pressures achieved during the tests since the UO_2 material had a small initial moisture content (no greater than 0.4 w/o or approximately 4 gm H_2O). This effect was not considered in the internal pressure calculations. It is concluded from the above that the internal pressures which were generated within the packages during the fire test properly simulated the pressures which would have been experienced by a PAT-1 package loaded with maximum PuO_2 contents having maximum moisture content.

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*The original free volume was calculated by taking the TB-1 internal volume (1460 cm^3) and subtracting (1) the volume of the PC-1 product can (25 cm^3), (2) the volume of the aluminum honeycomb spacer (13 cm^3), (3) the volume of PuO_2 contents assuming maximum particle density of 8 gm/cm^3 (250 cm^3), and (4) the original volume occupied by the H_2O (16 cm^3).

REFERENCES

1. U.S. Nuclear Regulatory Commission, "Qualification Criteria to Certify A Package for Air Transport of Plutonium," NUREG-0360, January 1978. Available for purchase from National Technical Information Service (NTIS), Springfield, VA 22161.

2. Leakage Tests on Packages for Shipment of Radioactive Materials, USNRC Regulatory Guide 7.4, June 1975. Available from the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

3. L. C. Schwendiman, et al., "Study of Plutonium Oxide Leak Rates from Shipping Containers," Battelle, Pacific Northwest Laboratories Report No. BNWL-2260-4. Available in source file for USNRC Report NUREG-0361, February 1978.

5.0 SHIELDING EVALUATION

5.1 Discussion and Results

The PAT-1 package meets the radiation dose-rate standards prescribed in DOT (49 CFR §173.393(i)) and NRC (10 CFR §71.36(a)(1)) regulations. The package also meets the dose-rate standards specified in the "NRC Qualification Criteria to Certify a Package for Air Transport of P[illegible]tonium" (NUREG 0360). Table 5.1 summarizes the dose rates calculated for the PAT-1 package under normal and accident conditions, which are well within regulatory standards.

The materials to be transported in the PAT-1 package will not require extensive shielding for dose rates to be within allowable limits. Thus, the difference in dose rate between normal conditions (undamaged AQ-1 overpack) and accident conditions (damaged overpack) for the PAT-1 package will be small. Since these dose rates do not differ greatly, a PAT-1 package which meets the radiation levels for normal conditions would also be within allowable limits for accident conditions.

The contents of the PAT-1 package are li[illegible] a maximum internal decay heat load of 25 watts. The results in Table 5.1 are based upon [illegible]ckage being loaded with 2.0 kg of recycle plutonium oxide having a high concentration of americium. Due to the 25-watt heat load limitation, the maximum quantity of high americium concentrated material that could be transported in the PAT-1 would actually be limited to approximately 1648 grams. Accordingly, the dose rates shown in Table 5.1 would be reduced.

5.2 Calculational Method

Radiation dose-rate calculations were made with ANISN (Ref. 1), the one-dimensional discrete ordinates multigroup computer program. Hansen and Roach 16-group neutron cross sections (Ref. 2) and an 11-group gamma cross section library, generated by GAMLEG (Ref. 3), were used with the program. The first-order Legendre polynomial anisotropic scattering approximation was used with fourth-order direction cosines and weighting value quadratures. The difference between calculated results with first-order and third-order Legendre polynominals for scattering was found to be insignificant for these problems.

The gamma and neutron source strengths and spectra used in this evaluation were derived by assuming a reactor initial fuel charge which consists of 1.25 w/o U^{235} and 98.75 w/o U^{238}. Through use of the ORIGEN computer program (Ref. 4) this fuel was irradiated in a thermal neutron flux of 10^{14} n/cm^2-sec for one year. The plutonium isotopes were then separated and radioactive decay was allowed to take place for 13.5 years to permit a high build-up of ${}_{95}Am^{241}$. This calculation is based on the conservative assumption of a greater-than-normal neutron source within the package and is used to demonstrate that if the package meets the radiation levels for normal conditions of transport (49 CFR §173.393(i)) it will also meet the accident dose rate requirements in 10 CFR §71.36(a)(1), regardless of age of contents.

Table 5.1

CALCULATED RADIATION DOSE RATES FOR A PAT-1 PACKAGE LOADED WITH 2.0 Kg PuO_2 HAVING HIGH AMERICIUM CONTENT[a]

A. Undamaged Package

(i) Dose Rate at Container Surface

Primary gammas	12.9
Secondary gammas	0.3
Neutrons	26.5
Total	39.7 mrem/hr
Regulatory Limit	200 mrem/hr

(ii) Dose Rate at Three Feet from Surface

Primary gammas	0.7
Secondary gammas	-
Neutrons	1.2
Total	1.9 mrem/hr
Regulatory Limit	10.0 mrem/hr

B. Damaged Package (TB-1 Containment Vessel Assumed to be Bare)

(i) Dose Rate at Three Feet from Surface

Primary gammas	1.5
Secondary gammas	-
Neutrons	3.1
Total	4.6 mrem/hr
Regulatory Limit	1000 mrem/hr

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[a] Plutonium oxide daughter product.

5.3 Source Specification

The gamma and neutron source strengths calculated later in this section are based on a 1648 gms of recycle PuO_2, which corresponds to the maximum authorized internal decay heat load of 25 watts. The results reported in Table 5.1 for 2000 grams of this material were extrapolated from the calculations for 1648 grams of PuO_2 described below.

5.3.1 Gamma Source

The neutron and gamma radiation source terms were obtained from decay chain calculations with the ORIGEN computer program. Identical radiation sources were used in the damaged and undamaged package models.

Calculations indicate that the radiation source strength of the fuel increases as a function of time, primarily as a result of the decay of ${}_{94}Pu^{241}$ into ${}_{95}Am^{241}$, which has a half life of approximately 13.5 years. The controlling isotope for alpha decay thermal power is ${}_{95}Am^{241}$, with a half-life of approximately 466 years.

Table 5.2 shows the gamma source spectra for the assumed package contents and the weighted energy spectrum values for converting photon source strength into gamma dose rates (Ref. 5).

Table 5.2

GAMMA SOURCE SPECTRA FOR 1648 gms PuO_2 WITH HIGH Am CONTENT*

Group	Mean Energy (Mev)	Upper Energy (Mev)	Source Strength (Photons/sec)	Response[5] mrem/hr / (Photons/cm^2-sec)
1	3.25	3.50	6.40×10^4	4.36×10^{-3}
2	2.75	3.00	1.56×10^7	4.00×10^{-3}
3	2.38	2.60	8.17×10^4	3.71×10^{-3}
4	1.99	2.20	4.46×10^5	3.24×10^{-3}
5	1.55	1.80	1.02×10^6	2.77×10^{-3}
6	1.10	1.35	2.05×10^6	2.30×10^{-3}
7	0.630	0.900	1.83×10^8	1.51×10^{-3}
8	0.300	0.400	5.09×10^8	8.30×10^{-4}
9	0.150	0.200	1.28×10^{10}	3.60×10^{-4}
10	0.050	0.100	5.69×10^{12}	3.70×10^{-4}
11	0.005	0.010		3.70×10^{-4}
		Total	5.70×10^{12}	

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*25 watts total internal decay heat.

5.3.2 Neutron Source

The neutron source strength for PuO_2 is primarily produced by spontaneous fission and by α-n reactions, the calculated neutron source strength for which is shown in Table 5.3. The isotopic composition of the PuO_2 as a function of decay time was calculated with the ORIGEN decay chain program.

The calculated spontaneous fission neutron source strength of the various isotopes and other data are presented in Table 5.3.

The spontaneous fission neutron spectrum was obtained by distributing the source strength over a $_{94}Pu^{239}$ neutron fission spectrum to give the values shown in Table 5.4.

The α-n neutrons are produced by interaction of the energetic alpha decay particles (from actinide isotopes) with the lighter nuclides (primarily oxygen) in the PuO_2. The α-n neutron sources were calculated from the following relation (Ref. 4):

$$\frac{\text{neutrons}}{\text{alpha disintegration}} = 1.0 \times 10^{-10}\, E_\alpha^{\;3.65}$$

where E_α is the alpha particle energy in MeV.

Table 5.3

SPONTANEOUS FISSION NEUTRON SOURCE STRENGTH BY ISOTOPE FOR 1648 gms RECYCLE** PuO_2

Isotope	N No. Atoms	λ (sec^{-1})	(n/fission)	SF (n/sec)	F Fraction
Pu-236	6.613×10^{15}	6.227×10^{-18}	-----------	0.	0.
Pu-238	3.633×10^{22}	5.111×10^{-19}	2.33	4.33×10^{4}	7.77×10^{-2}
Pu-239	2.228×10^{24}	3.997×10^{-24}	2.89	2.57×10^{1}	4.62×10^{-5}
Pu-240	9.178×10^{23}	1.801×10^{-19}	2.26	3.73×10^{5}	6.70×10^{-1}
Pu-241	2.780×10^{23}	3.997×10^{-24}*	3.05	3.40	6.10×10^{-6}
Pu-242	1.996×10^{23}	3.232×10^{-19}	2.18	1.41×10^{5}	2.52×10^{-1}
			Total	5.57×10^{5}	

---

*Value for Pu-241 not available; Pu-239 value used.

**25 watts total internal decay heat.

Table 5.4

SPONTANEOUS FISSION NEUTRON SPECTRUM FOR 1648 gms PuO_2 WITH HIGH Am CONTENT*

Neutron Energy Group	Upper Energy (Mev)	Normalized Pu-239 Fiss. Spectrum	PuO_2 Spont. Fiss. (n/sec.)
1	10.00	0.225	1.25×10^{5}
2	3.012	0.133	7.41×10^{4}
3	2.300	0.208	1.16×10^{5}
4	1.496	0.167	9.30×10^{4}
5	0.9072	0.142	7.90×10^{4}
6	0.4979	0.109	6.08×10^{4}
7	0.1111	0.0143	7.97×10^{3}
8	3.183×10^{-2}	0.0017	9.47×10^{2}
9	9.119×10^{-3}	0.	0.
10	3.355×10^{-3}	0.	0.
11	9.611×10^{-4}	0.	0.
12	2.754×10^{-4}	0.	0.
13	6.144×10^{-5}	0.	0.
14	1.371×10^{-5}	0.	0.
15	3.059×10^{-6}	0.	0.
16	4.140×10^{-7}	0.	0.
		Total	5.57×10^{5}

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*25 watts total internal decay heat.

The results of these calculations are presented in Table 5.5 for the PuO_2 with high Am content.

Table 5.5 shows that isotopes ${}_{94}Pu^{238}$ and ${}_{94}Am^{241}$ are primarily responsible for the alpha particles which generate α-n neutrons.

The α-n neutron spectrum was obtained by fitting the neutron source to an experimental ${}_{94}Pu^{238}$ and boron α-n neutron source spectrum (Ref. 6), the results for which are given in Table 5.6.

5.4 Model Specification

5.4.1 Description of Radial and Axial Shielding Configuration

Dose-rate calculations were made with ANISN, a one-dimensional computer program using spherical geometry. A spherical geometry approximation is justified on the basis of source size and actual geometry in relation to the distances at which allowable dose rates are prescribed. Spherical geometry is also more accurate with the ANISN program than either cylindrical or plane geometry. In the spherical model, the thicknesses of the various material regions correspond to the actual design thicknesses, and the diameter of the source region corresponds to the inside diameter of the PuO_2 container. The spherical geometry configuration for the undamaged package model is given in Table 5.8; the geometrical configuration of a damaged package model is given in Table 5.9.

5.4.2 Shield Regional Densities

The material composition and the atomic-number densities of all regions used in the ANISN program are shown in Table 5.11.

Table 5.5

α-NEUTRON SOURCE STRENGTH BY ISOTOPE
FOR 1648 gms PuO_2 WITH HIGH Am CONTENT**

Isotope	N No. Atoms	λ (sec^{-1})	Neuts/α-Dis.	Neuts/Sec	Fract.
Pu-236	6.613×10^{15}	7.711×10^{-9}	5.904×10^{-8}	3.01	--------
Pu-238	3.633×10^{22}	2.543×10^{-10}	4.945×10^{-8}	4.97×10^{5}	3.78×10^{-1}
Pu-239	2.228×10^{24}	9.020×10^{-13}	3.933×10^{-8}	7.91×10^{4}	6.02×10^{-2}
Pu-240	9.178×10^{23}	3.340×10^{-12}	3.550×10^{-8}	1.09×10^{5}	8.29×10^{-2}
Pu-241	2.790×10^{23}	1.665×10^{-9}*	3.261×10^{-8}	3.64×10^{2}	--------
Pu-242	1.996×10^{2}	5.799×10^{-14}	3.273×10^{-8}	3.79×10^{2}	--------
Am-241	2.480×10^{23}	5.074×10^{-11}	4.992×10^{-8}	6.28×10^{5}	4.78×10^{-1}
Am-243	2.685×10^{20}	2.981×10^{-12}	4.326×10^{-8}	3.46×10^{1}	--------
Total				1.31×10^{6}	

---

* α + β emissions

**25 watts total internal decay heat.

Table 5.6

α-n NEUTRON SOURCE SPECTRUM FOR 1618 gms PuO_2 WITH HIGH Am CONTENT*

Neutron Energy Group	Upper Energy (MeV)	Normalized α-n Spectrum	α-n Neutrons n/sec
1	10.00	0.1047	1.375×10^5
2	3.012	0.3964	5.205×10^5
3	2.300	0.2392	3.141×10^5
4	1.496	0.1526	2.051×10^5
5	0.9072	0.1071	1.406×10^5
6	0.4979	0.	0.
7	0.1111	0.	0.
8	3.183×10^{-2}	0.	0.
9	9.119×10^{-3}	0.	0.
10	3.355×10^{-3}	0.	0.
11	9.611×10^{-4}	0.	0.
12	2.754×10^{-4}	0.	0.
13	6.144×10^{-5}	0.	0.
14	1.371×10^{-5}	0.	0.
15	3.059×10^{-6}	0.	0.
16	4.140×10^{-7}	0.	0.
Total			1.317×10^6

The total neutron source strength of the PuO_2 is summarized in Table 5.7.

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*25 watts total internal decay heat.

Table 5.7

TOTAL NEUTRON SOURCE SUMMARY FOR 1648 gms PuO_2 WITH HIGH Am CONTENT*

Neutron Energy Group		SF (n/sec)	α-n (n/sec)	Total (n/sec)	Fract
1		1.25×10^{5}	1.38×10^{5}	2.63×10^{5}	0.140
2		7.41×10^{4}	5.21×10^{5}	5.95×10^{5}	0.317
3		1.16×10^{5}	3.14×10^{5}	4.30×10^{5}	0.229
4		9.30×10^{4}	2.05×10^{5}	2.98×10^{5}	0.159
5		7.90×10^{4}	1.41×10^{5}	2.20×10^{5}	0.117
6		6.08×10^{4}	0.	6.08×10^{4}	3.24×10^{-2}
7		7.97×10^{3}	0.	7.97×10^{3}	4.25×10^{-3}
8		9.47×10^{2}	0.	9.47×10^{2}	5.05×10^{-4}
9		0.	0.	0.	
10		0.	0.	0.	
11		0.	0.	0.	
12		0.	0.	0.	
13		0.	0.	0.	
14		0.	0.	0.	
15		0.	0.	0.	
16		0.	0.	0.	
	Total	5.57×10^{5}	1.32×10^{6}	1.88×10^{6}	

---

*25 watts total internal heat.

Table 5.8

UNDAMAGED PACKAGE SPHERICAL GEOMETRY CONFIGURATION

Zone	Material	Thickness (cm)	Outer Radius (cm)
1	PuO_2	5.351	5.351
2	304 SS	3.300×10^{-2}	5.384
3	PH13-8Mo SS	1.397	6.781
4	Air Gap	2.032	8.813
5	Redwood	5.105	13.92
6	6061 Al	1.270	15.18
7	Redwood	12.62	27.81
8	304 SS	0.3048	28.11
9	Air	91.44	119.6

Table 5.9

DAMAGED PACKAGE* SPHERICAL GEOMETRY CONFIGURATION

Zone	Material	Thickness (cm)	Outer Radius (cm)
1	PuO_2	5.351	5.341
2	304 SS	3.300×10^{-2}	5.384
3	PH13-8Mo SS	1.397	6.781
4	Air	91.44	98.22

*TB-1 containment vessel assumed to be bare.

The volume of the PuO_2 region in the spherical geometry model is 646.5 cm^3, and the total density (including radioactive decay products) of the 1751-gram source material (1648 grams of PuO_2) is, therefore, 2.708 gm/cm^3. These weights are consistent with the 25-watt internal decay heat limitation.

The inside volume of the actual PuO_2 containment vessel is approximately 1080 cm^3. This is 1.67 times the volume of the spherical model. Therefore, the total PuO_2 material density would be 1.62 gm/cm^3 for the actual container. The PuO_2 region composition is given in Table 5.10.

The gamma and neutron radiation source terms were calculated on the basis of the above composition. The PuO_2 region for the gamma dose rate problem was represented in the computer program by the following elemental densities:

Element	Atoms / barn-cm
Pu	6.060×10^{-3}
O	1.133×10^{-2}

Table 5.10

ISOTOPIC DENSITIES FOR PuO_2 WITH HIGH Am CONTENT

Isotope	Weight (gm)	Atoms / barn-cm
Pu-236	2.588×10^{-6}	1.023×10^{-11}
Pu-238	1.434×10^{1}	5.620×10^{-5}
Pu-239	8.232×10^{2}	3.446×10^{-3}
Pu-240	3.653×10^{2}	1.420×10^{-3}
Pu-241	1.115×10^{2}	4.316×10^{-4}
Pu-242	8.009×10^{1}	3.087×10^{-4}
Am-241	9.910×10^{1}	2.836×10^{-4}
Am-243	1.082×10^{-1}	4.154×10^{-7}
U-234	1.557	6.205×10^{-6}
U-235	3.337×10^{-1}	1.325×10^{-6}
U-236	4.985×10^{-1}	1.907×10^{-6}
Np-237	1.172	3.010×10^{-6}
O	1.944×10^{2}	1.133×10^{-2}

The PuO_2 region for the neutron dose rate problem was represented in the computer program as follows:

Element	Atoms / barn-cm
Pu-239	3.857×10^{-3}
Pu-240	1.420×10^{-3}
U-238	7.680×10^{-4}
U-235	1.325×10^{-6}
O	1.133×10^{-2}

Appropriate gamma and neutron radiation source terms were calculated on the basis of the above material composition. However, in order to accommodate the computer program cross-section library, the PuO_2 region for the gamma dose-rate problem was actually represented by the following elemental densities:

Element	Atoms / barn-cm
Pu	4.851×10^{-3}
O	8.486×10^{-3}

The PuO_2 region for the corresponding neutron dose rate problem was represented as follows for the computer program:

Isotope or Element	$\frac{\text{Atoms}}{\text{barn-cm}}$
Pu-239	2.890×10^{-3}
Pu-240	1.052×10^{-3}
U-238	9.220×10^{-4}
U-235	9.820×10^{-7}
O	8.486×10^{-3}

The material composition of other regions in the model, surrounding the PuO_2 region, is given in Table 5.11. The damaged package model consists of only the first four regions itemized in Table 5.9.

Table 5.11

REGIONAL MATERIAL DENSITIES FOR CALCULATIONAL MODEL

Element	Atoms/barn-cm
Region 1 - PuO_2	
See Table 5.10	
Region 2 - 304 SS (Density 7.92 gm/cm^3)	
C	3.184×10^{-4}
Si	1.700×10^{-3}
Cr	1.745×10^{-2}
Ni	7.728×10^{-3}
Fe	6.021×10^{-2}
Region 3 - PH13-8Mo SS (Density 7.76 gm/cm^3)	
Cr	1.147×10^{-2}
Ni	6.376×10^{-3}
Al	1.907×10^{-3}
Fe	6.358×10^{-2}
Region 4 - Air (Density 1.0×10^{-3} gm/cm^3)	
N	3.290×10^{-5}
O	8.860×10^{-6}

Region 5 - Redwood (Density 0.359 gm/cm^3)

A literature survey provided very little information on the composition of redwood; however, since redwood is very similar to spruce, its composition was substituted for that of redwood. Chemical analysis of a redwood sample at Sandia Laboratories later verified the appropriateness of this substitution.

Element	Atoms/barn-cm
Region 5 - Redwood (approximated by spruce)	
C	8.93×10^{-3}
H	1.338×10^{-2}
N	2.781×10^{-5}
O	5.949×10^{-3}
Ca	7.914×10^{-6}
Fe	1.291×10^{-6}
Si	2.007×10^{-7}
Region 6 - 6061 Al (Density 2.70 gm/cm^3)	
Si	3.479×10^{-4}
Fe	2.041×10^{-4}
Cu	6.917×10^{-5}
Cr	7.827×10^{-5}
Ti	5.098×10^{-5}
Al	6.080×10^{-2}

Region 7 - Redwood

Same as Region 5

Region 8 - 304 SS

Same as Region 2

Region 9 - Air

Same as Region 4

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6.0 CRITICALITY EVALUATION

6.1 Discussion and Results

The PAT-1 package meets the subcriticality requirements of 10 CFR Part 71 and the criteria set forth in the NRC "Qualification Criteria to Certify a Package for Air Transport of Plutonium" (NUREG-0360). A single PAT-1 package and an array of PAT-1 packages are subcritical under normal conditions of transport and the accident conditions specified in the NRC Qualification Criteria. Since the PAT-1 package meets the subcriticality requirements for the NRC qualification tests, it would also meet the subcriticality requirements for the accident tests in Appendix B of 10 CFR Part 71. The PAT-1 package design meets Fissile Class I requirements when fully loaded with its maximum authorized contents of 2.0 kg of PuO_2 and its associated daughter products in any solid form, or mixtures of natural or depleted UO_2 with PuO_2. The fissile contents may be at any density up to their maximum theoretical value, containing the equivalent of 16 grams of water. Two single-layer polyethelene bags may be used to package the contents.

Results of the supporting criticality calculations are given in Table 6.1.

Table 6.1

KENO CALCULATIONS ESTABLISHING PAT-1 PACKAGE AS FISSILE CLASS I FOR 2.0 KG PuO_2

Condition	Requirements-Subcritical	Calculated k_{eff}*
NORMAL	Infinite number of undamaged packages.	0.402 ± 0.005
NRC QUALIFITION CRITERIA	280** damaged packages, maximum reactive array; water reflecton on all sides	0.390 ± 0.005
SINGLE PACKAGE	Single TB-1 vessel with water leakage homogeneously mixed with 2.0 kg PuO_2; water reflected.	0.584 ± 0.006

*15,000 neutron histories; Hansen-Roach 16-group neutron cross sections.
**250 damaged packages required to be subcritical pursuant to 10 CFR 71.

Parametric calculations indicate that any degree of interspersed moderation between PAT-1 packages loaded with PuO_2 or between isolated TB-1 containment vessels will increase neutron absorption in the TB-1 steel and thus reduce reactivity. Hence, void among an infinite array of touching PAT-1 packages for normal conditions, and void among an array of 250 damaged PAT-1 packages represent the most reactive environment for conditions of transport.

Simplifications in the calculations which result in overestimating the k_{eff} are as follows:

a. Use of Pu-239 as the only plutonium isotope in the PuO_2.

b. Use of redwood only to surround the loaded TB-1 for normal conditions; other package materials are neglected.

c. Use of maximum theoretical density of 11.46 gms/cm^3 for PuO_2 for normal and accident conditions.

d. Use of only the clustered TB-1 containment vessels are considered in the 280 damaged PAT-1 array for accident conditions; other package materials are neglected.

e. Choice of local clustering of TB-1 containment vessels considered the damage to the packages to be greater than the damage produced by the qualification tests.

6.2 Calculational Method

All criticality analyses on the PAT-1 package were performed with the 3-D KENO Monte Carlo computer program (Ref. 1), together with the Hansen-Roach 16-group neutron cross-section set (Ref. 2). The KENO program was especially developed for reactivity estimates for arrays of units. The cross-section set has successfully calculated fast and epithermal uranium and plutonium homogeneous systems, as well as solutions containing these isotopes. The two unmoderated PuO_2 criticals discussed in Section 6.5 show that k_{eff}'s are calculated slightly higher than unity when this cross-section set is used. Use of the Hansen-Roach set is therefore conservative for the PAT-1 package analyses.

Both ordinary and generalized geometry options were employed in KENO to describe explicity in 3-D the various model configurations for normal and accident conditions of transport. Details are discussed in Section 6.4 on Model Specifications.

To effect an infinite array in KENO in both ordinary and generalized geometry, a specular boundary condition is applied on the six faces of the confining planes parallel to the X, Y, and Z coordinate system basic to KENO. These planes form a CUBOID, within which is the repeating lattice. For the single-package analysis, this boundary condition is replaced by the no-neutron return, flux fall-off condition.

6.3 Contents

The PAT-1 contents are described in Section 6.1. The contents may have a moisture content equivalent to 16 grams of water. The interspersed hydrogen from the plutonium moisture content is a neutron poison for both bare and reflected systems characterized by a H/Pu of about 0.25. Additionally, the polyethelene bags slightly increase neutron absorption in the TB-1 steel. For these reasons, the moisture content and polyethelene bags may be neglected in the criticality modeling.

All plutonium in the PuO_2 was assumed to be Pu-239. Fast fission cross sections for Pu-240 and Pu-242 are smaller than those for Pu-239 over all neutron energies and fall off rapidly below 1 Mev. Pu-241 fission cross sections are also smaller than Pu-239 above 0.5 Mev, but are significantly larger than Pu-239 at energies below 0.5 Mev. However, because Pu-241 will exist only in the presence of considerably more Pu-240, Pu-242, or both, the presence of Pu-239 as the single-fissionable isotope represents the most reactive contents and is a major conservative assumption in the calculated k_{eff}'s.

Two specific densities for the 2.0 kilograms of PuO_2 in the TB-1 containment vessel were assumed. The first, taken as 1.608 gms/cm^3, represents complete filling of the 2.0 kgs PuO_2 within the TB-1 volume (1243.7 cm^3). The second was taken as 11.46 gms/cm^3, the theoretical density of PuO_2. The space remaining within the TB-1 vessel was considered a void. Both normal and accident conditions were analyzed using each density separately. The reactivity of this density range shows that all densities of PuO_2 are subcritical for the PAT-1 package. The results are given in Section 6.4.1.

Since any amount of $Pu239O_2$ is more reactive neutronically than a corresponding amount of $U235O_2$, the authorized PuO_2-$U_{nat}O_2$ mixture presents less of a criticality hazard than the analyzed 2.0 kgs $Pu239O_2$ contents.

6.4 Model Specification

This section summarizes the geometric modeling of the KENO cases for the normal and accident condition criticality analyses of the PAT-1 package.

6.4.1 Normal Conditions - (10 CFR §71.35 and 10 CFR §71.38)

Normal conditions were analyzed using the ordinary geometry available in the KENO program employing three concentric cylinders, i.e., the contents region, the TB-1 steel region, and the redwood region.

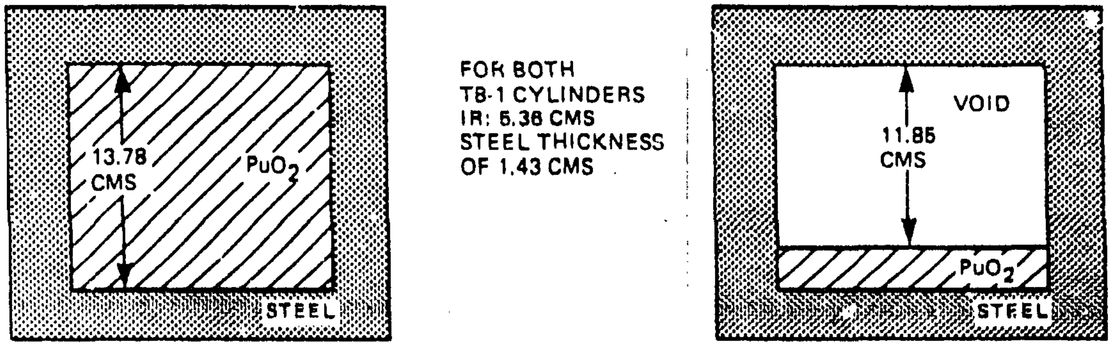
For the case in which 2.0 kg of dry PuO_2 fills the entire volume of the TB-1 (1.608 gms/cm^3) the contents region of the TB-1 was described by a cylinder with a radius of 5.36 cms and a height of 13.78 cms (Figure 6.1(A)). When 2.0 kg of dry PuO_2 was assumed at a density of 11.46 gms/cm^3 (theoretical crystalline density) and occupies a corresponding volume (174.5 cm^3), the PuO_2 region was taken as a cylinder with a radius of 5.36 cms and a height of 1.93 cms. An empty space (VOID), modeled as a cylinder with a radius 5.36 cms and a height of 11.85 cms, sits above the concentrated PuO_2 cylinder completing the description of the inner contents (Figure 6.1(B)).

The steel walls of the TB-1 were taken as a 1.43-cm thick cylindrical annular region with the same thickness for top and bottom walls for both of the above contents.

The redwood region of the PAT-1 was taken as a cylinder with a radius of 29.53 cms and a height 104.0 cms. The heights of both cylinders were specified in a manner that places the center of the contents region at the geometric center of the redwood region.

The nuclides from the Hansen-Roach neutron cross section set and the atom number densities averaged over appropriate regions in the model are given in Table 6.2.

A CUBOID (a rectangular parallelepiped - 6 planes parallel to X, Y, and Z axes basic to the KENO geometry) was placed tightly encasing the redwood cylinder. On each of the six planes, a specular (MIRROR) boundary was placed (i.e., 100% return of all neutrons), thus giving an infinite array of PAT-1 packages in contact with one another (Figure 6.2).



(A)
PuO_2 DENSITY OF 1.608 gm/cm^3

(B)
PuO_2 DENSITY OF 11.46 gm/cm^3

Figure 6.1 TB-1 Geometry Used in KENO For Two Density Contents Considered Normal and Accident Conditions

Table 6.2

ATOM NUMBER DENSITIES
(In Units of 10^{24} Atoms/cm^3 of Region)

FOR ARRAYS (Normal & Damaged)

REGION OR MATERIAL	NUCLIDE	DENSITY PuO_2 (gms/cm^3) 1.608	11.46
Contents in TB-1	Pu-239 O	0.0035751 0.0071502	0.025473* 0.050945*
Steel TB-1	Cr Ni Fe	0.01745 0.007728 0.060210	
Redwood	O C H Fe Al	0.05455 0.008209 0.01230 0.001437 0.001738	
Water Reflector	H O	0.06688 0.03344	

*Averaged over 174.5 cm^3 of volume corresponding to a 2.0 kg PuO_2 at density 11.46 gms/cm^3 in TB-1.

FOR SINGLE PACKAGE

Contents in TB-1	Pu-239 H O	0.0035751 0.057497 0.035898
Steel TB-1	Cr Ni Fe	0.01745 0.007728 0.060210
Water Reflector	H O	0.06688 0.03344

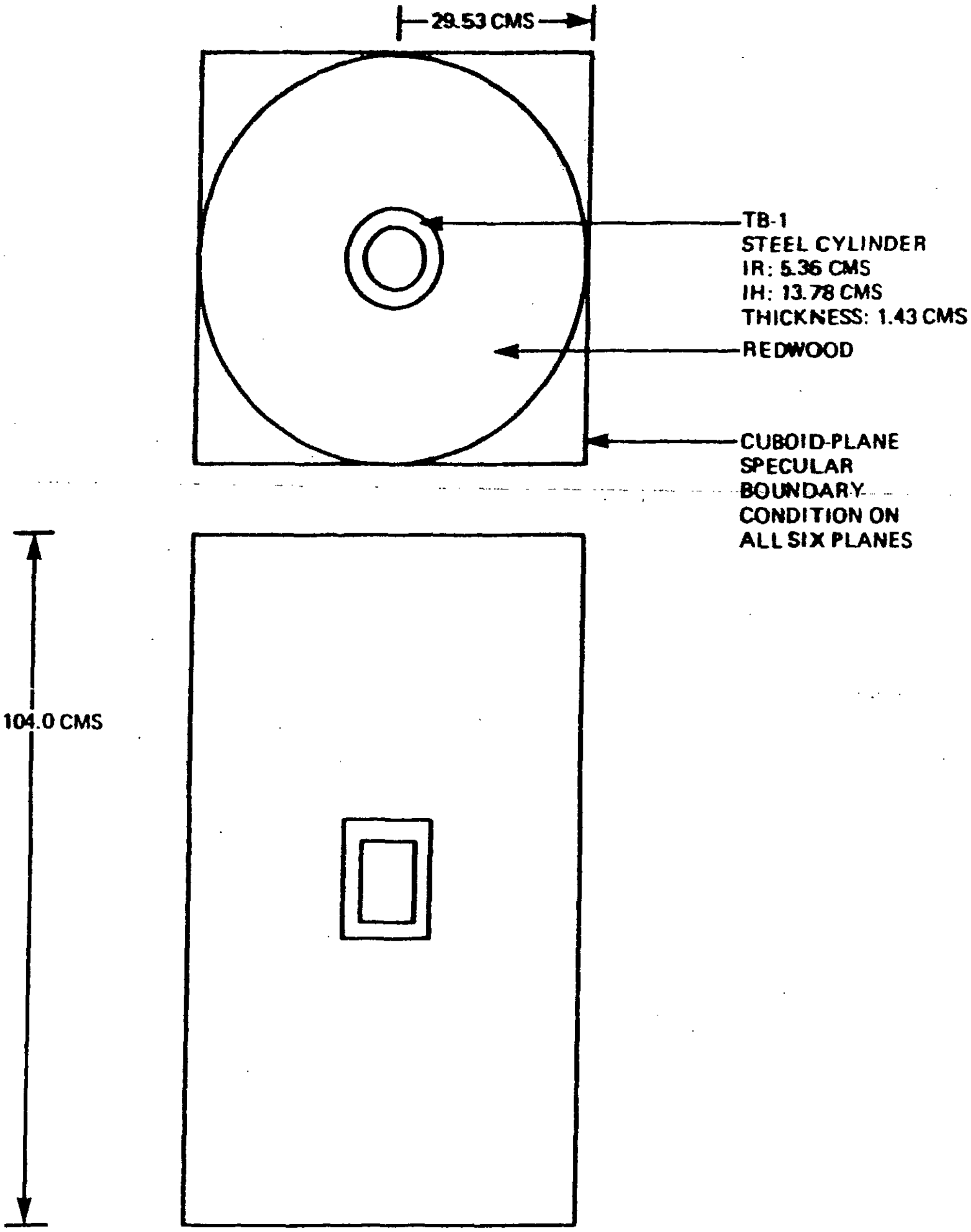


Figure 6.2 Model of Repeating Undamaged Array Used In KENO

The KENO k_{eff}'s for these infinite arrays of PAT-1 packages under normal conditions of transport were calculated as 0.238 ± 0.003 for the 1.608 gm/cm^3 case and 0.402 ± 0.05 for the 11.46 gms/cm^3 case respectively.

6.4.2 Accident Conditions - NRC Qualification Criteria

The KENO configuration chosen for damaged conditions (see Section 2.8.2.7) was an array of 280 crushed packages modeled as 140 hemicylinder pairs with their respective TB-1 containment vessels touching (Figure 6.3). The array was represented as ten PAT-1 packages (five pairs of crushed hemicylinders) along the X axis, seven rows of such crushed cylinders along the Y axis, and four tiers high along the Z axis. This modeling used two MIXED BOXES; the first was the TB-1 with its contents, the second represented what would ordinarily be the redwood and the intra-PAT-1 regions. Calculations were performed considering the density of the PuO_2 contents to be 1.608 gm/cc and 11.46 gm/cc, with the redwood region and intra-package space taken as void. These calculations were repeated with the void replaced by a five percent density water medium. All four calculations used a one-foot full density water reflector surrounding the array. For the number of neutron histories used no distinction was discernable between the k_{eff}'s for the void and five-percent water density. The k_{eff} for the 11.46 gm/cm^3 PuO_2 case was calculated as 0.390 ± 0.005 versus a k_{eff} of 0.239 ± 0.003 for the 1.608 gm/cm^3 PuO_2 case. A total of 15,000 neutron histories were used in all calculations.

In addition to the calculations described above, a second KENO configuration of 288 crushed packages (Figure 6.4) was analyzed using the GENERALIZED geometry option. A basic cell of six damaged packages was repeated three times along the X axis, four times along the Y axis, and four tiers high along the Z axis. In this 3-D modeling, quadric surfaces and planes were used to describe the six TB-1 vessels in the six hemicylinders; with the two central TB-1 vessels touching, surrounded by the four other TB-1 vessels. The array was considered to be reflected on all sides by one foot of water at full density. The PICTURE computer program (Ref. 5) was used to verify that the geometry was modeled correctly. The density of the PuO_2 contents was taken as 11.46 gm/cm^3. Calculations were performed considering the composition of the redwood and the intra-package space to be void and to be water at 5%, 10%, and 15% of its normal density. The k_{eff}'s that resulted from these calculations are listed in Table 6.3 and show that the void case is the most reactive configuration. A total of 15,000 neutron histories were used in all calculations.

Table 6.3

KENO K_{eff}* WITH GENERALIZED GEOMETRY FOR 288 CRUSHED PAT-1 PACKAGES (FIGURE 6.4)

COMPOSITION OF REDWOOD AND INTRA-PACKAGE SPACES (PERCENT OF NORMAL-DENSITY WATER)	KENO K_{eff}
15%	0.376 ± 0.003
10%	0.374 ± 0.003
5%	0.383 ± 0.004
0% (void)	0.387 ± 0.004

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*Hansen-Roach cross sections

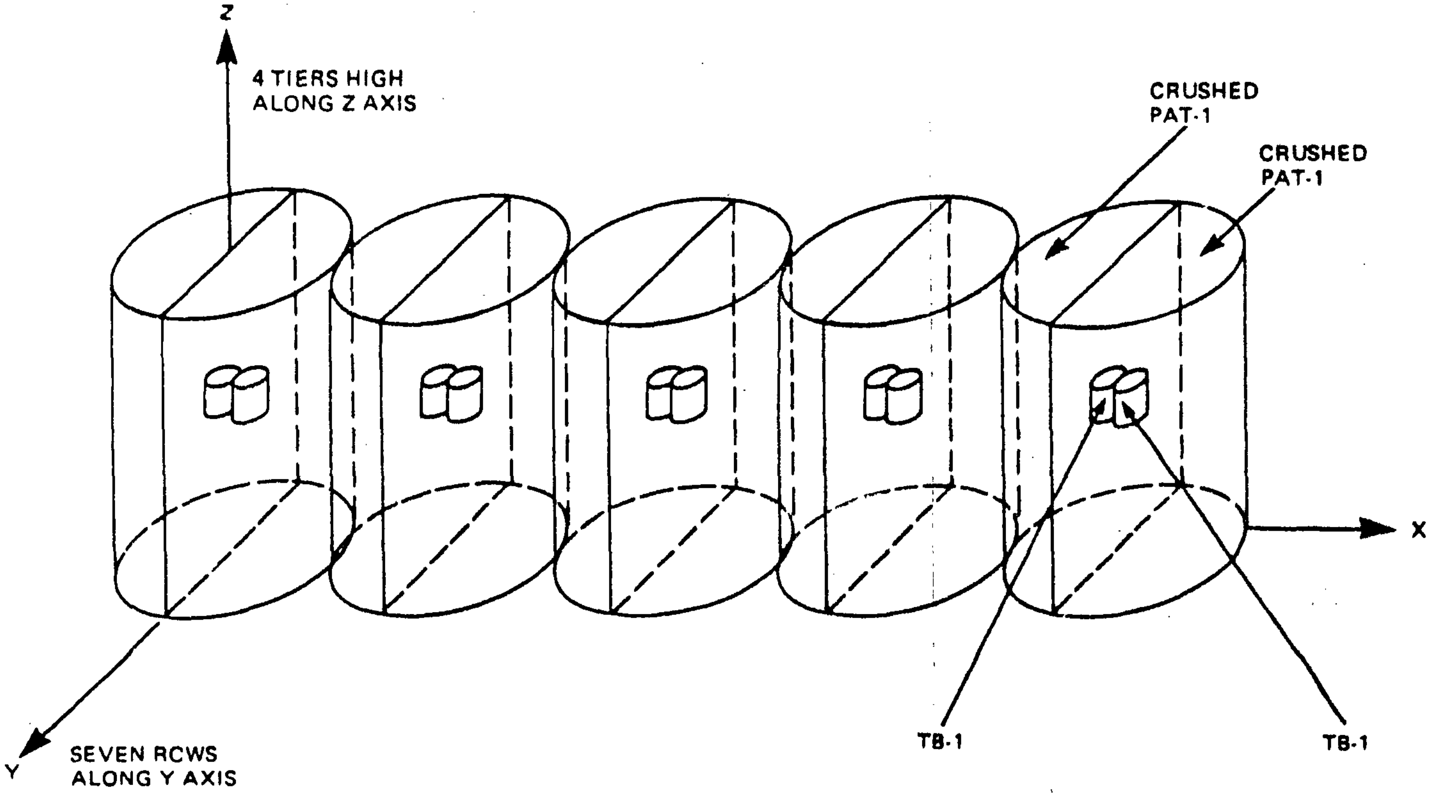

Figure 6.3 KENO Model For the 280 Damaged Case
(X Axis Only Shown)

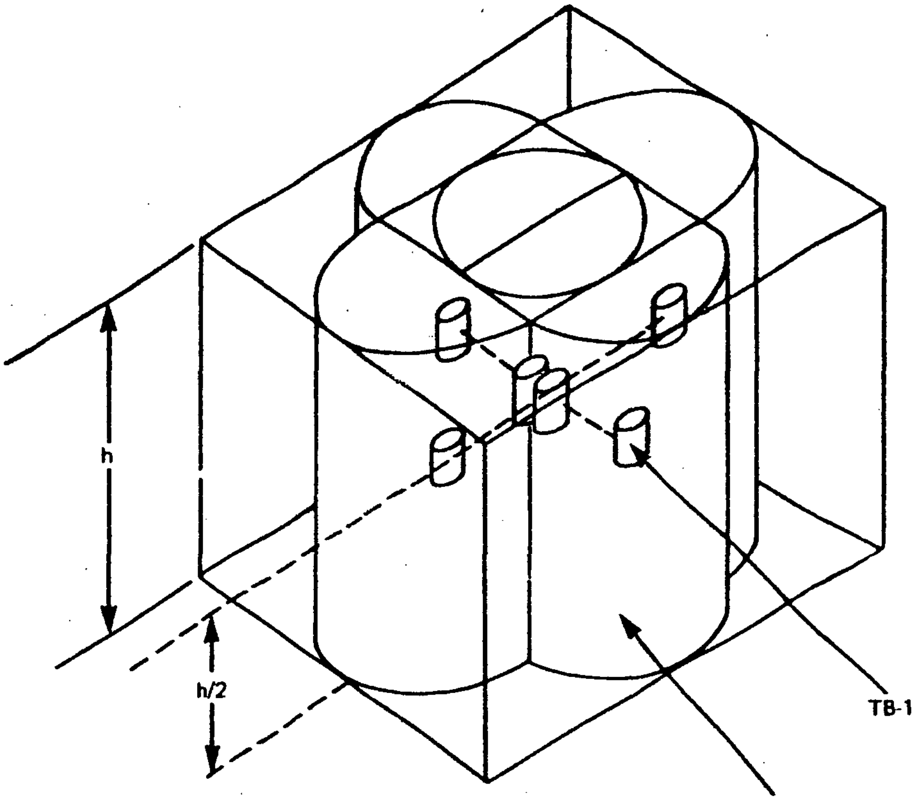

Figure 6.4 Model of Repeating Damaged Array Used in KENO With Generalized Geometry

6.4.3 Single Package - (10 CFR 71.33)

Ordinary KENO geometry was used for a single-package case in which 2,000 grams of Pu-239, intermixed with water, fill the TB-1 region. The ratio of hydrogen to Pu-239 under these conditions was 16.1, the maximum possible for a TB-1 vessel with 2,000 grams Pu-239. The TB-1 vessel was surrounded on all sides by a one-foot normal density water reflector. The KENO k_{eff} was calculated to be 0.584 ± 0.006 for 15,000 neutron histories.

6.5 Validation of Calculational Method

In order to ascertain the relative accuracy of the calculated k_{eff}'s for the PAT-1 package, three criticals were calculated using exactly the same methods and cross sections as in the PAT-1 analyses. A brief description of the criticals with the resulting k_{eff}'s are given in Table 6.4. Since the k_{eff}'s for the unmoderated PuO_2 systems are calculated higher than unity, it can be reasonably concluded that the k_{eff}'s for the PAT-1 package were calculated conservatively.

Table 6.4

KENO K_{eff} RESULTS FOR THREE CRITICALS

No.	Details of Critical	Critical Mass (kg-Pu)	k_{eff}	Ref.
1	JEZEBEL; fast bare Pu-239 metal sphere. Crit Dims: Radius of 6.31 cms.	16.25	1.005 ± 0.008	3
2	PuO_2 compacts; unmoderated bare system; PuO_2 ∿ 5.79 gm/cm^3; 18.35 w/o Pu-240. Crit Dims: 30.78 cms x 30.78 cms x 20.90 cms.	114	1.027 ± 0.007	4
3	Same as Number 2, but reflected by ∿ 6" plexiglas on all sides. Crit Dims: 25.65 cms x 25.65 cms x 10.03 cms.	38	1.034 ± 0.007	4

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7.0 OPERATING PROCEDURES

7.1 Loading the PAT-1 Package for Transport

A cutaway illustration of a PAT-1 package loaded and assembled for shipment is shown in Figure 7.1. Prior to loading the PAT-1 package, verify that the requirements specified in Section 8.0 have been met.

7.1.1 Loading PC-1 Product Can with Plutonium Oxide

1. The PC-1 product can must be loaded in a controlled environment which provides adequate exhaust filtration and control of surface cleanliness.

2. Visually inspect the PC-1 product can for cleanliness and freedom from defects.

3. Load the contents into the PC-1 product can. Verify that the weight of the radioactive contents does not exceed 2.0 kg. The contents may be contained within no more than two single-layer polyethlene bags individually taped or heat-sealed closed. Verify that the decay heat load of the contents does not exceed 25 watts and that no more than 16 grams of moisture (or equivalent) plus nine grams of polyethlene bags are present.

4. Roll crimp the lid to the body of the PC-1 with a standard canning tool or machine. Clean and inspect the exterior of the PC-1 product can by standard wipe tests. Seal the product can using an appropriate welding or silver soldering procedure.

5. Verify that the sealed PC-1 product can meets the requirements specified in Section 8.2.2.

7.1.2 Loading PC-1 Product Can Into TB-1 Containment Vessel

1. Visually inspect the components of the TB-1 vessel and top spacer for defects, damage, cleanliness, and for correct part.

2. Place loaded PC-1 product can, followed by top spacer, into the TB-1 vessel.

3. Install an unused copper gasket (see Table 8.1) into the seal groove at the top of the TB-1 body.

4. Coat the elastomeric O-ring (see Table 8.1) with silicone grease and install in the groove on the TB-1 lid.

5. Insert the TB-1 lid into the TB-1 body, being careful not to damage the O-ring.

6. Install the 12 socket head bolts (0.500-20), fingertight, through the TB-1 lid into the body.

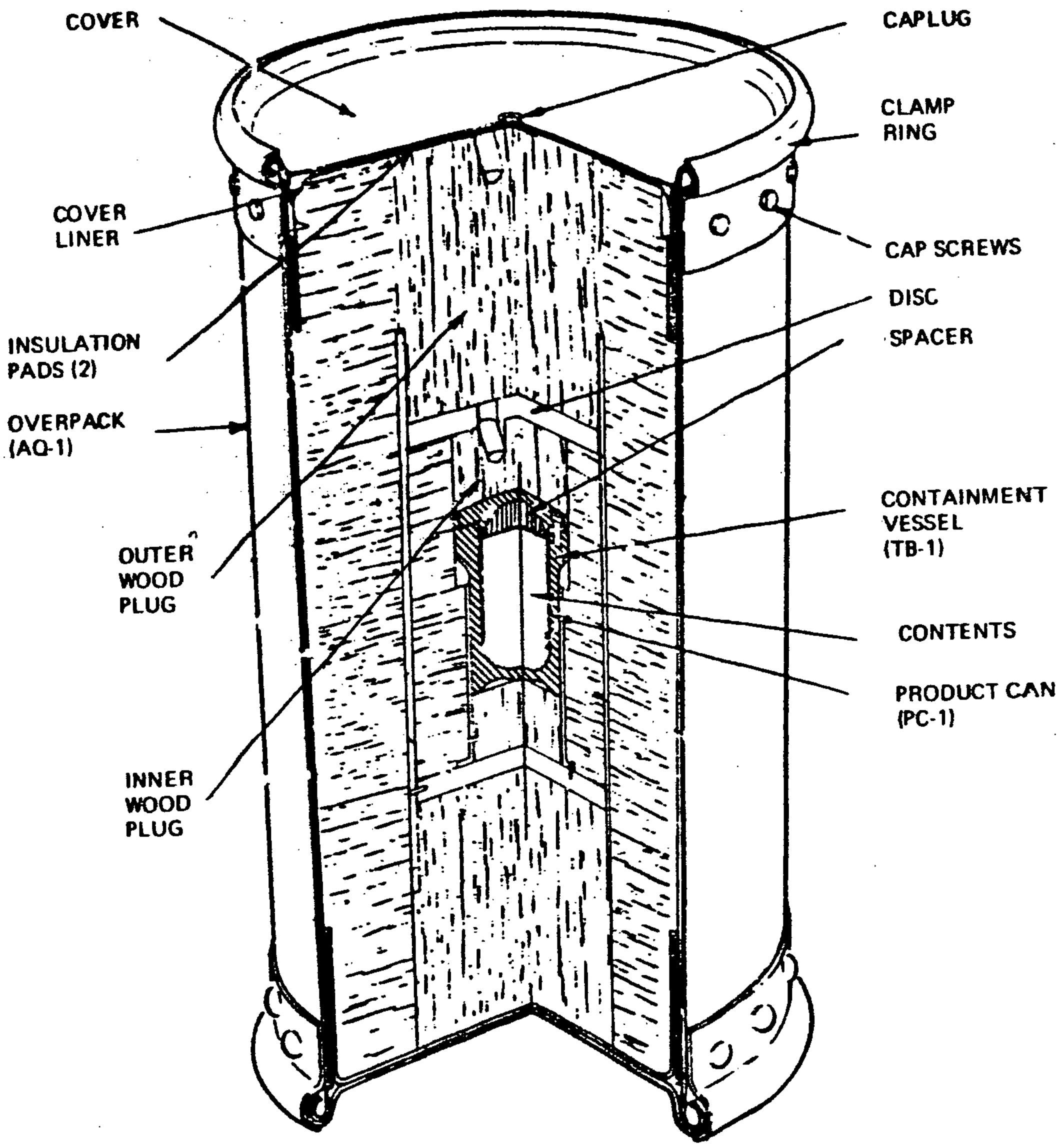

Figure 7.1 Assembled PAT-1

7. Tighten the 12 lid bolts, in two steps, in the following sequence: 1-7, 4-10, 2-8, 11-5, 3-9, 12-6. Tighten all bolts to 50 foot-pounds in the first step and to 75 foot-pounds in the second step.

8. Attach the lifting sling to the TB-1 lid, using the three cap screws (0.250-28UNF) and washers.

9. Verify that the assembled TB-1 containment vessel meets the requirements specified in Section 8.2.3.

7.1.3 Loading TB-1 Containment Vessel into AQ-1 Overpack

1. Visually inspect the AQ-1 components for defects, damage, cleanliness, and for correct part.

2. Using the lifting sling, place the TB-1 containment vessel into the AQ-1 Overpack; make sure the TB-1 is fully seated.

3. Place the inner wood plug (smaller) on top of the TB-1 vessel, aligning the notches in the plug to clear the lifting sling screws in the TB-1.

4. Insert in order the aluminum disc, the outer wood plug, and the inner insulation pad (larger).

5. Insert in order the cover line, the outer insulation pad (smaller), the cover, and the clamp ring. During installation, align the index marks on the cover liner, the cover and the clamp ring with the index mark on the AQ-1 overpack.

6. Install the 23 hex-head screws, fingertight, through the assembled clamp ring, cover, and cover liner.

7. Tighten the 23 cap screws to 15 foot-pounds.

8. Install the four-inch long hex head screw in the clamp ring and tighten to 50 foot-pounds.

9. Install the locking nut on the four-inch long screw and tighten to 30 foot-pounds.

10. A security wire and seal may be installed through the holes provided in the clamp ring lugs.

7.2 Procedures for Unloading the Package

1. Remove the PAT-1 from the skid, if present.

2. Remove the security wire and seal, if present.

3. Remove the 23 hexagon head screws at the top of the package.

4. Remove the clamp ring bolt and lock nut.

5. Remove the clamp ring.

6. Remove the outer drum cover.

7. Remove the insulation pad.

8. Remove the inner cover.

9. Remove the outer redwood plug.

10. Remove the 12-inch diameter aluminum load spreader plate.

11. Remove the inner redwood plug.

12. Remove the TB-1 containment vessel.

13. Remove the lifting sling from the TB-1 vessel.

CAUTION: Pressure relief action may accompany removal of the TB-1 vessel lid in the following steps.

14. Remove the 12 socket head screws which secure the lid to the TB-1 vessel.

15. Remove the lid from the TB-1 vessel. This can be done by re-installing the three screws (used for the lifting sling) and turning them approximately evenly until the lid releases.

16. Remove the aluminum honeycomb top spacer.

17. Remove the PC-1 product can with contents.

NOTE: When storing or preparing an empty TB-1 vessel for return shipment, care should be taken to avoid damaging the knife-edges (that engage the copper gasket) on the lid and body of the vessel.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests To Be Performed Prior to First Use of Each Package

8.1.1 Fabrication Inspections

Before first use of each packaging, the inspections and determinations specified in Section 9.0 shall be completed.

8.1.2 Structural, Pressure, and Leak Rate Tests of the TB-1 Containment Vessel

Before its first use, each TB-1 containment vessel must be determined to be leaktight* when assembled as for shipment, but without the elastomeric O-ring seal and subjected to an internal pressure 50 percent higher than maximum normal operating pressure (1.5 x 34.3 psia = 51.4 psia).

8.2 Tests To Be Conducted Prior to Each Shipment

8.2.1 Visual Inspection

Note: The following steps are not necessarily in sequential order. To accomplish a complete visual inspection, the TB-1 vessel and AQ-1 overpack would have to be disassembled in accordance with Section 7.2.

8.2.1.1 AQ-1 Overpack

a. Check that there are no indentations or damage points deeper than one-half inch in the visible interior redwood assemblies.

b. Check that there are no large breaks in the fiberglass covering of the copper heat conductor tube.

c. Check that there are no indentations or damage points deeper than one-half inch in the outer steel drum and covers.

d. Check that the twenty-three bolt head covers are in place around the bottom of the drum.

e. Check that the twenty-three 3/8-inch diameter bolts are in place around the top end of the drum (when the AQ-1 overpack is assembled).

f. Check that the 5/8-inch diameter, by four-inch long, clamp ring bolt and lock nut are in place at the top of the drum (when the AQ-1 overpack is assembled).

g. Check that the vent plug covers are in place on the drum bottom and on the drum lid.

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*10^{-7} atm-cc/sec. per USNRC Regulatory Guide 7.4 which references ANSI N14.5.

8.2.1.2 TB-1 Containment Vessel

a. Check that the copper gasket is in place on the TB-1 lid, and that it is free of any gouge or irregularity.

b. Check that the elastomeric O-ring is in place on the TB-1 lid and that it is free of gouges and lightly lubricated with the specified silicone grease.

c. Check for visible damage to the small circular knife edge in the TB-1 body (the knife edge on the lid will normally be hidden by the copper gasket).

d. Check for the presence of the 12 socket head bolts which secure t closure to the TB-1 and three bolts and washers for the nylon lifting sling (when the TB-1 vessel is assembled).

8.2.1.3 Rejection

Mechanical damage as described in Section 8.2.1.1 or 8.2.1.2 shall be cause for rejection. Damage to the knife-edge will be cause to perform a leakage test as described in Section 8.1.2 to determine that the TB-1 vessel is acceptable.

8.2.2 PC-1 Product Can

Prior to placing the loaded PC-1 product can into the TB-1 containment vessel, a leakage test shall be completed on the PC-1. This test shall indicate leakage less than 10^{-3} atm cm^3/sec from the assembled PC-1. (An acceptable test would be one in which the PC-1 is placed in a closely fitting chamber, a vacuum is rapidly drawn, and any subsequent rise in chamber pressure is correlated with leak rate.)

8.2.3 TB-1 Containment Vessel

As part of preparation for each shipment, the TB-1 containment vessel will be assembled in accordance with the checklist described in Section 7.1.2 and a leakage test shall be completed on the TB-1 together with its radioactive contents. This test shall indicate leakage less than 10^{-3} atm cm^3/sec from the assembled TB-1. (An acceptable test would be one in which the TB-1 is placed in a closely fitting chamber, a vacuum is rapidly drawn, and any subsequent rise in chamber pressure is correlated with leak rate.)

8.3 Periodic Test and Maintenance

8.3.1 TB-1 Containment Vessel

After every third use of a TB-1 containment vessel to transport radioactive materials, or if the leak test described in Section 8.1.2 has not been performed on that particular TB-1 vessel within the preceding 12-month period, the TB-1 shall be determined to meet the leak test requirement described in Section 8.1.2.

8.3.2 Replacement of Gaskets on Containment Vessel

The copper gasket and the elastomeric O-ring for the TB-1 containment vessel shall be replaced in accordance with the schedule shown in Table 8.1.

Table 8.1

REPLACEMENT SCHEDULE FOR COPPER SEAL AND O-RING

TB-1	Replacement Schedule
Copper Seal	Prior to final closure for each shipment of loaded TB-1
Elastomeric O-ring	Prior to each 4th shipment of radioactive material, or annually, whichever occurs more frequently.

9.0 SPECIFICATIONS AND DRAWINGS

9.1 Quality Assurance

The program to design, develop, and test the Plutonium Air Transportable Package, Model PAT-1, and to demonstrate that the package design meets the NRC Qualification Criteria (NUREG-0360), was conducted by Sandia Laboratories under contract to the Nuclear Regulatory Commission.

Model PAT-1 packages must be procured, fabricated, inspected, accepted, operated, maintained, and repaired in accordance with a Quality Assurance Plan which meets the requirements of 10 CFR Part 71, Appendix E, and approved by the NRC.

9.2 Fabrication Requirements

9.2.1 General Requirements

The following establishes the general requirements for fabrication and inspection of the Plutonium Air Transportable Package, Model PAT-1. All items are to be in accordance with the drawings, standards, procedures, and material specifications to the extent specified herein.

9.2.2 Documents

The following documents form a part of this specification to the extent specified herein.

Document	Issue	Title
PAT-1028	-	Testing, Leak Rate, Mass Spectrometer, PAT Package
PAT-1029	-	Material Specification, Redwood for PAT Package
PAT-1030	-	Welding, Corrosion Resistant Steel, PAT Package
1001	A	PAT-1 Assembly
1002	A	Overpack, AQ
1003	A	Container, Subassembly
1004	A	Drum
1005	A	Cover, Modified
1006	A	Ring, Clamp, Modified
1007	A	Cover, Liner
1008	A	Cylinder, Wood
1009	A	Cylinder, Wood
1010	A	Plug, Wood, Fixed
1011	A	Cylinder, Wood
1012	A	Plug, Wood, Fixed
1013	A	Plug, Wood, Removable
1014	A	Plug, Wood, Removable
1015	A	Spacer, Top

Document	Issue	Title
1016	A	Load Spreader Assembly
1017	A	Containment Vessel
1018	A	Bolt, Socket, Head Special .500-20
1019	A	Gasket, Copper
1020	A	Lid, TB
1021	A	Forging, TB Lid
1022	A	Body, TB
1023	A	Forging, TB Body
1024	B	Can Assembly
1025	A	Cylinder, Liner
1026	A	Pad, Insulation
1027	A	Pad, Insulation

9.2.3 Standards of Manufacture

9.2.3.1 Quality Control

Unless otherwise specified, the requirements of 10 CFR Part 71, Appendix E, shall apply.

9.2.3.2 Welding Method

Welding and fabrication shall be in accordance with PAT-1030.

9.2.3.3 Glued Assemblies

a. In gluing wood pieces together (wood to wood), polyvinyl acetate resin emulsion per MMM-A-180 shall be used. As an alternate, glue per 9.2.3.3.b may be used, unless otherwise specified.

b. In gluing wood to metal, or metal or metal parts, the bond material shall be a mixture of the following by weight.

100 parts Uniroyal B635 resin
15 parts Benzoflex 988 plasticizer
9 parts Uniroyal 3080 hardener

The material shall be processed as follows: Upon receipt of the five gallon cans of Uniroyal B635, heat for 12 hours at 130 ± 10°F and then shake for 30 minutes in a paint shaker. This is necessary because the material will freeze at close to room temperature. Before use, the material shall be a clear, high viscosity liquid. If it is cloudy, lumpy, or resembles an "icy slush," repeat the heating and shaking process.

After withdrawing B635 material from the can, the air space above the material should be thoroughly flushed with dry nitrogen, and the can tightly sealed. Care should be taken to prevent moisture in the air from reacting with the material and forming a crystalline layer on the surface. However, if a layer forms, it can be removed and the material used.

In mixing, first blend the B635 and the Benzoflex 988 plasticizer together, next add the 3080 hardener and mix thoroughly. For small batches of 100 to 200 grams, two minutes of vigorous hand mixing with a spatula will be satisfactory. For larger batches, mix thoroughly to insure uniformity. To extend the pot life of the adhesive, mixing should be done as rapidly as possible.

c. Glue lines, resulting from the dimensions of finished mating parts, shall be 0.001 to 0.100 inch.

9.2.3.4 Protection

All parts and assemblies shall be adequately protected from accumulation of foreign matter, corrosion, physical damage or deterioration. This requirement shall apply to all manufacturing operations from receipt of raw material to completion of a finished product, to product held in any storage area, and to product prepared for shipment.

a. Protective measures used during processing, fabrication, and packaging must not only guard against obvious damage and deterioration but also against the creation of latent conditions that may later cause unsatisfactory performance, accelerating deterioration, or malfunction.

b. Raw material and parts at all levels of production shall be kept adequately segregated and identified at all times. Parts shall be transported in a manner which will assure adequate protection from damage.

c. All items such as raw material, parts, subassemblies, assemblies, etc., not in immediate use, shall be adequately packaged, identified, and stored.

9.2.3.5 Cleanup of Parts and Assemblies

All finished parts and subassemblies shall be adequately cleaned before final assembly. Final assembly and necessary subassembly shall be performed in an environment appropriate to the type of product. All parts and assemblies shall be thoroughly cleaned to remove foreign and manufacturing waste material such as:

Superfluous hardware, wire, and insulation clippings.
Chips, filings, abrasives, machining lubricants.
Soldering, brazing, and welding fluxes, solder droppings, weld spatter, slag, and welding rod ends.
Drippings of lubricants, adhesives, and sealing compounds.
Paint droppings, splatter, and overspray.
Residues from liquid baths used in plating and chemical treatments.
Temporary tags and packaging.

9.2.3.6 Part Number Marking

a. All finished parts, assemblies, and subassemblies shall be permanently marked with the applicable part number, using ink marking with covercoat. The vertical height of characters shall be not less than 0.12 inch.

b. Part numbers shall be located in any readily observable location which does not affect function.

9.2.3.7 Standards

The following documents form a part of this specification to the extent specified herein:

ANSI Y 14.5, 1973 Dimensioning and Tolerancing
ANSI B1.1, 1974 Unified Inch Screw Threads (UN and UNR Thread Form)

9.2.4 Quality Assurance Provisions

9.2.4.1 The supplier responsible for the manufacture of the PAT Package must establish and maintain a Quality Assurance Program which meets the requirements of 10 CFR Part 71, Appendix E.

9.2.4.2 Material Certification

Certification from material suppliers verifying that all materials used in the fabrication of the PAT-1 Package are in accordance with applicable drawings and specifications.

9.2.4.3 Drawing Compliance

The PAT-1 assembly and component parts shall be inspected either by open set-up or gaging methods, to assure that the dimensional requirements specified on the applicable drawings are met.

9.3 Final Acceptance Testing

The following tests and inspections shall be performed on all units. Tests may be performed in any sequence, as appropriate.

9.3.1 Visual Inspection

The following steps are not necesarily in sequential order.

9.3.1.1 AQ-1 Overpack

a. Check that there are no indentations or damage points in the visible interior redwood assemblies.

b. Check that there are no breaks in the fiberglass covering of the innermost tubular member (copper heat conductor tube).

c. Check that there are no indentations or damage points in the outer steel drum and covers.

d. Check that the 23 bolt head covers are in place around the bottom of the drum.

e. Check that the twenty-three 3/8-inch diameter bolts are in place around the top end of the drum (when AQ-1 is assembled).

f. Check that the 5/8-inch diameter, by four-inch long, clamp ring bolt and lock nut are in place at the top of the drum (when AQ-1 is assembled).

g. Check that the vent plug covers are in place on the drum bottom and on the drum lid.

9.3.1.2 TB-1 Containment Vessel

a. Check that the copper gasket is in place on the TB-1 lid and that it is free of any gouge or irregularity.

b. Check that the elastomeric O-ring is in place on the TB-1 lid and that it is free of gouges and lightly lubricated with the silicone grease specified on the drawings, or equivalent.

c. Check for visible damage to the small circular knife edge in the TB-1 body (the knife-edge in the lid will normally be hidden by the copper gasket).

d. Check for the presence of the 12 socket head bolts which secure the closure to the TB-1 and three bolts and washers for the nylon lifting sling (when TB-1 is assembled).

9.3.1.3 Rejection

Mechanical damage as described in Sections 9.3.1.1 and 9.3.1.2 shall be cause for rejection. Damage to the knife-edges will be cause to perform a leakage test as described in Section 9.3.2 to determine that the TB-1 vessel is acceptable.

9.3.2 Structural, Pressure, and Leak Rate Tests of the TB-1 Containment Vessel

Each TB-1 containment vessel, before its first use, must be determined to be leaktight when assembled as for shipment but without the elastomeric O-ring seal and subjected to an internal pressure 50 percent higher than maximum normal operating pressure (1.5 x 34.3 psia = 51.4 psia). Leak rate shall not exceed 1 x 10^{-7} atm-cc/sec (air) as determined in accordance with PAT-1028.

9.3.3 Function and Fit

The PAT-1 shall be visually and mechanically inspected to assure that all of the component parts fit into the assembly properly, as specified in the drawings.

PAT-1028 TESTING, LEAK RATE, MASS SPECTROMETER, PAT PACKAGE

1.0 GENERAL

1.1 Scope

This specification defines the requirements for the quantitative measurement of the leak rate of a sealed component of the Plutonium Air Transportable Package, Model PAT-1. A mass spectrometer type leak detector is used.

1.2 Product Description

The item to be leak tested per this specification is the Containment Vessel, TB, drawing number 1017, which is a major component of the PAT Package, drawing number 1001. The detail parts of the Containment Vessel, TB, are:

TB Body
TB Lid
Copper Gasket
O-Ring
Bolt, Socket Head, Special, 0.500-20UNF (12 required)

1.3 Definitions

1.3.1 Background

Test system background is included in the leak rate results. This may be spurious output of the leak detector expressed in suitable terms, due to the response to all gases other than the actual leakage of tracer gas from the product being tested and/or the known leak. The background may be inherent in the detector or extraneous, and includes absorbed tracer gas.

1.3.2 Units

1.3.2.1 Pressure Units

a. Millimeter of Mercury (mmHg). A unit of pressure corresponding to a column of mercury exactly 1 millimeter high at 0°C under standard gravity acceleration of 980.665 cm/sec^2.

b. Micron of Mercury (uHg). A unit of pressure equal to 1/1000 of the millimeter of mercury pressure unit.

c. Torr. A unit of pressure equal to 1/760 of a standard atmosphere; differs by only one part in 7 million from a millimeter of mercury. Torr is the preferred pressure unit for low pressure (vacuum) measurement.

1.3.2.2 Leak Rate Units

(cubic centimeter per second, standard temperature and pressure). A flow rate of gas in terms of cubic centimeters per second in which the gas volume is reduced to standard temperature and pressure. 1.315 cc/sec. = 1 Torr-liter/sec.

1.3.3 STP (Standard Pressure and Temperature)

Defined as 0°C and 760 Torr.

1.3.4 K Factor

A factor used to convert from a tracer gas leak rate obtained under the specified test conditions to an equivalent air leak rate at those specific test conditions. For purposes of this specification:

$$K = \sqrt{\frac{\text{Molecular weight of helium}}{\text{Molecular weight of air}}}$$

K = 0.372

1.3.5 Sealed Product

A product which is capable of maintaining, or of being sealed by special fixtures to maintain, an internal pressure or vacuum.

1.3.6 Tracer Gas

A gas that is used to measure the leak rate of the product being tested.

1.3.7 Leak Rate

The quantity of gas flowing in unit time into, or out of, the product under test, reduced to units of volume at standard temperature and pressure.

1.3.7.1 Tracer Gas Leak Rate

The leak rate tests results, calculated without application of a K factor, from the leak detector readings.

1.3.7.2 Total Gas Leak Rate

An estimate of the product leak rate, obtained by multiplying the tracer gas leak rate by the specified K factor.

1.3.7.3 Maximum Permissible Leak Rate

The maximum total gas leak rate limit allowable for product acceptance.

1.3.8 Known Leak

A calibrated device from which tracer gas is emitted at a known rate.

2.0 DOCUMENTS

The following documents, of the exact issue shown, form a part of this specification to the extent specified herein.

Specifications:

Federal:

BB-H-1168b	Helium, Technical

3.0 REQUIREMENTS

3.1 Equipment Capability

3.1.1 Leak Detector System

The system shall consist of a mass spectrometer type leak detector together with a suitable test chamber that will completly enclose the product, auxiliary pressurization equipment, and instrumentation necessary for performance of the test under the specified conditions.

3.1.2 Location of Known Leak

The known leak shall be connected directly to the vacuum system as closely as possible to that point at which the test item will be connected.

3.1.3 Vacuum Gages

Gages used to ascertain that the pressure in the test chamber or fixture is not greater than the specified maximum shall be suitably located to read the pressure of the test chamber or fixture. If leak detectors having gages capable of reading pressures indicated below are available, it is permissible to use these gages provided:

a. An indicated test pressure of 5×10^{-5} Torr (mmHg) or lower is used for helium.

b. An essentially short direct connection is maintained between the leak detector and the test chamber or fixture.

Under the present state-of-the-art, calibration of vacuum gages below one micron of mercury is not quaranteed by Primary Standards and, therefore, is not required.

3.1.4 Attenuation Setting on Leak Detector

The leak detector shall be operated on the most sensitive readable scale.

3.2 Gases

The tracer and fill gas used shall be helium per BB-H-1168b, Type 1, Grade A.

3.3 Calibration of Known Leak

The known leaks used shall be calibrated by the Primary Standards Laboratory specified in the contract or purchase order. Calibration shall be performed prior to initial use and at intervals thereafter in accordance with policies established by the Primary Standards Laboratory.

3.4 Procedure (Leak Rate Measurement)

3.4.1 General

a. Readability of the leak detector output meter shall be checked per 3.1.3.

b. Pressures at which a test is to be performed shall not exceed 5×10^{-4} Torr (mmHg) helium.

3.4.2 Product Leak Test

3.4.2.1 The TB to be leak tested will be received disassembled, and it will be necessary to assemble the unit as the leak test progresses, as follows.

a. Invert the TB Body and place it on the edge of a clean work surface, with approximately one-fourth the interior diameter of the Body extending out from the work surface.

b. Insert the nozzle of the helium tracer gas line into the interior of the TB Body, and flood the interior with helium for a period of at least 20 seconds.

c. Remove the nozzle and, with the TB still in the inverted position, place the TB Body in position over the TB Lid (the copper seal should be used for this test, the elastomeric O-ring should not be in place at this time). While holding the Lid firmly against the Body, invert both and place them in the up-right position on the work surface.

d. Align the holes in the Lid with the threaded holes in the Body (orientation optional) and install the 12 socket heat bolts onto the unit. Using a suitable strap-type holding device and torque wrench, torque the bolts to 50 ±5 foot-pounds.

e. Place the assembled TB in the chamber of the mass spectrometer leak tester. Readings shall be taken from the leak detector output meter for each test, as follows:

R_1 = Background
R_2 = Background & Known Leak
R_3 = Product Leak & Background

3.4.2.2 Leak Rate Calculation

Readings R_1, R_2, and R_3, as obtained in e. above, permit calculation of the total gas leak rate as follows:

$$L = \frac{(C)(K)(R_3 - R_1)}{R_2 - R_1}$$

Where:

L = Total gas Leak rate
C = Calibrated value of known leak
K = See 1.3.4

3.4.2.3 Maximum Permissible Leak Rate

The leak rate for the TB shall not exceed 1×10^{-7} atm-cc/sec (air).

3.4.3 Test Records

The following information shall be recorded by the testing laboratory. Copies of test records shall be distributed as specified in the contract or purchase order.

a. Product part number and serial number.

b. Purchase order or contract number.

c. Make and model number of leak detector used.

d. Value of known leaks used.

e. Test pressures (internal and external).

d. Tracer gas and concentration used.

g. Fill gas used.

h. Leak detector output readings per 3.4.2.1.e.

i. Calculated total gas leak rate.

j. Date of test.

PAT-1029 MATERIAL SPECIFICATION, REDWOOD FOR PAT PACKAGE

1.0 GENERAL

1.1 Scope

This specification defines the requirements for the redwood material used in fabrication of the Plutonium Air Transportable Package, Model PAT-1.

1.2 Definitions

Definitions of terms used in this specification may be found in the document listed in 2.1, below.

2.0 DOCUMENTS AND EQUIPMENT

The following documents and equipment form a part of this specification to the extent specified herein. Unless otherwise specified the latest issues shall be used. In the event of conflict between documents referenced herein and the contents of this specification, the contents of this specification shall be a superseding requirement.

2.1 Documents

"Standard Specification for Grades of California Redwood Lumber" published by Redwood Inspection Service, San Francisco, California.

2.2 Equipment

Moisture Register, Model L, made by the Moisture Register Co., Alhambra, California, or equivalent.

3.0 REQUIREMENTS

3.1 Material Description

a. The material to be used shall be clear, kiln dried redwood, free of defects, as defined in Para. 104 of the "Standard Specifications" document. Knots are not permissible.

b. Assemblies shall be fabricated of one inch or greater nominal thickness.

c. Moisture content shall not exceed 12%. The material shall be protected, as necessary, to assure this condition.

d. Finger-joined and edge-glued lumber is acceptable.

   1. Parts shall be assembled in accordance with the applicable drawings, using polyvinyl acetate resin emulsion per MMM-A-180, or Resorcinal adhesive per MMM-A-181.

2. Glue lines shall be 0.030 inch maximum.

3.2 Grain Defects

Burls and birdseyes of less than 0.375 inch diameter are acceptable, providing there are not more than six such defects in a six inch diameter, in a maximum of 5% of the lumber in a subassembly.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Visual Inspection

All material shall be visually inspected to assure that it meets the requirements of Section 3 of this specification.

4.2 Moisture Content

The material shall be inspected, after final machining and just before application of sealant, to assure that the moisture content specified in 3.1.c is not exceeded. Inspection shall be conducted as follows:

a. Zero the Moisture Register in accordance with the manufacturer's instruction.

b. Twenty percent of the material in each subassembly shall be checked for moisture content, using the Moisture Register per the manufacturer's instructions. The Register readings shall not exceed 24.

5.0 PREPARATION FOR DELIVERY

The lumber to be used shall be packaged by the subcontractor so that it will meet the requirements of this specification after processing by the fabricator of the PAT. Vapor barriers shall be used in packaging to maintain the minimum moisture content requirement specified.

PAT-1030 WELDING, CORROSION RESISTANT STEEL, PAT PACKAGE

1.0 GENERAL

1.1 Scope

This specification defines the fabrication and inspection requirements for the welding of corrosion resistant steel parts used on the Plutonium Air Transportable Package, Model PAT-1.

1.2 Definitions

1.2.1 Welding Terms and Definitions

Welding terms and definitions used in this specification shall be in accordance with AWS A2.0, except for the following:

Porosity. Voids in the weld metal of approximately spherical shape.

1.2.2 Welding Symbols

Welding symbols used on the product drawings shall be in accordance with AWS A2.0.

2.0 DOCUMENTS

The following documents form a part of this specification to the extent stated herein. Unless otherwise specified use latest issues.

AWS A 2.0-58	Welding Symbols
AWS A 3.0-51	Welding Terms and Definitions
MIL-I-6866B	Inspection, Penetrant Method of

3.0 REQUIREMENTS

3.1 Welding Process

Welding shall be done by any of the arc welding processes, using manual, semiautomatic, or automatic techniques.

3.2 Weld Preparation

Loose scale, slag, rust, grease, oil, and other foreign matter shall be removed from surfaces to be welded. Beveling and weld preparation may be done by flux-oxygen cutting, provided cracking does not occur in the metal and provided at least 0.125 inch of metal is removed from all cut edges by mechanical means, grinding, etc.

3.3 Weld Defects

Imperfections that exceed the limits specified in Table 1 shall be considered defects and are unacceptable, except as specified below.

3.4 Repair of Defects

Repair of defects is permissible if the required weldment, the repair weld itself, and the adjacent parent metal meet the requirements of the original weldment. A repaired weldment shall be reinspected in the same manner as the original weldment.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General

4.1.1 Responsibility for Inspection

The Supplier performing the welding shall be responsible for the performance of all tests and inspections specified herein.

4.1.2 Inspection Records

The Supplier shall maintain records of all inspections performed per 4.2. Copies shall be distributed as specified in the contract or purchase order.

4.1.3 Inspection Sequence

Weldments may be inspected at any time after the weld preparation and cleaning requirements of Section 3 have been met.

4.1.4 Rejected Units

Parts that fail to meet any of the requirements of this specification shall be rejected. Repair as defined in 3.4 is permissible.

4.2 Product Inspection and Testing

The following inspections shall be performed on the weldments on parts of the PAT Package on which welding is performed.

4.2.1 100% Visual Inspection

Parts shall be visually inspected 100% for the imperfections defined in Table 1. No magnification is required.

Table 1

LIMITS OF IMPERFECTIONS IN ACCEPTABLE WELDS

IMPERFECTION	LIMIT	
Cracks in weld bead	Unacceptable	
Cracks in parent metal	Unacceptable	
Crater cracks	Unacceptable	
Incomplete fusion and inadequate joint penetration	The aggregate length of the imperfections shall not exceed 1-1/2T in a weld length of 6T, and the length of any individual imperfection shall not exceed 1/2T. If the weld length is less than 6T the aggregate length of the imperfections shall not exceed 1/4 the weld length, and the length of any individual imperfection shall not exceed 1/12 the weld length. (See Note)	
Porosity (Internal)	Not applicable	
Inclusions (Internal)	Not applicable	
Undercut	Unacceptable	
Overlap	Unacceptable	
Concavity	Unacceptable in butt welds. In fillet welds, actual throat shall be not less than the theoretical throat for specified weld size.	
Convexity of butt welds on either side	Weld Size	Maximum Reinforcement Height
	Up to 0.125 inch	0.050 inch
	0.125 to 0.500 inch	25% of weld size
	0.500 inch and larger	0.125 inch
Size of fillet welds	Specified weld size (length of legs) +50%, -0.	

Note: (T) is the specified weld size.

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

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TITLE CAN ASSEMBLY			
SIZE C		DWG. NO. 1024	
SCALE 1/1		SHEET 1 OF 1	

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