SAND81-0001
Unlimited Release

PAT-2 (Plutonium Air-Transportable Model 2)

Safety Analysis Report

John A. Andersen
E. James Davis
Thomas A. Duffey
Stephen A. Dupree
Oscar L. George, Jr.
Zachary Ortiz

Sandia Laboratories

* TOTAL PAGES: 431
* In various pagings

SAND81-0001
Printed July 1981
Unlimited Distribution

PAT-2 (PLUTONIUM AIR-TRANSPORTABLE MODEL 2) SAFETY ANALYSIS REPORT

John A. Andersen
E. James Davis*
Thomas A. Duffey*
Stephen A. Dupree*
Oscar L. George, Jr.
Zachary Ortiz

Sandia National Laboratories
Albuquerque, New Mexico 87185
Operated by
Sandia Corporation
for the
U.S. Department of Energy

This work sponsored and funded by the DOE Office of Safeguards and Security, International Support Branch.

*Consultants

CONTENTS

Chapter		Page
1	GENERAL INFORMATION	1-1
	1.1 Introduction	1-1
	1.2 Package Description	1-2
	1.2.1 General	1-2
	1.2.2 Packaging	1-3
	1.2.3 Operational Features	1-7
	1.2.4 Contents of Package	1-8
2	STRUCTURAL EVALUATION	2-1
	2.1 Summary	2-1
	2.2 Mass Properties and Mechanical Properties	2-2
	2.2.1 Weights and Center of Gravity	2-2
	2.2.2 Mechanical Properties of Materials	2-2
	2.3 Containment Vessel Stress Analyses	2-4
	2.3.1 TB-2 Maximum Normal Operating Stress	2-4
	2.3.2 TB-2 Maximum Credible Accident Stress	2-4
	2.3.3 C-1 Capsule Stress Analysis	2-5
	2.4 General Standards for All Packages (10 CFR 71.31)	2-5
	2.4.1 Chemical and Galvanic Reactions	2-5
	2.4.2 Positive Closure	2-6
	2.4.3 Lifting and Tiedown Devices	2-6
	2.5 Standards for Type B and Large-Quantity Packaging (10 CFR 71.35)	2-19
	2.5.1 Load Resistance per 10 CFR 71	2-19
	2.5.2 External Pressure	2-19
	2.6 Normal Conditions of Transport Tests per 10 CFR 71 Appendix A	2-20
	2.6.1 General	2-20
	2.6.2 Heat	2-20
	2.6.3 Cold	2-20
	2.6.4 Pressure	2-21
	2.6.5 Vibration	2-21
	2.6.6 Water Spray	2-22
	2.6.7 Free Drop/Corner Drop	2-22
	2.6.8 Penetration	2-22
	2.6.9 Compression	2-22
	2.6.10 Post-Test Summary of Package Damage	2-24

2.7 Hypothetical Accident Conditions Tests per 10 CFR 71 Appendix B 2-24
2.7.1 General 2-24
2.7.2 Free Drop 2-25
2.7.3 Puncture 2-25
2.7.4 Thermal (Fire) 2-25
2.7.5 Water Immersion 2-29
2.7.6 Post-Test Summary of Package Damage 2-29
2.8 NUREG-0360 Qualification Criteria for Air Transport 2-31
2.8.1 Summary and Results 2-31
2.8.2 Impact 2-32
2.8.3 Crush 2-41
2.8.4 Puncture 2-41
2.8.5 Slash (Ripping/Tearing) 2-45
2.8.6 Fire 2-48
2.8.7 Immersion 2-48
2.8.8 Post-Test Summary of Package Damage 2-48
2.8.9 Individual Hydrostatic Test 2-57
2.8.10 Free-Fall Impact 2-57
2.8.11 Other Requirements of NUREG-0360 2-65
2.8.12 Alternate Operational Control -- Aircraft Stowage Location 2-67
Appendices
2A -- Redwood Impact Limiter/Heat Shield Material 2-71
2B -- Maplewood Impact Limiter/Heat Shield Material 2-73
2C -- TB-2 Containment Vessel and C-1 Capsule Stress Analyses 2-75
2D -- Load Resistance per 10 CFR 71 2-109
2E -- PAT-2 Test Protocol 2-115
2F -- Test Facilities 2-131
2G -- PAT-2 Package Impact Analysis 2-139
2H -- TB-2 Hydrostatic Stress Analysis 2-151
References 2-153
3 THERMAL EVALUATION 3-1
3.1 Summary and Results 3-1
3.2 Thermal Properties of Materials 3-2
3.3 Thermal Evaluation for Normal Conditions of Transport 3-2
3.3.1 Thermal Models 3-2
3.3.2 Maximum Temperatures 3-2
3.3.3 Moderately Hot Day without Insolation 3-5

3.3.4 Minimum Temperatures 3-7

3.3.5 Maximum Normal Internal Pressure and Temperature 3-7

3.3.6 Maximum Thermal Stress 3-7

3.3.7 Thermal Evaluation of Package Performance for Normal Conditions of Transport 3-8

3.4 Thermal Accident Evaluation -- 10 CFR 71 3-8

3.4.1 Thermal Models 3-8

3.4.2 Package Conditions and Environment 3-9

3.4.3 Package Temperature 3-13

3.4.4 Maximum Internal Pressure 3-13

3.4.5 Maximum Thermal Stress 3-15

3.4.6 Evaluation of Package Performance for the 10 CFR 71 Accident Conditions 3-15

3.5 NUREG-0360 Air Transport Criteria -- Thermal Accident Evaluation 3-15

3.5.1 General 3-15

3.5.2 Package Conditions and Environment 3-16

3.5.3 Package Temperatures 3-20

3.5.4 Maximum Internal Pressure 3-20

3.5.5 Maximum Thermal Stresses 3-20

3.5.6 Evaluation of Package Performance for NUREG-0360 Criteria Thermal Conditions 3-26

References 3-30

4 CONTAINMENT 4-1

4.1 Summary 4-1

4.2 Containment Boundary 4-2

4.2.1 TB-2 Containment Vessel 4-2

4.2.2 C-1 Capsule 4-2

4.2.3 Closure 4-3

4.3 Requirements for Normal Conditions of Transport 10 CFR 71 4-5

4.3.1 Pressurization of Containment Vessel 4-5

4.3.2 Release of Radioactive Contents 4-6

4.4 Requirements for Accident Conditions of Transport 10 CFR 71 4-6

4.4.1 Pressurization of Containment Vessel 4-6

4.4.2 Release of Radioactive Contents 4-6

4.5 Requirements for NUREG-0360 Criteria 4-7

4.5.1 Summary 4-7

4.5.2 Pressurization of TB-2 Containment Vessel 4-8

4.5.3 Release of Radioactive Contents 4-9

Appendices

4A -- Characterization of Surrogate UO_2 Powder 4-13

4B -- Pressure Calculation, Test Results, and Surrogate for $Pu(SO_4)_2 \cdot 4H_2O$ 4-15

4C -- Pressure Calculations and Surrogate for $Pu(NO_3)_4 \cdot 2H_2O$ 4-23

4D -- Pressure Calculations and Surrogate for Sintered Pellets for PuO_2 4-29

4E -- Pressure Calculations and Surrogate for Mixed Powders of PuO_2 and UO_2 4-33

4F -- Gas Leakage Rate and Equivalent Capillary Diameter 4-37

4G -- Calculated Theoretical PuO_2 Release 4-41

4H -- Additional Practical Considerations Regarding Possible Plutonium Release 4-43

4J -- Deformation of the TB-2 Vessel at Elevated Temperature and Pressure 4-45

References 4-47

5 RADIATION SHIELDING EVALUATION 5-1

5.1 Summary 5-1

5.2 General 5-1

5.3 Source Definition 5-2

5.4 Shielding Calculations 5-4

5.4.1 One-Dimensional, Normal Operation (ANISN) 5-4

5.4.2 One-Dimensional TB-2 Containment Vessel Model (ANISN) 5-5

5.4.3 Two-Dimensional, Normal Operation (MORSE) 5-5

5.4.4 Three-Dimensional, Post-Accident (MORSE) 5-5

5.5 Results 5-12

5.6 Special Shielding Analyses Required for Type B(U) Packagings 5-14

5.7 Neutron Activation of the PAT-2 5-16

Appendix

5A -- IAEA Payload Definition for the PAT-2 5-19

References 5-25

6 CRITICALITY EVALUATION 6-1

6.1 Summary 6-1

6.2 General 6-1

6.3 Calculational Models 6-3

6.4 Effect of PAT-2 Payload (Isotope Content) Composition on System k_{eff} 6-5

6.5 Results 6-5

References 6-8

7 OPERATING PROCEDURES 7-1
7.1 General 7-1
7.1.1 General Standards 7-1
7.1.2 Permissible Contents 7-1
7.1.3 Optional Use of Canisters 7-1
7.1.4 Use of PVC 7-2
7.2 Loading the C-1 Capsule 7-2
7.2.1 Loading 7-2
7.2.2 Capsule Sealant 7-2
7.2.3 Positive Closure 7-2
7.2.4 Capsule Leak-Rate Test 7-2
7.3 Loading the TB-2 Containment Vessel 7-3
7.3.1 Shim C-1 Capsule To Fit TB-2 Containment Vessel 7-3
7.3.2 Install Capsule 7-3
7.3.3 Install Copper Gasket 7-3
7.3.4 Assemble TB-2 Containment Vessel 7-3
7.3.5 Positive Closure 7-3
7.3.6 Containment Vessel Leak-Rate Test 7-4
7.4 Assembly of the PAT-2 Package 7-4
7.4.1 Install TB-2 Containment Vessel and Plug 7-4
7.4.2 Assemble Load Spreader 7-4
7.4.3 Install Gasket and Plug 7-4
7.4.4 Documents 7-4
7.4.5 Install and Secure AQ-2 Covers 7-4
7.4.6 Security Seals 7-5
7.4.7 Shipping Labels 7-5
7.5 Disassembling and Unloading the PAT-2 Package 7-5
7.5.1 General 7-5
7.5.2 Remove TB-2 from AQ-2 7-5
7.5.3 Open the TB-2 7-5
7.5.4 Open the C-1 Capsule 7-6
Appendices
7A -- Operating Procedures for Loading Canisters 7-7
7B -- PAT-2 Package Detailed Assembly Procedure 7-11
8 PAT-2 PACKAGE ACCEPTANCE AND PRE-SHIPPING TESTS AND MAINTENANCE 8-1
8.1 Leak-Rate and Pressure Tests of the TB-2 and C-1 prior to First Use 8-1
8.1.1 TB-2 Leak-Rate Test 8-1
8.1.2 TB-2 Leak-Rate Test at 150% MNOP per 10 CFR 71.53(b) 8-1

8.1.3 C-1 Leak-Rate Test 8-2
8.2 Inspections and Tests To Be Performed prior to Each Use of the PAT-2 Package 8-2
8.2.1 Visual Inspection 8-2
8.2.2 Tests to Verify Proper Assembly prior to Each Shipment 8-4
8.3 Periodic Test and Maintenance 8-4
8.3.1 TB-2 Containment Vessel and C-1 Capsule 8-4
8.3.2 Replacement of Gasket on TB-2 Containment Vessel 8-4
9 QUALITY ASSURANCE 9-1
9.1 General 9-1
9.2 Quality Assurance Program 9-1
9.2.1 Organization 9-2
9.2.2 Design Control 9-2
9.2.3 Procurement Document Control 9-3
9.2.4 Instructions, Procedures, and Drawings 9-4
9.2.5 Document Control 9-4
9.2.6 Control of Purchased Material 9-4
9.2.7 Identification and Control of Material Parts and Components 9-4
9.2.8 Control of Special Processes 9-5
9.2.9 Inspection 9-5
9.2.10 Test Control 9-5
9.2.11 Control of Measuring and Test Equipment 9-5
9.2.12 Handling and Related Functions 9-5
9.2.13 Inspection, Test, and Operating Status 9-6
9.2.14 Noncomforming Materials, Parts, or Components (in service) 9-6
9.2.15 Corrective Measures 9-6
9.2.16 Quality Assurance Records 9-6
9.2.17 Audits 9-6
9.3 Certification of Compliance 9-6
Appendices
9A -- PAT-2 Specifications and Design Definitions 9-7
9B -- Certification of Compliance 9-85
10 CONFORMANCE OF THE PAT-2 PACKAGE TO IAEA SAFETY STANDARDS 10-1
10.1 General 10-1
10.2 Packaging and Design Requirements 10-2
10.3 Specific Additional Requirements for Type B(U) Packages 10-9
10.4 Controls for Transport and Storage in Transit 10-12
10.5 Fissile Materials 10-15
10.6 Test for Packaging 10-20
10.7 Approval of Package Designs -- Paragraphs 804 and 805 10-24

PAT-2 (PLUTONIUM AIR TRANSPORTABLE MODEL 2)
SAFETY ANALYSIS REPORT

CHAPTER 1

GENERAL INFORMATION

1.1 INTRODUCTION

This Safety Analysis Report (SAR) for the PAT-2 (Plutonium Air Transportable Model 2) package is primarily in accordance with requirements of the U.S. Nuclear Regulatory Commission (NRC) and is also in accordance with requirements of the United States IAEA Competent Authority (the U.S. Department of Transportation) and requirements of the IAEA (International Atomic Energy Agency).

The PAT-2 package is designed for the safe transport of plutonium and/or uranium in small quantities, especially as used in international safeguards activities, and especially as transported by air.

The PAT-2 package is resistant to severe accidents, including that of a high-speed jet aircraft crash, and is designed to withstand such environments as extreme impact, crushing, puncturing and slashing loads, severe hydrocarbon-fueled fires, and deep underwater immersion, with no escape of contents. The accident environments may be imposed upon the package singly or sequentially.

The package meets the requirements of 10 CFR 71* for Fissile Class I packages with a cargo of 15 grams of Pu-239, or other isotopic forms described herein, not to exceed 2 watts of thermal activity.

This SAR presents design and operational information including evaluations and analyses, test results, operating procedures, maintenance, and quality assurance

---

*Title 10 of the Code of Federal Regulations, Part 71, contains the rules and regulations of the NRC for the transportation of nuclear material. In referring to these and other regulations in the Code of Federal Regulations, an abbreviated form is used: 10 CFR 71.35(a) means Paragraph (a) of Section 71.35 of Part 71 of Title 10 in the Code of Federal Regulations.

information. Both tests and analyses were applied to confirm that the PAT-2 package meets the various statutory and regulatory requirements. Structural analyses address all of the stated requirements and, additionally, treat the containment vessel by finite element analysis and the overpack by an energy balance analysis.

Thermal analyses define maximum normal operating temperature with thermally active radioisotopic contents; thermal tests define maximum credible accident temperatures of the containment.

Leak-rate testing and plutonium containment analyses treat the problem of plutonium transport through very small apertures or cracks, for various extreme post-accident conditions imposed on the containment vessel and its internal capsule. Plutonium containment is confirmed to be orders of magnitude in excess of IAEA requirements (essentially, there would be no plutonium release).

Nuclear criticality analysis confirms, through the use of benchmarked (proven) codes, that the PAT-2 package qualifies as a Fissile Class I package, meaning that infinite arrays of damaged packages with the most fissionable contents permitted and with water shielding remain highly subcritical. However, since the PAT-2 is only intended for 15 grams maximum of fissile contents, it is Fissile Class exempt.

Nuclear shielding analyses confirm the required protection for biota from the effects of ionizing radiation in both the normal and post-accident conditions, conservatively satisfying all regulatory conditions.

1.2 PACKAGE DESCRIPTION

1.2.1 General

The PAT-2 package weighs between 70 and 74 pounds (33 kg nominally), due both to natural variations in the materials of construction and to fabrication variables, when loaded with 15 grams of plutonium. The package has an outside diameter of 15 inches (381 mm) and is 14 inches (356 mm) high. Its external appearance approximates that of a smooth stainless steel, right-circular cylinder with two protruding handles, as shown in Figure 1.2.1-1.

Engineering drawings and specifications for the package are included in Chapter 9, Appendix 9A. Material lists, dimensions, and material, process, and acceptance specifications are included on the drawings or in the specification documents.

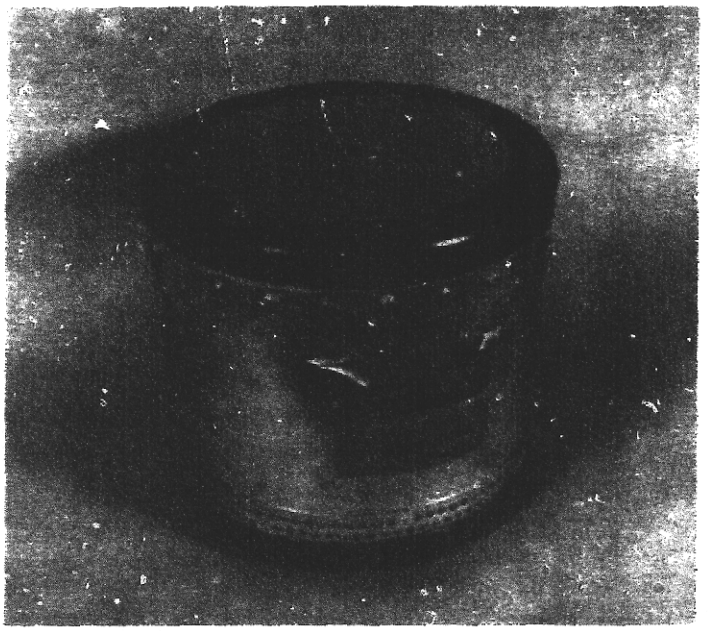


Figure 1.2.1-1. PAT-2 Package

1.2.2 Packaging

The PAT-2 packaging comprises three basic parts: (1) an iron-base superalloy containment vessel (designated TB-2 containment vessel), (2) a protective overpack assembly of redwood and maplewood with an embedded titanium inner assembly and a double-walled outer stainless-steel drum (all designated as the AQ-2 overpack), and (3) a stainless steel capsule (designated the C-1 capsule) within the TB-2 containment vessel. The TB-2 serves as the primary containment vessel, while the C-1 capsule provides the secondary containment required by 10 CFR 71, Part 42, for plutonium in excess of 20 Ci.

Figure 1.2.2-1 shows a cutaway view of the PAT-2 package and its essential elements.

The AQ-2 overpack consists of a double-walled outer drum of 0.056 inch (1.4 mm) 304 stainless-steel sheet metal with an overlapping and rounded top and bottom joint design, riveted at the bottom and bolted at the top. Immediately interior to this stainless steel container is an outer region of 3.6-inch (91-mm) thick grain-oriented redwood, a 0.25-inch (6.35-mm) thick titanium load spreader (7.5 inches (190 mm) in diameter) with ceramic felt backface insulation, and an inner region of grain-oriented maplewood, 1.6 inches (40 mm) thick. Redwood is used for high specific energy absorption on a volumetric and mass basis and for good char performance (fire protection). Maplewood is used for high ultimate crush strength within the smaller region of the load spreader. Titanium is used for its high strength-weight

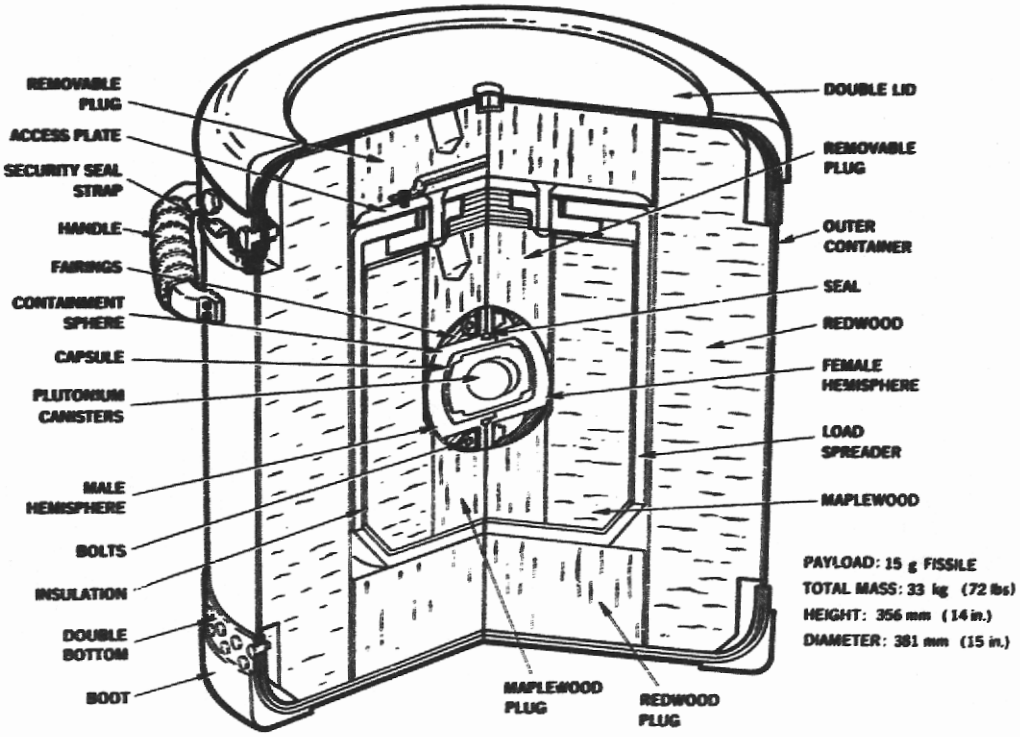


Figure 1.2.2-1. Cutaway View of the PAT-2 Package

ratio and for its high liquidus temperature. Components of the AQ-2 that do not need to be removed for access, to load and unload contents, are bonded in place with a high-strength flexible epoxy adhesive. The top and bottom corners of the AQ-2 are protected by a tough molded-in-place polybutadiene-based urethane (i.e., synthetic rubber) boot to protect the intentionally hollowed corners from denting during ordinary handling. Vent plugs at the top and bottom of the AQ-2 function in the high-speed impact and thermal accident environments.

The TB-2 spherical containment vessel, shown in Figures 1.2.2-2 and 1.2.2-3, is 88 mm (3.5 inches) outside diameter, is made of A-286 iron-base superalloy and is bolted shut with 20 A-286 bolts. The bolts are installed to a specified torque and the vessel is sealed by a copper gasket formed in place between knife-edge sealing beads in each hemisphere. An integral shear shoulder is included in the joint. This is a tough, sealed, high-temperature and high-pressure containment, which does not become vented in the accident environment.

The C-1 capsule, shown in Figures 1.2.2-4 and 1.2.2-5, is fabricated from Nitronic 60 stainless steel and utilizes a torqued screwthread joint with a sealant. The C-1 capsule provides double containment for plutonium contents greater than 20 Ci.

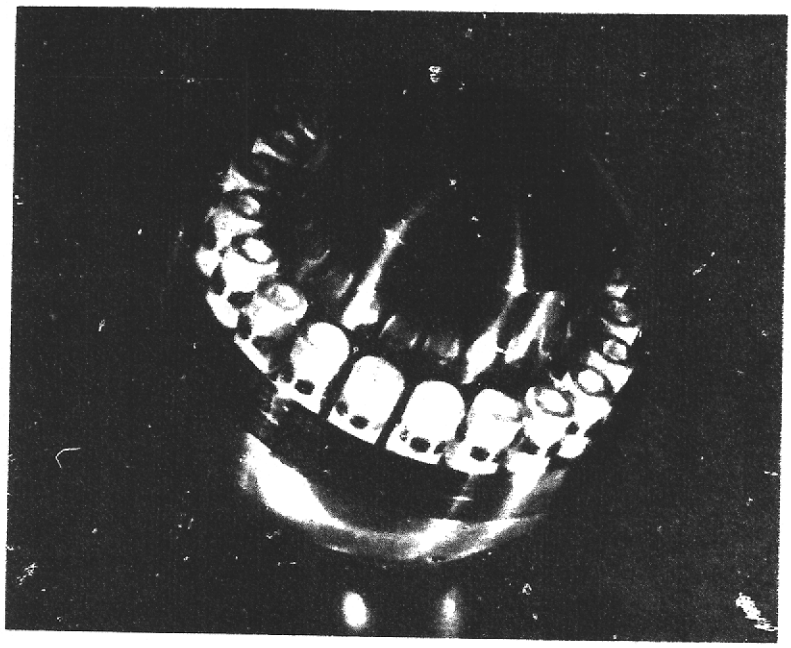


Figure 1.2.2-2. TB-2 Containment Vessel

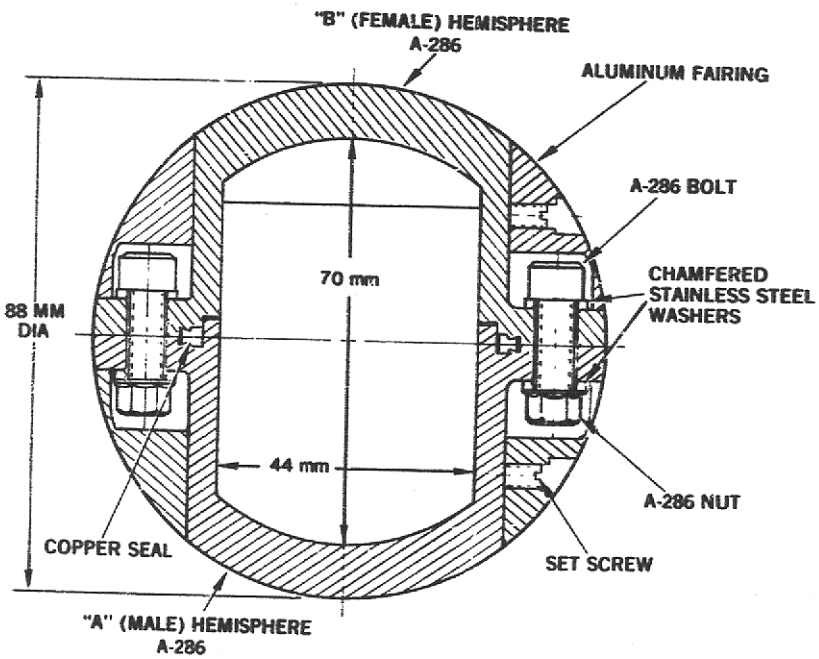


Figure 1.2.2-3. TB-2 Cross Section

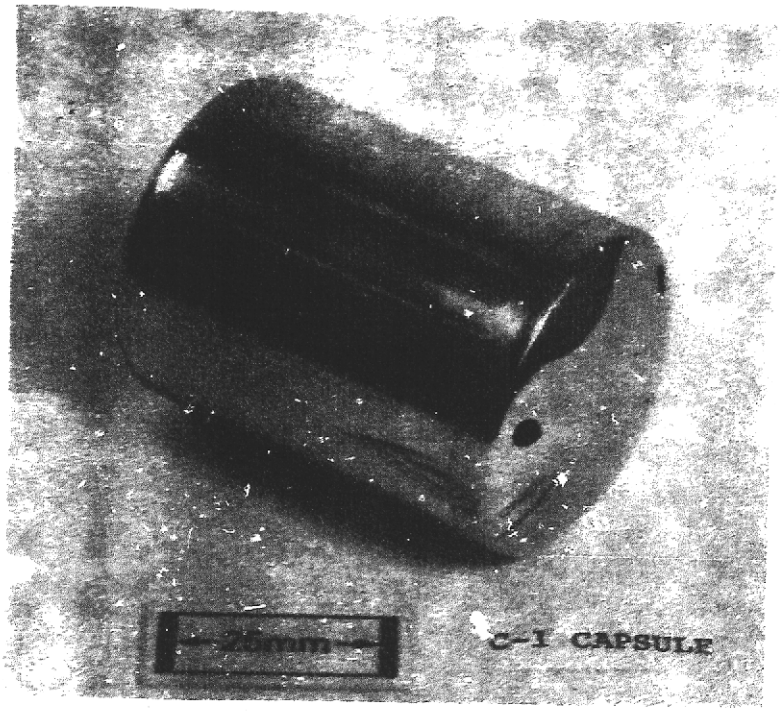


Figure 1.2.2-4. C-1 Capsule

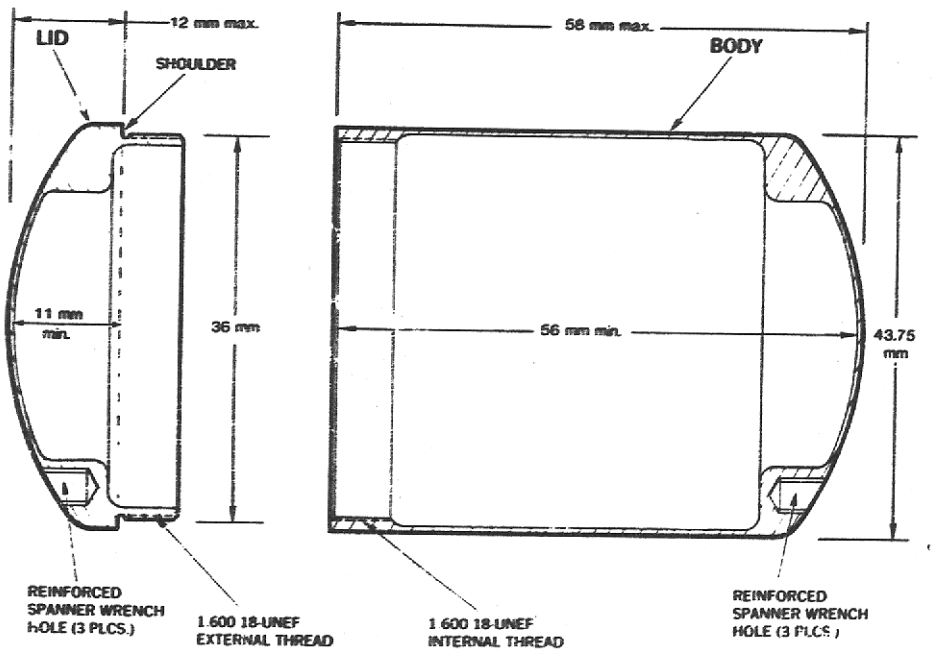


Figure 1.2.2-5. C-1 Capsule Cross Section

1.2.3 Operational Features

The PAT-2 package is intended to be one-man transportable if necessary and can be assembled or disassembled with hand tools. A pair of leather-padded handles are provided for hand-carry and tiedown, and fastening points are present to enable the attachment of security seals. The urethane boots, top and bottom, provide a rugged, skid-resistant surface for transport handling. An international radiation symbol (trefoil) is laser-beam embossed on the outer top cover.

The AQ-2 covers are fastened in place with twenty-four 1/4-inch aircraft bolts; finger grips are provided to aid in removing the outer cover, and finger holes are provided in the inner cover; the outer removable redwood plug has finger holes. The titanium load spreader has a removable cover held in place with internal lugs and four screws. Upon removal of these screws, the cover may be rotated 1/4 turn using the handle provided, and then the cover may be removed. The inner removable maplewood plug has finger holes to facilitate removal.

The TB-2 containment vessel, which is spherical in shape, may be rolled out of its location into the operator's hand by tilting the AQ-2 overpack. Aluminum fairings or rings, which cover the TB-2 closure bolts, are held in place with three nylon-tipped setscrews, which are loosened with a small screwdriver. The twenty 1/4-inch superalloy bolts may be assembled or disassembled with a hex-drive wrench and a socket wrench; tightening requires the use of a torque wrench. The TB-2 is sealed by means of a copper gasket, which can be replaced as necessary.

The C-1 capsule is opened or closed by using a special three-pin spanner wrench (provided); tightening requires the use of a torque wrench; sealing is accomplished by the use of Teflon™ tape on the threaded joint.

Brass or aluminum canisters may be used internal to the C-1 capsule to accommodate various radioactive contents. The canisters, which may also be equipped with quartz liners for nuclear sample processing, provide a means for the initial packaging of a radioactive material and provide separation for groups of samples or payloads.

These features of the PAT-2, when operationally used according to the procedures described in Chapter 7 and when maintained and tested as described in Chapter 8, assure that this package will meet acceptance criteria, as described in Chapters 4, 5, and 6, with regard to plutonium containment under normal and accident conditions of transport.

The relatively small size and weight of the PAT-2 is intended to make it compatible with a wide variety of air transport services.

1.2.4 Contents of Package

The contents of the PAT-2 package are limited by the following requirements:

1. Material type: Plutonium and/or uranium in various isotopic compositions, subject to the following limitations.

2. Material form: The plutonium and/or uranium must be in solid form; the solid form may be an oxide powder, a sintered pellet of oxides, a metal, or hydrated salts of plutonium or uranium (derived from dried liquids).

3. Material quantity:
   a) The maximum mass of fissile isotopes U-235, Pu-239, and Pu-241 is limited to 15 grams total,
   b) The total mass of plutonium oxide or uranium oxide material in powder form is limited to 40 grams (the 15-gram fissile limitation is not to be exceeded).
   c) The total mass of oxide material in sintered form is limited to 120 grams; the total mass of metal material is limited to 120 grams; in each case the 15-gram fissile limitation is not to be exceeded.
   d) The total mass of plutonium sulfate tetrahydrate, $Pu(SO_4)_2 \cdot 4H_2O$, is limited to 3 grams.
   e) The total mass of plutonium nitrate dihydrate, $Pu(NO_3)_4 \cdot 2H_2O$, is limited to 3 grams.
   f) The total mass of Pu-238 is limited to 3.57 grams (this will be a 2-watt heat source--see item 5 below); Pu-238 may be in combination with the isotopes listed in (a) above, with the total fissile mass limited to 15 grams.

4. Moisture content: For contents of powders or salts, a maximum of 0.5 gram of moisture content (water) in addition to the waters of hydration in the salts, is permissible.

5. Internal decay heat: The isotopic composition of all contents must be such that a thermal activity of 2 watts is never exceeded while contents are in the PAT-2 package; this may be calculated as follows:

$$\frac{\text{watts}}{g}\,{}^{238}Pu \times g\,{}^{238}Pu + \frac{\text{watts}}{g}\,{}^{239}Pu \times g\,{}^{239}Pu$$

$$+ \frac{\text{watts}}{g}\,{}^{240}Pu \times g\,{}^{240}Pu + \frac{\text{watts}}{g}\,{}^{241}Pu \times g\,{}^{241}Pu$$

$$+ \frac{\text{watts}}{g}\ {}^{242}Pu \times g\ {}^{242}Pu + \frac{\text{watts}}{g}\ {}^{241}Am \times g\ {}^{241}Am$$

$$+ \frac{\text{watts}}{g}\ \text{(fission products or other transuranic isotopes)}$$

$$\times\ g\ \text{(fission products or other transuranic isotopes)} < 2\ \text{watts.}$$

Note: Due to the increase of decay power with time, the maximum decay power is calculated for the isotopic composition which will exist at the longest storage time, or the peak power period.

6. Volatile packaging material permitted within the C-1 capsule is limited to 9 grams maximum polyvinylchloride (PVC) plastic in the form of seals and bags and 0.3 gram maximum of polytetrafluoroethylene (PTFE), e.g., Teflon™, tape for sealing the C-1 capsule threads.

7. Nonvolatile packaging material permitted within the C-1 capsule is limited to 18 grams maximum of quartz (SiO_2) or glass and 50 grams maximum of brass or 16 grams of aluminum.

8. The only materials or items permitted within the TB-2 containment vessel are
   a) A C-1 capsule loaded in accordance with the above limitations 1 through 7,
   b) A maximum of 2 grams of aluminum foil to shim the fit between the spherical ends of the C-1 capsule and the interior spherical portion of the TB-2 containment vessel, and
   c) The copper seal (part number T67004) for the TB-2 containment vessel.

CHAPTER 2

STRUCTURAL EVALUATION

2.1 SUMMARY

Structural evaluation of the PAT-2 package was accomplished by both test and analysis. The principle structural and test criteria were developed from:

- NUREG-0360, Qualification Criteria to Certify a Package for Air Transport of Plutonium[1]
- Code of Federal Regulations, Title 10, Part 71, "Packaging of Radioactive Materials for Transport and Transportation of Radioactive Materials Under Certain Conditions"[2]
- IAEA Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1973 ed., amended 1979.[3]

Of these criteria, the design-determining environment is the synergistic effect of high-speed impact onto an unyielding target, in sequence with puncture, double-slash, and a high-temperature, 1-hour, jet fuel fire (all from NUREG-0360), with package acceptance criteria of containment, shielding, and subcriticality.

Six final-design PAT-2 packages were subjected to the required sequential tests of NUREG-0360, with varying impact attitudes and varying radioisotopic contents.

One containment vessel was subjected to the individual hydrostatic test required by NUREG-0360. An aerodynamic free-fall velocity analysis is presented, as required. Another final-design PAT-2 package was subjected to the normal conditions of transport requirements of 10 CFR 71 Appendix A, examined, and reassembled, and then subjected to the 10 CFR 71 Appendix B hypothetical accident conditions of transport. Also, two PAT-2 packages were subjected to a special test sequence relating to large longitudinal crush loads from forward locations in crashed cargo aircraft.

The results of these tests and of various structural analyses follow; it will be shown that the PAT-2 package successfully survives all tests and that all analyses indicate adequate performance and/or factors of safety.

2.2 MASS PROPERTIES AND MECHANICAL PROPERTIES

2.2.1 Weights and Center of Gravity

Typical weights of major elements of the PAT-2 package are as shown:

	lb	kg
TB-2 Containment Vessel (typical, complete with C-1 capsule and a payload)	4.3	1.95
AQ-2 Overpack	67.7	30.7
PAT-2 Package	72.0	32.66

The weight of the AQ-2 overpack varies by about ±2 pounds, largely due to the natural variation in the weight of available kiln-dried redwood and maplewood.

The centroid of the PAT-2 package is located approximately at its geometric center -- on the package longitudinal center line and approximately 7-1/8 inches (188 mm) above the bottom surface.

2.2.2 Mechanical Properties Of Materials

The references cited for each material are the primary sources for the mechanical properties given.

2.2.2.1 Stainless Steel 304[4 5]

The mechanical properties of stainless steel 304 are

f_{tu} = 75 ksi (517 MPa) minimum,

f_{ty} = 30 ksi (207 MPa),

E = 29,000 ksi (200 GPa) (dynamic and low temperature),

μ = 0.26,

ρ = 0.29 lb/in^3 (8.03 x 10^3 kg/m^3),

40% elongation in 2 inches (5 cm), and

50% minimum reduction in area.

2.2.2.2 Redwood[6 7]

The mechanical properties of clear redwood, kiln dried, per SS-T67026, with a maximum density of 0.014 lb/in^3 (0.38 g/cm^3), are

$$\rho = 0.012 \text{ to } 0.014 \text{ lb/in}^3 \ (0.33 \text{ to } 0.38 \text{ g/cm}^3),$$

Specific Energy Absorbed = 22,380 ft.lb_f/lb_m (66.9 kJ/kg), and

$$f_c = 5{,}380 \text{ psi } (37.1 \text{ MPa}) \text{ at room temperature.}$$

See Appendix 2A for additional information on redwood materials.

2.2.2.3 Maplewood[8]

The maplewood is hard northern, select or better, kiln dried, rough, per National Hardwood Lumberman's Association Rules. The mechanical properties of maple are

$$\rho = 0.02 \text{ lb/in}^3 \ (0.55 \text{ g/cm}^3) \text{ maximum and}$$

Specific Energy Absorbed = 19,000 ft.lb_f/lb_m (56.8 kJ/kg).

See Appendix 2B for additional information on maplewood materials.

2.2.2.4 A-286 Iron-Base Superalloy[9]

The mechanical properties of A-286 iron-base superalloy are

$$f_{tu} = 150 \text{ ksi } (1.03 \text{ GPa}),$$

$$f_{ty} = 100 \text{ ksi } (0.69 \text{ GPa}),$$

$$E = \begin{cases} 29{,}000 \text{ ksi } (200 \text{ GPa}) \text{ at } 75°\text{F } (24°\text{C}) \\ 23{,}500 \text{ ksi } (162 \text{ GPa}) \text{ at } 1000°\text{F } (538°\text{C}) \\ 22{,}900 \text{ ksi } (158 \text{ GPa}), \text{ at } 1100°\text{F } (593°\text{C}) \end{cases}$$

$$\mu = \begin{cases} 0.306 \text{ at } 75°\text{F } (24°\text{C}) \\ 0.328 \text{ at } 1{,}000°\text{F } (538°\text{C}) \\ 0.331 \text{ at } 1{,}100°\text{F } (593°\text{C}), \end{cases}$$

$$\rho = 0.286 \text{ lb/in}^3 \ (7.89 \text{ g/cm}^3), \text{ and}$$

$$\alpha(80\text{-}1{,}200°\text{F}) = 9.9 \times 10^{-6} \text{ in./in./°F } (1.8 \times 10^{-5} \text{ cm/cm/°C}).$$

2.2.2.5 Aluminum 6061-T6[10]

The mechanical properties of aluminum 6061-T6 are

$$f_{tu} = 42 \text{ ksi } (290 \text{ MPa}),$$

$$f_{ty} = 35 \text{ ksi } (241 \text{ MPa}),$$

$$E = 9{,}900 \text{ ksi } (68 \text{ GPa}),$$

$$\mu = 0.33, \text{ and}$$

$$\rho = 0.098 \text{ lb/in}^3 \ (2.71 \text{ g/cm}^3).$$

2.2.2.6 110 Electrolytic Tough Pitch Copper[11]

The mechanical property of 110 electrolytic tough pitch copper is

$$\alpha = 9.8 \times 10^{-6} \text{ in./in./°F } (1.8 \times 10^{-5} \text{ cm/cm/°C}).$$

2.2.2.7 Nitronic 60 Stainless Steel[11]

The room-temperature properties of Nitronic 60 stainless steel are

$$E = 28 \times 10^{6} \text{ psi } (1.93 \times 10^{5} \text{ MPa}),$$

$$\sigma_y = 56{,}000 \text{ psi } (386 \text{ MPa}),$$

$$\sigma_{ult} = 101{,}000 \text{ psi } (696 \text{ MPa}), \text{ and}$$

$$\text{Elongation} = 60\%.$$

2.3 CONTAINMENT VESSEL STRESS ANALYSES

The TB-2 containment vessel and the C-1 capsule were evaluated extensively by test, as described in the remainder of this chapter. Due to the importance of the TB-2 and the C-1 to the PAT-2 package, it is desirable to analyze the most severe cases of stress and to calculate the factors of safety.

2.3.1 TB-2 Maximum Normal Operating Stress (MNOP)

The MNOP factor of safety (based upon the highest combined stress component) can be determined from the 3,280 psi calculation performed in Appendix 2C by utilizing linear superposition. For the maximum normal operating pressure of 31 psia, the factor of safety is 471, whereas for 1.5 times MNOP, the factor of safety is 292.

2.3.2 TB-2 Maximum Credible Accident Stress (MCAP)

The MCAP of the TB-2 is calculated in Chapter 4 to be 3,280 psi (22.6 MPa) based upon an accident temperature bounding assessment of 1,080°F (582°C); see Chapter 3. Details of the analysis are presented in Appendix 2C. The finite-element static-elastic computer program SASL was utilized for this load case with suitable closed-form calculations for general verification of the SASL program for the particular geometry of the TB-2. Material properties utilized were those corresponding to the 1,080°F (582°C) test temperature.

Profiles of the stress fields in the TB-2 vessel are shown in Appendix 2C. Extreme stresses were found to be as follows:

Stress Component	Maximum Value ksi (MPa)	Minimum Value ksi (MPa)	Factor of Safety
Radial	16.1 (111)	-19.7 (-136)	
Axial	26.1 (180)	-16.4 (-113)	
Circumferential	17.1 (118)	- 6.0 (- 41)	
Combined (von Mises)	22.4 (154)	---	4.46

Comparison of any of these individual values, particularly the von Mises stress, to the material yield stress of 100 ksi (689 MPa) indicates that the vessel is stressed only to a fraction of the yield stress under this internal pressure of 3,280 psi (22.6 MPa).

The bolted joint, also analyzed in Appendix 2C, is calculated to sustain a stress of 99.368 ksi (685 MPa) per bolt at the MCAP condition; 145 ksi (1000 MPa) is the allowable stress at this condition, giving a factor of safety of approximately 1.46. The shear load in each nut at MCAP is 3,617 lb_f (16.09 kN), and the capacity is 10,000 lb_f (44.48 kN).

2.3.3 C-1 Capsule Stress Analysis

The most severe requirements on the C-1 capsule are that it provide double (secondary) containment under the conditions of 10 CFR 71 Appendices A and B, and that it be tested at 150% MNOP. Both of these conditions, as developed in Sections 3.3.5, 3.4.4, 4.3.1, and 4.4.1, are satisfied by a 50-psia (345-kPa) internal pressure condition. At this condition, the maximum normal stress in the C-1 body is 4,000 psi (27.6 MPa), the maximum normal stress in the C-1 cap is 4,134 psi (28.5 MPa), and the maximum stress in the threaded joint is 187 psi (1.29 MPa); the lowest factor of safety associated with those stresses is 13.5. Appendix 2C presents a complete stress analysis of the C-1 capsule.

2.4 GENERAL STANDARDS FOR ALL PACKAGES (10 CFR 71.31)

2.4.1 Chemical and Galvanic Reactions

There are no significant chemical or galvanic reactions among the PAT-2 package components or between the package and package contents.

The majority of surface contacts within the PAT-2 package involve epoxy-bonded woods and ceramic felt insulation. Metallic contacts include the 304 stainless steel drum of the AQ-2 overpack contacting cadmium-plated steel bolts and highly corrosion-resistant A-286 rivets, the titanium load spreader contacting an aluminum handle and cadmium-plated steel screws, the A-286 alloy containment vessel

contacting 6061 aluminum fairings (outside) and Nitronic 60 stainless steel and a copper gasket (inside), and the C-1 capsule (Nitronic 60 stainless steel) contacting the various radioisotopic contents, usually in brass canisters. These interfaces present no significant or known corrosion problems.

2.4.2 Positive Closure

Positive closure of the double PAT-2 cover is provided by twenty-four 1/4-inch steel aircraft-quality bolts, passing through the double wall of the AQ-2 drum and through both the outer and inner covers, into internal nut plates. The bottom end of the AQ-2 is secured by one hundred eighty 1/8-inch A-286 rivets, with a joint designed to equal the parent strength of the drum body or covers. In severe crash and vibration testing, these drum joints have never opened.

The titanium load spreader is closed by a pattern of four large lugs in the body which correspond to lugs on the titanium cover. Four 3/8-inch screws prevent rotation of the lugs to an open position. In severe crash and vibration testing, this joint has never opened.

Positive closure of the TB-2 containment vessel is provided by twenty 1/4-inch A-286 bolts and nuts, and positive closure of the C-1 capsule is provided by a 1.600-inch threaded joint. These closures are further discussed in Chapter 4, Containment.

2.4.3 Lifting and Tiedown Devices

Para. II.D.2 of NUREG-0360 requires that plutonium packages on board aircraft must be securely cradled and tied down with a tiedown system capable of providing package restraint against the following forces acting separately relative to the deck of the aircraft:

- Upward -- 2g
- Forward -- 9g
- Sideward -- 1.5g
- Downward -- 4.5g

Cases 1, 2, and 3, following, will snow that the permanent (riveted and welded) PAT-2 handles are qualified for a 9g load up, down, or at 45° up from the down direction, and 9g laterally, with the handles in line with the direction of travel or sideward to the direction of travel. Thus, the NUREG-0360 tiedown requirement can be satisfied by proper air carrier attachments to these handles.

Additionally, 10 CFR 71.31(d)(1) requires that the tiedown device (handle) be capable, without yielding, of reacting a combined loading of

- Vertical -- 2g (up or down)
- Horizontal -- 10g (in direction of flight)
- Horizontal -- 5g (transverse)

Cases 5 and 6, following, will address this requirement.

In most cases, FAA-approved carrier-provided cargo containers or securing nets would logically be used with the PAT-2. The PAT-2 handles are only about 9 inches (230 mm) above the container base, and most commercial directly applied aircraft tiedown devices would be too large to accommodate this small package; the handles are actually provided for hand-carry by personnel. However, since in-flight use of the handles is not blocked or otherwise prohibited, the following analyses are required by the regulations cited above.

Also, 10 CFR 71.31(d)(3) elicits the following response. If the PAT-2 handles are forcibly ripped off the package by severe overload, failure of the highly ductile 304 stainless steel drum body is not expected, and shear failure in the heat-affected zone of the weld at the handle attachment point is predicted. The resultant four holes, about 1 square inch each, would have a negligible affect on package survivability when viewed in the reality of the NUREG-0360 puncture and double-slash tests, which open large holes in the AQ-2 overpack (as reported in detail, with supporting photographs, later in this chapter). Also, all appropriate NUREG-0360 high-speed impact tests onto an unyielding target were done directly on these handles, wherever possible, with no affect on package survivability.

Details of the lifting handles are shown in Figure 2.4.3-1. The handles are fabricated from 3/4-inch, type 304 stainless steel tubing, 0.065 inch (1.65 mm) thick, and are fastened to the outer skin of the PAT-2 package, as shown in Figure 2.4.3-2, by a combination of riveting and welding. As a conservative measure in this analysis, the strength of the rivets is ignored. The weld region, as indicated in Figure 2.4.3-1, extends all around each end of the handles.

The weld design, at minimum dimensions, is illustrated in Figure 2.4.3-3(a). For further conservatism, the weld thickness is taken at the smallest throat thickness, based on the dimension of the handle stock being welded, as shown in Figure 2.4.3-3(b).

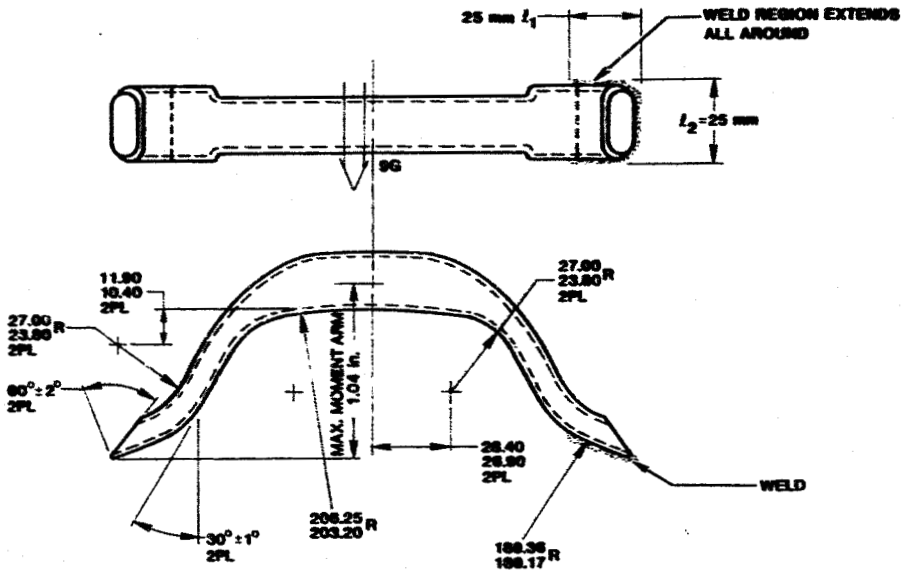


Figure 2.4.3-1. Details of Lifting Handle

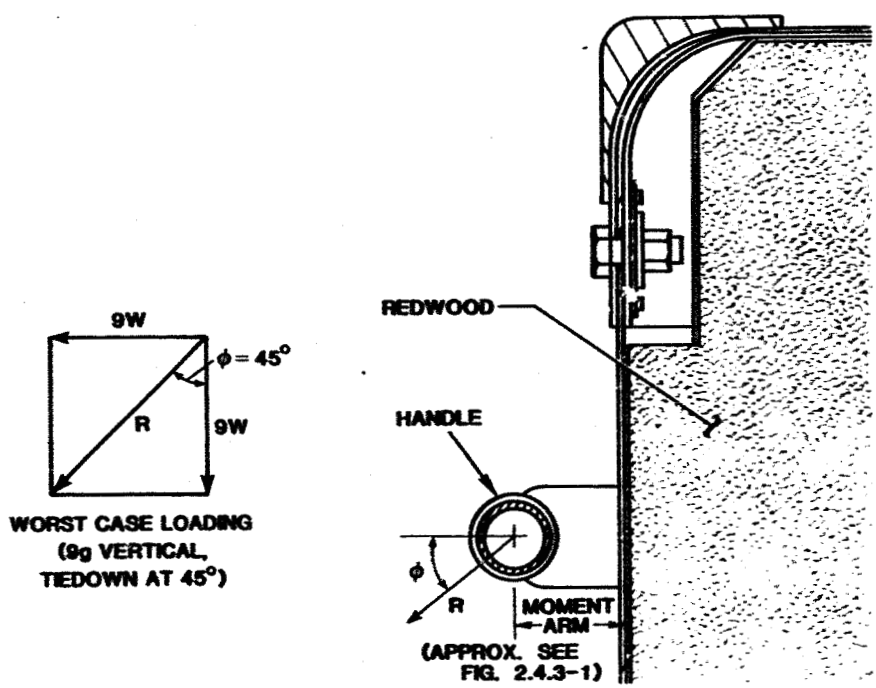
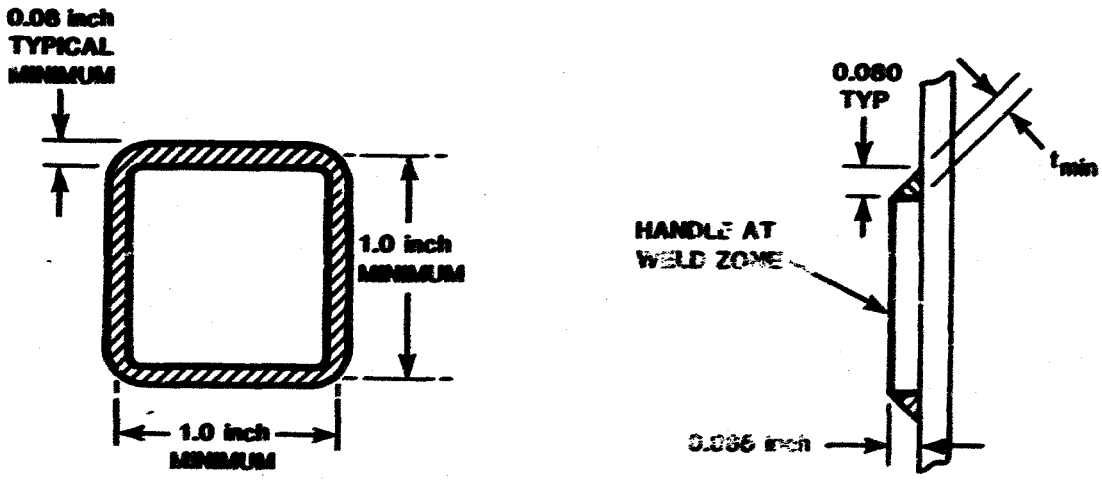


Figure 2.4.3-2. Mounting of Handle on Outer Skin



a) Weld Design, Minimum Dimensions

b) Handle Dimensions and Minimum Throat Thickness

Figure 2.4.3-3. Weld Design on PAT-2 Handles

The minimum throat thickness is calculated as follows:

$$t_{min} = 0.707h$$
$$= 0.707\ (0.0605)$$
$$= 0.046 \text{ inch}$$

Shear failure theory is now applied to this minimum weld throat thickness.

For annealed 304 stainless steel, the minimum tensile yield strength is[11]

$$S_y = 35{,}000 \text{ psi.}$$

For the American Institute of Steel Construction (AISC) welding code, the permissible working stress for a butt or fillet weld in shear is*

$$\sigma_{allow} = 0.40S_y$$
$$= 0.40(35{,}000) = 14{,}000 \text{ psi.}$$

*Joseph E. Shigley, Mechanical Engineering Design, 2nd ed. (New York: McGraw Hill, 1972).

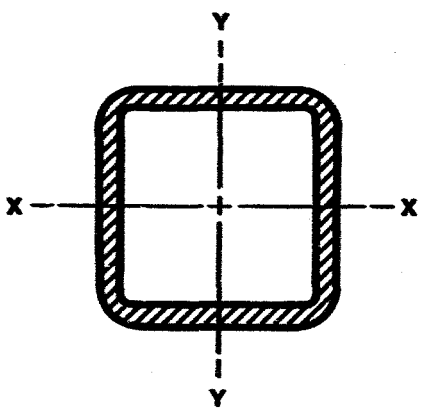
For the maximum shear stress failure theory, the factor of safety (F.S.) is*

$$F.S. = \frac{S_y}{2\,\tau_{max}} ,$$

where τ_{max} is the maximum shearing stress. The minimum weld shear area is

$$A = (4)(1)(0.046) = 0.184 \text{ in}^2 .$$

The moments of inertia, I_{xx} or I_{yy}, are illustrated and derived in Figure 2.4.3-4.



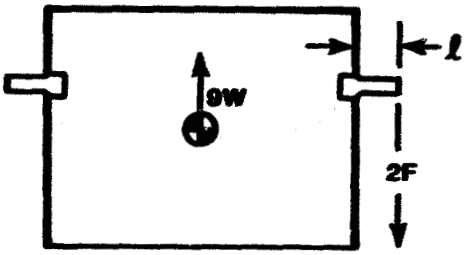
$$I = 2\left[\frac{(1)(0.046)^3}{12} + (0.046)(1)(0.5)^2\right] + 2\left[\frac{(0.046)(1)^3}{12}\right] = 0.0307 \text{ in}^4$$

Figure 2.4.3-4. Moments of Inertia

In the following five cases, the handle is assumed to be very rigid (3/4-inch o.d. stainless steel tubing, 0.065-inch-thick wall) compared to the PAT-2 skin (15-inch o.d. stainless steel wall, double 0.028-inch-thick sheet, 0.056 inch total thickness). Shear and moment loads carry through the rigid handle and are reacted by the welds.

Case 1 assumes a 9g tiedown, with the load straight down. For the package to be in static equiblibrium, both handles must be tied down and both must react the load. The load on one handle is illustrated and derived in Figure 2.4.3-5.

*Glenn Murphy, Advanced Mechanics of Materials (New York: McGraw Hill, 1946), article 36; and Michael R. Lindeburg, Mechanical Engineering Review Manual, 5th ed. (San Carlos, CA: Professional Engineering Registration Program, 1980), p 12-4.



$2F = 9(72/2)$

$= 324$ pounds per handle

Figure 2.4.3-5. Forces Acting on Package in Case 1

For the rigid symmetrical handle, welded at both ends, the factor of safety is derived as follows:

$F = 324/2 = 162$ pounds per attachment point

$\ell = 1.5$ inches

$\text{Moment} = F\ell = (162)(1.5) = 243\ \text{lb}_f\cdot\text{in.}$

$$\sigma = \frac{F}{A} + \frac{Mc}{I_{xx}} = \frac{162}{0.184} + \frac{(243)(0.523)}{0.0307} = 880\ \text{psi}\ \overset{+}{\sigma}_{s_y} + 4{,}140\ \text{psi}\ \overset{+}{\sigma}_x$$

The principal stress is

$$\sigma_{princ} = \frac{\sigma_x}{2} + \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + (\sigma_s)^2} = \frac{4{,}140}{2} + \sqrt{\left(\frac{4{,}140}{2}\right)^2 + 880^2}\ .$$

$$\sigma_{max} = 2{,}070 + 2{,}250 = 4{,}320\ \text{psi}$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + \sigma_s^{\ 2}} = 2{,}250\ \text{psi}$$

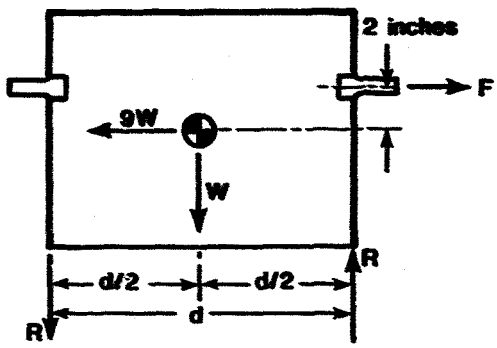
$$\text{F.S.} = \frac{14{,}000}{2{,}250} = 6.2 \quad \text{(AISC code)}$$

or

$$\text{F.S.} = \frac{35{,}000}{(2)(2{,}250)} = 7.8 \quad \text{(maximum shear stress failure theory)}$$

Note that the identical situation exists for a 9g upward reaction on the handle.

Case 2 assumes a 9g tiedown load in a lateral direction. In this case, the package cannot be in static equilibrium if only one handle reacts the load in the lateral direction, due to the moment caused by the 2-inch offset between the package center of gravity and the handle location. This imbalance can be restored by a 86.4-pound downward force acting vertically through the two handle attachment points (Figure 2.4.3-6), or 43.2 pounds additional shear load per weld. Any practical tie-down system must (and will) include the ability to react vertical loads.



$F = 9W = (9)(72) = 648$ pounds

$d = 15$ inches

$\Sigma M_{cg} = 0$

$(648)(2) = Rd = 15R$

$R = 86.4$ pounds

Figure 2.4.3-6. 9g Tiedown Load in Lateral Direction

Applied to the two locations, each weld has the stress:

$$\sigma = \frac{R/2}{A} + \frac{F/2}{A}$$

$$= \frac{43.2}{0.184} + \frac{324}{0.184} = 235 \text{ psi } \overset{+}{\sigma}_{s_y} + 1{,}761 \text{ psi } \overset{+}{\sigma}_x$$

The factor of safety is derived as follows:

The maximum principal stress is

$$\sigma_{max} = \frac{\sigma_x}{2} + \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + (\sigma_s)^2} = \frac{1{,}761}{2} + \sqrt{\left(\frac{1{,}761}{2}\right)^2 + 235^2} = 880 + 911$$

$$= 1{,}791 \text{ psi} .$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + (\sigma_s)^2} = 911 \text{ psi}$$

---

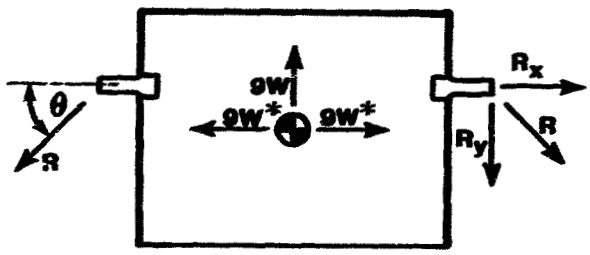
*Murphy, 1946; article 36.

$$F.S. = \frac{14,000}{911} = 15.4 \text{ (AISC code)}$$

or

$$F.S. = \frac{35,000}{(2)(911)} = 19.2 \text{ (maximum shear stress failure theory)}$$

Case 3 assumes a 9g tiedown load at a 45° angle. In Case 3, both handles react the 9g vertical reaction, as in Case 1, and one handle will additionally react the 9g lateral load without restoring moment load (the vertical downward component of loading at each handle maintains static equilibrium). The forces acting on the package are illustrated in Figure 2.4.3-7, and the previously calculated stresses are combined using linear superposition.



$$\sigma_{case\ 1} = 880 \overset{+}{\sigma}_{s_y} + 4,140 \overset{+}{\sigma}_x$$

$$\sigma_{case\ 2} = 1,761 \overset{+}{\sigma}_x \text{ (lateral component only)}$$

*9g lateral load may be applied in either direction but does not occur in both directions simultaneously.

Figure 2.4.3-7. Forces with a 9g Tiedown Load, 45° Angle

The factor of safety for this case is derived as follows:

$$\sigma_{case\ 3} = 880 \overset{+}{\sigma}_{s_y} + 4,140 \overset{+}{\sigma}_x + 1,761 \overset{+}{\sigma}_x$$

$$= 880 \overset{+}{c}_{s_y} + 5,901 \overset{+}{\sigma}_x$$

$$\sigma_{max} = \frac{\sigma_x}{2} + \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + (\sigma_s)^2} = 2,950 + 3,079 = 6,029 \text{ psi}$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + (\sigma_s)^2} = 3,079 \text{ psi}$$

$$F.S. = \frac{14,000}{3,079} = 4.5 \quad \text{(AISC code)}$$

or

$$F.S. = \frac{35,000}{(2)(3,079)} = 5.7 \quad \text{(maximum shear stress failure theory)}$$

Case 4 addresses a cargo loading configuration in which the package handles are fore and aft on board an aircraft and where the handles are subject to 10g in the direction of travel, 5g laterally, and 2g up or down. Figure 2.4.3-8 illustrates Case 4.

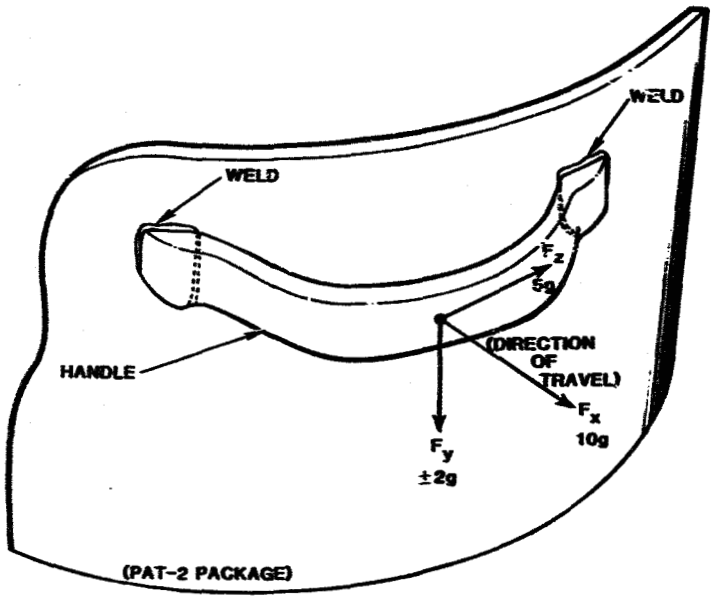


Figure 2.4.3-8. Load for Handles Fore and Aft on Board Aircraft

In spite of the fact that the up or down loads, F_y (±2g), and the side loads, F_z (5g), must be reacted by both handles for static equilibrium to exist, the above loads will be conservatively assumed to act simultaneously on one handle. The shear and normal stresses for each component of load are determined separately, and then the stresses are combined by linear superposition, as shown in the following.

$$\sigma_{F_x} = \frac{10}{9}\left(\sigma_{\text{case 2 lateral}}\right) = \frac{10}{9}(1,761) = 1,957 \text{ psi } \vec{\sigma}_x$$

Note that Case 1 was 9g up or down on two handles. Then,

$$\sigma_{F_y} = (2)(2/9)(\text{Case 1}) = (4/9)(\text{Case 1})$$

$$= (4/9)(880) + (4/9)(4{,}140)$$

$$= 391 \text{ psi } \overset{\downarrow}{\sigma}_{s_y} + 1{,}840 \text{ psi } \overset{\rightarrow}{\sigma}_x$$

σ_{F_z}: $F_z = (72)(5) = 360$ pounds

$\ell = 1.5$ inches

$M_{tot} = F_z \ell = 540 \text{ lb}_f \cdot \text{in.}$

Conservatively assuming that the rigid handle is split across its center and that each welded end must independently react half this moment, then

$$M_{act} = \frac{F_z \ell}{2} = 270 \text{ lb}_f \cdot \text{in., each weld}$$

Also, both welds will react the shear component of F_z, and the shear load is

$$F = \frac{F_z}{2} = \frac{360}{2} = 180 \text{ pounds, each weld}$$

Then,

$$\sigma_{F_z} = \sigma_s + \sigma_{normal}$$

$$= \frac{180}{0.184} + \frac{(270)(0.5)}{0.0307}$$

$$= 978 \text{ psi } \overset{\nearrow}{\sigma}_{s_z} + 4{,}397 \text{ psi } \overset{\rightarrow}{\sigma}_x$$

These stresses are now summed by linear superposition (Figure 2.4.3-9).

$$\sigma_{x_{total}} = \sigma_{x_x} + \sigma_{y_x} + \sigma_{z_x} = 1{,}957 + 1{,}840 + 4{,}397 = 8{,}113 \text{ psi}$$

$$\sigma_{s_y} = 391 \text{ psi}$$

$$\sigma_{s_z} = 978 \text{ psi}$$

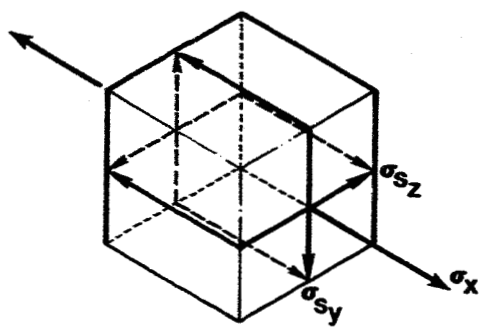


Figure 2.4.3-9. Sum of Stresses

The resultant shear stress is

$$\sigma_{s_{result}} = \sqrt{(391)^2 + (78)^2} = 1{,}053 \text{ psi}$$

Thus simplified, the stresses are as shown in Figure 2.4.3-10.

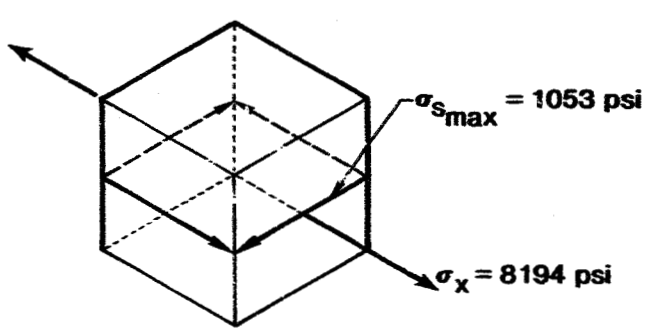


Figure 2.4.3-10. Principal Stresses

The maximum principal stress is then

$$\sigma_{max} = \frac{\sigma_x}{2} + \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + (\sigma_s)^2}$$

$$= \frac{8{,}194}{2} + \sqrt{\left(\frac{8{,}194}{2}\right)^2 + (1{,}053)^2}$$

$$= 4{,}097 + 4{,}230 = 8{,}327 \text{ psi}$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + (\sigma_s)^2} = 4{,}230 \text{ psi}$$

$$F.S. = \frac{14{,}000}{4{,}230} = 3.3 \quad \text{(AISC code)}$$

or

$$F.S. = \frac{35{,}000}{(2)(4{,}230)} = 4.1 \quad \text{(maximum shear stress failure theory)}$$

Case 5 assumes that the handles are athwartships on board an aircraft and are subject to 10g in the direction of travel, 5g laterally, plus 2g up or down. Figure 2.4.3-11 illustrates this case.

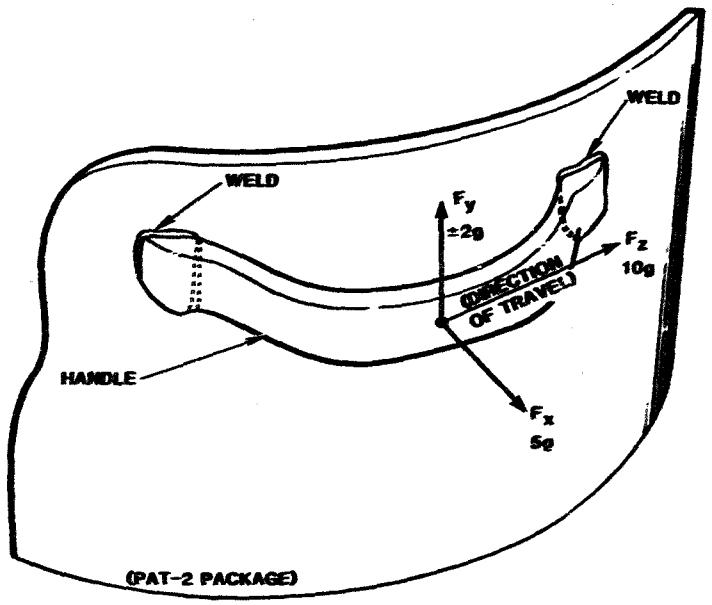


Figure 2.4.3-11. Case 5: Handles Athwartships on Board Aircraft

For conservatism, is it again assumed that all of the loads can act simultaneously on one handle. The shear and normal stresses are derived for each component of the load, and the stresses are again combined by linear superposition.

$$\sigma_{F_x} = (1/2)(\sigma_{Case\ 4}) = (1/2)(1{,}957) = 979 \text{ psi } \overset{+}{\sigma}_x$$

$$\sigma_{F_y} = \sigma_{Case\ 4} = 391 \text{ psi } \overset{+}{\sigma}_{s_y} + 1{,}840 \text{ psi } \overset{+}{\sigma}_x$$

$$\sigma_{F_z} = (2)(\text{Case } 4) = (2)(978) + (2)(4{,}397)$$
$$= 1{,}956 \underset{\sigma_{s_z}}{\nearrow} + 8{,}794 \underset{\sigma_x}{\rightarrow}$$

Summing these stresses by linear superposition,

$$\sigma_{x_{total}} = 979 + 1{,}840 + 8{,}984 = 11{,}613 \text{ psi}$$

$$\sigma_{s_y} = 391 \text{ psi}$$

$$\sigma_{s_z} = 1{,}956 \text{ psi}$$

The resultant shear stress is

$$\sigma_{s_{result}} = \sqrt{391^2 + 1{,}956^2} = 1{,}995 \text{ psi}$$

Thus simplified, the stresses are as shown in Figure 2.4.3-12.

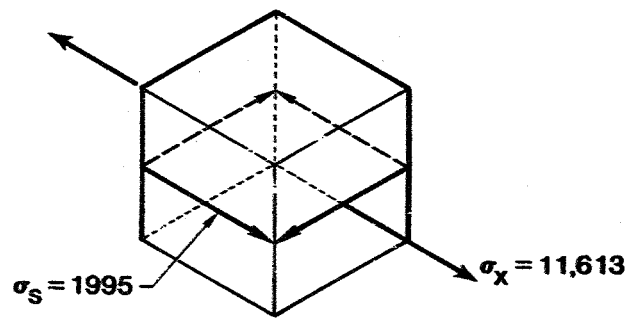


Figure 2.4.3-12. Stresses in Case 5

The maximum principal stress is then

$$\sigma_{max} = \frac{\sigma_x}{2} + \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + (\sigma_s)^2}$$
$$= \frac{11{,}613}{2} + \sqrt{\left(\frac{11{,}613}{2}\right)^2 + (1{,}995)^2}$$
$$= 5{,}806 + 6{,}140 = 11{,}946 \text{ psi}$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + (\sigma_s)^2} = 6{,}140 \text{ psi}$$

The factor of safety in Case 5 is thus

$$F.S. = \frac{14,000}{6,140} = 2.3 \quad \text{(AISC code)}$$

or

$$F.S. = \frac{35,000}{(2)(6,140)} = 2.8 \quad \text{(maximum shear stress failure theory)}$$

Cases 1 through 5 are summarized in Table 2.4.3-1.

Table 2.4.3-1

Minimum Factors of Safety for Five Loading Configurations

Loading	Tiedowns	Minimum Factor of Safety
9g up or down	Vertical	6.2
9g lateral	Lateral	15.4
9g up, down, or lateral	45°	4.5
10 g in dir. of travel, plus 5g lateral and 2g up or down	Fore and aft	3.3
10g in dir. of travel, plus 5g lateral and 2g up or down	Athwartships	2.3

2.5 STANDARDS FOR TYPE B AND LARGE-QUANTITY PACKAGING (10 CFR 71.35)

2.5.1 Load Resistance per 10 CFR 71

A detailed analysis of the PAT-2 package under conditions of simple beam bending is presented in Appendix 2D. It is shown that bending stresses induced in the package are negligible when the package is subjected to a uniformly distributed load equal to 5 times its own weight and supported on its ends.

2.5.2 External Pressure

The TB-2 containment vessel was tested to a 5000 psig (34.5 MPa) 8-hour external pressure hydrostatic test, with no permanent deformation and no water leakage (see Section 2.8.3). The TB-2 was also helium leaktight ($\dot{q} < 10^{-10}$ cm^3/s) after this test. This test was performed to satisfy the NUREG-0360 600-psi (4.1-MPa) pressure requirement. An analysis of the TB-2 at the 600-psi (4.1-MPa) condition reveals a positive factor of safety of over 5. Therefore, the TB-2 meets the 25-psig external pressure requirement of 10 CFR 71.32(b).

2.6 NORMAL CONDITIONS OF TRANSPORT TESTS PER 10 CFR 71 APPENDIX A

2.6.1 General

The PAT-2 package was tested to demonstrate that it complies with the standard for normal conditions of transport. A final-design phase-4 PAT-2 package, serial number X15, was sequentially subjected to all environments stated in 10 CFR 71 Appendix A. To generate maximum internal pressure (see Test Protocol, Appendix 2E), a severe surrogate of plutonium sulfate tetrahydrate was the payload in the C-1 capsule within the TB-2 containment vessel. In addition to the required 0.5-atmosphere pressure test, a 150% overpressure test was conducted by heating the containment.

Following the full Appendix A test sequence, the TB-2 exhibited a helium leakage rate of $< 10^{-10}$ cm^3/s. Also, the C-1 capsule exhibited an unchanging helium leak rate of 1.5×10^{-9} cm^3/s (5×10^{-10} cm^3/s air) both before and after the complete Appendix A test series. (A leakage rate of 10^{-7} cm^3/s or less, based on dry air at 77°F (25°C) and for a pressure differential of 1 atm against a vacuum of 10^{-2} atm or less, is considered to represent leaktightness.[13])

The geometric form of the PAT-2 package and its TB-2 containment vessel was essentially unchanged after the test series, and the following requirements of 10 CFR 71.35 were satisfied: (1) no substantial reduction in the effectiveness of the package occurred, (2) the total effective volume on which nuclear safety was assessed was not reduced by more than 5%, and (4) no aperture in the outer surface of the package large enough to permit entry of a 4-inch (10.2-cm) cube was evident.

Therefore, the PAT-2 package meets the 10 CFR 71 requirements for normal conditions of transport.

2.6.2 Heat

PAT-2 package X15 was subjected to a 215°F (102°C) environment for 48 hours. As indicated by the thermal analysis in Chapter 3, a 215°F (102°C) external environment will generate a peak PAT-2 package redwood temperature equal to that which would occur if the package was exposed to prolonged severe solar insolation at an ambient temperature of 130°F (54°C) in still air with the contents generating a maximum heat output of 2 watts. No degradation of the PAT-2 package was observed, and none is expected as a result of operations in a 215°F (102°C) environment.

2.6.3 Cold

Following the heat test, the same PAT-2 package was cold-soaked at -40°F (-40°C) for 48 hour. No degradation of the PAT-2 package was observed, and none is expected as a result of operations in a -40°F (-40°C) environment.

2.6.4 Pressure

The PAT-2 package, specifically the TB-2 containment vessel, must be able to withstand an atmospheric pressure half that of standard atmospheric pressure, per 10 CFR 71, and one-quarter of atmospheric pressure, per IAEA Safety Series 6 (S.S. 6). 10 CFR 71.53(b) also requires that the TB-2 containment vessel will be leaktight at an internal pressure 50% higher than the MNOP prior to first use.

To demonstrate compliance with both these requirements, the TB-2 containment vessel, following the heat and cold tests, was removed from the AQ-2 overpack and was heated to 250°F (121°C) for 8 hours. As calculated in Chapter 4, this produced an internal pressure of 49.5 psia (341.3 kPa), which is about 162% of the MNOP of 30.55 psia (210.6 kPa).

Leak-rate testing of the TB-2 containment vessel and the C-1 capsule, as separate entities, was done throughout the test program in the vacuum chamber of a mass spectrometer at a pressure of 0.0 psia (kPa); compliance with the 10 CFR 71 Appendix B 0.5-atm and the S.S. 6 0.25-atm exposures was thus repeatedly demonstrated, with leaktight results or no detectable leak.

2.6.5 Vibration

The TB-2 which was removed from the AQ-2 overpack for the pressure test was reassembled with the AQ-2, reconstituting the orginal PAT-2 X15 package. This PAT-2 package, which was subjected to the heat and cold tests per 10 CFR 71 Appendix A, was subjected to a very severe transportation vibration environment which encompasses road transportation (Standard Freight Trailer (SFT)), rail transportation (vibration on railcars and humping shock on cushioned underframe cars), and air transportation (vibration in aircraft). The test setup for the longitudinal axis vibration is shown in Figure 2.6.5-1.

The PAT-2 package transportation shock and vibration test was conducted under the following conditions:

- 0.2 g^2/Hz -- 30-150 Hz
- 6 dB/octave rolloff -- 150-2000 Hz
- 8-hour duration -- longitudinal axis
- 8-hour duration -- transverse axis.

The rail shock, if tested as a separate entity, would be a longitudinal 9g, 53-ms half-sine pulse. This is negligible in view of the 4-foot (1.2-metre) drops specified in 10 CFR 71 and the 288-mph (129-m/s) (minimum) crash perpendicular to an unyielding target for the NUREG-0360 criteria, and was therefore not tested.

This test produced a light coating of a grey-colored dust within the package, which was traced to the ceramic felt insulation within the titanium load spreader. This dust could not be discerned as a package degradation; all of the following Appendix A and Appendix B tests, including fire, were performed in sequence on this same package, X15, with no adverse result. During the development program, PAT-2 packages were frequently air-shipped, and no dusting appeared within the packages.

2.6.6 Water Spray

PAT-2 package X15 was subjected to a water spray test in accordance with 10 CFR 71 Appendix A.5. The actual test, shown in Figure 2.6.6-1, utilized a 3-inch (7.6-cm) diameter fire hose equipped with a fog nozzle, delivering more than 124 gal/min (0.47 m^3/min). The upper PAT-2 surface was continuously sprayed for more than 30 minutes, and then the side was also sprayed. 10 CFR 71 requires that the effect of this test not be individually assessed, but assessed in conjunction with free drops done 1-1/2 to 2-1/2 hours later.

2.6.7 Free Drop/Corner Drop

Approximately 2 hours after the water spray test, the PAT-2 package was subjected to a 4-foot (1.2 metre) free drop onto an unyielding surface in a top-corner impact orientation, which was assessed as being the most vulnerable orientation. To assure that the PAT-2 has a wide design margin to withstand such drops, a similar package, X13, was dropped 4 feet (1.2 metres) onto its top, top corner, bottom, and bottom corner. Visual evidence revealed inconsequential damage from these 4-foot (1.2-metre) drop tests. Figure 2.7.2-2, p 2-16, shows the results of a similar 30-foot (9.1-metre) drop.

2.6.8 Penetration

In the penetration test, a 13-pound (5.9-kg), 1-1/4-inch (3.2-cm) diameter steel cylinder with a hemispherical end was dropped 40 inches (1 metre) onto the PAT-2. Figure 2.6.8-1 shows the test setup for the penetration test. As shown in Figure 2.7.3-2, p 2-17, the package sustained a slight dimple from the test.

2.6.9 Compression

Package X15 was subjected to the compression test of 10 CFR 71 Appendix A.9. This test requires a compressive load five times the package weight [5 x 72 lb = 360 lb (163 kg)] or 2 psi x cross-section area [2 x 71 $(15)^2/4$ = 354 lb (160 kg)], whichever is greater. A load of 690 pounds (313 kg), a conveniently available mass (determined by weighing; label in Figure 2.6.9-1 was for original pre-damaged weight

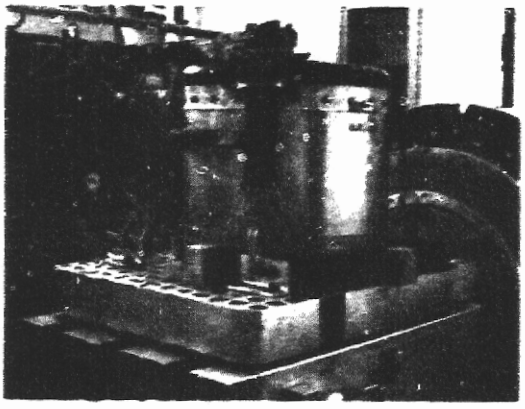


Figure 2.6.5-1. Longitudinal Axis Vibration Test Setup

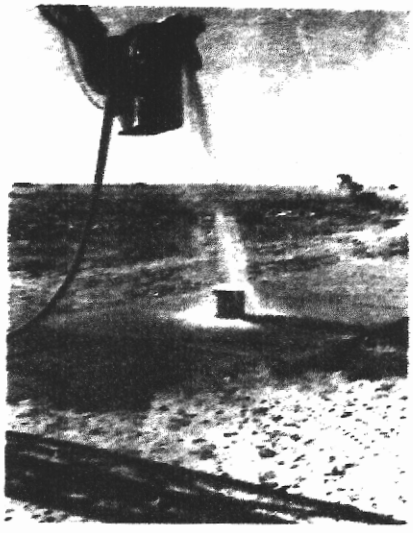


Figure 2.6.6-1. Water Spray Test

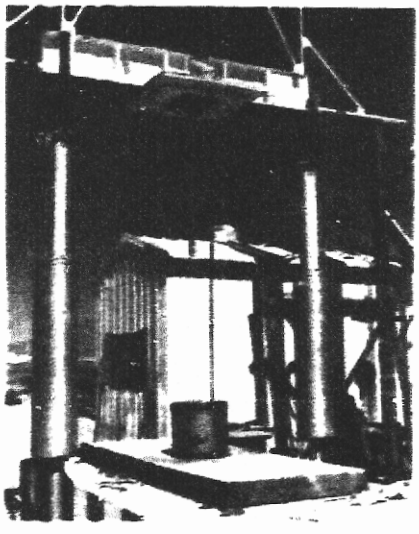


Figure 2.6.8-1. Penetration Test Setup

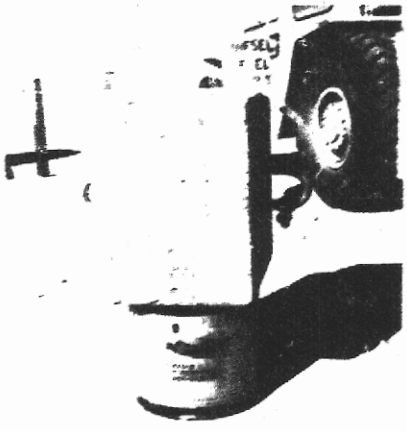


Figure 2.6.9-1. Compression Test

of block) was placed on top of the PAT-2 package for over 24 hours. The package rested on a massive steel plate, which in turn rested on a massive concrete block (see Figure 2.6.9-1). There was no apparent or observed effect.

2.6.10 Post-Test Summary of Package Damage

Following all of the above 10 CFR 71 Appendix A tests performed in sequence on PAT-2 package X15, the PAT-2 containment vessel was removed from the AQ-2 overpack and was found to have no dectable leak of helium ($\dot{q} < 10^{-10}$ cm^3/s). For verification, some of the 20 bolts were loosened, and the presence of helium was readily apparent. The C-1 capsule then was removed and leak-rate-tested on the helium-type mass spectrometer. It exhibited the same 1.5×10^{-9} cm^3/s helium ($\sim 5 \times 10^{-10}$ air) leak rate as at original assembly prior to the tests. The C-1 capsule was not further opened since both leaktightness and the presence of helium were proven.

With no repairs or maintenance, other than wiping out the grey powder observed from the vibration test, PAT-2 package X15 was reassembled for the 10 CFR 71 Appendix B tests.

2.7 HYPOTHETICAL ACCIDENT CONDITIONS TESTS PER 10 CFR 71 APPENDIX B

2.7.1 General

The PAT-2 package's ability to meet the requirements of 10 CFR 71 Appendix B for accident conditions of transport could be inferred from the package's ability to acceptably withstand the far more severe NUREG-0360 criteria detailed in Section 2.8. However, 10 CFR 71.42(b) requires that radioactive material in excess of 20 Ci per package be packaged in a separate inner container which shall not release plutonium when the entire package is subjected to the normal and accident test conditions specified in 10 CFR 71 Appendices A and B. Primarily to demonstrate that the C-1 capsule complies with this inner container requirement, PAT-2 package X15, with its $Pu(SO_4)_2 \cdot 4H_2O$ surrogate contents inside the C-1 capsule, was sequentially subjected to the test conditions of 10 CFR 71 Appendix B (after it had undergone the tests of Appendix A).

Following the 10 CFR 71 Appendix B tests, including the 30-foot (9.1-metre) drop, the 40-inch (1-metre) puncture drop, fire, and submersion, the TB-2 containment vessel was leaktight (N.D.L.; $\dot{q} < 10^{-10}$ cm^3/s helium), and the C-1 capsule leak rate was unchanged from original assembly ($\dot{q} = 1.5 \times 10^{-9}$ cm^3/s helium, $\sim 5 \times 10^{-10}$ cm^3/s air). The interior of the TB-2 and exterior of the C-1 capsule were monitored for uranium contamination; none was detected. Compliance of the C-1 with the containment requirement of 10 CFR 71.42, and of the TB-2 with the requirements of 10 CFR 71.36 was demonstrated.

Since the geometry of the PAT-2 package was not significantly changed, the reduction of shielding resulting from the 10 CFR 71 Appendix B test series is insignificant, and the radiation level at 3 feet (0.9 metre) from the external surface of the package would be limited to less than 0.40 mrem/h (see Chapter 5). This clearly meets the shielding requirements of 10 CFR 71.36(a), and the damaged package meets the criticality requirements of 10 CFR 71.36(b); details are in Chapters 5 and 6.

2.7.2 Free Drop

Package X15 was dropped 30 feet (9.1 metres) onto an unyielding surface in a top-corner-impact orientation (assessed to be the most vulnerable; see Figure 2.7.2-1). Figure 2.7.2-2 shows the minor denting of the outer stainless steel drum of the AQ-2. To assure that the PAT-2 package has a wide design margin to withstand such drops and that all primary impact orientations were tested, a similar PAT-2 package was subjected to similar drops onto its top end, top corner, bottom end, and bottom corner, with no adverse results.

2.7.3 Puncture

PAT-2 package X15 was a free-dropped 40 inches (1 metre) onto a 6-inch (15 cm) diameter, 10-inch (25.4-cm) long steel bar mounted on an unyielding horizontal surface, as defined by 10 CFR 71 Appendix B.2 and as shown in Figure 2.7.3-1. The point of contact between the bar and the PAT-2 package was the cover of the package. Following this test, the PAT-2 received a minor imprint in the outer drum (Figure 2.7.3-2), and some black paint transferred from the blunt probe; the integrity of the drum was not affected. Figure 2.7.3-2 also shows the slight dimple from the Appendix A penetration test.

During the development program, a PAT-2 package was subjected to this puncture test on its side (Figure 2.7.3-3) with no apparent effect on the package (Figure 2.7.3-4).

2.7.4 Thermal (Fire)

The dropped and puncture-tested package X15 was subjected to a fire test which exposed the package to the thermal-radiation environment defined in 10 CFR 71 Appendix B.3. The apparatus used for this test included the 10-foot (3-metre) diameter fuel pool and surrounding 16-foot (4.9-metre) diameter by 25-foot (2.6 metre) tall chimney used to attain the higher temperatures required by the NUREG-0360 fire test (see Chapter 3). As indicated by the measurements shown in Figure 2.7.4-1, the temperatures within the fire and on the package surface met the 1475°F (802°C) requirement for more than 30 minutes, as specified in the regulations. Afterburn was permitted to persist until the package was cool to the touch of a bare hand.

Figure 2.7.2-1. Free Drop Setup for Top-Corner Impact

Figure 2.7.2-2. Result of Top-Corner Impact, Free Drop

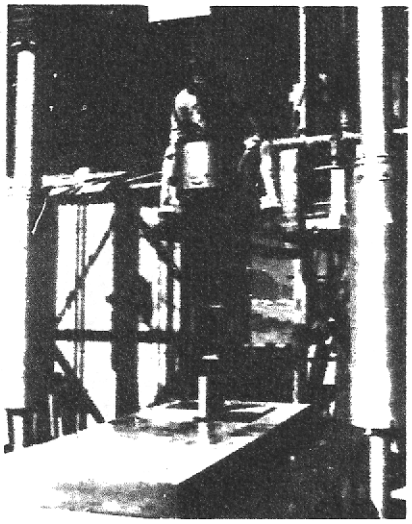


Figure 2.7.3-1. Appendix B Puncture Test Setup

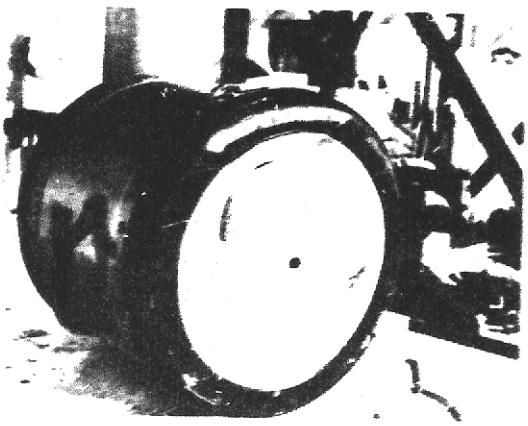


Figure 2.7.3-2. Appendix A and B Puncture Tests Results

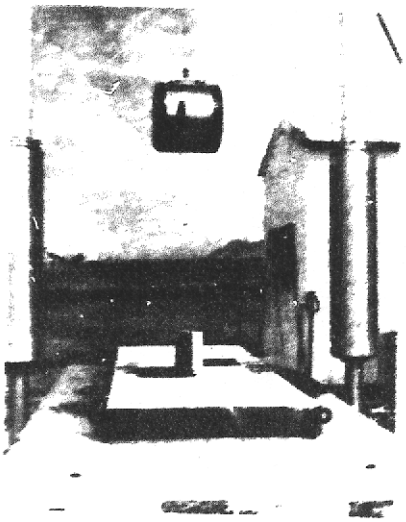


Figure 2.7.3-3. Appendix B Puncture Test, Side Impact

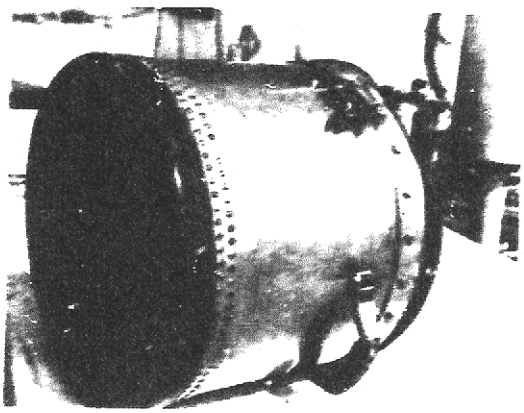
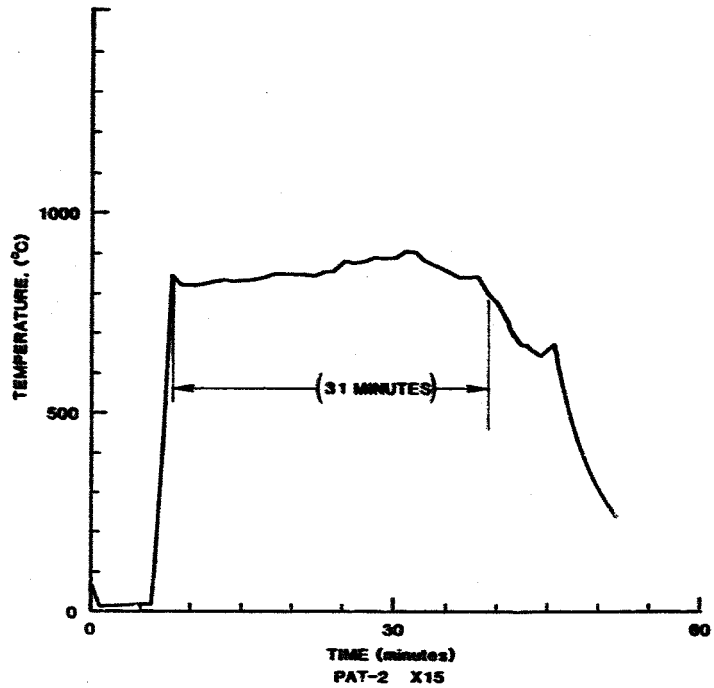
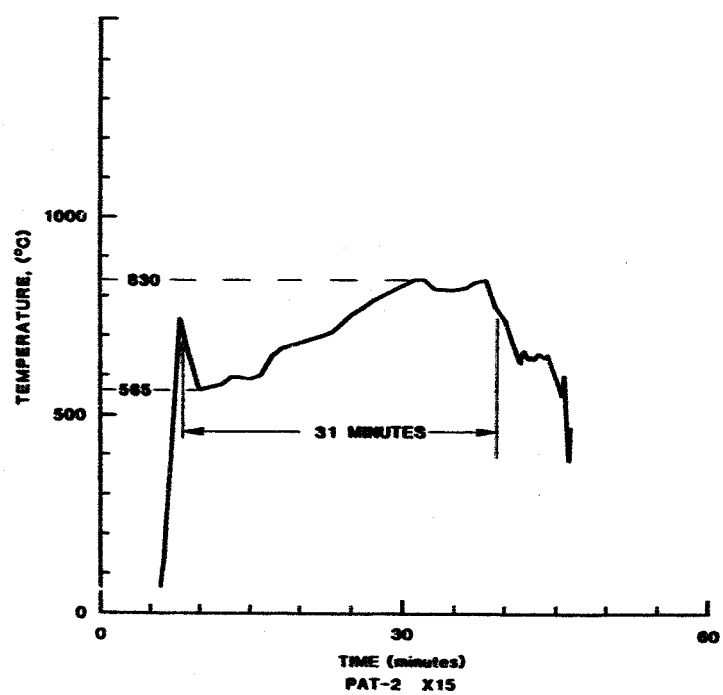


Figure 2.7.3-4. PAT-2 Package after Side-Impact Puncture Test



a. Fire Temperature



b. Skin Temperature

Figure 2.7.4-1. 10 CFR 71 Appendix B Thermal Test of PAT-2 Package

Figure 2.7.4-2 shows the package with thermocouple instrumentation installed, ready for the burn test; Figure 2.7.4.3 shows the package on the burn test stand after the 30-minute fire.

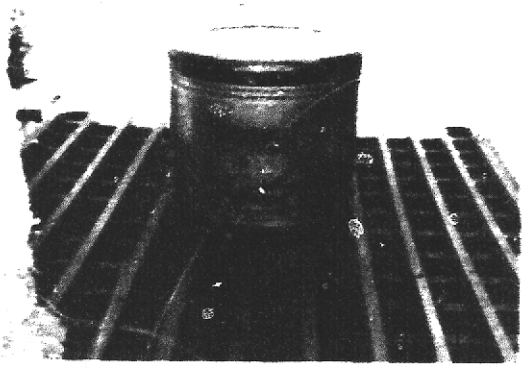


Figure 2.7.4-2. Instrumented PAT-2 prior to Appendix B Burn Test

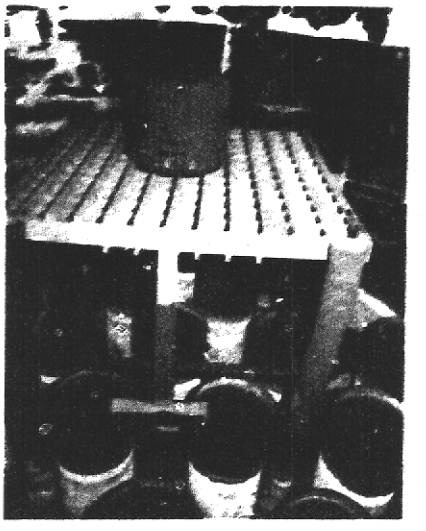


Figure 2.7.4-3. Package after 30-minute Fire

Sections 3.4.2 and 3.4.3 of this report present more discussion of this test.

2.7.5 Water Immersion

After the fire test, PAT-2 package X15 was submerged in more than 3 feet (0.9 metre) of water for approximately 24 hours.

2.7.6 Post-Test Summary of Package Damage

Subjecting the same PAT-2 package to both the 10 CFR 71 Appendix A and B tests resulted in only minor damage to the outer steel drum. The outer layer of redwood charred to about 1.5 inch (38 mm) depth (Figure 2.7.6-1), while the maplewood within the load spreader was essentially unaffected. The TB-2, except for dirty water picked up in the immersion test, showed no visible effects from this series of tests. The TB-2 containment vessel was leaktight ($\dot{q} < 10^{-10}$ cm^3/s helium) following this series of 10 CFR 71 tests, and the PAT-2 package met the requirements of 10 CFR 71.36(a) and 10 CFR 71.36(b). Post-test disassembly of the TB-2 indicated a helium-rich internal atmosphere, therefore validating the leak-test measurement.

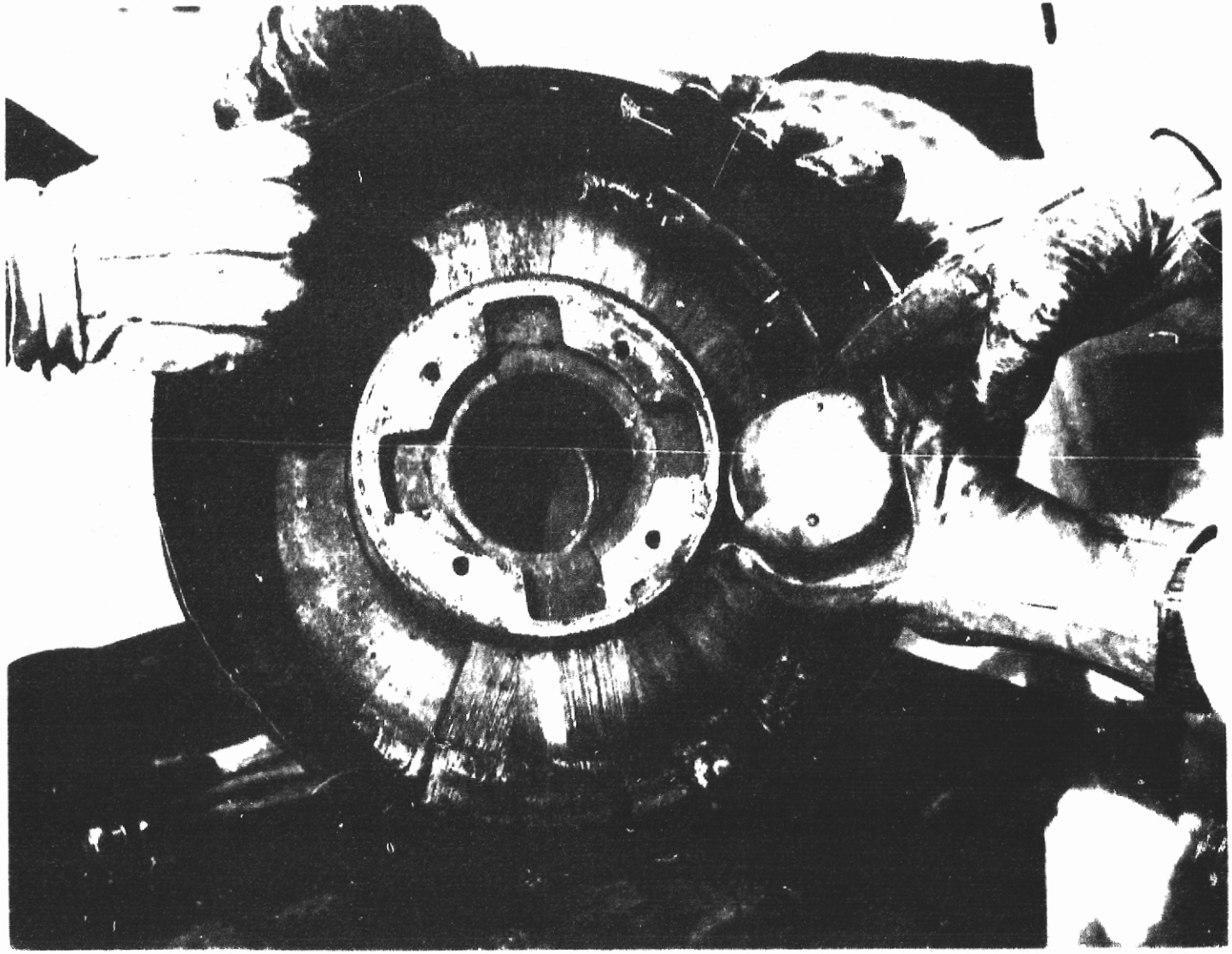


Figure 2.7.6-1. Package X15, Post-Test, Showing Redwood Char

The C-1 capsule exhibited an unchanged leak rate of 1.5×10^{-9} cm^3/s helium, or 5×10^{-10} cm^3/s air, meeting the double containment requirement of 10 CFR 71.42(b) of 17 June 1978 for plutonium in excess of 20 Ci. The C-1 capsule included a maximum-pressure-producing surrogate payload, modeling $Pu(SO_4)_2 \cdot 4H_2O$, as described in detail in Chapter 4.

2.8 NUREG-0360 QUALIFICATION CRITERIA FOR AIR TRANSPORT

2.8.1 Summary and Results

The PAT-2 package meets the qualification criteria of NUREG-0360 to certify a package for the air transport of plutonium. The aircraft accident conditions were satisfied by the demonstration of six final-design PAT-2 packages subjected to the sequential tests, an aerodynamic analysis for terminal free-fall velocity, the demonstration of one TB-2 containment vessel in the deep submersion test, testing of packages with severe surrogate loadings to model all intended actual contents, and testing at -50°F (-46°C) and 220°F (104°C).

The sequential tests utilized PAT-2 packages X07 through X12, with each package initially impacted at a different principal attitude, followed by a similar test sequence of crush, puncture, slash (ripping/tearing), fire, immersion, and inspection. The results were as follows:

Containment -- No detectable leak on five TB-2 containment vessels; ~ 7×10^{-6} cm^3/s air leak rate on one TB-2; no rupture and no loss of contents; details in Chapter 4.

Shielding -- Shielding of damaged package adequate for < 1 rem/h at 3 feet (0.9 metre); details in Chapter 5.

Criticality -- An infinite array of closely nested damaged packages would be very subcritical; details in Chapter 6.

Aerodynamic analysis confirmed that freefall terminal velocity, under a variety of aircraft accident conditions, would always be less than the 422-ft/s (129-m/s) impact velocity required in the sequential tests. Thus, an individudal terminal velocity impact test was not required.

An individual containment vessel passed the 600 psi (4.1 MPa) hydrostatic test requirement (5,000 psi (34.5 MPa) was used) with no leakage of water.

Severe surrogate contents ("payloads") for plutonium oxide powder, plutonium sulfate, and plutonium nitrate solids, sintered fuel pellets, and solid metallic pellets were included in the sequential tests to assure that the presence of any actual contents would have no further adverse affect.

One package in the sequential test series was impact-tested at -50°F (-46°C), and one was impacted at 220°F (104°C), with no further adverse affect.

These results are summarized in Table 2.8.1-1.

2.8.2 Impact

The NUREG-0360 test requirement is:

> Impact at a velocity of not less than 422 ft/s 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.

This test is accomplished on a rocket-powered pulldown facility, described in Appendix 2F.

The only intended variable in the six impact tests was the package attitude (orientation) upon impact with the unyielding surface. The trajectory path was perpendicular to the surface of the unyielding target, package attitude along the trajectory was controlled by individual towing rigs, and the desired impact attitude always occurred well within the permissible ±10° of error. Since the impact orientation which would produce maximum package damage at the conclusion of the test sequence could not be conclusively proven by analysis prior to tests, top-end, top-corner, side, bottom-corner, and bottom-end impacts were conducted. Where applicable, the package handle was impacted and "absorbed" into the flattened impact area.

Table 2.8.2-1 illustrates the conditions and results of the six impact tests. The table indicates the AQ-2 overpack orientation, the contents, (payload), the low- and high-temperature impact conditions, and the individual averaged impact velocity. NUREG-0360 requires a minimum velocity of 422 ft/s (129 m/s); test X09, side at -50°F (-45°C), was at 97.9% of the required velocity, or 413 ft/s (126 m/s). The side orientation was repeated on package X12, at 220°F (104°C) and a velocity of 433 ft/s (132 m/s). The average of the six impact velocities is 436 ft/s (133 m/s), or 103% of the required velocity. The one test series resulting in a detectable helium leak on the TB-2, PAT-2 X08, impacted at 440 ft/s (134 m/s), which is 104% of the required impact velocity.

In all cases, the AQ-2 overpacks did not come apart or release redwood or any other part of the packaging. In some cases, limited tearing of the outer stainless steel drum revealed the interior redwood and, in the case of the top corner orientation, the titanium load spreader could be seen.

Table 2.8.1-1

PAT-2 Phase 4 Licensing Demonstration Tests

NUREG-0360 Sequential Tests

(✓ = done)

Pkg. Serial Number	Canisters[a] and Surrogated Contents[b]	Impact Orientation, AQ-2 / TB-2 Velocity		Crush	Puncture	Slash	Burn	H_2O	$\dot{q}$ TB-2[c]
X07	3 ea. BC-4 3 g $Pu(NO_2)_4 \cdot 2H_2O$	Top 456 fps	Equator	✓	✓	✓ ✓	1010°C >1 hour	✓	N.D.L.
X08	2 ea. BC-1 40 g PuO_2 powder	Top Corner 440 fps	Polar	✓	✓	✓ ✓	1010°C >1 hour	✓	~7 x 10^{-6} cm^3/s air
X09	6 ea. BC-5 120 g Pellets/metal $PuO_2/Pu/U$	Side -46°C 413 fps	Equator	✓	✓	✓ ✓	1010°C >1 hour	✓	N.D.L.
X10	2 ea. BC-2; 1 ea. BC-3 3 g $Pu(SO_4)_2 \cdot 4H_2O$	Bottom Corner 435 fps	Equator	✓	✓	✓ ✓	1010°C >1 hour	✓	N.D.L.
X11	No canisters 3 g $Pu(SO_4)_2 \cdot 4H_2O$	Bottom 438 fps	Polar	✓	✓	✓ ✓	1010°C >1 hour	✓	N.D.L.
X12	6 ea. BC-5 120 g Pellets/metal	Side 104°C 433 fps	Equator	✓	✓	✓ ✓	1010°C >1 hour	✓	N.D.L.

NUREG-0360 Individual Test

X16	5000 psig, 8-hour hydrostatic test in dyed water; no leakage.	N.D.L.

10 CFR 71 Appendix A and Appendix B Tests

X15	One package passed all tests, in sequence.	N.D.L.

[a]Canisters explained in "Test Protocol," Chapter 2.

[b]Surrogates for contents are described in Chapter 4.

[c]N.D.L. = No detectable leak ($\dot{q} \leq 10^{-10}$ cm^3/s helium; helium present in TB-2 upon opening).

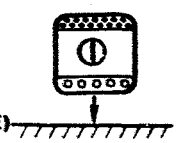
Table 2.8.2-1

PAT-2 Phase 4 Impact Test Details

X07 AQ-2: TOP TB-2: EQUATOR

C-1 3 ea. BC-4 CANISTERS

3 gm. Pu $(NO_3)_4 \cdot 2H_2O$ (SURROGATE)



456 fps

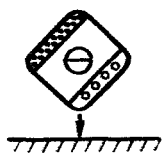
X08 AQ-2: TOP CORNER TB-2: POLE

C-1 2 ea. BC-1 CANISTERS

40 gm. PuO_2 (SURROGATE)

[40 g UO_2, 10 g PVC, 38.6 g BRASS

16 g SiO_2, 0.5 g H_2O]



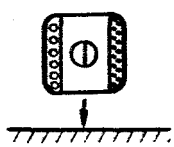
440 fps

X09 AQ-2: SIDE-COLD TB-2: EQUATOR

C-1 6 ea. BC-5 CANISTERS

120 gm. PuO_2 PELLETS (SURROGATE)

[123.6 g D-38, 10 g PVC, 31.4 g BRASS]



-50°F

413 fps

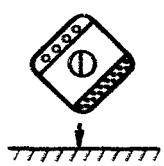
X10 AQ-2: BOTTOM CORNER TB-2: EQUATOR

C-1 2 ea BC-2 & 1 ea. BC-3 CANISTERS

3 gm. Pu $(SO_4)_2 \cdot 4H_2O$ (SURROGATE)

[3 g UO_2, 10 g PVC, 47.4 g BRASS, 19 g SiO_2,

0.66 ml H_2SO_4, 0.66 ml H_2O]



435 fps

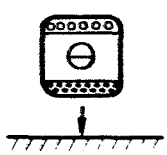
X11 AQ-2: BOTTOM TB-2: POLE

C-1 NO CANISTERS

3 gm. Pu $(SO_4)_2 \cdot 4H_2O$ (SURROGATE)

[3 g UO_2, 10 g PVC, 50 g BRASS, 18 g SiO_2,

0.66 ml H_2SO_4, 0.66 ml H_2O]



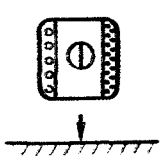
438 fps

X12 AQ-2: SIDE-HOT (200/220°F)

C-1 6 ea. BC-5 CANISTERS

120 gm. PuO_2 PELLETS (SURROGATE)

[123.6 g D-38, 10 g PVC, 31.4 g BRASS]



220°F

433 fps

Results of the impact tests may be observed in the Figures 2.8.2-1 through 2.8.8-12. Top-impacted package X07 is shown in Figures 2.8.2-1 and 2.8.2-2. Top corner impact package X08 is shown, after impact, crush and puncture, in Figure 2.8.4-4 and, with the crushed-up dimension and ready for the fire test, to the right in Figure 2.8.6-1. Side impact (low-temperature) package X09 is shown in the temperature conditioning chamber in Figure 2.8.2-3, rigged and ready for rocket pulldown in Figure 2.8.2-4, and post-impact in Figure 2.8.2-5. The rocket pulldown towing rig with explosive cutters, for bottom-corner impact package X10, is shown in Figure 2.8.2-6.

Package X10, post-impact, is shown in Figure 2.8.2-7. Bottom-end impact package X11 is shown ready for the test in Figure 2.8.2-8 and post-impact in Figures 2.8.2-9 and 2.8.2-10. High-temperature conditioning equipment for hot side-impact package X12 is shown in Figure 2.8.2-11; X12 is seen post-impact in Figure 2.8.2-12.

The dimensions that have been added to some of the post-impact photographs were the typical or average major package dimensions measured with normal reference to the impacted surface. Post-puncture Figures 2.8.4-1 through 2.8.4-8 show additional details of the impacted surfaces, such as the handles absorbed into the impacted surface. Post-impact radiographs of all six packages following the crush, puncture, and slash tests are given as Figures 2.8.8-14 through 2.8.8-20, pp 2-58 through 2-64.

During phase 3 development tests, a similar full group of packages were impact tested and then crushed, punctured, slashed, burned, submerged in water while hot (not permitted to cool naturally), and then examined and leak-rate tested. All of the TB-2 containment vessels exhibited no dectable leak ($\dot{q} \leq 10^{-10}$ cm^3/s helium).

An analysis of this high-speed impact of the PAT-2 package perpendicular to an unyielding surface is presented as Appendix 2G.

Figure 2.8.2-1. Package X07 After Top Impact

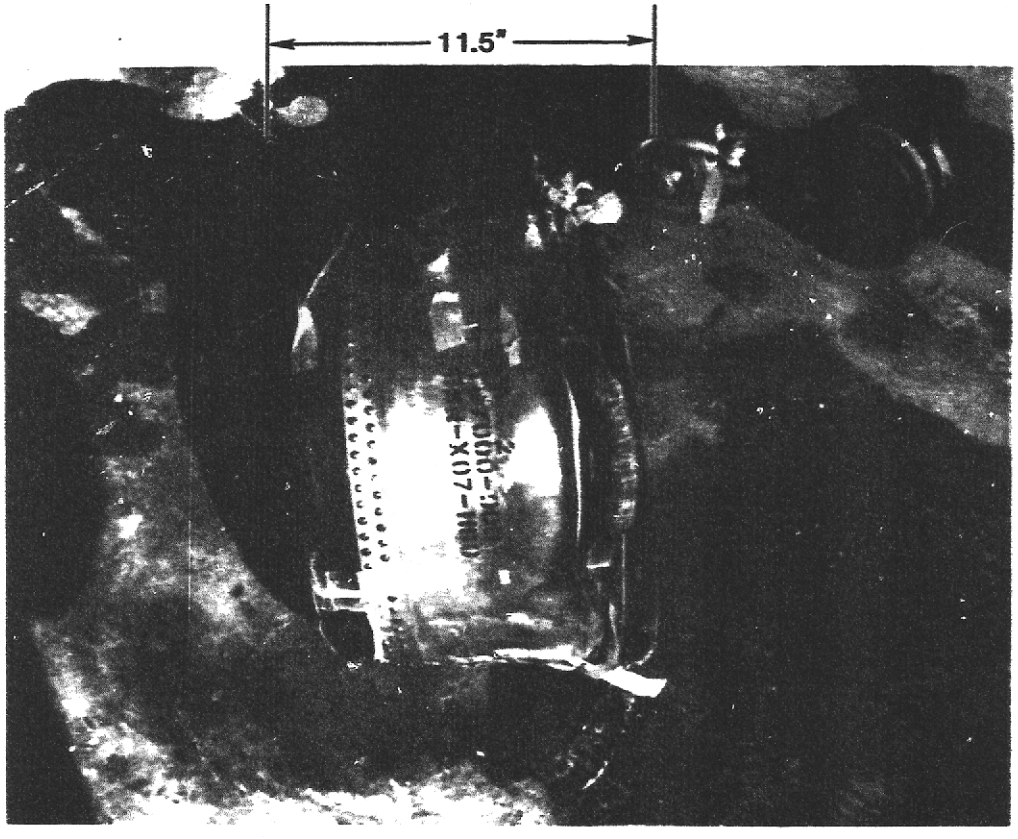


Figure 2.8.2-2. Package X07 Side View

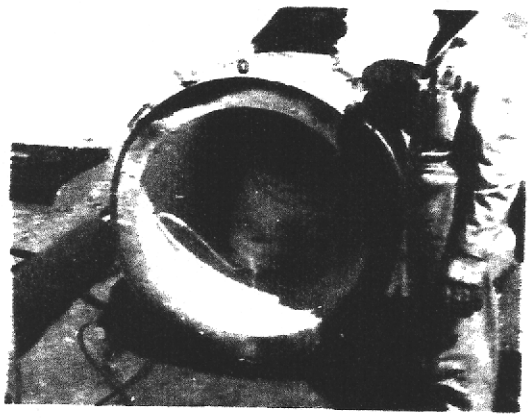


Figure 2.8.2-3. X09, Pre-Impact, in Temp. Conditioning Chamber

Figure 2.8.2-4. Package X09, Rigged for Impact

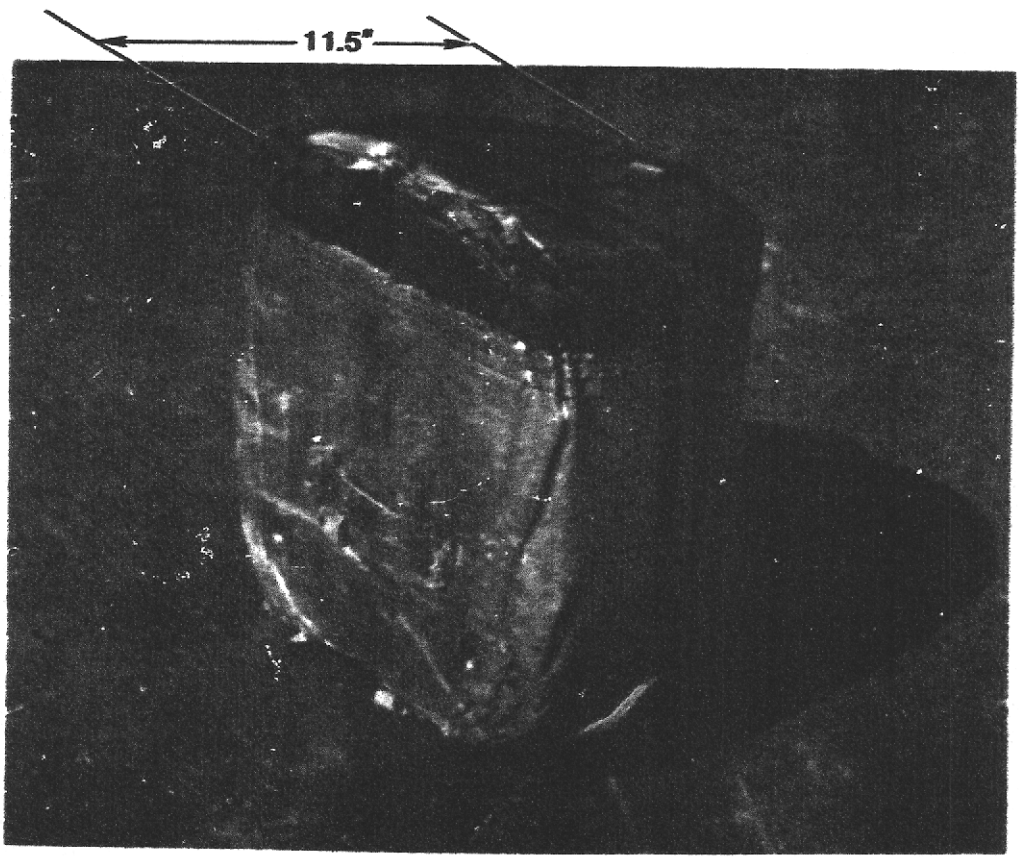


Figure 2.8.2-5. Package X09 after Side Impact

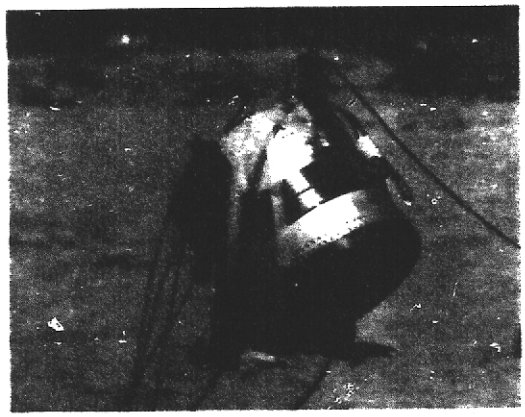


Figure 2.8.2-6. Rocket Pulldown Towing Rig

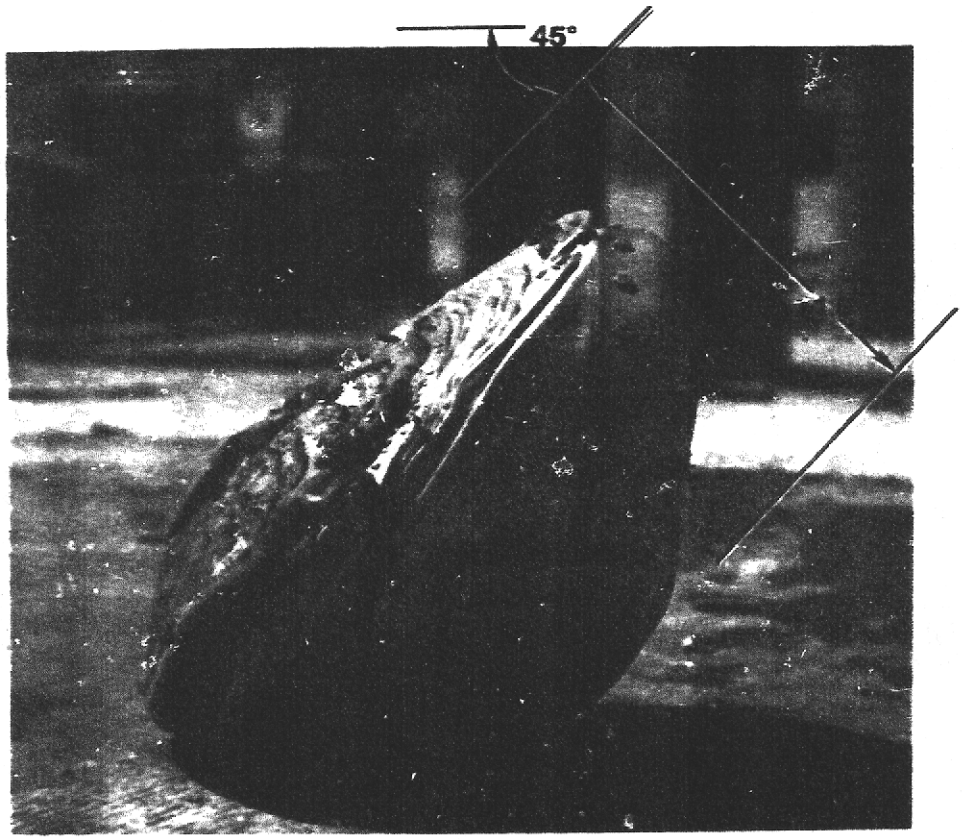


Figure 2.8.2-7. Package X10, Post-Impact

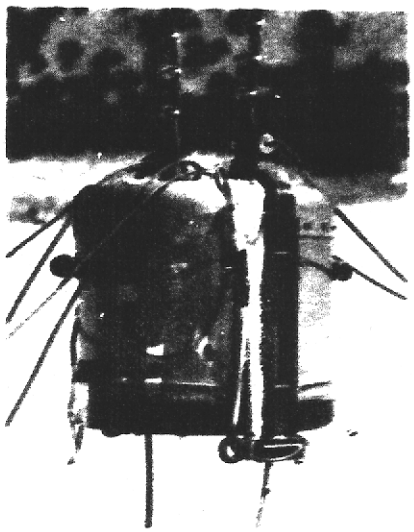


Figure 2.8.2-8. Package X11, Pre-Impact

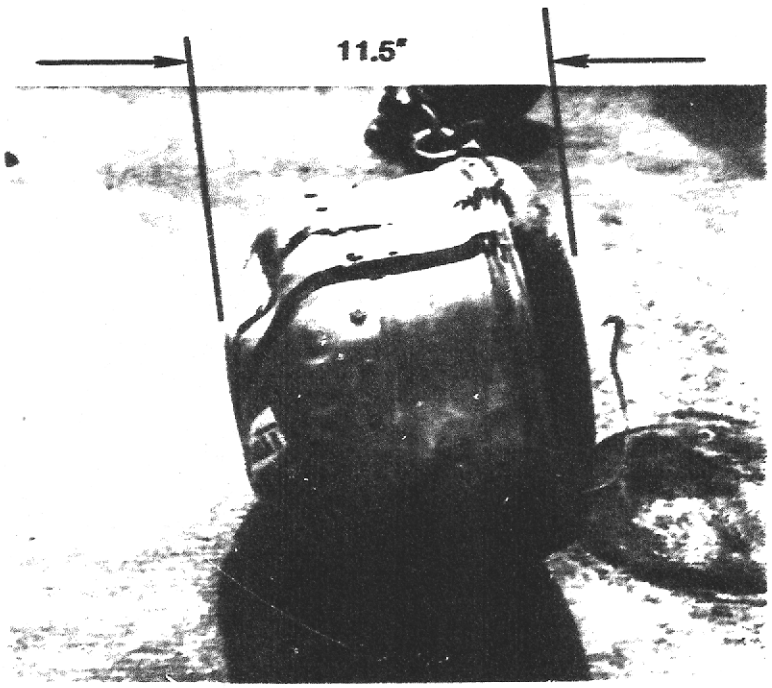


Figure 2.8.2-9. X-11, Post-Impact, Bottom View

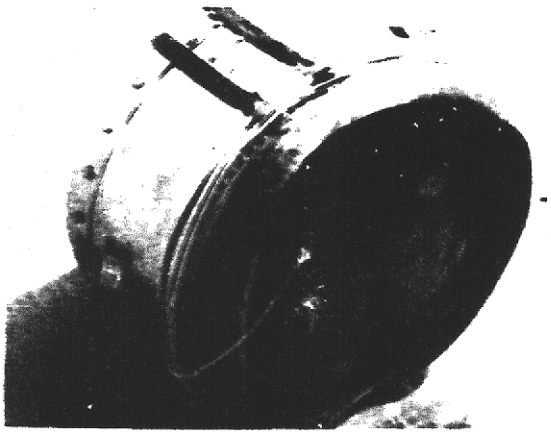


Figure 2.8.2-10. X11 Post-Impact, View

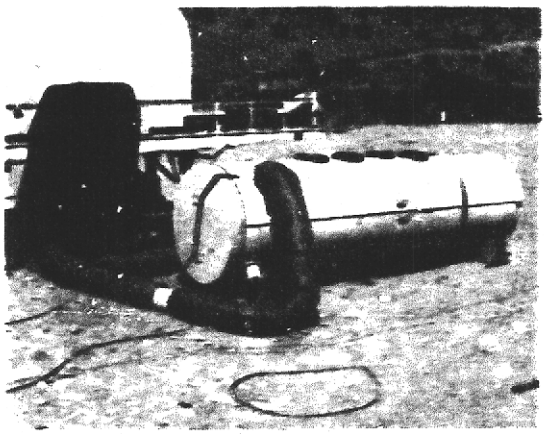


Figure 2.8.2-11. Temp. Conditioning Equipment

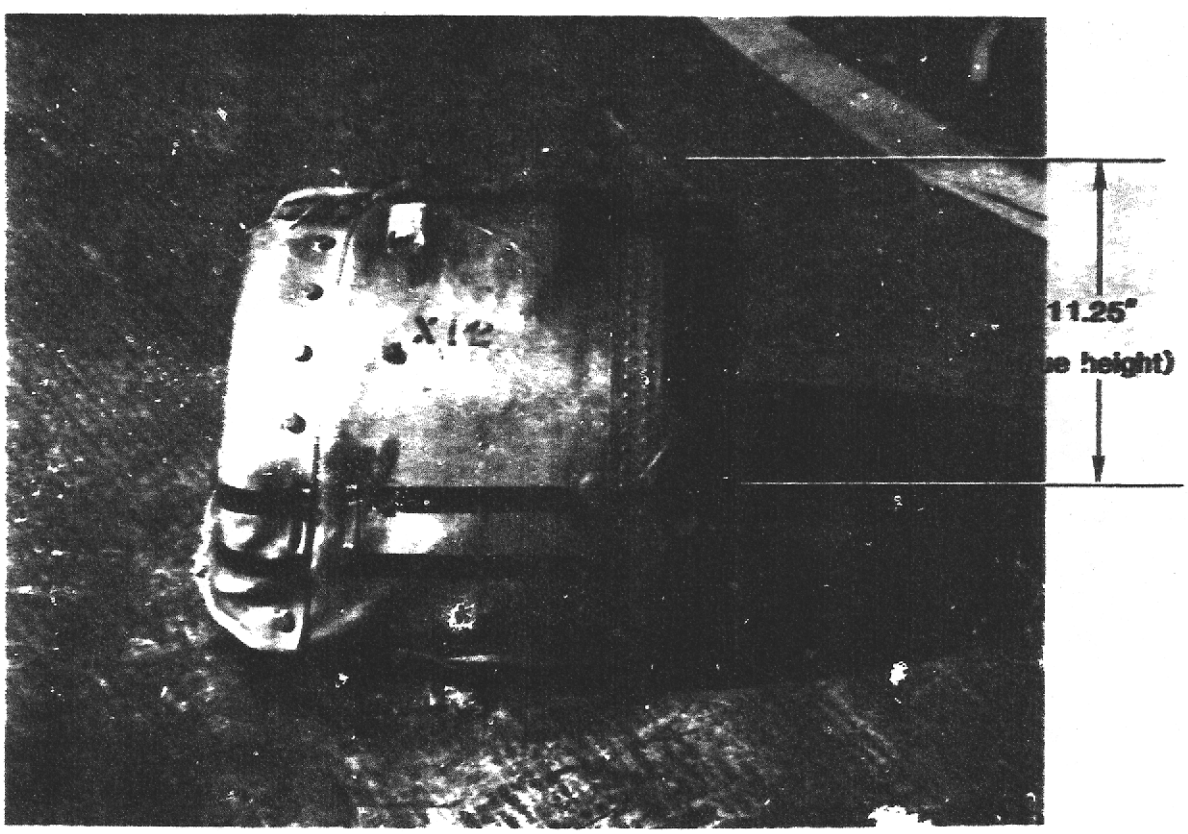


Figure 2.8.2-12. X12 after Side Impact at 104°C

2.8.3 Crush

The NUREG-0360 test requirement is:

> A static compressive load of 70,000 pounds applied in the orientation expected to result in maximum damage at the conclusion of the 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.

In the crush test, 70,000 lb_f (0.311 MN) was applied through a rigid 2-inch (5-cm) wide steel beam to the most vulnerable point on the impacted PAT-2 packages, as revealed by radiographs. This test produced negligible effects on the PAT-2 package, as shown in Figures 2.8.3-1 (crush test of a top-corner-impacted package), 2.8.3-2 (crush test of a side-impacted package), and Figure 2.8.3-3 (crush test of an end-impacted package). Although these photographs are of phase 3 development tests, phase 4 packages X07 through X12 were all subjected to the required crush test.

2.8.4 Puncture

The NUREG-0360 test requirement is:

> 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 and 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.

The 10-feet (3-metre) drop of the 500-pound (227-kg) steel spike onto the same contact point used for the crush test generally opened a 2-inch (5-cm) diameter hole into the AQ-2 drum, penetrating into the redwood. Figure 2.8.4-1 shows the typical puncture test setup (X07 is being punctured); the packages are positioned on an unyielding surface, and the probe's fall is guided. Figure 2.8.4-2 shows the probe impaled in package X07; the resultant hole is shown in Figure 2.8.4-3. Figure 2.8.4-4 shows the puncture hole in corner-impacted package X08, Figure 2.8.4-5 shows package X09 post-puncture, Figure 2.8.4-6 shows package X10, Figure 2.8.4-7 shows package X11, and Figure 2.8.4-8 shows package X12, post-puncture.

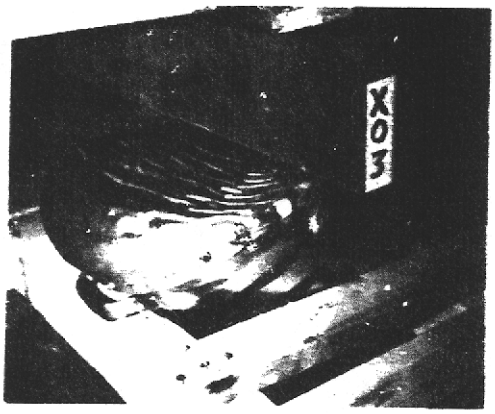


Figure 2.8.3-1. Crush Test of Top-Corner-Impacted Package

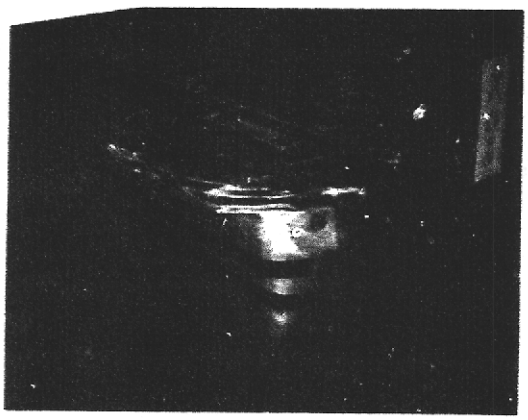


Figure 2.8.3-2. Crush Test of Side-Impacted Package

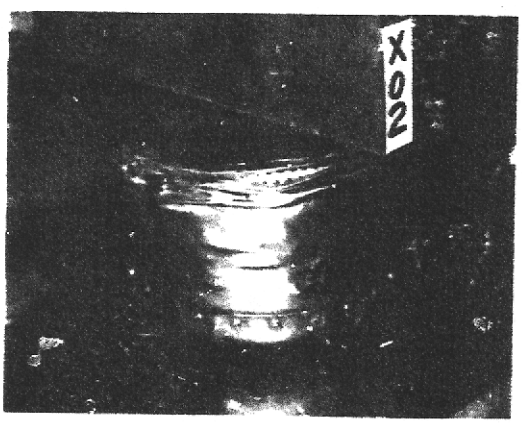


Figure 2.8.3-3. Crush Test of End-Impacted Package

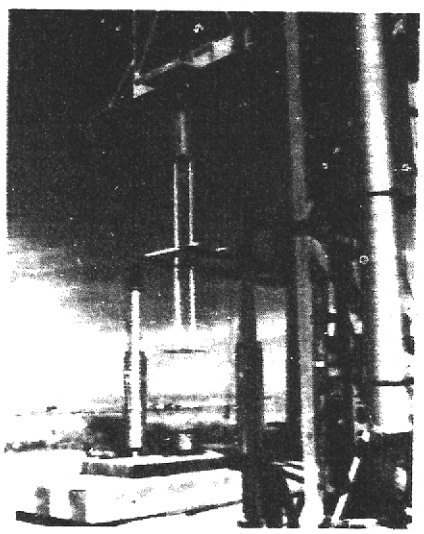


Figure 2.8.4-1. Puncture-Test Setup

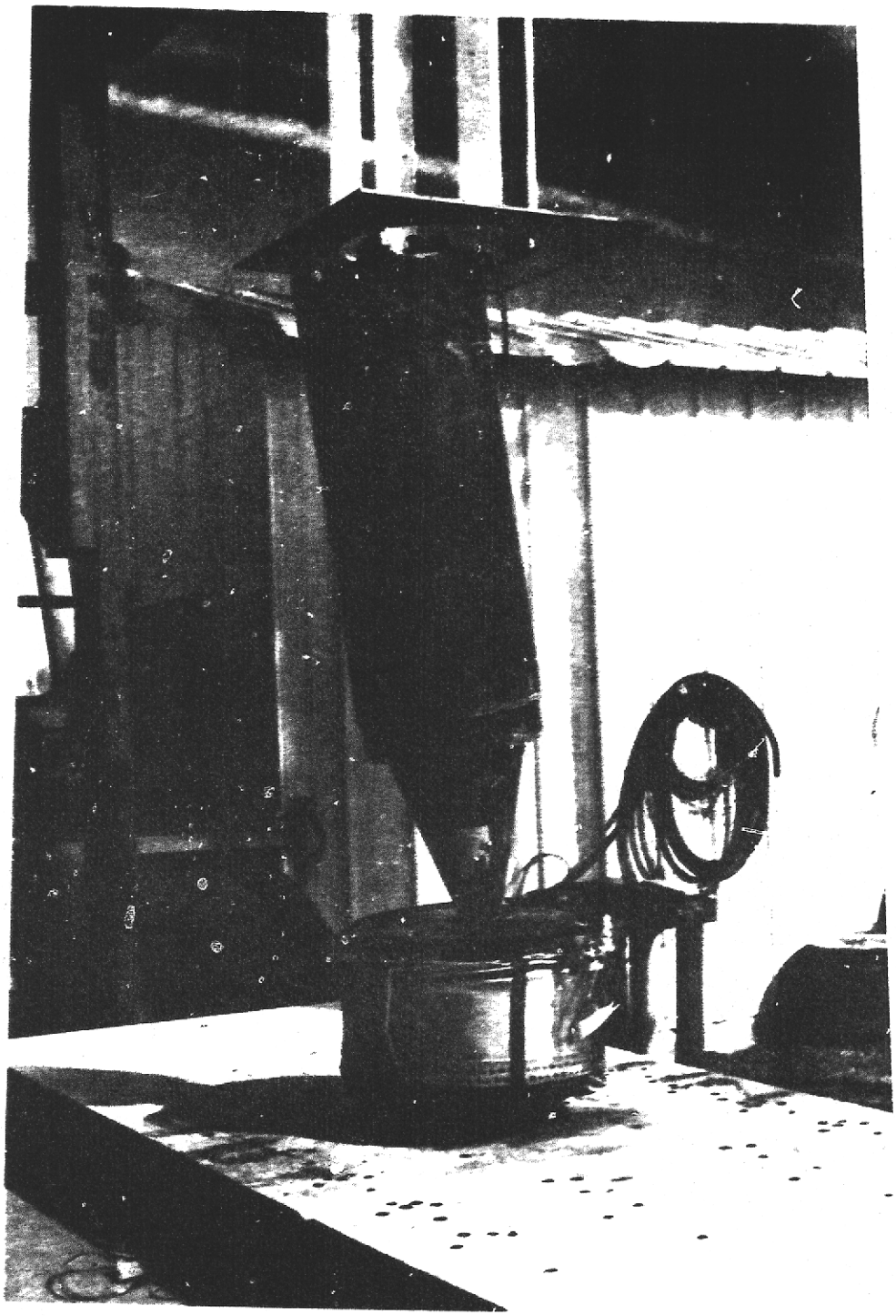


Figure 2.8.4-2 Probe Impaled in X07

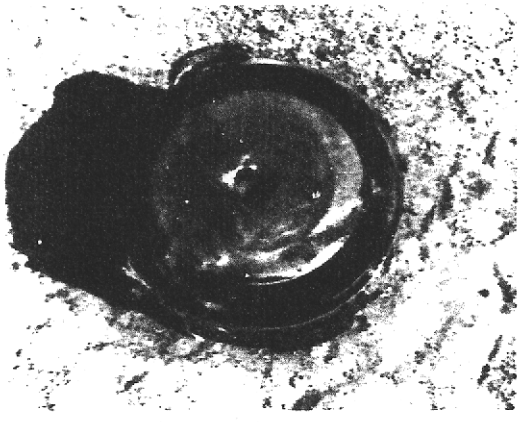


Figure 2.8.4-3. X07, Post-Puncture

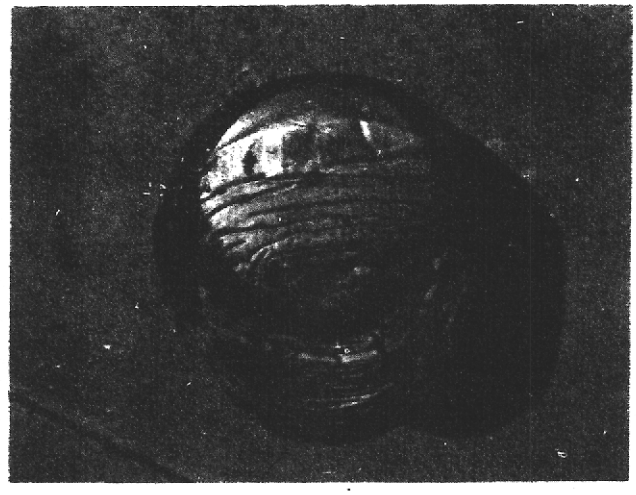


Figure 2.8.4-4. X08, Post-Puncture

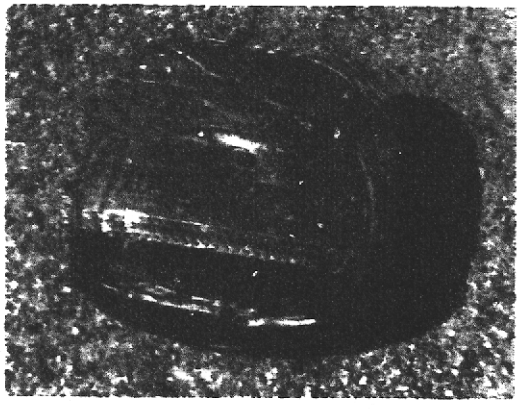


Figure 2.8.4-5. X09, Post-Puncture

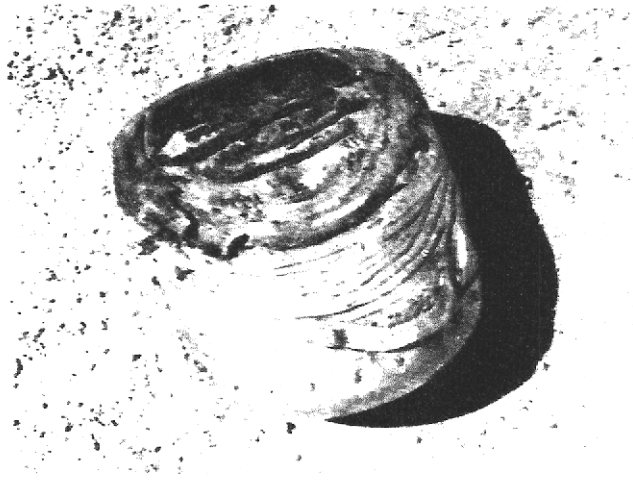


Figure 2.8.4-6. X10, Post-Puncture

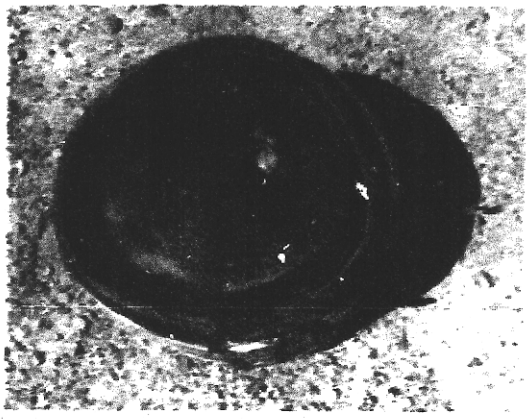


Figure 2.8.4-7. X11, Post-Puncture

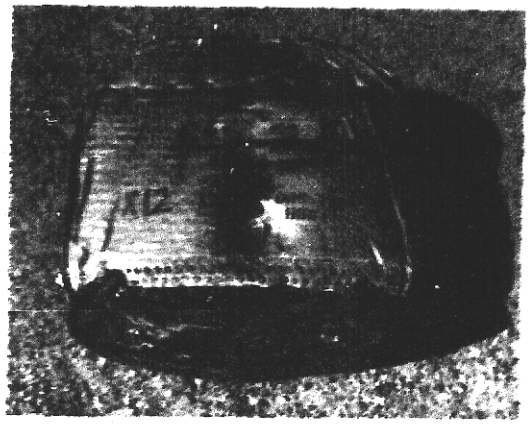


Figure 2.8.4-8. X12, Post Puncture

2.8.5 Slash (Ripping/Tearing)

The NUREG-0360 test requirement is:

> The package to be firmly restrained and supported such that its longitudinal axis is inclined approximately 45° 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 1/2-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° about its longitudinal axis and struck by the steel angle section falling as before.

The arbitrary slash test produces a major effect on the small PAT-2 package, penetrating the outer stainless-steel drum, generally to a depth of approximately 4 inches (10 cm) along the trajectory path, or about 3 inches (7 cm) of penetration normal to a drum surface. The slash projectile did not reach the titanium load-spreader structure embedded within the outer redwood components. The effects of this double test are shown in Figures 2.8.5-1 (X07), 2.8.5-2 (X08), 2.8.5-3 (X08), 2.8.5-4 (X09), 2.8.5-5 (X10), 2.8.5-6 (X11), 2.8.5-7 (X12), and 2.8.5-8 (typical effects of impact, crush, puncture, double-slash tests on three packages).

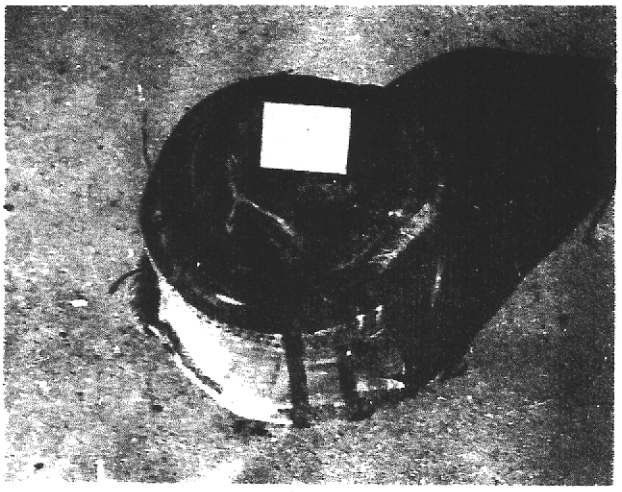


Figure 2.8.5-1. X07, Post-Double-Slash

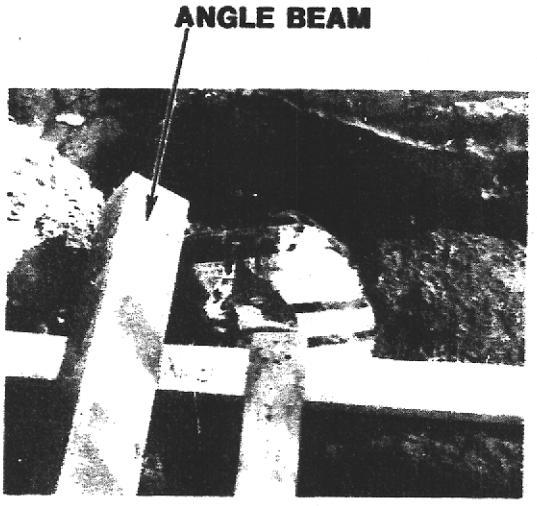


Figure 2.8.5-2. X08, Post-Double-Slash

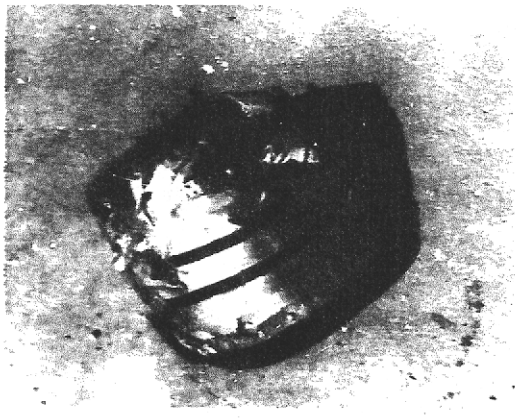


Figure 2.8.5-3. X08, Post-Double-Slash

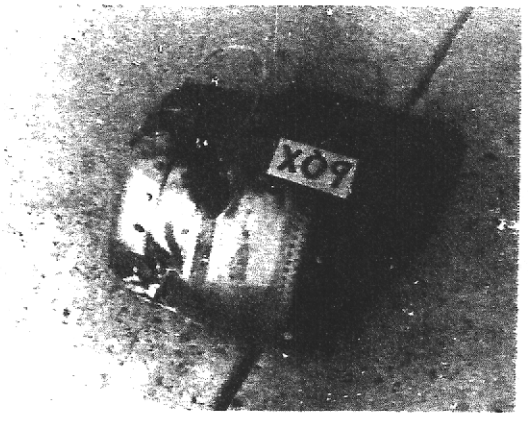


Figure 2.8.5-4. X09, Post-Double-Slash

Figure 2.8.5-5. X10, Post-Double-Slash

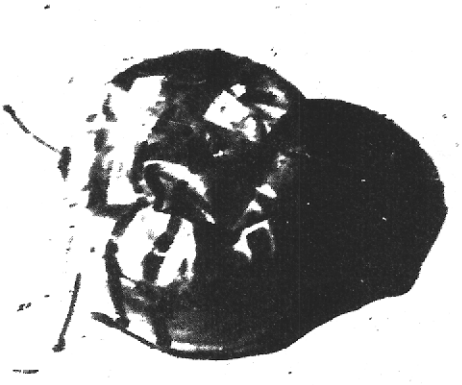


Figure 2.8.5-6. X11, Post-Double-Slash

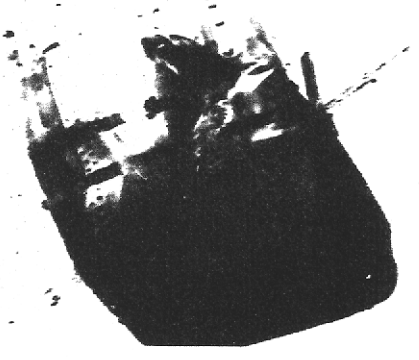


Figure 2.8.5-7. X12, Post-Double-Slash

Figure 2.8.5-8. Typical Effects of Impact, Crush, Puncture, and Double-Slash Tests on Three Packages

2.8.6 Fire

The NUREG-0360 test requirement is:

> The package to be exposed to luminous flames from a pool fire of JP-4 or JP-5 aviation fuel for a period of 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.

The six PAT-2 packages were thermally tested in the burn test facility described in Chapter 3, Thermal Evaluation. Typical package orientations on the test stand are shown in Figures 2.8.6-1 and 2.8.6-2. The burn test facility during the test of package X09 is shown in Figure 2.8.6-3. A typical post-burn, naturally cooled package is shown in Figure 2.8.6-4. Chapter 3 presents pertinent test data regarding flame temperatures and package temperatures of the five fires utilized to test the six packages.

2.8.7 Immersion

The NUREG-0360 test requirement is:

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

This test was conducted on packages X07 through X12 in a deep water tank installed adjacent to the burn test facility. The commencement of a typical submersion test, showing the cage which keeps packages at or below the required depth and which permits package recovery from the water, is shown in Figure 2.8.7-1.

2.8.8 Post-Test Summary of Package Damage

The six sequentially tested PAT-2 packages were disassembled with cutting torches, a large, water-cooled, machine-fed band saw, and hand tools. Disassembly of top-impacted PAT-2 package X07 is shown in Figure 2.8.8-1; top-corner-impacted PAT-2 package X08 is shown in 2.8.8-2.

Side-impacted PAT-2 package X09 is shown in Figure 2.8.8-3; the effect of the puncture test on its titanium load spreader is shown in Figure 2.8.8-4. Recovery of the TB-2 containment vessel, typical of all package tests, is shown in Figure 2.8.8-5.

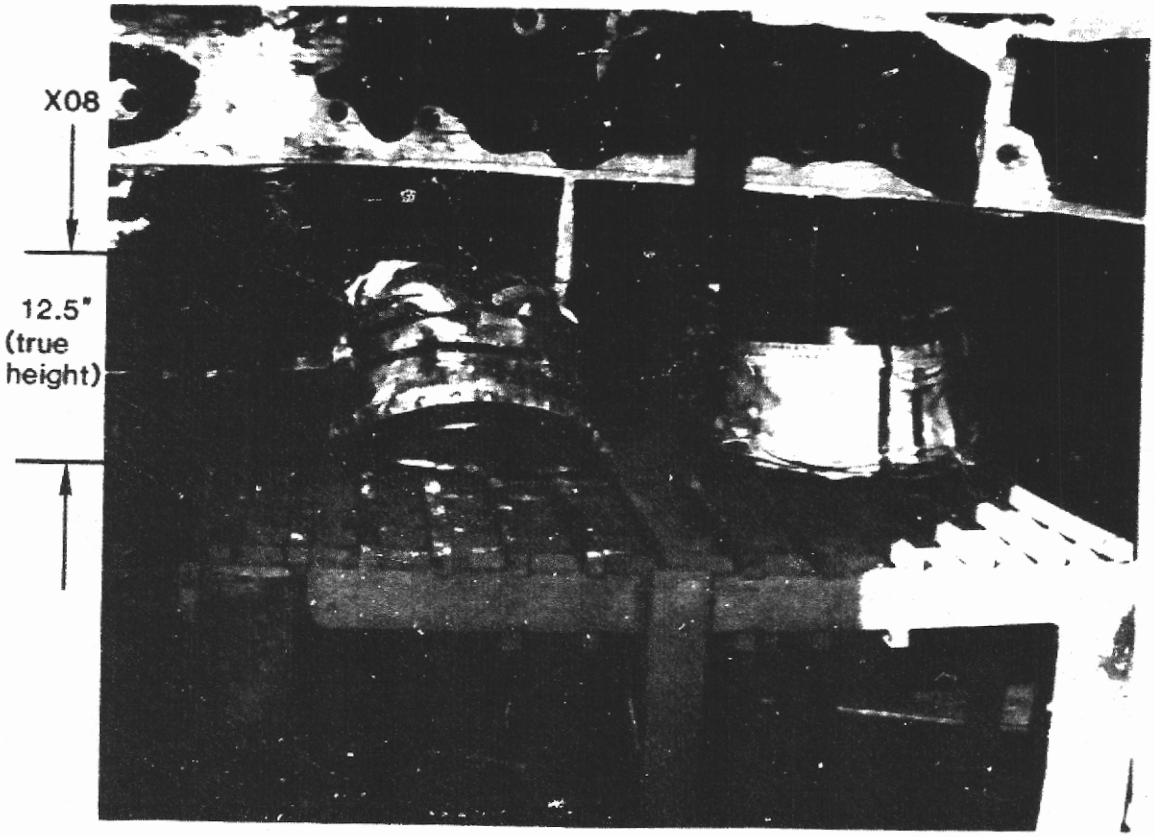


Figure 2.8.6-1. Packages Prior to Burn Test

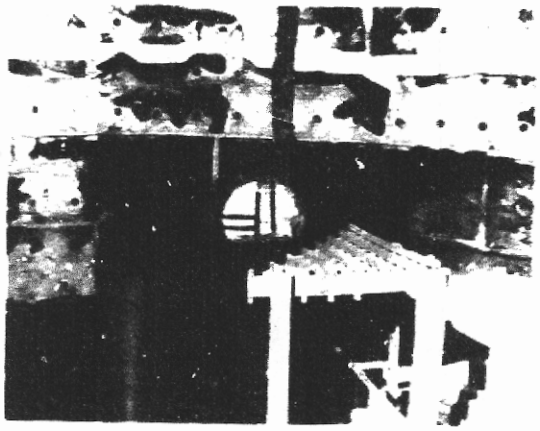


Figure 2.8.6-2. Package Prior to Burn Test

Figure 2.8.6-3. Burn Test Facility

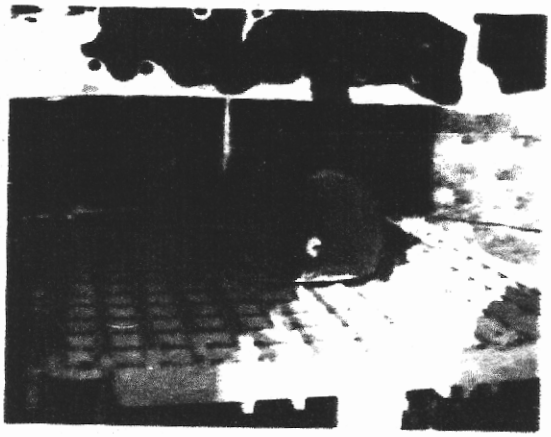


Figure 2.8.6-4. Typical Package, Post-Burn

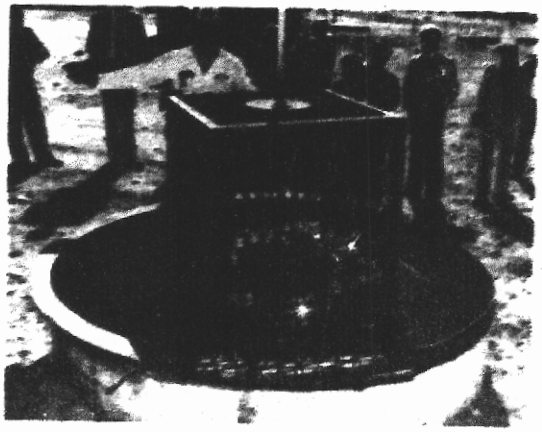


Figure 2.8.7-1. Typical Submersion Tests, Showing Water Tank and Cage

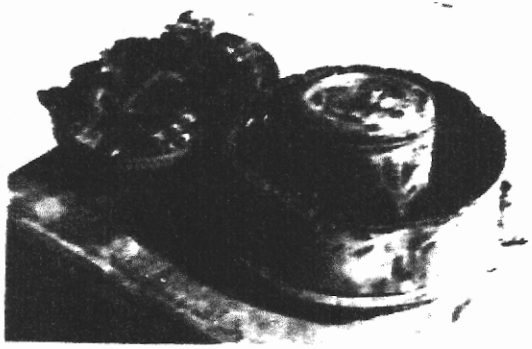


Figure 2.8.8-1. X07 Post-Test Disassembly

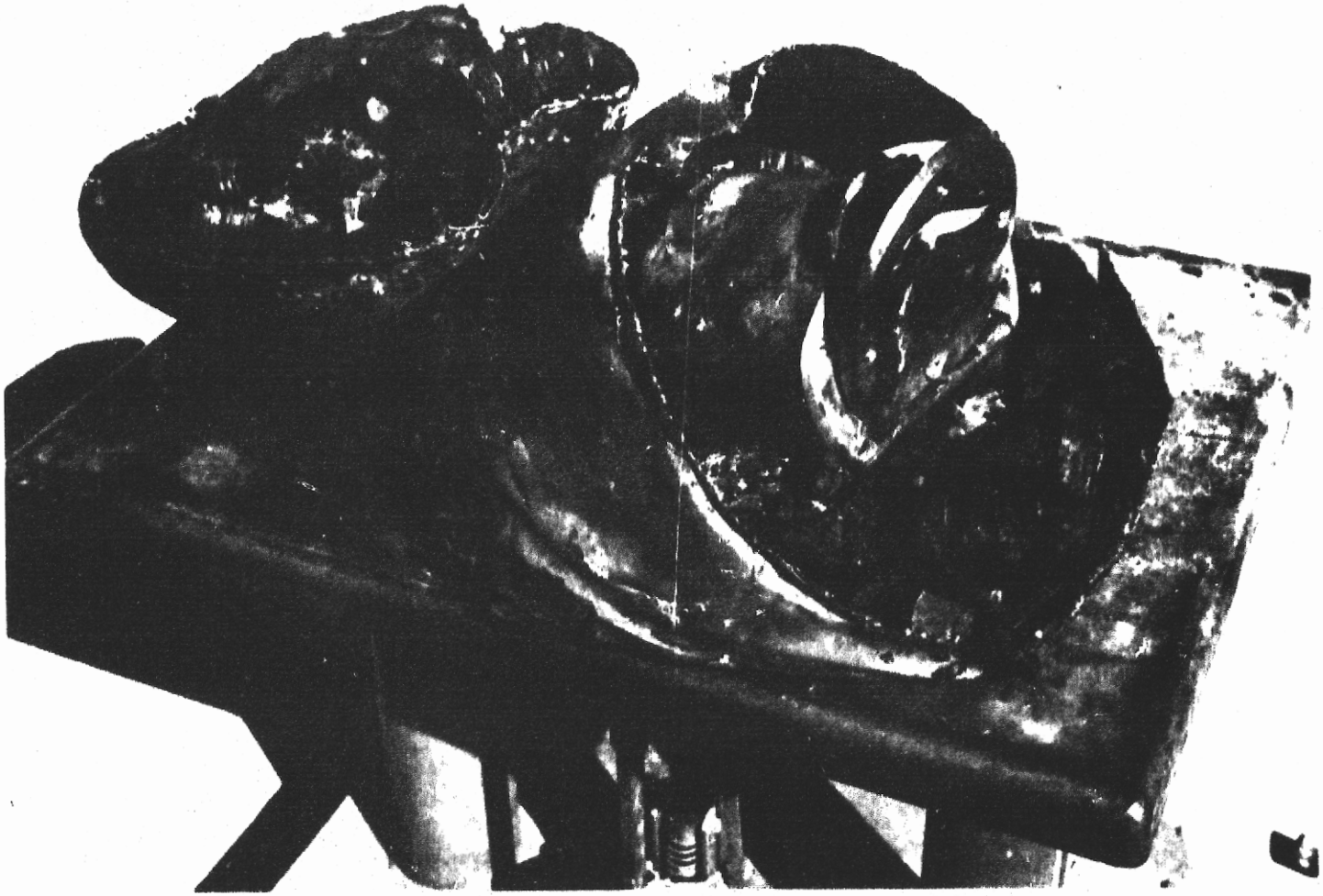


Figure 2.8.8-2. X08 Post-Test Disassembly

Figure 2.8.8-3. X09 Post-Test Diassembly

Figure 2.8.8-4. Effects of Puncture Test on X09 Load Spreader

Figure 2.8.8-5. Typical TB-2 after Test Sequence

Bottom-corner-impacted package X10 is shown disassembled in Figure 2.8.8-6; the recovered X10 TB-2 containment vessel, with aluminum fairing rings removed, is shown in Figure 2.8.8-7.

Bottom-end-impacted PAT-2 package X11 is being disassembled in front of an international group in Figure 2.8.8-8. The titanium load spreader was cut open with a high-temperature torch (Figure 2.8.8-9), and the TB-2 containment vessel was recovered (Figure 2.8.8-10).

The disassembly of side-impacted (hot) package X12 is shown in Figures 2.8.8-11 and 2.8.8-12.

Swipe tests were taken of all TB-2 containment vessels as they emerged from the charcoal during the postmortems, and uranium fluorimetry measurements sensitive to 10^{-8} gram uranium revealed no uranium on any surface or in any crevice of any TB-2.

In all cases, the aluminum fairing rings on the TB-2 were solid and intact, indicating that the aluminum liquidus temperature, ~ 1080°F (582°C), had not been reached. This finding is discussed more thoroughly in Chapter 3, Thermal Evaluation.

As seen in the preceding figures, the TB-2 was charred and partially blackened by the pyrolysis of the surrounding maplewood. This char and contamination of the surface of the TB-2 vessels inhibited the use of highly sensitive mass-spectrometer helium-leak-detection equipment. Therefore, the vessel exterior was rigorously cleaned with solvents, hot vapor-degrease processes, and glass-bead shot peening. After this cleaning, the TB-2s looked essentially like new and were completely intact, tight-appearing, and structurally sound. TB-2 X08 is shown at this stage in Figure 2.8.8-13.

For all TB-2 vessels, there was sufficiently low pressure of deleterious gases to permit helium detection, and, in one case, package X08, helium was detected in a sufficiently small quantity to stay below the saturation level of the instrument. Five of the six TB-2s had no detectable leak ($\dot{q} \leq 10^{-10}$ cm^3/s helum); upon disassembly (the loosening of from 3 to 9 bolts) and reinsertion of the TB-2 into the mass spectrometer vacuum vessel, a very strong positive indication of helium was obtained, confirming that the leaktight TB-2 still contained helium. The readable helium leak of 1.5×10^{-5} cm^3/s (equivalent to ~ 7×10^{-6} cm^3/s air) from X08 stayed at this same reading over a period of several months following the test sequence. A more detailed discussion of these leak rate results appears in Chapter 4.

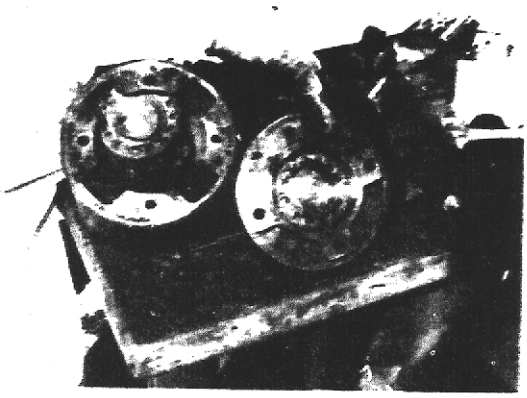


Figure 2.8.8-6. X10 Post-Test Disassembly

Figure 2.8.8-7. X10 TB-2 after Test Sequence

Figure 2.8.8-8. X11 Post-Test Disassembly

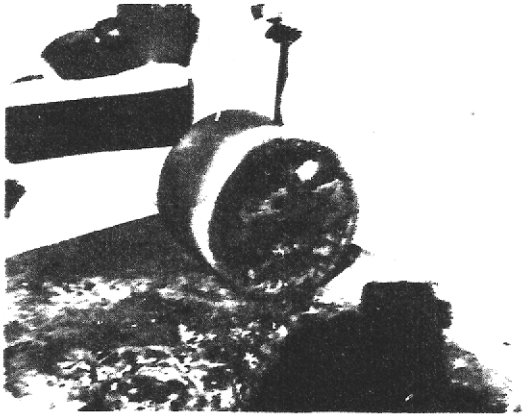


Figure 2.8.8-9. X11 Load Spreader, Post-Test Disassembly

Figure 2.8.8-10. Recovery of X11 TB-2

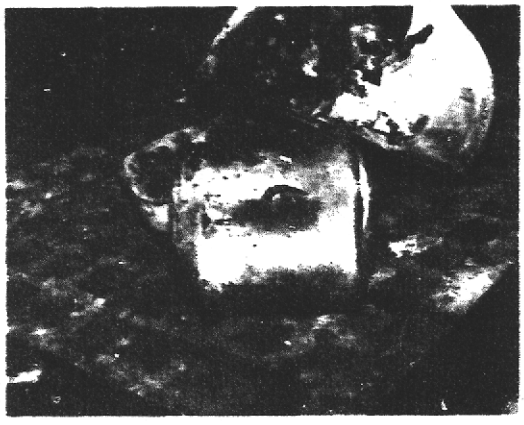


Figure 2.8-11. X12 Post-Test Disassembly

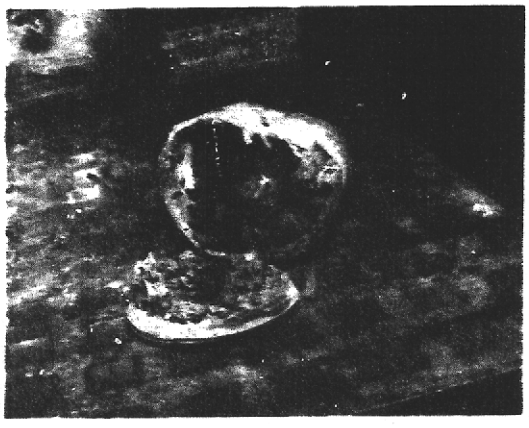


Figure 2.8-12. X12 Post-Test Disassembly

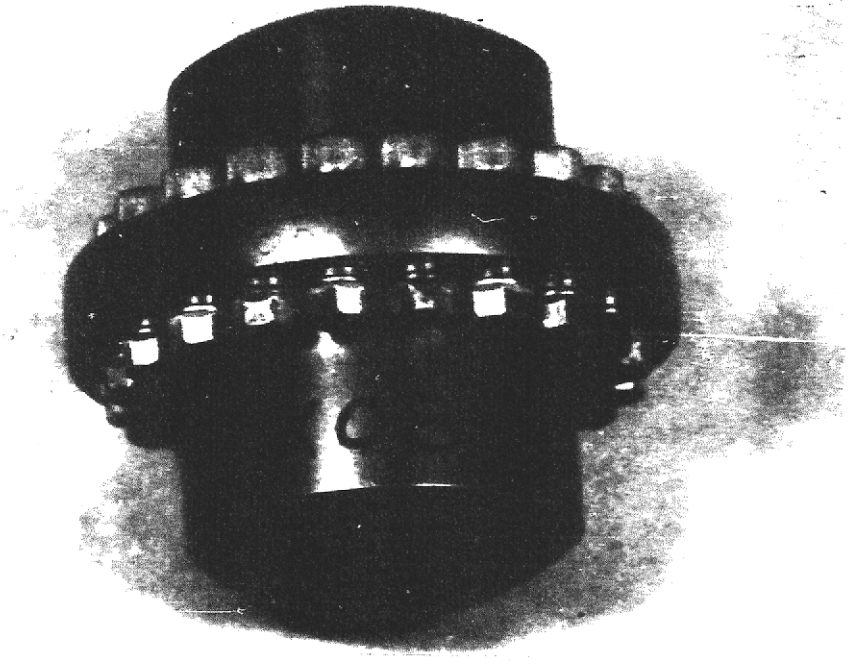


Figure 2.8.8-13. X08 TB-2 after Cleaning

Radiographs of the packages X07 through X12 following the impact, crush, puncture, and double-slash (including two views of a typical package, X12) are shown as Figures 2.8.8-14 through 2.8.8-20. Radiographs were also taken after impact only to direct the point of application of following tests to the worst point, as required by NUREG-0360.

2.8.9 Individual Hydrostatic Test

The NUREG-0360 test requirement is:

> The package to be submerged and subjected to an external water pressure of at least 600 psi for not less than eight hours.

A TB-2 containment vessel was assembled with an internal atmosphere of helium and determined to have no detectable leak. The vessel was then subjected to an external hydrostatic pressure of more than 5,000 psig (34.5 MPa) for more than 8 hours in color-dyed water. The helium leak rate of the vessel was $< 10^{-10}$ cm^3/s both before and after hydrostatic testing. When the TB-2 was opened, there was no indication of dye or water inside of the copper seal region.

Due to the importance of the TB-2 containment vessel in the PAT-2 package design, a stress analysis of the pressured vessel is presented as Appendix 2H. By analysis, the TB-2 factor of safety at 600 psi (4.1 MPa) external pressure is conservatively over 5, relative to yield strength. The 5000-psig test, an overload factor of 8.333, produced no adverse affect, as stated above.

2.8.10 Free-Fall Impact

The NUREG-0360 requirement is:

> Physical test of an undamaged package to the following conditions. This test is not required if the calculated terminal free-fall velocity of the package is less than 422 ft/sec or if a velocity not less than either 422 ft/sec or the calculated terminal free-fall velocity of the package is used in Test 1 of the sequential tests, above.
>
> (Note: Test 1 is the impact test of Section 2.8.2, this document.)

Reference 14, "Calculated Trajectories for the Lightweight Air Transportable Accident Resistant Container," is an aerodynamic study of the possible terminal velocities and impact velocities of a PAT-2 package under a variety of aircraft accident conditions. To simulate loss of the PAT-2 package from aircraft in flight, trajectory velocities were calculated at flight levels of 1,000, 5,000, 20,000, and 40,000 feet and at Mach numbers varying from 0 to 0.87. Drag coefficients of $0.75C_D$

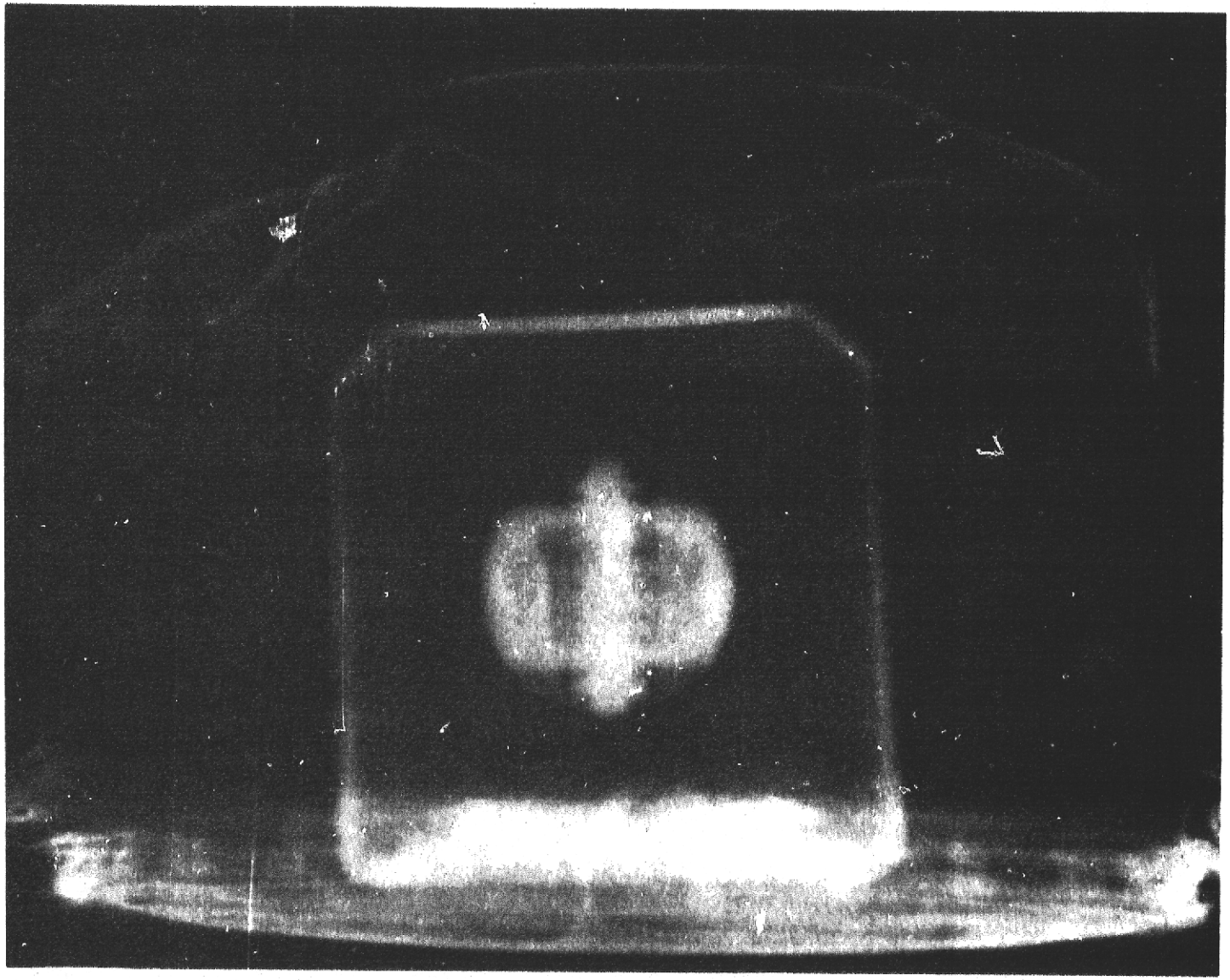


Figure 2.8.8-14. Radiograph of X07

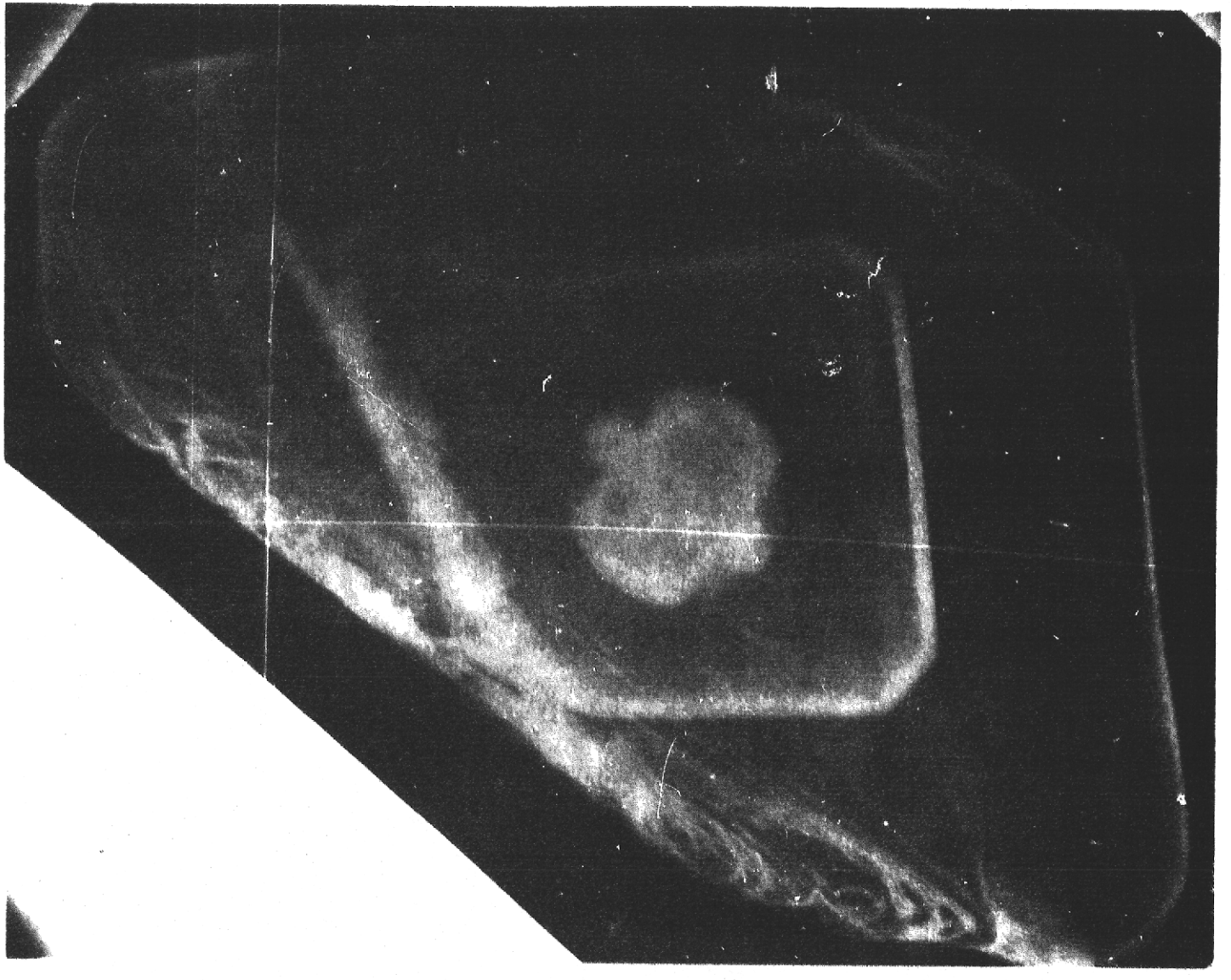


Figure 2.8.8-15. Radiograph of X08

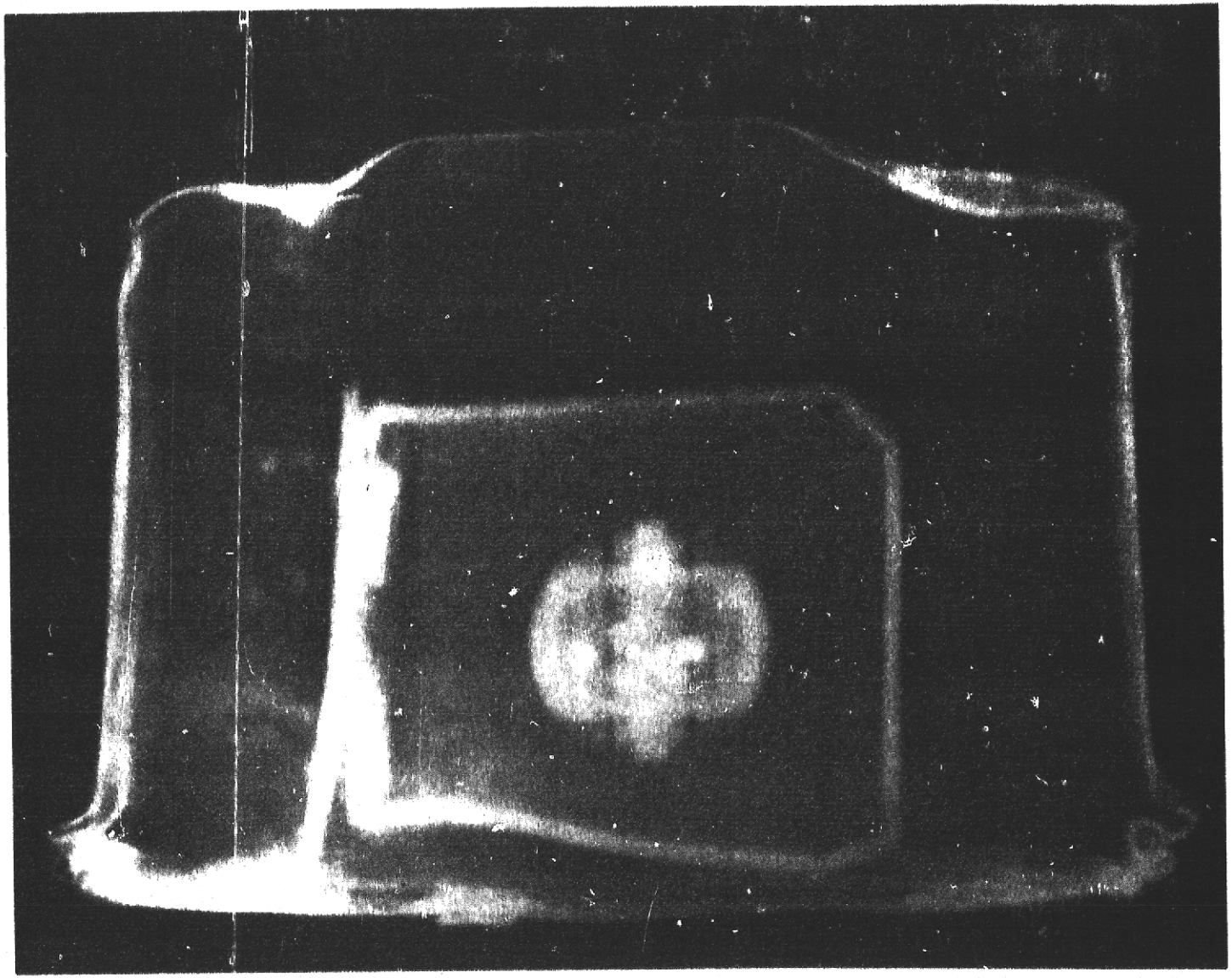


Figure 2.8.8-16. Radiograph of X09

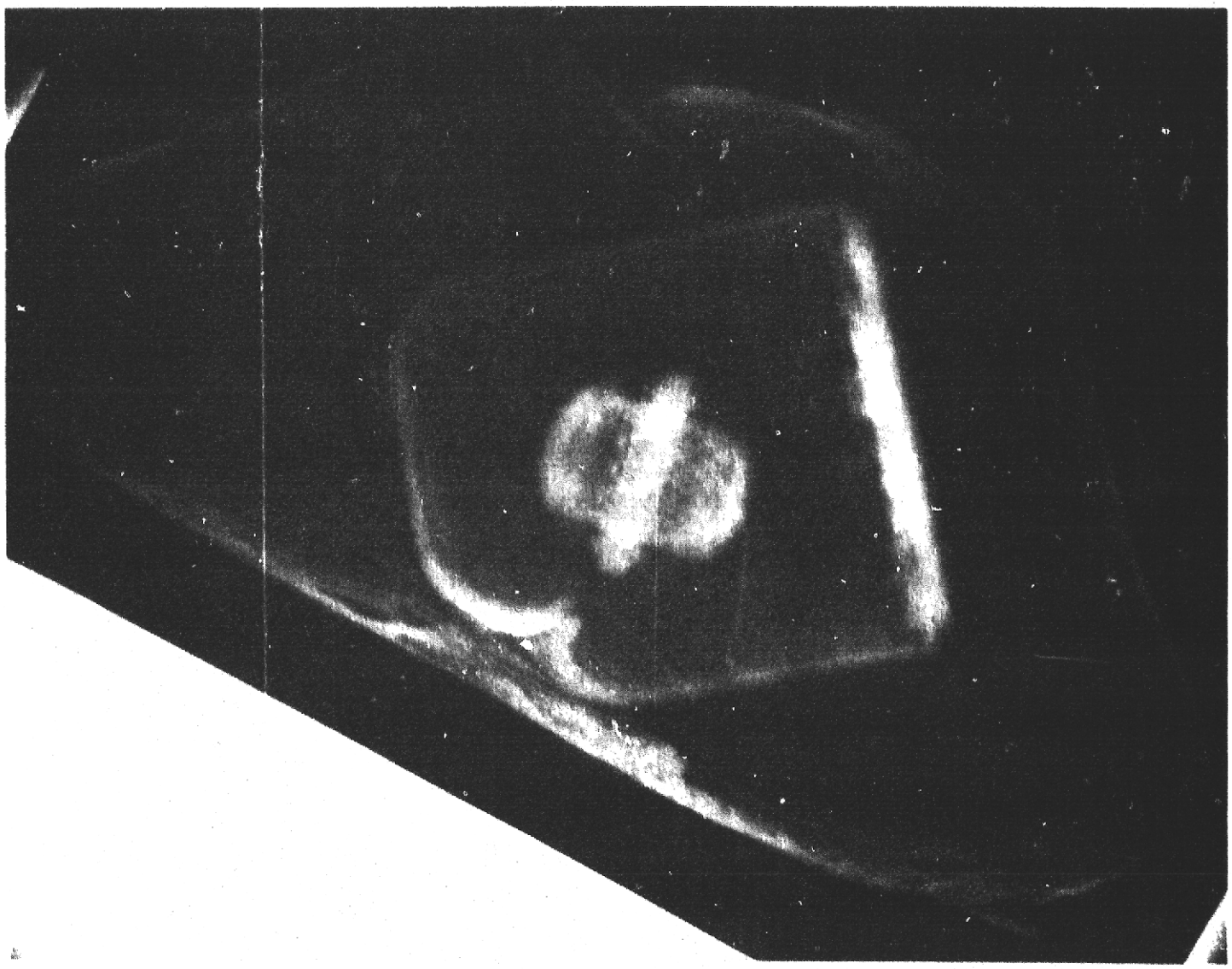


Figure 2.8.8-17. Radiograph of X10

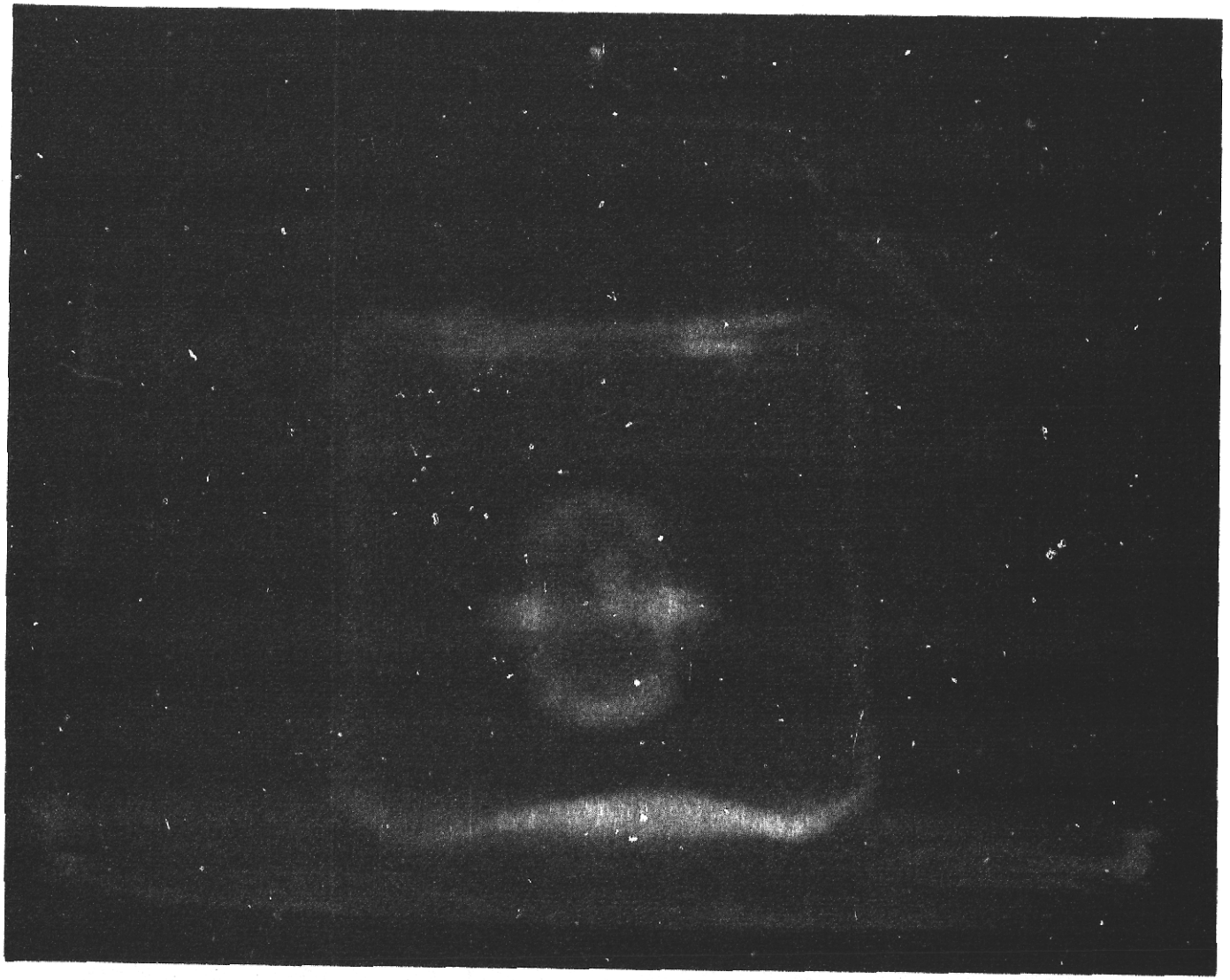


Figure 2.8.8-18. Radiograph of X11

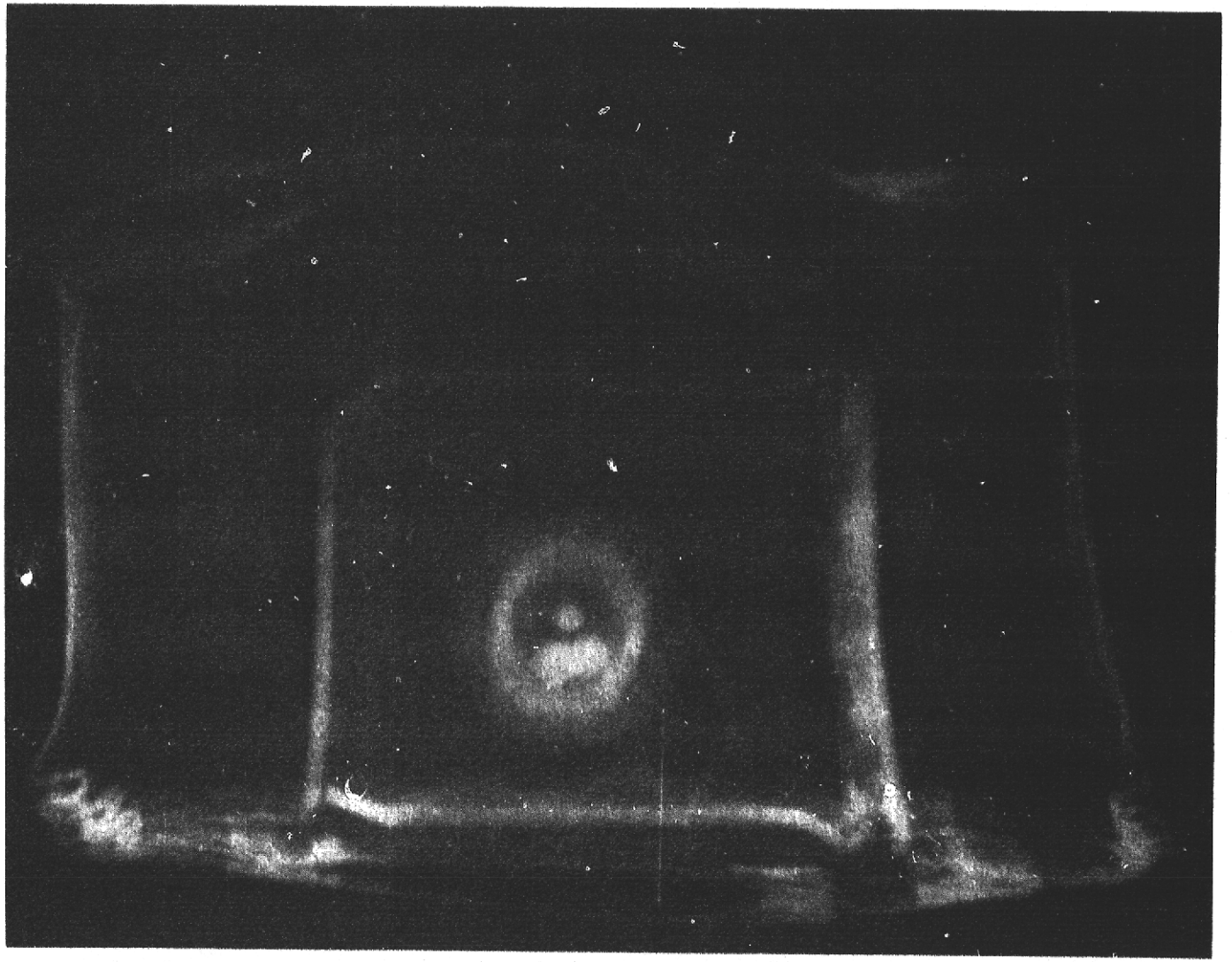


Figure 2.8.8-19. Radiograph of X12

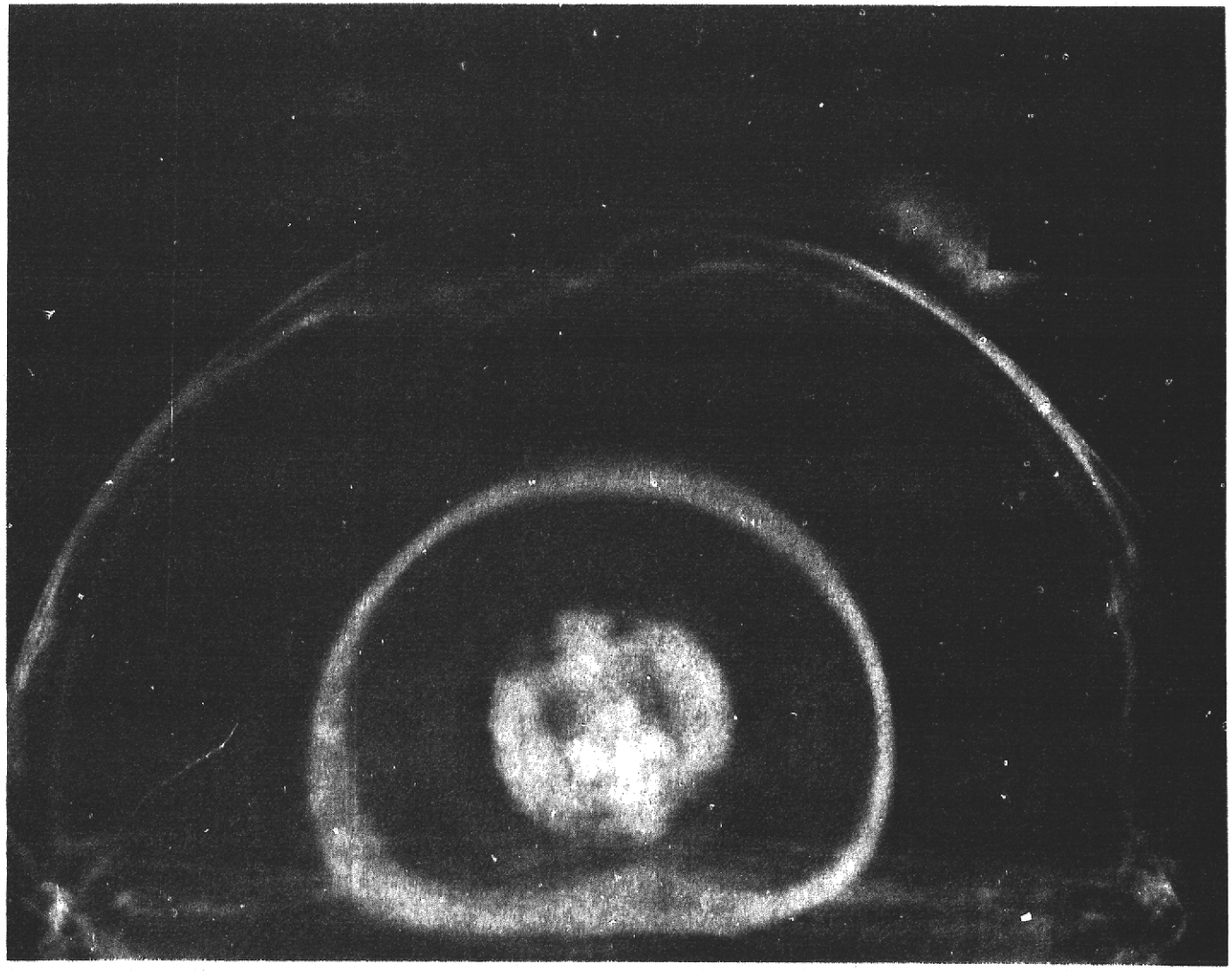


Figure 2.8.8-20. Radiograph of X12

to $1.25C_D$ were applied to cover all possible side-on, end-on, and tumbling configurations. The results, shown in Figure 2.8.10-1, indicate that the required impact test velocity of 250 knots or 422 ft/s (129 m/s) is always in excess of any possible aerodynamic trajectory velocity, in the atmosphere or upon impact, and no additional impact test is required.

2.8.11 Other Requirements of NUREG-0360

NUREG-0360 requires that the following additonal conditions be met by a transportation package:

1. Demonstration or analytical assessment showing that the results of the physical testing for package qualification would not be adversely affected to a significant extent by:
   a. The presence, during the test, of the actual contents that will be transported in the package, and
   b. Ambient water temperatures ranging from +35°F to +100°F for those qualification tests involving water, and ambient atmospheric temperatures ranging from -40°F to +130°F for the other qualification tests.
2. Demonstration or analytical assessment showing that the ability of the package to meet the acceptance standards prescribed for the accident condition sequential tests would not be adversely affected if one or more tests in the sequence were deleted.

Requirement 1a was satisfied by the presence, in packages X07 through X12, of a worst-case surrogate for every form of contents described in Chapter 1. These surrogates, described in detail in Chapter 4, present bounding maximums of pressure, corrosivity, mass, and likelihood of release and represent worse threats to containment than the actual contents to be transported in the PAT-2 package.

The water-temperature requirements of 1b (33°F to 100°F) were approached with the outdoor immersion tank used for the underwater test; package tests at greater extremes of temperatures produced no adverse results. The results of high-speed impact tests at -50°F and 220°F (-46°C and 104°C), along with other information presented in Chapter 3, qualify the PAT-2 for the -40°F to 130°F (-40°C to 54°C) ambient atmospheric temperature range.

Requirement 2, that the deletion of a NUREG-0360 test (or tests) would not adversely affect package performance, is satisfied. The severe sequence of (1) high-velocity (rocket pulldown) impact perpendicular to an unyielding target (reducing the package volume by about 50% in the most severe attitude), (2) 70,000-pound (311-MN) crush, (3) 5,000-lb_f·ft (6.8-kJ) puncture, (4) 15,000-lb_f·ft (20.4-kJ) slash (deliberately tearing the double outer drum), (5) a large JP-4 fuel fire at

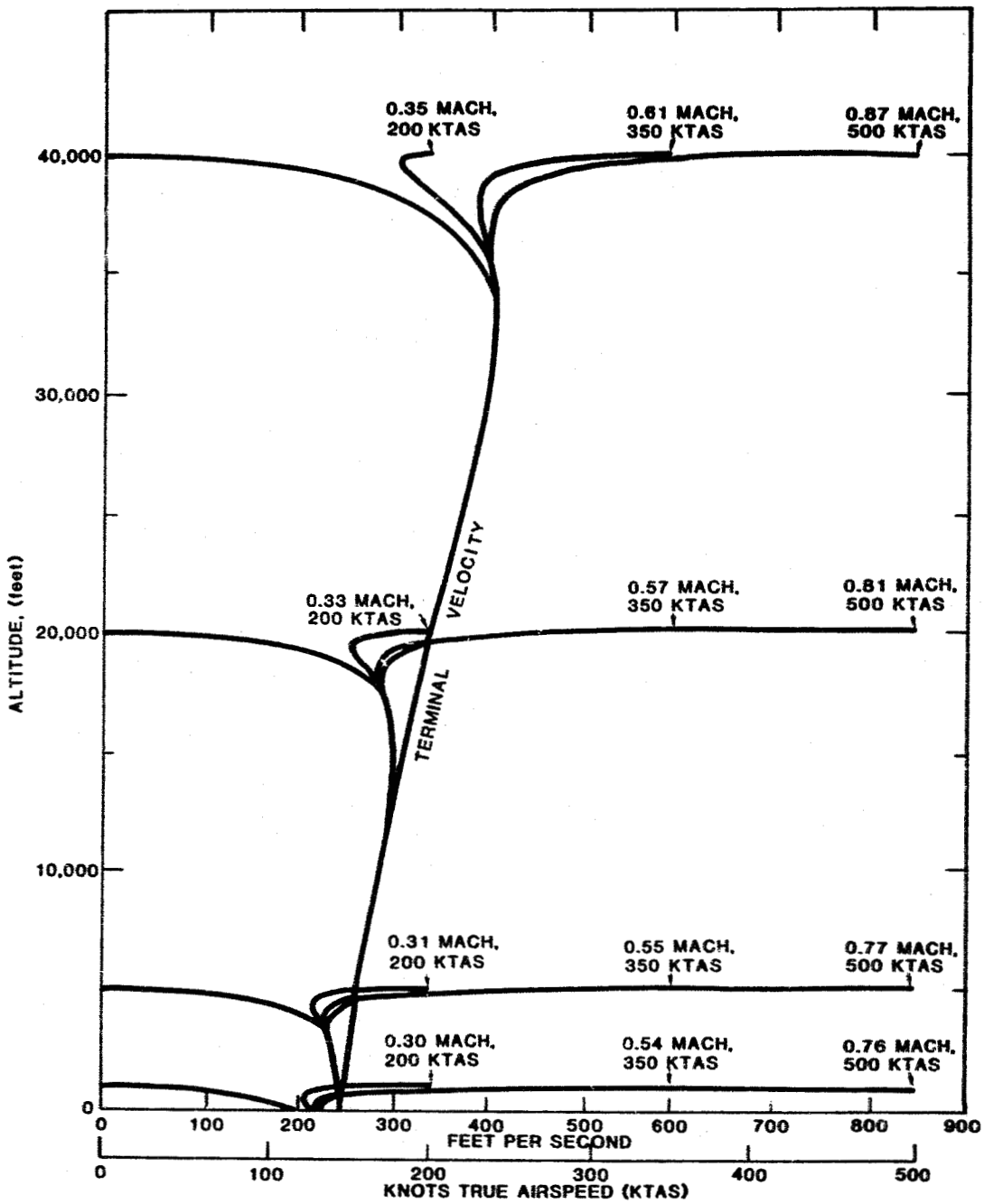


Figure 2.8.10-1. Effect of Initial Velocity Variation on Trajectory Velocities as a Function of Altitude for PAT-2

approximately 1850°F (1010°C) on the package surface for at least 1 hour, and (6) underwater immersion, produces far greater deterioration of the PAT-2 package than the effect produced by any of those tests singly, and the sequence produces greater deterioration than would result by eliminating one or more of the tests.

2.8.12 Alternate Operational Control -- Aircraft Stowage Location

2.8.12.1 Discussion

At the present time, NUREG-0360 (Sections II.D.1, pp 9, 10; and II.D.2, pp 29-31)[1] requires that plutonium packages must be stowed on the main deck of cargo aircraft in the aft-most location possible for cargo of this size and weight, with no other type of cargo stowed aft of such packages. In the development of NUREG-0360, as discussed on p 29 of that document,[1] the possible accident-caused crush loadings on a plutonium package in a main deck stowage location, with additional cargo located aft of the plutonium package, were considered but were not defined because "no satisfactory means was found to simulate or bound this environment by a specific test." Therefore, aft-most stowage was specified to provide protection against longitudinal crush.

In most cases, this restriction makes it impractical to air transport the PAT-1 or PAT-2 packages. The problem with aft-most stowage on the main deck is that practically all commercial cargo aircraft load from the front; therefore, aft-most cargo must be first on, last off, and aft cargo handling at an intermediate stop is not possible without completely unloading and then reloading the entire aircraft, involving large tonnages of cargo. In lieu of this, some commercial carriers (e.g., Flying Tigers at JFK airport, New York) have proposed carrying the PAT-1 as the sole cargo on board a four-engine jet; this results in prohibitive cost.

However, NUREG-0360 does address "belly" or lower compartment crush loads and states that "a package located in a cargo compartment below the main deck would be compressed between the hull and the floor structure." This condition was evaluated,[15] and a severe and conservative test is included as the second of the NUREG-0360 required sequential tests. The test consists of a 70,000-pound (0.31-MN) crush load, applied to the package through a 2-inch wide steel beam, with the package supported on a rigid steel surface, and applied in such a manner as to cause maximum package damage.

The NUREG-0360 discussion also states that "a package which can withstand the other physical tests included in the qualification criteria has an inherently high resistance to damage from this cause" [crush]. Test results on many PAT-2

packages have demonstrated that the rocket pulldown impact test results in substantially more package deformation and damage than is imposed by crush loads. In the development of the PAT-2 package, repeated application of the 70,000-pound (0.31-MN) crush test produced no discernible effect, as reported earlier in this chapter. In addition, for purposes of engineering development investigation of high-crush environments, final-model developmental PAT-2 packages were subjected to extended crush tests, one to 210,000 pounds (0.93 MN) and the other to 500,000 pounds (2.2 MN), in lieu of the 422-ft/s (129-m/s) rocket pulldown impact test. These packages were then punctured, slashed, burned, and immersed (in accordance with the NUREG-0360 sequential tests), and both packages were still leaktight and met all of the acceptance criteria of containment, shielding, and subcriticality. This extended crush testing is based on work presently being completed in an attempt to define acceptable longitudinal crush loads for severe aircraft accidents.[16]

In the development of NUREG-0360, the probability of occurrence of static crush environments resulting from aircraft accidents was estimated to be in the range of 0.01 to 0.06.* For a package much smaller than the one envisioned during the formulation of NUREG-0360 (PAT-2 vs. PAT-1), the probability of the smaller package being crushed either statically or inertially would be much lower. Another principle difference between the PAT-1 and PAT-2 packages, regarding any risk from a potential crush environment, is the much smaller quantity of fissile material that can be transported in the PAT-2. With all other conditions being equal, the 15-gram maximum allowed in the PAT-2 will result in a two-order-of-magnitude decrease in risk from the already low risk value for the PAT-1, which is licensed to transport 2 kg of plutonium.

Operational constraints and risk concerns associated with carriage of radioactive material packages in main deck cargo compartments are diminished if transport in the lower cargo compartment is considered. The present NUREG-0360 criteria includes the above-described 70,000-pound (0.31-MN) crush environment for the lower compartments. Enroute access and loading or unloading at intermediate stops are greatly facilitated, and the 9g tiedown requirement can still be maintained.

---

*From Reference 1, p 31, and SLA 74-0001, Severities of Transportation Accidents, Sandia Laboratories, July 1976.

The urgency of licensing (certificating) the PAT-2 package to make it available to the IAEA for international air shipments in the most practical manner possible leads to a request for the PAT-2 Certificate of Compliance to include an additional operational control; namely, lower cargo compartment stowage for air shipment.

2.8.12.2 Summary of Significant Points

1. NUREG-0360, Qualification Criteria to Certify a Package for Air Transport of Plutonium, presently includes a vertical crush test for plutonium packages stowed in a cargo compartment below the main deck of an aircraft, the lower cargo compartment.

2. All PAT-2 packages that provide the test data base in the PAT-2 Safety Analysis Report have been subjected to the NUREG-0360 crush test with no adverse effect.

3. PAT-2 packages have also been subjected to even more severe extended crush tests, with no adverse effect.

4. The smaller size of the PAT-2 package, compared to the licensed PAT-1, will result in a corresponding decrease in the probabilities for both inertial and static crush.

5. The PAT-2 package contents are limited to only 15 grams maximum of fissile material, two orders of magnitude less than that for the presently licensed PAT-1 package.

6. There is a current, urgent, practical need to air-transport plutonium samples worldwide, by the IAEA, in support of the Non-Proliferation Treaty.

7. Permission to carry the PAT-2 package under the main deck (in the lower cargo compartment) would alleviate many of the operational problems without an increase in risk.

2.8.12.3 Request

For the foregoing reasons, it is requested that an alternate operational control be permitted, by statement in the package Certificate of Compliance and/or by addendum to NUREG-0360, permitting lower cargo compartment stowage or location of the PAT-2 package, on board transport aircraft.

APPENDIX 2A

Redwood Impact Limiter/Heat Shield Material

The specific energy absorption is evaluated under the following conditions and constraints:

1. Motion of the flat crushing surface is in the direction of the grain; the surface is perpendicular to the grain.
2. Values are an average of five tests performed at room temperature.
3. Specimens are statically loaded.
4. The value is the average energy absorbed per pound of redwood taken to lockup, a strain corresponding to crushing to approximately 37% of original volume.

The average specific energy data over a wide range in test temperatures is presented in Figure 2A-1.

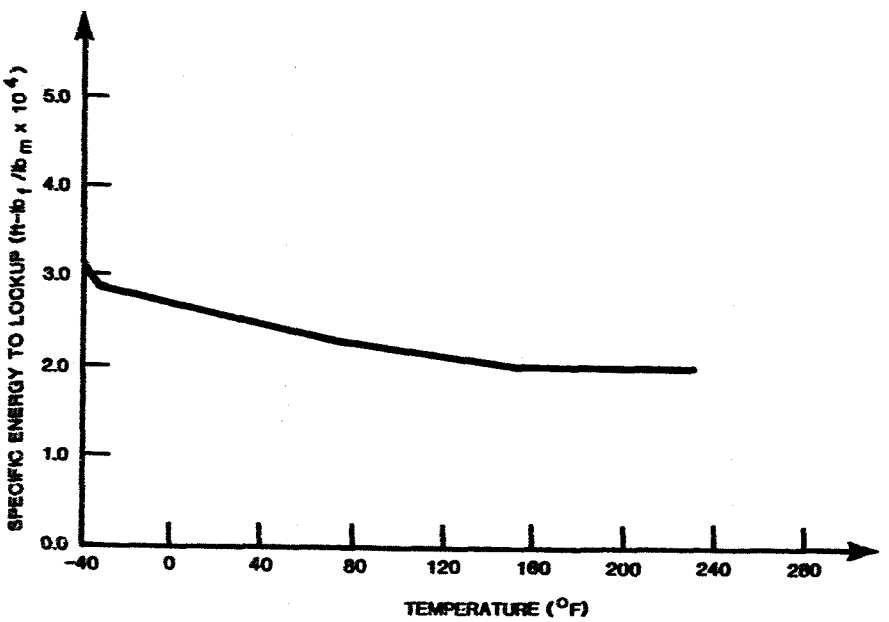


Figure 2A-1. Specific Energy to Lockup for Redwood Compressed in the Direction of the Grain

The crush strength value, 5,380 psi (37.1 MPa) at room temperature, is the average unit force to lockup for room-temperature test conditions. A typical load-displacement curve (or stress-displacement curve since a 1 in^2 (6.45×10^{-4} m^2) platen face was utilized) at room temperature is presented in Figure 2A-2. The variation in average crush strength with test temperature is indicated in Figure 2A-3.

Details of the test procedure, sample size, etc., are presented in Reference 6.

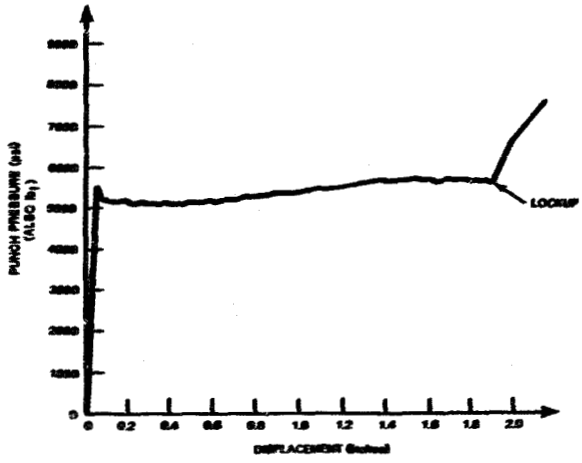


Figure 2A-2. A Typical Load-Displacement Curve for Redwood (at room temperature)

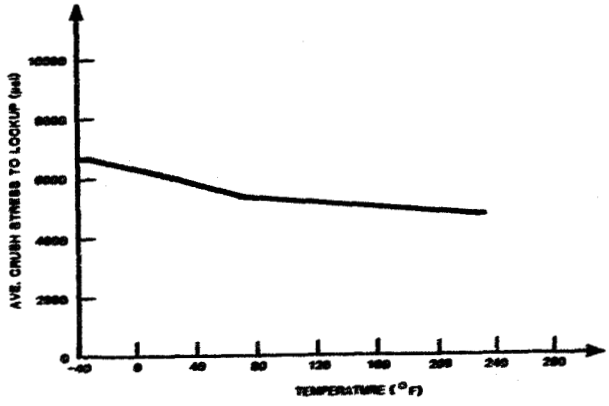


Figure 2A-3. Average Crush Stress for Redwood as a Function of Temperature

APPENDIX 2B

Maplewood Impact Limiter/Heat Shield Material

Crush and energy-absorption data are not presently available for maplewood. However, data for a variety of other woods are presented in Reference 8 and are shown in Figure 2B-1. The specific energy absorption capabilities of a variety of organic and inorganic crushable materials are included. Note that with the exception of plywood,* all woods tested lie in a reasonably narrow specific energy absorption band. While maplewood results are not specifically reported in the cited reference, the specific energy absorption of maplewood can be reasonably approximated by using the average value of the specific energy range shown in Figure 2B-1 for wood compressed in the direction of the grain. This value is $\epsilon = 1.9 \times 10^4$ $ft \cdot lb_f/lbm$ (56.8 kJ/kg).

Note that energy absorption capabilities for the various woods compressed perpendicular to the grain (denoted by $\perp$ in Figure 2B-1) are roughly a factor of 5 below the parallel compression values. Such strength and energy absorption capability in nonparallel directions is conservatively neglected in the impact analysis of the PAT-2.

---

*Due to the fact that plywood is layered with alternating grain orientation and includes glue lines, the differences that are indicated when plywood is compared to other woods are not considered an anomaly. Such gross differences would in fact be expected.

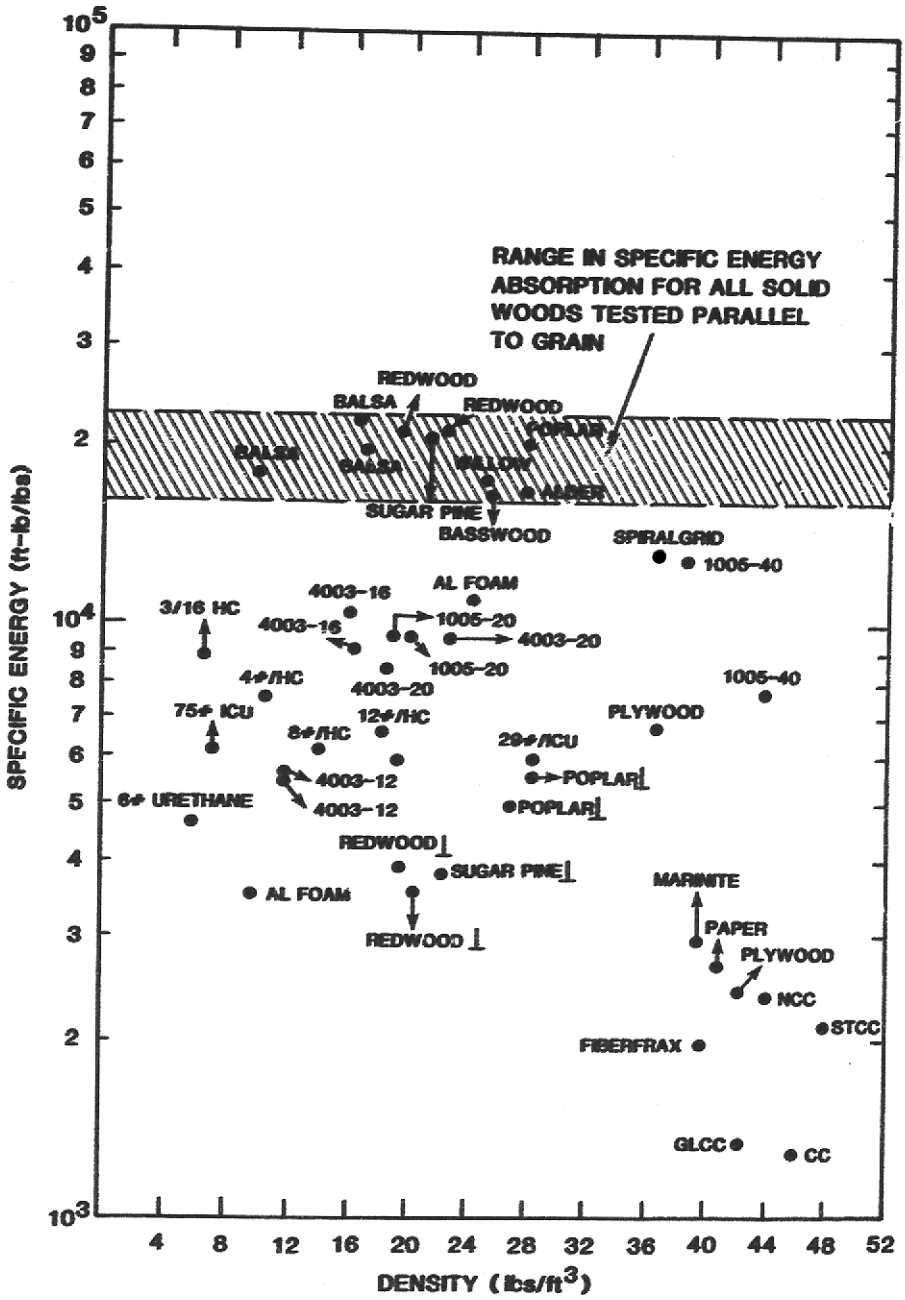


Figure 2B-1. Specific Energy Absorption Capabilities for a Variety of Materials[8]

APPENDIX 2C

TB-2 Containment Vessel and C-1 Capsule Stress Analyses

2C.1 INTRODUCTION

A number of different static stress analyses of the TB-2 containment vessel and C-1 capsule are required by 10 CFR 71 and NUREG-0360 for both internal and external pressure loading. The results are presented in Sections 2.3.1, "Maximum Normal Operating Stress;" 2.3.2, "TB-2 Maximum Credible Accident Stress;" 2.3.2, "C-1 Capsule Stress Analysis;" 2.5.2, "External Pressure;" Appendix 2H, "TB-2 Containment Vessel Hydrostatic Stress Analysis;" and Section 4.5.2, "Pressurization of TB-2 Containment Vessel."

The TB-2 stress analyses are presented in Section 2C.2, followed by those of the C-1 in Section 2C.3.

2C.2 TB-2 STRESS ANALYSES

The computer model used to perform the TB-2 stress analyses is detailed in Sections 2C.2.1 and 2C.2.2, a closed-form verification of the computer program is presented as Section 2C.2.3, and a brief analysis of fracture mechanics is given in Section 2C.2.4.

2C.2.1 Details of Computer Model

A single finite-element structural model was generated and then subjected to the appropriate magnitude of external or internal pressure specified for the various load cases, using the appropriate material properties corresponding to the temperature at which the specific load case is applied.

The stress/displacement field analyses were performed using the SASL computer program,[17] which is a version of the SAAS II finite-element program slightly modified by Sandia National Laboratories. For convenience, the SASL runs were performed in conjunction with the QMESH automated mesh generation scheme.[18]

The details of the mesh generated by QMESH are shown in Figure 2C.2.1-1. Note that the problem was modeled as one of axisymmetry, so only one-half the cross

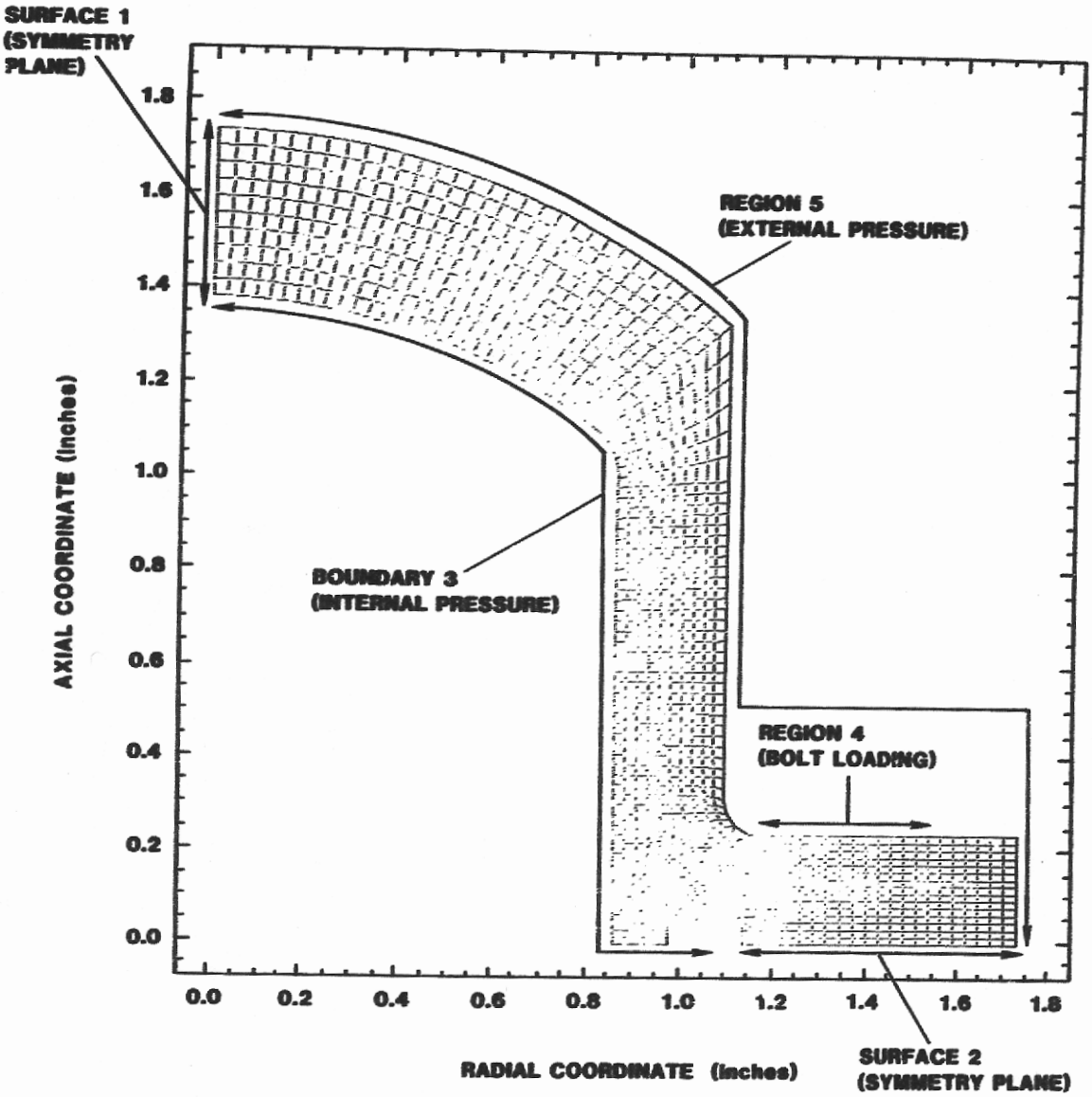


Figure 2C.2.1-1. Details of the TB-2 Mesh and Boundary Conditions

section of one side of the TB-2 vessel is shown. Surface 1 was given "symmetry plane" boundary conditions; i.e., displacements were not permitted in the radial direction on this plane, although vertical displacements were permitted. Similarly, symmetry plane conditions were applied along a portion of the flange surface 2 of Figure 2C.2.1-1, permitting radial motions with displacements constrained in the z direction as dictated by the symmetry of the problem.

For load cases involving internal pressure, such pressure is applied normal to boundary 3 of Figure 2C.2.1-1, at all points inboard of the knife-edge seal.

Twenty highly torqued bolts close the two halves of the TB-2 vessel. Since these bolts lie close together around the bolt circle, their influence is incorporated by assuming an equivalent ring loading of radial width equal to the bolt washer diameter. This rather high intensity distributed load is shown applied over region 4 in Figure 2C.2.1-1.

For problems involving external loading, the pressure is applied over region 5 in Figure 2C.2.1-1.

For improved accuracy, the aspect ratio of all finite elements are better than 2 to 1, and in regions which are more important to the results, a finer mesh has been established.

The TB-2 containment vessel is fabricated of A-286 iron-base superalloy. The material properties are considered to be linear elastic. The properties, e.g., elastic modulus, used in the analysis correspond to the actual properties at the temperature for the particular load case. For example, at the 1,080°F (582°C) environment associated with the maximum credible accident pressure (MCAP) of 3,280 psi (22.6 MPa), the elastic modulus reduces to a value 22% lower than the room-temperature value.

The stress field is of importance because failure, either through excessive plastic yielding and resultant ductile fracture or through brittle fracture, which has been found to occur in ductile materials subjected to a triaxial state of stress, must be avoided.

Displacements are important since any significant relative displacement of the knife-edge and the copper seal may result in leakage.

2C.2.2 MCAP Analysis by SASL

The MCAP, which occurs at 1,080°F (582°C), results in a calculated worst-case internal pressure of 3,280 psi (22.6 MPa) acting on the TB-2 vessel. The deformed shape of the vessel is shown in Figure 2C.2.2-1 at a displacement magnification of 100. Note the slight bulging of the vessel and lifting up in the knife-edge region. However, it is absolutely essential that it be understood that the deformations, which are visible to the unaided eye in Figure 2C.2.2-1, have been grossly magnified. The actual deformation field for the same problem is shown in Figure 2C.2.2-2 (overlaid with the initial configuration of 70°F (21°C) unpressurized). Included in this figure are the effects of the uniform dilation caused by thermal expansion.* Magnification in this case is 1.0. Although the thermal growth can be detected in this overlay, the bulging and knife-edge lift-up are both imperceptible.

The stress fields generated by the MCAP condition are shown as isostress contours for radial, axial, and circumferential stress components in Figures 2C.2.2-3, 2C.2.2-4, and 2C.2.2-5, respectively, while the equivalent von Mises stress field is shown in Figure 2C.2.2-6. The maximum von Mises stress is only 22.4 ksi (154.4 MPa) and that this value occurs at a sharp inside corner where a local stress concentration is present. Compared to a uniaxial yield stress of 100 ksi (690 MPa) for A-286 material, the stresses are well below the yield stress, even for this extreme case of MCAP.

An expanded view of the SASL-modeled region of the seal is shown in Figure 2C.2.2-7. Motion of the tip of the seal (node 1032, Figure 2C.2.2-7) is caused by both the applied internal pressure as well as the thermal expansion of the TB-2 vessel as it is heated from room temperature to 1,080°F (582°C). The vertical displacement components due to internal pressure and due to thermal expansion are very nearly equal and are additive, the total value being 0.540×10^{-3} inch (13.72×10^{-3} mm). The tip of the seal initially is in contact with (and in fact is driven into) a copper ring to effect the sealing process. The coefficient of expansion of the copper material is 9.8×10^{-6} in./in./°F (1.8×10^{-5} cm/cm/°C), a value just slightly lower than that of the TB-2 vessel material, 9.9×10^{-6} in./in./°F (1.8×10^{-5} cm/cm/°C).

---

*For this problem, no thermal stresses are generated by the increase in temperature from room temperature to 1,080°F (582°C).

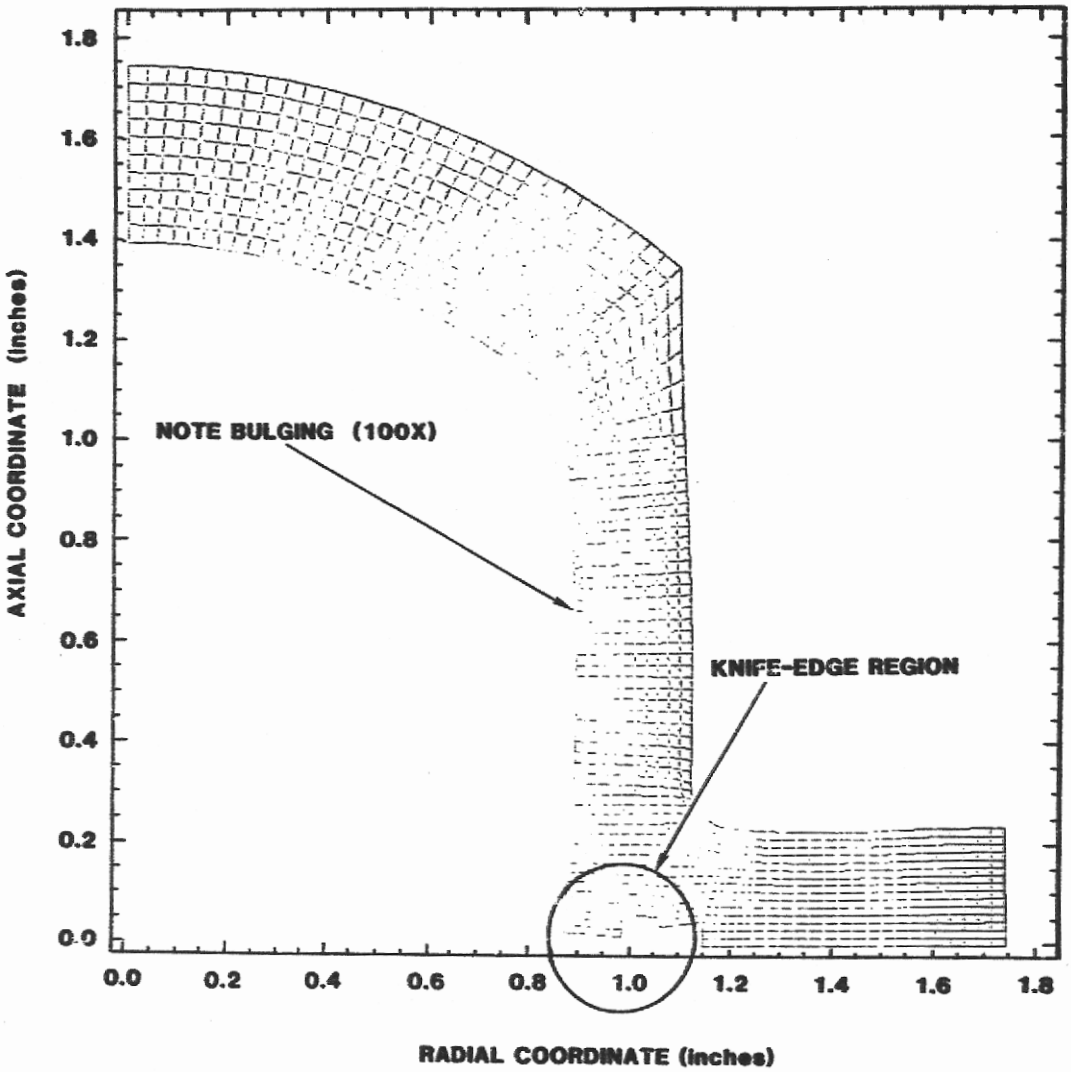


Figure 2C.2.2-1. Deformed Displacement Field (Magnification = 100) for TB-2 Vessel Subjected to 3,280-psi (22.6-MPa) Internal Pressure at 1,080°F (582°C)

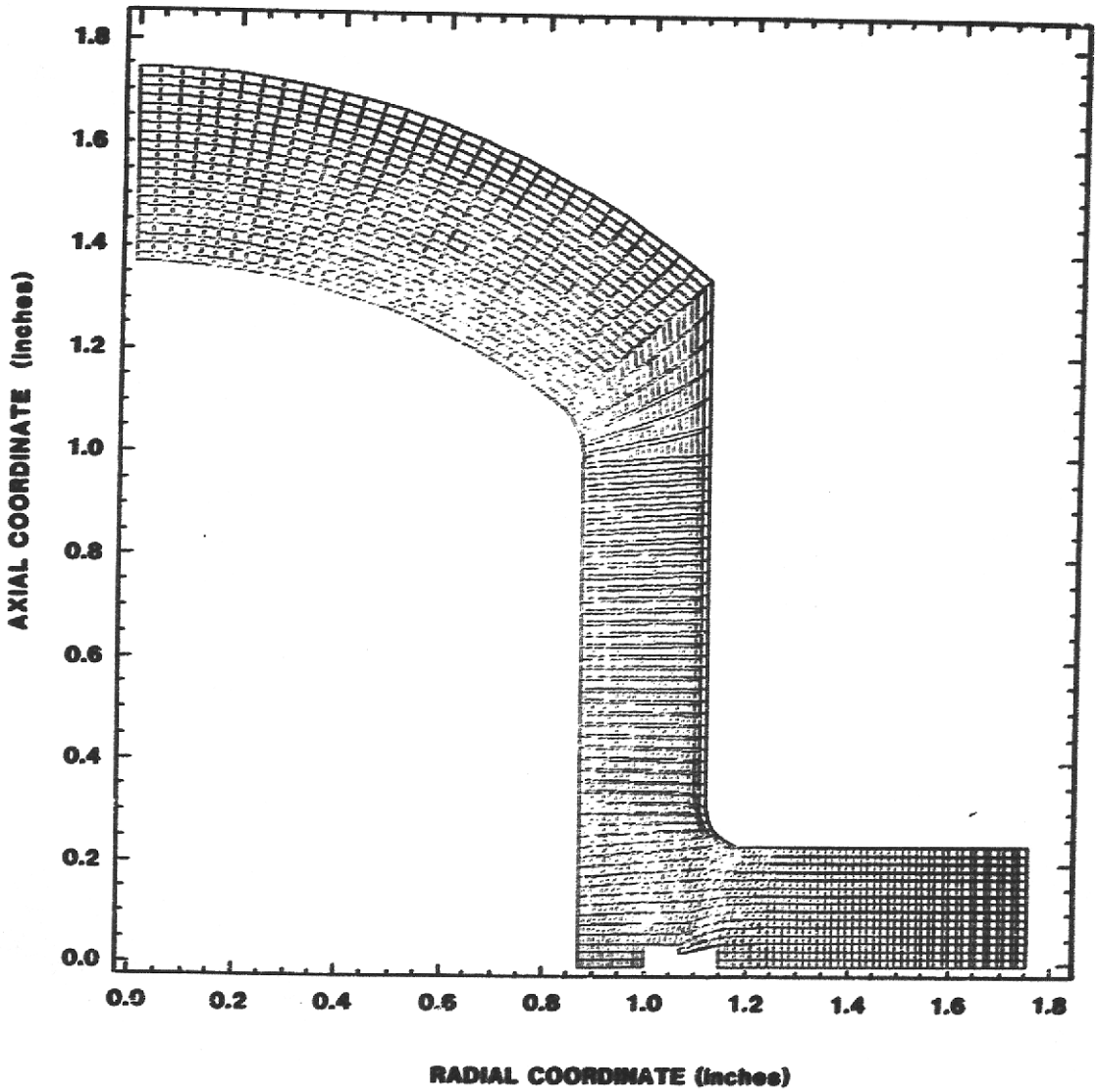


Figure 2C.2.2-2. Actual Pressure- and Temperature-Induced Displacement Field Superimposed with Room-Temperature Unpressurized Configuration

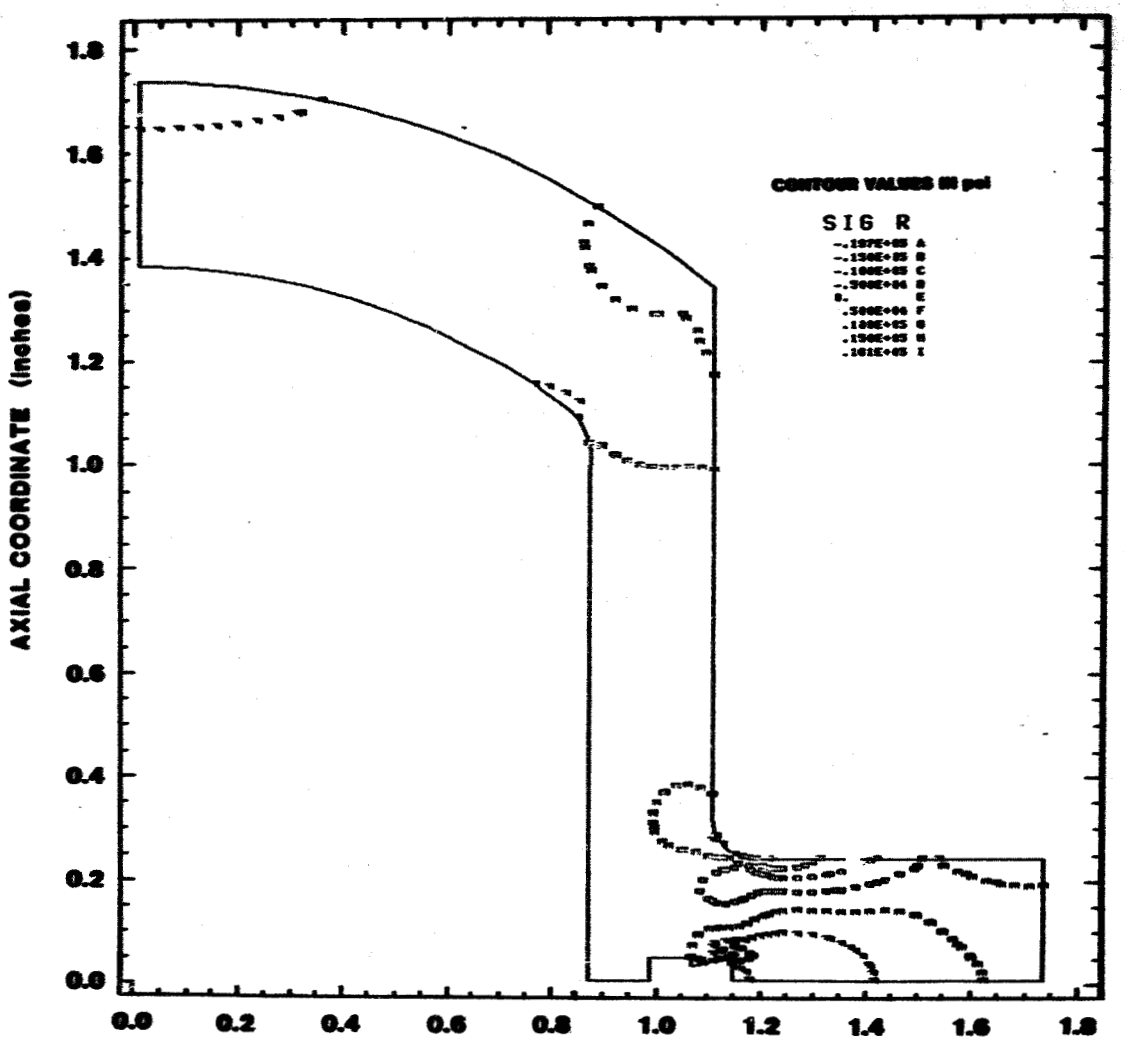
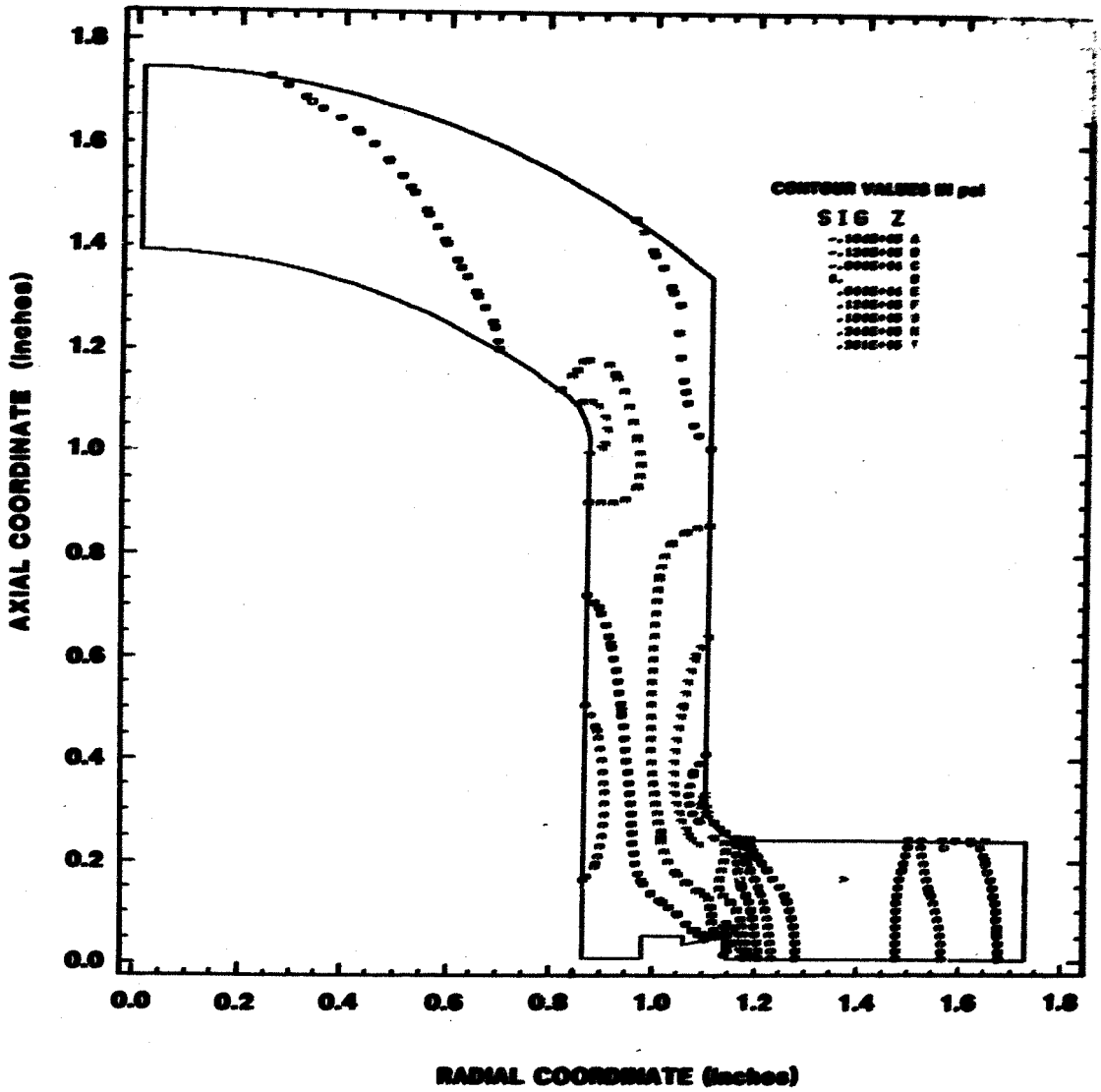


Figure 2C.2.2-3. Isostress Contours at 3,280 psi (22.6 MPa) Internal Pressure (Radial Stresses)



2C.2.2-4. Isostress Contours at 3,280 psi (22.6 MPa) Internal Pressure (Vertical or Axial Stresses)

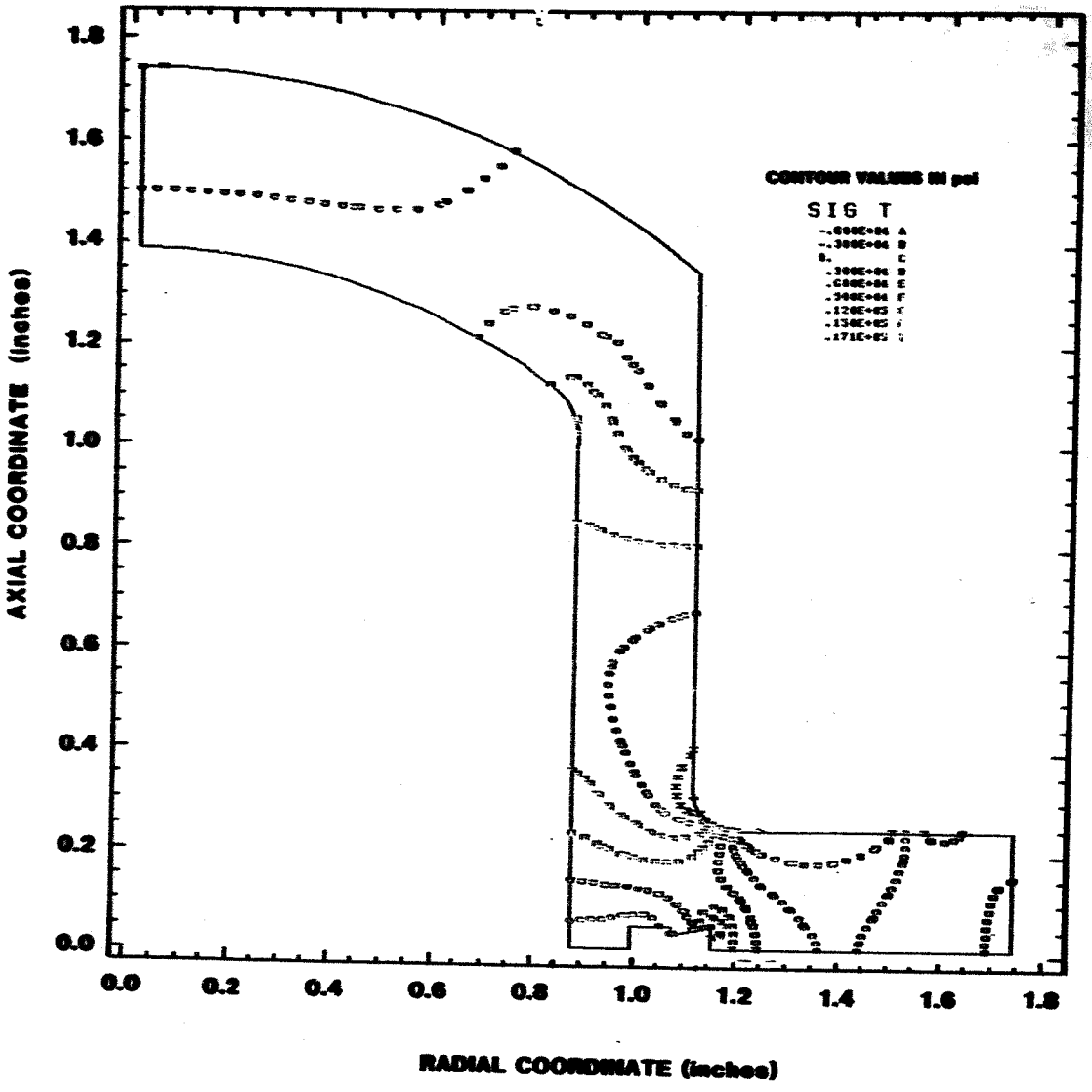


Figure 2C.2.2-5. Isostress Contours at 3,280 psi (22.6 MPa) Internal Pressure (Circumferential Stresses)

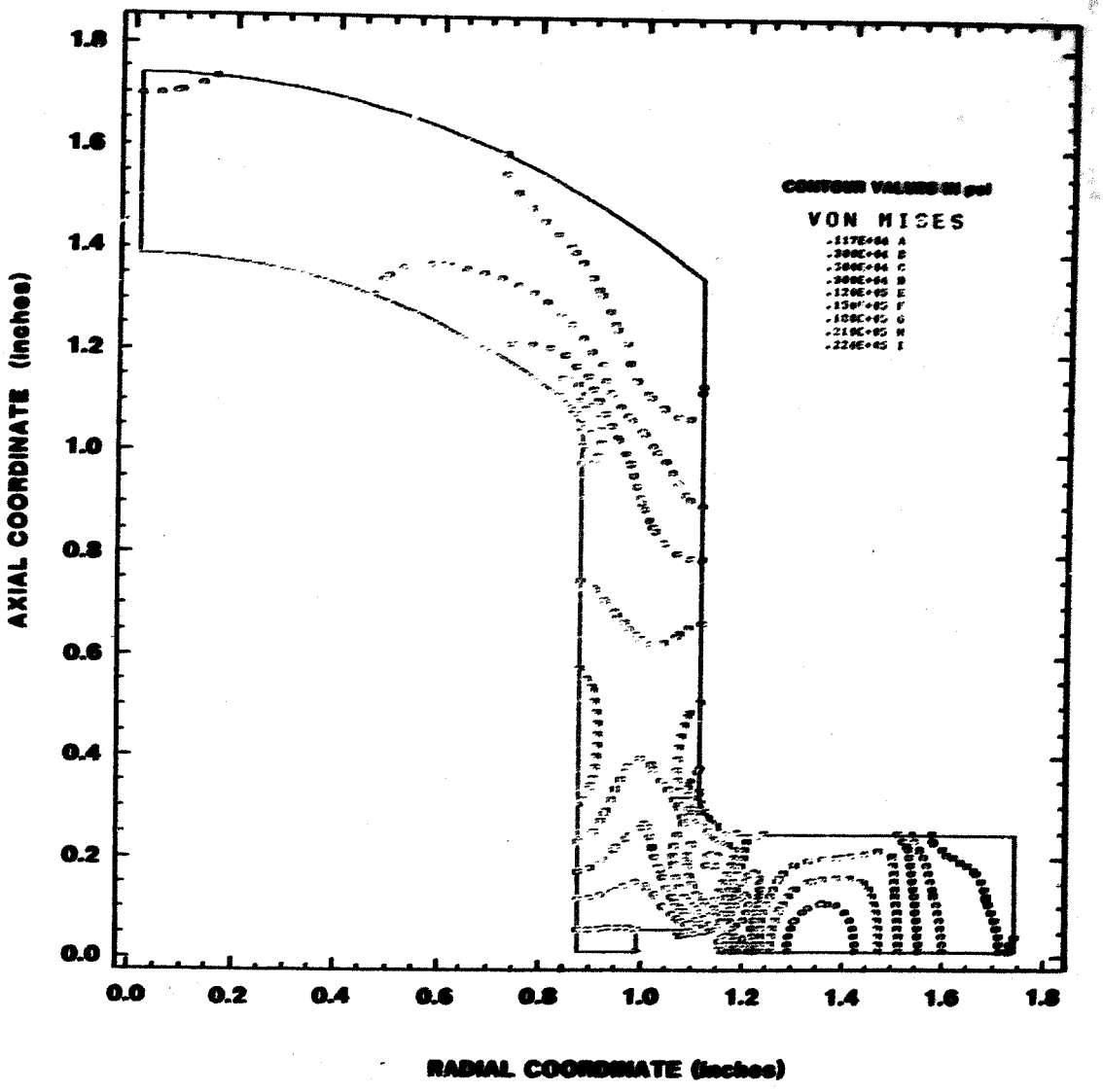


Figure 2C.2.2-6. Isostress Contours at 3,280 psi (22.6 MPa) Internal Pressure (von Mises Effective Combined Stresses)

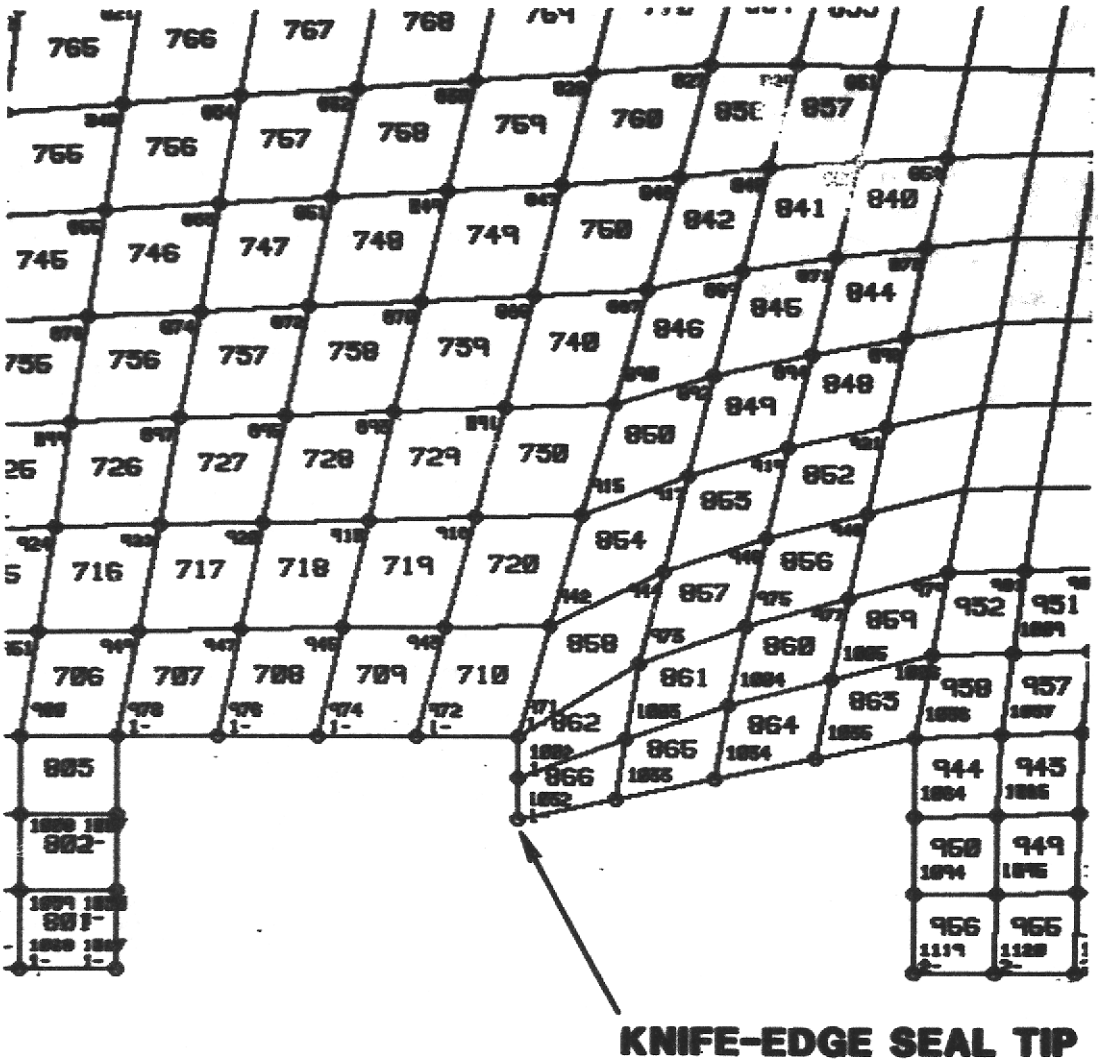


Figure 2C.2.2-7. Detailed View of SASL Computer Model in Vicinity of Sealing Region

Unconstrained vertical thermal displacement of the copper seal at the knife-edge tip location is 0.287×10^{-3} inch (7.3×10^{-3} mm) at 1,080°F (582°C). Thus, there is a net apparent relative displacement (a gap) of the A-286 knife-edge tip and the copper seal of 0.253×10^{-3} inch (6.43×10^{-3} mm). As the vessel is pressurized and the knife-edge seal tip begins to move off the seal, the copper seal will undergo elastic recovery, reducing this relative displacement. It is difficult to predict the extent of this elastic recovery accurately. Any possible leakage can best be verified by test results and is discussed in Appendix 4H, "Additional Practical Considerations Regarding Possible Plutonium Release," which relates the possible gap to a measured leak rate. The containment-vessel-to-gasket displacement at the outside diameter of the sealing gasket (e.g., mesh zones 863 and 956 in Figure 2C.2.2-7) is undetectable, hence a seal is maintained.

2C.2.3 Theoretical Verification of the SASL-PAT-2 Analysis

This section compares the SASL-calculated stress fields with "exact" formulas, where possible, for verification that SASL is correctly performing the calculations and that no gross errors have been committed -- for instance, in the input data supplied to the program.

Figure 2C.2.1-1 reveals that the cylindrical portion of the TB-2 containment vessel has a radius-to-thickness ratio of 4.22, which places the geometry in the thick-shell regime, ruling out the use of conventional thin shell stress analysis formulas for comparison. However, the shaded elements in Figure 2C.2.3-1 are located well away from the influence of the hemispherical head and the lower flange. Although the shaded region will still be somewhat influenced by bending effects caused by the hemispherical head and the flange, stresses can be reasonably approximated in this region by a closed, long, thick-walled cylinder subjected to internal pressure loading.

The long cylinder solution is only an approximation to the problem being modeled by SASL, so that results should not be precisely the same, primarily due to the absence of bending in the closed-form solution. However, reasonable correlations should be anticipated.

The thick cylinder is under a state of triaxial stress. Since the geometry is axisymmetric and the cylinder is long, the stress field is a function of the radial coordinate, r, only. The stresses are given by

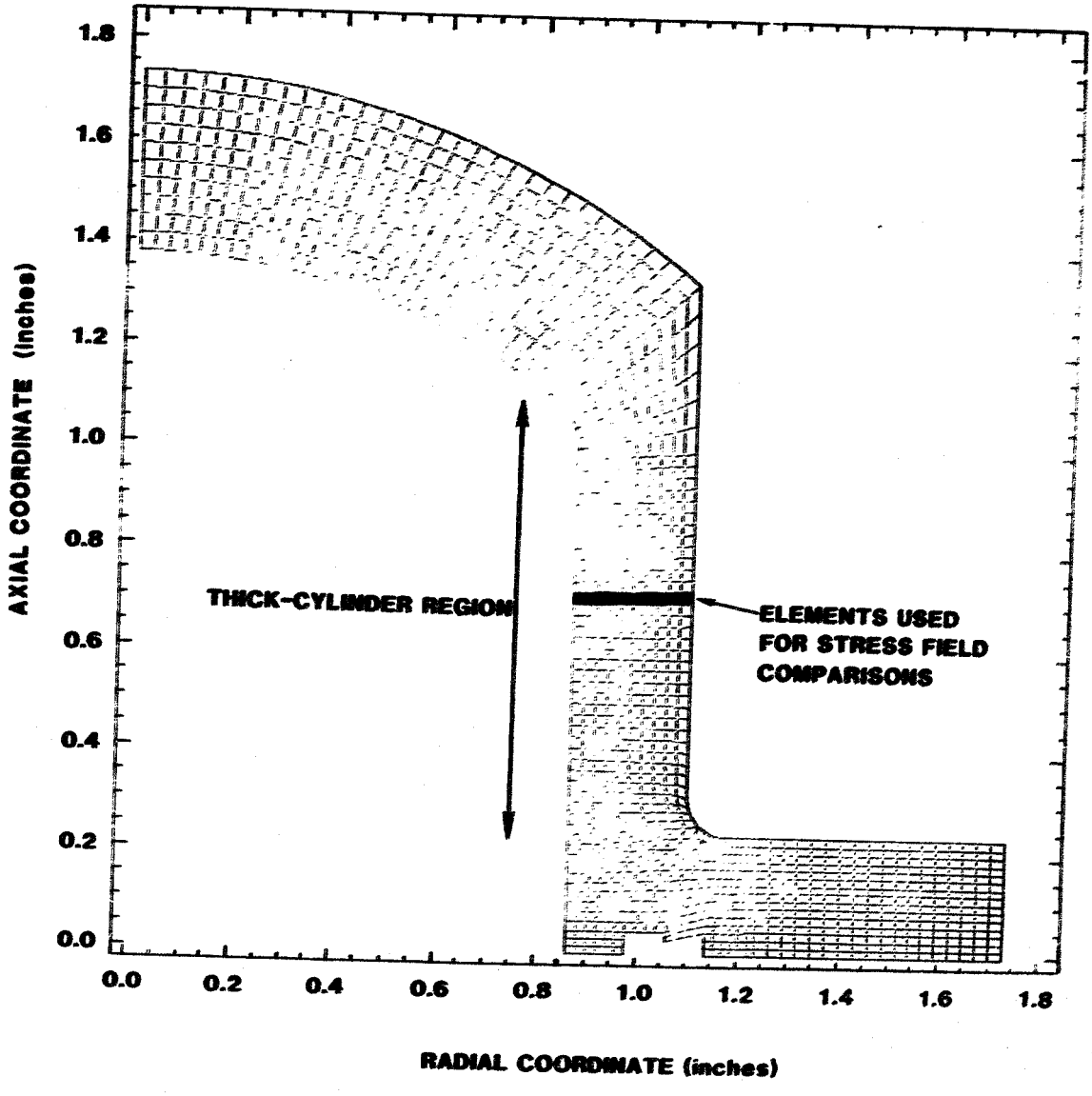


Figure 2C.2.3-1. Location in Cylindrical Region of TB-2 Vessel for Closed-Form Comparisons

$$\sigma_r \text{ (radial stress)} = -p \frac{a^2(b^2 - r^2)}{r^2(b^2 - a^2)}$$

$$\sigma_\Theta \text{ (circumferential stress)} = p \frac{a^2(b^2 + r^2)}{r^2(b^2 - a^2)}$$

$$\sigma_Z \text{ (axial stress)} = p \frac{a^2}{b^2 - a^2}$$

where

p = internally applied pressure,
a = inner radius of the cylinder, and
b = outer radius.

See Figure 2C.2.3-2 for the geometric configuration and sense of the stresses.

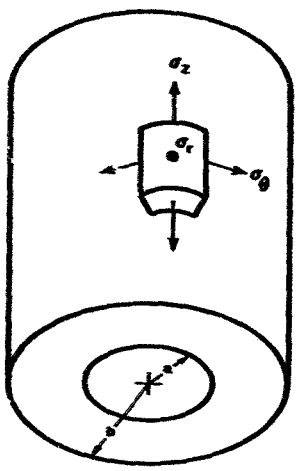


Figure 2C.2.3-2. Thick-Walled Cylinder Showing Sense of Stress Components

Figures 2C.2.3-3, 2C.2.3-4, and 2C.2.3-5 show the radial, circumferential, and axial stresses, respectively, as a function of the radial coordinate, with MCAP = 3,280 psi (22.6 MPa), a = 0.866 inch (2.19 cm), and b = 1.102 inches (2.79 cm). These figures also show the stresses calculated by the SASL computer program through the thickness at the location shown in Figure 2C.2.3-1. Consider first Figure 2C.2.3-3. Comparison of SASL and closed-form calculations indicates good agreement for the radial stress field. Such agreement was anticipated since the inner and

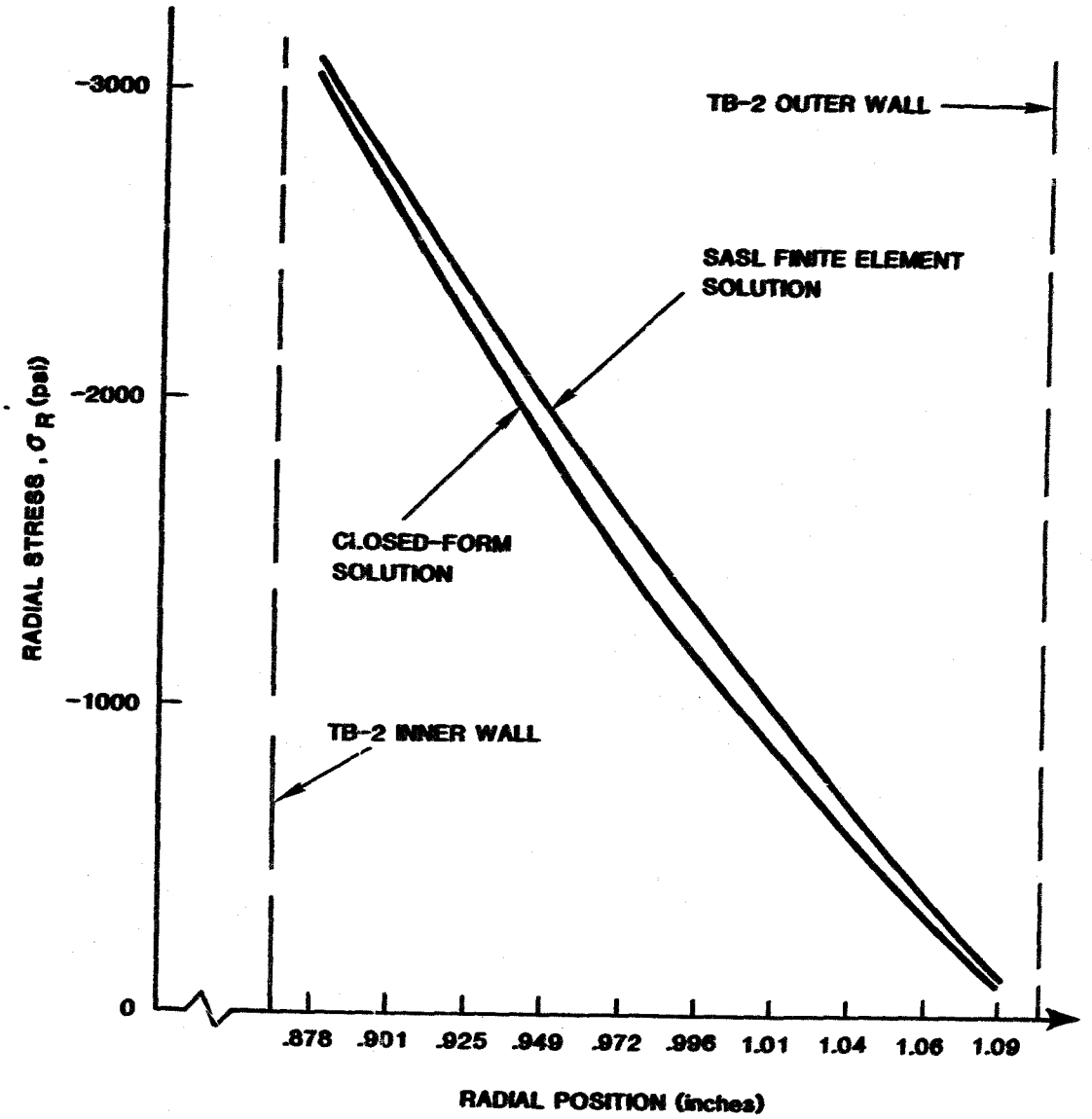


Figure 2C.2.3-3. Comparison of Closed-Form and Finite Element Predictions--Radial Stress Field

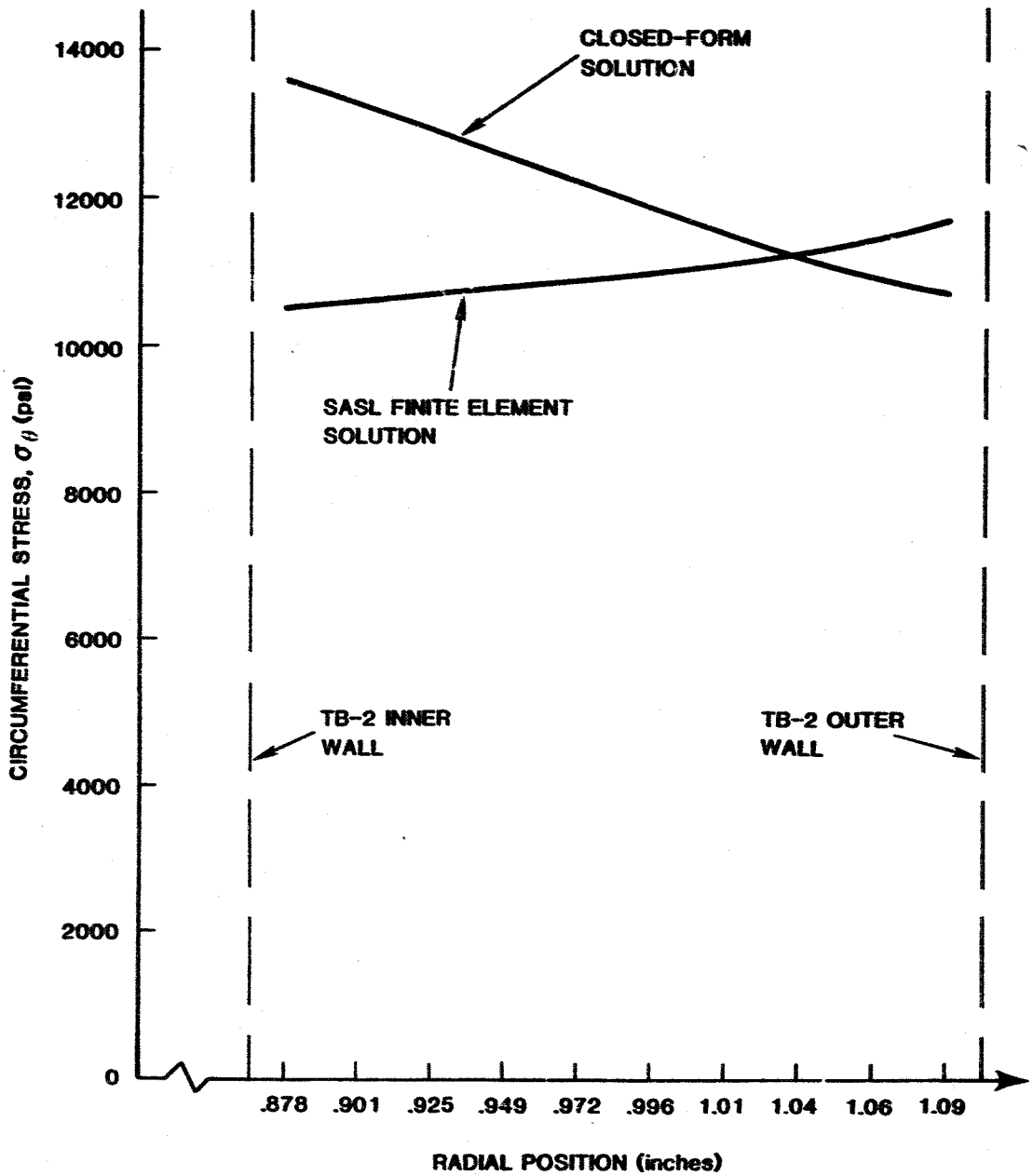


Figure 2C.2.3-4. Comparison of Closed-Form and Finite Element Predictions--Circumferential Stress Field

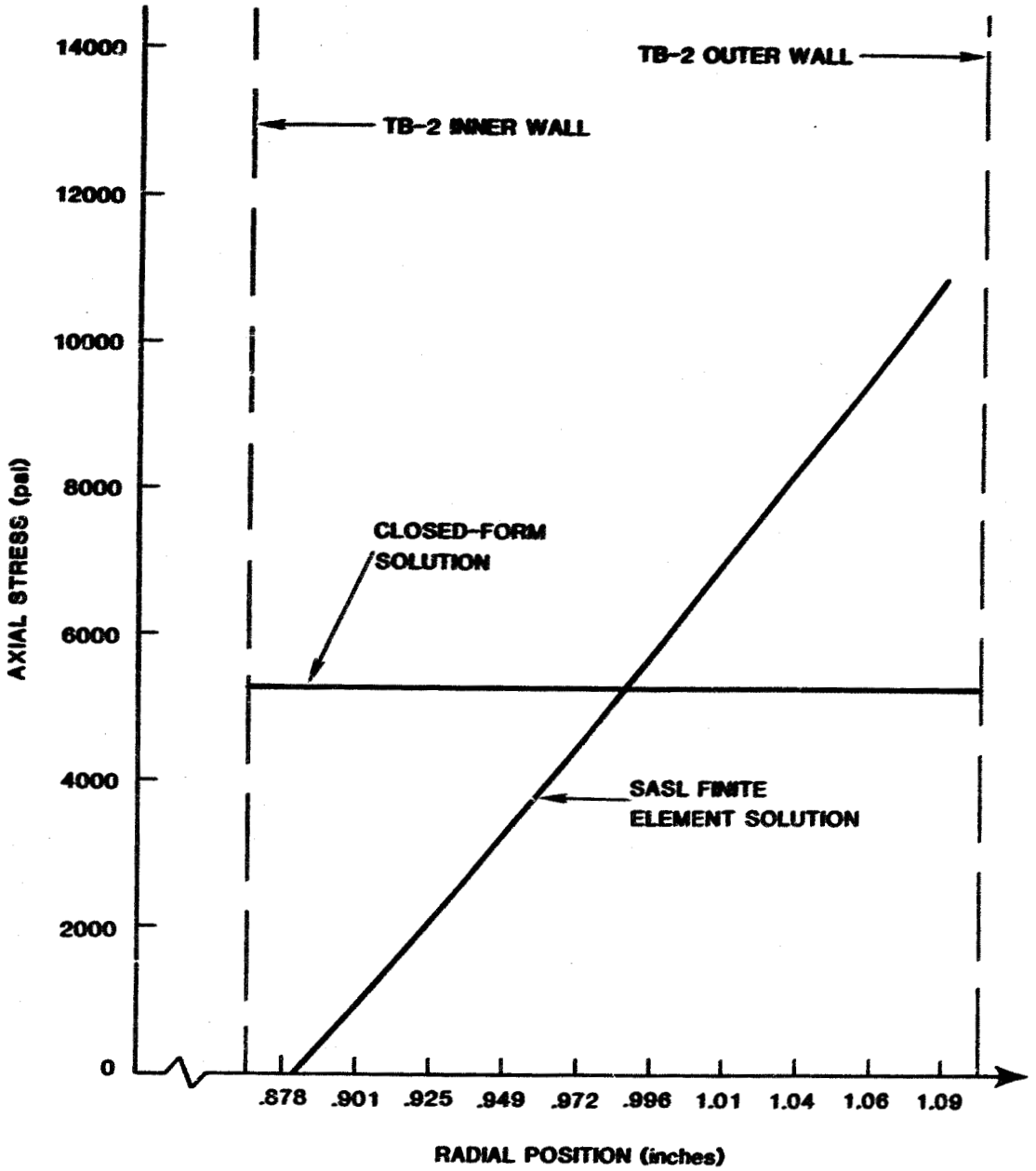


Figure 2C.2.3-5. Comparison of Closed-Form and Finite Element Predictions--Axial Stress Field

outer wall stresses (-p and o, respectively) must agree, and the influence on the radial stress field several wall thicknesses in from the hemispherical cap and the flange is small.

Circumferential stress calculations, Figure 2C.2.3-4, are in good agreement as to average magnitude. Differences are caused by the influence of the end attachments in the actual problem (SASL) which are not modeled in the closed-form solution.

Finally, the axial stress-field comparison shown in Figure 2C.2.3-5 shows excellent agreement in average value (as it must from considerations of equilibrium) but a nearly linear variation through the thickness for the SASL calculation corresponding to the presence of bending in the actual problem.

The location of the TB-2 hemishperical region chosen for comparison, the pole, is shown in Figure 2C.2.3-6. The closed-form comparison model is a thick-walled sphere with geometry and sense of stresses as shown in Figure 2C.2.3-7. The in-plane stress field will be balanced-biaxial. Stresses in such a complete sphere are reasonable approximations for a semi-spherical cap (again, except for bending stresses induced at the edge of the cap if it is physically connected to a cylinder). Figure 2C.2.3-6 reveals that a complete hemisphere is not present in the TB-2, but only a semi-sphere, so that stresses calculated on the basis of a complete spherical shell will differ significantly from the SASL model. Comparisons of radial stress are shown in Figure 2C.2.3-8, while the (balanced) in-plane stress field is shown in Figure 2C.2.3-9; comparisons in both cases are made with the set of radial finite elements shown in Figure 2C.2.3-6. Comparison of the radial stress field is seen to be reasonable. Again, while the functional form of the in-plane stress fields shown in Figure 2C.2.3-9 differ drastically (again due to the presence of bending effects), maximum values are in reasonable agreement.

In conclusion, results calculated from SASL show reasonable agreement with closed-form problems which represent geometric idealizations of the SASL geometry, differing results being introduced by bending effects present in the more detailed geometry utilized in the SASL runs. Therefore, the results from SASL are considered to be reliable.

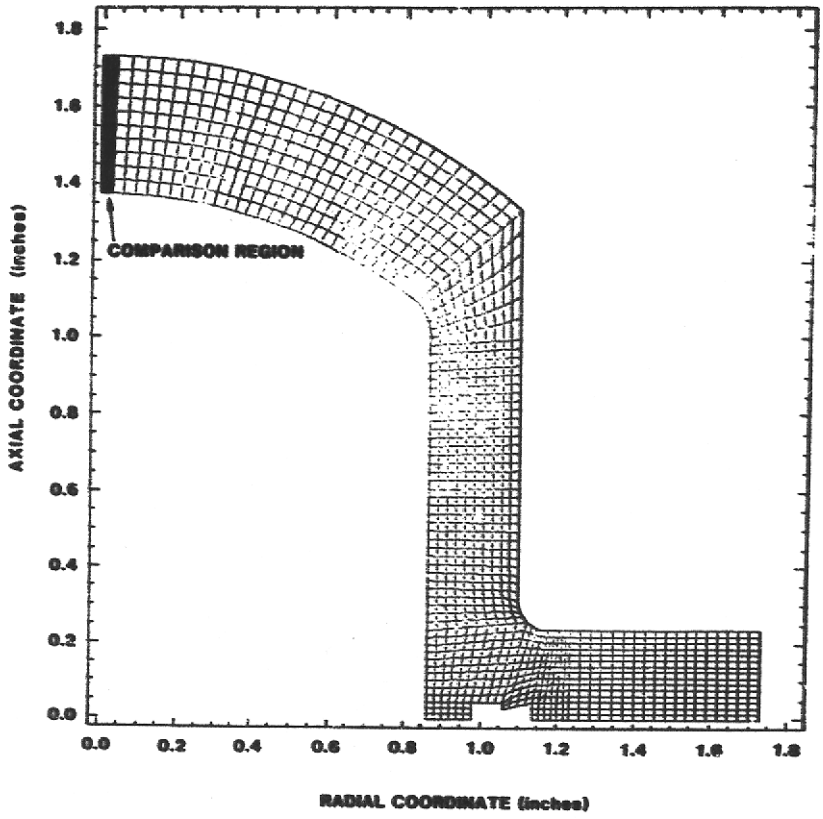


Figure 2C.2.3-6. Location at which Radial and In-Plane Stresses in Spherical Cap are Compared

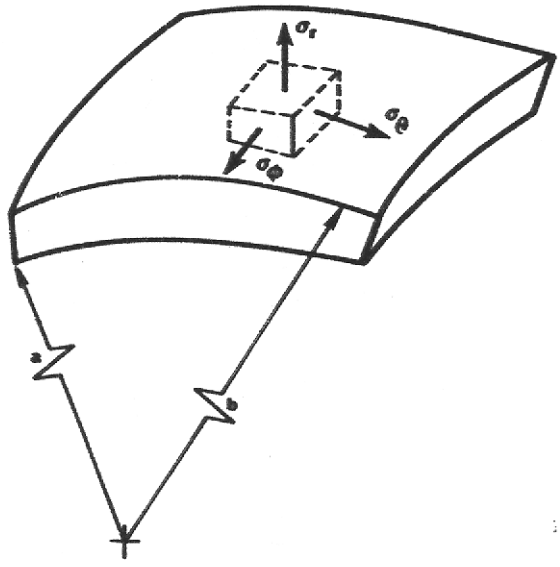


Figure 2C.2.3-7. Spherical Cap Geometry and Stresses

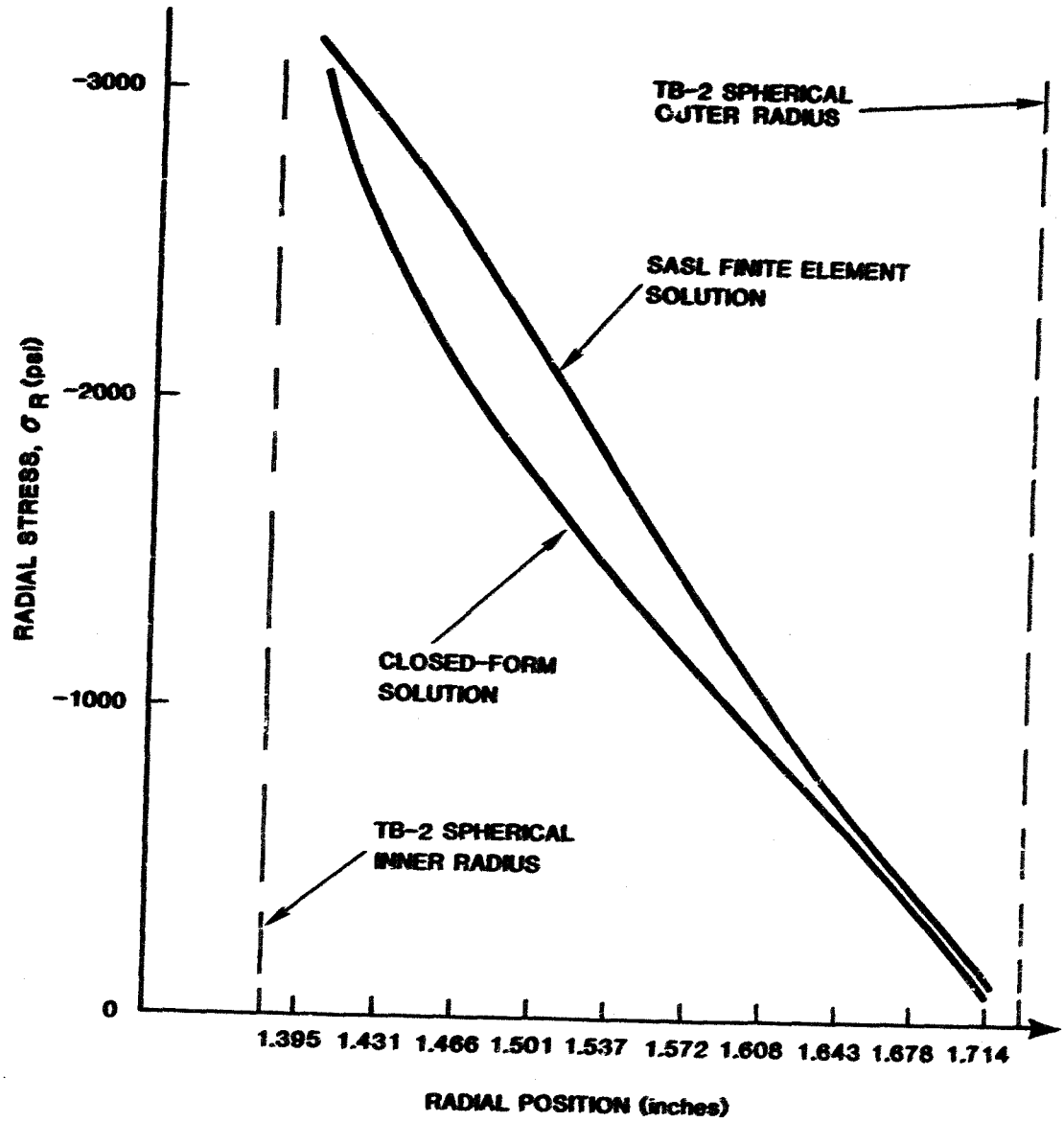


Figure 2C.2.3-8. Comparison of Closed-Form and Finite-Element Predictions--Radial Stress Field

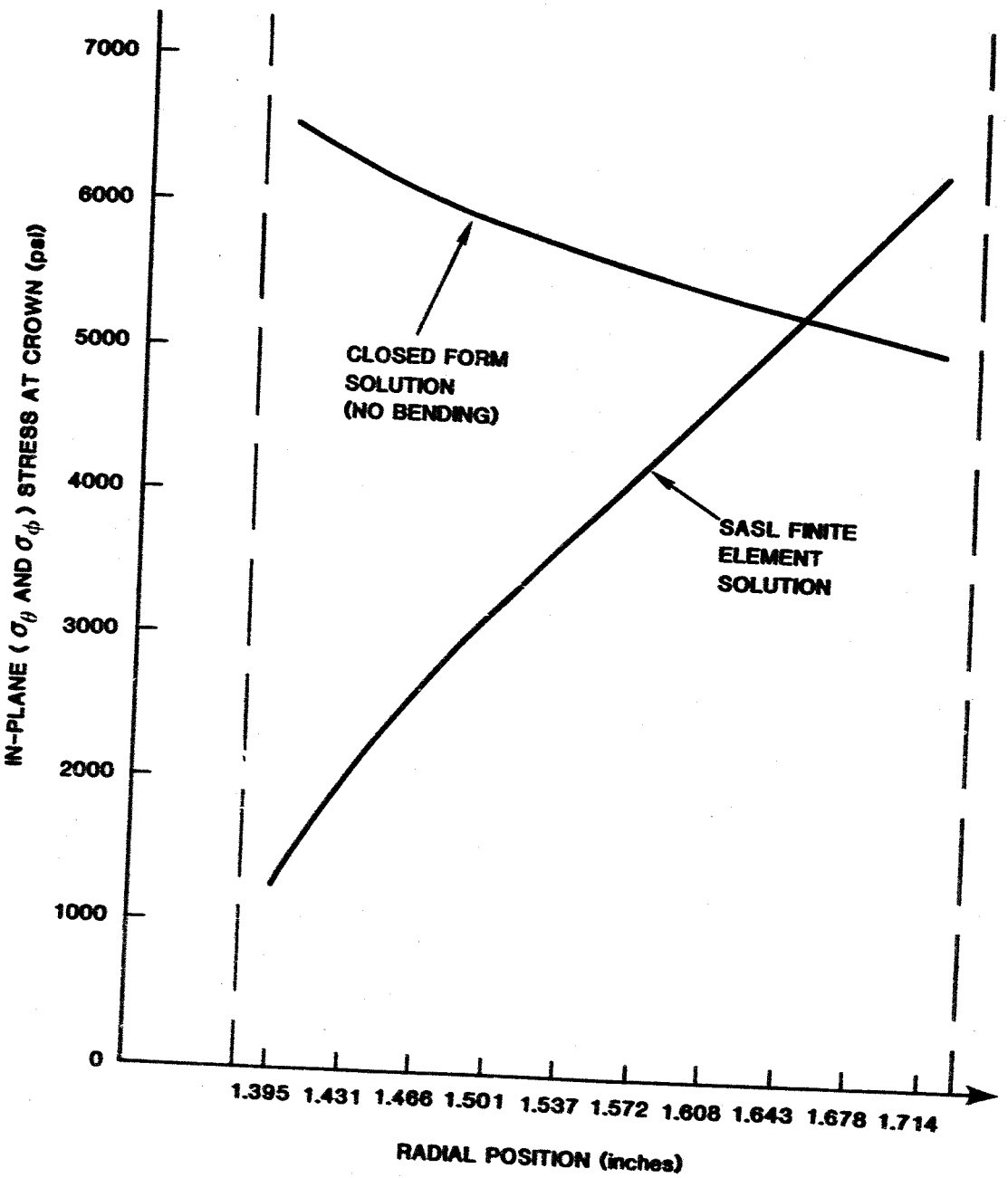


Figure 2C.2.3-9. Comparison of Closed-Form and Finite-Element Predictions--In-Plane Stress Field at Crown

TB-2 Closure Bolt Stress Analysis -- The torqued closure bolts are loaded as shown in Figure 2C.2.3-10. During closure of the TB-2, each bolt is torqued to 180 lb_f·in (20.3 N·m). Conservatively assuming this to be only 170 lb_f·in. (19.2 N·m) torque, this induces a tensile preload, F_i, shown in Figure 2C.2.3-10 and expressed approximately as[19]

$$F_i = \frac{T}{0.20\ d},$$

where T is applied torque and d is the diameter of the bolt. For T = 170 lb_f·in. (19.2 N·m) and d = 0.250 inch (6.35 mm), F_i = 3,400 lb_f (15,124 N).

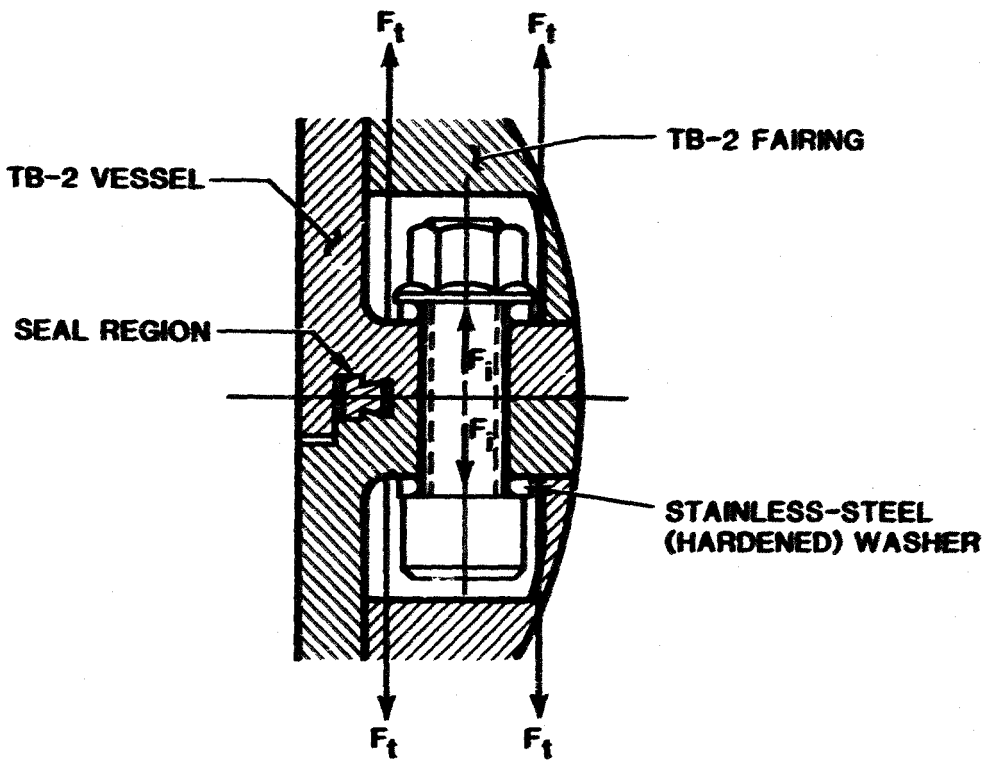


Figure 2C.2.3-10. Detail, Pretorqued Closure Bolt

The TB-2 may be subjected to the MCAP of 3,280 psi (22.6 MPa). This internal pressure effectively causes an external tensile load, F_t (also indicated on Figure 2C.2.3-10), that equals 583 lb_f (2,593 N) for each bolt. This force is determined by calculating the projected pressurized area of the TB-2 vessel to the knife-edge seal, multiplying this area by the internal pressure, and dividing by the total number of bolts.

Since the bolt is initially in tension, it will experience an increase in load when the MCAP is applied. The resulting load on the bolt is given by[19]

$$F = \frac{K_b F_t}{K_b + K_m} + F_i ,$$

where

$$K_b = \frac{A_b E_b}{l_b} = \text{the bolt stiffness constant and}$$

$$K_m = \frac{A_m E_m}{l_m} = \text{the stiffness constant of the connected members}$$

Since the bolt and connected members are approximately the same length and have the same elastic modulus, the stiffness ratio is $K_b/K_m = A_b/A_m = 0.592$. The single-bolt load when the TB-2 is pressurized to the MCAP is calculated to be 3,617 lb_f (16,089 N). The resulting bolt stress, 99.4 ksi (685 MPa) is well below the 145-ksi (1-GPa) ultimate tensile stress of the A-286 bolt material. The thread shear load capacity is approximately 10,000 lb_f (44.43 kN), well above the 3,617-lb_f (16.09-kN) maximum load on the bolt. Thus, bolt-thread or nut-thread shearing failure will not occur.

The 1080°F (580°C) thermal environment associated with the 3,280-psi (22.6-MPa) pressure produces no thermal stresses in the bolt closure region since the bolts and the surrounding material are both A-286. Slight differential expansion of the 15-5 stainless-steel washers has been neglected, and the maximum compressive stress experienced by the washer, 58.81 ksi (405.6 MPa), is well below the yield stress of this hardened stainless steel.

2C.2.4 Fracture Mechanics Considerations

Materials which appear ductile when tested under a uniaxial state of stress at, say, room temperature, and at quasi-static rates of loading do not necessarily exhibit the same degree of ductility when loaded under a triaxial state of stress and at lower temperatures. Brittle failure may result at stresses which are below the yield stress in these cases.

One approach to the evaluation and prevention of fracture is the "Transition Temperature" approach to fracture control.[20] In this approach, a given material is tested for fracture toughness by, for instance, the Charpy V-Notch test. The transition temperature is determined, which manifests itself as a sudden increase in

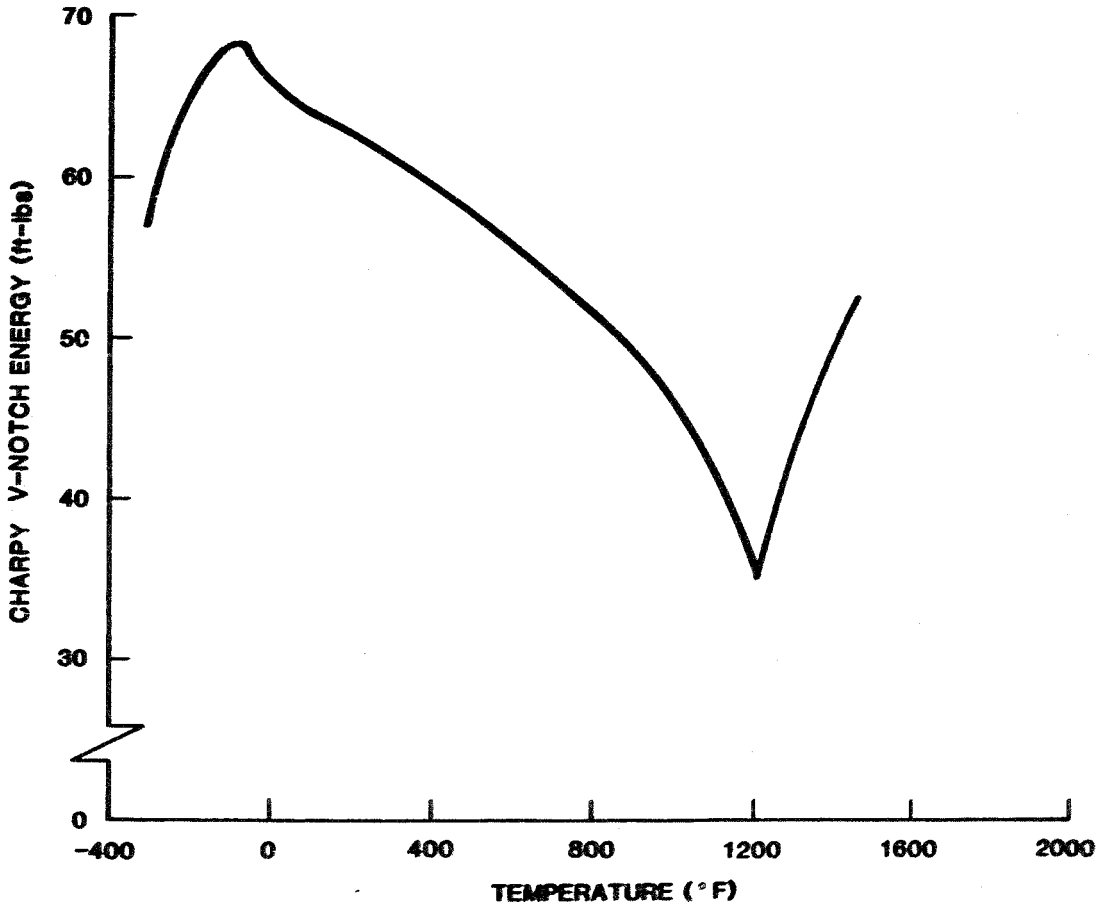


Figure 2C.2.4-1. Charpy Energy as a Function of Temperature for A-286 Ni-Cr-Ti-Mo Iron Base Alloy

Charpy energy, and the material selected for the given application is checked to ensure that it will operate in service at temperatures at least a certain number of degrees above its brittle-ductile transition temperature.

Charpy V-notch data[9] are plotted in Figure 2C.2.4-1 in the form of Charpy energy needed to cause fracture as a function of sample temperature for A-286 alloy. The data cover a broad temperature range far beyond the extremes to which the TB-2 containment vessel will be subjected. There is no brittle-ductile transition temperature for this material, and magnitudes of Charpy energies indicate reasonably tough, fracture resistant behavior. Therefore, brittle fracture will not be of concern for the statically pressurized TB-2 vessel, and plastic yielding will form the design-limitation basis.

The ASME Pressure Vessel Code for Nuclear Reactors (Part 3) specifies fracture toughness requirements for pressure vessels; it also requires (with several exceptions) that pressure-retaining material be impact-tested for toughness determination. However, Section NC-2311 states that "material with a nominal section thickness of 16 mm and less" is exempted from such fracture mechanics testing. The thickest section of the TB-2 is considerably less than 16 mm.

2.C.3 STRESS ANALYSES OF C-1 CAPSULE

The C-1 capsule fits closely within the TB-2 containment vessel. It is fabricated from Nitronic 60 stainless steel and is closed by a screw-thread joint with a Teflon™ tape sealant; the screw-thread joint is tightened to a torque of 450 $lb_f \cdot in.$ (50.8 N·m). For the 150% MNOP requirement, the C-1 capsule must withstand an internal pressure of 50 psi (345 kPa) at a temperature of 250°F (121°C) without loss of containment.

Section views of the threaded lid and the main body of the C-1 capsule are shown in Figure 2C.3-1.

Stress analysis of the C-1 capsule has been partitioned into three separate analyses: (1) stresses in a thin, finite-length, closed cylinder clamped at both ends, (2) stresses in a pressurized spherical cap clamped along its periphery, and (3) thread shear evaluation at the closure end. The three analyses follow.

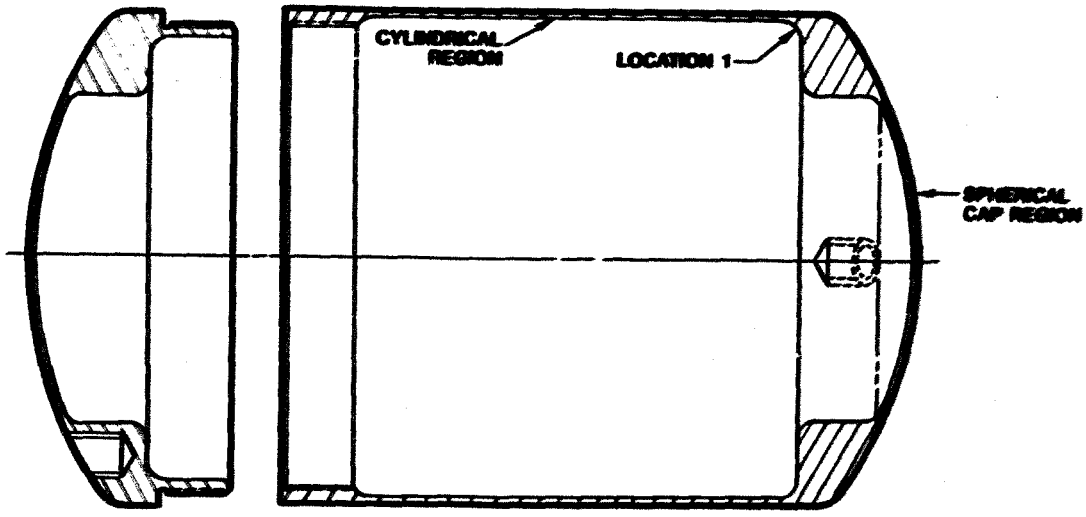


Figure 2C.3-1. C-1 Capsule

2C.3.1 Stresses in the Cylindrical Shell Region

The stress field in the pressurized cylindrical portion of the C-1 capsule is determined by superposing stresses due to

1. Internal pressure, P, acting in a closed cylindrical pressure vessel.
2. Transverse edge shear force, V_0, per unit circumferential length, acting on the end of the cylinder.
3. Uniform edge moment, M_0, per unit circumferential length, acting on the end of a semi-infinite cylinder.

The shear force and moment are induced in the end of the cylindrical shell because the region's thickness and rigidity, shown in Figure 2C.3-1, effectively prevent its radial displacement and rotation during pressurization.

The above load cases are solved individually and then superimposed.

1. As shown in Figure 2C.3.1-1, hoop and axial membrane stresses induced by internal pressure are, respectively,[21]

$$\sigma_{\theta\theta} = \frac{Pa}{t}$$

$$\sigma_{ZZ} = \frac{Pa}{2t}$$

where

P = internal pressure

a = average cylinder radius, and

t = cylinder thickness.

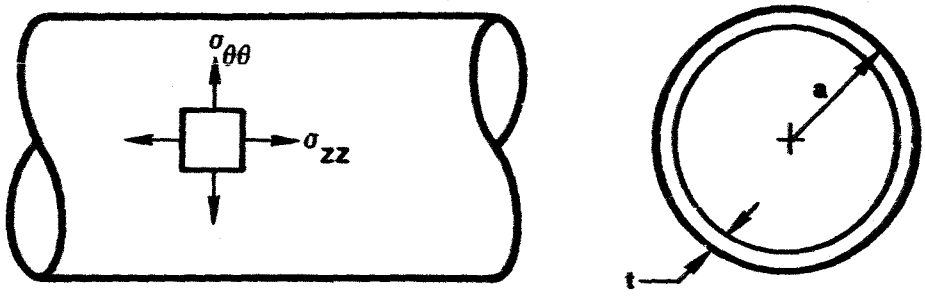


Figure 2C.3.1-1. Membrane Stresses due to Internal Pressure

2. For uniform radial shear loading shown in Figure 2C.3.1-2,, the hoop stress is

$$\sigma_{\theta\theta} = \frac{-2V_o}{t}\left(\lambda a\ e^{-\lambda Z} \cos \lambda Z\right),$$

and the axial bending stress is

$$\sigma_{ZZ} = \frac{6}{t^2}\frac{1}{\lambda}V_0\left(e^{-\lambda Z} \sin \lambda Z\right),$$

where

V_o = shear force per unit circumferential length,

$\lambda = \sqrt[4]{\frac{3(1 - \nu^2)}{a^2t^2}}$,

ν = Poisson's ratio of the cylinder material, and

z = axial coordinate.

3. Finally, for the uniform edge moment, M_0, shown in Figure 2C.2.1-3, the hoop stress is[21]

$$\sigma_{\theta\theta} = \frac{2\lambda^2\ aM_o\ e^{-\lambda Z}\ (\cos \lambda Z - \sin \lambda Z)}{t}$$

$$\sigma_{ZZ} = -\frac{6}{t^2}\ M_o\ e^{-\lambda Z}\ (\text{coz}\ \lambda Z + \sin \lambda Z)$$

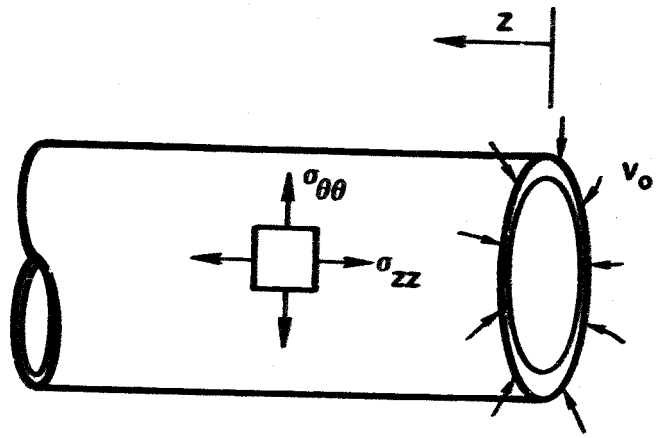


Figure 2C.3.1-2. Uniform Radial Shear on a Long Cylinder

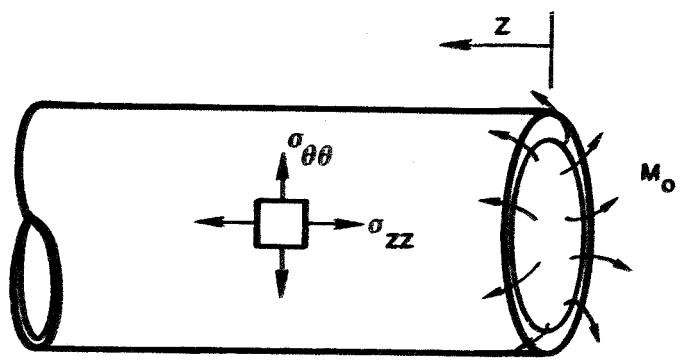


Figure 2C.3.1-3. Uniform Radial Edge Moment on a Long Cylinder

The transverse-edge shear force and the uniform edge moment are determined so that the earlier equations can be evaluated. The "clamped" edge condition at location 1, Figure 2C.3-1, is precisely equivalent from a stress-analysis viewpoint to a long cylindrical shell, as shown in Figure 2C.3.1-4, with a rigid reinforcing ring at its center, and subjected to a uniform internal pressure, P.

The edge moment and shear for this interpretation are $M_o = P/2\lambda^2$ and $V_o = P/\lambda$, where

$$\lambda = \sqrt[4]{\frac{3(1-\nu^2)}{a^2t^2}} .$$

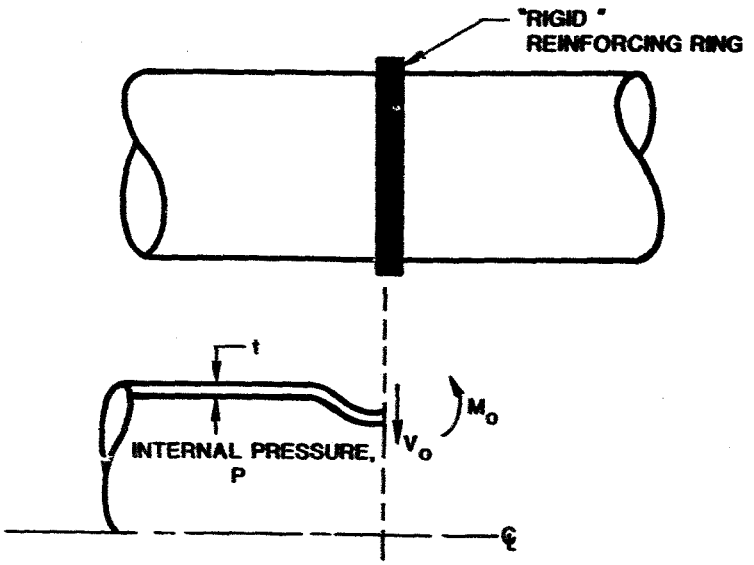


Figure 2C.3.1-4. Equivalent Stress Field--Long Cylinder with Rigid Reinforcing Ring

Superposing cases 1 through 3 for the C-1 capsule results in the following hoop stress as a function of the axial coordinate, Z:

$$\sigma_{\theta\theta} = \frac{Pa}{t} + \left[\left(\frac{2\lambda^2 aM_o - 2V_o\lambda a}{t}\right)\cos \lambda Z - \frac{2\lambda^2 aM_o}{t}\sin \lambda Z\right] e^{-\lambda Z} ,$$

where

$$M_o = \frac{P}{2\lambda^2} ,$$

$$V_o = P/\lambda, \text{ and}$$

$$\lambda = \sqrt[4]{\frac{3(1 - \nu^2)}{a^2 t^2}} .$$

Superposition of the axial stresses for the C-1 capsule results in

$$\sigma_{ZZ} = \frac{Pa}{2t} \pm \frac{6}{t^2} e^{-\lambda Z}\left[\left(\frac{V_o}{\lambda}\right) - M_o \sin \lambda Z - M_o \cos \lambda Z\right] ,$$

where the (+) applies to outer surface fibers and the (-) applies to inner surface fibers.

For the C-1 capsule, the following parameters apply:

$P = 50$ psi (345 KPa),

$a = 0.861$ inch (21.88 mm),

$t - 0.025$ inch (0.64 mm),

$\nu = 0.3$,

$M_o = 0.3256$ lb_f·/in./in. (1.448 N·m/m)

$V_o = 5.707$ lb_f/in. (999.5 N/m).

The hoop stress is plotted in Figure 2C.3.1-5 as function of distance, Z, from the end of the cylindrical portion of the C-1 capsule, and the corresponding axial stress/distance plot is shown in Figure 2C.3.1-5. The maximum value of hoop stress (Figure 2C.3.1-5) is 1,796 psi (12.4 MPa), and the maximum value of axial stress (Figure 2C.3.2-6) is 4,000 psi (27.6 MPa). These resultant stresses are negligible compared to the 56,000-psi (386-MPa) yield stress of the Nitronic 60 stainless steel.

2C.3.2 Stresses in Spherical Cap

As shown in Figure 2C.3-1, the thin spherical cap closing the end of the C-1 capsule body is effectively rigidly clamped against radial displacements and rotations by the thick ring section.

The solution for the bending and membrane stress fields can be obtained using a superposition procedure outlined in Reference 22. The geometry and loading are shown in Figure 2C.3.2-1.

Timoshenko lists the following formulas for the maximum absolute stress which occurs at extreme fibers of the cross-section:[22] *

$$\text{For } \frac{a \sin^2\alpha}{h} < 3, \quad \sigma = P\left(\frac{a \sin\alpha}{h}\right)^2 \left[0.75 - 0.038\left(\frac{a \sin\alpha}{h}\right)^2 \sin^2\alpha\right].$$

$$\text{For } 3 < \frac{a \sin^2\alpha}{h} < 12, \quad \sigma = 1.2\,\frac{aP}{h}.$$

---

*A sign modification has been made here on the pressure term.

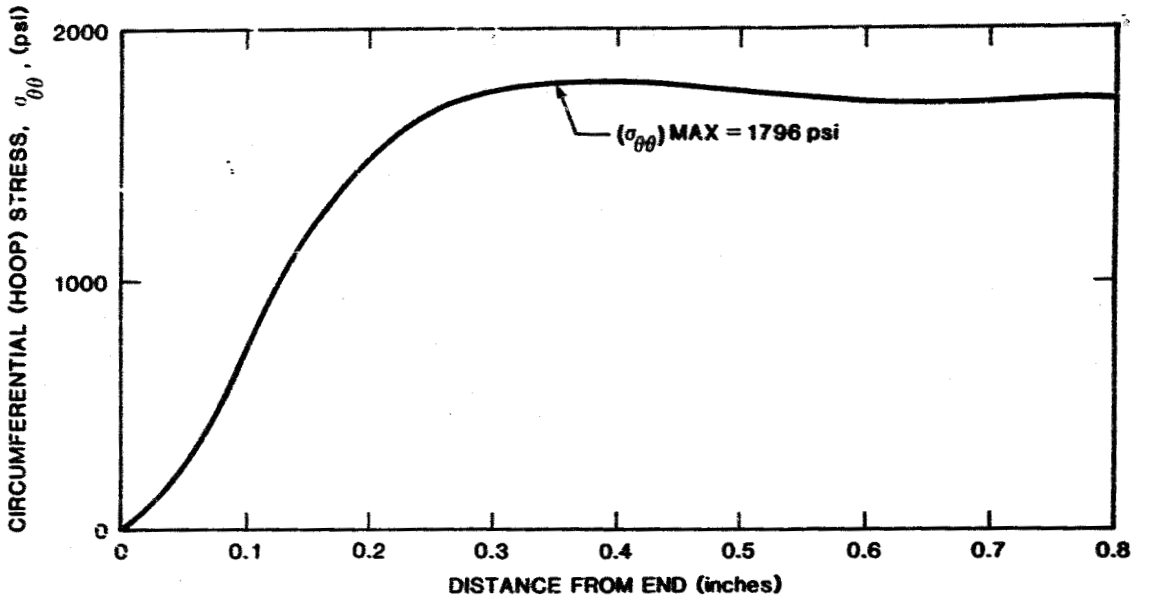


Figure 2C.3.1-5. Circumferential Stress in Cylindrical Portion of C-1 Capsule

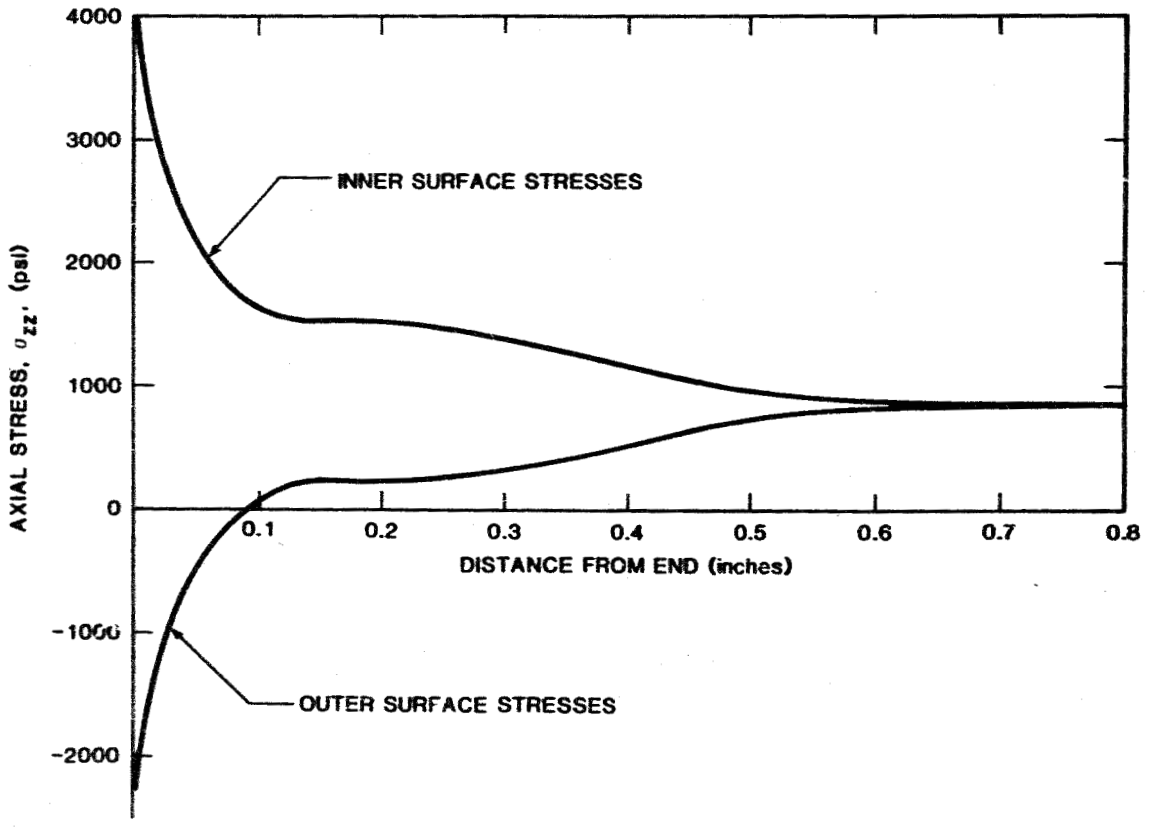


Figure 2C.3.1-6. Inner and Outer Surface Axial Stress -- Cylindrical Portion of the C-1 Capsule

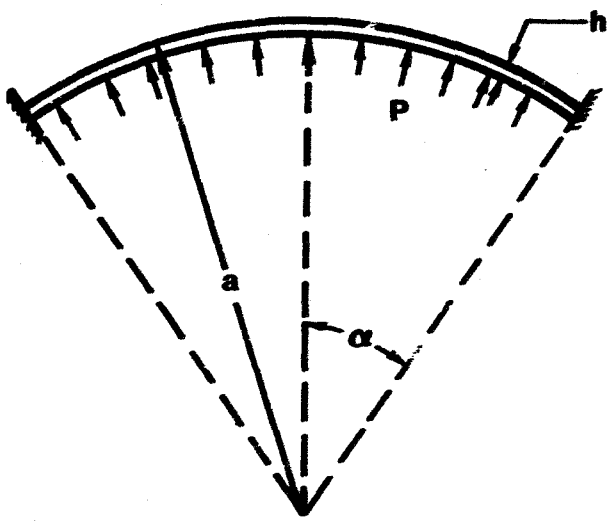


Figure 2C.3.2-1. Internally Pressurized, Clamped Spherical Cap

In the spherical cap of the C-1 capsule, the following numerical values apply:

P = 50 psi (345 kPa),
a = 1.38 inches (35.00 mm),
h = 0.020 inch (0.508 mm), and
sin α = 0.389.

The maximum stress is 4,134 psi (38.5 MPa). With a material yield stress value of σ_y = 56,000 psi (386 MPa), plastic yielding will not occur in the cap (even in the worst case where the remaining stress component is equal in magnitude and opposite in sign at the same location). Therefore, plastic deformations in the spherical cap region will not occur.

2C.3.3 Investigation of Thread Shear

The minimum thread engagement depth on the C-1 capsule lid is 0.197 inch (5.004 mm). The approximate shear stress induced in the threads is calculated by balancing the force due to the internal pressure with the force which is exerted by the threads (using half the thread area). The resulting shear stress, τ, is given by

$$\tau = \frac{PD}{2\ell}$$

where

P = internal pressure,

D = pitch diameter,

ℓ = thread engagement length, and

τ = shear stress.

When P is 50 psi (345 kPa), D is 1.475 inches (37.49 mm), and ℓ is 0.197 inch (5.004 mm), the shear stress is 187 psi (1.29 MPa). This value is negligible in comparison to one-half the yield stress of the Nitronic 60 stainless steel of 28,000 psi (193 MPa). Thread shear failure will therefore not occur at the 50-psi (345-kPa) pressure level.

APPENDIX 2D

Load Resistance per 10 CFR 71

For the load resistance analysis, the package is treated as a simple beam supported at both ends and subjected to a uniformly distributed load equal to five times the package weight (as per 10 CFR 71.32(a)).

The model is shown in Figure 2D-1. For this uniformly loaded beam, the maximum moment occurs at midspan and is[21]

$$M_{max} = \frac{5WL}{8} , \qquad (2D\text{-}1)$$

where

W = package weight and
L = overall length of package.

A cross-sectional view of the PAT-2 package is shown in Figure 2D-2. In the beam-bending mode, the only effective materials in carrying tensile or compressive stresses along the span are the outer container assembly and the outer cylinder of redwood. The load spreader, maplewood cylinder, and the wood plugs cannot carry significant bending loads because these components do not run the entire span of the "beam." These materials (as well as the TB-2 containment sphere) do, however, serve the important function of a shear core.

It is assumed that the packaging consists of two basic load-carrying components for beam bending: the double-skin outer container (304 stainless steel) and the outer redwood cylinder with radial-grain orientation. The cross section of the simple beam-bending model is shown in Figure 2D-3. The model consists of two concentric, hollow, bonded circular cylinders, the redwood cylinder defined over $r_a < r < r_b$ (region 1) and the outer container defined over $r_b < r < r_c$ (region 2).* The maximum stress occurring in each of these two cylinders must be calculated and checked individually for yielding.

---

*The outer cylinder is actually constructed of two concentric cylindrical shells of 22-gauge 304 stainless steel which are press-fitted together. The two cross sections are assumed to be a single cross section having the composite thickness of 0.056 inch (1.42 mm).

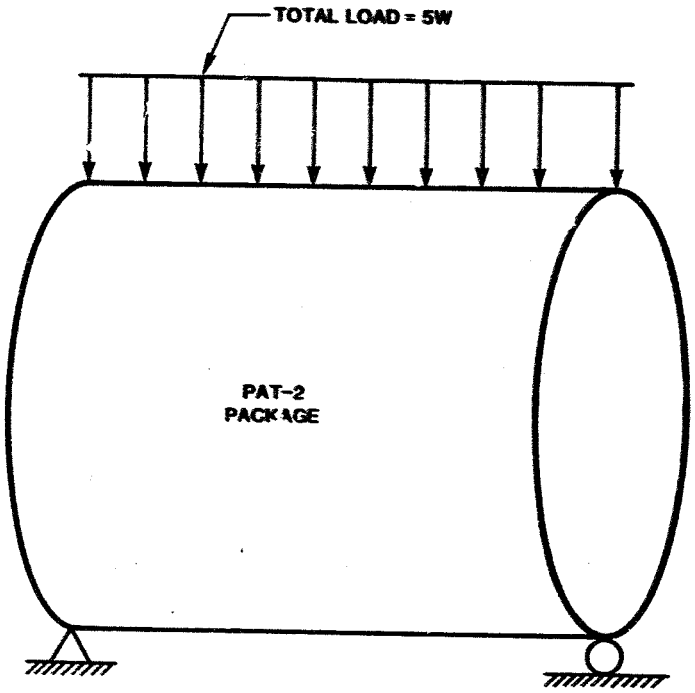


Figure 2D-1. Simple-Beam Bending Model

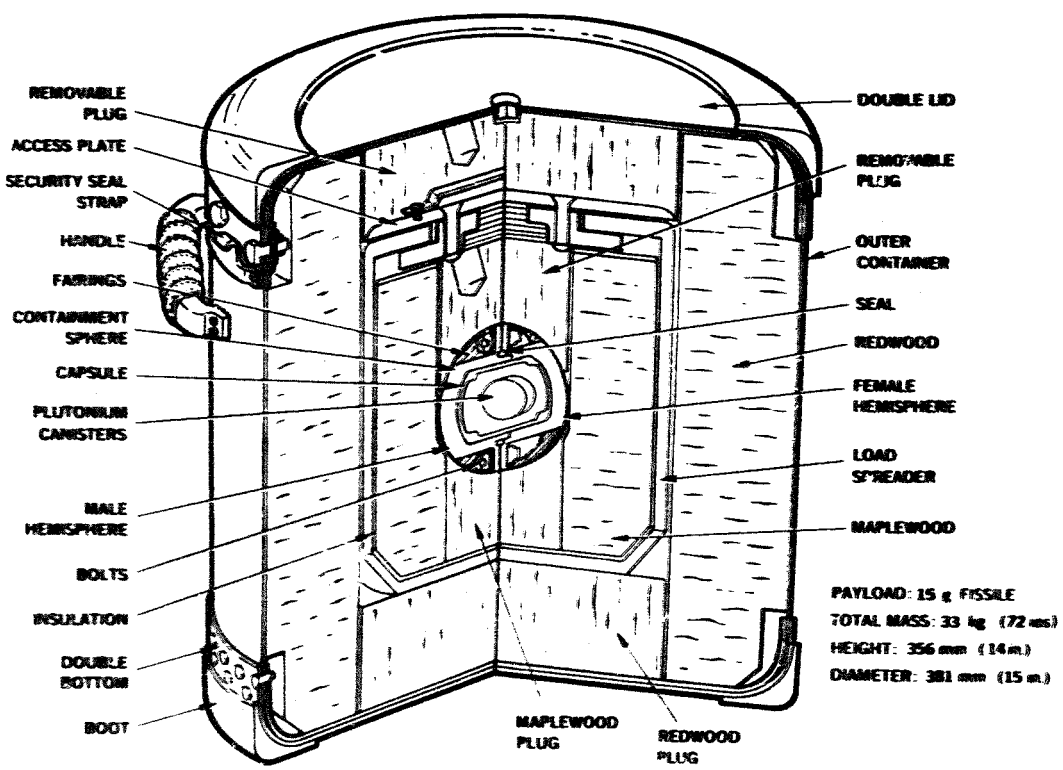


Figure 2D-2. Cross Section of PAT-2 Package

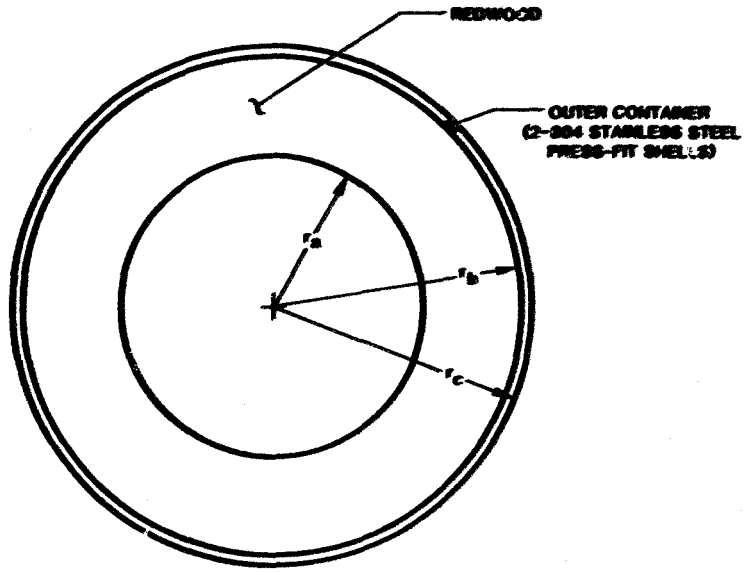


Figure 2D-3. Conservative Cross Section for Simple Beam-Bending Model

The standard beam-stress formula cannot be directly applied to the package because the cross section consists of materials with differing elastic moduli (and, hence, bending stiffness). The method of equivalent cross sections is not directly applicable since the cross sections are circular rather than rectangular. Simple (Bernoulli-Euler) beam theory is therefore employed.

Simple beam theory is based upon the assumption that, under pure bending, plane sections perpendicular to the neutral axis remain plane during deformation. This kinetic assumption implies that the nature of the geometric deformation is independent of the stress-strain behavior of the material. Thus, bending strain and beam curvature are uniquely related and are independent of the material layers. The strain is[23]

$$\varepsilon_x = \frac{y}{\rho} \tag{2D-2}$$

where

y = distance off the neutral axis (Figure 2D-4),

ρ = radius of curvature of the neutral axis (Figure 2D-4), and

ε_x = in-plane bending strain component.

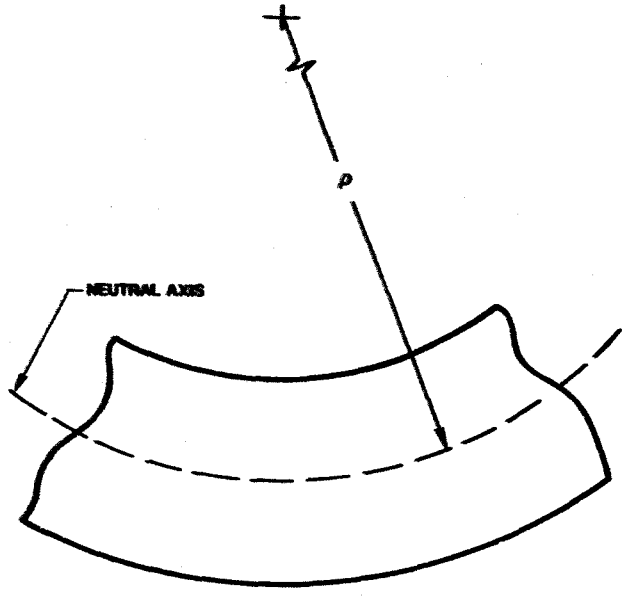


Figure 2D-4. Simple Beam Undergoing Pure Bending

Further, in a given region of the cross section, Hooke's Law reduces to

$$\sigma = \epsilon E \tag{2D-3}$$

where E = the appropriate elastic modulus.

In one of the hollow sections, the stress is

$$\sigma = \frac{My}{I} \tag{2D-4}$$

where

M = applied moment and
I = area moment of inertia about the neutral axis.

Each of the two cylinders, acting as a unit under bending, carries some of the total available moment. In the elastic range, the moment-curvature relationship for a single cylinder is given by

$$\frac{1}{\rho} = \frac{M}{EI} \tag{2D-5}$$

so that for some arbitrary but fixed curvature, $1/\rho$, the contribution of each of the two cylinders to the total moment is

$$M_1 = \frac{E_1 I_1}{\rho} \text{ and } M_2 = \frac{E_2 I_2}{\rho} .$$

The total moment at the cross section, M_{max}, [Eq. (2D-1)], is the sum of these two moments, i.e.,

$$M_{max} = M_1 + M_2 = \frac{1}{\rho} \; E_1 I_1 + E_2 I_2 . \tag{2D-6}$$

The only unknown in this equation is ρ, the resulting radius of curvature.

From Eqs. (2D-2), (2D-3), and (2D-6),

$$\sigma = E\frac{y}{\rho} = \frac{E\, M_{max}}{\sum_{i=1}^{2} E_i I_i}\, y . \tag{2D-7}$$

From this equation and the fact that $I = \pi/4 \; r_o^4 - r_o^4$, where r_o is the outer radius and r_i the inner radius of a given cylinder, the maximum stresses in each of the two concentric cylinder materials are

<u>Redwood</u>

$$\sigma_{max_1} = \frac{2.5E_1(WLr_b)}{\pi\left[E_1\left(r_b^4 - r_a^4\right) + E_2\left(r_c^4 - r_b^4\right)\right]} \tag{2D-8}$$

<u>Outer Container</u>

$$\sigma_{max_2} = \frac{2.5E_1(WLr_c)}{\pi\left[E_1\left(r_b^4 - r_a^4\right) + E_2\left(r_c^4 - r_b^4\right)\right]} . \tag{2D-9}$$

For a single continuous material, i.e., $E_1 - E_2$, the equations reduce to the simple beam-bending stress formula.

Consider now the following numerical values:

r_a = 3.809 inches (9.675 cm)
r_b = 7.333 inches (18.626 cm)

r_c = 7.389 inches (18.768 cm)

W = 70.0 lb (31.8 kg)

L = 13.560 inches (34.442 cm)

E_1 = 1.34 x 10^6 psi (9.24 x 10^3 MPa)

E_2 = 29.0 x 10^6 psi (2 x 10^5 MPa)

$\sigma_{1_{yield}}$ = 6,900 psi (47.6 MPa)(proportional limit)

$\sigma_{2_{yield}}$ = 30,000 psi (207 MPa)(yield)

Using Eqs. (2D-8) and (2D-9), the resulting maximum stresses are

σ_{max_1} = 1.2 psi (8.3 kPa) and

σ_{max_2} = 26.2 psi (180.6 kPa) .

Comparing these stresses to corresponding material yield values listed above shows that stresses due to the stated bending load are neglible.

Appendix 2E

PAT-2 Test Protocol

Appendix 2E describes the package assemblies and test procedures utilized in the qualification testing of the PAT-2 package. These tests have been designed to demonstrate and assure that the container will conform to or surpass the qualification criteria set forth by the U.S. Nuclear Regulatory Commission and the IAEA. Data generated from these tests will be evaluated for package certification and licensing purposes.

The PAT-2 test program has been formulated to the requirements stipulated in References 1, 2, and 3.

2E.1 PACKAGE PREPARATION

2E.1.1 Contents

Surrogate material for various forms of plutonium and/or uranium contents have been utilized; when a powder form was used, the surrogate was natural UO_2 sinterable powder, provided by Eldorado Nuclear Ltd., Port Hope, Ontario, Canada, Specification ENL-1, Issue 5. The particle size distribution and the dry process performance of this powder makes it an excellent surrogate for evaluating a potential plutonium-oxide powder leak. When the metallic form of a radioactive material was used, depleted uranium metal (D-38) was the surrogate. When hydrated sulfate and nitrate salts of plutonium were used, surrogates were formulated with the UO_2 powder, acids, and water. The formulation and "surrogateness" (appropriateness) of these contents have been developed in detail in the appendices to Chapter 4. The need for these various contents, or payloads, stems from the various safeguards samples to be packaged in the PAT-2; see Section 1.2.4 for Contents of Package (licensing basis) and Appendix 5A for IAEA Payload Definition for the PAT-2. As developed in Chapter 4, each surrogate comprised a surplus of pressure-producing materials (water, plastics, acids) to qualify as a severe and conservative bounding case. As will be developed in Section 2E.2, Test Plan, these various contents were utilized in a matrix of test conditions to assure testing of a number of variables. Table 2.8.2-1, p 2-24, indicates the contents for each test package.

2E.1.2 Canisters

Plutonium safeguards sample preparation and handling, which normally occurs in a glovebox, require some initial container, processing dish, or vial. A family of brass canisters to fit inside the C-1 capsule was developed for use by the IAEA and its inspectorate and host operators. Use of these canisters is not required but is permitted by the conditions set forth in Section 1.2.4. The canisters have a screw-thread closure and a PVC plastic seal; they are simply finger-tightened by an operator.

The C-1 capsule is able to accommodate the following canister complements:

Two BC-1 canisters (Figures 2E.1.2-1 and 7A.2-1 (p 7-8)), or

Two BC-2 (Figures 2E.1.2-2 and 7A.2-2 (page 7-8)) with one BC-3 (Figures 2E.1.2-3 and 7A.2-2 (page 7-8)), or

Three BC-4 (Figures 2E.1.2-4 and 7A.2-3 (page 7-8)), or

Up to six BC-5 (Figures 2E.1.2-5 and 7A.2-4 (page 7-8)).

Each of these configurations was included in one or more PAT-2 package test assemblies. Each canister used was engraved with a test identification number (e.g., BC 1-1, X08). Two C-1 capsule assemblies intentionally contained no canisters (PAT-2 X11 for NUREG-0360 and PAT-2 X15 for 10 CFR 71 double containment verification) to indicate that the containment seals are not dependent on the canister seals; these assemblies used brass ballast to account for the presence of canisters. The combinations of contents and canisters (or no canisters) utilized is given in Section 2E.2.

The canister sets, when used, were heat-sealed in PVC plastic bags, just as is required for health physics reasons in glovebox bagouts of actual plutonium samples. As noted earlier, the 10 CFR 71 Appendix A and B assembly, X15, contained no canisters; also, the TB-2 containment vessel temperature (1,080°F (582°C); see Chapters 3 and 4) destroyed all PVC material, canister seals and PVC bags alike, in the NUREG-0360 tests. This PVC plastic is the greatest contributor to pressurization of the containment (Chapter 4); the mass of PVC was always maximized (overloaded) to obtain conservative test results.

2E.1.3 C-1 Capsule

Each C-1 capsule was engraved with a test identification number (e.g., X07). All C-1 capsules were assembled in a glove bag under positive helium pressure (> 14.7 psi (96.5 kPa)). All were sealed with Teflon™ tape in accordance with the assembly procedures of Chapter 7 and were torqued shut with 450 $lb_f \cdot in.$ (50.8 N·m) minimum, as measured by a torque wrench. All capsules were then leak-rate-checked with a helium-type mass spectrometer.

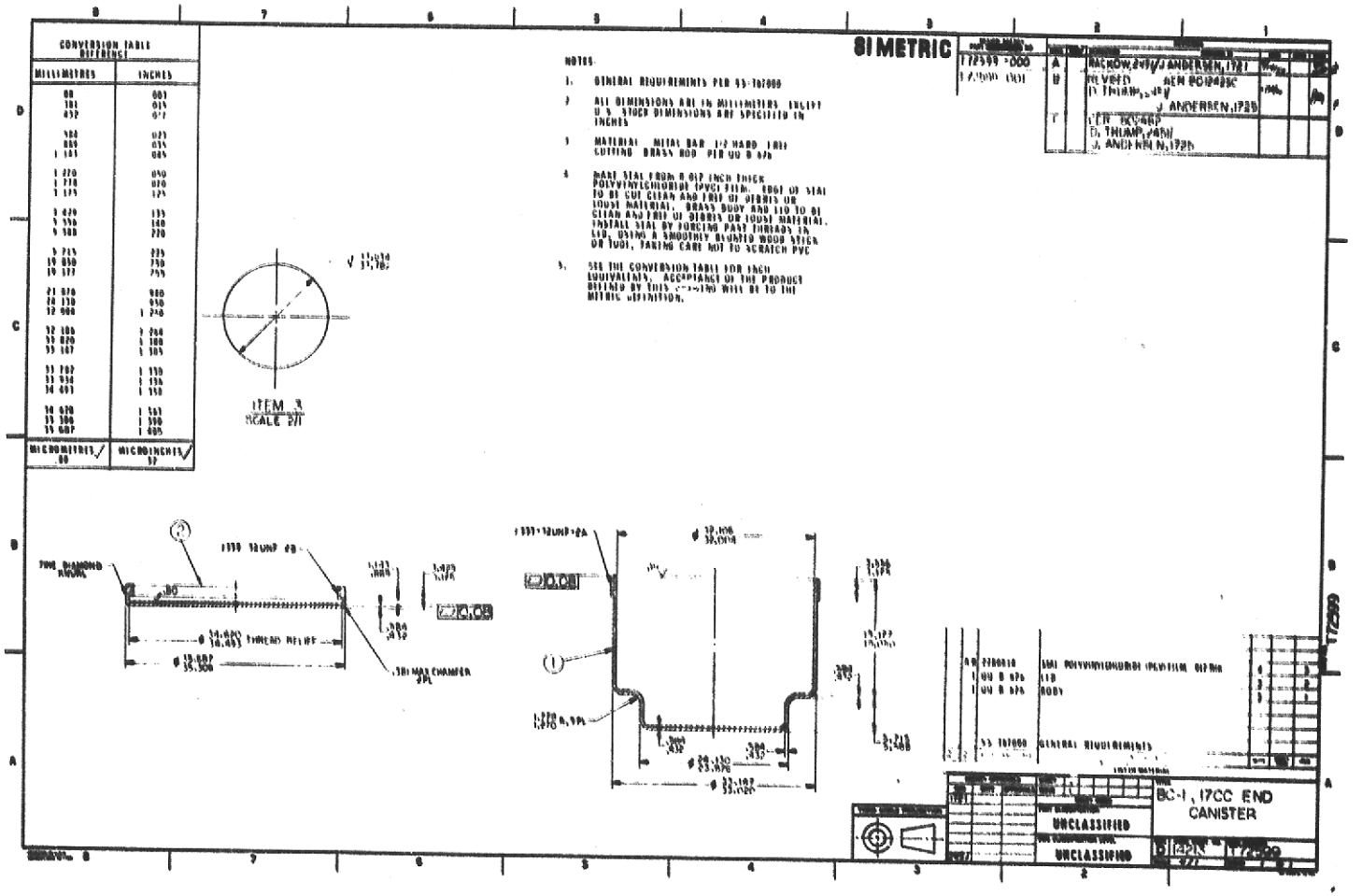


Figure 2E.1.2-1. BC-1 Canister Design Definition

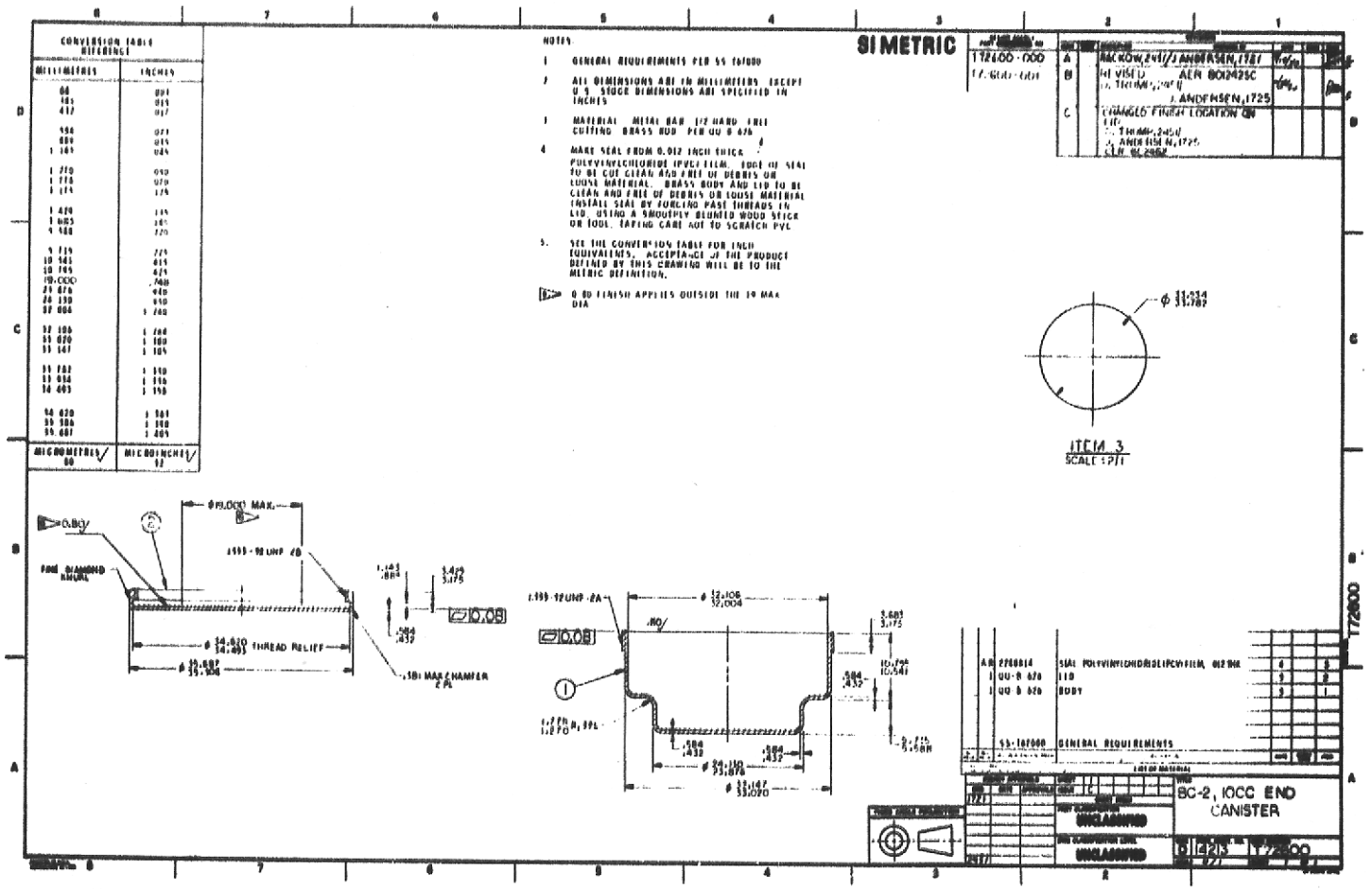


Figure 2E.1.2-2. BC-2 Canister Design Definition

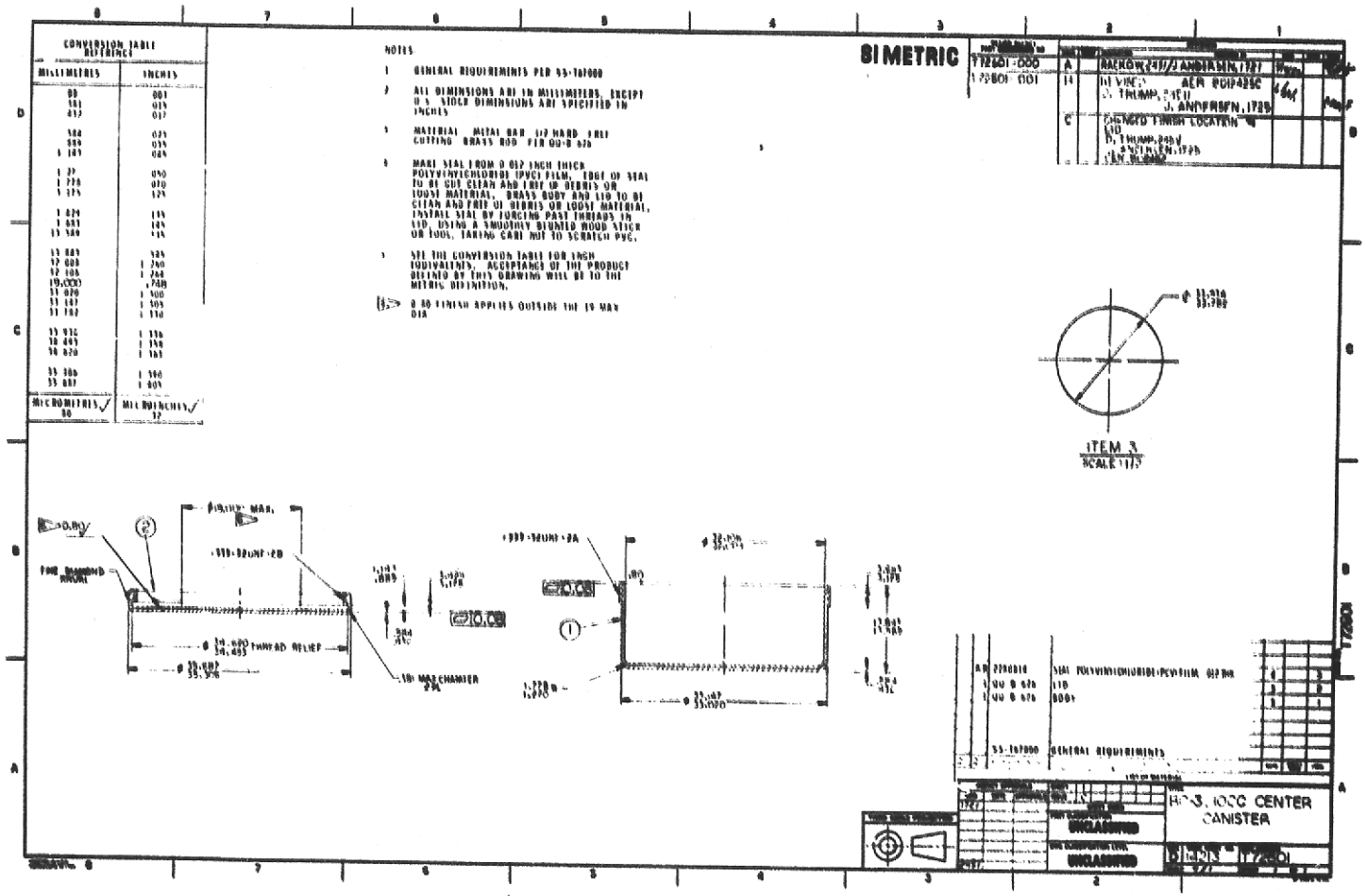


Figure 2E.1.2-3. BC-3 Canister Design Definition

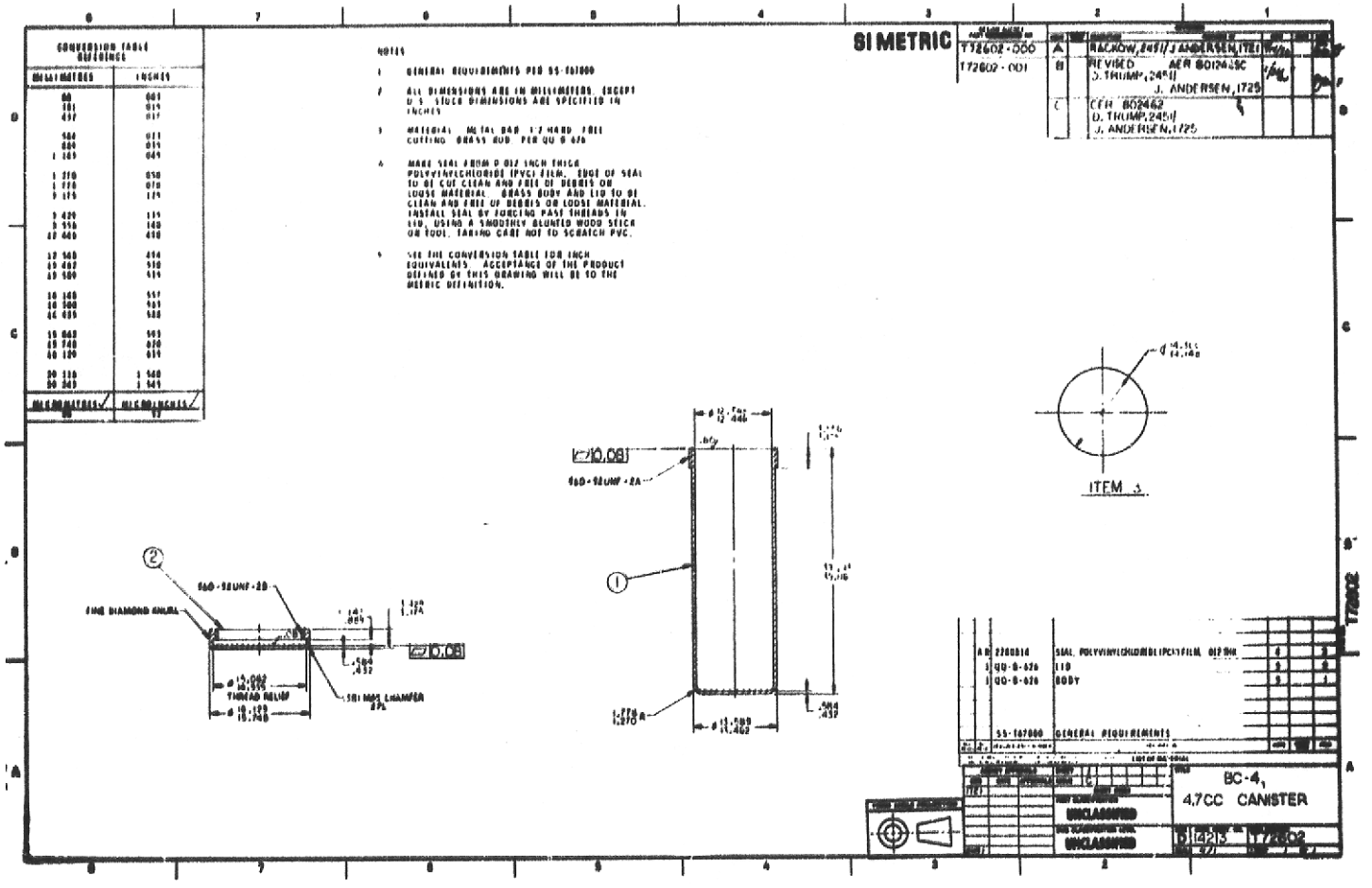


Figure 2E.1.2-4. BC-4 Canister Design Definition

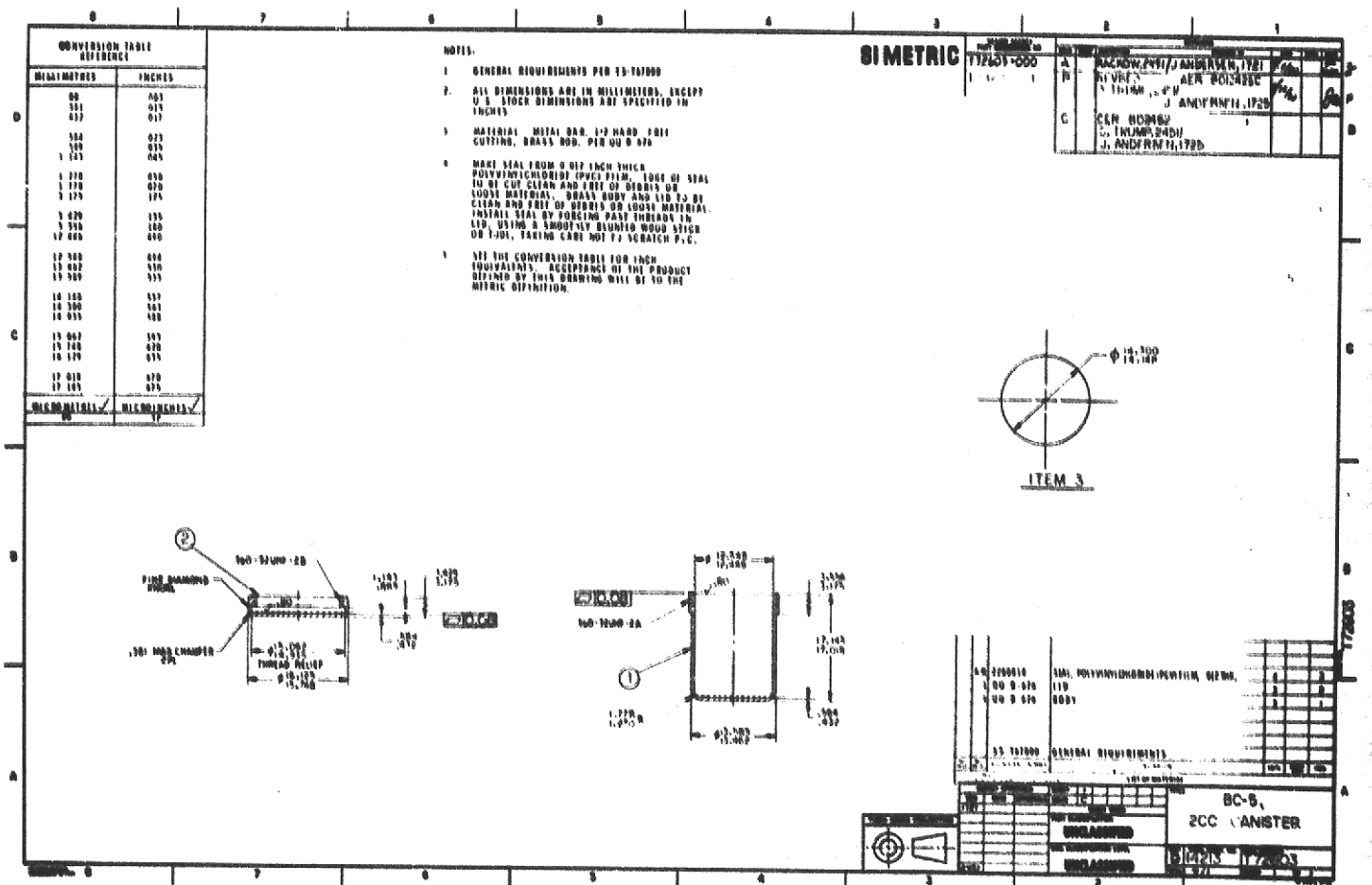


Figure 2E.1.2-5. BC-5 Canister Design Definition

2E.1.4 TB-2 Containment Vessel

Each TB-2 was engraved with a test identification number (e.g., X08). The C-1 capsules were shimmed in place within the TB-2 containment vessel with aluminum foil. A stock of 0.001-inch (0.025-mm)-thick foil, in a rough square about 1 inch (25 mm) on a side, was used to take up the small clearance gap between the longitudinal axis (domed ends) of the exterior of the C-1 and the corresponding interior shape of the TB-2. This was accomplished by a trial fit. A stack of foil (10 to 20 thicknesses) was placed in one hemispherical shell of the TB-2, in the domed region; the assembled C-1 was placed on top of the foil, the other TB-2 hemisphere was mated (without the copper gasket, which would interfere at this point), the flange was closed by hand pressure only, and the assembly was shaken by hand, to detect movement of the C-1 within the TB-2, by feel and sound. Foil was added until relative motion was not sensed; if the flanged joint between the TB-2 hemispheres did not come completely together, by visual check, some foil was removed.

Next, the parts to be assembled were placed in a glove bag with a positive overpressure of helium; the copper gasket was positioned on the (male) TB-2 spherical containment vessel A as explained in Chapter 7, Operating Procedures; the two hemispheres were correctly mated; and the 20 bolts with washers and the 20 nuts with washers were all installed and properly torqued to 180 $lb_f \cdot in.$ (20.3 N·m) minimum (again, refer to the assembly procedures in Chapter 7). All TB-2 assemblies were then leak-rate checked, using a helium-type mass spectrometer. All assembled TB-2s registered N.D.L. after allowing some time (< 1 hour) to degasify the bolts and nuts (helium becomes entrapped in the tightly torqued hardware that is external to the copper gasket that seals the interior cavity of the TB-2). Upon disassembly, all TB-2s contained easily detected, large-scale quantities (by mass spectrometry) of helium.

2E.1.5 AQ-2 Overpack and PAT-2 Package

Each AQ-2 overpack was stenciled with package identification, using epoxy paint per the drawing requirements (see Chapter 9).

Each TB-2 with C-1 was assembled into the AQ-2 overpack, installing the inner maplewood plug, the titanium load spreader cover with four screws, the rubber gasket, the redwood plug, the inner cover, the outer cover. and the twenty-four 1/4-inch bolts, aligning all match marks and following the assembly procedure of Chapter 7.

Towing rigs for the rocket pulldown test were installed onto the package, as appropriate.

2E.2 TEST PLAN

Six final-design, certified PAT-2 assemblies (see Chapter 9) from Phase 4 of the LAARC (Lightweight Air-Transportable Accident Resistant Container) project, were utilized to demonstrate compliance with NUREG-0360. One similar PAT-2 package, serial No. X15, was utilized to demonstrate compliance with 10 CFR 71, 49 CFR 173, and IAEA S.S. 6.

The following summary of test plan variables is presented in Table 2E.2-1 as a matrix which indicates the plan that was implemented. Table 2.8.2-1, p 2-24, is a simpler, more graphic presentation of the six packages for NUREG-0360.

The test plan variables included the payload type, the number and types of canisters within the C-1 capsule, the impact orientation of the AQ-2 overpack and the TB-2, and the impact temperature.

There were four types of test payloads:

- Six 20-gram D-38 depleted uranium pellets, modeling the maximum 120-gram weight of mixed-oxide sintered pellets or solid plutonium or uranium metal,
- 40 grams of uranium oxide (UO_2) powder, modeling the maximum 40-gram weight of PuO_2 powder,
- 3 grams of uranium nitrate dihydrate with excess water, modeling 3 grams of plutonium nitrate dihydrate ($Pu(NO_3)_4 \cdot 2H_2O$,
- 3 grams of uranium sulfate tetrahydrate with excess water, modeling 3 grams of solid plutonium sulfate tetrahydrate ($Pu(SO_4)_2 \cdot 4H_2O$.

Each of these payloads was enclosed within a particular combination of canisters as shown in Table 2E.2-1. The four possible combinations were

- Two BC-1 canisters per assembly
- Two BC-2 canisters and one BC-3 canister per assembly
- Three BC-4 canisters per assembly
- Six BC-5 canisters per assembly.

The assembled PAT-2 packages underwent the NUREG-0360 impact test (upon an unyielding target) in five different package attitudes and at three different temperatures -- ambient, 104°C (220°F), and -46°C (-50°F). Packages were impacted in four orientations -- top, top corner, bottom corner, and bottom -- at the ambient temperature. Side orientation was selected for the temperature-extreme impacts because the least amount of correctly oriented wood (with respect to the grain) is

available for energy absorption. Finally, the TB-2 containment vessel joint was tested with both polar and equatorial orientation with respect to the unyielding target.

Table 2E.2-1

PAT-2 Test Matrix

Package S/N	Payload Type[a]	Canisters	Impact	TB-2	Test Criteria
X07	$Pu(NO_3)_4 \cdot 2H_2O$	3 BC-4	Top	Equatorial	NUREG-0360
X08	PuO_2	2 BC-1	Top Corner	Polar	NUREG-0360
X09	Pellets/metal	6 BC-5	Side, -50°C	Equatorial	NUREG-0360
X10	$Pu(SO_4)_2 \cdot 4H_2O$	2 BC-2 1 BC-3	Bottom Corner	Equatorial	NUREG-0360
X11	$Pu(SO_4)_2 \cdot 4H_2O$	None	Bottom	Polar	NUREG-0360
X12	Pellets/metal	6 BC-5	Side, 104°C	Equatorial	NUREG 0360
X15	$Pu(SO_4)_2 \cdot 4H_2O$	None	Top Corner[b]	N/A[c]	10 CFR 71

[a]Using uranium surrogates.
[b]From package X08 results, top corner determined to be most vulnerable.
[c]TB-2 is not normally fixed in orientation within AQ-2.

Although 192 combinations of the above-cited variables are possible for the NUREG-0360 criteria alone, only 6 packages were available to expend in test (plus one package for 10 CFR 71), so the conditions selected for the test plan satisfied these leading considerations:

- Every form of payload was included in one or more full test series;
- Every canister combination, including no canisters at all, was subjected to the NUREG-0360 criteria;
- Every principle impact attitude was tested;
- The TB-2 containment vessel was both polar- and equatorial-oriented for corner and end package-crash attitudes, and equatorial-oriented (assumed worst) for the hot and cold side impacts;
- Side impact, believed to undergo greatest deceleration, always had the maximum mass payload (> 120 grams metallic uranium);

- The only TB-2 containment vessel to develop a detectable leak, X08, contained powder, the payload form most likely to be released;
- The 10 CFR 71 Appendixes A and B test unit, X15, contained the worst-case payload and no canisters to prove double containment.

2E.3 TEST CONDUCT -- 10 CFR 71

Although the 10 CFR 71 Appendix A tests for normal conditions of transport are not required to be sequentially cumulative, they were applied in sequence to one PAT-2, along with the tests of 10 CFR 71 Appendix B accident conditions of transport; the Appendix B tests must be sequential. The tested PAT-2 consisted of a sealed C-1 capsule containing surrogate $Pu(SO_4)_2 \cdot 4H_2O$ contents, a sealed TB-2 containment vessel, and an AQ-2 overpack.

2E.3.1 10 CFR 71 Appendix A -- Normal Conditions for Transport

Heat -- Although thermal equilibrium would have occurred in less than 24 hours, the PAT-2 was exposed to 215°F (102°C) for 48 hours for conservatism.

Cold -- The package was exposed to -40°F (-40°C) for 48 hours.

Pressure -- The TB-2 was removed from the AQ-2 overpack, heated to 250°F (121°C) for 8 hours, and then helium leak-rate checked while hot to demonstrate compliance with the 150% maximum normal operation pressure test of 10 CFR 71.53. Analysis in Chapter 3 demonstrates that 250°F (121°C) produces an internal TB-2 pressure of 150% MNOP.

The TB-2 was allowed to cool to ambient temperature and again was helium leak-rate tested. The helium leak-rate tests were conducted in a vacuum vessel, hence both the 10 CFR 71 0.5-atm and the IAEA S.S. 6 0.25-atm pressure-test requirements were satisfied repeatedly.

Vibration -- The TB-2 and AQ-2 were reassembled into a PAT-2 and subjected to 16 hours of vibration -- 8 hours on the longitudinal axis, 8 hours on the vertical axis -- at 30 to 2,000 Hz. The package was exposed to 0.2 g^2/Hz between 30 and 150 Hz and to 6 dB/octave rolloff between 150 and 2,000 Hz.

Water Spray -- The package was exposed to a 124-gal/min spray for more than 30 minutes.

Free Drop -- The package was dropped 4 feet (1.2 metres) in a top-corner impact orientation approximately 2 hours after the water spray test. A similar

package was dropped the same distance onto its top, top corner, bottom corner, and bottom.

Penetration -- A 13-pound (5.9-kg), 1.25-inch (3.2-cm) diameter steel cylinder with a hemispherical end was dropped onto the top of the PAT-2 package.

Compression -- A 690-pound (3-13-kg) weight was placed on the PAT-2 for over 24 hours.

2E.3.2 10 CFR 71 Appendix B -- Standards for Hypothetical Accidents

The PAT-2 package used in the Appendix A tests was properly assembled and sequentially tested in accordance with the 10 CFR 71 Appendix B hypothetical accident conditions of transport.

Free Drop -- The package was dropped 30 feet (9.1 metres) onto an unyielding surface in its most vulnerable attitude, top corner.

Puncture -- The PAT-2 was dropped 40 inches (1 metre) upon a 10-inch (25-cm) long, 6-inch (15-cm) diameter, steel spike supported on a large reinforced concrete block. A man dropped the package in the top-corner impact attitude.

Thermal -- The package was exposed to a temperature greater than 1,475°F (802°C) for more than 30 minutes in a JP-4 aviation fire combusted in the burn test facility described in Appendix 2F, Section 2F.4.

Water Immersion -- The package was submerged for approximately 24 hours in more than 3 feet (1 metre) of water.

2E.3.3 Containment Acceptance Test Measurements

Containment acceptance tests were conducted on the package after both the Appendix A test series and the Appendix B series. Uranium fluorimeter monitoring sensitive to 10^{-8} gram of uranium was used to test for uranium release, and helium leak-rate testing was done with mass spectrometry sensitive to 10^{-10} cm^3/s helium.

2E.4 TEST CONDUCT -- NUREG-0360

The impact, crush, puncture, double-slash, fire, and immersion tests described in Section 2E.4.1 through 2E.4.6 were conducted sequentially in the order given. The sole nonsequential test, hydrostatic pressure, is described in Section 2E.4.7, and post-test measurements are described in Section 2E.4-8.

2E.4.1 Impact or Crash Test

The impact tests were done at the SNLA Coyote Test Field rocket pulldown cable test site, shown and described in Appendix F. The PAT-2 packages were accelerated to a minimum of 250 knots (129 m/s) as measured by redundant photometrics, and the velocity vector of package motion was perpendicular to the face of the unyielding target.

Packages were impacted in five crash attitudes:

1. Top end impact (0° attitude)
2. Top corner impact (45° attitude)
3. Side impact (90° attitude)
4. Bottom corner impact (135° attitude)
5. Bottom end impact (180° attitude).

Attitude was controlled to within ±10° and was measured by redundant photometrics.

2E.4.2 Static Crush Test

A Tinius-Olsen static test machine was utilized to impart a 70,000 lb_f (0.311 MN) load upon the point of contact chosen as the most threatening to the TB-2 (the point of minimum dimension of redwood between the TB-2 and the AQ-2). The principal surface remaining after the crash test of each PAT-2 package rested upon the essentialy unyielding steel bed of the test machine. The load was applied perpendicular to this bed through a 2-inch (5-cm) wide, 7-inch (18-cm) deep, mild steel bar that was longer than the widest PAT-2 contact surface.

2E.4.3. Puncture Test

Puncture tests were conducted at the SNLA Area III 185-foot tower. A blunt steel spike was dropped 10 feet (3 metres) onto the crashed and crushed PAT-2, at the point of contact again chosen to be most threatening to the TB-2 (the point of minimum dimension of redwood between the TB-2 and the AQ-2). The 500-pound (227-kg) spike, in the shape of the frustum of a right circular cone, was 12 inches (30.5 cm) long, 8 inches (20 cm) in diameter at the base, and 1 inch (2.5 cm) in diameter at the tip or puncture contact point. The PAT-2 package rested on an unyielding surface.

2E.4.4. Slash Test

A structural-steel angle-iron, approximately 7 feet (2 metres) long, was twice dropped more than 150 feet from the SNLA Area III 300-foot test tower upon each PAT-2 package subjected to the NUREG-0360 test sequence. The slash projectile

was guided by a drop carriage to prevent tumbling, and the falls were photometrically recorded. The projectile had equal legs, > 5 inches long and 0.5 inch thick, that were 90° apart. The square ends of the angle-iron provided a relatively sharp three-axis 90° corner for slashing the packages; the drop carriage guided the projectile such that this sharp corner struck the package first, with the PAT-2 longitudinal axis approximately evenly bisecting the 90° angle between the legs.

Each package was firmly restrained and supported in tamped earth such that its longitudinal axis was inclined ~45° to the horizontal. The area of the package which made first contact with the impact surface in the crash test was in the lowermost position, and the projectile struck the package at the approximate center of its vertical projection. After one slash test, each package was rotated ~90° about its longitudinal axis and slashed again as before.

2E.45. Thermal Exposure or Fire Test

Crashed, crushed, punctured, and slashed PAT-2 packages were exposed to a JP-4 aviation fuel fire with a minimum temperature of 1,850°F (1,010°C) for more than 1 hour. The controlled fire was combusted in a 25-foot high by 16-foot diameter (8- by 5-metre) chimney fabricated from steel plate and insulated on its inside surface.

A stainless-steel stand in the center of the tub held the PAT-2 packages ~3 feet (1 metre) above the JP-4 fuel surface. The stand surface is an open grid; the packages were oriented on the stand with the crashed surface faced downward. Time-versus-temperature records were made from thermocouples affixed above, below, even with, and attached to the surface of the package. The packages were allowed to cool naturally, remaining in place until cool to the bare hand.

2E.4.6 Water Immersion Test

The packages subjected to the foregoing tests were immersed in 3 feet (0.91 metre) of water (minimum depth to any point on the PAT) for at least 8 hours.

2E.4.7 Nonsequential Hydrostatic Pressure Test

One clean, dry TB-2 was subjected to 600-psi (4.1-MPa) minimum hydrostatic water pressure for a minimum of 8 hours in a hydrostatic test vessel filled with color-dyed water; the test was actually performed at 5,000 psig, the maximum permissible operating pressure of the hydrostatic test facility.

2E.4.8 Containment Acceptance Test Measurements

After the nonsequential hydrostatic pressure test, the TB-2 interior was examined for water. After the sequential test series, the TB-2 exterior was monitored for uranium material release or contamination with a fluorimeter sensitive to 10^{-8} gram of uranium. A mass-spectrometer helium leak-rate test sensitive to 10^{-10} cm^3/s helium was also conducted on the sequentially tested TB-2s, and leak-rate results were converted to cm^3/s air leak rate.

2E.5 DATA

Data from the above-described 10 CFR 71 and NUREG-0360 tests consisted primarily of the following:

- Pre-test quality control inspection data or manufacturer's certification on the PAT-2, AQ-2, TB-2 and C-1 assemblies, including leak-rate test data on the TB-2 vessel and C-1 capsule before environmental testing.
- Photometric data of the impact tests (velocity and attitude).
- Post-impact radiographs of PAT-2 showing location of TB-2 with respect to the AQ-2.
- Laboratory test reports (observed measurements of the crush, puncture, slash, and hydrostatic tests).
- Thermocouple data as described earlier for the burn (fire) tests.
- Health physics swipe test results of TB-2 and C-1 as required for radiological and uranium (chemistry) monitoring, 10^{-8} gram uranium sensitivity.
- Laboratory standard leak-rate testing by helium-type mass spectrometer, of the TB-2 and C-1, after environmental test sequences.
- Post-test observation of TB-2 copper and C-1 Teflon™ seals.
- Approximate dimensional descriptions of PAT-2s after test series, prior to destructive opening to recover TBs.
- Extensive photographic (still and motion picture) coverage of major test events; still photos of PAT-2, AQ-2, TB-2, and C-1 after tests or test series.

APPENDIX 2F

Test Facilities

The facilities utilized to perform the sequential test series include (1) the SNLA Coyote Test Field facility, at which controlled-attitude, high-velocity impacts onto an unyielding target were performed; (2) a Tinius-Olsen static test machine to crush the packages as required; (3) two SNLA Area III tower facilities utilized to perform the puncture and slashing tests; (4) a fire-test facility; and (5) an immersion tank. This appendix describes these facilities and the test and data acquisition methods utilized to assure that the desired test environments were properly produced.

2F.1 ROCKET PULLDOWN IMPACT TEST FACILITY

The rocket pulldown impact test facility used for package impact tests consists of a tensioned aerial cable suspended over a canyon between two ridges, a carriage which can be hoisted from a ground-based target up to the aerial cable, an unyielding target of armor-plated concrete, a sled track, a rocket-propelled sled, and control and instrumentation capabilities. An overall view is shown in Figure 2F.1-1. Figure 2F.1-2 shows the unyielding target, towing lines, pulleys, and a PAT-2 package equipped with an explosively deployed towing rig for a bottom-corner impact. Figure 2F.1-3 shows the sled track and the berm box which captures the expended sled and rockets; Figure 2F.1-4 is another overall view of the facility. The PAT-2 package is suspended approximately 185 feet (56 metres) above and perpendicular to the unyielding target. Rocket sled tow lines (a continuous wire rope used in a loop so there appears to be two tow lines, one on each side of the PAT-2 package) are attached to the PAT-2 by means of towing rigs such that high-speed towing will be stable and the package will impact in the desired attitude. The towlines route vertically downward from the PAT-2 package and pass through pulleys that straddle the unyielding target; the towlines then route horizontally to the rocket sled, where they are firmly attached. The rocket sled uses a variable number of 5-inch ZUNI high-velocity aerial rocket motors that have 6,500 lb·s (2,950 kg·s) impulse. The desired impact velocities are attained or exceeded by adjusting the package height above the target and varying the number of rockets installed on the sled.

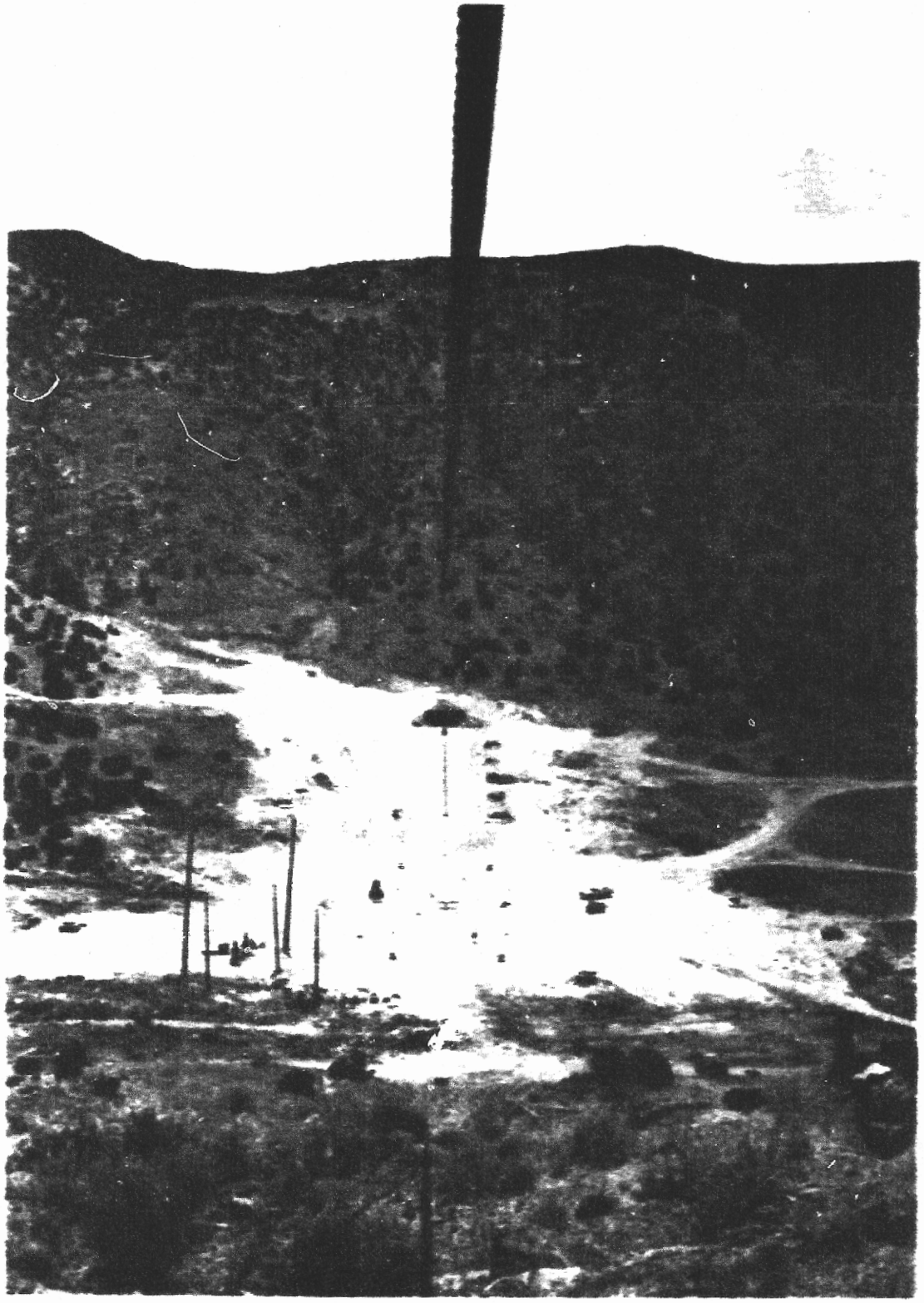


Figure 2F.1-1. Rocket Pulldown Test Facility

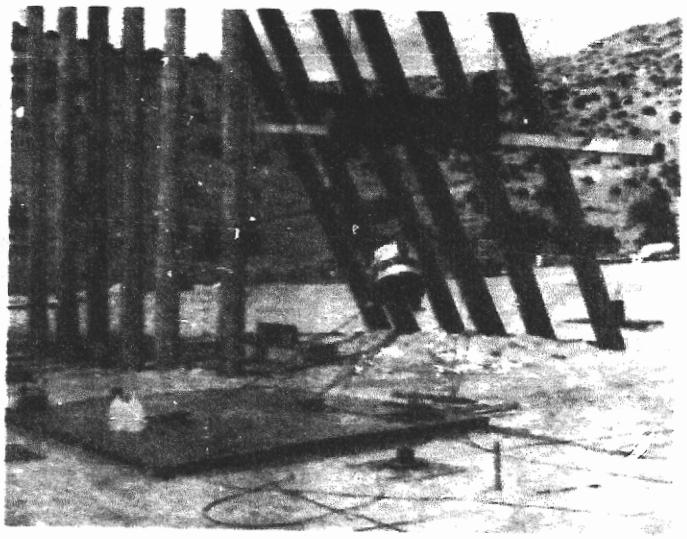
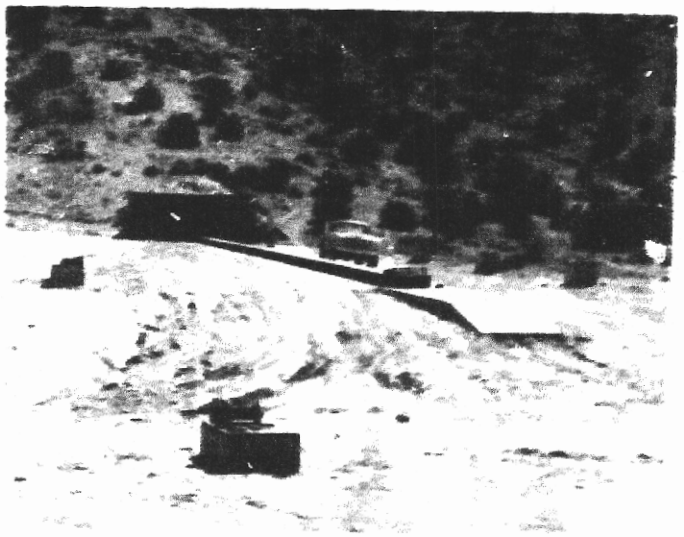


Figure 2F.1-2. PAT-2 Package Rigged for Bottom-Corner Impact



F gure 2F.1-3. Sled Track and Berm

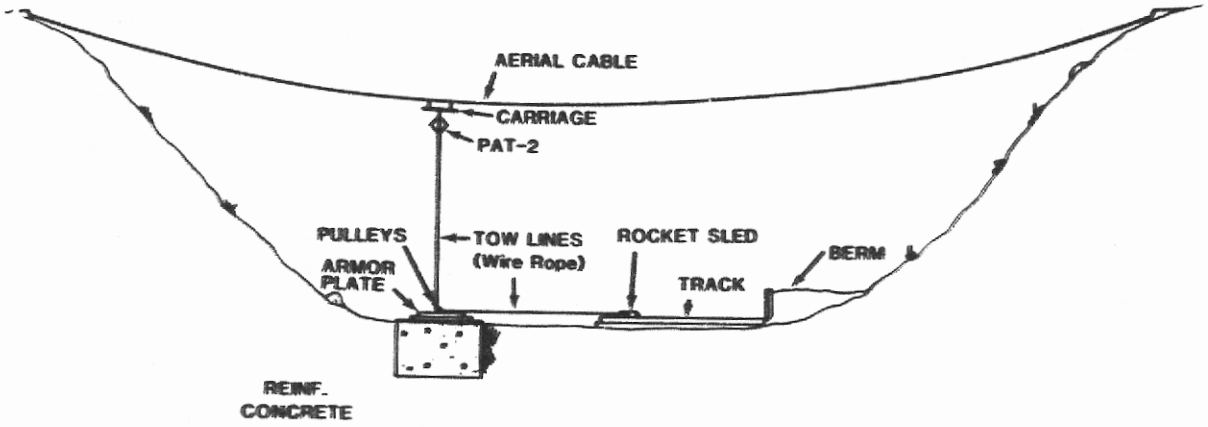


Figure 2F.1-4. Rocket Pulldown Facility, Side View

The operation sequence involves staged rocket ignition and wire rope cutters. Between first- and second-stage rocket ignition, the package suspension wire rope is cut, and towing commences. The tow lines are cut to separate the PAT-2 just prior to impact; this action is triggered by sled passage through a breakwire on the monorail track. The towing rig, which was attached to the PAT-2 by wire ropes equipped with explosive cable cutters, is released from the package at this same time.

The unyielding target is an extensively reinforced 526,000-pound (239-Mg) block of concrete, approximately 20 feet (6 metres) in diameter and 11.5 feet (3.5 metres) deep into prepared (tamped) earth. It is faced with a 10-foot (3-metre) square slab of battleship armor plate, with an average thickness of 4 inches (10 cm). The steel facing is welded to the rebar in the concrete and is grouted to the concrete plug with iron-filings-filled cement grout.

Redundant high-speed photometrics measure PAT-2 package impact velocity and attitude. A visicorder measures down time, from rocket ignition to breakwire function.

The rocket sled with two rockets is shown in the arming stage in Figure 2F.1-5. High- or low-temperature environmental conditioning equipment, available at the target site, is shown in Figure 2F.1-6. A cold-soaked PAT-2 package, final-armed and ready for hoisting, is shown over the unyielding target in Figure 2F.1-7.

2F.2 STATIC TEST MACHINE

The crush tests were accomplished with a Tinius Olsen static test machine (Figures 2.8.3-1, 2.8.3-2, 2.8.3-3, p 2-32). Radiographs of the PAT-2 after impact were used to establish that this crush and the subsequent puncture test caused maximum package damage (i.e., the distance between the TB-2 containment vessel and the point of applied load were minimized).

2F.3 DROP TOWER FACILITIES

Two drop towers of 185 feet (56 metres) and 300 feet (91 metres) were utilized to accomplish the puncture and slashing tests, respectively. Both facilities provided for proper impact location and orientation control of the test probes when impacting the PAT-2 package.

The puncture test involved dropping a 500-pound (227-kg) blunt conical probe 10 feet (3 metres) onto a package which is supported on a concrete-backed steel-plate target. A guide tube assured proper impact orientation control of the probe. The general arrangement for this test is shown in Figure 2.8.4-1.

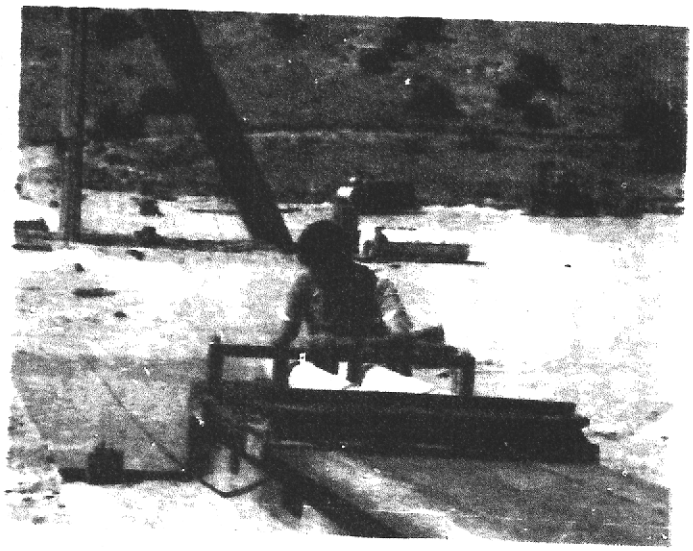


Figure 2F.1-5. Armed Rocket Sled

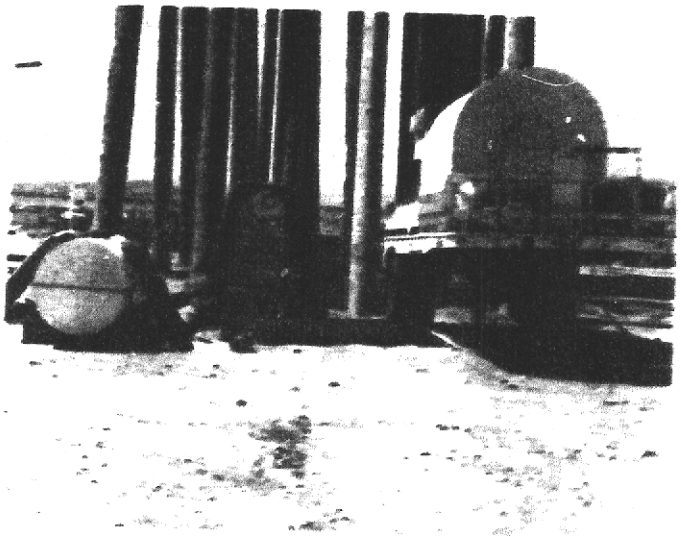


Figure 2F.1-6. High- and Low-Temp. Conditioning Equip.

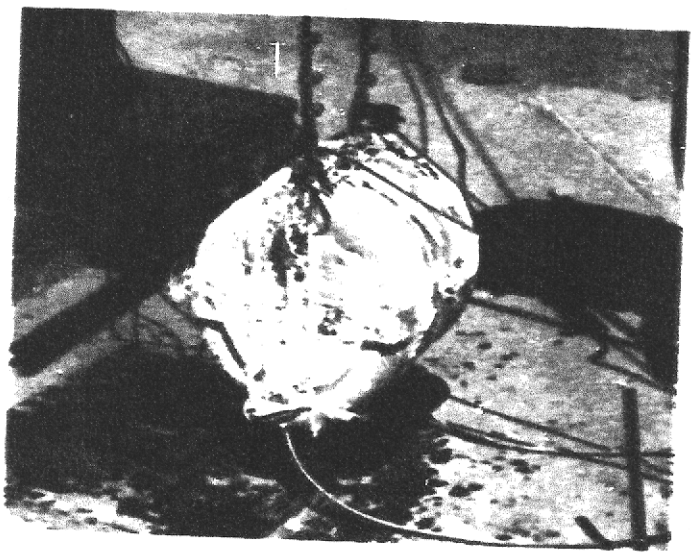


Figure 2F.1-7. Cold-Soaked PAT-2 prior to Impact

The slash test was accomplished with a guided carriage on the 300-foot drop tower. The ~7-foot (2-metre) angle-iron projectile, with squared-off ends, was attached perpendicular to the mounting deck of this guided carriage. The angle-iron was oriented as detailed in Appendix 2E, Section 2E.4.4. In the tests, the carriage with the steel beam was hoisted to a correct drop height, allowing for friction on the guide wires, and then allowed to slide down the guide wires toward the PAT-2 package (Figure 2F.3-1). The steel projectile was separated from the carriage just above the PAT-2 package when it broke a glass rod which triggers an explosive cable cutter, allowing unrestrained final free-flight into the PAT-2. Impact velocities are determined through photometrics.

2F.4 FIRE TEST FACILITY

The fire test facility is a 25-foot high by 16-foot diameter (8- by 5-metre) chimney fabricated of steel plate and insulated on its inside surface. Figure 2.8.6-3, p 2-40, is a photograph of the facility, and Figure 2F.4-1 is a functional schematic.

To permit flame height adjustment and temperature control, fuel (commonly JP-4) is floated on water in a steel tub, approximately 10 feet (3 metres) in diameter, with minimum freeboard above the ground. A controlled supply of air is delivered to the fire through a symmetric pattern of nineteen 19-inch (48-cm) diameter air pipes, which pass from an underground plenum upward through the water and fuel. The air supply is controlled with inlet-tunnel louvers which respond to feedback from a control thermocouple at the level of the item being tested.

Test items rest approximately 3 feet (1 metre) above the fuel on an open-grid steel test stand which is centered in the burn tub. The open construction of the stand maximizes incident heat upon an item.

2F.5 WATER IMMERSION FACILITY

The water immersion facility is a 6-foot (1.83- metre) diameter tank, 6.4 feet (1.95 metres) deep, set below grade and filled with water. It is adjacent to the fire test facility. A drowning cage, Figure 2.8.7-1, assures that the PAT-2 package remains submerged below the required 3-foot (0.9-metre) depth of water.

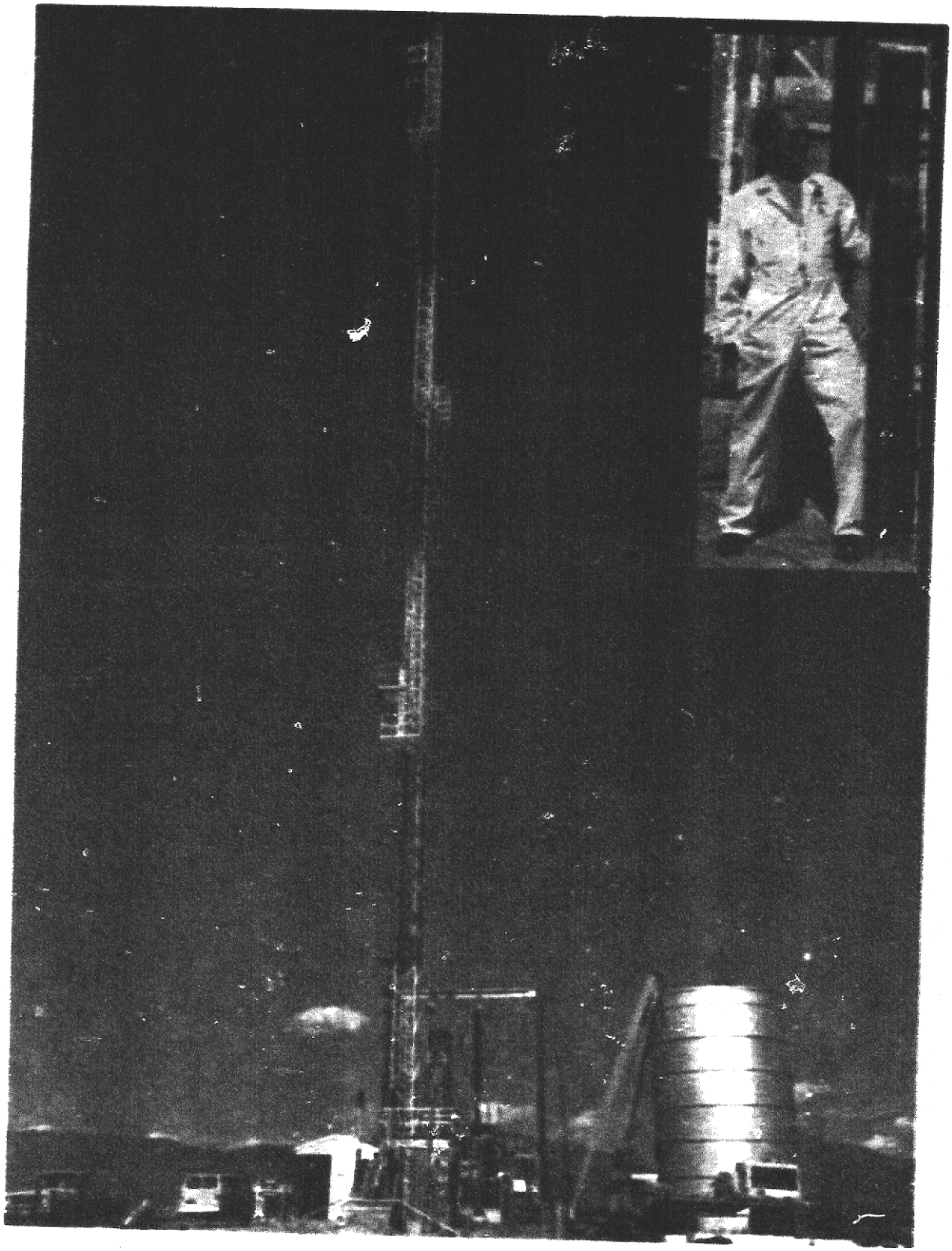


Figure 2F.3-1. Slash Test at 300-foot Drop Tower

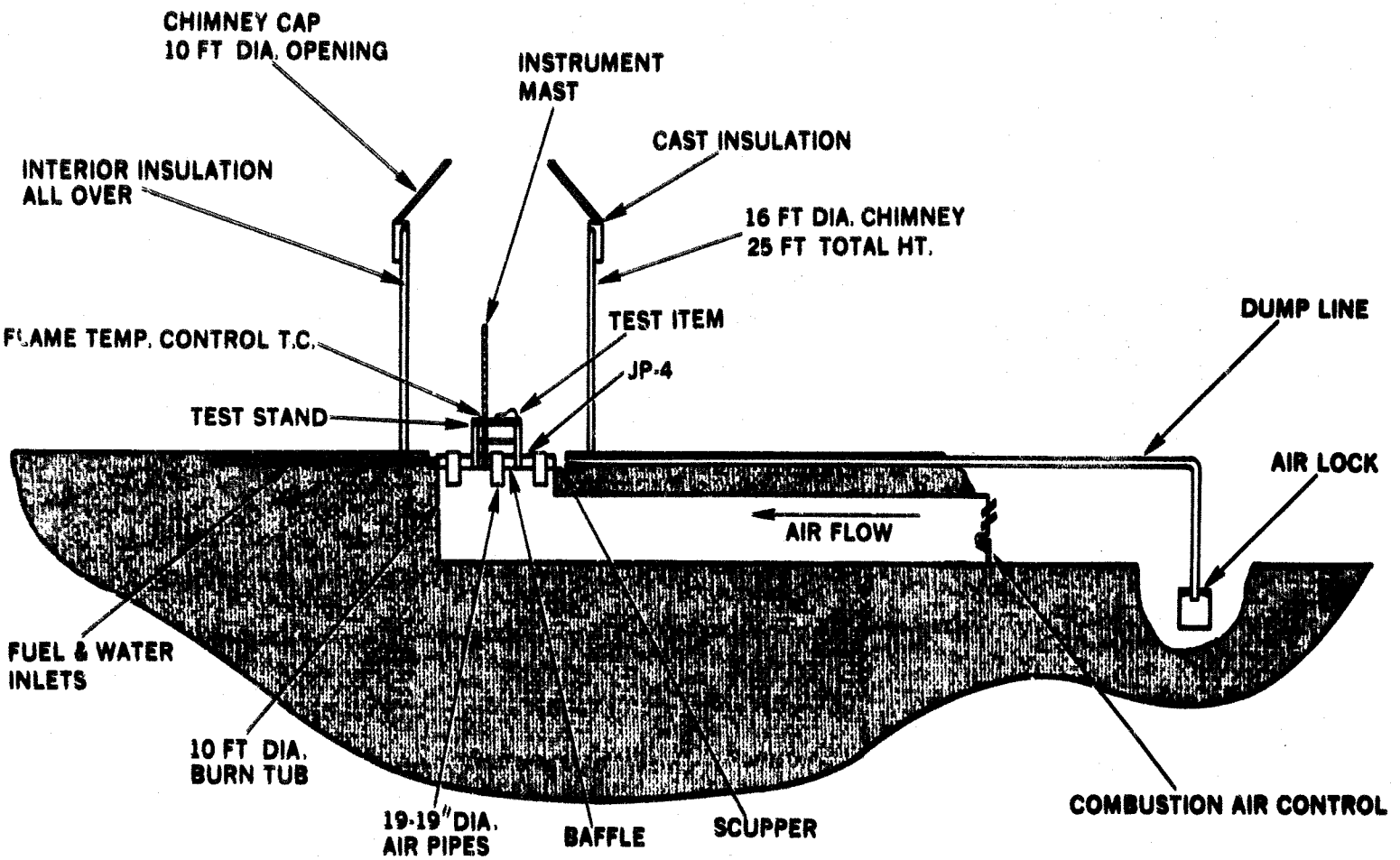


Figure 2F.4-1. Fire Test Facility Schematic

APPENDIX 2G

PAT-2 Package Impact Analysis

2G.1 PURPOSE AND GENERAL APPROACH

This appendix analyzes the capability of the PAT-2 package to survive a 250-knot (129-m/s) impact on an unyielding target, a requirement specified in NUREG-0360. End-on and side-on configurations are considered. The corner impact situation, which is not amenable to solution, is, instead, validated by impact testing.

A view of the PAT-2 package showing all components is displayed in Figure 2G.1-1. The basic approach used in the design of the package is to absorb the impact energy by a combination of material crushing (in the case of crushable, distended materials) and plastic work (in the case of metals). The aim is to isolate the inner containment vessel from excessive shock.

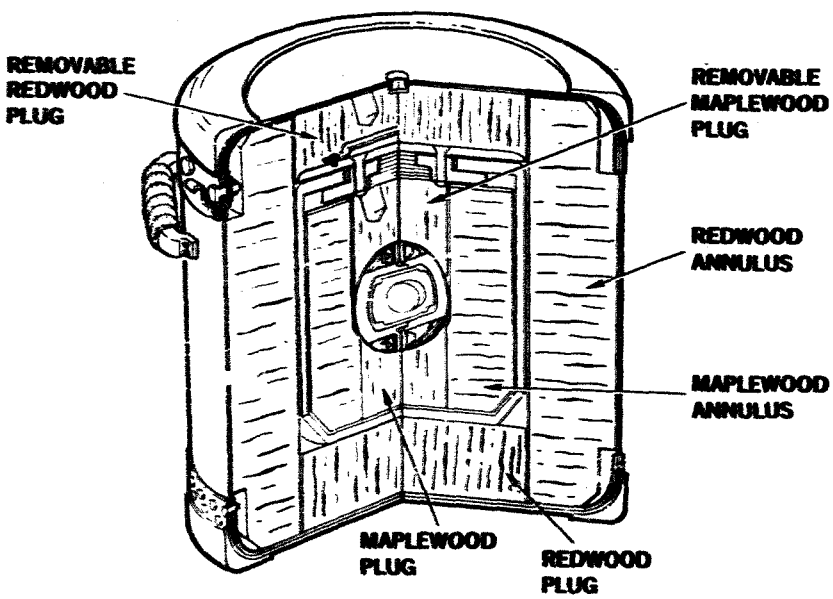


Figure 2G.1-1. PAT-2 Package Components Showing Grain Orientation of Energy-Absorbing Redwood and Maplewood

The containment vessel is treated as a rigid object, the motion of which must be stopped by wood crushing and (to a lesser extent) plastic deformations of the outer cylinder, lids, and load spreader. Note that the load spreader assembly distributes the inertial loading over a larger area of energy-absorbing redwood than would be distributed by the projected area of the TB-2 containment vessel alone. The maplewood immediately surrounding the TB-2 is quite stiff and serves to fairly directly couple the sphere with the load spreader, although the maplewood is, of course, capable of crushing itself. Therefore, the maplewood affords shock isolation for the TB-2, although at considerably higher shock loading levels than with redwood.

Methods utilized for analyzing the various impact configurations are those indicated by Andersen and Duffey[24] for the PAT-1 package and consist of equating the initial kinetic energy available with the energy which can be absorbed by the crushable material up to the point of "lockup," as shown in the following equation.

$$K.E. = \int_V \left[\int_{\epsilon_{ij}} \sigma_{ij} d\epsilon_{ij} \right] dV ,$$

where the inner integral of the energy absorption expression on the right is the strain energy density taken over all strain states at a given point. This strain energy density is then integrated over the volume of deformed material. Many crushable materials, and wood in particular, when loaded parallel to (in line with) the grain, exhibit a uniaxial load-deflection (or stress-strain) behavior as shown schematically in Figure 2G.1-2. In the case of wood, the largest energy absorption capability is in crushing in line with the grain orientation. The stress state is therefore taken as uniaxial for these materials along the grain orientation direction. The strain energy density then becomes

$$\int \sigma \, d\epsilon$$

which represents the area under the uniaxial load deflection curve for the crushable material when compressed in line with the grain (energy absorption in other directions is conservatively neglected).

Details of testing and results for the energy-absorbing wood material properties are described in Appendix 2A. In any case, the procedure consists of cutting the wood sample into the form of a right-circular cylinder and putting the cylinder

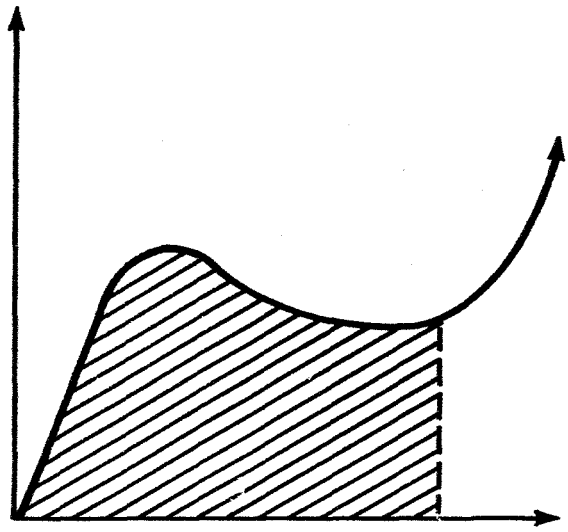


Figure 2G.1-2. Typical Load-Deflection Behavior of Distended, Crushable Materials

inside a close-fitting metal sleeve which provides confinement. A piston is then driven into the specimen, and the force-deflection behavior is recorded and integrated to obtain the energy-absorption capability of the material. After the particular sample is crushed on the order of 60% to 70% (for typical woods), "lockup" or bottoming-out occurs and loads which cause further deformation of the sample increase rapidly. Energy absorption is only considered up to the point of lockup. Note that the area under the load-deflection curve of Figure 2G.1-2 corresponds to the energy absorbed by the crushing process. Again, it is this energy absorption capability that is primarily used to protect the TB-2 containment vessel.

Treatment of end- and side-impact orientations are considered in the following two sections, respectively.

2G.2 END-ON IMPACT ANALYSIS

Consider the situation of end-on impact of the PAT-2 onto a rigid, unyielding surface. As shown in Figure 2G.2-1, the load spreader, which contains the TB-2 vessel, effectively serves as a piston on impact, compressing the lower redwood plug. Deceleration of the load spreader assembly (including contained maplewood and

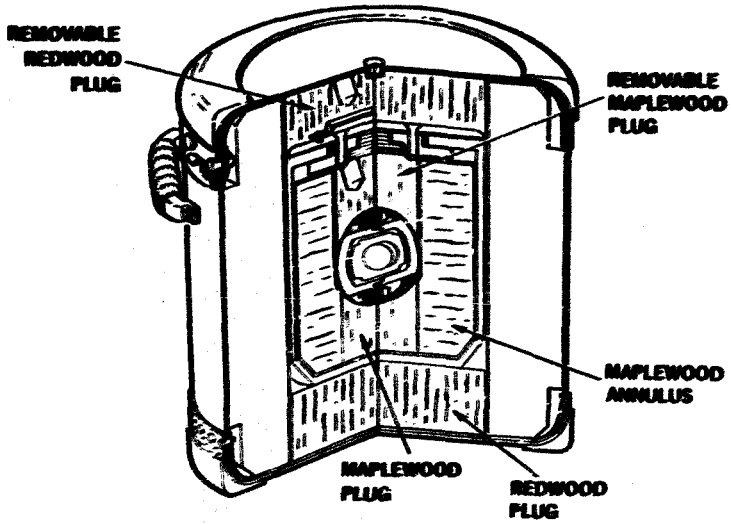


Figure 2G.2-1. PAT-2 Package Showing Column of Materials Used in End-On Impact Analysis

the TB-2) is thus provided by the lower redwood plug up to the point of lockup of the redwood. Note that the upper, removable, redwood plug serves only to add mass to the column. Particular attention should be paid to the grain orientations indicated in Figure 2G.2-1.

The first calculation to be made is a determination of whether the lower redwood plug, in itself, is sufficient to stop the load spreader assembly without redwood lockup. This portion of the dynamic response is termed Phase I.

The total effective mass of the column of material shown in Figure 2G.2-1 consists of the top redwood plug, the access plate and load spreader can, the bottom redwood plug, and the TB-2 containment vessel assembly (loaded), as well as the maplewood surrounding the TB-2, which comprises the annulus and the two end plugs. These items and their respective masses are included as Table 2G.2-1. Note that the total column mass is 25.1 lb_m (11.4 kg). At an impact velocity of 422 ft/s (129 m/s), the kinetic energy of the column of material shown in Figure 2G.2-1 is

$$K.E. = \frac{1}{2} mV^2 .$$

For

$m = 25.1\ lb_m$ (11.4 kg) and

$V = 422$ ft/s (129 m/s),

The kinetic energy associated with the column of materials shaded in Figure 2G.2-1 is

$$K.E. = 69{,}408\ lb_f \cdot ft\ (94.12\ kJ)\ .$$

Table 2G.2-1

Masses of PAT-2 "Outer Column" Components: Phase I

Component	Mass lb (kg)
1. TB-2 containment vessel (loaded mass, including fairings)	4.3 (2.0)
2. Titanium load spreader (complete assembly, including access plate)	11.4 (5.2)
3. Maplewood (total)	6.1 (2.8)
4. Top redwood plug	1.65 (0.7)
5. Bottom redwood plug	1.65 (0.7)
Total "column" mass	25.1 (11.4)

Now consider the bottom redwood plug. The total energy absorption capacity (to lockup) of this plug is

$$\text{Total Energy Absorption} = (\text{Specific Energy})(\text{Mass})\ .$$

Using a mass for the bottom redwood plug of 1.65 lb_m (0.75 kg) and a specific energy absorption* for redwood of 22,380 $lb_f \cdot ft/lb_m$ (66.9 kJ/kg), the total impact energy absorption capacity is

$$\text{Total Energy Absorption} = 36{,}927\ lb_f \cdot ft\ (50.07\ kJ)\ .$$

*Specific energy absorption is $\int \sigma\, d\varepsilon$, the area under the stress-strain curve discussed earlier.

Comparing the kinetic energy and energy capacity values above indicates that, for end drop, the redwood bottom disk (nearest impact) cannot absorb all the energy of the column by itself. As a result, the bottom redwood will lock up, transmitting large loads to the titanium load spreader.

The residual velocity of the column just at the instant of lockup is calculated as follows: The change in column kinetic energy is equated with the total energy absorption of the redwood plug, i.e.,

$$\frac{1}{2} mV^2 - \frac{1}{2} mV_f^2 = 36{,}927 \text{ lb}_f\text{-ft } (50.07 \text{ kJ}) ,$$

where the final velocity, V_f, is calculated to be

$$V_f = 288.6 \text{ ft/s } (88 \text{ m/s}) .$$

Now Phase II of the deformation begins. The materials involved are shown in Figure 2G.2-2, and consist of the loaded TB-2 containment vessel, the upper maplewood plug, and the lower maplewood plug. The masses of the components are indicated in Table 2G.2-2. Basically, the load spreader is assumed to be stopped at this point and the inner column effectively impacts on the stopped load spreader at an impact velocity of 288.6 ft/s (88 m/s). Again, the procedure is to calculate the kinetic energy of this (smaller) column and determine if the maplewood plug has sufficient energy absorption capability to decelerate the column to rest without reaching lockup.

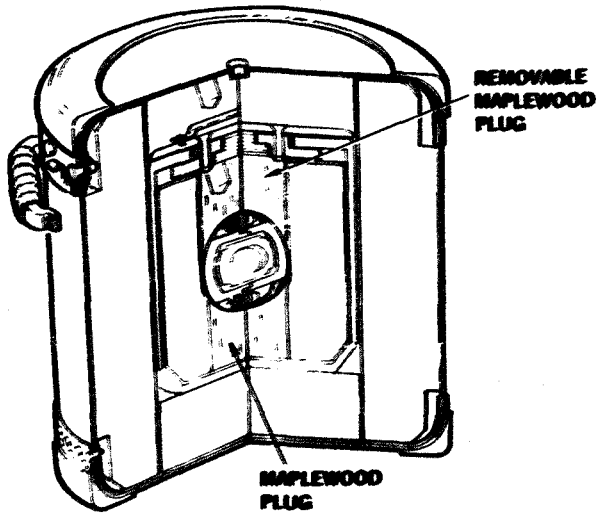


Figure 2G.2-2. Inner Column Energy Absorption Region; End-On Impact

Table 2G.2-2

Masses of PAT-2 "Inner Column" Components
(Phase II of End-On Impact Process)

Component	Mass lb (kg)
1. TB-2 containment vessel (loaded mass, including fairings)	4.3 (2.0)
2. Upper maplewood plug	0.600 (0.27)
3. Lower maplewood plug	0.600 (0.27)
Total column mass	5.5 (2.5)

The kinetic energy of the column is, again,

$$K.E. = \frac{1}{2} mV^2.$$

where now

m = 0.1708 slugs (5.5 lbm or 2.5 kg) and

V = 288.6 ft/s (88 m/s)

resulting in

$$K.E. = 7{,}113 \text{ lb}_f\cdot\text{ft } (9.645 \text{ kJ}).$$

The maplewood energy absorption capacity (to lockup) is, again,

$$\text{Total Energy Absorption} = (\text{Specific Energy})(\text{Mass}).$$

Using a mass for the lower maplewood plug of 0.600 lbm (0.27 kg) and a specific energy of 19,000 $\text{lb}_f\cdot\text{ft/lb}_m$ (69 kJ/kg),

$$\text{Total Energy Absorption} = 11{,}400 \text{ lb}_f\cdot\text{ft } (15{,}46 \text{ kJ}) .$$

Comparing the energy absorption capability of the maple before lockup, 11,400 $\text{lb}_f\cdot\text{ft}$ (15.46 kJ), with the kinetic energy necessary to stop the column containing the TB-2, 7.113 $\text{lb}_f\cdot\text{ft}$ (9.645 kJ), indicates that the TB-2 will be decelerated to rest well before the maplewood locks up.

Overall conclusions regarding the end impact are that sufficient energy absorption capacity is available in the PAT-2 to cause the TB-2 vessel to be decelerated, at low loading, to rest, during impact. However, the load spreader assembly may well experience plastic deformation.

2G.3 SIDE-ON IMPACT ANALYSIS

The side-on impact analysis is done similarly to the end-on analysis of the previous section. First, the volume of crushable material involved in decelerating the load spreader and its contents is calculated, and the energy capable of being absorbed is determined up to the point of lockup. This is taken as Phase I of the response.

The portion of redwood which decelerates the load spreader is shown in Figures 2G.3-1 and 2G.3-2. The indicated region is that which would be involved in crushing during side-on impact before damage to the load spreader would occur.

The volume of redwood material involved in this initial crush consists of a solid with the cross section of a circle. Application of elementary formulas[25] results in a calculated volume of material involved of 241.3 in^3 (3954 cm^3). Note that the length of the affected material does not run the full length of the PAT-2 -- only under the load spreader, as indicated in Figure 2G.3-1.

Note further that crushup of this redwood occurs primarily parallel to the grain. The grain orientation of the redwood and maplewood pieces was designed so that this would be the case. Using methods outlined in the previous section, the total energy which can be absorbed by the region indicated in Figures 2G.3-1 and 2G.3-2 is calculated to be (up to the state of lockup)

$$\text{Total Energy Absorption} = 81{,}264\ lb_f \cdot ft\ (110.2\ kJ)\ .$$

Next, the kinetic energy, which (if possible) is to be stopped by crushup of this redwood, is determined by first totaling the materials whose energy must be dissipated, to as large an extent as possible, by redwood crush. The list of the materials and their total mass are indicated in Table 2G.3-1 (see Figures 2G.3-1 and 2G.3-2).

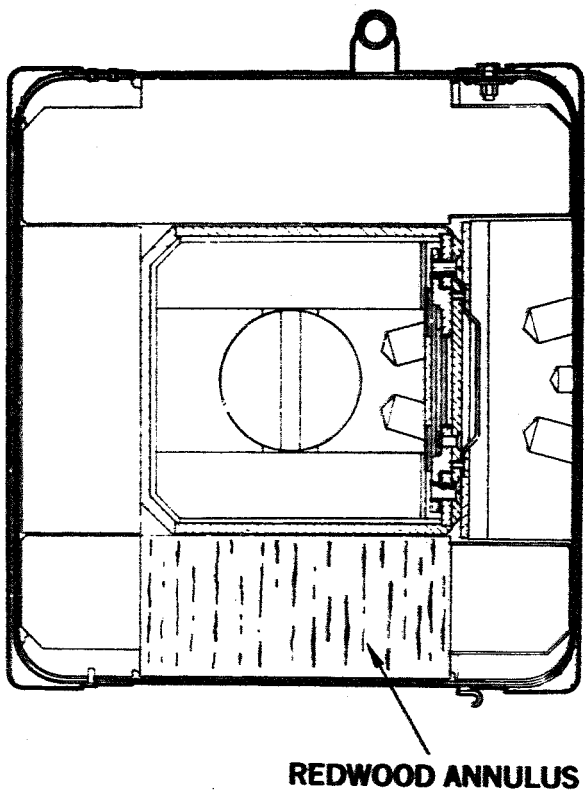


Figure 2G.3-1. Portion of Redwood which Decelerates Load Spreader -- Phase I, Side Impact

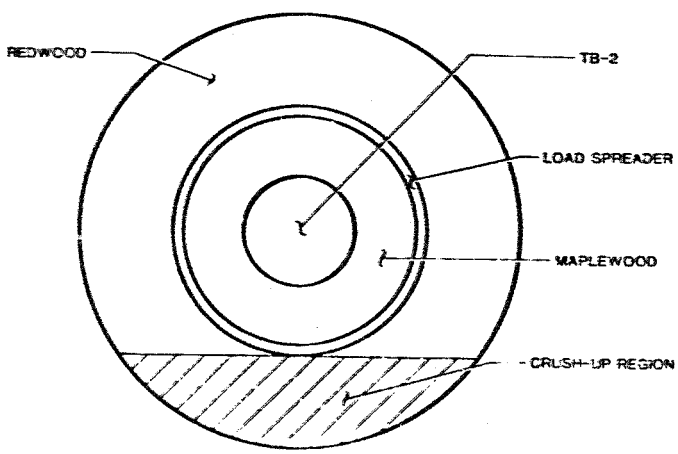


Figure 2G.3-2. Cross Section of PAT-2 Showing Volume of Material Involved in Lateral Crush

Table 2G.3-1

Masses Involved in Side-On Impact (Phase I)

Component	Mass lb (kg)
1. Portion of redwood cylinder	12.4 (5.6)
2. Loaded TB-2 vessel assembly	4.3 (2.0)
3. Load spreader assembly	11.4 (5.2)
4. Three maplewood pieces	6.1 (2.8)
Total mass	34.2 (15.6)

As in the end impact analysis, the kinetic energy of this "column" of material is given by

$$K.E. = \frac{1}{2} mV^2.$$

For

$$V = 422 \text{ ft/s } (129 \text{ m/s}) \text{ and}$$

$$m = 34.2 \text{ lb}_m \ (15.5 \text{ kg}),$$

the kinetic energy is

$$K.E. = 94{,}572 \text{ lb}_f \cdot \text{ft } (128.2 \text{ kJ}) .$$

Comparison of this "available" kinetic energy with the total energy absorption capability value calculated above, 81,264 $lb_f \cdot ft$ (110.2 kJ), reveals that the redwood, acting alone, is insufficient to fully decelerate the load spreader assembly (and TB-2 vessel) to rest without lockup and prevent the transmittal of attendant high loads to the TB-2.

When the softer redwood "locks up," the load spreader assembly is effectively stopped and may well undergo plastic deformations. Such deformations will, of course, add to the plastic energy absorption capacity. Conservatively, such additional capacity will be ignored for the present and included, if necessary, later.

Following lockup of the redwood and stopping of the load spreader, the TB-2 still has a residual velocity which is dissipated by crushing of the maplewood.

This is Phase II of the response. Consider first the velocity lost by the load spreader and contents up to the point of redwood lockup. The change in kinetic energy of the components itemized in Table 2G.3-1 is equated to the energy absorbed by the redwood:

$$\frac{1}{2} mV^2 - \frac{1}{2} mV_f^2 = 81{,}264 \text{ lb}_f \cdot \text{ft } (110.2 \text{ kJ}) .$$

The velocity, V_f, of the load spreader assembly and all inside components just at the point of lockup is therefore calculated to be

$$V_f = 158.4 \text{ ft/s } (48.2 \text{ m/s}) \text{ residual velocity.}$$

Following redwood lockup, the load spreader stops, the TB-2 container is still traveling at 158.4 ft/s (48.3 m/s) (to the right of Figure 2G.3-3). As seen in Figure 2G.3-3, an annulus of maplewood with the grain oriented mostly perpendicular to the motion of the TB-2 serves to decelerate the TB-2.

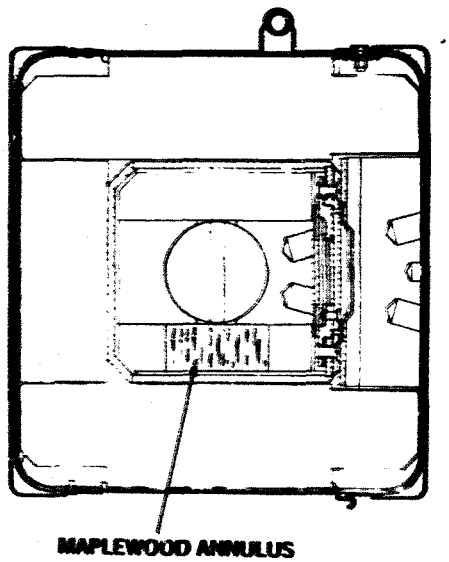


Figure 2G.3-3. Column of Maplewood that Decelerates TB-2 Container Phase II; Side-On Impact

The total mass of material being considered is now the TB-2 assembly and the annulus of maplewood shown in Figure 2G.3-3 with cross-sectional area equal to the projected area of the TB-2.

The kinetic energy for this phase is

$$K.E. = \frac{1}{2} mV^2 .$$

For

$$m^* = (4.952\ lb_m\ (2.25\ kg) \text{ and}$$
$$V = 158.4\ ft/s\ (48.3\ m/s),$$

the kinetic energy is

$$K.E. = 1{,}932\ lb_f\text{-}ft\ (2.62\ kJ).$$

Based upon a specific energy absorption capacity for maplewood of 19,000 $lbf\text{-}ft/lb_m$ (56.8 kJ/Kg), the total energy absorption capacity of the shaded portion of maplewood shown in figure 2G.3-2 is

$$\varepsilon = 11{,}400\ lb_f\text{-}ft\ (15.5\ kJ).$$

Comparing the two above numbers indicates (1) a surplus of energy absorption capacity, (2) the maplewood will not lock up, and (3) the TB-2 will be decelerated smoothly at levels well below values that could induce permanent deformations. Again, however, the load spreader will probably sustain plastic deformations. These analytical predictions were confirmed by the impact tests (see radiographs, Figures 2.8.8-14 through 2.8.8-20).

---

*Corresponds to a loaded TB-2 of 4.3 lb_m (1.95 kg) and a maplewood plug of 0.672 lb_m (0.305 kg).

APPENDIX 2H

TB-2 Containment Vessel Hydrostatic Stress Analysis

NUREG 0360 requires that the TB-2 containment vessel withstand an external pressure of 600 psi (4.1 MPa).* The techniques used to analyze this load case are described in Appendix 2C. A static elastic finite element analysis was performed using the SASL computer program with a 600-psi (4.1-MPa) external pressure applied over the outer boundary of the TB-2 containment vessel. The resulting calculated extreme stresses are

Stress Component	Maximum Value psi (MPa)	Minimum Value psi (MPa)	Factor of Safety
Radial	8,250 (56.9)	- 5,880 (40.5)	
Axial	1,570 (10.8)	-23,100 (159.3)	
Circumferential	2,340 (16.1)	- 7,240 (49.9)	
von Mises	19,400 (133.8)	---	5.15

Comparing these stresses, particularly the von Mises effective stress value, to the 100-ksi (689-MPa) yield strength of the material reveals that the hydrostatic load requirement will not cause failure of the TB-2 containment vessel. Note that the vertical displacement of the knife-edge seal tip is -0.864×10^{-4} inch (-2.19×10^{-3} mm). That is, due to the presence of the external pressure, the A-286 knife-edge will be driven slightly farther into the copper seal, serving to improve the sealing of the TB-2.

---

*The AQ-2 overpack is vented, and this hydrostatic condition does not apply.

REFERENCES

[1] U.S. Nuclear Regulatory Commission, Qualification Criteria to Certify a Package for Air Transport of Plutonium, NUREG-0360, (Washington: U.S. NRC, January 1978).

[2] Code of Federal Regulations, Title 10, Part 71, "Packaging of Radioactive Material for Transport under Certain Conditions" (Washington: Government Printing Office).

[3] International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Materials, IAEA Safety Standards, Safety Series No. 6, 1973 revised ed. (as amended November 1979) (Vienna: IAEA, 1979).

[4] U. S. Government Metallurgy Specification QQ-S-766c.

[5] Aerospace Structural Metals Handbook.

[6] W. A. von Riesemann et al, The Effects of Temeprature on the Energy-Absorbing Characteristics of Redwood, SAND77-1589 (Albuquerque: Sandia Laboratories, 1977).

[7] W. W. Joseph and T. K. Hill, Energy-Absorbing Characteristics of California Redwood Subjected to High Strain, SAND76-0087 (Albuquerque: Sandia Laboratories, April 1976).

[8] T. K. Hill and W. W. Joseph, Energy-Absorbing Characteristics of Materials, SLA-74-0159 (Albuquerque: Sandia Laboratories, May 1979).

[9] Product Data Sheet for ARMCO A-286, Armco Steel Corporation, Advanced Materials Division, Baltimore, MD.

[10] U.S. Department of Defense, Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5C (Washington DoD, September 1976).

[11] Materials Engineering 1978 Materials Selector, December 1978.

[12] Welding Handbook, 3rd ed. (American Welding Society, 1950), pp 1566-1567.

[13] American National Standards Institute ANSI N14.5, and/or U.S. Nuclear Regulatory Commission Regulatory Guide 7.4, "Leakage Tests on Packages for Shipment of Radioactive Materials."

[14] Stark, James A., "Calculated Trajectories for the Lightweight Air-transportable Accident Resistant Container" (Albuquerque: Sandia Laboratories, Experimental Aerodynamics Division, October 1979).

[15] J. D. McClure and W. A. Von Riesemann, The Crush Environment for Small Containers Carried by U. S. Commercial Jet Aircraft, SAND76-0533 (Albuquerque: Sandia Laboratories, August 1977).

[16] J. D. McClure and W. F. Hartman, An Analysis of the Crush Environment for the Light-Weight Air-Transportable Accident Resistant Container (LAARC), SAND80-0898, TTC-0099 (Albuquerque: Sandia National Laboratories, July 1980).

[17] R. M. Jones and J. G. Crose, SAAS II -- Element Stress Analysis of Axisymmetric Solids with Orthotropic, Temperature-Dependent Material Properties, TR-0200 (S-4980)-1 (San Bernadino, CA: The Aerospapce Corporation, September 1968).

[18]R. E. Jones, Users Manual for QMESH, a Self-Oranizing MESH Generation Program, SLA-74-0239 (Albuquerque: Sandia Labortories, July 1974).

[19]J. E. Shigley, Machine Design (New York: McGraw-Hill, 1956), p 190.

[20]R. W. Hertzberg, Deformation and Fracture Mechanics of Engineering Materials (New York: John Wiley and Sons, 1976), ch. 9.

[21]R. J. Roark and W. C. Young, Formulas for Stress and Strain (New York: McGraw-Hill 1975).

[22]S. Timoshenko and S. Woinowsky-Krieger, Theroy of Plates and Shells (New York: McGraw-Hill, 1959), p 551.

[23]S. H. Crandall and N. C. Dahl, An Introduction to the Mechanics of Solids (New York: McGraw-Hill, 1959).

[24]J. A. Andersen and T. A. Duffey, "Design of an Extreme Crash Resistant Transport Package," Journal of Mechanical Design 101:342-347, April 1979.

[25]R. S. Burington, Handbook of Mathematical Functions (Sandusky, OH: Handbook Publishers, Inc., 1958).

CHAPTER 3

THERMAL EVALUATION

3.1 SUMMARY AND RESULTS

The PAT-2 package is designed to safely contain plutonium under a variety of normal and accident conditions, as delineated in Chapter 2, including various thermal conditions. These thermal conditions have been evaluated by tests (Chapter 2) and by analysis, as presented in this chapter. Evaluation of thermal conditions also contributes to a definition of the allowable contents of the package (Chapter 1) and to containment pressurization (Chapters 3 and 4). The results of the thermal evaluations are summarized below.

- Internal decay heat -- The heat generated within the package by the radioactive contents is to be limited to 2 watts. With this limitation, the PAT-2 package will experience no thermal degradation during normal conditions of transport.[1]

- Normal conditions of transport -- Under severe insolation and with a 2-watt internal source, the maximum PAT-2 surface temperature is 217°F (103°C), the maximum redwood temperature is 213°F (100.6°C), and the maximum TB-2 containment vessel temperature is 203°F (95°C). Under the conditions specified in IAEA regulations,[2] the maximum temperature of the PAT-2 surface is less than 122°F (50°C). Minimum temperatures stabilized near -40°F (-40°C). These conditions were exceeded during the tests, the package remained leaktight, and thermal stresses were negligible.

- 150% maximum normal operating pressure -- For 150% maximum normal operating pressure, a temperature of 250°F (121°C) was used. The TB-2 containment vessel remained leaktight under these conditions.

- Thermal accident environment -- A bounding value of 250°F (121°C) was determined for the TB-2 containment vessel temperature under the fire conditions specified in 10 CFR 71 Appendix B (1,475°F, 30 minutes). For the fire conditions specified in NUREG-0360[3] (1,850°F, 1 hour) the bounding temperature was 1,080°F (582°C).

3.2 THERMAL PROPERTIES OF MATERIALS

The thermal properties of materials used in the thermal calculations for the PAT-2 package are summarized in Table 3.2-1.

Table 3.2-1

Thermal Properties of Materials*

Material	Thermal Conductivity (W/cm°C)	Specific Heat (W·hr/g°C)	Density (g/cm^3)	Solar Absorptance/ Emittance
Cerafelt™	0.00072	0.00023	0.38	N.A.
Titanium	0.21	0.00015	4.5	N.A.
304 stainless steel	0.147	0.00014	7.9	0.45/0.2 at 100°C
Containment vessel and payload	0.237	0.00013	5.1	N.A.
Maplewood	$k^{\parallel} = 0.0042$ $k^{\perp} = 0.0016$	0.00064	0.71	N.A.
Redwood	$k^{\parallel} = 0.0043$ $k^{\perp} = 0.0015$	0.00051	0.35	N.A.

*See References 4 through 9.

3.3 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT

3.3.1 Thermal Models

Computer thermal models of the PAT-2 package were designed using the HEATMESH[10] and CINDA[11] computer codes. The geometry of an 85-node model was developed using the HEATMESH code and was then input to the CINDA finite-difference heat transfer code for analysis.

A cross-sectional view of the cylindrical PAT-2 package is shown in Figure 3.3.1-1. For both ease of modeling and conservatism, only the portion of the container between planes A and B was modeled, and planes A and B were assumed to be adiabatic surfaces.

3.3.2 Maximum Temperatures

The condition of a hot day with insolation was maximized by assuming an ambient temperature of 130°F (54°C) and a high solar flux impinging on the PAT-2 for 16 h/day followed by 8 hours of darkness. The worst case for insolation of the

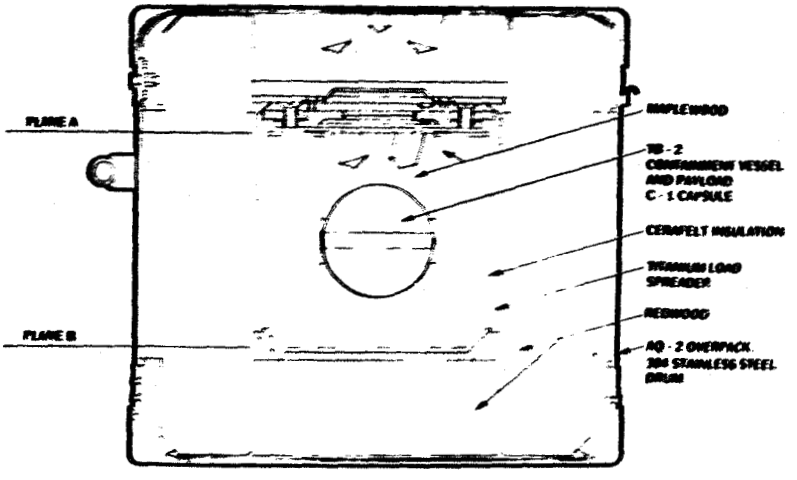


Figure 3.3.1-1. Cross-Section of PAT-2

PAT-2 is when the container is resting on its side so that the sun passes directly overhead, moving in a plane perpendicular to the PAT-2 centerline. This worst-case situation was modeled; Figure 3.3.2-1 shows the various modes of heat transfer for this situation.

The purpose of the analysis was to determine the maximum thermal payload which could be accommodated in the TB-2 containment vessel without exceeding the acceptable operational temperatures for the functional PAT-2 components. The functional material with the lowest acceptable operating temperature is the redwood. The redwood is conservatively estimated to have an acceptable operational temperature of 215°F (102°C), which is 9°F (5°C) less than the value used for redwood for the PAT-1 package (Reference 6, Eq. 21). The computer model was run until a periodic steady-state temperature distribution was achieved. The conservative features built into this model are

1. The geometric orientation maximizes absorption of solar flux,
2. A constant high value of solar flux, 930 W/m^2 (295 $Btu/h \cdot ft^2$) is assumed for 16 h/day,
3. An ambient temperature of 130°F (54°C) is assumed for 24 h/day,
4. There is no heat loss at the flat ends of the container, and
5. There is no wind to enhance convective cooling.

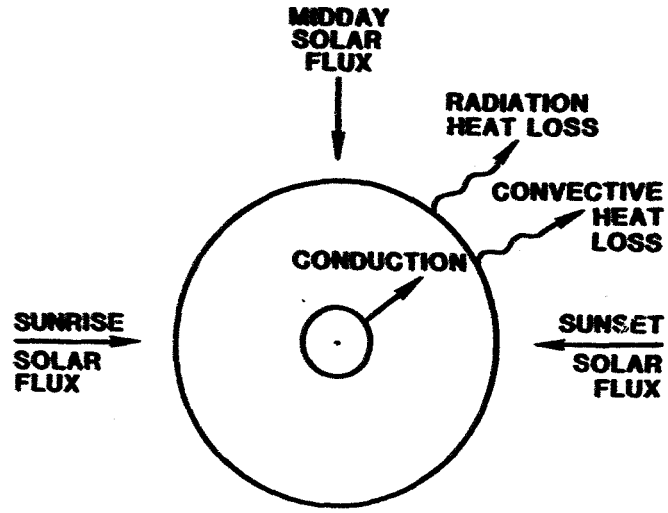


Figure 3.3.2-1. Schematic of Thermal Model

Calculational results indicate that while the physical model of the PAT-2 is axisymmetric, the temperature distribution throughout the PAT-2 is not. Examination of Figure 3.3.2-1 indicates that, at sunset, the right-hand side of the container is exposed to the solar flux while the left-hand side is totally shadowed. Figure 3.3.2-2 represents the maximum temperature of the indicated parts (as a function of thermal payload) at any time during a 24-hour period after periodic steady-state has been achieved. The uppermost curve represents the hottest part of the PAT-2, the stainless steel exterior; its temperature is seen to be a very weak function of the thermal payload.

With the conditions described above and an internal heat of 2 watts generated by the radioactive contents, the redwood would reach 213°F (100.5°C). Thus, it is chosen to limit the internal decay heat load to 2 watts. Note that this is not a marginal condition in that a heat load of 2.5 watts would cause a redwood temperature of only 214°F (101°C).

As shown in Figure 3.3.2-2, the maximum skin temperature is 217°F (103°C) for a 2-watt payload thermal output, the maximum redwood temperature is 213°F (100.5°C), and the maximum TB-2 containment vessel temperature is 203°F (95°C).

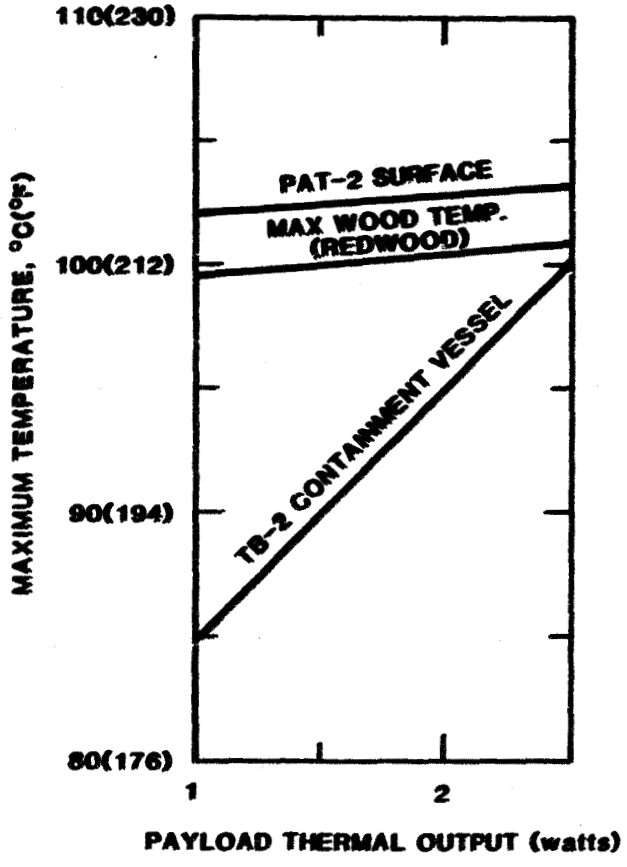


Figure 3.3.2-2. Maximum Temperature vs. Thermal Payload

3.3.3 Moderately Hot Day Without Insolation

The condition of a moderately hot day without insolation consists of an ambient temperature of 100°F (38°C) and no solar input, e.g., the package is shaded. The IAEA requires that, under these conditions, the exterior surface of the container shall not reach a temperature in excess of 122°F (50°C).

The physical model described in Section 3.3.2 was used to analyze this problem. Conservative features 4 and 5 of Section 3.3.2 apply for the present model; thermal model calculations were run until steady-state was achieved. Figure 3.3.3-1 shows the resulting temperatures of both the exterior surface and the containment vessel as a function of payload thermal output. For a 2-watt payload, the stainless steel exterior skin is 105°F (40.7°C), and the TB-2 containment vessel is 139°F (59.5°C).

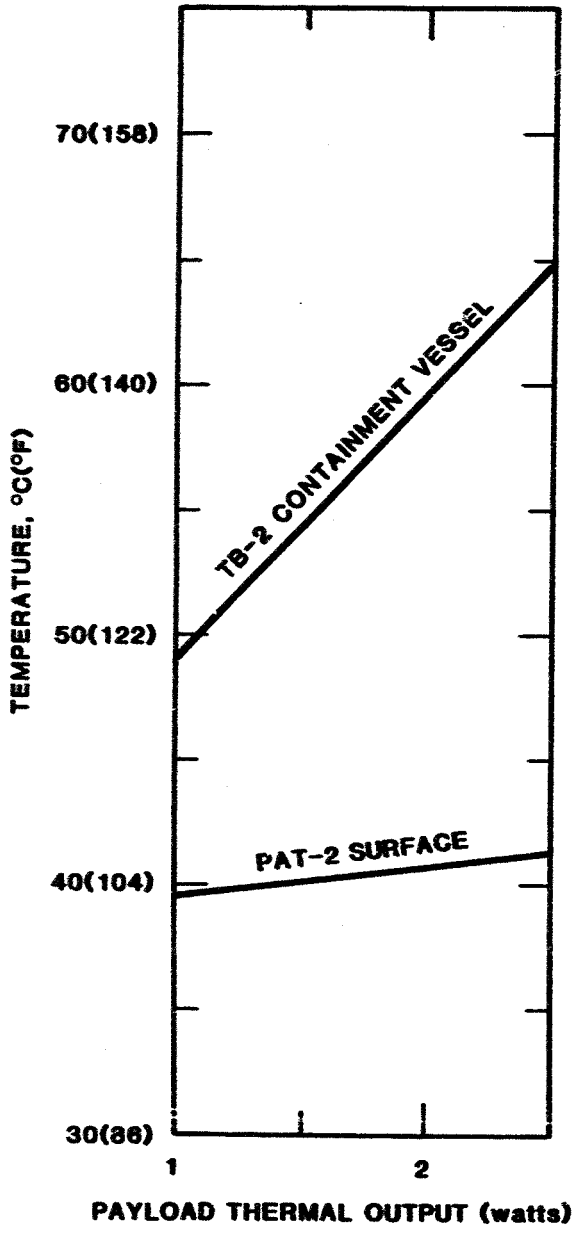


Figure 3.3.3-1. Steady-State Temperature vs. Thermal Payload

3.3.4 Minimum Temperatures

Using the thermal properties and thermal model previously described -- a PAT-2 package in an external ambient temperature of -40°F (-40°C) with no solar flux and no wind, and an internal heat load of 2 watts -- the temperature of the TB-2 containment vessel was calculated to be 0.5°F (-17.5°C), and the AQ-2 outer skin temperature was calculated to be -33.7°F (-36.5°C). With no internal heat source (0 watts), all package temperatures would stabilize at the ambient temperature.

3.3.5 Maximum Normal Internal Pressure and Temperature

As shown in Figure 3.3.2-2, the maximum normal TB-2 containment vessel temperature will be 203°F (95°C). As calculated in Chapter 4, this results in a pressure of 30.55 psia (210.6 kPa). Also, as shown in Chapter 4, a temperature of 244°F (118°C) is sufficient to increase this pressure by 50%, the pressure level needed to conduct the pressure test on the TB-2, as required by 10 CFR 71.53(b). (A temperature of 250°F (121°C) was used as a rounded-up temperature for this test.)

3.3.6 Maximum Thermal Stress

At low temperature, the temperature difference between the AQ-2 outer skin and the TB-2 containment vessel is approximately 34.2°F (19°C), as stated in Section 3.3.4. The metal parts are essentially isothermal, with the temperature drops occurring across the insulating materials (redwood, Cerafelt™, and maplewood). The thermal stresses resulting from this condition are insignificant, and the cold test performed according to 10 CFR 71 Appendix A (see Chapter 2) produced no discernable effect on the PAT-2 package.

At high temperature, the greatest temperature difference occurs between a TB-2 with no internal heat load and an AQ-2 outside skin under insolation, as shown in Section 3.3.2. This condition was tested per the 10 CFR 71 Appendix A hot test (see Chapter 2) with no adverse effect on the PAT-2 package. When the heat load within the TB-2 was increased to 2 watts, as shown in Figure 3.3.2-2, the inside-to-outside temperature difference for the high-temperature case became small. The resulting thermal stresses are negligible.

The TB-2 containment vessel and the C-1 capsule, under similar thermal conditions as cited above, remained leaktight throughout the development program.

PAT-2 packages were temperature stabilized at -40°F (-40°C) and 215°F (102°C) and subjected to high-speed impact tests, as reported in Chapter 2. These packages did not respond differently from packages tested at ambient temperature, again indicating that thermal stress in the PAT-2 package is negligible.

3.3.7 Thermal Evaluation of Package Performance for Normal Conditions of Transport

The ability of the PAT-2 package to safely contain plutonium under normal conditions of transport has been demonstrated by the test and evaluation cited in Chapter 2, which is supported by information in this chapter. Over the range of normal operating temperatures, -40°F (-40°C) to 217°F (103°C), the TB-2 design has demonstrated capability to maintain its contents under leaktight conditions. Long-term performance of the iron-base superalloy vessel and its copper gasket is unaffected by this range of temperatures.

The C-1 capsule, operating over essentially the same temperature range as the TB-2 containment vessel, demonstrated the ability to retain its contents without leakage. The Teflon™-sealed screw thread closure was unaffected by the normal-condition performance tests and will not be degraded during its use over the range of normal operating temperatures.

The metal components of the AQ-2 overpack are unaffected by the temperature range of normal transport, e.g., -40°F (-40°C) to 217°F (103°C) for the outer stainless-steel drum. The mean temperature range for the redwood, -40°F (-40°C) to 215°F (101°C), has no detrimental effects on redwood material properties, and the redwood properties experience no long-term degradation when subjected to temperatures within this range. Additional information, developed for the similar PAT-1 package, may be found in Reference 6.

3.4 THERMAL ACCIDENT EVALUATION--10 CFR 71

Compliance of the PAT-2 package to the requirements of 10 CFR 71 Appendix B was accomplished by test, as cited in Chapter 2.

3.4.1 Thermal Models

An analytical model for a redwood-protected package with the thermal threat of a blackbody radiation source at 1,850°F (1,010°C) (rather than the 1,475°F (802°C) thermal source specified in 10 CFR 71 Appendix B) is described in Reference 6. This model predicted a char depth of 2.1 inches (5.3 cm) in the outer redwood of a package after 30 minutes of fire exposure, with a char front velocity of about 0.28 ft/h (0.085 m/h), a char front temperature (for fully contained redwood) of about 550°F (288°C), and a temperature in the redwood ahead of the char front (internal to the package) of about 227°F (108°C). Application of that study to the PAT-1 program led to the conclusion that the containment vessel at the package centerline would be at approximately that same temperature, i.e., 227°F (108°C). That thermal model may be compared to the test described in the following paragraphs,

which resulted in a char depth of about 1.5 inches (3.8 cm) in the outer redwood and no observable thermal damage within the titanium load spreader or to the TB-2 containment vessel. Therefore, it is believed that this is a conservative thermal model for the PAT-2 package. Further discussion appears in Section 3.4.3.

3.4.2 Package Conditions and Environment

A PAT-2 package, Phase 4 serial number X15, was subjected to all of the tests specified as normal and accident conditions of transport in 10 CFR 71 Appendices A and B, up to the thermal test. These tests on the package included heat (215°F (102°C) instead of 130°F (54°C)), cold (-40°F (-40°C)), pressure, vibration, water spray, dropping from a 4-foot (1.2-metre) height, penetration, compression, dropping from a 30-foot (9.1-metre) height, and puncture, all in sequence on the one package. The effects of all these tests were negligible, as shown in Figure 3.4.2-1; the package was completely intact, with only minor dents in the AQ-2 outside skin. The package entered the thermal test in this condition.

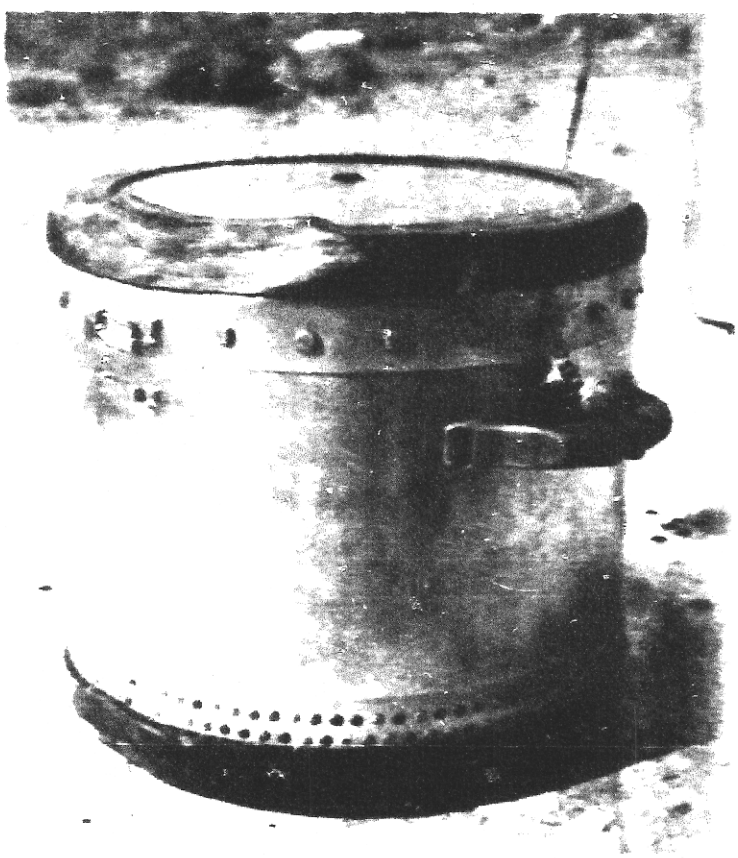


Figure 3.4.2-1. PAT-2 Package X15 Prior to Burn Test

The thermal test environment was provided by use of a specially constructed burn test facility, additionally described in Section 3.5.2.2 and Appendix 2F. Figure 3.4.2-2 shows package X15 in the burn test stand. The package was supported on an open-grid stainless steel rack 3 feet (1 metre) above the fuel surface of a 10-foot (3-metre) diameter JP-4 aviation jet fuel burn tub, within a 16-foot (4.9-metre) diameter insulated chimney, 25 feet (7.6 metres) high. The package was completely enveloped in luminous flame for the test duration. A discussion of flame emissivity and package absorptivity, as related to the 10 CFR 71 Appendix B burn test definition, is given in Section 3.5.2.2. The flame temperature at package height, on a time basis, is shown in Figure 3.4.2-3; a typical PAT-2 package skin (AQ-2 drum) temperature is shown in Figure 3.4.2-4. Table 3.4.2-1 summarizes the test environment and results. Figure 3.4.2-5 shows the blackened package after the burn test.

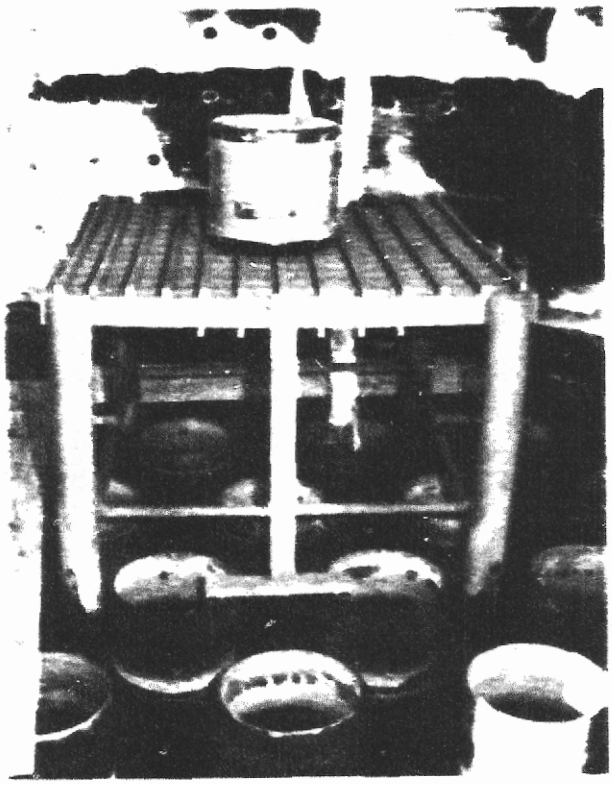


Figure 3.4.2-2. PAT-2 X-15 in Burn Test Facility

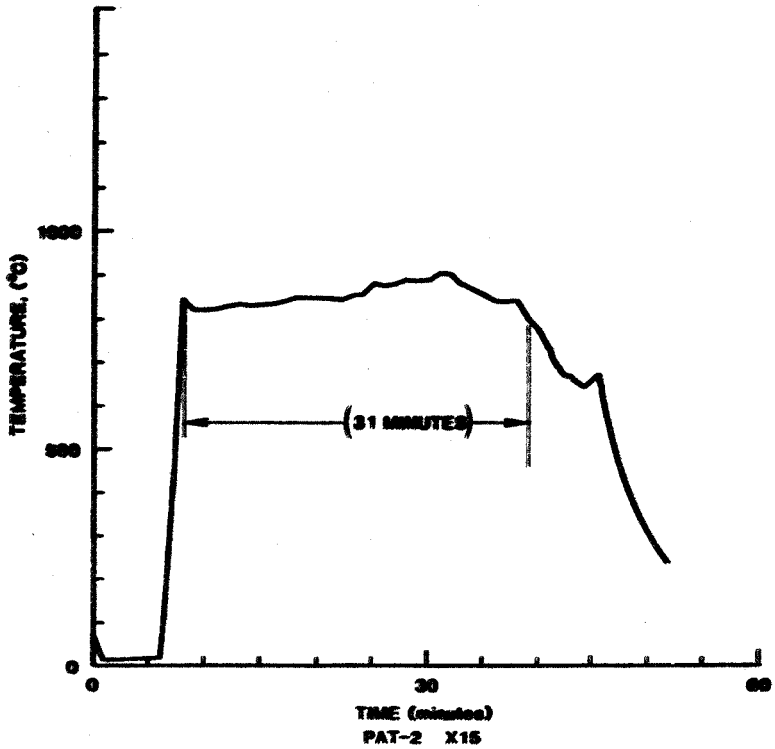


Figure 3.4.2-3. Temperature vs. Time Plot for Package X15 Burn Test

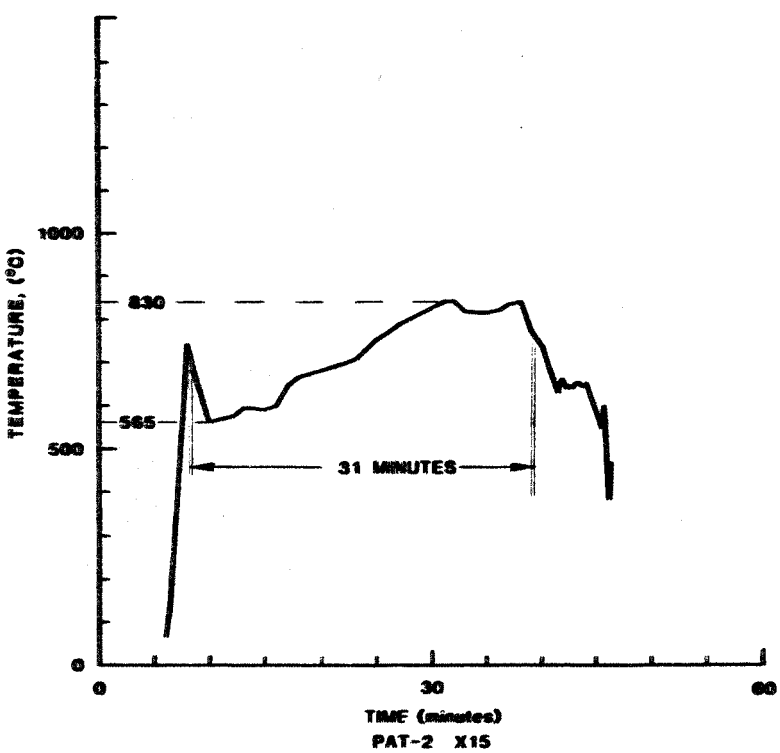


Figure 3.4.2-4. Skin Temperature Plot for Package X15 Burn Test

Table 3.4.2-1

10 CFR 71 Appendix B Burn Test

erature at package level	1,500°F to 1,640°F (815°C to 893°C)
servation	0.52 hour
e range on AQ-2 drum	~ 1050°F to 1525°F (565°C to 830°C)
in redwood	1.5 inches (38 mm)
TB-2 max. temperature	250°F (121°C)
ar rate	0.25 ft/h (0.021 mm/s)

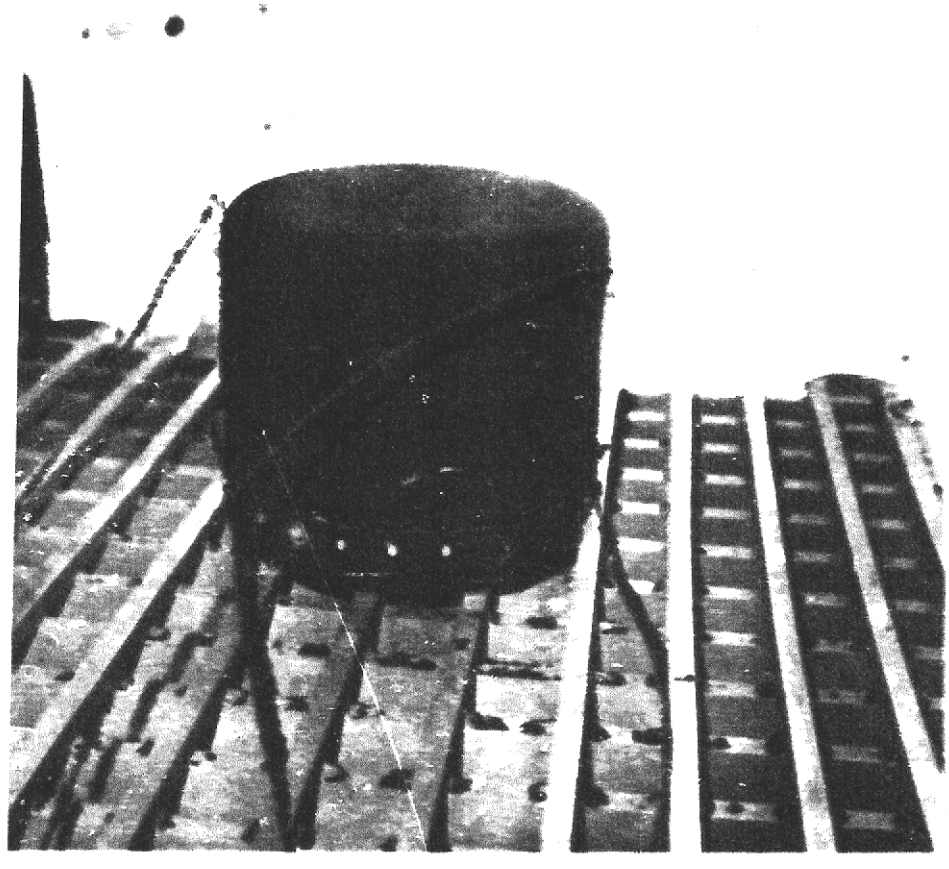


Figure 3.4.2-5. PAT-2 Package X15 After Burn Test

3.4.3 Package Temperature

A typical temperature plot of the AQ-2 drum during the 10 CFR 71 Appendix B burn test is shown in Figure 3.4.2-4. At the beginning of the burn test, the package is absorbing heat, and the wood begins to char. Following the burn and water-submersion tests, the package was opened (see Figure 3.4.3-1). The average char depth inside the outer skin of the AQ-2 was observed to be about 1.5 inches (38 mm). From a region external to the titanium load spreader inward to the TB-2 containment vessel, only minor indications of the thermal test were observed (see Figure 3.4.3-2). The ceramic felt insulation, other than being wet, appeared to be the same as it was when examined after the 10 CFR 71 Appendix A (normal conditions of transport) tests. The epoxy-coated maplewood interior parts were not noticeably discolored, and the epoxy surface exhibited no indications of thermal degradation. The TB-2 containment vessel, although wet with dirty water (the char inside the AQ-2 dirties the water used in the immersion test), appeared unaffected and exhibited no detectable leak ($\dot{q} < 10^{-10}$ cm^3/s, helium). Containment vessel and capsule contents were as specified in the Test Protocol of Chapter 2 (severe plutonium sulfate surrogate model).

Independent furnace tests of sealed TB-2 containment vessels, supported on wood plugs (a component part of the AQ-2), were conducted during the PAT-2 design development program. One such development test, conducted at 315°F (157°C), caused a discernable darkening of the wood plug; another test at 250°F (121°C) caused a less noticeable darkening; the plug from the 10 CFR 71 burn test was even less visibly affected. Taking these observations into account with the 227°F (108°C) TB-2 temperature prediction from Section 3.4.1, a conservative upper bound on TB-2 post-accident temperature of 250°F (121°C) is assumed. Note that this is the temperature that was used for the 150% normal pressure test of a TB-2, as cited in Section 3.3.5.

3.4.4 Maximum Internal Pressure

The AQ-2 overpack is a vented package in accident conditions. The sealed containment for the prevention of loss of plutonium or other radioactive materials is the TB-2 containment vessel. A TB-2 at 250°F (121°C) will have a maximum internal pressure of 49.5 psia (341.3 kPa).

PAT-2 packages, including TB-2 vessels with C-1 capsules, have been tested to this condition or worse, and both the TB-2 containment vessel and the C-1 capsule were leaktight.

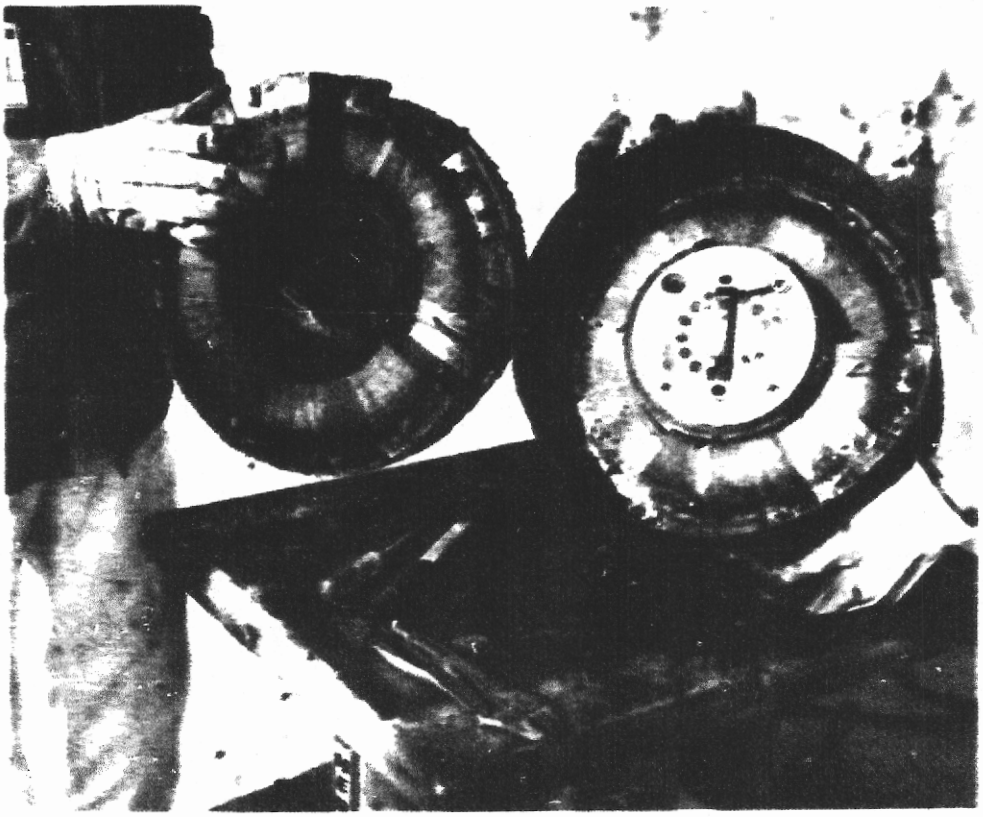


Figure 3.4.3-1. PAT-2 X15 after Burm Test

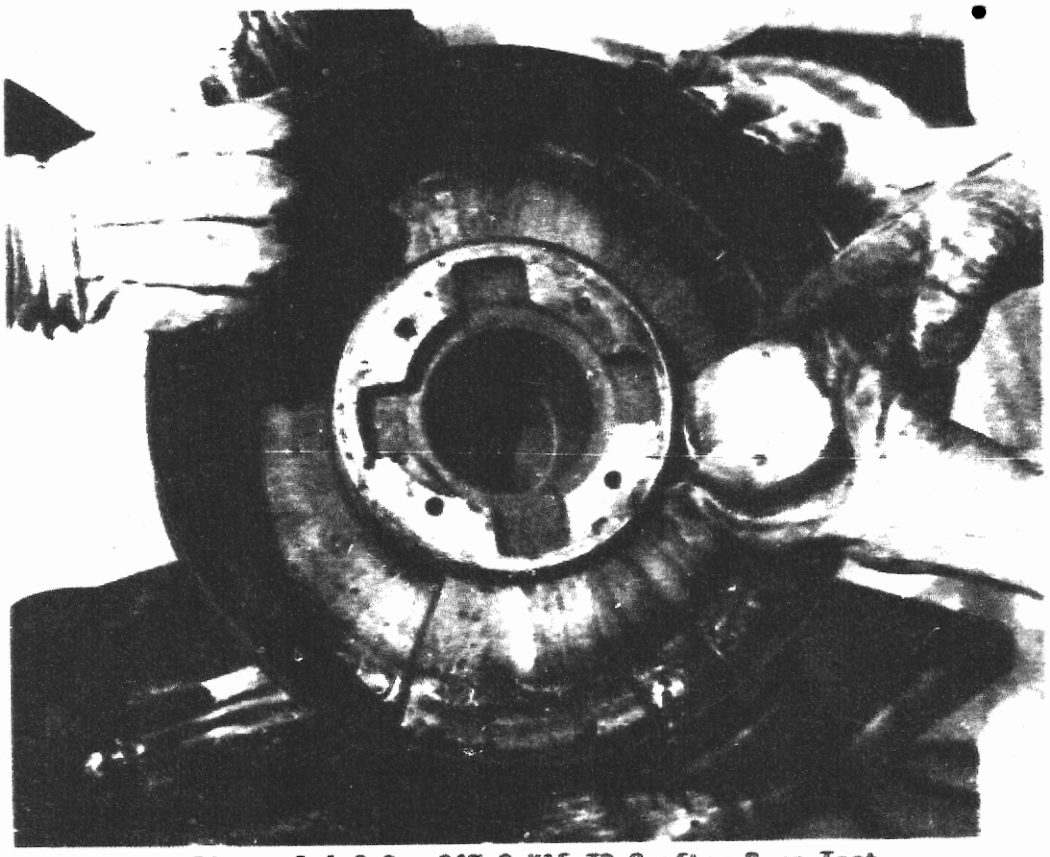


Figure 3.4.3-2. PAT-2 X15 TB-2 after Burm Test

3.4.5 Maximum Thermal Stress

The topic of maximum thermal stress in a PAT-2 package, following the 10 CFR 71 fire test, could only apply to the sealed TB-2 containment vessel and C-1 capsule; the AQ-2 overpack is essentially deliberately sacrificed to protect the containments. The TB-2 and C-1 were leaktight, as reported in the following subsection, supporting the contention that thermal stresses from the 250°F (121°C) environment are negligible for this high-temperature-design containment.

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

The PAT-2 package that endured the 10 CFR 71 Appendices A and B tests (all on the same package), including the thermal test, contained a TB-2 containment vessel that exhibited no detectable leak ($\dot{q} < 10^{-10}$ cm^3/s, helium) both before and after all of the tests, and a C-1 capsule that was leaktight and unchanging in leak rate ($\dot{q} < 2 \times 10^{-9}$ cm^3/s) before and after all of the tests. This capsule was loaded with a conservative (high-pressure-producing) surrogate of plutonium sulfate tetrahydrate. The TB-2 and the C-1 were in completely reusable condition. Note that the PAT-2 package is designed to survive a much more severe test sequence, as cited in the following section.

3.5 NUREG-0360 AIR TRANSPORT CRITERIA--THERMAL ACCIDENT EVALUATION

Compliance of the PAT-2 package with the NUREG-0360 plutonium air transport criteria was demonstrated by a comprehensive group of burn tests. Results of these tests will be used both to demonstrate thermal accident survival and also to establish an upper temperature bound on the containment, which is used in pressurization and potential release calculations described in Chapter 4.

3.5.1 General

The sequential test requirements of NUREG-0360 specify that the package must first be subjected to a high-speed impact perpendicular to an unyielding target, and to crush, puncture, and ripping/slashing tests, prior to the thermal (burn) test. The PAT-2 package is small (72 pounds (33 kg) mass) and some of these tests do not scale, i.e., the package is static, and the kinetic energies of the puncture and slashing probes are independent of the package. The NUREG-0360 criteria were developed in concert with the PAT-1 package, which is much larger (499 pounds (227 kg) mass) than the PAT-2. In developing the smaller PAT-2 package, the effect of these arbitrary puncture and slash tests in opening the AQ-2 overpack was acute. The puncture-and-slash damage to the AQ-2 overpack, from the fixed-size probes, caused a larger relative opening in the AQ-2. The size and volume of the PAT-2, which directly relate to its thermal bulk, were severely limited by the operational

necessity to be one-man portable. Early development test series with LAARC (Lightweight Air-Transportable Accident-Resistant Containers, the acronym for the PAT-2 development program) packages that were designed with internal heat conductors to permit thermal loadings greater than 2 watts, and with uninsulated aluminum load spreader structures to reduce weight, were unsuccessful. The solution to these design problems was a containment vessel made from a high-temperature jet engine component alloy, deletion of the internal heat conductor, and the use of a titanium load spreader (the aluminum models melted) with ceramic-felt backface insulation.

It was also determined during the development program that maximum damage from the thermal test resulted when the packages were permitted to cool naturally rather than utilizing water cooling (Reference 3, II.B.5, page 7). In this case, the redwood continues to char, post-burn. Coupled with the extent of damage discussed above, this resulted in complete loss of redwood char in those areas between the titanium load spreader and the relatively large holes in the AQ-2 drum from the puncture and slash damage. Thus, the PAT-2 design is based on providing sufficient thermal protection within the load spreader; this protection is provided by the Cerafelt™ and the charred maplewood. This design keeps the maximum TB-2 containment vessel temperature at or below the liquidus temperature of aluminum (the TB-2 has aluminum ring covers or fairings over the closure bolts).

At the fire temperatures and package temperatures presented in this chapter, the temperature differential caused by the possible 2-watt internal heat source would be inconsequential.

Package loadings, specified in the Test Protocol appendix to Chapter 2, assured that all intended types of plutonium/uranium payloads were tested, and that the thermal tests would produce maximum containment pressure for each particular type of payload.

3.5.2 Package Conditions and Environment

3.5.2.1 Package Conditions

The major variable in performing the series of sequential tests prior to the burn test was package orientation with respect to the target at impact. Top, top-corner, side, bottom-corner, and bottom impacts were conducted followed by the crush, puncture, and slashing tests. These packages were then subjected to the specified fire test. The package condition just prior to the fire (burn) test is best described by the various post-test photographs and by the pre-burn (post-impact, post-crush, post-puncture, post-slash) radiographs shown throughout Chapter

2. The puncture and slash openings in the AQ-2 drums directly expose the package redwood to the fire, permitting a chimney-like effect to cause severe burning and charring of the redwood, ultimately exposing the titanium load spreader to the fire. A typical pre-burn setup is shown in Figure 3.5.2.1-1.

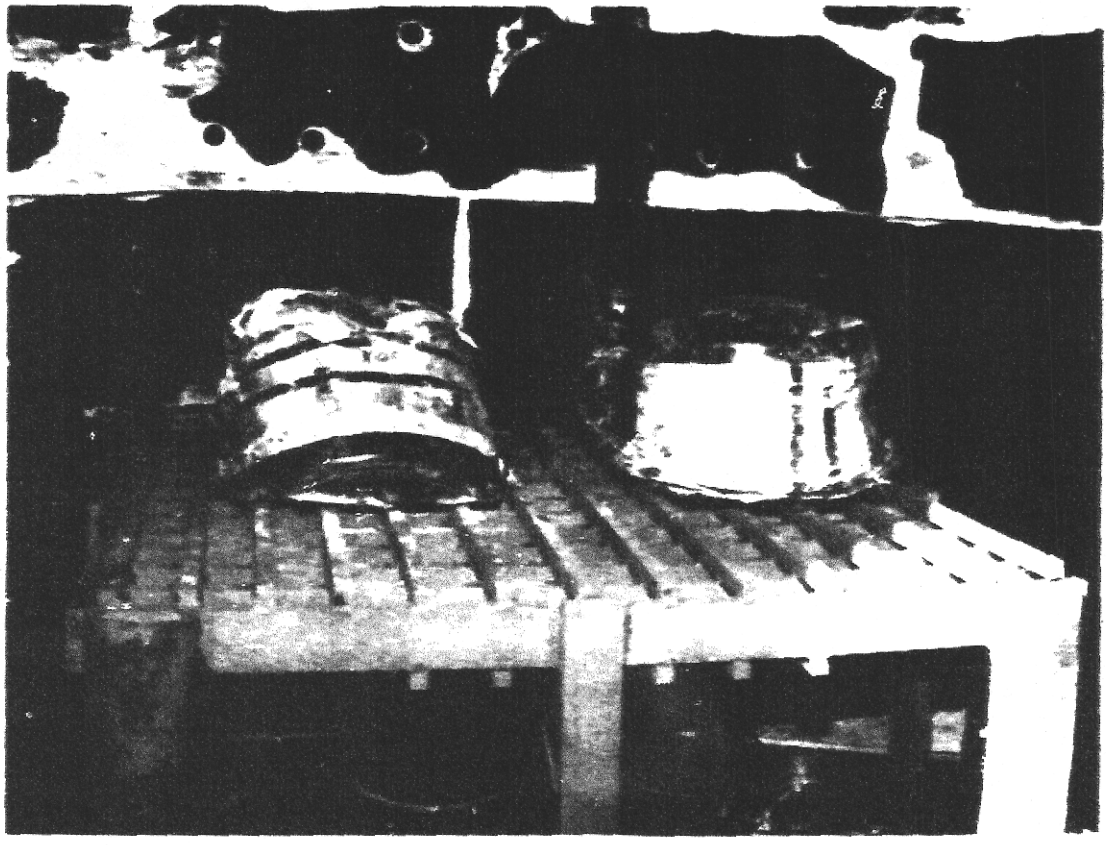


Figure 3.5.2.1-1. PAT-2 Packages X07 and X08 Prior to Burn Test

3.5.2.2 Package Environment

The package environment is the fuel fire environment within the burn test stand. The NUREG-0360 requirement is as follows:

> The package to be exposed to luminous flames from a pool fire of JP-4 or JP-5 aviation fuel for a period of 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.[3]

A burn test facility (see Figure 3.5.2.2-1) was designed and developed to perform this test; the facility is also described in Section 3.4.2. JP-4 aviation jet fuel is burned at a controlled fuel/air ratio in a 10-foot (3-metre) diameter burn tub which floats the fuel on water. Air supply pipes penetrate the liquid level in a uniform pattern from a controlled underground plenum. An insulated chimney, 16 feet (4.9 metres) in diameter and 25 feet (7.6 metres) high, surrounds the burn tub. A chimney cap retards the counterflow of entrained air (from above) from supplying the combustion process. This height of chimney, with the cap, provides excellent isolation of the fire from the affects of surface winds. A burn test stand, supported on the floor of the burn tub, supports the packages at an optimized height to assure a flame temperature of at least 1,850°F (1,010°C) at package level. Luminous flame completely fills the chimney at the package level, as determined through viewing windows in the chimney. Fuel and water are admitted through electrically controlled valves, by gravity flow, from storage tanks located uphill. The burn tub is surrounded by a scupper which is connected to a waste pit by a dump line and airlock. Thus, the fire test may be terminated by raising the water level; fuel is skimmed off into the scupper and passed to the waste pit; burning fuel is extinguished by the air lock to prevent fire in the waste pit.

Temperature data during the tests were provided by an array of thermocouples (T/Cs) located at various positions on the package skin and the burn test stand (including a vertical mast for temperature measurements at various heights, and T/Cs on the chimney cap, at the fuel level, and on the test stand).

The minimum temperature of 1,850°F (1,010°C) is designated in support of NUREG-0360, which cites the work of Bader[12] at Sandia, indicating that a blackbody radiation source of 1,850°F (1,010°C) provides a good simulation of a JP-4 aviation fuel fire.

Sandia studies of air transport accidents[13] indicate that a 3-foot (1-metre) thick JP-4 flame has an effective total emissivity of greater than 0.95.

During the conduct of a fire test, the AQ-2 outer stainless steel surface becomes deeply blackened. From Reference 14, the emissivity of blackened 18-8 stainless steel (the AQ-2 skin is made of alloy 304, which is an 18-8 stainless) is estimated to be about 0.85.

Furthermore, data taken from Touloukian[15] for carbon-black coated surfaces, indicates that they exhibit grey-body behavior with an absorptance and/or emittance of approximately 0.9.

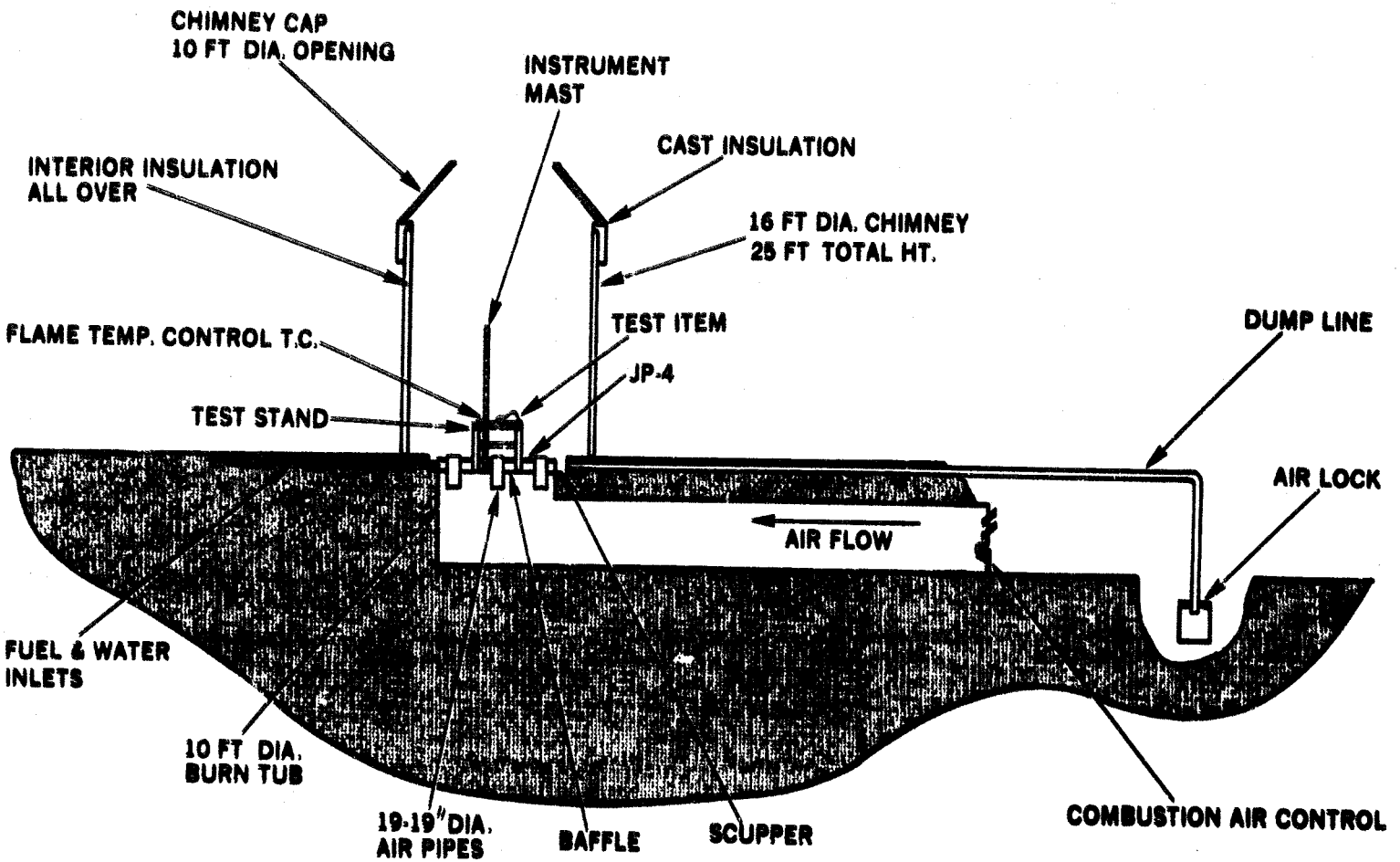


Figure 3.5.2.2-1. PAT-2 Burn Stand

Thus, the package environment in the thermal tests, considering the data in Section 3.5.3, meets or exceeds the conditions specified in 10 CFR 71 and NUREG-0360.

3.5.3 Package Temperatures

Temperature versus time records for the fire (burn) tests involving PAT-2 packages in a NUREG-0360 thermal environment are shown as Figure 3.5.3-1. All packages were at a flame temperature > 1,850°F (1,010°C) for > 60 minutes. A typical AQ-2 skin temperature record from each burn test, where available, is shown in Figure 3.5.3-2.

No packages were penetrated in order to mount thermocouples on the TB-2 containment vessel; experience gained during PAT-1 studies[6] indicated that this would be inadvisable. The condition of each TB-2 immediately upon disassembly (no cleaning) from the burned, naturally cooled, and water-immersed PAT-2 packages is shown in Figures 3.5.3-3 through 3.5.3-8. Note that the containment joint is intact with no visible or apparent opening and that the aluminum fairings or cover rings over the TB-2 bolts are intact and not melted. The maplewood is charred but not reduced to ash. Wood chars at about 550°F (288°C) (see Chapter 2) and, for some species, burns with an open flame of about 1,100°F (593°C), reducing to ash. Considering only the maplewood char, an estimate of the TB-2 temperature is

$$550°F\ (288°C) < T_{TB-2} < 1{,}100°F\ (593°C).$$

From the liquidus temperature of the alloy 6061-T6 aluminum fairings, the TB-2 temperature is estimated to be < 1,080°F (582°C). Thus, a conservative (high) bounding assessment of maximum temperature for the TB-2 containment vessel in the severe NUREG-0360 accident environment is 1,080°F (582°C).

3.5.4 Maximum Internal Pressure

For a TB-2 containment vessel at 1,080°F (582°C) with the worst-case payload (maximum limits on volatile contents, as specified in Section 1.2.4), the internal pressure would be 3,280 psia (22.6 MPa). Details of this analysis are given in Section 4.5.1.

3.5.5 Maximum Thermal Stresses

Substantiation that the thermal stresses in the TB-2 do not adversely affect its containment integrity was provided by testing six PAT-2 packages using the required test sequence. The conductivity of the TB-2 iron-base alloy is such that significant temperature differences within a vessel would not be expected. A detailed stress analysis of the TB-2 at elevated temperature is presented in Chapter 2, Appendix 2C.

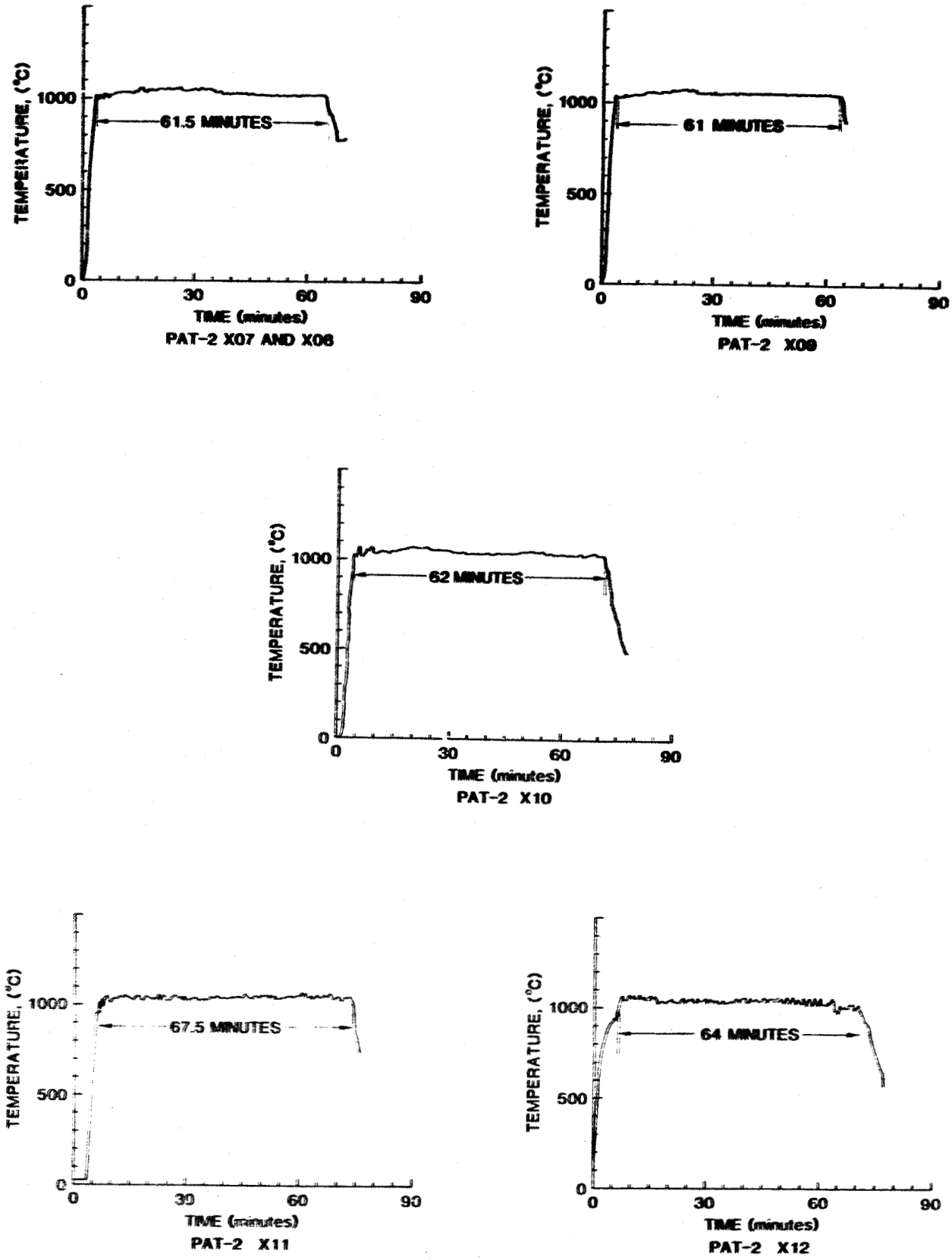


Figure 3.5.3-1. Flame Temperature at Package Height

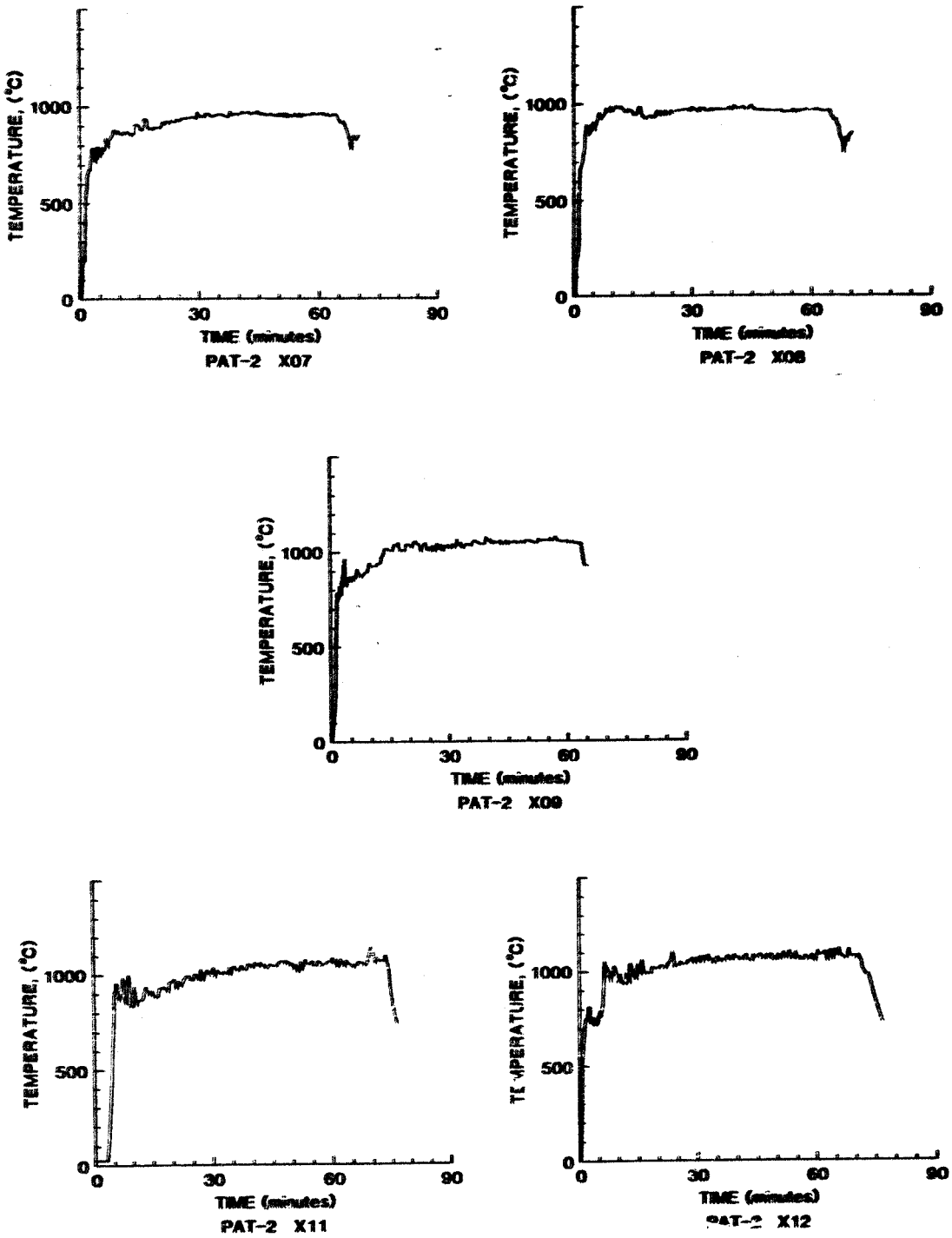


Figure 3.5.3-2. AQ-2 Skin Temperature

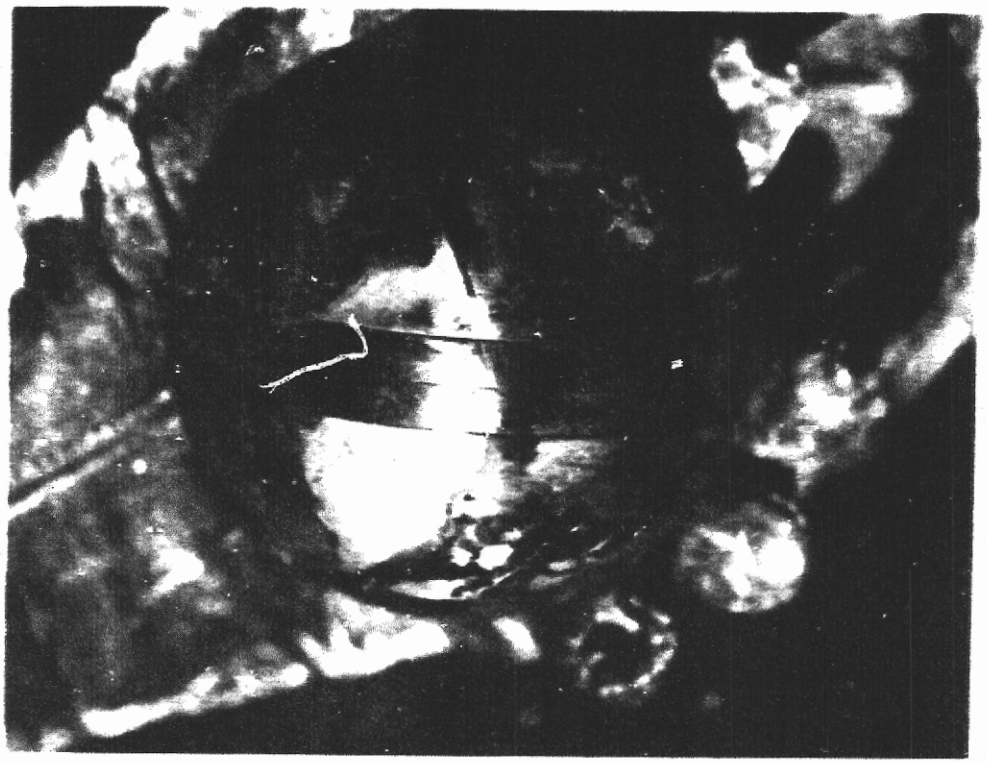


Figure 3.5.3-3. X07 TB-2 after Burn Test

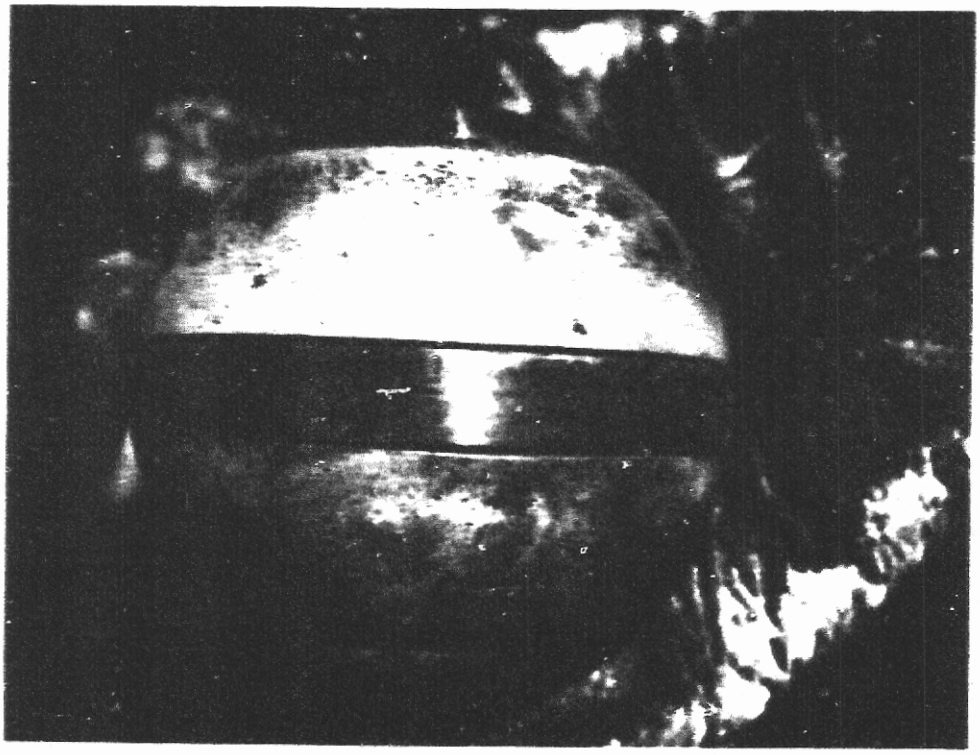


Figure 3.5.3-4. X08 TB-2 after Burn Test

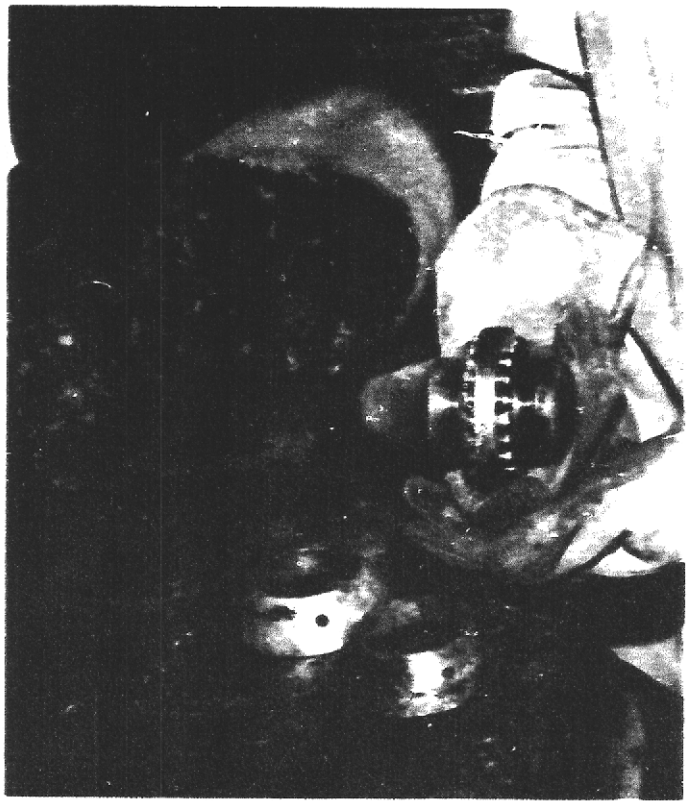


Figure 3.5.3-5. X09 TB-2 after Burn Test

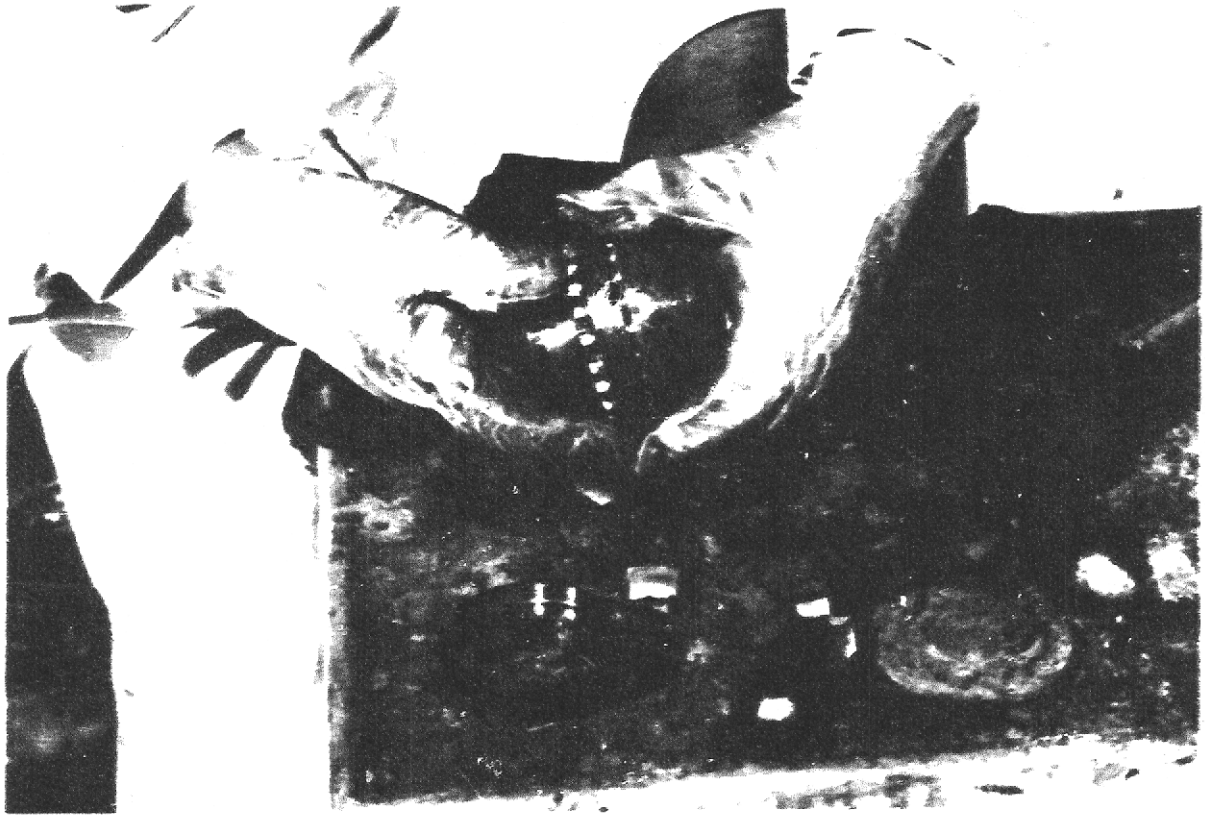


Figure 3.5.3-6. X10 TB-2 after Burn Test

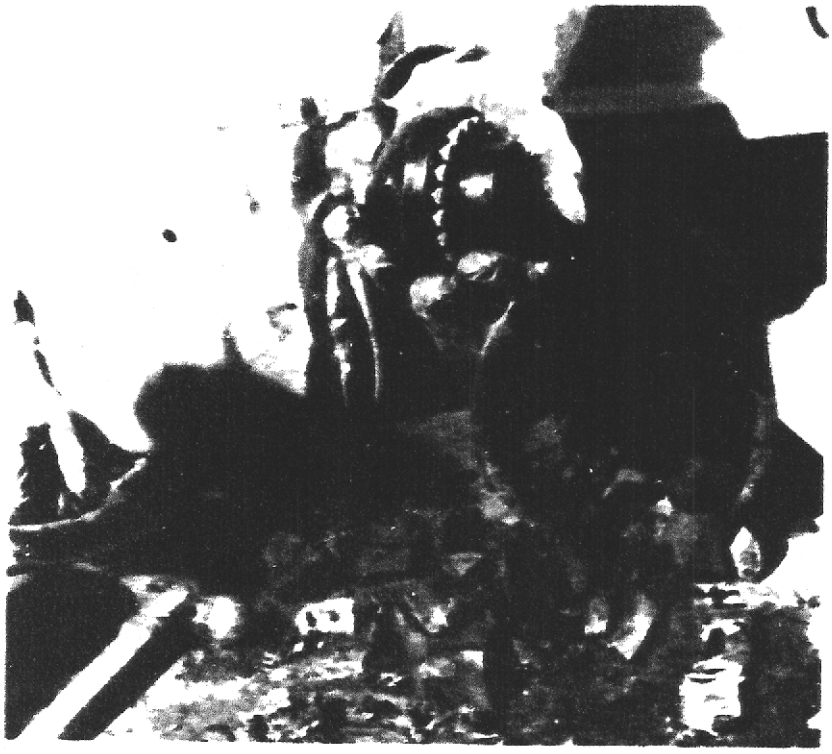


Figure 3.5.3-7. X11 TB-2 after Burn Test

Figure 3.5.3-8. X12 TB-2 after Burn Test

3.5.6 Evaluation of Package Performance for NUREG-0360 Criteria Thermal Conditions

The ability of the PAT-2 package to safely contain plutonium and uranium throughout the sequential testing required by NUREG-0360, including the thermal environment, has been demonstrated in six test sequences. Comparisons of pre-test and post-test gas leak rate measurements across the TB-2 seal indicate that leaktightness of the containment vessel did not change in five test series ($\dot{q} < 10^{-10}$ cm^3/s, helium = N.D.L -- no detectable leak) and changed from N.D.L to $\dot{q} = 7 \times 10^{-6}$ cm^3/s, air, in one test sequence (top-corner-impacted package). As developed in Chapter 4, this change in leak rate has no adverse effect on package safety; an analytical correlation between this minute leak and the maximum theoretical radioactive material leakage indicates compliance with the acceptance criteria by orders of magnitude. No surrogate materials were released. [Five developmental package test sequences that included all the NUREG-0360 sequential tests, including the 1-hour JP-4 fire, but which were water-cooled (rapidly quenched by submersion) after the fire, resulted in N.D.L on all five TB-2s.]

Following the thermal tests, the packages were allowed to cool naturally, permitting the charring process to proceed to termination; the redwood and maplewood were completely charred, as expected. In every case, the stainless steel outside shell of the AQ-2 overpack did not melt and still contained the titanium load spreader. The titanium load spreader appeared to be unaffected by the fire (in development tests, the titanium load spreaders were salvaged from burn tests, cleaned, straightened, and reused in new developmental package fabrication). The load spreader always retained the maplewood char (which was never ash) and the TB-2 containment vessel. The TB-2 containment vessels always appeared to be structurally sound and tight, and, upon opening to confirm the presence of helium gas inside the seal, all 20 bolts were always very tight and required considerable effort to open. All bolts could always be disassembled with no breakage. Inside the TB-2, the C-1 capsule was still intact in every case; some were even leaktight, a condition not required for the NUREG-0360 qualification tests and not accounted for (no "credit" taken for extra containment) in the analytical assessment of leakage performed in Chapter 4. A maximum temperature of 1,080°F (582°C) was utilized in establishing the maximum internal pressure used in the assessment of content leakage described in Chapter 4.

Figures 3.5.6-1 through 3.5.6-6 correspond to some of the above post-burn test observations. In all six cases, the AQ-2 drum was opened with a high-temperature burning tool (electrochemical torch). As shown in the photographs of PAT-2 packages X07 and X12, the titanium load spreader was also opened with the high-temperature torch, to reveal the inner maplewood char and the TB-2 containment vessel. Some titanium load spreaders were opened with hand tools, in the normal manner through the removable cover.

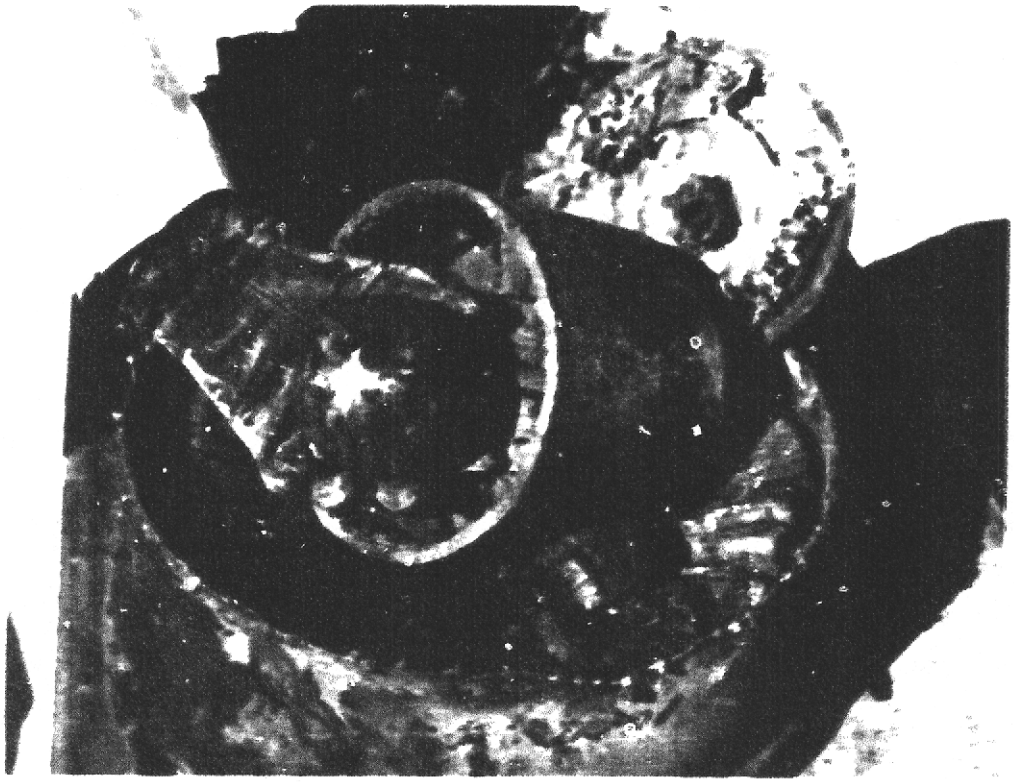


Figure 3.5.6-1. PAT-2 X07 Post-Burn Disassembly

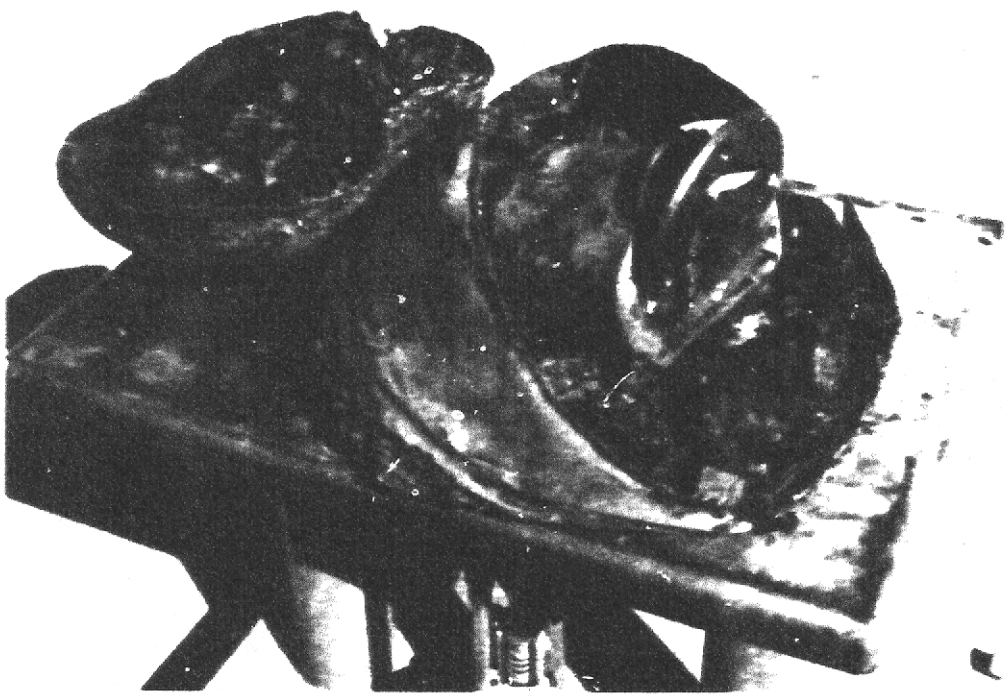


Figure 3.5.6-2. PAT-2 X08 Post-Burn Disassembly

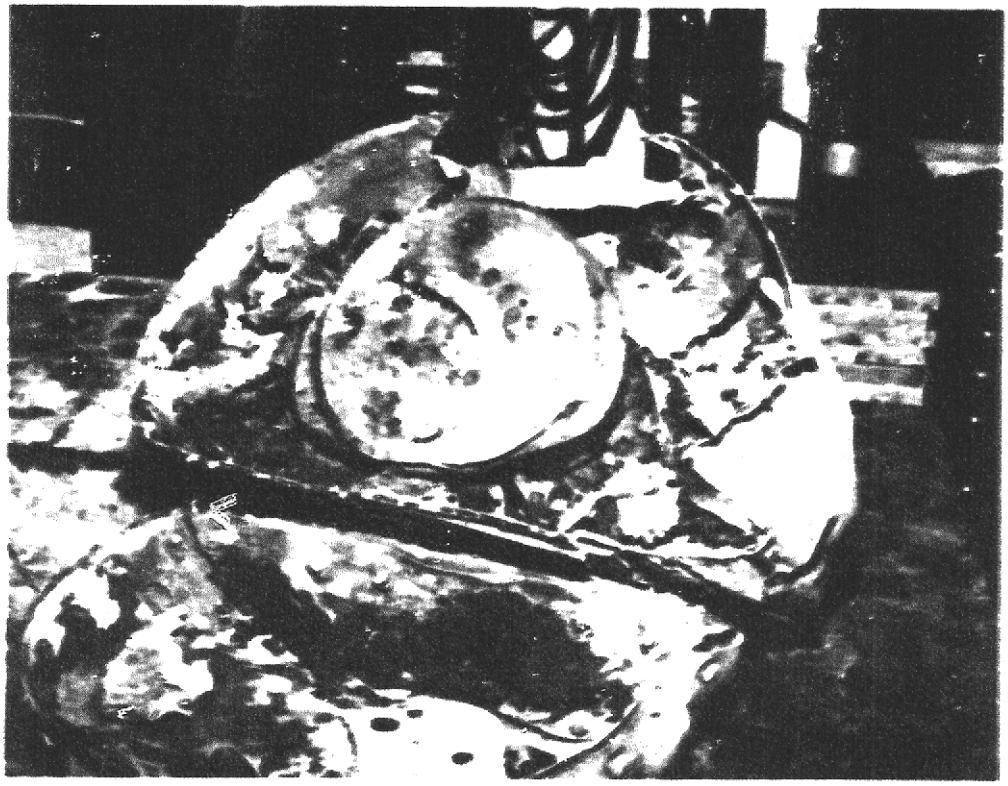


Figure 3.5.6-3. PAT-2 X09 Post-Burn Disassembly

Figure 3.5.6-4. PAT-2 X10 Post-Burn Disassembly

Figure 3.5.6-5. PAT-2 X11 Post-Burn Disassembly

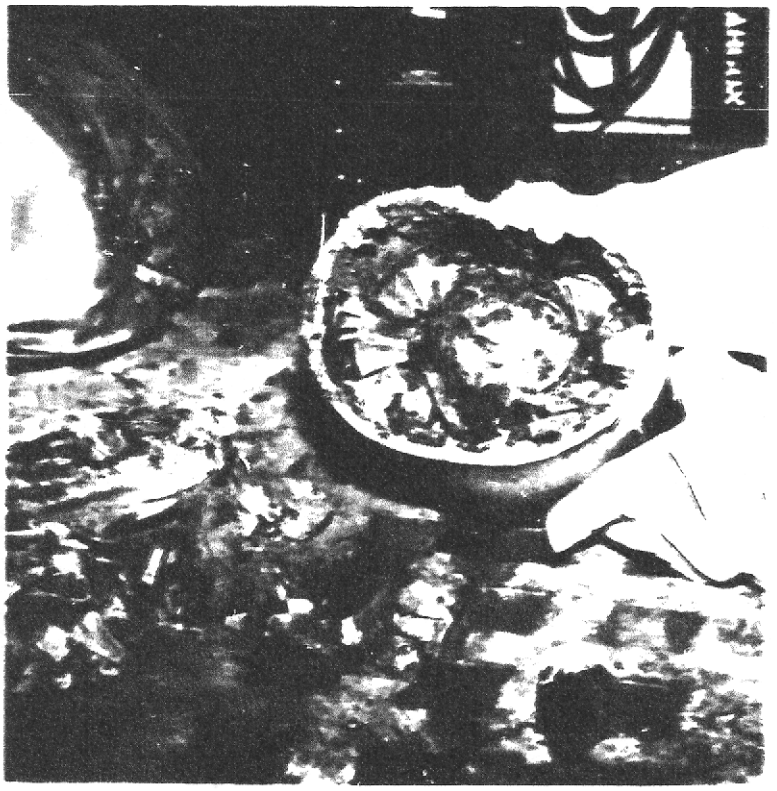


Figure 3.5.6-6. PAT-2 X12 Post-Burn Disassembly

REFERENCES

[1]Code of Federal Regulations, Title 10, Part 71, "Packaging of Radioactive Material for Transportation Under Certain Conditions" (Washington: Government Printing Office).

[2]International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Materials, IAEA Safety Standards, Safety Series No. 6, 1973 revised ed., as amended November 1979 (Vienna: IAEA, 1979).

[3]U.S. Nuclear Regulatory Commission, Qualification Criteria to Certify a Package for Air Transport of Plutonium, NUREG-0360 (Washington: U.S. NRC, January 1978).

[4]A. L. Edwards, A Compilation of Thermal Property Data for Computer Heat-Conduction Calculation, UCRL-50589 (Livermore: Lawrence Radiation Laboratory, February 1969).

[5]K. Raznjevic, Handbook of Thermodynamic Tables and Charts (Washington: Hemisphere Publishing Corp., 1976).

[6]J. A. Andersen et al, PARC (Plutonium Accident Resistant Container) Program Research, Design, and Development, NUREG/CR-0030 (SAND76-0587) (Albuquerque: Sandia Laboratories, July 1978).

[7]"Cerafelt" Specification Data," IND-3075 11-78 (Denver: Johns-Manville Corp., November 1978).

[8]Materials Engineering 88(6):C-5 (1978).

[9]F. Kreith, Principles of Heat Transfer, (3rd ed; New York: Intext Press, 1973).

[10]V. K. Gabrielson, HEATMESH-71: A Computer Code for Generating Geometrical Data Required for Studies of Heat Transfer in Axisymmetric Structures, SLC-DR-720004 (Livermore,CA: Sandia Laboratories, September 1972).

[11]D. R. Lewis, J. D. Gaski, and L. R. Thompson, Chrysler Improved Numerical Differencing Analyzer for 3rd Generation Computers, TN-AP-67-287 (New Orleans: Chrysler Corporation Space Division, October 1967).

[12]B. E. Bader, "Heat Transfer in Liquid Hydrocarbon Fuel Fires," Chemical Engineering Progress Symposium Series 61(56):78-90 (1965).

[13]W. F. Hartman et al, Severities of Transportation Accidents, SLA 74-0001 (Albuquerque: Sandia Laboratories, July 1976).

[14]J. D. Parker, J. H. Boggs, and E. F. Blick, Introduction to Fluid Mechanics and Heat Transfer (Reading, Massachusetts: Addison-Wesley Publishing Company, 1969).

[15]Y. S. Touloukian, Thermophysical Properties of High Temperature Solid Materials, Vol. 3 (New York: Macmillian, 1967).

CHAPTER 4

CONTAINMENT

4.1 SUMMARY

The containment acceptance criteria for the PAT-2 package are (1) no release of radioactive material from the TB-2 containment vessel and C-1 capsule following the normal and accident condition tests of 10 CRF 71[1] and (2) the release of no more than an "A2" quantity of plutonium in 1 week from the TB-2 containment vessel following the tests prescribed in NUREG-0360.[2] An "A2" quantity is defined in Table VII of the IAEA regulations for the Safe Transport of Radioactive Materials, IAEA Safety Series No. 6.[3]

The primary method of verifying containment was the measurement of helium leakage across the TB-2 and C-1 containment vessel boundaries using a mass-spectrometer-type helium leak detector. The leak-detection test was capable of detecting $\geq 10^{-10}$ cm^3/s of helium. The leak-rate data were then used to perform a bounding analytical/experimental correlation to establish upper bounds on possible plutonium release. This correlation involved experimental work by Battelle Pacific Northwest Laboratories on plutonium oxide and uranium oxide particulate release.[4,5]

Another method of verifying containment was a direct measurement to detect if any surrogate contents* (UO_2) had escaped during the performance tests. The measurement procedure involved submitting standard health physics swipe samples, collected from the containment vessels at the completion of tests, to analysis with a fluorimeter capable of detecting $\geq 10^{-8}$ gram of uranium.

Summary results of the containment verification tests are tabulated in Table 4.1-1.

---

*Surrogate contents are defined in Appendices 4B through 4E.

TABLE 4.1-1

PAT-2 Package Containment--Post-Test Results

Component	Test Condition	Requirement (Regulatory Acceptance Standard)	Results: Helium Leak Rate (cm^3/s)	Results: Uranium Detection Measurement	Containment Achieved
TB-2	Normal conditions of transport (Appendix A of 10 CFR 71)	No release	$<1 \times 10^{-10}$	No release[a]	No release
	Hypothetical accident conditions (Appendix B of 10 CFR 71)	No release	$<1 \times 10^{-10}$	No release[a]	No release
	NUREG-0360 criteria	A2/week[b]	$<2 \times 10^{-5}$	No release[a]	$<A2 \times 10^{-5}$ [c]
C-1	Normal conditions of transport (Appendix A of 10 CFR 71)	No release	$<2 \times 10^{-9}$	No release[a]	No release
	Hypothetical accident conditions (Appendix B of 10 CFR 71)	No release	$<2 \times 10^{-9}$	No release[a]	No release

[a]No release above detection capability of 10^{-8} gram.

[b]For a typical mixture of recycle plutonium-oxide powder, an A2 quantity is approximately 2.55 mg of plutonium.

[c]Calculated value; no actual release.

4.2 CONTAINMENT BOUNDARY

One containment boundary in all performance test environments is the TB-2 containment vessel. The C-1 capsule provides the second containment required by 10 CFR 71.42, effective June 17, 1978,[1] for plutonium contents in excess of 20 Ci. The boundary provided by the C-1 capsule is required by the 10 CFR 71 normal and accident condition tests but is not required by the test sequences defined by NUREG-0360.

4.2.1 TB-2 Containment Vessel

The TB-2 containment vessel is described in Chapter 1 (see Figure 1.2.2-2, page 1-5); stress analyses, material properties, and tests with results are described in Chapter 2. Drawings and specifications are included in Chapter 9, Appendix 9A. Further TB-2 descriptions are given in Section 4.2.3.1.

4.2.2 C-1 Capsule

The C-1 capsule is described in Chapter 1 (see Figure 1.2.2-3, page 1-5); drawings and specifications are included in Appendix 9A. Further C-1 capsule descriptions are given in Section 4.2.3.2.

4.2.3 Closure

4.2.3.1 TB-2 Containment Vessel Closure

Positive closure of the TB-2 containment vessel is provided by 20 1/4-inch-diameter bolts and nuts made from A-286 iron-base superalloy, a high-temperature, high-strength alloy which is described in Chapter 2. These bolts fasten the "A" hemisphere (equipped with a protruding shear shoulder) to the "B" hemisphere (equipped with a mating groove), acting through a ductile copper gasket which is formed in place within grooves in each hemisphere. The grooves in each hemisphere include a knife-edge sealing bead which embeds within the copper gasket. Washers are used under both the head of the bolts and under the nuts; the bolts and nuts are silver-plated for lubricity. Figure 4.2.3.1-1 illustrates the features of the TB-2 containment vessel. The bolts are installed with a torque wrench to a minimum of 180 lb_f-in. (20.3 N-m); this torque elastically elongates the bolt and preloads the joint, precluding leakage at the pressures cited in Section 4.5.1. This assembly is performed according to procedures described in Chapter 7.

4.2.3.3 C-1 Capsule Closure

Positive closure of the C-1 capsule is provided by a 1.600-inch, 18-UNEF internal thread in the capsule body and a mating external thread in the shouldered capsule lid. Figure 4.2.3.2-1 illustrates these features. Polytetrafluoroethylene (Teflon™) tape is applied to the external thread; 3-pin spanner wrenches (provided) are used on both the capsule body and lid; the lower wrench is secured in a bench vise; a torque wrench fits into a socket adapter on the upper spanner wrench, and the assembly is tightened to a minimum torque of 450 lb_f-in. (50.9 N-m). These procedures, detailed in Chapter 7, result in a leaktight C-1 assembly. The Nitronic 60 capsule material, basically an austenitic (18-8) stainless steel, has the added features of high strength with great ductility and nongalling threads for good tightening and loosening performance.

Teflon™ tape is used extensively on a commercial basis* to seal threaded joints for gases and corrosives over a temperature range of -250°F (121°C) to 500°F (260°C) and to pressures up to 10 ksi (69 MPa).

---

*Chemquip Products Co "TEPtape," Crawford Fitting Co. "STRIP TEEZE," Saunders Corp. Teflon™ Valve and Gasket Packing, Friesland Plastics Co. "Tape-Seal®," Crane Packing Co. "THRED-TAPE," Fluoro-Plastics Inc. "FLURO-TAPE," Chemplast Inc. "CHEMFLUOR"" Thread Tape, etc.

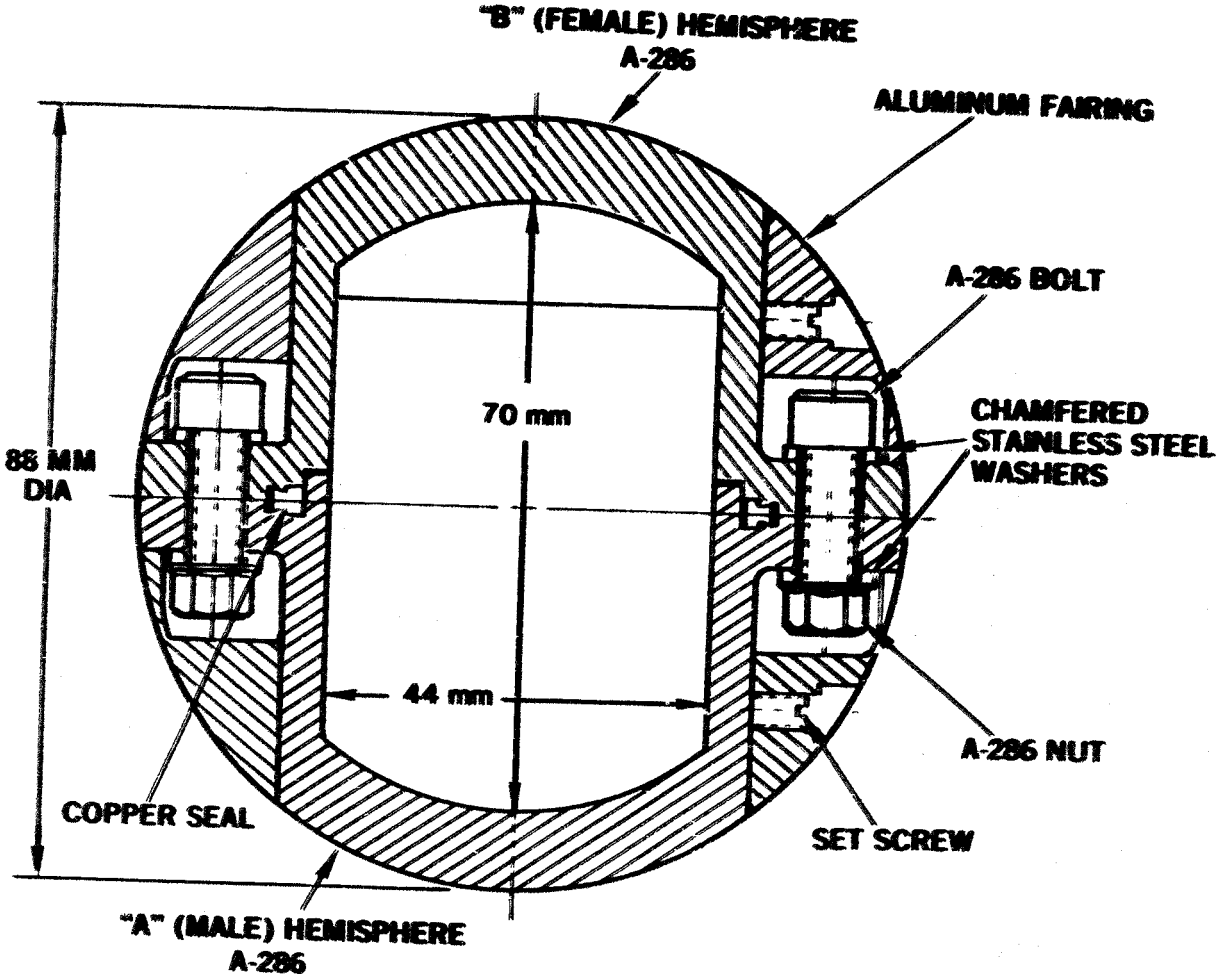


Figure 4.2.3.1-1. TB-2 Containment Vessel

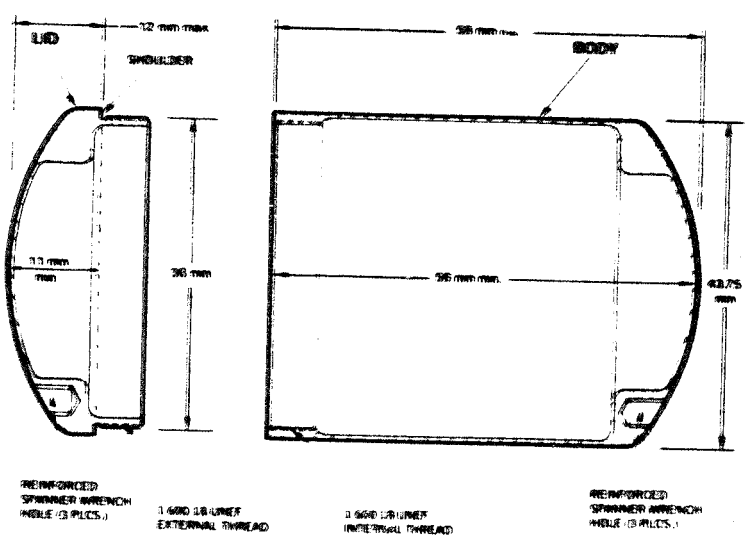


Figure 4.2.3.2-1. C-1 Capsule

4.3 REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT 10 CFR 71

4.3.1 Pressurization of Containment Vessel

The sealed containment vessels of the PAT-2 package may become pressurized from heating; in this case, the total pressure is the sum of the partial pressures of the heated entrapped air (or helium in the case of test assemblies), the vapor pressure of any water in the system, and the decomposition of organics or volatiles that may be included in the assembly.

For normal conditions of transport, the maximum TB-2 temperature is 203°F (95°C), as shown in Figure 3.3.2-2, page 3-5, which is based on a 2-watt payload under extreme solar flux at a high ambient temperature. At this temperature, the forms of plutonium or uranium permitted as PAT-2 payloads (see Section 1.2.4) do not decompose or volatize and do not contribute to pressurization; this is also true of the PVC plastic material. The containment pressure will be caused by the vapor pressure from the maximum allowance of 0.5 gram water and the sealed air. From saturation steam tables,[6] the pressure increase in water vapor from 70°F (21°C) to 203°F (95°C) will be 12.15 psia (83.8 kPa). The pressure increase in the entrapped air is given by

$$P_{air} = 14.7 \times \frac{203 + 460}{70 + 460} = 18.4 \text{ psia} .$$

The total pressure increase is

$$P_{tot} = P_{H_2O} + P_{air} = 12.15 + 18.4 = 30.55 \text{ psia} .$$

Therefore, 30.55 psia (210.6 kPa) is the maximum normal operating pressure (MNOP).

10 CFR 71.53(b) requires testing at 150% of MNOP. For test assemblies containing 0.5 gram of water and sealed air or helium, overheating may be utilized to achieve a pressure of 150% MNOP, i.e., (1.5)(30.55) or 45.8 psia (315.8 kPa). For example, at 244°F (118°C), the pressure is

$$P_{tot} = P_{steam} + P_{air}$$

$$= 26.82 + 14.7 \frac{244 + 460}{70 + 460} = 46.35 \text{ psia (or 151.7\% of MNOP)} .$$

At 250°F (121°C), the pressure is 49.5 psia (341.3 kPa), 162% of MNOP. This condition was used in the tests for conservatism and because it matches the 10 CFR 71 Appendix B, "Hypothetical Accident Condition," maximum TB-2 temperature, reported in Section 3.4.3.

4.3.2 Release of Radioactive Contents

Through the use of the helium leak-detection method, it was verified that both the TB-2 and the C-1 do not release radioactive contents under the defined normal conditions of transport. During assembly of the PAT-2 packages, both the TB-2 containment vessel and the C-1 capsule were filled with helium at ambient temperature and pressure and checked with a mass-spectrometer-type helium leak detector for leaktightness. The TB-2 containment vessel exhibited no detectable leak (N.D.L: $q < 10^{-10}$ cm^3/s helium) before and after the 10 CFR 71 Appendix A test sequence. The C-1 capsule exhibited an unchanging leak rate, $< 2 \times 10^{-9}$ cm^3/s helium ($\sim 5 \times 10^{-10}$ cm^3/s air),* both before and after the 10 CFR 71 Appendix A test sequence. Disassembly of the TB-2 containment vessel and the C-1 capsule confirmed that helium had remained in the vessels.

The C-1 capsule was assembled with a severe surrogate model loading including UO_2; no uranium could be detected, after the tests, on or in the TB-2 or on the C-1; the limit of detection was $> 10^{-8}$ gram of uranium.

4.4 REQUIREMENTS FOR ACCIDENT CONDITIONS OF TRANSPORT 10 CFR 71

4.4.1 Pressurization of Containment Vessel

For the 10 CFR 71 hypothetical accident conditions of transport, the thermal model cited in Section 3.4.1 predicted a TB-2 temperature of about 227°F (108°C); the test results cited in Section 3.4.3 estimated the bounding maximum post-accident temperature of the TB-2 to be 250°F (121°C). As calculated in Section 4.3.2, the maximum TB-2 pressure at this temperature, with worst-case contents, is 49.5 psia (341.3 kPa).

4.4.2 Release of Radioactive Contents

The two methods described previously for gas leakage and uranium detection verify that the TB-2 and C-1 meet the containment requirements for radioactive contents under the accident conditions of transport defined by 10 CFR 71 Appendix B. Specifically, the post-test gas leakage measurement established that the TB-2 containment vessel and the C-1 capsule remained leaktight,* and the uranium detection measurement confirmed that no release of surrogate contents (depleted UO_2) had occurred throughout the prescribed test series.

During assembly of the PAT-2 packages, both the TB-2 containment vessel and the C-1 capsule were filled with helium at ambient temperature and pressure and were checked with a mass-spectrometer-type helium leak detector for leaktightness.

---

*Reference 7 defines 25°C dry air leak rate $< 10^{-7}$ cm^3/s as leaktight.

The TB-2 containment vessel exhibited no detectable leak ($\dot{q} < 10^{-10}$ cm^3/s helium) before and after the 10 CFR 71 Appendix B test sequence, which included 30-foot (9-metre) drop tests, puncture, fire, and submersion, as required. The C-1 capsule exhibited an unchanging leak rate of $< 2 \times 10^{-9}$ cm^3/s helium ($\sim 5 \times 10^{-10}$ cm^3/s air) both before and after the 10 CFR 71 Appendix B test sequence. Disassembly of the TB-2 and the C-1 confirmed that helium remained in the vessels.

The C-1 capsule was assembled with a severe surrogate model loading including UO_2 (see Test Protocol, Appendix 2E); no uranium could be detected after the tests, on or in the TB-2 or on the C-1; the limit of detection was $> 10^{-8}$ gram of uranium.

4.5 REQUIREMENTS FOR NUREG-0360 CRITERIA

4.5.1 Summary

Six PAT-2 (phase 4 final-design) packages were subjected to the NUREG-0360 accident-modeling environments of impact, crush, puncture, double slash, intense JP-4 fire, and submersion, as detailed in Chapter 2. Each package was impacted differently, as described in Chapter 2, Appendix 2E.

The containment system of each package was assembled in a helium atmosphere with various uranium surrogate loadings, as presented in detail in Section 4.5.2 (and supporting appendices). Through the use of a mass-spectrometer-type helium leak detector, the post-test leak rate of each TB-2 containment vessel was determined. Also, a uranium fluorimeter with a sensitivity of $> 10^{-8}$ gram uranium was utilized in conjunction with standard health-physics swipes to determine the escape of uranium surrogate. The results of these tests are summarized in Table 4.5.1-1.

Table 4.5.1-1

NUREG-0360 Sequential Tests
Post-Test TB-2 Helium and Air Leakage Rates

PAT-2 Package	Surrogated Contents[a]	Impact Attitude	He $\dot{q}$ (cm^3/s)	Air $\dot{q}$ (cm^3/s)	Uranium Detection[b]
X07	$Pu(NO_3)_4 \cdot 2H_2O$	Top	$<10^{-10}$	$<10^{-10}$	N.D.
X08	PuO_2	Top corner	$\sim 2 \times 10^{-5}$	$\sim 7 \times 10^{-6}$	N.D.
X09	D-38 pellets	Side; cold	$<10^{-10}$	$<10^{-10}$	N.D.
X10	$Pu(SO_4)_2 \cdot 4H_2O$	Bottom corner	$<10^{-10}$	$<10^{-10}$	N.D.
X11	$Pu(SO_4)_2 \cdot 4H_2O$	Bottom	$<10^{-10}$	$<10^{-10}$	N.D.
X12	D-38 pellets	Side; hot	$<10^{-10}$	$<10^{-10}$	N.D.

[a]The actual surrogates used are defined in Section 4.5.2
[b]N.D. = Nothing Detected; detection capability $> 10^{-8}$ gram uranium

The maximum pressure at which leak rates could occur is defined in Section 4.5.2; a bounding assessment of theoretical maximum possible plutonium loss through the leak is developed in Section 4.5.3. It is shown that the containment requirement of NUREG-0360 (that the loss be less than an A2 quantity in 1 week) and the IAEA B(U) requirement (that release be < A2 x 10^{-3} in 1 week) are satisfied. These results are summarized by the worst case, presented in Table 4.5.1-2.

Table 4.5.1-2

NUREG-0360 Sequential Tests
PAT-2 Worst-Case Theoretical PuO_2 Release

Pressure (psia)	He $\dot{q}$ (cm^3/s)	A Calculated Total Pu Release (μg)	B IAEA B(U) Quantity[a] of Pu[b] (μg)	C IAEA B(U) Quantity[a] of Pu-238 (μg)
3,280	2 x 10^{-5}	<0.00514	2.55	0.176

[a]A quantity of A2 x 10^{-3}
[b]Typical plutonium mixture

Note that the ratio A/B = 2 x 10^{-3}, A/C = 3 x 10^{-2}

4.5.2 Pressurization of TB-2 Containment Vessel

The maximum credible accident pressure (MCAP) resulting from the NUREG-0360 accident-modeling criteria depends on the form of the PAT-2 plutonium contents, its chemical association, its packaging, and the post-accident maximum temperature of the TB-2 containment vessel. Four cases, all at 1,080°F (582°C), have been considered: (1) solid plutonium sulfate tetrahydrate, $Pu(SO_4)_2 \cdot 4H_2O$, (2) solid plutonium nitrate dihydrate, $Pu(NO_3)_4 \cdot 2H_2O$, (3) sintered plutonium oxide, PuO_2 or mixed oxide pellets, and (4) mixed uranium oxide and plutonium oxide powders.

The MCAPs which were calculated for each of the above species are listed in Table 4.5.2-1; details of the calculations are presented in Appendices 4B through 4E.

The largest pressure calculated (3,280 psia) for the radioisotopic contents shown in Table 4.5.2-1 is for $Pu(SO_4)_2 \cdot 4H_2O$ powder. In this case, the calculated MCAP is only slightly above that of the nitrate form. As shown in Appendices 4B and 4C, the larger pressures calculated for these systems are due to the volatile species formed when the hydrated salts decompose. For all of the systems considered, however, the predominant contribution to the pressure generated by the NUREG-0360 accident-modeling conditions is the decomposition of the PVC packaging material to HCl gas and a solid residue.

Table 4.5.2-1

Calculated TB-2 Maximum Credible Accident Pressures at 1,080°F (582°C)

Radioisotopic Contents*	Pressure (psia)
3 grams $Pu(SO_4)_2 \cdot 4H_2O$ powder	3,280
3 grams $Pu(NO_3)_4 \cdot 2H_2O$ powder	3,250
6 sintered pellets of PuO_2	2,777
40 grams mixed PuO_2 or UO_2	3,043

*Additional contents are described in Appendices 4B through 4E

The formation of H_2SO_4 and H_2O from the decomposition of $Pu(SO_4)_2 \cdot 4H_2O$ together with the formation of HCl from the PVC degradation constitute the worst-case system from both the considerations of pressure generation and corrosivity. Furthermore, the finely divided powder state of the decomposed hydrated salts and of mixed powders of PuO_2 and UO_2 has a greater tendency to aerosolize in the event of containment failure.

The containment of six sintered PuO_2 pellets represents a lesser problem than the containment of $Pu(SO_4)_2 \cdot 4H_2O$ and $Pu(NO_3)_4 \cdot 2H_2O$ because (1) a lower MCAP is predicted and (2) the release of plutonium from a damaged PAT-2 package containing sintered pellets is most unlikely since aerosolization of the PuO_2 is not expected to occur. Furthermore, sintered pellets are not likely to undergo either decomposition or degassing* at the maximum credible accident temperature encountered (1,080°F).

4.5.3 Release of Radioactive Contents

4.5.3.1 Summary

The TB-2 containment vessels were all intact and appeared to be completely serviceable following all tests. Helium gas leakage measurements were made across the TB-2 containment vessel boundary following the accident-modeling tests of NUREG-0360 and 10 CFR 71. The helium and air leak rates for all of the packages tested are shown in Table 4.5.3.1-1.

*The processing of fuel pellets involves temperatures of approximately 3,092°F (1,700°C) so that decomposition of the binder and of the PuO_2 and degassing are not likely to occur at 1,080°F (582°C).

Table 4.5.3.1-1

Post-Test TB-2 Helium and Air Leakage Rates

Package S/N	Surrogate Contents	Impact Attitude	He, $\dot{q}$ (cm^3/s)	Air, $\dot{q}$ (cm^3/s)
NUREG-0360 Sequential Tests				
X07	$Pu(NO_3)_4 \cdot 2H_2O$	Top	$<10^{-10}$	$<10^{-10}$
X08	PuO_2	Top corner	$\sim 2 \times 10^{-5}$	$\sim 7 \times 10^{-6}$
X09	Pellets	Side, cold	$<10^{-10}$	$<10^{-10}$
X10	$Pu(SO_4)_2 \cdot 4H_2O$	Bottom corner	$<10^{-10}$	$<10^{-10}$
X11	$Pu(SO_4)_2 \cdot 4H_2O$	Bottom	$<10^{-10}$	$<10^{-10}$
X12	Pellets	Side, hot	$<10^{-10}$	$<10^{-10}$
10 CFR 71 Appendix A & B Tests				
X15	$Pu(SO_4)_2 \cdot 4H_2O$	Top corner	$<10^{-10}$	$<10^{-10}$

Using correlations established by means of experiments on the transmission of PuO_2 powder through small openings,[4] the maximum theoretical PuO_2 leakage from the TB-2 vessel was calculated to be considerably less than 0.176 μg/wk. That is, the maximum theoretical PuO_2 loss is orders of magnitude less than an A2 x 10^{-3} quantity of Pu-238, with an even greater margin of safety for the containment of Pu-239.

Calculations of the TB-2 vessel deformations at the maximum calculated accident pressure and temperature indicate no failure of the TB-2 vessel containment boundary.

Also, a detection measurement of the UO_2 used as a PuO_2 surrogate was made after the sequential tests of the accident-modeling conditions of NUREG-0360. No UO_2 contamination was detected (to the detectability limit of 10^{-8} gram of uranium).

4.5.3.2 Gas Leak-Rate Measurements

During assembly of the PAT-2 test packages, the TB-2 containment vessels were filled with helium at ambient temperature and a slight positive pressure. Each TB-2 vessel was then leak tested using a mass spectrometer capable of detecting a helium leak rate as low as 1 x 10^{-10} cm^3/s. All vessels indicated N.D.L. (no detectable leak).

When the accident-modeling tests were completed and the package had reached ambient temperature, the TB-2 vessels were removed, cleaned, and again tested for

helium leakage. The purpose of the cleaning was to remove char and volatile compounds deposited on the surface which might interfere with the leak detection. The results, converted to air leakage rates, are summarized in Table 4.5.3.1-1. Only one of the vessels, X08, indicated a detectable leakage of helium: $\sim 2 \times 10^{-5}$ cm^3/s. TB-2 X08, shown in Figure 4.5.3.2-1 after the full NUREG-0360 test sequence, appears undamaged and serviceable.

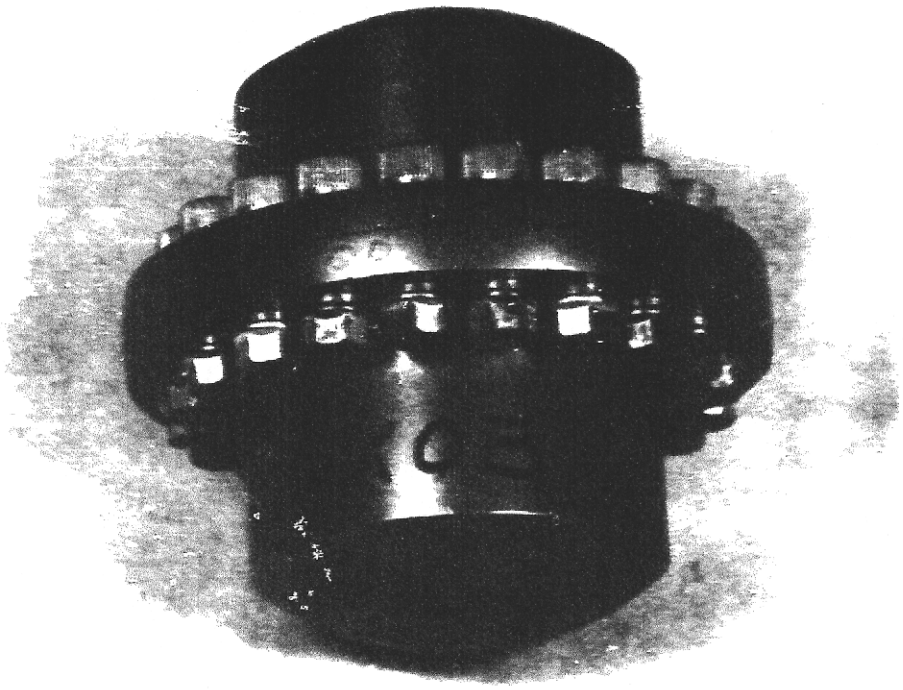


Figure 4.5.3.2-1. TB-2 X08

4.5.3.3 Calculated Plutonium Oxide Loss

The tests performed on the PAT-2 package involved UO_2 powder as a surrogate of PuO_2 powder, but estimates of possible PuO_2 loss have been made based on the work reported in Reference 4 on the transmission of PuO_2 powder through small openings, including capillaries and orifices. Using the relations between leak flow rates and diameter developed in Reference 5 and discussed in Appendix 4F, the leakage rates listed in Table 4.5.3 can be used to estimate the diameter of a capillary or orifice having the same flow rate. From this dimension and the MCAP, an estimate of the PuO_2 loss rate can be obtained from the correlations developed in Reference 4 and discussed in Appendix 4G.

The system which corresponds to the highest leakage rate is package X08. The MCAP for this package is calculated to be 3,280 psia.

As shown in Appendix 4F, this leakage rate corresponds to a capillary diameter of 6.77 μm for laminar flow in a capillary of length 0.716 cm. Using the Battelle correlation[4] for the PuO_2 release rate, which correlates the PuO_2 transport with the product of the capillary cross sectional area, A, and the square root of the pressure, p, the calculated maximum theoretical PuO_2 release is 0.00514 μg, as shown in Appendix 4G. This total release, which is independent of time, corresponds to a release orders of magnitude lower than an A2 quantity of plutonium. The IAEA value for an A2 quantity of Pu-238 is 176 μg; for a plutonium mixture, the value for an A2 quantity is 2,550 μg. Furthermore, the PuO_2 release predicted is several orders of magnitude lower than A2 x 10^{-3} for Pu-238.

4.5.3.4 TB-2 Deformations at Elevated Temperature and Pressure

The calculated PuO_2 losses given in Section 4.5.3.3 were based on helium leak rates measured at ambient temperature. At the maxima of temperature and pressure of the accident-modeling tests, the TB-2 vessel is subjected to greater stresses than at ambient conditions, and there is degradation of strength of the metal. An analysis of the stresses and deformation of the TB-2 vessel at elevated temperature and pressure has been performed; details of that analysis are given in Appendix 4J and Appendix 2C. The analysis shows that under the bolt preloading conditions that were applied, no failure of the TB-2 vessel containment boundary is expected. These results are consistent with the test findings that no UO_2 was detected after the accident-modeling tests were performed.

4.5.3.5 Uranium Detection Measurements

During assembly of some PAT-2 packages, the TB-2 containment vessels were assembled with a finely divided uranium dioxide powder as a surrogate for PuO_2 powder (see Appendix 4A).

After the sequential tests corresponding to the NUREG-0360 accident-modeling conditions had been performed on a PAT-2 package containing a maximum practical quantity (40 grams) of the UO_2 powder, the TB-2 vessel was subjected to uranium fluorimeter detection measurement to determine if UO_2 was released. No UO_2 was detected. The 10^{-8} gram limit of detectability is approximately five orders of magnitude below a mass of plutonium powder associated with an A2 quantity.

APPENDIX 4A

Characterization of Surrogate UO_2 Powder

Depleted sinterable UO_2 powder was used as a surrogate for PuO_2 during testing of the PAT-2 packages. Selection of this material was based primarily on its ability to replicate the aerosol characteristics of PuO_2 and the capability to detect very small quantities (10^{-8} gram) of this material. This detection capability was utilized as one of the two methods to demonstrate container compliance with the performance specifications. Other similarities of this UO_2 surrogate with PuO_2 include (1) U and Pu are both actinide rare earths with similar atomic properties and (2) UO_2 and PuO_2 have similar heat capabilities, surface tensions, and thermal conductivity. The bulk density of the UO_2 powder (1 - 1.25 g/cm^3) is also similar to PuO_2 formed in the oxalate process (1.2 - 1.5 g/cm^3).

The depleted UO_2 powder used in the PAT-2 testing program was supplied by Eldorado Nuclear, Ltd., Port Hope, Ontario, Canada, as specification ENL-1-Issue 5--Depleted Sinterable UO_2.

The powder was examined by the Nuclear Materials Division, Savannah River Laboratory (SRL), by agitating it in an isoton solution by ultrasonic means and then taking measurements with both an electron-beam microscope and a Coulter counter.

Eldorado reported the bulk density to be 1.00 ± 0.25 g/cm^3 per ASTM-B329 (the 40,000-psi sintered density would be 5 to 6 g/cm^3). SRL reported the particle size as

3.01 µm median
5.59 µm mean
52.74% of population < 1 µm
5.65% of volume < 1 µm.

For comparison purposes, SRL reports the following data group as the low (small-particle) group of four direct-strike oxalate precipitation $^{239}PuO_2$ samples:

28.06 µm median
29.14 µm mean
No particles < 6 µm.

The above data show that the UO_2 examined was much finer than at least one specific PuO_2 powder examined by SRL; the individual PuO_2 powder grain was typically "briquette-like or straw-like," whereas the individual UO_2 powder grain was more nearly spherical or "sandlike."

The particle size distribution of the UO_2 used in the PAT-2 qualification tests is given in Table 4A.

Table 4A

Particle Size Distribution of Depleted UO_2 Powder, PAT-2

μm Range	Volume %	Population %
0.63 - 0.79	2.60	33.23
0.79 - 1.00	3.05	19.51
1.00 - 1.26	5.77	18.42
1.26 - 1.59	7.24	11.56
1.59 - 2.00	10.41	8.31
2.00 - 2.52	12.50	5.00
2.52 - 3.17	11.03	2.20
3.17 - 4.00	10.75	1.07
4.00 - 5.04	9.43	0.47
5.04 - 6.35	6.22	0.16
6.35 - 8.00	4.07	0.05
8.00 - 10.00	2.88	0.02
10.08 - 12.70	2.94	0.009
12.70 - 16.00	3.28	0.005
16.00 - 20.16	2.43	0.001
20.16 - 25.40	1.70	0.0006
25.40 - 32.00	2.55	0.0005
32.00 - 40.32	0	0.0005
40.32 - 50.00	1.13	------
	100.00	100.01615

APPENDIX 4B

Pressure Calculation, Test Results, and Surrogate for $Pu(SO_4)_2 \cdot 4H_2O$

At the request of the IAEA* and others, a study of the containment of the hydrated plutonium salts was performed. The hydrated plutonium salts considered were $Pu(SO_4)_2 \cdot 4H_2O$ and $Pu(NO_3)_4 \cdot 2H_2O$, which result from treating nuclear materials with sulfuric acid (H_2SO_4) and nitric acid (HNO_3), respectively. This appendix considers those tests performed using $Pu(SO_4)_2 \cdot 4H_2O$.

At elevated temperatures, T > 1,112°F (600°C), the hydrated sulfate decomposes according to the following reactions:[8]

$$Pu(SO_4)_2 \cdot 4H_2O \rightarrow PuO_2 + 2H_2SO_4 + 2H_2O \ .$$

It should be pointed out that temperatures in excess of 1,112°F (600°C) were never attained within the TB-2 vessel in the tests performed. The bounding assessment of the maximum accident temperature for the PAT-2 package is 1,080°F (582°C), as discussed in Chapter 3.

The packaging of the hydrated salts involves more potential problems in the event of an accident than the packaging of PuO_2 powders and pellets because the formation of H_2SO_4 and HNO_3 acids introduces the problem of corrosivity, as well as pressure generation in the containment package. Such problems were examined by analysis of the contributions to the total pressure and by testing PAT-2 packages containing a surrogate of $Pu(SO_4)_2 \cdot 4H_2O$.

4B.1 PRESSURE CALCULATION FOR PLUTONIUM SULFATE TETRAHYDRATE

The basis for the $Pu(SO_4)_2 \cdot 4H_2O$ pressure calculations are summarized in Table 4B.1-1.

The decomposition of 3 grams of the hydrated salt produces 1.615 grams of PuO_2, 1.169 grams of H_2SO_4, and 0.215 gram of H_2O. Thus, at elevated temperatures, the H_2SO_4 and H_2O will contribute to the pressure increase in the TB-2 vessel.

---

*IAEA Memo from S. Deron to A. von Baeckman dated 5 May 1980 and transmitted to J. Andersen.

Table 4B.1-1

Basis for the $Pu(SO_4)_2 \cdot 4H_2O$ Pressure Calculations

Mass of $Pu(SO_4)_2\ 4H_2O$	3.0 g
Mass of PVC	9.0 g
Moisture content (unbound H_2O)	0.5 g
Brass canister mass	50.0 g
Quartz vial mass	18.0 g
Sealant (Teflon™)	0.3 g
Temperature	582°C

The decomposition of the PVC leads to the formation of HCl according to the reaction[9]

$$(C_2H_3Cl) \rightarrow HCl + \text{solid residue}\ .$$

From the stoichiometry of this PVC reaction, 9 grams of PVC will produce 5.25 grams of HCl and 3.75 grams of a solid residue, which for purposes of calculation is assumed to be carbon with a density of 1.5 g/cm^3. Since HCl is a gas at elevated temperatures, it will also contribute to an increase in pressure within the TB-2 vessel.

Additional pressure is developed by the decomposition of any sealants present. This is accounted for in the following calculations.

Provided that no leak develops, the air or helium trapped in the TB-2 vessel during assembly will also contribute to the total pressure increase as the package heats during the fire test of a test sequence.

A calculation of the maximum pressure attained in the TB-2 vessel for the contents listed in Table 4B.1-1 follows.

The free volume, V_f, can be found by use of the following data:

TB-2 internal volume	= 95.1 cm^3
Cl capsule solid volume	= 16.2 cm^3
Volume of brass	= 5.75 cm^3
Volume of quartz	= 7.2 cm^3
Volume of PVC residue	= 2.50 cm^3
Volume of sealant residue	= 0.25 cm^3
Volume of PuO_2	= 0.20 cm^3

Thus,

$$V_f = 95.1 - (16.2 + 5.75 + 7.2 + 2.50 + 0.25 + 0.20)$$
$$= 63.00 \text{ cm}^3 .$$

To use English-unit steam tables, this is converted to 2.22×10^{-3} ft^3.

Partial Pressure of the Steam

The partial pressure of steam is calculated by

$$\text{Spec. Vol. of Steam} = \frac{2.22 \times 10^{-3} \text{ ft}^3}{0.715 \text{ g}/453.6 \text{ g/lb}} = 1.409 \text{ ft}^3/\text{lb} .$$

By interpolation from the steam tables[6] at a temperature of 1,080°F (582°C),

$$P_{steam} = 636.3 \text{ psi } (4.39 \text{ MPa}) .$$

Partial Pressure of the Helium (or Air)

The TB-2 vessel was assembled in a helium environment for the surrogate tests under consideration. The partial pressure of helium, assuming no leakage, is given by

$$P_{He} = 14.7 \times \frac{855 \text{ K}}{298 \text{ K}} = 42.2 \text{ psi } (0.29 \text{ MPa}) ,$$

where the loading conditions have been taken to be p = 14.7 psi (0.10 MPa) and T = 77°F (25°C).

Partial Pressure of the Sulfuric Acid

From the stoichiometry of the reaction discussed above, the molar volume of the H_2SO_4 produced is calculated to be

$$V_{H_2SO_4} = 63.00 \text{ cm}^3 \div \frac{1.169 \text{ gmol}}{98} = 5{,}281 \text{ cm}^3/\text{gmol} .$$

The molar volume of an ideal gas at 1,080°F (582°C) and a partial pressure of p (in psi) is given by

$$V = 22{,}400 \frac{cm^3}{gmol} \times \frac{855\ K}{273\ K} \times \frac{14.7}{p} = \frac{1.0313 \times 10^6}{p}\ cm^3/gmol\ .$$

Thus, if H_2SO_4 is assumed to be an ideal gas at 1,080°F (582°C) and at the pressure in the TB-2 vessel, the partial pressure of H_2SO_4 is given by

$$p_{H_2SO_4} = \frac{V}{V_{H_2SO_4}} = \frac{1.0313 \times 10^6}{5{,}281} = 195.3\ psi\ (1.35\ MPa)\ .$$

Partial Pressure from PVC Decomposition

If the HCl formed by decomposition of PVC is assumed to be an ideal gas, the partial pressure of the 5.25 grams of HCl (0.144 gmol) produced from 9 grams of PVC is

$$P_{HCl} = \frac{V}{V_{HCl}} = \frac{1.0313 \times 10^6}{63.0/0.144} = 2{,}357.3\ psi\ (16.25\ MPa)\ .$$

Partial Pressure from Teflon™ Decomposition

Using Teflon™ tape as the sealant, the partial pressure resulting from the thermal degradation is due to the formation of the gaseous monomer, tetrafluoroethylene.[10] Teflon™ thermally degrades to the monomer nearly stoichiometrically at appreciable rates above 797°F (425°C). The degradation reaction is

$$(-CF_2 = CF_2 -)_n \rightarrow n(CF_2 = CF_2)\ .$$

From the stoichiometry of the reaction, 0.3 gram of Teflon™ yields 0.3 gram of monomer (0.003 gmol monomer). Assuming the monomer to be an ideal gas yields

$$p_{monomer} = \frac{V}{V_{monomer}} = \frac{1.0313 \times 10^6}{63.0/0.003} = 49.1\ psi\ (0.34\ MPa)\ .$$

Total Pressure for Plutonium Sulfate Tetrahydrate at 582°C

The maximum total pressure in the TB-2 vessel, calculated for the loading given in Table 4B.1-1, is

$$P = p_{steam} + p_{He} + p_{H_2SO_4} + p_{HCl} + p_{teflon}$$

$$= 636.3 + 42.2 + 195.3 + 2357.3 + 49.1 = 3,280 \text{ psi } (22.6 \text{ MPa}).$$

Note that the major contribution to the pressure is associated with the decomposition of PVC and, hence, it is desirable for the operator to minimize the amount of PVC used to bag the canisters contained in the C-1 capsule, even though the surrogate conservatively involves the use of a surplus (10 grams vs. 9 grams) of PVC.

4B.2 TEST RESULTS WITH THE SURROGATE OF PLUTONIUM SULFATE TETRAHYDRATE

In order to establish that the hydrated salts of plutonium can be contained as effectively as PuO_2, an early developmental test sequence corresponding to the accident condition tests described in Chapter 2 (with two exceptions in the test sequence as discussed below) was performed on a developmental PAT-2 package containing a surrogate of $Pu(SO_4)_2 \cdot 4H_2O$. The pressures generated by the surrogate exceed the pressures generated by the intended contents summarized in Table 4B.1-1.

Based on the stoichiometry of the decomposition reaction for the hydrated sulfate, the surrogate listed in Table 4B.2-1 was prepared and placed in the C-1 capsule. The hydrated sulfate was selected for this test rather than the hydrated nitrate because of the greater corrosivity of sulfuric acid compared with nitric acid for many ferrous and nonferrous materials. Furthermore, only the hydrated sulfate was of interest to the IAEA. However, the hydrated nitrate was also tested later due to the U.S. interest in this form.

Table 4B.2-1

First Surrogate Used for $Pu(SO_4)_2 \cdot 4H_2O$ Testing

Concentrated H_2SO_4 (96.0% by weight)	0.664 ml
Water	0.666 ml
Mass of PVC	10 g
Mass of Brass Slug	50 g
Sealant (oil/clay type, not Teflon™)	0.5 g

The concentrated H_2SO_4 (96.0% weight) and water, which were added to make the surrogate, are equivalent to H_2SO_4 produced from the decomposition of 3.0 grams of $Pu(SO_4)_2 \cdot 4H_2O$ and water resulting from the decomposition and introduction of moisture.

The pressure calculated for this surrogate loading, under the 1,080°F (582°C) accident condition, exceeds all pressures listed in Section 4.5.1 for actual PAT-2 loadings and has a value of 3,466 psi (23.8968 MPa). This calculation is summarized as follows: the steam generated from the initial moisture (0.666 ml H_2O added to the 96% concentrated H_2SO_4 to simulate the bound water in 3 grams of $Pu(SO_4)_2 \cdot 4H_2O$ and the arbitrarily added 0.5 gram of H_2O) is 574.5 psi (3.961 MPa), the pressure of the gas (air or helium) included at the time of assembly is 42.2 psi (0.291 MPa), the H_2SO_4 vapor produced by the decomposition is 176 psi (1.213 MPa); the HCl gas produced by decomposition of the PVC is 2,363 psi (16.292 MPa), the product of decomposition of the oil-base sealant is 310 psi (2.137 MPa),* and the total pressure is 3,466 psi (23.897 MPa).

All of the contents listed in Table 4B.2-1 were placed in the C-1 capsule, and the capsule was closed, but not tightly, to permit acid vapors to be emitted from the capsule to allow possible chemical attack on the copper seal of the TB-2 vessel.

An oil/clay ("pipe dope") type sealant, 0.5 gram in mass, was used to produce pressure in lieu of the final design intent of 0.3 gram Teflon™ tape. Calculations indicate that the substitute sealant produced a partial pressure of 310 psia in place of the 49.2 psi (0.339 MPa) from the Teflon™. Furthermore, the sealant was deliberately placed inside the cap of the C-1 capsule and not on the threads so that gases would deliberately escape the C-1 and would directly threaten the copper-gasket-sealed TB-2 containment vessel.

A brass slug was used in place of the brass canisters to simulate the volume occupied by the canisters and to provide information on the possible chemical reactions between the decomposition products and the brass, which would tend to consume the acids generated. The brass slug was shaped as a right-circular cylinder to minimize the surface area of the brass compared to the area of the actual brass canisters. This was done to assure a greater abundance of H_2SO_4 vapor available to threaten the TB-2 copper seal, rather than consuming the acid by reaction with the brass, if that were to occur.

The C-1 capsule was then placed in the TB-2 vessel together with thin samples of pure zinc and pure tin. The tin and zinc samples were included to provide information on the temperatures reached by the TB-2 vessel in the fire test. The

---

*It was estimated that the hydrocarbon material in 0.5-gram mass of sealant would produce approximately 0.021 gmol of CO or 0.58 gram of CO.

zinc was wedged between the bottom of the C-1 capsule and the TB-2; the tin was inserted between the top of the C-1 capsule and the TB-2.

The assembly of the TB-2 was carried out in a helium environment, and after the TB-2 was assembled it was tested for leaktightness using a mass spectrometer capable of detecting leakage as low as 10^{-10} cm^3/s of helium. No leakage was detected.

After the leak test on the TB-2 was performed, the PAT-2 package was assembled and tested. With two exceptions, the normal test sequence for accident conditions was performed. The first exception was that the rocket pulldown test was replaced by a crush test using a force of 500,000 pounds (22.24 MN) on the package to simulate the damage produced on an unyielding target by the rocket pulldown. The second exception was the deletion of the post-fire water submersion test. To establish a worst-case thermal condition, the package was permitted to self-extinguish over a period of 2 days (this complete charring does produce the highest TB-2 temperature).

After the PAT-2 package reached the ambient temperature, the package was cut open, and the TB-2 vessel was recovered. Examination of the PAT-2 contents showed that the maple was charred down to the TB-2 spherical containment vessel. The 6061 aluminum fairings attached to the TB-2 were discolored and weakened (no longer in T6 condition) but not melted. The aluminum fairings suffered embrittlement, evidenced by pieces breaking off during their removal from the TB-2 vessel.

After cleaning to remove char and volatile residue from the TB-2, it was leak tested using the mass spectrometer; a helium leakage rate of 2.16×10^{-8} cm^3/s, equivalent to 8.0×10^{-9} cm^3/s for air, was noted. As explained in the following paragraph, it was later determined, by another technique, that there was no detectable leak (N.D.L). Next, a hole was drilled partially through the TB-2 vessel, and then the thin diaphragm which remained was punctured while operating the leak detector. A vigorous helium leak was detected; the leak was audible and had an odor.

The hole in the TB-2 was tapped, and a test valve was inserted. The TB-2 vessel was then repressurized using helium to 40 psig (27.58 kPa) and leak tested with the mass spectrometer; the 20-bolt pattern was left undisturbed. No measurable leakage was detected ($\dot{q} < 10^{-10}$). The unit was then disassembled and examined. The copper seal was found to be clean and bright with no observable chemical attack. The pure tin sample had melted (liquidus temperature ~ 450°F (~ 232°C)), and was adhered to the stainless steel (Nitronic 60) C-1 capsule. The pure zinc strip had also melted (liquidus temperature ~ 750°F (~ 398°C)). The zinc also partially adhered to

the C-1 capsule, and it appeared to have undergone a chemical reaction. A yellow residue resembling elemental sulfur was associated with the remains of the zinc.

The C-1 capsule could not be opened by means of a torque to unscrew it, so it was cut open and examined. The brass slug inside the capsule was thickly coated with a carbonaceous residue, and the interior of the C-1 capsule was coated with this residue. The Nitronic 60 C-1 capsule did not appear to have been attacked chemically.

From the foregoing analyses and test, it was concluded that 3 grams of $Pu(SO_4)_2 \cdot 4H_2O$, with the packaging limits set in Table 4B.1-1, can be accommodated in the PAT-2 package.

4.B.3 CALCULATIONS FOR SURROGATE OF PLUTONIUM SULFATE TETRAHYDRATE FOR PHASE 4 TESTS

Following the above development test, qualification tests on the final-design PAT-2 packages were conducted using surrogates of plutonium sulfate (see Table 4B.3-1), as reported in Chapter 2. Two PAT-2 packages (Serial Nos. X10 and X11) containing uranium sulfate surrogates were subjected to the NUREG-0360 criteria and were found to have no detectable leak. One package (Serial No. X15) containing a uranium sulfate surrogate was subjected to the 10 CFR 71 Appendix A and B environments and was found to have no detectable leak ($\dot{q} < 10^{-10}$) of the TB-2 containment vessel. These final surrogates of $Pu(SO_4)_2 \cdot 4H_2O$ are listed in Table 4.B.3-1. The surrogate was designed to exceed the MCAP listed in Table 4.5-2 for $Pu(SO_4)_2 \cdot 4H_2O$.

Table 4B.3-1

Final Surrogate Used for $Pu(SO_4)_2 \cdot 4H_2O$ Testing

Concentrated H_2SO_4 (96.0% by weight)	0.67 ml
Water	0.67 ml
Depleted UO_2 powder	3.0 g
Mass of PVC	10.0 g
Mass of brass	50.0 g*
Teflon™	0.3 g

*X10 used 47.35 grams of brass; X15 used 38.76 grams of brass; all others used 50 grams of brass.

APPENDIX 4C

Pressure Calculations and Surrogate for $Pu(NO_3)_4 \cdot 2H_2O$

This appendix presents test results obtained using $Pu(NO_3)_4 \cdot 2H_2O$.

The decomposition of plutonium nitrate dihydrate, $Pu(NO_3)_4 \cdot 2H_2O$, is given by the following reaction:

$$Pu(NO_3)_4 \cdot 2H_2O \rightarrow PuO_2 + 4HNO_3$$

4C.1 PRESSURE CALCULATIONS FOR PLUTONIUM NITRATE DIHYDRATE

The basis for the $Pu(NO_3)_4 \cdot 2H_2O$ pressure calculation is summarized in Table 4C.1-1.

Table 4C.1-1

Basis for the $Pu(NO_3)_4 \cdot 2H_2O$ Pressure Calculations

Mass of $Pu(NO_3)_4 \cdot 2H_2O$	3 g
Mass of PVC	9 g
Moisture Content (unbound H_2O)	0.5 g
Brass canister mass	50 g
Quartz vial mass	18 g
Sealant (Teflon™)	0.3 g
Free volume	63.26 cm^3
Maximum temperature	582°C

From the chemical stoichiometry of the decomposition reaction, 3 grams of $Pu(NO_3)_4 \cdot 2H_2O$ powder yields 1.555 grams of PuO_2 and 1.445 grams of HNO_3 (0.02295 gmol). HNO_3 is a gas at the temperature and pressure of the system during the fire test.

Partial Pressure of the Steam

The specific volume of the steam is given by

$$v = \frac{63.26\ cm^3/(30.48\ cm/ft)^3}{0.5\ g/453.6\ g/lb} = 2.027\ ft^3/lb\ (126.52\ cm^3/g)\ .$$

By interpolation from the steam table at 1,080°F (582°C), the steam pressure is

$$P_{steam} = 437.5\ psi\ (3.0165\ MPa)\ .$$

Partial Pressure of the Air

For assembly of the TB-2 vessel at atmospheric pressure of 760 mm Hg and 77°F (25°C), the molar volume of air is

$$V_{air} = 24{,}451\ cm^3/gmol\ .$$

As shown in Appendix 4A, for an ideal gas at 1,080°F (582°C) and a pressure, p, in psia, the molar volume is given by

$$V = \frac{1.0313 \times 10^6}{p}\ cm^3/gmol\ .$$

If no leakage occurs, the volume of gas per gmol remains constant, and the partial pressure of the air is obtained by equating V_{air} with the above equation for V and solving for p to give

$$P_{air} = \frac{V}{V_{air}} = \frac{1.0313 \times 10^6}{24{,}451} = 42.2\ psi\ (0.291\ MPa)\ .$$

Partial Pressure of the Nitric Acid

The molar value of HNO_3 is

$$V_{HNO_3} = \frac{63.26\ cm^3}{0.02295\ gmol} = 2{,}756\ cm^3/gmol\ .$$

Assuming the HNO_3 to be an ideal gas, the partial pressure calculation follows from that of the air. Thus,

$$P_{HNO_3} = \frac{V}{V_{HNO_3}} = \frac{1.0313 \times 10^6}{2,756} = 374.2 \text{ psi } (2.58 \text{ MPa}) .$$

Partial Pressure from PVC Decomposition

The HCl produced from the decomposition of 9 grams of PVC is 0.144 gmol. Assuming HCl to be an ideal gas, the partial pressure generated is given by

$$P_{HCl} = \frac{V}{V_{HCl}} = \frac{1.0313 \times 10^6}{63.26/0.144} = 2347.6 \text{ psi } (16.186 \text{ MPa}) .$$

Partial Pressure from Teflon™ Decomposition

The thermal degradation of 0.3 gram of Teflon™ yields 0.003 gmol of the monomer gas, $CF_2 = CF_2$. If the monomer is assumed to be an ideal gas, the partial pressure becomes

$$P_{monomer} = \frac{V}{V_{monomer}} = \frac{1.0313 \times 10^6}{63.26/0.003} = 48.9 \text{ psi } (0.337 \text{ MPa}) .$$

Total Pressure for Plutonium Nitrate Dihydrate

The total pressure is the sum of the above partial pressures. Thus

$$P = 437.5 + 42.2 + 374.2 + 2347.6 + 48.9 = 3250 \text{ psi } (22.41 \text{ MPa}) .$$

4C.2 CALCULATIONS FOR SURROGATE OF PLUTONIUM NITRATE DIHYDRATE FOR PHASE 4 TESTS

For the Phase 4 tests corresponding to the NUREG-0360 accident modeling criteria, a surrogate of the TB-2 containment vessel loading of Table 4C.1-1 was prepared. The surrogate was designed to exceed the MCAP calculated in Section 4C.1 and listed in Table 4.5.2-1. This was accomplished by adding an additional 1.0 gram of PVC.

The basis for the calculations included the following:

Mass of $Pu(NO_3)_4 \cdot 2H_2O$	3.0 g
Mass of PVC	10.0 g
Mass of moisture (unbound H_2O)	0.5 g
Mass of brass canister	50 g
Mass of Teflon™ tape	1.0 g
Mass of quartz	18 g

The stoichiometry for the reaction is

$$\begin{array}{ccccc} Pu(NO_3)_4 \cdot 2H_2O & \rightarrow & PuO_2 & + & 4HNO_3 \\ (MW = 523) & & (MW = 271) & & (MW = 63) \\ 3.0\ g & \rightarrow & 1.555\ g & + & 1.445\ g \end{array}$$

In order to provide the required amounts of HNO_3 and H_2O in the surrogate, two grades of nitric acid were mixed. The concentrations and specific gravities of these reagents are

90.0% nitric acid; sp. gr. = 1.50
70.4% nitric acid; sp. gr. = 1.42 .

The nitric acid requirements were calculated as follows:

Let m_{90} = the mass of 90.0% acid
m_{70} = the mass of 70.4% acid
V_{90} = the volume of 90.0% acid
V_{70} = the volume of 70.4% acid .

By material balance on the HNO_3 and H_2O,

$$0.704\ m_{70} + 0.900\ m_{90} = 1.445\ g\ HNO_3$$
$$0.296\ m_{70} + 0.100\ m_{90} = 0.500\ g\ H_2O\ .$$

Solving these two equations simultaneously yields

$$m_{70} = 1.559\ g \text{ of } 70.4\%\ HNO_3$$
$$m_{90} = 0.386\ g \text{ of } 90.0\%\ HNO_3\ .$$

The volumes of nitric acid required are

$$V_{70} = 1.559\ g/1.42\ g/ml = 1.10\ ml \text{ of } 70.4\%\ HNO_3$$
$$V_{90} = 0.386\ g/1.50\ g/ml = 0.26\ ml \text{ of } 90.0\%\ HNO_3\ .$$

The contents of the surrogate of $Pu(NO_3)_4 \cdot 2H_2O$ are summarized in Table 4C.2-1. The calculated MCAP for this loading is 3,646 psia, which exceeds the pressure listed in Table 4.5-2 for $Pu(NO_3)_4 \cdot 2H_2O$ powder by 12.6%.

Table 4C.2-1

Surrogate of $Pu(NO_3)_4 \cdot 2H_2O$ Powder

Mass of uranium oxide powder	1.555 g
Volume of 70.4% HNO_3	1.10 ml
Volume of 90.0% HNO_3	0.26 ml
Mass of PVC	10.0 g
Mass of brass slug	50.0 g
Mass of Teflon™ tape	1.0 g
Mass of quartz	18.0 g

APPENDIX 4D

Pressure Calculations and Surrogate for Sintered Pellets of PuO_2

This appendix presents test results obtained using sintered pellets of PuO_2.

4D.1 PRESSURE CALCULATIONS FOR SINTERED PELLETS OF PLUTONIUM OXIDE

Six sintered pellets of PuO_2 can be inserted into six BC-5 canisters (2.70 cm^3 total volumetric displacement per canister). In this case, no quartz liner is necessary for processing. Allowing for 0.5 gram of moisture and assuming that the pellets fill the entire void space of the BC-5 canisters (very conservative estimates), the basis for the pressure calculation is given in Table 4D.1-1.

Table 4D.1-1

Basis for the Pressure Calculations for PuO_2 Pellets

6 sintered pellets of PuO_2	120.0 g
Mass of PVC	9.0 g
Moisture content (unbound H_2O)	0.5 g
Teflon™ tape	0.3 g
Free volume	65.73 cm^3
Temperature	582°C

As in the cases considered in Appendices 4B and 4C, the pressure generated consists of contributions due to steam from the moisture, HCl gas from the decomposition of PVC, gaseous tetrafluoroethylene from the decomposition of the Teflon™, and a pressure increase due to the heating of trapped air.

Partial Pressure of the Steam

The specific volume of the steam is given by

$$V = \frac{65.73\ cm^3/(30.48\ cm/ft)^3}{0.5\ g/453.6\ g/lb} = 2.106\ ft^3/lb\ (131.4\ cm^3/g)\ .$$

By interpolation from the steam table at 1,080°F (582°C) the steam pressure is

$$P_{steam} = 428.3 \text{ psi } (2.953 \text{ MPa}) .$$

Partial Pressure of the Air

As shown in Appendix 4B, the partial pressure of the air is

$$P_{air} = \frac{V}{V_{air}} = 42.2 \text{ psi } (0.291 \text{ MPa}) .$$

Partial Pressure of the Decomposed PVC

As shown in Appendix 4B, the partial pressure of the HCl gas formed by decomposition of the PVC is

$$P_{HCl} = \frac{V}{V_{HCl}} = \frac{1.0313 \times 10^6}{65.73/0.144} = 2259.4 \text{ psi } (15.58 \text{ MPa}) .$$

Partial Pressure from Teflon™ Decomposition

As shown in Appendix 4B, the partial pressure of the monomer resulting from the decomposition of the Teflon™ is

$$P_{monomer} = \frac{V}{V_{monomer}} = \frac{1.0313 \times 10^6}{65.73/0.003} = 47.1 \text{ psi } (0.325 \text{ MPa}) .$$

Total Pressure for Plutonium Oxide Pellets at 582°C

The maximum total pressure in the TB-2 vessel, corresponding to the loading given in Table 4D.1-1, is

$$p = 428.3 + 42.2 + 2259.4 + 47.1 = 2777 \text{ psi } (19.147 \text{ MPa})$$

4D.2 CALCULATIONS FOR SURROGATE OF PLUTONIUM OXIDE PELLETS FOR PHASE 4 TESTS

For the NUREG-0360 accident modeling tests, a surrogate of loading listed in Table 4D.2-1 was prepared. The surrogate was designed to exceed the MCAP listed in Table 4.5.2-1 for six sintered PuO_2 pellets. This was accomplished by using depleted uranium metal as a surrogate for the PuO_2. The uranium metal was machined into six pellets, each with a mass of 20.6 grams. These pellets were placed in six brass BC-5 canisters, which had a total mass of brass of 31.4 grams. To closely match the calculated pressure for the PuO_2 pellets, 10 grams of PVC was used rather than the 9

grams of PVC indicated in Table 4D.1-1. The additional PVC was included to offset the reduction in free volume caused by the use of uranium metal in place of PuO_2. The free volume associated with the surrogate was 65.9 cm^3. The surrogate contents are listed in Table 4D.2-1.

Table 4D.2-1

Surrogate for Six Sintered Pellets of PuO_2

Mass of depleted uranium metal	123.6 g
Mass of PVC	10 g
Moisture content (unbound H_2O)	0.5 g
Teflon™ tape	0.2 g
Brass canister mass	31.4 g

The MCAP calculated for the surrogate is 3,005 psi (20.718 MPa), which is considerably higher than the pressure calculated for the loading listed in Tables 4D.1-1 and 4.5.2-1, 2,777 psi (19.147 MPa).

APPENDIX 4E

Pressure Calculations and Surrogate for Mixed Powders of PuO_2 and UO_2

This appendix presents test results obtained using mixed powders of PuO_2 and UO_2.

4E.1 PRESSURE CALCULATIONS FOR MIXED POWDERS

For the mixed powders of PuO_2 and UO_2 described in the IAEA memo,* the TB-2 vessel loading is listed in Table 4E.1-1, followed by the calculation of the MCAP corresponding to that loading.

Table 4E.1-1

Basis for Pressure Calculations for Mixed Powders of PuO_2 and UO_2

Mass of mixed powder	40 g
Mass of PVC	9 g
Moisture content (unbound H_2O)	0.5 g
Teflon™ tape	0.3 g
Mass of quartz	18.0 g
Mass of brass	50.0 g
Free volume	59.91 cm^3
Temperature	582°C

The total pressure involves the same contributions considered in Appendix 4D.

Partial Pressure of the Steam

The specific volume of the steam is given by

$$V = \frac{59.91\ cm^3/(30.48\ cm/ft)^3}{0.5\ g/453.6\ g/lb} = 1.919\ ft^3/lb\ (119.82\ cm^3/g)\ .$$

*IAEA Memo from S. Deron to A. von Baeckman dated 5 May 1980 and transmitted to J. Andersen.

By interpolation from the steam table at 1080°F, the steam pressure is

$$P_{steam} = 470.3 \text{ psi } (3.243 \text{ MPa}) .$$

Partial Pressure of the Air

As in Appendix 4B, the partial pressure of the air is

$$P_{air} = \frac{V}{V_{air}} = 42.2 \text{ psi } (0.291 \text{ MPa}) .$$

Partial Pressure from PVC Decomposition

As shown in Appendix 4A, the partial pressure of the HCl gas is given by

$$P_{HCl} = \frac{V}{V_{HCl}} = \frac{1.0313 \times 10^{-6}}{59.91/0.144} = 2{,}478.8 \text{ psi } (17.09 \text{ MPa}) .$$

Partial Pressure from Teflon™ Decomposition

The partial pressure of the monomer resulting from the decomposition of Teflon™ is given by

$$P_{monomer} = \frac{V}{V_{monomer}} = \frac{1.0313 \times 10^{-6}}{59.91/0.003} = 51.6 \text{ psi } (0.356 \text{ MPa}) .$$

Total Pressure for Mixed Powders at 582°C

The maximum total pressure in the TB-2 vessel, corresponding to the loading given in Table 4D.1-1, is

$$p = 470.3 + 42.2 + 2{,}478.8 + 51.6 = 3{,}043 \text{ psi } (20.981 \text{ MPa}) .$$

4E.2 CALCULATIONS FOR SURROGATE OF MIXED POWDERS FOR PHASE 4 TESTS

For the NUREG-0360 accident-modeling tests, a surrogate of the loading listed in Table 4E.1-1 was prepared. The surrogate was designed to exceed the MCAP given in Table 4.5.2-1, 3,043 psi (20.981 MPa). This was accomplished by using 10 grams of PVC rather than the 9 grams listed in Table 4E.1-1. Furthermore, two quartz liners totaling 16.0 grams were placed in two BC-1 brass canisters, and a disk of brass was added, totaling 49.2 grams of brass. The free volume in this case was 60.0 cm^3. The surrogate contents are listed in Table 4E.2-1.

Table 4E.2-1

Surrogate for Mixed Powders of PuO_2 and UO_2

Mass of UO_2 powder	40.0 g
Mass of PVC	10.0 g
Moisture content (unbound H_2O)	0.5 g
Teflon™ tape	0.3 g
Mass of quartz	18.0 g
Mass of brass (2 BC-1 canisters plus a disk of brass)	49.2 g

The MCAP calculated for this surrogate was 3,313 psi (22.842 MPa), which is somewhat larger than the MCAP calculated for the loading listed in Tables 4.5.2-1 and 4E.1-1, 3,043 psi (20.98 MPa). Thus, the NUREG-0360 accident-modeling tests using the surrogate involved considerably more stringent conditions than for the loading given in Table 4E.1-1.

APPENDIX 4F

Gas Leakage Rate and Equivalent Capillary Diameter

4F.1 METHOD FOR CALCULATIONS

Owzarski et al[5] studied the flow of gases through capillaries and orifices and provided a computer code (CAPIL) for calculating the flow rate through rough capillaries. Their results[4] are plotted in Figure 4F.1-1. For the very low leakage rates encountered in these tests, it is more convenient to use the following expression for flow in smooth capillaries,

$$\dot{q} = \frac{\pi D^4}{256\,\mu L}\,(p_i^{\,2} - p_f^{\,2}) \ ,$$

where D is the capillary diameter, μ is the gas viscosity, L is the capillary length, and p_i and p_f are the upstream and downstream pressures, respectively.

For the standard leakage test using helium at 77°F (25°C) and for a capillary length of 0.28 inch (0.716 cm) (the length of the probable leakage path for the TB-2 vessel), the flow rate is given by

$$\dot{q}_{He} = (9.506 \times 10^7)\ D^4 \ ,$$

where $\dot{q}_{He}$ has units of $cm^3 \cdot atm/s$, and D is in cm.

For air at 77°F (25°C), the equivalent expression is

$$\dot{q}_{air} = (8.675 \times 10^7) D^4 \ .$$

These equations for helium and air flow rates are also plotted on Figure 4F.1-1 (the broken lines). For a given leakage rate, they predict a somewhat larger diameter than the results of Owzarski et al, and, hence, they provide upper bounds for the calculated cross-sectional areas of the capillaries.

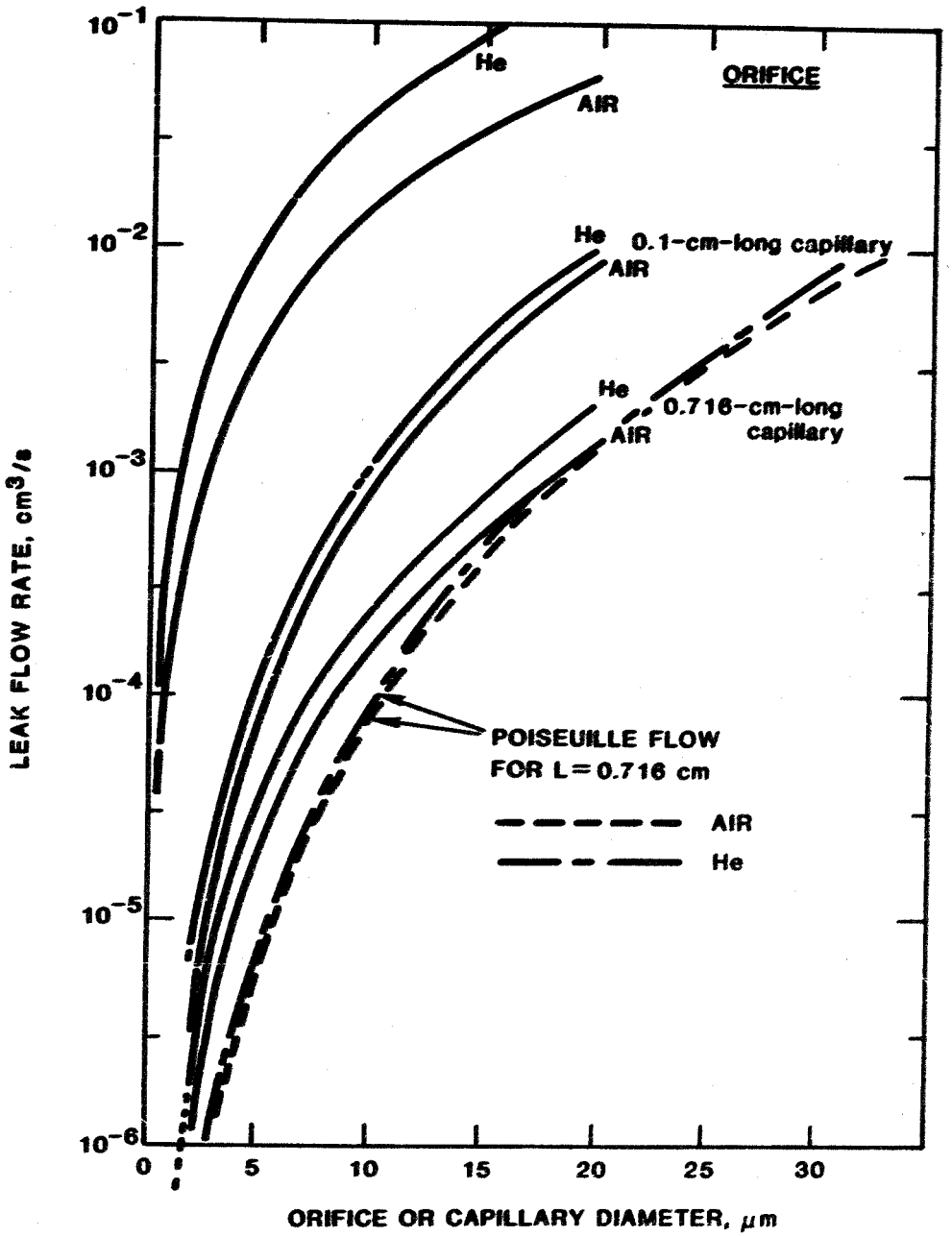


Figure 4F-1. Standard Leakage Rates (1 atm, 32°F) for Helium and Air through Orifices and Smooth Capillaries of Various Diameters

4F.2 EQUIVALENT CAPILLARY DIAMETER FOR THE LARGEST MEASURED LEAK

For test package X08, which contained a surrogate of PuO_2, the post-test measured helium leakage rate was 2×10^{-5} cm^3/s. Using the above equation for $\dot{q}_{He}$, the capillary diameter is calculated to be

$$D = (2 \times 10^{-5}/9.506 \times 10^{7})^{1/4} = 6.77 \times 10^{-4} \text{ cm} = 6.77 \ \mu\text{m} .$$

It is informative to compare this calculated diameter with the results of Owzarski et al. From their results a diameter of about 3.5 μm is obtained.

It should be pointed out that most of the measured leakage rates were smaller than 1×10^{-10} cm^3/s; a diameter of 0.32 μm corresponds to a helium leakage rate of 1×10^{-10} cm^3/s. Thus, for most of the test results, any leakage path had an equivalent diameter less than 0.32 μm.

APPENDIX 4G

Calculated Theoretical PuO_2 Release

The results of extensive measurements of the transmission of PuO_2 and UO_2 powders through small openings have been correlated with the product of the cross-sectional area, A, of the opening and the square root of the upstream pressure, p. The correlations for the mass of PuO_2 released, m_{PuO_2}, as recommended by Owzarski et al, are

$$\ln\left(m_{PuO_2}\right) = -5.78, \text{ for } \ln(A\sqrt{p}) < 6.414 ,$$

and

$$\ln\left(m_{PuO_2}\right) = -9.5260 + 0.5840 \ln(A\sqrt{p}) , \text{ for } 6.414 < \ln(A\sqrt{p}) < 10.5 ,$$

where A has the units μm^2, p is in psia, and m_{PuO_2} is the total mass of PuO_2 released in μg.

It was emphasized by Owzarski et al that the mass released is independent of time; i.e., the total transport of PuO_2 aerosol through the orifice or capillary occurs in a relatively short time. After the initial burst of aerosol occurs, either the opening plugs with particulates or the aerosolization process ceases to produce a suspension of particulates in the gas.

4G.1 SAMPLE CALCULATIONS FOR THE SURROGATE OF PLUTONIUM SULFATE TETRAHYDRATE

As shown in Appendix 4F, the helium leak rate measured after the test sequence for the surrogate of PuO_2 corresponds to a capillary diameter of 6.77 μm. The area of this capillary was calculated to be 36.0 μm^2, and the pressure is 3,313 psia (22.842 MPa).* Thus,

$$\ln(A\sqrt{p}) = \ln(36.0\sqrt{3313}) = 7.636 .$$

*3,313 psia is the pressure with the surrogate; the PAT-2 MCAP is 3,280 psia, as shown in Table 4.5.1-2.

Since $\ln(A\sqrt{p})$ is in the range between 6.414 and 10.5, the recommended correlation is

$$\ln\left(m_{PuO_2}\right) = -9.5260 + 0.5840 \ln(A\sqrt{p})$$

Hence, the total mass of PuO_2 powder released is calculated to be

$$m_{PuO_2} = 0.00631 \ \mu g \ .$$

This release of plutonium is considerably lower than an A2 quantity. For Pu-238, an A2 quantity is 176 µg; for a typical plutonium mixture, an A2 quantity is 2,550 µg.

APPENDIX 4H

Additional Practical Considerations Regarding Possible Plutonium Release

The application of the Battelle correlations[4] to the PAT-2 package with the TB-2 containment vessel involves extrapolations to much lower gas leak rates than those associated with the Battelle PuO_2 transmission experiments. The air flow rates measured through the capillaries and orifices used by Battelle were generally much larger than 0.1 cm^3/s; that is, they were several orders of magnitude larger than the leak rates measured after the PAT-2 accident-modeling tests. At very low flow rates, the PuO_2 powder is not likely to aerosolize and become entrained in the escaping gas, so the Battelle correlations are likely to overpredict the PuO_2 loss at low leak rates.

Further evidence that PuO_2 emissions through small openings are extremely small has been provided by Schwendiman et al[11] and Yesso et al.[12] Leak rates measured using a simulated crack indicated that, with the exception of four experiments which involved vibration, no PuO_2 was emitted through a crack formed by a split tapered disk. The helium leak rates for the experiments which showed PuO_2 transmission were of the order of 2 cm^3/s, and the total PuO_2 which escaped in each of the four experiments was less than 0.001 μg.

Based on the helium leakage rate measured for test package X08 listed in Table 4.5.3.1-1, a capillary diameter of 6.77 μm was estimated above. This diameter corresponds to a cross-sectional area of the leak of 36.0 μm^2. If this cross-sectional area is considered to be that of a crack between two bolt holes of the TB-2 containment vessel rather than a capillary path of circular cross section, the width of the crack (the distance between the edges of two bolt holes) is 4.5 mm. The height of the crack, assuming a rectangular cross section with an area of 36.0 μm^2, is calculated to be 80 Å. Thus, the only aerosol which could pass through a crack with such a small height would have molecular dimensions, and the mass of aerosol which could escape, if escape were even possible, would be extremely small.

For most of the tests, $\dot{q}_{He} < 1 \times 10^{-10}$ cm^3/s. The capillary diameter corresponding to a helium leak rate of 1×10^{-10} cm^3/s is calculated to be 0.32 μm. In this case only aerosol particles with diameters less than 0.32 μm could escape, and larger particles are likely to plug the escape path.

It is instructive to examine predicted PuO_2 release as a function of the helium leak rate and system pressure, and such predicted results are shown in Table 4H. The calculations for Table 4H are based on helium leakage from a capillary 0.716 cm in length, using the recommended equations in NUREG/CR-0958 and given above. At the lower leak rates ($\dot{q}_{He} < 10^{-6}$ cm^3/s), the term $\ln(A/\sqrt{p})$ corresponds to the lowest range of release data obtained by Owzarski et al. For this range [$\ln(A/\sqrt{p}) < 6.14$], the total release correlation yields a constant mass of 0.00309 μg; that is, the PuO_2 release is independent of the system variables. Table 4H shows that even for leak rates larger than any measured in these tests, the calculated PuO_2 release is well below an A2 quantity, and well below an A2 x 10^{-3} quantity.

Table 4H

Calculated Plutonium Release for Various Conditions

P, Pressure (psia)	$\dot{q}_{He}$, Helium Leak Rate (cm^3/s)	Total Pu Release (μg)	IAEA A2 for a Pu Mixture (μg)	IAEA A2 for Pu-238 (μg)
	10^{-4}	0.00363		
	10^{-5}	0.00309		
100	10^{-6}	0.00309	2,550	176
	10^{-8}	0.00309		
	10^{-10}	0.00309		
	10-4	0.0101		
	10-5	0.00514		
3280	10^{-6}	0.00309	2,550	176
	10^{-8}	0.00309		
	10^{-10}	0.00309		

APPENDIX 4J

Deformation of the TB-2 Vessel at Elevated Temperature and Pressure

At the maximum credible accident temperature of 582°C (1,080°F), the strength of the A-286 iron-base superalloy used for the TB-2 vessel is reduced by 22%.[13] To verify that the containment boundary remains undamaged at the elevated temperature and pressure of the fire test, numerical computations of the stresses and distortion of the TB-2 vessel were performed. The finite element computations incorporated the actual preload conditions imposed on the bolts, the reduction of strength associated with the elevated temperature, and the thermal expansion of the A-286 and the copper gasket. Figure 2C.2.3-1 shows the undeformed TB-2 cross section and the mesh used for the calculations. Figure 2C.2.2-1 shows the computed deformations corresponding to an internal pressure of 3,280 psi (23.897 MPa), the pressure calculated for the MCAP condition. The most significant feature is the distortion of the inner corner of the vessel. At the knife edge, the vessel was calculated to raise or lift about 0.00025 inch (6.4 μm). It is important to note that the surface of contact between the copper gasket and the region of the TB-2 vessel outward from the gasket remains unraised or unlifted.

These calculations indicate that the containment boundary remains essentially intact at the elevated temperature and pressure of the test sequence. Examination of the copper gaskets removed from the sealing grooves of the TB-2 vessels tested in the accident modeling indicated no discernable distortion of the copper, or any evidence of leakage, confirming that the containment boundary remained essentially unimpaired.

REFERENCES

[1]Code of Federal Regulations, Title 10, Part 71, "Packaging of Radioactive Material for Transportation under Certain Conditions" (Washington: Government Printing Office).

[2]U.S. Nuclear Regulatory Commission, Qualification Criteria to Certify a Package for Air Transport of Plutonium, NUREG-0360 (Washington: U.S. NRC, January 1978).

[3]International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Materials, IAEA Safety Standards, Safety Series No. 6, 1973 revised ed., as amended 1979 (Vienna: IAEA, 1979).

[4]P. C. Owzarski et al, Analysis of Particulate Transmission through Small Openings Resulting from Container Stresses, NUREG/CR-0958 (Richland, WA: Battelle Pacific Northwest Laboratories, April 1980).

[5]P. C. Owzarski et al, Measured and Predicted Gas Flow Rates through Rough Capillaries, NUREG/CR-00745, PNL-2623 (Richland, WA: Battelle Pacific Northwest Laboratories, June 1979).

[6]J. H. Keenan and F. G. Keyes, Steam Tables (New York: John Wiley & Sons, Inc., 1969).

[7]American National Standards Institute ANSI N14.5 and/or U.S. Nuclear Regulatory Commission Regulatory Guide 7.4, "Leakage Tests on Packages for the Shipment of Radioactive Materials."

[8]Ahrland et al, The Chemistry of the Actinides, Vol. 10 of the Pergamon Texts in Inorganic Chemistry (New York: Pergamon Press).

[9]R. R. Stromberg, S. Straus, and B. G. Achhamer, Journal of Polymer Science 35:355, 1959.

[10]M. M. Bikales, ed., Encyclopedia of Polymer Science and Technology, Vol. 13 (New York: Interscience Publishers, 1970), pp 623-670.

[11]L. C. Schwendiman et al, Study of Plutonium Oxide Leak Rates from Shipping Containers, PNL-2260-7 (Richland, WA: Battelle Pacific Northwest Laboratories, August 29, 1978).

[12]Yesso et al, NUREG/CR-1302, PNL-3278 (Richland, WA: Battelle Pacific Northwest Laboratories).

[13]Department of Defense, Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5C (Washington: DoD, September 1976).

CHAPTER 5

RADIATION SHIELDING EVALUATION

5.1 SUMMARY

The PAT-2 package was evaluated to determine the radiation environment external to the package when loaded with an excess* of plutonium or mixed uranium/plutonium-bearing materials. A variety of payload isotopic compositions was considered and a specific mixture selected for use in determining the external dose rates. The intensity of the selected worst-case source model will not be exceeded by any real payload. The calculated dose rates external to the package, including the effect of ground scatter, show that the package meets all shielding requirements of 49 CFR 173.393, 10 CFR 71.36, and IAEA Safety Series 6 (S.S. 6) for B(U) packages. The calculated results for normal operation and for worst-case post-accident radiation tissue dose rates for the assumed source are shown in Table 5.1-1.

5.2 GENERAL

The purpose of this chapter is to show that the radiation levels external to the PAT-2, when loaded according to the specifications given in Section 1.2.4, are within the regulatory limits set by the U.S. and international authorities (49 CFR 173, 10 CFR 71, and IAEA S.S. 6). The regulatory limit for normal operation specifies a maximum tissue dose rate of 10 mrem/h at a distance of 3 feet (0.91 metre) from any accessible surface of the package and a maximum tissue dose rate of 200 mrem/h on the surface of the package. The limit under accident conditions is 1,000 mrem/h at 3 feet (0.91 metre) from the package surface.

The radiation in the PAT-2 is produced by the natural radioactivity (including spontaneous fissions) of the uranium and plutonium isotopes that constitute the payload, the daughter products of these isotopes that may have accumulated since the material was extracted from its parent fuel, and induced reactions with oxygen or other low-Z materials that might be present. The source strength is limited by the concurrent constraints placed on the contents (see Section 1.2.4).

---

*As will be explained, a loading of 47 grams of plutonium, rather than 15 grams, is used in this chapter. This loading provides an additional 47/15, or 3.13, factor of safety.

Table 5.1-1

Calculated Dose Rates External to the PAT-2 Containing Worst-Case Source (47 grams Pu, 2 watts thermal)

Normal Operation		
Dose rate on the surface		7.6 mrem/h
Dose rate 3 ft (0.91 m) from the surface		0.24 mrem/h
Postaccident Case		
Dose rate 3 ft (0.91 m) from the surface		0.40 mrem/h
IAEA Safety Series 6, B(U) Packages		
Quantity of ^{192}Ir required to produce 10 mrem/hr at 1 m from the surface, normal operating conditions	side	0.068 Ci
	top	0.063 Ci
Postaccident dose rate 1 m from the surface if the package contains 0.063 Ci of ^{192}Ir, worst location		15 mrem/h
Neutron source (fission spectrum) required to produce 10 mrem/hr neutron dose rate at 1 m from the surface, normal operating conditions		6.2×10^6 n/s
Postaccident dose rate 1 m from the surface if the package source is 6.2×10^6 n/s		17 mrem/h

5.3 SOURCE DEFINITION

Definition of the worst-case radiation source for the PAT-2 is based on the payload definitions for IAEA safeguards analytical samples.[1] These contents or payload definitions are discussed in detail in Appendix 5A. They cover a variety of mixtures of plutonium and uranium that might occur in various thermal and fast reactor fuel cycles.

For the payload candidates identified in Appendix 5A, the thermal power and nuclear radiation produced by the payload of the PAT-2 will depend primarily on the quantity and isotopic mix of the plutonium. The common uranium isotopes U-235, U-236, and U-238 are long-lived and produce very small amounts of heat and radiation

compared with the plutonium isotopes of concern. The short-lived isotope U-232 is a decay product of Pu-236 and is therefore present in samples that contain this isotope.*

The worst-case safeguards sample payload identified by the IAEA[1] is shown in Table 5A-4, Appendix 5A. It consists of 8 grams plutonium in a mixed plutonium/uranium oxide powder. The thermal source from this payload will be about 0.34 watt at 14.6 years (and less than that from zero to 14.6 years), or well below the 2-watt PAT-2 limit. Although it is unlikely that the radiation source in the PAT-2 payload would exceed that shown in Table 5A-4, this study uses a source model of 47 grams plutonium (which produces 2 watts thermal) as a bounding assessment, with the isotopic mix shown in Table 5A-4. This clearly validates the 15-gram plutonium contents specified in Section 1.2.4.

The worst-case gamma-ray source was obtained from Table 5A-1 of Reference 2 and is shown later in Table 5.4.4-3. These data represent a payload with a shelf life of 14.6 years, i.e., in which approximately half the Pu-241 initially present has decayed to Am-241. The neutron source rate assumes the presence of oxygen and includes the resulting (α,n) contribution. No mixture of plutonium isotopes that would be produced in quantity from existing sources has been identified that would result in a significantly higher radiation source than that for the case selected. The assumption of a 2-watt thermal source of plutonium for the PAT-2 exceeds by almost a factor of 6 the thermal activity of the mass-limited worst-case payload identified in Appendix 5A. Additional conservatism in the source does not appear warranted.

The neutron source strength for the selected plutonium isotopic mix, using the 47-gram source model in the PAT-2, is 1.5×10^5 n/s.** About 20% of these neutrons originate from spontaneous fission, the remainder arising from (α,n) reactions. The gamma-ray source for the maximum payload is 2.3×10^{10} γ-MeV/s.†

---

*U-232 is also generated in thorium fuel cycles and will be a constitutent of any uranium extracted from such fuel cycles. The radiation source in such samples can exceed that from the plutonium samples considered for the PAT-2. However, this is not an IAEA safeguards payload and thus has not been used in this analysis.

**From Table 5A-4, 2.5×10^4 n/s for 8 grams; $(47/8)(2.5 \times 10^4) = 1.5 \times 10^5$.

†From Table 5A-4, 3.9×10^9 γ-MeV/s for 8 grams; $(47/8)(3.9 \times 10^9) = 2.3 \times 10^{10}$.

5.4 SHIELDING CALCULATIONS

A series of radiation transport calculations was performed on the PAT-2 in normal and post-accident configurations to determine the radiation environments on the suface and 3 feet (0.91 metre) from the surface of the package. All one-dimensional calculations were performed with the ANISN discrete ordinates code.[3] Two- and three-dimensional calculations were performed with the MORSE code.[4] The shielding afforded by the PVC bagging, brass canisters, quartz vials, stainless steel C-1 capsule, and self-attenuation of the payload material was conservatively eliminated. Fissions induced in the payload material were also neglected since they contribute negligibly to the source (see Chapter 6). The geometries considered are described in the following paragraphs.

5.4.1 One-Dimensional, Normal Operation (ANISN)

The PAT-2 was modeled in spherical geometry using layer thicknesses based on the minimum shielding path through the bottom of the package. For the neutron transport calculations, 3 feet (0.91 metre) of air was assumed external to the package followed by a 1.2-inch (3-cm) thick water phantom. This geometry is shown in Figure 5.4.1-1 and Table 5.4.1-1. The effect of the water phantom, included in some of the calculational models to account for perturbation of the radiation field by a human body, is small. No water phantom was included in the gamma-ray calculations.

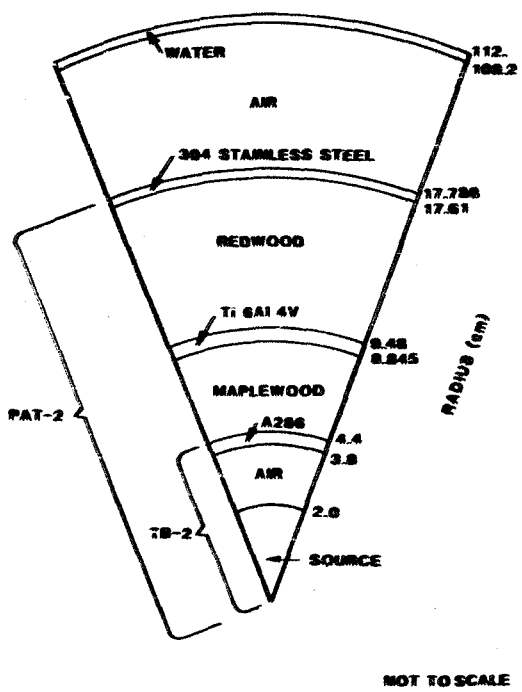


Figure 5.4.1-1. One-Dimensional Model of the PAT-2 (Normal Operation)

Table 5.4.1-1

One-Dimensional Model of the PAT-2
(Normal Operation)

Zone	Zone Outer Radius (cm)	Thickness (cm)	Material
1	2.0	2.0	Source
2	3.8	1.8	Air
3	4.4	0.6	A-286 steel
4	8.845	4.445	Maplewood
5	9.48	0.635	Ti-6Al-4V
6	17.61	8.13	Redwood
7	17.788	0.178	304 Stainless steel

5.4.2 One-Dimensional TB-2 Containment Vessel Model (ANISN)

The TB-2 portion of the PAT-2 model shown in Figure 5.4.1-1 was used separately in air to determine the radiation environment from the worst-case source when the loaded TB-2 containment vessel is outside the AQ-2 overpack. This does not correspond to a post-accident model for the PAT-2 because the load spreader is not included. In this model, a water phantom was again placed 3 feet (0.91 metre) from the TB-2 for the neutron calculations.

5.4.3 Two-Dimensional, Normal Operation (MORSE)

A detailed model of the PAT-2 was developed using the MORSE combinatorial geometry. A cross section of this geometry, generated using the PICTURE code,[4] is shown in Figures 5.4.3-1 and 5.4.3-2. The model included 1.6 inches (4 cm) of ground underneath the package, 16.4 feet (5 metres) of air vertically, and 8.2 feet (7.5 metres) of air radially around the package. No water phantom was used.

The material compositions used in the MORSE model were identical to those used in the ANISN model with the addition of soil and aluminum. The soil composition used was identical to that used in Reference 2 for the PAT-1.

5.4.4 Three-Dimensional, Post-Accident (MORSE)

Following the impact and other tests performed on the PAT-2, the package was deformed and the minimum distance between the TB-2 and the package surface was decreased (see Chapter 2). The impact orientation that resulted in the TB-2 being

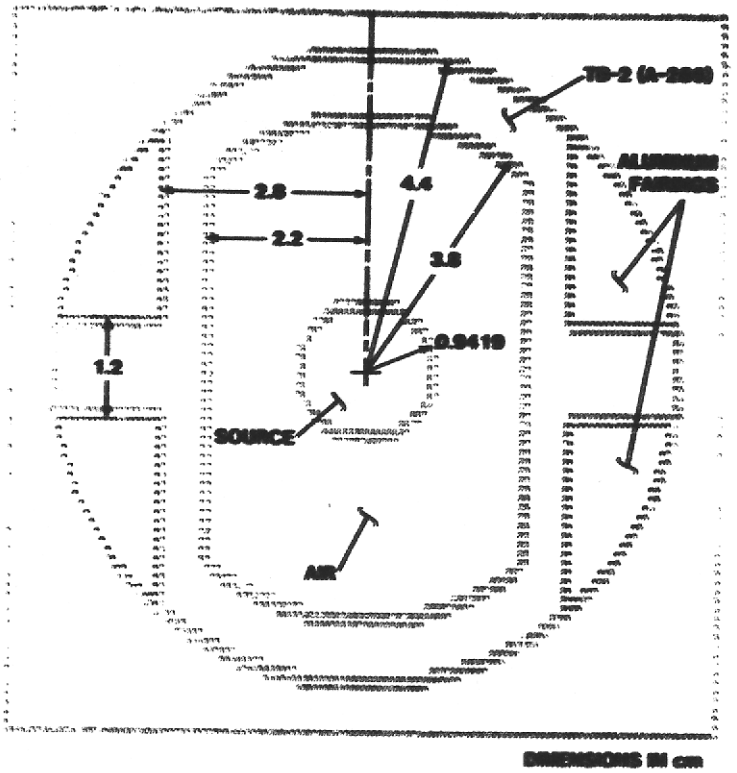


Figure 5.4.3-1. Two-Dimensional MORSE Model of the TB-2 (Side View)

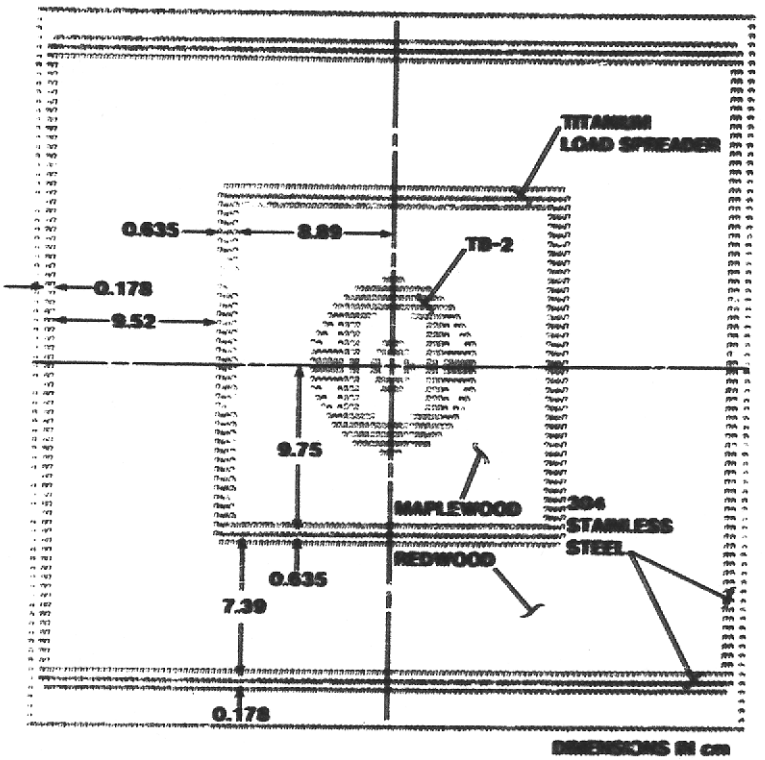


Figure 5.4.3-2. Two-Dimensional MORSE Model of the PAT-2 (Side View)

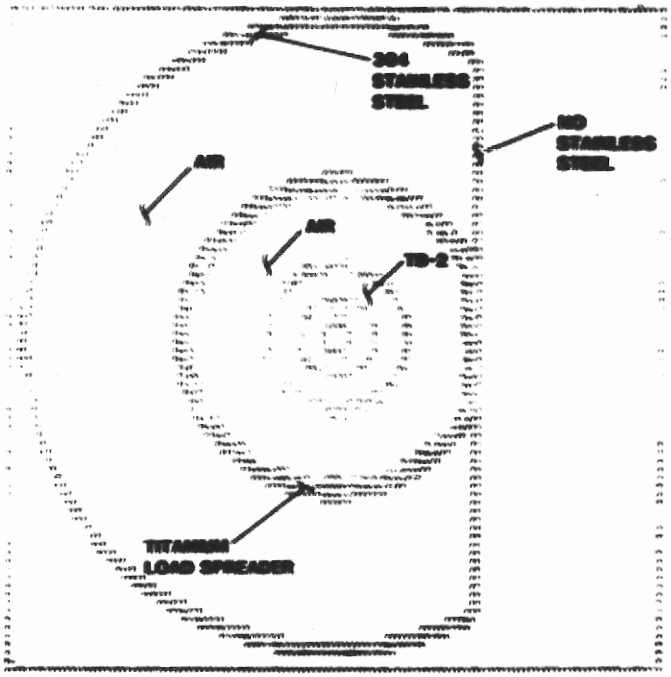
closest to the external package surface was the side impact, and thus the configuration of Figure 2.8.2-5 was modeled to determine the post-accident radiation environment. This geometry is shown in Figure 5.4.4-1. The minimum distance between the TB-2 and the outer surface of the load spreader in this geometry is 1.4 inches (3.5 cm).

Following the qualification tests to which the package shown in Figure 2.8.5-4 was subjected, the 304 stainless steel outer covering of the package was intact except for where it had been slashed or punctured by the test sequence, and for short tears on the impacted surface in corner impacts. Because the stainless steel skin was breached in places and because its absence from the impacted surface maximizes the calculated external radiation dose rate, the stainless steel was omitted entirely from the impacted surface of the package in the post-accident calculational model. The essentially undamaged skin on other portions of the package was included in the model, adding conservatism as will be explained.

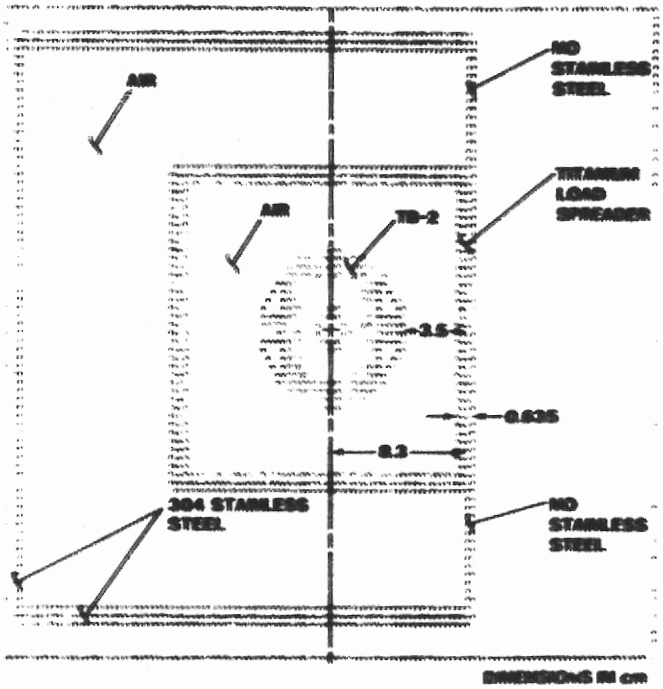
The qualification test series included exposing the damaged package to a 60-minute JP-4 jet fuel fire, following which a rigid, carbonaceous char remained from the redwood and maplewood. This char held the load spreader and the TB-2 in place inside the stainless steel outer skin. However, because characterization of this char is difficult for shielding application and because omission of the char will maximize the post-accident external radiation levels, the residue from the wood was neglected and the wood volume was assumed to to be filled with air. Thus the MORSE post-accident model considered the TB-2 inside the deformed but otherwise empty load spreader, with a shell of stainless steel around the back side. This shell served to reflect a portion of the radiation that would escape the TB-2 in the direction away from the damaged face, and thus the model maximized the dose rate in the open, damaged direction. The post-accident model also included ground and air, as in the two-dimensional model described above.

The elemental compositions of the various materials used in the above models are shown in Table 5.4.4-1. The redwood composition is identical to that used in Reference 2. The elemental composition of maplewood was assumed to be the same as that of redwood, but was assumed to have a density of 0.71 g/cm^3. The calculated results are not sensitive to the composition or density of the woods used, and the present model is believed to be both reasonable and accurate.

The composition of A-286 steel was taken from Reference 5, while those used for 304 stainless steel and soil were identical to those in Reference 2. The load spreader was assumed to be Ti-6Al-4V[5] in the one-dimensional calculations. In the



a. End View



b. Side View

Figure 5.4.4-1. Three-Dimensional MORSE Model for the Post-Accident PAT-2

Table 5.4.4-1

Compositions of Materials Used in the PAT-2 Shielding Analyses

Material	Density (g/cm3)	Element	Composition (atoms/barn cm)
A286 Steel	7.91	Ti	2.139×10^{-3}
		Cr	1.375×10^{-2}
		Fe	4.830×10^{-2}
		Ni	2.029×10^{-2}
		Mo	6.210×10^{-4}
Aluminum	2.70	Al	6.020×10^{-2}
Maplewood	0.71	H	2.432×10^{-2}
		C	1.788×10^{-2}
		O	1.181×10^{-2}
Ti 6Al 4V	4.43	Al	5.936×10^{-3}
		Ti	5.016×10^{-2}
		V	2.096×10^{-3}
Unalloyed Ti	4.50	Ti	5.660×10^{-2}
Redwood	0.36	H	1.242×10^{-2}
		C	9.131×10^{-3}
		O	6.034×10^{-3}
304 Stainless Steel	7.9	Cr	1.738×10^{-2}
		Mn	1.732×10^{-3}
		Fe	5.785×10^{-2}
		Ni	8.103×10^{-3}
Air	1.21×10^{-3}	N	4.1×10^{-5}
		O	9.7×10^{-6}
Soil	1.7	H	3.40×10^{-2}
		O	3.98×10^{-2}
		Al	8.81×10^{-3}
		Si	3.71×10^{-3}

actual PAT-2 design, the sides and top of the load spreader are composed of unalloyed Ti, while the bottom is made from Ti-6Al-4V. This difference has a negligible effect on the radiation shielding properties of the load spreader.

The C-1 capsule was neglected in all of the radiation transport calculations presented here. The nominal wall thickness of this container is 0.030 inch (0.77 mm), and it has a negligible effect on the radiation shielding provided by the TB-2 containment vessel.

The Monte Carlo calculations assumed a point source located on the axis of the TB-2, 0.3 inch (2 cm) above the midplane. Because the nonradioactive contents of the TB-2 and the self-shielding of the source were omitted from the model, thereby maximizing the amount of escaping radiation, a spatially distributed source was not needed. By offsetting the source point, the line-of-sight between the source and the closest point on the PAT-2 surface did not pass through the flange of the TB-2. A series of calculations was performed in which the location of the source point and the orientation of the TB-2 were varied (source point centered in the TB-2 and offset by 0.8 inch (2 cm); flange horizontal, inclined at 45°, and vertical). The effect of such variations on the external dose rate was less than two Monte Carlo standard deviations in every case. Therefore only the offset source/horizontal flange results are presented.

The present neutron and secondary gamma ray calculations were performed using the P_3 BUGLE cross sections,[6] collapsed into the 15-neutron, 8-gamma ray energy group structure* shown in Table 5.4.4-2. This set is similar to the 12-8 set discussed in Reference 2. The comparison calculations reported in that reference, and other calculations performed with the 15-8 set, indicate that it is reliable and accurate for the type of shielding calculations of concern in this study. The primary gamma-ray transport calculations were made using the P_3, 11-energy-group cross section library discussed in Reference 2. The energy structure of this library is shown in Table 5.4-4-3. As in Reference 2, the neutron and secondary-gamma transport was calculated separately from the primary gamma-ray transport.

The source in the neutron transport calculations used the prompt-fission neutron energy spectrum shown in Table 5.4.4-2. Calculations reported in Reference 2 showed that the external dose rates calculated using this source spectrum differed only slightly from those obtained using an (α,n) source spectrum. The source used in the primary gamma-ray transport calculations is shown in Table 5.4.4-3.

Table 5.4.4-2

Cross-Section Group Structure and Dose Factors for PAT-2 Neutron Shielding Calculations

Group No.	Neutrons: Upper Energy Bound	Neutrons: Dose Factor (mrem/hr per n/cm²•s)	Neutrons: Fission Spectrum
1	14.92 MeV	0.209	0
2	13.50 MeV	0.149	0.007
3	7.408 MeV	0.153	0.236
4	2.725 MeV	0.127	0.325
5	1.353 MeV	0.122	0.297
6	497.9 keV	0.051	0.117
7	111.1 keV	0.014	0.014
8	24.79 keV	4.3×10^{-3}	0.001
9	5.531 keV	3.6×10^{-3}	0
10	1.234 keV	3.8×10^{-3}	0
11	275.4 eV	4.1×10^{-3}	0
12	101.3 eV	4.3×10^{-3}	0
13	37.27 eV	4.4×10^{-3}	0
14	10.68 eV	4.6×10^{-3}	0
15	0.414 eV	3.7×10^{-3}	0
	10^{-5} eV		

Group No.	Gamma Rays: Upper Energy Bound (MeV)	Gamma Rays: Dose Factor (mrem/hr per γ/cm²•s)
1	14.	8.8×10^{-3}
2	8.	7.3×10^{-3}
3	6.	5.8×10^{-3}
4	4.	4.4×10^{-3}
5	2.5	3.2×10^{-3}
6	1.5	2.3×10^{-3}
7	1.0	1.56×10^{-3}
8	0.45	0.7×10^{-3}
	0.01	

Table 5.4.4-3

Cross-Section Group Structure and Dose Factors for PAT-2 Gamma-Ray Shielding Calculations

Group No.	Upper Energy Bound (MeV)	Dose Factor (mrem/hr per $\gamma/cm^2 \cdot s$)	Worst-Case PAT-2 Gamma Ray Source Spectrum (γ/s per 47 g Pu)
1	3.5	4.36×10^{-3}	2.7×10^{3}
2	3.0	4.00×10^{-3}	1.11×10^{5}
3	2.6	3.71×10^{-3}	4.7×10^{3}
4	2.2	3.24×10^{-3}	1.05×10^{4}
5	1.8	2.77×10^{-3}	2.4×10^{4}
6	1.35	2.30×10^{-3}	3.0×10^{4}
7	0.9	1.51×10^{-3}	6.2×10^{6}
8	0.4	0.83×10^{-3}	1.45×10^{7}
9	0.2	0.36×10^{-3}	9.3×10^{7}
10	0.1	0.37×10^{-3}	2.4×10^{11}
11	0.01	0.37×10^{-3}	*
	0.001		

* Source photons below 10 keV are neglected because of their low penetrating power.

5.5 RESULTS

A number of radiation transport calculations have been performed on the PAT-2 using the computer codes, cross sections, and geometries described in Section 5.4. The calculated total dose rates are shown in Table 5.5-1. The undamaged PAT-2 is 14 inches (35.56 cm) high and 15 inches (38.1 cm) in diameter. Thus the dose rates at the top and bottom of the package are slightly greater than that at the side of the package. However, as shown in the table, this difference is small. On the other hand, the worst-case side and top dose rates differ significantly in the side-impact post-accident geometry since the minimum distance between the source and the package exterior is considerably modified by the impact. All of the dose rates shown in Table 5.5-1 are well within the regulatory requirements and qualification criteria for the PAT-2.

Table 5.5-1 shows both the one-dimensional discrete ordinates results and the multi-dimensional Monte Carlo results for the dose rate external to the PAT-2 in normal operation. The results from the two codes are in good agreement. The ANISN

Table 5.5-1

Calculated Dose Rates (in mrem/h) External to the PAT-2 with Worst-Case Source Model (47 grams Plutonium)

Operation	Neutron	Secondary Gamma Ray	Primary Gamma Ray	Total
Normal				
One-dimension (ANISN)				
surface	3.2	0.027	4.2	7.4
3 ft	0.13	0.004	0.18	0.31
Two-dimension (MORSE)				
surface (top)	3.6 ± 0.13	NM	4.0 ± 0.2	7.6 ± 0.3
3 ft (top)	0.080 ± 0.003	NM	0.15 ± 0.005	0.24 ± 0.01
3 ft (side)	0.091 ± 0.005	NM	0.14 ± 0.008	0.23 ± 0.01
Postaccident				
Three-dimension (MORSE)				
3 ft (top)	0.15 ± 0.0015	NM	0.18 ± 0.005	0.33 ± 0.01
3 ft (side)	0.17 ± 0.003	NM	0.23 ± 0.01	0.40 ± 0.01
Bare TB-2				
One-dimension (ANISN)				
surface	22	0.05	41	63
3 ft	0.22	0.005	0.38	0.55

result for the dose rate at the surface of the bare TB-2 is 10.7 mrem/h for a typical payload of 8 grams plutonium, as identified in Appendix 5A, or 63 mrem/h for the 47-gram source model used in the present calculations. No one-dimensional calculations of the post-accident dose rate were performed, although the dose rate calculated at 3 feet (0.91 metre) from the bare TB-2 containment vessel, 0.55 mrem/h, is in reasonable agreement with the post-accident, three-dimensional model result of 0.4 mrem/h (which includes the titanium load spreader). All of the results in Table 5.5-1 assume a 2-watt, 47-gram plutonium source model in the TB-2.

The uncertainties in the results presented here arise from uncertainties in the source terms, the cross sections, the computer models, and the solution convergence. The uncertainties in each of these factors are comparable to those reported in Reference 2. The largest uncertainty is again in the source definition. For this analysis, an extremely conservative (47/15 or 313% oversized) source term has been used. The cumulative uncertainty in the other areas should not exceed ±25%. The uncertainties shown in Table 5.5-1 indicate one Monte Carlo standard deviation and do not include these effects.

5.6 SPECIAL SHIELDING ANALYSES REQUIRED FOR TYPE B(U) PACKAGINGS

To qualify as Type B(U), a package must meet several stringent shielding requirements in addition to those specified for other types of packages. Specifically, a Type B(U) packaging must provide sufficient shielding in the post-test configuration to produce a dose rate everywhere less than 1 rem/h at 3.3 feet (1 metre) from the package surface if the package contained sufficient Ir-192 to produce a dose rate of 10 mrem/h at 3.3 feet (1 metre) from the surface prior to the tests. Where the packaging is restricted to particular radionuclides, those radionuclides may be used as the reference source in place of Ir-192. If the packaging is to be used for neutron emitters, an appropriate neutron source should also be used. For the PAT-2, the Ir-192 source is about equally stringent for meeting the B(U) photon source requirements as the gamma-ray source in Table 5.4.4-3.

To verify that the PAT-2 qualifies as a B(U) package, transport calculations were performed with MORSE, using the geometry models described in Section 5.4 and the 1-Ci Ir-192 source[7] shown in Table 5.6-1. The P_3, 11-group gamma-ray cross-section library (Table 5.4.4-3) was used. The results obtained from these calculations are shown in Table 5.6-2.

From Table 5.6-2 it is apparent that approximately 0.063 Ci of Ir-192 is required to produce a dose rate of 10 mrem/h 3.3 feet (1 metre) from the ends of an undamaged PAT-2; approximately 0.068 Ci will produce the same dose rate 3.3 feet (1 metre) from the sides of the package. In the side-impact post-test configuration, the dose rate at 3.3 feet (1 metre) from the damaged face was calculated to be 15 mrem/h assuming a source of 0.063 Ci of Ir-192.

The neutron (and secondary gamma-ray) dose rate 3.3 feet (1 metre) from the ends of the package in the normal condition will be 10 mrem/h if the neutron source rate is 6.2×10^6 n/s; i.e., about 42 times that from the worst-case source model (47 grams Pu, 2 watts). For this source, the post-test dose rate 3.3 feet (1 metre) from the side of the package will be about 17 mrem/h.

From the above results, it is clear that the PAT-2 meets the IAEA requirements for a B(U) package. In effect, such a package must retain enough shielding following the qualification tests to keep any increase in the external radiation dose rate to within a factor of 100 independently for neutrons and gamma rays. For the worst-case gamma source identified for the PAT-2, the qualification tests increase the dose rate external to the package by a factor of 1.5 (see Table 5.5-1), which is the same factor as that calculated for the Ir-192 source. For neutrons, this ratio is 1.9. In effect, much of the radiation shielding contained in the PAT-2 is provided by the TB-2, which is undamaged by the qualification tests. Hence the shielding effectiveness of the package is not seriously degraded by the tests.

Table 5.6-1

Ir-192 Gamma Source (Normalized to 1 Ci β Decay)

Energy Group	Upper Energy Bound (MeV)	Discrete ^{192}Ir Gamma Energy (MeV)	Photons per Decay	Photons/s per Ci by Group*
6	1.35	1.062	4.25×10^{-4}	1.73×10^{8}
		0.8846	4.25×10^{-3}	
7	0.9	0.61243	0.0585	2.7×10^{10}
		0.60438	0.08825	
		0.5886	0.04165	
		0.4891	0.0034	
		0.4846	0.034	
		0.46805	0.51	
		0.4166	≤0.00255	
8	0.4	0.3746	0.0051	5.6×10^{10}
		0.3165	0.85	
		0.30843	0.3145	
		0.2959	0.306	
		0.2834	0.0034	
		0.20579	0.0323	
		0.20128	0.00476	
9	0.2	0.13634	0.002295	8.5×10^{7}

* Source is zero in groups 1-5 and 10-11.

Table 5.6-2

Calculated Dose Rates External to the PAT-2 Assuming a Source of 1 Ci of Ir-192*

Normal Operation	Dose Rate (mrem/hr/Ci)
top	159 ± 2
side	146 ± 3
Postaccident	
top	196 ± 2
side	238 ± 6

* All results were obtained using MORSE.

5.7 NEUTRON ACTIVATION OF THE PAT-2

Because the PAT-2 is designed to carry radionuclides that emit neutrons, the package materials will become slightly radioactive by exposure to the neutrons from the source. The materials close to the source will receive a larger neutron flux and therefore will receive a higher activation per unit volume than materials far from the source. Although some charged particle reactions will occur, in particular the Ni-58(n,p)Co-58 and Fe-54(n,p)Mn-54 reactions,[8] most of the activation will be due to neutron absorption.

Using the neutron fluxes in the various materials predicted by the ANISN one-dimensional calculations discussed in Section 5.4, ORIGEN[9] calculations were performed, using a liquid metal fast-breeder reactor (LMFBR) neutron energy spectrum, to estimate the amount of activation that would occur in the various materials of the PAT-2. The maximum neutron source of 1.5×10^5 n/s was assumed. The brass (BC) containers, the nitronic 60 C-1 capsule, and the A-286 TB-2 containment vessel were considered, as shown in Table 5.7-1; the results of these calculations are shown in Table 5.7-2. Although these results are subject to a relatively large uncertainty, they are indicative of the magnitude of the activity that will be induced in the PAT-2 components by the postulated maximum neutron source.

For example, after exposure to the assumed neutron flux for 1 year, the TB-2, which has a mass of approximately 4.4 pounds (2 kg), will be activated to a total of 3×10^{-10} Ci. This activity will consist of gamma rays with energies on the order of 1 MeV or less.

The maximum amount of brass permitted inside the PC-1 is 50 grams. The calculated activity for this brass after exposure to the maximum neutron source for 1 year is 1.2×10^{-9} Ci, or about 50 gamma rays per second. This corresponds to a dose rate on the surface of the container of about 0.1 mrem/h, or a factor of ~ 5 above normal background in the U.S. This dose rate will decay to roughly background levels after about 1 day. Such dose rates are attained only in the immediate vicinity of the container and are negligible compared with the radiation environments normally present in facilities that handle radioactive materials.

Table 5.7-1

Material Compositions Used for Neutron Activation Calculations

	Element	Weight %
Brass	Cu	61.5
	Zn	35.5
	Pb	3.0
Nitronic 60	Si	4.0
	Cr	17.0
	Mn	8.0
	Fe	62.5
	Ni	8.5
A-286	Ti	2.15
	Cr	15.0
	Fe	56.6
	Ni	25.0
	Mo	1.25

Table 5.7-2

Gamma-Ray Activity Induced in PAT-2 by the 47-gram Worst-Case Neutron Source Model

Material	Induced Activity (Ci/kg) After Exposure for			Activity (Ci/kg) Following 1 yr Exposure Plus Decay of		
	1 mo	3 mo	1 yr	2 hr	1 day	10 days
Brass (8C) canisters	2.4×10^{-8}	2.5×10^{-8}	2.5×10^{-8}	1.7×10^{-8}	6.0×10^{-9}	1.2×10^{-9}
Nitronic 60 (C-1) capsule	1.0×10^{-9}	1.1×10^{-9}	1.1×10^{-9}	7.2×10^{-10}	1.4×10^{-10}	1.2×10^{-10}
A286 (TB-2) containment vessel	1.0×10^{-10}	1.2×10^{-10}	1.5×10^{-10}	1.2×10^{-10}	1.1×10^{-10}	7.0×10^{-11}

APPENDIX 5A

IAEA Payload Definition for the PAT-2

The IAEA Safeguards Analytical Laboratory (SAL) has identified five different payload types for the PAT-2:[1]

1. Breeder reactor mixed-oxide (MOX) pellets,
2. Thermal reactor MOX pellets,
3. PuO_2 or MOX powder containing more than 20% Pu,
4. MOX powder containing less than 20% Pu, and
5. Dried aliquots of solutions of Pu product material.

These payload types are described in detail in Table 5A-1. The table indicates that the maximum payload of plutonium would be contained in source type 4, which consists of a maximum of 40 grams of a mixed oxide powder containing up to 20%, or a maximum of 8 grams, of plutonium.

Since the IAEA did not specify the isotopic composition of the plutonium, it was necessary to consider the various sources of plutonium with which the IAEA may be concerned and determine which source would produce the most penetrating radiation. In a previous survey of alternative sources of plutonium for the PAT-1 package, (Appendix 5A of Reference 2), it was concluded that LWR recycle plutonium constituted the worst-case source. Some modifications have since been made to the plutonium isotopic composition from the various sources.[10 11] These data are partially summarized in Table 5A-2, and represent third-generation reprocessed LWR MOX fuel.

Since the isotopes Pu-238 and Pu-241 (actually the Pu-241 daughter product Am-241) are the most important radiation sources in plutonium, it is apparent that LWR plutonium from UO_2/PuO_2 fuel is the worst-case source.

Table 5A-3 shows the activities produced by 1 gram of the various plutonium isotopes and their daughter products. The Pu-236 isotope has been omitted from this table because of its extremely small mass fraction in the isotope mixtures in Table 5A-2. Oxygen is assumed to be present, and the (α,n) neutron source is included.*

---

*The neutron source from oxide fuels is typically twice to four times larger than that from metal fuels.[2]

Table 5A-1

IAEA/SAL Payload Types for PAT-2

TYPE 1: **Breeder Reactor Mixed Oxide Pellets**
Payload = 6 Pellets @ 5 g max.

	Element	Wt %	Mass (g)
Total	U	66	19.8*
	Pu	22	6.6
	O	12	3.6

*20% max. enrichment; therefore 4 g max. fissile.

TYPE 2: **Light-Water Reactor Mixed Oxide Pellets**
Payload = 6 Pellets @ 20 g max.†

	Element	Wt %	Mass (g) (Worst-Case)
Total	U	85-87	101.4‡
	Pu	0.5-3.5	4.2
	O	12	14.4

†More pellets at less weight are likely, e.g., 8 pellets @ 10 g each.
‡4% max. enrichment; therefore, 4.1 g max. fissile.

TYPE 3: **PuO_2 or Mixed Oxide Powder >20%Pu**
Payload = 6 samples @ 0.5 g max.

	Element	Wt %	Mass (g) (Worst-Case)
Total	U	0-67.5	0
	Pu	20-87.5	2.6
	O	9-12	0.3
	H_2O	0.5-3	0.1

Table 5A-1

IAEA/SAL Payload Types for PAT-2 (Continued)

TYPE 4: Mixed Oxide Powder <20%Pu
Payload = 2 samples @ 20 g max.

	Element/Compound	Wt %	Mass (g) (Worst-Case)
Total	U	67-87	28.2*
	Pu	0.5-20	8.0
	O	9-12	3.6
	H_2O	0.5-3	0.2

*20% max. enrichment; therefore 5.6 g max. fissile.

TYPE 5: Dried Aliquot of Pu Solutions
Payload = 3 samples @ 0.3 g Pu max.

(A) LASL - Recommended Procedure (ref 12):

	Element/Compound	Wt %	Mass (g)
Total	Pu	87.7	0.9
	O	9-12	0.1
	H_2O	0.5-3	0.03

(B) SAL - Recommended Procedure:

	Element/Compound	Wt %	Mass (g)
Total	Pu	48	0.9
	SO_4	38	0.7
	H_2O	14	0.3

Table 5A-2

Possible Isotopic Mixtures of Plutonium (in weight-percent)

Isotope	LMFBR (ref 2)		LWR (ref10)		CANDU (ref11) (Slightly Enriched)
	FFTF	CRBR	UO_2	MOX	
^{236}Pu	5×10^{-9}	2×10^{-8}	7×10^{-8}	1×10^{-8}	Nil
^{238}Pu	0.2	1.5	1.4	4	0.4
^{239}Pu	80	61	55	36	48
^{240}Pu	18	29	25	31	36
^{241}Pu	1.3	5	13	18	9
^{242}Pu	0.3	4	5	11	7

Table 5A-3

Radiation Sources from Plutonium Isotopes with Daughter Products

Isotope	n/s/g*	γ-MeV/s/g	Watts/g	Ci/g
^{238}Pu	3.5×10^{4}	1.7×10^{7}	0.56	17
^{239}Pu	95	9.0×10^{4}	2×10^{-3}	0.06
^{240}Pu	1.3×10^{3}	8.9×10^{7}	7×10^{-3}	0.2
^{241}Pu**	6.2×10^{3}	2.6×10^{9}	0.1	100
^{242}Pu	2.0×10^{3}	1.5×10^{6}	1×10^{-4}	4×10^{-3}

* In presence of oxygen.

** Includes ^{241}Am daughter product at 70-yr shelf life.

A shelf life of 70 years for Pu-241 (the maximum for gamma production in Pu-241 daughter products) is assumed so that the entry for Pu-241 (14.6-year half life) is, in fact, mostly Am-241 (see Appendix 5A of Reference 2). From Table 5A-3 it is clear that on a per-unit weight basis, the Am-241 and Pu-238 dominate the neutron sources, while the Am-241 dominates the gamma sources.

The radiation characteristics of the IAEA/SAL maximum 8-gram plutonium payload for the PAT-2 are shown in Table 5A-4, assuming it consists of the worst-case LWR MOX plutonium (from Table 5A-2). As this plutonium ages, the neutron source increases slightly because the reduction from Pu-238 decay (87.4-year half life) is slightly exceeded by the increase from Am-241 buildup. The gamma-ray source, on the other hand, increases to a maximum at a shelf life of about 70 years as the Pu-241 decays to Am-241. To represent these effects realistically, the data in Table 5A-4 represent the Pu-238 at a 0-year shelf life and the Pu-241 at a 14.6-year shelf life. The data thus closely approximate the worst source that could be achieved by an actual plutonium sample having this initial composition since further increases in the Am-241 neutron and gamma-ray source beyond the 14.6-year shelf life are partially accounted for by the zero shelf-life Pu-238 neutron source. The maximum Am-241 activity is reached after about 70 years, at which time the Pu-238 activity has decayed to 57% of its initial value. On the other hand, the Am-241 gamma source at 14.6 years has reached about 55% of its maximum value. The Pu-238 and Pu-241 source changes result in a roughly constant penetrating source* between shelf lives of 14.6 and 70 years.

Table 5A-4

Radiation Characteristic of the IAEA/SAL 8-gram Payload of LWR MOX Plutonium

Isotope	Mass (g)	n/s[a]	γ-MeV/s	Watts	Ci
^{236}Pu	8×10^{-8}	0.08	1×10^{5}	1×10^{-6}	4×10^{-5}
^{238}Pu[b]	0.32	1.1×10^{4}	5×10^{6}	0.18	5.4
^{239}Pu	2.88	2.7×10^{2}	3×10^{5}	6×10^{-3}	0.17
^{240}Pu	2.48	3.2×10^{3}	2.2×10^{8}	1.7×10^{-2}	0.50
$^{241}Pu + ^{241}Am$	1.44	8.9×10^{3}[c]	3.7×10^{9}[c]	0.14[c]	150[b] to 70[c]
^{242}Pu	0.88	1.8×10^{3}	1×10^{6}	10^{-4}	2×10^{-3}
Total	8.0	2.5×10^{4}	3.9×10^{9}	0.34[c]	156[b] to 75[c]

a. In presence of oxygen.

b. Zero shelf life.

c. 14.6-yr shelf life.

*All neutrons plus gamma rays above 20 keV.

The gamma-ray spectra produced by the plutonium isotopes and their daughter products are shown in Table 5A-1 of Reference 2. Using these data and the isotope masses shown in Table 5A-4, the source spectrum shown in Table 5.4.4-3 was obtained.

REFERENCES

[1]S. Deron and E. Kuhn, ISPO A-59, IAEA Interoffice Memorandum to A. E. von Baeckmann, 30 May 1980, Vienna, Austria, transmitted by letter from A. E. von Baeckmann to J. A. Andersen, Sandia National Laboratories, Albuquerque, New Mexico, 20 June 1980.

[2]J. A. Andersen et al, PARC (Plutonium Accident Resistant Container) Program Research, Design, and Development, NUREG/CR-0030, SAND76-0587 (Albuquerque: Sandia Laboratories, July 1978).

[3]W. W. Engle, Jr., A Users Manual for ANISN, K-1693 (Oak Ridge, TN: Union Carbide Corp., Nuclear Division, March 1967).

[4]S. A. Dupree and R. E. Lighthill, Sandia National Laboratories CDC 7600 Version of MORSE-SGC, SAND80-1337 (Albuquerque: Sandia National Laboratories, 1981).

[5]U. S. Department of Defense, Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5C (Washington: DoD, September 1976).

[6]R. W. Roussin and C. R. Weisbin, BUGLE Coupled 45 neutron, 16 gamma-ray, P_3, Cross Sections for Studies by the ANS 6.1.2 Shielding Standards Working Group on Multigroup Cross Sections, DLC-47 (Oak Ridge, TN: Oak Ridge National Laboratory, Radiation Shielding Information Center, 1977).

[7]R. L. Heath, "Gamma Energies and Intensities of Radionuclides," in CRC Handbook of Chemistry and Physics, 60th ed., R. C. Weast, ed. (Boca Raton, FL: CRC Press, Inc., 1979-80), p B-321.

[8]S. A. Dupree, Prompt and Delayed Radiation Environments and Shielding Studies for Electron Beam Fusion Facility, SAND79-0753 (Albuquerque: Sandia Laboratories, March 1980).

[9]D. E. Bennett III, Sandia ORIGEN Users Manual, SAND79-0299 (Albuquerque: Sandia Laboratories, 1979).

[10]A. G. Croff et al, Revised Uranium-Plutonium Cycle PWR and BWR Models for the ORIGEN 2 Computer Code, ORNL/TM-6051 (Oak Ridge, TN: Oak Ridge National Laboratory, September 1978).

[11]A. G. Croff and M. A. Bjerke, Once-Through CANDU Reactor Models for the ORIGEN 2 Computer Code, ORNL/TM-7177 (Oak Ridge, TN: Oak Ridge National Laboratory, November 1980).

[12]Communication with G. R. Waterbury, Group Leader, Analytical Chemistry, CMR, Los Alamos National Laboratory, April 1980.

[13]Code of Federal Regulations, Title 10, Part 71, "Packaging of Radioactive Materials for Transportation under Certain Conditions" (Washington: Government Printing Office).

CHAPTER 6

CRITICALITY EVALUATION

6.1 SUMMARY

A series of nuclear criticality calculations has been performed on the PAT-2 package assuming a maximum fissile payload of 15 grams per 1.2.4. Packages were considered both singly and in infinite, closest-packed arrays. The results, summarized in Table 6.1-1, indicate that the PAT-2 package would qualify as a fissile Class 1 package in accordance with 10 CFR 71, but, due to the 15-gram maximum limitation on fissile contents, is Fissile Class exempt. By thus restricting the maximum fissile payload and having external dimensions that exceed 3.9 inches (10 cm), the package, although subject to International Air Transport Association (IATA) Restricted Articles Regulations, is IATA fissile exempt.

The dimensions of the undamaged packages used in the criticality calculations were based on the design values; dimensions of the impact-damaged packages were obtained from measurements of packages that had undergone sequential testing to the NRC qualification criteria, NUREG-0360. The side-impact configuration was selected since it resulted in a configuration that allowed the TB-2 to be closest to the surface of the damaged package, and also provided a regular geometry for hypothesizing an infinite array. The neutronic interaction between adjacent undamaged or damaged packages was found to be small for cases in which the wood was left in place or in which the wood was replaced with water. The interaction increased when the wood was replaced with air. None of these changes affect the conclusion regarding the criticality safety of the PAT-2 package.

Although water leakage into the TB-2 under the postulated accident environments is precluded by the package and vessel designs, calculations show that should the vessel (with worst-case contents) become flooded with water and be externally water reflected, the system would remain critically safe.

6.2 GENERAL

The national and international regulatory agencies concerned with the handling and transportation of fissile materials do not specify a maximum neutron self-multiplication (k_{eff}) which a shipment will be permitted to reach. It is required, of course, that fissile material not become critical ($k_{eff} = 1$) under any normal or

Table 6.1-1

Results of Criticality Calculations for the
Fissile Class 1 PAT-2 Package
(Nominal Payload of 15 grams Pu-239)

Normal Conditions	Results
Number of undamaged packages calculated to be subcritical	∞
k_{eff} of infinite array of undamaged packages*	0.053 (± 0.0002)
Package size	right circular cylinder: diameter--38.1 cm (15 in.) height--35.6 cm (14 in.)

Accident Conditions	Results
k_{eff} of infinite array of packages damaged by impact, wood not consumed by fire, no water present	0.055 ± 0.001
k_{eff} of infinite array of packages damaged by impact, wood replaced with water	0.084 ± 0.002
k_{eff} of infinite array of packages damaged by impact, wood replaced with air	0.33 ± 0.01
k_{eff} of a single TB-2 with water moderation of contents and full water reflection on all sides	0.098 ± 0.0002
Package size	See Figure 5.4-3

* Result is independent of water moderation between packages.

credible accident configuration. In practice, persons knowledgeable in criticality safety typically permit stationary assemblies to reach no more than k_{eff} = 0.98 under worst-case conditions when verified by experiment, or k_{eff} = 0.95 (including three standard deviations to envelope the 99% confidence level if Monte Carlo is used) when based on calculations. When fissile material is to be moved, the maximum k_{eff} is commonly limited to about 0.95 under worst-case accident conditions. The conditions under which the PAT-2 is to be handled and shipped in no way indicate the existence of extraordinary circumstances which would exclude it from accepted practical limits of criticality safety and control.

Packagings for transporting fissile material are classified (e.g., Fissile Class I, etc.) by 10 CFR 71; the PAT-2 will be shown to meet the high integrity requirements of Class I but will be Fissile Class exempt. For a packaging to qualify for this class, it is required that an array of any number of undamaged packages, in any arrangement and with optimum interspersed moderator, be subcritical. It is also required that an array of 250 such packages, each having been subjected to the required accident conditions, be subcritical in any arrangement, with optimum interspersed moderator and full reflection.

6.3 CALCULATIONAL MODELS

The calculational models of the PAT-2 discussed in Section 5.4 were used for the criticality eigenvalue calculations discussed in this chapter. Most of these calculations were performed in two- or three-dimensions with the MORSE code,[1] with some additional calculations being performed in one-dimension using ANISN.[2] Infinite, closest-packed arrays of packages were modeled using the albedo or reflecting boundary condition options in these codes, with interspersed moderator or air as desired.

The one-dimensional calculations described in this chapter used the Hansen/Roach 16-group cross-section set.[3] This set was designed for use with fast metal systems and is generally considered to be as good as any cross-section set available for such applications. However, the Hansen/Roach set has but one thermal group and is not considered the most accurate available set for application to thermal systems. Therefore, a second set of cross sections, the 27-group P_3 set derived from the Criticality Safety Research Library,[4] described by Westfall et al[5] and by Andersen et al,[6] was used in the Monte Carlo calculations. This cross-section set has 16 thermal groups. Benchmark calculations using this 27-group set are described in Section 6.4 of Reference 6. The results achieved in these benchmark calculations indicate that the 27-group cross sections are accurate when applied to problems such as those presently under investigation.

The maximum fissile isotope content of the PAT-2 is 15 grams. For purposes of analysis, it was assumed that this 15 grams consists of Pu-239. Whether this material is a metal or an oxide is inconsequential. Although both Pu-239 and the other fissile isotopes, U-235, Pu-238, and Pu-241, may be present in various amounts depending on the payload, the reactivity worth of Pu-239 is at least as great as any of these combinations. In addition, the isotope content may contain up to 105 grams of nonfissile plutonium and/or uranium. As is shown in Section 6.4, the reactivity worth of this nonfissile component is negative. Therefore, in the calculations presented in this chapter, the nonfissile component of the payload has been omitted. The neutron self-multiplication in the PAT-2 is not sensitive to the density of the fissile material, and an oxide density of 5 g/cm^3 was assumed.[6] Compression of the payload in an impact[7] will not affect the PAT-2 criticality.

It has been assumed for pressurization and containment analysis (Chapter 4) that the PAT-2 payload will include up to 0.5 gram water. This value is considered high, and achieving a water content in excess of 0.5 gram is considered possible only if the TB-2 containment vessel and C-1 capsule are not properly sealed. In addition, the payload criteria permit the inclusion of up to 18 grams of quartz (SiO_2), 50 grams of brass or 16 grams of aluminum, 9 grams of polyvinylchloride (PVC), and 0.3 gram of Teflon™. For criticality purposes, only the water and, to a lesser extent, the PVC are significant. Unless otherwise stated, the criticality results presented here assume that 0.5 gram of water is uniformly interspersed with the fissile material in a spherical configuration, and that the mixture is surrounded by a spherical shell containing 9 grams of PVC having a density of 0.9 g/cm^3. The effect of the quartz, brass, and Teflon™ will be negligible except for the brass: if all of the fissile material is inside a single brass container, the effect of the brass will also be negligible; if more than one brass canister is used for the payload, the system k_{eff} will decrease.

To address the requirements of 10 CFR 71.33(a), a criticality assessment was made of a single TB-2 including the effects of water flooding and moderation. The PVC was omitted from this calculation, and the water was assumed homogeneously mixed with the fissile material. The 27-group cross-section set was used.

All of the Monte Carlo results quoted in this chapter include a best-estimate of the one standard deviation uncertainty. This is a statistical quantity and does not account for nonstatistical sources of uncertainty such as geometry approximations, cross sections, and material compositions. Thus, the quoted statistical standard deviations overestimate the accuracy to which the system k_{eff} values are known. However, the additional uncertainty introduced by the nonstatistical factors may be concluded to be small, because of the agreement achieved in comparisons with benchmark results (Section 6.4 of Reference 6) and the fact that the cross sections

of the most important materials in the problem (Pu-239, O, H, Fe, Cr, and Ni) are reasonably well known. A more conservative estimate of the uncertainty (e.g., the ±0.01 uncertainty of the 0.33 k_{eff}) in the reported k_{eff} values would be two or three times the amounts shown.

Many of the calculated results presented in this chapter are shown to three significant digits in order to facilitate making certain comparisons and to indicate trends. Although the statistical standard deviation quoted with each number generally warrants this level of numerical precision, the actual level of accuracy to which the neutron self-multiplication is known does not justify use of the third significant digit.

6.4 EFFECT OF PAT-2 PAYLOAD (ISOTOPE CONTENT) COMPOSITION ON SYSTEM k_{eff}

A series of criticality calculations has been performed with the ANISN Code[2] using the Hansen/Roach 16-group neutron cross sections[3] to determine the effect of payload composition on the PAT-2 system criticality. Although the simple one-dimensional calculations with the Hansen/Roach cross sections are not as accurate as the multi-dimensional Monte Carlo calculations using the 27-group CSRL cross sections, they agree well with the latter and are quite sufficient for the present parameter studies.

The model used to calculate the neutron self-multiplication for a simple PAT-2 system was identical to that described in Section 5.4 for the one-dimensional calculations, with the exception that the source volume contained 15 grams of fissile isotope content along with 0.5 gram of water and various amounts of U-238, the predominant nonfissile isotope of interest in these studies. The source region was surrounded with 9 grams of PVC, as described in Section 6.3.

Figure 6.4-1 shows the k_{eff} for a single PAT-2 containing 15 grams of U-235 or Pu-239, along with varying amounts of U-238. The heavy-metal oxide density was assumed to be 5 g/cm^3 in each case; i.e., the density of a packed oxide powder.[6] On the basis of these results, the worst case for criticality safety is seen to be pure Pu-239. All results presented in this chapter assume this composition.

6.5 RESULTS

The neutron self-multiplication of a single PAT-2 under normal operating conditions, containing 15 grams of Pu-239, has been calculated to be 0.050 ± 0.00007. Stacking undamaged PAT-2 packages, each with the maximum fissile payload, in an infinite closest-packed array increased the k_{eff} to 0.053 ± 0.0002 (slightly less if

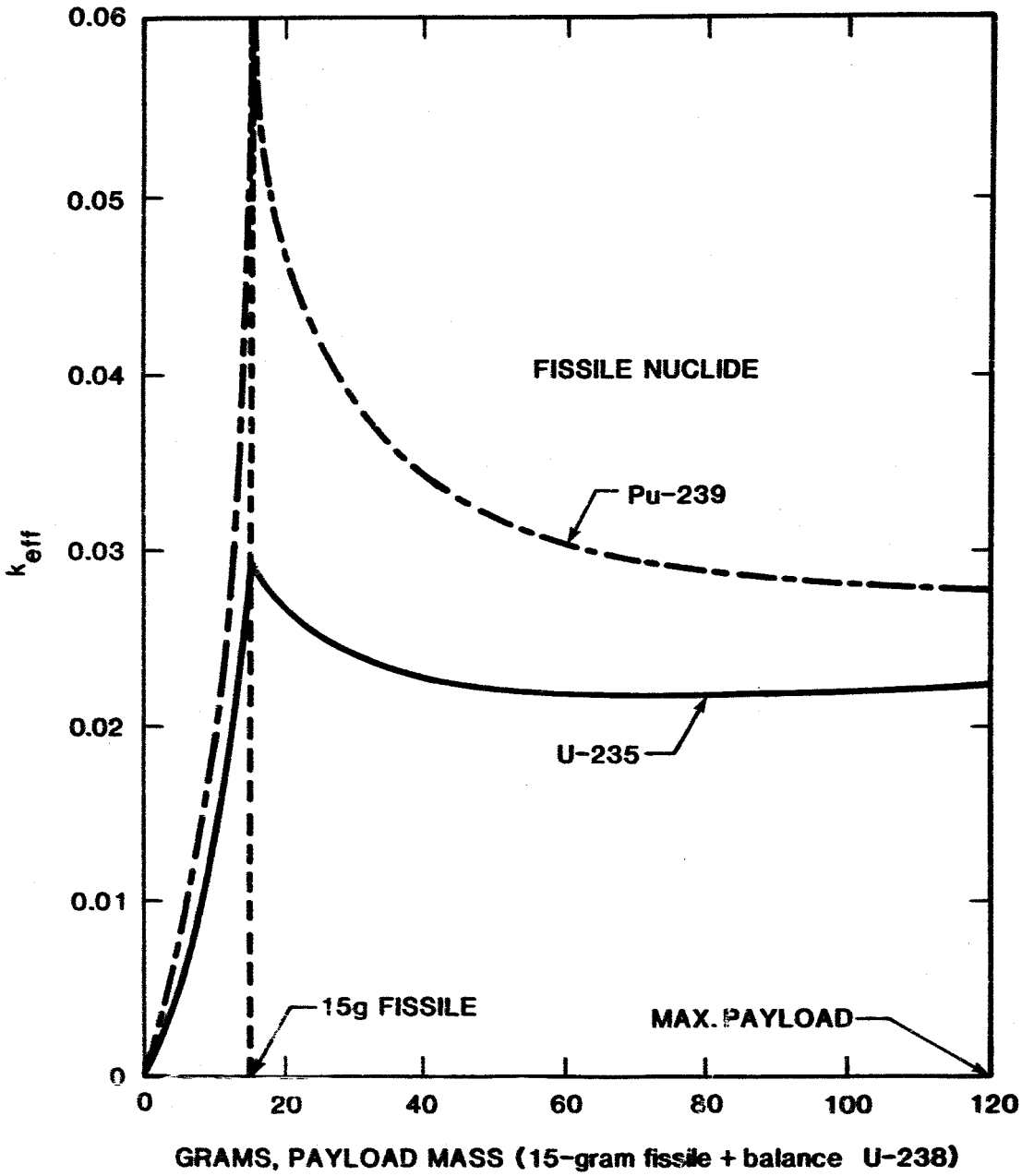


Figure 6.4-1. Neutron Self-Multiplication of PAT-2 Payloads as a Function of U-238 Content

the intervening spaces are filled with water). Thus the AQ-2 overpack is an efficient neutron decoupler, and each undamaged package can be treated independent of any number of other packages; i.e., the presence or absence of additional containers near an undamaged PAT-2 has essentially no effect on the k_{eff} of the system. The k_{eff} of a single PAT-2 package in the post-accident configuration is identical to that of a single undamaged package. If the wood is replaced with water, the system k_{eff} increases to 0.060 ± 0.002.

The k_{eff} of an array of damaged PAT-2 packages depends on the details of their configuration and the presence or absence of interspersed moderator. The use of reflecting boundary conditions in the model of a single damaged package corresponds to an infinite rectangular array of packages stacked such that the damaged faces of adjacent pairs are touching and the payloads of the two packages are as close together as possible. This represents an extremely severe model for criticality safety. The calculated neutron self-multiplication for an infinite array of such closest-packed post-accident PAT-2 packages is 0.084 ± 0.002 if the wood is replaced with water, and 0.33 ± 0.01 if the wood is replaced with air. The latter value is by far the largest k_{eff} that was encountered in this study. It results from the unimpeded streaming paths possible in the absence of solid material around the TB-2 units and the fact that an infinite array necessarily implies an infinite mass of Pu-239 in the calculations. In such a configuration, the neutron multiplication depends on the ratio of neutron absorptions in the fuel to neutron absorptions in the structural material. The combined mass of the TB-2, the titanium load spreader, and the stainless steel skin of the PAT-2 is more than sufficient to terminate the neutron reaction chains in the resulting system.

The k_{eff} of a single water-filled and water-reflected TB-2 containing the maximum fissile payload was calculated as required by 10 CFR 71.33(a). The resulting system k_{eff} was calculated to be 0.098 ± 0.0002.

Even with optimum neutron moderation and reflection, many kilograms of fissile material are required to achieve a critical configuration (see, for example, References 8 and 9). Limiting the PAT-2 fissile loading to 15 grams is expected therefore to result in a system with a very small k_{eff}. It would require the fissile payloads for more than 350 maximally loaded PAT-2s to equal the 5.6-kg mass required to make a water-reflected sphere of Pu-239 become critical.[8] This fact, plus the calculations in this chapter, provide a high degree of confidence in the conclusion that assembling any number of damaged or undamaged PAT-2 packages in such a way as to make them critically unsafe is impossible, provided their payloads meet the criteria specified in Chapter 1. The present analysis indicates that the PAT-2 package meets all requirements for a Fissile Class 1 package, as defined in 10 CFR 71, and has been found to be critically safe under any normal or credible accident conditions.

REFERENCES

[1]S. A. Dupree and R. E. Lighthill, Sandia National Laboratories CDC 7600 Version of MORSE-SGC, SAND80-1337 (Albuquerque: Sandia National Laboratories, 1980).

[2]W. W. Engle, Jr., A Users Manual for ANISN, K-1693 (Oak Ridge, TN: Union Carbide Corporation, Nuclear Division, March 1967).

[3]G. E. Hansen and W. H. Roach, Six and Sixteen Group Cross Sections for Fast and Intermediate Critical Assemblies, LAMS-2543 (Los Alamos: Los Alamos Scientific Laboratory, December 1961).

[4]W. E. Ford, III, C. C. Webster, and R. M. Westfall, A 218-Group Neutron Cross-Section Library in the AMPX Master Interface Format for Criticality Safety Studies, ORNL/CSD/TM-4 (Oak Ridge, TN: Oak Ridge National Laboratory, 1976).

[5]R. M. Westfall, W. E. Ford, III, and C. C. Webster, "Design Criteria for the 218-Group Criticality Safety Reference Library," presented at the RSIC Seminar-Workshop on Multigroup Cross Sections, 14-16 March 1978, sponsored by the Radiation Shielding Information Center, Oak Ridge National Laboratory, Oak Ridge, TN.

[6]J. A. Andersen et al, PARC (Plutonium Accident Resistant Container) Program Research, Design, and Development, NUREG/CR-0030, SAND76-0587 (Albuquerque: Sandia Laboratories, July 1978).

[7]R. J. Lawrence and A. C. Marshall, The Effect of Densification on Reactivity of Plutonium-Based Reactor Materials in an Air-Transportable Package During High-Speed Impact, SAND77-1516 (Albuquerque: Sandia Laboratories, 1978).

[8]R. D. Carter, G. R. Kiel, and K. R. Ridgway, Criticality Handbook, ARH-600 (Richland, WA: Atlantic Richfield Company, 1968).

[9]G. E. Hansen and H. C. Paxton, Reevaluated Critical Specifications of Some Los Alamos Fast-Neutron Systems, LA-4208 (Los Alamos: Los Alamos Scientific Laboratory, 1969).

CHAPTER 7

OPERATING PROCEDURES

This chapter describes how to load and unload the PAT-2 package.

7.1 GENERAL

7.1.1 General Standards

Preparing radioactive materials for packaging in the PAT-2 is an operator responsibility and would generally be done under controlled conditions for environmental (health physics) reasons (e.g., in a glove box at negative pressure or under an exhaust hood with adequate filtration).

7.1.2 Permissible Contents

The contents permitted in the PAT-2 packaging are limited to those specified in Section 1.2.4. That section defines all permitted packaging and containing materials as well as all permitted radioactive materials.

7.1.3 Optional Use of Canisters

The operator may use one or more of a group of five different brass or aluminum canisters that are designed to accomodate plutonium safeguards samples or other radioactive materials within the C-1 capsule of the PAT-2 package. Appendix 7A provides the specific procedures for packaging with these canisters. The procedures in Sections 7.2 through 7.4 assume that the radioactive material is already packaged to the following extent:

1. The radioactive material is contained within a canister or equivalent operator-furnished device, which has been sealed in polyvinyl chloride (PVC) plastic film prior to removal of the loaded canister from a glove box or hood, or
2. The radioactive material has been directly sealed in PVC plastic film without the use of a canister, or
3. Radioactive material in the form of a solid single mass (not powdered or finely subdivided), such as a piece of metal or a sintered pellet, may be placed directly into the C-1 capsule, at the operator's discretion.

7.1.4 Use of PVC

In addition to the explicit 9-gram mass limitation per Section 1.2.4, item (b), the use of PVC plastic film per 7.1.3 (1) or (2) above should be minimized so that the PVC material will not interfere with the screw threads on the C-1 body or lid.

7.2 LOADING THE C-1 CAPSULE

A sealed C-1 capsule is not required for radioactive contents with a plutonium radioactivity level below 20 Ci. However, its use without the leak-rate check requirement is still required since it provides a means for loading the TB-2 containment vessel.

A detailed procedure for loading the C-1 capsule, provided in Appendix 7B.1, includes the following essential points.

7.2.1 Loading

Insert the radioactive material into the body of the C-1 capsule. With PVC-encased materials, take care to keep PVC material away from possible engagement in the C-1 capsule threads.

7.2.2 Capsule Sealant

Seal the capsule screw threads with Teflon™ tape; apply per Appendix 7B.

7.2.3 Positive Closure

Using a pair of the special 3-pin spanner wrenches provided (or, using an operator-supplied wrench that meets the requirements of drawing T67038, provided in Appendix 9A), screw the capsule lid onto the capsule body with a closing torque of 450 inch-pounds [51 N·m (newton-metres)] minimum to 500 inch-pounds (57 N·m) maximum. Details appear in Appendix 7B. Trim off excess Teflon™ tape.

7.2.4 Capsule Leak-Rate Test

Prior to shipping with plutonium contents in excess of 20 Ci, the assembled C-1 capsule must be checked by a leak rate test per Section 8.2.2.1.

Note: For shipments of < 20 Ci plutonium, this leak rate test could be waived.

7.3 LOADING THE TB-2 CONTAINMENT VESSEL

A detailed procedure for loading the TB-2 containment vessel, provided in Appendix 7B.2, includes the following essential points.

7.3.1 Shim C-1 Capsule To Fit TB-2 Containment Vessel

To take up the slack or free play between the domed (convex) ends of the C-1 and the internal domed (concave) end of the TB-2, place aluminum foil shims (2 grams maximum) inside TB-2 Spherical Containment Vessel-A, part no. T67002-001, at the domed (concave) end, and fit-test the C-1 to the TB-2, as described in Appendix 7B.

7.3.2 Install Capsule

Place either end of the C-1 capsule onto the aluminum shims in the A vessel.

7.3.3 Install Copper Gasket

Place a new copper gasket, part no. T57004-001, over the shoulder of the A vessel. Remove used gasket first, if present.

7.3.4 Assemble TB-2 Containment Vessel

Place the B vessel (part no. T67003-001, TB-2 Spherical Containment Vessel-B) over the A vessel, engaging the shoulder of the A vessel into the groove of the B vessel. Place a washer, part no. T67042-001, under the head of all 20 bolts (item 8, drawing T67001), match up the 20 holes in the flanges of the A and B vessels, place the twenty bolts with washers through the holes, place another washer (part no. T67042-001) over the end of each bolt, under the flange of the A vessel, and engage a nut (item 9, drawing T67001) onto each bolt. Only the nuts, bolts, and washers provided with the PAT-2 package or designated on the design drawings (Appendix 9A) may be used;* absolutely no substitutes are to be used. Tighten the 20 nuts and bolts approximately finger-tight.

7.3.5 Positive Closure

Following the assembly of 7.3.4, there is a pronounced gap between the A and B TB-2 vessels. This is caused by the relatively thick copper gasket, which will next be formed in place within knife-edge-equipped grooves in the A and B vessels. Tighten the 20 nuts and bolts to approximately 100 to 120 inch-pounds (12 N·m) torque; this will require several sequential passes around the TB-2 vessel as the copper is drawn down into the groove. Repeat the tightening process to assure

---

*Note that drawing T67001 specifies a modification to the as-purchased bolt and nut.

that all 20 bolts are drawn up tight. Then increase the tightening torque to a minimum of 180 inch-pounds (20 N·m), and make at least 2 complete tightening passes around the TB-2, assuring twice that all 20 bolts and nuts have at least 180 inch-pounds (20 N·m) closing torque and that there are no loose bolts. The maximum permissible tightening torque is 200 lb_f·in. (23 N·m). Verify visually that the TB-2 vessel flanges are now in intimate contact all around, with no apparent gap.

7.3.6 Containment Vessel Leak-Rate Test

Prior to shipment with radioactive contents, the assembled TB-2 containment vessel must be checked by a leak rate test per Section 8.2.2.2.

7.4 ASSEMBLY OF THE PAT-2 PACKAGE

A detailed procedure for assembly of the PAT-2 package is provided in Appendix 7B; the main points follow.

7.4.1 Install TB-2 Containment Vessel and Plug

Install the TB-2 containment vessel into the inner cavity of a completely disassembled AQ-2 overpack, and install the small maplewood plug over the TB-2.

7.4.2 Assemble Load Spreader

Install the titanium load spreader cover by engaging the lugs into the four recesses in the load spreader; push inward and rotate 1/4 turn in either direction; install the four screws and tighten.

7.4.3 Install Gasket and Plug

Place the rubber gasket on top of the titanium load spreader, centered around the handle, and install the large redwood plug over the load spreader, aligning the slot in the plug with the handle on the load spreader cover.

7.4.4 Documents

Place the thin packet of documents, if required, on top of the redwood plug.

7.4.5 Install and Secure AQ-2 Covers

Install the inner stainless steel cover inside the drum body and align the match mark. Install the outer stainless steel cover outside the drum body and align the match mark. Align the holes of the inner and outer covers with the holes through the drum body, and install the 24 bolts without fully tightening. Once all

24 bolts are started, tighten them in a criss-cross manner tight enough so that the bolt head pulls the cover inward slightly.

7.4.6 Security Seals

Install security seals, if required, at the two positions provided; the seal strap should pass under and over the security-seal fitting provided on the cover, and the seal strap should pass under and around one end of the carrying handle on the drum body.

7.4.7 Shipping Labels

Apply shipping and marking labels, as required, using tape whenever possible. Do not cover the embossed trefoil symbol on the package cover, and do not cover the stencilled information on the package body.

7.5 DISASSEMBLING AND UNLOADING THE PAT-2 PACKAGE

7.5.1 GENERAL -- CAUTION

CAUTION SHOULD BE EXERCISED IN OPENING THE TB-2 CONTAINMENT VESSEL AND THE C-1 CAPSULE. THESE LEAKTIGHT, UNVENTED VESSELS MAY BE PRESSURIZED DUE TO THERMAL EFFECTS, ALTITUDE DIFFERENCE, OUTGASSING OF PACKAGING MATERIALS, OR INTERNAL VAPOR PRESSURE. IN THE CASE OF RADIOACTIVE MATERIAL SHIPMENTS, THESE VESSELS SHOULD BE OPENED IN A NEGATIVE-PRESSURE, FILTERED ENVIRONMENT SUCH AS A GLOVE BOX OR EXHAUST HOOD. THEY SHOULD BE OPENED GRADUALLY, WITHOUT FULLY DISENGAGING THE SCREW THREADS AT FIRST, TO ALLOW THEM TO VENT, IF NECESSARY.

7.5.2 Remove TB-2 from AQ-2

Properly remove and preserve security seals, if present. Remove 24 bolts, remove outer and inner covers (finger grips are provided on each cover; a screwdriver may be used to pry up the inner cover, if necessary), remove document packet (if present), and remove redwood plug and rubber gasket. Then, remove four screws from load spreader, turn cover 1/4 turn in either direction (push inward if necessary), remove cover, and remove inner maplewood plug. Next, tilt the package sideways, using the handles to maintain a safe grip, until the TB-2 containment vessel rolls out into the operator's hand.

7.5.3 Open the TB-2

Note the caution in 7.5.1 above. Using properly fitting tools, loosen the 20 bolts and nuts, but do not permit any nuts to completely disengage from the bolts. Separate the two halves of the TB-2, if necessary, by gently forcing a knife

blade into the joint, tapping with a small hammer; do this at several locations; take care not to damage the containment vessel.

7.5.4 Open the C-1 Capsule

Note the caution in 7.5.1 above. Using two of the special spanner wrenches provided and securing the bottom wrench in a bench vise so that the capsule lid is upright, gradually open the capsule by applying counterclockwise torque. Allow time for capsule venting, if required, after one full turn. Finish unscrewing the lid.

APPENDIX 7A

Operating Procedures for Loading Canisters

7A.1 GENERAL

These procedures apply to the operation of loading radioactive materials into the BC-1 (part no. T72599-001), BC-2 (part no. T72600-001), BC-3 (part no. T72601-001), BC-4 (part no. T72602-001), or the BC-5 (part no. T72603-001) canisters.

The preparation of radioactive materials for packaging in these canisters is an operator responsibility, and this loading procedure would generally be done under controlled conditions for environmental (health physics) reasons (e.g., in a glove box at negative pressure or under an exhaust hood with adequate filtration).

Individual BC canisters may be marked for identification purposes by indelible ink marking on the cover and/or the body.

Records of tare weight, net weight, gross weight, radioactivity levels, radioisotope identification, and other information are operator responsibilities and are not addressed in this procedure.

7A.2 APPLICATION

The BC canisters are designed for use as fitted sets within the C-1 capsule. The correct combinations are

- 2 each BC-1, T72599-001 (package these with flat covers facing each other). See Figure 7A.2-1.
- 2 each BC-2, T72600-001, with one each BC-3, T72601-001 (package with BC-3 in middle; BC-2 flat covers facing inward). See Figure 7A.2-2.
- 3 each BC-4, T72602-001 (fewer than 3 may be used). See Figure 7A.2-3.
- 6 each BC-5, T72603-001 (fewer than 6 may be used). See Figure 7A.2-4.

The BC canisters may be equipped with a quartz liner in which nuclear material processing may be conducted (e.g., the reduction of a liquid containing plutonium and/or uranium to an evaporated solid, or the firing (calcining) of an evaporated solid to an oxide powder). For accountability of minute quantities of radioactive materials, these quartz liners may then be directly inserted into the appropriate BC canister; see Figure 7A.2-5.

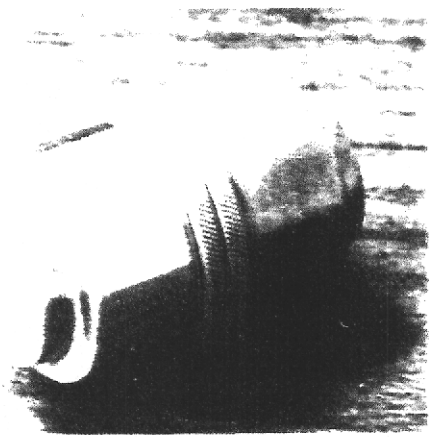


Figure 7A.2-1. Two BC-1 Canisters

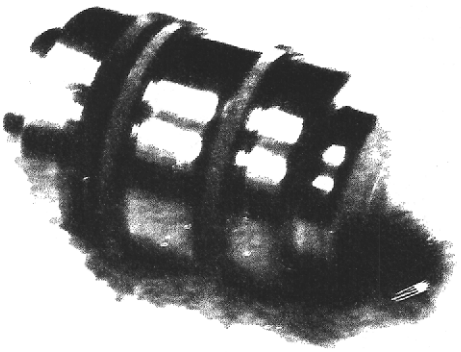


Figure 7A.2-2. Two BC-2 Canisters and One BC-3 Canister

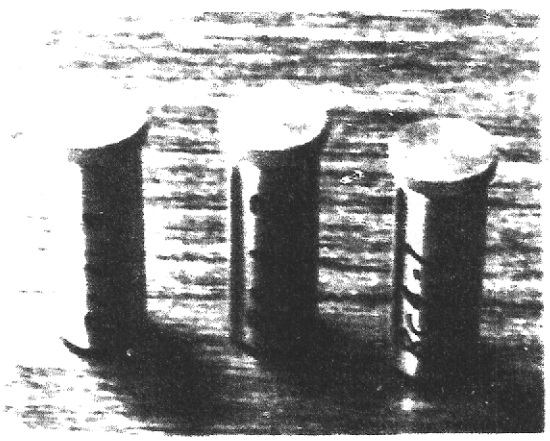


Figure 7A.2-3. Three BC-4 Canisters

Figure 7A.2-4. Six BC-5 Canisters

Figure 7A.2-5. Inserting Quartz Liner into a BC Canister

7A.3 Pre-Use Inspection

The cover for the brass canister is furnished with a PVC gasket or seal inside the lid. Visually verify that it is present and undamaged. The thin edge of the brass body, at the screw thread, should be undamaged (no dents or noticeable scratches or gouges), as determined visually and by feel. These parts should be clean and free of debris of any type.

7A.4 LOADING, SEALING, BAGGING

Place the radioactive material into the canister. Screw the cover on, taking care not to cross-thread; clockwise turning tightems the cover. Firmly grasp the canister body by hand and securely tighten the cover by grasping the knurled diameter, by hand. Wait 5 to 10 minutes, allowing for cold flow of the PVC seal, and reapply a very forceful closing torque by hand (do not use tools to close canisters). If required or desired by the operator, the closed and sealed canister may be heat-sealed within PVC plastic film; this process will be referred to as "bagging." Free air within this PVC bag should be minimized, and can be eliminated

by use of a small vacuum line equipped with a syringe (hypodermic) needle. The operator would be obligated to observe due precautions if the inside of the PVC bag, adjacent to the canister, is considered to be contaminated with radioactive material. If the original shape of the PVC bag is intentionally long on at least one side at the time of sealing (by application of heat, such as with an electric resistance or RF-heating "welding" tool), the bag thus formed can be punctured by the needle inward of this seal, and the bag can be evacuated by the vacuum line. The PVC can then be pulled out flat and free of wrinkles, and a new final seal can be made closer to the canister, inside of the needle puncture hole. Excess PVC material is to be avoided: trim where possible (see Figure 7A.4-1). Note the 9-gram limitation on PVC, which includes the PVC seal inside the canister cover. Allow 0.5 gram (each) for the PVC seal in BC-1, BC-2, and BC-3 canisters. Allow 0.1 gram (each) for the PVC seals in BC-4 and BC-5 canisters.

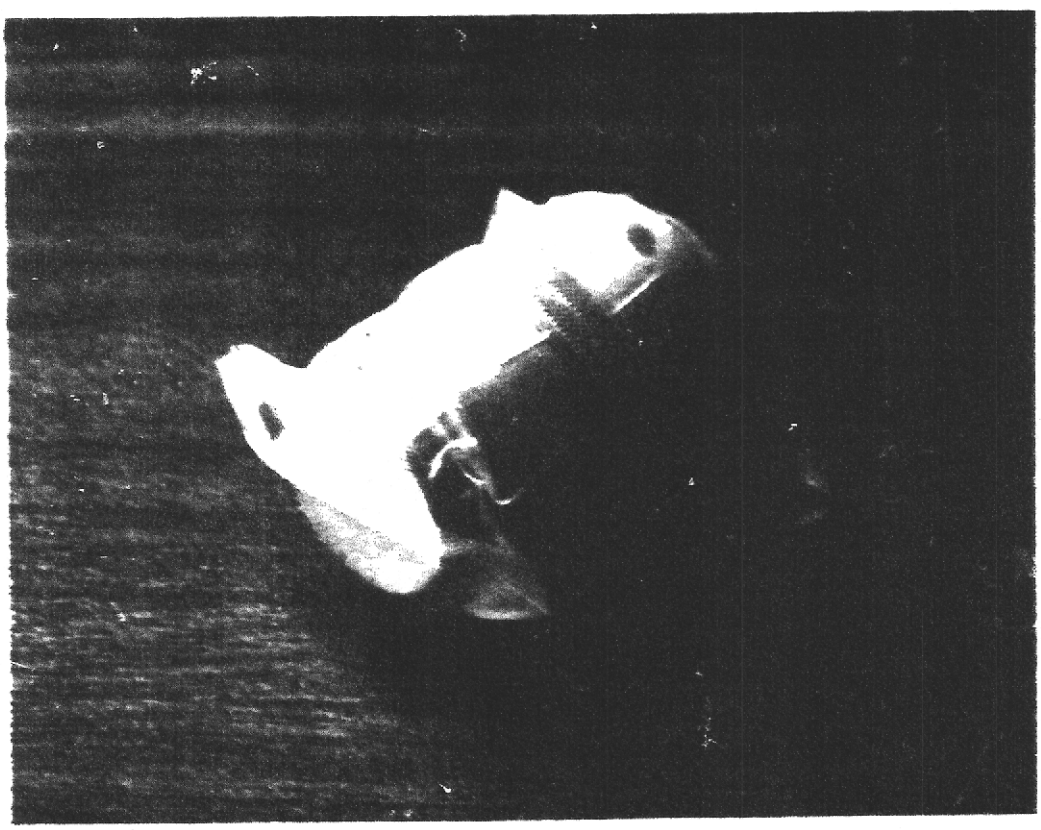


Figure 7A.4-1. Canisters Heat-Sealed (Bagged) within PVC

APPENDIX 7B

PAT-2 Package Detailed Assembly Procedure

7B.1 LOADING THE C-1 CAPSULE

The parts and materials required for loading the C-1 capsule are listed in Table 7B.1-1; the tools and equipment required are listed in Table 7B.1-2. All parts should be visually inspected for the correct part number and for any obvious defects or damage, and all parts should be clean and free of foreign material or debris.

Table 7B.1-1

Parts and Materials for C-1 Loading

Quantity	Item	Part Number
1 each	C-1 Capsule Body	T67008-001
1 each	C-1 Capsule Lid	T67037-001
As Req'd	PTFE Tape	Mil Std. T27730A; ~ 1/2 inch wide, 0.003 to 0.004 inch thickness
As Req'd	Radioactive Contents	

Table 7B.1-2

Tools and Equipment for C-1 Loading

Quantity	Item	Part Number
2 each	Capsule Wrench	T67038-002
1 each	Bench vise	(none)
1 each	Torque wrench, 1/2-in. sq. drive, 500-in.-lb (57 N-m) working capacity	(none)
1 each	Tongue depressor or blunted wood tool	(none)
As req'd	Single-edge safety razor blades	
1 each	Leak-rate tester	

Step 1: Apply Sealing Tape

Wrap PTFE (polytetrafluoroethylene, or "Teflon"") tape tightly around the screw threads of the C-1 capsule lid. The wrap direction must be clockwise when viewing the interior of the cap, the wrap must overlap the shoulder of the lid, and the tape should not split or crack on the screw threads or on the shoulder edge. Complete two full turns or wraps; break the tape by pulling until it breaks (do not cut), and smooth the broken end in a clockwise direction to blend it in with the wrap. Figure 7B.1-1 indicates the proper appearance.

Figure 7B.1-1. Apply Sealing Tape

Step 2: Set Body Up in Wrench and Vise

Secure a capsule wrench in an appropriate bench vise by means of the flats on the wrench. Place the C-1 capsule body on this wrench, engaging the three pins of the wrench into the three spanner wrench holes in the capsule body. Refer to Figure 7B.1-2.

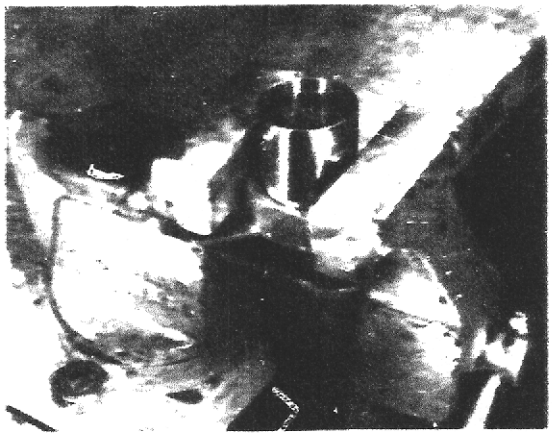


Figure 7B.1-2. Capsule within Capsule Wrench

Step 3: Load Contents into Capsule

Insert the radioactive material payload into the capsule body. If the payload is encased in PVC plastic film, push the film out of contact with the capsule screw threads with a small blunt wooden tool, such as a tongue depressor. Refer to Figure 7B.1-3.

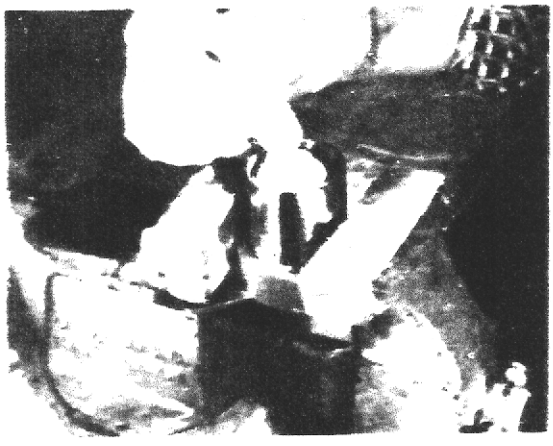


Figure 7B.1-3. Load Contents in Capsule

Step 4: Close Capsule

Screw the capsule lid onto the capsule body with finger pressure; assure that the connection is not cross threaded. Tighten by hand to a practical extent; see Figure 7B.1-4.

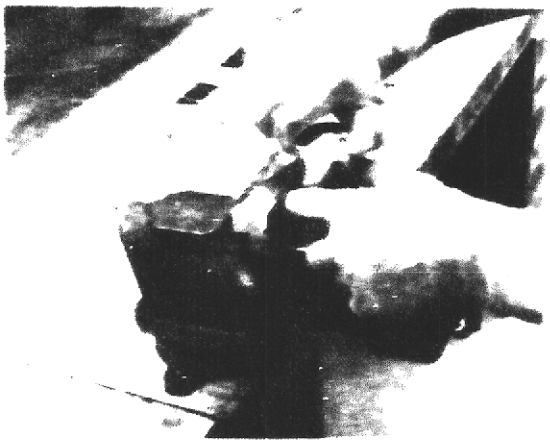


Figure 7B.1-4. Close Capsule

Step 5: Seal Capsule

Place another capsule wrench over the lid, engage the three pins, and engage a torque wrench in the socket on the capsule wrench. Tighten (clockwise) to 450 inch-pounds (about 51 N•m) minimum, 500 inch-pounds (57 N•m) maximum. Take care not to twist the capsule out of the wrenches by applying some downward force on the wrench (Figure 7B.1-5).

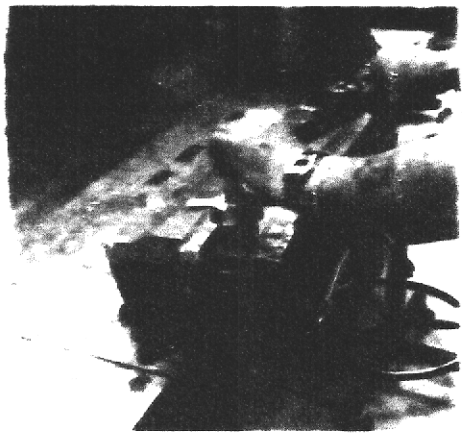


Figure 7B.1-5. Seal Capsule

Step 6: Trim Excess Sealant

Trim the excess tape from the joint with an appropriate sharp tool. Refer to Figure 7B.1-6.

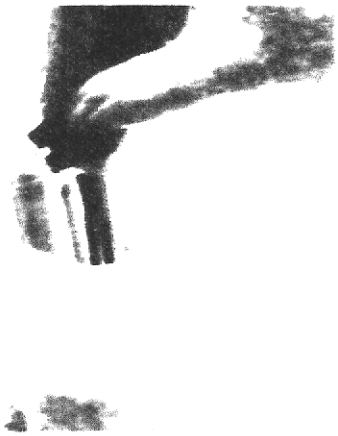


Figure 7B.1-6. Trim Excess Sealant

Step 7: Check Seal

Conduct the leak rate test, if required, per Section 8.2.2.1.

7B.2 LOADING THE TB-2 CONTAINMENT VESSEL

The parts and materials required for loading the TB-2 containment vessel are listed in Table 7B.2-1; the tools and equipment required are listed in Table 7B.2-2. All parts should be visually inspected for the correct part number and for any obvious defects or damage, and all parts should be clean and free of foreign material or debris.

Table 7B.2-1

Parts and Materials for TB-2 Loading

Quantity	Item	Part Number
1 each	TB-2 Spherical Containment Vessel A	T67002-001
1 each	TB-2 Spherical Containment Vessel B	T67003-001
1 each	Copper Seal	T67004-001
20 each	Socket Head Cap Screw, 1/4-28, A-286 alloy, silver plated, 0.820/0.830 inch long	NAS1351-M4145
20 each	Nut, 1/4-28, A-286 alloy, silver plated	FM1014-428
40 each	Washer, stainless steel, double chamfered	T67042-001
2 each	TB-2 Spherical Containment Vessel Fairing	T67048-000
6 each	Slotted head set screw, nylon-tipped	CS-4
As req'd	Aluminum foil, approx. 0.001 inch (0.025 mm) thick, approx. 1 ft^2 (30 cm^2)	----
1 each	C-1 capsule assembly with contents	----

Table 7B.2-2

Tools and Equipment for TB-2 Loading

Torque wrench [0-250 lbs (0-28 N·m)]; 3/8-inch drive

Scissors

Bench vise

Leak rate tester

Small common screwdriver (or jeweler's screwdriver)

5/16-inch six-point socket nut driver

5/16-inch six-point socket wrench; 3/8-inch ratchet drive

3/16-inch hex wrench; 3/8-inch ratchet drive

Step 1: Place C-1 Capsule in "A" Vessel

Place the assembled C-1 capsule into the TB-2 A vessel (the "hemisphere" with the protruding lip in the region of the flange); see Figure 7B.2-1.

Figure 7B.2-1. Place Capsule in TB-2 A

Step 2: Loose Fit of Capsule

Place the B vessel over the C-1. Clamp the TB-2 vessel flanges together with the fingers as in Figure 7B.2-2, and shake the assembly to note, by sound, any indication of free play or slack between the C-1 capsule and the interior of the TB-2, in the direction of the domed (spherical) ends.

Figure 7B.2-2. Clamp Flanges Together

Step 3: Install Shims

Remove the B vessel and remove the C-1 capsule from the A vessel. Prepare approximately 15 to 20 thicknesses of aluminum foil (0.001-inch (0.025-mm) thickness assumed) in approximately 1-inch (25-mm) squares; the foil may be folded to avoid individual pieces. Place the foil in the spherical cavity of the A vessel (Figure 7B.2-3), and tamp the foil in place by pushing on it with the C-1 capsule.

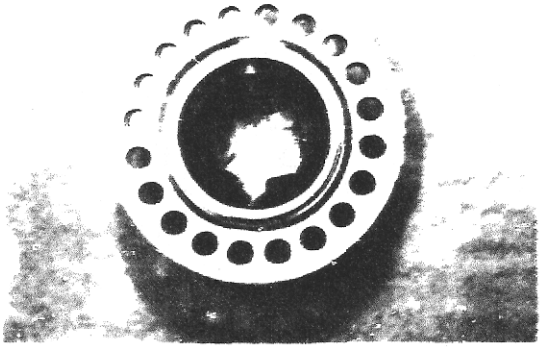


Figure 7B.2-3. Place Foil in Vessel A

Step 4: Shimmed Fit of C-1 Capsule

With the capsule in place, replace the B vessel, clamp the flanges together with hand pressure, and assure that there is no gap at the flange (Figure 7B.2-4). Shake the assembly, as in Step 1, to listen for the rattle of free play. If there is no audible sound of the C-1 capsule striking the interior of the 7B-2, this step is completed. If noise can be heard, apply more shims, assure that the flange closes flat and tight by hand pressure, and listen again for sound. Repeat as necessary until no movement of the C-1 inside the 7B-2 is apparent. Remove the aluminum shim stock and weigh it; the shim must not exceed 2 grams. If overweight, retain the total thickness of the shim but reduce its area by trimming with scissors. Reinstall the shim.

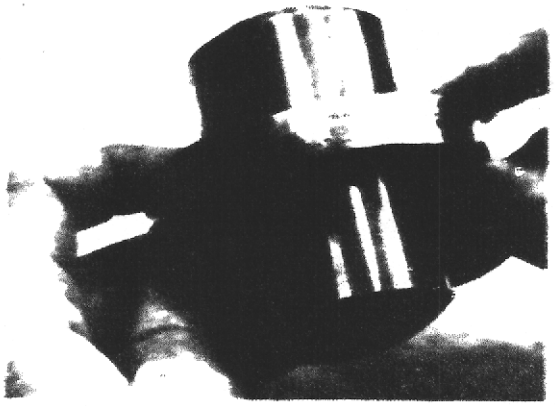


Figure 7B.2-4. Check for Free Play

Step 5: Install Copper Seal

Open the assembly by lifting off the B vessel, exposing the C-1 capsule. Check that the sealing grooves in both the A and B vessels are clean and free of debris, such as aluminum foil. Place a clean copper gasket over the protruding lip of the A vessel, as in Figure 7B.2-5.

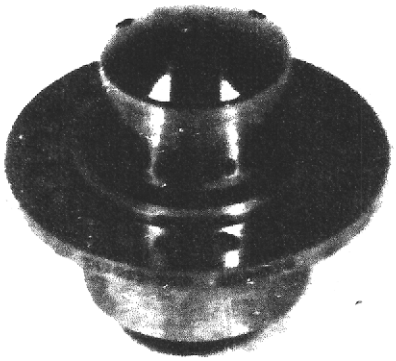


Figure 7B.2-5. Install Copper Seal

Step 6: Assemble A and B Vessels

Place the B vessel over the A vessel with the C-1 capsule inside, engaging the protruding lip of the A vessel into the mating groove of the B vessel. The copper seal will cause a large gap between the flanges (Figure 7B.2-6). If desired, align the part marking on the flanges, as shown.

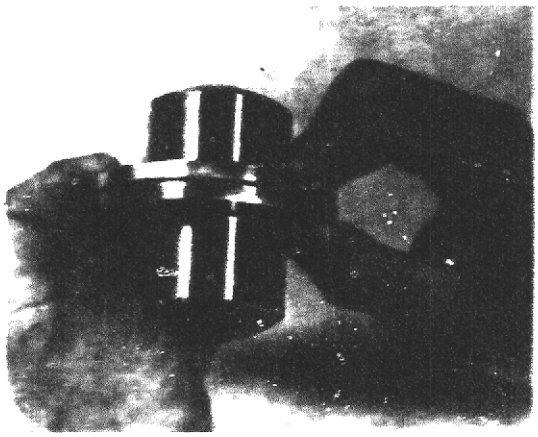


Figure 7B.2-6. Assemble A and B Vessels; Note Gap

Step 7: Install Bolts, Washers, and Nuts

In this sequence, every bolt must have the specified washer under the head of the bolt, and another of these washers must be under each nut. All bolt heads should be on the B vessel, all nuts should be on the A vessel, and the part marking should be legible, right-side-up; see Figure 7B.2-7. Using the correct wrenches, install the 20 sets of bolts, 2 washers, and nuts, and tighten all 20 approximately hand tight, using the small hand tools (hex wrench and nut driver).

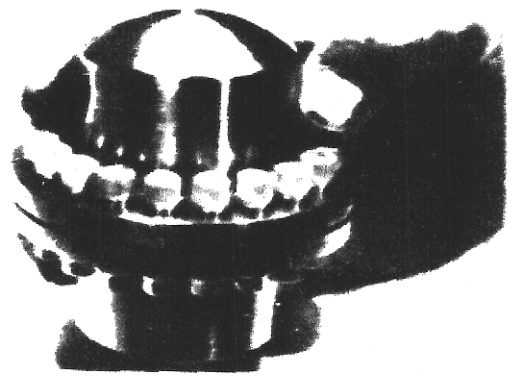


Figure 7B.2-7. Install Bolts, Washers, and Nuts

Step 8: Torque the Bolts

In this sequence, the copper seal will be forcibly formed in place within knife-edge sealing grooves in the A and B vessels. At first, as each bolt is tightened, the next adjacent bolt will be very loose. Several circular tightening sequences are required. Begin at a convenient identifiable point, such as the engraved part marking. Proceed in either direction, but do not skip any bolt. Torque all screws to about 100 inch-pounds (11 N·m), or to a comfortable level of torque for unaided hand work. Repeat at least twice around all 20 bolts. Observe that the flanged joint between the A and B vessels is now tightly shut, as in Figure 7B.2-8. If not, repeat at a higher torque, approximately 120 inch-pounds (14 N·m).

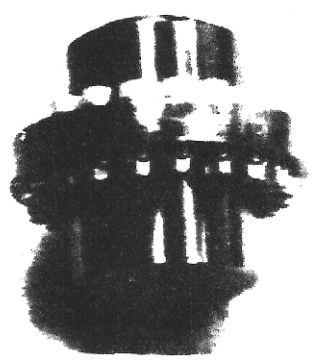


Figure 7B.2-8. Torque the Bolts

Step 9: Final Bolt Tightening

Place the TB-2 assembly in a bench vise with padded jaws (a covering of aluminum or brass sheet metal) and firmly compress the TB-2 on its flange, so that the flange and bolts are accessible for further tightening, as in Figure 7B.2-9. Again beginning at an identifiable point and proceeding in either direction, tighten every bolt to 180 inch-pounds (20 N•m) minimum. Tighten vise as necessary to resist torque. Repeat this procedure so that every bolt has been torqued twice at a level of at least 180 inch-pounds (20 N•m), 200 inch-pounds (23 N•m) maximum. Remove TB-2 from vise.

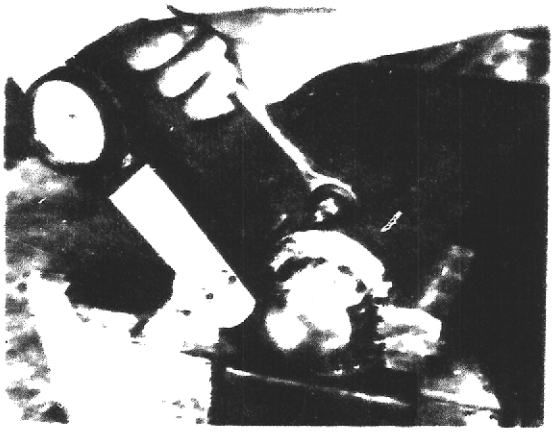


Figure 7B.2-9. Place TB-2 in Vise for Final Tightening

Step 10: Check Seal

Prior to shipment with radioactive contents, the TB-2 containment vessel must be leak-rate-tested per 8.2.2.

Step 11: Install Fairings

Following the leak-rate test, install the fairings by slipping them over the A and B vessels, and tighten the small nylon-tipped set screws with a small flat-bladed screwdriver; see Figure 7B.2-10.

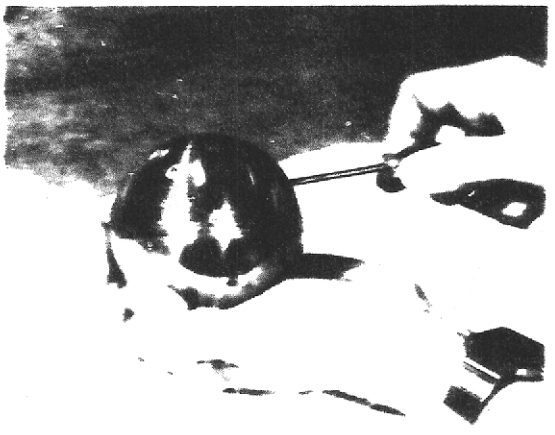


Figure 7B.2-10. Install Fairings

7B.3 LOADING THE AQ-2 OVERPACK

The parts and materials required for loading the AQ-2 overpack are listed in Table 7B.3-1; the tools and equipment required are listed in Table 7B.3-2.

Table 7B.3-1

Parts and Materials for AQ-2 Loading

Quantity	Item	Part Number
1 each	AQ-2 overpack, disassembled	T67014-000
1 each	Removable maple plug	T67010-000
1 each	Removable disk with handling strap	T67011-001 T67013-001
4 each	Flat-head countersink screws	T67014, item 14
1 each	Silicone rubber ring	T67014, item 6
1 each	Removable redwood plug	T67022-000
1 each	Inner top cover	T67029-000
1 each	Outer top cover	T67030-000
24 each	1/4-28 aircraft bolts	AN4C4A
1 each	Assembled and loaded TB-2	
As req'd	Document envelope	
As req'd	Shipping labels	
As req'd	Security seals	
As req'd	Filament-reinforced tape	

Table 7B.3-2

Tools for AQ-2 Loading

Heavy (No. 3) cross-tip screwdriver

7/16-inch six-point socket wrench with 3/8-inch speed drive

7/16-inch six-point socket wrench with 3/8-inch ratchet drive

Medium (No. 2) cross-tip screwdriver or tapered pin

Wire cutter (small)

Step 1: Place TB-2 in AQ-2

Tilt the AQ-2 overpack subassembly sideways, and insert the assembled TB-2 containment vessel into the inner cavity. Return the AQ-2 to an upright position; see Figure 7B.3-1.

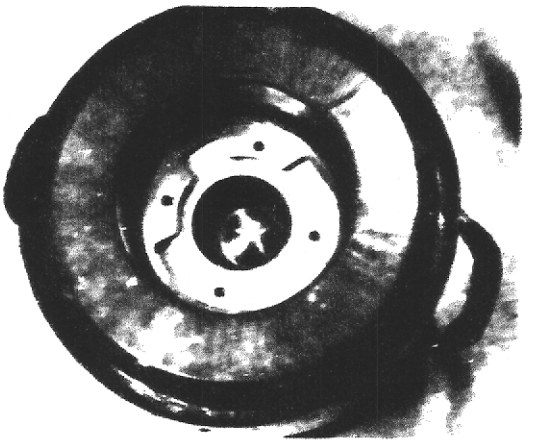


Figure 7B.3-1. Place TB-2 in AQ-2

Step 2: Insert Inner Maplewood Plug

Using the finger holes provided, place the small inner maplewood plug over the TB-2; see Figure 7B.3-2.

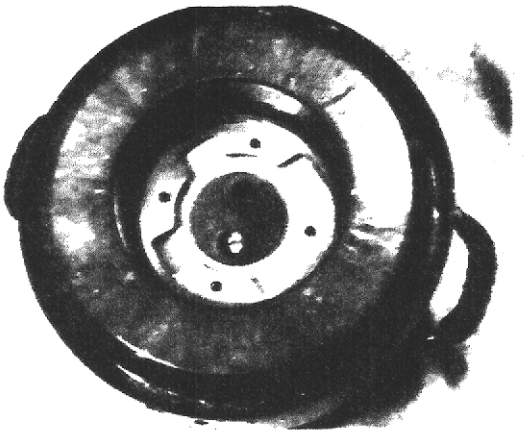


Figure 7B.3-2. Insert Inner Maplewood Plug

Step 3: Install Removable Disk

Using the handle provided, install the removable disc by engaging the lugs on the underside of the disc into the slots in the load spreader. Turn cover 1/4 turn in either direction; push inward as necessary to permit lugs to engage. Align the four holes, and loosely install the four cross-recessed-head screws. After all four screws have been engaged, tighten each screw firmly; see Figure 7B.3-3.

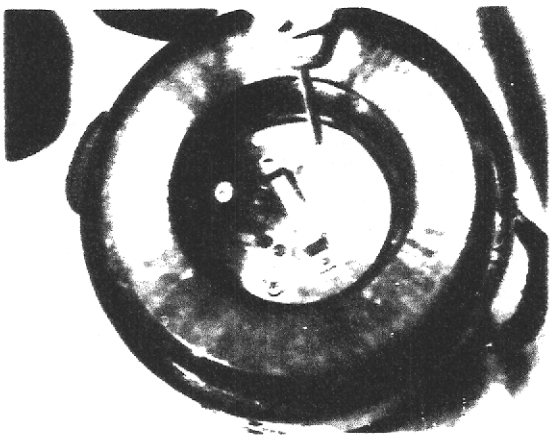


Figure 7B.3-3. Install Removable Disk

Step 4: Install Gasket

Lay the rubber gasket in place on top of the removable disc; see Figure 7B3-4.

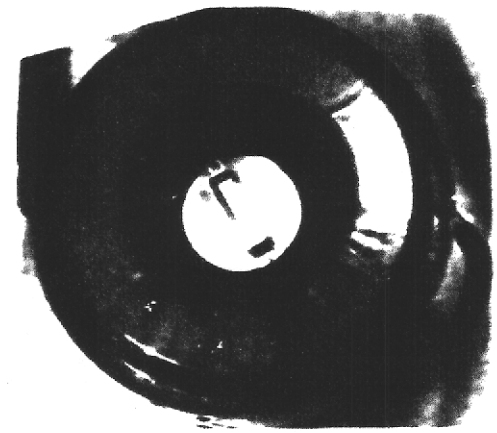


Figure 7B.3-4. Install Gasket

Step 5: Install Outer Redwood Plug

Using the finger holes provided, install the large redwood plug; rotate the plug so that the groove in the bottom surface fits over the handle on the disc. The plug will fit approximately flush with the fiberglass-covered redwood in the AQ-2 subassembly; see Figure 7B.3-5. A thin envelope of documentation, if required, may be placed on top of the redwood plug.

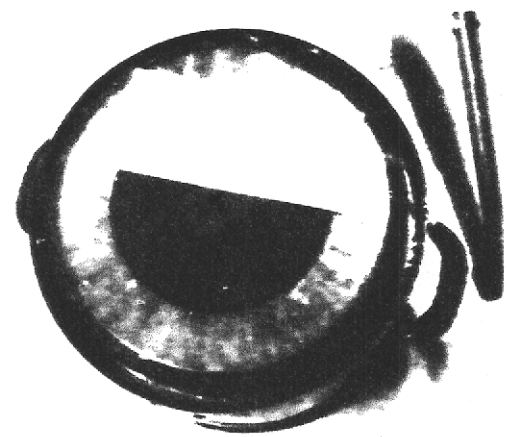


Figure 7B.3-5. Install Outer Redwood Plug

Step 6: Install Inner Cover

Install the inner stainless-steel cover (the cover with the floating nut plates riveted to the inner surface) by fitting it inside the drum wall of the AQ-2; align the match mark as in Figure 7B.3-6. The finger holes in the sidewall of this cover are primarily intended to aid disassembly.

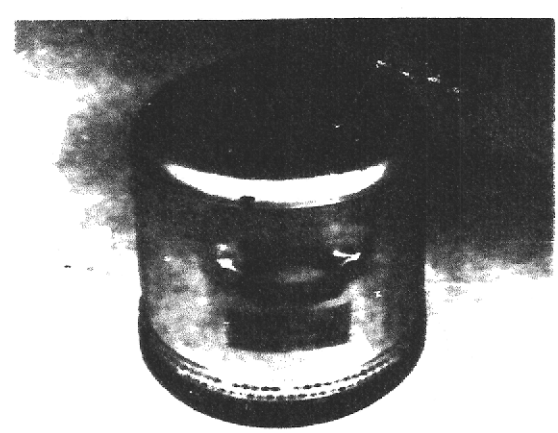


Figure 7B.3-6. Install Inner Cover

Step 7: Install Outer Cover

Fit the outer stainless steel cover over the outside of the drum body, align the match marks, and push down on the cover to approximately visually align the holes; see Figure 7B.3-7.

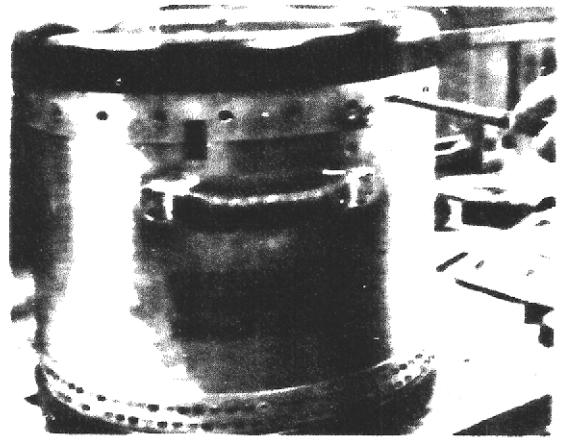


Figure 7B.3-7. Install Outer Cover

Step 8: Install 24 Bolts

Using a convenient blunt steel tool such as a small cross-recessed-tip screwdriver, align the hole pattern which passes through the outer cover, the drum wall, and the inner cover (with nut plates). Install the 24 1/4-inch bolts. A speed wrench may be used for convenience. Do not fully insert or tighten any bolt at first; assure that all 24 bolts get started. Then, using a ratchet wrench, tighten the bolts in a criss-cross, diametrically alternating manner, first at about 0° and 180°, next at about 90° and 270°, next at about 45° and 225°, then at about 135° and 315°, and then all remaining bolts in any sequence, tightening the bolt heads only enough to touch the outer cover. After all 24 bolt heads are touching, retighten all 24 bolts to a good, tight, mechanic's feel. Assure twice that all 24 bolts are tight. Refer to Figure 7B.3-8.

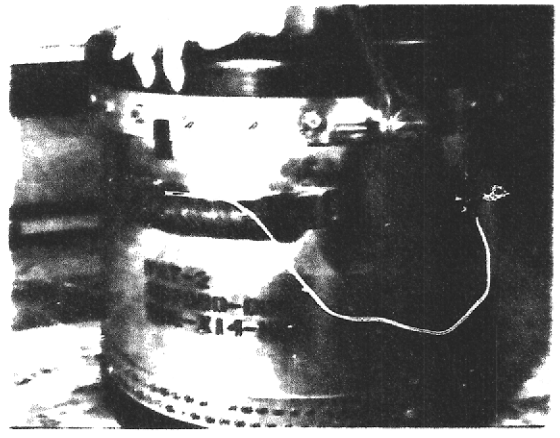


Figure 7B.3-8. Install 24 Bolts

Step 9: Security Seals

If security seals are required, they are to be installed between the cover and the body at the two positions provided, which are approximately 180° apart. The security seal strap should pass up and over the fitting provided on the cover and down and around the base of the carrying handle on the drum body, which is aligned with the fitting on the cover. For protection from incidental damage in shipment, the seal body may be additionally secured to the PAT-2 package with tape, restricting free movement of the seal and protecting it from being pulled off by engagement with adjacent objects. See Figure 7B.3-9.

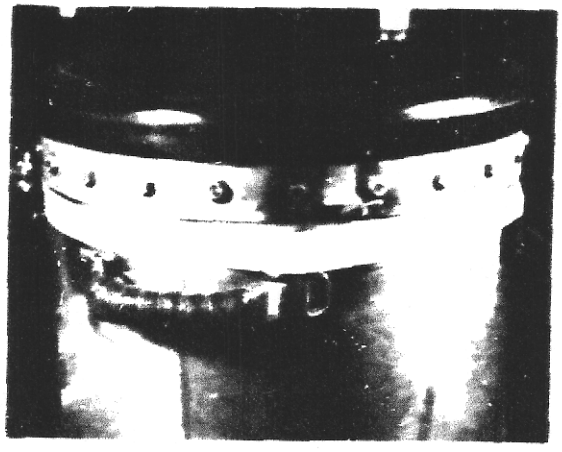


Figure 7B.3-9. Security Seal Attachment

Step 10: Shipping Labels and Documents

Labels and shipping documents may be taped to the PAT-2 package; do not place such items over the embossed trefoil symbol on the package cover or over the stencilled information on the drum body. Tags may be attached to the carrying handles, near the attachment point and away from the hand grip.

CHAPTER 8

PAT-2 PACKAGE ACCEPTANCE AND PRE-SHIPPING TESTS AND MAINTENANCE

The "Product Specification, Plutonium Air Transportable Package, Model 2 (PAT-2)," PS-T67000-000, as presented in Chapter 9, Appendix 9A, is the authoritative statement establishing the requirements for manufacture and manufacturer's acceptance of those Model PAT-2 packages that were produced for Sandia National Laboratories and that were used in the tests documented throughout this report. Additional information in this chapter is provided as instructions for users of the PAT-2 package.

8.1 LEAK-RATE AND PRESSURE TESTS OF THE TB-2 AND C-1 PRIOR TO FIRST USE

If the PAT-2 package is assembled, the TB-2 containment vessel and the C-1 capsule will be inaccessible. See Chapter 7 for package disassembly instructions. Also, as noted in Section 9.2.13, package users must provide appropriate markings,* tags, labels, routing cards, check lists, or other records assuring satisfactory completion of the inspections, tests, and/or replacements described in this chapter.

8.1.1 TB-2 Leak-Rate Test

Every TB-2, part no. T67001-001, which is supplied as part of a PAT-2 packaging and which is made in accordance with PS-T6700, is leak-rate tested as part of the quality control plan and final acceptance requirements, prior to shipment to a user. This test should satisfy certain State (national) or international regulations that require a leak-rate test prior to first use.

8.1.2 TB-2 Leak-Rate Test at 150% MNOP per 10 CFR 71.53(b)

10 CFR 71.53(b) states:

> Prior to the first use of any packaging for the shipment of licensed materials, where the maximum normal operating pressure will exceed 5 pounds per square inch gauge, the licensee shall test the containment vessel to assure that it will not leak at an internal pressure 50 percent higher than the maximum normal operating pressure.

---

*No structural alterations to the packaging are permitted; do not add holes, bolts, rivets, screws, or embossments. Markings should be made on paper products. Metal tags, if used, may only be wired to the handles of the packaging.

Since this test is incumbent on a U.S. NRC licensee, a manufacturer's test does not satisfy the regulation. The maximum normal operating pressure (MNOP) is 30.55 psia (210.6 kPa); see Section 4.3.1. A condition that is 151.7% of MNOP, or 46.35 psia (319.6 kPa), can be attained by placing 0.5±1 gram (0.5 cm^3 or 0.5 ml) water in an empty TB-2, sealing the TB-2 in a helium atmosphere using the procedures of Section 7.3, and heating the assembly to 244°F (118°C) minimum (250°F (121°C) is recommended as a maximum). While at this temperature, conduct a leak-rate test using a helium-type mass spectrometer.

8.1.3 C-1 Leak-Rate Test

Each C-1 capsule, before its first use by any operator, must be demonstrated to be leaktight when assembled as for shipment (see Chapter 7 for assembly procedures). This leakage test shall have a senstitivity of at least 10^{-4} cm^3/s and shall indicate a leak rate less than 10^{-3} cm^3/s. (An acceptable test would be one in which the C-1 is placed in a closely fitting chamber, a vacuum is rapidly drawn, and any subsequent rise in chamber pressure, over a period of time, is correlated with leak rate.)

8.2 INSPECTIONS AND TESTS TO BE PERFORMED PRIOR TO EACH USE OF THE PAT-2 PACKAGE

8.2.1 Visual Inspection

Note: The following steps are not necessarily in sequential order. To accomplish a complete visual inspection, the AQ-2 and TB-2 must be disassembled in accordance with Section 7.2.

8.2.1.1 AQ-2 Overpack

1. Check that there are no indentations deeper than 1/2 inch (13 mm) in the outer steel drum and covers, including the rubber-like boots on the top and bottom corners.
2. Open the AQ-2 overpack in accordance with instructions in Section 7.2.
3. Check that there are no large, obvious breaks in the fiberglass covering of the inner redwood member.
4. Check that the insulation and rubber pad on the underside of the titanium load spreader cover are in place.
5. Check that there are no obvious missing segments or deep indentations (> 1/2 inch or 13 mm) in the maplewood inside the titanium load spreader.
6. Check that the inner maplewood plug, the outer rubber ring, and the outer redwood plug are available and intact (not broken).
7. Check that the eight plastic vent plugs are in place on the drum bottom and the one vent cap on the center of the outer cover.

8. Check that the four cross-recessed screws for the load spreader cover are present or available.
9. Check that the twenty-four 1/4-inch bolts for the cover are present or available.
10. Check that the two handles on the drum body and the two security seal straps on the outer cover are present and undamaged.

8.2.1.2 TB-2 Containment Vessel

1. Check for the presence of the 24 socket-head bolts and the 24 nuts, with washers under each (48 washers, total).
2. Without the copper gasket, mate the two TB-2 hemispheres (the "A" or male shell and the "B" or female shell) together and observe that they make a flat, no-gap joint at the flange.
3. Check for visible damage to the small circular knife-edge in the TB-2 hemispheres (one knife-edge may be hidden by a used copper gasket, which would need to be removed).
4. Check that a new copper gasket is available and that it is free of any major gouge or irregularity.

8.2.1.3 C-1 Capsule

1. Check for any deep dents (> 1/8 inch or 3 mm) or deep scratches in the polished exterior surface.
2. Check for the presence of three spanner-wrench holes both in the lid and in the base of the body.
3. Check for any radially oriented scratches or gouges across the open end of the capsule body (the thin edge adjacent to the screw threads).
4. Check for any radially oriented scratches or gouges across the shoulder of the lid (the narrow step above the screw threads).
5. Check for smooth hand operation of the screw-thread connection between the lid and the body.

8.2.1.4 Replacement Parts

Missing or damaged parts may be replaced if (1) the replacement part meets the design requirements as described in the drawings of Appendix 9A, and (2) no other damage to the PAT-2 package is evident as a result of the missing or damaged part.

8.2.1.5 Rejection

Mechanical damage as described in Sections 8.1.1.1, 8.1.1.2, or 8.1.1.3 is cause for rejection of the part in question, or, if not a replaceable part, of the PAT-2 package. Damage to the knife-edge or copper gasket is cause to perform a leakage test as described in Section 8.1.2 to demonstrate TB-2 acceptability.

8.2.2 Tests To Verify Proper Assembly Prior To Each Shipment

8.2.2.1 C-1 Capsule

If required (due to plutonium contents in excess of 20 Ci), a leakage test shall be conducted on the C-1 capsule (with contents) that has been sealed per 7.2, prior to loading it into the TB-2 containment vessel. This leakage test shall have a sensitivity of at least 10^{-4} cm^3/s and must indicate leakage less than 10^{-3} cm^3/s in the assembled C-1. (An acceptable test would be one in which the C-1 is placed in a closely fitting chamber, a vacuum is rapidly drawn, and any subsequent rise in chamber pressure, over a period of time, is correlated with leak rate.)

8.2.2.2 TB-2 Containment Vessel

As part of preparation for each actual shipment, the TB-2 containment vessel will be assembled in accordance with the procedure described in Section 7B.2, and a leakage test shall be completed on the TB-2 together with its C-1 capsule and radioactive contents. This leakage test shall have a sensitivity of at least 10^{-4} cm^3/s and must indicate leakage $< 10^{-3}$ cm^3/s for the assembled TB-2. (An acceptable test would be one in which the TB-2 is placed in a closely fitting chamber, a vacuum is rapidly drawn, and any subsequent rise in chamber pressure, over a period of time, is correlated with leak rate.)

8.3 PERIODIC TEST AND MAINTENANCE

There is no scheduled or required maintenance, other than 8.3.2 below, for the PAT-2 package; the acceptance tests of 8.2, required prior to each use, assure that damage or missing parts have been noted and that corrections have been made.

8.3.1 TB-2 Containment Vessel and C-1 Capsule

Periodic testing of the TB-2 and C-1 containments is not necessary due to the TB-2 leak-rate tests before first use and before each shipment and the C-1 leak rate tests before first use and before each shipment (for Pu in excess of 20 Ci).

8.3.2 Replacement of Gasket on TB-2 Containment Vessel

The only component of the TB-2 having a replacement schedule is the copper gasket. A new gasket is to be used for each shipment of radioactive material.

CHAPTER 9

QUALITY ASSURANCE

9.1 GENERAL

Chapter 9 identifies the quality assurance requirements that were used for Sandia National Laboratories' design, purchase, fabrication, and test of the PAT-2 package, and recommends certain requirements* applicable to users of the package. The preceding chapters of this report provide full information regarding environmental tests and most of the design information; Appendix 9A provides a complete design definition. This chapter meets the intent of 10 CFR 71, Appendix E.

9.2 QUALITY ASSURANCE PROGRAM

An effective quality assurance program is maintained at both of the Department of Energy (DOE) agencies involved in design, fabrication, and testing of the PAT-2: Sandia National Laboratories, Albuquerque (SNLA; responsible for package design and test) and the Bendix Corporation, Kansas City Division (BKC; responsible for package fabrication). The overall program forestalls the procurement or inclusion of defective material and assures that defects or other unsatisfactory conditions are discovered at the earliest practical point. The programs assure that adequate quality control is maintained from the the time of material procurement, and that it continues during the receipt, identification, stocking, and issue of material, and throughout entire PAT-2 fabrication process. All materials procured from suppliers are subjected to adequate quality controls and/or inspections to assure conformance to specification requirements. The program provides readily available recorded evidence of quality in the form of inspection and test results.

The specific quality assurance provisions for the PAT-2 are cited in Section 4, Quality Assurance Provisions, of the "Product Specification, Plutonium Air Transportable Model 2 (PAT-2) Package," PS-T67000-000. That section covers inspection per MIL-I-45208, calibration per MIL-C-45662, serial numbers, test records, tests conditions, rejected units, certification of compliance, tolerances, in-process inspection and testing, final acceptance testing, function and fit, leak rate, and drawing compliance.

---

*Specifically, the requirements in Sections 9.2.13, 9.2.14, and 9.2.15.

9.2.1 Organization

At both BKC and SMLA, the administration, coordination, and evaluation of the quality assurance program is able to ensure objective decisions by contractor management. The responsible organizations are staffed by technically competent personnel with freedom to make appropriate objective judgments. recommendations, and decisions consistent with delegated authority. Copies of organizational charts for both companies can be obtained that indicate the level of authority and independence delegated to the quality assurance function.

9.2.2 Design Control

Sandia National Laboratories has overall responsibility for the design of the PAT-2 package. The Project Engineer is responsible for validation and application of all analyses used in the design phase of the package.

However, the package qualification criteria were sufficiently severe that complete reliance on analysis was not possible, and the overall design adequacy of the PAT-2 was verified by a comprehensive demonstration test program. The specifications for the PAT-2 have required that all the packages tested conform to designs and design reviews that assured the proper performance of the package with respect to the qualification criteria.

A design definition system was formalized and controlled by EP401221, "Definition Control for Plutonium Air Transportable Package Model 2 (PAT-2)," an engineering procedure issued specifically for this task. EP401221 defines the following:

1. Drawing Definitions -- The drawing control and drawing numbers are described in D10521, "Nonweapon Drawing Set." The nine-digit part number system applies to all parts on this program and allows precise part identification referenced to design definition.

2. List of Data -- A "List of Data" document, LD-T67000-000, lists the drawings and specifications by issue which are required for procurement of the PAT-2; it is maintained by the Sandia Specifications Engineer. This document is used to authorize specific development build definitions.

3. Engineering Release -- All drawings (including specifications) were initially released, after preliminary design and review, by an Advance Engineering Release (AER), issued by Sandia Division 1725. At a later date, after development work was completed, a Complete Engineering Release (CER) was issued.

4. Change -- After release of the drawings by AER, specific changes to the design are made by change order. The change order may authorize specific engineering action during the life of the development contract. Changes to the drawings may be either by Advance Change Order (ACO) or Final Change Order (FCO). ACOs are issued before the drawing changes are incorporated in a new drawing issue, and FCOs identify a change document issued after the drawing changes are incorporated in a new drawing issue.

5. Approvals -- The Division 1725 Project Engineer and Division Supervisor (or his authorized delegate) approves all releases and change orders.

6. Distribution -- The distribution of engineering releases and change orders shall be SLA No. 1 (an SNLA internal distribution list), the buyer, the Division 1725 Project Engineer, the Division 2433 Specifications Engineer, and others as determined by the Project Engineer.

7. Responsibility for Preparation of Releases and Change Orders -- The Specifications Engineer will be responsible for preparation of releases and change orders. After approval by the project engineering division, Sandia Section 2431-1 will process the documents and make distribution.

8. Deviations -- Deviation from development build definition must be agreed to verbally and confirmed in writing through a Specification Exception Release (SXR). These SXRs may originate at BKC but must be approved by the 1725 Project Division.

9. Disposition of Original Tracings -- After the development contract has been completed and the original tracings are no longer needed, the project engineering division will authorize archiving the drawings and specifications by an Archive Engineering Release.

9.2.3 Procurement Document Control

Engineering Procedure EP401221, "Definition Control for PAT-2 Package," provided in Appendix 9A, is the authoritative procurement document control for the development contract and drawing definitions.

Product Specification PS-T67000-000 cites all documents required for PAT-2 quality and fabrication control.

9.2.4 Instructions, Procedures, and Drawings

Instructions, procedures, and drawings are as cited in the previously referenced Engineering Procedure EP401221, Product Specification PS-T67000-000, and in

the "List of Data, PAT-2 Package," LD-T67000-000 (provided in Appendix 9A). Instructions for users are in Chapters 7 and 8 of this report.

9.2.5 Document Control

The complete set of specifications, drawings, and control documents for the PAT-2 package are included in Appendix 9A.

9.2.6 Control of Purchased Material

The BKC purchasing documents specify the requirements of the contract via engineering drawings with the noted design requirements and by citing specifications in purchase orders. All material must conform to the drawing requirements; inspection of material upon receipt assures this conformance. Any discrepant material is either rejected to the supplier or, if usable, approved for use via a nonconforming approval system. Any nonconforming approval request is processed to the Sandia Project Engineer for his approval or rejection.

Certification of compliance is required on critical items (refer to paragraph 4.1.5 of PS-T67000-000; Appendix 9A).

9.2.7 Identification and Control of Material Parts and Components

All material received within BKC is properly bagged or tagged to allow referral to appropriate specifications and inspections. Records are generated during fabrication of these materials into a PAT-2 to allow traceability to any previous analysis or inspection. These data are maintained for use by any appropriate organization.

Each PAT-2, AQ-2, TB-2, and C-1 is permanently marked with a serial number in ascending numerical order corresponding to the sequence of manufacture. Once assigned, a serial number is not assigned to another item.

9.2.8 Control of Special Processes

Qualified personnel, acting in accord with specifications included in Appendix 9A, perform and control all special processes.

Special specifications have been issued as follows:

SS-T67000	General Requirements, PAT-2 Package
SS-T67001	Testing, Leak Rate, Mass Spectrometer, PAT-2 Package
SS-T67016	Welding, Titanium
SS-T67025	Covering, Fiberglass

SS-T67026 Material Specification, Redwood for PAT-2 Package
SS-T67027 Welding, Corrosion Resistant Steel, PAT-2 Package.

Compliance with these specifications is required on the drawings and in the overall Product Specification PS-T67000-000. Copies of these specifications are included in Appendix 9A.

9.2.9 Inspection

All inspections are performed in accordance with MIL-I-45208 by qualified personnel who utilize calibrated inspection devices and standard inspection techniques in accordance with MIL-C-45662. All inspection personnel are assigned to the independent inspection organization.

Specific inspection details (final acceptance testing) are cited in paragraph 4.3 of PS-T67000-000, provided in Appendix 9A.

9.2.10 Test Control

Test control for environmental tests is per the "PAT-2 Test Protocol," Appendix 2E, and per the facility descriptions presented in Appendix 2F. Tests required in manufacturing are specified in the applicable drawings and specifications.

9.2.11 Control of Measuring and Test Equipment

The quality assurance program described above embodies the control of MIL-C-45662 for calibration, MIL-I-45208 for inspection, and MIL-Q-9858 for quality control, as specified in PS-T67000-000.

All inspection tools used have been calibrated within a system that is periodically recertified by the National Bureau of Standards. At SNLA, the Primary Standards Laboratory maintains these calibration standards. A secondary standards laboratory at BKC periodically recertifies their standards against those of the Sandia Primary Standards Laboratory. Periodic audits of the BKC system are performed by Primary Standards personnel as well as personnel from the DOE.

9.2.12 Handling and Related Functions

No special measures to control handling, storage and shipping, cleaning, and preservation of materials and equipment are required beyond those previously addressed in this section.

9.2.13 Inspection, Test, and Operating Status

Appropriate markings, tags, labels, routing cards, check lists, or other suitable means of assuring satisfactory completion of the inspections, tests, and replacements described in Chapters 7 and 8 must be provided by the user of the PAT-2. These records should include a user's verification of the torque used in tightening the C-1 capsule and the TB-2 bolts.

9.2.14 Nonconforming Materials, Parts, or Components (in service)

Appropriate measures shall be established by the PAT-2 package user to assure that nonconforming parts are not inadvertently used.

9.2.15 Corrective Measures

Design and fabrication corrective measures have been addressed previously in this chapter, corrective measures required during package loading operations have been identified in Chapter 8, and corrective measures required during transport operations must be identified by the user or carrier.

9.2.16 Quality Assurance Records

The provisions for maintaining sufficient records of design, fabrication, and test activities have been addressed previously in this chapter.

9.2.17 Audits

A comprehensive system of planned and periodic audits is included in the authority delegated to the quality assurance organizations at SNLA and BKC, under DOE directives.

9.3 CERTIFICATION OF COMPLIANCE

The Bendix Corporation Certificate of Compliance letter appears as Appendix 9B. The referenced Specification Exceptions are on file with the Sandia National Laboratories Project Engineer (Division 1725 as of March 1981).

APPENDIX 9A

PAT-2 Specifications and Design Definitions

This appendix provides all of the required specifications and design definitions for the PAT-2 package. The second document, LD-T67000, is a listing, by revision issue, of all of these specifications and design definitions.

The engineering procedure EP 401221 is only applicable to those packages fabricated by the Bendix Corporation for Sandia National Laboratories. Any other agency or organization undertaking PAT-2 package fabrication should issue their own procedures to assure quality control and would need to communicate with the Transportation Certification Branch, Division of Fuel Cycle and Material Safety, U.S. Nuclear Regulatory Commission, Washington, D.C., 20555, United States of America.

Pmt 12/18/80

DEFINITION CONTROL FOR PLUTONIUM AIR TRANSPORTABLE PACKAGE, MODEL 2 (PAT-2)

Page	1	2	3
Issue	B	A	A

1. GENERAL.

1.1 Purpose. This procedure establishes the design definition system to be used for development units of the Plutonium Air Transportable Package, Model 2 (PAT-2), and the release and change procedures for that definition. The responsible project engineering group for PAT-2 is the Safeguards Systems Engineering Division, 1725, of the Sandia National Laboratories.

1.2 Development Contract. The development contract with the Bendix Corp., Kansas City Division (BKC) is the controlling document for:

a. Scope of work

b. Quantities

c. Price

d. Deliveries

e. Administrative conditions

f. General terms and conditions of contract

The development contract shall call for this engineering procedure for the purposes described.

2. DRAWING DEFINITIONS.

a. The drawing control and drawing numbers are described in D10521 (see reference 1). The 9-character part numbering system shall apply for all parts of this program.

2. continued

b. An LD (List of Data) document that lists the drawings, by issue, that are required for procurement of the PAT-2 will be maintained by the Sandia specifications engineer. This document may be used to authorize specific development build definitions.

3. DRAWING RELEASE AND CHANGE SYSTEM.

3.1 Release. All drawings (including specifications) will be initially released after preliminary design and review by an Advance Engineering Release (AER), issued by Sandia Division 1725. At a later date, after development work has been completed, a Complete Engineering Release (CER) will be issued.

3.2 Change. After release of the drawings by AER, specific changes to the design will be made by change order. The change order may authorize specific engineering action during the life of the development contract. Class of change will not be used in this program. Changes to the drawings may be either by Advance Change Order (ACO) or Final Change Order (FCO). ACO's are issued prior to the drawing changes being incorporated in a new drawing issue, and FCO's identify a change document issued after the drawing changes are incorporated in a new drawing issue.

3.3 Approvals. The Division 1725 Project Engineer and Division Supervisor (or his authorized delegate) approves all releases and change orders.

3.4 Distribution. The distribution of engineering releases and change orders shall be SLA #1, the Buyer, the Div. 1725 Project Engineer, the Div. 2433 Specifications Engineer, and others as determined by the Project Engineer.

3.5 Responsibility for Preparation of Releases and Change Orders. The Specifications Engineer will be responsible for preparation of releases and change orders. After approval by the project engineering division, Sandia Section 2431-1 will process the documents and make distribution.

4. DEVIATING MATERIAL. Deviation from development build definition must be agreed to verbally and confirmed in writing through a Specification Exception Release (SXR). These may be originated at BKC, but must be approved by the 1725 Project Division.

5. **DISPOSITION OF ORIGINAL TRACINGS.** After completion of the development contract, and there is no longer a need for use of the original tracings, the project engineering division will authorize archiving the drawings and specifications by an Archive Engineering Release.

6. **REFERENCES.**

1. D10521, "Nonweapon Drawing Set".

LIST OF DATA, PAT-2 PACKAGE

Page	1	2
Issue	D	D

Document No.	Issue	Title
*EP401221	B	Definition Control for PAT-2 Package
PS-T67000	D	Product Specification, PAT-2 Package
SS-T67000	C	General Requirements, PAT-2 Package
SS-T67001	C	Testing, Leak Rate, Mass Spectrometer, PAT-2 Package
SS-T67016	B	Welding, Titanium
SS-T67025	[illegible]	Covering, Fiberglass
SS-T67026	D	Material Specification, Redwood for PAT-2 Package
SS-T67027	C	Welding, Corrosion Resistant Steel, PAT-2 Package
T67000	D	PAT-2 Package
T67001	F	TB-2, Spherical Containment Vessel Assembly
T67002	D	TB-2, Spherical Containment Vessel-A
T67003	E	TB-2, Spherical Containment Vessel-B
T67004	C	Seal, Copper
T67008	D	Body, C-1 Capsule
T67010	C	Plug, Top, Inner, Maple, Removable
T67011	G	Disk, Removable

*Applies only for contracts involving Bendix Corp. and Sandia National Laboratories.

Document No.	Issue	Title
T67012	B	Strap, Seal, Security
T67013	C	Strap, Handling
T67014	D	AQ-2 Overpack
T67015	E	Load Spreader Assembly
T67016	E	Load Spreader
T67021	C	Plug, Inner, Maple
T67022	D	Plug, Top, Redwood, Removable
T67024	E	Plug, Bottom, Redwood
T67025	E	Subassembly, Outer, Cylinder
T67026	E	Toroid, Outer, Redwood
T67027	F	Cylinder, Outer
T67028	E	Handle
T67029	C	Cover, Top, Inner
T67030	F	Cover, Top, Outer
T67031	B	Cover, Bottom, Inner
T67032	B	Cover, Bottom, Outer
T67035	E	Subassembly, Outer Shell
T67037	D	Lid, C-1 Capsule
T67038	E	Wrench, Capsule
T67042	D	Washer
T67047	B	Lock Ring
T67048	D	Fairing, TB-2, Spherical Containment Vessel
T67049	C	Toroid, Inner, Maple

PRODUCT SPECIFICATION, PLUTONIUM AIR TRANSPORTABLE PACKAGE, MODEL 2 (PAT-2)

Page	1	2	3	4	5	6	7	8	9
Issue	D	D	D	D	D	D	D	D	D

1. GENERAL

1.1 Scope. This specification establishes the requirements for manufacture and acceptance of the Plutonium Air Transportable Package, Model 2 (PAT-2).

1.2 Item Description. The Plutonium Air Transportable Package, Model 2 covered by this specification is a packaging system suitable for use in transporting (including transportation by air) limited quantities of plutonium and similar material. It is designed to meet the requirements of CFR 10, Part 71, and CFR 49, Parts 170 through 178, NUREG-0360, "Qualification Criteria to Certify a Package for Air Transport of Plutonium," and IAEA Safety Series No. 6.

The PAT-2, drawing number T-67000, is made up of the following major components.

a. AQ-2 overpack, drawing number T-67014.

b. TB-2 Spherical Containment Vessel, drawing number T-67001.

c. C-1 Capsule, drawing numbers T-67008 and T-67037.

1.3 Dimensional System. The PAT-2 drawings are in the SI (metric) system, except for certain commercial items such as metal stock, hardware, etc., which are defined in U.S. (inch-pound) units.

2. DOCUMENTS

The following documents 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. continued

Standards:

Military:

MIL-STD-129	Marking For Shipment and Storage

Drawings:

LD-T67000	List of Data, PAT-2 (and the drawings and specifications listed therein)

Other Publications:

Regulations:

10 CFR 71	Packaging of Radioactive Material For Transport and Transportation of Radioactive Material Under Certain Conditions
49 CFR 170-178	Transportation
NUREG-0360	Qualification Criteria to Certify a package for Air Transport of Plutonium
IAEA	Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials 1973 Revised Edition (As Amended)

Procedures:

*EP401221	Definition Control for Plutonium Air Transportable Package, Model 2 (PAT-2)

3. REQUIREMENTS

The provisions of SS-T67000, General Requirements, PAT-2, shall apply.

3.1 Performance. The PAT-2 shall provide a sealed, accident resistant packaging system suitable for use in transporting small quantities of plutonium by air.

*Applies only for contracts involving Bendix Corp. and Sandia National Laboratories.

3.2 Construction.

3.2.1 Production Drawings. The PAT-2 shall be fabricated and assembled in accordance with the drawings and other documents listed on LD-T67000, and the additional documents specified therein.

3.2.2 Standards Of Manufacture.

3.2.2.1 Quality Control. Unless otherwise specified, the requirements of 10 CFR 71, Appendix E shall apply.

3.2.2.2 Workmanship. The provisions of SS-T67000 shall apply.

3.2.2.3 Welding Methods. Welding and fabrication shall be in accordance with SS-T67016 and SS-T67027.

3.2.2.4 Glued Assemblies.

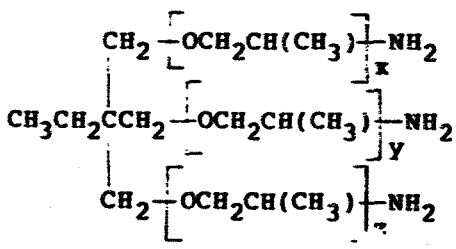
a. In gluing wood to wood, insulation to metal, or insulation to insulation, polyvinyl acetate resin emulsion per MMM-A-180 shall be used. As an alternate, glue per 3.2.2.4.b may be used, unless otherwise specified.

b. In gluing wood to metal, or wood to insulation, the bond material shall be a flexible epoxy adhesive consisting of the following, by weight.

(1) 100 parts CTBN (carboxy-terminated butadiene nitrile) modified epoxy.

(2) 25 parts ATBN (amine-terminated butadiene nitrile) modified epoxy.

(3) 35 parts curing agent. Curing agent to be an aliphatic poly-oxypropyleneamine, with light color, low viscosity, low vapor pressure, and high primary amine content, having the following structure:



$x + y + z = 5.3$ (approx.)

3.2.2.4 continued

The typical analysis and physical properties are to be:

Total Acetylatables, meq./g.	6.75
Total Amines, meq./g.	6.45
Primary Amines, meq./g.	6.16
Water, wt. %	0.08
Color, Pt-Co	10
Viscosity, cs., 25°C.	76.5
cs., 20°C.	97
Specific Gravity 20/20°C	0.9812
Refractive Index, 20°C	1.4606
Flash Point, COC, °F	380
pH, 1% aq. soln.	11.2
pH, 5% aq. soln.	11.6
Vapor Pressure, mm Hg/°C.	1/181. 5/207

(4) 3.5 parts amine accelerator. Accelerator to be an epoxy curing promotor designed for use with amine hardeners. Typical properties shall be:

Appearance	Clear, pale yellow slightly viscous liquid
Apparent Equivalent Weight (g per reactive hydrogen)	65
Flash Point (COC) °F	220
Pour Point, °F	5
Specific Gravity, 20/20°C	1.0944
Viscosity, cps, 25°C	920

(5) 5-10 parts finely divided silica filler.

Mix (1) through (5) thoroughly to insure uniformity. To extend the pot life of the adhesive, mixing should be done as rapidly as possible.

3.2.2.4 continued

c. In gluing rubber to insulation a rubber-base contact adhesive compatible with silicone rubber, per MMM-A-121, shall be used.

d. Glue lines, resulting from the dimensions of finished mating parts, shall be 0.025 to 3.18 mm.

3.2.2.5 Part Number Marking. Product marking shall be per Section 3.5 of SS-T67000.

3.3 Preproduction Sample. Preproduction samples are required.

3.3.1 Sample Items. The preproduction sample shall consist of the following items which have been manufactured and assembled by the supplier using the same continuous production processes, procedures, and equipment which will be used in fulfilling the production contract.

one (1) Overpack, AQ-2, part number T67014-000.

one (1) Spherical Containment Vessel, TB-2, part number T67001-001.

one (1) Capsule, C-1, part numbers T67008-001 and T67037-001.

The sample shall be accompanied by certificates of compliance in accordance with 4.1.5.

3.3.2 Sample Testing. The preproduction sample shall be subjected to the tests specified in 4.3.

3.3.3 Sample Rejection. If any assembly or component fails to comply with any of the applicable requirements, the preproduction sample shall be rejected. In the event of rejection, the supplier shall take corrective action and submit new preproduction samples until such time as an acceptable sample is submitted. Until the first preproduction sample is accepted, the supplier is not authorized to begin or resume regular production, unless otherwise directed.

4. QUALITY ASSURANCE PROVISIONS

4.1 General. The supplier responsible for the manufacture of the PAT-2 is responsible for the accomplishment of all of the tests and inspections specified herein.

4.1.1 Serial Numbers. Each PAT-2, AQ-2, TB-2, and C-1 shall be permanently marked, as specified on the applicable product drawing, with a serial number in ascending numerical order corresponding to the sequence of manufacture, beginning with 101. Once assigned, a serial number shall not be assigned to another item.

4.1.2 Test Records. The supplier shall maintain records of all tests performed per 4.3. Copies shall be distributed as required by the contract or purchase order.

4.1.3 Test Conditions. Unless otherwise specified, all measurements and tests shall be performed at standard ambient conditions.

4.1.4 Rejected Units. Units that fail any test shall be rejected. Rejected units shall not be reworked, unless otherwise directed, and shall be marked in red to prevent accidental use.

4.1.5 Certificate of Compliance. The supplier of the PAT-2 shall obtain and supply, as requested, certificates of compliance from subcontractors verifying that the following materials used in fabrication of the PAT-2 are in accordance with the applicable drawings and specifications.

a. The stainless steel for the Overpack, AQ-2, see T67014.

b. The redwood for the AQ-2, per SS-T67026.

c. The titanium for the load spreader assembly, see T67015.

d. The A286 iron-base super alloy for the TB-2 vessel, see T67001.

e. The copper for the seal, see T67004.

f. The nitronic 60 stainless steel for the C-1 capsule, see T67008 and T67037.

g. The quartz for the canister liners, see T74073 through T74077.

h. The 0.250-28 bolts and nuts for the TB-2, see T67001. Certify bolt and nut A-286 material and silver plating.

i. The stainless steel for the 40 washers used on the TB-2, see T67042.

4.1.6 Tolerances. Limiting values specified in the drawings and specifications shall be absolute, as defined in SS-T67000.

4.2 In-Process Inspection and Testing. The supplier shall perform such in-process inspection and testing as he deems necessary to obtain product which meets the requirements of this specification.

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

4.3.1 Function and Fit. The PAT-2 shall be visually and mechanically inspected to assure that all of the component parts fit into the assembly properly, as specified in the drawings.

4.3.2 Leak Rate. The TB-2 shall be leak tested utilizing mass spectrometer leak rate measurement methods in accordance with SS-T67001. Helium leak rates, when present, shall be converted to equivalent air leak rates. The leak rate shall not exceed 1×10^{-8} ATM cm^3/sec (air).

4.3.3 Drawing Compliance. Drawing dimensions are in SI metric units. The PAT-2 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, as follows.

4.3.3.1 Package, PAT-2, Drawing No. T67000.

a. Verify presence of item 2, TB-2.

b. Verify that marking is as specified, with same serial number on AQ-2 and PAT-2.

4.3.3.2 Overpack, AQ-2, Drawing No. T67014.

a. Verify 0.250 inch bolts, item 13, in place (24 required).

b. Verify that there are no missing rivets in the bottom joint pattern, except for d. below, where plastic plugs are specified.

c. Verify that marking is as specified for both impression stamping and painted index marks.

d. Verify presence of eight plastic plugs, item 17, in place.

e. Verify presence of end cover cap plug, item 16, in place.

4.3.3.3 TB-2, Spherical Containment Vessel-A, Drawing No. T67002.

a. Verify that all dimensional requirements are met.

b. Verify material condition and hardness per Note 3, unless already certified per 4.1.5.d.

c. Verify engraved part and serial numbers per Note 5.

d. Verify all finishes including the overall finish per Note 4, the special finish per Note 7, and the finish of datum surface A.

4.3.3.4 TB-2, Spherical Containment Vessel-B, Drawing No. T67003.

a. Verify that all dimensional requirements are met.

b. Verify material condition and hardness per Note 3, unless already certified per 4.1.5.d.

c. Verify engraved part and serial numbers per Note 5.

d. Verify all finishes including the overall finish per Note 4, the special finish per Note 7, and the finish of datum surface A.

4.3.3.5 Seal, Copper, Drawing No. T67004.

a. Verify that all dimensional requirements are met.

b. Verify surface finish per Note 4.

4.3.3.6 Body, C-1 Capsule, Drawing No. T67008.

a. Verify that all dimensional requirements are met.

b. Verify material and condition per Note 3, unless already certified per 4.1.5.d.

c. Verify presence of sleeve, item 3, three places.

d. Verify overall finish per Note 7 and Note 9.

4.3.3.7 Lid, C-1 Capsule, Drawing No. T67037.

a. Verify that all dimensional requirements are met.

b. Verify material and condition per Note 3, unless already certified per 4.1.5.d.

c. Verify presence of sleeve, item 3, three places.

d. Verify overall finish per Note 7 and Note 9.

5. PREPARATION FOR DELIVERY

5.1 Marking. Marking for shipment shall be in general accordance with the requirements of MIL-STD-129 and shall have the following minimum information legibly marked or labeled:

a. "PAT-2" and its Part Number.

b. Contractor's Code.

c. Serial Number.

d. Date Code.

Example: PAT-2
T67000-000
BBN-XXX-D80

6. NOTES

Procurement documents shall specify the following:

a. Title, number, and date of this specification.

b. Applicability of Preproduction Sample Approval (paragraph 3.3).

c. Any exceptions to this specification.

JAN 7 1981

FSCM NO. 14213
CER 802462SC
OWENS 2433 PRO 12/18/80
ANDERSEN 1725 PRO 12/18/80
STEPS NO. EA1795

SS-T67000
-000

GENERAL REQUIREMENTS, PAT-2 PACKAGE

Page	1	2	3	4	5	6	7	8	9
Issue	C	A	A	A	A	A	B	A	A

1. GENERAL

1.1 Scope. This specification defines the general requirements for product fabrication and inspection of parts and assemblies used on the Plutonium Air Transportable Model 2 (PAT-2) Package, T67000. It also provides interpretation of certain requirements specified on the product drawings. Specific requirements on the product drawings shall take precedence over these general requirements and interpretations.

2. DOCUMENTS

The following documents form a part of this specification to the extent specified herein. Unless otherwise specified, the issues shown shall be used.

ANSI Y14.5-1973	Dimensioning and Tolerancing
ANSI B1.1-1974	Unified Inch Screw Threads (UN and UNR Thread Form)

3. REQUIREMENTS

3.1 Drawing Interpretation. The product drawings utilize the "True Position" drawing system, as defined in ANSI Y14.5. An understanding of the provisions in the ANSI document is essential for the proper interpretation of the dimensions and tolerances on the PAT-2 drawings.

3.2 Dimensions, Tolerances, and Measurements. The product is defined using SI (International System of Units) dimensions except for screw threads and U.S. gage thicknesses.

3.2.1 Absolute Tolerance Concept. Design requirements are based on the absolute tolerance concept, which means the true value of the characteristic shall be within the tolerance stated. An acceptable degree of conformance of product to the intent of absolute tolerances is required. To judge the degree of conformance, consideration shall be given to the inherent measurement uncertainty in relation to the specified tolerances. Information concerning production process distribution (both centering and dispersion), if available, may also be used in determining conformance.

3.2.2 Decimal Places. As many (or as few) decimal places are used as are needed to express design requirements.

3.2.3 Interpretation of Dimensional Limits. Regardless of the number of decimal places, the maximum and minimum limits are considered to be followed by a single (implied) zero. Any measurement made beyond this implied zero reading shall be disregarded; rounding is not applicable. There is no need to measure past the single implied zero.

3.2.4 Measurement Temperatures. Physical measurements of a product are considered to apply only at a temperature of 20°C. If referee measurements are required, the measurement shall be made at 20°C or adjusted to 20°C to account for differences in thermal expansion or contraction in the material of the gage and/or parts. The tolerance on the 20°C temperature is controlled by the degree of accuracy required for the measurement being made.

3.2.5 Counterbores. In curved surfaces or on flat surfaces where the hole axis is not perpendicular to the surface, the depth of a counterbore is the minimum distance from the bottom of the rim as shown in Figure 1. The interior corner at the bottom of a counterbore produced by a standard tool is acceptable.

3.2.6 Countersinks. In curved surfaces or on flat surfaces where the hole axis is not perpendicular to the surface, the diameter of a countersink is the diameter of the lowest point on the rim in a plane perpendicular to the hole axis. See Figure 1. Countersink for flat head screws to allow head of screw to be flush to .25 mm below the surface.

3.2.7 Stock Material Tolerances. When the drawing specifies nominal cross-sectional dimensions for material used to fabricate the part, but does not specify tolerances for these dimensions, the widest tolerances applicable to the material, form, and process may be used.

3.3 Manufacturing Practices.

3.3.1 Removing Burrs and Sharp Edges. All burrs and sharp edges shall be removed to the extent that material fragments are not visible and sharpness cannot be felt. Either a 0.25 mm maximum x 0.25 mm maximum chamfer or 0.25 mm maximum radius is satisfactory treatment in breaking edges and deburring. Only those edges that appear to exceed these limits upon visual inspection need be measured for conformance to these dimensions. If it is necessary to break sharp edges or to deburr after application of chemical surface treatment, the bared metal shall be touched up as required. Flash on molded plastic parts that does not cause the part to exceed maximum dimensional limits need not be removed. These requirements do not apply to rough and semi-finished metal castings and forgings.

3.3.2 Free-State Variations. If material flexibility or normal internal stresses can be expected to cause parts to be out of tolerance, appropriate inspection procedures shall be obtained prior to the manufacture of parts.

3.3.3 Holes Called for on Assembly Drawings. Where holes are called out on assembly drawings, they may be provided in the detail parts, either full size or less than full size, as required to facilitate manufacture. Inspection of such holes is not required, however, until final assembly, at which point the holes must meet all assembly drawing requirements.

3.3.4 Machine or Molded Diameters. Where no concentricity requirement (position or runout tolerance) is specified, any two or more diameters having a common axis (including hole countersinks, counterbores) shall be concentric within a full indicator movement (FIM) of one-half the arithmetic sum of their size tolerance. The diameter having the smallest tolerances shall be the datum feature for all related diameters. If size tolerance values are equal, the diameter having the longest axis shall be used as the datum feature.

3.3.5 Threaded Parts.

3.3.5.1 Form and Class of Fit. All threads shall conform to the requirements of ANSI B1.1.

3.3.5.2 Appearance. All threads shall be free from burrs, nicks, and rough or chattered surfaces, that are visible without magnification.

3.3.5.3 Gaging.

a. Measurement Over Wires. Thread wires and measurement indicators may be used.

b. "GO" Gages. When "GO" gages are used, the product shall allow the "GO" gage to enter or to be entered the specified full length or depth of the thread; however, the thread must be functional.

c. "NOT GO" Gages. Threads are acceptable as within material limits if, when plug ring thread gages are used, the "NOT GO" plug gage does not enter or the "NOT GO" ring gage is not entered. Threads may be accepted if all complete threads can enter in or be entered by the "NOT GO" gage provided a definite drag results from metal-to-metal contact on or before the third turn of entry. For threads having three or fewer turns, the drag shall occur on or before the first one-half turn of actual thread engagement. Neither working nor final inspection "NOT GO" gages should be forced after the drag is definite.

d. Three-Roll Indicating-Type Gage Readings. When this type gage is used on Class 2A or 3A threads, the gage reading may not exceed the basic pitch diameter by more than 1/8 turn of the screw providing the maximum gage reading does not exceed the basic pitch diameter by more than 50 percent of the difference between basic pitch diameter and minimum 2A or 3A pitch diameter, as applicable (See 3.3.5.6.c).

e. Threads in Installed Commercial Hardware and Inserts. Thread size and class of fit callouts may appear on assembly drawings in conjunction with installed commercial hardware and inserts. Unless such callouts are modified by reference to specific notes on the assembly drawing, the size and class of fit shown are for information purposes only and the commercial part thread limits shall be governed by the limits of the commercial part specified on the assembly drawing.

3.3.5.4 Assembly. When two or more threaded fasteners are used to attach a part, a sequential tightening pattern shall be established that will equalize fastener load throughout the part.

3.3.5.5 Torque Wrenches.

a. When torque limits are specified for threaded assemblies or fasteners, the torque wrench used shall be selected so that the limits specified for each feature will fall within approximately the middle 75 percent of the wrench scale.

b. A procedure for the routine periodic calibration and repair of all torque wrenches used to assemble items to specified limits shall be established and maintained.

c. Torque wrench readings shall be taken in a direction that will tighten the part.

3.3.5.6 External Threads.

a. Thread Length. Dimensions of axial thread length shown on drawings indicate minimum required length of complete threads. When the dimensioned thread length terminates at a shoulder and an undercut is not specified, the two threads next to the shoulder may be incomplete.

b. Chamfer. The leading end of externally threaded parts shall be chamfered. The resulting incomplete threads are included in the measurement of thread length but must not exceed two pitches in length.

c. Coated Class 2A Threads. Class 2A threads to which metallic plating, chemical-film coatings, resin bonded dry film lubricants, or any combination thereof have been applied may be gaged with basic "GO" gages in determining conformance to maximum size limits.

3.3.5.7 Internal Threads.

a. Tap Drills. Select a standard tap drill size that will assure approximately 75% of full thread.

b. Blind Hole Depth. The tap drill point shall not break through or deform the surface opposite the mouth of the hole.

c. Thread Depth. Dimensions of axial thread depth shown on drawings indicate minimum required depth of complete threads.

d. Perpendicularity. The perpendicularity or normality of threaded holes in flat or curved surfaces shall be within 1°0'.

3.3.5.7 continued

e. Chamfer. The leading ends of internal threads shall be chamfered as shown in Figure 2. If accessible, both ends of through-tapped holes shall be chamfered. Chamfering shall not result in elimination of more than one pitch of thread depth. For the purpose of determining the number of complete threads from the surface adjacent to the hole, the chamfered thread may be counted.

3.3.6 Metal Heat Treatment.

a. When necessary to facilitate fabrication, parts made from heat-treatable alloys, for which material is specified in terms of the final temper or condition required, may be fabricated from raw stock of a temper or condition different from the final temper and then heat-treated to the specified temper or condition.

b. After the completion of in-process heat-treatment, sample parts from each heat-treat lot shall be tested to determine that the material properties influenced by heat-treatment conform to the applicable material specification requirements. If tests of actual parts are impractical, suitable samples of the same alloy and starting condition as the parts shall be heat-treated with the lot and tested for conformance to the applicable requirements.

c. Parts specified to be made from a work-hardened temper of a non-heat-treatable alloy must be fabricated from material of the required temper or condition.

d. Thermal treatments such as hot forming, stress-relieving, drying, bonding, and baking, other than those specifically permitted by the product drawings, shall not be used.

3.4 Requirements for Cleaning, Protection, and Identification of Raw Material, Parts, and Assemblies.

3.4.1 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, fabricating, 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.

3.4.1 continued

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.

3.4.2 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.

3.5 Part Number Marking.

a. When required by the product drawing, finished parts, assemblies, or subassemblies shall be permanently marked with the applicable part number, e.g., T67002-001, using ink marking with covercoat unless otherwise specified (e.g., engraving and impression stamp). 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, unless otherwise specified.

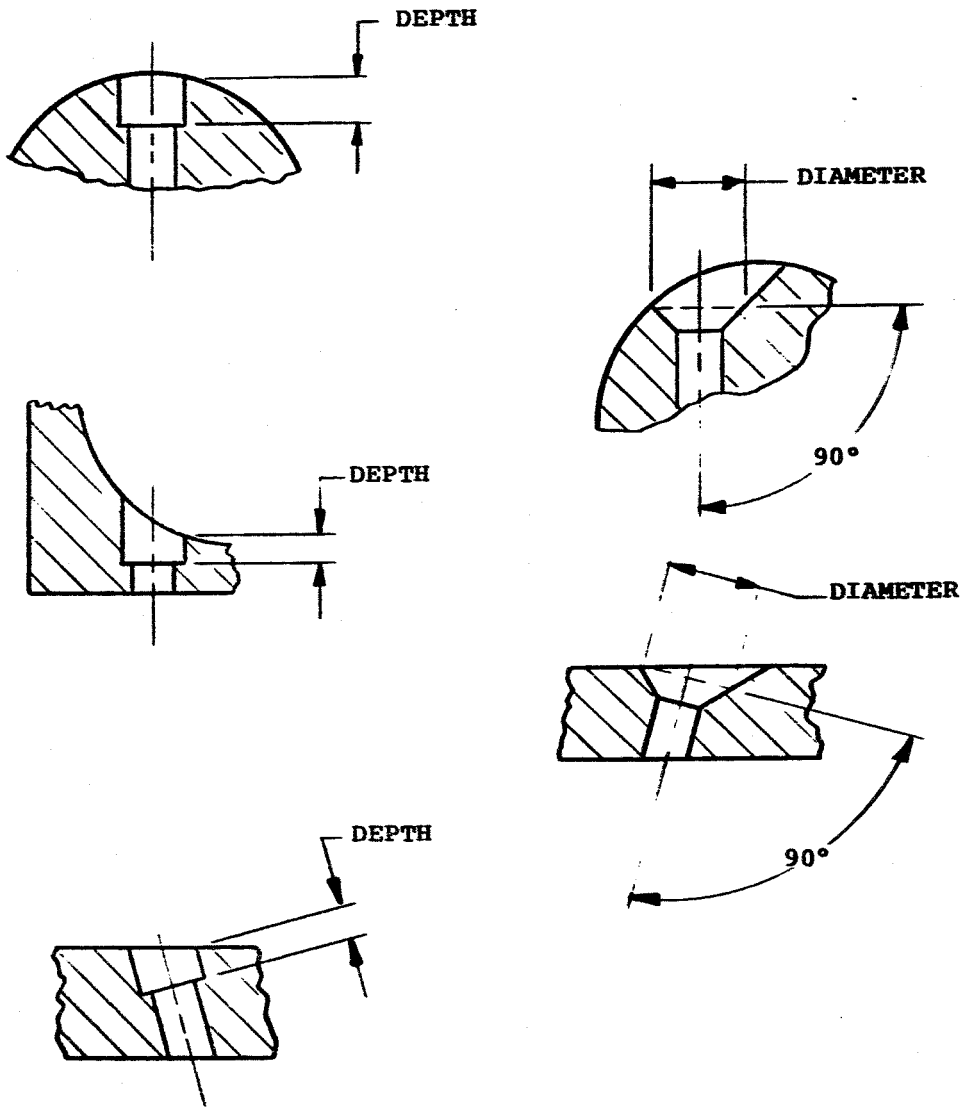


FIGURE 1 - COUNTERBORES AND COUNTERSINKS

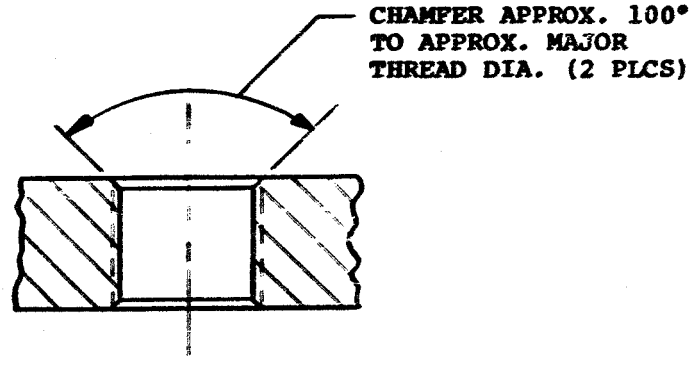


FIGURE 2 - INTERNAL THREAD CHAMFER

JAN 7 1981

FSCM NO. 14213
CER 802462SC
OWENS 2433 PRO 12/18/80
ANDERSEN 1725 12/18/80
STEPS NO. EA1802

SS-T67001
-000

TESTING, LEAK RATE, MASS SPECTROMETER, PAT-2 PACKAGE

Page	1	2	3	4	5	6	7
Issue	C	A	B	A	A	B	A

1. 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 2 (PAT-2). A mass spectrometer type helium leak detector is used.

1.2 Product Description. The item to be leak tested per this specification is the Spherical Containment Vessel, TB-2, part number T67001-001, which is a major component of the PAT-2 Package, T67000-000. The detail parts of the Spherical Containment Vessel, TB-2, are:

Spherical Containment Vessel-A, TB-2, T67002-001.

Spherical Containment Vessel-B, TB-2, T67003-001.

Seal, Copper, T67004-001.

Screw, Cap, Socket Head, A286 alloy, silver plated, .250-28 UNF, NAS 1351 N4, 0.830 - 0.820 inch long (20 required).

Nut, Flexloc, Hexagon, A286 alloy, 1000°F, 145 ksi, flanged, featherweight, silver plated, FN 1014-428 (20 required).

Washer, T67042-001 (40 required).

1.3 Definitions.

1.3.1 Background. Test system background is included in the leak rate result. 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^3/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.

a. cm^3/sec. STP (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 cm^3/sec. = 1 Torr-liter/sec.

1.3.3 STP (Standard Temperature and Pressure). 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:

$$K = \sqrt{\frac{\text{Molecular weight of helium}}{\text{Molecular weight of air}}} = \sqrt{\frac{4}{29}}$$

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 test result, 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. DOCUMENTS AND EQUIPMENT

2.1 Documents.

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

SS-T67000	General Requirements, PAT-2 Package
BB-H-1168b	Helium, Technical

2.2 Equipment.

a. Mass Spectrometer Type Helium Leak Detector.

b. Allen (Hex) Wrench and Nut Driver, (for 1/4 inch cap screw and nut).

c. Torque Wrench, see paragraph 3.3.5.5 of SS-T67000.

d. Plastic Glove Bag (or similar device to contain helium).

3. REQUIREMENTS

3.1 Equipment Capability.

3.1.1 Leak Detector System. The system shall consist of a mass spectrometer type helium leak detector together with a suitable test chamber that will completely 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 guaranteed 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 gas used shall be helium per BB-H-1168b, Type I, 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 Vessel Assembly. The TB-2 Spherical Containment Vessel, T67001, 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. The TB-2 Spherical Containment Vessel-A, the TB-2 Spherical Containment Vessel-B, the copper seal, the 20 cap screws, 20 nuts, and 40 washers must be clean and free of debris or foreign material. Clean using isopropyl alcohol, acetone, methyl ethyl ketone, or other degreasing solvent. Air flush to dryness before inserting parts in helium environment. Minimize fingerprinting or other contamination. Place these parts and all tools needed (described below, be sure tools are clean) in a helium-rich environment. The use of a disposable commercial plastic (polyethylene) glove bag is recommended for this purpose. Flush the bag with helium, eliminating as much air as possible. Keep the glove bag under a slight positive pressure of helium.

b. Place the "A" vessel, T67002, dome end down (large opening facing up) and drop the copper seal, T67004, over the flange, being certain that the seal rests flat (not cocked) in the sealing groove. Flush the open vessel out with a direct stream of helium. Grasp the "B" vessel, T67003; flush it out with a direct stream of helium, and place it over the "A" vessel. Align the engraved markings on the rims of the "A" and "B" vessels so that the markings are one above the other.

c. Install the 20 bolts, 20 nuts, and 40 washers, one set at a time, as follows. Place a washer under the head of a bolt and place the bolt through one pair of aligned holes in the vessel. The head of the bolt, and its washer, should be on the flange of the "B" vessel (T67003). Place a washer over the protruding threaded end of the bolt and thread a nut onto the bolt so that this nut and washer are against the flange of the "A" vessel (T67002). Tighten hand tight using a nut driver and an Allen (hex) wrench, but do not use heavy force at this time. Proceed by installing the remaining 19 bolts in similar fashion.

3.4.2.1 continued

d. Using the torque wrench, tighten the bolts to 13.1 Nm (100 inch-pounds) torque. It will probably require 2 or 3 complete turns through the bolt circle, or about 40 to 60 torque readings, to close the gap between flanges and bring every bolt to the required torque level. The assembled vessel may now be removed from the helium-rich environment.

e. For convenience in final tightening, a bench vise may be used. Cover the steel jaws of the vise with soft metal (aluminum or copper) to protect the vessel. Clamp the vessel by its flanges and again torque all bolts, this time to a torque of 14.1 Nm (125 inch-pounds). Go around the bolt circle at least twice to accomplish this.

f. Flush the exterior of the TB-2 vessel with clean, dry, pressurized air or nitrogen.

3.4.2.2 Leak Rate Determination.

a. Place the assembled TB-2 vessel in a mass spectrometer leak tester and pump down until a hard vacuum is reached, with a stable indication. Take readings as follows:

R_1 = Background

R_2 = Background + Known Leak

R_3 = Product Leak + Background

b. Calculate 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-2 shall not exceed 1×10^{-8} ATM cm^3/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).

f. Tracer gas used.

g. Leak detector output readings per 3.4.2.2.a.

h. Calculated total gas leak rate.

i. Date of test.

4. QUALITY ASSURANCE PROVISIONS

Not applicable.

5. PREPARATION FOR DELIVERY

Not applicable.

6. NOTES

Not applicable.

JAN 7 1981

FSCM NO. 14213
CER 802462SC
OWENS 2433 PRO 12/18/80
ANDERSEN 1725 JRA 12/18/80
LEX/CAS NO. PR1

SS-T67016
-000

WELDING, TITANIUM, PAT-2 PACKAGE

Page 1 2 3 4
Issue B B B B

1. GENERAL

1.1 Scope. This specification defines the fabrication and inspection requirements for the electron beam welding of titanium parts used on the Plutonium Air Transportable Package, Model 2 (PAT-2).

1.2 Definitions.

1.2.1 Weld Schedule. The weld schedule is the particular procedure, including specific machine settings, that has been approved by the supplier performing the welding as satisfying the requirements of this specification.

1.2.2 Qualified Welding Operator. A qualified welding operator is a person capable of producing acceptable weldments in accordance with this specification using the electron beam welding process. The qualifcation of operators shall be the responsibility of the supplier performing the welding.

1.2.3 Production Group. This is a group of parts welded by the same operator using the same equipment during a single eight-hour work shift.

2. DOCUMENTS.

Not Applicable.

3. REQUIREMENTS

3.1 Welding Equipment. The equipment used shall produce weldments in a vacuum by heating the titanium with accelerated electrons.

3.1.1 Equipment Calibration. The supplier performing the welding shall be responsible for calibration of the equipment used.

3.1.1.1 Items to be Calibrated. The following controls, meters, and gages on each electron beam welder shall be calibrated; for items a. through c. below a minimum accuracy of ±2% of the full scale reading is required.

a. Beam current meter

b. Voltage controls and voltage meter

c. Fixture speed controls.

d. High vacuum gage.

3.1.1.2 Calibration Interval. Calibration and functional testing shall occur as follows:

a. At intervals no greater than six months.

b. Prior to production use if the welding equipment has not been used for three months or more.

c. Whenever there is a machine malfunction. Only those machine elements related to the malfunction need be recalibrated.

3.1.2 Equipment Maintenance.

3.1.2.1 Cleaning. The inside of the welding chamber, and the welding gun, fixtures, etc., shall be cleaned of metal vapor deposits and foreign particles as frequently as necessary for satisfactory operation of the equipment.

3.1.2.2 Manufacturer's Recommendations. Maintenance activity similar to that recommended by the manufacturer of the welding machine shall be carried out.

3.2 Processing.

3.2.1 Welding Operations. The electron beam welding shall be performed only by qualified welding operators on calibrated equipment to weld schedules as specified in this specification.

3.2.2 Part Cleanliness. Parts to be welded shall be free of oil, grease, scale, deleterious marking material, foreign particles, or other contaminants that might be detrimental to weld quality; do not use methanol solutions.

3.2.3 Tack Welding. Electron beam tack welding is to be used on the titanium load spreader, T67016. Tack each joint to be welded in at least four places, approximately 90° apart, prior to the full penetrant pass.

3.2.4 Filler Material. No filler material shall be used.

3.2.5 Test Specimens. Test specimens are required, as defined in 4.3.

3.2.6 Repair. Repair of welds is not permitted.

3.3 Weld Schedules. A weld schedule shall be prepared for each weld joint design before parts are welded. Changes in weld schedules shall not be made without the approval of the responsible process engineer.

3.3.1 Contents. A weld schedule shall include the following:

a. Identification of the welding equipment, auxiliary equipment, and fixtures to be used.

b. Weld schedule identification and part identification for the assembly to be welded.

c. Part material identification including alloy and condition or temper.

d. Control settings of applicable welding equipment and accessories.

e. Allowable ranges of schedule parameters.

f. Other variables effecting the weld schedule.

g. Signature of the responsible process engineer, and date.

4. QUALITY ASSURANCE PROVISIONS

4.1 General.

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

4.1.2 Records. The Supplier shall maintain records of all tests and inspections, including weld schedules and test specimen data. Copies shall be distributed as specified in the contract, purchase order, or quality control plan.

4.2 Weld Inspection. Inspection of welds and test specimens shall verify the following.

a. Depth of weld, measured along joint interface, shall be 0.250 inch, minimum.

b. Weld shall be continuous for full length of joint.

c. Weld surface shall appear smooth after welding.

d. Down slope (ramping/tail off power decay) at the termination of the weld is required, and this shall blend in smoothly to the surface of the weld.

e. There shall be no cracks or voids in the weld bead.

f. There shall be no cracks in the parent metal.

g. There shall be no evidence of use of filler material.

h. Full penetration weld shall be accomplished in one pass.

4.3 Test Specimens.

a. At least one test specimen shall be welded before and after the processing of each production group. The test specimen shall be used to verify inspection requirements as defined in 4.2.

b. The test specimen(s) shall be welded in accordance with the weld schedule. The schedule shall not be changed, and maintenance shall not be performed on the welding equipment, during welding of a test specimen.

c. Test specimens shall be similar to the production weldments they represent, and the weld joint design shall be identical to production part design.

d. Each test specimen shall be visually examined at 10 to 20 magnification to verify the inspection requirements of 4.2 b, c, d, e, f, and g.

e. Each test specimen shall be sectioned and metallurgically examined to verify the inspection requirements of 4.2 a, e, f, and h. This shall include metallographic sectioning of the weld joint, and an examination for weld defects. Typical photomicrographs shall be taken and retained per 4.1.2.

5. PREPARATION FOR DELIVERY

Not applicable.

6. NOTES

Not applicable.

FIBERGLASS COVERING SPECIFICATION, PAT-2

Page	1	2	3	4
Issue	D	D	D	D

1. GENERAL

1.1 Scope. This specification defines the requirements for a fiberglass covering used as reinforcement on the AQ-2 Subassembly, a part of the PAT-2 Package.

2. DOCUMENTS

The following document forms a part of this specification to the extent specified herein. Unless otherwise specified use latest issues.

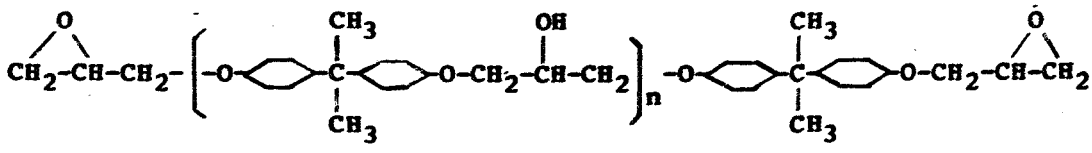
T67025 Subassembly, Outer Cylinder

3. REQUIREMENTS

The following material processing shall be followed in the application of the fiberglass covering, Item 5 of drawing T67025.

3.1 Material.

3.1.1 Epoxy Resin. This material shall be epoxy resin, Type A, epichlorohydrin/bisphenol, light colored, low viscosity, containing a reactive diluent, suitable for wet lay-up laminating, per ASTM D-1763-62, Type 1, Grade 2. Typical molecular structure shall be:



3.1.1 continued

Additional properties shall be as follows:

Weight per Gallon, lb., 20°C.	9.5
Density, g./ml., 20°C.	1.133
Refractive Index, 25°C.	1.545-1.560
Flash Point, Tag Open Cup, °F.	>175
Hydroxyl Content, equiv. OH/100 g. resin	0.05
Avg. Molecular Weight (approx.)	330

COLOR, 25°C. (GARDNER)[1]	VISCOSITY, 25°C. POISES[2]	EPOXIDE EQUIVALENT[3]
5 max.	5-7	175-195

(1) Color of Transparent Liquids, SMS 456 (ASTM D1544)

(2) Kinematic Viscosity, SMS 170 (ASTM D445)

(3) Grams of resin containing one gram-equivalent of epoxide: a-Epoxy Group Content, SMS 766 (ASTM D 1652)

3.1.2 Triethylenetetramine.

a. The triethylenetetramine shall meet the following requirements:

Property	Value	Test Method
Specific gravity, 20/20°C	0.978 to 0.984	ASTM D 891
Distillation, °C	No more than 5 percent of the material shall distill below 260°C. The dry point shall be at a temperature no higher than 290°C.	ASTM D 1078 (An all glass distillation system may be used.)
Color	7, maximum	ASTM D 1544
Water, percent by wt.	0.5, maximum	ASTM-D-2849-69 (except that 10 ml of reagent grade glacial acetic acid shall be introduced along with the 100 ml of titration solvent.

3.1.2 continued

WARNING

This material may produce contact dermatitis and sensitization or allergy. Skin contact is to be avoided in handling. If accidental skin contact occurs, the contaminated skin should be washed with soap and water. The precautions associated with handling aliphatic polyamine compounds should be maintained.

b. Storage and Use Limitations. When stored at normal room temperatures (90°F, maximum) the shelf life of this material is one year from date of shipment from the Supplier. Any material that exceeds this age shall be reinspected before use for conformance to the water content and color requirements. If it meets both the requirements, the shelf life may be extended an additional 6 months. By retesting, the shelf life may be extended for 6 month intervals until the material is either used or discarded.

3.1.3 Fiberglass Fabric. The fiberglass fabric shall be a woven material suitable for wet layups, of such a nature that the fabric will conform to the three-dimensional surface of the part being covered, without wrinkling or overlapping. This fabric style is commonly called "360° fabric". The fabric also shall meet the following requirements.

a. The material shall have a thickness of 0.015 $\pm$0.002 inches when tested per ASTM-D-1777 using a pressure of 4.7 to 5.3 psi on a 1.0 inch diameter foot.

b. The fabric shall be free of conductive foreign material and shall be treated with a suitable coupling agent, containing silicone, to promote adhesion of epoxy resins to glass fiber.

c. Material shall be stored in dry areas, free from wide temperature fluctuations. Packages shall be resealed after opening to prevent contamination by foreign materials. Rolls shall be stored horizontally in the original shipping container. Containers shall not be stacked more than three high.

Excessive handling with the bare hands is to be avoided to minimize contamination by moisture, oil, or salt from the hands.

d. This material has unlimited shelf life as long as it remains clean and dry and the integrity of the container is maintained.

NOTE: The ratio of epoxy resin per 3.1.1 to curing agent per 3.1.2 shall be 100:12 parts by weight.

3.2 Processing.

a. Sand the surfaces of the redwood in the areas to be covered on Items 2 and 3 of T67025.

b. Wipe sanded areas with solvent.

c. Thoroughly mix the above ratio of epoxy resin and curing agent at room temperature. Pot-life of this mixture is approximately 20 minutes for a 100 gram batch.

d. Paint a thin layer of the resin mixture on the surface to be covered.

e. Apply pre-cut fiberglass fabric.

f. Paint on additional resin to completely cover, or "wet" the fiberglass cloth. Work out all air bubbles and remove excess resin.

g. Repeat Steps e. and f. for the second layer of fabric.

h. Cure at room temperature until resin is gelled (2 to 4 hours), then cure at 140°F for 2 hours.

4. QUALITY ASSURANCE PROVISIONS

Not applicable.

5. PREPARATION FOR DELIVERY

Not applicable.

6. NOTES

Not applicable.

MATERIAL SPECIFICATION, REDWOOD FOR PAT-2 PACKAGE

Page	1	2
Issue	D	D

1. GENERAL

1.1 Scope. This specification defines the requirements for the redwood material used in fabrication of the Plutonium Air Transportable Model 2 (PAT-2) Package.

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

2. 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, 1 Lombard, San Francisco, California.

2.2 Equipment. A suitable instrument for measuring the moisture content of wood is required.

3. REQUIREMENTS

3.1 Material Description.

a. The material to be used shall be clear, kiln dried redwood, free of defects, as defined in para. 103 of the "Standard Specifications" document. Knots are not permissible.

b. Assemblies shall be fabricated of 25.4 mm (one inch) or greater nominal thickness.

3.1 continued

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 0.76 mm (0.030 inch) maximum.

3.2 Grain Defects. Burls and birdseyes of less than 9.5 mm (0.375 inch) diameter are acceptable, providing there are not more than six such defects in a 152 mm (six inch) diameter, in a maximum of 5% of the lumber in a subassembly.

4. 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 instructions.

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 (12%).

5. 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-2. Vapor barriers shall be used in packaging to maintain the minimum moisture content requirement specified.

WELDING, CORROSION RESISTANT STEEL, PAT-2 PACKAGE

Page	1	2	3
Issue	C	A	A

1. 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 2 (PAT-2).

1.2 Definitions.

1.2.1 Welding Terms and Definitions. Welding terms and definitions used in this specification shall be in accordance with AWS A 2.0 and AWS A 3.0, 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 A 2.0.

2. 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

3. 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 3.2 mm (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. 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. Some rework, as defined in 3.4, is permissible.

4.2 Product Inspection and Testing. Parts shall be visually inspected 100% for the imperfections defined in Table 1. No magnification is required.

5. PREPARATION FOR DELIVERY

Not applicable.

6. NOTES

Not applicable.

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 1)
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 / Max. Reinforcement Height Up to 3.2 mm / 1.3 mm 3.2 mm to 12.7 mm / 25% of weld size 12.7 mm and larger / 3.2 mm
Size of fillet welds	Specified weld size (length of legs) +50%, -0.

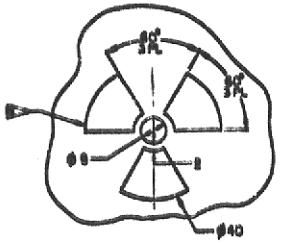
NOTE:

1. (T) is the specified weld size.

SI METRIC

167000-000

C	REVISED & REDRAWN WITH THE FOLLOWING REVISIONS; RE-VISED VIEW TO SCALE AND TO DEPICT DETAIL DWG. REV - TRIPOD, ADDED TREFOIL SYM. D. TRUMP, 2454 J. ANDERSEN, 1725 CEN. CONSTR.	
D	REVISED PER ACO 81110486 D. TRUMP, 2454 J. ANDERSEN, 1725	



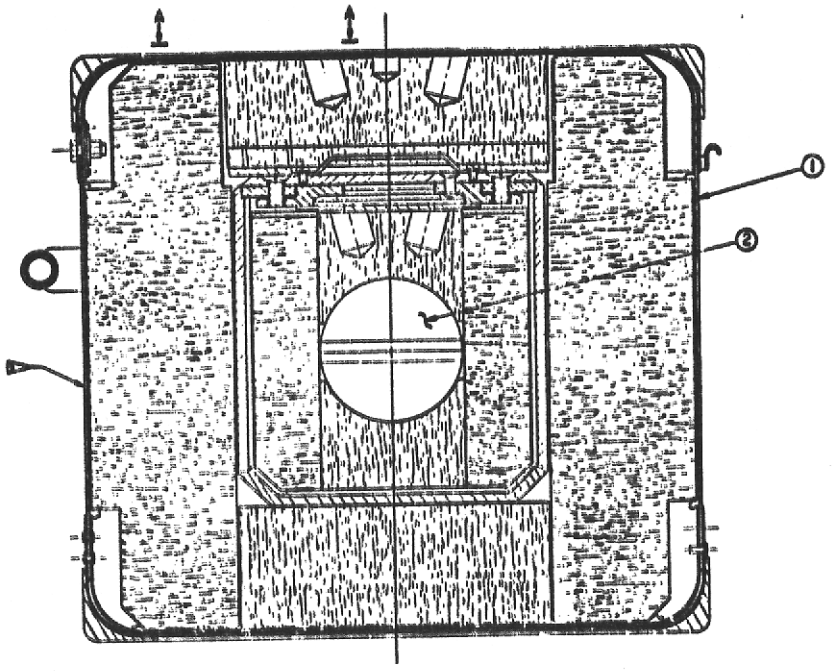
VIEW A-A
(SCALE 1:2)

NOTES:

1. PS-167000, PRODUCT SPECIFICATION, PLUTONIUM AIR TRANSPORTABLE PACKAGE MODEL 2 (PAT-2), IS A REQUIREMENT OF THIS DRAWING WHERE, OR APPLICABLE.
2. THE CAVITY INSIDE ITEM 2 IS FOR CONTENTS THAT ARE IN ACCORDANCE WITH REGULATIONS AND SPECIFICATIONS WHICH ARE IN ADDITION TO PS-167000, e.g., CERTIFICATES OF COMPLIANCE ISSUED BY NATIONAL COMPETENT AUTHORITIES.
3. STENCIL, USING BLACK EPOXY PAINT AND COVER COAT, IN 12 (MIN) INCH BLOCK LETTERS AS FOLLOWS. THE PAT-2 SERIAL NO. SHALL BE THE SAME AS THAT APPLIED TO THE AO-2 ITEM 1 USED ON THIS ASSEMBLY.

   PAT-2 TYPE B (U)
   DIN 167000 REF
   MANUFACTURER'S CODE
   SIN XXX
   DATE CODE

4. APPLY EMBOSSED TREFOIL SYMBOL, APPROXIMATELY AS SHOWN, USING A PERMANENT MARKING METHOD RESISTANT TO THE EFFECTS OF FIRE AND WATER.



SECTION VIEW ROTATED TO SHOW PERTINENT ITEMS

UNCLASSIFIED

UNCLASSIFIED

PAT-2 PACKAGE

167000-000

CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
88.00	3.464

NOTES:

6. STAINLESS STEEL NYLON-TIPPED SET SCREW, 8-32 THREAD, SLOTTED HEAD, APPROX. 19/64-INCH OVERALL LENGTH.

7. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.

1. GENERAL REQUIREMENTS PER SS-T67000.

2. PS T67000 PRODUCT SPECIFICATION. PLUTONIUM AIR TRANSPORTABLE PACKAGE MODEL 2 (PAT 2) IS A REQUIREMENT OF THIS DRAWING WHENEVER APPLICABLE.

3. INSPECTION AND ACCEPTANCE PER SS-T67003.

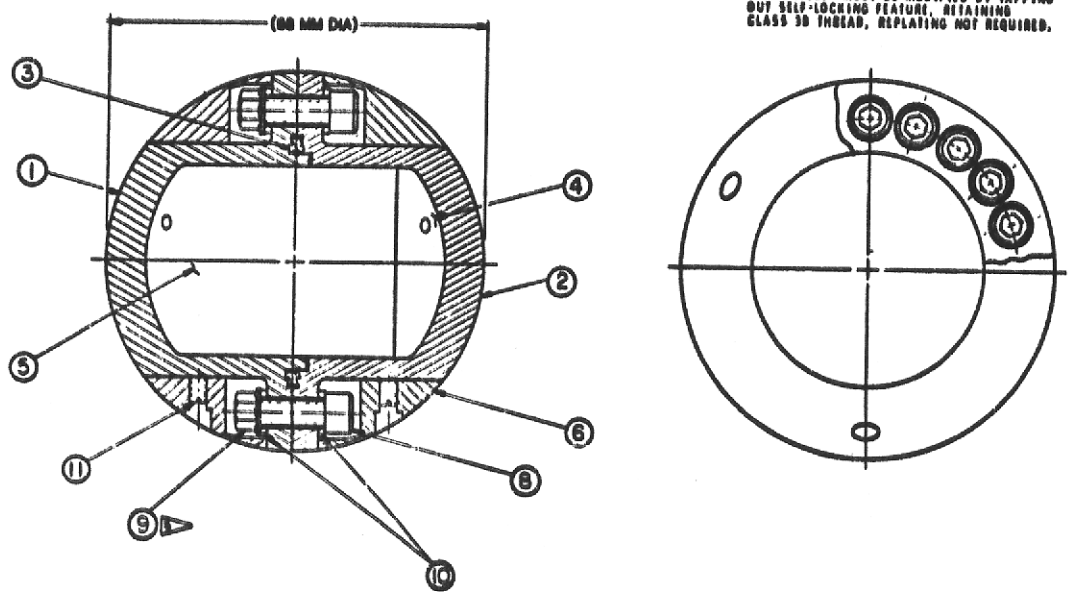
4. MS-1351N4-14-5 SOCKET HEAD CAP SCREW MAY BE PURCHASED IN ONE-INCH LENGTH. MODIFY BY SHORTENING TO INDICATED DIMENSION.

9. NUT (FN1014-428) CANNOT BE USED AS PURCHASED. MUST BE MODIFIED BY TAPPING OUT SELF-LOCKING FEATURE, RETAINING CLASS 3B THREAD, REPLATING NOT REQUIRED.

SI METRIC

T67001-001

C	REVISED & REDRAWN R. PARSON, 2451/ J. ANDERSEN, 1721	
D	REVISED AER 8012485C D. TRUMP, 2451/ J. ANDERSEN, 1725	
E	REVISED NOTE 4 D. TRUMP, 2451/ J. ANDERSEN, 1725 CER 8024622C	
F	REVISED PER ACO 8111048C REVISED NOTES 4 & 6 AND L/M. D. TRUMP, 2451/ J. ANDERSEN, 1725. FCO 8115275C	



6		8-32 NYLON-TIPPED SET SCREW	A	11
40		WASHER		10
10		NUT, FN1014-428	A	9
10		SCREW, CAP, SOCKET HD., 3/8-, 1/8 IN. LONG	A	8
7		FAIRING, TB-2, SPHERICAL CONTAINMENT VESSEL		6
1		BODY, C-1 CAPSULE		5
1		LID, C-1 CAPSULE		4
1		SEAL, COPPER		3
1		TB-2 SPHERICAL CONTAINMENT VESSEL-B		2
1		TB-2 SPHERICAL CONTAINMENT VESSEL-A		1
NA	SS-T67001	LEAK TESTING		
NA	PS-T67000	PRODUCT SPECIFICATIONS		
NA	SS-T67000	GENERAL REQUIREMENTS		

LIST OF MATERIAL

UNCLASSIFIED

UNCLASSIFIED

TB-2, SPHERICAL CONTAINMENT VESSEL ASSEMBLY

T67001

SI METRIC

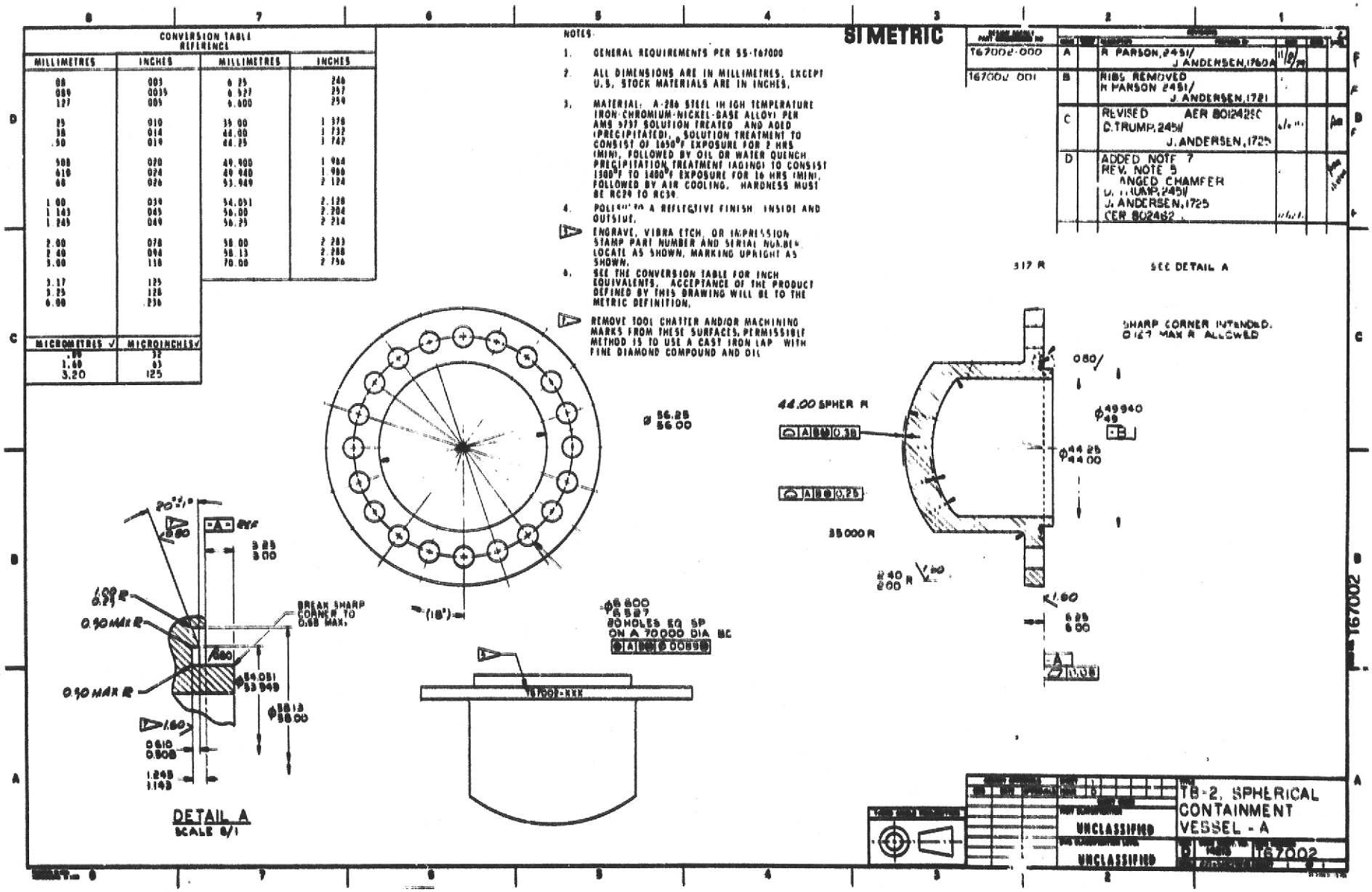
CONVERSION TABLE REFERENCE			
MILLIMETRES	INCHES	MILLIMETRES	INCHES
.08	.003	6.25	.246
.089	.0035	6.527	.257
.127	.005	6.600	.259
.25	.010	35.00	1.378
.36	.014	44.00	1.732
.50	.019	44.25	1.742
.500	.020	49.900	1.964
.610	.024	49.940	1.966
.68	.026	53.949	2.124
1.00	.039	54.051	2.128
1.143	.045	56.00	2.204
1.245	.049	56.25	2.214
2.00	.078	58.00	2.283
2.40	.094	58.13	2.288
3.00	.118	70.00	2.756
3.17	.125		
3.25	.128		
6.00	.236		

MICROMETRES √	MICROINCHES √
.80	32
1.60	63
3.20	125

NOTES:

1. GENERAL REQUIREMENTS PER SS-167000
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: A-286 STEEL (HIGH TEMPERATURE IRON-CHROMIUM-NICKEL-BASE ALLOY) PER AMS 5737 SOLUTION TREATED AND AGED (PRECIPITATED). SOLUTION TREATMENT TO CONSIST OF 1650°F EXPOSURE FOR 2 HRS (MIN), FOLLOWED BY OIL OR WATER QUENCH. PRECIPITATION TREATMENT (AGING) TO CONSIST 1300°F TO 1400°F EXPOSURE FOR 16 HRS (MIN), FOLLOWED BY AIR COOLING. HARDNESS MUST BE RC29 TO RC39.
4. POLISH TO A REFLECTIVE FINISH INSIDE AND OUTSIDE.
5. ENGRAVE, VIBRA ETCH, OR IMPRESSION STAMP PART NUMBER AND SERIAL NUMBER. LOCATE AS SHOWN, MARKING UPRIGHT AS SHOWN.
6. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
7. REMOVE TOOL CHATTER AND/OR MACHINING MARKS FROM THESE SURFACES. PERMISSIBLE METHOD IS TO USE A CAST IRON LAP WITH FINE DIAMOND COMPOUND AND OIL.

PART NUMBER	REV	DESCRIPTION	DATE
167002-000	A	R PARSON, 2451/ J ANDERSEN, 1760A	11/8/78
167002-001	B	RIBS REMOVED R PARSON 2451/ J. ANDERSEN, 1721	
	C	REVISED AER 802425C D. TRUMP, 2451/ J. ANDERSEN, 1725	
	D	ADDED NOTE 7 REV. NOTE 5 ANGED CHAMFER D. TRUMP, 2451/ J. ANDERSEN, 1725 CER 802482	

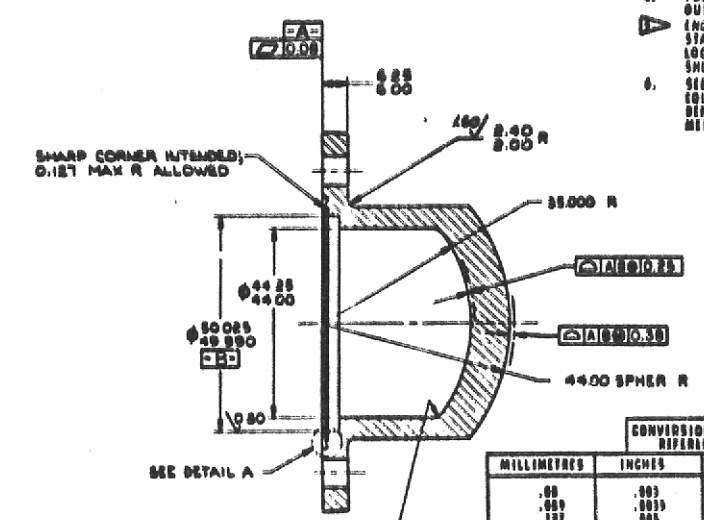


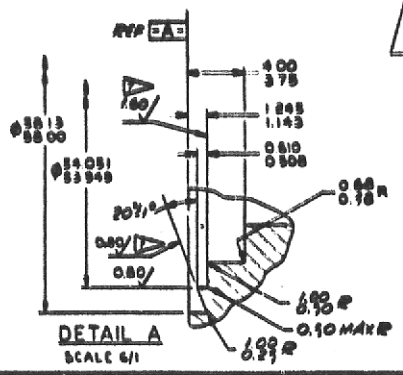
SI METRIC

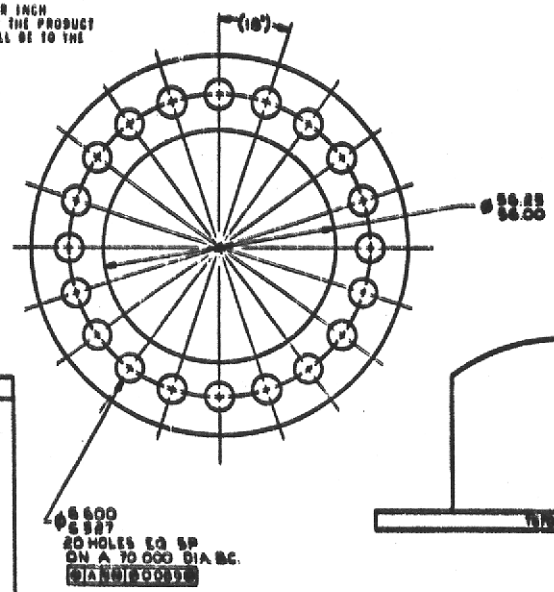
NOTES:

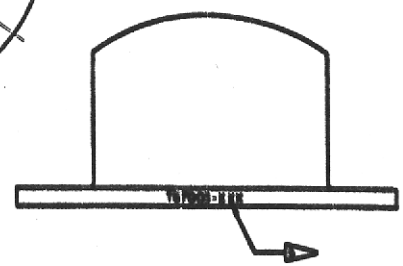
1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: A-286 STEEL (HIGH TEMPERATURE IRON-CHROMATE-NICKEL-BASE ALLOY) PER AMS 5737 SOLUTION TREATED AND AGED (PRECIPITATED). SOLUTION TREATMENT TO CONSIST OF 1650°F EXPOSURE FOR 2 HRS (MIN), FOLLOWED BY OIL OR WATER QUENCH. PRECIPITATION TREATMENT (AGING) TO CONSIST 1300°F TO 1400°F EXPOSURE FOR 16 HRS (MIN), FOLLOWED BY AIR COOLING. HARDNESS MUST BE RC29 TO RC39.
4. POLISH TO A REFLECTIVE FINISH, INSIDE AND OUTSIDE.
5. ENGRAVE, VIBRA ETCH, OR IMPRESSION STAMP PART NUMBER AND SERIAL NUMBER. LOCATE AS SHOWN. MARKING UPRIGHT AS SHOWN, ALIGNED WITH ENGRAVING ON T67008.
6. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.

REMOVE TOOL CHATTER AND/OR MACHINING MARKS FROM THESE SURFACES. PERMISSIBLE METHOD IS TO USE A CAST IRON LAP WITH FINE DIAMOND COMPOUND AND OIL.









CONVERSION TABLE REFERENCE

MILLIMETRES	INCHES	MILLIMETRES	INCHES
.08	.003	6.35	.246
.089	.0035	6.927	.267
.127	.005	6.800	.299
.25	.010	35.000	1.378
.38	.015	44.00	1.732
.50	.019	44.25	1.742
.508	.020	49.990	1.968
.610	.024	50.025	1.969
.67	.026	53.949	2.124
1.00	.039	54.051	2.128
1.143	.045	55.00	2.166
1.245	.049	56.25	2.214
2.00	.078	58.00	2.283
2.40	.094	58.13	2.288
3.17	.125	70.00	2.756
3.75	.147		
4.00	.157		
5.00	.196		

MICROMETRES ✓	MICROINCHES ✓
.80	32
1.60	63
3.20	125

PART NUMBER	REV	DESCRIPTION	DATE	APPROVED
T67003-000	A	R PARSON, 2451/ J. ANDERSEN, 1760 A	1/10/71	
T67003-001	B	RIBS REMOVED R PARSON, 2451/ J. ANDERSEN, 1781		
	C	REVISED AER 802425C D. TRUMP 2451/ J. ANDERSEN, 1725		
	D	ADDED NOTE 7 REV. NOTE 5 D. TRUMP, 2451 J. ANDERSEN, 1725 CLR 802462		
	E	REVISED PER ACO 811104SC D. TRUMP, 2451 J. ANDERSEN, 1725		

UNCLASSIFIED

UNCLASSIFIED

TB-2, SPHERICAL CONTAINMENT VESSEL - B

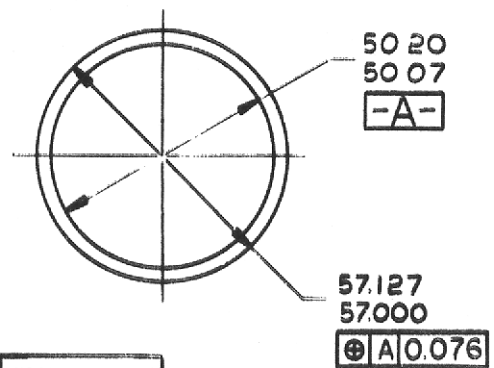
D 14213 T67003

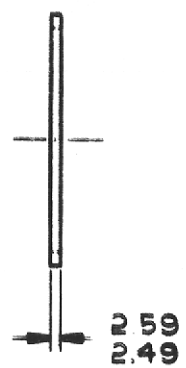
SI METRIC

NOTES:

1. GENERAL REQUIREMENTS PER SS-T67000.
2. MATERIAL: COPPER, HALF HARD 110 ETP PER QQ-C-576.
3. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN MILLIMETERS.
4. 1.60 ✓ ALL OVER.
5. SURFACE TEXTURE IS IN MICROMETERS.
6. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.

DESIGN AGENCY PART [redacted] NO.	REVISIONS ISSUE	DESCRIPTION / PREPARED BY	DATE	CHKR	ENGR
T67004-000	A	PARSON, 2451/ J. ANDERSEN, 1760A	11/8/79		
T67004-001	B	CHANGED THICKNESS PARSON, 2451/ J. ANDERSEN, 1721	8/5/80		
		AER 801242SC	6/11/81		
	C	CER 802462SC D. TRUMP, 2451/ J. ANDERSEN, 1725	[illegible]		





CONVERSION TABLE REFERENCE

MILLIMETRES	INCHES	MICROMETRES ✓	MICROINCHES ✓
.076	.003	1.60	63
2.49	.098		
2.59	.102		
50.07	1.971		
50.20	1.976		
57.000	2.244		
57.127	2.249		

THIRD ANGLE PROJECTION

AGENCY APPROVALS	ORG	DATE	INITIALS

SHEET 1
ISSUE C
SHEET INDEX
PART CLASSIFICATION: UNCLASSIFIED
DWG. CLASSIFICATION LEVEL: UNCLASSIFIED

TITLE: SEAL, COPPER

SIZE B | CODE IDENT. NO. 14213 | DWG. NUMBER T67004

SCALE 1/1 | SHEET 1 OF 1

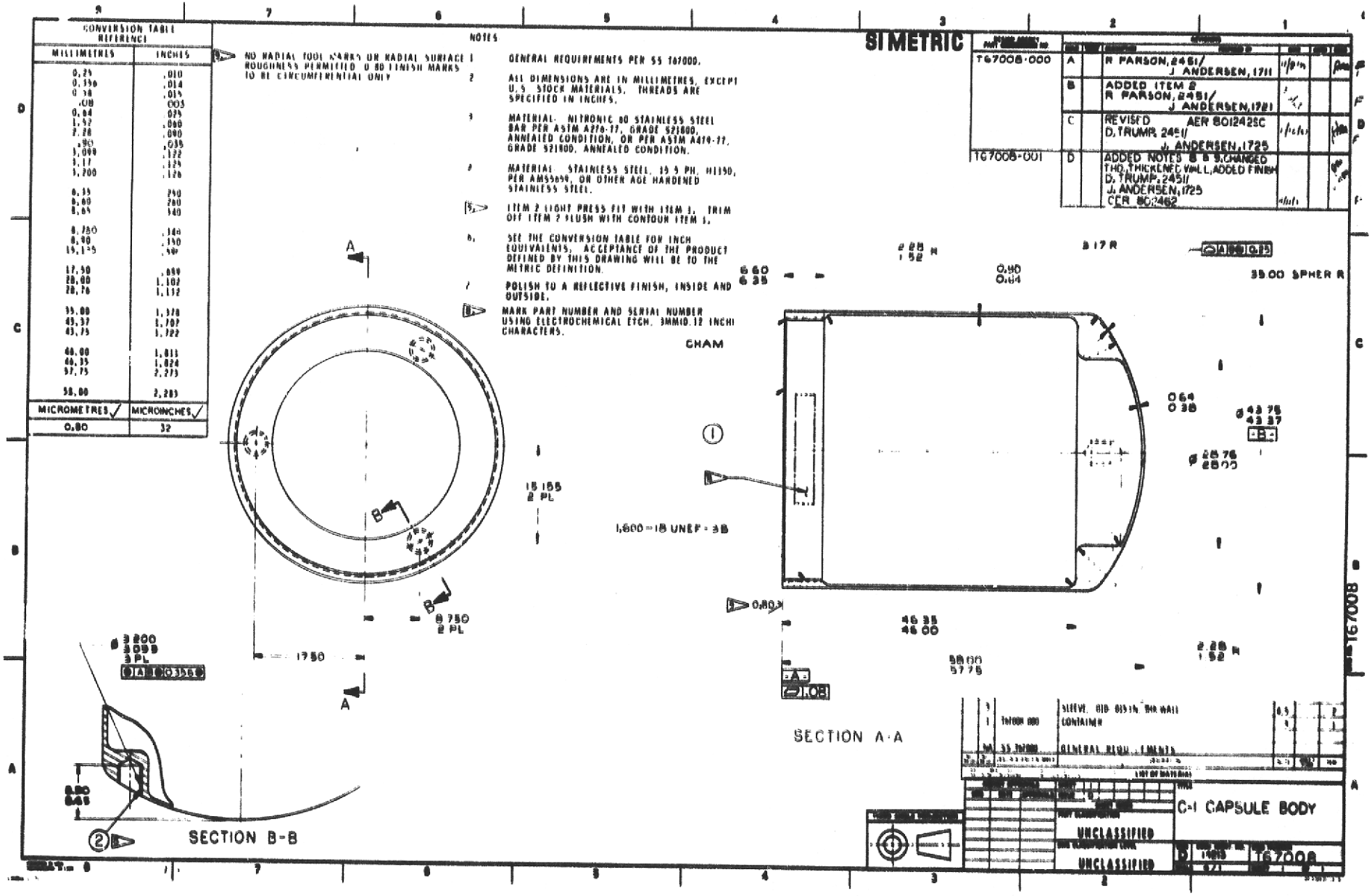
CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
0.25	.010
0.356	.014
0.38	.015
.08	.003
0.64	.025
1.52	.060
2.28	.090
.90	.035
3.099	.122
3.17	.125
3.200	.126
6.35	.250
6.60	.260
8.89	.350
8.780	.346
8.90	.350
15.135	.596
17.50	.689
28.00	1.102
28.36	1.117
35.00	1.378
45.37	1.787
45.75	1.802
46.00	1.811
46.35	1.824
57.75	2.273
58.00	2.283
MICROMETRES ✓	MICROINCHES ✓
0.80	32

NOTES

1. NO RADIAL TOOL MARKS OR RADIAL SURFACE ROUGHNESS PERMITTED. 0.80 FINISH MARKS TO BE CIRCUMFERENTIAL ONLY
2. GENERAL REQUIREMENTS PER SS 167000.
3. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS, THREADS ARE SPECIFIED IN INCHES.
4. MATERIAL: NITRONIC 60 STAINLESS STEEL BAR PER ASTM A276-77, GRADE S21800, ANNEALED CONDITION, OR PER ASTM A479-77, GRADE S21800, ANNEALED CONDITION.
5. MATERIAL: STAINLESS STEEL, 15-5 PH, H1150, PER AMS5659, OR OTHER AGE HARDENED STAINLESS STEEL.
6. ITEM 2 LIGHT PRESS FIT WITH ITEM 3. TRIM OFF ITEM 2 FLUSH WITH CONTOUR ITEM 3.
7. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
8. POLISH TO A REFLECTIVE FINISH, INSIDE AND OUTSIDE.
9. MARK PART NUMBER AND SERIAL NUMBER USING ELECTROCHEMICAL ETCH. 3MM±0.12 INCH CHARACTERS.

SI METRIC

PART NUMBER				
T67008-000	A	R PARSON, 2451/ J ANDERSEN, 1711		
	B	ADDED ITEM 2 R PARSON, 2451/ J ANDERSEN, 1721		
	C	REVISED AER 80124250 D. TRUMP, 2451/ J. ANDERSEN, 1725		
T67008-001	D	ADDED NOTES 8 & 9. CHANGED THD. THICKNESS, WALL, ADDED FINISH D. TRUMP, 2451/ J. ANDERSEN, 1725 CER 80/2462		



SI METRIC

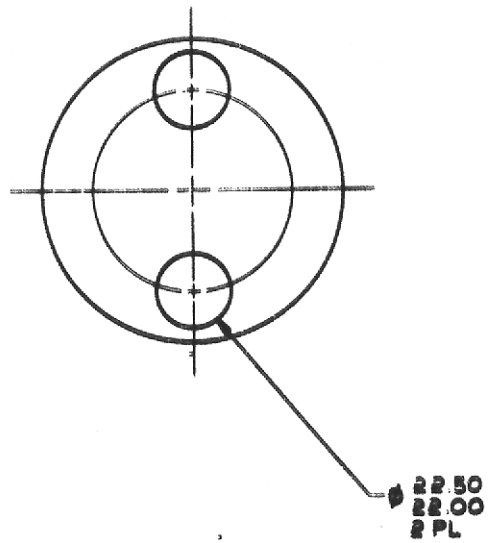
CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
22.00	.866
22.22	.875
22.50	.886
24.00	.945
25.00	.984
25.40	1.000
39.88	1.570
40.13	1.580
44.38	1.747
44.76	1.762
66.00	2.598
67.00	2.638
84.60	3.331
89.06	3.508
89.31	3.516

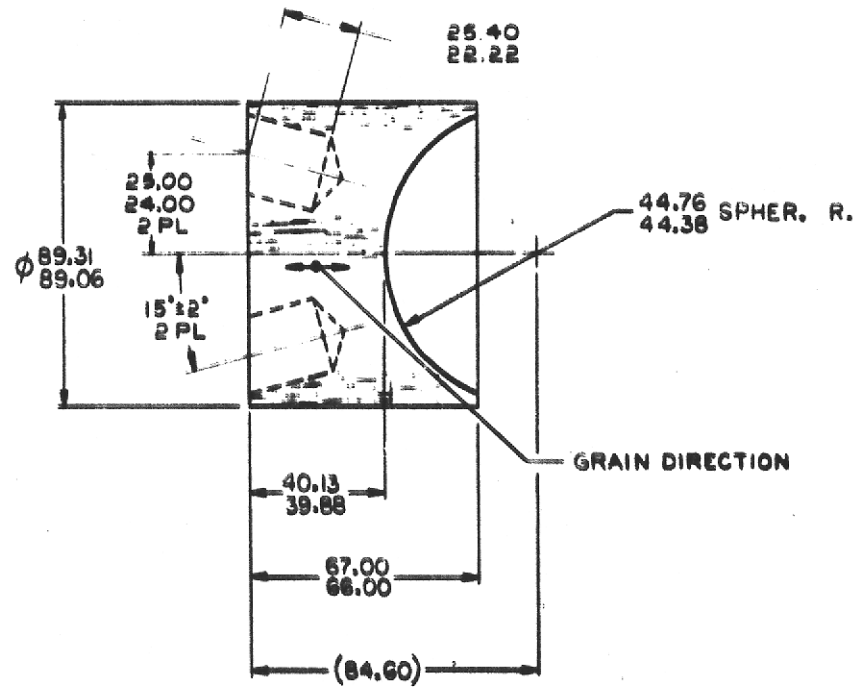
NOTES

1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES
3. IF BONDING IS NECESSARY, BOND PER PS-T67000, USING MMM-A-180.
4. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
5. AS SOON AS POSSIBLE AFTER FINISHING, COAT PIECE PART WITH ADHESIVE PER PS-T67000, USING FLEXIBLE EPOXY RESIN, AND BAG WITH DESICCANT MATERIAL.
6. MATERIAL: MAPLE, HARD NORTHERN, SELECT AND BETTER, KILN DRIED, ROUGH, PER NATIONAL HARDWOOD LUMBERMAN'S ASSO. (NHLA) RULES.
7. MAXIMUM MAPLE WOOD DENSITY TO BE 0.96 GRAMS/CC.

DESIGN AGENCY PART [redacted] NO T67010-000

REVISIONS					
ISSUE	DESCRIPTION	PREPARED BY	DATE	CHKD	ENGR
A	R. PARSON, 2451/ J. ANDERSEN, 1760 A		11/8/79		
B	REVISED R. PARSON, 2451/ J. ANDERSEN, 1721				
	AER 801242SC				
C	REVISED NOTE 3 ADDED NOTES 6 & 7 ADDED DIMENS. D. TRUMP, 2451/ J. ANDERSEN, 1725 CER 802462				





THIRD ANGLE PROJECTION

UNCLASSIFIED

UNCLASSIFIED

TITLE PLUG, TOP, INNER, MAPLE, REMOVABLE

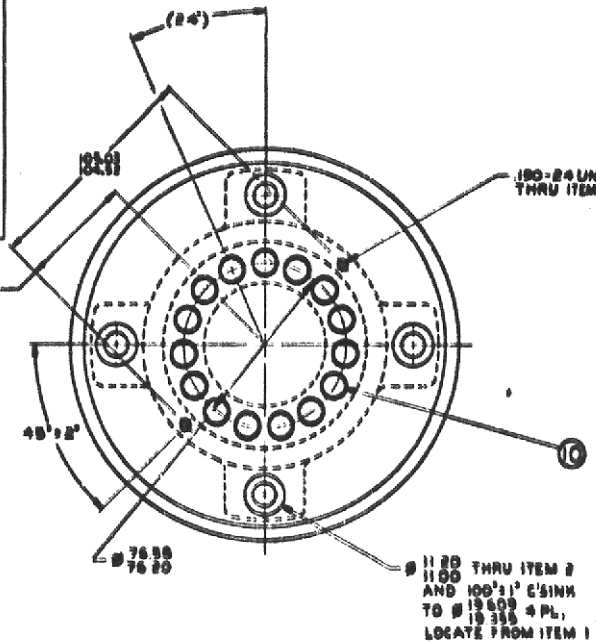
SIZE C | CODE IDENT NO. 14213 | DWG NO. T67010

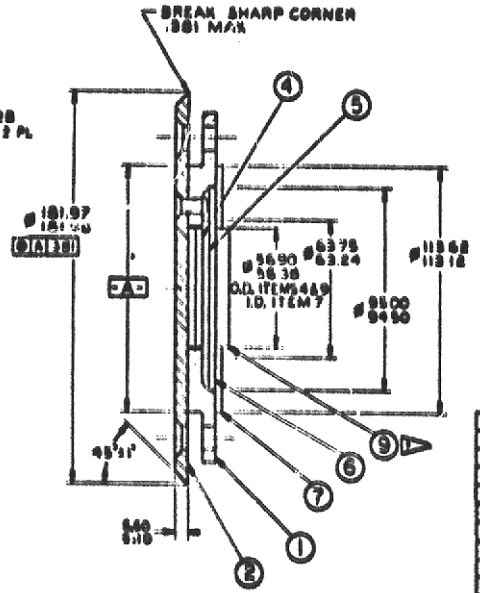
SCALE 1/1 | SHEET 1 OF 1

CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
.381	.015
11.00	.433
11.20	.440
19.355	.762
19.609	.772
51.06	2.001
52.06	2.041
58.38	2.270
58.90	2.240
63.24	2.490
65.75	2.590
76.20	3.000
76.58	3.015
94.58	3.720
95.00	3.740
104.32	4.115
105.03	4.135
113.12	4.453
113.62	4.473
181.46	7.144
181.97	7.164
6.10	.240
6.60	.260

NOTES:

1. GENERAL REQUIREMENTS PER SS-167000.
2. ALL DIMENSIONS ARE IN MILLIMETERS, EXCEPT U.S. STOCK MATERIALS AND THREADS ARE SPECIFIED IN INCHES.
3. MATERIAL: TITANIUM, PLATE, PER ASTM B381, GRADE 4 (COMMERCIALLY PURE, 70,000 PSI YIELD).
4. BOND ITEMS 4, 5, 6 AND 7 PER PS-167000 TO ITEM 1 AS SHOWN AFTER RIVETING.
5. CUT ITEM 9 TO FIT ID OF ITEM 7 AND BOND IN PLACE PER PS-167000.
6. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
7. MATERIAL: SILICONE RUBBER, CLOSED CELL, EXTREME TEMPERATURE, EXTRA SOFT, PER MIL-STD-6700-TES.





8. MATERIAL: REFRACTORY FIBER FELT INSULATION, 1/8 THK, DENSITY APPROX. 24 LBS/FT³, 2000°F SERVICE TEMPERATURE, MADE FROM 2.5 MICRON DIAMETER (APPROX.) FIBERS, WITH APPROX. COMPOSITION OF 45% Al_2O_3 (ALUMINA) AND 55% SiO₂ (SILICA), WITH AN ORGANIC BINDER. THE FELT SHOULD HAVE 25 TO 35 WEIGHT IGNITION LOSS. THERMAL CONDUCTIVITY TO BE 0.9 ± 0.3 BTU - INCH/FT²/°F/HR AT 1000°F.
9. RIVET ITEM 1 TO ITEM 2 PER MIL-STD-4030, APPLICABLE PARTS OF PARA. 6.5, 5.2, 5.6.

SI METRIC

T67011-001

D	REVISED AND REDRAWN R. PARSON, 2451/ J. ANDERSEN, 1721		
E	REVISED AER 80124250 D. TRUMP, 2451/ J. ANDERSEN, 1725		
F	REVISED ITEM 2 & 9 D. TRUMP, 2451/ J. ANDERSEN, 1725 CETI 80245F		
G	REVISED NOTE 4 D. TRUMP, 2451/ J. ANDERSEN, 1725 FCO 811527SC		

10	NAS-1303-5-12	RIVET - SOLID - 100° PAN HD, ALUM		10
9		RUBBER, SILICONE, .25 THK.	3	1
8				
7		INSULATION, 1/8 THK, 24 LBS/FT³	0.0	1
6		INSULATION, 1/8 THK, 24 LBS/FT³	0.0	1
5		INSULATION, 1/8 THK, 24 LBS/FT³	0.0	1
4		INSULATION, 1/8 THK, 24 LBS/FT³	0.0	1
3				
2		TITANIUM, PLATE	1	1
1	T67067-100	LOCK RING		1
	NA MIL-STD-4030	RIVETING		
	NA PS-167000	BONDING		
	NA SS-167000	GENERAL REQUIREMENTS		

DISK, REMOVABLE

UNCLASSIFIED

UNCLASSIFIED

T67011

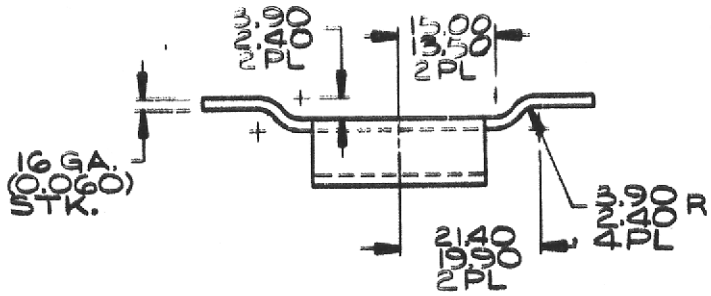
SI METRIC

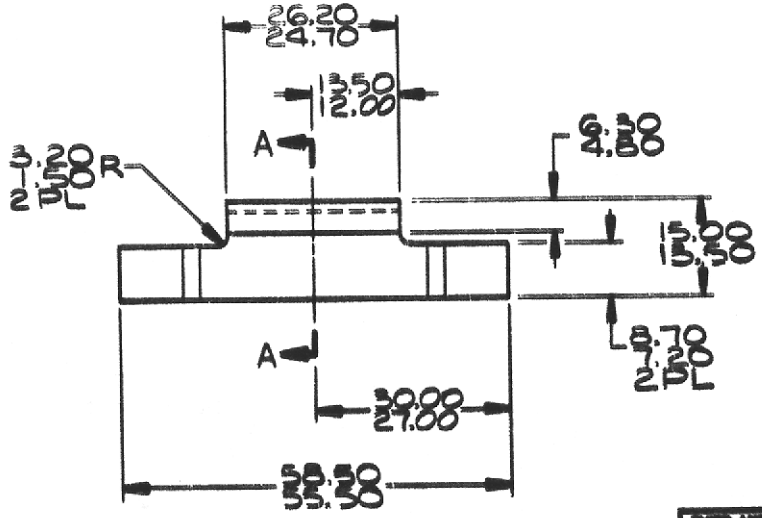
DESIGN AGENCY PART [redacted] NO. T67012-000

REVISIONS					
LTR	DESCRIPTION	PREPARED BY	DATE	CHGD	CHKD
A	S. HUSA, 2451 / J. ANDERSEN, 1760A	11/21/71	GAA	[illegible]	F
	AER 801242SC	6/8/[illegible]		[illegible]	
B	CER 802462SC D. TRUMP, 2451 J. ANDERSEN, 1725	4/14/[illegible]		[illegible]	14 [illegible]

NOTES

1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETERS, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: SHEET, CORROSION RESISTING STEEL, TYPE 304, CONDITION A PER QQ-S-766, 16 GA. (0.060) THICK.
4. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
5. PASS [illegible] TABLE I





SECT. A-A

CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
1.50	.059
2.40	.094
3.20	.125
3.90	.153
4.80	.189
6.30	.248
7.20	.283
8.70	.342
12.00	.472
13.50	.531
15.00	.590
19.90	.783
21.40	.842
24.70	.972
26.20	1.031
27.00	1.063
30.00	1.181
55.50	2.185
58.50	2.303

THIRD ANGLE PROJECTION

DESIGN APPROVALS

UNCLASSIFIED

UNCLASSIFIED

STRAP, SEAL, SECURITY

SIZE C | CODE IDENT NO. 14813 | DWG NO. T67012

SCALE 2/1 | SHEET

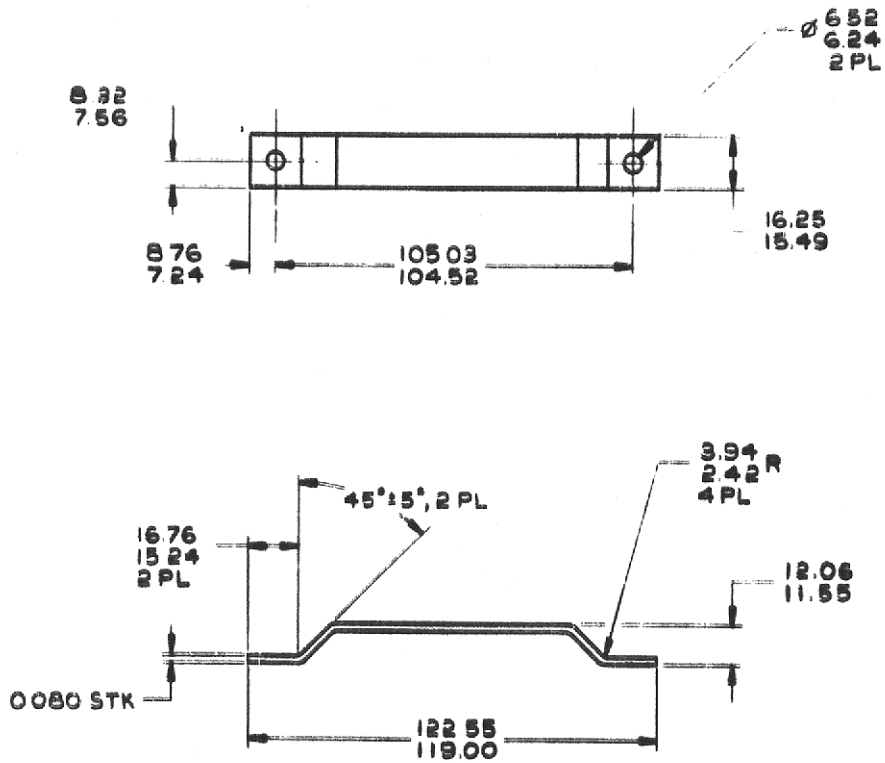
SI METRIC

NOTES

1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETERS, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: ALUMINUM, SHEET, 6061-T6, .080 THK.
4. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
5. ANODIZE PER MIL-A-8625, TYPE II, CLASS 1, COLOR CLEAR.

SENDER AGENCY PART [redacted] NO. T67013-001

REVISIONS					
ISSUE	DESCRIPTION	PREPARED BY	DATE	CHKD	APPD
B	R PARSON, 2451/ J. ANDERSEN, 1721 REVISED & REDRAWN				
	AER 801242SC				
C	CER 802462SC D. TRUMP, 2451/ J. ANDERSEN, 1725				



CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
2.42	.095
3.94	.155
6.24	.245
6.56	.257
7.24	.285
7.56	.297
8.32	.327
8.76	.345
11.55	.455
12.06	.475
15.24	.600
15.49	.610
16.25	.640
16.76	.660
104.52	4.115
105.03	4.135
119.00	4.685
122.55	4.824

THIRD ANGLE PROJECTION

AGENCY APPROVALS

CODE	DATE	INITIALS

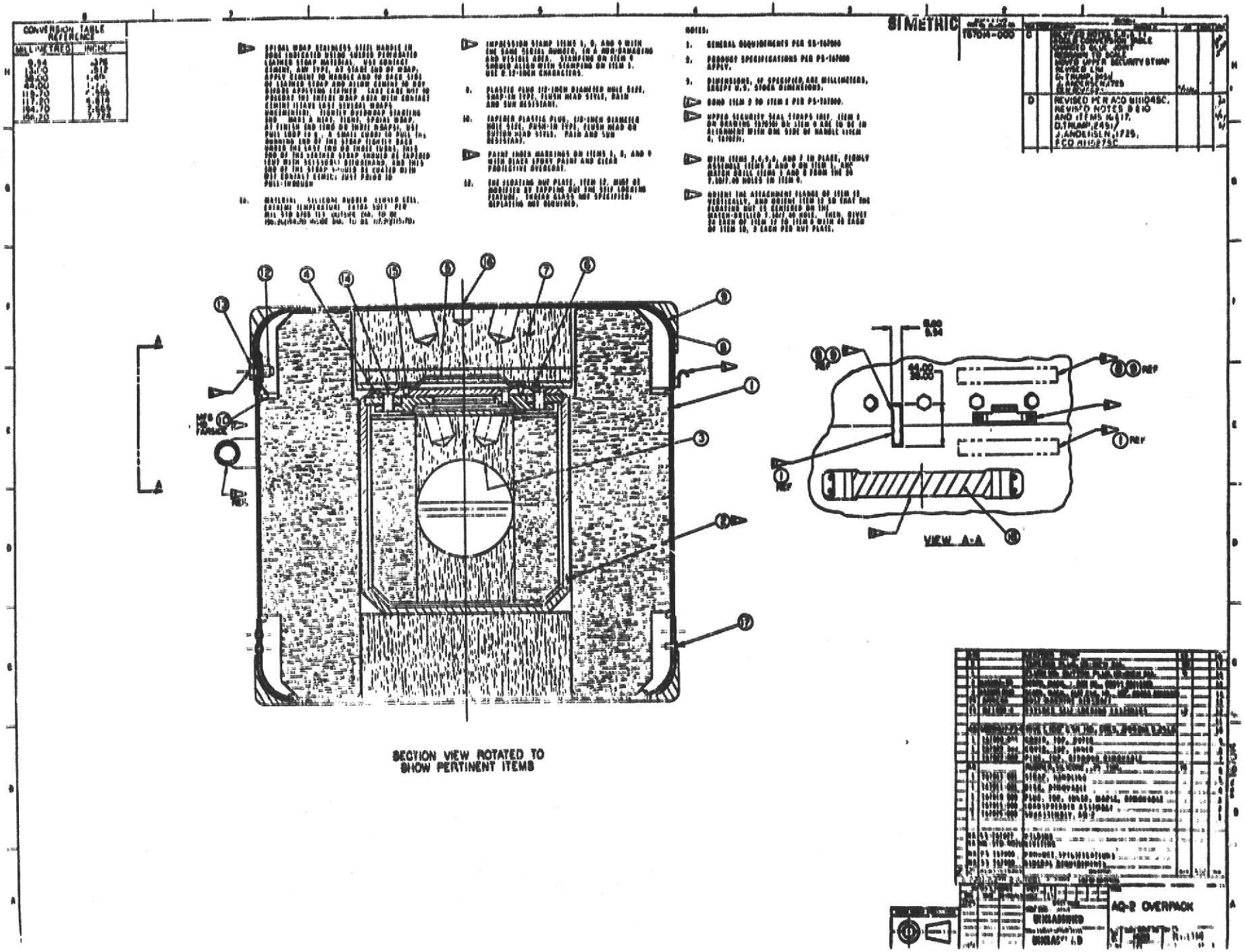
SHEET 1 OF 1

SECURITY LEVEL
PART DESCRIPTION: UNCLASSIFIED
DWG. DESCRIPTION LEVEL: UNCLASSIFIED

TITLE: STRAP, HANDLING

SIZE C | CODE IDENT. NO. 14213 | DWG. NUMBER T67013

SCALE 1/1 | SHEET 1 OF 1


SIMETRIC
CONVERSION TABLE REFERENCE
MILLIMETERS
INCHES
NOTES:
SECTION VIEW ROTATED TO SHOW PERTINENT ITEMS
VIEW A-A
AQ-2 OVERPACK

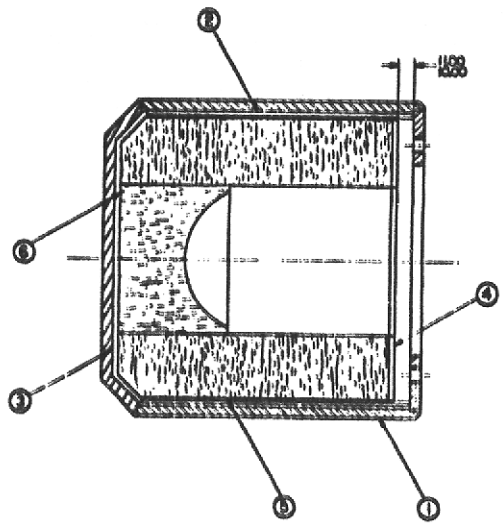
CONVERSION TABLE DIFFERENCE	
MILLI-METERS	INCHES
10.00	.394
11.00	.433

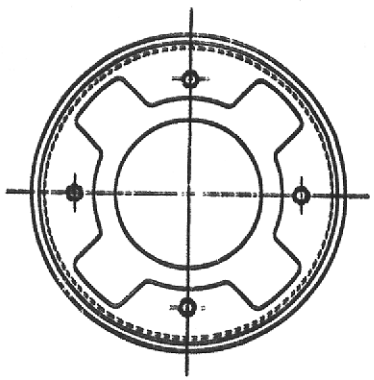
NOTES:

1. GENERAL REQUIREMENTS PER SS-16F000.
2. ALL DIMENSIONS ARE IN MILLIMETERS, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES
3. MATERIAL, REFRACTORY FIBER FELT (ROWAL TION, VIS INC. DENSITY APPROX. 24 LBS/FT³, SHOW SERVICE TEMPERATURE, MADE FROM 2.5 MICRON DIAMETER (APPROX.) FIBERS, WITH APPROX. COMPOSITION OF 44% BIND ALUMINA AND 56% ST OX (SILICA), WITH AN ORGANIC BINDER. THE FELT SHOULD HAVE 25 TO 30 WEIGHT IGNITION LOSS. THERMAL CONDUCTIVITY TO BE 0.9 ± 0.3 BTU • INCH/FT²/°F/HR AT 1000°F.
4. INSTALL INSULATION, ITEMS 2, 3 AND 4, WITH ADEQUATE WORKMANSHIP TO MINIMIZE VOIDS OR OPENINGS IN THE INSULATION. BOND TO ITEM 1 USING GLUE PER ITEM 7.
5. INSTALL MAPLEWOOD PARTS (ITEMS 5 AND 6, USING FLEXIBLE EPOXY GLUE PER PS-16F000 WITH ADEQUATE WORKMANSHIP TO APPROXIMATELY EQUALIZE THE GAPS BETWEEN WOOD SEGMENTS.
6. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.

SI METRIC

B	REVISED AND REDRAWN R. PARSON, 2401/ J. ANDERSEN, 1721		
C	REVISED AEN SCHEMPC D. TRUMP, 2434 J. ANDERSEN, 1725		
D	REVISED LM D. TRUMP, 2434 J. ANDERSEN, 1725		
E	REVISED NOTE 3 D. TRUMP, 2434 J. ANDERSEN, 1725		

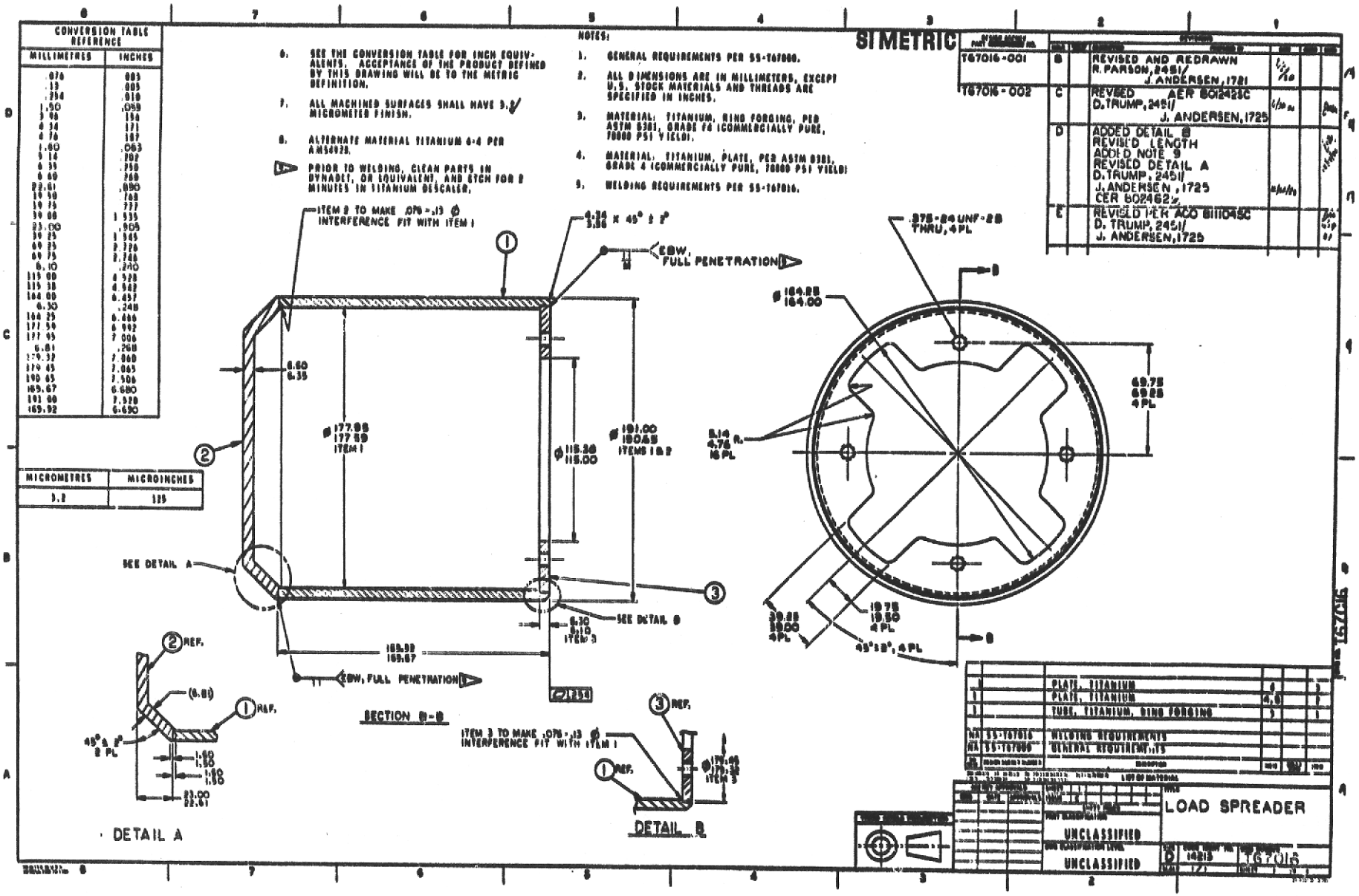




LOAD SPREADER ASSEMBLY

UNCLASSIFIED

UNCLASSIFIED


SI METRIC
CONVERSION TABLE REFERENCE
MILLIMETRES | INCHES
MICROMETRES | MICROINCHES
NOTES:
1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETERS, EXCEPT U.S. STOCK MATERIALS AND THREADS ARE SPECIFIED IN INCHES.
3. MATERIAL: TITANIUM, RING FORGING, PER ASTM B381, GRADE F4 (COMMERCIALLY PURE, 70000 PSI YIELD).
4. MATERIAL: TITANIUM, PLATE, PER ASTM B381, GRADE 4 (COMMERCIALLY PURE, 70000 PSI YIELD)
5. WELDING REQUIREMENTS PER SS-T67016.
6. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
7. ALL MACHINED SURFACES SHALL HAVE 3.2 MICROMETER FINISH.
8. ALTERNATE MATERIAL TITANIUM 6-4 PER AMS4928.
PRIOR TO WELDING, CLEAN PARTS IN DYNADET, OR EQUIVALENT, AND ETCH FOR 2 MINUTES IN TITANIUM DESCALER.
ITEM 2 TO MAKE .076-.13 Ø INTERFERENCE FIT WITH ITEM 1
EBW, FULL PENETRATION
SEE DETAIL A
SEE DETAIL B
SECTION B-B
DETAIL A
DETAIL B
ITEM 3 TO MAKE .076-.13 Ø INTERFERENCE FIT WITH ITEM 1
T67016-001
T67016-002
REVISED AND REDRAWN
R. PARSON, 2451
J. ANDERSEN, 1721
REVISED AER 802425C
D. TRUMP, 2451
J. ANDERSEN, 1725
ADDED DETAIL B
REVISED LENGTH
ADDED NOTE 9
REVISED DETAIL A
D. TRUMP, 2451
J. ANDERSEN, 1725
CER 802462
REVISED PER ACO 811104SC
D. TRUMP, 2451
J. ANDERSEN, 1725
PLATE, TITANIUM
PLATE, TITANIUM
TUBE, TITANIUM, RING FORGING
WELDING REQUIREMENTS
GENERAL REQUIREMENTS
LOAD SPREADER
UNCLASSIFIED
UNCLASSIFIED
T67016

SI METRIC

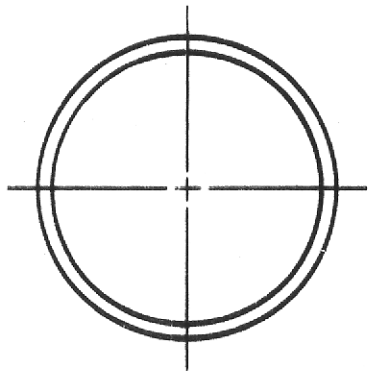
CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
36.20	1.425
36.45	1.435
44.38	1.747
44.76	1.762
62.32	2.454
63.32	2.493
89.06	3.506
89.31	3.516

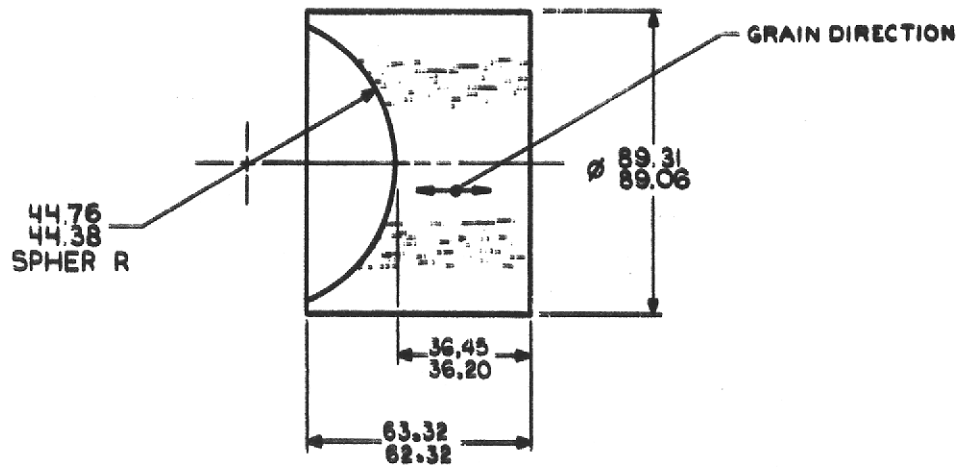
NOTES.

1. GENERAL REQUIREMENTS PER 55-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: MAPLE, HARD NORTHERN, SELECT AND BETTER, KILN DRIED, ROUGH, PER NATIONAL HARDWOOD LUMBERMAN'S ASSOC. (NHLA) RULES.
4. IF BONDING IS NECESSARY, BOND PER PS-T67000, USING MMM-A-180.
5. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
6. MAXIMUM MAPLE DENSITY 56 GRAMS/CM^3.
7. AS SOON AS POSSIBLE AFTER FINISHING, BAG PART WITH DESICCANT MATERIAL.

DESIGN AGENCY PART NO. T67021-000

REVISIONS					
ISSUE	DESCRIPTION	PREPARED BY	DATE	CHKR	APPR
A	R. PARSON, 2451/ J. ANDERSEN, 1760 A		11/8/79		
B	REVISED R. PARSON, 2451/ J. ANDERSEN, 1721		3/12/80		
	AER 801242SC		6/24/81		
C	REVISED LENGTHS D. TRUMP, 2451/ J. ANDERSEN, 1725 CER 802462		14/11/81		





THIRD ANGLE PROJECTION

ROUTED APPROVALS

FUNC	DATE	INITIALS
DRAWN		
CHKD		
ENGR		
PROJ ENGR		
QA		

UNCLASSIFIED

UNCLASSIFIED

TITLE PLUG, INNER, MAPLE

SIZE C | CODE IDENT. NO. 14213 | DWG. NUMBER T67021

SCALE 1/1 | SHEET 1 OF 1

SI METRIC

CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
8.00	.315
10.00	.393
12.00	.474
12.42	.489
15.75	.620
16.50	.649
16.76	.660
18.29	.720
22.00	.866
22.22	.875
22.50	.885
25.40	1.000
38.00	1.496
40.00	1.574
63.76	2.510
64.64	2.545
197.24	7.765
197.62	7.780

8 MAXIMUM REDWOOD DENSITY .38 GRAM[illegible]

9 AS SOON AS POSSIBLE AFTER FINIS[illegible] COAT PIECE PART WITH ADHESIVE [illegible] PS [illegible]7000 USING FLEXIBLE EPOXY [illegible] AND BAG WITH DESICCANT MATERI[illegible]

[illegible] 15 PER SS-767000

[illegible] IN MILLIMETRES, EXCEPT [illegible] TIALS ARE IN INCHES.

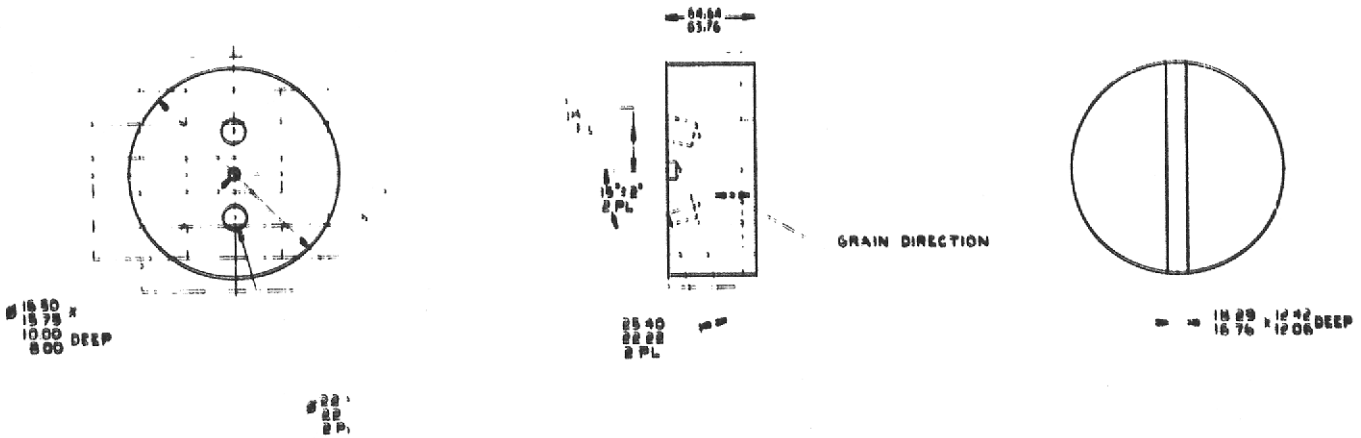
[illegible] 2 INCH WIDE STOCK [illegible] ACES.

[illegible] REDWOOD, KILN DRIED PER

[illegible] 100. USING MMM-A 180

[illegible] JOINTS.

[illegible] TENSION TABLE FOR INCH [illegible] ACCEPTANCE OF THE PRODUCT [illegible] THIS DRAWING WILL BE TO THE [illegible] TION.



PART NUMBER	REVISIONS			
167022-000	B	REVISED AND REDRAWN R PARSON, 2451/ J ANDERSEN, 1721		
	C	REVISED AER 80124250 D. TRUMP, 2451/ J. ANDERSEN, 1725		
	D	CER 80246220 D. TRUMP, 2451/ J. ANDERSEN, 1725		

UNCLASSIFIED

UNCLASSIFIED

PLUG, TOP REDWOOD REMOVABLE

D 1/2 167022

167022

CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
75.01	2.953
78.31	2.965
190.50	7.500
190.88	7.515

7. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
8. MAXIMUM REDWOOD DENSITY .35 GRAMS/CM^3.
9. AS SOON AS POSSIBLE AFTER FINISHING, BAG PART WITH DESICCANT MATERIAL.

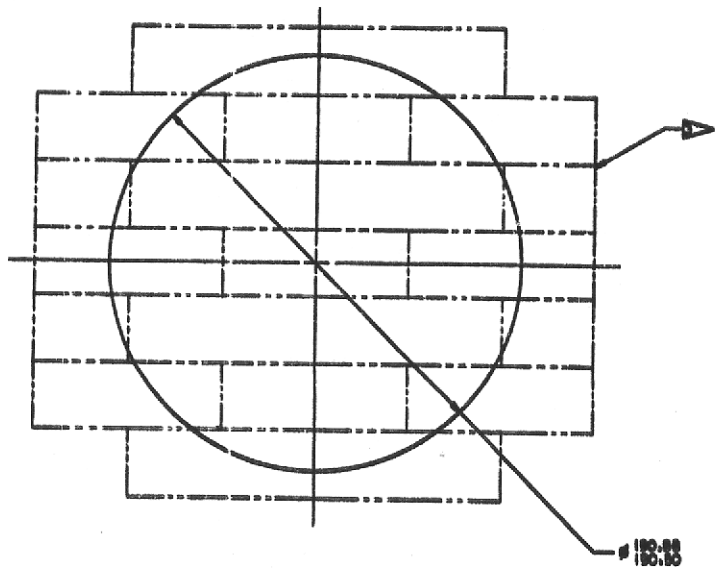
NOTES:

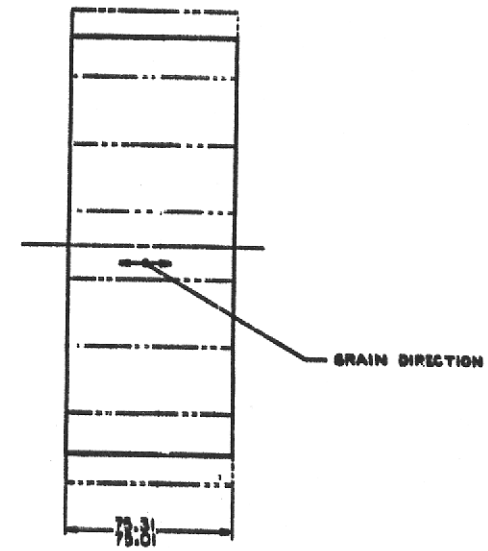
1. GENERAL REQUIREMENTS PER SS-167000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. TYPICAL STACK UP, 2 INCH WIDE STOCK, MACHINE ALL SURFACES.
4. MATERIAL: CLEAR REDWOOD, KILN DRIED PER SS-167026.
5. BOND PER PS-167000, USING MMM-A-188.
6. STAGGER ALL GLUE JOINTS.

SI METRIC

PART NUMBER 167024-000

A	R. PARSON, 2451/ J. ANDERSEN, 1760 A	11/5/80	
B	REVISED R. PARSON, 2451/ J. ANDERSEN, 1721	2/2/81	
C	REVISED AER 8012428C D. TRUMP, 2451/ J. ANDERSEN, 1725	4/30/81	
D	REVISED LENGTH & DIAM. D. TRUMP, 2451/ J. ANDERSEN, 1725 CER 8024822	[illegible]	
E	REVISED LENGTH D. TRUMP, 2451/ J. ANDERSEN, 1725 ECO 8115278C		





UNCLASSIFIED

UNCLASSIFIED

PLUG, BOTTOM, REDWOOD

D 14813 167024

SI METRIC

T67025-000

D	REDRAWN TO SCALE ADDED PROTECTIVE BOOT D. TRUMP, 2451 J. ANDERSEN, 1725 CER 80846	
E	REVISED NOTE 8 D. TRUMP, 2451 J. ANDERSEN, 1725 FCO 81152760	

8. MATERIAL FOR ITEM 4 IS TO BE A TOUGH, FLEXIBLE, RESILIENT POLYBUTADIENE - BASED URETHANE, COLOR BLACK, TO BE MOLDED AND BONDED IN PLACE PER NOTE 9.

△ BOND ITEM 4 TO ITEM 1 PRIOR TO ASSEMBLY OF ITEMS 2 AND 3. PREPARE FAYING SURFACE OF ITEM 1 BY WET OR DRY BLAST CLEANING, MOLD ITEM 4 IN PLACE.

△ BOND ITEM 1 AND 2 PER PS-T67000.

△ BOND ITEM 3 TO ITEM 1 AND 2 PER PS-T67000.

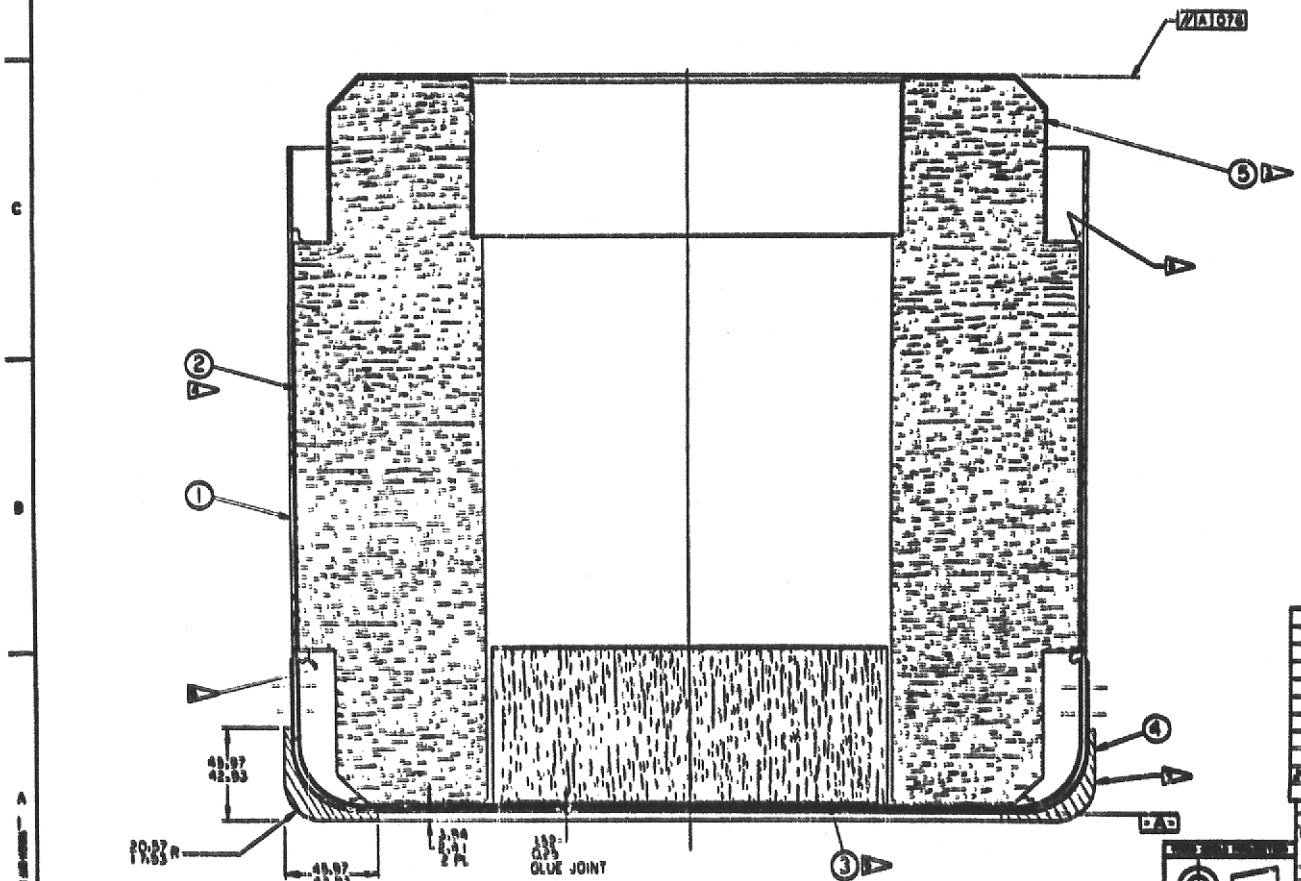
△ MINIMIZE EXCESS GLUE BUILD-UP IN VOID.

7. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.

NOTES:

1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.

△ APPROXIMATELY 0.76mm THICK FIBERGLASS COATING PER SS-T67025



CONVERSION TABLE REFERENCE

MILLIMETRES	INCHES
.013	.001
.025	.001
.10	.004
.13	.005
.25	.010
.51	.020
.76	.030
1.27	.050
2.54	.100
5.08	.200
25.40	1.000
27.94	1.100

A2		FIBERGLASS SHEET	3	0
A1		COVER, INC. RED. PROTECTIVE	0.10	0
1	T67026-000	PLUG, BOTTOM, REDWOOD		1
1	T67026-000	TORSIO, OUTER, REDWOOD		1
1	T67025-001	SUBASSEMBLY, OUTER SHELL		1
	SS-T67025	FIBERGLASS COVERING		
NA	PS-T67000	PRODUCT SPECIFICATION		
NA	SS-T67000	GENERAL REQUIREMENTS		

LIST OF MATERIAL

SUBASSEMBLY, AQ-2

UNCLASSIFIED

UNCLASSIFIED

D 1725 T67025

8. MAXIMUM REDWOOD DENSITY .38 GRAMS/CM³.

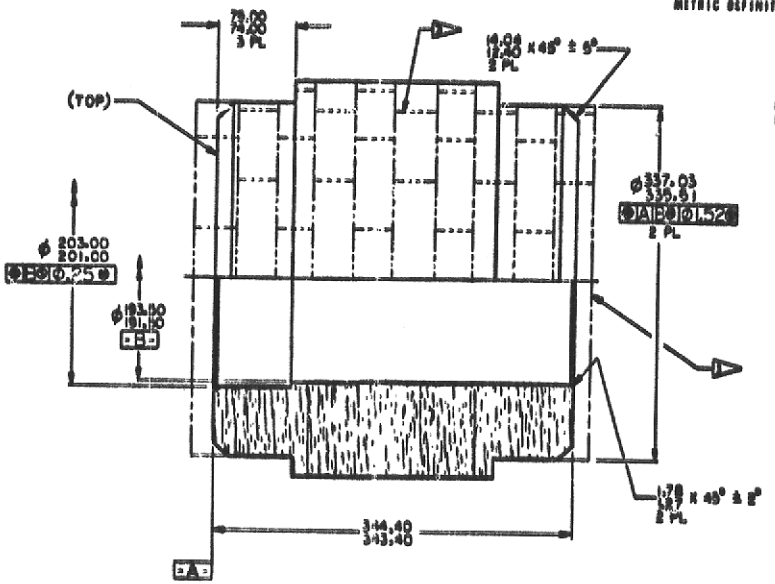
9. AS SOON AS POSSIBLE AFTER FINISHING BAG PART WITH DESICCANT MATERIAL.

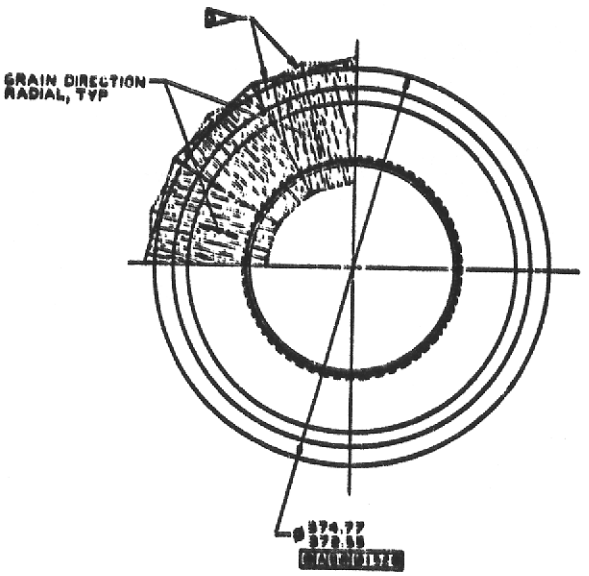
NOTES:

1. GENERAL REQUIREMENTS PER SS-167000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. TYPICAL STACK UP, 2 INCH WIDE STOCK. MACHINE ALL SURFACES.
4. MATERIAL: CLEAR REDWOOD, KILN DRIED PER SS-167020.
5. BOND PER PS-167000, USING MMM-A-180.
6. STAGGER ALL GLUE JOINTS.
7. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.

SI METRIC

PART NUMBER	REV	DESCRIPTION	DATE	APPR
167026-000	D	ELIMINATED BOTTOM C'BORE REVISED TOP C'BORE REDRAWN TO SCALE D. TRUMP, 2451/ J. ANDERSEN, 1725 CER 802462		
	E	REVISED PER ACO 811104SC D. TRUMP, 2451/ J. ANDERSEN, 1725		





CONVERSION TABLE REFERENCE

MILLIMETRES	INCHES
0.25	.010
0.51	.020
1.27	.050
2.54	.100
1.78	.070
12.40	.488
14.00	.551
74.00	2.913
75.00	2.952
87.00	3.425
96.00	3.543
98.00	3.622
191.00	7.520
193.00	7.598
198.00	7.795
200.00	7.874
201.00	7.913
203.00	7.992
335.51	13.200
337.03	13.260
343.40	13.520
344.49	13.560
368.00	14.488
369.00	14.527
372.55	14.667
374.77	14.754

UNCLASSIFIED

UNCLASSIFIED

TOROID, OUTER, REDWOOD

D 16818 167026

CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
0.71	.028
1.753	.069
2.00	.080
4.90	.193
5.90	.232
7.20	.283
8.70	.342
12.00	.472
13.50	.531
74.00	2.913
75.00	2.953
78.00	3.070
79.00	3.110
286.60	11.283
287.00	11.323
375.35	14.769
378.71	14.909

NOTES:

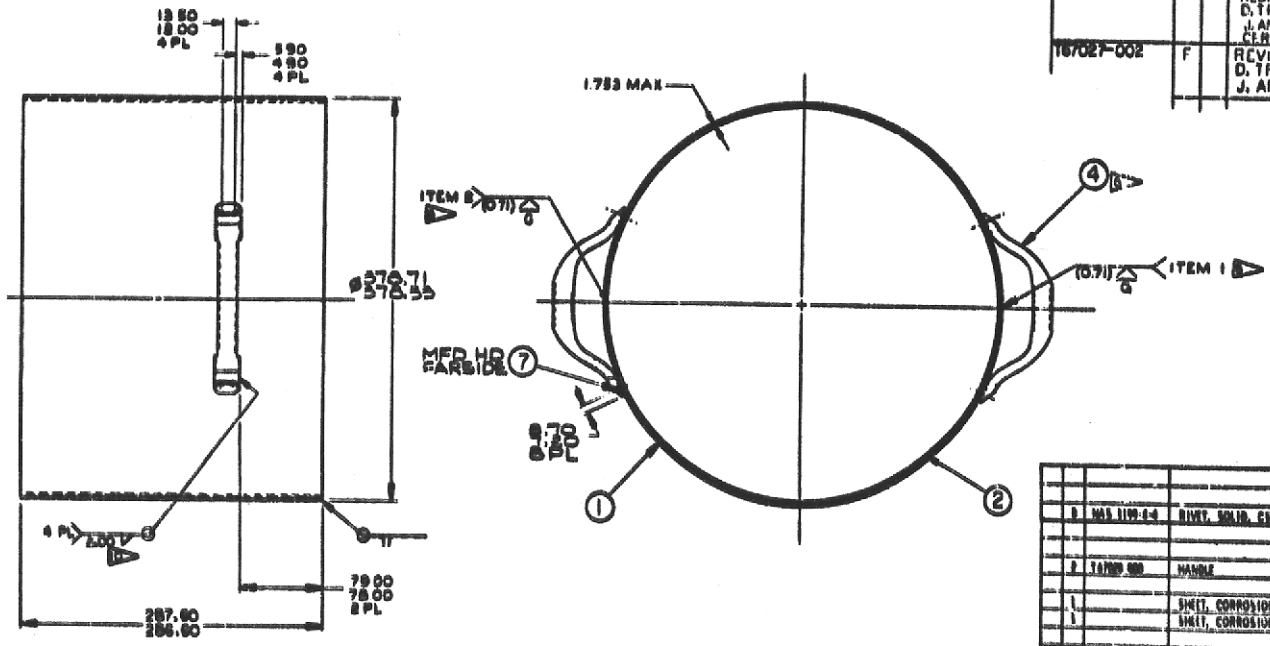
1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. WELD PER SS-T67027.
4. RIVET PER MIL-STD-403B, APPLICABLE PARTS OF PARA. 4.5, 5.2, 5.4.
5. MATERIAL: SHEET, CORROSION RESISTING STEEL, TYPE 304, CONDITION A PER QQ-S-766, 22 GA. (0.0281 THK.
6. CENTER HANDLE (ITEM 4) OVER WELD AS SHOWN AND POSITION HANDLES 180° ± 1° APART.
7.

LONGITUDINAL WELDS ON ITEMS 1 AND 2 TO BE 180° ± 5° APART.

SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.

USE OF 304SS, FILLER WIRE OR WELD ROD AT WELD LOCATION UNDER HANDLE IS PERMISSIBLE.

SI METRIC



PART NUMBER	REV	REVISIONS			
T67027-000	A	S. HUSA, 2451/ J. ANDERSEN, 1760A			
	B	REVISED ITEM 2. S. HUSA, 2451/ J. ANDERSEN, 1760A			
T67027-001	C	REVISED R PARSON, 2451/ J. ANDERSEN, 1721			
	D	REVISED AER 801242SC D. TRUMP, 2451/ J. ANDERSEN, 1725			
	E	ELIMINATED SECURITY SEAL STRAP & NOTE 7 ADDED WELD REDRAWN TO SCALE D. TRUMP, 2451/ J. ANDERSEN, 1725 CER 802462			
T67027-002	F	REVISED PER ACO 811104SC D. TRUMP, 2451/ J. ANDERSEN, 1725			

8	MS 3199-4-4	RIVET, SOLID, CSK HD, 1.0833, 1/8 DIA X 1/4 LG
2	T67000-000	HANDLE
1		SHEET, CORROSION RESISTANT STEEL
1		SHEET, CORROSION RESISTANT STEEL
NAVWEP-STD-403B		RIVETING
NA SS-T67027		WELDING, CORROSION RESISTANT STEEL
NA SS-T67000		GENERAL REQUIREMENTS

LIST OF MATERIAL

UNCLASSIFIED

UNCLASSIFIED

CYLINDER, OUTER

D 14813 T67027

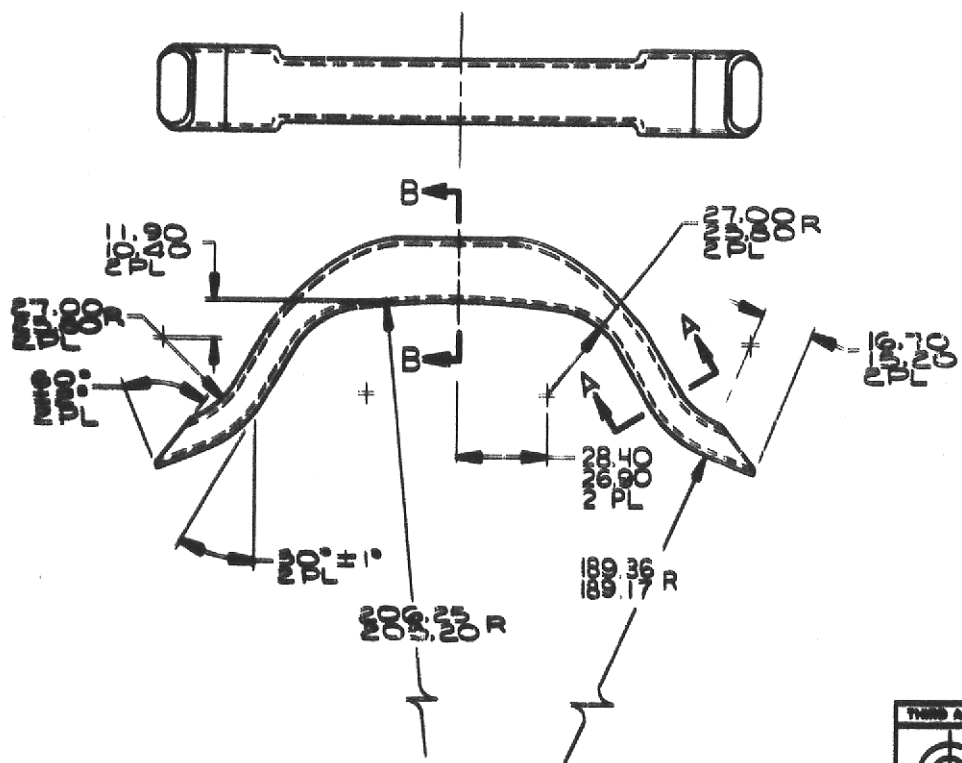
CONVERSION TABLE REFERENCE			
MILLIMETRES	INCHES	MILLIMETRES	INCHES
8.80	.346	26.90	1.059
10.30	.405	27.00	1.062
10.40	.409	28.40	1.118
11.90	.468	189.13	7.446
15.20	.598	189.36	7.455
16.70	.657	203.20	8.000
23.80	.937	206.25	8.120
24.00	.945		
25.00	.657		
23.80	.937		
24.00	.945		
25.00	.984		

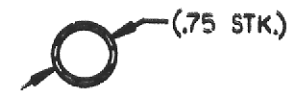
SI METRIC

NOTES:

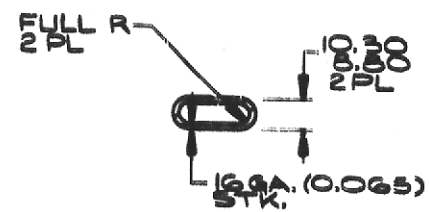
1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETRES EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: 3/4 TUBING, CORROSION RESISTING STEEL, TYPE 304 PER ASTM-A269, 16 GA. (.065) THICK.
4. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
5. PASSIVATE PER QQP-35, TYPE 1.

DESIGN AGENCY PART NO.	REVISIONS ISSUE	DESCRIPTION / PREPARED BY	DATE	CHKD	ENGR
T67028 -000	A	S. HUSA, 2451/ J. ANDERSEN, 1760A	1/2/71	GGA	
	B	MATERIAL WAS SS SHEET. S. HUSA, 2451/ J. ANDERSEN, 1760A	11/8/79		
	C	CHANGED 22.5°±1° TO RADIUS DIMENSION D. BELLER 2451/ J. ANDERSEN, 1760 A	3/		
T67028 - 001	D	REVISED AER 801242SC D. TRUMP, 2451/ J. ANDERSEN, 1725	6/30/8		
	E	CER 802462 SC D. TRUMP, 2451/ J. ANDERSEN, 1725	10/1/8		





SECT. B-B



SECT. A-A

THIRD ANGLE PROJECTION

DRAWING APPROVED

UNCLASSIFIED

UNCLASSIFIED

HANDLE

C 14213 T67028

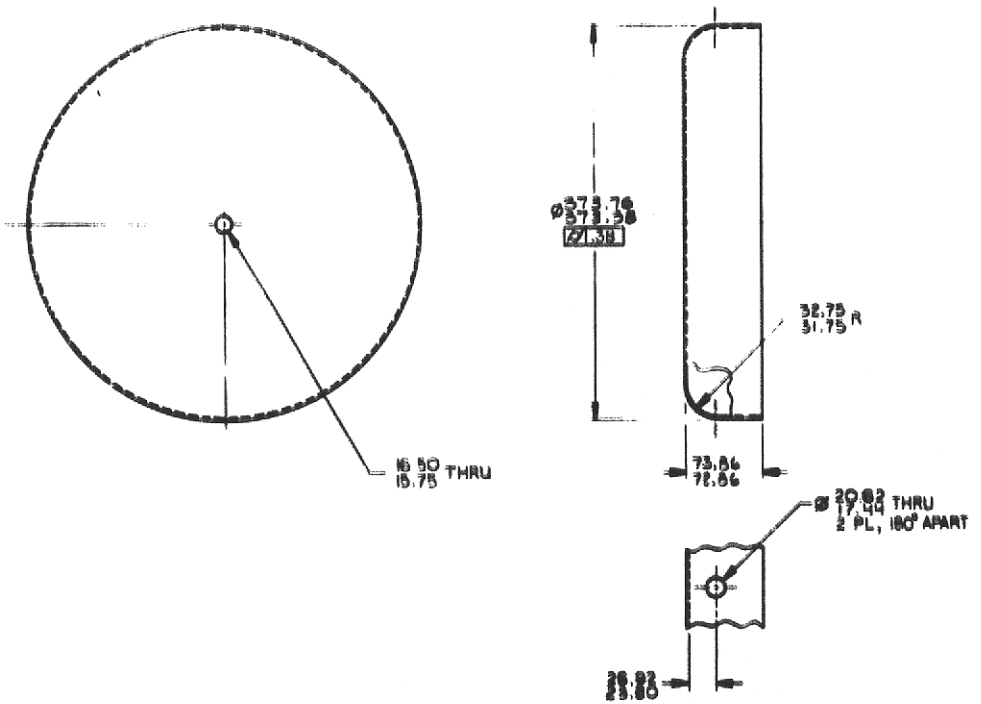
CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
.38	.015
15.75	.620
16.50	.650
17.44	.687
20.82	.819
23.80	.937
26.92	1.060
31.75	1.250
32.75	1.289
72.86	2.869
73.86	2.907
373.38	14.700
373.76	14.714

SI METRIC

NOTES:

1. GENERAL REQUIREMENTS PER SS-167000.
2. ALL DIMENSIONS ARE IN MILLIMETRES. STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: SHEET, CORROSION RESISTING STEEL, TYPE 304, CONDITION A PER QQ-S-766, 20 GA, (0.0351 THICK.
4. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
5. ANNEAL DURING OR AFTER FORMING AT 954°C (1750°F) TO 1038°C (1900°F) FOR 15 TO 30 MINUTES IN A VACUUM FURNACE AND COOL TO BELOW 190°C (300°F) IN AN INERT ATMOSPHERE.

PART NUMBER				
167029-550	A	S. HUSA, 2427 J. ANDERSEN, 1760A		
	B	DELETED FINGER HOLES, ADDED TWO HOLES AND ENLARGED PLUG HOLE D BELLER, 2451 J. ANDERSEN, 1760 A		
		AFR 80124251.		
	C	REMOVED DETAIL A VIEW ADDED NOTE 5 D. TRUMP, 2451 J. ANDERSEN, 1725 CER 80246211		



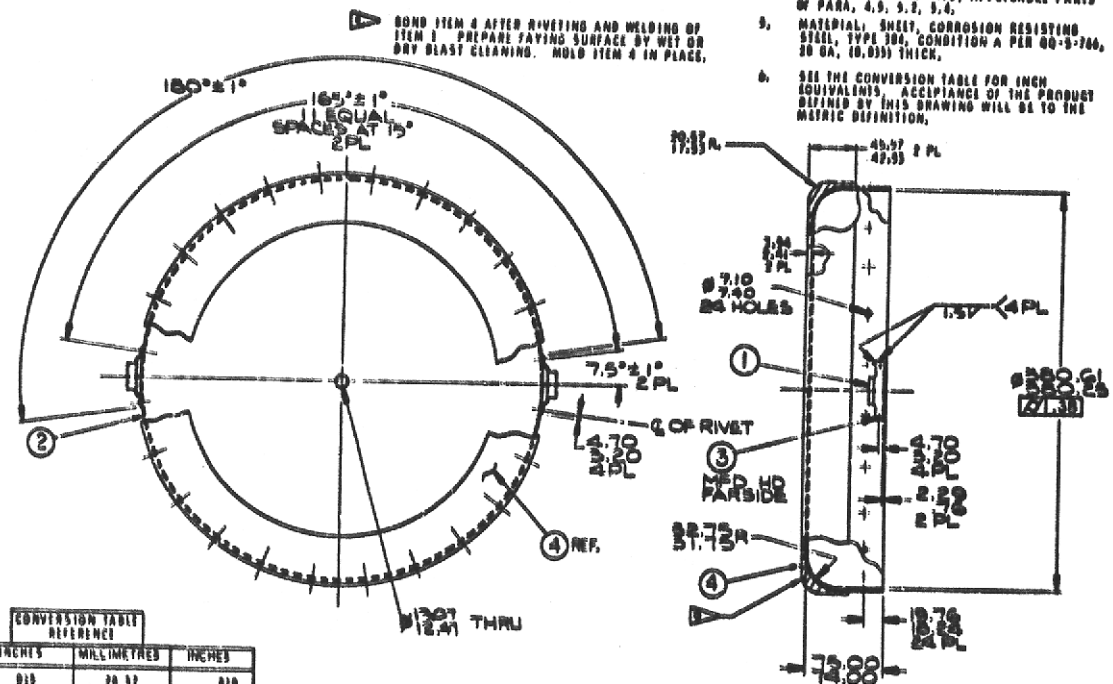
UNCLASSIFIED	COVER, TOP, INNER	
UNCLASSIFIED	D	167029

167029

SI METRIC

NOTES:

1. GENERAL REQUIREMENTS PER SS-167000.
2. ALL DIMENSIONS ARE IN MILLIMETRES. STOCK MATERIALS ARE IN INCHES.
3. WELD PER SS-167027.
4. RIVET PER MIL-STD-4038, APPLICABLE PARTS OF PARA. 4.5, 5.2, 5.4.
5. MATERIAL: SHEET, CORROSION RESISTING STEEL, TYPE 304, CONDITION A PER QQ-S-766, 20 GA. (0.035) THICK.
6. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
7. ANNEAL DURING OR AFTER FORMING AT 954°C (1750°F) TO 1038°C (1900°F) FOR 15 TO 30 MINUTES IN A VACUUM FURNACE AND COOL TO BELOW 150°C (300°F) IN AN INERT ATMOSPHERE.
8. MATERIAL FOR ITEM 4 IS TO BE A TOUGH, FLEXIBLE, RESILIENT POLYBUTADIENE - BASED URETHANE, COLOR BLACK, TO BE MOLDED AND BONDED IN PLACE PER NOTE 9.
9. BOND ITEM 4 AFTER RIVETING AND WELDING OF ITEM 1. PREPARE FAYING SURFACE BY WET OR DRY BLAST CLEANING. MOLD ITEM 4 IN PLACE.



CONVERSION TABLE REFERENCE			
MILLIMETRES	INCHES	MILLIMETRES	INCHES
.38	.015	26.37	1.038
.76	.030	31.75	1.250
1.50	.060	32.75	1.289
2.29	.090	42.93	1.690
2.41	.095	45.97	1.810
3.20	.126	74.00	2.913
3.94	.155	75.00	2.952
4.70	.185	380.23	14.970
7.10	.279	380.01	14.964
7.40	.291		
12.47	.491		
13.07	.514		
17.53	.690		
18.24	.718		
19.76	.777		

A	S. HUSA, 2451 / J. ANDERSEN, 1760A			
B	REVISED WELDING OF ITEM 1. S. HUSA, 2451 / J. ANDERSEN, 1760A			
C	REVISED MATERIAL LIST R. PARSON, 2451 / J. ANDERSEN, 1721			
D	REVISED AER U012426C D. TRUMP, 2451 / J. ANDERSEN, 1725			
E	ADDED NOTES 7, 8, AND 9 ADDED ITEM 4 D. TRUMP, 2451 / J. ANDERSEN, 1725 CLR 8C2462F			
F	REVISED NOTE 8 D. TRUMP, 2451 / J. ANDERSEN 1725 FCO 8U15275C			

4		COVER, MOLDED PROTECTIVE	
3	MS35190-723	RIVET SOLID, CSS, 100° HEADS, 1/8 DIA.	
2		SHEET, CORROSION RESISTANT STEEL	S
1	167012-000	STRAP, SEAL, SECURITY	

NAVSHIPS-STD-4038 RIVETING
NAVSHIPS SS-167027 WELDING, CORROSION RESISTANT STEEL
NAVSHIPS SS-167000 GENERAL REQUIREMENTS

UNCLASSIFIED

UNCLASSIFIED

COVER, TOP, OUTER

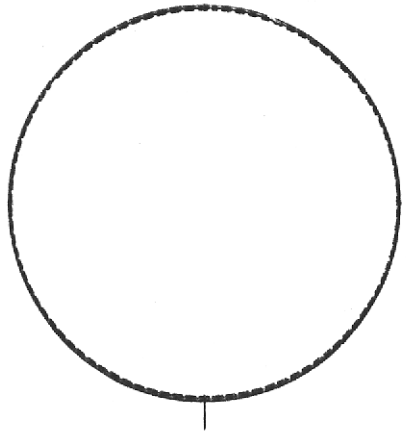
D 167030

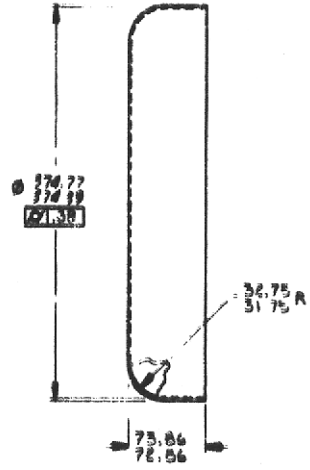
CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
.38	.015
31.75	1.250
32.75	1.289
72.86	2.869
73.86	2.907
374.39	14.740
374.77	14.754

SI METRIC

NOTES:

1. GENERAL REQUIREMENTS PER SS-167000.
2. ALL DIMENSIONS ARE IN MILLIMETRES. STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: SHEET, CORROSION RESISTING STEEL, TYPE 304, CONDITION A PER QQ-S-766, 20 GA, (0.035) THICK.
4. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
5. ANNEAL DURING OR AFTER FORMING AT 954°C (1750°F) TO 1038°C (1900°F) FOR 25 TO 30 MINUTES IN A VACUUM FURNACE AND COOL TO BELOW 350°C (300°F) IN AN INERT ATMOSPHERE





PART NUMBER					
T67031-050	A	S. HUSA 24517 J. ANDERSEN, 1760A			
		AER B012422C			
	B	ADDED NOTE 5 D. TRUMP, 24511 J. ANDERSEN, 1725 CER B02462			

UNCLASSIFIED

UNCLASSIFIED

COVER, BOTTOM, INNER

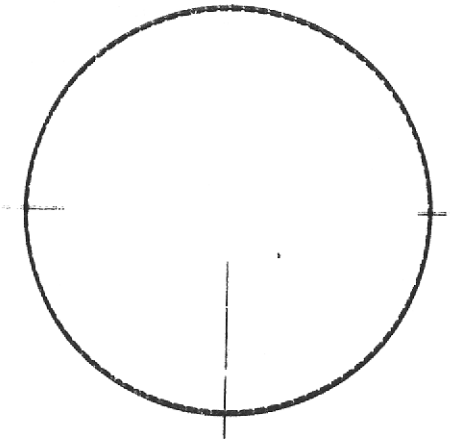
T67031

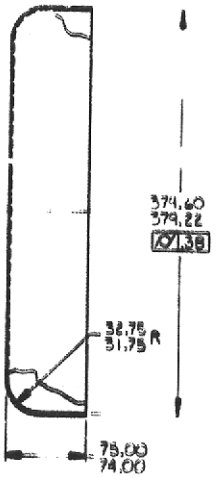
CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
.38	.015
31.75	1.250
32.75	1.289
76.00	2.913
75.00	2.952
379.22	14.930
379.60	14.944

SI METRIC

NOTES:

1. GENERAL REQUIREMENTS PER 55-167000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: SHEET, CORROSION RESISTING STEEL, TYPE 304, CONDITION A PER QQ-S-766, 20 GA. (0.0351 THICK.
4. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
5. ANNEAL DURING OR AFTER FORMING AT 994°C (1750°F) TO 1038°C (1900°F) FOR 15 TO 30 MINUTES IN A VACUUM FURNACE AND COOL TO BELOW 150°C (300°F) IN AN INERT ATMOSPHERE.





PART NUMBER 167032-000

A	S. HUSA, 2251 / J. ANDERSEN, 1760A		
	AER 801242SC		
B	ADDED NOTE 5 D. TRUMP, 2451 J. ANDERSEN, 1725 CER 802462		

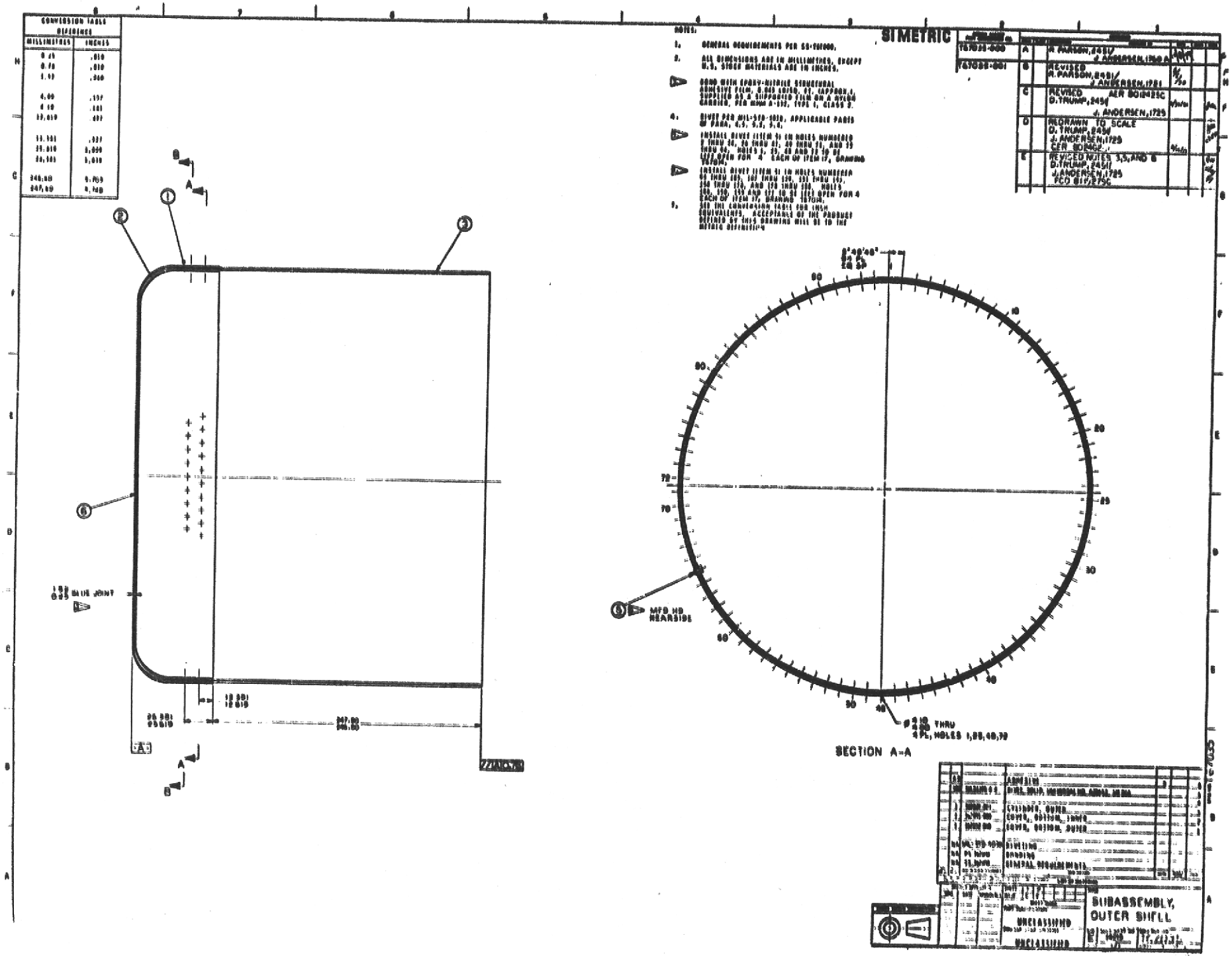
UNCLASSIFIED

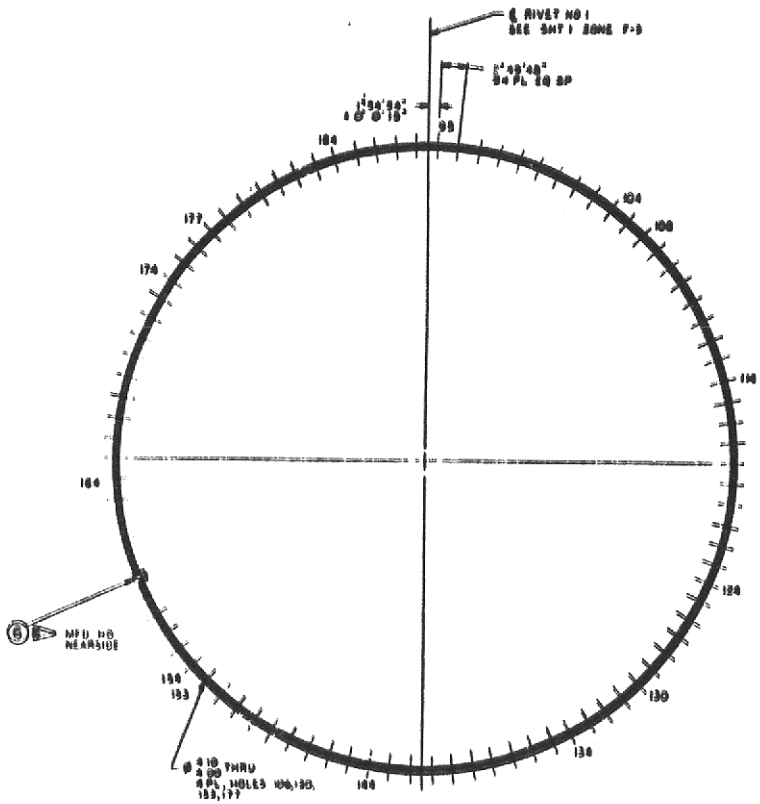
UNCLASSIFIED

COVER, BOTTOM OUTER

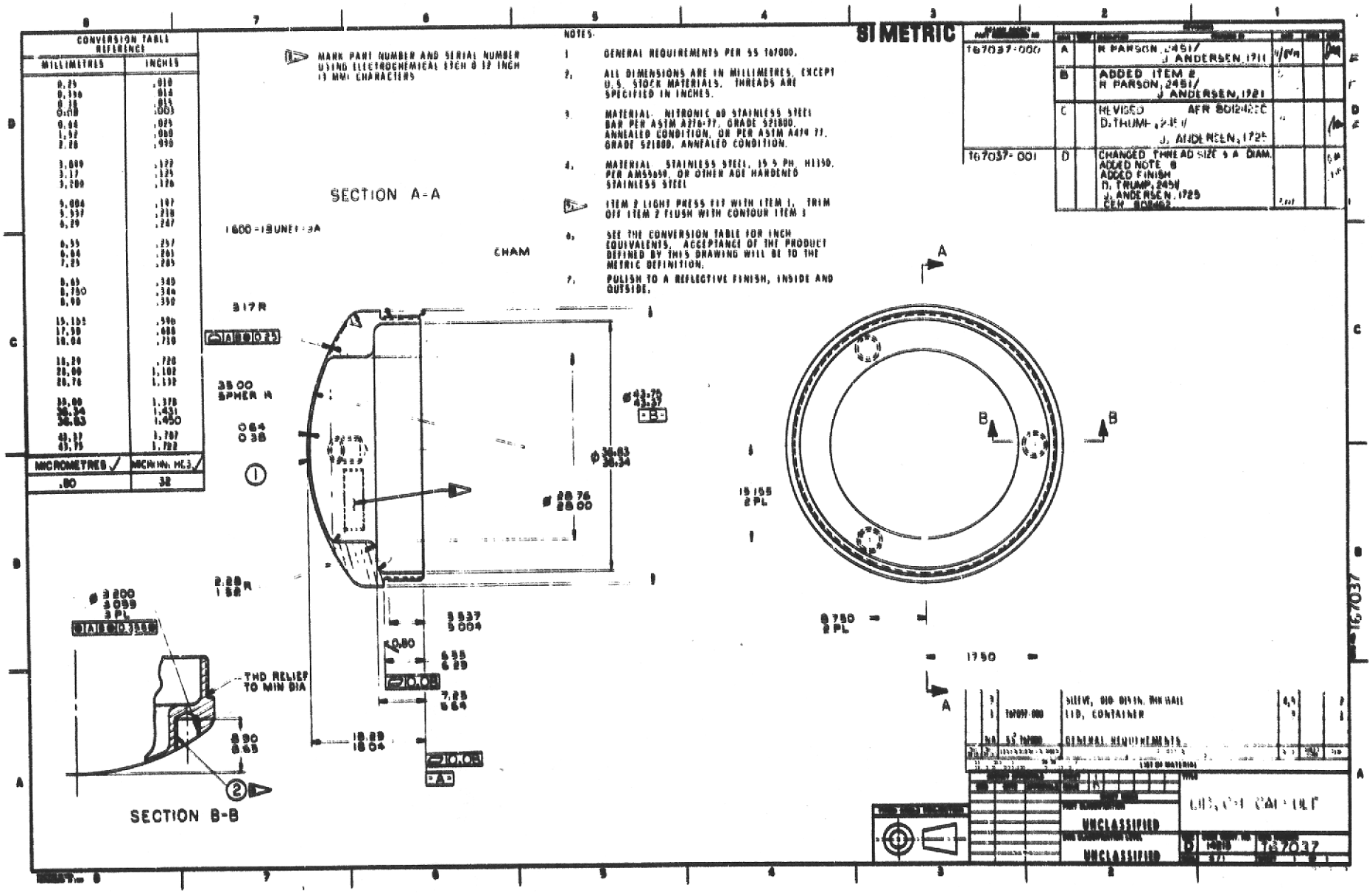
D 167032

167032


CONVERSION TABLE
DIFFERENCE
MILLIMETRES
INCHES
SI METRIC
NOTES:
1. GENERAL REQUIREMENTS PER SS-[illegible].
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. BOND WITH EPOXY-NITRILE STRUCTURAL ADHESIVE FILM, 0.005 LOSS, 91, APPROX. 4, SUPPLIED AS A SUPPORTED FILM ON A NYLON CARRIER, PER MMM A-132, TYPE 1, CLASS 2.
4. RIVET PER MIL-STD-1013, APPLICABLE PARTS OF PARA. 4.3, 5.2, 5.4.
INSTALL RIVET ITEM 31 IN HOLES NUMBERED 1 THRU 16, 20 THRU 27, 40 THRU 71, AND 75 THRU 84. HOLES 1, 25, 48 AND 72 IS OF LIFT OPEN FOR 4 EACH OF ITEM 17, DRAWING [illegible].
INSTALL RIVET ITEM 31 IN HOLES NUMBERED 85 THRU 101, 107 THRU 139, 151 THRU 167, 174 THRU 178, AND 180 THRU 208. HOLES 102, 120, 139 AND 177 IS OF LIFT OPEN FOR 4 EACH OF ITEM 17, DRAWING [illegible].
5. SEE THE CONVERSION TABLES FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
MFD HD NEARSIDE
SECTION A-A
SUBASSEMBLY, OUTER SHELL
UNCLASSIFIED


℄ RIVET NO 1
SEE SHT 1 ZONE F-5
95
184
104
108
114
124
130
134
144
153
164
174
177
MFD NO
NEARSIDE
153
Ø 4.10 THRU
4.00
4 PL. HOLES 106,130,
153,177

SECTION B-B


SI METRIC
CONVERSION TABLE REFERENCE
MILLIMETRES
INCHES
MICROMETRES
MICROINCHES
.80
32
MARK PART NUMBER AND SERIAL NUMBER USING ELECTROCHEMICAL ETCH 8 32 INCH 13 MM CHARACTERS
NOTES:
1. GENERAL REQUIREMENTS PER SS 167000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS. THREADS ARE SPECIFIED IN INCHES.
3. MATERIAL: NITRONIC 60 STAINLESS STEEL BAR PER ASTM A276-77, GRADE S21800, ANNEALED CONDITION, OR PER ASTM A479 77, GRADE S21800, ANNEALED CONDITION.
4. MATERIAL: STAINLESS STEEL, 15 5 PH, H1150, PER AMS5659, OR OTHER AGE HARDENED STAINLESS STEEL
5. ITEM 2 LIGHT PRESS FIT WITH ITEM 1. TRIM OFF ITEM 2 FLUSH WITH CONTOUR ITEM 1
6. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
7. POLISH TO A REFLECTIVE FINISH, INSIDE AND OUTSIDE.
SECTION A-A
SECTION B-B
THD RELIEF TO MIN DIA
CHAM
167037-000
167037-001
R PARSON, 2451/ J ANDERSEN, 1711
ADDED ITEM 2 R PARSON, 2451/ J ANDERSEN, 1721
REVISED AFR 80124
D. TRUMP, 2451/ J. ANDERSEN, 1725
CHANGED THREAD SIZE & A DIAM. ADDED NOTE 6 ADDED FINISH D. TRUMP, 2451 J. ANDERSEN, 1725
SLEEVE, OID DIVIN, THK WALL
LID, CONTAINER
GENERAL REQUIREMENTS
UNCLASSIFIED
UNCLASSIFIED
167037

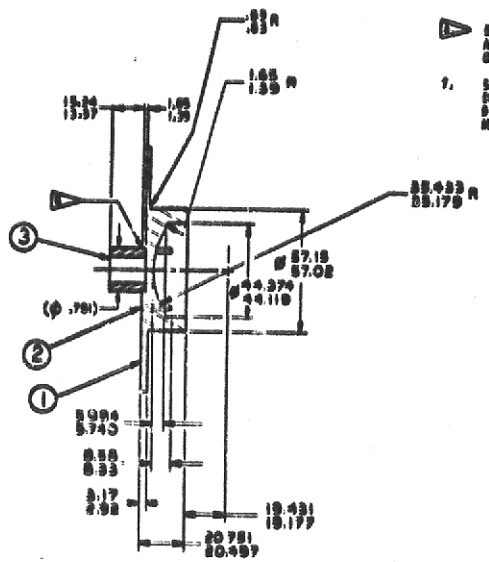
CONVERSION TABLE REFERENCE	
MILLIMETERS	INCHES
.03	.001
.05	.002
1.59	.063
1.65	.065
2.38096	.093750
2.57210	.101339
2.92	.115
3.17	.125
3.96	.156
5.53	.218
5.740	.226
5.994	.236
7.13	.281
8.331	.328
8.509	.335
13.97	.550
8.71	.343
10.31	.406
11.44	.450
15.24	.600
17.55	.691
18.24	.718
19.177	.755
19.431	.765
19.84	.781
20.497	.807
20.701	.815
33.170	1.305
33.655	1.325
44.120	1.737
44.374	1.747
56.33	2.218
57.07	2.245
57.15	2.250
57.93	2.281

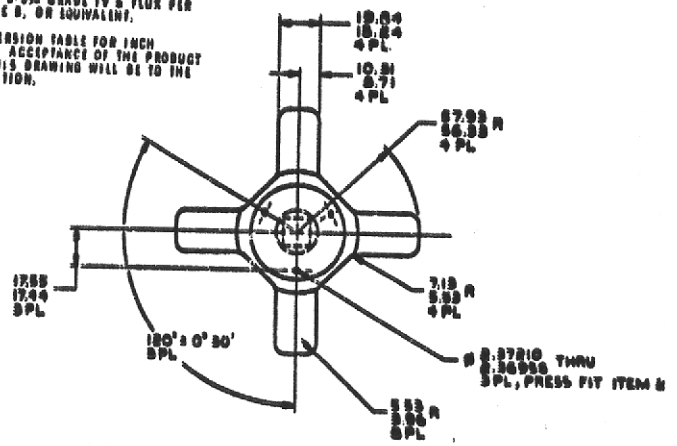
NOTES:

1. GENERAL REQUIREMENTS PER SS-167000.
2. ALL DIMENSIONS ARE IN MILLIMETERS, EXCEPT U.S. STOCK MATERIALS ARE SPECIFIED IN INCHES.
3. DRYBLAST USING 1000 MESH GLASS BEADS FOR UNIFORM MATTE FINISH.
4. ELECTROLESS NICKEL PLATE PER MIL-C-26074, CLASS 1, .0005 THICK.
5. ROUND STEEL SLEEVE, APPROX. 0.781-INCH OUTSIDE DIAMETER, WITH 11/2-INCH SQUARE INSIDE HOLE, MAY BE COMMERCIALLY PURCHASED STOCK. ANY STEEL ALLOY COMPATIBLE WITH BRAZING PER NOTE 6 AND SUITABLE FOR HAND TOOL SERVICE MAY BE USED.
6. BRAZE PER MIL-B-7883, ANY METHOD, USING ALLOY PER QQ-B-654 GRADE IV & FLUX PER O-F-499C, TYPE B, OR EQUIVALENT.
7. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.

SI METRIC

PRELIMINARY PART NUMBER	REVISIONS			
T67038-001	B	REVISED AND REDRAWN R. PARSON, 2451 / J. ANDERSEN, 1721		
T67038-002	C	REVISED AER 802421C D. TRUMP, 2451 / J. ANDERSEN, 1725		
	D	CER 802462 3C D. TRUMP, 2451 / J. ANDERSEN, 1725		
	E	REVISED NOTE 5 & ITEM 3 ON LIM D. TRUMP, 2451 / J. ANDERSEN 1725 FCO 811527SC		





A2	SLEEVE, 1½" SQUARE HOLE	5	5
4 AN122000	PIN, STRAIGHT SGL, [illegible]	4	4
3	STEEL, [illegible]		3
NA 55-121000	GENERAL REQUIREMENTS		

UNCLASSIFIED

UNCLASSIFIED

WRENCH, CAPSULE

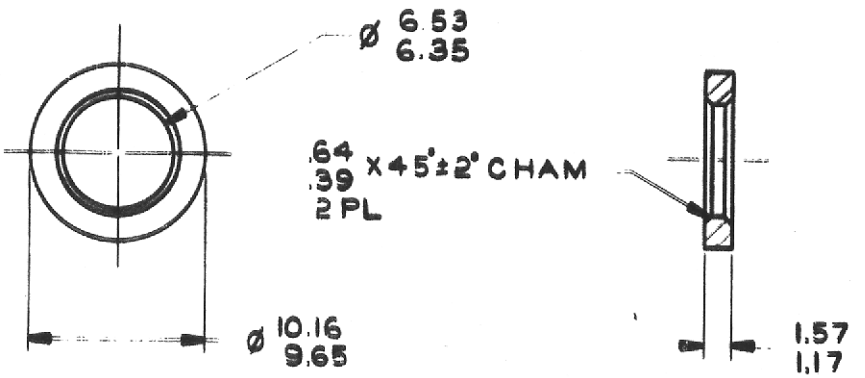
T67038

SI METRIC

NOTES:

1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS. THREADS ARE SPECIFIED IN INCHES.
3. MATERIAL: STAINLESS STEEL BAR, 15-5 PH PER AMS 5659C, HEAT TREAT CONDITION H1150 PER MIL-H-6875.
4. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
5. PASSIVATE PER QQP-35, TYPE I.

DESIGN AGENCY PART NO.	REVISIONS				
	ISSUE	DESCRIPTION / PREPARED BY	DATE	CHKR	ENGR
T67042-000	A	R. PARSON, 2451/ J. ANDERSEN, 1721	11/8/79		
T67042-001	B	REVISED R. PARSON, 2451/ J. ANDERSEN, 1721	3/5/80		
	C	REVISED AER 801242SC D. TRUMP, 2451/ J. ANDERSEN, 1725	6/30/80		
	D	CER 802462SC D. TRUMP, 2451/ J. ANDERSEN, 1725	11/22/80		



CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
.39	.015
.64	.025
1.17	.046
1.57	.062
6.35	.250
6.53	.257
9.65	.380
10.16	.400

THIRD ANGLE PROJECTION

AGENCY APPROVALS		
ORG	DATE	INITIALS

SHEET 1 ISSUE D

PART CLASSIFICATION: UNCLASSIFIED

DWG. CLASSIFICATION LEVEL: UNCLASSIFIED

TITLE: WASHER

SIZE B | CODE IDENT. NO. 14213 | DWG. NUMBER T67042

SCALE 4/1 | SHEET 1 OF 1

PRINTED IN U.S.A. BARCLAY BROTHERS 100-6 GRAPHLER

CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
1.07	.042
1.32	.052
4.76	.187
5.14	.202
6.10	.240
6.73	.265
6.86	.270
11.00	.433
11.20	.440
18.75	.738
19.00	.748
37.75	1.486
38.00	1.496
56.90	2.240
57.40	2.260
69.25	2.726
69.75	2.746
95.00	3.740
95.50	3.760
113.62	4.473
114.00	4.488
162.75	6.407
163.00	6.417
12.45	.490
12.95	.510

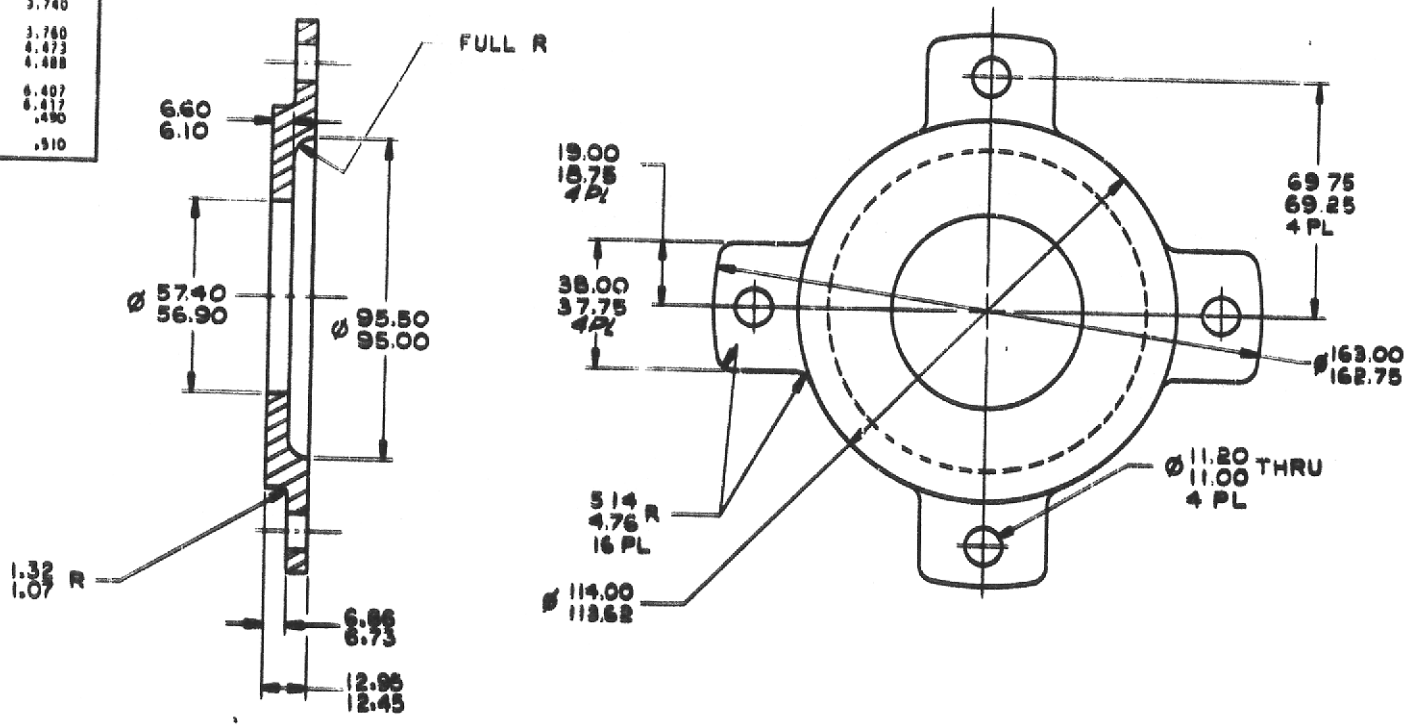
NOTES:

1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: TI-6Al-4V, PLATE, PER MIL-T-9046, SOLUTION TREATED & AGED.
4. SEE THE CONVERSION TABLE FOR INCH EQUIVALENT. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.

SI METRIC

MORAN ARDNEY PART NO. T67047-000

REVISIONS				
ISSUE	DESCRIPTION / PREPARED BY	DATE	CHKD	APPD
A	R. PARSON, 2451/ J. ANDERSEN, 1721	3/5/80		
	AER 801242SC	6/20/91		
B	CHANGED A RADIUS, AND TWO THICKNESS DIMENSIONS D. TRUMP, 2451/ J. ANDERSEN, 1725 CER 802462SC	11/22/90		



THIRD ANGLE PROJECTION

AGENCY APPROVALS

UNCLASSIFIED

UNCLASSIFIED

TITLE: LOCK RING

SIZE C | CODE IDENT. NO. 14213 | DWG. NUMBER T67047

SCALE 1/1 | SHEET 1 OF 1

CONVERSION TABLE REFERENCE			
MILLI-METRES	INCHES	MILLI-METRES	INCHES
.25	.010	9.50	.374
.50	.020	9.75	.384
1.57	.040	15.00	.630
2.36	.093	16.50	.650
4.75	.187	44.00	1.732
5.00	.197	44.40	1.748
5.25	.207	56.50	2.224
6.25	.246	56.75	2.234
6.35	.250	57.00	2.244
6.50	.256		
6.75	.266	57.25	2.254
7.05	.276		

MICROMETRES	MICROINCHES
.80	32

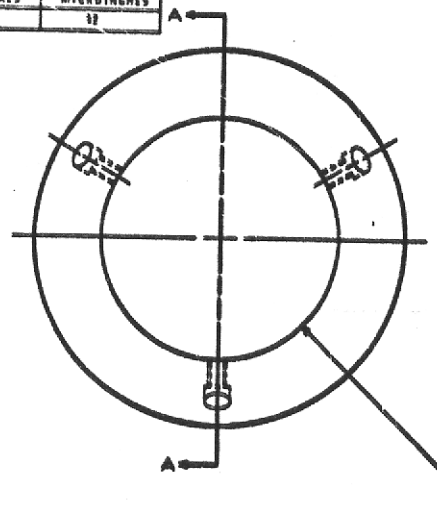
NOTES:

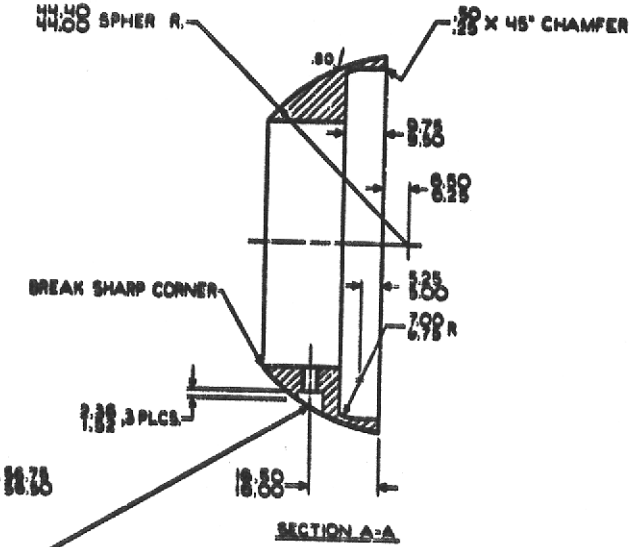
1. GENERAL REQUIREMENTS PER SS-T47060.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. MATERIAL: ALUMINUM ALLOY, 6061-T6 PER QQ-A-250, OR QQ-A 225/8B
4. SURFACE TEXTURE IS IN MICROMETRES.
5. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
6. POLISH TO REFLECTIVE FINISH ON 44.00 SPHER R. ONLY.

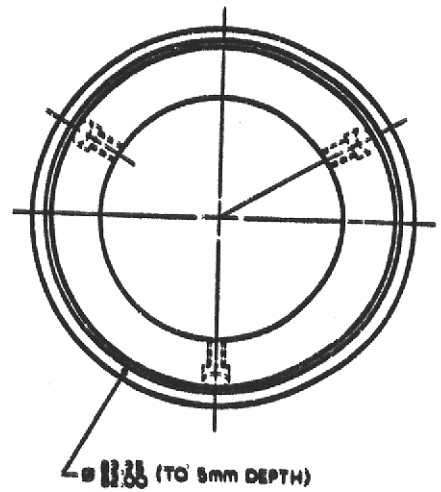
SI METRIC

T67048-000

A		BELLER, 2451/ANDERSEN, 1721	
B		REVISED AER 8012425C D. TRUMP, 2451/ J. ANDERSEN, 1725	
C		CER 8024E2 SC D. TRUMP, 2451/ J. ANDERSEN, 1725	
D		REVISED PER ACO 81110450 D. TRUMP, 2451/ J. ANDERSEN, 1725	







UNCLASSIFIED

UNCLASSIFIED

FAIRING, TB-2, SPHERICAL CONTAINMENT VESSEL

CONVERSION TABLE REFERENCE	
MILLIMETRES	INCHES
.120	.005
.381	.015
.51	.020
1.52	.060
19.05	.750
19.30	.760
80.31	3.161
89.02	3.505
130.20	5.126
150.95	5.150
162.05	6.400
162.55	6.415
169.99	6.691
170.18	6.700

NOTES:

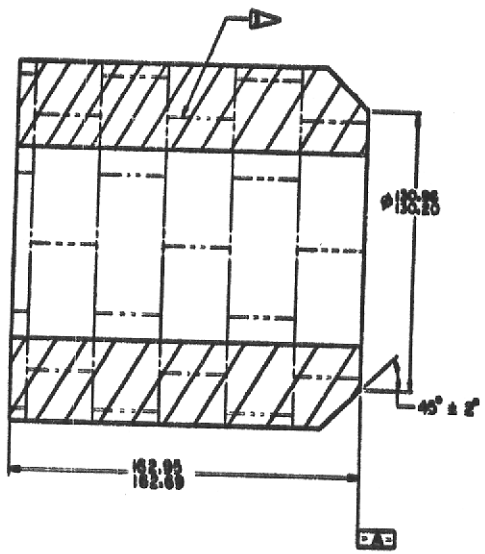
6. STAGGER ALL GLUE JOINTS.
7. MAXIMUM MAPLE DENSITY .56 GRAMS/CM³.
8. FINISHED PART MUST MEET OUTSIDE DIAMETER, INSIDE DIAMETER, AND VOIDS BETWEEN PARTS AS NOTED ON DRAWING.
9. SEE THE CONVERSION TABLE FOR INCH EQUIVALENTS. ACCEPTANCE OF THE PRODUCT DEFINED BY THIS DRAWING WILL BE TO THE METRIC DEFINITION.
10. AS SOON AS POSSIBLE AFTER FINISHING, BAG PART WITH DESICCANT MATERIAL.

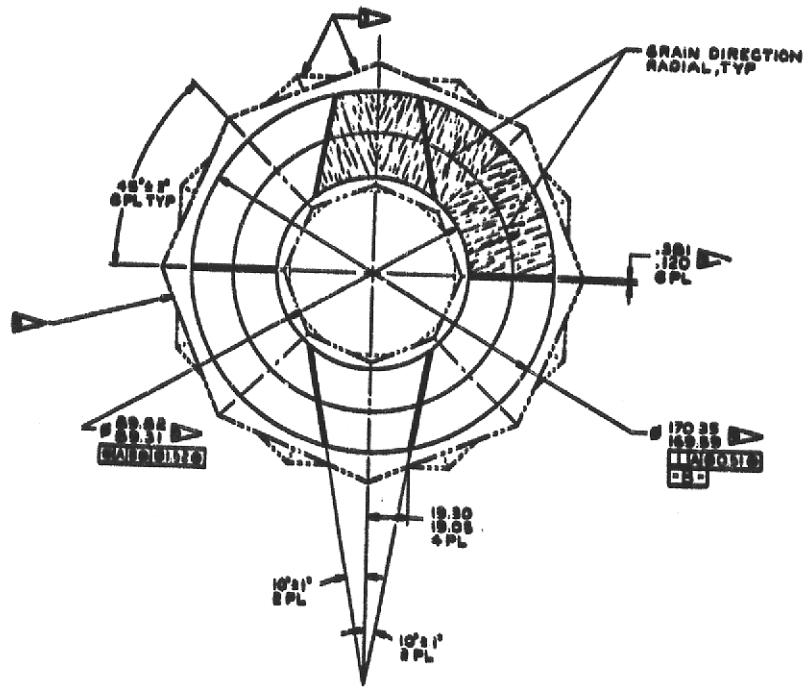
1. GENERAL REQUIREMENTS PER SS-T67000.
2. ALL DIMENSIONS ARE IN MILLIMETRES, EXCEPT U.S. STOCK MATERIALS ARE IN INCHES.
3. TYPICAL STACK UP, 2 X 4 STOCK. MACHINE ALL SURFACES.
4. MATERIAL: MAPLE, HARD NORTHERN, SELECT OR BETTER, KILN DRIED, ROUGH, PER NATIONAL HARDWOOD LUMBERMAN'S ASSOC. (NHLA) RULES.
5. BOND PER PS-T67000, USING MMM-A-100.

SI METRIC

T67049-000

A	R. PARSON, 2451/ J. ANDERSEN, 1781	1/10
	AEA 8012431C	
B	CEA 8024623C D.TRUMP, 2451 J.ANDERSEN, 1725	
C	REVISED PER ACO 8111048C REVISED LENGTH D.TRUMP, 2451/ J.ANDERSEN, 1725 FCO 8115275C	





UNCLASSIFIED

UNCLASSIFIED

TOROID, INNER, MAPLE

T67049

APPENDIX 9B

PAT-2 Certification of Compliance

January 12, 1981

TO: John A. Andersen
Organization 1725
Sandia Laboratories

FROM: E. F. Kluber, D/823

SUBJ: Certification of Compliance - PAT - 2 PACKAGE - T67000

RE: SNLA Order No. 42-4504

DRAWINGS: LD - T67000

REQUIREMENTS: PS - T67000 Product Specification, PAT - 2 Package
SS - T67000 General Requirements, PAT - 2 Package
SS - T67001 Testing, Leak Rate, Mass Spectrometer, PAT - 2 Package
SS - T67016 Welding, Titanium
SS - T67025 Covering, Fiberglas
SS - T67026 Material Specification, Redwood for PAT - 2 Package
SS - T67027 Welding, Corrosion Resistant Steel, PAT - 2 Package

DEVIATIONS: Specification exception numbers: N3705, N3706, N3707, N3708, N3805, N3863, N3864BX80SC

The PAT - 2 Packages, Serial Numbers X07 through X15 inclusive, were fabricated at Bendix, Kansas City and are hereby certified to conform to all requirements and drawings set forth except for the deviations as listed above.

E. F. Kluber
BKC - Product Engineer

W. D. Schultz
BKC - Quality Control Engineer

C. E. Spitzkeit
BKC - Engineering Supervisor

J. O. Christy
BKC - Quality Control Supervisor

RAAU6UEU RHEGACA1567 2351639-UUUU--RHEGSNM.
ZNR UUUUU UNCLASSIFIED/N O N W D/NARR
R 221639Z AUG 80

SXR NO: N37058X80SC SUBJECT: SPECIFICATION EXCEPTION RELEASE

REV NO: 0 FROM: BX/E KLUBER 823
PROGRAM: PAT-2 TO: SC/J ANDERSEN 1721

REASON FOR REVISION

DRAWING NUMBER	SUFFIX DA PA	USE LIMITATION	QUANTITY	PART NAME
T67002	001	UNRESTRICTED USE	9	TB-2 VFSSEL-A

****INTERIM ASSEMBLIES UNIQUE ASSEMBLIES

DRAWING REQUIREMENT & VARIATION FROM DRAWING

T67002-001 ISS 6. SPECIFICATION	SER #	EXCEPTION
1. 54.051/53.949	X07	54.061 OR .010 OHL
	X09	54.054 OR .003 OHL
	X10	54.056 OR .005 OHL
	X12	54.059 OR .008 OHL
	X13	54.053 OR .002 OHL
	X14	54.092 OR .041 OHL
2. 58.13/58.00	X07	58.158 OR .028 OHL
	X08	58.151 OR .021 OHL
	X09	58.17 OR .04 OHL
	X10	58.17 OR .04 OHL
	X12	58.158 OR .028 OHL
	X14	58.136 OR .006 OHL
	X15	58.16 OR .03 OHL
3. 3.17R	X07	3.63 OR .21 OHL
	X08	3.60 OR .18 OHL
	X09	3.52 OR .10 OHL
	X10	3.52 OR .10 OHL
	X11	3.51 OR .09 OHL
4. 49.940/49.900	X07	49.886 OR .014 ULL
	X08	49.891 OR .009 ULL
	X12	49.896 OR .004 ULL
	X14	49.875 OR .025 ULL
	X15	49.890 OR .010 ULL
5. 35.00OR	X11	35.39 OR .14 OHL
6. 20 DEG +- 1 DEG	X12	21 DEG 11' OR 11' OHL
	X14	21 DEG 14' OR 14' OHL
7. 1.245/1.143	X15	1.258 OR .013 OHL

PREVIOUS SXR'S

END PAGE 1 UNCLASSIFIED/N O N W D/NARR

PAGE 2 RHEGKCA1567 UNCLASSIFIED/N O N W D/NARR

SXR NO: N3705RX80SC
REV NO: 0

MARKING REQUIREMENTS

MARKING NOT REQUIRED

CORRECTIVE ACTION

PROCESS ENGINEER REVIEWING N.C. TAPES

REFERENCES & REMARKS

DOC CODE	REV	APPROVED BY		AGENCY	ORG	DATE
SXR	0	J ANDERSEN	TELECON	SALA	1721	8/22/80

PA INFORMATION

RSX NO.	DATE	QTY REQUESTED	QTY INTERIM ASSY ACCEPTED
41524			

DEPT/VENDOR

RR NUMBER	QTY REJECTED

REASON FOR REJ/DISP APPLICABILITY

APPROVAL

E KLUBEK 623 8/22/80

DISTRIBUTION

N GOULDSMITH D/623
W SCHULTZ D415

END PAGE 2 OF 2 UNCLASSIFIED/N O N W D/NARR
SAS 21052
DT
21567
NNNN

RAAU56ED RHEGKCA156& 2351839-UUUU--RHEGSNM.
ZNR UUUUU UNCLASSIFIED/N D N W D/MARR
R 221839Z AUG 80

SXR NO: N3705RX80SC SUBJECT: SPECIFICATION EXCEPTION RELEASE

REV NO: 0 FROM: AX/E KLUBEK 823
PROGRAM: PAT-2 TO: SC/J ANDERSEN 1721

REASON FOR REVISION

DRAWING NUMBER	SUFFIX DA PA	USE LIMITATION	QUANTITY	PART NAME
T67003	001	UNRESTRICTED USE	8	TB-2 VESSEL-B

****INTERIM ASSEMBLIES UNIQUE ASSEMBLIES

DRAWING REQUIREMENT & VARIATION FROM DRAWING

T67003-001 ISS. P

	SPECIFICATION	EXCEPTION
1.	20 DEG +- 1 DEG	S/N X07 21 DEG 38' OR 38' OHL
		X12 21 DEG 6' OR 6' OHL
2.	3.17R	X07 3.8 OR .38 OHL
		X08 3.62 OR .20 OHL
		X09 3.52 OR .10 OHL
		X11 3.89 OR .47 OHL
		X15 3.46 OR .04 OHL
3.	54.051/53.949	X08 53.934 OR .015 ULL
		X14 53.815 OR .134 ULL
4.	50.025/49.990	X09 49.970 OR .02 ULL
		X12 49.977 OR .013 ULL
		X14 49.924 OR .066 ULL
5.	1.245/1.143	X10 1.135 OR .008 ULL
6.	.58R/.36R	X12 .24 OR .14 ULL

PREVIOUS SXR'S

MARKING REQUIREMENTS

MARKING NOT REQUIRED

CORRECTIVE ACTION

N.C. TAPES BEING REVIEWED.

REFERENCES & REMARKS

END PAGE 1 UNCLASSIFIED/N D N W D/MARR

PAGE 2 RHEGKCA1566 UNCLASSIFIED/N O N W D/NARR

SXR NO: N37063X80SC
REV NO: 0

DOC CODE	REV	APPROVED BY		AGENCY	ORG	DATE
SXR	0	J ANDERSEN	TELECON	SNLA	1721	8/22/80

PA INFORMATION

RSX NO.	DATE	QTY REQUESTED	QTY INTERIM ASSY ACCEPTED
41523			

DEPT/VENDOR

RR NUMBER QTY REJECTED

REASON FOR REJ/DISP APPLICABILITY

APPROVAL

E KLUBER 823 8/22/80

DISTRIBUTION

N GOULDNSITH BX823
W SCHULTZ BX415

END PAGE 2 OF 2 UNCLASSIFIED/N O N W D/NARR
BA 2140Z
RT
#1568
NNNN

RAAU66ED RHEGRCA1569 2341839-UUUU--RHEGSNM.
ZNR UUUUU UNCLASSIFIED/N O N M D/NARR
R 221839Z AUG 80

SXR NO: N3707BX80SC SUBJECT: SPECIFICATION EXCEPTION RELEASE

REV NO: 0 FROM: BX/E KLUBER 823
PROGRAM: PAT-2 TO: SC/J ANDERSEN 1721

REASON FOR REVISION

DRAWING NUMBER	SUFFIX DA PA	USE LIMITATION	QUANTITY	PART NAME
T67004	001	UNRESTRICTED USE	2	SEAL, COPPER

****INTERIM ASSEMBLIES UNIQUE ASSEMBLIES

DRAWING REQUIREMENT & VARIATION FROM DRAWING

1. 50.20/50.07 - ONE PART IS 50.06 OR .01 ULL ONE PLACE
2. 1.60 SURFACE FINISH - ONE PART IS 3.1, ONE SURFACE

PREVIOUS SXR'S

MARKING REQUIREMENTS

MARKING NOT REQUIRED

CORRECTIVE ACTION

OPERATOR INFORMED

REFERENCES & REMARKS

DOC CODE	REV	APPROVED BY		AGENCY	ORG	DATE
SXR	0	J ANDERSEN	TELECON	SNLA	1721	8-22-80

PA INFORMATION

RSX NO.	DATE	QTY REQUESTED	QTY INTERIM ASSY ACCEPTED
41522			

DEPT/VENDOR

QR NUMBER QTY REJECTED

END PAGE 1 UNCLASSIFIED/N O N M D/NARR

PAGE 2 RHEGKCA1569 UNCLASSIFIED/N O N W D/NARR

SXR NO: N3707BX8GSC
REV NO: 0

REASON FOR REJ/DISP APPLICABILITY

APPROVAL

E F KLUGER 623 8-22-80

DISTRIBUTION

N GOULDSMITH BX623
W SCHULTZ BX415

END PAGE 2 OF 2 UNCLASSIFIED/N O N W D/NARR
PB 21032
BT
#1569
NNNN

RAAU86ED RHEGKCA1570 2351839-UUUU--RHEGSNM.
ZNP UUUUU UNCLASSIFIED/N O N W D/NARR
R 221639Z AUG 80

SXR NO: A37068X80SC SUBJECT: SPECIFICATION EXCEPTION RELEASE

REV NO: 0 FROM: 6X/E KLUBER 823
PROGRAM: PAT-2 TO: SC/J ANDERSEN 1721

REASON FOR REVISION

DRAWING NUMBER	SUFFIX DA	SUFFIX PA	USE LIMITATION	QUANTITY	PART NAME
737011	001		UNRESTRICTED USE	1	DISK REMOVABLE

****INTERIM ASSEMBLIES UNIQUE ASSEMBLIES

DRAWING REQUIREMENT & VARIATION FROM DRAWING

BREAK SHARP CORNER .381 MAX. CORNER IS BROKEN (SQUARE) APPROX. 1.016

PREVIOUS SXR'S

MARKING REQUIREMENTS

MARKING NOT REQUIRED

CORRECTIVE ACTION

OPERATOR CAUTIONED

REFERENCES & REMARKS

DOC CODE	REV	APPROVED BY		AGENCY	ORG	DATE
SXR	0	J ANDERSEN	TELECON	SMLA	1721	8/22/80

PA INFORMATION

RSX NO.	DATE	QTY REQUESTED	QTY INTERIM ASSY ACCEPTED
41519			

END PAGE 1 UNCLASSIFIED/N O N W D/NARR

PAGE 2 RHEGKCA1570 UNCLASSIFIED/N D N W D/NARR

SXR NO: N37086X60SC
REV NO: 0

DEPT/VENDOR

RR NUMBER QTY REJECTED
--- ---

REASON FOR REJ/DISP APPLICABILITY

APPROVAL

E F KLUGER 623 8/22/80

DISTRIBUTION

W SHULTZ 6X415

END PAGE 2 OF 2 UNCLASSIFIED/N D N W D/NARR
SDS 12552
BT
#1570
NNNN

RAAU66ED RHEGKCA2063 2421806-UUUU--RHEGSNN.
ZNR UUUUU UNCLASSIFIED/N D N N D/NARR
R 291808Z AUG 80

SXR NO: N3805BX80SC SUBJECT: SPECIFICATION EXCEPTION RELEASE

REV NO: 0 FROM: BX/E KLUBER 823
PROGRAM: PAT-2 TO: J ANDERSEN 1721

REASON FOR REVISION

DRAWING NUMBER	SUFFIX DA	PA	USE LIMITATION	QUANTITY	PART NAME
567014	000		UNRESTRICTED USE	1	AQ-2 OVERPACK

****INTERIM ASSEMBLIES UNIQUE ASSEMBLIES

DRAWING REQUIREMENT & VARIATION FROM DRAWING

RUBBER SHEET, 1.4 INCH THICK, ITEM 6.
RUBBER SHEET OF S/N X14 IS 3/8" THICK

PREVIOUS SXR'S

MARKING REQUIREMENTS

MARKING NOT REQUIRED

CORRECTIVE ACTION

N/A.

REFERENCES & REMARKS

DOC CODE	REV	APPROVED BY		AGENCY	ORG	DATE
SXR	0	J ANDERSEN	TELECON	SMLA	1721	8/29/80

END PAGE 1 UNCLASSIFIED/N D N N D/NARR

PAGE 2 RHEGKCA2063 UNCLASSIFIED/N D N W D/NARR

SXR NO: N3805BX3050
REV NO: 0

PM INFORMATION

RSX NO.	DATE	QTY REQUESTED	QTY INTERIM ASSY ACCEPTED
41504			

DEPT/VENDOR

PR NUMBER QTY REJECTED

REASON FOR REJ/DISP APPLICABILITY

APPROVAL

E F KLUBER 823 8/29

DISTRIBUTION

W SCHULTZ RX415

END PAGE 2 OF 2 UNCLASSIFIED/N D N W D/NARR
SDS 1932Z
BT
#2063
NNNN

RAAO66ED RHEGKCAD265 2491354-UUUU--RHEGSKA.
ZNR UUUUU UNCLASSIFIED/N O N W D/NARR
P 0513542 SEP 86

SXR NO: N36639480SC SUBJECT: SPECIFICATION EXCEPTION RELEASE

REV NO: 0 FROM: 6X/E KLUBER 823
PROGRAM: PAT-2 TO: SC/J ANDERSEN 1721

REASON FOR REVISION

DRAWING NUMBER	SUFFIX DA	PA	USE LIMITATION	QUANTITY	PART NAME
T67033	000		UNRESTRICTED USE	5	BODY, PC-2 CAPSULE

****INTERIM ASSEMBLIES UNIQUE ASSEMBLIES

DRAWING REQUIREMENT & VARIATION FROM DRAWING

FEATURE	BODY, PC-2 CAPSULE T67008 SER #	DEV.
1. 6.60/6.35	X11	6.21 OR .14 ULL
	X12	5.47 OR .88 ULL
	X13	5.43 OR .92 ULL
	X14	5.79 OR .56 ULL
	X15	6.06 OR .29 ULL
2. 2.26/1.52 R.	X11	25 DEG ANGLE
	X12	1.24 OR .28 ULL
	X13	25 DEG ANGLE
	X14	25 DEG ANGLE
	X15	25 DEG ANGLE
3. .64/.38 ZONE C3	X11	.66 OR .02 OHL
	X13	.645 OR .005 OHL
4. .64/.38 ZONE C2	X11	.71 OR .07 OHL
	X12	.693 OR .053 OHL
	X13	.66 OR .02 OHL
	X14	.67 OR .03 OHL
	X15	.653 OR .013 OHL
5. 56.00/57.75	X11	56.12 OR .12 OHL
	X12	56.085 OR .085 OHL
	X13	56.11 OR .11 OHL
	X14	58.18 OR .18 OHL
	X15	58.097 OR .097 OHL
6. 45.35/46.30	X11	46.44 OR .09 OHL
	X12	46.406 OR .056 OHL
	X13	46.37 OR .02 OHL
	X14	45.53 OR .18 OHL

END PAGE 1 UNCLASSIFIED/N O N W D/NARR

SXR NO: [illegible]
REV NO: [illegible]

DRAWING REQUIREMENT & VARIATION FROM DRAWING /CONT/

7. 9.30/0.65	X11	9.06 OR .16 OHL
	X12	8.925 OR .026 OHL
		8.974 OR .074 OHL
		9.032 OR .132 OHL
	X13	8.97 OR .07 OHL
		9.01 OR .11 OHL
	X14	9.27 OR .37 OHL
		9.15 OR .25 OHL
	X15	9.03 OR .13 OHL
8. 3.200/3.099	X14	3.089 OK .01 ULL
		3.043 OK .056 ULL
		3.043 OK .056 ULL
	X15	3.07 OR .029 ULL

PREVIOUS SXR'S

MARKING REQUIREMENTS

MARKING NOT REQUIRED

CORRECTIVE ACTION

PROCESSING NOTIFIED

REFERENCES & REMARKS

DOC CODE	REV	APPROVED BY		AGENCY	ORG	DATE
SXR	0	J ANDERSEN	TELECON	SNLA	1721	9/4/80

PA INFORMATION

RSX NO.	DATE	QTY REQUESTED	QTY INTERIM ASSY ACCEPTED
41514			

DEPT/WORKUP

RK NUMBER	QTY REJECTED

REASON FOR REJ/DISP APPLICABILITY

PAGE 3 KHEGKCA0265 UNCLASSIFIED/N 3 N W D/NARR

SXR NO: N5863EX605C
REV NO: 0

PPROVAL

E F KLUBER 623 9/5/80

DISTRIBUTION

N GOLDSMITH 3X823
J SCHULTZ PA415

END PAGE 3 OF 3 UNCLASSIFIED/N 3 N W D/NARR
SDS 1905Z
BT
#0265
NNNN

RAAU66ED RHEGKCA0266 2491354-UUUU--RHEFSNM.
ZNR UUUUU UNCLASSIFIED/N D N W D/MARR
R 051354Z SEP 80

SXR NO: N3664BX80SC SUBJECT: SPECIFICATION EXCEPTION RELEASE

REV NO: 0 FROM: BX/E KLUBER 823
PROGRAM: PAT-2 TO: SC/J ANDERSEN 1721

REASON FOR REVISION

DRAWING NUMBER	SUFFIX DA PA	USE LIMITATION	QUANTITY	PART NAME
T67037	000	UNRESTRICTED USE	5	LID, PC-2 CAPSULE

****INTERIM ASSEMBLIES UNIQUE ASSEMBLIES

DRAWING REQUIREMENT & VARIATION FROM DRAWING

FEATURE	LID, PC-2, CAPSULE T67037 SER #	DEV.
1. 1.625-18UNEF-3A	X11	ACCEPTS NO-GO GAGE
2. 6.55/6.29	X12	6.217 OR .073 ULL
	X13	6.26 OR .01 ULL
3. 18.29/16.04	X11	17.97 OR .07 ULL
	X12	17.910 OR .13 ULL
	X13	17.986 OR .054 ULL
	X14	17.927 OR .113 ULL
4. 8.90/8.65	X11	8.94 OR .04 OHL (1 PL)
	X12	8.218 OR .432 ULL (1 PL)
	X13	8.451 OR .199 ULL (1 PL)
	X14	8.214 OR .436 ULL (1 PL)
	X15	8.504 OR .146 ULL (1 PL)
5. THREAD RELIEF	X11	.09 OHL
TO MIN. DIA.	X12	.09 OHL
	X13	.11 OHL
	X14	.10 OHL
	X15	.09 OHL
6. 3.17 R	X11	3.32 OR .15 OHL
	X15	3.36 OR .19 OHL
7. 35.00 SPHERICAL R	X11	.08 OHL AT 15 DEG
		.14 OHL AT 30 DEG

PREVIOUS SXR'S

MARKING REQUIREMENTS

MARKING NOT REQUIRED

END PAGE 1 UNCLASSIFIED/N D N W D/MARR

PAGE 2 XHEGNC02o6 UNCLASSIFIED/N 3 N a D/MARR

SXP NO: A5Bc4oXP35C
REV NO: C

CORRECTIVE ACTION

PROCESSING NOTIFIED

REFERENCES & REMARKS

DOC CODE	REV	APPROVED BY		AGENCY	ORG	DATE
SXP	0	J ANDERSEN	TELECON	SALA	1721	9/4/80

A INFORMATION

RSX NO.	DATE	QTY REQUESTED	QTY INTERIM ASSY ACCEPTED
41513			

DEPT/VENDOR

RR NUMBER	QTY REJECTED

REASON FOR REJ/DISP APPLICABILITY

APPROVAL

F KLUSER 823 9/5/80

DISTRIBUTION

N GOLDSMITH BX823
W SCHULTZ BX415

END PAGE 2 OF 2 UNCLASSIFIED/N 0 N a D/MARR
SDS 1925Z
BT
N0206
NNNN

CHAPTER 10

CONFORMANCE OF THE PAT-2 PACKAGE TO IAEA SAFETY STANDARDS

10.1 GENERAL

This chapter addresses those paragraphs in IAEA Safety Series 6 (S.S. 6)* designated by the IAEA safety staff** in Vienna as being appropriate to gain Competent Authority B(U) designation of the PAT-2 package. S.S. 6 paragraphs concerning transport index, category labeling, fissile class, and integrity of containment and shielding have also been addressed.

The PAT-2 (Plutonium Air Transportable Model 2) design meets the IAEA Fissile Class I B(U) requirements for the safe transport of up to 15 grams of Pu-239 in solid form, as well as up to 15 grams of other fissile isotopes of plutonium and/or uranium in solid form, not to exceed 2 watts of thermal activity. Any number of PAT-2 packages, with the defined payload limitations, would be nuclearly safe in any number and in any arrangement under all foreseeable circumstances of transport. However, since the PAT-2 payload is limited to 15 grams of fissile material, the package is exempt from Fissile Class prescription.†

In the following sections, the IAEA S.S. 6 paragraph number and requirement is cited first, followed by a statement on those aspects of the PAT-2 package which address the requirement. Cross references to sections and appendices elsewhere in this Safety Analysis Report which contain supporting information appear last, in brackets.

---

*The edition used is IAEA Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1973 revised edition (as amended November 1979), Vienna, Austria.

**PAT-2 meetings with the IAEA safety staff in Vienna on 19 and 20 November 1980; attended by J. A. Andersen, R. F. Barker, B. C. Bernardo, M. Krivanek, D. Pal, and M. White.

†S.S. No. 6, paragraph 601(a).

10.2 PACKAGING AND PACKAGE DESIGN REQUIREMENTS

10.2.1 Paragraphs 201 and 202

> 201. The packaging shall be so designed that the package can be easily handled and can be properly secured in or on the conveyance during transport.
>
> 202. A package of gross weight 10 kg or more and up to 50 kg shall be provided with means for manual handling.

The PAT-2 package weighs approximately 72 pounds (33 kg) and is equipped with a sturdy pair of padded handles, which may be used for hand-carry or for tie-down. The small size of PAT-2, 14 inches (35.6 cm) high by 15 inches (38.1 cm) in diameter), easily adapts to cargo containers and the use of cargo nets. [1.2.1, 1.2.3]

10.2.2 Paragraphs 204 and 205

> 204. The design shall be such that any lifting attachments on the package, when used in the intended manner, do not impose unsafe stresses on the structure of the package; assessment shall take account of appropriate safety factors to cover "snatch" lifting.
>
> 205. Attachments and any other features on the outer surface of the packaging which could be used to lift the packages shall be removable or otherwise rendered inoperable for transport or shall be designed to support the weight of the package in accordance with the requirements of para. 204.

The PAT-2 handles are qualified by test and stress analysis to meet U.S. Federal Aviation Administration (FAA) "9g" (nine times package weight) tiedown requirements; they also meet the U.S. NRC "10g + 5g + 2g" simultaneous loading requirements. [2.4.3]

10.2.3 Paragraph 206

> 206. The outer layer of packaging shall be so designed as to avoid, as far as practicable, the collection and the retention of water.

The PAT-2 package exterior is generally smooth and watertight, with no recesses or concave surfaces. The package has passed a severe 30-minute fire-hose water spray test (> 124 gpm). [2.6.6]

10.2.4 Paragraph 207

> 207. The external surfaces of packaging shall, as far as practicable, be so designed and finished that they may be easily decontaminated.

See Section 10.2.3 above for package exterior. Those elements of the package more likely to become exposed to radioactive material are the TB-2 containment

vessel and the C-1 capsule. The TB-2 is fabricated from corrosion-resistant A-286 iron-base superalloy, with a polished finish explicitly to aid in decontamination. The C-1 capsule is fabricated from very corrosion-resistant Nitronic 60 stainless steel, with a highly polished finish explicitly to aid in decontamination. [9A: design drawings T67002, T67003, T67008, T67037.]

10.2.5 Paragraph 208

> 208. Any features added to the package at the time of transport which are not part of the package shall not reduce the safety of the package.

The PAT-2 package has been extensively and severely tested for conditions of impact, puncture, and slashing/tearing. The only devices likely to be added for transport are security seals and tiedown hardware; the safety of the package will not be reduced. [2.7.3, 2.8.2, 2.8.4, 2.8.5]

10.2.6 Paragraph 210

> 210. The smallest overall external dimension of the packaging shall not be less than 10 cm.

The PAT-2 package is 14 inches (35.6 cm) high by 15 inches (38.1 cm) in diameter. [1.2.1]

10.2.7 Paragraph 211

> 211. The outside of every package shall incorporate a feature such as a seal, which is not readily breakable and which, while intact, will be evidence that the package has not been opened.

The PAT-2 package cover has a pair of security seal straps, riveted and welded in place, which align with securing points of the handles on the body, also riveted and welded in place. IAEA-approved seals may be secured to both sides of the package by means of these features. Seals may also be taped to the side of the package to secure them from incidental motion. The rigid protruding handles will help prevent the seal from being crushed or torn off. [1.2.3]

10.2.8 Paragraph 212

> 212. As far as practicable, packaging shall be designed so that the external surfaces are free from protruding features.

Other than the necessary handles per para. 202, the package exterior is free of protrusions except for bolt and rivet heads and plastic vent plugs. [1.2.1]

10.2.9 Paragraph 213

> 213. The design of the packaging shall take into account the variations in temperature to which the packaging may be subjected during transport and storage. In this respect, −40°C and 70°C shall be considered as satisfactory limits to be used in the selection of the materials; special attention, however, must be given to brittle fracture over this temperature range.

The PAT-2 package has been tested for normal conditions of transport at 215°F (102°C) and -40°F (-40°C) and has been subjected to a impact test at -50°F (-46°C) and 220°F (104°C), all successfully. The containment vessel materials (A-286 and Nitronic 60) exhibit no brittle-ductile transition temperatures over a temperature spectrum even broader than the required temperatures. [2C.5; 2.6.2, 2.6.3, 2.8.11, 3.3, 3.4, 3.5]

10.2.10 Paragraph 214

> 214. The design, fabrication and manufacturing techniques for welded, brazed, or other fusion joints shall be in accordance with national or international standards or with standards acceptable to the competent authority.

All PAT-2 fusion joints are controlled by special specifications: SS T67016 for titanium welding and SS T67027 for corrosion-resistant steel welding. [9A]

10.2.11 Paragraph 215

> 215. The package shall be capable of withstanding the effects of any acceleration, vibration or vibration resonance which may arise during normal transport without any deterioration in the effectiveness of the closing devices on the various receptacles or in the integrity of the package as a whole. In particular, nuts, bolts and other securing devices shall be so designed as to prevent them from becoming loose or being released unintentionally, even after repeated use.

The PAT-2 package has successfully passed a severe vibration test of two 8-hour periods, in longitudinal and transverse orientations. The test spectrum encompassed shock and vibration frequencies and energy levels representative of long service life in truck, rail, and air transport. All PAT-2 fasteners are highly torqued upon installation (by assembly requirements) or are held in place by permanent deformation (e.g., rivets) or by compression pads (e.g., load spreader cover screws). [2.6.5]

10.2.12 Paragraphs 216 and 218

> 216. The design shall include a containment system securely closed by a positive fastening device which cannot be opened unintentionally or by a pressure which may arise within the package.
>
> 218. If a containment system forms a separate unit of the packaging, it shall be capable of being securely closed by a positive fastening device which is independent of any other part of the packaging.

The C-1 capsule is closed with 450 $lb_f \cdot in.$ (51 N·m) torque and is qualified to remain sealed under an internal pressure of 50 psia (0.34 MPa). The TB-2 containment vessel is closed with 20 bolts, each torqued to 180 $lb_f \cdot in.$ (20.3 N·m) and will remain sealed under an internal pressure of 3280 psia (22.6 MPa). These vessels have never opened under extensive environmental testing. [4.2.3.1, 4.2.3.2, 4.3, 4.4, 4.5.2]

10.2.13 Paragraph 219

> 219. The materials of the packaging and any components or structures shall be physically and chemically compatible with each other and with the package contents; account shall be taken of their behaviour under irradiation.

There are no significant chemical, galvanic, or radioisotopic reactions among the PAT-2 package components or between the package and package contents. [2.4.1, 5.2, 5.7]

10.2.14 Paragraph 220

> 220. The design of any component of the containment system shall take into account, where applicable, the radiolytic decomposition of liquids and other vulnerable materials and the generation of gas by chemical reaction and radiolysis.

The generation of gas by chemical reaction in the containment vessels, for all permitted payload forms, has been extensively studied and tested, including conditions at 1080°F (582°C) and > 2777 psia (19.14 MPa); the package always remained safe. [4.5.2; 4B, 4C, 4D, 4E]

10.2.15 Paragraph 221

> 221. The containment system shall retain its radioactive contents under the reduction of ambient pressure to 0.25 kg/cm².

The C-1 capsule and the TB-2 containment vessel were repeatedly determined to be helium leaktight in the condition of a hard vacuum (< 1 μm external pressure, ~ 1 atm internal pressure). [2.6.4]

10.2.16 Paragraph 222

> 222. All valves, other than pressure relief valves, through which the radioactive contents could otherwise escape shall be protected against unauthorized operation and shall be provided with an enclosure to retain any leakage from the valve.

The PAT-2 package containment vessels have no valves or openings.

10.2.17 Paragraph 223

> 223. A radiation shield which encloses a component of the packaging specified as a part of the containment system shall be so designed as to prevent the unintentional release of that component from the shield. Where the radiation shield and such component within it form a separate unit, the radiation shield shall be capable of being securely closed by a positive fastening device which is independent of any other packaging structure.

The AQ-2 overpack of the PAT-2 package provides substantial radiation shielding and securely retains the TB-2 containment vessel in a very severe test sequence of high-speed impact at any package attitude onto an unyielding target, followed by crush, puncture, slashing attack, fire, and submersion. The AQ-2 is closed by a unique combination of double covers, double sidewalls, multiple fasteners, and judicious location of impact-absorbing materials and vents. Additionally, the TB-2 containment vessel alone provides adequate post-accident shielding. [2.1, 2.6.7, 2.7.2, 2.8, 2.8.2, 5.1, 5.5, 5.6]

10.2.18 Paragraph 224

> 224. Any tie-down attachments on the package shall be so designed that, under both normal and accident conditions, the forces in those attachments shall not impair the ability of the package to meet the requirements of the Regulations.

The PAT-2 handles are qualified by test and stress analysis to meet U.S. FAA 9g tiedown requirements. [2.4.3]

10.2.19 Paragraph 225

> 225. Type A packaging shall be so designed that, if it were subjected to the tests specified in Section VII, paras 709–714, it would prevent:
>
> (a) loss or dispersal of the radioactive contents, and
> (b) any increase of the maximum radiation level recorded or calculated at the external surface for the condition before the test.

The effect of the tests in paras. 709 through 714 on the PAT-2 package are negligible. There is no loss or dispersal of the radioactive contents (both containment vessels remain leaktight), and there is no change in radiation shielding. [2.6.1 through 2.6.10]

10.2.20 Paragraph 228

> 228. Except as specified in para. 233, Type B(U) packages shall be designed to meet all the additional requirements for Type A packages specified in paras 210 to 225.

The PAT-2 package meets the requirements of all these paragraphs, as stated in the preceding sections that cite each paragraph.

10.2.21 Paragraph 229

> 229. The packaging shall be so designed that if it were subjected to the tests in Section VII, paras 718–721, it would retain sufficient radiation shielding to ensure that the radiation level at 1 m from the surface of the package would not exceed 1 rem/h had the package contained sufficient iridium-192 to produce a radiation level of 10 mrem/h at 1 m from the surface before the tests. Where the use of the packaging is to be restricted to particular radionuclides, those radionuclides may be used as the reference source in place of iridium-192. In addition, if the packaging is to be used for neutron emitters, an appropriate neutron reference source should also be used.

The PAT-2 package meets this condition as summarized below:

Quantity of Ir-192 required to produce 10 mrem/h, 1 metre from the surface, normal operating conditions	Side 0.068 Ci Top 0.063 Ci
Post-accident dose rate 1 metre from the surface if the package contains 0.063 Ci of Ir-192, worst location	15 mrem/h
Neutron source (fission spectrum) required to produce 10 mrem/h neutron dose rate 1 metre from the surface, normal operating conditions	6.2×10^6 n/s
Post-accident dose rate 1 metre from the surface if the package source is 6.2×10^6 n/s	17 mrem/h

This hypothetical case will not determine the transport index for the PAT-2. (The transport index is defined in IAEA S.S. 6 as the dose rate in mrem/h measured at a distance of 1 metre from a package. The U.S. Code of Federal Regulations specifies a distance of 3 feet.)

The PAT-2 package also meets these post-accident-modeling-test shielding requirements with 15 grams of fissile plutonium, uranium, or mixtures thereof; with 40 grams of PuO_2 and/or UO_2 powder (not to exceed the 15-gram fissile content limitation); with 120 grams of sintered fuel pellets (again, not to exceed the 15-gram fissile content limitation); and with various lesser radioisotopic contents. [5.1, 5.2, 5.3, 5.4 5.5, 5.6; 5A]

10.2.22 Paragraphs 230 and 231

230. Type B(U) packages shall be so designed, constructed, and prepared for shipment that, under the ambient conditions specified in para. 231, they shall satisfy the conditions in (a) and (b) below.

(a) Heat generated within the package by the radioactive contents will not, under conditions encountered in transport (as demonstrated by the tests in Section VII), adversely affect the package in such a way that it will fail to meet the applicable requirements for containment and shielding if left unattended for a period of one week. Particular attention shall be paid to the effects of heat which may:

(i) alter the arrangement, the geometrical form or the physical state of the radioactive contents or, if the material is enclosed in a can or receptacle (for example, clad fuel elements), cause the can, receptacle or material to melt;
(ii) lessen the efficiency of the packaging through differential thermal expansion or cracking or melting of the radiation shielding material;
(iii) in combination with moisture, accelerate corrosion.

(b) The temperature of the accessible surfaces of a Type B(U) package shall not exceed 50°C in the shade unless the package is transported as a full load.

231. In applying para. 230 above, the following conditions shall be assumed:

(a) ambient temperature 38°C;
(b) insolation data according to Table III.

TABLE III. INSOLATION DATA

Form and location of surface	Insolation in gcal/cm² for 12 hours per day
Flat surfaces transported horizontally:	
– base	none
– other surfaces	800
Flat surfaces not transported horizontally:	
– each surface	200[a]
Curved surfaces	400[a]

[a] Alternatively, a sine function may be used, adopting an absorption coefficient and neglecting the effects of possible reflection from neighbouring objects.

Contents for PAT-2 package are limited to 2 watts thermal activity. Under essentially infinite (steady-state response) reception of 295 Btu/h•ft^2 (930 W/m^2) insolation per day, with a constant ambient temperature of 130°F (54°C) for 24 hours per day, and with a 2-watt payload heat source, the PAT-2 package maintains full physical integrity, including its geometric form; suffers no degradation due to differential thermal expansion; no degradation of shielding material; and no accelerated corrosion. In the shade at an ambient temperature of 100°F (38°C) and with a 2-watt payload, the package exterior will be approximately 105°F (40.7°C), and the internal TB-2 containment vessel will be approximately 139°F (59.5°C). [3.1, 3.3, 3.3.3, 3.3.6, 3.3.7]

10.2.23 Paragraph 232

> 232. Packaging which includes thermal protection for the purpose of satisfying the requirements of the thermal test specified in Section VII, para. 720, shall be so designed that such protection will remain effective if the packaging is subjected to the tests specified in Section VII, paras 709–714 and 719. Any such protection on the exterior of the package shall not be rendered ineffective by conditions commonly encountered in normal handling or in accidents and not simulated in the tests referred to above, e.g. by ripping, cutting, skidding, abrasion or rough handling.

The redwood and ceramic felt insulation and maplewood thermal barrier material utilized in the AQ-2 overpack of the PAT-2 package remain effective when the thermal test of para. 720 is conducted following the sequential application,to a single package, of the normal tests of paras. 709 through 714 as well as the free drop (para. 716), penetration (para. 717), and "mechanical" (30-foot (9-metre) drop and 3-foot (0.9-metre) puncture drop) tests for the accident conditions of transport. In addition, the thermal barrier remains effective when severe puncture and slash tests are added to the test series and when a much more severe thermal test is conducted. [2.1, 2.6, 2.7, 2.8, 3.1, 3.4, 3.5]

10.3 SPECIFIC ADDITIONAL REQUIREMENTS FOR TYPE B(U) PACKAGES

10.3.1 Paragraph 233

> 233. The package shall be so designed that, if it were subjected to the tests referred to below, it would:
>
> (a) with regard to the tests specified in Section VII, paras 709–714, restrict the loss of radioactive contents to not more than $A_2 \times 10^{-6}$ per hour;
>
> (b) with regard to the tests specified in Section VII, paras 718–721, restrict the accumulated loss of radioactive contents to not more than $A_2 \times 10^{-3}$ in a period of one week.

With regard to requirement (a), two prototypes of the PAT-2 package were subjected to the tests of para. 709: water spray (controlled by para. 710 and specified in para. 711), free drop (para. 712), compression (para. 713), and penetration (para. 714). In addition, these packages were subjected to 215°F (101°C) heat, -40°F (-40°C) cold, pressure (150% maximum normal operating pressure and -1 atm underpressure), and vibration tests. Following these tests, which were all performed in sequence on each package, the TB-2 containment vessel was leaktight (no detectable leak, $\dot{q} < 10^{-10}$ cm^3/s helium). The containment vessel contained a radioisotopic surrogate, $U(SO_4)_2 \cdot 2H_2O$, designed to create a worst-case internal pressure and atmosphere. No uranium material was released, as determined by uranium fluorimetry (detection sensitivity of 10^{-8} gram). Therefore, the PAT-2 package restricts

the loss of radioactive material to less than A2 x 10^{-6} per hour under these normal conditions of transport; in fact, there is no release. [2.6, 4.3]

With regard to requirement (b), two prototypes of the PAT-2 package were subjected to the sequential tests of para. 718, which are the two drops of para. 719, the thermal (fire) test of para. 720, and the immersion test of para. 721. Both packages passed all the tests of para. 709 as stated above. The TB-2 containment vessels of both packages were leaktight (no detectable leak, $\dot{q} < 10^{-10}$ cm^3/s helium), and no surrogate uranium contents were released (detection sensitivity of 10^{-8} gram). Therefore, the PAT-2 package restricts the loss of radioactive material to less than A2 x 10^{-3} in a period of 1 week under these accident conditions of transport; in fact, there is no release. [2.7, 4.4]

10.3.2 Paragraphs 234, 235, and 236

> 234. Compliance with the permitted activity release limits shall depend neither upon filters nor upon a mechanical cooling system.
>
> 235. A package shall not incorporate a feature which is intended to allow continuous venting during transport.
>
> 236. The package shall not include a pressure relief system from the containment system which would allow the release of radioactive material to the environment under the conditions of the tests specified in Section VII, paras 709–714 and 718–721.

The TB-2 containment vessel of the PAT-2 package has no filters, no mechanical cooling system, no vents, and no pressure relief system. It is a completely sealed containment, able to contain any possible internally generated pressure.

10.3.3 Paragraph 237

> 237. Where the maximum normal operating pressure (see Section I, para. 122) of the containment system added to any differential pressure below mean sea level atmospheric pressure to which any component of the packaging specified as part of the containment system may be subjected exceeds 0.35 kg/cm², that component shall be capable of withstanding a pressure of not less than one and a half times the sum of those pressures; the stress at this latter pressure shall not be more than 75% of the minimum yield strength and not more than 40% of the ultimate strength of that component at the maximum expected operating temperature.

The maximum normal operating pressure (MNOP) of the TB-2 containment vessel within the PAT-2 package is 30.55 psia (210.6 kPa; 2.15 kg/cm^2). This condition occurs at a temperature of 203°F (95°C); this temperature is caused by the combination of solar heat load (insolation) and a 2-watt internal heat load (from isotopic contents). As part of the "Normal Conditions of Transport" tests, the TB-2 was

heated to 250°F (121°C), causing a pressure of 49.5 psia (341.3 kPa; 3.48 kg/cm^2), which is 162% of MNOP. The containment vessel was leaktight at this condition ($\dot{q}$ < 10^{-10} cm^3/s helium). The maximum calculated containment vessel stress at this condition (combining radial, axial, and circumferential stresses at 49.5 psia, by von Mises failure theory) is approximately 338 psi (2.33 MPa). The yield strength of the A-286 is 100,000 psi (689 MPa), and the ultimate strength is 146,000 psi (1,007 MPa). Therefore, at more than one and a half times the maximum normal absolute operating pressure, the stress is approximately 0.34% of the minimum yield strength (factor of safety ~ 294) and is approximately 0.23% of the ultimate strength (factor of safety ~ 435). With such negligible stresses and such large factors of safety, and in view of the TB-2 qualification at MCAP conditions of 3,280 psia (22.6 MPa), it follows that the TB-2 containment vessel would be very adequate if there were no atmospheric pressure at this condition (e.g., differential pressure of 49.5 psi + 14.7 psi, or 64.2 psia). [4.3.1, 4.4.1, 4.5.2, 3.3.2, 3.4.4, 3.5.4, 2.6.4, 2.3.1, 2.3.2, and 2C]

10.3.4 Paragraph 238

> 238. When the package at the maximum normal operating pressure (see Section I, para. 122) is subjected to the thermal test specified in Section VII, para. 720, the pressure in any component of the packaging specified as a part of the containment system shall be demonstrated not to exceed the pressure which corresponds to the minimum yield strength of that component at the maximum temperature which it would be expected to reach in the test.

PAT-2 packages were subjected to the thermal test of para. 720 within a large burn test facility utilizing JP-4 aviation jet fuel, with a package-level temperature of > 1475°F (802°C) for over 30 minutes and with a measured flame emissivity coefficient of > .90 (approached 1.0). The bounding assessment of maximum TB-2 containment vessel temperature was 250°F (121°C). This would produce a maximum internal pressure of approximately 49.5 psia (3.48 kg/cm^2), giving the same extremely low stresses (0.34% of yield, 0.23% of ultimate) cited in Section 10.3.3 above. [3.4.2, 3.4.3, 3.4.4, 3A]

10.3.5 Paragraph 239

> 239. The package shall not have a maximum normal operating pressure (see Section I, para. 122) in excess of 7 kg/cm^2 (gauge).

The maximum normal operating pressure of the TB-2 containment vessel in the PAT-2 package is 30.55 psia (210.6 kPa; 2.15 kg/cm^2 absolute). [4.3.1]

10.3.6 Paragraph 240

> 240. The maximum temperature of any surface readily accessible during transport of the package shall not exceed 82°C in the shade under normal conditions of transport (see also para. 230(b)).

The PAT-2 package, when loaded with the maximum permissible 2-watt payload, in an ambient temperature of 100°F (38°C) and in the shade, will have a maximum skin (exterior) temperature of 105°F (40.7°C). [3.1, 3.3.3]

10.3.7 Paragraph 241

> 241. The containment system of a package containing liquid shall not be impaired if the package is subjected to a temperature of −40°C under normal conditions of transport.

The PAT-2 package is approved for solid form contents only.

10.4 CONTROLS FOR TRANSPORT AND STORAGE IN TRANSIT

10.4.1 Paragraph 137

> 137. Transport index for a package shall mean:
>
> (a) The number expressing the maximum radiation level in millirem per hour at 1 m from the external surface of the package; or
>
> (b) For Fissile Class II and Class III packages, the larger of the following numbers:
>
> the number expressing the maximum radiation level under (a) above;
> the number obtained by dividing 50 by the allowable number of such packages.

With the worst-case source model (47 grams of multi-recycled plutonium, much more radioactive than the 15 grams permitted as actual contents), the radiation is 0.24 mrem/hr at 0.91 metre (3 feet) from the package. Therefore, the actual transport index for the PAT-2 package is 0.24 or lower, as given in Table 10.4.1-1. [5.1 (Table 5.1-1)]

Since PAT-2 is Fissile Class exempt, the requirements of 137(b) above are not applicable.

Table 10.4.1-1

Calculated Dose Rates External to the PAT-2 Containing Worst-Case Source*

Normal Operation	
Dose rate on the surface	7.8 mrem/h
Dose rate 3 feet (0.91 metre) from the surface	0.24 mrem/h
Postaccident Case	
Dose rate 3 feet (0.91 metre) from the surface	0.40 mrem/h

*Worst-case source model is 47 grams plutonium, which would produce 2 watts of thermal activity.

10.4.2 Paragraph 501

> 501. A package containing radioactive material shall not contain any other items except such articles and documents as are necessary for the use of the radioactive material. Such items may be included, provided that there is no interaction between them and the packaging or contents that would reduce the safety of the package.

A document package up to about 1/8-inch (3-mm) thick may be placed on top of the outer redwood plug, under the inner top cover of the AQ-2 overpack of the PAT-2 package with no reduction in safety.

10.4.3 Paragraph 504

> 504. *Packages:* A package shall be in Category I—WHITE when the radiation level originating from the package at any time during normal transport does not exceed 0.5 mrem/h at any point on the external surface of the package, and the package does not belong to Fissile Class II or Class III, and when it is not being transported under special arrangement.

The PAT-2 package is Fissile Class exempt (see paras. 604 through 610). With the worst-case source (conservatively modeled as a 2-watt, 47-gram source of highly radioactive, multi-reprocessed plutonium, where only 15 grams is permitted as actual contents) the highest dose rate on the surface is calculated to be 7.8 mrem/h. With actual safeguards sample loadings, radioactivity measurements would often support use of the Category I-WHITE label on a shipment.

10.4.4 Paragraph 506

> 506. *Packages:* A package shall be in Category II-YELLOW when the package does not belong to Fissile Class III, when it is not being transported under special arrangement, and when either the radiation level limit in para.504 is exceeded or the package belongs to Fissile Class II provided that:
>
> (a) the radiation level originating from the package at any time during normal transport does not exceed 50 mrem/h at any point on the external surface of the package; and
>
> (b) the transport index at any time during normal transport does not exceed 10.

The PAT-2 package is Fissile Class exempt and will not have a radiation level over 7.8 mrem/h, in normal transport, at any point on the external surface. The transport index under this extreme-worst case model is 0.24 (0.24 mrem/h at 0.91 metre (3 feet) from the surface). Therefore, Category II-YELLOW would be the highest level label needed on a PAT-2 shipment.

10.4.5 Paragraph 516

> 516. Each package which conforms to a design approved under Section VIII, paras 804–814, shall be plainly and durably marked on the outside of the package with the identification mark allocated to that design by the competent authority and, in the case of a Type B(U) or Type B(M) package design, with "Type B(U)" or "Type B(M)".

The PAT-2 package is stenciled in a protected location with the "Type B(U)" legend, using epoxy paint with a clear cover coat. This marking was legible after all the tests of para. 709 (including paras. 710, 711, 712, 713, and 714) and para. 718 (including paras. 719; 720, the fire test; and 721, the submersion test). [9A]

10.4.6 Paragraph 517

> 517. Each package which conforms to a Type B(U) or Type B(M) package design shall have the outside of the outermost receptacle which is resistant to the effects of fire and water plainly marked by embossing, stamping or other means resistant to the effects of fire and water with the trefoil symbol shown in Fig.1.

The trefoil symbol, 4 cm in diameter, is laser-beam embossed onto the outer stainless steel cover of the PAT-2 package.

10.5 FISSILE MATERIALS

10.5.1 Definition of Fissile Contents for the PAT-2 Package

The contents of the PAT-2 package are limited by the following requirements:

1. Material type: Plutonium and/or uranium in various isotopic compositions, subject to the following limitations:

2. Material form: The plutonium and/or uranium must be in solid form; the solid form may be an oxide power, a sintered pellet of oxides, a metal, or hydrated salts of plutonium or uranium (derived from dried liquids);

3. Material quantity:

   a) The maximum mass of the fissile isotopes U-235, Pu-239, and Pu-241 is limited to 15 grams total;

   b) The total mass of plutonium oxide or uranium oxide material in powder form is limited to 40 grams (the 15-gram fissile limitation is not to be exceeded);

   c) The total mass of oxide material in sintered form is limited to 120 grams; the total mass of metal material is limited to 120 grams; in each case, the 15-gram fissile limitation is not to be exceeded;

   d) The total mass of plutonium sulfate tetrahydrate [$Pu(SO_4)_2 \cdot 4H_2O$] is limited to 3 grams;

   e) The total mass of plutonium nitrate dihydrate [$Pu(NO_3)_4 \cdot 2H_2O$] is limited to 3 grams;

   f) The total mass of Pu-238 is limited to 3.57 grams (this will be a 2-watt heat source -- see para. 5 below); the Pu-238 may be in combination with the isotopes listed in (a) above, with the total fissile mass limited to 15 grams;

4. Moisture content: For contents of powders or salts, a maximum of 0.5 gram of moisture content (water) in addition to the waters of hydration in the salts, is permissible;

5. Internal decay heat: The isotopic composition of all contents must be such that a thermal activity of 2 watts is never exceeded while contents are in the PAT-2 package; this may be calculated as follows:

$$\frac{\text{watts}}{g}\,{}^{238}Pu \times g\,{}^{238}Pu + \frac{\text{watts}}{g}\,{}^{239}Pu \times g\,{}^{239}Pu$$

$$+ \frac{\text{watts}}{g}\,{}^{240}Pu \times g\,{}^{240}Pu + \frac{\text{watts}}{g}\,{}^{241}Pu \times g\,{}^{241}Pu$$

$$+ \frac{\text{watts}}{g}\,{}^{242}Pu \times g\,{}^{242}Pu + \frac{\text{watts}}{g}\,{}^{241}Am \times g\,{}^{241}Am$$

$$+ \frac{\text{watts}}{g}\,(\text{fission products or other transuranic isotopes})$$

$$\times\, g\,(\text{fission products or other transuranic isotopes}) < 2 \text{ watts.}$$

Note: Due to the increase of decay power with time, the maximum decay power is calculated for the isotopic composition which will exist at the longest storage time, or the peak power period.

6. Volatile packaging material permitted within the C-1 capsule is limited to 9 grams maximum polyvinylchloride (PVC) plastic, in the form of seals and bags, and 0.3 grams maximum of polytetrafluoroethylene (PTFE); e.g., Teflon™ tape for sealing the C-1 capsule threads;

7. Nonvolatile packaging material permitted within the C-1 capsule is limited to 18 grams maximum of quartz (SiO_2) or glass, and 50 grams of brass or 16 grams of aluminum.

8. The only materials or items permitted within the TB-2 containment vessel are

   a) A C-1 capsule loaded in accordance with the limitations in paras. 1 through 7 above,

   b) A maximum of 2 grams of aluminum foil to shim the fit between the spherical ends of the C-1 capsule and the interior spherical portion of the TB-2 containment vessel, and

   c) The copper seal (part number T57004) for the TB-2 containment vessel. [1.2.4; 5A (Table 5A-4)]

10.5.2 Provisions Specific to Fissile Class 1 Packages

Para. 601(a) exempts fissile quantities under more than 15 grams.* However, it is useful to demonstrate the fissile class of the PAT-2 design. Sections 10.5.2.1 through 10.5.2.6 give the IAEA S.S. 6 criteria for Fissile Class I packages and, also, show how those criteria are met by the PAT-2 design.

---

*Hence, the PAT-2 package may be labelled "Type B(U)", not "Type B(U)F".

10.5.2.1 Paragraph 605

605. Each Fissile Class I package shall be so designed that, if it were subjected to the tests specified in Section VII, paras 709–714:

(a) water would not leak into or out of any part of the package unless water inleakage to or outleakage from that part, to the optimum foreseeable extent, had been assumed for the purposes of para.609; and

(b) the configuration of the contents and the geometry of the containment system would not be altered so as to increase the reactivity significantly.

With regard to requirement 605(a), the TB-2 containment vessel does not leak, as proved by the high-pressure hydrostatic test (see Section 10.6.11).

With regard to requirement 605(b), the geometry of the PAT-2 package is not altered by the test of paras. 709 through 714 in any manner that results in any increase in reactivity. [6.1]

10.5.2.2 Paragraphs 606 and 607

606. Fissile Class I packages shall satisfy the nuclear safety criteria specified in Section VI, paras 607–610.

The individual package considered in isolation

607. The following conditions shall be assumed:

(a) the package is "damaged" (for this purpose "damaged" shall mean the evaluated or demonstrated condition of the package if it had been subjected either to the tests specified in Section VII, paras 709–714 and 718–720 followed by that in paras 722–724, or to the tests specified in Section VII, paras 709–714 and 721, whichever combination is the more limiting); and

(b) water can leak into or out of all void spaces of the package, including those within the containment system, except that, where the package design incorporates special features to prevent the leakage of water into or out of certain void spaces even as a result of human error, absence of leakage may be assumed in respect of those void spaces. Such special features may include either:

(i) multiple high standard water barriers, each of which would remain leaktight if the package were subjected to the combinations of tests specified in para.607(a); or

(ii) high degree of quality control in the production and maintenance of packaging, coupled with special tests to demonstrate closure of each package before shipment.

Nuclear criticality calculations for the damaged PAT-2 package assumed much more extensive damage than these requirements assumed.

With regard to requirement 607(b), although water leakage into the TB-2 containment vessel of the PAT-2 package, under the postulated accident environments, is precluded by the package and vessel designs, calculations show that should the vessel (with worst-case contents) become flooded with water and be externally water reflected, the system remains critically safe. [6.1]

10.5.2.3 Paragraph 608

608. The package shall be sub-critical by an adequate margin under the conditions specified in para.607, the physical and chemical characteristics being taken into account, including any change in those characteristics which could occur under the conditions of para.607, and with the conditions of moderation and reflection as specified below:

(a) with the material within the containment system:

(i) the most reactive configuration and moderation foreseeable under the conditions of para.607;
(ii) close full water reflection of the containment system or such greater reflection of the containment system as may additionally be provided by the surrounding material of the packaging; and, in addition,

(b) if any part of the material escapes from the containment system under the conditions of para.607:

(i) the most reactive configuration and moderation considered credible;
(ii) close full water reflection of the material.

The features of the system that satisfy requirement 607(b) also satisfy requirement 608(a). The PAT-2 package remains highly subcritical under these postulated conditions.

With regard to requirement 608(b), there is extensive evidence that the TB-2 containment vessel of the PAT-2 package does not release nuclear material under even more severe test conditions then those required here. [2, 4]

10.5.2.4 Paragraph 609

609. Any number of undamaged packages of one design in any arrangement shall be sub-critical; for this purpose "undamaged" shall mean the condition in which the packages are designed to be presented for transport.

Table 10.5.2.4-1 gives results of relevant criticality calculations for the PAT-2 package. [6.1 (Table 6.1-1)]

10.5.2.5 Paragraph 610

610. 250 such packages when "damaged" shall be sub-critical if stacked together in any arrangement and closely reflected on all sides of the stack by the equivalent of water (for this purpose "damaged" shall mean the evaluated or demonstrated condition of the package if it had been subjected either to the tests specified in Section VII, paras 709–714 and 718–720, followed by that in paras 722–724, or to the tests specified in Section VII, paras 709–714 and 721, whichever combination is the more limiting). Hydrogenous moderation between packages, and water leakage into or out of the packages consistent with the test results shall be assumed to the extent which results in the greatest reactivity.

Table 10.5.2.4-1

Results of Criticality Calculations for Undamaged PAT-2 Packages
(nominal payload of 15 grams Pu-239)

Normal Conditions	Results
Number of undamaged packages calculated to be subcritical	*
k_{eff} of infinite array of undamaged packages	0.053 (± 0.0002)
Package size	Right-circular cylinder: diameter -- 15 in. (38.1 cm) height -- 14 in. (35.6 cm)

*Result is independent of water moderation between packages.

An infinite array (not just the required 250 packages), with assumed damage much worse than that required here, is highly subcritical under all of the above-specified assumptions and conditions. The criticality calculations are given in Table 10.5.2.5-1. [6, (Table 6.1-1)]

Table 10.5.2.5-1

Results of Criticality Calculations for Damaged PAT-2 Packages

Accident Conditions	Results
k_{eff} of infinite array of packages damaged by impact, wood not consumed by fire, no water present	0.055 ± 0.001
k_{eff} of infinite array of packages damaged by impact, wood replaced with water	0.084 ± 0.002
k_{eff} of infinite array of packages damaged by impact, wood replaced with air	0.33 ± 0.01
k_{eff} of a single TB-2 with water moderation of contents and full water reflection on all sides	0.098 ± 0.0002
Package damage	AQ-2 overpack crushed down to titanium load-spreader; TB-2 touching load-spreader.

10.6 TESTS FOR PACKAGING

10.6.1 Paragraph 708

Target for the drop tests specified in paras 712, 716, 719 and 732

708. The target shall be a flat, horizontal surface of such a character that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase the damage to the specimen.

The target for these drop tests was a thick layer of steel plate intimately connected to a massive reinforced concrete foundation. [2F]

10.6.2 Paragraph 709

Tests for demonstrating ability to withstand normal conditions of transport

709. The tests are: the water spray test, the free drop test, the compression test and the penetration test. Prototypes of the package must be subjected to the free drop test, the compression test and the penetration test, preceded in each case by the water spray test. One prototype may be used for all the tests, provided that the requirements of para. 710 are complied with.

The water-resistant PAT-2 package was first subjected to hot, cold, pressure, and vibration tests, then water-sprayed for 30 minutes with a fog-nozzle-equipped 3-inch fire hose delivering a minimum of 124 gal/min (0.469 m^3/min), and then the free drop test, the compression test, and the penetration tests were done in sequence, without repeating the water test as stated in para. 709. Repetition of the water test (prior to the drop test and again prior to the penetration test) would have been of no consequence. [2.6]

10.6.3 Paragraph 710

710. The time interval between the conclusion of the water spray test and the succeeding test shall be such that the water has soaked in to the maximum extent, without appreciable drying of the exterior of the specimen. In the absence of any evidence to the contrary, this interval shall be taken to be about two hours if the water spray is applied from four directions simultaneously. No time interval should elapse, however, if the water spray is applied from each of the four directions consecutively.

About 2 hours (10 CFR 71 Appendix A permits from 1-1/2 to 2-1/2 hours) after the above-described water spray test, the succeeding tests were commenced. [2.6.6]

10.6.4 Paragraph 711

711. *Water spray test:* Any water spray test shall be considered as satisfactory provided that:

(a) the amount of water per unit of ground area is approximately equivalent to a rainfall rate of 5 cm per hour;

(b) the water impinges upon the specimen at an angle of approximately 45° from the horizontal;

(c) the water is approximately uniformly distributed, as in a rainfall, over the entire surface of the specimen in the direction of the spray;

(d) the duration of the spray is at least one hour;

(e) the orientation of the packaging is such that the effects are expected to be the most severe for the features under investigation, and the specimen is supported so that it does not sit in a pool of water.

The water spray test, already described in 10.5.2 above, was generally in accordance with para. 711 except that it lasted 30 minutes per 10 CFR 71 Appendix A, not 60 minutes. The difference is of no consequence to the PAT-2 package, due to the double-walled stainless exterior construction and fiberglass-and-expoxy-coated wood internals for the overpack. [2.6.6]

10.6.4. Paragraph 712

712. *Free drop test:* The specimen shall fall onto the target so as to suffer maximum damage in respect of the safety features to be tested.

(a) The height of fall measured from the lowest point of the package to the upper surface of the target shall be not less than 1.2 m; except that for packages weighing more than 5000 kg, the height of fall shall not be less than the distance specified in Table XXVII for the applicable package weight.

(b) For Fissile Class II packages, the free drop specified above shall be preceded by a free drop from a height of 0.3 m on each corner or, in the case of a cylindrical package, onto each of the quarters of each rim.

(c) For fibreboard or wood rectangular packages not exceeding 50 kg in weight, a separate specimen shall be subjected to a free drop onto each corner from a height of 0.3 m.

(d) For fibreboard cylindrical packages not exceeding 100 kg in weight, a separate specimen shall be subjected to a free drop onto each of the quarters of each rim from a height of 0.3 m.

The PAT-2 package meets the intent of the above requirement; in development, packages were dropped 30 feet (9 metres) onto an unyielding target in top-end, top-corner, side, bottom-corner, and bottom-end attitudes with no consequential results, as well as much-higher-velocity impacts in all these attitudes, with excellent survival of the TB-2 containment vessel. [2.6.7, 2.7.2, 2.8.2]

10.6.6 Paragraph 713

713. *Compression test:* the specimen shall be subjected, for a period of 24 h, to a compressive load equal to the greater of the following:

(a) the equivalent of 5 times the weight of the actual package;
(b) the equivalent of 1300 kg/m^2 multiplied by the vertically projected area of the package.

The load shall be applied uniformly to two opposite sides of the specimen, one of which shall be the base on which the package would normally stand.

This test was done with a 313-kg concrete mass (5 x 32 kg, the PAT-2 mass, is 160 kg) for a period of over 24 hours. Note that the requirement of 713(b), [1300 kg/m^2)(0.114 m^2) = 148.2 kg], results in a lesser load. There was no apparent or observed effect on the PAT-2 package from this test. [2.6.9]

10.6.7 Paragraph 714

714. *Penetration test* the specimen shall be placed on a rigid, flat, horizontal surface which will not move significantly while the test is being carried out.

(a) A bar of 3.2-cm diameter with a hemispherical end and weighing 6 kg shall be dropped and directed to fall, with its longitudinal axis vertical, onto the centre of the weakest part of the specimen, so that, if it penetrates sufficiently far, it will hit the containment system. The bar shall not be significantly deformed by the test performance.
(b) The height of fall of the bar measured from its lower end to the upper surface of the specimen shall be 1 m.

This test resulted in a slight dimple, about 1/8 inch (3 mm) deep, in the outer stainless-steel skin of the AQ-2 overpack of the PAT-2 package. [2.6.8]

10.6.8 Paragraph 718

Tests for demonstrating ability to withstand accident conditions in transport

718. The specimen shall be subjected to the cumulative effects of the mechanical tests specified in para.719 and the thermal test specified in para.720, in that order. A separate specimen shall be subjected to the effect of the water immersion test in para.721.

The PAT-2 package was subjected to the following tests of paras. 719 and 720 on the same package. The water immersion test of para. 721 was done, to a lesser head, on the same packages, and, to a much greater head, on a separate specimen.

10.6.9 Paragraph 719

719. *Mechanical test:* the test shall consist of two drops onto a target. The order in which the specimen is subjected to the two drops shall be such that, on completion of the mechanical test, the specimen will have suffered such damage as will lead to the maximum damage in the thermal test which follows.

(a) For drop I, the specimen shall fall onto the target so as to suffer the maximum damage, and the height of fall measured from the lowest point of the specimen to the upper surface of the target shall be 9 m. The target shall be as defined in para.708.

(b) For drop II, the specimen shall fall onto the target so as to suffer the maximum damage, and the height of fall measured from the intended point of impact of the specimen to the upper surface of the target shall be 1 m. The target shall be the upper end of a solid mild steel bar of circular section, 15 cm ± 0.5 cm in diameter. The target surface shall be flat and horizontal with its edges rounded off to a radius of not more than 6 mm. The bar shall be rigidly mounted perpendicularly on the foundation target described in para.708 and shall be 20 cm long unless a longer bar would cause greater damage; in that case, a bar of sufficient length to cause maximum damage shall be used.

With regard to requirement 719(a), the PAT-2, in development, was dropped 30 feet (9 metres) five times onto the unyielding target of para. 708, in the following attitudes: top, top corner, side, bottom corner, and bottom, with no results of consequence. [2.7.2]

The PAT-2 was dropped 3 feet (0.9 metre) onto the blunt probe specified in 719(b), onto both an end and the cylindrical side, with almost imperceptible (and inconsequential) results. [2.7.3]

10.6.10 Paragraph 720

720. *Thermal test:* any thermal test shall be considered as satisfactory provided that the heat flux incident on the specimen is not less than that which would result from exposure for 30 minutes of the whole specimen to a radiation environment of 800°C with an emissivity coefficient of at least 0.9. For purposes of calculation, the surface absorptivity shall be either that value which the package may be expected to possess if exposed to a fire or 0.8, whichever is greater. In addition, when significant, convective heat input shall be included on the basis of still ambient air at 800°C during the thirty-minute period. After cessation of the external heat input to the specimen:

(a) the specimen shall not be cooled artificially until another three hours have elapsed or until it has been demonstrated that all internal temperatures have begun to fall, whichever is the earlier; and

(b) any combustion of materials of the specimen shall be allowed to proceed for three hours after the cessation of external heating to the specimen unless it terminates earlier naturally.

Two PAT-2 packages (Serial Nos. X13 and X15) were subjected to a very large JP-4 jet fuel fire test for more than 30 minutes. The fire had a measured

emissivity of > 0.9 at or above the package level and had a measured temperature at or above 800°C at the package level. The blackened stainless steel package would have an absorptivity of > 0.8. Following the burn tests, the packages were permitted to cool naturally (until cool to the human hand), for about 24 hours.

Upon disassembly, the TB-2 containment vessels were found still nested in unburned wood (all of the maplewood inside the titanium load spreader was unburned, and much of the redwood outside the load spreader was unburned); the containments were undamaged and leaktight ($\dot{q} < 10^{-10}$ cm^3/s helium). [2.7.4, 3.4.2, 3.4.3, 3.4.4, 3.4.5, 3.4.6]

10.6.11 Paragraph 721

> 721. *Water immersion test:* the specimen shall be immersed under a head of water of at least 15 m for a period of not less than eight hours. For test purposes, an external pressure of water of 1.5 kg/cm² (gauge) will be considered to meet these conditions.

A separate TB-2 containment vessel was hydrostatically tested for more than 8 hours at a pressure of 5000 psia (34.47 MPa; 351.5 kg/cm^2 gauge) with no ingress of water. [2.7.5, 2.8.9]

10.6.12 Paragraph 724

> 724. The specimen shall be immersed under a head of water of at least 0.9 m for a period of not less than eight hours and in the attitude for which maximum leakage is expected. For this test an ambient temperature of 38°C is not required.

The PAT-2 packages dropped and burned per Sections 10.5.9 and 10.5.10 above were submerged for more than 24 hours under a 3-foot (0.9-metre) head, with no ingress of water into the containment.

10.6.13 Paragraph 725

> **Tests for integrity of containment and shielding**
>
> 725. Any test or inspection method can be employed to determine whether the requirements of Section VII have been met after the specimen has been subjected to the tests in paras 709–721, provided that the method can be demonstrated to meet the relevant requirements of Section II.

For containment, helium leak detection (as determined by a mass spectrometer with a sensitivity of 10^{-10} cm^3/s) was utilized to prove leaktightness. Also, a uranium surrogate was employed in every test assembly; a uranium fluorimeter with a detection capability of 10^{-8} gram was utilized to detect release. Both methods showed no leak of the containment and no release of the surrogate.

For shielding, the calculational model discarded the stainless-steel overpack on its crushed face and also discarded the hydrogenous materials (unburned redwood and unburned maplewood) inside the overpack, both for conservatism. In the tests required by S.S. 6, the overpack's stainless steel drum remained intact, and most of the internal wood remained unburned. [2.7.6, 4.4.2, 5.1, 5.2, 5.4]

DISTRIBUTION:

U.S. DOE (25)
Office of Safeguards and Security
Attn: John Dailey DP 343

U.S. NRC (18)
Division of Fuel Cycle and Material Safety
Transportation Certification Branch
Washington, DC 20555
Attn: Charles E. MacDonald, Chief
C. R. Chappell
Wm. Lake (12)
Henry W. Lee
C. Murata
Ralph Jones, OSD/Transp. Stds. Br.
R. Odegaarden

U.S. Department of Transportation (2)
Materials Transportation Bureau
Office of Hazardous Materials Regulations
Washington DC 20590
Attn: R. R. Rawl, U.S. IAEA Competent Authority

Brookhaven National Laboratory (5)
International Safeguards Project Office
Upton, NY 11973
Attn: Leon Green, Head (5)

International Atomic Energy Agency (12)
Division of Development and Technical Support
Department of Safeguards
P.O. Box 100
A-1400 Vienna
AUSTRIA
Attn: A. E. von Baeckmann, Director
E. Kerr
Wm. H. Perriam
Stein Deron
Erwin Kuhn
Gaston Martinez-Garcia (7)

International Atomic Energy Agency (12)
Nuclear Safety Division
P.O. Box 100
A-1400 Vienna
AUSTRIA
Attn: Robert Barker
M. C. White (11)

U.S. DOE (2)
Operational and Environmental Safety Division
Occupational Safety Branch
Washington, DC 20545
Attn: Donald M. Ross, Chief
T. L. Dunckel

U.S. DOE (2)
ETW--Transportation Branch
Washington, DC 20545
Attn: Richard Chitwood, DOE/ET 972
James A. Sisler

U.S. DOE (4)
Albuquerque Operations Office
Albuquerque, New Mexico 87185
Attn: E. C. Hardin
K. Carlson
E. L. Barraclough, OSD
D. L. Mulryan, TSD

U.S. NRC
Systems Performance Branch
SAFER Division
MS 1130 SS
Washington, DC 20555
Attn: William Lahs

Embassy of Japan
Suite 900, Watergate
600 New Hampshire Avenue, NW
Washington, DC 20037
Attn: Scientific Attaché Kurihara

PNC--Tokai Works
Tokai-mura, Ibaraki-Ken
JAPAN
Attn: Kazua Sakamoto

Japan Atomic Energy Research Institute
Tokai-mura, Ibaraki-Ken
JAPAN
Attn: Kanji Tasaka

PNC Corporation
2600 Virginia Avenue, NW, #908
Washington, DC 20037
Attn: Hiromasa Nakano

Minoru Kubo
PNC Corp., Tokyo, Japan
c/o Transportation Technology Center
Org. 4553, Sandia National Laboratories
Albuquerque, New Mexico 87185

Central Research Institute of Electric Power Industry
1646 Abiko City
Chiba
JAPAN
Attn: Yasuro Maki

DISTRIBUTION (Continued):

Hitachi Shipbuilding and Engineering
Co. Ltd.
Chemical and Nuclear Design Department
3-40, Sakurajima 1-Chome
Konohana-Ku, Osaka
JAPAN
Attn: A. Onodera

Kobe Steel Ltd.
Structural Engineering Laboratory
Doi-Cho
Amagasaki
JAPAN
Attn: Kazuo Ikeda

Mitsubishi Heavy Industries Ltd.
5-1, Marunouchi 2-Chome
Chiyoda-Ku
Tokyo 100
JAPAN
Attn: Yoshikuni Fujise, Project
Manager, Development Dept.

Japan Atomic Industrial Forum Inc.
Nuclear Industry Development Dept.
1-13, Shimbashi 1-Chome
Minato-Ku, Tokyo 105
JAPAN
Attn: Tetsuo Goto

Department of Transport
RMT Division RS 17/11
2 Marsham Street
London SW1 P3 EB
ENGLAND
Attn: R. H. Partridge, Competent
Authority of the United Kingdom

United Kingdom Atomic Energy
Authority (4)
Safety and Reliability Directorate
Wigshaw Lane
Culcheth
Warrington WA3 4NE
ENGLAND
Attn: John Thomas Daniels (3)
(for TRAMAC, TRAD, and TRICWP)
E. Bevitt

United Kingdom Atomic Energy Authority
Risley Nuclear Power Development
Establishment
Warrington, Cheshire WA3 6AT
ENGLAND
Attn: R. S. Butterfield

The Radiochemical Centre
AERE Harwell
Didcot, Oxfordshire OX 11 ORG
ENGLAND
Attn: C. B. G. Taylor

United Kingdom Atomic Energy
Establishment
Winfrith Laboratory
Dorset
ENGLAND
Attn: W. D. Curren and R. D. Bond (1)

United Kingdom Atomic Energy
Authority (2)
Dounreay Nuclear Power Development
Establishment
Thurso
Caithness, SCOTLAND, United Kingdom
KW14 7TZ
Attn: Mike Brown
Don Sinclair, Bldg. 1226/16

British Defence Staff ACO(W)
British Embassy
3100 Massachusetts Avenue, NW
Washington, DC 20008
Attn: K. Johnston and T Wilson (1)

British Nuclear Fuels Limited
Risley, Warrington, WA3 6AS
Cheshire, ENGLAND
Attn: Stan Williamson

Ove Arup and Partners
13 Fitzroy Street
London, ENGLAND W1P 6BQ
Attn: Michael Shears

Bundesanstalt für Materialprüfung
(BAM) (3)
Unterden Eichen 87
D-1000 Berlin 45 (West Berlin)
FEDERAL REPUBLIC OF GERMANY
Attn: B. Schulz-Forberg
H. Hübner
H. Kowalewsky

Nuclear Research Center
Kernforshungszentrum
Karlsrühe
FEDERAL REPUBLIC OF GERMANY
Attn: D. Sellinschegg

Produktleiter der Radiopharmaka
von Heyden GmbH
Donastaufer Str. 378, Postfach 177,
D-8400 Regensburg 1
FEDERAL REPUBLIC OF GERMANY
Attn: Wolfram Eckhardt

DISTRIBUTION (Continued):

Departement des Estudes Mechaniques et Thermiques
Commissariat a l'Energie Atomique
C.E.N-Saclay
B.P. No. 2-91190 GIF-SUR-YVETTE
FRANCE
Attn: Eric G. Tomachevsky

CEA-CESTA
BP No. 2
33 Le Barp
FRANCE
Attn: Raphaël Brissier

C.E.N. Fontenay
Departement de Securite des Matieres Nucleaires
B.P. No. 6 - 92260 Fontenay Aux Roses
FRANCE
Attn: Pierre Grandperret

Transnucleaire SA
11 Rue Christophe Colomb
75008 Paris, FRANCE
Attn: B. Kirchner, P.T. Blum and H. Bernard (1)

Atomic Energy Control Board
Box 1046
Ottawa K1P 5S9
CANADA
Attn: K. R. Schultz

Atomic Energy of Canada, Ltd.
P.O. Box 6300, Station J
Ottawa K2A 3W3
CANADA
Attn: Jiri Kotler

Netherlands Energy Research Foundation
Isotope Production Service
3, Westerduinweg, Petten (NH)
THE NETHERLANDS
Attn: H. J. Nieuwenhuizen

Belgonucleaire
Rue du Champs de Mars 25
B-1050 Bruxelles
BELGIUM
Attn: J. Draulans and J. P. Fabry

New Brunswick Laboratory, D-350 (2)
9800 South Cass Avenue
Argonne, IL 60439
Attn: Carleton D. Bingham, Director
Bruce W. Moran

Los Alamos National Scientific Laboratory (8)
Los Alamos, NM 87545
Attn: D. R. Smith, Q-14 MS 560 (3)
J. C. Fuller, WX-1
Glenn R. Waterbury, CMB-1
J. E. Rein, CMB-1, MS 740
Eldon Christiansen, TA-55
J. C. Mark, MS 210

Lawrence Livermore National Laboratory (6)
P.O. Box 808
Livermore, CA 94550
Attn: M. S. Coops, L-234
O. L. Meadors L-347
W. E. Nelson L-101
R. J. Craig L-125
A. W. Lundberg L-101
C. L. Wraith L-122

Rockwell International, Rocky Flats Plant (2)
P.O. Box 938
Golden, CO 80401
Attn: Frank E. Adcock (1)
Library (1)

Battelle Pacific Northwest Laboratories (4)
Battelle Boulevard
P.O. Box 999
Richland, WA 99352
Attn: Russell E. Rhoads
Jofu Mishima
Lysle C. Schwediman
Peter Owzarski

Rockwell Hanford Operations (2)
P.O. Box 800
Richland, WA 99352
Attn: Marsha Bell, Packaging and Shipping Systems Engr.

Labowitz and Labowitz
Attorneys-at-Law
605 Prince Street
Alexandria, VA 22314
Attn: Allan M. Labowitz

The Bendix Corporation
P.O. Box 1149
Kansas City, MO 64141
Attn: Edward F. Kluber, Jr.

GPU Service Corporation
Three Mile Island Nuclear Station
P.O. Box 480
Middletown, PA 17057
Attn: R. A. Knief, Training Mgr.

DISTRIBUTION (Continued):

The Flying Tiger Line
7401 World Way West
International Airport
Los Angeles, CA 90009
Attn: Kenneth Snow, Manager, Hazardous Materials Control

Tiger Air
c/o The Flying Tiger Line
7401 World Way West
International Airport
Los Angeles, CA 90009
Attn: John McDonald

Nuclear Power Systems
Boeing Engineering and Construction
P.O. Box 3707, MS 9A-4B
Seattle, WA 98124
Attn: James W. Baxter, Engr. Mgr.

Isotope Products, Inc.
1800 N. Keystone Street
Burbank, CA 91504
Attn: Ken Helm

Hanford Engineering Development Laboratory
P.O. Box 1970
Richland, WA 99352
Attn: Ed Higgins

E. I. duPont de Nemours and Co.
Savannah River Plant
Aiken, SC 29801
Attn: James L. Leeth, Special Programs Department, Spent Fuel Storage

Laboratoire Central d'Analyse et de Controle
C.E.N.G. -- Bâtiment K
85 X
38041 Grenoble CEDEX
FRANCE
Attn: J. Laverlochere

Central Bureau for Nuclear Measurements
Commission of the European Communuties
B-2440 GEEL
BELGIUM
Attn: Paul De Bièvre

Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830
Attn: Lawrence B. Shappert

The Institute of Paper Chemistry
P.O. Box 1039
Appleton, WI 54912
Attn: E. James Davis

Thomas Duffey
Consulting Engineer
P.O. Box 4404
Albuquerque, NM 87196

Stephen A. Dupree
Los Alamos Technical Associates
3040 Ole Court, NE
Albuquerque, New Mexico 87111

Ridihalgh, Eggers, & Associates
Nuclear and Thermal Energy Systems Consultants
2112 Iuka Avenue
Columbus, OH 43201
Attn: J. L. Ridihalgh

Nuclear Fuel Services, Inc.
P.O. Box 218
Erwin, TN 37650

Nuclear Material Control Center
Safeguards Analytical Laboratory
2-53 Shirane Shirakata
Tokai-Mura Ibaraki-Ken
JAPAN
Attn: Masao Takahashi, Dept. Manager

Power Reactor and Nuclear Fuel Development Corporation
Tokai Works
3371 Tokai-Mura, Naka Gun
Ibaraki Prefecture
JAPAN
Attn: Yukio Wada

Note: The following 88 copies are for a part of the US NRC "RT" distribution, as reviewed by Sandia and DOE/OSS, for SAND81-0001.

DISTRIBUTION (Continued):

U.S. DOE Richland Operations
Safety and environmental Protection
Division
P.O. Box 550
Richland, WA 99352
Attn: Director

U.S. NRC
ACRS
H1016
Washington, DC 20555
Attn: Executive Director

U.S. NRC
ASLBP
EW450
Washington, DC 20555
Attn: Chairman

U.S. NRC
NMSS Technical Planning Information
Branch
Washington, DC 20555
Attn: Branch Chief

U.S. NRC
NRR-Div. of Engineering
P-932
Washington, DC 20555
Attn: Assist Director, Components and
Structure Engineering

U.S. NRC
SD
NL 5650
Washington, DC 20555
Attn: Office Director

U.S. NRC Region II
Office of the Director
101 Marietta Street
Suite 3100
Atlanta, GA 30303
Attn: Director

Westinghouse Electric Corp.
Nuclear Energy Systems Library
P.O. Box 355
Pittsburgh, PA 15230
Attn: Librarian

U.S. DOE Savannah River Operations
Savannah River Oper. Office
P.O. Box A
Aiken, SC 29801
Attn: Manager

U.S. NRC
ACRS
H1016
Washington, DC 20555
Attn: Executive Director

U.S. NRC
IE
EW359
Washington, DC 20555
Attn: Office Director

U.S. NRC
NMSS Uranium Recovery Lic. Br.
483 SS
Washington, DC 20555
Attn: Branch Chief

U.S. NRC
NRR-Div. Safety Technology
P-1102
Washington, DC 20555
Attn: Director

U.S. NRC
SD
Div. of Siting Health and Safeguards
Standards
NL5650
Washington, DC 20555
Attn: Division Director

U.S. NRC
NMSS Div. of Safeguards
881-SS
Washington, DC 20555
Attn: Mary Fadden

U.S. NRC
NMSS Division of Fuel Cycle and
Material Safety
Advanced and Spent Fuel Lic. Br.
396 SS
Washington, DC 20555
Attn: John P. Roberts

U.S. NRC Region III
799 Roosevelt Road
Glen Ellyn, IL 60137
Attn: William B. Menczer, Regional
State Liaison Officer

Westinghouse Electric Corp.
ECF LWBR
P.O. Box 2068
Idaho Falls, ID 83401
Attn: William D. Rowland, Associate
Engineer

DIST'BUTION (Continued):

Oak Ridge National Laboratory
Central Research Library
4500 N, Rm. I103
P.O. Box X
Oak Ridge, TN 37830

Teledyne Energy Systems
Library
110 W.Timonium Road
Timonium, MD 21093
Attn: Lawrence A. D'Apice

Transnuclear, Inc.
One North Broadway
White Plains, NY 10601
Attn: Bill R. Teer

University of California
Dept. of Physics
ACRS
Santa Barbara, CA 93106
Attn: Harold W. Lewis

NLO Industries
D&D
P.O. Box 39158
Cincinnati, OH 45239
Attn: G. L. Stukenbroeker

Oak Ridge National Laboratory
P.O. Box X, Bldg. 1000
ACRS
Oak Ridge, TN 37830
Attn: Myer Bender

Union Carbide Corp.
Nuclear Division
P.O. Box P, Bldg. K-1001
MS-189
Oak Ridge, TN 37830
Attn: D. W. Swindle, Jr.

University of California
School of Engr. and Applied Sci.
5532 Boelter Hall
ACRS
Los Angeles, CA 90024
Attn: David Okrent

U.S. DOE
Div. of Environmental and Safety Engineering
Office of Environment
EV-14
Washington, DC 20545
Attn: Director

U.S. DOE Idaho Operations
Div. of Program Analysis and Eval.
550 Second Street
Idaho Falls, ID 83401
Attn: Director

U.S. Envir. Protection Agency
Office of Radiation Programs
401 M Street, SW
ANR-458
Washington, DC 20460
Attn: Deputy Asst, Administrator

U.S. NRC
Adm. Document Control Desk
PDR
016
Washington, DC 20555

U.S. NRC
NMSS Div. of Fuel Cycle and Material Safety
396SS
Washington, DC 20555
Attn: Division Director

U.S. NRC
NRR
P-428
Washington, DC 20555
Attn: Director

U.S. NRC
RES
Washington, DC 20555
Attn: Office Director

U.S. NRC
SD
Trans. and Product Standards Branch
NL5650
Washington, DC 20555
Attn: Branch Chief

U.S. NRC
NMSS Division of Fuel Cycle and Material Safety
Uranium Fuel Licensing Branch
396-SS
Washington, DC 20555
Attn: Fred D. Fisher

U.S. NRC
NMSS WMHL
905SS
Washington, DC 20555
Attn: David M. Rohrer

DISTRIBUTION (Continued):

U.S. NRC Region IV
Program Assist. to the Deputy Dir.
611 Ryan Plaza Drive
Suite 1000
Arlington, TX 76011
Attn: Asst. to the Director

Wyle Laboratories
Library
P.O. Box 1008
Huntsville, AL 35807

U.S. Library of Congress
Federal Documents Section
10 First Street, SE
Washington, DC 20540

U.S. NRC
ASLAP
EW529
Washington, DC 20555
Attn: Chairman

U.S. NRC
NMSS Low-Level Waste Lic. Branch
905 SS
Washington, DC 20555
Attn: Branch Chief

U.S. NRC
NRR-Div. of Engineering
AR-5111
Washington, DC 20555
Attn: Asst. Director, Environmental Technology

U.S. NRC
RES
1130SS
Washington, DC 20555
Attn: Chief Scientist

U.S. NRC
SD
NL5650
Washington, DC 20555
Attn: Asst. Director, General Eng. Standards

U.S. NRC
NMSS SGTI
881-SS
Washington, DC 20555
Attn: A. Girratana

U.S. NRC Region I
Office of the Director
631 Park Avenue
King of Prussia, PA 19406
Attn: Director

U.S. NRC Region V
Office of the Director
1990 N. California Boulevard
Suite 202
Walnut Creek, CA 94596
Attn: Director

Wyle Laboratories
P.O. Box 160
Norco, CA 91760
Attn: Jack Bertram

Monsanto Research Corporation
Mound Lab
P.O. Box 32
Miamisburg, OH 45342
Attn: Librarian

Nuclear Assurance Corp.
24 Executive Park West
Atlanta, GA 30329
Attn: Librarian

Reynolds Electric & Engr. Co.
Technical Library, MS 707
55CUB01-REL 321
3084 S. Highland Drive
Las Vegas, NV 89102

University of California
Lawrence Livermore Laboratory
Technical Information
P.O. Box 808
Livermore, CA 94550

University of Illinois
214 Nuclear Engineering Lab
103 S. Goodwin Avenue
Urbana, IL 61801

U.S. DOE
Division of Naval Reactors
H 404
Washington, DC 20545
Attn: Director

U.S. DOE Nevada Operations
Nevada Operations Office
P.O. Box 14100
Las Vegas, NV 89114

New Mexico Radiation Protection Agency
Environ. Improvement Division
Dept. of Health and Environment
P.O. Box 968
Santa Fe, NM 87503
Attn: Theodore Wolff

DISTRIBUTION (Continued):

Nuclear Fuel Services, Inc.
P.O. Box 124
West Valley, NY 14171
Attn: Larry W. Wiedemann,
Transportation Engr.

Stanford Linear Accel. Center
Library
P.O. Box 4349
Stanford, CA 94305

University of California
Nuclear Safety Reference Library
2567 Boelter Hall
Los Angeles, CA 90024

University of Michigan
Department of Nuclear Engr.
Phoenix Lab, North Campus
ACRS
Ann Arbor, MI 48109
Attn: William Kerr

U.S. DOE
Division of Reactor Research and
Technology
F-309
Washington, DC 20545
Attn: Asst. Dir., Reactor Safety

U.S. DOE Oak Ridge Operations
Research and Technical Support
P.O. Box E
Oak Ridge, TN 37830
Attn: Director

Dade W. Moeller
27 Wildwood Drive
ACRS
Bedford, MA 01730

Atlantic Richfield Hanford Co.
Document Services
P.O. Box 250
Richland, WA 99352

Bechtel Power Corp.
Technical Library
P.O. Box 3965
San Francisco, CA 94119

Calif. Institute of Technology
Engineering Science Dept.
ACRS
Pasadena, CA 91125
Attn: M. S. Plesset

E. I. duPont de Nemours & Co.
Savannah River Laboratory
Technical Information Service
773A
Aiken, SC 29801

Exxon Nuclear Company, Inc.
2955 George Washington Way
Richland, WA 99352
Attn: Roy Nilson, Manager, Licensing

Goodyear Corp.
X-710 Library
P.O. Box 628
MS-2206
Piketon, OH 45661

Argonne National Laboratory
Report Section
9700 South Cass Avenue
203-CE125
Argonne, IL 60439

Battelle Columbus Laboratories
505 King Avenue
Columbus, OH 43201

Brookhaven National Laboratory
Research Library
Bldg. 130
Upton, NY 11973
Attn: Librarian

E. I. duPont de Nemours & Co.
Savannah River Laboratory
ACRS
Building 773A, A219
Aiken, SC 29801
Attn: David A. Ward

Harold Etherington
84 Lighthouse Drivce
ACRS
Jupiter, FL 33458

Paul G. Shewmon
2477 Lytham Road
ACRS
Columbus, OH 43220

Argonne National Laboratory
Special Materials
Building 331
9700 South Cass Avenue
Argonne, IL 60439
Attn: Ronald G. Damm

DISTRIBUTION (Continued):

Battelle Pacific Northwest Laboratory
Technical Information Section
P.O. Box 999
Richland, WA 99352

Brookhaven National Laboratory (2)
Dept. of Nuclear Energy
Upton, NY 11973
Attn: Walter Y. Kato, Assoc. Chairman
Herbert J. C. Kouts, Bldg. 197

Chem. Nuclear Systems, Inc.
Regulatory Affairs
P.O. Box 1866
Bellevue, WA 98009
Attn: J. S. Corbett, Licensing

Edlow International
1100 17th Street, NW
Washington, DC 20036
Attn: Jack Edlow

General Atomic Company
Library
P.O. Box 81608
San Diego, CA 92138

Lehigh University
Department of Mechanical Engineering
Bethlehem, PA 18015
Attn: J. Chen

William M. Mathis
455 Mainmast Court
ACRS
Richland, WA 99352

Chester P. Siess
805 Hamilton Drive
ACRS
Champaign, IL 61820

Battelle Pacific Northwest Laboratory
P.O. 999
ACRS
Richland, WA 99352
Attn: S. Y. Bush

EG&G Idaho, Inc.
Library
P.O. Box 1625
Idaho Falls, ID 83401

General Electric Co.
Nuclear Energy
175 Curtner Avenue
M/C 861
San Jose, CA 95125
Attn: D. Dawson

Department of Transport
P.O. Box 367
Canberra City, A.C.T. 2601
AUSTRALIA

Ministère de la Santé Publique
et de la Famille
Service des Nuisances de
l'Admin. de l'Hygiène Publique
Cité Administrative de l'Etat
Quartier vésale
B-1010 Bruxelles
BELGIUM

Sundhedsstyrelsen
Statens institut for stralehygiejne
Frederikssundsvej, 378
DK-2700 Brønshøj
DENMARK

Ministère des Transports
Transport des Matières Dangereuses
35-37 rue de Frémicourt
75015 Paris
FRANCE

Bundesminister für Verkehr
Kennedyallee 72
D-5300 Bonn 2
FEDERAL REPUBLIC OF GERMANY

Bundesminister des Innern
Graurheindorfer Str. 198
D-5300 Bonn 1
FEDERAL REPUBLIC OF GERMANY

Physikalisch-Technische Bundesanstalt
Bundesallee 100
D-3300 Braunschweig
FEDERAL REPUBLIC OF GERMANY

Ministry of Transport
Secretariat to the Minister
2-1-3 Kasumigaseki
Chiyoda-ku
Tokyo
JAPAN

Science and Technology Agency
Director General of Nuclear Safety
Bureau
2-2-1 Kasumigaseki
Chiyoda-ku
Tokyo
JAPAN

DISTRIBUTION (Continued):

Ministry of Health and Environmental
Protection
Director Radiation Sector
Dokter Reijersstraat 10
Leidschendam
NETHERLANDS

Director-General of Transport
Department of Dangerous Materials
Plesmanweg 1
The Hague
NETHERLANDS

National Institute of Radiation
Protection
Fack
SWEDEN

Swedish Nuclear Power Inspectorate
Box 27106
S-102 52 Stockholm
SWEDEN

1533	F. H. Mathews
1535	D. C. Bickel
1700	W. C. Myre
1720	C. H. Mauney
1725	J. H. Davis
1725	J. A. Andersen (25)
1725	Z. R. Ortiz
1759	R. R. Nason
1760A	W. F. Hartman
2433	P. R. Owens
2451	D. L. Trump
4372	R. R. Bailey
4400	A. W. Snyder
4442	W. A. von Riesemann
4550	R. M. Jefferson
4551	R. E. Luna
4551	J. D. McClure
4551	R. T. Reese
4552	R. B. Pope
4552	E. H. Lamoreaux
4552	S. H. Sutherland
4553	H. R. Yoshimura
5513	O. L. George, Jr. (3)
5520	T. B. Lane
5634	J. A. Stark
5832	J. W. Munford
5834	R. G. Dosch
8214	M. A. Pound
3141	L. J. Erickson (5)
3151	W. L. Garner (3) for DOE/TIC
3154	J. Hernandez (25) for DOE/TIC