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Fire Testing and Analysis of TRUPACT-I Thermal Test Article

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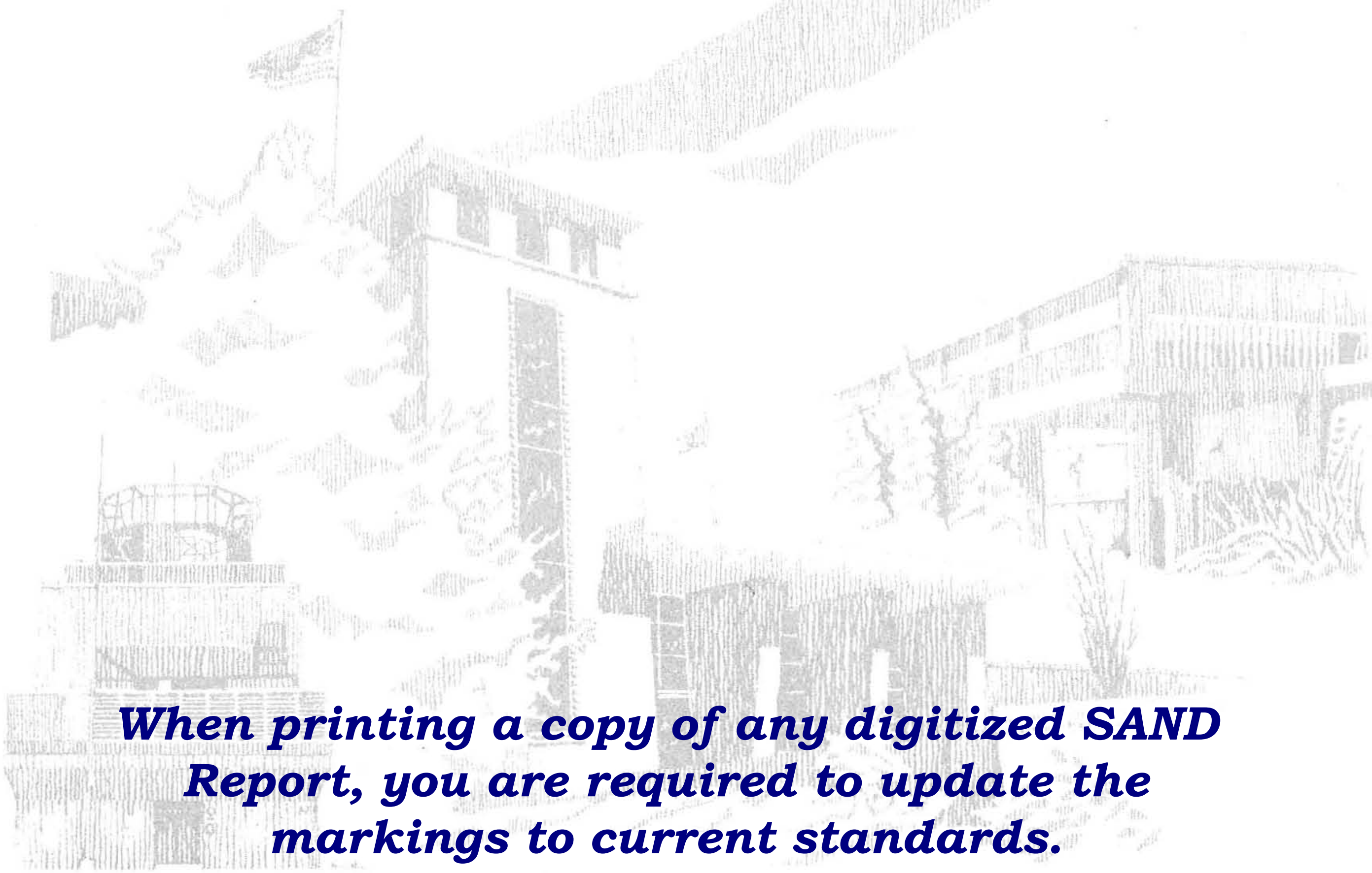

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FIRE TESTING AND ANALYSIS OF TRUPACT-I THERMAL TEST ARTICLE*

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ABSTRACT

This report documents the fabrication and thermal test of a full-scale prototype of the revised TRUPACT-I design (herein referred to as a full-scale Thermal Test Article or Test Article). The fire test demonstrated that the response of the Test Article to a jet-fueled pool fire, subsequent to the impact and puncture tests defined in DOE Order 5480.3 and 10CFR71, meets the impact, puncture, and thermal performance requirements of the regulations governing transport of radioactive materials.

The Test Article was a replica of the front half (closure end) of the revised TRUPACT-I design. To simulate the cumulative effect of the regulatory hypothetical accident sequence, the Test Article included the structural damage found in TRUPACT-I, Unit 0 after regulatory drop and puncture testing. The Test Article was totally engulfed in a pool fire fueled by JP-4 jet fuel for 46 minutes. The maximum temperature reached at the inner door seals was 149°C (300°F) and the maximum temperature at the inner door filters was 171°C (340°F). Both temperatures are within the normal working range for these components. Post-test leak rate measurements of 0.0041 atm-cm^3/s (ANSI

* This work performed at Sandia National Laboratories, Albuquerque, New Mexico, Supported by the U.S. Department of Energy under Contract DE-AC04-76DP00789

** A United States Department of Energy Facility standard air) between the innermost pair of door seals and 0.0046 atm-cm^3/s (ANSI standard air) between the outermost pair of door seals verified that the performance of the silicone seals met the design requirements. Since no detectable leakage was measured to a sensitivity of 1.0E-7 atm-cm^3/s for the filter installation seal or quick-connect valve seal post-test, the total leak rate for the containment system was less than the maximum allowable 0.01 atm-cm^3/s ANSI standard air). Hence, the revised TRUAPCT-I design has been shown to meet the impact, puncture, and thermal regulatory requirements for certification.

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SUMMARY

The thermal event in the hypothetical accident sequence to demonstrate compliance with the federal regulations governing transport of radioactive materials involved subjecting the Thermal Test Article to an engulfing JP-4 fueled fire for 46 minutes on February 26, 1986. To simulate the cumulative effect of the regulatory accident sequence, the Test Article included the structural damage found in TRUPACT-I, Unit 0 after the two 9-m (30-ft) drops and the puncture testing of the seal area. The previously tested Unit 0 inner liner, puncture plates, and inner and outer door frames were used to fabricate the Test Article. Structural damage in these members from prior mechanical tests was retained. Damage to other components was added based on Unit 0 damage or damage predicted for the modified design. The Test Article configuration with defined damage is detailed.

The test procedure was nearly identical to the TRUPACT-I, Unit 0 test procedure (Ref. 1) and was in accordance with the International Atomic Energy Agency (IAEA) Safety Series No. 37, "Advisory Material for the Application of the IAEA Transport Regulations" for an open pool fire test. The test article was supported on an insulated stand 1 m (40 in.) above the initial fuel surface in a 9-m x 18-m (30-ft x 60-ft) pool. Twenty-six Type K thermocouples were located on four 6-m (20-ft) high water-cooled towers in the pool to monitor the fire temperature. A total of 116 Type K thermocouples were positioned in the Test Article. In addition to the thermocouples, temperature indicating paints and labels were installed in the Test Article. Heat tape was attached to drums in the cavity to simulate internal heat generation.

The heat tape preheated the drums to between 31° and 40°C (88° and 105°F), depending on location. The initial containment liner temperature was between 25° and 40°C (77° and 104°F) and the temperature at the seal cavities initially ranged from 30° to 34°C (87° to 94°F). These initial temperatures are slightly below the regulatory specified initial temperatures--that is, in equilibrium with 38°C (100°F) ambient air.

The same test facility and procedures were used as for the Unit 0 fire test and the resulting thermal environment was nearly identical except for the fire duration. For the Unit 0 fire test the flames fully engulfed TRUPACT-I for 35 minutes. The Test Article was fully engulfed for the 46-minute duration of the burn and was allowed to cool unhindered. Data acquisition continued for 51 hours until all temperatures had peaked and were less than 93°C (200°F). Maximum temperatures recorded by the temperature-indicating paints and labels at critical locations in the Test Article are as follows:

Location	Max. Temperature °C (°F)
o Inner door seal	149 (300)
o Filter	171 (340)
o Inner door	171 (340)
o Containment liner	135 (275)
o Surface of contents	77 (170)

Peak seal temperatures occurred at the top left corner of the inner door. Manufacturer performance data indicates that silicone seal material can seal indefinitely at continuous use temperatures up to 232°C (450°F). A post-test leak rate measurement of 0.0041 atm-cm^3/s (ANSI standard air) for the inner pair of seals and 0.0046 atm-cm^3/s for the outer pair of seals verified successful performance of the silicone seals in the Test Article. Since no

detectable leak was measured for the filter installation seals or the quick-connect valve seal post-test to a sensitivity of 1 x 10^{-7} atm-cm^3/s (Helium), the total containment system leak rate was less than the maximum allowable 0.01 atm-cm^3/s (ANSI standard air). Welds in the containment liner were also examined using a nondestructive examination technique (dye penetrant weld inspection) to demonstrate that no weld cracks were present after the thermal event.

Maximum temperatures indicated by the paints and labels show that all of the temperature limit design criteria were met. The maximum measured filter temperature of 141°C (340°F) is below the design guideline of 260°C (500°F). Sidewall foam was uncharred from the containment liner to the puncture plates, and even near the pyrolysis gas relief holes. Thus, the body thermal protection design changes provided adequate thermal resistance between the flames and containment liner. Disassembly observations indicated the successful performance of the thermal radiation shield and the convection seal. The Kevlar panels in the outer door were severely burned. Despite this damage, the outer door thermally protected the containment system's filters, valves, and inner door.

The full-scale fire test of the TRUPACT-I Thermal Test Article demonstrated that the revised packaging design performance is within design guidelines and that integrity was maintained after the regulatory hypothetical thermal accident. The measured leak rates were within design criteria limits, which demonstrated that containment was maintained. All components performed satisfactorily, thus verifying the thermal design of TRUPACT-I.

FIRE TESTING AND ANALYSIS OF TRUPACT-I THERMAL TEST ARTICLE

1.0 INTRODUCTION

The TRansUranic PACkage Transporter (TRUPACT-I) is a Type B packaging compatible with both truck and rail transport (bimodal). The ability of the TRUPACT-I to restrict leakage to less than the maximum allowable rate of A_2/week (equivalent to 0.01 atm-cm^3/s of air) was demonstrated by fabricating a full-scale prototype unit (Unit 0) and subjecting it to a series of regulatory tests (Refs. 2 and 3). The TRUPACT-I system was in the developmental stage and these were the first tests of a full-scale unit under controlled and monitored conditions. As a result, the test program was established to provide design information as well as to demonstrate compliance with the regulations. The following impact, puncture, and thermal tests were performed consecutively to evaluate the package response:

- three impacts of 5.9-kg (13-lb) bar onto the outer surface,
- 0.3-m (12-in.) drop onto bottom surface,
- 9-m (30-ft) drop onto top left edge,
- 9-m (30-ft) drop center-of-gravity over outer door corner,
- four 1-m (40-in.) drops onto a 15-cm (6-in.) diameter puncture bar,
- 30-minute JP-4 fuel pool fire.

Damage was recorded by measuring accelerations, strains, deformations, and seal leak rates. After the pool fire test on Unit 0 the seal leak rate exceeded the allowable rate due to inner door seal degradation resulting from excessive burning of the polyurethane foam in the outer door. Details on the Unit 0 thermal test are presented in Refs. 1 and 4. Design changes were made to remove combustible materials and add insulation. The prototype was refabricated to incorporate the design changes. The rebuilt Test Article was subjected to a pool fire test to verify the thermal redesign. Results of the Unit 0 thermal test are summarized in the following material. The redesigned TRUPACT-I is described later in this section, with results of the successful thermal test on the Test Article presented in Section 5.

1.1 TRUPACT-I, Unit 0 Description and Design

The major components of TRUPACT-I, Unit 0 are illustrated in Figure 1.1-1. The waste containers are placed inside of the containment system which is protected by the outer structure.

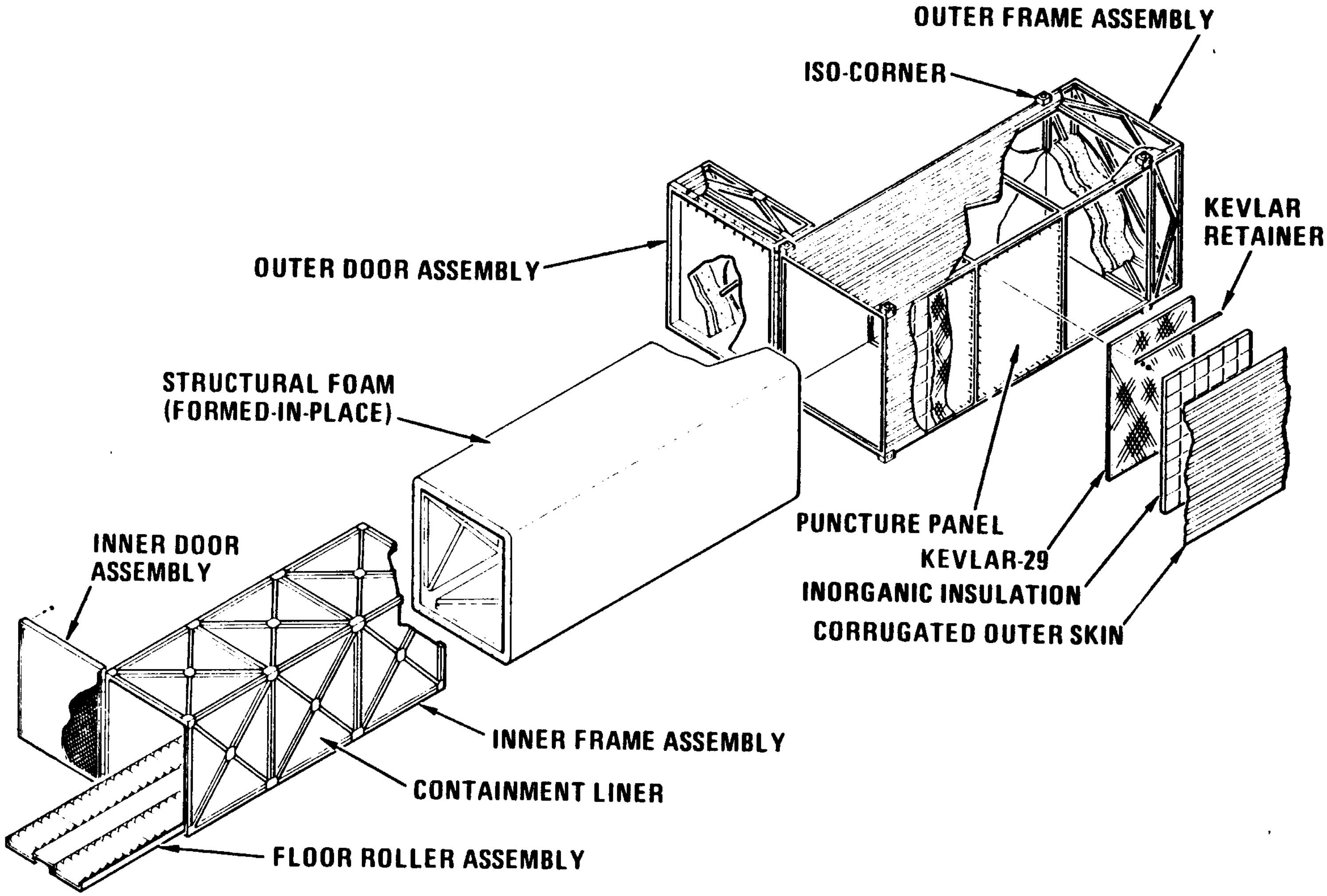


Figure 1.1-1. TRUPACT-I, Unit 0, Prototype Schematic

1.1.1 Containment System

The containment system of TRUPACT-I, Unit 0 has an interior cavity 5.8 m long, 1.9 m wide, and 2.2 m high (19'2" x 6'2" x 7'2"). The high integrity system prevents release of radionuclides. The containment liner is 4.8-mm (3/16-in.) welded stainless steel plate supported by an inner frame built with longitudinal, circumferential, and diagonal stainless steel structural tubing. The open end is sealed by a bolted and hinged 10-cm (4-in.) thick inner door. The inner door has a tubular steel edge frame and center panel of sandwich construction; the sandwich panel has bonded stainless steel face sheets and an aluminum honeycomb core. Leakage between the inner door and the inner frame is prevented by compressing three concentric elastomeric seals when the 36 door bolts are tightened. Seal integrity is checked using a pressure rise leak test. Quick-connect fittings are provided to connect leak testing equipment. Four high efficiency filters are located in the top of the inner door frame to equilibrate cavity pressure while preventing release of airborne particulates.

1.1.2 Outer Protective Structure

The primary function of the outer protective structure is to protect the containment system during normal and accident conditions. Components of the outer structure are 1) outer frame assembly, 2) stainless steel puncture panels, 3) Kevlar (registered trademark of Dupont) puncture panels, 4) insulation, 5) exterior skins, 6) polyurethane foam, and 7) outer door. Stainless steel is used throughout the outer protective structure. Outside dimensions with the doors secured are 7.6 m x 2.4 m x 2.7 m (25'1" x 8'0" x 9'0") LWH. The outer framework is built of 75-mm (3-in.) square tubing and provides corner castings for handling and tie-down per the International Organization for Standardization Technical Committee 104 (ISO/TC 104). The rectangular frame contains 3.8-mm (0.15-in.) stainless steel plates and panels of Kevlar 30 layers thick in its sidewalls to form the puncture protection system and to provide in-plane stiffness to the frame. Because of the inboard position of the puncture protection system in the ends, the stainless steel was increased to 4.8 mm (0.19 in.) and the Kevlar increased to 44 layers in each end.

Outside the puncture protection system in the sidewalls of TRUPACT-I, Unit 0 ceramic fiber insulation blankets 25 mm (1.0 in.) thick, and 96 kg/m^3 (6 lb/ft^3) in density are installed. The complete assembly is covered with an aluminum honeycomb panel used to stiffen an external skin of 0.31-mm (0.012-in.) stainless steel.

Rigid polyurethane foam is poured-in-place between the inner and outer frame. The foam performs both structural and thermal functions and has a nominal density of 96.0 kg/m^3 (6 lb/ft^3).

The outer door provides impact protection. It is built of square tubing and rigid foam (during redesign the foam was removed), and includes the stainless steel/Kevlar puncture protection system. The outer door is hinged from the outer frame and is attached in the closed position by a rapid actuating system of worm gear driven locking pins. The door is sealed with an elastomeric weather seal (Neoprene) which is not intended to provide containment.

1.1.3 Weight Limits

The gross weight of the TRUPACT-I is limited to 22.7 tonne (50,000 lbs) for a legal weight package for highway transport. The resultant cargo capacity at the maximum weight is 7.0 tonne (15,400 lbs). The tests described herein were performed with a variety of simulated waste products in 55-gallon drums at a gross package weight of 22.6 tonne (49,800 lbs).

1.2 Regulatory Testing--TRUPACT-I, Unit 0

The following is a synopsis of tests performed and results obtained. For more complete information see Refs. 1 and 4.

1.2.1 Penetration Bar Drop

A mild steel bar weighing 5.9 kg (13 lb) having a 4-cm (1.5-in.) hemispherical end was dropped onto the TRUPACT-I top surface from a height of 1 m (40 in.) to simulate normal handling abuse. Impact positions were selected in the center, corner, and along the edge of a region of the outer frame. These tests produced minimal damage on the outer skin and none were considered to render the package incapable of continuing in service.

1.2.2 Drop on Bottom

The 0.3-m (12-in.) drop flat onto the bottom surface of TRUPACT-I demonstrated the ability of the package to withstand abuse that might be encountered during normal handling. The test target for this, and all other impact tests, was the Drop Test Facility at Oak Ridge National Laboratory, TN. Results of the test indicated no unacceptable damage.

1.2.3 Drop on Edge

The 9-m (30-ft) hypothetical accident drop on the top left edge of TRUPACT-I was included in the test sequence because of the large loads and deformations that are input perpendicular to the containment centerline. This orientation was one of the two most severe tests on a quarter-scale model. Large deformations in the inner door seal area could result in excessive leak rates.

Results of the test indicated that the containment leakage limit of 0.01 atm-cm^3/s was not exceeded. The edge of the packaging was crushed inward an average of 7.6 cm (3 in.) resulting in a flattened region averaging 15 cm (6 in.) in width and covering the full length of the edge.

1.2.4 Drop on Corner

A second 9-m (30-ft) drop was of engineering interest because of the large out-of-plane loads that develop due to the interaction of the cargo with the inner door. The packaging was suspended with the center-of-gravity above the bottom left corner of the outer door and dropped. The corner of the outer door was crushed inward 0.81 m (31.8 in.) and the triangular footprint went completely across the bottom edge of the outer door and about two-thirds of the distance up the left vertical edge. The inner door and containment were found to be undamaged when the package was later disassembled. Results verified that the impact design was adequate.

1.2.5 Puncture Tests

Four 1-m (40-in.) drop puncture tests were performed on TRUPACT-I. The positions impacted were 1) bottom center--perpendicular to surface, 2) aft end--perpendicular to surface, 3) bottom left corner of outer door--oblique impact, 4) top middle of outer door--oblique impact. The third test attacked the inner door seal and frame in the corner predamaged in the 9-m (30-ft.) corner drop. The fourth test attacked the inner door in the region of the inner door seals and pressure equilibration system, stressing the inner door frame and filter housing. In all the puncture tests, the line of action of the puncture bar was through the center-of-gravity of the package.

In the fourth puncture test, the puncture bar passed through the outer door, making minimal contact with the structural members. The edge connection of the puncture protection system was torn from the frame thus exposing the foam. Containment was not breached in any of the four puncture tests and the inner door seal leak rate did not exceed the maximum allowable.

1.2.6 Pool Fire Test

The damaged package was next exposed to an open-pool fire at Sandia National Laboratories, Lurance Canyon Burn Site. The package was centered in a 9-m x 18-m (30-ft x 60-ft) open concrete-lined pool and supported 1 m (40 in.) above the JP-4 fuel surface (Ref. 1). The burn duration was 35 minutes. Flame temperatures varied from 260°C (500°F) to 1310°C (2400°F) with the average being about 980°C (1800°F). After the test, TRUPACT-I no longer met the required containment leak rate limits. The thermal design criteria for the hypothetical accident condition were not met. Excessive temperatures for safety-related components and the resulting loss of containment were primarily due to foam burning in the outer door. A large tear in the stainless steel puncture plate weld at the top edge of the outer door resulted from the fourth puncture test, exposed foam to the fire, and provided air access to support combustion (Ref. 4). As a result, the seals and adhesives overheated and could no longer maintain an acceptable leak rate.

1.3 Redesign Activity

Design changes were made to 1) improve the attachment of the outer skin by doubling the number of rivets and adding a sealing tape, 2) eliminate foam burning in the outer door by replacing organic foam with aluminum honeycomb, 3) prevent material from burning adjacent to the inner door by reinforcing the edge connection of the outer door puncture panel and by replacing organic foam behind the outer door puncture panel with welded stainless steel honeycomb, 4) reduce charring and burning of sidewall foam by adding insulation boards behind outer frame tubes, adding flame retardant to the foam, and adding inorganic insulation in areas of potentially high structural damage, 5) reduce temperatures on the inner door seals, filters, and inner door by improving the convection seal, replacing organic with inorganic materials, and changing to high temperature rated silicone seal material, 6) improve the temperature rating of the covering and stitching material used in sidewall insulation blankets, and 7) eliminate a leak that developed during the full-scale prototype tests by removing an adhesive bond line from the containment boundary.

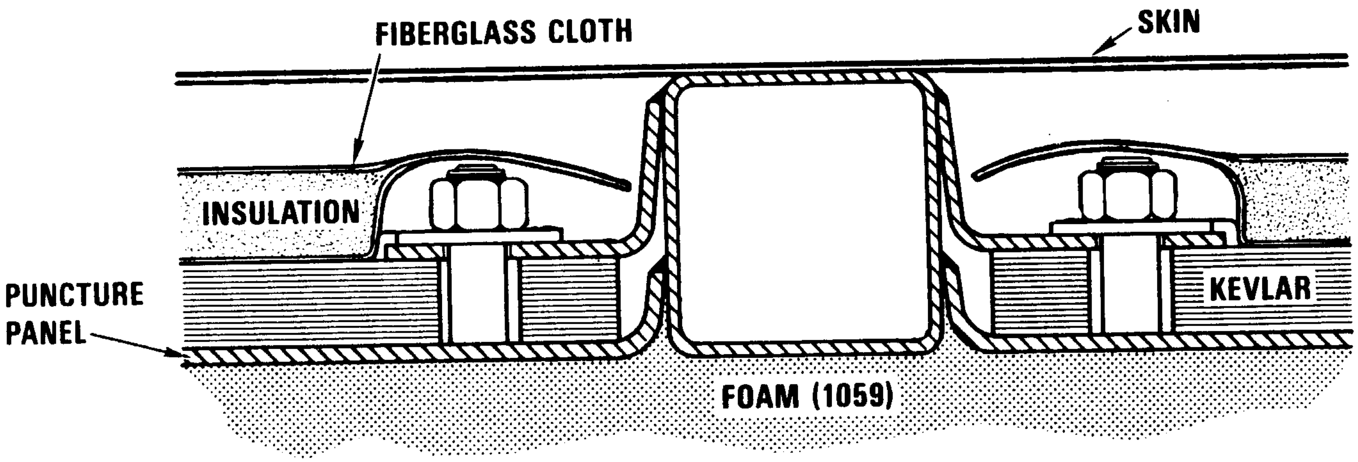
Adequacy of the thermal redesign was indicated by analysis and component tests completed prior to the final pool fire test (Ref. 5). The component tests examined the behavior of TRUPACT-I, Unit 0 combustible materials and possible replacement materials in a simulated open-pool fire environment.

Foam in the sidewalls of the body was isolated from the high heat input of the fire event by adding insulating materials. Insulation boards were added behind the longitudinal and transverse tubes on the outer framework. Inorganic insulation was added to fill the interior space of the outer frame members. The covering on the insulation blankets between the Kevlar mats and the outer skin was changed to a high temperature silica cloth. These changes are illustrated in Figure 1.3-1.

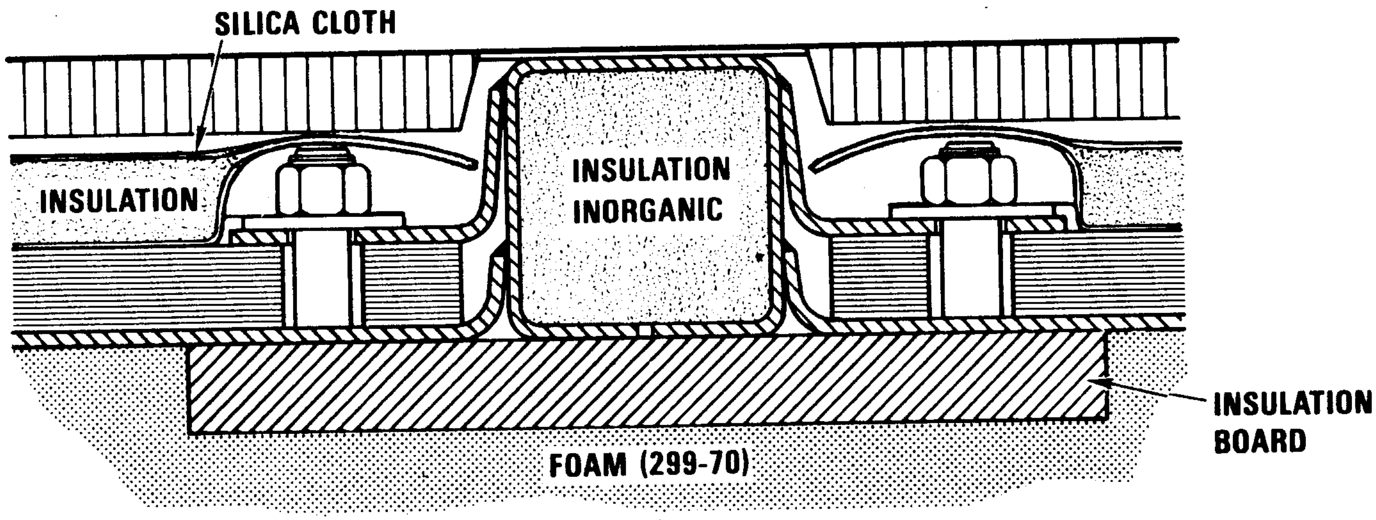
Air ingress to the polyurethane foam was reduced by placing blocks of flexible silicone foam material, having a much higher combustion temperature, in locations where cracks in the outer frame and stainless steel puncture plates are likely, see Figure 1.3-2. Hard spots exist in the outer frame at the locations of the ISO corner castings. If these areas become deformed there is a potential for foam to be exposed to the flames. Insulation boards placed behind the tubular members of the outer frame are much wider than the tubes and provide an additional barrier between the flames and the polyurethane foam, see Figure 1.3-1. Air ingress through failure of the puncture plate welded connection in the outer door and closed end was minimized by strengthening the joint design, see Figure 1.3-3. The polyurethane foam in the outer door was completely eliminated, as will be discussed later.

Organic materials in close proximity to the inner door and inner door seals were eliminated from the body, and insulation was added to minimize the heat input to the seals. Changes were made to the sidewall to remove the polyurethane foam within about 17.8 cm (7 in.) of the door jamb. A double foam cap was included in the new design and the 17.8-cm (7-in.) space created was filled with two layers of 2.5-cm (1.0-in.) flexible silicone foam and inorganic insulation, see Figure 1.3-4.

The inner door seals, filter seals, and quick-connect valve seals were changed to a silicone material that exhibits excellent sealing properties and has a normal operating temperature range from -18.3°C to 232°C (-65°F to 450°F). The new material is manufactured to comply with AMS-3304F specifications. Degradation of the seal material occurs at temperatures above the 232°C (450°F)



a. TRUPACT-I, Unit 0



b. TRUPACT-I Redesigned

Figure 1.3-1. TRUPACT-I Sidewall

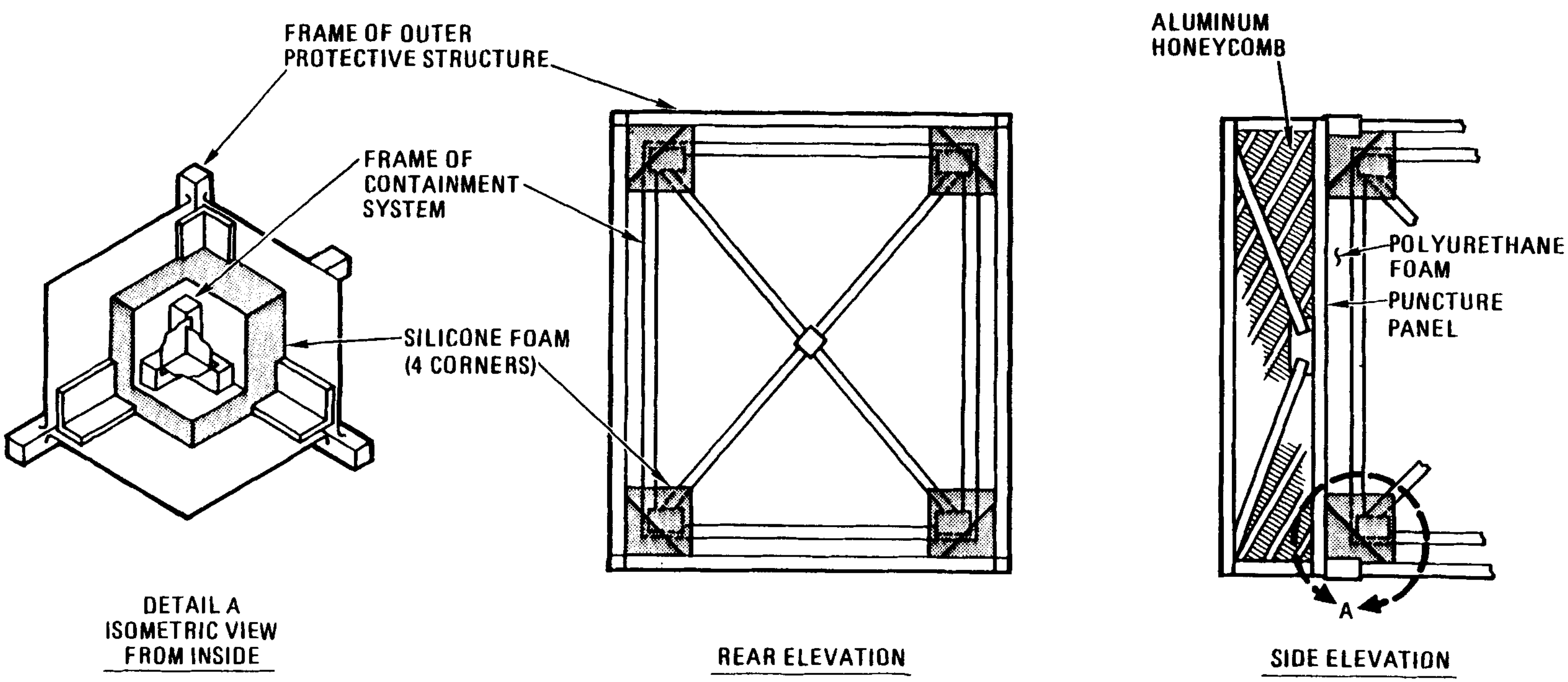


Figure 1.3-2. TRUPACT-I Closed End

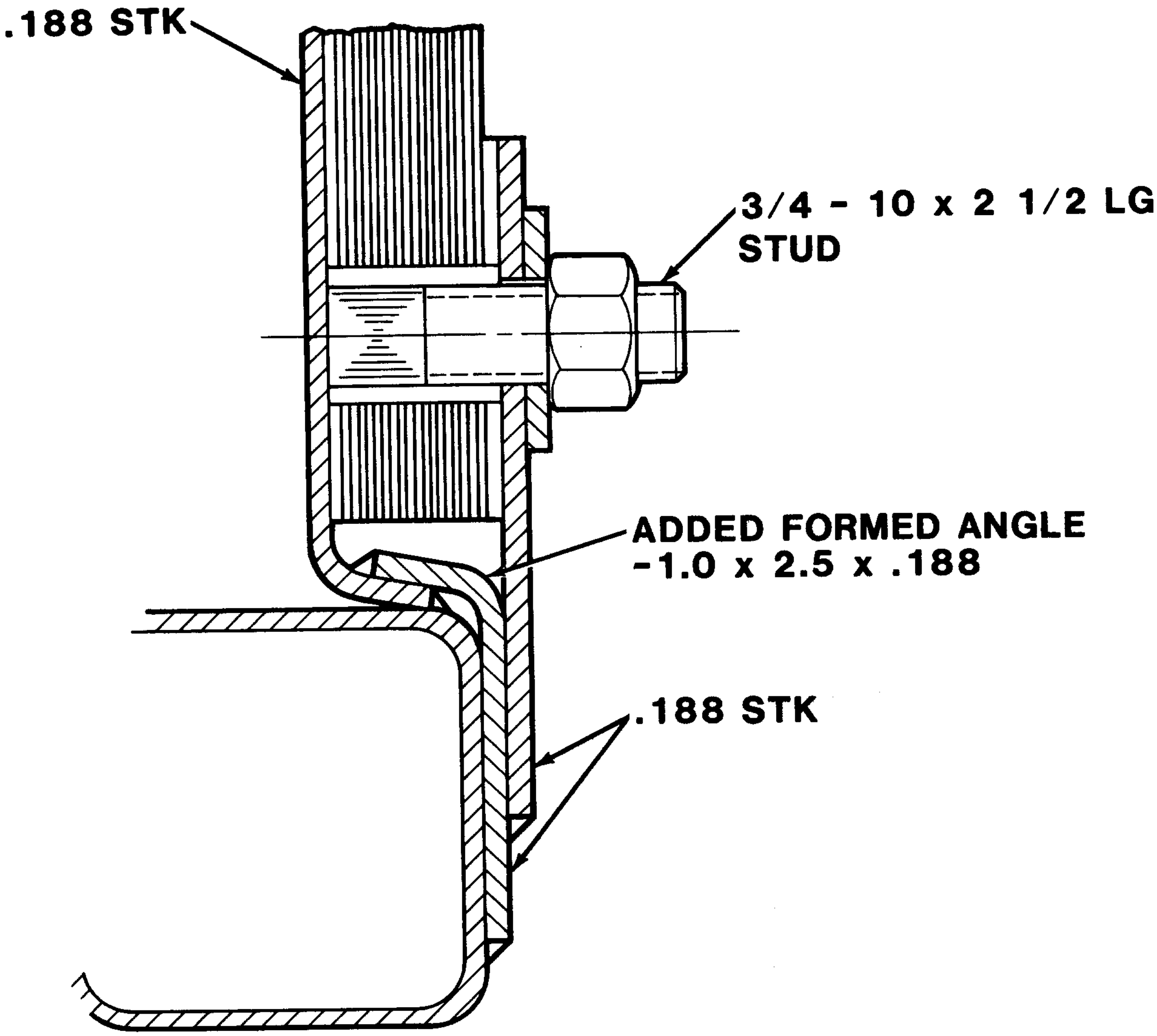
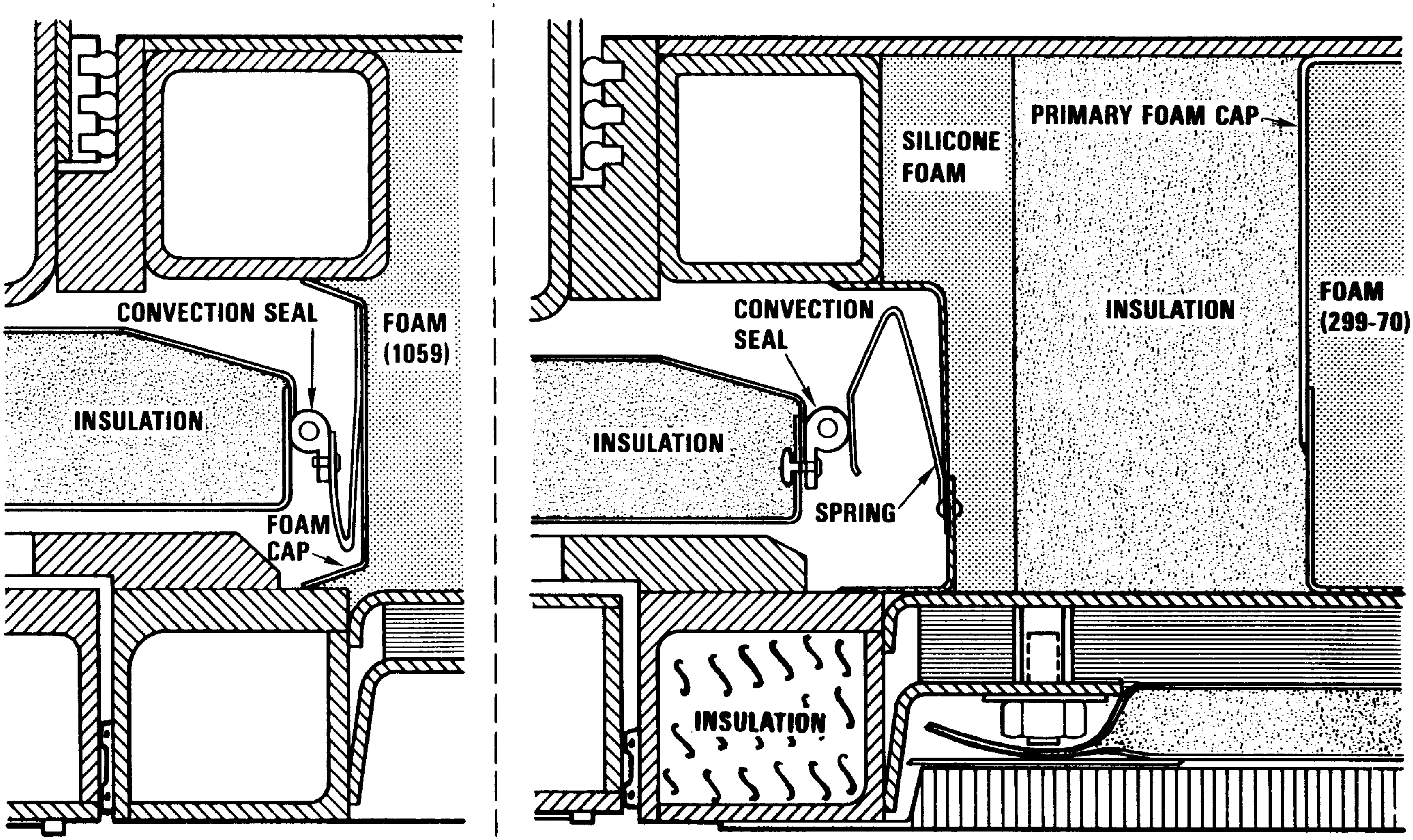


Figure 1.3-3. Outer Door Puncture Panel Connection Redesign



a. Unit 0

b. Redesigned Configuration

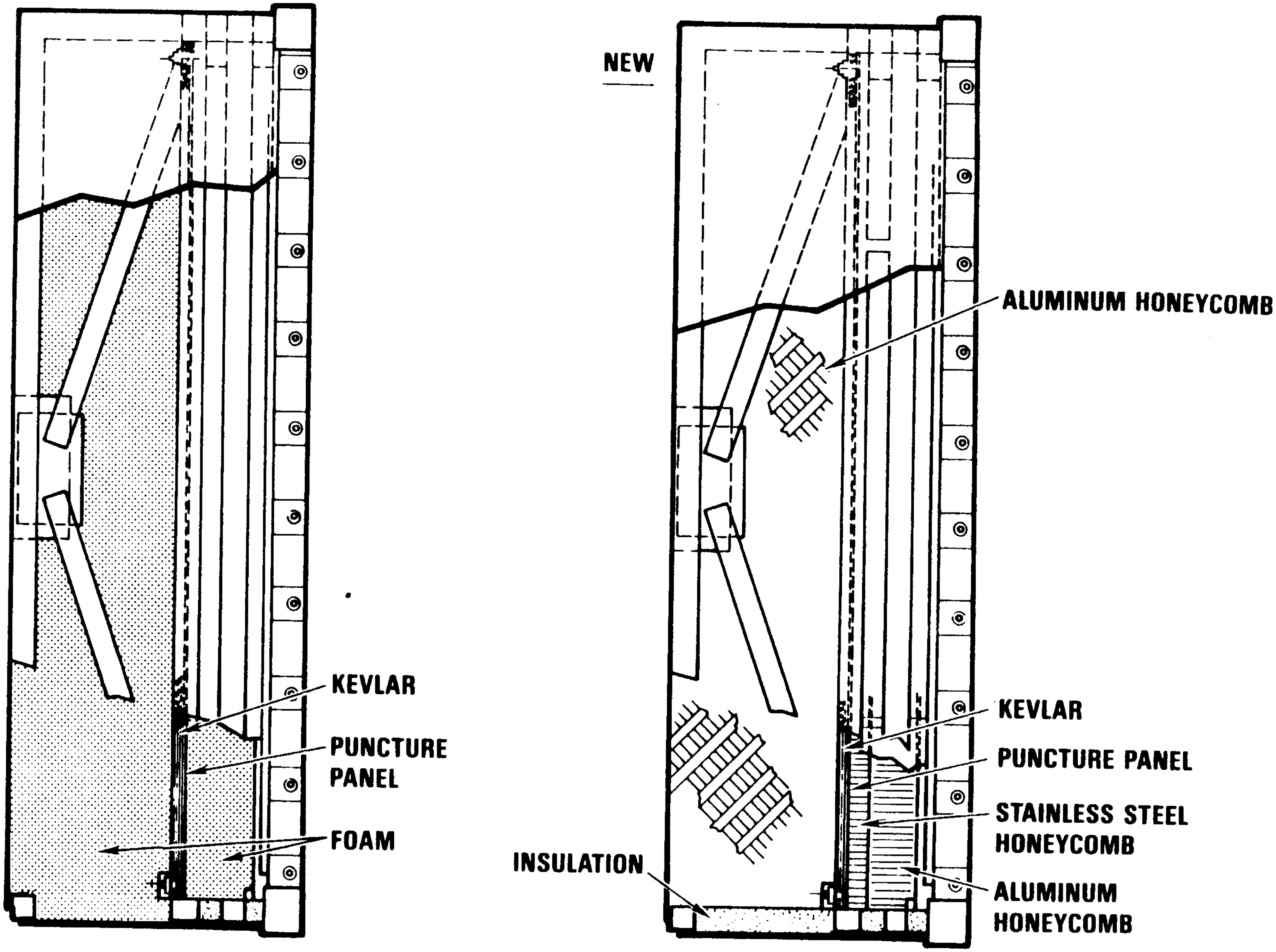
Figure 1.3-4. TRUPACT-I Convection Seal and Foam Cap normal operation limit. Manufacturer's literature indicates the seal life for this material is 30 hours at 260°C (500°F). Scoping tests at Sandia Laboratories demonstrated that the seal material in the TRUPACT-I configuration is capable of exceeding the manufacturer's estimate for performance time at 260°C (500°F) by a factor of 5.

Organic materials were removed from the outer door to eliminate material which could burn in a thermal accident environment, see Figure 1.3-5. All of the rigid foam was replaced with honeycomb materials. The foam outside of the puncture protection system in the outer door and aft end of the packaging was replaced with aluminum honeycomb having a crush strength equal to the foam that it replaced. The rigid foam between the puncture protection system and the inner surface of the outer door was replaced with two thicknesses of all welded (or alternately, brazed) stainless steel honeycomb; foam in this location in the aft end of the packaging was not replaced. Additional insulating material was added to the outer door adjacent to the inner door seals. Inorganic insulation was placed in the structural tubes forming the door jamb on the end of the outer frame, and insulation was placed along the sides of the aluminum honeycomb in the outer door between the honeycomb and the outer skin.

Additional changes were made to improve the overall system performance and ease of operation. Containment seals were removed from the inner surface of the inner door to eliminate an adhesive bond line from the containment boundary since the adhesive developed a leak during the Unit 0 tests. The seals are now retained in grooves machined into the end of the inner frame, see Figure 1.3-6. The location of the quick-connect valves was also changed to make them easier to access. The configuration of the convection seal was altered (Figure 1.3-4) to increase the range of motion over which the seal could operate. In addition, the relative positions of the spring metal and convection seal (a tadpole type oven furnace seal material) were altered to improve fabricability, see Figure 1.3-4.

1.4 Testing of Test Article

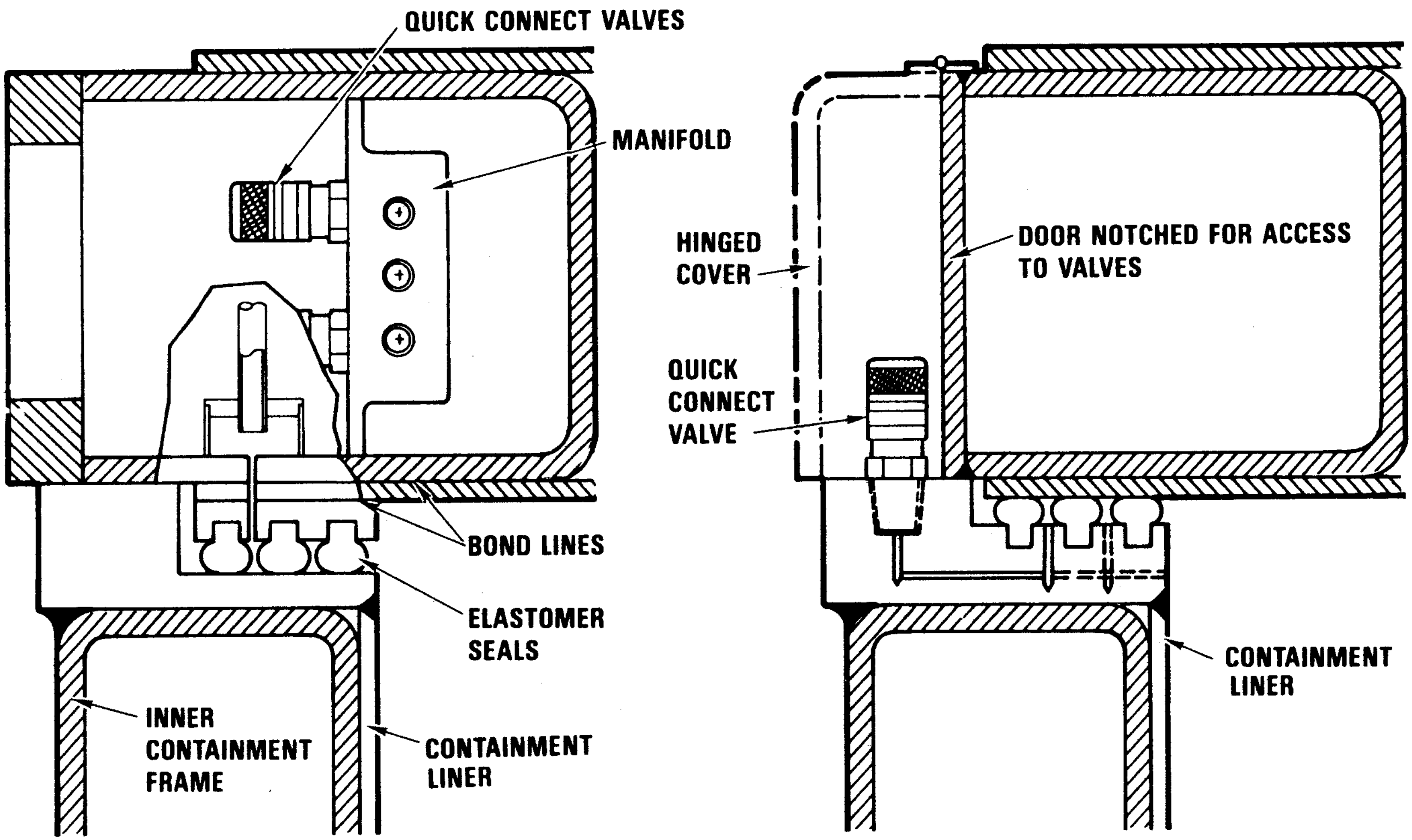
To support the demonstration of compliance with applicable federal regulations (Ref. 2 and 3), a TRUPACT-I Test Article incorporating the new design features was designed, fabricated, and tested in a pool fire. The specifications for the full-scale Test Article are contained in Ref. 6; the test procedure is described in Section 4 and is contained in Ref. 7. The Test Article as-built drawings are contained in Appendix A. The remainder of this report describes the pool fire test in detail.



a. Unit 0

b. Redesigned Configuration

Figure 1.3-5. TRUPACT-I Outer Door



a. Unit 0

b. Redesigned Configuration

Figure 1.3-6. TRUPACT-I Inner Door Seal

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2.0 DESCRIPTION OF TRUPACT-I THERMAL TEST ARTICLE

This section describes how the Test Article was refabricated from the forward portion of the full-scale prototype that was drop, puncture, and fire tested in the summer and fall of 1984. The hardware from the Unit 0 tests was remanufactured to preserve the damage delivered in the 1984 testing of the prototype.

2.1 Dimensions and Materials

The width and height dimensions of the Test Article were the same as those of the full-scale prototype (Unit 0). The Test Article was not as long as the prototype. The body of Unit 0 was cut off at a dimension of 3.87 m (152.5 in.) from the outer surface of the closure end. The remainder of the sidewall and the aft end of the packaging were not modeled for this test because of the similarity between the two ends and because components sensitive to thermal failure are located at the closure end. Hence, the seals, filters, and features added during the thermal redesign to reduce heat input to critical components of the packaging were modeled in the Test Article. The dimensions and material specifications for the Test Article are contained in Appendix A.

Materials in the Test Article were the same as those which will be used in the fabrication of production units. Materials that remained unchanged from the prior design include:

* stainless steel plates,
* square tubular stainless steel frames,
* Kevlar puncture panels,
* inner door with stainless steel perimeter frame and face sheets bonded to an aluminum honeycomb core material,
* outer door frame with quick closure latching mechanism,
* inner door bolts,
* stainless steel ISO corner castings,
* nitronic gussets in outer frame, and
* outer stainless steel covering.

Changes that were made to improve performance include the following:

* addition of flame retardant material to the rigid polyurethane foam,
* addition of fibrous insulation board behind outer frame members to keep foam temperatures below 454°C (850°F) and to minimize air ingress to the foam,
* elimination of organic materials in the body near the inner door, addition of insulation in the region of the outer door/frame interface to keep inner door temperatures below 149°C (300°F),
* replacement of the inner door EPDM seal material with a silicone seal material, and
* addition of silicone foam behind ISO corners in the closed end to minimize air ingress to the foam.

2.2 Construction

Construction of the Test Article was accomplished by rebuilding the forward portion of the previously tested full-scale prototype (Unit 0) to incorporate the redesign features. Unit 0 had been destructively disassembled to investigate the extent of damage received during the September 1, 1984 thermal event.

Parts from Unit 0 were completely disassembled, cleaned, and refurbished. An oxygen lance (burn bar), Figure 2.2-1, was used to cut around the perimeter of the Unit 0 outer and inner frame assemblies. Soot and charred materials from the 1984 test were removed by sandblasting the metal parts, Figure 2.2-2. Portions of the stainless steel puncture panels and frame members that had been removed to inspect damage were reinstalled in the frame assemblies, Figure 2.2-3. The inner door was similarly cleaned, then returned to the manufacturer to be refabricated using the same perimeter frame and face sheets to preserve the mechanical damage incurred during the Unit 0 tests, Figure 2.2-4. The outer door frame was cleaned by sandblasting; the deformation of the puncture panel due to puncture testing in the area damaged during the center-of-gravity over corner drop was repaired since damage from that puncture test was not being modeled, and the torn weld on the top edge of the puncture panel was repaired using the revised joint design, Figure 2.2-5.

The cut end of the containment liner was sealed by welding a 6.4 mm (0.25 in.) plate of stainless steel across the opening, Figure 2.2-6. Inner and outer assemblies were nested together and a foam cap was installed across the gap between the two frames near the closure end, Figure 2.2-7. This assembly was then uprighted to stand on the closure end, braced to minimize sidewall movement, and preheated. Polyurethane foam, with 8 percent flame retardant (phosphate ester) was poured in the annulus, Figures 2.2-8, 2.2-9, and 2.2-10. Exterior frame members were filled with granulated vermiculite to eliminate thermal radiation across the members during the hypothetical thermal accident condition test. Kevlar mats, insulation blankets, and exterior skins were attached to the sidewalls. The aft end of the Test Article was covered with 30.5 cm (12 in.) of inorganic blanket insulation and a sheet of 0.012-in. stainless steel minimized thermal input.

Outer door fabrication was completed by installing Kevlar, honeycomb materials outside and inside of the puncture protection system, insulation materials, inner surface metal covering, thermal radiation shield, convection seal, and quick-actuating closure latching mechanisms. Installation of the secondary foam cap and the spring metal for the convection seal on the end of the foamed body assembly was completed, Figure 1.3-4b. The inner door was hung from its original hinges and secured in position with the original type bolts, Figure 2.2-11. The outer door was reinstalled after the Test Article was placed on the stand at the pool test facility, Figure 2.2-12. The outer door was secured in position by the hinge assembly on the left sidewall and with straps of metal welded between the outer door and outer frame along the other three sides. The gap between the outer door and the outer frame was the original gap in the Unit 0 thermal test.

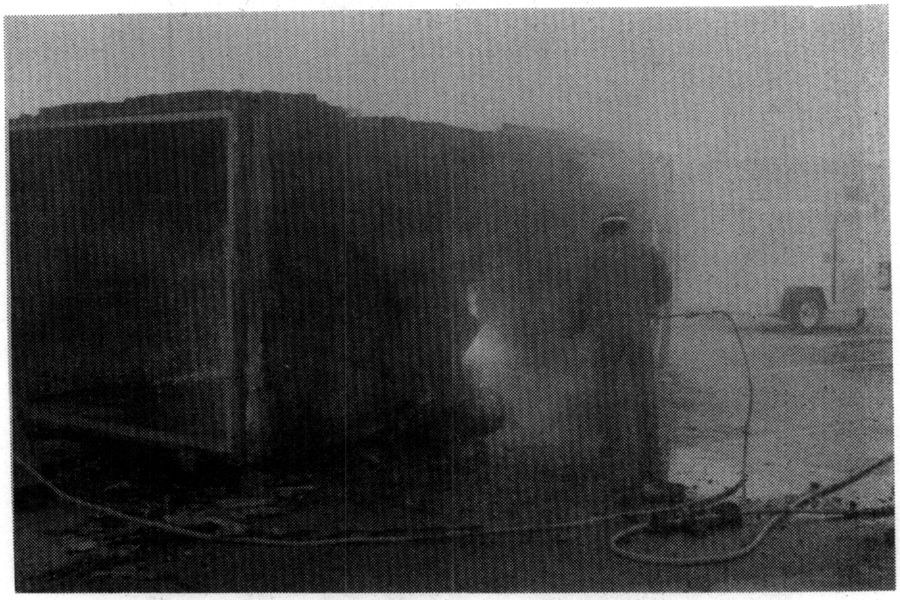


Figure 2.2-1. Oxygen Lance Cutting Unit 0

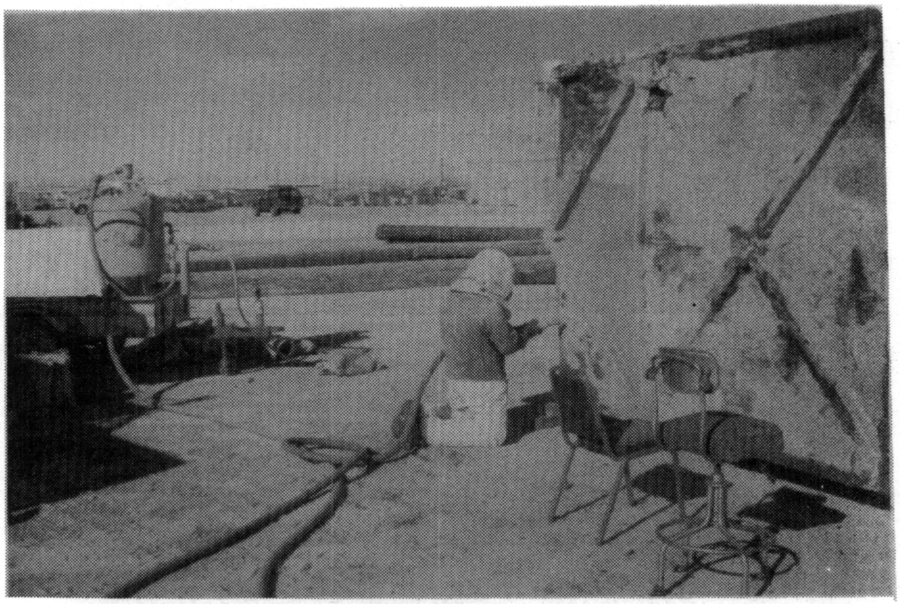


Figure 2.2-2. Sandblasting Inner Frame

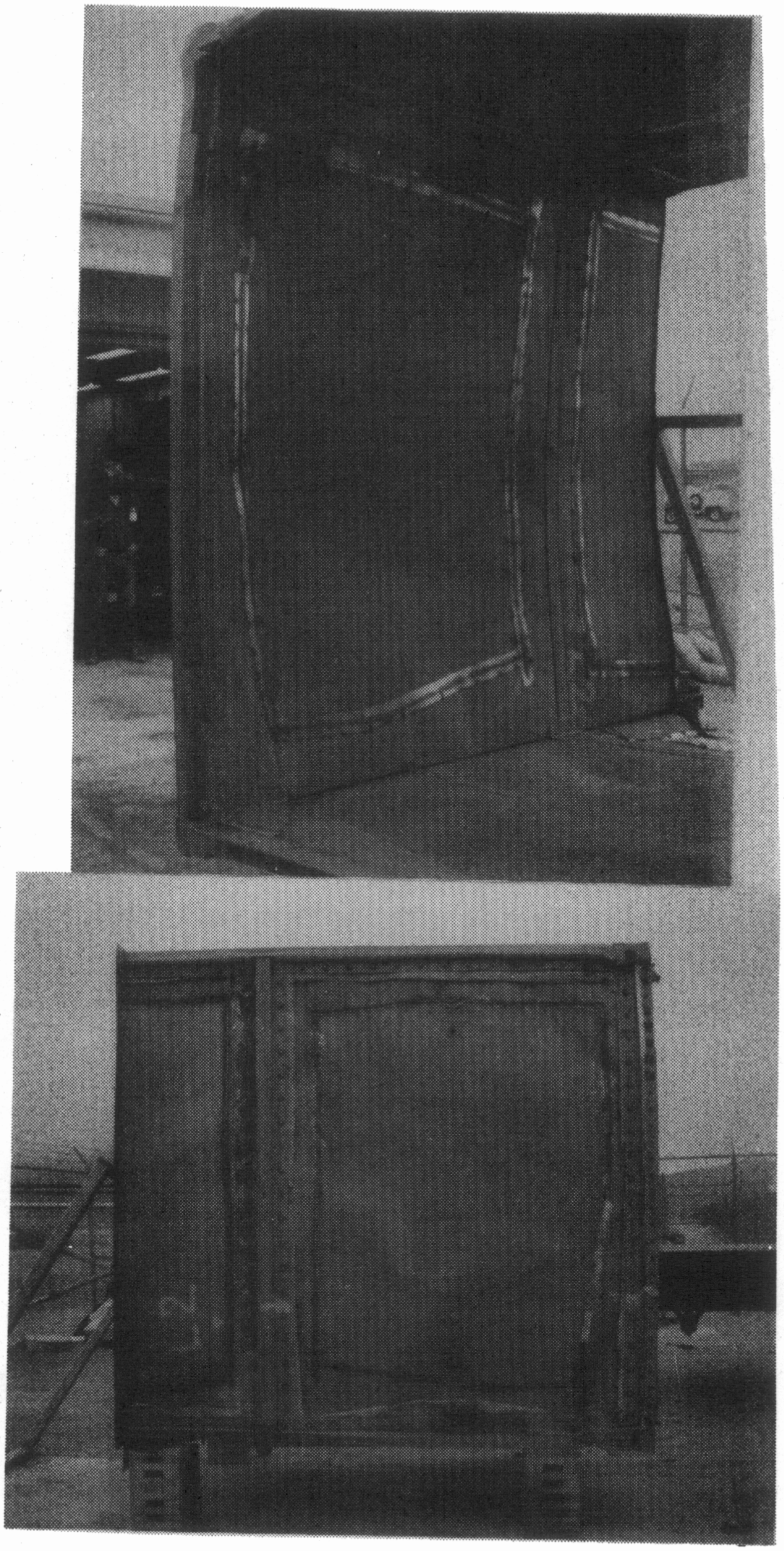


Figure 2.2-3. Installation of Puncture Panels

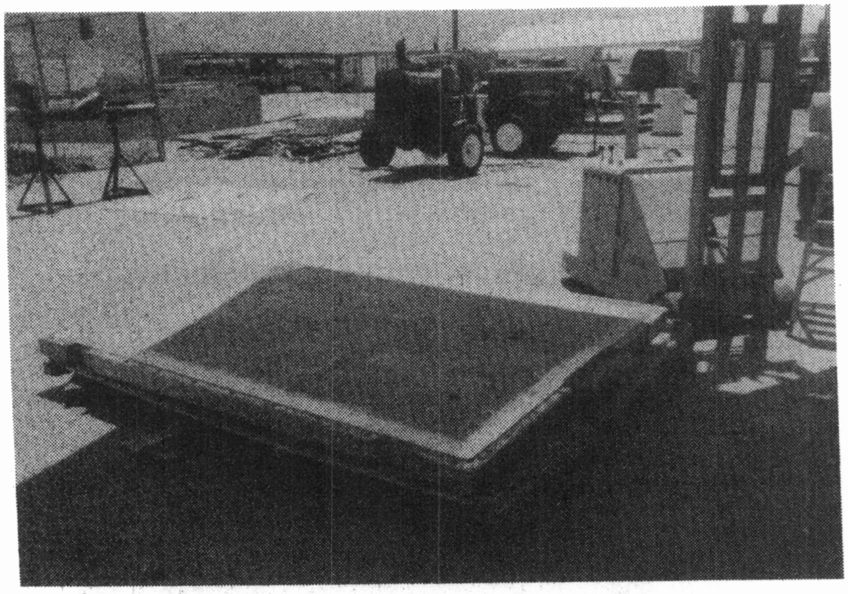


Figure 2.2-4. Inner Door After Remanufacture

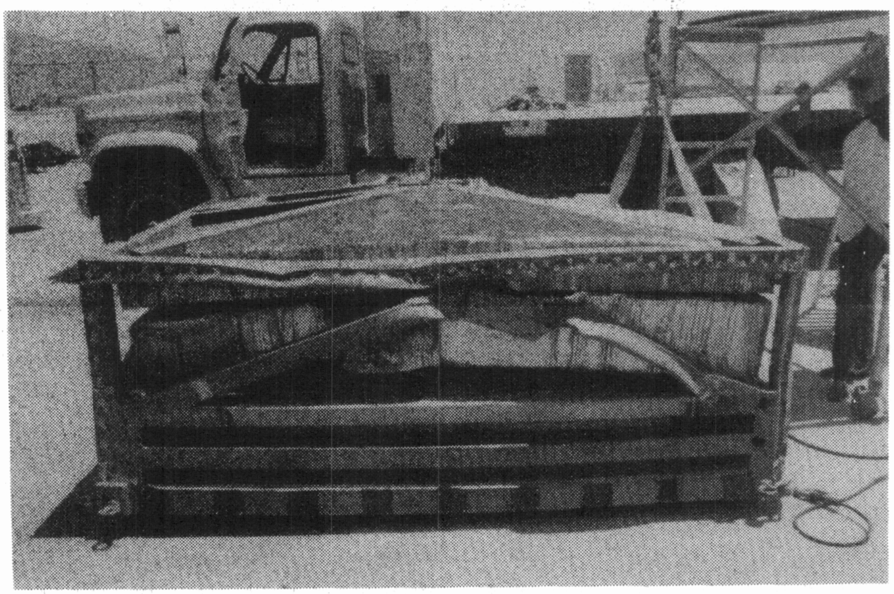


Figure 2.2-5. Outer Door During Remanufacture

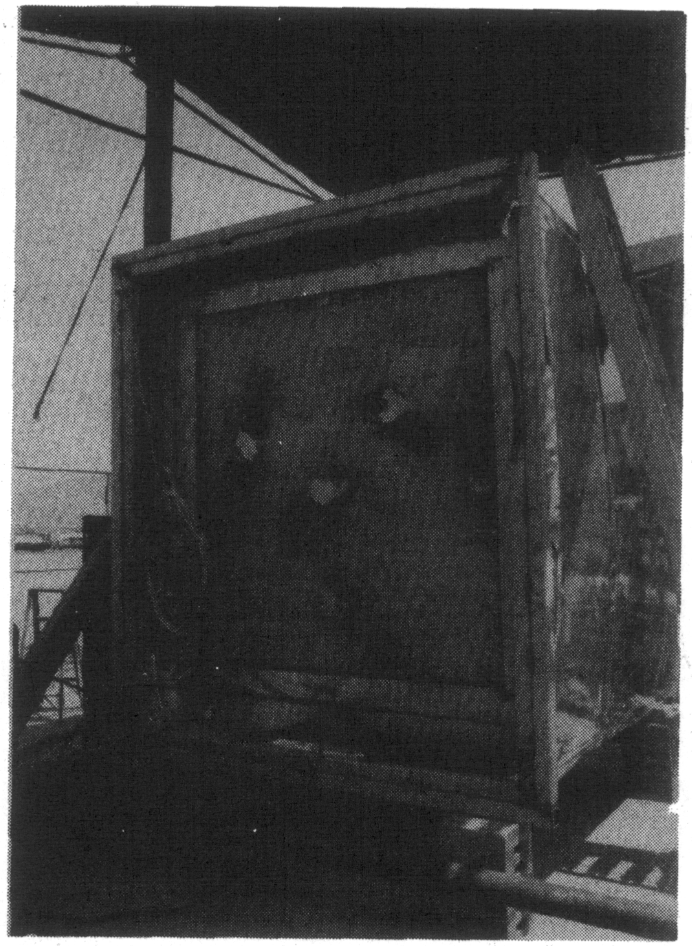


Figure 2.2-6. Sealing Plate for Cut End of Containment Liner

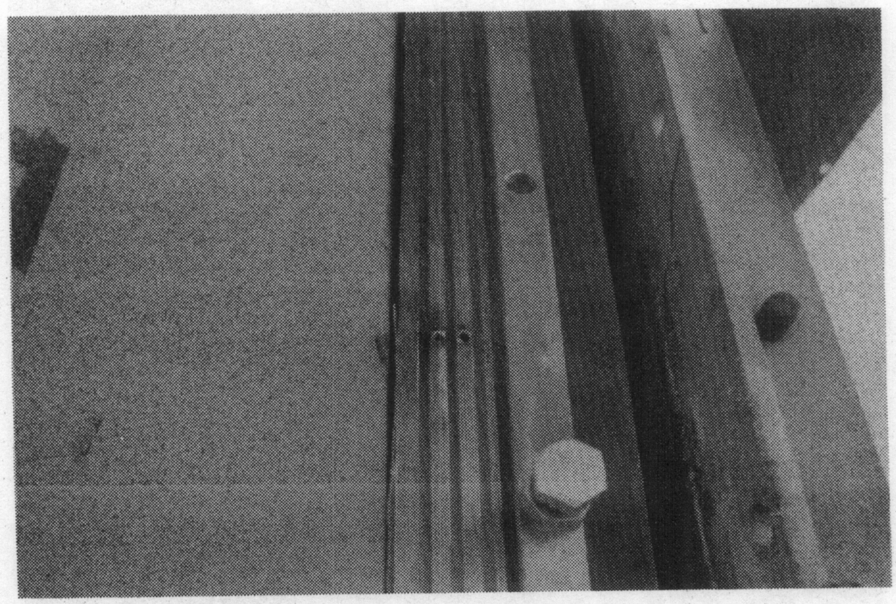


Figure 2.2-7. Foam Cap

Figure 2.2-8. Foaming Operation (Mixing Machine)

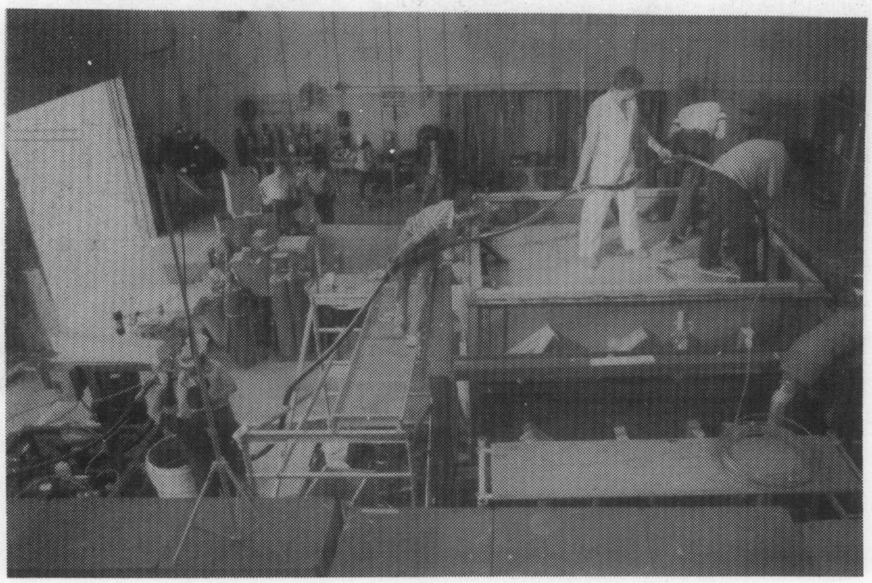


Figure 2.2-9. Foaming Operation (Placing Foam in Upright Body)

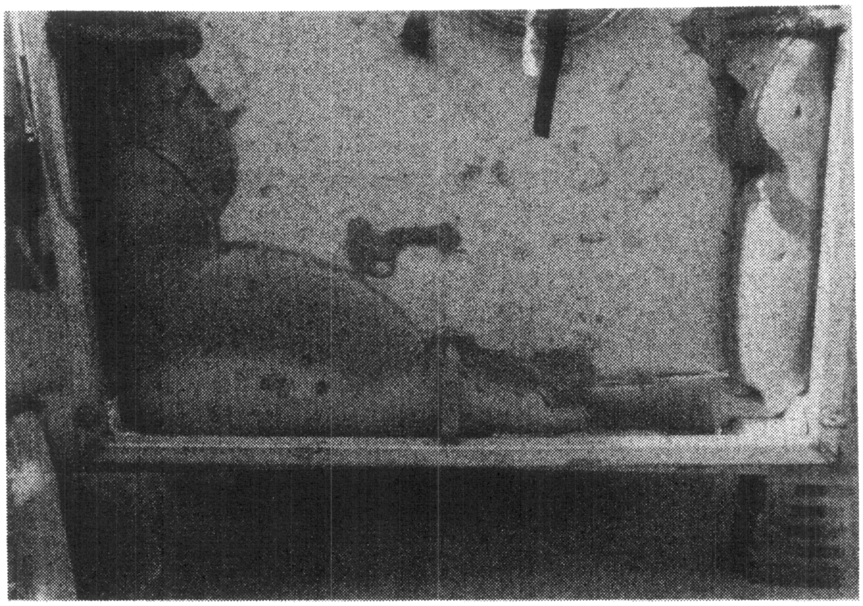


Figure 2.2-10. Foaming Operation (End of Foam Pour)

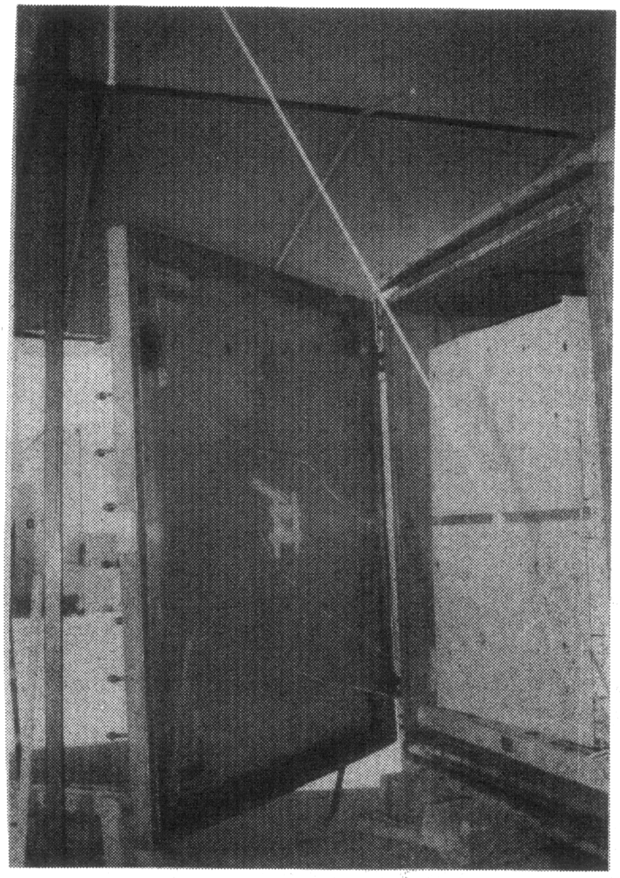


Figure 2.2-11. Inner Door in Position

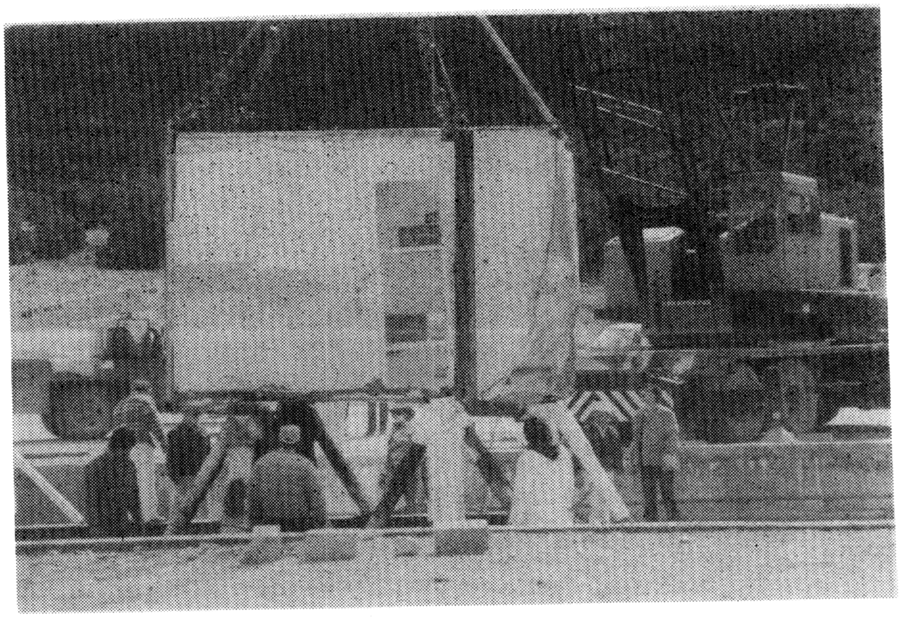


Figure 2.2-12. Outer Door in Position

2.3 Damage Modeled

Structural damage resulting from two 9-m (30-ft) drop tests and one 1-m (40-in.) puncture test was modeled in the Test Article. Damage was included from the impact of the closure end of TRUPACT-I, Unit 0 during the 9-m (30-ft) edge drop and CG-over-corner drop (two separate drop tests). Damage produced by the 9-m (30-ft) drop tests existed in the hardware since the structure used to build the Test Article came from the Unit 0 prototype. Puncture bar damage to the inner door frame and filter assemblies was modeled in the Test Article based on 1/4-scale model test results. The damage modeled is illustrated and documented in the Test Article drawings contained in Appendix A and summarized as follows:

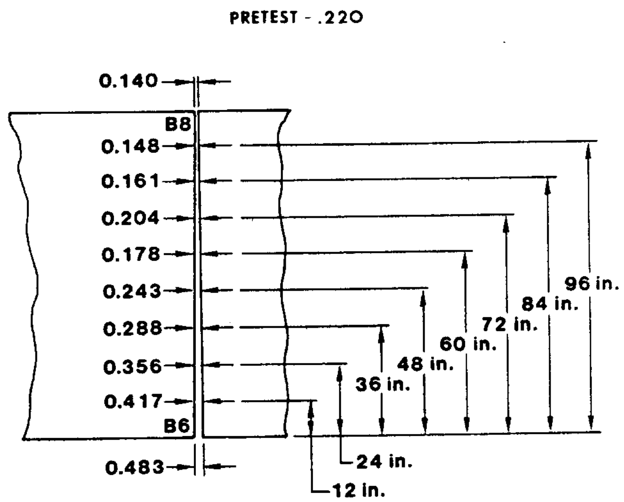
* 9-m (30-ft) Edge Drop

  1. Edge deformation: Retained in outer frame used from Unit 0.

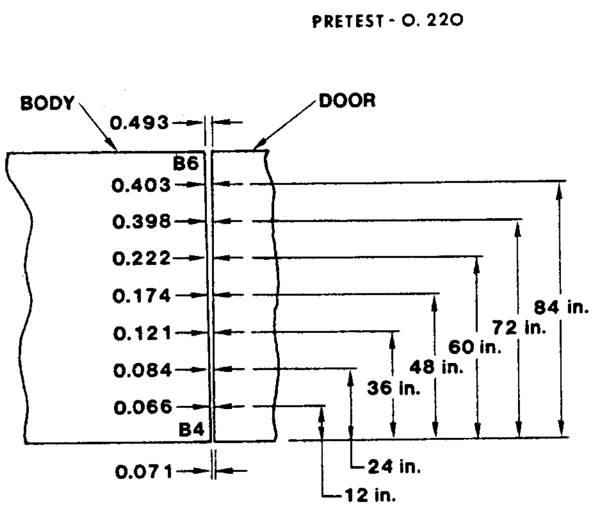
  2. Outer door gap: The outer door was fitted to the body and Unit 0 gaps were reproduced to the extent possible. Gaps recorded in Unit 0 testing are presented in Figure 2.3-1 and are taken from Ref. 1.

  3. Body foam cap tears: The redesigned foam cap between the inner and outer frame consists of a primary and secondary sheet metal cap continuously welded, rather than riveted, into position (Figure 1.3-4b). A tensile test performed on the new foam cap configuration indicated that tearing of the primary foam cap metal would occur at the welded edge attachment in those locations where the inner and outer frames separated for a distance of more than 21.6 cm (8.5 in.). Separation distances between the inner and outer frames were measured, and one tear was created in the primary foam cap where the dimension exceeded 21.6 cm (8.5 in.). The location of the tear was on the top segment of the foam cap; the tear started 61 cm (24 in.) from the left outer surface and extended continuously for 46 cm (18 in.). The tear was modeled at the welded connection between the foam cap and the outer frame.

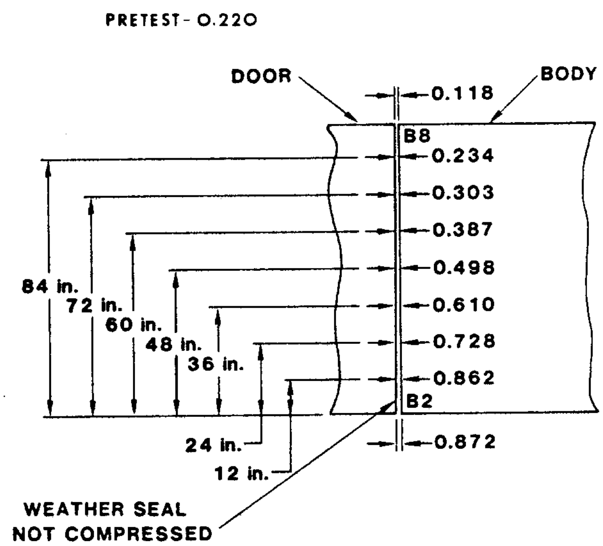
  4. Skin damage: Damage to the redesign skin with a thin stainless steel outer covering adhesively bonded to a stiffening panel of aluminum honeycomb was modeled. To model detachment of the skin, rivets were not installed in the Test Article where the outer frame was buckled. The double rows of rivets used to attach the outer skins were not installed since their function is to secure the skins mechanically during the dynamic tests and the rivets do not affect the thermal performance. No other skin detachments could be discerned from the Unit 0 test photometric data.



UZ-5: Outer Door Joint Deformations - Right Side



UZ-5: Outer Door Joint Deformations - Top



UZ-5: Outer Door Joint Deformations - Bottom

Figure 2.3-1. Unit 0--Outer Door Joint Deformations

* 9-m (30-ft) Center-of-Gravity-Over-Corner Drop

    1. Corner footprint: Retained in the outer door frame that was tested in the Unit 0 tests.

    2. Holes on inside surface of outer door: Holes on the inside surface of the outer door from the Unit 0 tests were retained in the Test Article as shown in Figure 2.3-2.

    3. Convection seal/thermal radiation shield: The shield was pushed into the inside surface of the outer door and caused the failure of rivets, as documented in Ref. 1, page 287. The riveted seal surface along the hinge side was separated 122 cm (48 in.) up from the lower left corner and the outer surface had been moved inward approximately 2.5 cm (1 in.). The right side of the thermal radiation shield was pushed out 1.3 cm (0.5 in.) approximately 1.07 m (42 in.) from the corner. The top side of the seal surface was pushed in along the length of the radiation shield. The thermal radiation shield from Unit 0 was refilled with new moldable ceramic fibrous insulation and reused. The installation of the radiation shield conformed to the Unit 0 damage as nearly as was practical. The convection seal was mounted on the tip of the thermal radiation shield to model the revised design.

    4. Dunnage: Dunnage in the Test Article was simulated using air bags and sheets of plywood. Plywood sheets were placed along the sides of the cargo and the airbags were not inflated. The uninflated airbags were used to model ruptured air bags which were assumed to have ruptured during a 9-m (30-ft) drop event.

* Filter Puncture Test

    1. Outer Door Hole: A hole was cut through the exterior skin on the top surface of the outer door and the honeycomb material was deformed to create a direct path for fire flames to reach the Kevlar in the outer door puncture protection system. The hole was the same size as the Unit 0 puncture hole. Dimensions of the opening in the outer skin are shown in Figure 2.3-3.

    2. Outer door puncture plate: Based on results from 1/4-scale model puncture tests the redesigned outer door puncture plate attachment would not fail. Therefore, a puncture plate tear was not modeled in the Test Article. However, deformations in the puncture panel and outer frame were retained.

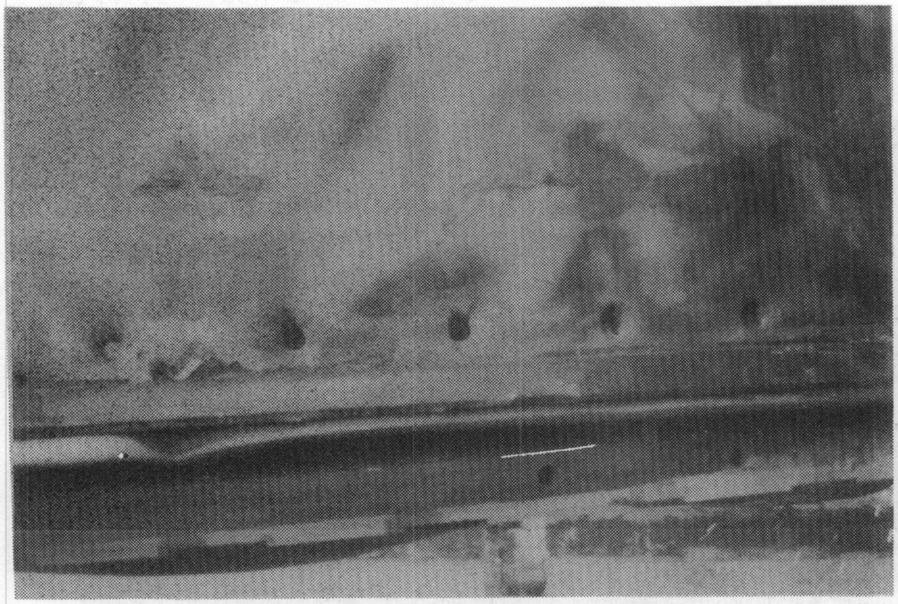
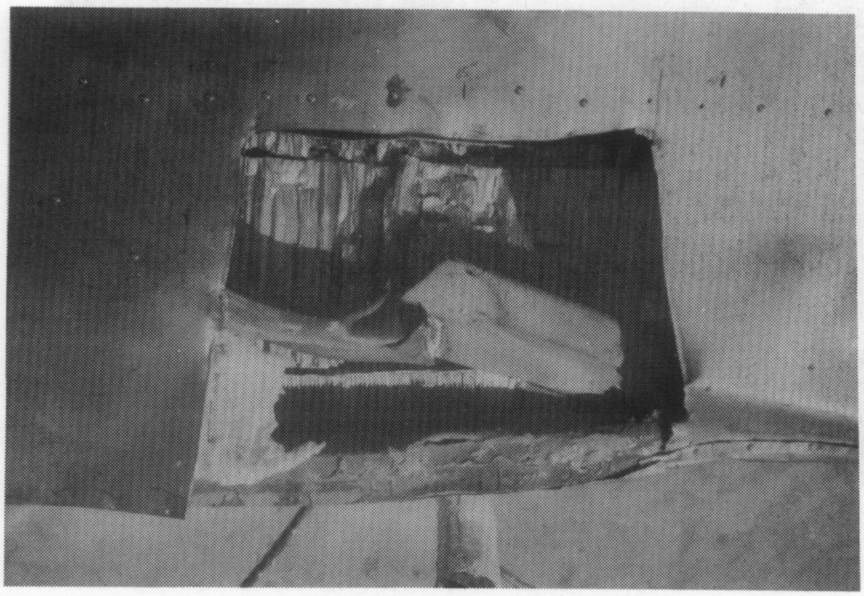


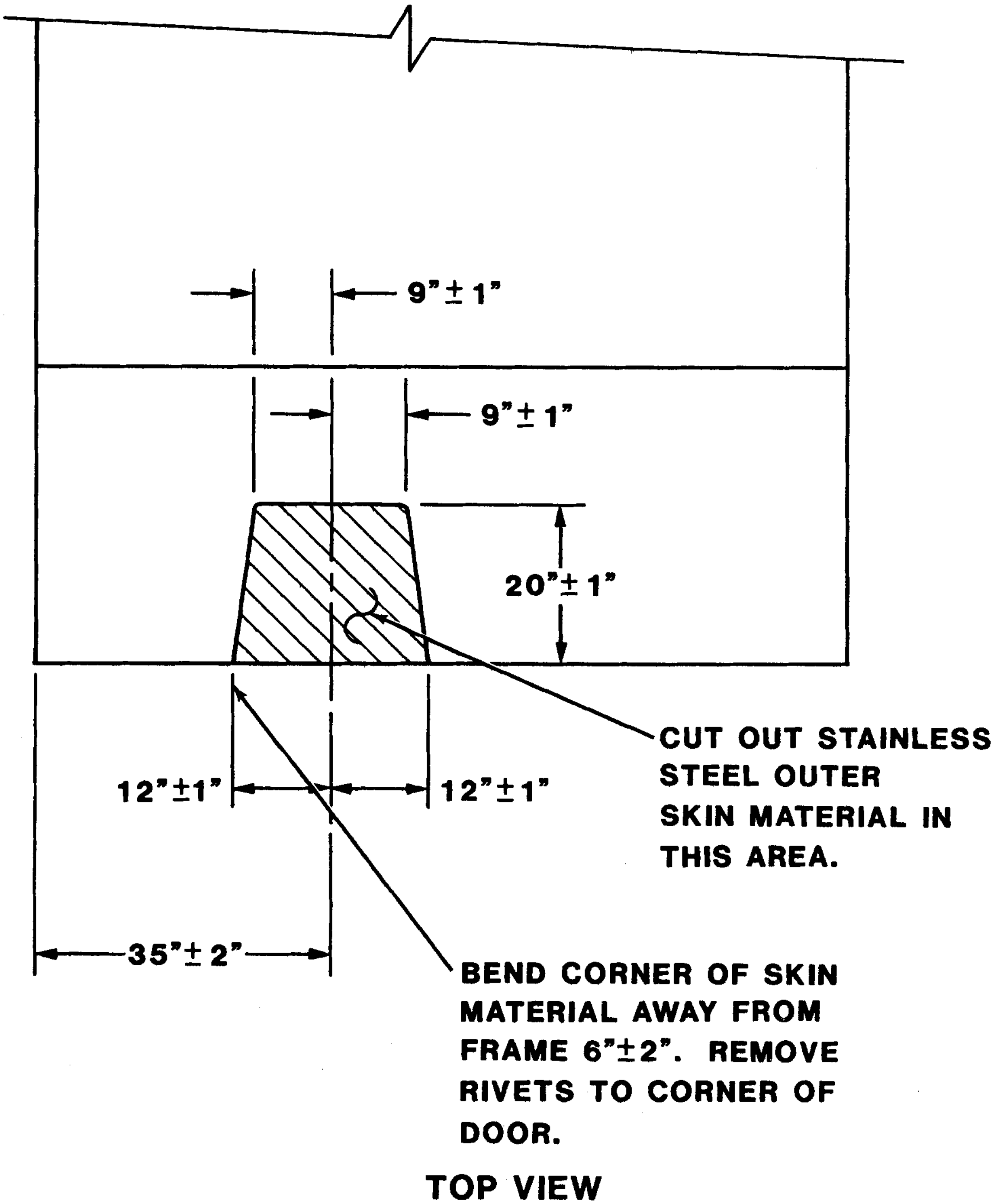
Figure 2.3-2. Inner Surface of Outer Door - Bolt Holes From Unit 0

a. Unit 0 Damage (top view of outer door/body following Filter Puncture Test)



b. Test Article Damage (view rotated 90° counter-clockwise from view of Unit 0 Damage)

Figure 2.3-3. Puncture Damage Model for Outer Door Skin



c. Test Article Damage Dimensions

Figure 2.3-3. Puncture Damage Model for Outer Door Skin (Continued)

2.4 Contents and Dunnage

Material placed into the containment cavity of the Test Article included containers of simulated waste, dunnage, roller floor, thermal heating tape, thermocouples, and passive thermal indicators. Sixteen 55-gallon drums were placed into the containment cavity. Placement of waste containers is illustrated in Appendix A. The bottom eight drums contained 700 ±20 lb of simulated sludge (soil), and the top eight contained 200 ±10 lb of paper. The simulated waste was packaged by first placing the waste materials into double polyethylene bags and then placing the bags into a rigid polyethylene liner within a 55-gallon drum. Levels of confinement of the waste material were sealed by tightly taping the bags, by adhesively cementing the liner lid, or by the clamping ring on the drum compressing a seal on the drum lid. The portion of the roller floor from the Unit 0 tests that fit within the reduced length of the Test Article was included in the model to provide an appropriate thermal mass. Similarly, sheets of plywood were positioned around the waste containers and deflated plastic-lined paper air bags were positioned between the plywood sheets and the containment liner to simulate deflated air bags. Strips of heat tape were wrapped around waste containers to heat the interior of the package prior to the test event. The power was adjusted to 160 watts, i.e., 10 watts average per drum.

3.0 INSTRUMENTATION

The Test Article was instrumented with a combination of active and passive temperature recording devices. Locations for the temperature measurements were chosen to monitor the primary areas of interest during the fire and throughout the cooldown period. Where it was practical, data collection points were selected to be the same as those in the Unit 0 test.

3.1 Thermocouples

Thermocouples used to monitor temperatures in the Test Article were Type K, manufactured by Xactpact No. 401-2104, Inconel 600 sheath, 0.063-in. diameter, 30.5-m (100-ft) long, grounded junction, with attached plug No. 900 and brazing adapter 925-063. To provide sufficient coverage of the regions of interest there were 116 thermocouples placed within the Test Article. The locations for the thermocouples in the Test Article are shown in Appendix A. Thermocouples within the packaging were used to monitor temperature profiles in the sidewalls, at potential hot spots in the outer protective structure, in the outer door, at the inner door seal cavities, at filter housings, at leak test valves, on the foam cap, on the radiation shield, and by the convection seal. Temperatures in the void space between the inner and outer door were also monitored. Flame temperatures within the fire were recorded by 26 ungrounded, stainless steel-sheathed, 0.159-cm (0.0625-in.) diameter, Type K thermocouples mounted on 6.1-m (20-ft) water-cooled towers at four positions in the fire and one 2.13-m (7-ft) tower located in front of the Test Article door (see Figure 3.1-1).

Thermocouple leads from the interior of the Test Article, Figure 3.1-2, were routed out the back end and through the water in the pool. Lengths of the thermocouple leads exposed to the open flames were covered with inorganic insulation for protection, see Figure 3.1-3. Penetrations through the containment liner and the remaining materials in the package were sealed with Sauereisen (a moldable inorganic insulation/sealant) and/or packed with loose insulation material to minimize inleakage of hot combustion products. Locations, methods of installation, routing, penetrations, and sealing methods are described in Ref. 7.

3.2 Temperature-Indicating Paints and Labels

Thermal paints and adhesive backed labels were installed at 30 locations throughout the Test Article to record peak temperatures. The paint was a product of Omega named "Omegalaq (Temperature Indicating Liquid)." The Omegalaq used was sensitive over the range from 66° to 316°C (150° to 600°F). Stick-on labels used were manufactured by Wahl and are referred to as "Temp-plate Temperature Recorders." The Temp-plate Temperature Recorders were sensitive over the range from 43° to 260°C (110°F to 500°F). Locations for the thermal indicators are shown in Ref. 7. The appearance of the paints and labels is illustrated in Figure 3.2-1(a). Both types of indicators were installed at each of the locations marked for placement of the passive thermal recorders. Omegalaq paints were protected from the effects of gases and soot by covering them with a sheet of 0.012-in. stainless steel sheet, Figure 3.2-1(b).

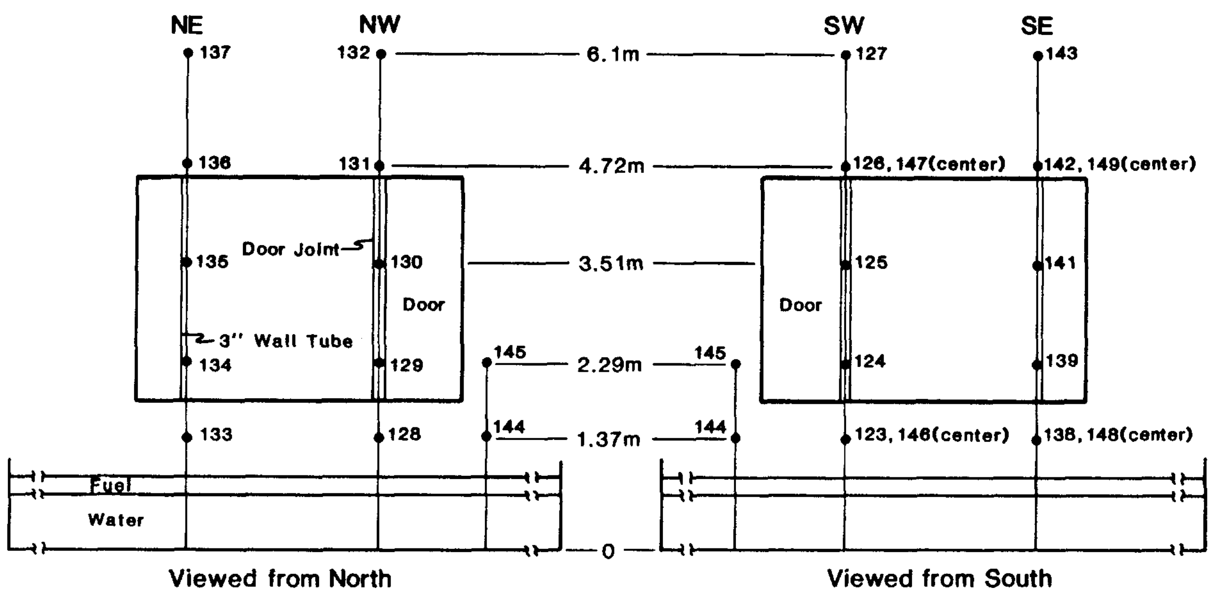


Figure 3.1-1. Location of External Thermocouples

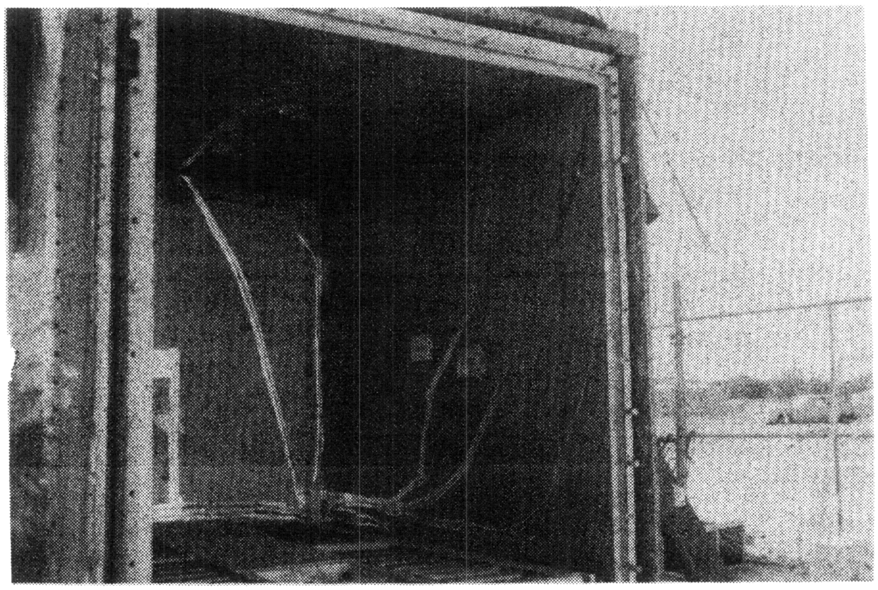


Figure 3.1-2. Containment Liner Thermocouples

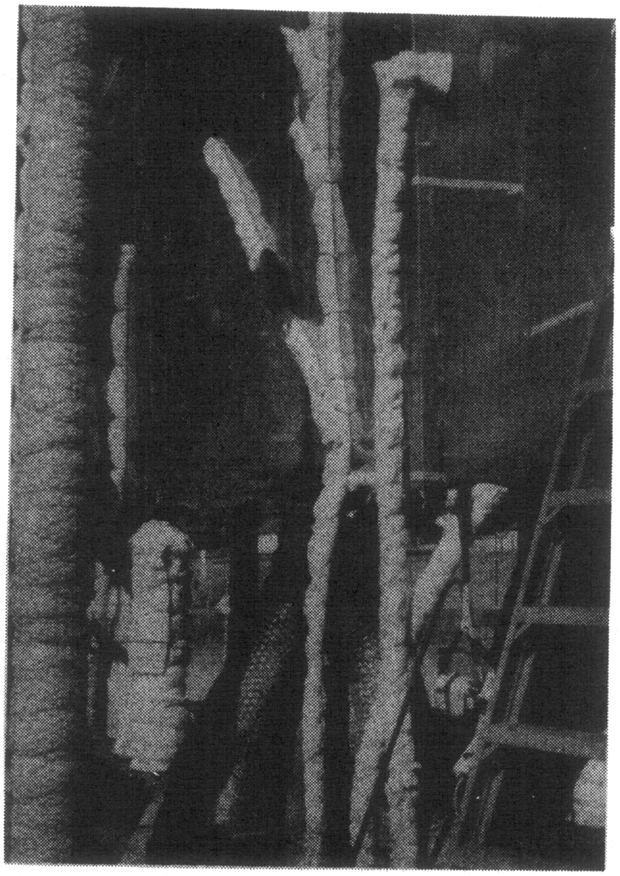
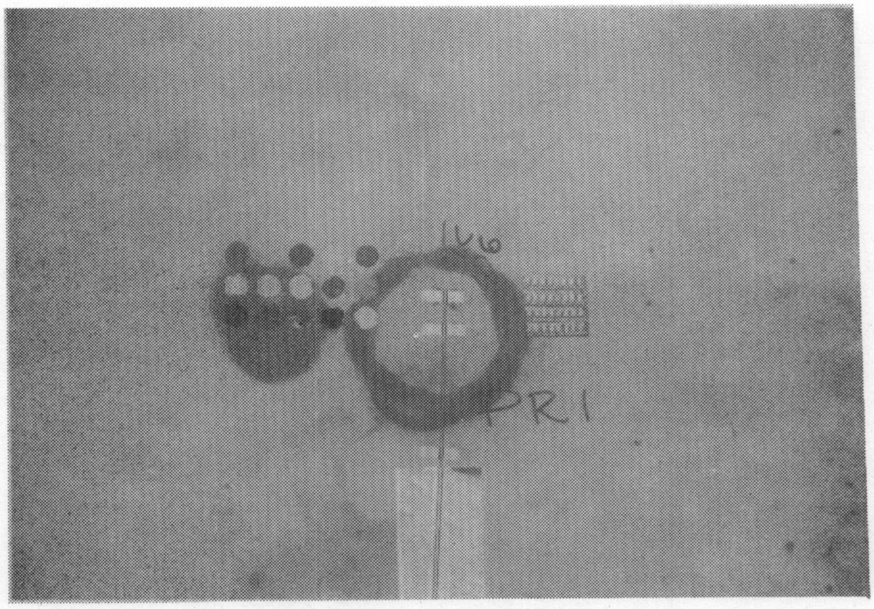
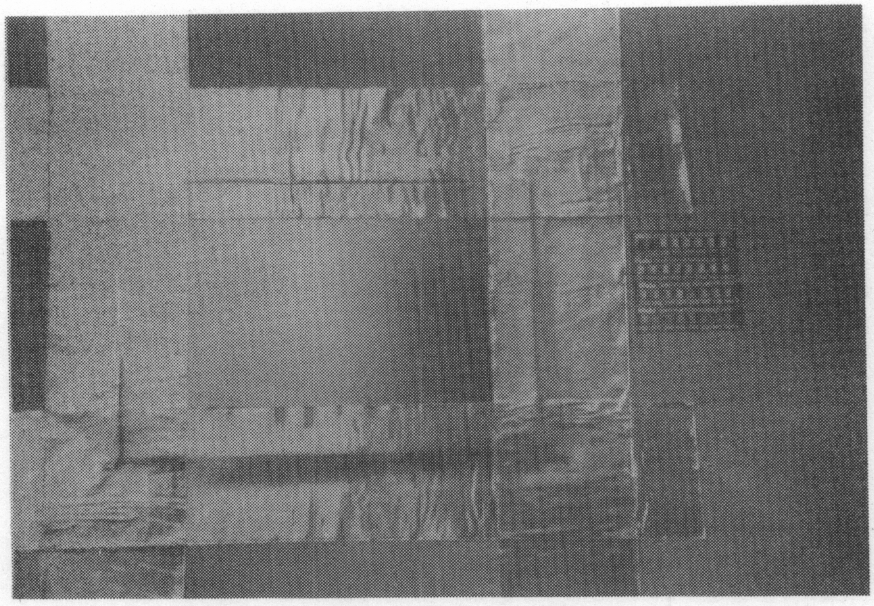


Figure 3.1-3. Protective Cover Over Thermocouple Leads Exposed to Open Flames



a. Omegalaq Paints (left side), Thermocouple (center), Temp-plate Labels (right side).



b. Protective Cover Over Omegalaq Paints

Figure 3.2-1. Typical Installation of Temperature-Indicating Paints and Labels

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4.0 FIRE TEST

4.1 Test Facility

The facility used to conduct the fire test was Sandia National Laboratories' Lurance Canyon Burn Site. This is the same facility that was used for the thermal test of TRUPACT-I, Unit 0, and the test procedure was nearly identical (Ref. 8).

4.2 Test Set-up

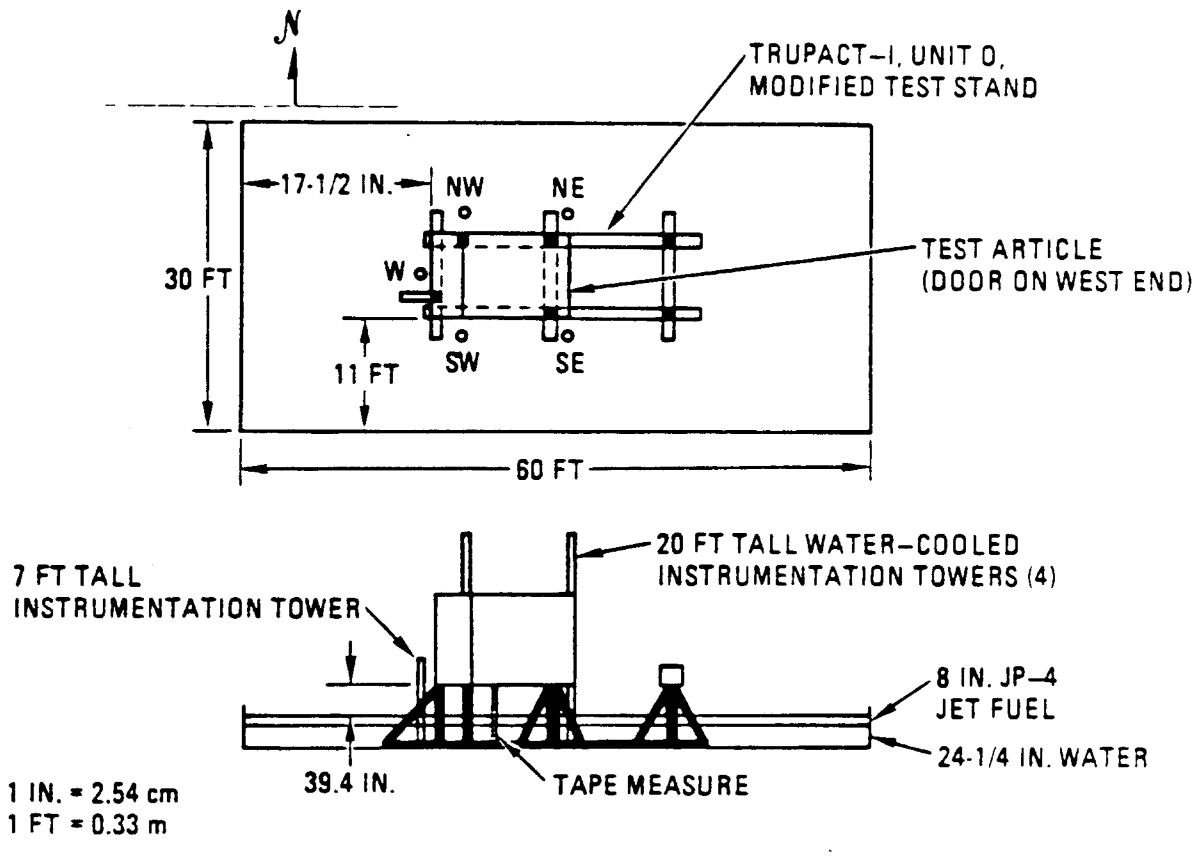
The door end of the Test Article was placed in the same position on the test stand as for the TRUPACT-I, Unit 0 test. The test stand was centered in the 9-m x 18-m (30-ft x 60-ft) open concrete-lined pool and supported the Test Article 1 m (40 in.) above the initial fuel surface. Portions of the test stand exposed to the open flames were protected by wrapping inorganic insulation blankets around the exposed members. The test setup is illustrated in Figure 4.2-1. Also illustrated in this figure are the depths of the water and fuel intended to provide a 32-min burn time in the pool facility, and the locations of the 6-m (20-ft) tall water-cooled instrumentation towers.

Internal heat generation by the waste was simulated by heat tape installed on drums. The heat tape was connected to a variable power supply. Initially a high power setting was used to increase the rate of heating, and 12 hours before test time, the power was reduced to 160 watts to simulate the heat output for the 16 drums of simulated waste. The initial containment liner temperature recorded by the automated data collection system was between 25° and 40°C (77° and 104°F), and the seal cavities initially ranged from 30° to 34°C (87° to 94°F).

Photometric coverage of the event was provided by a combination of fixed and mobile video cameras and by still and motion picture film. There was a fixed position video camera on each of the four sides of the Test Article, and there was one mobile video. Sixteen-mm motion picture cameras were positioned on the left side and in front of the closure end; there was an additional mobile 16-mm camera. One mobile fixed frame 35-mm camera was used to take still photographs.

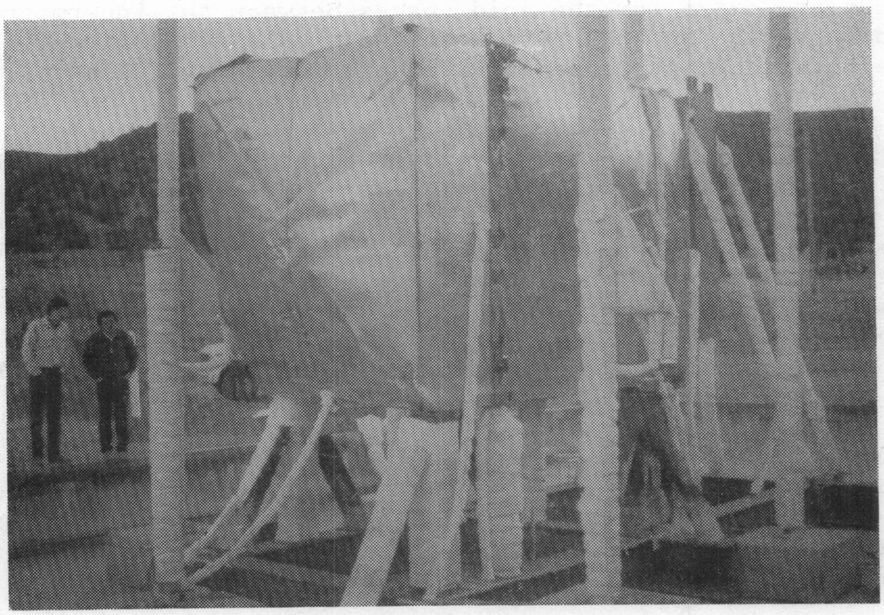
4.3 Test Procedure

The procedure for conducting the thermal test included the following major events: 1) assemble the Test Article, 2) install instrumentation internal and external to the Test Article, 3) position the Test Article in the Pool Fire Facility, 4) attach the instrumentation, 5) fill the Pool Fire Facility with water and fuel, 6) verify that meteorological conditions appear favorable for the test period, 7) activate the instrumentation, 8) ignite the fuel, and 9) record the time from ignition to burnout. Details of the thermal test procedure are contained in Ref. 8.

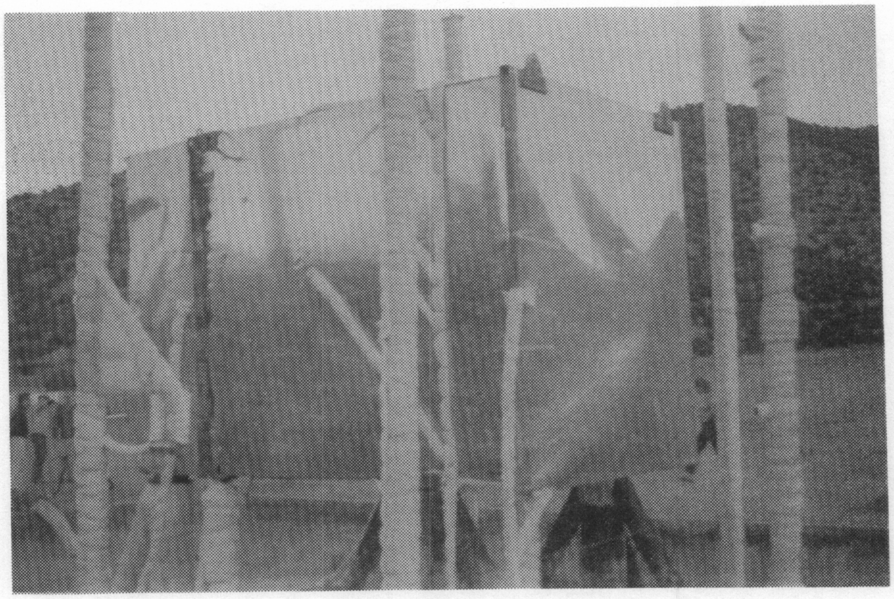


a. Schematic of Test Article Positioned in Pool

Figure 4.2-1. Test Article Thermal Test Set-up



b. Pre-test (viewed from door end)



c. Pre-test (viewed from aft end)

Figure 4.2-1. Test Article Thermal Test Set-up (Continued)

Before the thermal test, it was demonstrated that the leak rate provided by the inner door seal was less than 0.01 atm-cm^3/s (ANSI standard air). A typical leak rate indication was less than 0.004 atm-cm^3/s for the void spaces between the innermost and middle seals, and the outermost and middle seals (recall that there are three concentric seals which provide two void spaces for leak testing).

Before the fire was started, power to heat tape warming the drums of simulated waste was disconnected, and wind speed was verified to be less than 2 m/s with a very good probability that it would remain that low for the duration of the burn. Temperature and thermocouple resistance scans were initiated to record initial temperatures and to check-out the data acquisition system. JP-4 fuel was added to the pool to a depth of 20.32 cm (8 in.) to yield 32 minutes of burn time based on a previously determined burn rate of 0.25 in./min.

Cameras were started and the fuel was electronically ignited. Ignition time was recorded and data were collected for the duration of the burn and until all thermocouple temperatures indicated less than 93°C (200°F). The time at which the flames no longer engulfed the Test Article was recorded.

Essential data, measurements, and system functions were checked and verified by multiple observers, with the Principal Quality Assurance Coordinator for the Transportation System Development Department, Sandia National Laboratories, serving as a witness.

5.0 RESULTS

5.1 Test Environment

The test environment was characterized in terms of flame temperatures, flame velocities, ambient wind conditions, heat fluxes, and burn rate. Only flame temperatures and ambient wind conditions will be discussed here. The other environmental conditions are being analyzed by the test group and will be reported separately. The same fire characterization data was taken during the TRUPACT-I, Unit 0, thermal test. The TRUPACT-I Test Article should have been completely engulfed by the JP-4 fuel fire for 32 minutes. However, a faulty fuel valve at the pool fire test facility resulted in the fire lasting 46 minutes.

Average flame temperatures at individual thermocouple locations ranged from 982°C (1800°F) to 1093°C (2000°F), and instantaneous temperatures varied from 204°C (400°F) to 1371°C (2500°F) depending on time and position in the fire. For the Unit 0 test, average fire temperatures at individual thermocouple locations had ranged from 954°C (1750°F) to 1093°C (2000°F) and instantaneous temperatures had varied from 280°C (500°F) to 1315°C (2400°F).

Individual temperature histories from all thermocouple locations on the towers are shown in Appendix B. Also included in Appendix B are the pool water temperature history and the ambient temperature history.

As in the Unit 0 test, temperature oscillations due to wind effects were more pronounced as the height above the pool increased. The most stable flame temperature location appeared to be at 2.3 m (7 ft 6 in.) on all towers and the most unstable location at 6.1 m (20 ft).

Wind velocity was measured by an anemometer 61 m (200 ft) west of the pool at a height of 2.4 m (8 ft) above the ground. The wind velocity was recorded throughout the entire test to determine if it was less than the required 2 m/s (Ref. 8) for the test duration (see Figure 5.1-1). The average wind velocity over the duration of the fire was 1.68 m/s; therefore, the 2 m/s criterion was met. The wind velocity started to increase at approximately 30 minutes and increased to a maximum value of 4.2 m/s at 37 minutes. The one sigma standard deviation was 0.95 m/s. During the Unit 0 test (Ref. 1), the average wind speed was 1.24 m/s, with a maximum speed of 3.7 m/s. The one sigma standard deviation was 0.71 m/s.

5.2 Test Time Observations

The Test Article was engulfed in flames at 7:46 am on February 26, 1986. Flames ceased to engulf the Test Article at 8:32 am, resulting in a total engulfment time of 46 minutes.

Figure 5.2-1 shows the fire just after ignition. The Test Article cannot be seen because of complete engulfment by flames. At times during the test, winds blew the flames to the side exposing the Test Article, Figure 5.2-2.

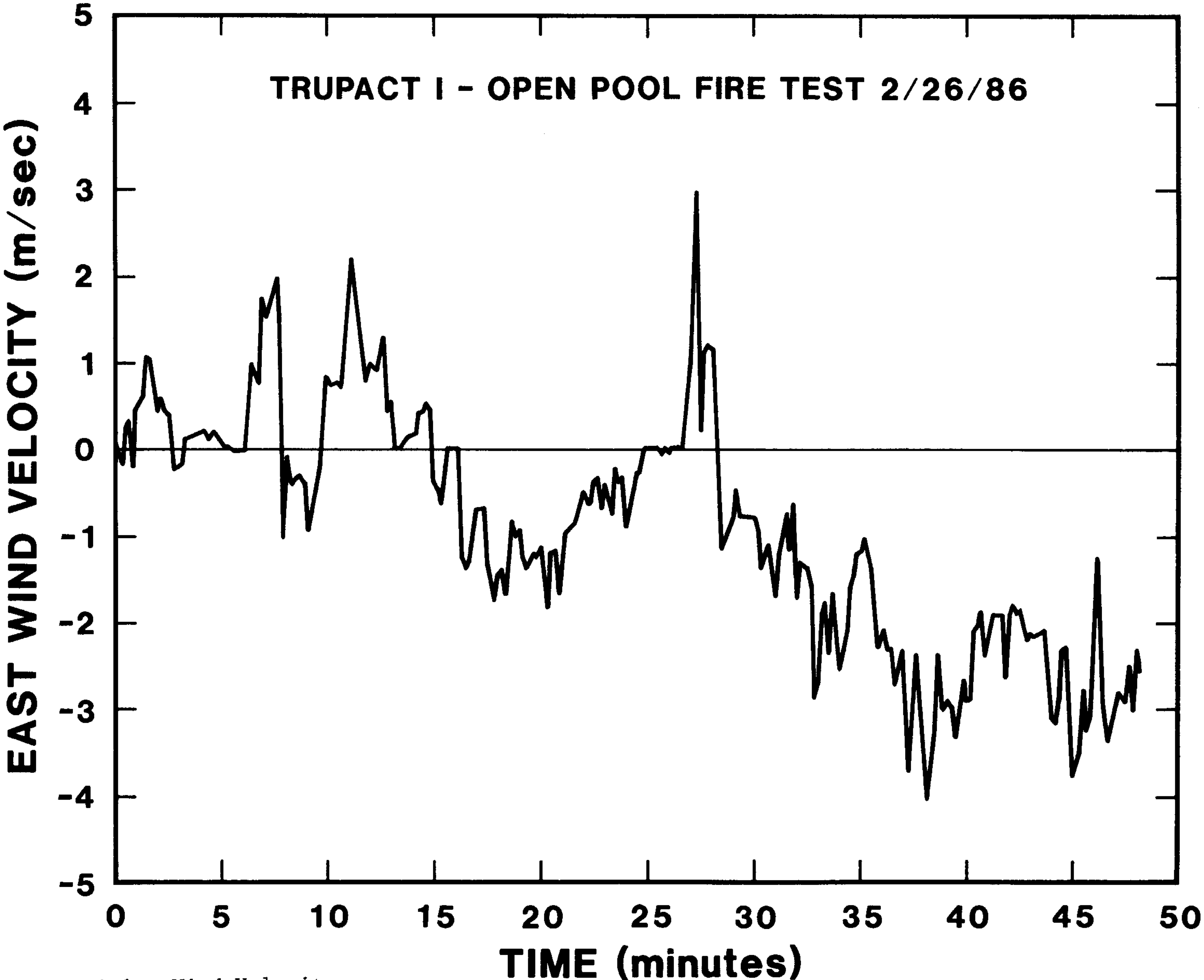


Figure 5.1-1. Wind Velocity

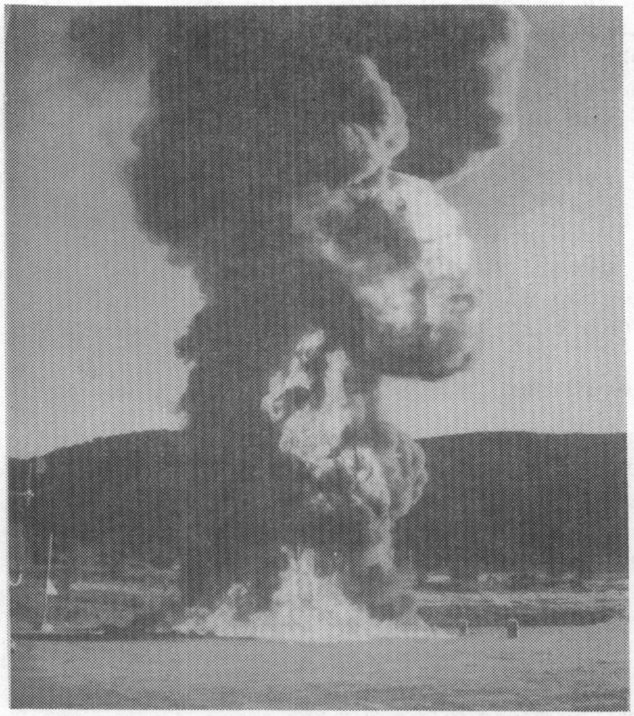


Figure 5.2-1. Test Article Completely Engulfed by Flames

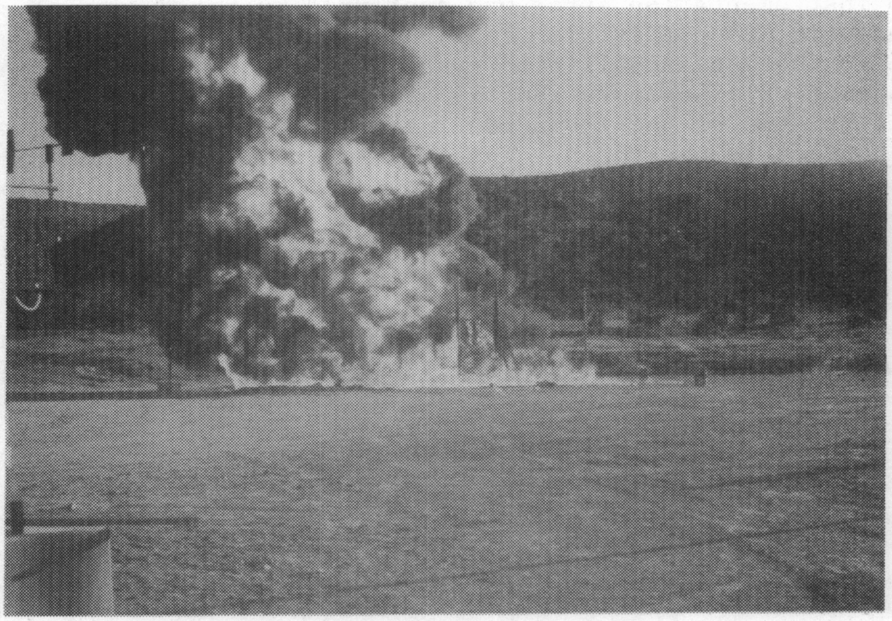


Figure 5.2-2. Wind Blowing Flames Away From Test Article

After flames ceased to engulf the Test Article, flames were still visible at numerous locations on the outer door and body. Heavy black smoke coming from the top of the outer door indicated that organic materials continued to burn (Figure 5.2-3). At the crushed corner of the outer door the heated structural members produced a white-hot glow (Figure 5.2-3). Molten material, later found to be aluminum, could be seen dripping from holes in the exterior stainless steel skins of the outer door and body.

Two hours after the fire self-extinguished, smoke was still coming out of the top of the outer door. Figure 5.2-4 shows the Test Article post-test after complete cooldown of the hardware.

5.3 Temperatures

Thermocouples interior to the Test Article indicated peak temperatures significantly greater than temperatures of adjacent passive thermal indicators, see Table 5.3-1. Oven tests had been conducted prior to the fire test to confirm the response of the passive thermal indicators so an instrumentation error was suspected. The general appearance of the Test Article drums, dunnage, and polyurethane foam substantiated the assumption that the lower temperatures recorded by the passive indicators reflected the actual test environment. Figure 5.3-1 shows the temperature history of thermocouples at the same location on the containment liner and puncture plate. The containment liner response is almost identical to the puncture plate response. A significant temperature difference would be expected between the two temperature records due to the presence of insulating polyurethane foam between them.

An instrumentation error was confirmed by the Thermal Test and Analysis Group (Division 7537) at Sandia. The problem was found to be in the data acquisition system. A relay shorted in one of the thermocouple scanners shortly after ignition of the fire, causing all but one of the grounded (interior) thermocouples to record incorrect temperatures. The fire environment thermocouples were unaffected since they were ungrounded. Temperature histories from thermocouples within the Test Article are not presented in this report; only passive thermal indicator data are presented. The locations of thermal indicators are given in Table 5.3-2.

Results from the Omegalaq temperature indicators and from the Wahl temp-plate indicators are listed in Table 5.3-2. Comparison of the Omegalaq and Wahl indicators at the same locations yielded a maximum temperature difference of 24°C (75°F) at locations PR2 and PR3. In general, the thermal indicators are in good agreement. The few instances where differences are large can be attributed to small differences in indicator locations (a few inches) and to difficulty in reading the Omegalaq paints. The accuracy of the Omegalaq paints is ±25°F for temperatures below 400°F and ±50°F for temperatures above 400°F. The accuracy of the Wahl temp-plate indicators was ±10°F below 350°F and 20°F above 350°F.

The response of each lot of Omegalaq and Wahl indicators was tested prior to installation in the Test Article and after the thermal test to verify accuracy.

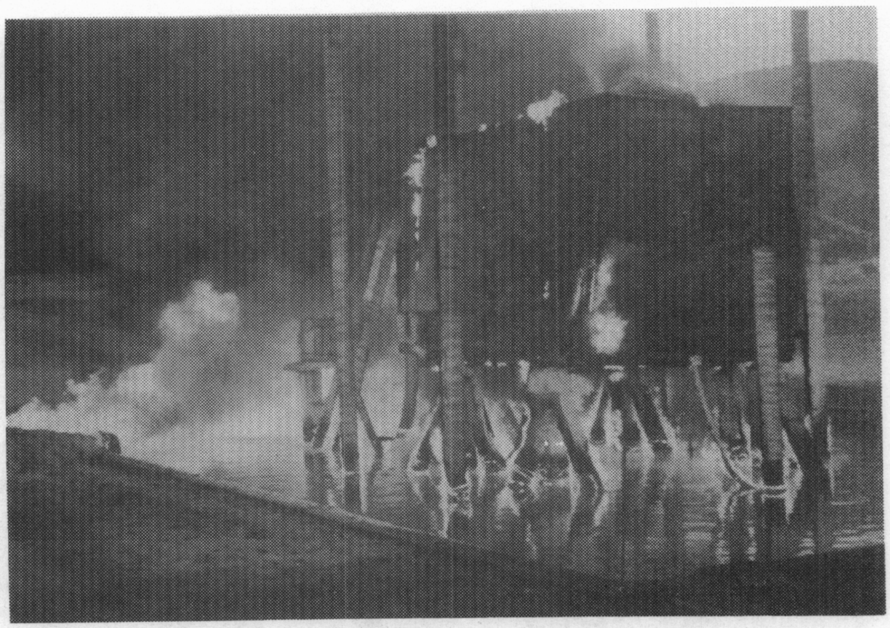


Figure 5.2-3. Outer Door Shortly After JP-4 Fuel Consumed

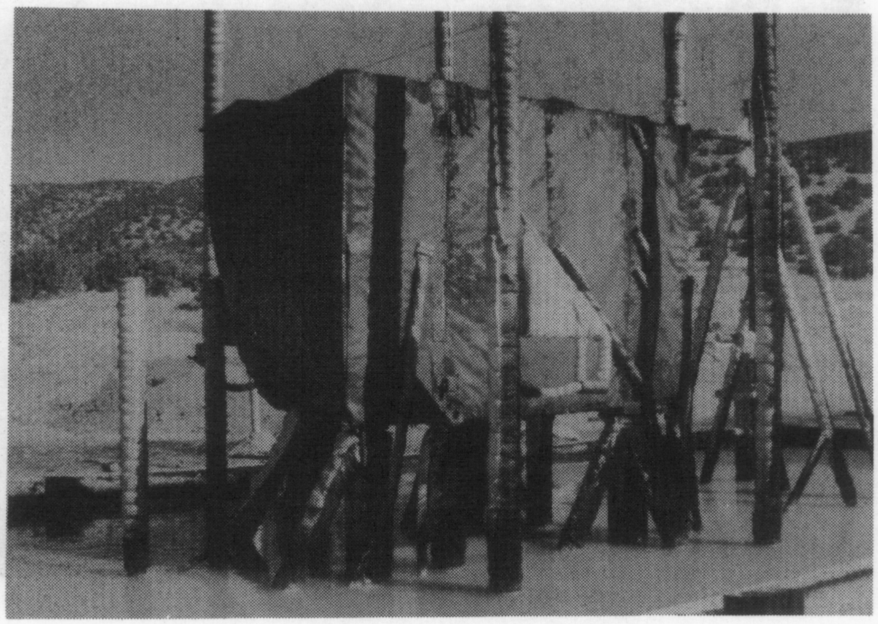


Figure 5.2-4. Test Article, Post-test (Cooldown Complete)

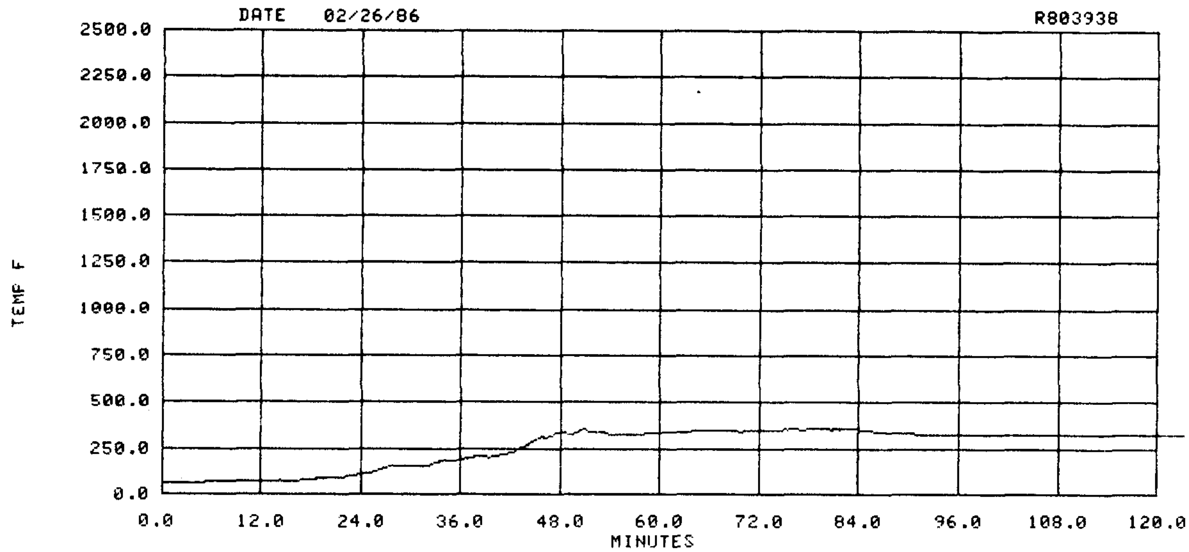
TABLE 5.3-1

Peak Temperature Recorded by
Thermocouples Versus Passive Thermal Indicators

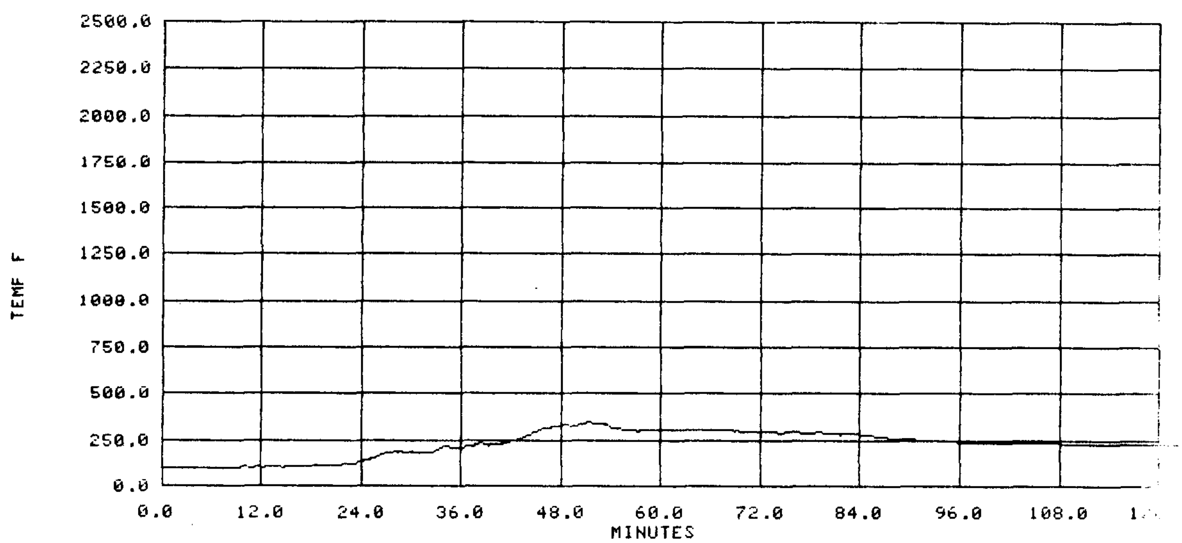
Location	Thermocouples, °F [a]	Passive Indicators [b]	
		Paint, °F	Label, °F
Outer Door, interior	400	550	≥ 500
	368	375	370
	626	≥ 325	≤ 350
Outer Door, exterior	333	250	250
	441	250	270
	394	≥ 300	340
Inner Door, interior	362	300	290
	358	275	250
	333	225	220
Containment Liner	321	≤ 150	130
	345	150	160
	359	275	200
	355	150	170
(Aft)	317	175	170
Top Right Drums	364	150	170
	337	150	170
Bottom Right Drums	324	150	130
	304	150	130
Top Left Drums	365	150	170
	364	150	170
Bottom Left Drums	339	150	130

a. Peak thermocouple temperatures listed in this table indicate incorrect maximums measured by the data recording system. See paragraph 5.3 for an explanation of the source of the error.

b. ≤indicates that temperature was less than value listed.
≥indicates that temperature was greater than value listed.



a. Thermocouple 77 (Puncture Plate)



b. Thermocouple 78 (Containment Liner)

Figure 5.3-1. Temperature Distribution Through TRUPACT Body, Right Side Center

TABLE 5.3-2

Temperature Differences Between Omegalaq and Wahl Indicators at Same Locations

Location	Location Description	Omegalaq Reading °F	Wahl Reading °F	Difference (Δ°F)
PR1	INNER CAVITY, CENTER OF AFT WALL	175	170	5
PR2	INNER CAVITY, TOP OF CENTER OF PANEL	≈275	200	75
PR3	INNER CAVITY, TOP CENTER	≈275	200	75
PR4	INNER CAVITY, RIGHT SIDE OF CENTER OF PANEL	≈150	160	10
PR5	INNER CAVITY, RIGHT SIDE CENTER	≈150	160	10
PR6	INNER CAVITY, BOTTOM OF CENTER OF PANEL	≤150	130	20
PR7	INNER CAVITY, BOTTOM CENTER	≤150	120	30
PR8	INNER CAVITY, LEFT SIDE OF CENTER OF PANEL	≈150	170	20
PR9	INNER CAVITY, LEFT SIDE CENTER	≈150	160	10
PR10	INNER DOOR, TOP RIGHT CORNER OF INTERIOR	≈300	280	20
PR11	INNER DOOR, TOP LEFT CORNER OF INTERIOR	300	290	10
PR12	INNER DOOR, CENTER OF INTERIOR	275	250	25
PR13	INNER DOOR, BOTTOM RIGHT CORNER OF INTERIOR	225	220	5
PR14	INNER DOOR, BOTTOM LEFT CORNER OF INTERIOR	≈200	190	10
PR15	INNER DOOR, TOP LEFT CORNER OF EXTERIOR	275	≤350	--
PR16	INNER DOOR, TOP RIGHT CORNER OF EXTERIOR	≈300	340	40
PR17	INNER DOOR, CENTER OF EXTERIOR	250	270	20
PR18	INNER DOOR, BOTTOM LEFT CORNER OF EXTERIOR	250	210	40
PR19	INNER DOOR, BOTTOM RIGHT CORNER OF EXTERIOR	250	250	0
PR20	OUTER DOOR, TOP RIGHT CORNER OF INTERIOR	325	≤350	--
PR21	OUTER DOOR, TOP LEFT CORNER OF INTERIOR	325	≤350	--
PR22	OUTER DOOR, CENTER OF INTERIOR	375	≈370	5
PR23	OUTER DOOR, BOTTOM RIGHT CORNER OF INTERIOR	≈550	≥500	--
PR24	OUTER DOOR, BOTTOM LEFT CORNER OF INTERIOR	300	310	10
PR25	DRUM 2A	≈150	170	20
PR26	DRUM 2B	≈150	170	20
PR27	DRUM 1D	≈150	130	20
PR28	DRUM 1E	≈150	130	20
PR29	DRUM 2G	≈150	≈170	20
PR30	DRUM 2H	≈150	≈170	20

5.4 Leak Rates

Leak rates of the inner door seals, filter installation seals, and quick-connect valve seal on the Test Article were measured both pre-test and post-test to determine if the maximum total leak rate (sum of the leakage from the inner door seals, valve seal, and filter seals) was less than the maximum allowable 0.01 atm-cm^3/s. Since the leak rate measurement technique is different for the inner door seals and for the filter and valve seal, the leak rate measurements are discussed separately.

5.4.1 Measurement of Leak Rate From Inner Door Seals

The leak rates were determined by evacuating the cavity between a pair of seals to approximately 0.05 torr and then recording the time necessary for a pressure rise of 1 torr. A schematic of the seal leak testing apparatus is shown in Figure 5.4-1. This method measures the actual gas leakage through both seals forming the cavity as well as any outgassing from the seals or other materials inside the cavity, and thus provides a conservative measurement for the leak rate from one seal.

Temperatures of the metal adjacent to the seals are used in calculating seal leak rates. Temperatures were measured prior to the thermal test using a Doric Model 412A temperature recorder. The data acquisition system malfunctioned, see Section 5.3, so the pre-test temperature was used in leak test calculations made after the pool fire test. Using the initial seal temperature to calculate the seal leak rates provides a bounding estimate of the leak rate since post-test temperatures would be higher. This can be explained by inspecting the equation used to calculate the leak rates (Ref. 9).

$$\text{Seal Leak Rate (atm-cm}^3\text{/s)} = \frac{(1\ \text{torr})\ (537°\text{R})}{t_{avg}\ (760\ \text{torr/atm})} \left(\frac{14.7}{P_{amb}}\right) \left(\frac{V_s}{T_{seal}} + \frac{V_t}{T_{amb}}\right)$$

Where

- P_{amb} = ambient pressure (psia)
- T_{seal} = seal temperature (°R)
- T_{amb} = ambient temperature (°R)
- t_{avg} = average time for a 1 torr rise in pressure (sec)
- V_s = volume of seal interspace (in.^{3})
- V_t = volume of tubing (in.^{3})

Note that the seal temperature, T_{seal}, is in the denominator of the equation. As the value of T_{seal} gets smaller, the leak rate gets larger. Calculated seal leak rates are shown in Table 5.4-1.

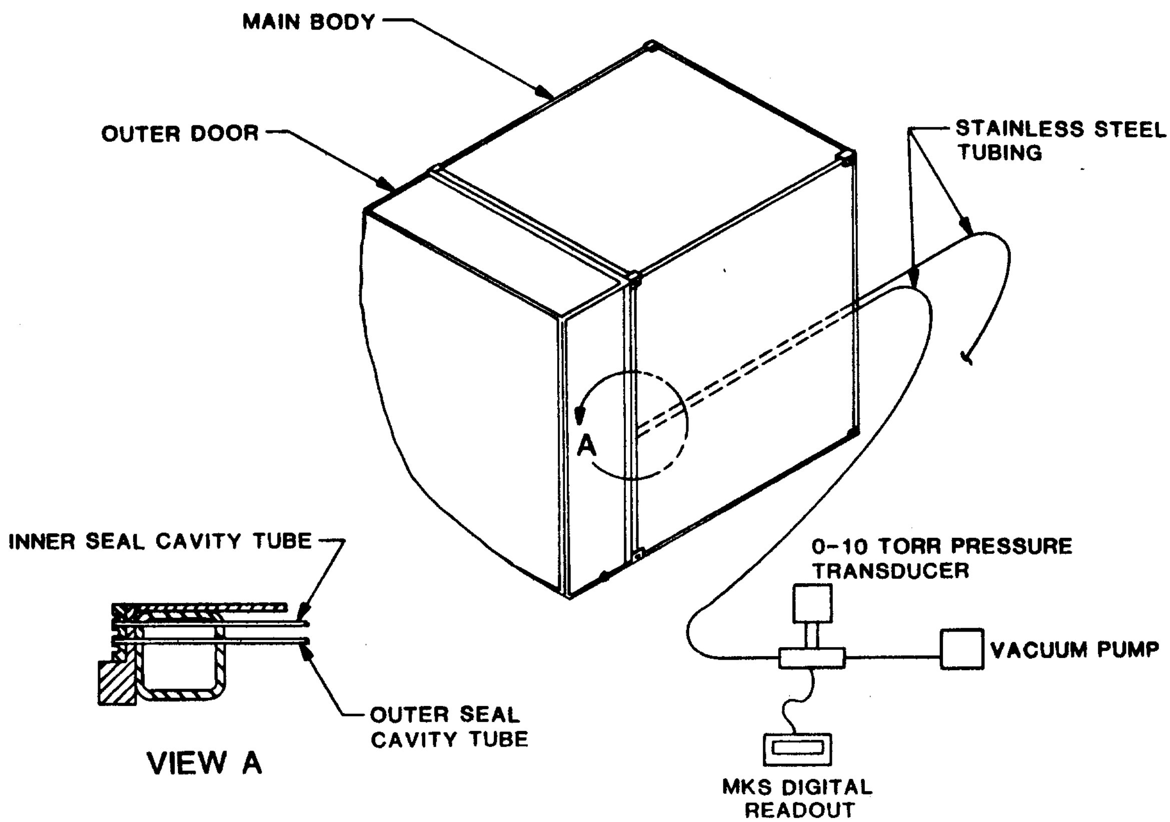


Figure 5.4-1. Inner Door Seal Leak Test Equipment Schematic

TABLE 5.4-1
Inner Door Seal Leak Rates[a]

Date	Pair of Inner Seals ($atm\text{-}cm^3/s$)	Pair of Outer Seals ($atm\text{-}cm^3/s$)
Pre-test 2/25/86	5.4×10^{-3}	5.8×10^{-3}
Post-test[b] 2/27/86	4.1×10^{-3}	4.6×10^{-3}

[a]Leak rates listed resulted from measurements taken after lengthy periods of evacuating the seal interspaces. Lengthy pumpdowns are required to remove moisture and to minimize outgassing from the silicone seals. The effect of outgassing from silicone seals has been demonstrated in the laboratory by performing a pressure-rise test immediately followed by a helium leak test. The helium leak test indicated no leakage to a sensitivity of 10^{-7} $atm\text{-}cm^3/s$ whereas the pressure-rise test gave results in the 10^{-3} $atm\text{-}cm^3/s$ range. The test goal is to demonstrate that leakage is less than 0.01 $atm\text{-}cm^3/s$, not to measure an absolute value.

[b]Lower leak rates post-test are assumed to be a result of reduced outgassing from the seals. The seal performance probably did not improve.

5.4.2 Measurement of Leak Rate From Filter Installation

There are normally four filters installed in the inner door. Pre-test, the filter cover on one of the filter housings could not be removed due to minor deformations resulting from the Unit 0 puncture test attacking the inner door filters and seals. Hence, three filters from different manufacturers were installed and tested in the Test Article. Leakage around a filter cartridge is prevented by a silicone compression seal on the inlet end of the filter.

The leak rate of the filter seals was measured using a mass spectrometer leak detector and Bureau of Mines high-purity, Grade A (99.995 percent pure) helium tracer gas. The filter installation and location where leak test apparatus are attached are shown in Figure 5.4-2. The cover plug assembly was removed and a mass spectrometer was attached. The pipe plug was then removed and the void space between the filter and filter housing was pressurized with helium to slightly greater than atmospheric pressure. The vacuum pump in the mass spectrometer was used to evacuate the void space inside the filter cartridge and inside the filter housing after the opening of the filter inlet was plugged with vacuum putty.

Of the three filters used in the Test Article, only the Matheson filter qualified for post-test investigation. Pre-test leak checks indicated that the Balston and Pall filter installation seals had not been, and could not be, properly installed. The results of the leak tests for the Matheson filter were:

Pre-test	No detectable leak to a sensitivity of 2.3×10^{-10} atm-cm^3/s (He).
Post-test	No detectable leak to a sensitivity of 1.8×10^{-9} atm-cm^3/s (He).

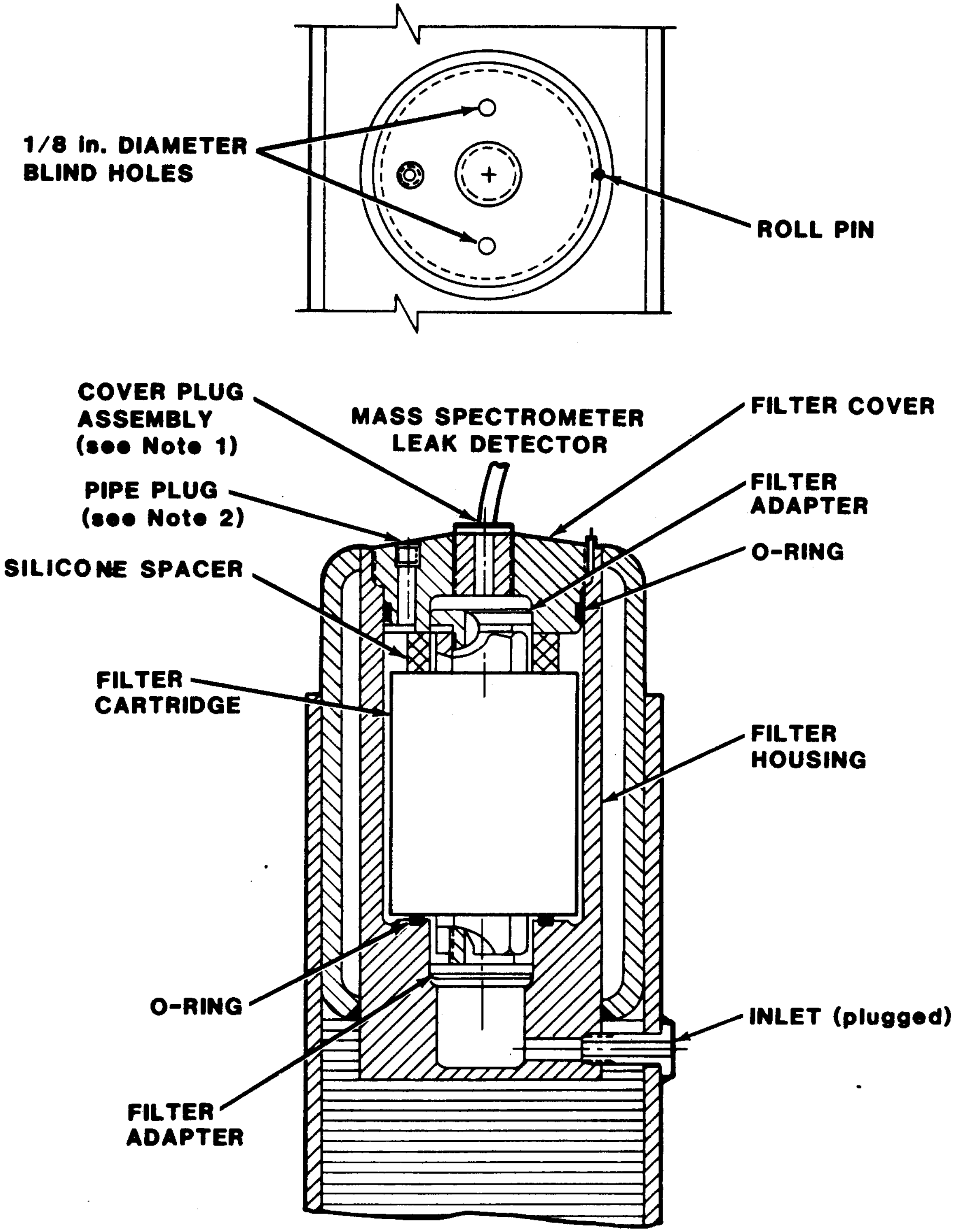
5.4.3 Measurement of Leak Rate From Quick-connect Valve Seal

The procedure for determining the leak rate of the seal in the quick-connect valve was similar to the procedure used for the filter seals. Each quick-connect valve was removed from TRUPACT-I and placed in a helium-pressurized plastic bag, Figure 5.4-3. The interior of the valve was evacuated, and the presence of tracer gas was measured with the mass spectrometer.

Four quick-connect valves were installed in the Test Article and leak tested pre- and post-test. Two quick-connect valves contained a silicone O-ring seal and the other two contained a Viton O-ring seal. The results of the leak tests are shown in Table 5.4-2.

5.5 Disassembly

Components of the Test Article were disassembled and examined to determine the effectiveness of the design changes made during the redesign. The outer door was dissected to examine the post-test condition of the stainless steel outer skin, aluminum honeycomb, Kevlar in the puncture panel system, welded stainless steel



NOTE 1: MASS SPECTROMETER LEAK DETECTOR ATTACHED TO THIS THREADED HOLE AFTER REMOVAL OF COVER PLUG.

NOTE 2: HELIUM INJECTED INTO THIS THREADED HOLE AFTER REMOVAL OF PIPE PLUG.

Figure 5.4-2. Filter Installation (Matheson Gas Products) Leak Test Equipment Schematic

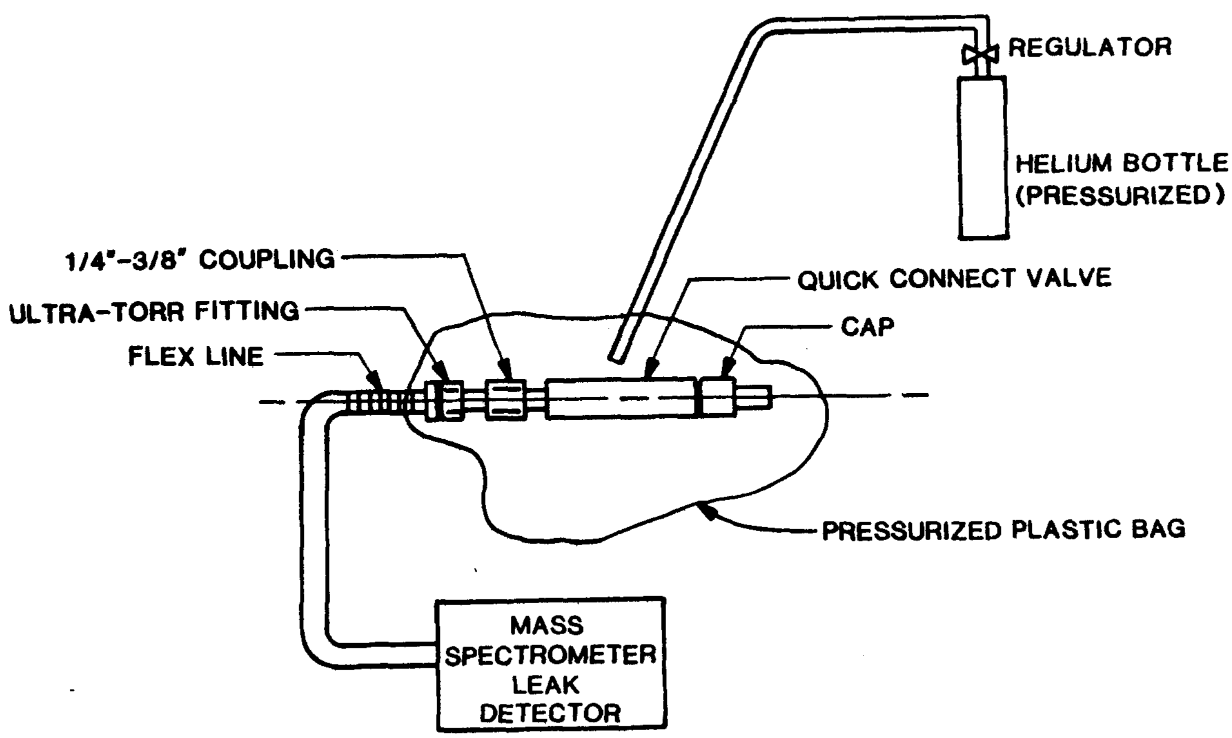


Figure 5.4-3. Quick-Connect Valve Seal Leak Test Equipment Schematic

TABLE 5.4-2

Quick-connect Valve Seal Leak Rates

Valve Seal	Leak Rate* ($atm\text{-}cm^3/s$, He)
Pre-test	
Viton #1, Viton #2	No detectable leak rate to a sensitivity of 1.28×10^{-9}
Silicone #1, Silicone #2	No detectable leak rate to a sensitivity of 1.28×10^{-9}
Post-test	
Viton #1	No detectable leak rate to a sensitivity of 3.55×10^{-10}
Viton #2	No detectable leak rate to a sensitivity of 3.55×10^{-10}
Silicone #1	No detectable leak rate to a sensitivity of 3.55×10^{-10}
Silicone #2	No detectable leak rate to a sensitivity of 3.55×10^{-10}

*For dry air at 25°C, and for pressure differential of 1 atm against a vacuum of 10^{-2} atm or less (Ref. 9).

honeycomb, stainless steel sheet on the inner surface of the outer door (foam cap), structural framework, insulation thermal radiation shield, and furnace seal. The inner door was similarly examined to investigate the condition of the adhesive used to laminate the sandwich construction. Inner door seals and quick-connect valves for testing seals and for containment sampling were tested to assure that acceptable leak rates were maintained and that there was no visual evidence of thermal degradation. The contents and the containment liner were also inspected for evidence of thermal damage. Stainless steel skins, insulation and Kevlar in the body of the Test Article were disassembled and examined to determine their effectiveness in providing thermal barriers to minimize heat input to the polyurethane foam and ultimately to the inner door seals.

5.5.1 Outer Door

Stainless Steel Outer Skin

The stainless steel skin remained intact throughout the fire test and provided significant resistance to thermal input. There were numerous small holes through the stainless steel skin on the front end and on the sides close to the bottom of the package, Figure 5.5-1. Molten aluminum had been dripping from these holes during and immediately following the fire and could be seen hanging from the holes in the form of stalactites after cooldown, Figure 5.5-2. The largest hole through the skin was located on the outer surface at the lower left corner crushed in the center-of-gravity-over-corner 1-m (30-ft) drop test. The hole measured 0.3 m (12 in.) high and 0.23 m (9 in.) wide. Flame temperatures measured during the fire test were below the melting temperature of stainless steel. However, there was a corrosive reaction between the stainless steel and the molten aluminum that involved diffusion and subsequent dissolution of the stainless steel.

Rivets used to attach the skins to the outer door frame kept the skins securely attached with the exception of a section along the right vertical edge at the door/body interface. In this location there was substantial shrinkage of the 0.03-in. stainless steel skin and the skin material was pulled from under the heads of about half of the rivets or had pulled the rivets out of the frame, Figure 5.5-3.

Aluminum Honeycomb

Aluminum in the core and facesheets of the 49.5-cm (19.5-in.)-thick bonded honeycomb in the outer region of the outer door had melted. During disassembly a few pieces of metal could be found and most of them looked like aluminum. Skeletal honeycomb cells remained visible but there was little or no aluminum in the matrix. A hard brittle skeleton of aluminum oxide remained in the form of the original materials. A portion of the aluminum had pooled in the lower region of the outer door and mixed with other materials to form a mass of charred materials, Figure 5.5-4. On the left side the mass was about 1.1 m (42 in.) high, while in the middle and to the right side, the mass was approximately 0.89 m (35 in.) high. Aluminum was found on the bottom of the door between the exterior skin and the Kaowool insulation.

Kevlar

Kevlar remaining in the outer door appeared black and was totally delaminated. In some areas of the Kevlar all 44 of the original layers had been charred away, Figure 5.5-5; in other areas there were 19 layers of Kevlar remaining. Approximately one-fourth of the surface of the stainless steel puncture panel was visible where the Kevlar had been totally consumed. Figure 5.5-6 maps out these regions. Table 5.5-1 gives a brief description of the areas shown in Figure 5.5-6.

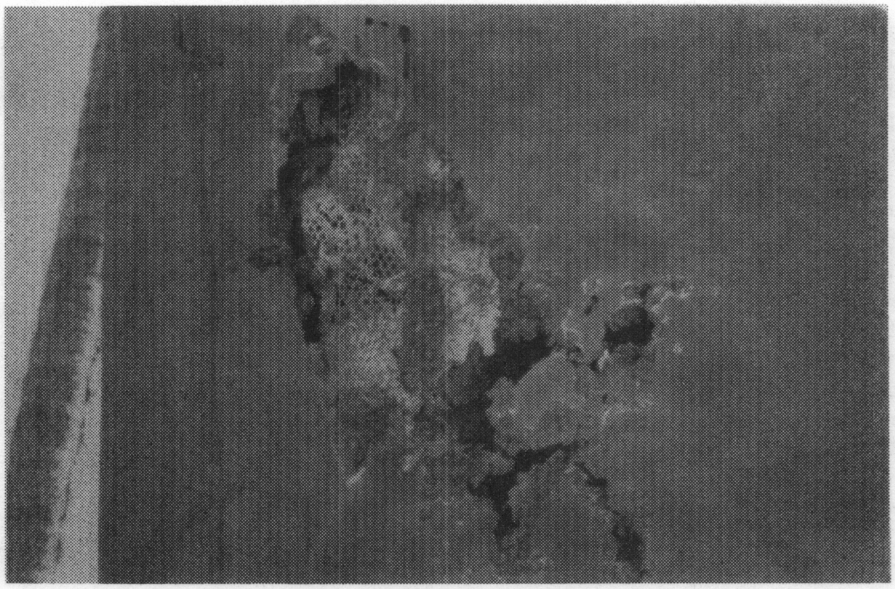


Figure 5.5-1. Condition of Outer Door Stainless Steel Skin, Post-test

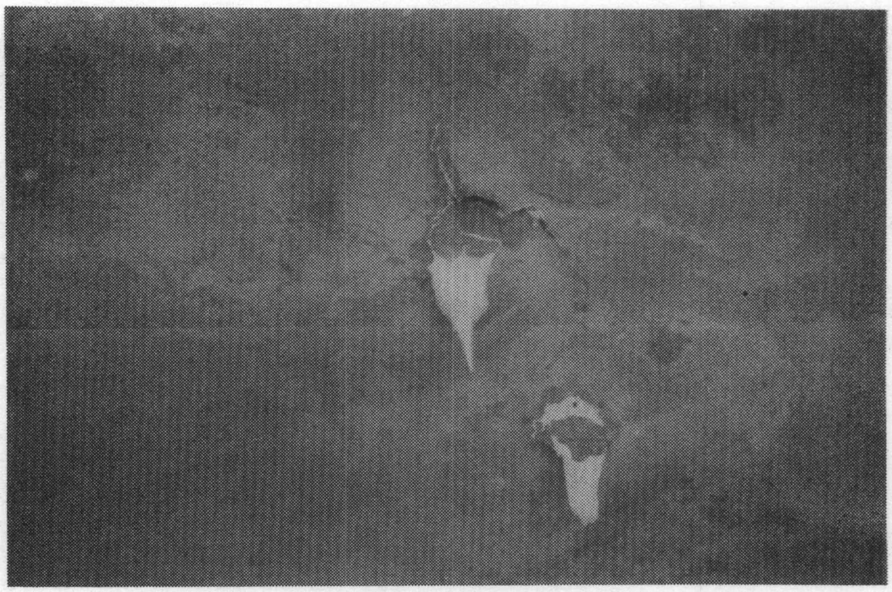


Figure 5.5-2. Solidified Aluminum Through Outer Door Stainless Steel Skin, Post-test

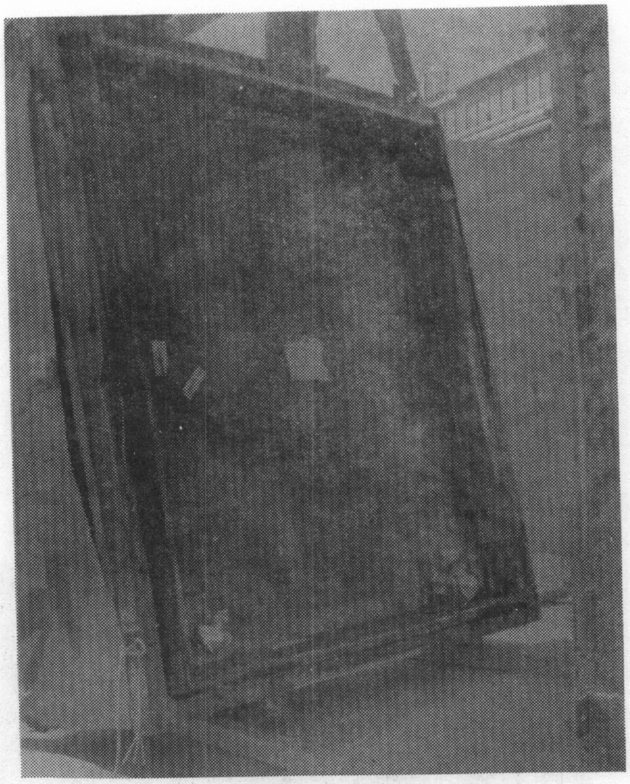


Figure 5.5-3. Side View of Outer Door Skin Pulled Away

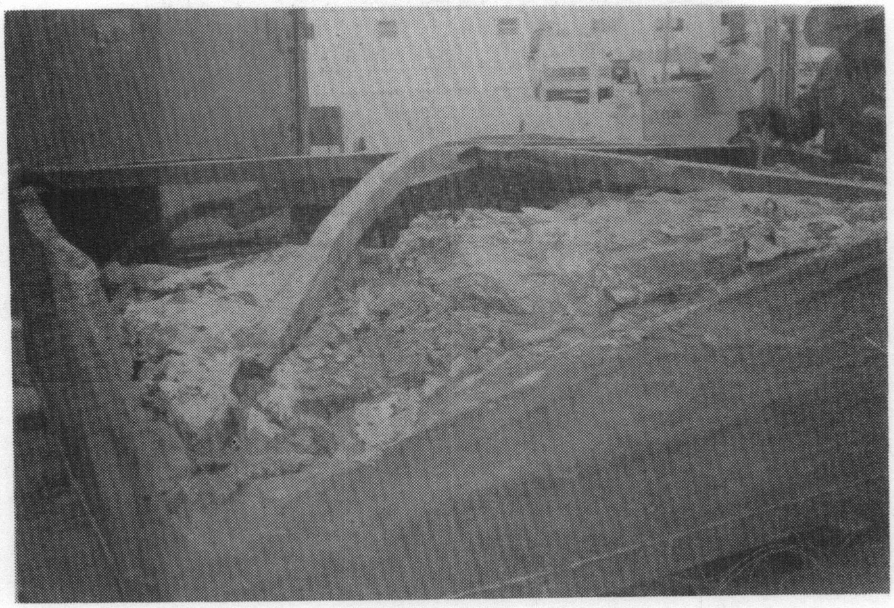


Figure 5.5-4. Side View of Condition of Outer Door Aluminum Honeycomb Post-test

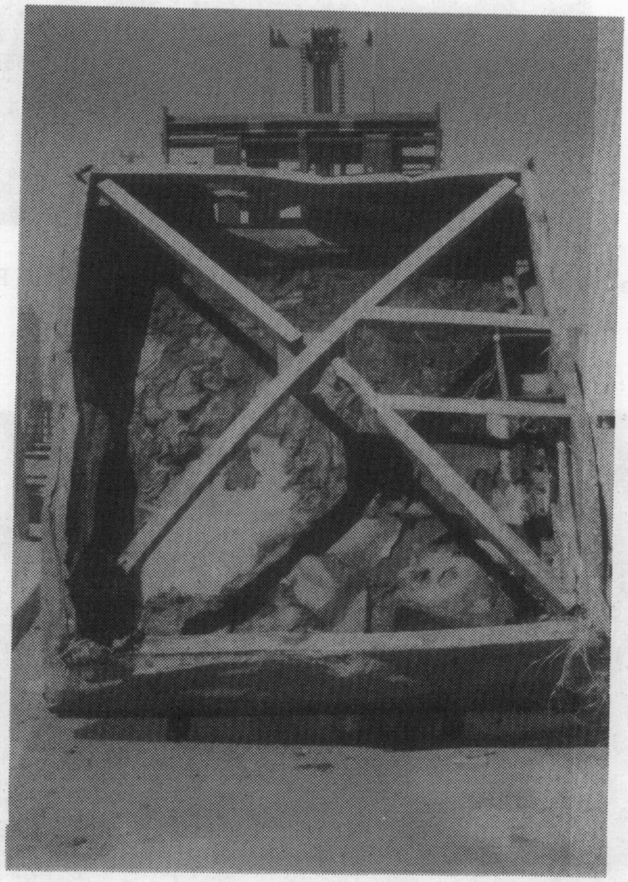


Figure 5.5-5. Front View of Outer Door, Post-test Condition of Kevlar

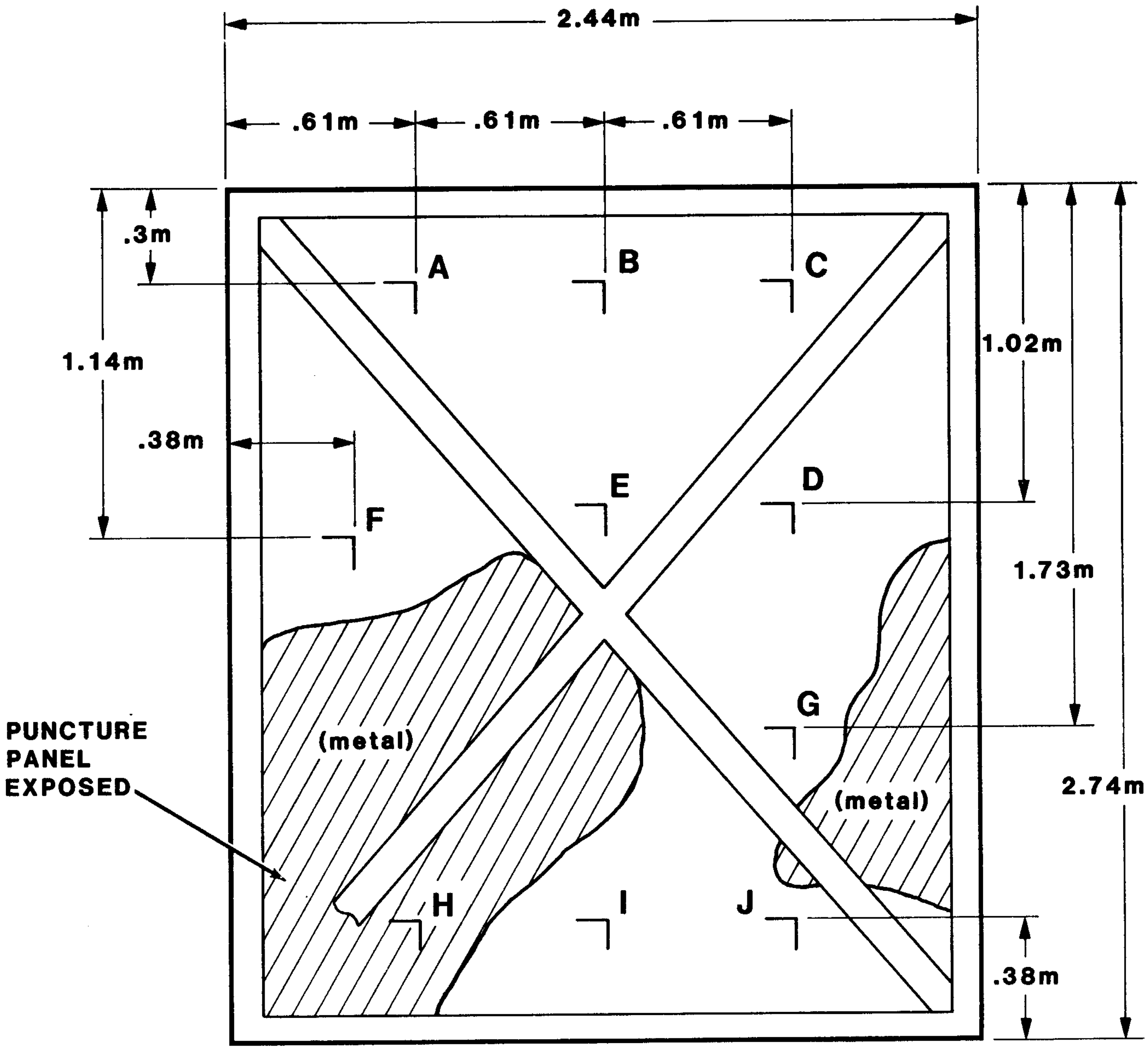


Figure 5.5-6. Post-test Regions of Remaining Kevlar, Outer Door (regions of exposed puncture panel are cross-hatched)

Table 5.5-1

Post-test Kevlar Thickness and Appearance

Location	Remaining Layers	Description
A	19	top eight layers charred black, bottom eleven layers dark brown
B	12	top three layers charred black, bottom nine layers dark brown
C	18	top seven layers charred black, bottom eleven layers dark brown
D	4	top three layers charred black, bottom layer dark brown
E	3	all layers charred black
F	2	both layers charred black
G	1	charred black
H	0	puncture panel exposed
I	18	all layers charred black
J	5	all layers charred black

Stainless Steel Honeycomb

The face sheets of the stainless steel honeycomb panels were covered with a thin layer of dark brown soot. The soot on these skins was streaked. The streaks were not covered with soot, but were a dull metallic color. It appeared as though water droplets had formed and cleaned off the thin layer of soot as the droplets ran down the surfaces of the honeycomb skins, Figure 5.5-7.

The individual layers of stainless steel honeycomb appeared to be only slightly discolored around the outer perimeter of the sides. The stainless steel skin on the honeycomb panel closest to the puncture panel was discolored in two areas between the two layers of honeycomb. The discoloration was only observed on the bottom left and top right corners on the one skin surface of the one layer. The areas were triangular in shape, approximately 0.36 m (14 in.) long and 0.36 m (14 in.) high.

Stainless Steel Inner Surface Covering

The interior surface of the stainless steel covering on the inside of the outer door was discolored, covered with a thin layer of dark

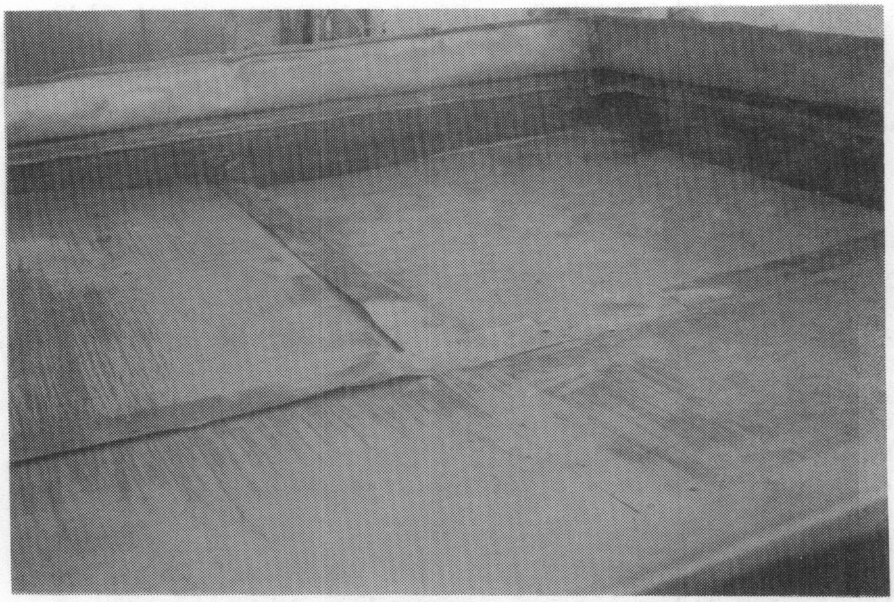


Figure 5.5-7. Post-test Condition of Outer Door Stainless Steel Honeycomb

Figure 5.5-8. Post-test Condition of Outer Door Structural Tubes

brown soot, and streaked. The streaks were black while the remaining surface was a dull metallic color. It appeared as though water droplets had formed and collected soot as the droplets ran down the surfaces of the honeycomb cap and left the residue after the moisture had evaporated.

Structural Framework of Outer Door

The stainless steel tubes in the structural framework of the outer door were soot covered but basically intact, Figure 5.5-8, with the exception of the lower legs of the x-brace on the front of the door where erosion of the stainless steel by molten aluminum was evident. On the lower left leg, which had been deformed in the CG-over-corner drop test, 0.41 m (16 in.) of the tubes had been eroded. In the same corner, 0.51 m (20 in.) of the vertical tubular frame member and 0.3 m (12 in.) of the horizontal member were partially eroded. The lower right leg of the x-brace also showed signs of erosion, but only in a small area on the inner surface of the tube.

Prior to the thermal test, vermiculite had been placed in the vertical and transverse tubes at the closure end of the outer frame, Figure 1.3-4. Holes were drilled into the individual structural tubes during disassembly to collect samples of the vermiculite. Vermiculite from the top, left, and right side tubes did not appear to have been affected by the test. The samples removed from the bottom tubes had the same texture but they did appear to be darker in color.

Insulation

Moldable ceramic fiber insulation located between the circumferential structural tubes closest to the outer door/frame interface was white with some black areas where soot had been deposited. The surface of the moldable insulation had a hard crust but the interior material was soft.

The inorganic insulation blanket located around the top and sides of the aluminum honeycomb was white in color with some black soot in areas on the surface, Figure 5.5-8. Insulation material in the bottom of the door was very hard and cream colored; it appeared to have been vitrified by the molten mass.

Thermal Radiation Shield

The moldable ceramic fiber insulation located inside the stainless steel shell of the thermal radiation shield was white with some black areas where soot had been deposited. The surface of the insulation had a hard crust but the interior material was soft, Figure 5.5-9.

Furnace Seal

The furnace seal located on the surface of the thermal radiation shield was white with some black areas where soot had been deposited. There were no obvious indications of gas paths past the seal itself. The surface of the furnace seal had a hard crust in areas but the seal itself was still very flexible.

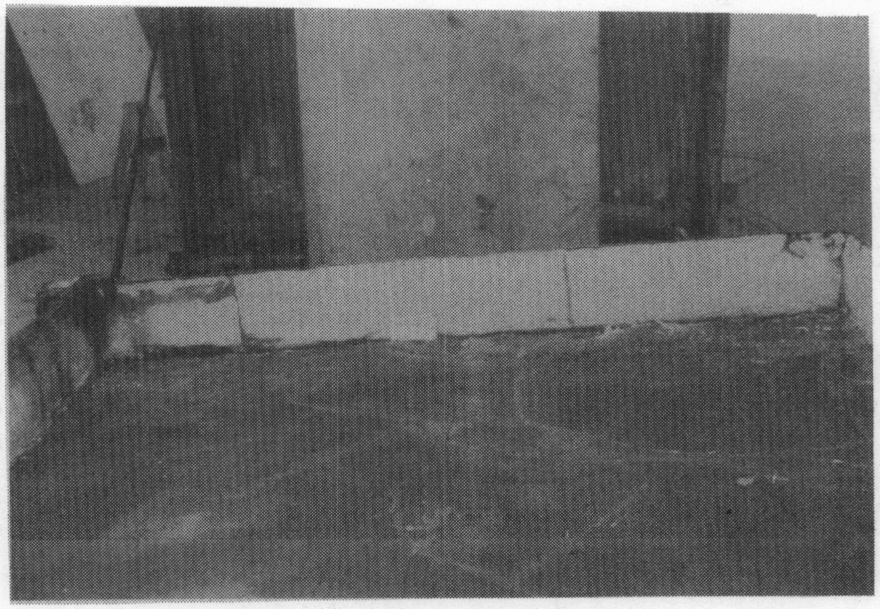


Figure 5.5-9. Post-test Condition of Thermal Radiation Shield

5.5.2 Inner Door/Seal Region

Door Adhesive

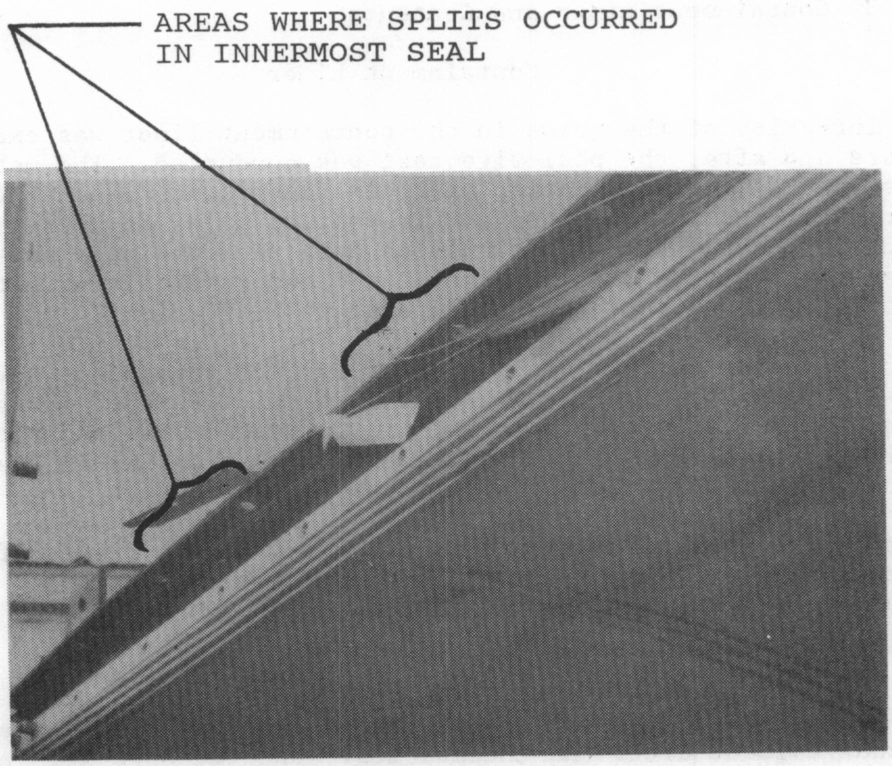
A 0.3-m (12-in.) square of material was removed from the inner door. The square was removed 0.3 m (12 in.) down and 0.3 m (12 in.) over from the top left corner by cutting the interior and exterior skins with a cutting wheel on a circular saw. The honeycomb core was not discolored and the adhesive appeared to have retained its original strength. The adhesive attaching the skins to the honeycomb core was the same gray metallic color as before the test; i.e., there was no visible discoloration.

Inner Door Seals

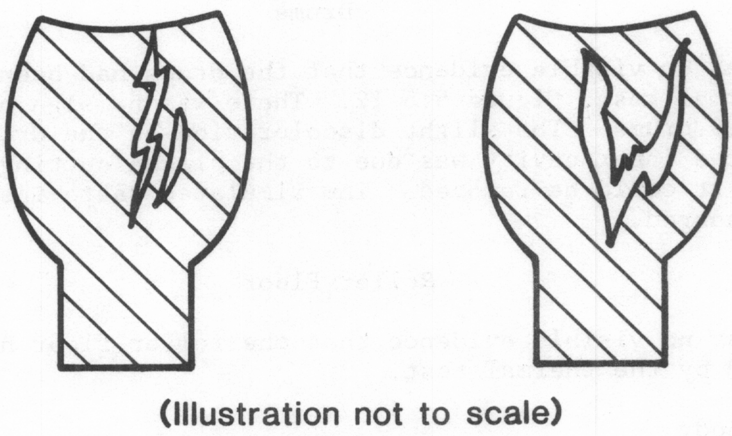
All three seals between the inner door and the containment liner were intact and maintained their seal better than the minimum acceptable requirement. Heat input to the seals was sufficient to cause some permanent set. New seals measure 6.35 mm (0.25 in.) wide x 17.5 mm (0.69 in.) high and are installed such that a free height of 11.4 mm (0.45 in.) is compressed to 6.8 mm (0.27 in.). When the seals were removed from the Test Article the width had increased by 1.5 to 2.0 mm (0.06 to 0.08 in.). A small amount of physical damage was evident on the innermost seal in the region of the center of the top of the inner door. The middle of the seal was split in the center along its length in two locations for lengths of 12.7 to 15.2 cm (5 to 6 in.), Figure 5.5-10. These splits are due to tension in the seal created when it was compressed from a tall slender member to a short wide seal. From the above numbers it can be seen that the compressed height is about half of the free height. The large amount of compression on the seal combined with a small amount of heat input from the fire reduced the ultimate tensile strength of the silicone seal material and allowed tensile failure in the direction of primary stress. There may have been a defect in the seal material in this area that contributed to the seal splitting. This phenomenon was not reproduced in any other region of the seal and did not occur in regions of the center or outermost seals immediately adjacent to the split inner seal. Leakage measurements of the seals pre- and post-test verified that the seal design is capable of meeting the required leak rates, so the occurrence of this type of separation in the seal material, although undesirable, is not detrimental to the performance of the seal.

Quick-connect Valves

The quick-connect values were covered with a thin film of black soot. This can be attributed to the fact that the cover plate over the sampling block was not in place for the test. The cover plate had accidentally been sheared off as the outer door was being installed.



a. Seals in Seal Grooves



b. Seal Cross Section at Splits

Figure 5.5-10. Post-test Condition of Silicone Seals

5.5.3 Containment Liner and Contents

Containment Liner

The integrity of the welds in the containment liner was examined before and after the pool fire test was conducted. The method consisted of the application of Zyglo fluorescent penetrant per manufacturer's instructions and inspection using an ultraviolet light to locate any discontinuities once the developer was applied. A second procedure using a magnaflux cleaner containing methyl chloroform was used to draw out relevant indications.

The inspection indicated a number of surface scratches, surface pin holes, excessive undercuts, and cold starts. Further investigation, which included grinding of the suspected flaw and retesting, indicated that there were no weld failures or cracks in the containment welds before or after the pool fire test.

There was no visible evidence that the interior surfaces of the containment liner had been affected by the thermal test, Figure 5.5-11.

Dunnage

The airbags used as dunnage were intact and undamaged. There was no char evident after the thermal test, and the bags were not discolored.

Plywood sheets between the drums and the airbags showed no char damage from the thermal test and there was no evidence of discoloration, Figure 5.5-12.

Drums

There was no visible evidence that the drums had been affected by the thermal test, Figure 5.5-12. There was no sign of char on any of the 16 drums. The slight discoloration on the drums in the aft end of the inner cavity was due to the plasma cutting of the aft wall so it could be removed. The simulated waste inside the drums was unchanged.

Roller Floor

There was no visible evidence that the roller floor had been affected by the thermal test.

5.5.4 Body

Stainless Steel Skin

The stainless steel outer skins had numerous small holes through them on all sides. Molten aluminum had corroded or eroded holes through the 0.3-mm (0.012-in.) thick skin material, solidified, and was hanging from many of the holes on the sides and bottom. This was the same phenomenon observed on the outer door.

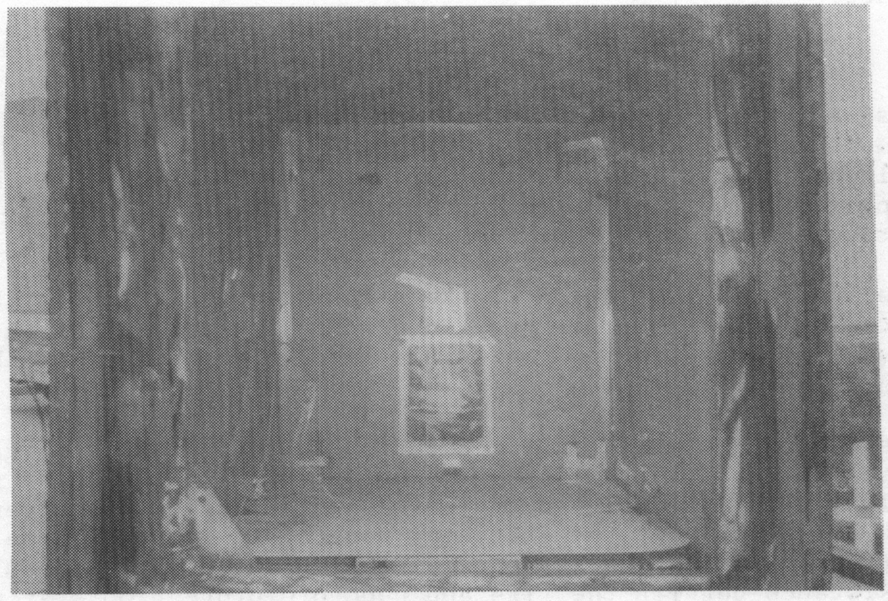


Figure 5.5-11. Post-test Condition of Inner Cavity

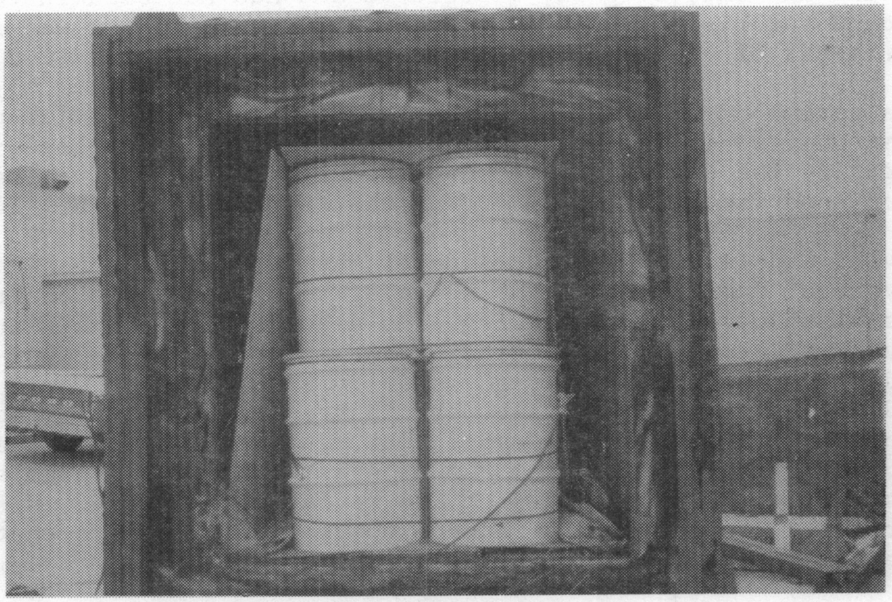


Figure 5.5-12. Post-test Condition of Drums and Dunnage

The sealing tape used as a weather seal between the individual skins and also between the outer skins and the structural frame had been totally burned away. Sealed rivets used to attach the skins to the tubular frame remained secure, holding the outer skins in place.

Insulation Blanket

Insulation blankets located behind the outer skins on the body sidewalls were intact but gray in color, Figure 5.5-13. The Siltemp material on the exterior surface of the blankets had approximately the same tear strength as it had originally and the Astroquartz II stitching was intact.

The inorganic insulation blankets sewn between layers of Siltemp material was intact but gray in color. It appeared as though the smoke had permeated the materials and deposited soot in the fibers causing the gray discoloration.

The Siltemp material on the interior surface of the inorganic insulation blankets was in very good condition and light gray in color. The material had approximately the same tear strength as it had originally and the stitching was intact. Thus, these materials performed satisfactorily and maintained the designed insulation resistance between the fire and puncture protection system.

Kevlar Puncture Panels

Kevlar on the top panel of the package was in the best condition of any of the panels on the Test Article. The outermost layer of Kevlar was only slightly discolored and had not delaminated except around the rigidized edges. The only charred Kevlar was around the perimeter of the panel where the edges had been rigidized.

The perimeter of the right side, bottom, and left Kevlar panels had been charred in the region where adhesive had been placed to rigidize the edges of each Kevlar panel. The adhesive itself had been vaporized and cooked out of the Kevlar, Figure 5.5-14.

Kevlar panels on the right side of the Test Article had only five layers of fabric out of the 30 layer total that were charred, discolored, partially missing, and debonded; the remaining 25 layers retained their original color and remained bonded. The left side was similar to the right side in appearance but only four individual layers of Kevlar were charred, discolored, missing, and debonded; there were 26 layers that retained their original appearance. On the bottom the damage to the Kevlar panels was the most severe. Seven layers of the Kevlar were charred, discolored, partially missing, and debonded; there were 23 layers that appeared the same as when they were installed.

Structural Tubes, Vermiculite, Polyurethane Foam, and Insulation Board

There was no visible evidence that the stainless steel tubular frame members had been affected by the thermal test.

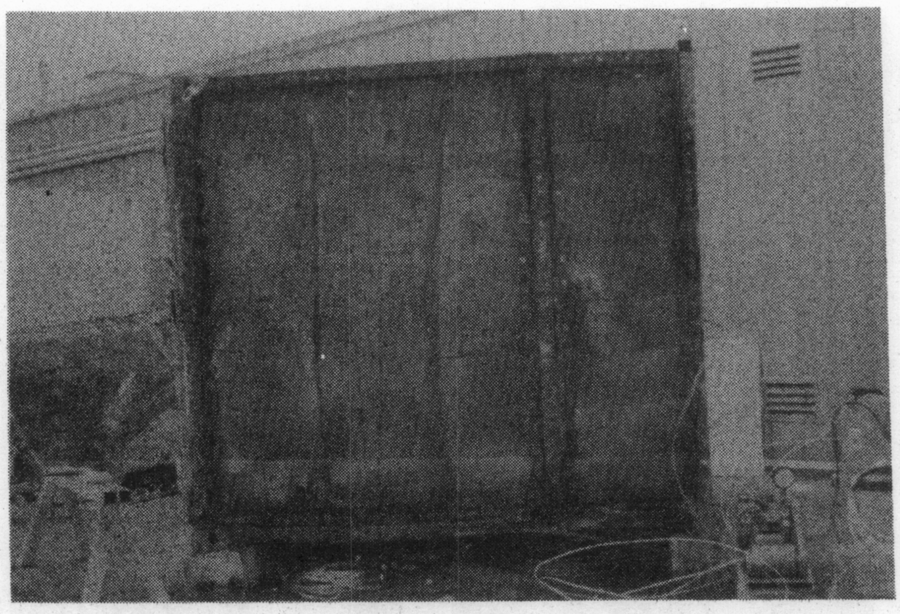


Figure 5.5-13. Post-test Condition of Insulation Blankets

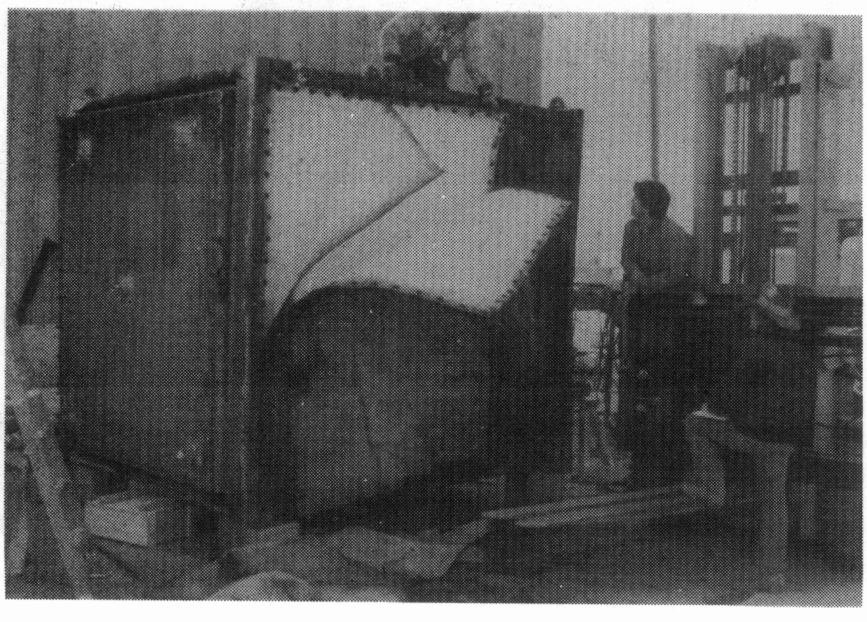


Figure 5.5-14. Post-test Condition of Main Body Kevlar, Right Side

Vermiculite placed inside all of the vertical, longitudinal, and transverse structural tubes of the outer frame of the Test Article was removed and examined. The only evidence that the vermiculite in the stainless steel tubular frame members had been affected by the thermal test was from the bottom left longitudinal tube. The vermiculite from this tube was much darker in color, some of the particles were black, and the sample smelled burned.

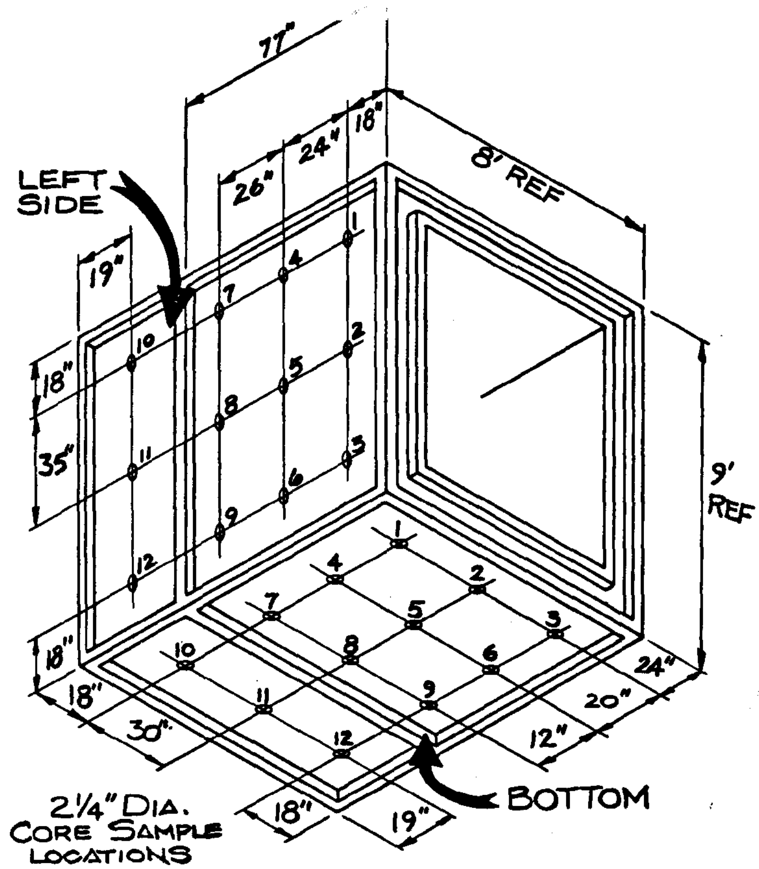
Figure 5.5-15 indicates locations where foam core samples were taken. Core samples near the aft end of the Test Article (core samples 10, 11, and 12 on all sides) were the most severely charred. The foam in this location was affected by heat input through the insulation used to cover the cut end of the Test Article. The results are presented to indicate that although a different boundary condition existed from a prototype unit, the foam performance was still outstanding.

In the bottom aft end, core samples 11 and 12 had approximately 0.64 cm (0.25 in.) of char extending into the sample. The core samples from the left and top near the aft end indicated approximately the same results as the bottom. On the right side, core sample 11 showed approximately 80 % char. Sample 11 was the worst-charred core sample.

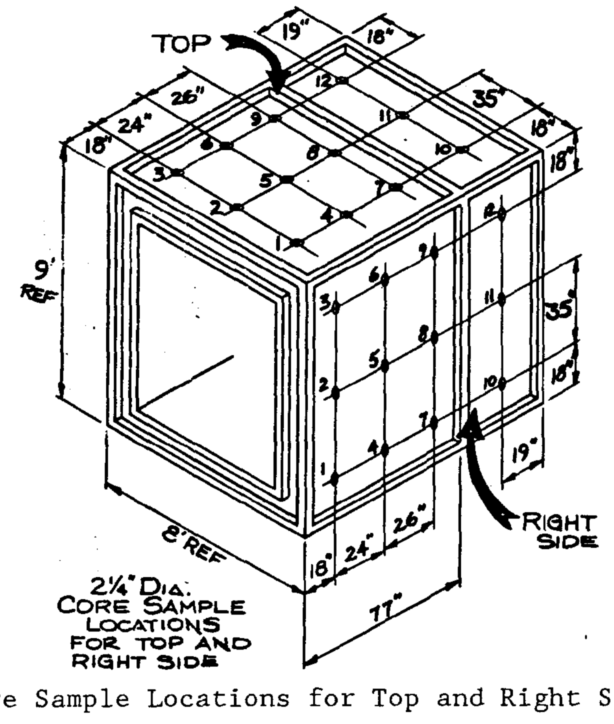
There was only slight surface charring of the foam in the main body of the Test Article.

Insulation Board

The insulation board behind structural members of the outer frame was examined. The exterior surface of the insulation boards had a hard crust but the interior material was soft. The surface of the insulation boards around the cutouts for release of pyrolysis gases had a hard black crust but the adjacent material was soft and pink in color.



a. Core Sample Locations for Bottom and Left Side



b. Core Sample Locations for Top and Right Side

Figure 5.5.15. Foam Core Sample Locations

6.0 CONCLUSIONS

6.1 Leak Rates

The inner door seals, filter installation seals, and quick-connect valve seal were leak tested after the fire test. A pressure rise test was performed, and leak rates of 0.0041 atm-cm^3/s between the innermost pair of door seals and 0.0046 atm-cm^3/s between the outermost pair of door seals were measured. Since the filter installation seals and the quick-connect valve seal remained essentially leaktight, the total leak rate (sum of leakage from the inner door seals, filter installation seals, and valve seal) is below the allowable leak rate of 0.01 atm-cm^3/s. This, along with the inspection of the containment liner welds, demonstrated that containment was maintained.

6.2 Temperatures

Although no usable thermocouple data were obtained, data from passive thermal indicators gave peak temperatures at critical locations. Maximum temperatures recorded at these locations are given below:

Location	Maximum Temperature °C (°F)
o Inner door seal	149 (300)
o Filter	171 (340)
o Inner door	171 (340)
o Containment liner	135 (275)
o Surface of contents	77 (170)

All of these temperatures are below the temperature limit criteria listed in the TRUPACT-I SARP (Ref. 10). The maximum inner door seal temperature and the maximum filter temperature are within the normal working range for these components.

6.3 Regulatory Compliance of Redesign

The TRUPACT-I Thermal Test Article fire test provided a thermal environment nearly identical to that of the TRUPACT-I, Unit 0 fire test. The fire test demonstrated that the package maintains its integrity after the regulatory hypothetical thermal accident. The inner door seals, filter installation seals, and quick-connect valve seal were leak tested after the fire test. The measured leak rates were within acceptable limits, which demonstrates that containment was maintained. Welds in the containment liner were also examined using a nondestructive examination technique (dye penetrant weld inspection) to demonstrate that no weld cracks were present after the thermal event. All components performed satisfactorily, thus verifying the thermal design of TRUPACT-I.

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7.0 REFERENCES

1. Mihalovich, G. S., Hudson, M., Joseph, B. J., Romesberg, L. E., "Data Report TRUPACT-I, Unit 0, SAND85-1695 (TTC-0553), Sandia National Laboratories, Albuquerque, NM, September 1985.

2. "Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Waste," U.S. DOE Order 5480.3, July 1985.

3. "Packaging and Transportation of Radioactive Material," U.S. Nuclear Regulatory Commission, 10 CFR, Part 71, Federal Register 48, No. 152, August 5, 1983; corrected Vol 48, No. 165, August 24, 1983.

4. Romesberg, L. E., Hudson, M. L., Osborne, D. M., "TRUPACT-I, Unit 0 Test Data Analysis, SAND85-0943 (TTC-0555), Sandia National Laboratories, Albuquerque, NM, September 1985.

5. Hudson, M. L., "High Temperature Testing of TRUPACT-I Materials: Kevlar, Honeycomb, Rigid Polyurethane Foam," SAND85-1299 (TTC-0638), Sandia National Laboratories, Albuquerque, NM, September 1985.

6. "Test Specifications for TRUPACT-I Full-Scale Thermal Test Article," SPE-953110, GA Technologies, Inc., San Diego, CA, January 31, 1985.

7. Joseph, B. J., Bronowski, D. R., "TRUPACT-I Test Article Instrumentation Installation Procedure," Sandia National Laboratories Test Procedure, Division 6322, TA-1, Rev. A., March 1985.

8. Hudson, M. L., "TRUPACT-I Test Article Thermal Test," Sandia National Laboratories Test Procedure, Division 6322, TA-5, Rev. C., January 1986.

9. "American National Standard for Leak Tests on Packages for Shipment of Radioactive Materials," ANSI N14.5-1977, American National Standards Institute, October 1977.

10. "Transuranic Package Transporter, TRUPACT-I, Safety Analysis Report for Packaging (SARP)," SAND83-7077 (TTC-0338), Sandia National Laboratories, Albuquerque, NM, May 1986.

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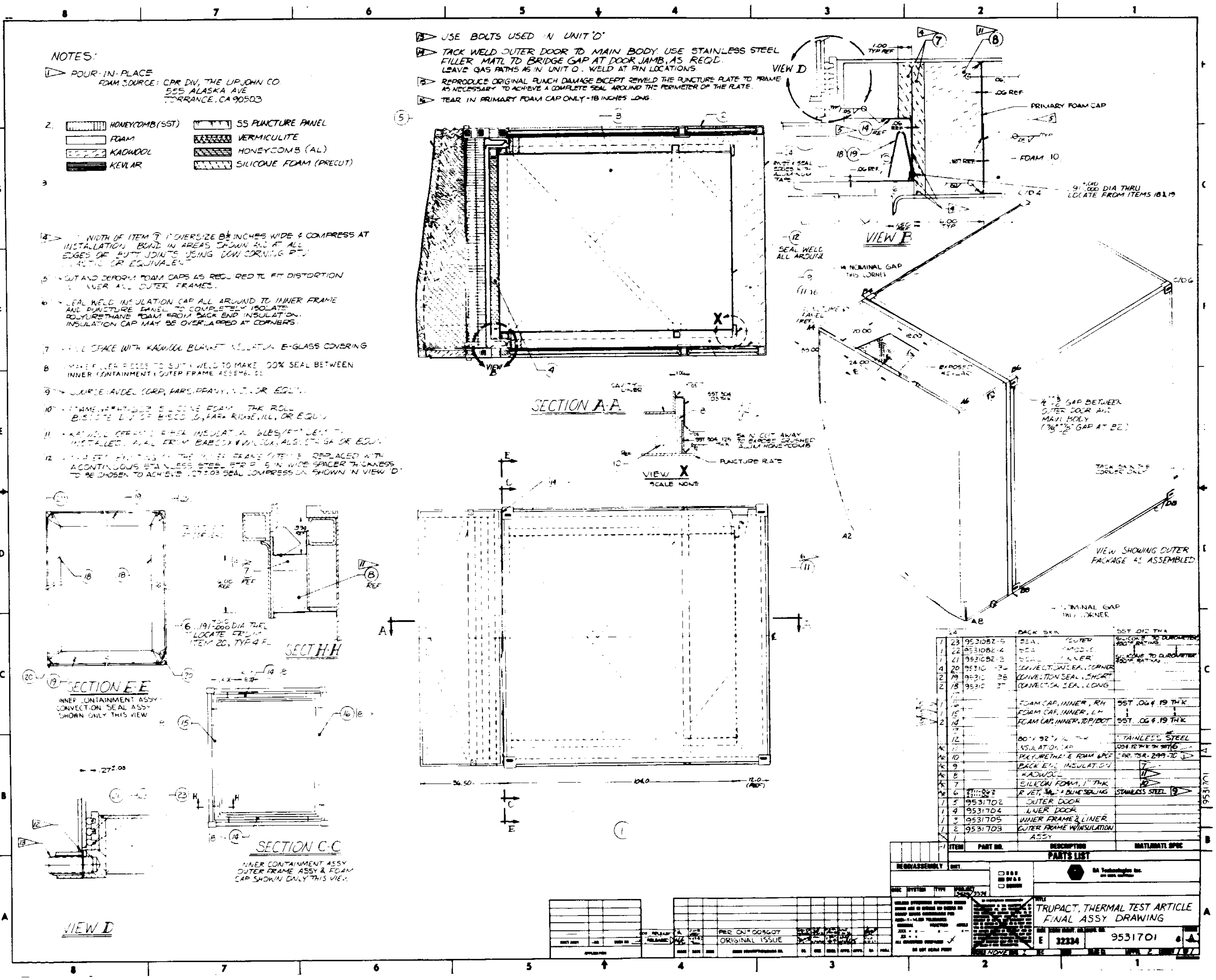
APPENDIX A

TEST ARTICLE AS-BUILT DRAWINGS

CONTENTS



QTY	ITEM	PART NO.	DESCRIPTION	MATL/MATL SPEC
	24		BACK SKIN	SST .012 THK
1	23	9531082-5	SEAL OUTER	SILICONE 70 DUROMETER, 450°F RATING
1	22	9531082-4	SEAL MIDDLE	
1	21	9531082-3	SEAL INNER	SILICONE 70 DUROMETER, 450°F RATING
4	20	9531[illegible]	CONVECTION SEAL, CORNER	
2	19	9531[illegible] 38	CONVECTION SEAL, SHORT	
2	18	9531[illegible] 37	CONVECTION SEAL, LONG	
	17			
1	16		FOAM CAP, INNER, RH	SST .06 & .19 THK
1	15		FOAM CAP, INNER, LH	
2	14		FOAM CAP, INNER, TOP/BOT	SST .06 & .19 THK
	13			
	12		80" x 92" [illegible] THK	STAINLESS STEEL
AR	11		INSULATION CAP	.034 .12 THK [illegible] SST 6
AR	10		POLYURETHANE FOAM 6PCF	CPR-TSR-299-70 1
AR	9		BACK END INSULATION	7
AR	8		KAOWOOL	11
AR	7		SILICON FOAM, 1" THK	10
AR	6	[illegible]	RIVET, [illegible] BLIND SEALING	STAINLESS STEEL 9
1	5	9531702	OUTER DOOR	
1	4	9531704	LINER DOOR	
1	3	9531705	INNER FRAME & LINER	
1	2	9531703	OUTER FRAME W/INSULATION	
	1		ASSY	

PARTS LIST

TRUPACT, THERMAL TEST ARTICLE FINAL ASSY DRAWING

E 32334 9531701 A

NOTES:

1. DAMAGE TO FRAMEWORK SHOWN IS RESULT OF "UNIT-O" DROP TESTS. THIS DAMAGE TO REMAIN "AS-IS" AND UNREPAIRED.

2 ASSY OF HONEYCOMB SHALL BE MANUALLY ADJUSTED TO CONFORM TO DROP TEST DAMAGE FOUND IN "UNIT-O" TUBE FRAME.

3 MANUALLY ADJUST OUTER SS FACE SHEET TO SIMULATE DAMAGE SUFFERED DURING DROP TEST.

4.

5. WHEN RETROFITTING OUTER DOOR, CARE SHALL BE TAKEN TO ENSURE THAT ALL "LIKE DAMAGED" AREAS OF THE DOOR AND BODY WILL MATCH AFTER ASSY.

6 SOURCE: REFRACTORY PRODUCTS CO. 500 W. CENTRAL RD MT PROSPECT, ILL MOLDABLE WET PACK HIGH ALUMINA FIBROUS INSULATION WRP-X-AQ MOIST FELT.

7 USE UNIT "O" RADIATION SHIELD. FILL WITH ITEM (11) ALL AROUND.

8 SOURCE: GASKETS INC., RIO, WISCONSIN

9 SOURCE: BABCOCK AND WILCOX OR EQUIV.

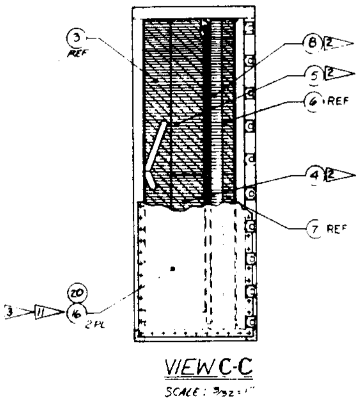
10 REINSTALL CLOSURE MECHANISMS (28 PLACES) MECHANISMS WILL NOT FUNCTION MECHANICALLY BUT WILL SIMULATE THERMAL EFFECT. REINSTALL MECHANISM COVERS.

11 BOND SKINS TO TUBING BEFORE RIVETING

12.

13 FACE SHEETS TO BE 316L SST, QUARTER HARD AVAILABLE FROM TRE CORP., ASTECH DIVISION, 3030 SOUTH RED HILL AVE, SANTA ANA, CA 92705

14 DENSITY 4.0 TO 7.0 LB/FT³, GRAIN SIZE .06 TO .31 INCHES AVAILABLE FROM STRONGLITE PRODUCTS CORP., 1120 OAK ST., DEKALB, IL



VIEW C-C

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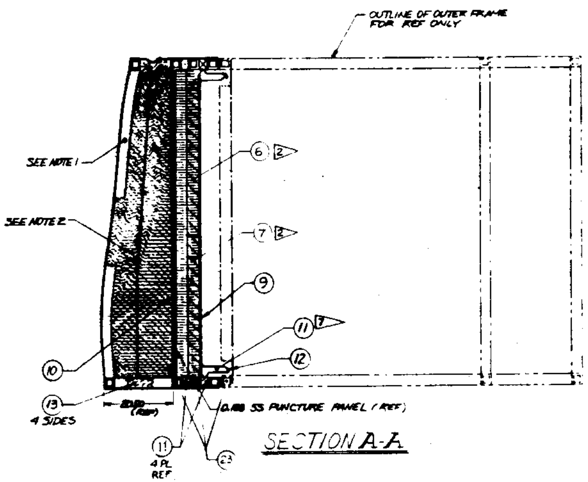
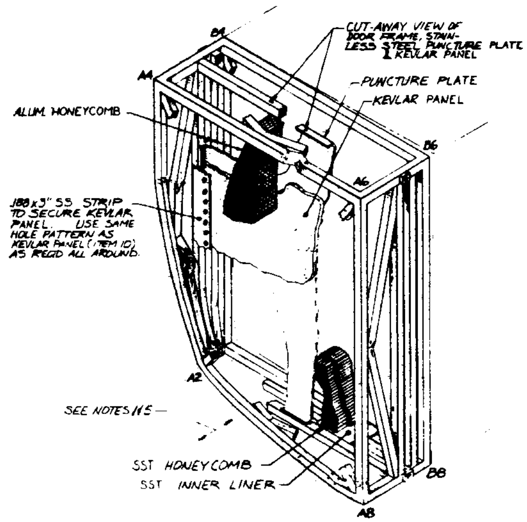
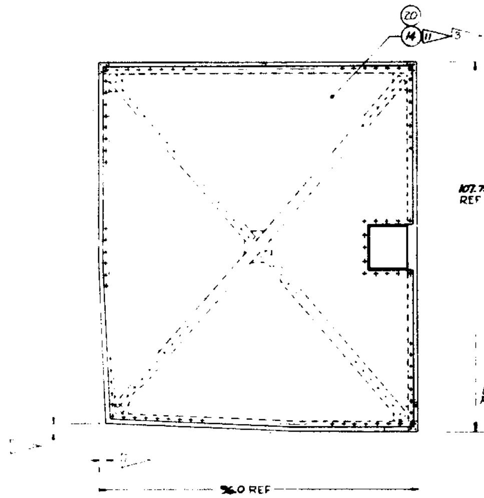
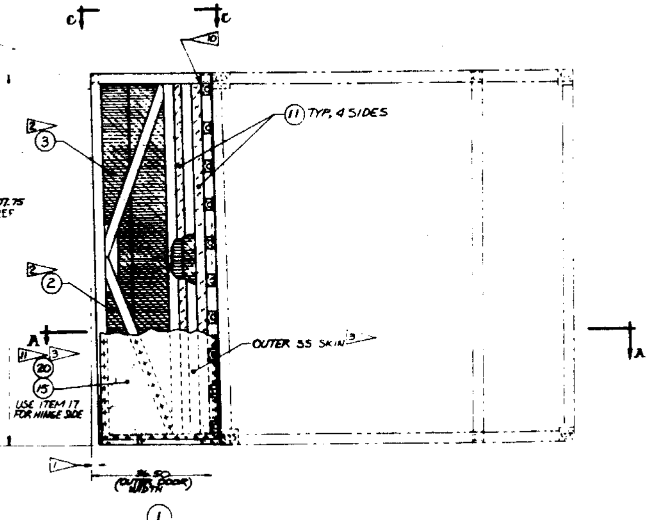


SECTION A-A



OUTER DOOR ASSY (CUT AWAY)





1

SCALE: 3/32=1"

	ITEM	PART NO.	DESCRIPTION	MATL/MATL SPEC
	23		VERMICULITE	14
	22			
	21			
AR	20	2216 B/A	ADHESIVE, 3M SCOTCHWELD	
AR	19	2711-0615 2711-0617	RIVETS	
	18			
1	17	9531004-35	SKIN, HINGE SIDE	
1	16	9531004-36	SKIN, TOP & BOTTOM	
1	15	9531004-37	SKIN, WINCH SIDE	
1	14	9531004-38	SKIN, BACK SIDE	9
AR	13		BLANKET, KAOWOOL, BASIC NEEDLED, 6#/FT³ FINISHED	
1	12	TYPE 25A-700-20	FLEXSEAL TADPOLE SEAL - 300°C	C-9/16, D-1 8
AR	11	WRP-X-AQ	INSULATION	6
1	10	9531007-15	KEVLAR PANEL	
1	9	9531035-3	FOAM CAP	
2	8	9531012-42	ALL WELDED ... HONEYCOMB	316 SST ANNEALED 13 2
1	7	9531012-43	ALL WELDED ... CELL, 2 MIL FOIL HONEYCOMB	316 SST ANNEALED 13 2
1	6	9531012-44	ALL WELDED ... CELL, 2 MIL FOIL HONEYCOMB	316 SST ANNEALED 13 2
1	5	9531012-19	HONEYCOMB, ALUMINUM	2
1	4	9531012-18	HONEYCOMB, ALUMINUM	2
1	3	9531012-17	HONEYCOMB, ALUMINUM	2
1	2	9531012-16	HONEYCOMB, ALUMINUM	2
X	1		ASSY	

PARTS LIST

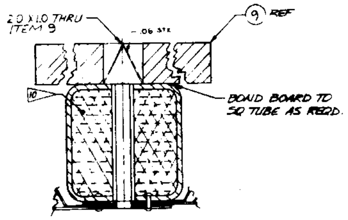
GA Technologies Inc.

PER CN 006607 ORIGINAL ISSUE

9531701

TRUPACT, THERMAL TEST ARTICLE, OUTER DOOR REMFGR

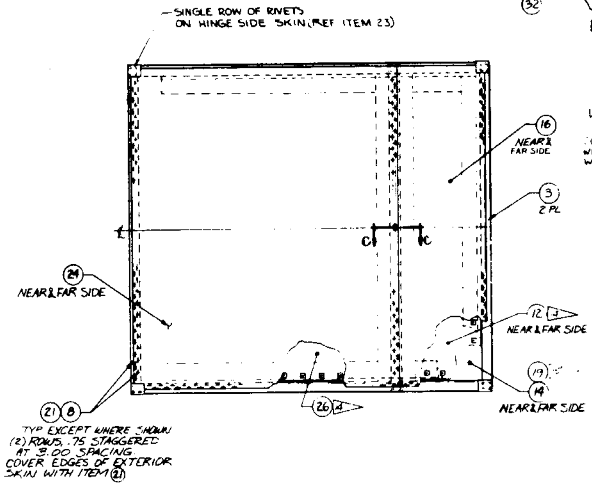
E 32334 9531702 A

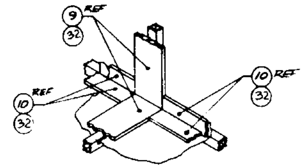


SECTION C-C
TYP 4 SIDES

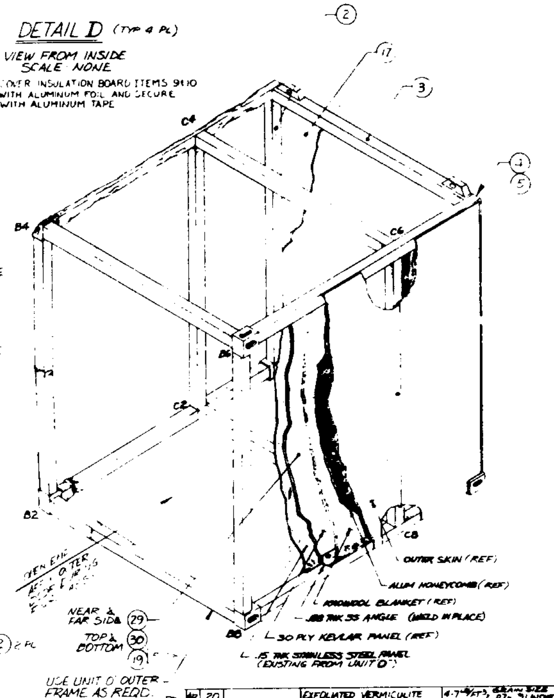
NOTES:

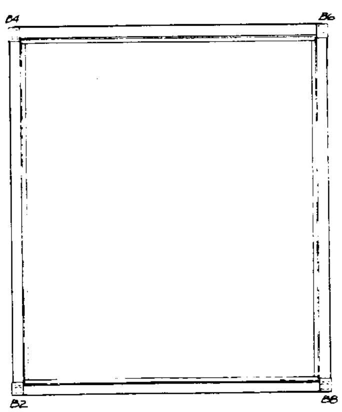
1. UNIT O OUTER FRAMEWORK TO BE STRIPPED AND READIED FOR ASSY WITH NEW INSULATION, PANELS & OTHER STRUCTURE/FIRE PROTECTION.
2. SHORTEN UNIT O FRAME TO 116 INCHES AND ADD FOUR 3X3 STAINLESS STEEL SQ TUBES TO SECURE END AREA FOR ASSY OF UNIT
3. DO NOT REPLACE, STRAIGHTEN, REPAIR OR ALTER 3X3 SQ TUBE FRAME, OTHER THAN THAT FOUND IN NOTES 1 & 2, ABOVE.
4.
5. ALL PANELS & BLANKETS TO BE ADJUSTED TO FIT SQ TUBE CONFIGURATION & SIMULATE DAMAGE CONTOUR AS REQD

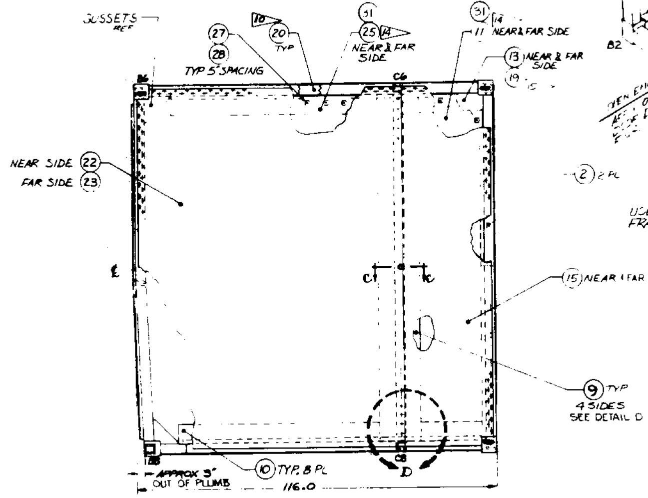




DETAIL D (TYP 4 PL)
VIEW FROM INSIDE
SCALE NONE
COVER INSULATION BOARD ITEMS 9 & 10 WITH ALUMINUM FOIL AND SECURE WITH ALUMINUM TAPE







SIDE VIEW

	ITEM	PART NO.	DESCRIPTION	MATL/MATL SPEC
AR	20		EXFOLIATED VERMICULITE	4-7 lb/ft³, GRAIN SIZE .07-.31 INCHES
AR	19	#2216 B/A	SCOTCHWELD ADHESIVE	9
	18			
1	17		SKIN, PANEL, REAR, 95.25 x 105.75 x 0.012	
2	16		SKIN, ASSY, 34.94 x 95.25	SST
2	15		SKIN, ASSY, 34.94 x 105.25	SST
2	14		KEVLAR, PANEL, 29.30 x 87.61	
2	13		KEVLAR, PANEL, 29.30 x 99.61	
2	12		KAOWOOL, BLKT, 30.44 x 88.75	
2	11		KAOWOOL, BLKT, 30.44 x 100.75	
AR	10	#3000	KAOWOOL, BOARD, 1.0 x 5.0 W	6
AR	9	#3000	KAOWOOL, BOARD, 1.0 x 10.0 W	6
	8			
	7			
	6			
	5			
2	4		LIFTING EAR	
2	3		TUBE, SQ, 3x3x.12 x 90.0 LG	STAINLESS STEEL
2	2		TUBE, SQ, 3x3x.12 x 101.75 LG	STAINLESS STEEL
	1		ASSY	

PARTS LIST

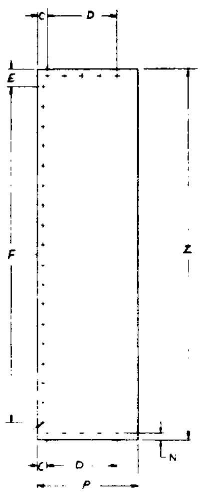
GA Technologies Inc.

TRUPACT, THERMAL TEST ARTICLE OUTER FRAME WITH INSULATION

E 32334 9531703 A

A	PER CN 005607	ORIGINAL ISSUE

9531701

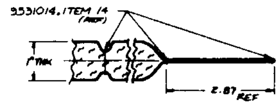


(13)(14)

KEVLAR PANEL

ITEM	Z	C	D	E	F	P	N
13	99.61	1.13	[illegible]	5.00	[illegible]	39.30	1.62
14	87.61	1.13	[illegible]	4.00	[illegible]	39.30	1.62

KEVLAR PANELS (ITEM 13 & 14) TO BE 30 PLY WITH TOTAL BONDED THICKNESS OF 1.04 - 1.10 INCHES.



SECTION A-A
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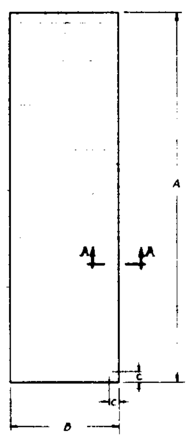
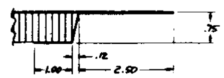


(11)(12)

KAOWOOL BLKT

ITEM	A	B	C
11	100.75	30.44	2.87
12	88.75	30.44	2.87

ALL STITCHING TO BE CONSISTENT WITH OTHER BLANKETS REGARDING SPACING, STYLE, ETC. AS FOUND ON DWG NO. 9531014
THERMAL BARRIER TO BE SILTEMP 84H FROM AMETEK, HAVEG DIV., 900 GREENBANK RD., WILMINGTON, DL. USE ASTROQUARTZ II SEWING THREAD FROM JP STEVENS, GREENVILLE, SC 29602



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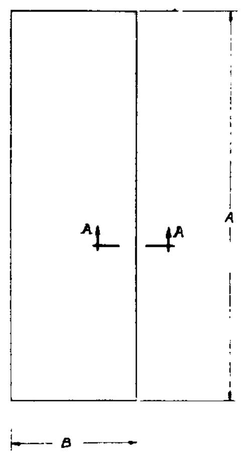


(15)(16)

EXTERIOR SKIN (WITH HONEYCOMB AFFIXED)

ITEM	A	B
15	105.25	34.94
16	93.25	34.94
31	105.25	34.94

NOTES (CON'T)

6. ITEMS 11, 12, 13, 14, 15, 16 & 31 (SHOWN ABOVE) MAY REQUIRE ADJUSTMENT TO FIT PROPERLY (DUE TO DAMAGE FROM DROP/BURN TEST OF UNIT "O")

7. COMPLETELY SEAL ALL SKIN EDGES, OVERLAPS, ISO CORNERS, ETC

[8]▷ SOURCE: BABCOK & WILCOX, INSULATIONS PRODUCT DIV., AUGUSTA, GA 30903

[9]▷ SOURCE: ADHESIVES COATING & SEALANT DIV/3M ST PAUL, MINN. 55101

[10]▷ FILL ALL SQUARE TUBING WITH VERMICULITE EXCEPT ITEMS (2) AND (3).

[11]▷ SOURCE: STRONG-LITE PRODUCTS CO. DE KALB, ILLINOIS 60115

[12]▷ 3M CO. #1202T WEATHERBAN OR EQUIV. INSTALL PER MFGR'S INSTRUCTIONS

[13]▷ SOURCE: TRW NELSON DIV. LORIAN, OHIO 44055

[14]▷ APPLY ADHESIVE (ITEM (32)) TO KEVLAR PANELS BEFORE INSTALLING INSULATION BLANKETS.

[15]▷ APPLY ADHESIVE (ITEM (9)) BETWEEN KEVLAR PANELS AND PUNCTURE PANELS AND BETWEEN KEVLAR PANELS AND RETAINERS

-1	ITEM	PART NO.	DESCRIPTION	MATL/MATL SPEC
AR	32	#34	INSULATION ADHESIVE	[9]▷
1	31		SKIN ASSY. 9531-105-25	
2	30	9531007-12	KEVLAR PANEL	
2	29	9531007-8	KEVLAR PANEL	
AR	28		SPEED CLIP, 10GA x 1" x 1/4"	MILD STL PLATED [13]▷
AR	27		INSULATION PIN, DBL PT	12GA x 2", 304 SS [13]▷
2	26	9531014-11	INSULATION BLANKET	
2	25	9531014-10	INSULATION BLANKET	
2	24	9531004-6	PANEL ASSY, TOP & BOT, FRNT	
1	23	9531004-2	PANEL ASSY, HINGE SD, FRNT	
1	22	9531004-1	PANEL ASSY, LOCK SD, FRNT	
AR	21		SEALING TAPE	[12]▷

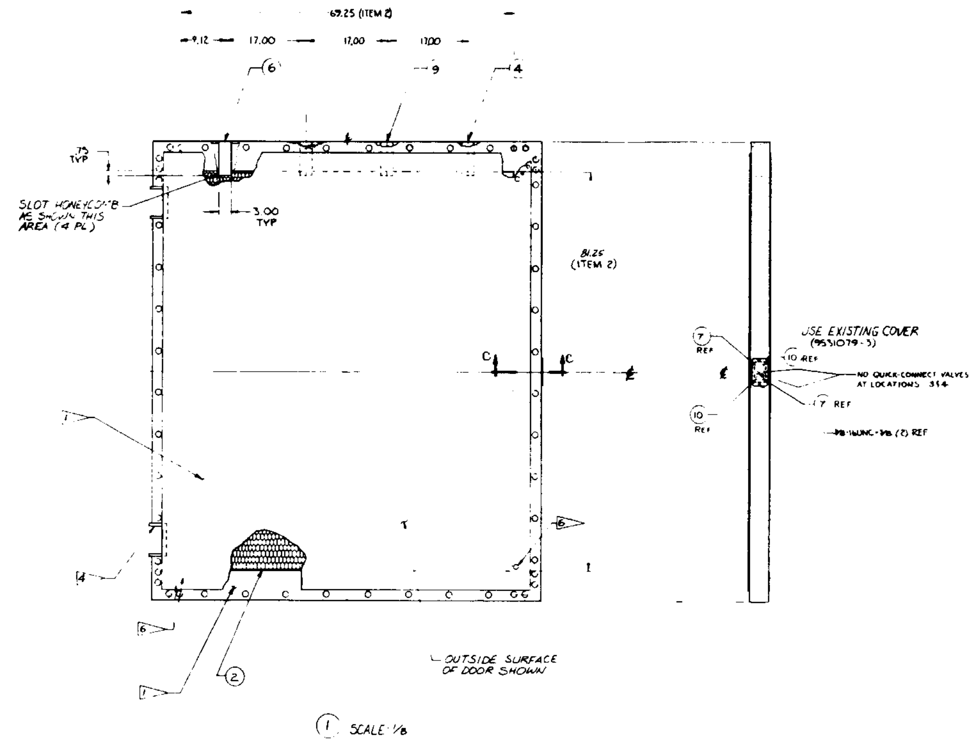
PARTS LIST

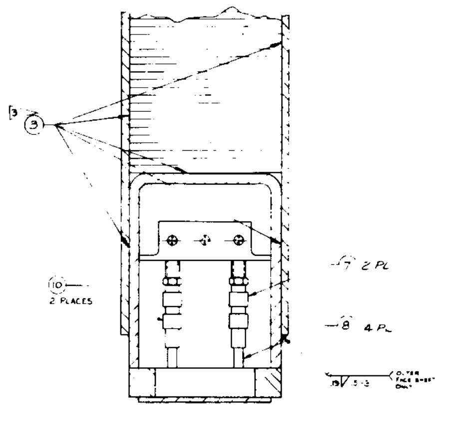
GA Technologies Inc.

TRUPACT, THERMAL TEST ARTICLE OUTER FRAME WITH INSULATION

E 32334 9531703 A

SEE SHEET 1





SECTION C-C
ROTATED 90° CW
SCALE: NONE

NOTES:

1. USE UNIT "O" INNER DOOR FRAMEWORK (REF. 9531077-1) AND SKIN (REF 9531016-3)
2. SOURCE HEXCEL, LOS ANGELES, CA.
3. ADHESIVE FOR BONDING STAINLESS STEEL SKINS TO DOOR FRAME AND HONEYCOMB SHALL MEET THE REQUIREMENTS OF MMM-A-132 FED SPEC. ADHESIVES, HEAT RESISTANT, AIRFRAME STRUCTURAL, METAL TO METAL, TYPE II.
4. USE EXISTING HINGE HARDWARE (2 PL)
5. SOURCE: SWAGELOK, DIV OF CRAWFORD FITTING CO., SOLON, OHIO
6. EXISTING HOLES IN INNER FACESHEET PREV. USED FOR UNIT "O" SEAL TESTING AND GAS SAMPLING TO BE WELDED SHUT USING SST FILLER

NOTE	QTY	ITEM	PART NO.	DESCRIPTION	MATL/MATL SPEC
5	2	10	SS-QC4-B-4PMSL	QUICK CONNECT SINGLE END SHUT OFF MALE BODY END, SILICONE O-RINGS	
	1	9		BALSTON HIGH TEMP FILTER	
5	4	8	SS-QC4-BP	BODY PROTECTOR PLUG	S/S 1/4 NPT
5	2	7	SS-QC4-B-4PM	QUICK CONNECT SINGLE END SHUT OFF MALE BODY END	S/S 1/4 NPT
	1	6		9531075-21, FILTER OPT #1	
		5			
	1	4		9531075-22, FILTER OPT #2	
3	AR	3		ADHESIVE	
2	AR	2		HONEYCOMB	ALUMINUM 5052
	X	1		ASSY	

PARTS LIST

GA Technologies Inc.

TRUPACT. THERMAL TEST ARTICLE INNER CONTAINMENT DOOR

E 32334 9531704 A

9531701

A PER CN 005607 ORIGINAL ISSUE

9531704

A-6

SNL

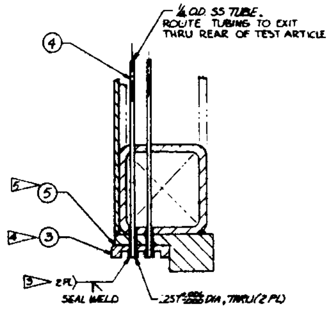
9531 704
Inner Containment Door
Thermal Test Article

NOTE:
1. USE EXISTING FRAMEWORK (SHORTENED) OF UNIT "D" INNER CONTAINMENT (REF. 9531055-1)
2.

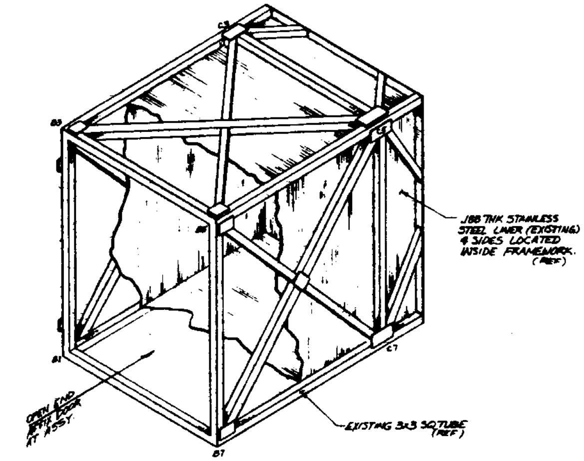
3. TEST SEAL WELD TO 1x10-4 ATM-3CC-SEC AIR.

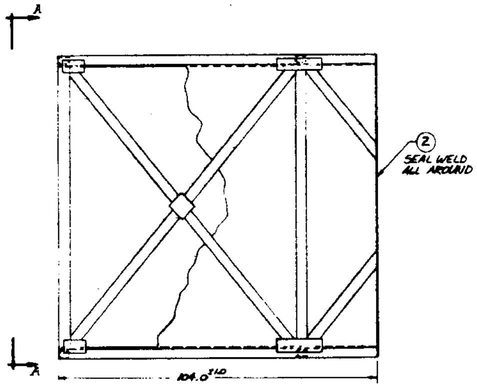
4. SEAL WELD EXISTING HOLES IN SEAL FRAME BEFORE ASSY (4 PL)

5. AVAILABLE FROM DEXTER CORP. HYSOL DIVISION, INDUSTRY, CA 91744



SECTION 13-13

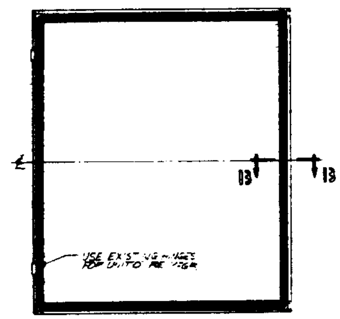




SIDE VIEW

SCALE: NONE

1



VIEW A-A

SCALE: NONE

QTY	ITEM	PART NO.	DESCRIPTION	MATL/MATL SPEC
*	5	EA934	ADHESIVE	
2	4		TUBE, 1/4 OD, LGTH - 45'	STAINLESS STEEL
1	3	9531082-1	DOOR SEAL RUNWAY	
1	2		SHEET, 92.4 x 80.4 x 1/4 THK	
X	1		ASSY	

PARTS LIST

GA Technologies Inc.

TRUPACT THERMAL TEST ARTICLE INNER FRAME & LINER

E | 32334 | 9531705 | A

ORIGINAL ISSUE

A-7

NOTES:

1. THERMOCOUPLES TO BE PURCHASED AND INSTALLED BY SANDIA NATIONAL LABORATORIES (SNL)

2. THERMOCOUPLE (TCXX) MOUNTING LOCATIONS AS SHOWN ON SECTIONS A-A, B-B, ISOMETRIC VIEW & TYPICAL SECTION C-C (SHOWN ON SHEET 2) TO BE AS FOLLOWS

TC NO.	LOCATION
1, 2, 4, 31, 32, 33, 34, 35	OUTER EDGE OF INNER DOOR SEAL PLATE
5, 6, 7, 8, 102	OUTER SURFACE OF INNER DOOR
9, 10, 78, 88, 96, 97	INNER SURFACE OF INNER LINER
11, 12, 53, 71, 73, 77, 80, 82, 83	INNER SURFACE OF PUNCTURE PLATE
13, 14, 69, 75	INNER SURFACE OF OUTER SKIN - AL HONEYCOMB
15, 25, 26, 52, 67	INNER SURFACE OUTER TUBULAR FRAME
17, 18, 19, 48	INNER SURFACE OUTER DOOR FOAM (HONEYCOMB) CAP
20, 21, 22	INNER SURFACE OF OUTER DOOR PUNCTURE PLATE
23, 24, 57, 58, 59, 60, 61, 62, 63, 64	OUTER SURFACE OF EXTERIOR SKIN AT TUBES
27, 28, 42, 43, 44, 45, 46, 47	OUTER SURFACE OF RADIATION SHIELD

3. SNL TO CONFIRM LOCATION OF EACH THERMOCOUPLE.

4. DETAILED ROUTING PROCEDURES ARE TO BE ESTABLISHED BY SNL. THE FOLLOWING SHOULD BE USED AS A GUIDELINE:
   - WHEN POSSIBLE WIRES SHOULD BE ROUTED OUT THE REAR AREA OF THE TEST ARTICLE.
   - ALL HOLES MADE FOR ROUTING MUST BE SEALED.
   - ANY ROUTING HOLES WHICH COULD ALLOW FIRE OR AIR INGRESS INTO THE FOAM SHOULD BE AVOIDED.
   - ROUTING WHICH COULD EFFECT THE PERFORMANCE OF THE CONVECTION SEAL SHOULD BE AVOIDED.

5. OMEGALAQ TEMPERATURE INDICATING PAINTS AND WAHL TEMP-PLATE RECORDERS SHOULD BE INSTALLED BY SNL IN THE SAME LOCATIONS USED FOR UNIT-O

6. TC NUMBERS NOT USED: 3, 16, 70, 89, 95

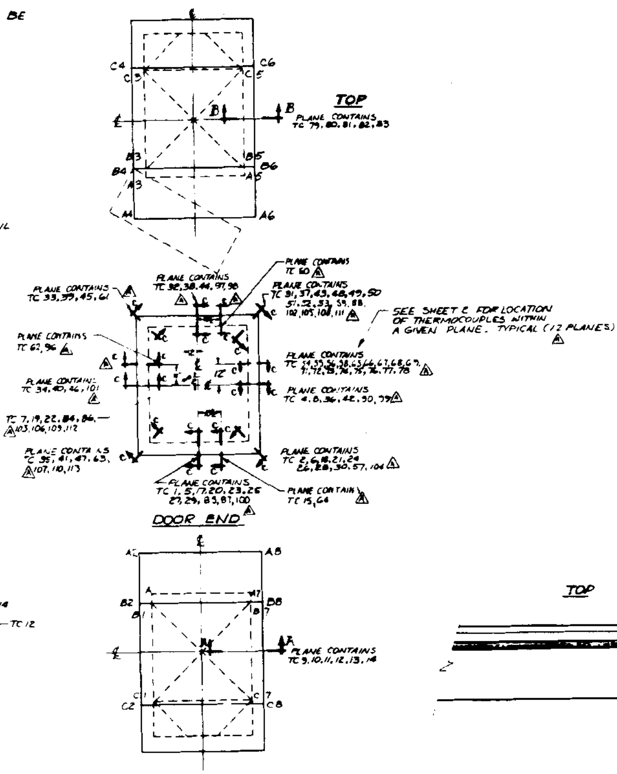
7. TC NUMBERS 1-30 SAME LOCATIONS AS TRUPACT UNIT "O", EXCEPT 25, 26

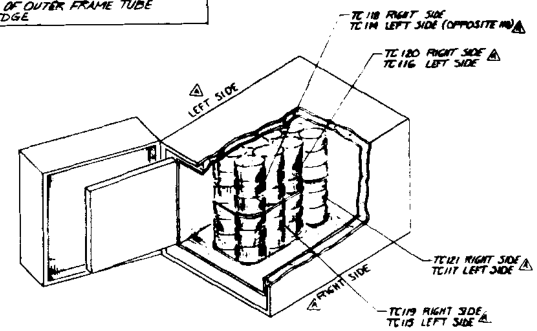
TABLE (CONT'D)

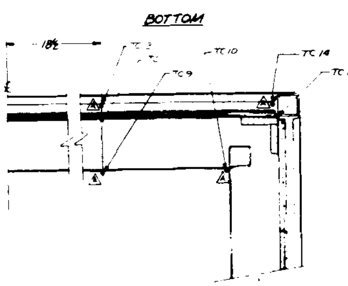
TC NO.	LOCATION
29, 30, 36, 37, 38, 39, 40, 41	INNER SURFACE OF RADIATION SHIELD
49, 98, 99, 100, 101	INNER EDGE OF INNER DOOR SEAL PLATE
50, 103, 104	INNER SURFACE OF INNER DOOR
51	INNER SURFACE OF CONVECTION SEAL SPRING
54, 55, 56	SECOND SIDEWALL FOAM CAP
65, 66	OUTER SURFACE OF OUTER TUBULAR FRAME
68, 72, 81	INNER SURFACE OF INSULATION BOARD
74	OUTER SURFACE OF EXTERIOR SKIN
76	INNER SURFACE OF INSULATION BLANKET
79	OUTER SURFACE OF OUTER FRAME TUBE AT PACKAGE EDGE

TABLE (CONT'D)

TC NO.	LOCATION
84, 85	OUTER SURFACE OF OUTER DOOR KEVLAR
86, 87	INNER SURFACE OF OUTER DOOR SS HONEYCOMB
90	INSIDE VENT TUBE
91, 92, 93, 94	FILTER CAPS
105, 106, 107	INNER SURFACE, BACK PLATE
108, 109, 110, 111, 112, 113	BACK END INSULATION
114, 115, 116, 117, 118, 119, 120, 121	OUTER SURFACE OF BARRELS

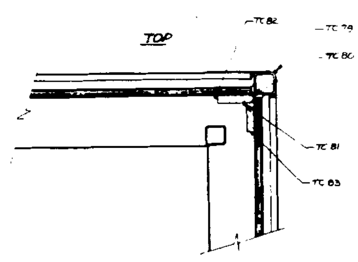






SECTION A-A

SEE "BOTTOM" VIEW FOR LOCATION OF THERMOCOUPLES SHOWN IN THIS SECTION.



SECTION B-B

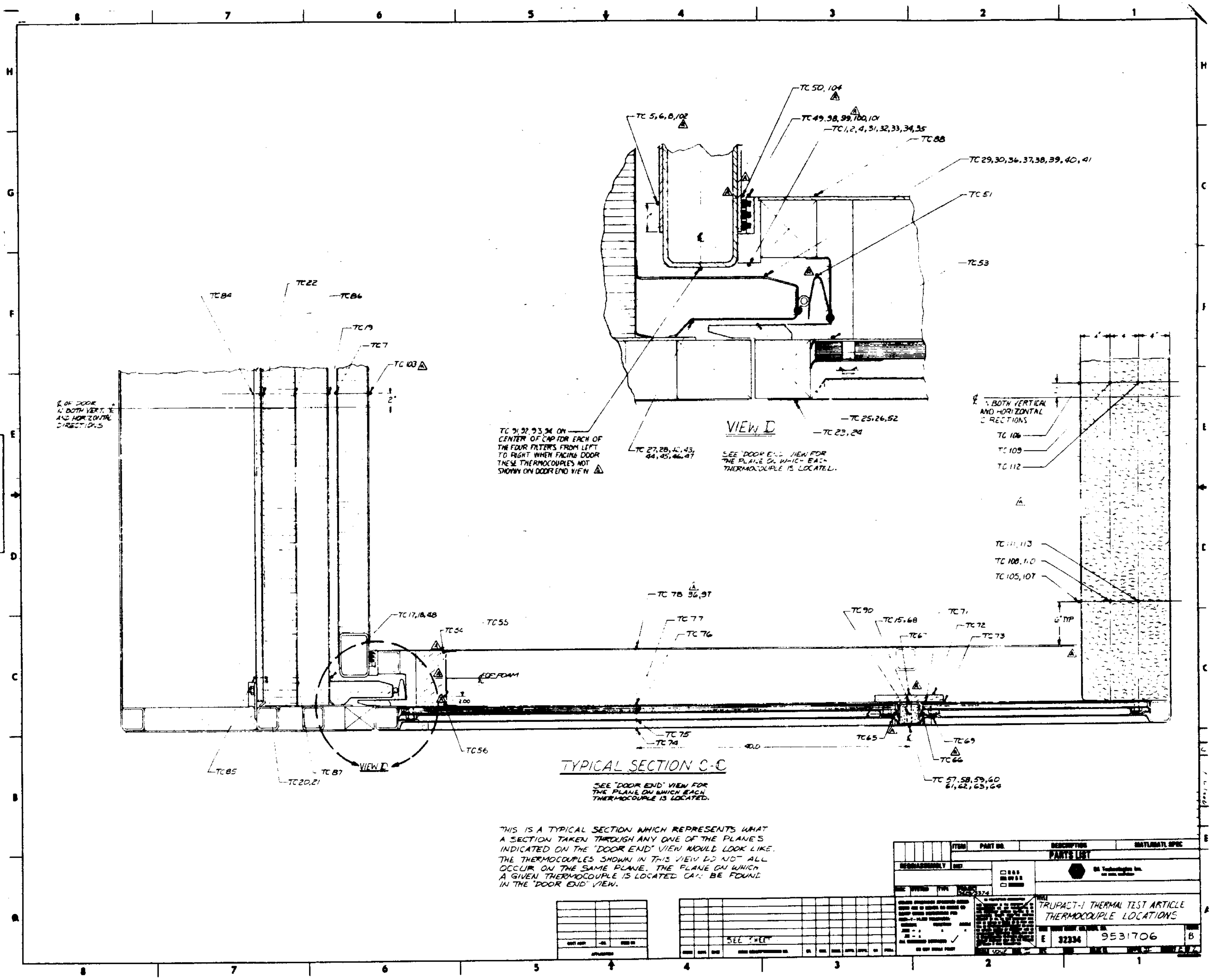
SEE "TOP" VIEW FOR LOCATION OF THERMOCOUPLES SHOWN IN THIS SECTION.

PARTS LIST

TRUPACT-II THERMAL TEST ARTICLE THERMOCOUPLE LOCATIONS

E 32334 9531706 B

PER CN 005607
PER CN 005420



VIEW D
TC 50, 104
TC 5,6,8,102
TC 49,98,99,100,101
TC 1,2,4,31,32,33,34,35
TC 88
TC 29,30,36,37,38,39,40,41
TC 51
TC 53
TC 91,92,93,94 ON CENTER OF CAP FOR EACH OF THE FOUR FILTERS FROM LEFT TO RIGHT WHEN FACING DOOR THESE THERMOCOUPLES NOT SHOWN ON DOOR END VIEW
TC 27,28,42,43,44,45,46,47
TC 25,26,52
TC 23,24
SEE "DOOR END" VIEW FOR THE PLANE ON WHICH EACH THERMOCOUPLE IS LOCATED.
TC 84
TC 22
TC 86
TC 19
TC 7
TC 103
TC 106
TC 109
TC 112
TC 108,110
TC 105,107
TC 78 96,97
TC 17,18,48
TC 54
TC 55
TC 77
TC 76
TC 90
TC 15,68
TC 71
TC 72
TC 73
6" TYP
FOAM
TC 75
TC 74
40.0
TC 65
TC 69
TC 66
TC 56
TC 85
TC 20,21
TC 87
TC 57,58,59,60,61,62,63,64
TYPICAL SECTION C-C
SEE "DOOR END" VIEW FOR THE PLANE ON WHICH EACH THERMOCOUPLE IS LOCATED.
THIS IS A TYPICAL SECTION WHICH REPRESENTS WHAT A SECTION TAKEN THROUGH ANY ONE OF THE PLANES INDICATED ON THE "DOOR END" VIEW WOULD LOOK LIKE. THE THERMOCOUPLES SHOWN IN THIS VIEW DO NOT ALL OCCUR ON THE SAME PLANE. THE PLANE ON WHICH A GIVEN THERMOCOUPLE IS LOCATED CAN BE FOUND IN THE "DOOR END" VIEW.
PARTS LIST
GA Technologies Inc.
TRUPACT-I THERMAL TEST ARTICLE THERMOCOUPLE LOCATIONS
E 32334 9531706 B

9531706

APPENDIX B

TEST ARTICLE ENVIRONMENTAL
THERMOCOUPLE DATA

CONTENTS

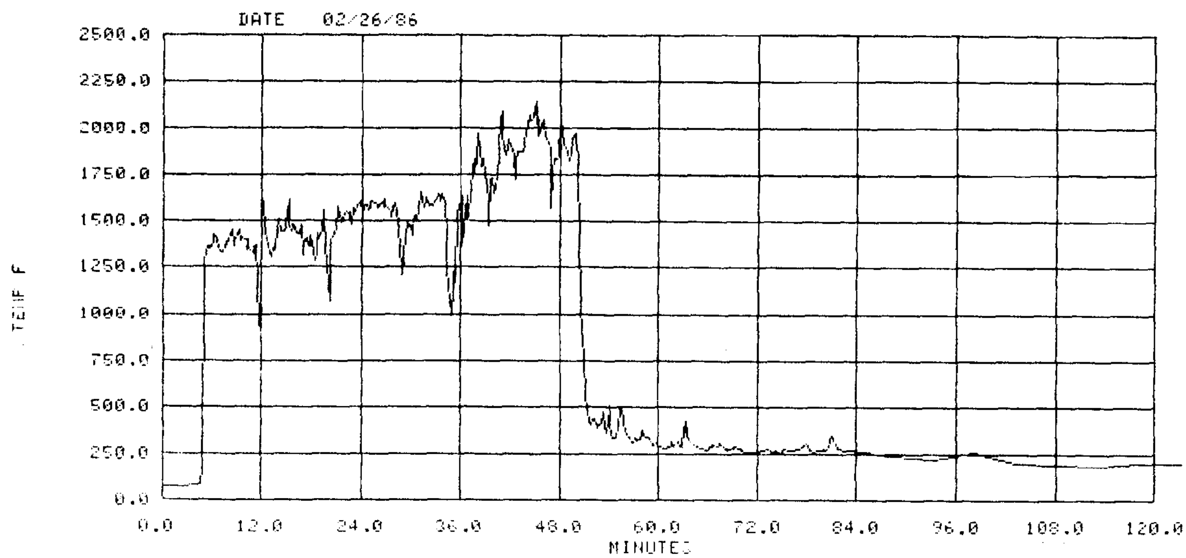


Figure B-1. TC123 SW Tower, 1.37 m

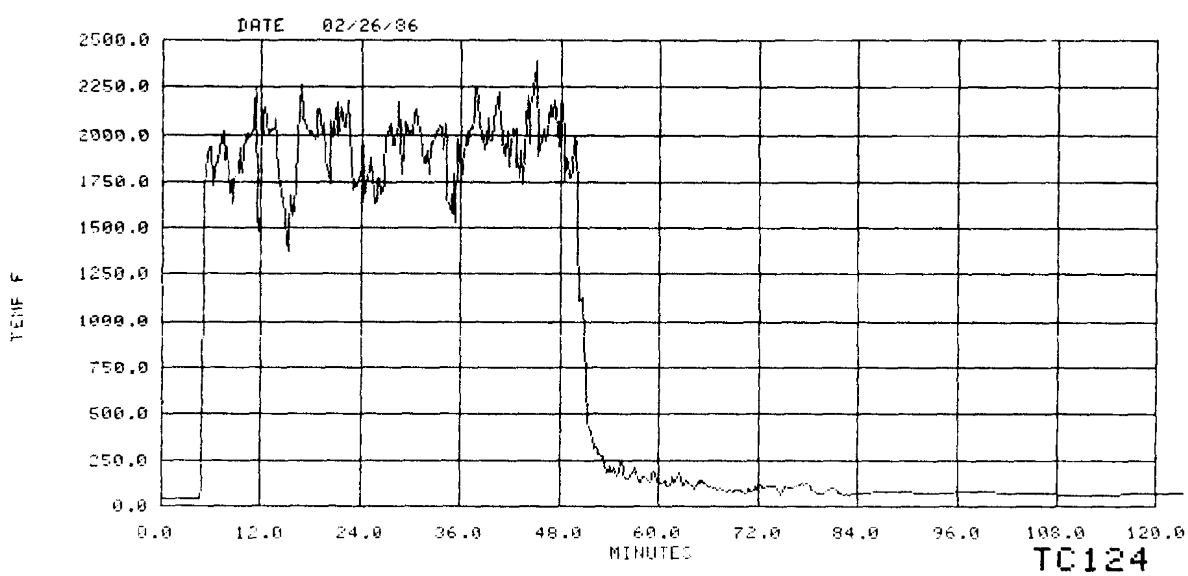


Figure B-2. TC124 SW Tower, 2.29 m

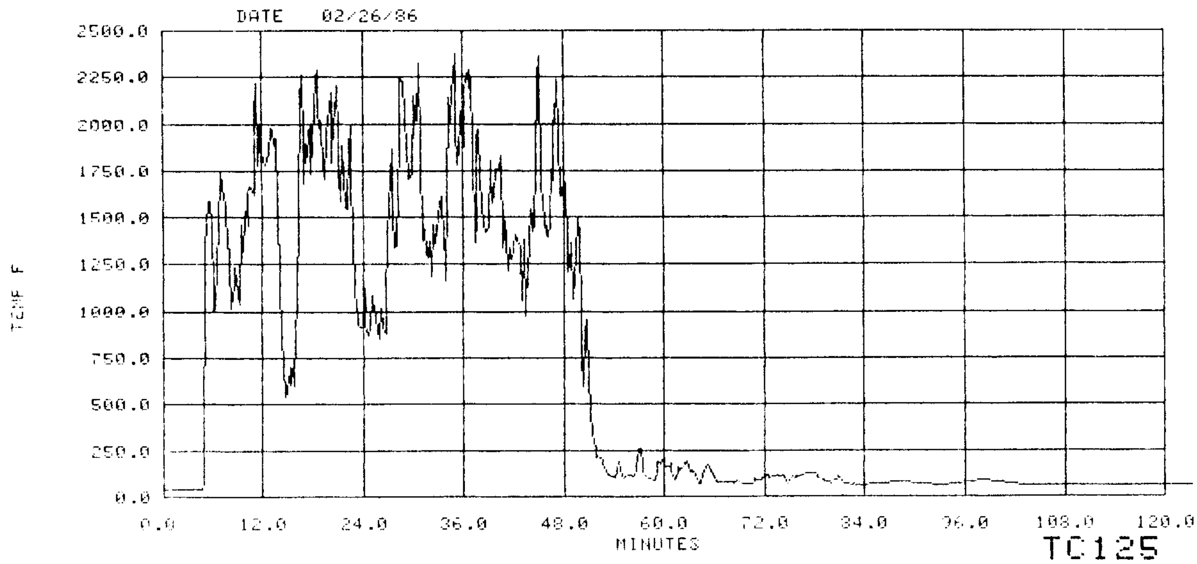


Figure B-3. TC125 SW Tower, 3.51 m

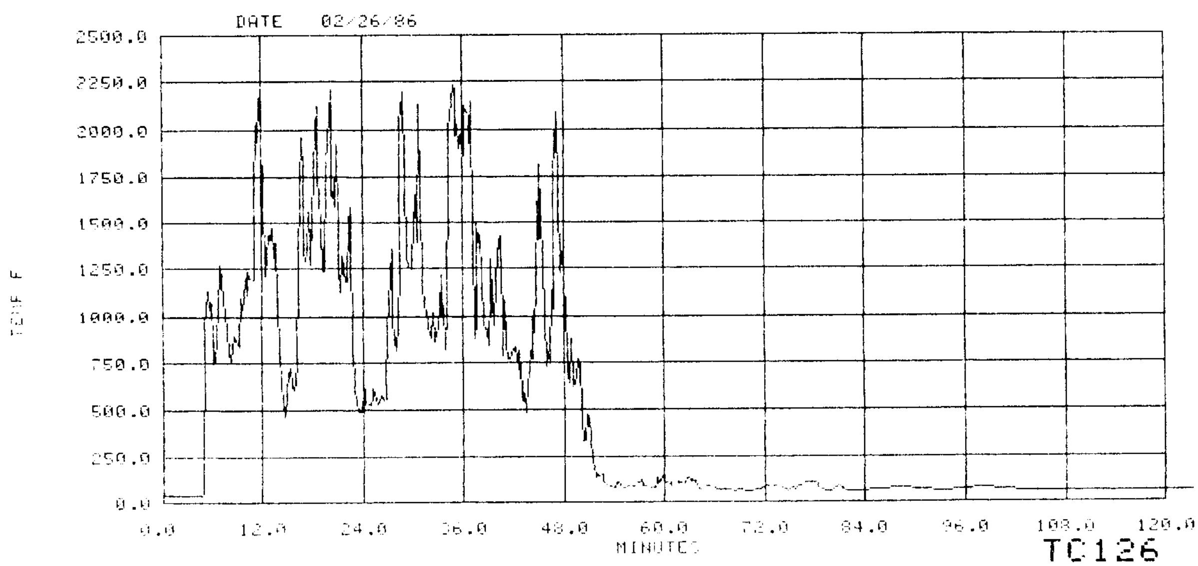


Figure B-4. TC126 SW Tower, 4.72 m

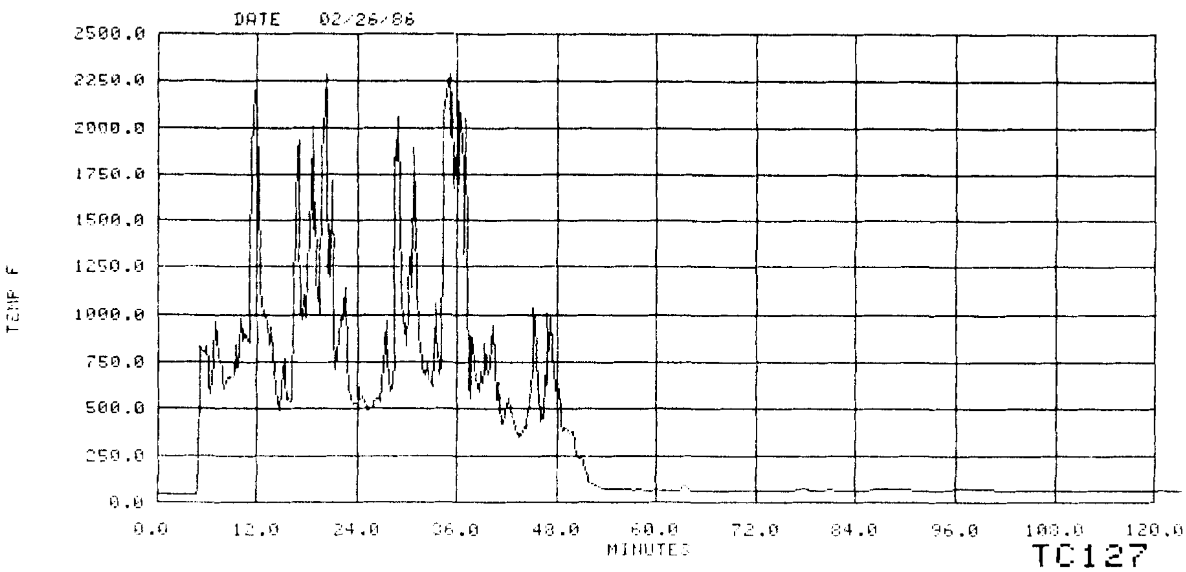


Figure B-5. TC127 SW Tower, 6.1 m

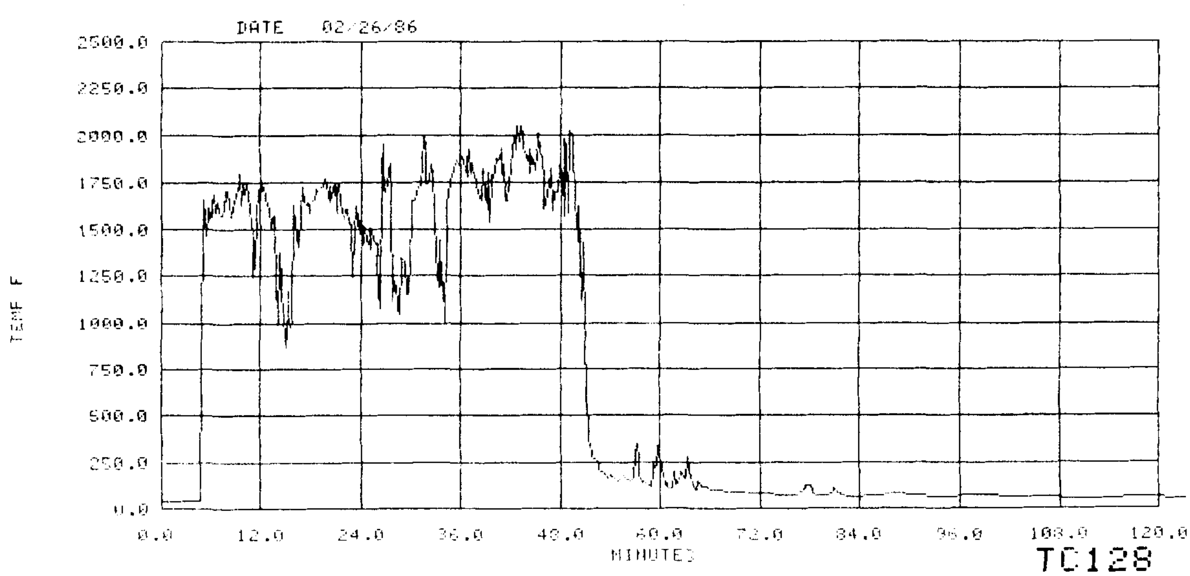


Figure B-6. TC128 NW Tower, 1.37 m

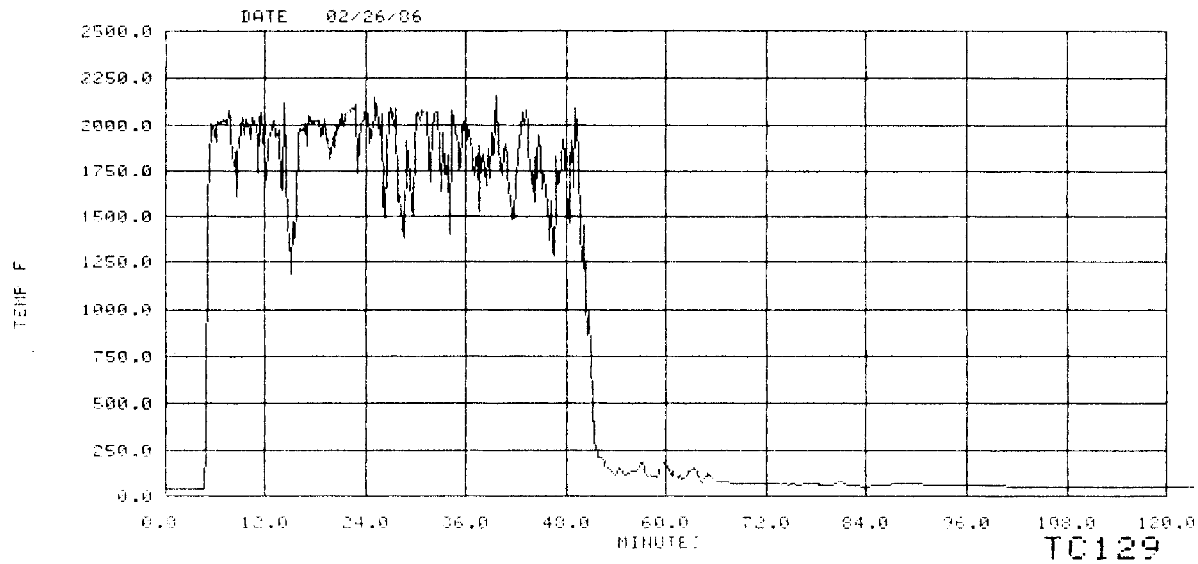


Figure B-7. TC129 NW Tower, 2.29 m

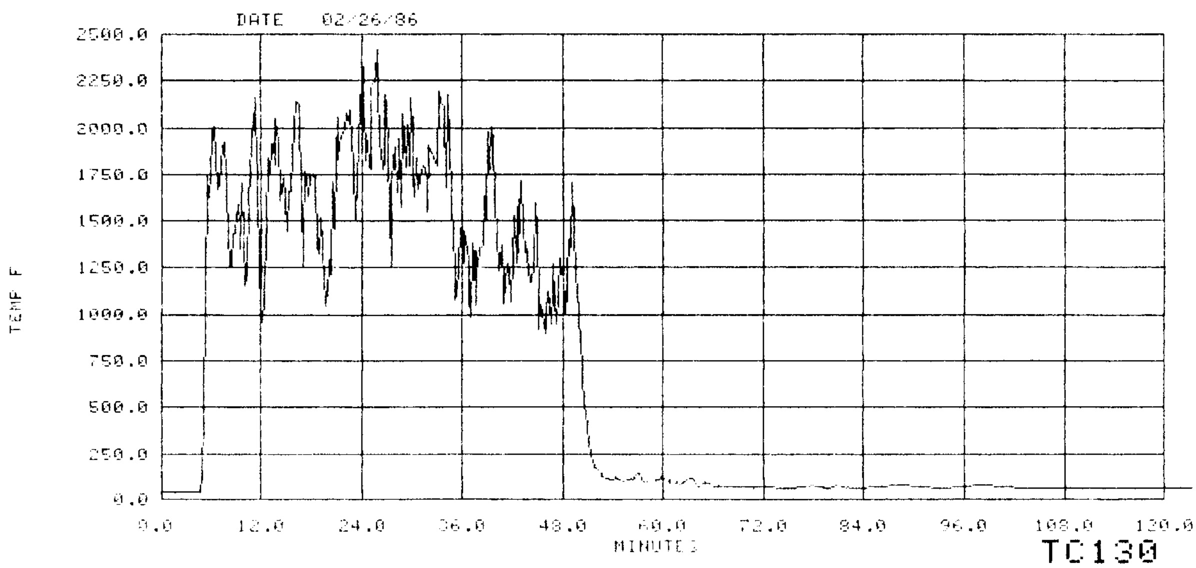


Figure B-8. TC130 NW Tower, 3.51 m

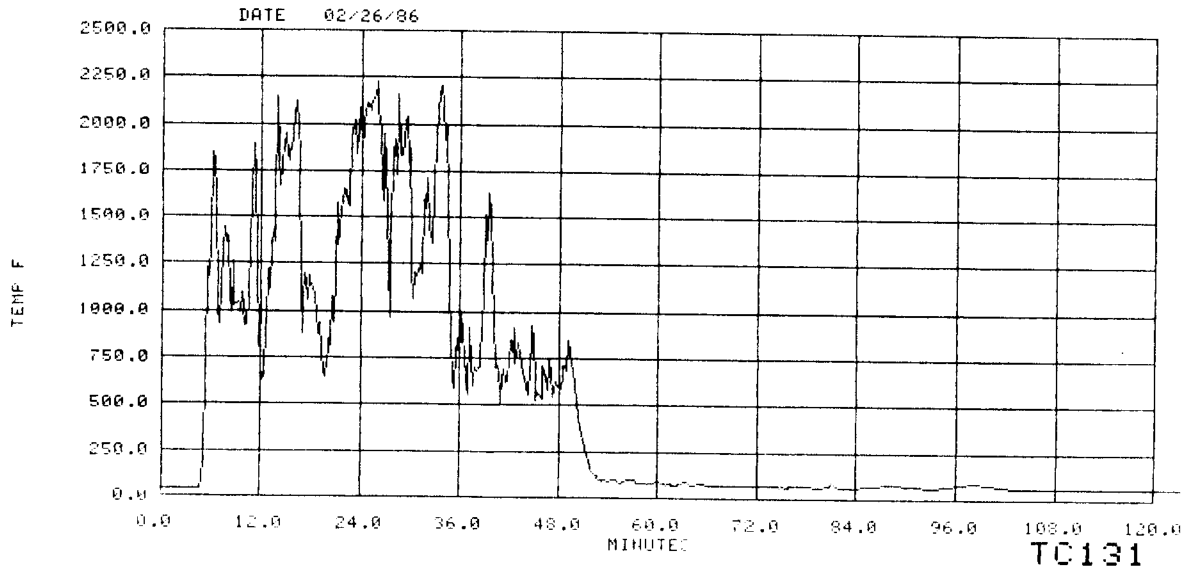


Figure B-9. TC131 NW Tower, 4.72 m

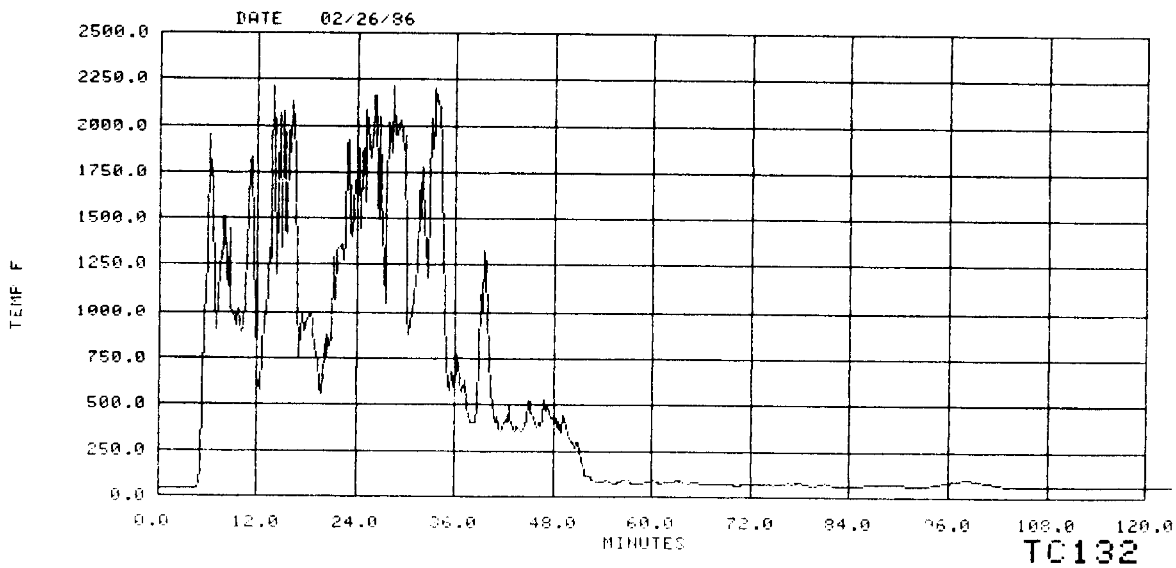


Figure B-10. TC132 NW Tower, 6.1 m

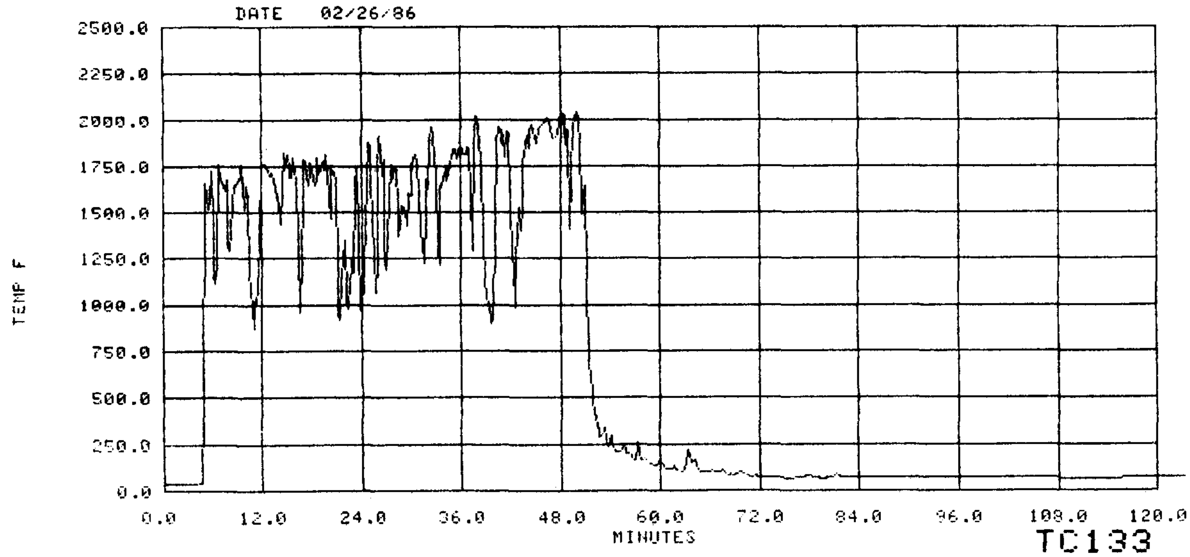


Figure B-11. TC133 NE Tower, 1.37 m

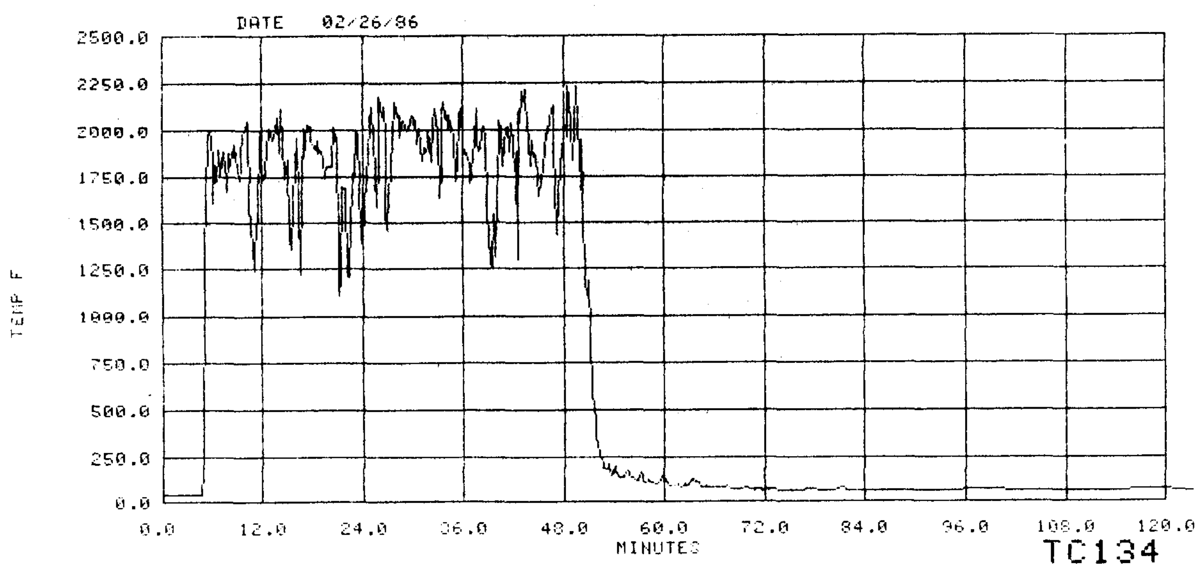


Figure B-12. TC134 NE Tower, 2.29 m

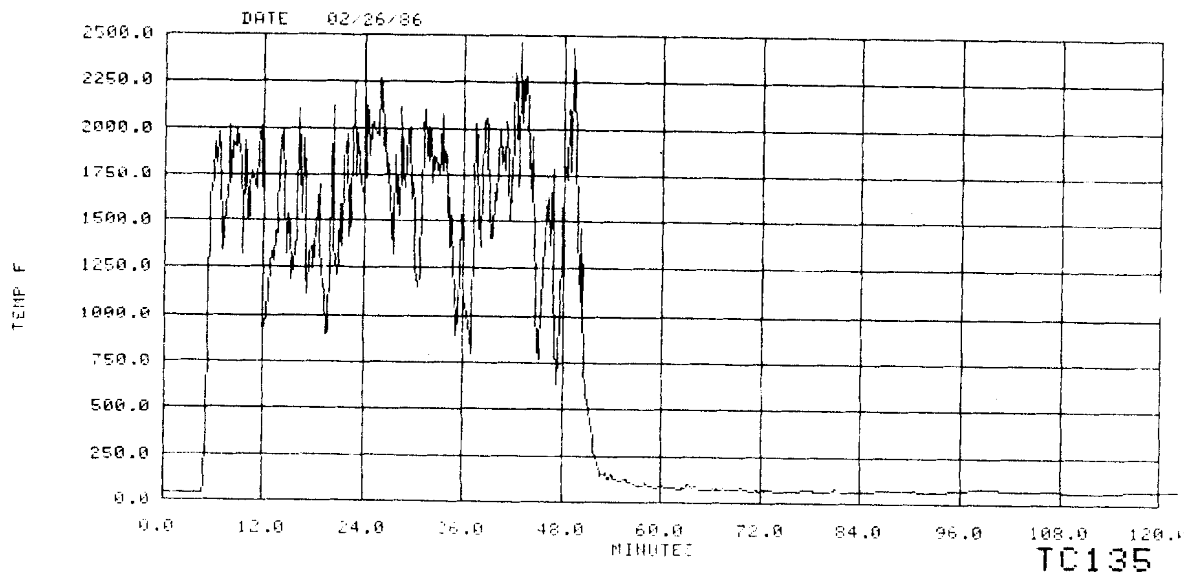


Figure B-13. TC135 NE Tower, 3.51 m

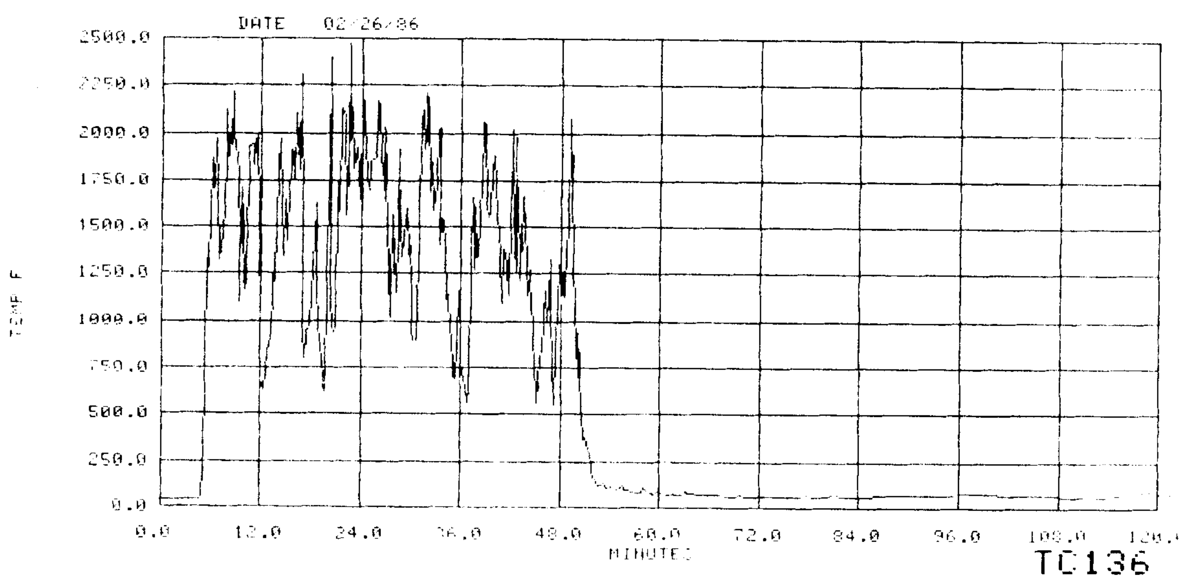


Figure B-14. TC136 NE Tower, 4.72 m

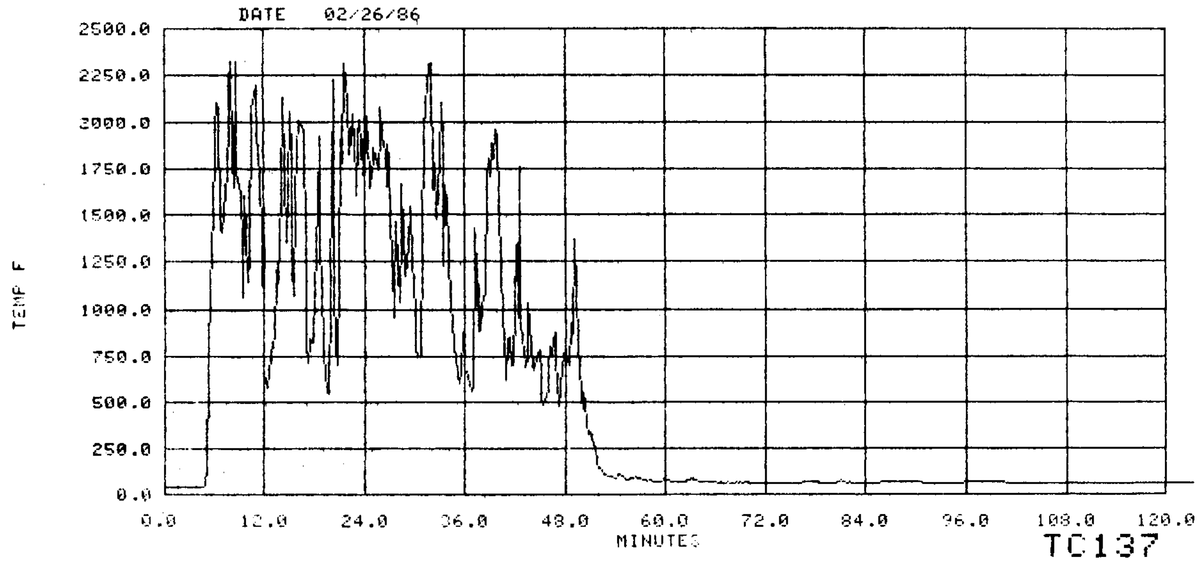


Figure B-15. TC137 NE Tower, 6.1 m

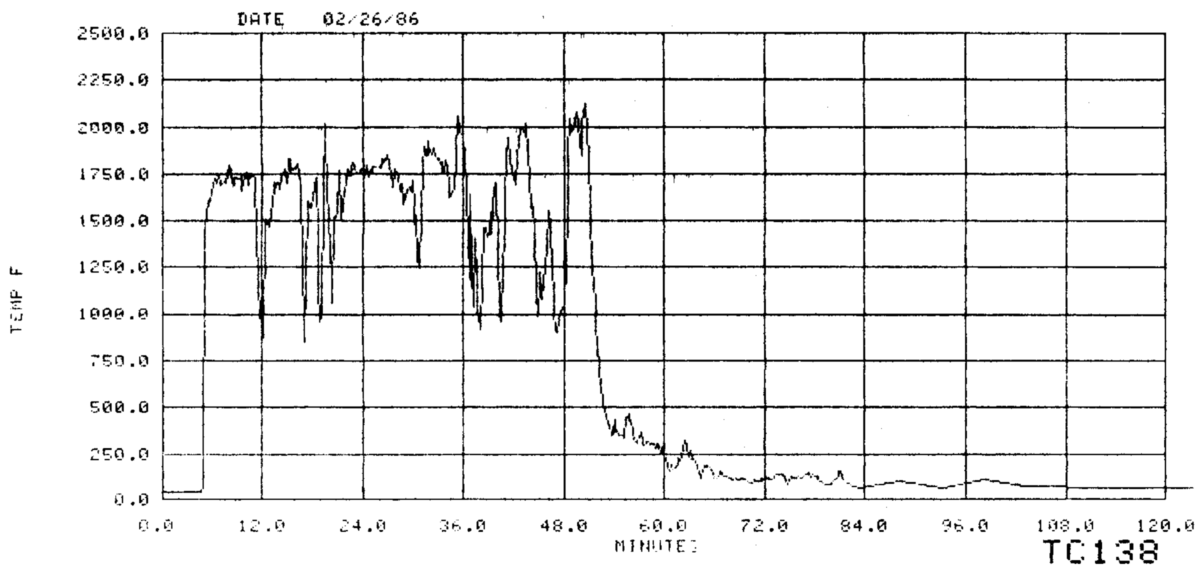


Figure B-16. TC138 SE Tower, 1.37 m

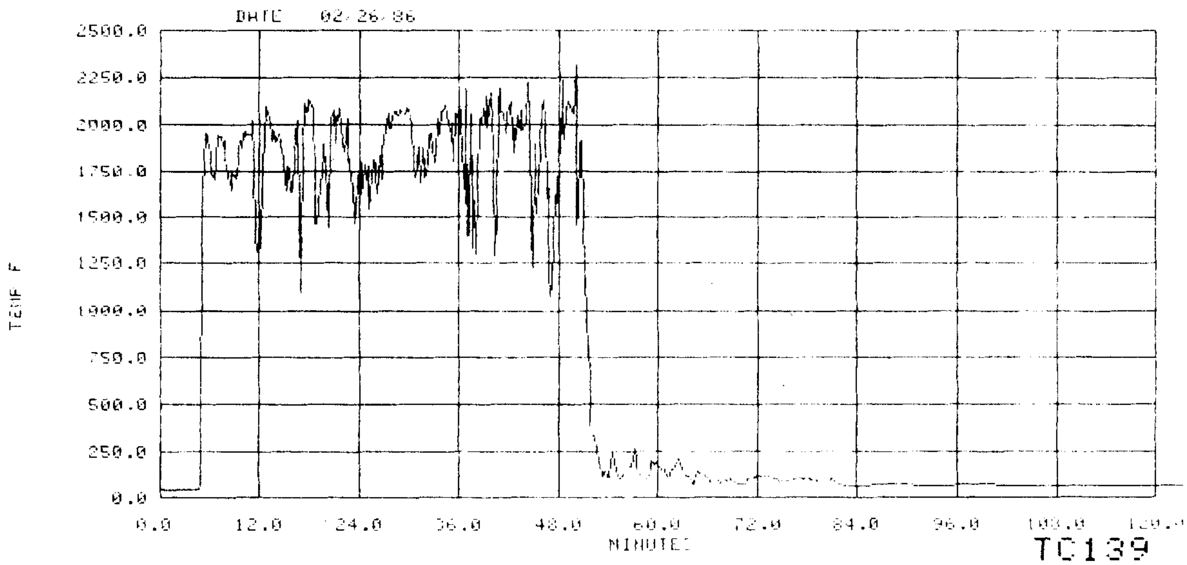


Figure B-17. TC139 SE Tower, 2.29 m

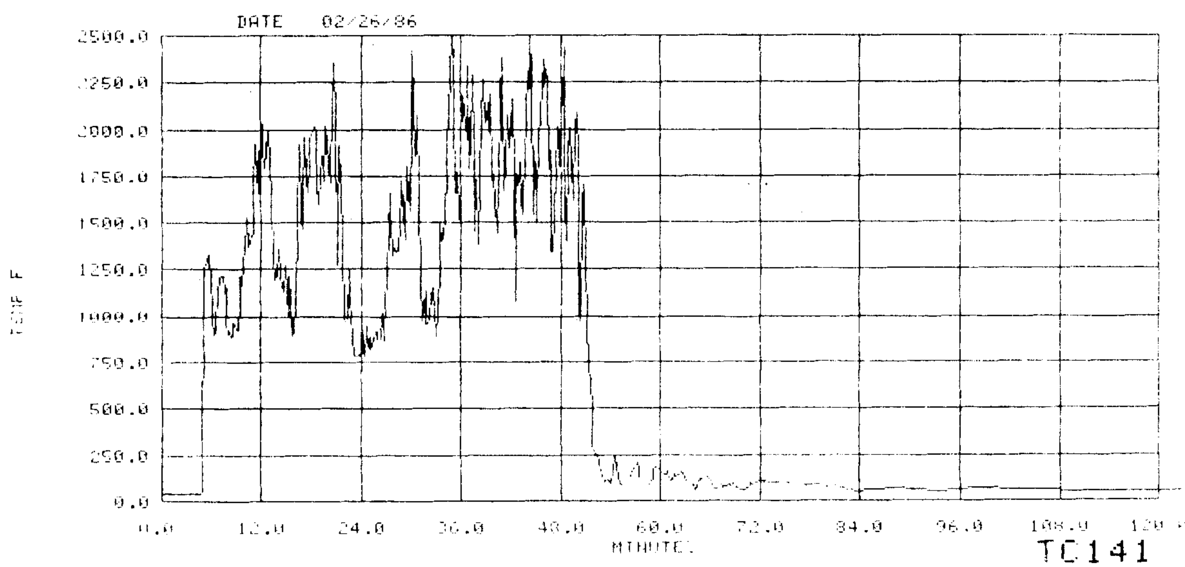


Figure B-18. TC141 SE Tower, 3.51 m

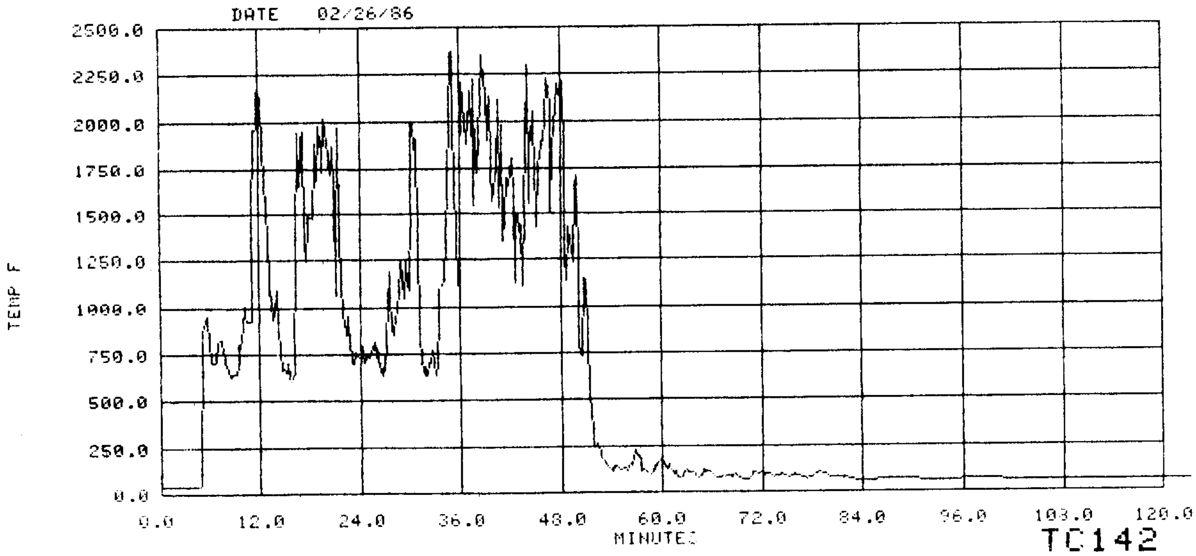


Figure B-19. TC142 SE Tower, 4.72 m

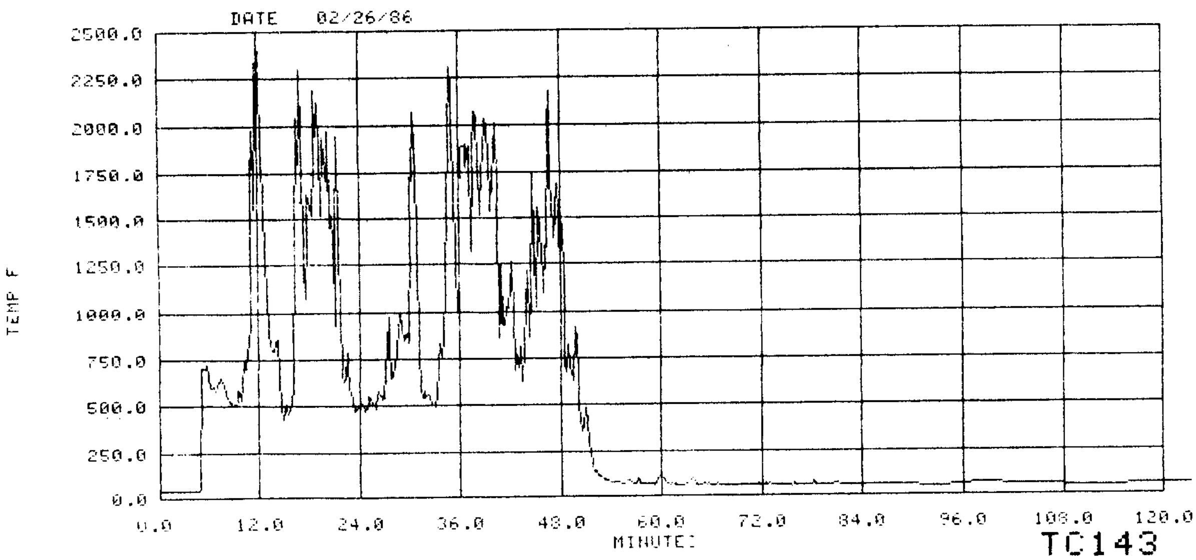


Figure B-20. TC143 SE Tower, 6.1 m

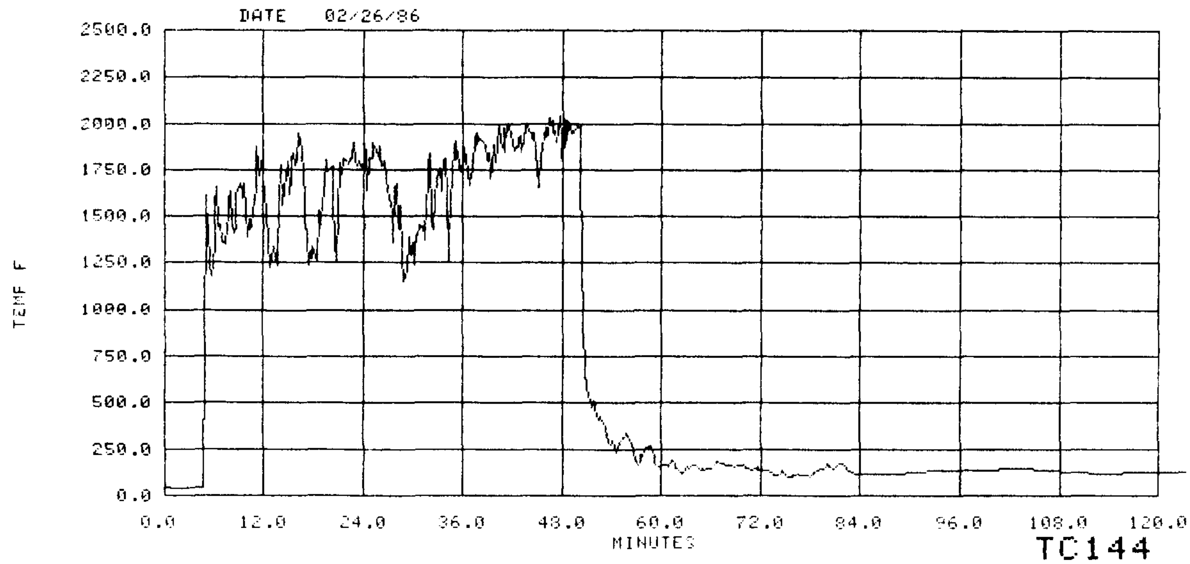


Figure B-21. TC144 W Tower, 1.37 m

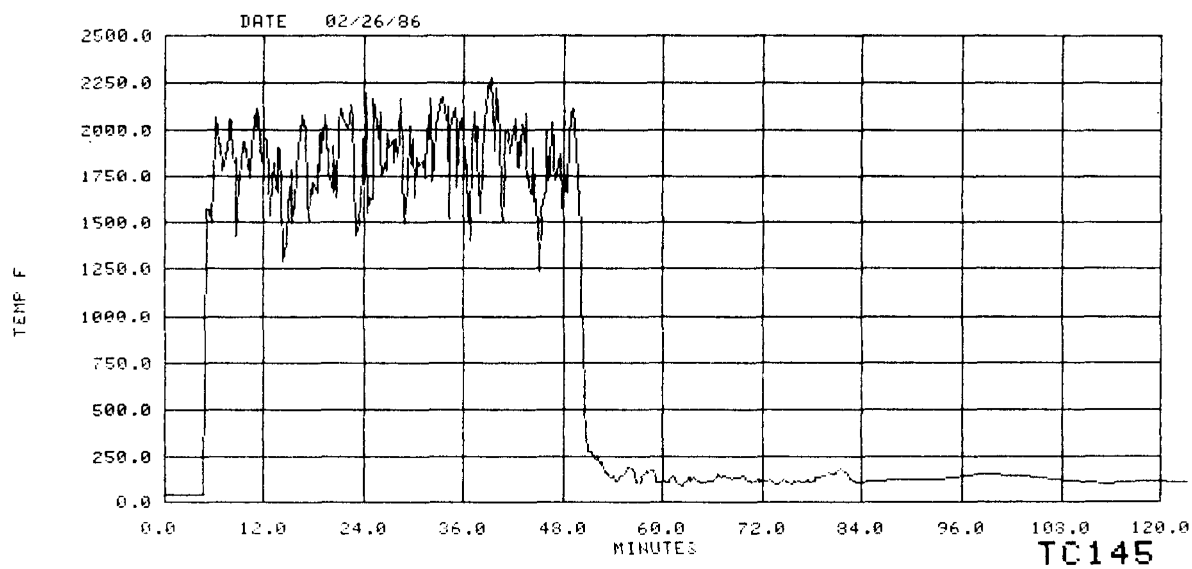


Figure B-22. TC145 W Tower, 2.29 m

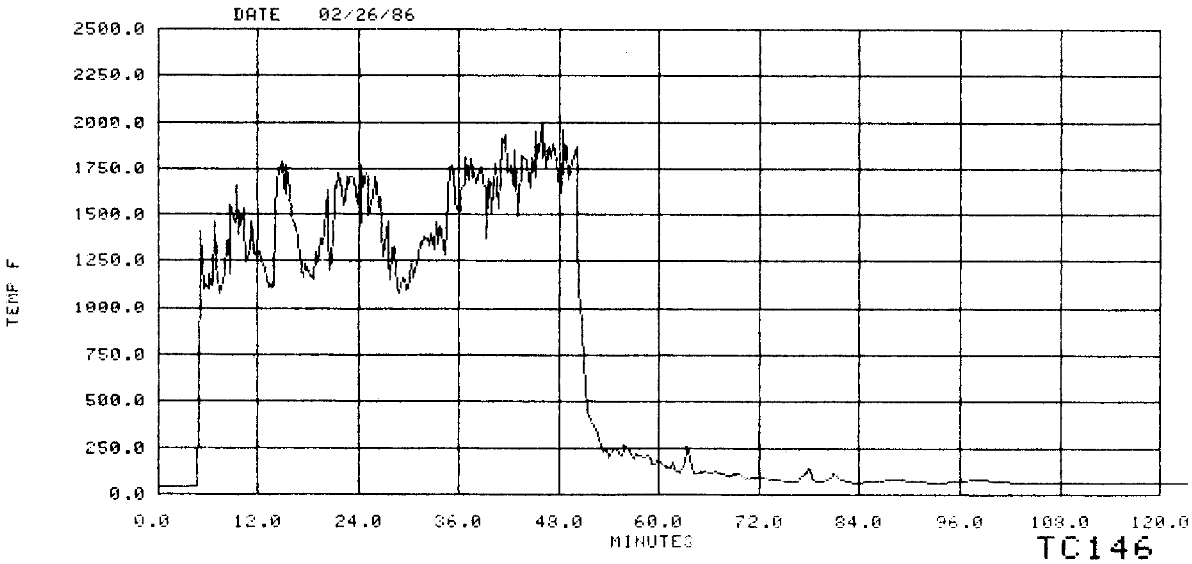


Figure B-23. TC146 Bottom Center West, 1.37 m

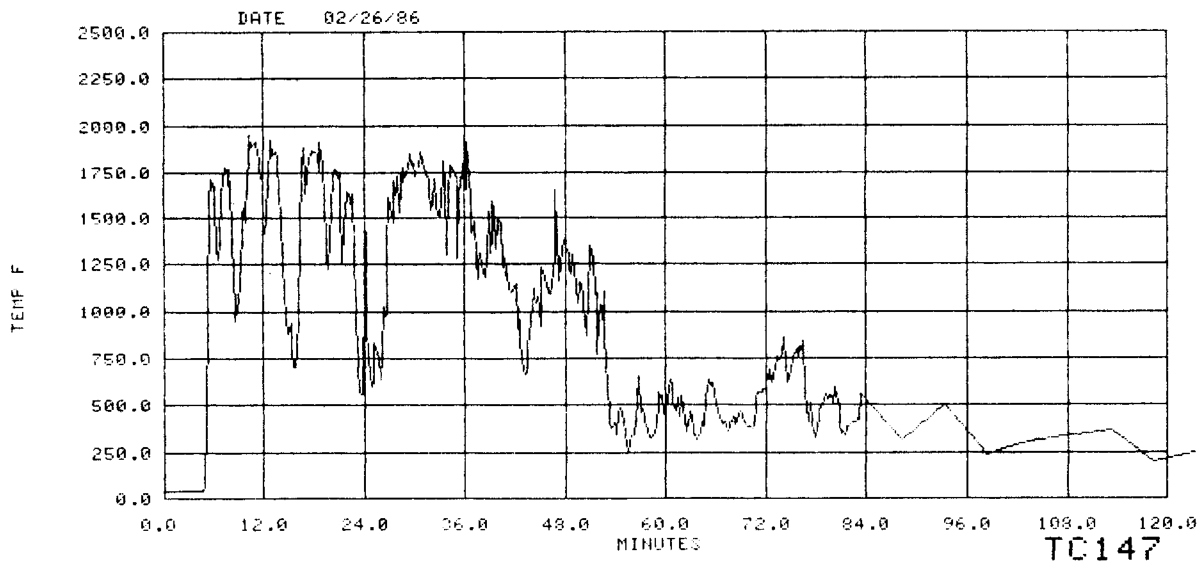


Figure B-24. TC147 Top Center West, 4.72 m

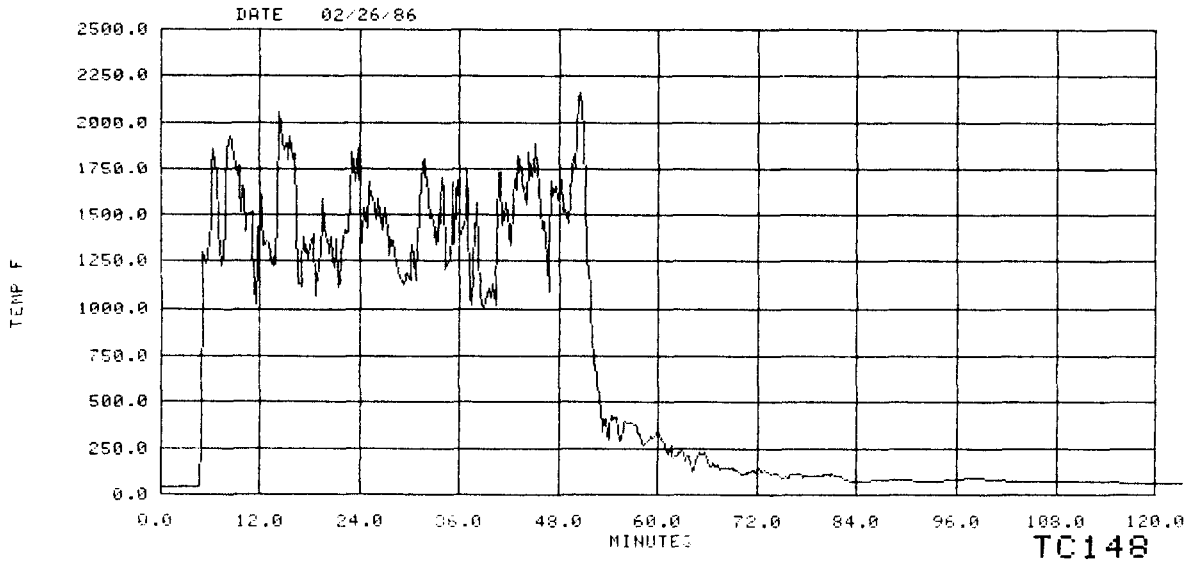


Figure B-25. TC148 Bottom Center East, 1.37 m

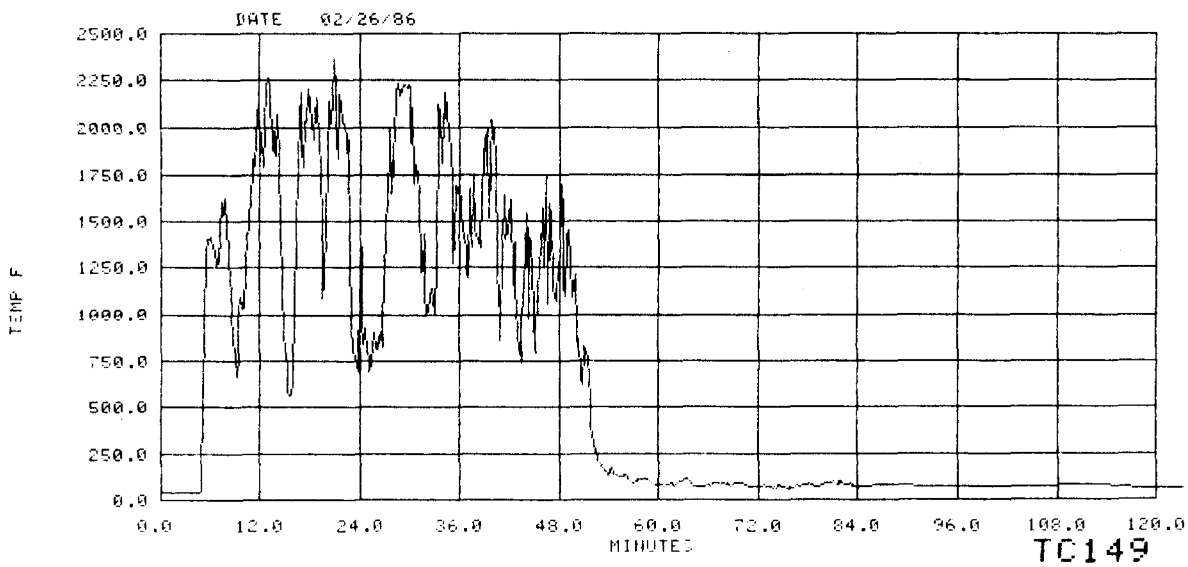


Figure B-26. TC149 Top Center East, 4.72 m

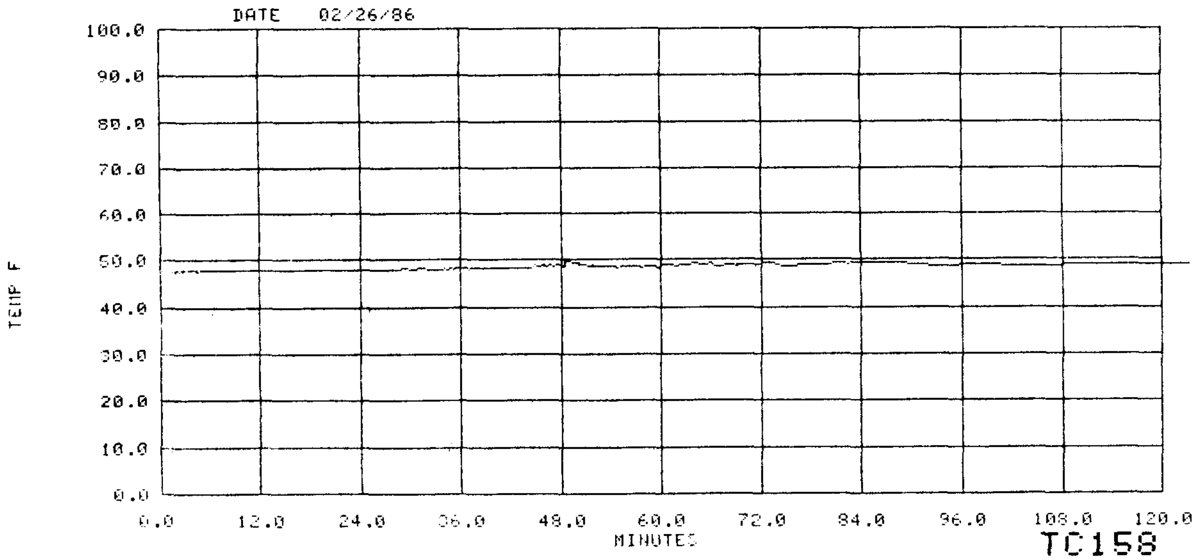


Figure B-27. TC158 Water Temperature

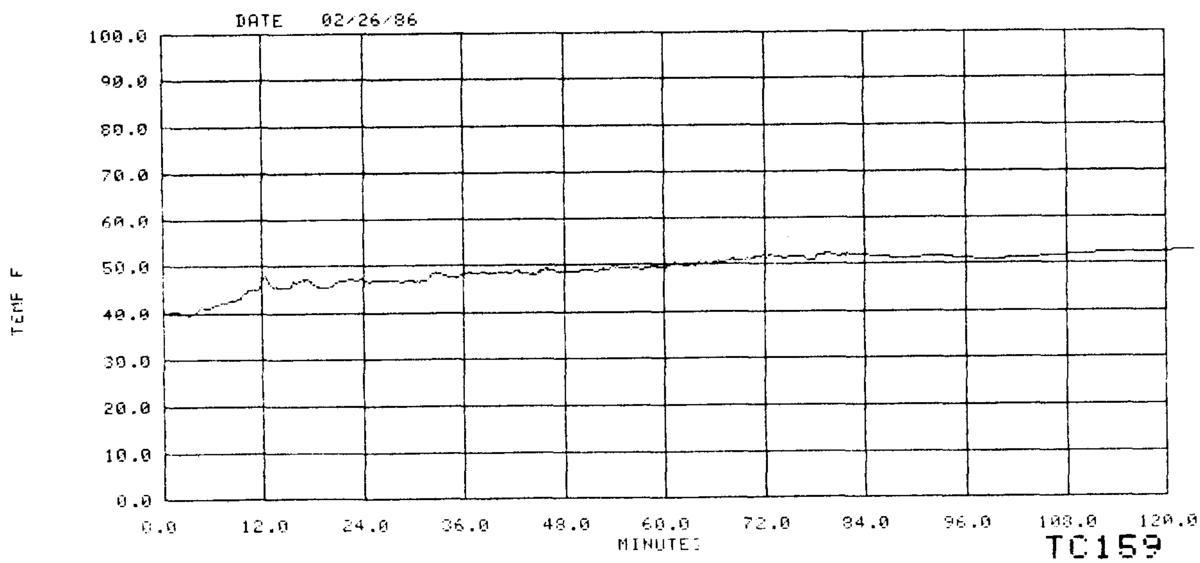


Figure B-28. TC159 Ambient Temperature

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