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MASTER

GLOVEBOX FIRE TESTS

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THE DOW CHEMICAL COMPANY
ROCKY FLATS DIVISION
P. O. BOX 888
GOLDEN, COLORADO 80401

U.S. ATOMIC ENERGY COMMISSION
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Prepared under Contract AT(29-1)-1106
for the
Albuquerque Operations Office
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The experiments were performed during June 1969 with the cooperation of many groups of The Dow Chemical Company, Rocky Flats Division: Considerable effort in constructing the fire test facility and test glovebox was supplied by the Maintenance department; suggestions for test conditions were elicited from the Engineering and Production departments; and the Photography department prepared a motion picture record of the experiments as they were performed by Fire department personnel.

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GLOVEBOX FIRE TESTS

William E. Domning and Richard W. Woodard

ABSTRACT

Fire tests were performed on a shielded glovebox to determine the necessary action to minimize damage which might result from a fire within a glovebox.

The most flammable shielding material tested was methyl methecrylate base plastic. Shielding fabricated from pressed fiberboard also burned, but it can be protected from fire by a covering of intumescent paint, stainless steel, or aluminum foil. Glovebox gloves can be protected by a glove protector designed at Rocky Flats.

Pyrex, safety glass, wired glass, and polycarbonate plastic are more suitable than methylmethacrylate for glovebox window materials. Gasket supported windows should have metal protectors which protect the window gasket and prevent the window from falling inward.

Sprinkler heads were effective in controlling glovebox fires; however, considerable damage to the box occurred before the heads operated. Stopping glovebox ventilation was effective in controlling a fire, but this could lead to an explosion.

1.0 INTRODUCTION

A serious fire occurred on May 11, 1969, in the plutonium foundry and fabrication building located at the Rocky Flats Division of The Dow Chemical Company. As a result of this fire, equipment design, materials of construction, ventilation systems, and fire detection and control systems were investigated.

The design and fire safety of the shielded glovebox were of particular interest. A previous investigation reported[1] on the compatibility of materials used for glovebox construction; however, a shielded glovebox was not investigated. The primary purpose of the glovebox is to physically contain plutonium and prevent exposure to personnel. Every effort must be made to design and construct gloveboxes that offer the best compromise between utility, containment, radiation protection, and fire safety.

The purpose of this test program was to investigate and recommend improvements in design and construction of gloveboxes and associated materials.

A series of burning tests was conducted. A surplus glovebox, not contaminated with plutonium, was fitted with windows and shielding typical of the Production

[1] Glovebox Fire Safety, A Guide for Safe Practices in Design, Protection, and Operation, TID 24236, Factory Mutual Research Corporation.

process equipment. Full size equipment was chosen to add a dimension to the test that cannot be readily duplicated by small scale laboratory experiments. The glovebox was burned, and was observed during and after the fire tests. Three glovebox fire tests were made, and they created an opportunity to test methods of controlling and extinguishing the advanced stages of a glovebox fire.

This report describes the tests and their results in the order in which they were performed.

2.0 EXPERIMENTAL

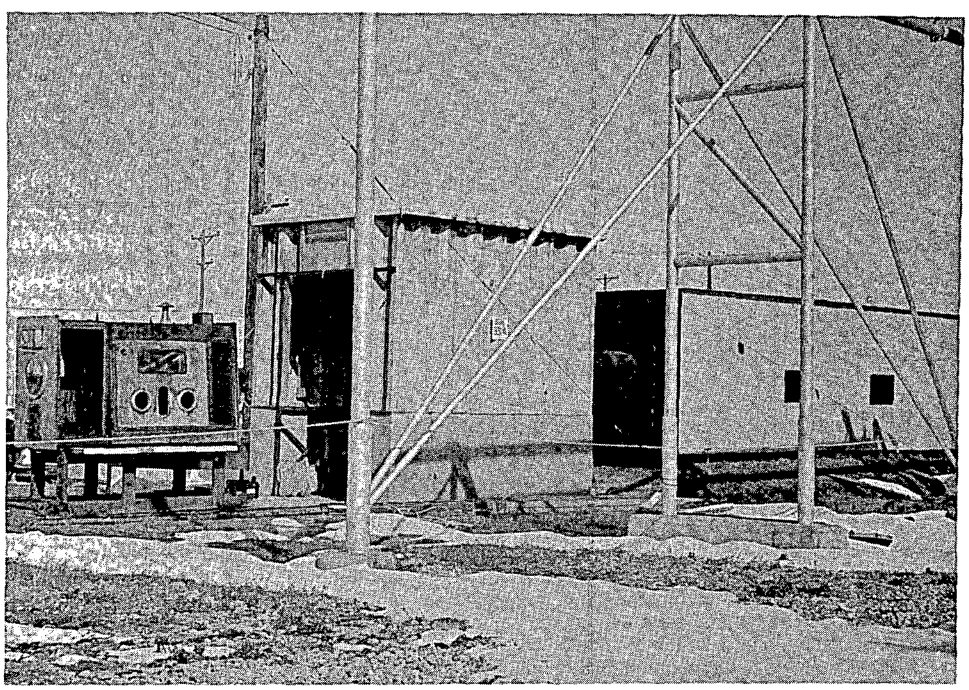
2.1 Equipment

2.1.1 Building Used for Fire Tests

A metal building, 12 feet high by 9 feet wide by 12 feet long, was procured to house the glovebox during the fire tests. The purpose of the building was to simulate installed glovebox facilities. One end of the building was left open for observation of the tests, and it also permitted the glovebox assembly to be moved in or out of the building without difficulty.

Electric power was provided to a smaller adjacent building which housed the instruments used in the test. Figure 1 shows the experimental facility.

Figure 1. Experimental Fire Test Facility.



2.1.2 Ventilation System for Glovebox

Ventilation for the glovebox was provided by air-moving equipment of two different sizes. In the first test, a Buffalo Belted Vent-Set, size 175E blower, was used.[2] The blower used a 3 horsepower, 440 volt, electric motor to move air at 200 cfm through the 4-inch-diameter exhaust piping. When the glovebox for the first fire test was assembled, an absolute filter (8 inch by 8 inch by 6 inch) was installed in the exhaust line. With these conditions, a maximum negative pressure of -0.3 inch water gauge pressure was maintained on the glovebox.

A larger Buffalo Industrial Exhauster, Type "AW" Air Wheel[2] blower, was used for the second and third tests. This fan was powered by a 10 horsepower motor driving the fan at 1300 rpm to move air at 4000 cfm through a 15-inch-diameter duct connecting the glovebox to the exhaust fan. A manually operated damper was provided to control the negative pressure in the glovebox at -0.7 inch water gauge pressure. A screen was placed in the duct to prevent passage of debris which could result from the fire.

2.1.3 Fire Test Glovebox

A surplus glovebox was obtained for the fire tests. It was constructed of stainless steel and measured 8 feet long by 4-1/2 feet high by 3 feet wide. The cross section of the glovebox was rectangular except for a 6-foot section, on one side, that sloped outward toward the bottom at an angle of 6 degrees. This box is typical of the type used at Rocky Flats.

Openings were provided for windows, air inlet, and air exhaust. A door was located at one end for access into the box.

Figures 2 and 3 depict the vertical and sloped sides of the box. A skid was constructed to support the test box with the shielding in place.

2.1.4 Glovebox Windows

The window materials used in the fire tests included Plexiglas ®[3] G and SE-3 (polymerized methymethacrylate),

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[2]Equipment manufactured by Buffalo Forge Company, Buffalo, New York.
[3]Plexiglas ® is a product of Rohm and Haas Company.

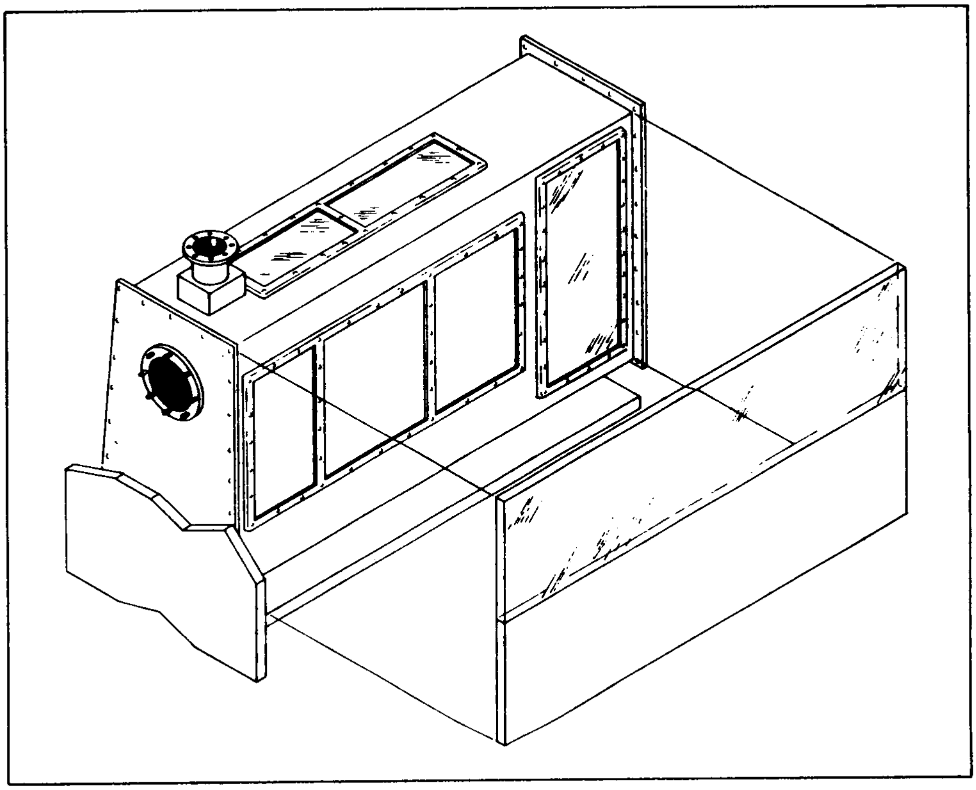

Figure 2. Vertical Side of Test Box.

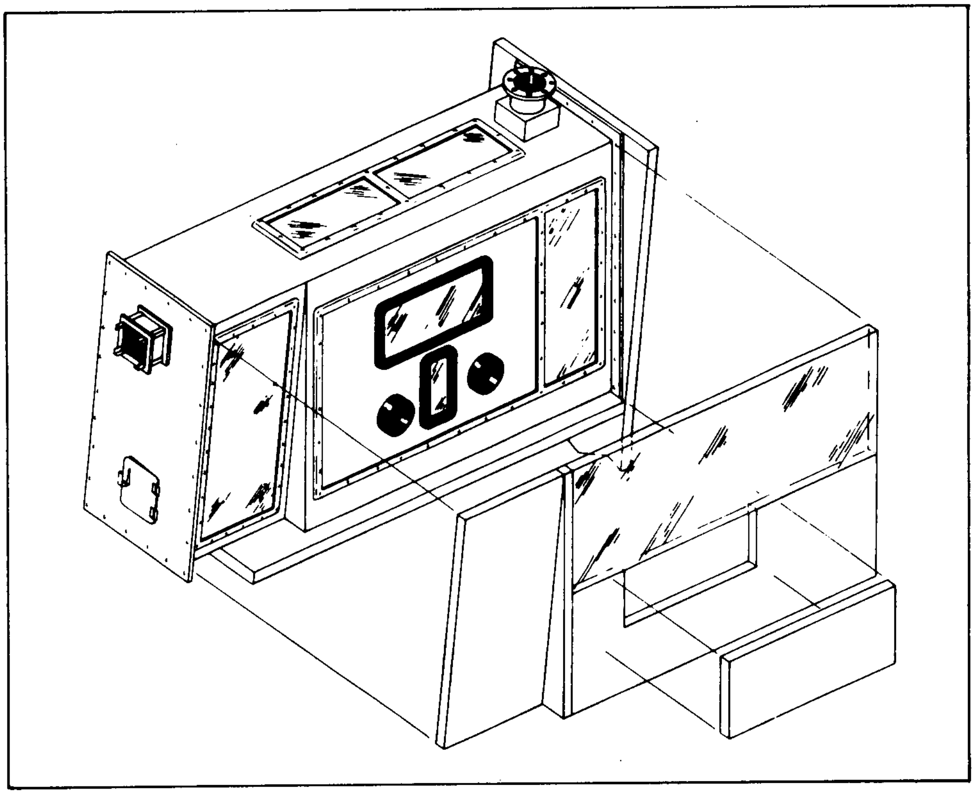

Figure 3. Sloped Side of Test Box.

Lexan ® [4] (polycarbonate), safety glass (1/4 inch), laminated lead glass (1/2 inch), and Missco ® [5] fire rated wire glass. The larger window panels were installed using bolted hold-down strips with a Neoprene ® [6] sponge rubber gasket around the edge of the window to effect a seal. Los Alamos-style windows were installed using a molded rubber Neoprene gasket with a self-sealing ("zipper") feature.

2.1.5 Shielding Panels

Neutron shielding panels were fabricated from 2-inch-thick Benelex ® [7] and 2-inch-thick Plexiglas G. The shielding on the vertical side (Figure 2) was placed 3 1/2 inches from the box wall. A Plexiglas panel was located in such a manner that the 3 1/2-inch space between the shielding and the glovebox could be observed. On the sloped side of the box (Figure 3), the spacing was 3/4-inch from the box wall, and viewing was not possible.

The Benelex which covered the outlet end of the box was located only 1/2-inch from the box wall. The Benelex shielding under the box was located approximately 2 inches from the bottom of the box.

All of the Benelex shielding was painted with a minimum of two coats of paint. Only Tenaco ® [8] white epoxy enamel was used for the first test. Intumescent paint, Albi 107A ® [9], was applied over a basecoat of Tenaco for the second and third tests.

In test Number 3 a stainless steel "pocket" attached to the box wall was filled with Gelgard ® [10] suspension.

Gamma shielding was normally provided by 1/8-inch-sheet lead. It was usually attached to the Benelex, although in some instances the lead was attached to the stainless steel glovebox sides. Lead glass (1/4-inch X-ray type) was used where visibility was required. It was attached to a plastic panel with lead tape in the one test where it was used.

[4] Lexan ® is a product of General Electric Company.
[5] Missco ® is a product of Mississippi Glass Company.
[6] Neoprene ® is a product of E. I. du Pont deNemoirs and Company.
[7] Benelex ® is a product of the Masonite Corporation.
[8] Tenaco ® is a product of Tuffy Products Company, Fairmont, Minnesota.
[9] Albi ® is a product of Albi Manufacturing Company, Rockville, Connecticut.
[10] Gelgard ® is a product of The Dow Chemical Company.

2.1.6 Instrumentation Used on Test Glovebox

Chromel-Alumel thermocouples were attached to the shielding and the box at various locations and connected to nullpoint type millivolt recorders located in the instrument house.
A vacuum gauge, range 0 to -1.0 inch water, and a pressure gauge, 0 to +23 ounce range were connected to the box.

2.1.7 Miscellaneous Materials

Although not of prime importance in the test, materials associated with glovebox operations were placed inside the glovebox. These materials were items as paper, rubber gloves, metal chips of magnesium as a substitute for plutonium, and cardboard cartons.

2.1.8 Fire Detection

Fenwall[11] heat detectors (flowerpot type) 2.5 amp/115 volts a.c., 120°F, which open on temperature rise, were evaluated on the second and third tests. Figure 4 shows a section view of the heat detector, which consists of a miniature thermoswitch and magnet potted in polysulfide rubber. In operation, the detectors were inserted into circuits containing synchronized clocks; the time of actuation of the miniature thermoswitch was read from the position of the stopped clocks. The locking feature of the circuit prevented restarting of the clock after cool-down of the detector switch.

2.2 Procedure

After the experiment had been designed, the glovebox and shielding designs were prepared. This design had to conform to the general shape of the box as shown in Figures 2 and 3. The box was then constructed and moved into the building for burning. The ventilation blower, thermocouples, and pressure and vacuum gauges were connected. Overheat detectors were connected to the circuit shown in Figure 5. The temperature recording and ventilation systems were checked for operational integrity.

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[11] Fenwall, Inc., Ashland, Massachusetts.

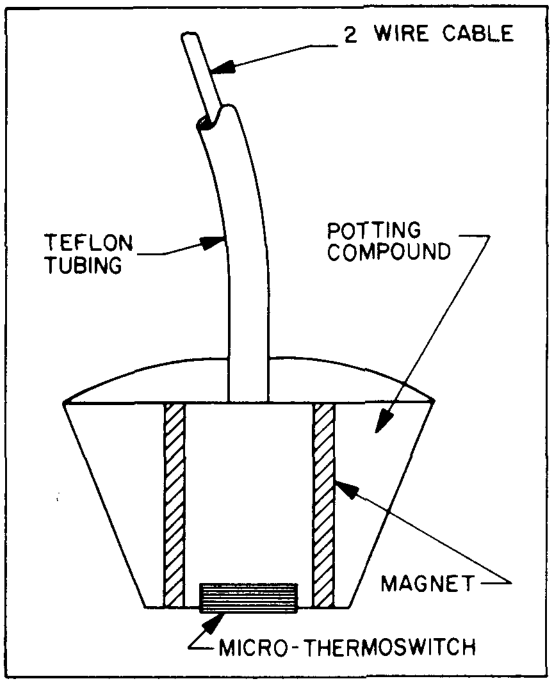

Figure 4. Flowerpot Type of Heat Detector.

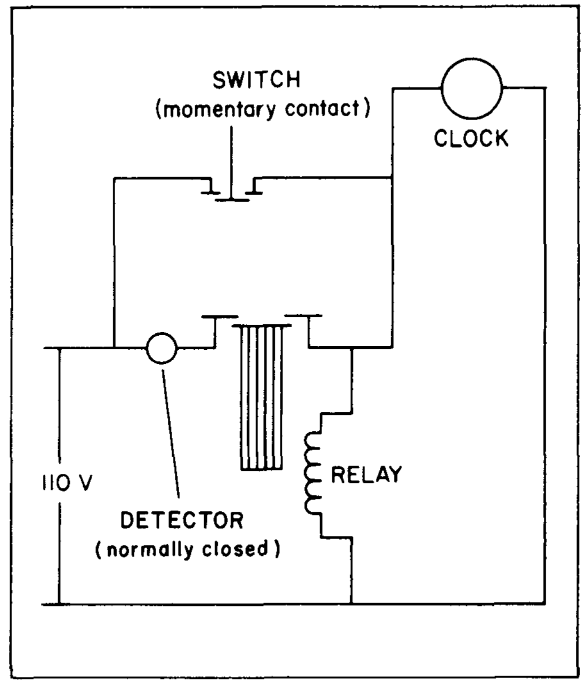

Figure 5. Test Circuit for Heat Detector.

The fire was started by igniting two quarts of solvent (kerosene fraction) in an 8 inch by 12 inch by 2 inch pan located on the glovebox floor under a gloveport. During the burning, motion pictures were taken, and data were recorded, of the progress of the fire.

The fire was extinguished by the fire department personnel who were also responsible for testing high expansion foam as well as sprinkler and hose-delivered water. After the fire was extinguished, the shielding and box were disassembled for inspection of the materials and assessment of damage.

3.0 RESULTS

3.1 Experiment Number 1

3.1.1 Objective

This initial test was designed to provide information on the damage that would be incurred under the existing construction of Buildings 776, 777, and 707. The results of this experiment were similar to damage found within Building 776 and therefore confirmed how the fire could propogate.

3.1.2 Glovebox Design

Figures 6 and 7 depict the configuration of the glovebox and the shielding panels. The numbers on the panels are keyed to Tables I, II, III, IV, and V. These tables describe the material used for a particular panel and the condition of that material and panel at the conclusion of the burning test.

A selection of materials which would normally be found within a glovebox line was placed inside the glovebox. This list of materials, as well as the damage to these materials during the fire is noted in Table VI.

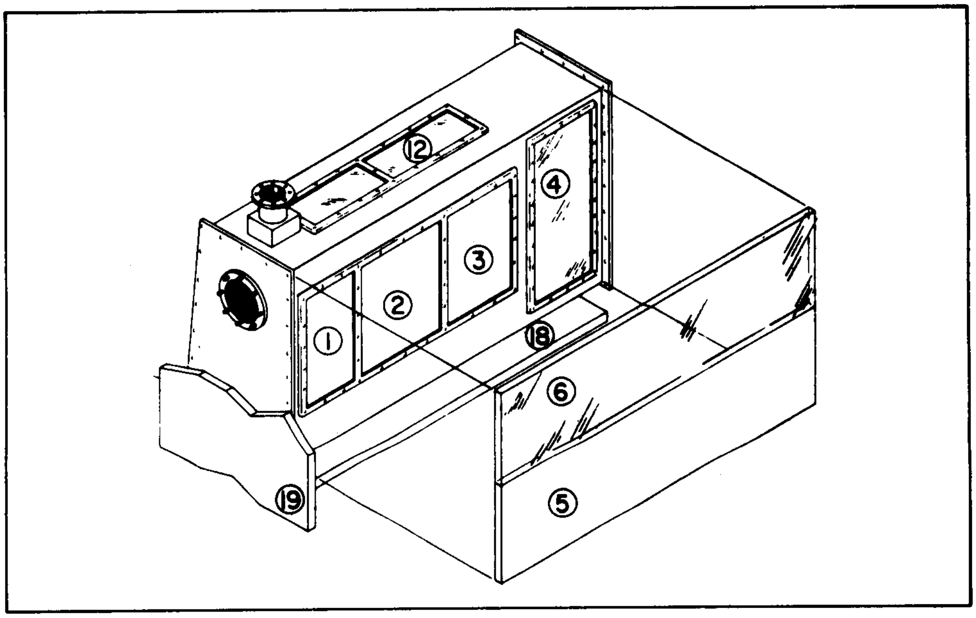

Figure 6. Vertical Side of Test Box. (Figures on panels refer to reference numbers in Tables I, II, III, and V.)

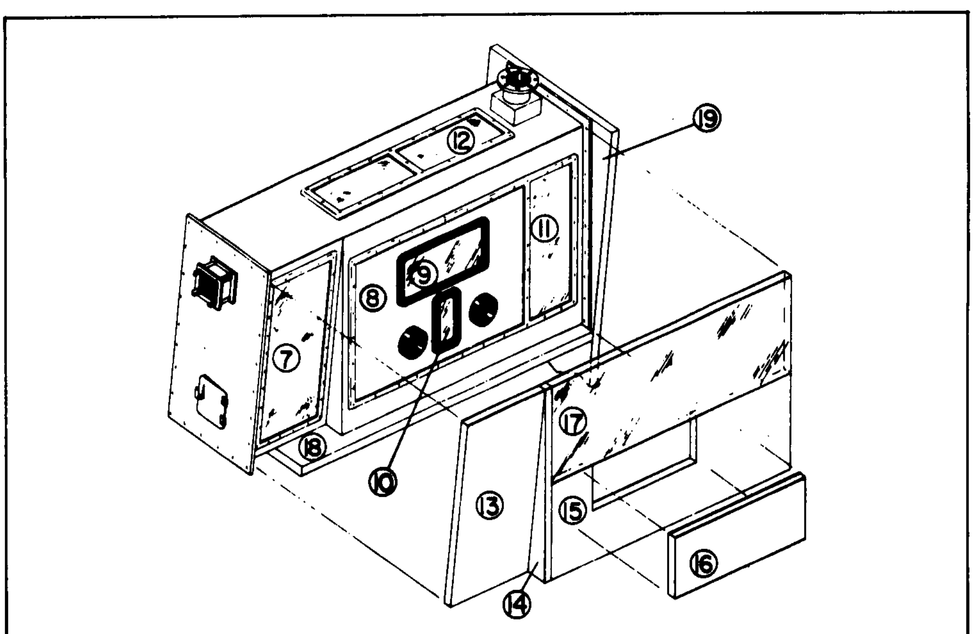

Figure 7. Sloped Side of Test Box. (Figures on panels refers to reference numbers in Tables III, IV, and V.)

TABLE I

Fire Test Results of Glovebox Experiment No. 1
Test Panels Mounted in Vertical Side of Box

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
1.	Plexiglas G[a] panel, 39 in. by 11 1/2 in. by 1/2 in., with plastic gloveport in lower half of panel.	Figure 6 Panel 1	Window had pulled from the hold down strips along top and right edge and had slumped toward front edge. The glove port cover and rubber gasket were still intact but had slipped below the deformed port. The surface of the exposed Plexiglas was badly pitted owing to volatilization of monomer from the surface. See Figure 8.
2.	Plexiglas SE-3[b] panel, 39 in. by 23 1/2 in. by 1/2 in., with two aluminum gloveports aligned vertically.	Figure 6 Panel 2	The Plexiglas in this window softened and the window slumped into the interior of the box onto the floor. The glove burned off the rings and only charred remnants remained. No portion of the panel was left in its holding frame.
3.	Sheet stainless steel (1/8 in.) with a lead overlay (1/8 in.) fastened with 1/4 in. stainless steel studs and nuts.	Figure 6 Panel 3	The lead melted away from the steel panel leaving only a slight amount of lead in the form of beads. Some of this lead had been oxidized to a yellow compound. Most of the lead dripped onto the lead-faced Benelex panel (Ref. No. 18) located under the box. See Figure 8.
4.	Plexiglas SE-3 panel, 48 in. by 22 in. by 1/2 in., with two aluminum gloveports, one centered in top and one centered in lower half. The gloveports were framed with sheet lead (1/8 in.) made by cutting a round hole for the port in a square piece of lead sheet (1 ft. by 1/8 in.). Lead sheet was taped to the top section of this panel above and to the left of the upper port. Lead glass (1/4 in.) was held on the remainder of the Plexiglas with lead tape.	Figure 6 Panel 4	This panel had slumped into the box and folded over. The gloves were burned away. The lead glass was found partly in the box, and some pieces were outside and underneath the box. This glass was badly crazed and crumbled easily.

Notes
[a]Plexiglas G is the standard methacrylate polymer.
[b]Plexiglas SE-3 is a methacrylate polymer containing additives to render it self-extinguishing.

TABLE II

Fire Test Results of Glovebox Experiment No. 1
Shielding Panels Mounted Outside Vertical Side of Box

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
5.	Benelex panel, 30 in. by 95 1/2 in. by 2 in., painted with white epoxy paint overlaid with 1/8-in. lead sheet also painted white (epoxy). A 3-in. separation existed between this panel and the wall of the glovebox.	Figure 6 Panel 5	The front portion (end of exhaust duct) of the panel was blackened with soot but the lead had not melted. This was the portion over panel No. 1. A narrow section (26 in.) of lead also was unmelted at the bottom edge of the Benelex. Lead was melted from the top half of the Benelex panel which covered panel Number 2, 3, and 4; the lead having melted down to the lower edge of the panel openings in the box. The Benelex panel is shown in Figure 9 (upper panel).
6.	Plexiglas G panel, 25 in. by 95 1/2 in. by 2 inches. This panel was made of two pieces spliced together.	Figure 6 Panel 6	The panel showed only a minor alteration of its original dimensions. The inside surface (toward box) was blackened with soot and had a sand-blasted texture. Some rounding of the top edge was noted where the Plexiglas was burned away. Figure 10 shows the Plexiglas after the fire test.

TABLE III

Fire Test Results of Glovebox Experiment No. 1
Test Panels Mounted in Sloped Side of Box

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
7.	Plexiglas SE-3 panel, 48 in. by 23 in. by 1/2 in., without glove ports.	Figure 7 Panel 7	The Plexiglas panel had slumped onto the box but was still clamped in its hold-down frame along the bottom edge. See Figure 11. A quantity of the plastic had been volatilized and the portion which remained was blackened and crazed.
8.	Stainless steel panel, 42 in. by 65 in. by 1/8-in. thick, with outer edge built-up to 1/2 in. with narrow stainless steel strips tack welded to the plate. Four openings were cut in the plate; two for glove rings, and two for Los Alamos-style windows. The panel was covered with 1/8 in. lead attached with studs and nuts.	Figure 7 Panel 8	The stainless steel panel was warped from the heat and lead had melted away from its surface. The molten lead accumulated in a puddle on the shielding below the box. The glove rings had been partially melted. The Los Alamos-style windows had fallen out of the panel. (See Figure 11.)
9.	Los Alamos-style window, 10 1/2 in. by 24 1/2 in. by 1/2 in., with laminated construction of 1/4 in. lead glass sandwiched between two 1/8 in. panes of safety glass by adhesive films. The window was installed in the stainless steel plate using the custom designed Neoprene "zipper" gasket. The window is actually smaller than the opening in the metal plate and in effect "floats" in the opening.	Figure 7 Panel 9	The window and its gasket dropped out of the opening and fell to the floor of the box. This event took place fairly early in the burning sequence. When this happened, the fire from the interior of the box gained direct access to the Plexiglas shielding. Figure 11 shows the opening in the stainless steel panel in which the window had been mounted.

TABLE III (continued)

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
10.	Los Alamos-style window, 4 1/2 in. by 12 in. by 1/2 in., with same laminated construction described under Ref. No. 9.	Figure 7 Panel 10	This window and its gasket fell into the box and was found on the box floor. The opening which resulted permitted direct access of the fire in the box to the Benelex shielding panels. Figure 11 shows the panel in which this window was mounted.
11.	Plexiglas SE-3 window panel, 39 in. by 12 1/2 in. by 1/2 in., without glove rings and gloves.	Figure 7 Panel 11	The panel was completely blackened and bulged outward. The panel did not slip out of its hold-down strips. A considerable degree of thinning occurred in the central area of the panel. (See Figure 11.)
12.	Two safety glass windows constructed of sheets of glass (1/8 in.) laminated with adhesive. The windows measured 26 in. by 12 in. by 1/4 in. A fluorescent light fixture reflector was placed on top of the box and covered the windows.	Figures 6 and 7 Panel 12	Both windows were ruined during the test with only small pieces of the glass remaining in the frame. The fire was hot enough to bend the thin glass which remained in the frame.

TABLE IV

Fire Test Results of Glovebox Experiment No. 1
Shielding Panels Mounted Outside Sloped Side of Box

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
13.	The dimensions of this panel were 55 in. by 24 in. by 2 inches. The panel was Benelex painted white with epoxy type paint overlaid with 1/8-in.-thick sheet lead, also painted white with epoxy paint. A 1-in. separation existed between this panel and the wall of the glovebox.	Figure 7 Panel 13	The most severe damage to this panel occurred along the front edge of the inner side. The lead had melted away and the exposed Benelex had charred and blistered. One area in the upper corner at the back end of the box was apparently in a cooler region. The panel is shown in Figure 12. (Top panel.)
14.	This panel was a wedge shaped piece cut from 2 in. Benelex. The panel was 55-in. long and measured 8-in. wide at the bottom and tapered to 3-in. wide at the top.	Figure 7 Panel 14	The side of the panel and its inner edges were charred badly. Flaking of the material was evident. Figure 12 (center).
15.	The overall dimensions of this Benelex panel were 30 in. by 69 in. by 2 inches. An opening 42-in. long by 16-in. wide was cut in the top edge of the panel to accommodate the glove rings mounted in panel No. 8. White epoxy paint covered the panel.	Figure 7 Panel 15	The inner surface of this panel was badly charred with the exception of the section protected by the narrow Plexiglas window which remained intact during the test. See Figure 10 (top).
16.	This Benelex panel was painted with white epoxy paint and covered with 1/8 in. lead sheet painted with white epoxy paint. The dimensions of this panel were 19 in. by 46 in. by 2 inches.	Figure 7 Panel 16	This gloveport cover panel was one of the most seriously damaged by the fire. The lead lining had melted away from all of the area exposed to the fire. There was no paint remaining on the burned area. Bulging and charring of the Benelex was apparent (see Figure 12 - bottom panel).
17.	Plexiglas G panel, overall dimensions 25 in. by 69 in. by 2 in. This piece was made of two pieces, 57 in. and 12 in., spliced with metal plate.	Figure 7 Panel 17	The panel was blackened and the side which faced the box had a sand-blasted texture. It was also noted that the area which was positioned over the Los Alamos-style window was eroded most severely. Panel is shown in Figure 13.

TABLE V

Fire Test Results of Glovebox Experiment No. 1
Shielding Panels Mounted Outside Glovebox

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
18.	This Benelex panel measured 81 in. by 48 in. by 2 in. overall, but was made up of two pieces. The panel was painted with two coats of epoxy paint. The surface was covered with lead sheet (1/8 in.) and also painted with white epoxy.	Figures 6 and 7 Panel 18	The panel under the box was only slightly affected by the heat from the fire. Lead, melted from the side shielding, ran onto the surface of the panels and fused to the lead sheet covering the central area. The paint was not scorched in most areas of the panel. Edge views of this panel are shown in Figures 8 and 11.
19.	Benelex shielding, 70 in. by 48 in. by 2 in., covered with sheet lead. Both Benelex and sheet lead were painted with epoxy paint. The panel was made up of two pieces, one 48 in. and one 32 in. high.	Figures 6 and 7 Panel 19	A large area of the sheet lead had melted away, especially in the upper region. The Benelex exposed under the lead had charred and blistered in the hottest areas near the top. The lead which had melted cascaded onto the Benelex shielding that extended below the bottom of the box. Figure 9 (bottom) shows the lower portion of this panel after the fire test.

TABLE VI

Effects of Fire on Materials Placed in Glovebox Fire Test No. 1

Material	Descriptive Information	Observations After Fire Test
Cellulosic:		
Oily Paper Towels	Paper towels in the form of pads 6 in. by 12 in. by 2 inches. The pads were soaked with hydraulic oil mixed with carbon tetrachloride to simulate waste that could be generated in boxes enclosing machine tools. The pads of towels were placed on the bottom of the box.	The towels on the surface of the pad were burned. Some of the towels on the interior of the pad were unaffected.
Cardboard	Two one-quart ice cream cartons were placed in the box.	Burned completely.
Benelex	Two pieces of Benelex measuring 4 in. by 2 in. by 2 inches.	The charred remains of the pieces of Benelex were found in the debris on the floor of the box.
Paint Brush	A 1 1/2-in. bristle paint brush was placed on the floor of the box.	Only the metal ferrule of the brush was found after the test.
Metals:		
Magnesium Alloy	A small slab of A2-91C Mg casting alloy was suspended on a wire frame. Size of slab was 3 in. by 2 in. by 3/8 inch.	The piece of magnesium, badly discolored, was found intact after the fire test. That it did not burn is attributed to the fact that it was knocked over and laid on the floor of the box. (Note: The same magnesium sample was placed in the box in the second fire test and did burn.)

TABLE VI (continued)

Material	Descriptive Information	Observations After Test
Magnesium Chips	A small quantity of magnesium chips (from machining) was scattered near the access door of the box.	The chips were burned.
Aluminum Metal	Aluminum angle 8 in. by 1 1/2 in. by 1 1/2 inches.	The portion of aluminum located highest above the box was partially melted.
Aluminum Metal	Aluminum strip 12 in. by 1 in. by 1/16 in. was wound into a very loose coil.	This piece of aluminum was not found after the fire test. It is assumed that it was melted.
Mild Steel Sheet, Stainless Steel Sheet	These pieces of sheet measured about 16 in. by 12 in. by 1/16 inch. They were bent to elevate part of the metal above the surface of the floor.	The metal was warped by the heat of the fire.
Plastics:		
Polyethylene	Two one-quart bottles and a parts carrier insert were placed in the box.	No evidence of the polyethylene items could be found after the test.
Vinyl Sheet	A vinyl plastic bag 10 in. in diameter by 72-in. long was used.	Burned completely.
Teflon	A small piece of Teflon, 5 in. in diameter, 1/4-in. thick, was used as a sample.	Burned completely.

3.1.3 Test Conditions

The box was connected to a 200-cfm blower and a pressure of -0.3 inch of water was noted. An absolute filter rated at 50 cfm was provided at the inlet of the box. No filter was installed in the outlet duct.

Three thermocouples were inserted into a thermowell which extended into the glovebox. The thermowell was located at the center of the box extending from the ceiling to the floor.

3.1.4 Burning Sequence

The sequence of burning, and the observations made, is as follows:

Time (Minutes)	Observation
0	Fire was started in box by igniting a small amount of kerosene.
4	Fire burned through one glove on vertical side of box.
5	Fire progressing very slowly. The access door was opened and a fan used to force more air into the box.
8	Fan removed.
9	A small amount of water was sprayed into the fire to react with magnesium chips and make it burn more vigorously.
15	Fire still progressing slowly; more kerosene added.
16	Stainless steel panel on end of box colored blue by heat from fire in box.
19	Fire still progressing slowly; inlet air filter pushed into box to provide additional draft.
23	Fire increasing in intensity; molten lead dripping from box.
24	Fire penetrated sloped side of box.
28	Roof of test building scorching; water from fire hose sprayed on roof.

30	High flames shooting from sloped side of box.
32	Flames erupting from both sides of box.
33	Foam added in an attempt to extinguish the fire. Although the quantity of foam was voluminous, it was blown back from the fire.
34	Water sprayed on fire and box with fire hoses.
38	Fire completely extinguished.

3.1.5 Effects of Fire

The effects of the fire on materials used for glazing and shielding are described in Tables I through V. Figures No. 8 through 13 are photographs of the box taken after the fire test.

Effects of the fire on the miscellaneous materials placed in the box are presented in Table VI.

Figure 14 shows a plot of the mean air temperature versus time for the thermocouples located inside the box.

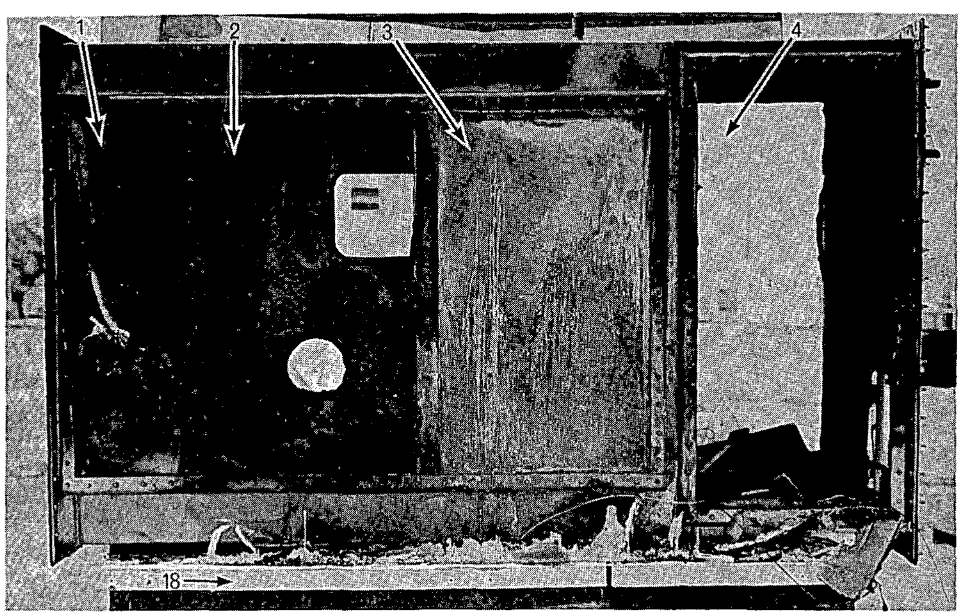

Figure 8. Vertical Side of Glovebox after Experiment No. 1 (See Table I and V for added description of reference numbers.)

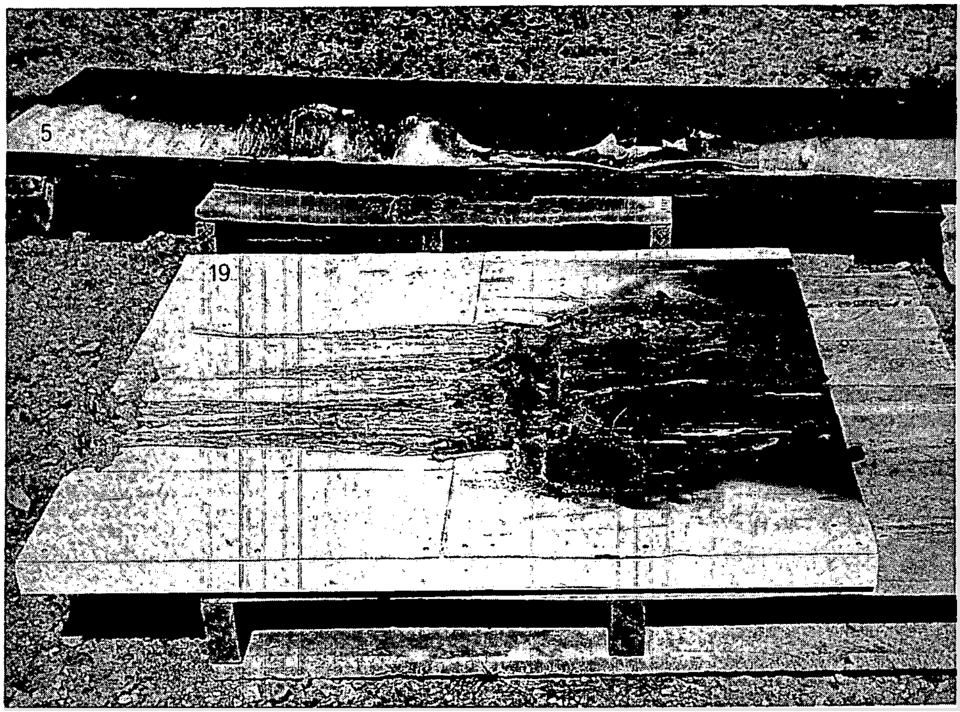

Figure 9. Shielding Panels after Experiment No. 1. (See Tables II and V for added description of reference numbers.

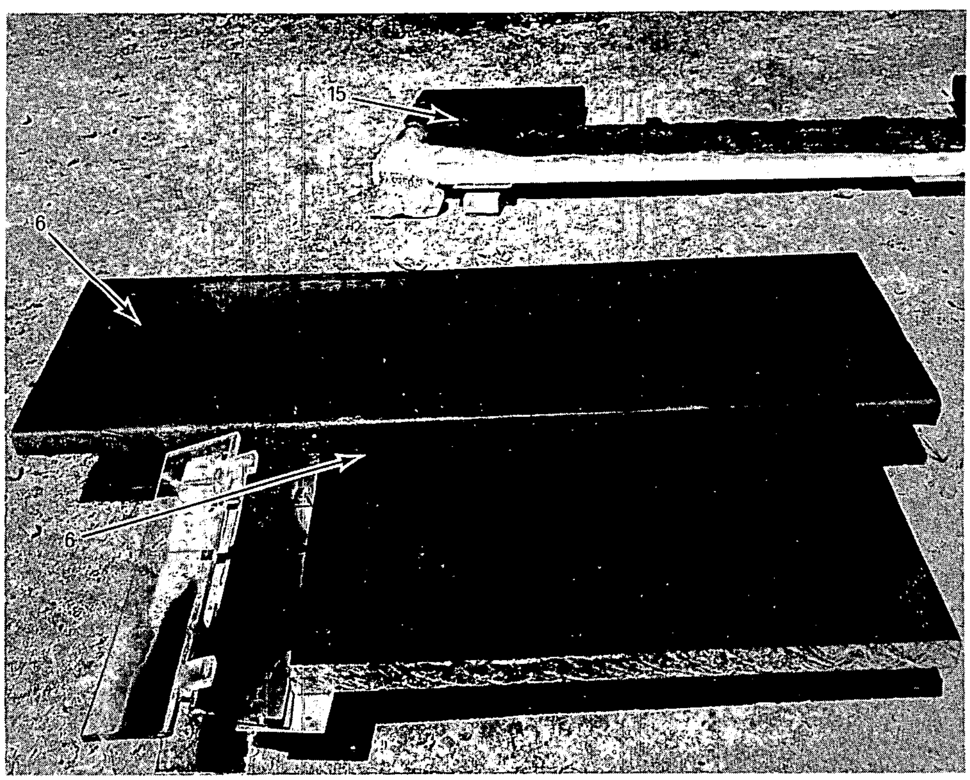

Figure 10. Shielding Panels after Experiment No. 1. (See Tables II and IV for added description of reference numbers.)

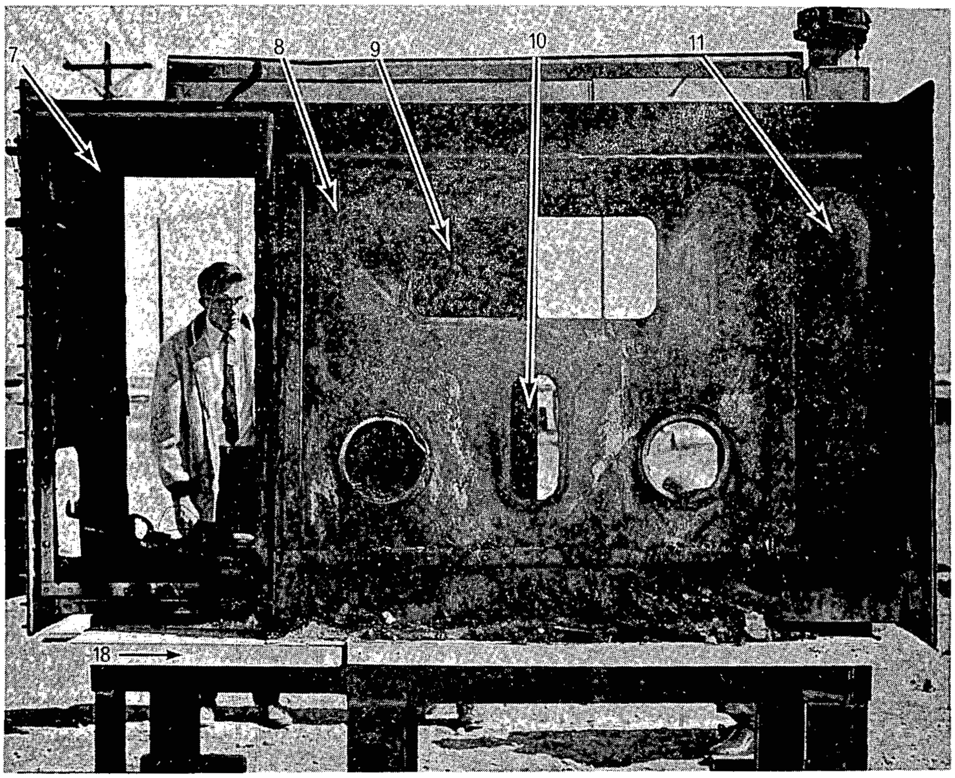

Figure 11. Sloped Side of Glovebox after Experiment No. 1. (See Tables III and V for added description of reference numbers.

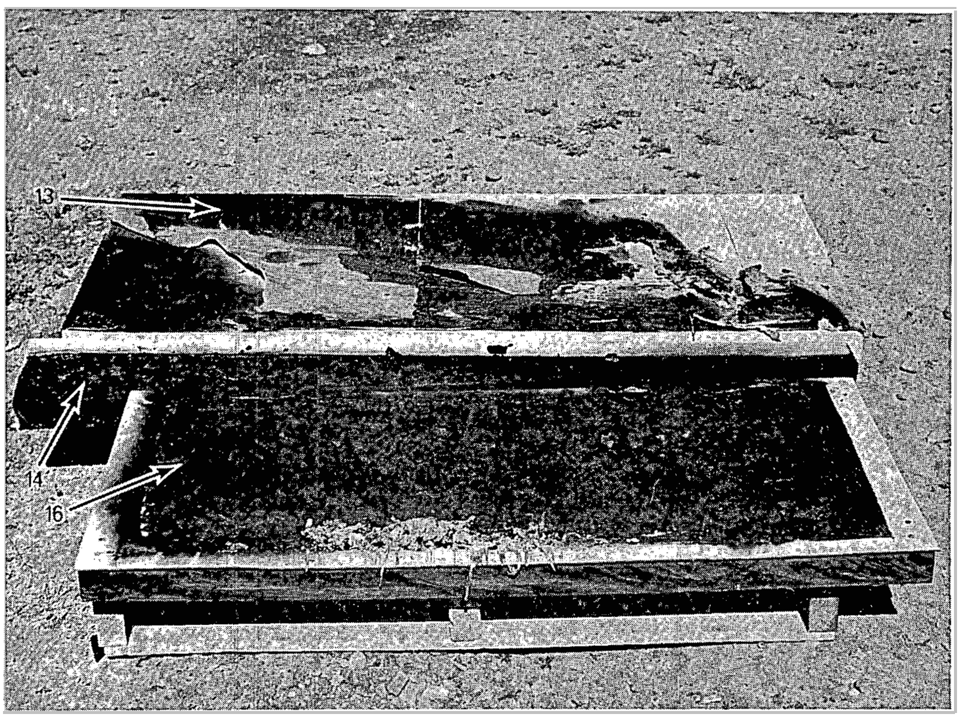

Figure 12. Shielding Panels after Experiment No. 1. (See Table IV for added description of reference numbers.

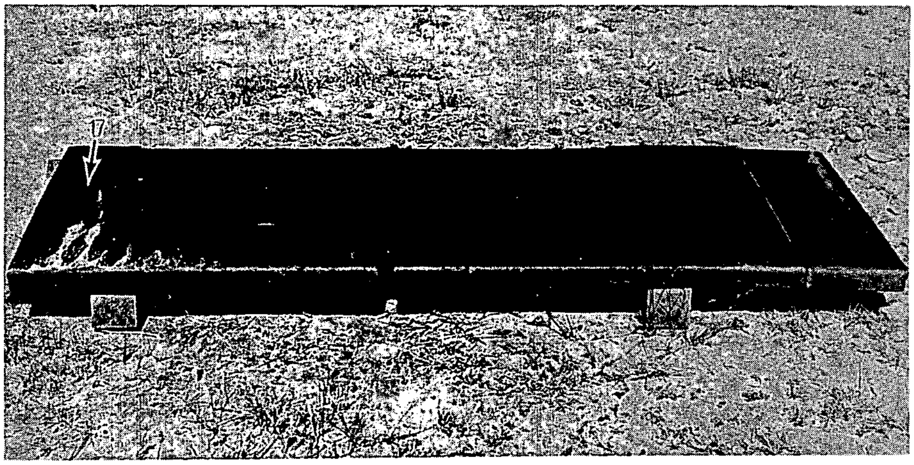

Figure 13. Shielding Panel after Experiment No. 1. (See Table IV for added description of reference number.)

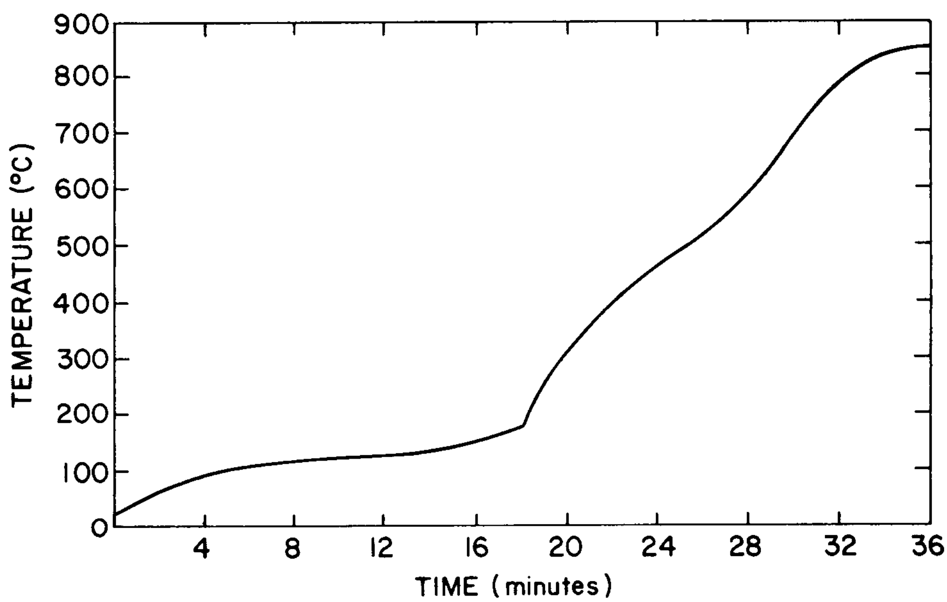

Figure 14. Mean Air Temperature versus Time, Experiment No. 1.

3.2 Experiment Number 2

3.2.1 Objective

The purpose of this test was to determine the value of recommendations made as a result of the first test. The following tests were made:

A. Test a prototype gasket protector for the Los Alamos-type window which would prevent the window from falling into the box.

B. Test the effectiveness of fire-retardant paint on Benelex.

C. Test other fire-retarding coverings for Benelex such as cement-asbestos board and stainless steel.

D. Test polycarbonate plastic (Lexan) as a window material.

E. Test the effect of increased air flow on this system.

F. Test fire resistant wired glass for top light-ports.

G. Test placement of heat detectors.

H. Test fusible head sprinklers located 6 feet above the glovebox.

3.2.2 Glovebox Design

The glovebox used in the previous test was cleaned and refurbished with the appropriate test panels as described above. New shielding panels were also made to test the fire suppressants recommended. Figures 6 and 7 reference the location of the panels to the descriptive text of Tables VII through XI.

3.2.3 Test Conditions

A 15-inch duct was connected to the outlet end of the glovebox. This duct, which did not have an outlet filter, connected to a fan having a capacity of 4000 cfm. A valve was provided in the line which enabled the box vacuum to be maintained at -0.7 inches of water pressure. The fire tended to pressurize the box and an attempt was made to maintain the -0.7 inches of water pressure; eventually the fire was blown out by the higher air flow rate. Two pendant-type fusible (165°F) plugs, 1/2-in. orifice sprinkler heads, were suspended 9 in. below the roof of the test building and positioned 6 feet above the top of the box.

Thermocouples were also placed inside this box and data obtained from them are shown in Figure 15.

TABLE VII

Fire Test Results of Glovebox Experiment No. 2
Test Panels Mounted in Vertical Side of Box

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
1.	Plexiglas G with plastic glove ring and metal cover.	Figure 6 Panel 1	Window bowed out, gloveport and cover okay--no penetration. See Figure 16
2.	Polycarbonate plastic. Two aluminum glove rings and Neoprene gloves.	Figure 6 Panel 2	Gloves burned, window slumped out of frame. Much more tendency of polycarbonate plastic to melt and flow than for Plexiglas. Although somewhat charred, most of the plastic did not burn. See Figure 16.
3.	Stainless steel panel.	Figure 6 Panel 3	Panel blackened on inside surface and lead sheet overlay melted from outside surface. Some warpage from heat. See Figure 16.
4.	Plexiglas SE-3. Two aluminum glove rings and gloves in vertical array.	Figure 6 Panel 4	Panel slumped out of frame onto box floor. Plexiglas burned away from lower ring. See Figures 16 and 17.

TABLE VIII

Fire Test Results of Glovebox Experiment No. 2
Shielding Panels Mounted Outside Vertical Side of Box

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
5.	Benelex panel painted with Tenaco epoxy paint; (a) the section of Benelex at the shielded end of the box overlaying panel 1 was covered with 1/4-in. cement asbestos board, (b) the central area overlaying panels 2 and 3 was covered with lead sheet painted with fire-retardant (Albi) paint, (c) the last section of the Benelex, overlaying panel 4, was covered with 20 gauge stainless steel sheet.	Figure 6 Panel 5	(a) Benelex under cement-asbestos board in excellent condition. No charring of paint or Benelex was noted. (b) Some of the lead had melted from the central section of the shielding and exposed an epoxy-painted surface which was not damaged. The fire-retardant paint, surrounding the area where the lead fused, had expanded and probably helped in forestalling fusion of the lead. (c) The stainless steel protected the Benelex and its epoxy-paint finish adequately; only slight damage was noted. See Figure 18.
6.	Plexiglas G panel 2 in. thick.	Figure 6 Panel 6	Little effect on this panel except for discoloration by soot, and slight roughening of the surface which faced toward the box.

TABLE IX

Fire Test Results of Glovebox Experiment No. 2
Test Panels Mounted in Sloped Side of Box

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
7.	Plexiglas SE-3 window. No gloveports.	Figure 7 Panel 7	Lower half of window burned away with appreciable thinning of top portion which was still held in frame. See Figure 19.
8.	Stainless steel panel with openings for two gloves and two Los Alamos-style windows. A simple frame was welded around the inside surface of the Los Alamos window opening to help protect the gasket and to prevent the window from falling in. Panel was covered with lead sheet painted with fire-retardant paint.	Figure 7 Panel 8	Gloves were burned off rings. Lead melted away from panel. Los Alamos windows and gaskets remained intact. See Figure 19.
9.	Los Alamos-style window. Because of warped panel it was necessary to seal window in part of the gasket with Duxseal.[a]	Figure 7 Panel 9	Window shattered but most pieces were still in frame. Outside laminate of glass still intact but cracked. See Figures 16 and 19. Note: Duxseal withstood fire test in excellent condition.
10.	Los Alamos-style window (small).	Figure 7 Panel 10	Most of this window remained in position during the test. The gasket was badly charred but still in place. See Figure 19.
11.	Plexiglas SE-3 window without glove rings.	Figure 7 Panel 11	Window was thinned but remained intact in its frame. See Figure 19.
12.	Fire-rated wire-glass windows covered with fluorescent light reflector	Figures 6 and 7 Panel 12	Windows cracked but remained intact. See Figure 20.

[a]Duxseal is a product of Johns Manville Company.

TABLE X

Fire Test Results of Glovebox Experiment No. 2
Shielding Panels Mounted Outside Sloped Side of Glovebox

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
13.	This Benelex panel was not painted but was covered with three layers of asbestos cloth.	Figure 7 Panel 13	The asbestos blanket prevented the Benelex from charring but the Benelex did blister. See Figure 21.
14.	Wedge-shaped panel with all sides painted with two coats fire-retardant paint (Albi).	Figure 7 Panel 14	Fire-retardant paint on sides of wedge-shaped panel was swollen. Paint had not adhered to the edge portion of this piece--apparently due to release of gases from the laminated structure. The edge was charred. See Figure 22.
15.	Benelex panel painted with two coats of fire-retardant paint (Albi).	Figure 7 Panel 15	The fire-retardant paint had expanded on the central (hottest) area in the fire test. Some minor charring also took place. See Figure 22.
16.	Two-inch Benelex panel painted with fire-retardant paint (Albi), then covered with sheet lead also painted with fire-retardant paint.	Figure 7 Panel 16	The lead had melted in the areas outside of the gloveport holes. Paint had expanded on surface of lead exposed to fire. Benelex was charred but not as seriously as in Test No. 1. See Figure 23.
17.	Plexiglas G (2-inch) panel.	Figure 7 Panel 17	Lower area of panel which faced toward the box was exposed to fire coming out of glove port. The fire eroded the surface of the plastic as shown in Figure 24.

TABLE XI

Fire Test Results of Glovebox Experiment No. 2
Shielding Panels Mounted Outside of Glovebox

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
18.	Two-inch Benelex panel painted with epoxy enamel. Benelex was then covered with lead painted with fire-retardant paint (Albi).	Figures 6 and 7 Panel 18	Little effect noted on panel. Some lead had melted from shielding panels and run onto the panel. Partial views of this panel are shown in Figures 16 and 19.
19.	Two-inch Benelex panel in two sections. Both sides of Benelex were painted with fire-retardant paint (Albi). Sheet lead, also painted with fire-retardant paint, was applied to one side. (a) The top section was placed with the Benelex side facing the box; (b) the bottom section was placed with the lead facing the box.	Figures 6 and 7 Panel 19	(a) Paint around exhaust pipe on top section was expanded. Also some blistering of Benelex surface was noted in certain areas. Lead was unaffected. See Figure 25. (b) Paint on surface of lead sheet was expanded although no lead was melted from the surface. See Figure 26.

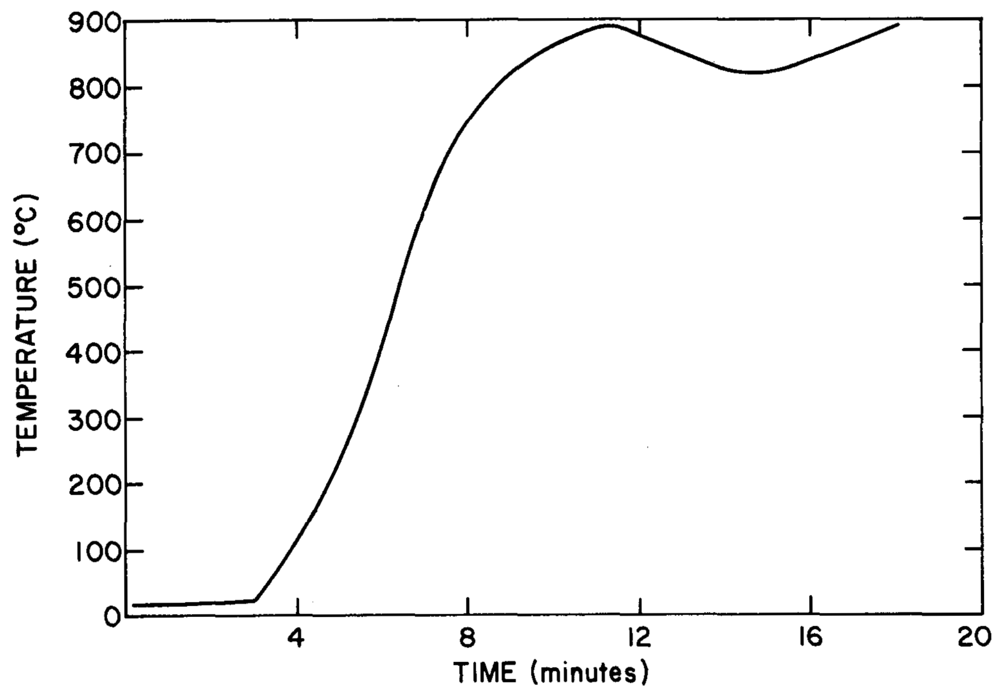

Figure 15. Mean Air Temperature versus Time, Experiment No. 2.

3.2.4 Burning Sequence

The events occurring during the burning experiment are listed as follows:

Time (Minutes)	Observation
0	Fire started; attempted to control box pressure by vent damper. Fire died out.
5	Fire started again.
7	Access door opened to provide more draft.
11	Fire penetrated vertical side of box.
12	Sprinkler heads released water.
13	Foam used to extinguish fire.
15	Fire under control.
19	Small fire still burning inside glovebox.
25	Fire hose turned into box to extinguish burning Plexiglas window panel on floor of box.

3.2.5 Effects of the Fire

The effects of the fire on the materials of construction used in Experiment Number 2 are described in Tables VII through XI and Figures 16 through 26.

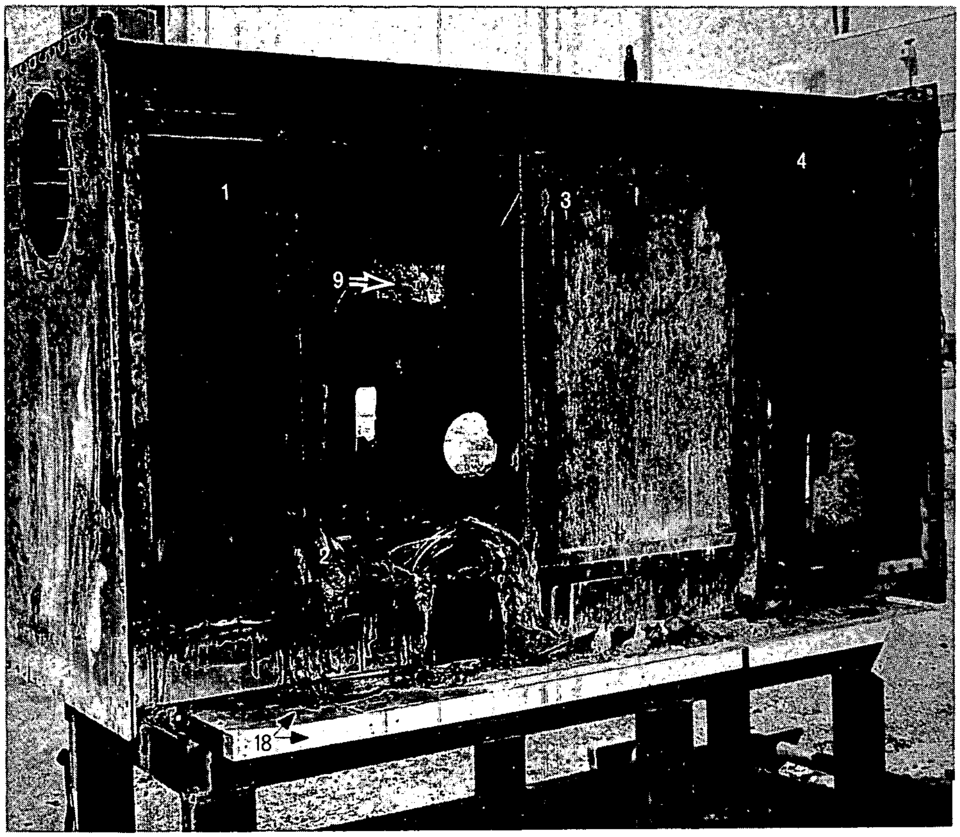

Figure 16. **Vertical Side of Glovebox after Experiment No. 2.** (See Tables VII, IX and XI for added description of reference numbers.)

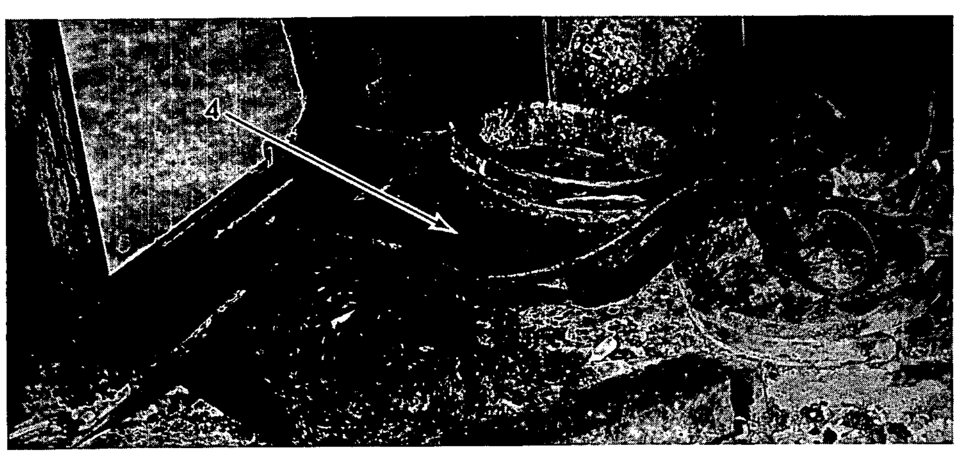

Figure 17. **Interior of Glovebox after Experiment No. 2.** (See Table VII for added description of reference number.)

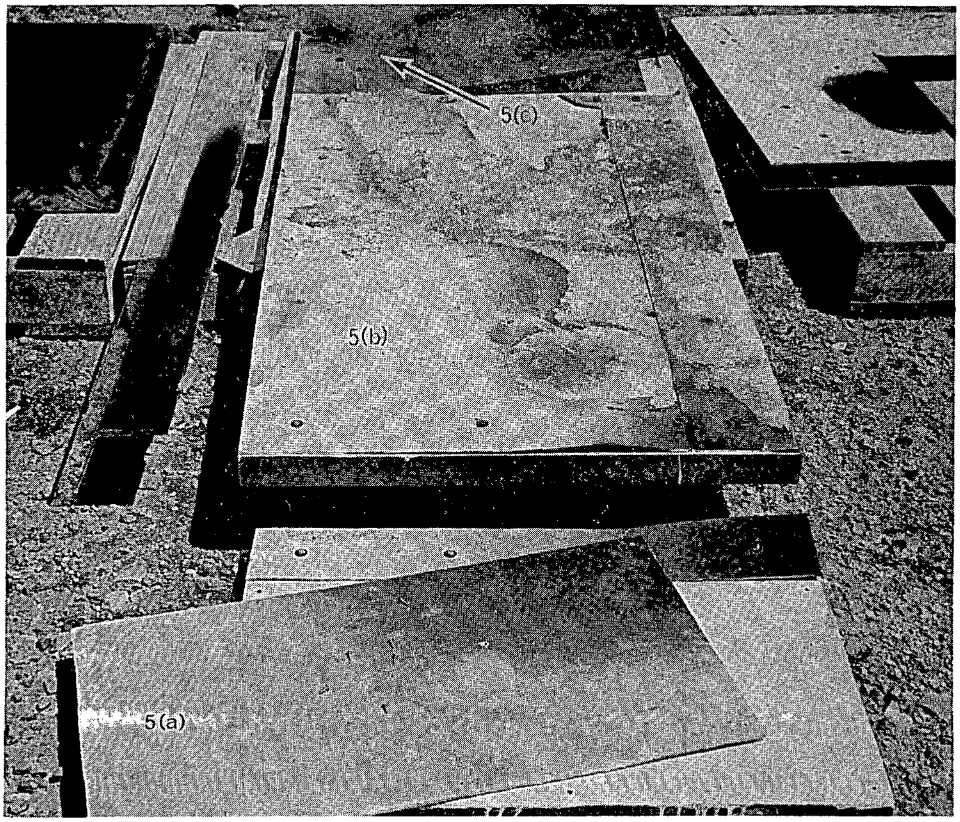

Figure 18. **Shielding Panels after Experiment No. 2.** (See Table VIII for added description of reference numbers.)

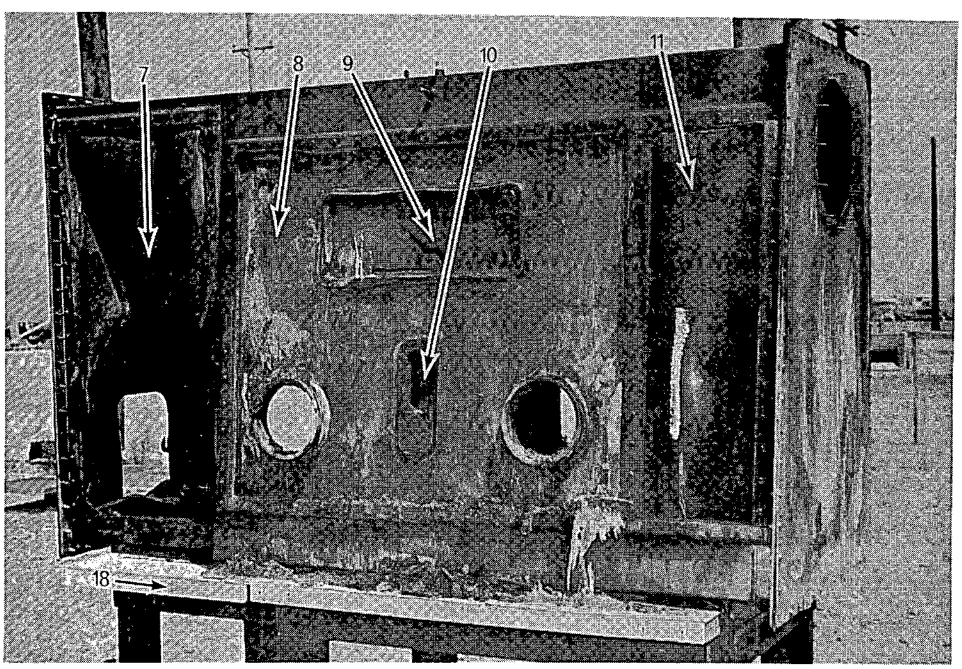

Figure 19. **Sloped Side of Glovebox after Experiment No. 2.** (See Tables IX and XI for added description of reference numbers.)

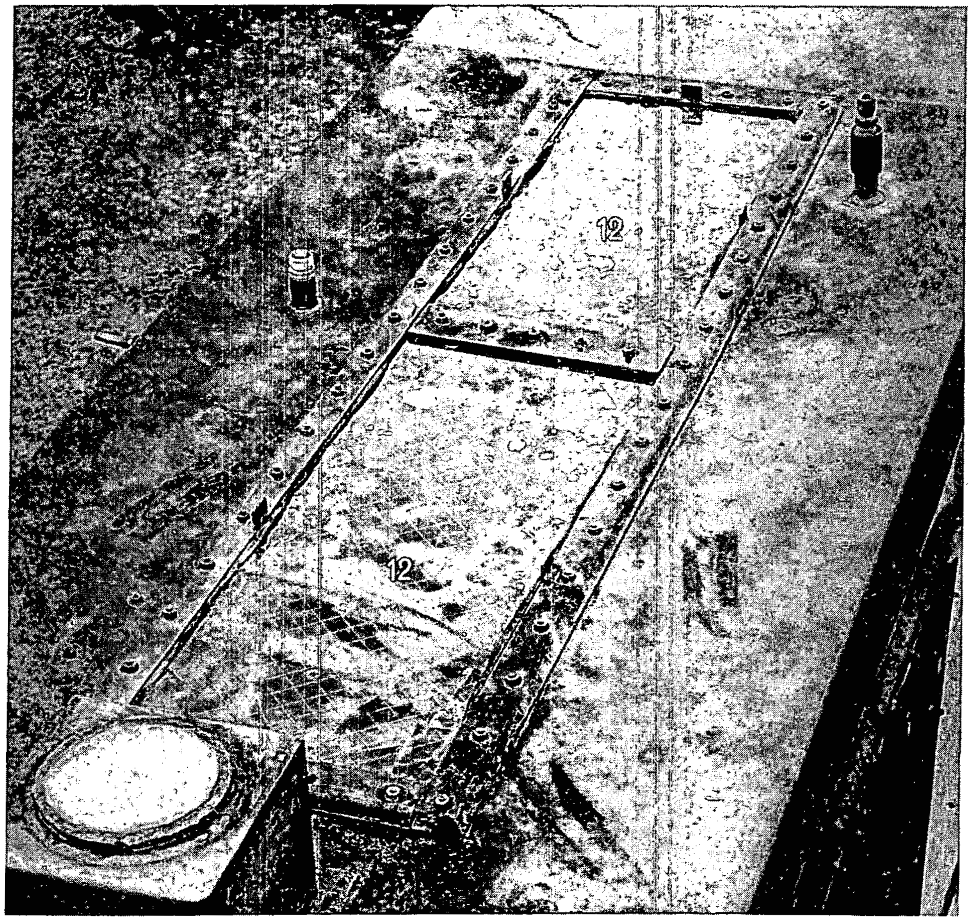

Figure 20. Top of Glovebox after Experiment No. 2. (See Table IX for added description of reference numbers.)

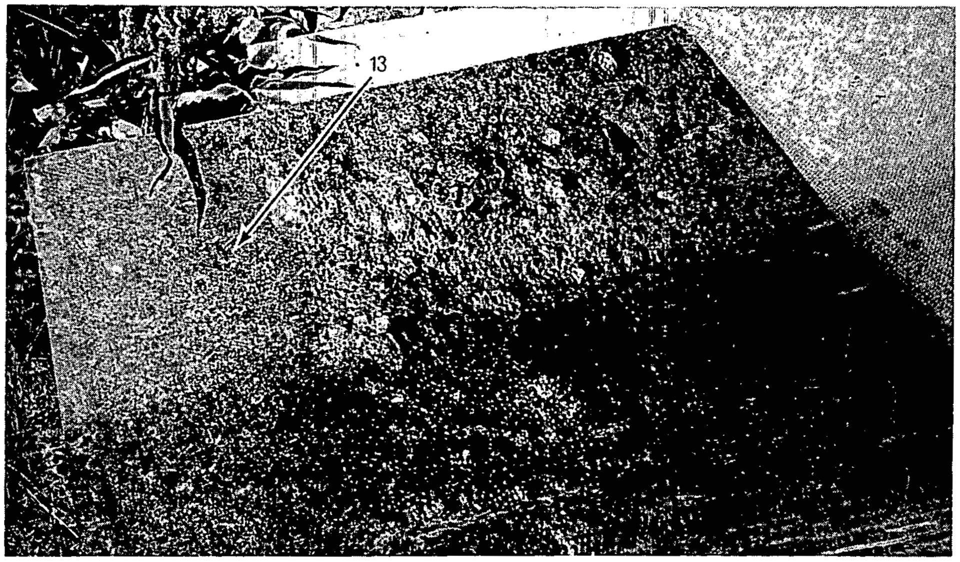

Figure 21. Shielding Panel after Experiment No. 2. (See Table X for added description of reference number.)

Figure 22. **Shielding Panels after Experiment No. 2.** (See Table X for description of reference numbers.)

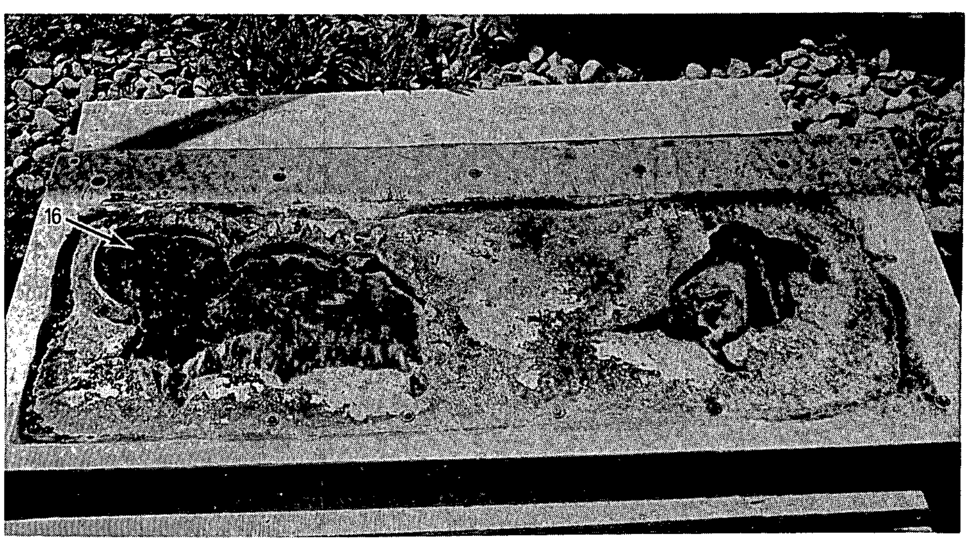

Figure 23. **Shielding Panel after Experiment No. 2.** (See Table X for added description of reference number.)

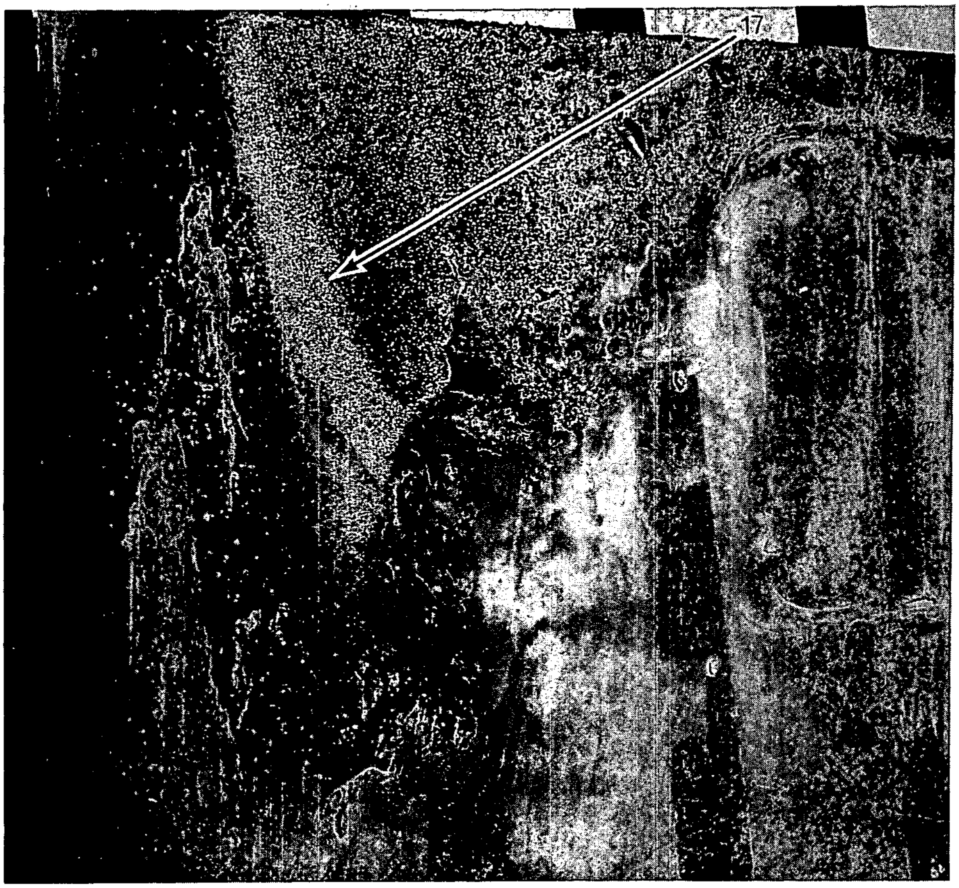

Figure 24. Shielding Panel after Experiment No. 2. (See Table X for added description of reference number.)

Figure 25. Shielding Panel after Experiment No. 2. (See Table XI for added description of reference number.

Figure 26. Shielding Panel after Experiment No. 2. (See Table XI for added description of reference number.)

3.3 Experiment Number 3

3.3.1 Objective

The purpose of this experiment was to test new shielding materials and to refine the data obtained from the previous experiments. The specific items tested are listed as follows:

A. Test water-filled panels and windows.

B. Test ventilation control as a means of suppressing fire.

C. Extend observations on fire-retardant paint on Benelex, and test use of aluminum foil for protecting Benelex.

D. Investigate fire protection afforded by use of covers for glove ports.

E. Test sprinkler heads mounted in building above box.

F. Extend tests on placement of heat sensors in the glovebox, and determine time required for actuation.

G. Test gasket protector for Los Alamos-type glovebox windows[12].

[12] Design supplied by C. F. Braun Drawing No. RF-BZ-20473-77 Issue O.

H. Test wired glass viewing window.

I. Test circular Pyrex ® [13] windows[14].

3.3.2 Glovebox Design

The overall glovebox configuration was not changed and the warped box was refurbished. The shielding panels remained the same as is shown in Figure 6. However, in Figure 7, panel 13 consisted of a thermopane window, while the remaining panels remained as shown in that view. Tables XII through XVI describe the configuration of the box in detail.

3.3.3 Test Conditions

The 4000-cfm blower assembly was used as reported for Experiment Number 2. The vacuum on the box was adjusted to -0.7 inches of water pressure.

Two heat detectors were located on the inside of the box, one in contact with the ceiling, and one suspended 6 inches from the ceiling. One detector was also placed outside the box in contact with the box bottom.

Thermocouples were placed into the thermowell, which was located inside the glovebox. The time-temperature curve produced by the recorder is shown in Figure 27.

A small number of hydraulic-oil-soaked paper towels were added to the box. The fire was initiated by starting a pan of kerosene (1 quart) afire under the gloveports having the fire covers (Figure 28).

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[13] Pyrex ® is a registered trademark of Corning Glass Works.
[14] Design supplied by Maintenance Department, Rocky Flats.

TABLE XII

Fire Test Results of Glovebox Experiment No. 3
Test Panels Mounted in Vertical Side of Box

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
1.	Plexiglas SE-3 protected on inside with a Silvabestos ®[a] drape. (Aluminized asbestos cloth.)	Figure 6 Panel 1	Panel bowed outward but still intact and in frame. Asbestos drape behind panel remained in place. See Figure 29.
2.	Stainless steel panel with three Pyrex (6-in. diameter by 1/2-in. thick) windows in specially designed ports.	Figure 6 Panel 2	Panel and windows remained intact and only slightly affected by the fire. See Figure 29.
3.	Stainless steel panel with a "tank" (38 in. by 22 in. by 2 in.) bolted on the outside surface. The tank was sealed with butyl caulk on its side and bottom edges and was filled with Gelgard ®[b]. See Figure 30.	Figure 6 Panel 3	Panel was not affected by the fire. A small quantity of water was evaporated from the Gelgard. See Figure 29.
4.	(a) The top half of this window panel was fire-rated wire glass. (b) The bottom section was fabricated from stainless steel sheet (1/8 in.) and provided with two gloveports positioned side by side. One of the ports was covered on the inside with a metal gloveport cover. The other was covered with an asbestos fabric curtain (Silvabestos). See Figure 28.	Figure 6 Panel 4	(a) The wire glass section was cracked in numerous places but remained intact. Some of these cracks developed shortly after installation. (b) The glove-port covers were in place after the test, although the gloves had burned away. The metal cover was functional and only blackened by soot. The asbestos cloth cover was fragile since most of its supporting fiber (not asbestos) had burned away during the test. See Figure 29.

®[a] Product of Raybestos Manhattan Company.
®[b] Product of The Dow Chemical Company.

TABLE XIII

Fire Test Results of Glovebox Experiment No. 3
Shielding Panels Mounted Outside Vertical Side of Box

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
5.	Benelex (2 in.) panel painted with fire-retardant paint and covered with sheet (1/8 in.) lead also painted with fire-retardant (Albi 107-A) paint.	Figure 6 Panel 5	Only one area on this panel showed any effect from fire. This was the area located outside of the gloveports (Panel Reference 4). The damage was limited to melting away of lead sheet in two very small areas. The fire damage occurred when two gloves burned in the space between the glovebox and its shielding. See Figure 31.
6.	Plexiglas G panel (2 in.).	Figure 2 Panel 6	The surface of the Plexiglas was eroded and discolored in the area above where the gloves burned. See Figure 31.

TABLE XIV

Fire Test Results of Glovebox Experiment No. 3
Test Panels Mounted in Sloped Side of Box

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
7.	Plexiglas SE-3 window with one gloveport.	Figure 7 Panel 7	Glove burned off and lower half of window was burned away. Top half of window was thin but it was still held in place by its frame. See Figure 32.
8.	Stainless steel (1/8 in.) panel with openings for two gloves and two Los Alamos-style windows. Panel was covered with sheet lead (1/8 in.) painted on its exterior surface with fire-retardant design (C. F. Braun) was used on the inside surface of the Los Alamos-style windows. See Figure 33.	Figure 7 Panel 8	Gloves were burned off although not completely. Rubber gaskets around Los Alamos windows were affected slightly by the fire. The sheet lead had melted away from about half of the area of the panel. See Figure 32.
9.	Los Alamos-style window mounted with "zipper" gasket. Frame on inside of box covered most of gasket. See Figure 33.	Figure 7 Panel 9	Much of the exterior glass lamination had cracked and fallen away but the lead glass laminate, although crazed, was intact. The Neoprene "zipper" gasket was in excellent condition. See Figure 32.
10.	Los Alamos-style window (small). See Figure 33.	Figure 7 Panel 10	Fire effect was very similar to that observed for Reference No. 9. See Figure 32.
11.	Plexiglas SE-3 window. No glove rings.	Figure 7 Panel 11	Window was covered with soot but remained in frame. See Figure 32.
12.	Fire-rated wire glass panes (two).	Figure 7 Panel 12	Windows cracked but remained intact in frame. See Figure 32.

TABLE XV

Fire Test Results of Glovebox Experiment No. 3
Shielding Panels Mounted Outside Sloped Side of Glovebox

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
13.	The panel for this test was a Thermopane ®[a] window held in place in a mortised Benelex frame. An attempt was made to fill the panel with water but it was broken by hydrostatic pressure. See Figure 34. The test was performed using a replacement panel but not filled with water.	Figure 7 Panel 13	The inner glass panel of the Thermopane window was shattered by the heat from the fire; the outer panel (away from the box) remained intact. The Benelex was charred in the area exposed to the fire. See Figure 35.
14.	Wedge-shaped piece for transition from vertical to sloped shielding. Painted with fire-retardant paint.	Figure 7 Panel 14	Only slight effect from fire was noted. See Figure 35.
15.	Benelex panel (2 in.) painted with two coats of fire-retardant paint and then covered with aluminum foil.	Figure 7 Panel 15	No significant fire damage was noted. Aluminum foil was still intact. See Figure 36.
16.	Benelex panel (2 in.) painted with fire-retardant paint, then covered with (a) stainless steel on one half and (b) cement asbestos board on the other half.	Figure 7 Panel 16	No damage was noted to this panel. This is of particular interest since this panel was usually the one most severely affected. Also significant is the fact that the fire did not come out of the box extensively in this test. See Figure 36.
17.	Plexiglas G panel.	Figure 7 Panel 17	Fire effect was limited to slight discoloration with soot. See Figure 36.

®[a] Thermopane is a product of Pittsburgh Plate Glass Company.

TABLE XVI

Fire Test Results of Glovebox Experiment No. 3
Shielding Panels Mounted Outside Glovebox

Ref. No.	Description of Test Section Before Fire Test	Location On Glovebox	Observations After Fire Test
18.	Two-inch Benelex panel painted with epoxy enamel.	Figures 6 and 7 Panel 18	Very little effect on panel. Apparently it did not get hot. Edge views of this panel can be seen in Figure 29.
19.	Two-inch Benelex panel in two pieces. Surface was painted with fire-retardant paint which was then covered with aluminum foil.	Figures 6 and 7 Panel 19	Nominal effect on panel. Slight scorching appeared around the opening for the exhaust duct and a small area where the stainless steel bulged out and contacted the surface of the shielding. See Figure 37.

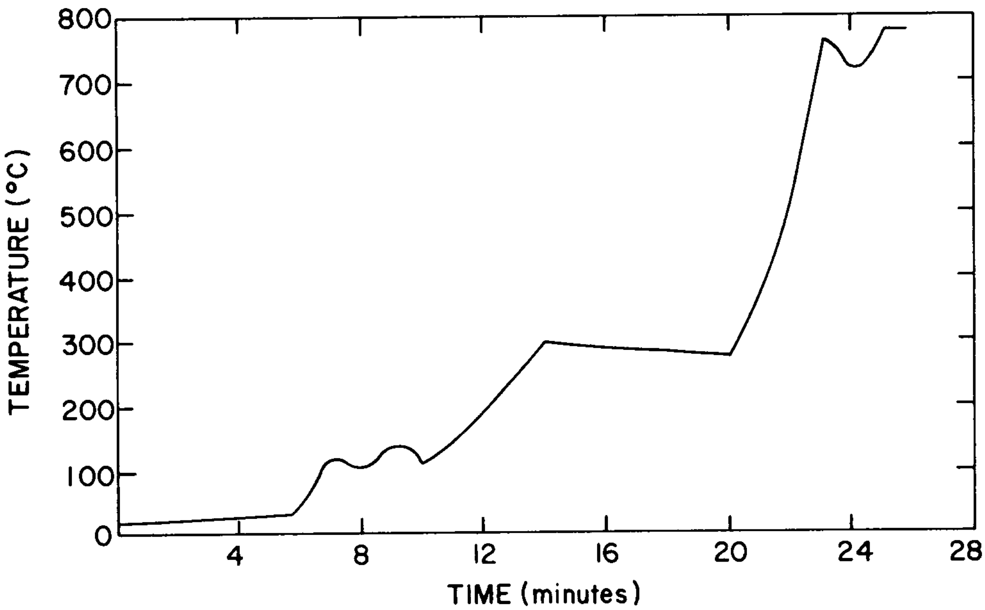

Figure 27. Mean Air Temperature versus Time, Experiment No. 3.

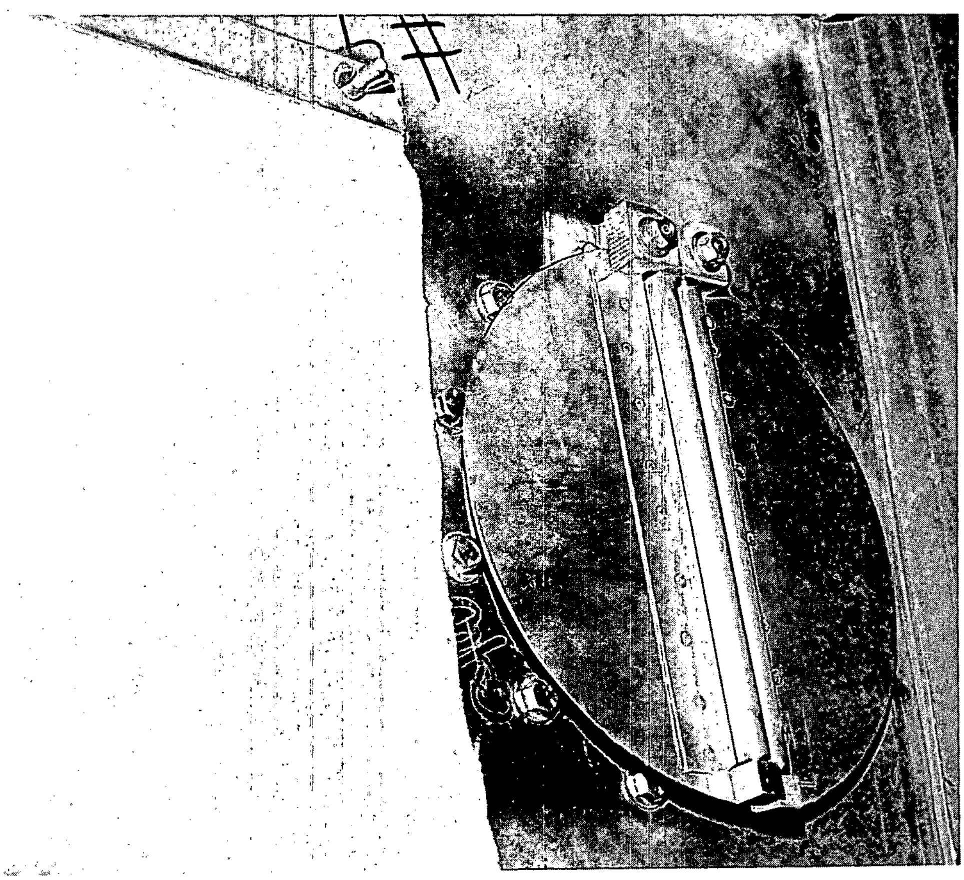

Figure 28. Gloveport Covers. Left – Asbestos fabric. Right – Stainless steel.

3.3.4 Burning Sequence

Notes made during the fire are listed as follows:

Time (Minutes)	Observation
0	Access door opened, fire started and access door was closed.
1	Exhaust damper closed.
2	Fire extinguished due to air starvation of fire.
4	Fire restarted.
5	Smoke puffs coming from around door, indicating fluctuation in pressure inside box.
7	Glove burned off.
14	Pressure adjusted with exhaust damper in attempt to maintain -0.7 inches water gauge pressure.
18	Right side of box breached.
19	Flames coming from box on right side, rising to ceiling of building.
19.5	Sprinkler heads in top of building actuated.
22.5	Fire brought under control, by firemen using water hoses.
25	Access on box door opened to complete extinguishing fire in box using water hose.

3.3.5 Effects of Fire

The effects of the fire on the materials of construction used in Experiment Number 3 are described in Tables XII through XVI and Figures 29 through 37.

4.0 DISCUSSION

4.1 Individual Test Observations

4.1.1 Fire Experiment Number 1

4.1.1.1 Gloves

The rubber gloves used on the box were the first items to start burning. This causes a loss of containment within the box.

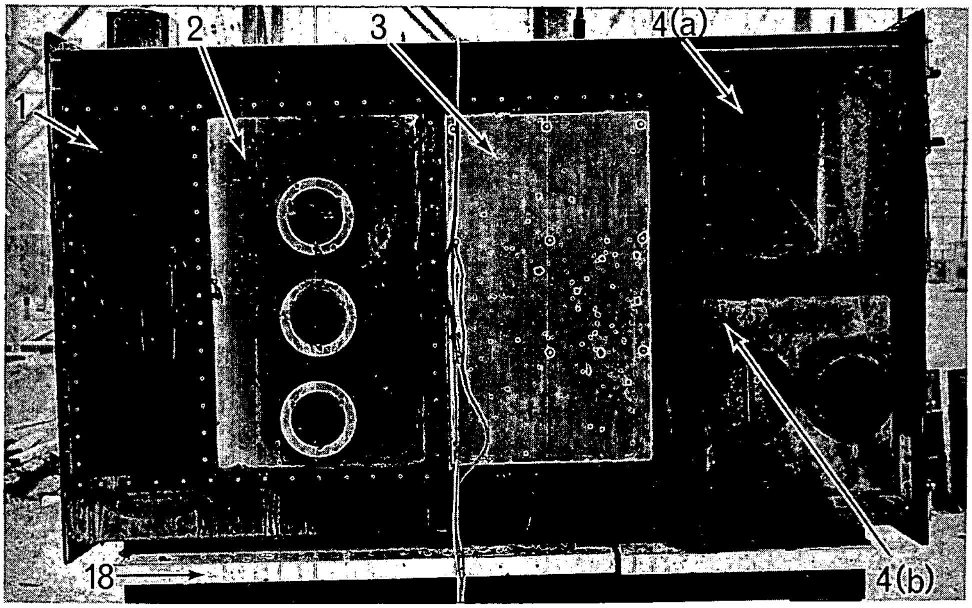

Figure 29. Vertical Side of Glovebox after Experiment No. 3. (See Table XII and XVI for added description of reference numbers.)

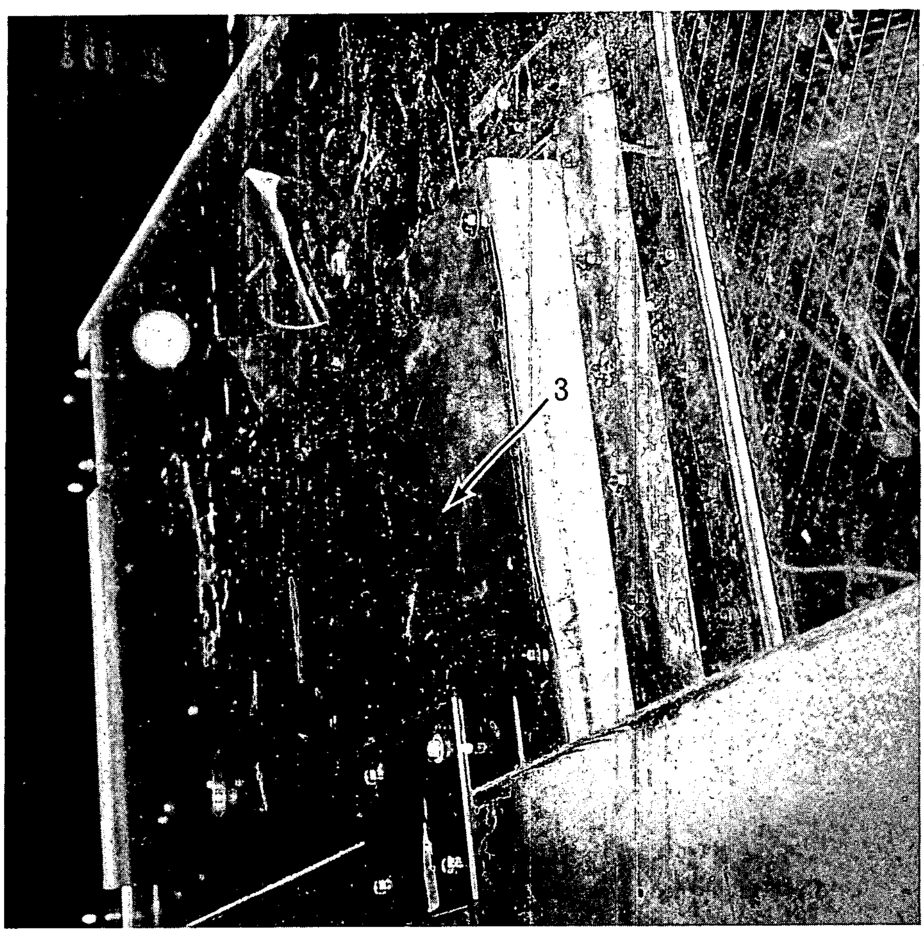

Figure 30. Tank on Vertical Side of Box Being Filled with Gelgard® Emulsion. (See Table XII for added description of reference number.)

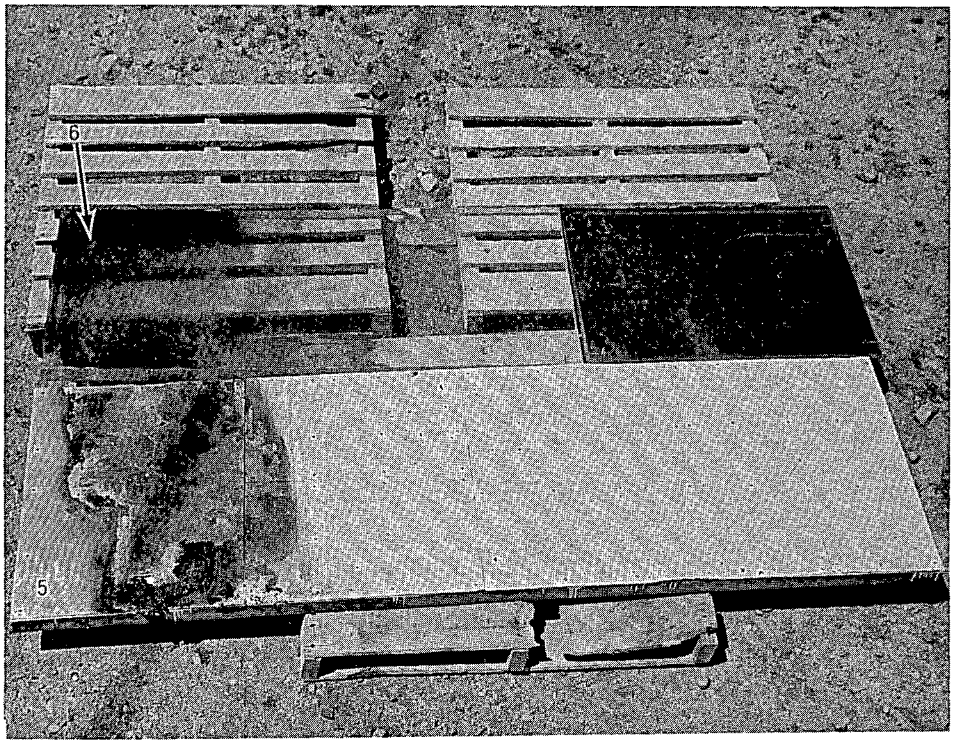

Figure 31. Shielding Panels after Test No. 3. (See Table XIII for added description of reference numbers.)

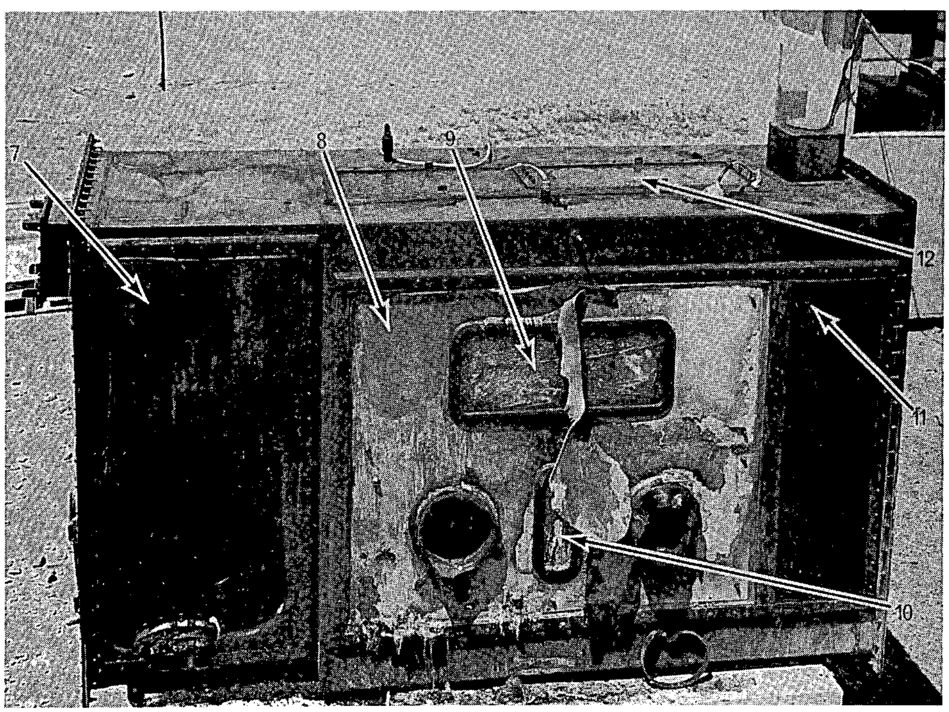

Figure 32. Sloped Side of Glovebox after Experiment No. 3. (See Table XIV for added description of reference numbers.)

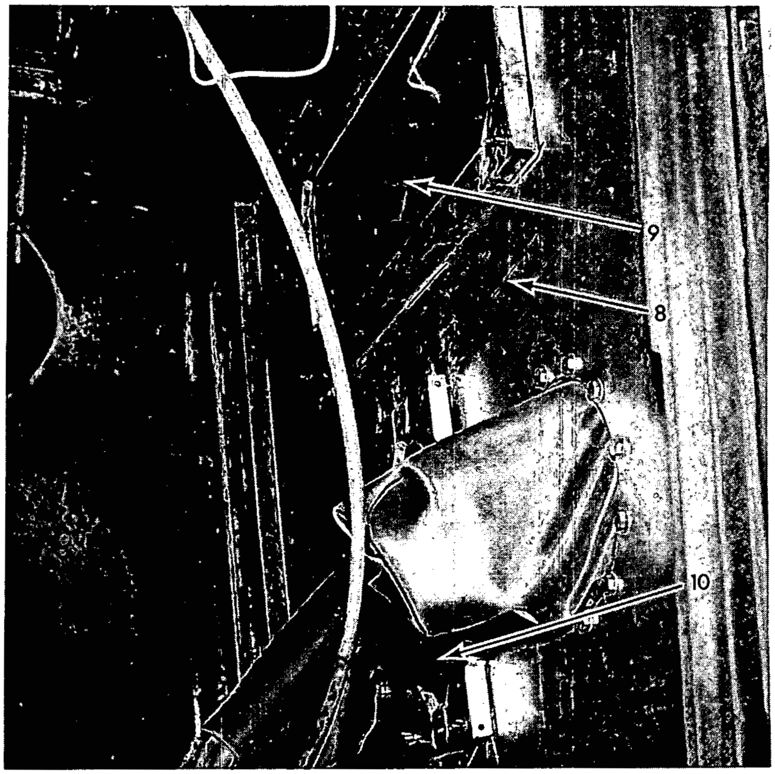

Figure 33. View of Interior of Glovebox Showing Frame for Protection of Los Alamos-Style Window Gasket. (See Table XIV for added description of reference numbers.

Figure 34. Shielding Installed on Sloped Side of Glovebox before Experiment No. 3. The thermopane panel (Reference No. 13) broke while being filled with water. It was replaced before test. (See Table XV for added descriptions of reference numbers.

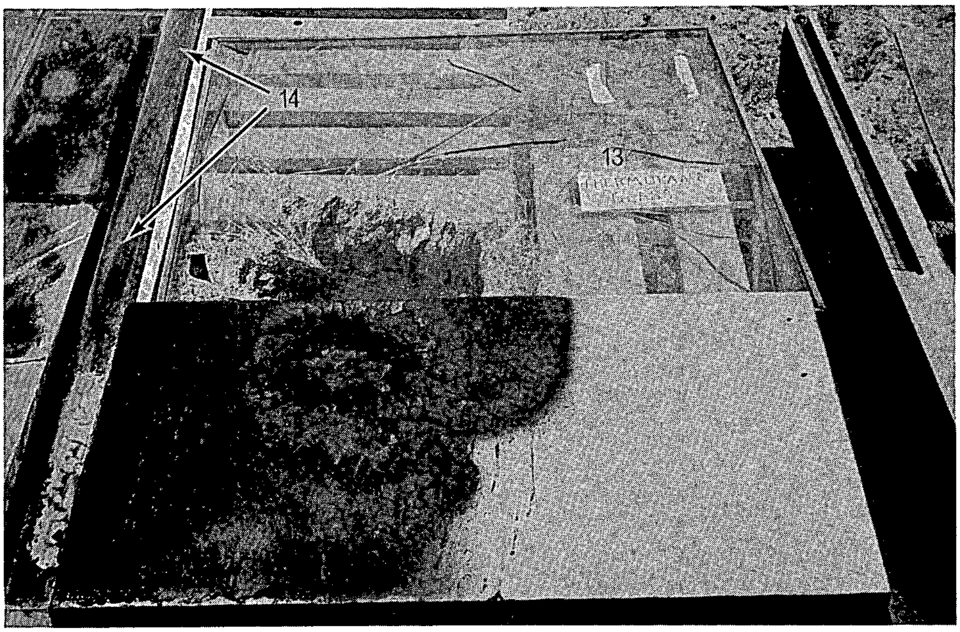

Figure 35. Shielding Panels after Experiments No. 3. (See Table XV for added description of reference number.)

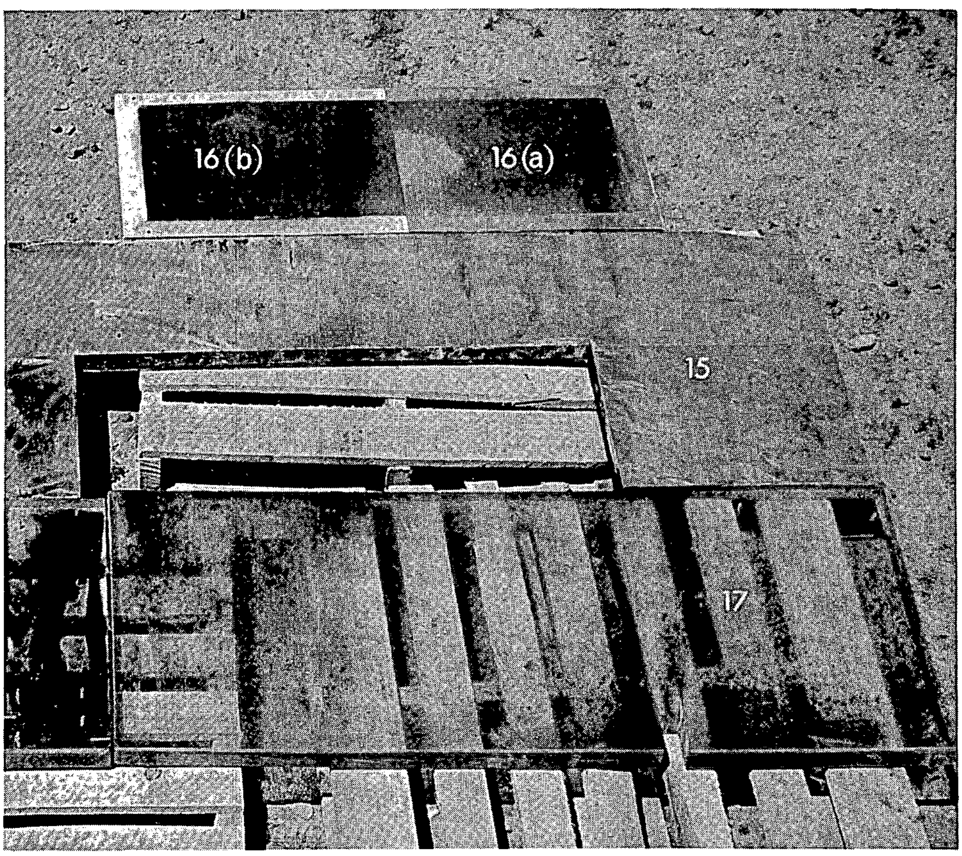

Figure 36. Shielding Panels after Experiment No. 3. (See Table XV for added description of reference numbers.)

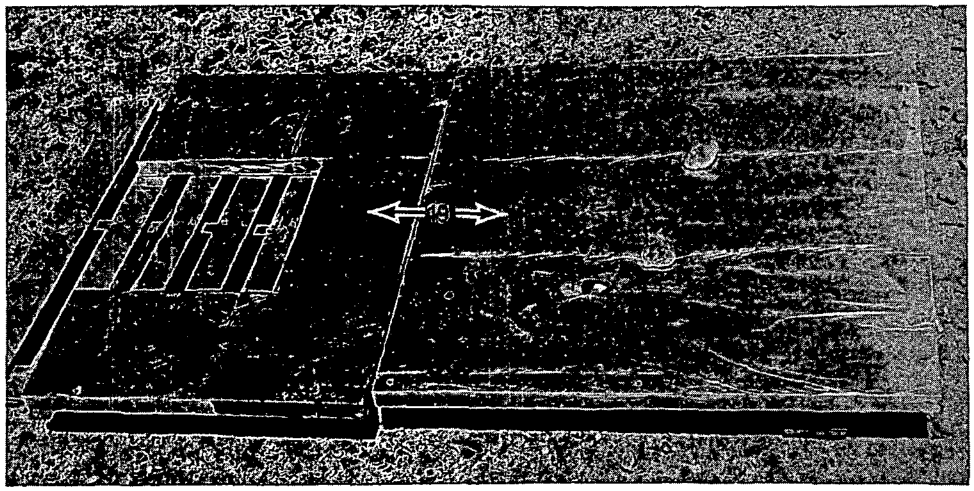

Figure 37. Shielding Panels after Experiment No. 3. (See Table XVI for added description of reference number.)

4.1.1.2 Windows

Four of the five windows fabricated from Plexiglas burned sufficiently to collapse into the box. No difference was observed between windows having self-extinguishing properties and those not so protected. This result is not surprising because Plexiglas depolymerizes on heating. The methyl methacrylate monomer has a boiling point of 100°C, which indicates a high vapor pressure at the temperatures recorded inside the box.

The window consisting of a lead glass-safety glass laminate fell into the glovebox because the support, which was a rubber gasket, burned away. In addition, the glass structure delaminated.

4.1.1.3 Shielding

The shielding positioned one inch from the box wall was severely damaged. It appears that any gap between the box wall and the shielding enhances the "chimney effect." Obviously, the closer the shielding, the higher the temperature to which the shielding is exposed.

In areas where the shielding was exposed to the interior of the box, e.g., burned off gloves and destroyed windows, the damage was greater. Lead covering on the Benelex shielding did not protect the material, instead the lead quickly melted and exposed the Benelex. The molten lead did not spread the fire to the Benelex on the underside of the box because little damage was noted on these panels.

The epoxy paint did not retard the spread of fire to the Benelex.

The 2-in.-thick Plexiglas G shielding was badly pitted and appeared eroded on the surface. A close study of the motion pictures taken of this test revealed that flame was evident above the space formed by the shielding and glovebox wall. This was evidently burning methyl methacrylate vapor from the depolymerization of the Plexiglas. Again the greatest damage occurred in areas opposite glovebox openings.

4.1.1.4 Ventilation

The maximum air flow supplied by the exhaust fan system was approximately 206 cfm, or two box volumes per minute. It was difficult to initiate and maintain combustion at this air flow because it was necessary to push in the inlet filter to obtain rapid combustion. The air flow-rate is directly related to the rate of combustion.

4.1.1.5 Materials Inside of the Box

Combustible materials placed in the glovebox were either burned completely or extensively damaged. This emphasizes that use of cellulosics, plastics, and certain metals should be eliminated or greatly restricted.

4.1.1.6 Fire Extinguishing

An attempt was made to extinguish the fire using high expansion foam. Copius quantities of foam were produced, but the convection currents surrounding the burning glovebox prevented the foam from building up and smothering the fire. Conventional hose techniques were used to extinguish the fire.

4.1.2 Fire Experiment Number 2

4.1.2.1 Drybox Gloves

All the gloves burned off the box. As in Experiment No. 1, these items were the first to burn.

4.1.2.2 Windows

Two out of four windows fabricated from Plexiglas failed. The two that remained were located in the cool region of the box.

The window fabricated from polycarbonate plastic (Lexan) failed by pulling out of its holding frame and slumping onto the floor of the glovebox. Since polycarbonate is a thermoplastic resin, this is not an unexpected result. Some burning and decomposition of the plastic was evident but it was not as extensive as in the case of Plexiglas panels. The floor of the burning glovebox is substantially cooler than the other portions of the box; therefore, when the polycarbonate slumped to the floor, it essentially cooled.

The Los Alamos-style windows were held in position by the relatively simple frames provided. The design of these frames also prevented gasket involvement.

Wired glass used in the top windows cracked, but did not fall out of the frames. Use of wire glass for illumination windows and other windows where appropriate is highly recommended. Because of the inflexible nature of glass, a suitable mounting method should be provided for this material. Conventional bolting and gasketing to the box, by the use of hold-down strips, has cracked the glass; especially in boxes which have been warped.

4.1.2.3 Shielding

Because of the protection provided for the Benelex, the overall damage to this shielding material was less than that observed in Experiment Number 1. Cement-asbestos board, stainless steel sheet

(16 gauge), asbestos cloth, and fire-retardant paint offered protection for the Benelex. The order of mention indicates the relative effectiveness of the protectant material. It is of interest to note that fire-retardant paint loses part of its effectiveness when the Benelex surface blisters underneath the layer of paint.

Comparing the second test to the first, less damage to Plexiglas shielding was observed because exposure time to fire was shorter and the box did not breach as extensively.

4.1.2.4 Ventilation

The maximum air flow supplied by the larger fan and ductwork was 4000 cfm, or forty box volumes per minute. The fire was of shorter duration but burned more fiercely owing to the larger volume of air flowing through the box. The increased air flow resulted in a slightly higher internal temperature; 872°C relative to 835°C for the lower air flow of Experiment Number 1. Either of these high air temperatures could damage the high efficiency filters located in exhaust plenums.

4.1.2.5 Overheat Detection

Two overheat detectors of the flowerpot type were placed inside the box. Each of these detectors was mounted in the upper region of the box and responded within 30 seconds after the fire was started. A third detector, located on the bottom of the box on the external surface, failed to respond.

4.1.2.6 Fire Extinguishing

The sprinkler heads actuated 7 minutes after the fire started; however, the water supply to the heads was turned off after actuation. This was done to prevent extinguishing the fire, and to make the intensity of this fire resemble the previous experiment. The foam generator was again used in an attempt to extinguish the fire. This time the foam proved more effective than on the first test. This is attributed to the higher volume that the exhaust fan was pulling (as much as 4000 cfm of air through the glovebox) and therefore there was less "rejection" of the foam as observed in Experiment Number 1. Water hoses were also needed to completely extinguish the fire.

4.1.3 Fire Experiment Number 3

4.1.3.1 Gloves

The metal glove port protector did not prevent the glove from burning off; however, the gloves burned off the opposite side of the box before they were destroyed on the protected side. The asbestos cloth-protected glove was burned before the metal-protected glove. The result of this experiment indicates that glove protectors cannot prevent glove burn-off but they can extend the time to burn off.

4.1.3.2 Windows

One out of the three Plexiglas windows failed in the burning test. The two that retained their integrity were located close to the exhaust duct.

The wire glass windows mounted in frames at the top and side of the glovebox were cracked, but were otherwise in good condition after the fire test.

The demountable frame for Los Alamos-style windows accomplished the purposes intended of shielding the Neoprene "zipper" gaskets and retaining the windows in position. Six-inch diameter Pyrex windows mounted in one panel showed virtually no effects from the fire. These windows had two types of gasketing. The Neoprene O-ring type proved superior to the 80-durometer injectable type. The simplicity of design of these windows affords a potential savings in maintenance costs on change-out.

4.1.3.3 Shielding

With better containment of the fire within the glovebox enclosure, considerably less damage could be expected to the shielding. Extensive areas of Benelex, painted with fire retardant paint and protected by aluminum foil, were not damaged. This method of dual protection appears adequate for short term installation of this material. The function of the aluminum foil is to protect the Benelex from radiant heat, and therefore the aluminum foil should not be painted.

The gelled-water panel was not damaged by the fire; however, some of the water had evaporated from the panel.

The water-filled thermopane broke during filling; therefore this concept was not tested. It should be noted that the seals around the window edge held water during the attempted filling procedure.

4.1.3.4 Ventilation

Shortly after starting the fire in the glovebox, it was extinguished by closing the damper in the exhaust duct. This adds evidence to the idea that fires can be localized by control of ventilation.

After the fire was restarted and the box was breached, a large volume of air was pulled through the system. This had the effect of withdrawing heat and delaying actuation of the fusible sprinkler heads mounted above the box.

The presence of fire in the glovebox produces a large "upset" in the glovebox pressure. This upset is cyclical in nature and in these tests had an estimated frequency of 20-50 cycles per minute. This unique pressurization phenomenon may be a suitable method for detecting fires in glovebox systems.

4.1.3.5 Heat Detection

Three locations for heat detector heads (120°F) were studied: The head located inside and 6 inches below the top of the box; the head fixed to the underside of the top of the box, alarmed 3 minutes after the fire started (this time is not corrected for the ventilation experiment); and the head located on the outside top of the box alarmed 4 minutes after the start of the fire.

These rather long times-to-alarm indicate that a more responsive overheat detector is desirable.

4.1.3.6 Fire Extinguishing

The sprinkler heads controlled the fire although they did not extinguish it. Water from hose lines was used for final extinguishment.

4.2 Conclusions

4.2.1 Ventilation

The rate of ventilation of a glovebox plays an important role in how readily a fire can be started, and whether the fire will propagate. It was concluded from results of the tests that boxes equipped to control air flow can effectively check the spread of fire. Control can be provided by automatic dampers and fire doors. In the event of a fire, roughing filters on exhaust ducts at the glovebox may also serve to limit air flow by becoming clogged. Caution should be used in indiscriminately stopping all air flow if there is a possibility of having explosive vapors form within a box from the time of ignition of the fire to cessation of ventilation. A good compromise might be a gross reduction in ventilation while cooling is applied to the burning box.

Building ventilation was not considered in these experiments but it may be possible that the filters in that system may also become plugged with smoke. This may be a more serious condition than having the glovebox ventilation system plug. Therefore, ventilation control should be an important part of glovebox fire fighting plans.

In addition, filter plenums should be designed with a discrete fire barrier so that filter breaching does not occur.

4.2.2 Glovebox Gloves

Rubber gloves are the most vulnerable part of the glovebox structure in regard to fire damage and breaching.

Some protection can be provided for the gloves by use of metal gloveport covers and making certain that gloves are pulled out of the box when they are not being used.

Because of the vulnerability of the gloves, it is certain that loss of contamination containment will occur under conditions of even a minor fire. Therefore, the design of buildings which house glovebox lines should be such that contamination spread is minimized. This can be achieved by compartmentalization with appropriate seal-offs between sections.

4.2.3 Glovebox Windows

After a glove becomes involved in a fire, sufficient heat is generated to burn a methacrylate plastic window. Little difference in the burning characteristics was noted between a self-extinguishing type of methyl methacrylate window and one without the fire retardant agent. This is not an unreasonable expectation when the depolymerization mechanism of this material is considered. Therefore, in a glovebox situation, the use of the self-extinguishing property should not be the basis for assuming that the material will not contribute to a fire.

Further use of methyl methacrylate windows in gloveboxes should be carefully considered, and only after investigating the possible application of other materials.

Polycarbonate or other thermoplastics appear better than methyl methacrylate because they slump away from the hot portion of the burning glovebox and do not add fuel to the fire. In choosing a window material, the smoke production of the material should also be considered relative to filter plugging.

Window materials fabricated from polyester resins were not tested in these experiments.

Pyrex glass and fire-rated wire glass were found to be the best noncombustible window materials and are recommended whenever they can be used. The next best material is 1/2-inch-thick laminated lead safety glass (if a means is provided to protect the window mounting gasket). Laminated safety glass, 1/4-inch thick, was the most unsatisfactory when compared with the other glass windows tested.

4.2.4 Shielding

Benelex shielding panels are flammable but do not burn readily. Some protection of Benelex is afforded by fire retardant (intumescent) paint but protection is greatly enhanced when reflective stainless steel sheet or cement-asbestos board covering is added.

No optimum location for the Benelex shielding was found inasmuch as panels 4 inches and 3/4 inch from the box were equally damaged.

The use of Plexiglas for see-through neutron shielding contributes fuel to the fire as mentioned previously. A new material is needed for replacement of this item.

The sheet lead (1/8 inch) used for gamma shielding melted readily. In some situations this could lead to a spread of fire and must therefore be considered as a potential hazard.

The gelled water section, tested during the last experiment, appears to merit further development work. This material is 99.9% water, but because of its non-Newtonian character, it does not present the criticality hazard of water.

4.2.5 Heat Detectors

An overheat detector having a more rapid response time than the Rocky Flats designed "flowerpot" should be specified. The detector should be located inside the box and preferably in the upper portion near an exhaust outlet. The location of any heat detector in a ventilated system should be checked by the use of smoke to determine if the rising heat will make rapid contact with the detector.

4.2.6 Materials Inside the Glovebox

Excluding or minimizing combustibles handled in glovebox lines is basic to fire safety. Materials such as paper, cardboard, wood, magnesium, solvents, and plastics are examples of materials, aside from plutonium metal, that can act as points for fire initiation or propagation.

4.2.7 Extinguishing Glovebox Fires

Control of ventilation can extinguish a fire in the early stage, and this type of fire control should be developed and implemented.

The foam type of extinguishing agent, when used in an advanced stage of the fire, was not an effective means of bringing the fire under control. Foam may work effectively at an early stage of the fire.

Sprinkler heads installed so that the spray is able to cool the burning box appear to be the most successful system demonstrated in this series of experiments. However, a conventional fusible sprinkler may not activate until after the fire has breached the box.