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Final Report

INTERIM TESTS OF THE EFFECTS OF LONG DURATION BLAST-TYPE FLOWS ON FIRES IN URBAN INTERIORS AND ON THE CONTENTS OF EMERGENCY OPERATING CENTERS (EOC)

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INTERIM TESTS OF THE EFFECTS OF LONG DURATION BLAST-TYPE FLOWS ON FIRES IN URBAN INTERIORS AND CONTENTS OF EMERGENCY OPERATING CENTERS (EOC)

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by

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January 1976

for the

DEFENSE CIVIL PREPAREDNESS AGENCY
Washington, D.C. 20301

Contract No. DAHC20-73-C-0195
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COTR - Dr. Michael A. Pachuta

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The objectives of the study were to extend the understanding of the manner in which long-duration air blast (from megaton weapons) interacts with fires ignited by the thermal pulse, it having been postulated that extinguishment would occur, for many materials, when subjected to such long-duration flows. To this end, tests were designed and conducted in the URS Long Duration Flow Facility (LDFF) at Fort Cronkhite, California, under the sponsorship of the Defense Civil Preparedness Agency.

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20. Abstract (continued)

A room (approximately 12 ft x 15 ft x 8.5 ft) in this facility was utilized to place burning materials and subject them to pressures of 1.0 to 3.5 psi, flows of 200 to 600 ft/sec and attendant flow durations of 1 to 2 seconds. The materials tested included, but were not limited to, paper (solid-pack and crumpled), cloth, vinyl, cardboard, and wood. In addition, two tests (without fire) of a simulated EOC (without blast-doors) were performed at 2 psi.

The results indicated that 2 psi (rather than 2.5 psi predicted) is a boundary for extinguishment of lighter materials, such as paper and cardboard. Those materials which readily support smouldering combustion, such as cotton batting and heavy cloth, do not extinguish even at 3.5 psi. The results of the EOC test indicated potentially severe damage to communications equipment, monitoring equipment, and furniture.

Summary Report

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SUMMARY REPORT

TYPE AND OBJECTIVES OF THE STUDY

This is a first report on an experimental program, the continuing objective of which is to investigate the effects of long duration blast type flows, simulating flows from megaton range weapons, on fires in urban interiors, and on the contents of Emergency Operating Centers (EOC). The experiments were conducted in a special facility called the Long Duration Flow Facility (LDFF) capable of generating flows with durations of several seconds.

In this summary, the capabilities of the LDFF are discussed first. This is followed by a brief review of the results of the test program, and some implications that can be drawn from these results.

THE LDFF

The LDFF occupies part of an underground tunnel complex of a former coast defense battery. One portion of the complex, called the compression chamber and occupying some 40,000 ft^3 is blocked off, then pressurized. A set of three shutters in a wall of the compression chamber can be opened, and the contents of the compression chamber discharged through the open area that resembles a window, generally into a simulated room formed by placing a wall with a doorway some 15 ft downstream from the shutter wall.

The air flows generated in the LDFF test room are similar to the flows that would be caused by the blast wave from a megaton range weapon after it strikes a relatively large building with a small opening (such as a basement shelter), or a smaller building in which openings are close to the building's edges. In the first case the pressure that would drive flow through the building opening is close to peak reflected pressure, somewhat more than twice incident blast pressure. These conditions can cause very high velocity flows (jets) into the room. For example, a 4 psi reflected blast wave pressure (or LDFF compression chamber pressure) can result in an inflow of some 420 ft/sec into a room with window and door openings occupying about 20% of their respective walls. (Average room pressure would become about 2 psi).

Flows generated by the LDFF do not simulate early blast generated conditions caused by reflections and interactions of shock waves in a room, but do, however, simulate the later high velocity flows (jets) caused by pressure differences across the openings.

TEST RESULTS AND CONCLUSIONS

For this program, the test room of the LDFF was furnished to resemble an office, a classroom, a clothing store, a warehouse, a living room, and a simulated Emergency Operating Center (EOC). Two tests were also run with cages containing various fuels placed in an otherwise empty test room. In all but the EOC configuration, various materials in the room were first ignited with propane sources and then exposed to the flow generated by opening the shutters between the test room and the compression chamber in the LDFF. Compression chamber pressures varied from 2 to 6.25 psi. In the two tests using the EOC configurations, (conducted with compression chamber pressures of 4 psi, but with two different shutter openings) fires were not set but damage to typical EOC equipment was monitored.

In virtually all tests, even with the lowest compression chamber pressures, all flames were extinguished. Materials incapable of supporting smouldering combustion (minor fuels) did not rekindle, nor did the lighter materials such as cloth or individual pieces of corrugated cardboard, ordinarily capable of supporting smouldering combustion. However, many of the heavier materials (major fuels -- mattresses, intact stacks of cardboard and the like) continued to smoulder, and some did rekindle after the tests.

Earlier blast fire tests had been made with flow durations ($\sim$0.1 sec) like those from very small weapons ($<$ 0.05 kT). Preliminary analysis suggests that the findings from these earlier tests for minor fuels were, if anything strengthened. (These fuels would be extinguished at or above about 2 psi by the later, longer duration, jet type LDFF flows.) The LDFF tests also suggest that more major fuels might be extinguished than was earlier assumed.

In the EOC tests, almost all equipment was damaged in the first test (three shutters open), and all equipment was damaged in the second test (two shutters open), with one item still operable. (Predicted maximum flow velocities through the two window openings were 450 and 550 ft/sec.)

ABSTRACT

The objectives of the study were to extend the understanding of the manner in which long-duration air blast (from megaton weapons) interacts with fires ignited by the thermal pulse, it having been postulated that extinguishment would occur, for many materials, when subjected to such long-duration flows. To this end, tests were designed and conducted in the URS Long Duration Flow Facility (LDFF) at Fort Cronkhite, California, under the sponsorship of the Defense Civil Preparedness Agency.

A room (approximately 12 ft x 15 ft x 8.5 ft) in this facility was utilized to place burning materials and subject them to pressures of 1.0 to 3.5 psi, flows of 200 to 600 ft/sec and attendant flow durations of 1 to 2 seconds. The materials tested included, but were not limited to, paper (solid-pack and crumpled), cloth, vinyl, cardboard, and wood. In addition, two tests (without fire) of a simulated EOC (without blast-doors) were performed at 2 psi.

The results indicated that 2 psi (rather than 2.5 psi predicted) is a boundary for extinguishment of lighter materials, such as paper and cardboard. Those materials which readily support smouldering combustion, such as cotton batting and heavy cloth, do not extinguish even at 3.5 psi. The results of the EOC test indicated potentially severe damage to communications equipment, monitoring equipment, and furniture.

ACKNOWLEDGMENTS

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The helpful comments and suggestions of the Contract Officer's Technical Representative, Dr. M. A. Pachuta, and of Mr. George Sisson are hereby gratefully acknowledged.

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Section 1

INTRODUCTION AND BACKGROUND

Section 1

INTRODUCTION AND BACKGROUND

About a third of the energy from a nuclear explosion in the lower atmosphere is liberated in the form of heat or thermal radiation that propagates radially from the burst point at approximately the speed of light. Under proper conditions, this radiation can lead to a substantial number of ignitions within buildings in an urban area. The blast wave from such a burst, which carries away about half the explosion energy, propagates much more slowly -- at speeds of the order of the speed of sound rather than the speed of light. Thus the blast wave -- a generally sharp fronted pressure wave characterized by an air flow field (the blast wind) -- always arrives at any location well after the thermal pulse. (From megaton range weapons, portions of the thermal pulse could be experienced at the same time as the blast pulse, generally where incident blast pressures exceed 10 psi.)

The effect of this flow field on the fires generated by the thermal pulse has been a matter of controversy since the first nuclear explosion. Until the present decade, the only experimental information on blast-fire interaction was that of Tramontini and Dahl in 1953 (Ref. 1) who ignited small quantities of forest kindling fuels (e.g. weathered ponderosa pine needles, madrone leaves, cheat grass, punk) and subjected them to flows resembling those behind a blast wave. Under certain conditions, extinguishment was observed, but it was difficult to apply their results to the urban fire problem because their test conditions were so far different from those in urban areas

Much of this difficulty was resolved by the work of Goodale in 1970 and 1971 (Ref 2, 3, and 4). In a shock tunnel capable of generating blast waves with durations of a tenth of a second, Goodale constructed a full scale room (12 ft wide, 8½ ft high, and 15 ft long) with window openings in its upstream face and a doorway in its downstream face, and furnished it in various ways (as an office, a living room, and a bedroom). Furniture and other materials in the room were ignited so that they were burning as they would from a thermal pulse. After a time interval approximating the time difference between arrival of the thermal pulse and the blast waves from a low air burst of low megaton range weapons, blast waves of various intensities (overpressures) were generated and entered the room. Goodale reported, in Ref. 2, that all flames -- as opposed to smouldering combustion -- appeared to be extinguished at shock overpressure levels somewhere between 1 and 2.5 psi (the flames were not blown out at 1 psi but were at 2.5 psi). This occurred with very large window openings (51% of the wall area) and relatively small window openings (14% of the wall area). Certain materials, however, such as mattress ticking, some cushion fillings, and certain cloth materials, were found to be smouldering after tests at 2.5 psi, 5 psi, (Ref. 2) and at up to 9 psi (Ref. 4). Many of these smouldering materials rekindled into flaming combustion after periods ranging from a few minutes to several hours.

Until the present program there existed no experimental information on the interaction of blast waves whose durations are on the order of seconds (instead of fractions of seconds) with the fires in urban interiors. Because such information would help delineate those areas in a city in which direct ignitions would be extinguished, and within which self-help extinguishment of secondary fires would be feasible, the DCPA sponsored the development of the facility called the Long Duration Flow Facility (LDFF) capable of generating air flows of several seconds duration. This facility occupies another portion of the underground tunnel complex in which the shock tunnel used by Goodale is located, and its test rooms are essentially the same size as those used in th earlier tests.

Initial calibration of the facility was completed during the previous reporting period; during this last reporting period, the new facility was used to investigate blast-fire interactions in various test room configurations including some similar to Goodale's (though, of course. with air flow durations more than an order of magnitude greater than those he used) and also to study the effects of long duration flows in rooms configured as Emergency Operating Centers (EOC).

The previous report on the facility contained a description of the design of the various elements; an analysis of the structural integrity and a comparison of the tests with a 1:12 scale model; and the first calibration tests in the full scale facility itself. The predicted capabilities were discussed only in general terms, however, and not enough data were gathered during the limited calibration test program to allow an adequate appraisal of how well its actual operation compared with predictions (Ref.5).

The recently completed test program, along with the earlier calibration tests, have gone a long way toward filling this information gap (a total of 29 tests have been carried out). Therefore, a major portion of this report (Section 2) is devoted to general LDFF considerations, including a brief analysis of its operation, in which anticipated flow parameters are derived (and presented in graphical form); a comparison of measured with predicted parameters; and finally, a discussion of how LDFF flow conditions relate to those that can be expected from nuclear weapon blast environments.

The final section of the report (Section 3) deals with the test program completed during this reporting period. It includes a discussion of the general design of the tests, a summary of important test results, and conclusions that can be drawn from these results.

The report also contains two Appendices: Appendix A is devoted to a detailed, test-by-test description of the conditions, geometries, and results of the latest test program; Appendix B summarizes relationships of the various nuclear weapon blast parameters that are germane to the operation of the LDFF.

Section 2

THE LONG DURATION FLOW FACILITY (LDFF):
DESCRIPTION, FLOW CHARACTERISTICS, AND
THEIR RELATIONSHIP TO NUCLEAR BLAST FLOWS

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THE LONG DURATION FLOW FACILITY (LDFF): DESCRIPTION, FLOW CHARACTERISTICS, AND THEIR RELATIONSHIP TO NUCLEAR BLAST FLOWS

GENERAL LDFF DESCRIPTION

The underground tunnel complex which contains both the LDFF and the shock tunnel used by Goodale is sketched in Fig. 2-1. A plan view of the LDFF is shown in Fig. 2-2. A compression chamber with a volume of about 40,000 ft^3 has been formed by blocking off the tunnel at Point A, and installing a wall, containing a set of heavy steel shutters at Point B. The shutters are held closed, as shown in the upper photo in Fig. 2-3, while the compression chamber is being pressurized. When the shutters are released, the compression chamber pressure forces them open, creating an opening resembling a window as shown in the lower photograph of Fig. 2-3.

A test room, 12 ft wide, 8½ ft high, and about 15 ft long, was created by the installation of a wall at Point C in Fig. 2-2. For this program, the wall at Point C included a doorway on one side that occupied about 20% of the wall area.

When the shutters are opened, air flows into the room through the "window" in the front wall, and begins to flow out of the room through the doorway opening in the back wall. The pressure in the compression chamber decreases as the chamber empties through the test room. This

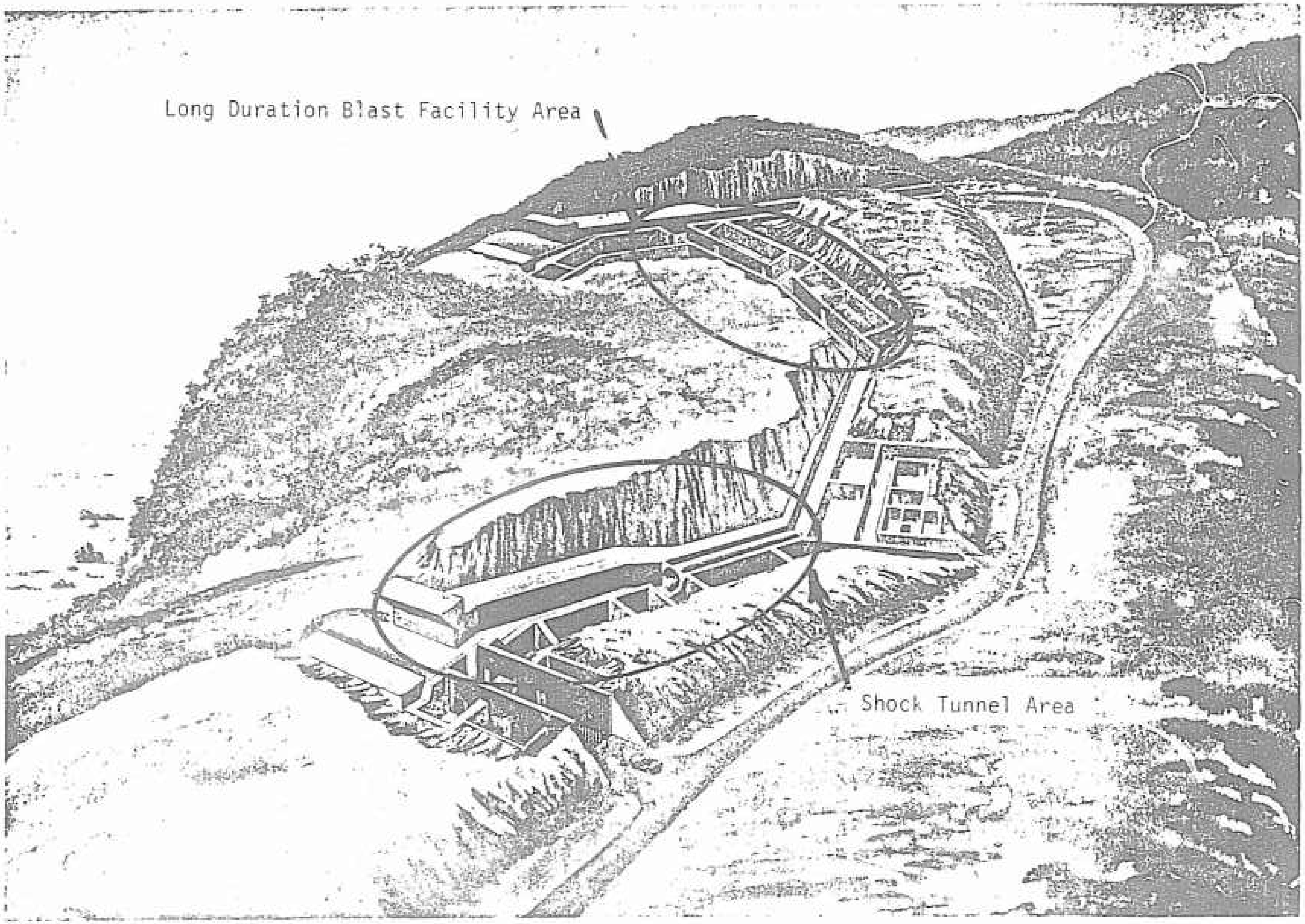


Fig. 2-1. Tunnel Complex

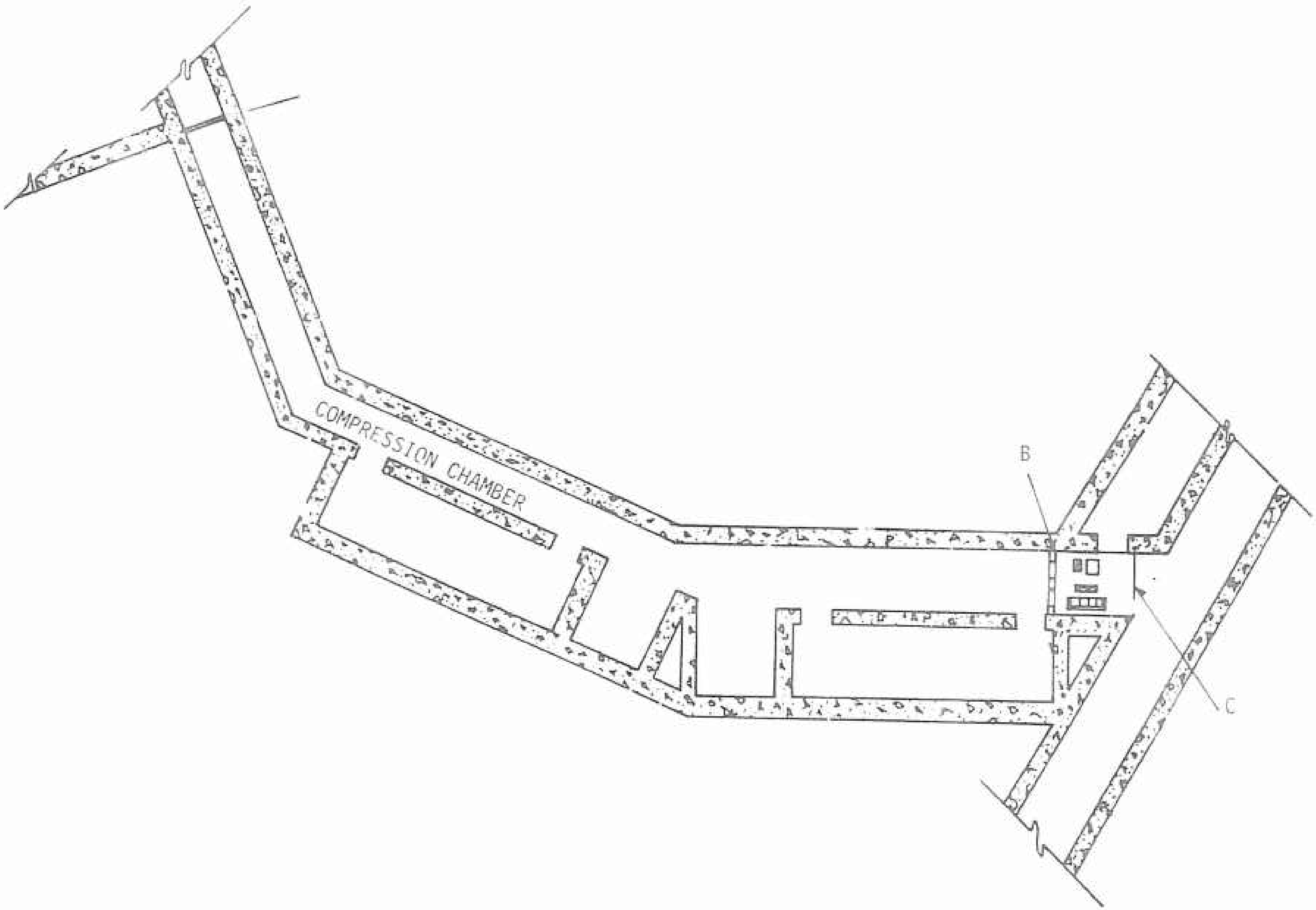


Fig. 2-2. Sketch of Long Duration Flow Tunnel Facility.

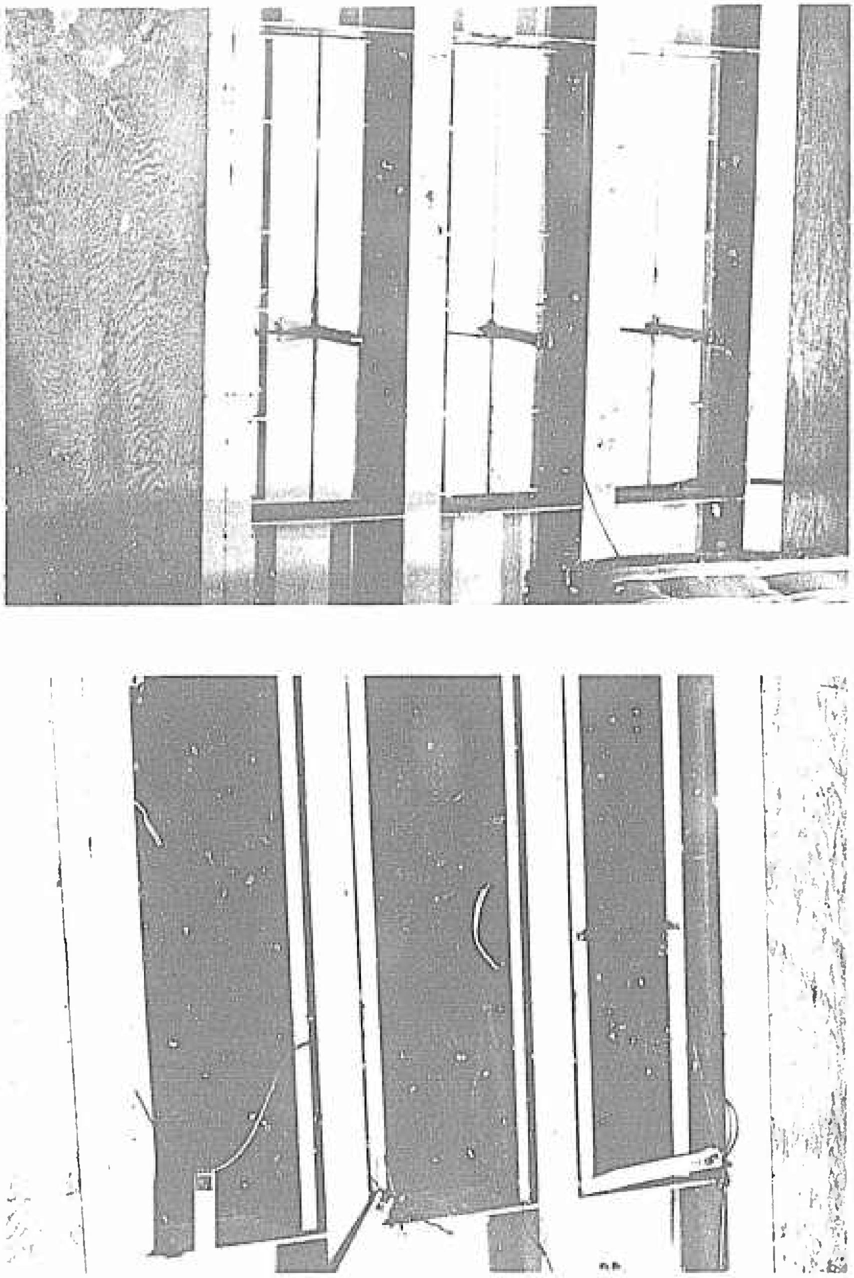


Fig. 2-3. Photographs of Diaphragm Mechanism.

pressure reduction, however, is slow enough that quasi-steady flow conditions are established. That is, both the average pressure in the room, and flow velocities through the openings decrease uniformly as the compression chamber pressure decreases and a sinuous flow "channel" with high flow velocities establishes itself between the window and the doorway openings. In other parts of the room -- in the back corner away from the doorway, for example -- flow velocities can be very low or even nonexistent, and can show strong reversals in direction.

In the following material some of the more important operational characteristics of the LDFF -- such as flow velocities through the window and doorway openings, and change of compression chamber pressure with time -- are derived.

ANALYSIS OF LDFF FLOW CHARACTERISTICS

The complex actual configuration of the LDFF shown in Fig. 2-2 can be simplified to the schematic form shown in Fig. 2-4, in which the areas are in the same relative proportion as the volumes of the compression chamber and the test room (40,000 and 1500 ft^3 respectively).

Without secondary effects, the mass flow rate, w, of a fluid through an orifice is:

$$w = \rho A u \qquad (2\text{-}1)$$

where ρ = fluid density

A = the orifice area

u = the flow velocity through the orifice.

If we assume incompressible flow, the velocity is given by the incompressible flow Bernoulli equation*

$$u = \sqrt{2\Delta p/\rho} \qquad (2\text{-}2)$$

where Δp = the pressure difference across the orifice.

* A more correct compressible flow relationship (assuming isentropic flow), derived from the compressible flow Bernoulli equation is

$$u^2 = [2\gamma/(\gamma-1)][(p/\rho)-(p_1/\rho_1)] = 7(p_1/\rho_1)[(p/p_1)^{0.286}-1] \qquad (2\text{-}2a)$$

where γ = ratio of specific heats for air = 1.4
p = driving pressure
ρ = air density at driving pressure
p_1 = ambient pressure
ρ_1 = air density at ambient pressure

and $(p/p_1) = (\rho/\rho_1)^\gamma$ for isentropic flow.

For the pressures of interest to blast-fire interaction studies (about 5 psi or less), the assumption of incompressible flow through the orifice introduces little error; with a pressure difference of 5 psi, the error is about 6%.

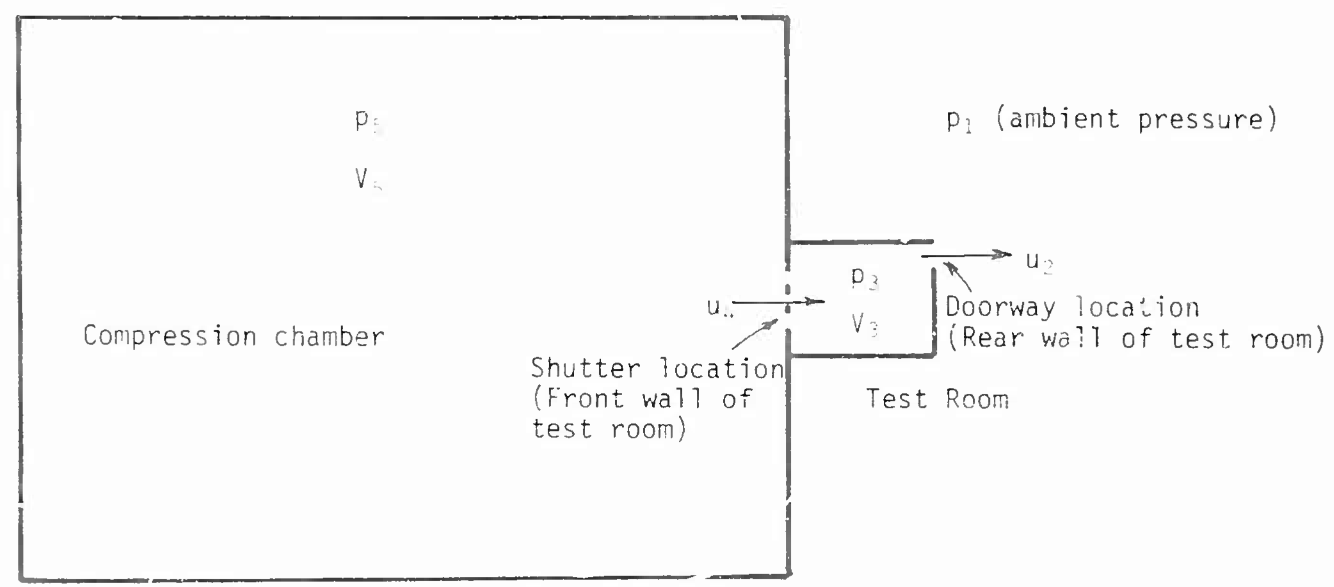


Fig. 2-4. Schematic of LDFF. p = pressure, V = volume, u = velocity. Subscript (5) refers to the compression chamber; (3) to the test room; and (1) to ambient conditions outside the facility. Subscript (4) refers to the "orifice" between the compression chamber and the test room; and (2) to the "orifice" between the test room and the outside world.

Eq. 2-1 then becomes:

$$w = A\sqrt{2\rho\Delta p} \qquad (2\text{-}3)$$

The rate of change of pressure within a volume when there is a mass flow rate, either into or out of it, through an orifice can be determined,* (assuming adiabatic flow) from the perfect gas law and the first law of thermodynamics as:

$$w = \frac{1}{g}(V/a^2)\dot{p} \qquad (2\text{-}4)$$

where V = the volume into or out of which flow takes place

a = the speed of sound of the air upstream from the orifice

$\dot{p}$ = rate of change of pressure with time = dp/dt

Eqs. 2-3 and 2-4 when applied to the configuration shown in Fig. 2-4 give the following differential equations for the pressures in the two chambers.**

$$\dot{p}_5 = -(a^2/V_5)(\sqrt{2\rho})[A_4\sqrt{(p_5-p_3)}]$$

$$\dot{p}_3 = (a^2/V_3)(\sqrt{2\rho})[A_4\sqrt{(p_5-p_3)}-A_2\sqrt{(p_3-p_1)}] \qquad (2\text{-}5)$$

Eq. 2-5 can be numerically integrated directly, but an analytical approximation that gives values quite close to those from the numerical integration can be derived as follows.

* See Ref. 6.

** Solution of these equations is simplified if it is assumed that the product $(a^2)(\sqrt{\rho})$ is constant.

Since volume V_3 is very much smaller than volume V_5, the pressure in the two chambers might be expected to adjust rapidly to values corresponding to a uniform flow rate (through the orifices) which decreases gradually with time. With this assumption, Eqs. 2-4 and 2-5 give:

$$p_5 - p_3 = (w/A_4)^2/(2\rho), \quad p_3 - p_1 = (w/A_2)^2/(2\rho) \text{ or}$$

$$(2\rho)(p_5 - p_1) = w^2[(1/A_4)^2 + (1/A_2)^2] \quad w^2/A^2 \qquad (2\text{-}6)$$

and

$$\dot{p}_5 = -(a^2/V_5)w \qquad (2\text{-}7)$$

where A is defined as the "effective flow area" corresponding to the two orifices A_4 and A_2. Combining Eq. 2-6 with Eq. 2-7 we have:

$$\dot{p}_5 = -(Aa^2/V_5)\,[\sqrt{2\rho\,(p_5 - p_1)}] \qquad (2\text{-}8)$$

Integration of Eq. 2-8 results in

$$\sqrt{2(p_5(o) - p_1)/\rho} - \sqrt{2(p_5 - p_1)/\rho} = (Aa^2/V_5)t \qquad (2\text{-}9)$$

where $p_5(o)$ = the initial compression chamber pressure.

The time t_f for the chamber pressure p_5 to reach its final value, p_1 can be found from Eq. 2-9, since the second term becomes zero.

$$t_f = (V_5/Aa^2)\,\sqrt{2(p_5(o) - p_1)/\rho} \qquad (2\text{-}10)$$

The compression pressure change with time can be found by combining the last two equations

$$(p_5 - p_1) = (p_5(o) - p_1)(1 - t/t_f)^2 \qquad (2\text{-}11)$$

The test room pressure change with time can be found by using Eqs. 2-6 and 2-11.

$$(p_3 - p_1) = (p_5(o) - p_1)(1 - t/t_f)^2 \, (A/A_2)^2 \qquad (2\text{-}12)$$

The room pressure change is identical with that for the change of chamber pressure in the preceding equation with the exception of the orifice factor A/A_2.

Flow velocities through the two orifices A_4 and A_2 can be calculated from Eq. 2-2

$$u_4 = (A/A_4)(1 - t/t_f) \sqrt{2(p_5(o) - p_1)/\rho}$$

and

$$u_2 = (A/A_2)(1 - t/t_f) \sqrt{2(p_5(o) - p_1)/\rho} \qquad (2\text{-}13)$$

Again, these are identical with the exception of the orifice factors A/A_4 and A/A_2.

Relationships derived from the preceding equations are plotted in Figs. 2-5 through 2-9 for the present LDFF configuration in which A_2 is fixed at about 20.4 ft . Fig. 2-5 gives initial room pressure*, and Fig. 2-6 gives initial flow velocities* through orifice A_4 (between the compression chamber and the test room) and through orifice A_2 (between the test room and the outside world), both as functions of initial chamber pressure. Fig. 2-7 gives t_f, the flow duration, also as a function of initial chamber pressure. Figs. 2-8 and 2-9 show pressure and velocity changes with time for a typical initial chamber

* These room pressures and flow velocities are actually those that occur as soon as quasi-steady flow is established.

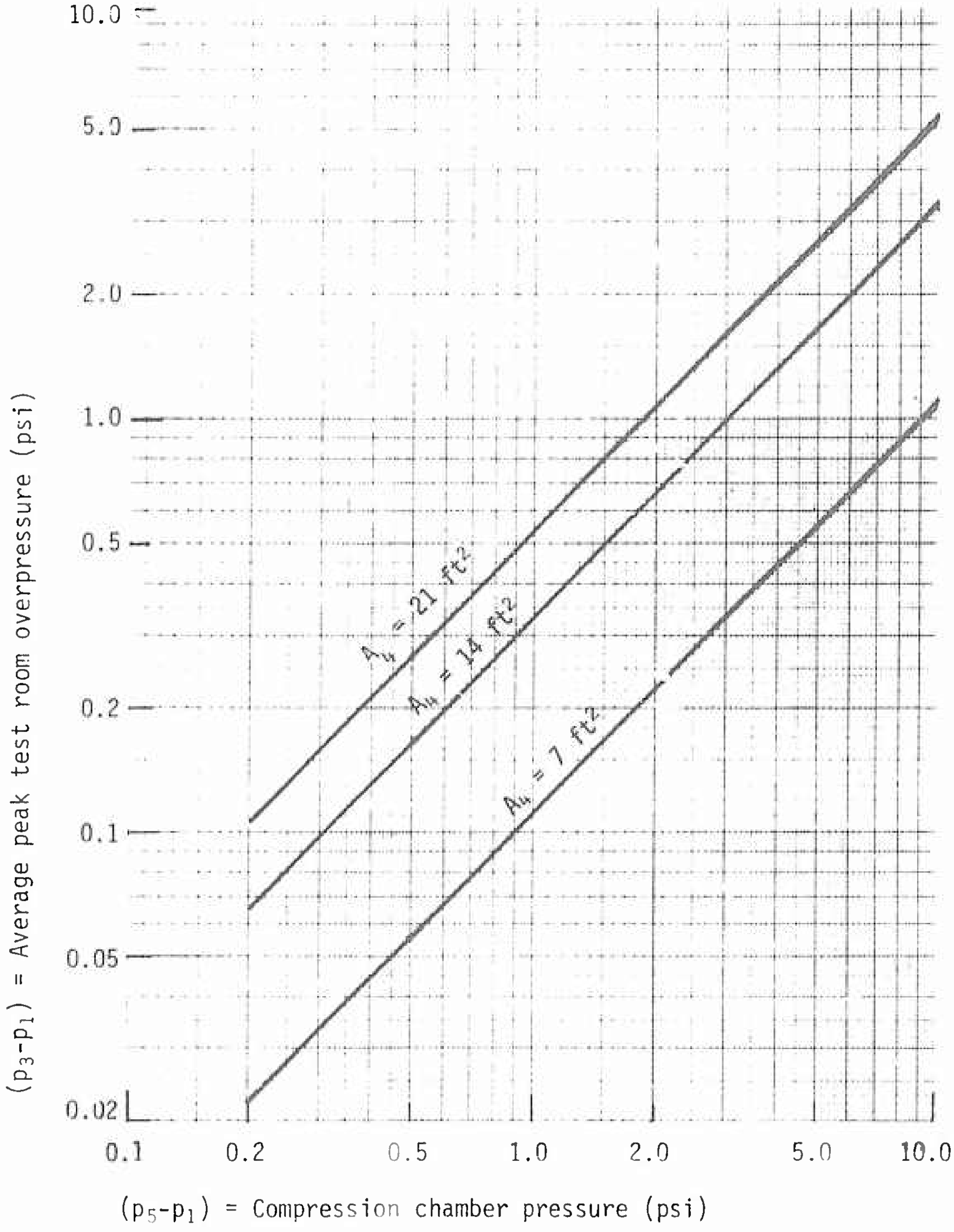


Fig. 2-5. Average Peak Test Room Overpressure, p_3-p_1, as a Function of Compression Chamber Overpressure, p_5-p_1, for Shutter Openings, A_4, of 7, 14, and 21 ft^2.

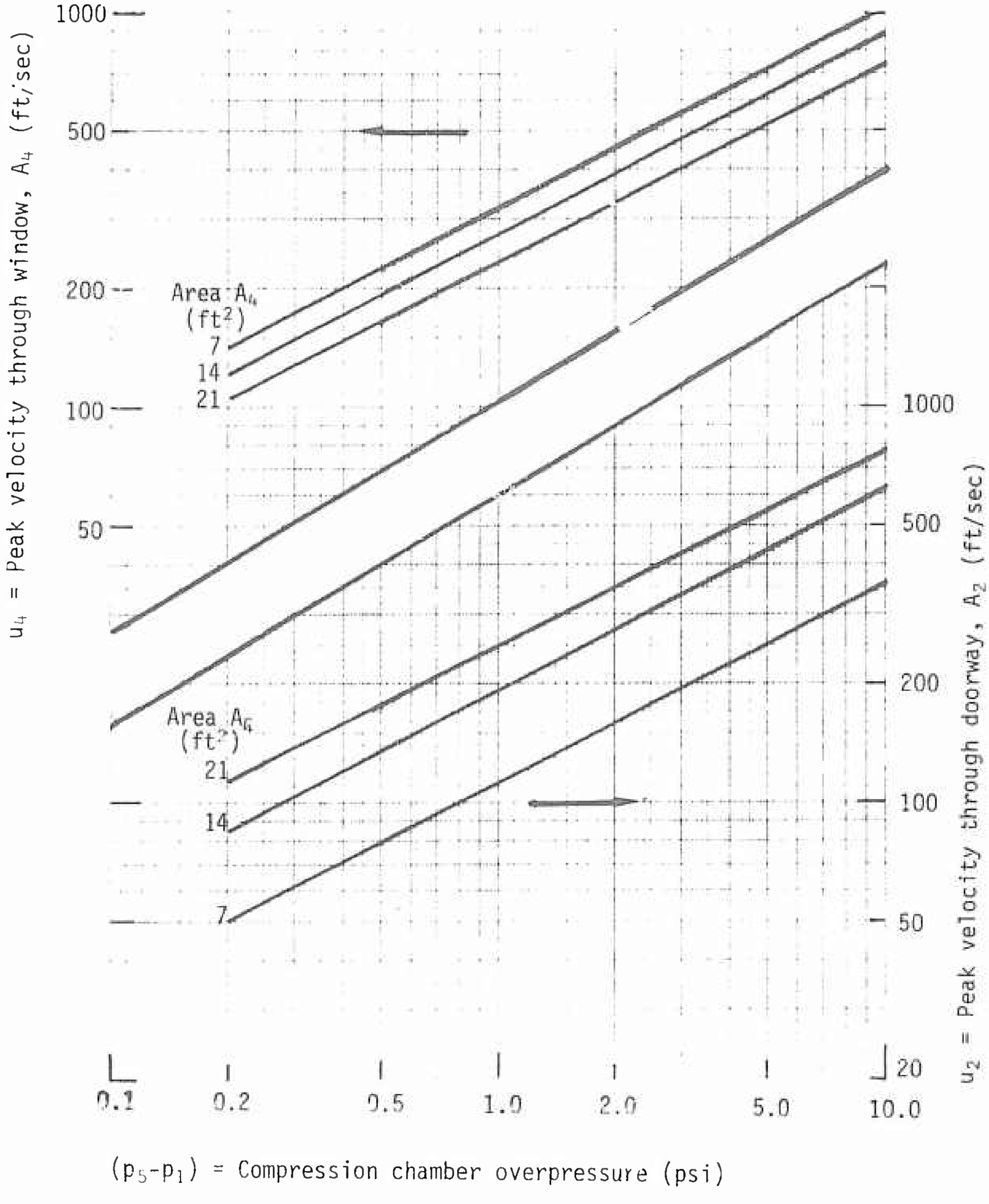


Fig. 2-6. Peak Flow Velocity, u_4, Through Front Window, A_4, and Peak Flow Velocity, u_2, Through Rear Doorway, A_2, vs. Compression Chamber Overpressure, p_5-p_1, for Shutter Openings, A_4, of 7, 14, and 21 ft^2.

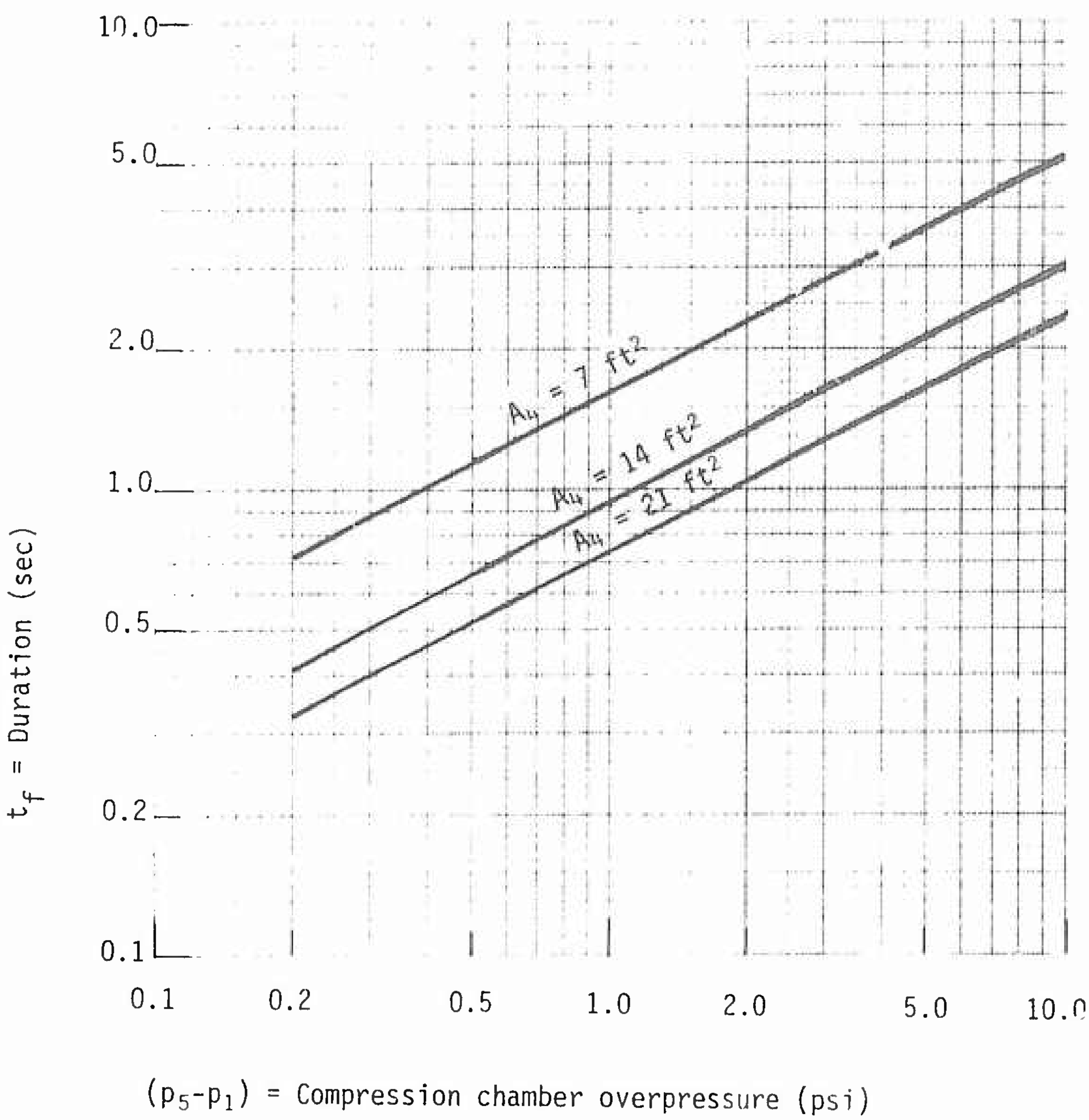


Fig. 2-7. Duration, t_f, of Flow in LDFF vs. Compression Chamber Overpressure for Shutter Openings, A_4, of 7, 14, and 21 ft^2.

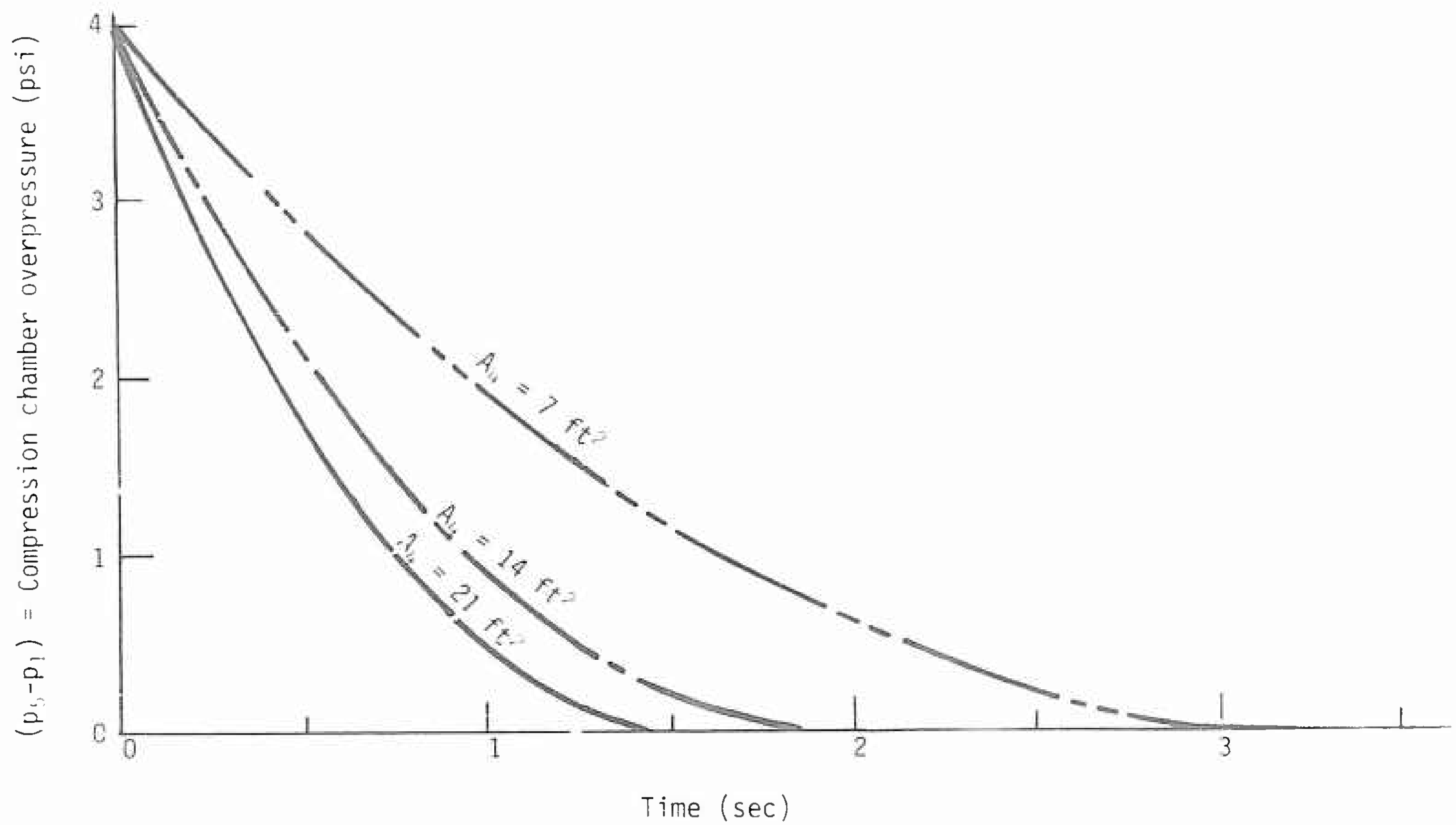


Fig. 2-8. Predicted Compression Chamber Overpressure vs. Time for Shutter Openings of 7, 14, and 21 ft^2.

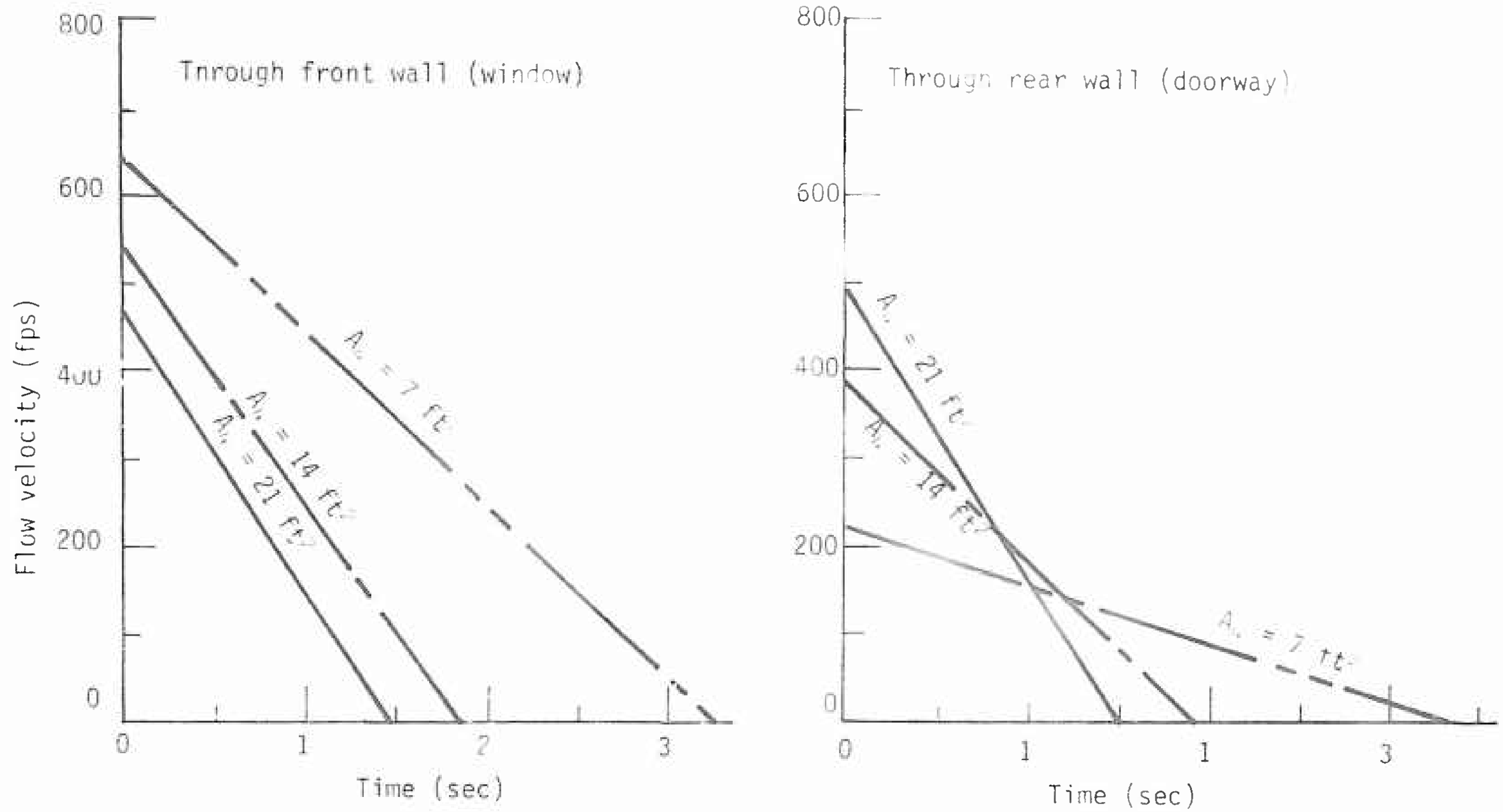


Fig. 2-9. Predicted Flow Velocities Through Front Wall (Window) and Rear Wall (Doorway) vs. Time for Shutter Openings, A_s, of 7, 14, and 21 ft^2.

pressure of 4 psi. Fig. 2-8 shows the change of chamber pressure with time, and Fig. 2-9 shows the flow velocities through the two orifices as functions of time.

COMPARISON OF PREDICTED WITH MEASURED LDFF BEHAVIOR

During the initial development work on the LDFF, nine tests with various window and doorway openings (orifices A_4 and A_2 respectively) were conducted, all at a compression chamber overpressure of about 2 psi. During the current testing program, an additional 20 successful tests were conducted with compression chamber pressures ranging from 2 psi to over 6 psi. Measured and predicted values (from Fig. 2-5 and 2-7) of room pressure and duration from these tests are given in Table 2-1.

The agreement between measured and predicted pressures and durations is really quite good. Test room pressures measured in the room side wall were all within 20% of predicted values, and 21 of the 29 measurements were within 10% of predicted values. Results of positive duration measurements were similar.

Particular attention is drawn to shots 4 and 17 of the second test series. Both were planned as shots with shutter openings of 7 ft^2, (only one shutter open). But in each case a comparison of measured with predicted durations indicated that something was amiss. For the two shots, the predicted durations for a 7 ft^2 opening were about 2.5 sec and 3.3 sec. more than twice the observed 1.2 sec and 1.9 sec. A subsequent careful examination of the motion pictures showed that in both cases, two shutters rather than one had opened. As can be seen in Table 2-1, predicted values for a shutter opening of 14 ft^2 are generally close to the measured values.

Table 2-1

Comparison of Measured and Predicted LDFF Quantities

Test Number	Compression Chamber Pressure (psi)	Shutter Opening (ft^2)	Doorway Opening (ft^2)	Peak Room Overpressure Measured (psi)	Peak Room Overpressure Predicted (psi)	Positive Phase Duration Measured (sec)	Positive Phase Duration Predicted (sec)	Predicted Peak Orifice 4 Into Room (ft/sec)	Flow Velocities Orifice 2 Out of Room (ft/sec)
First Test Series									
1	2	21	21	0.80	0.99	-	1.0	340	340
2	2	21	21	0.96	0.99	-	1.0	340	340
3	2	21	21	0.85	0.99	0.90	1.0	340	340
4	2	14	17	0.84	0.81	1.6	1.4	370	310
5	2	14	17	0.84	0.81	1.5	1.4	370	310
6	2	14	12.5	0.91	1.1	1.7	1.6	320	360
7	2	21	12.5	1.2	1.4	1.2	1.4	250	410
8	2	21	21	0.9	1.0	0.9	1.0	340	340
9	2	21	21	0.9	1.0	0.9	1.0	340	340
Second Test Series									
1	2.2	21	20	0.96	0.99	0.85	1.0	340	360
2	4.2	21	20	1.96	2.0	1.4	-	470	500
3	2.2	21	20	1.1	1.1	0.97	1.0	340	360
4	2.25	14(7)*	20	0.6	0.7	1.2	2.5	490	170
5	2.1	21	20	1.1	1.1	1.0	1.0	340	350
6	2.1	21	20	1.2	1.1	0.98	1.0	340	350
7	2.1	21	20	1.1	1.1	0.99	1.0	340	350
8	2.0	21	20	1.0	1.0	0.97	1.0	330	350

* Number in parenthesis indicates planned shutter opening.

Table 2-1 (cont.)

Comparison of Measured and Predicted LDFF Quantities

Test Number	Compression Chamber Pressure (psi)	Shutter Opening (ft^2)	Doorway Opening (ft^2)	Peak Room Overpressure Measured (psi)	Peak Room Overpressure Predicted (psi)	Positive Phase Duration Measured (sec)	Positive Phase Duration Predicted (sec)	Predicted Peak Flow Velocities Orifice 4 Into Room (ft/sec)	Predicted Peak Flow Velocities Orifice 2 Out of Room (ft/sec)
Second Test Series (cont.)									
9	4.0	-	20	-	-	-	-	-	-
10	3.0	21	20	1.4	1.5	0.97	1.2	400	420
11	4.0	21	20	1.8	2.0	1.2	1.4	450	490
12	2.0	21	20	1.1	1.0	0.97	1.0	330	350
13	3.9	21	20	1.7	2.0	1.3	1.4	460	480
14	4.0	21	20	2.1	2.0	1.4	1.4	460	490
15	5.75	21	20	3.0	2.9	1.4	1.7	550	580
16	6.25	21	20	3.0	3.2	1.4	1.7	570	600
17	4.0	14(7)*	20	0.8	1.5	1.9	3.3	650	220
18	4.25	21	20	2.4	2.1	1.3	1.4	470	500
19	2.0	21	20	1.1	1.0	0.94	1.0	330	350
20	6.1	21	20	3.0	3.0	1.5	1.7	560	600
21	5.5	21	20	2.8	2.8	1.4	1.6	540	570

*Number in parenthesis indicates planned shutter opening.

LOFF FLOWS COMPARED WITH NUCLEAR WEAPON BLAST FLOWS

Description of Nuclear Weapon Blast Environments

The characteristics of flow fields generated by blast waves from nuclear weapons in the vicinity of buildings within a city depend on a great variety of things, such as building geometry, building orientation relative to the burst point, and the location of a "target" building relative to nearby structures. However, in many cases, little error results from considering a target building to be isolated, and in assuming that the blast wave strikes the building head-on.

Broadly, for this simplified case , the flow into any opening of a structure -- a window, for example -- is first characteristic of that immediately behind the shock front. However, the pressure within the blast wave is immediately increased by the process of reflection from the solid portions of the building, and the increased pressure increases the flow velocity through the opening. Rarefactions from the edges of the building and other openings, propagate into the regions of high pressure outside the building and interact with each other in complex ways. The overall effect of these interactions is to reduce the pressure outside the window. The value to which the pressure decreases is highly dependent on the geometry of the situation including the placement of the opening relative to the building edges and roof, the number of openings in the building, and the length of the shock wave relative to the various building dimensions.

The general phenomena that can occur are schematically illustrated in Fig. 2-10, which shows the plan views of two simplified cases of buildings with a single opening. In the first case (see sketch A-1), the opening is far from the edges of the building; in the second case (see sketch A-2), the opening is much closer to the edges of the building. In the sketches, only one half the front wall is shown; the lowest line in each sketch is the centerline through the opening.

The sketches of Fig. 2-10 are highly simplified: however, conditions resembling those on the left of the figure could occur near an outside entrance to a basement in a large building. Conditions resembling those on the right could occur near an entrance to an isolated underground shelter where the entrance structure is relatively small. They could also occur near a relatively small structure, and, to some degree, near a structure whose window area occupies a significant fraction of its wall area.

The "A" sketches show conditions just before the shock wave, moving to the right, strikes the building. The light shaded area behind the shock wave indicates incident shock pressure. For simplicity, assume that the shock wave is very much longer than the building, so that pressure behind the shock front can be considered uniform.

The "B" sketches illustrate conditions just after the shock wave has struck the building. In each case, part of the wave enters the opening unchanged, and part reflects from the front wall. the dark areas in both

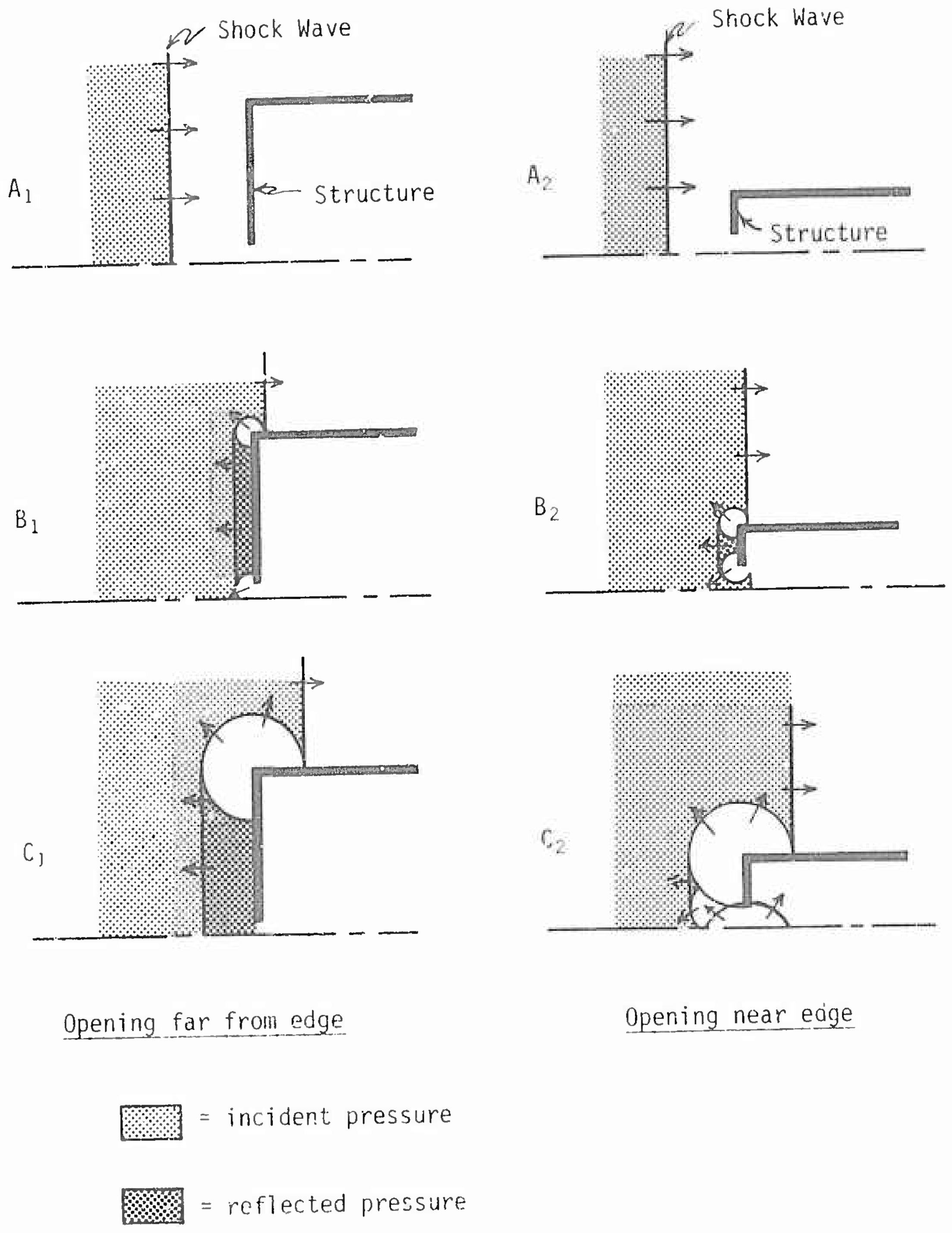


Fig. 2-10. Shock Wave Interactions With a Structure Containing an Opening.

cases represent areas of reflected overpressure, at least twice the value of incident overpressure. The curved lines centered at the corners of the building and the opening are wave fronts which propagate into the region behind the reflected shock, reducing the pressure there, and into the region behind the incident shock, increasing the pressure there.

The "C" sketches illustrate conditions at a later time. Note in sketch C-1 a large area near the opening is still experiencing reflected pressure, while in sketch C-2, reflected pressure still exists in only a small area, remote from the opening. Near the opening, where shock and rarefaction waves are interacting, pressure is generally above incident pressure, but closer to it than to reflected pressure.

Eventually, after a time known as the "clearing time" when the interacting shock and rarefaction wave fronts have dissipated, steady state conditions occur. Pressures at the openings in the two cases are close to stagnation pressure, the pressure that occurs on an object immersed in steady flow where the flow is at rest (for example, at the center of a flat plate oriented normal to the flow, or at the point of a sphere furthest upstream). For pressures of interest to blast-fire interaction problems (about 5 psi or less), stagnation pressures are close to incident pressures.

The time at which clearing occurs is much shorter for the geometry on the right in Fig. 2-10, where the opening is close to the building edges, than for the geometry on the left. In sketch C-2, the pressure in front of the opening has already been significantly decreased by rarefaction waves from the building edges, but in sketch C-1, rarefaction waves have not yet reached the area of the opening, and the pressure outside it is still shock wave reflected pressure.

Conditions in sketch C-1 are similar to the conditions discussed in some detail in the previous section: i.e., a pressure difference exists across an opening, and -- except in the immediate vicinity of the opening -- air on the high pressure side is largely at rest, as if it were part of a large reservoir. In sketch C-1, the high pressure is caused by reflected pressure; after clearing takes place, in both geometries, the high pressure would be caused by stagnation pressure. Such pressure differences across an opening result in flow through it as derived in Section 2.

In other words, flows through the openings shown in Fig. 2-10 change from those caused by the passage of a shock front through openings (sketches B-1 and B-2) to those more characteristic of flows through orifices driven by pressure differentials across them.

For convenience, relationships among the various shock parameters discussed in the previous paragraphs (reflected pressure, stagnation pressure, flow velocity behind the shock front, etc.) are summarized in Appendix B. These relationships permit construction of a schematic diagram of the pressures outside the openings for the two cases shown in Fig. 2-10. This is done in Fig.2-11 on which the letters and numbers used are keyed to the sketch designations of Fig. 2-10. For illustrative purposes, an incident overpressure of 2 psi has been assumed. Note that for both cases, at the time of shock arrival pressure across the opening is the incident pressure of 2 psi. Where the opening is distant from the building edges, this rises to peak reflected pressure of 4.2 psi, then eventually falls to stagnation pressure of 2.1 psi. Where the opening is near the building edges, pressure rises above incident, but not to peak reflected, then also falls to its stagnation value.

A similar plot, Fig. 2-12, can be made for flow through the opening (assuming the volume downstream from the opening to be so large that shock reflections within it would not interfere with the flow, and that pressure within it does not rise due to inflow). Again, in both cases, the initial value is that associated with the incident shock wave, about 100 ft/sec. In the case where the driving pressure becomes peak reflected pressure, this increases by almost a factor of seven to about 700 ft/sec (while the the pressure increase factor was only about two.) Eventually, the flow becomes that associated with stagnation pressure, about 490 ft/sec, still nearly five times that behind the incident shock wave. In the case where driving pressure becomes stagnation pressure at a fairly early time, flow velocity rises but stabilizes at the value associated with stagnation pressure, i.e., about 490 ft/sec.

It is clear that a shock wave <u>per se</u> is an inefficient mechanism for

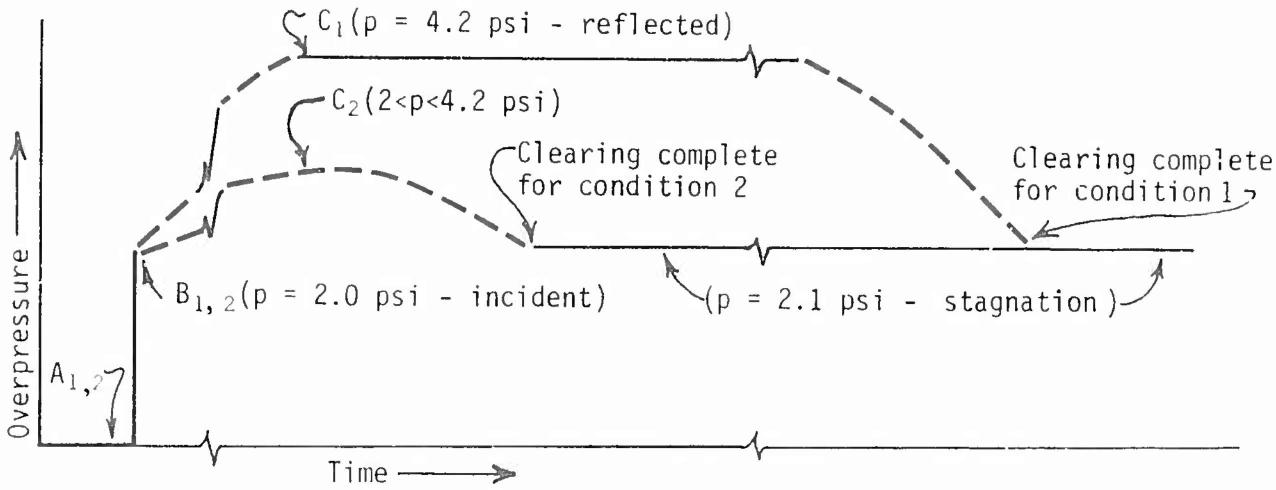


Fig. 2-11. Overpressure Outside Openings in Buildings Struck by Very Long Duration Blast Waves. Letters and numbers correspond to those in Fig. 2-10.

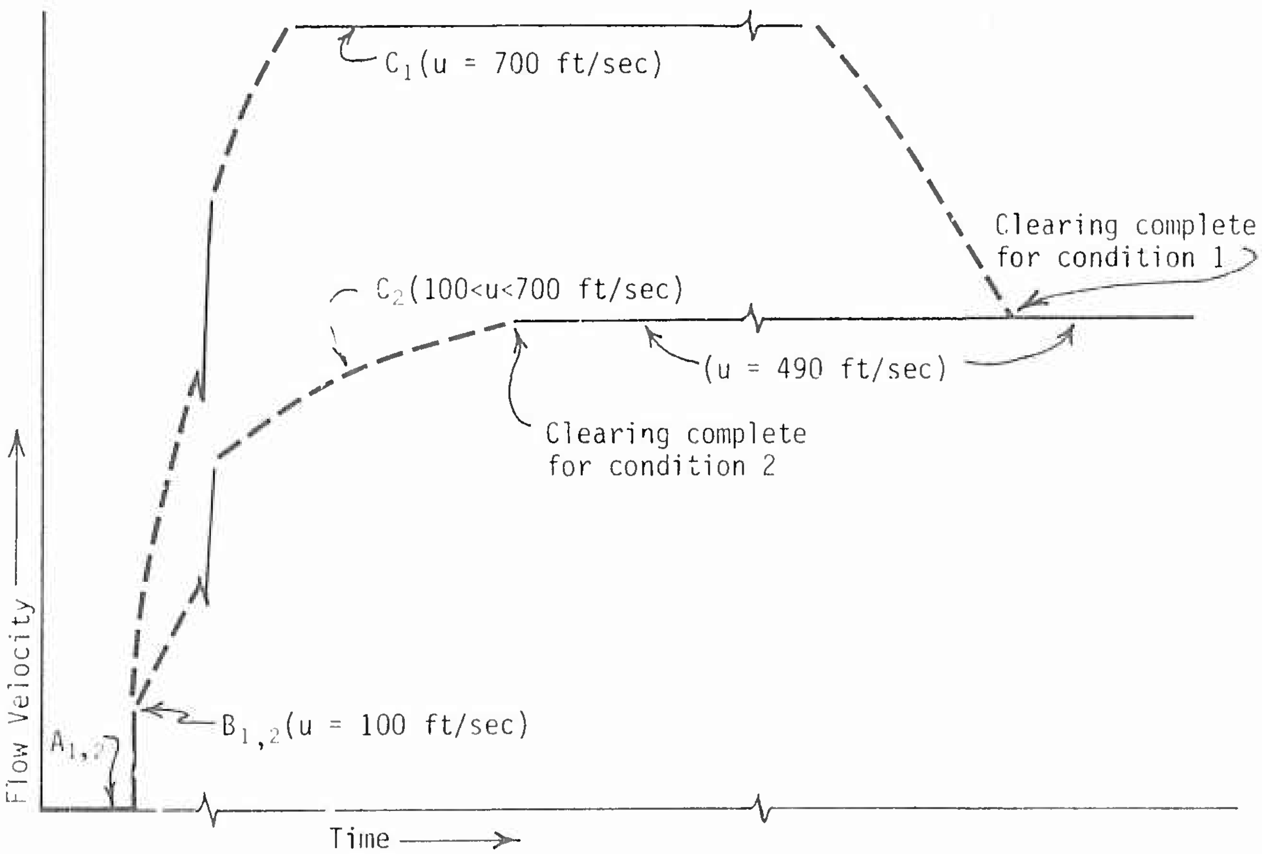


Fig. 2-12. Flow Velocities Through Openings in Buildings Struck by Very Long Duration Blast Waves. Letters and numbers correspond to those in Fig. 2-10.

accelerating flow; a far greater flow velocity through an opening can be generated by a particular pressure across it, than can be generated by a shock wave with the same pressure difference at its front that passes through the opening. As shown in Figs. 2-11 and 2-12, the 2 psi incident shock generates a flow velocity of 100 ft/sec, while the 2.1 psi stagnation pressure differential across the opening causes a velocity of 490 ft/sec. The 4.2 reflected pressure differential across the opening results in a velocity of 700 ft/sec, while a 4.2 psi shock wave would result in a velocity behind the shock front of about 200 ft/sec.

One further characteristic of the nuclear weapon blast wave environment should be discussed: the change of pressure with time. Incident blast wave pressures in the pressure range of interest are well represented by the classical Friedlander equation

$$\Delta p_i(t) = \Delta p_i(0)\ [(1-t/t^+)e^{-t/t^+}] \tag{2-14}$$

where $\Delta p_i(t)$ = overpressure as a function of time, t

and t^+ = the duration of the positive blast wave overpressure.

In constructing Figs. 2-11 and 2-12, it was assumed that the blast wave duration was long enough that any decrease in blast wave pressure during the time covered by the figures was negligible. To be correct, however, the figures should actually reflect a pressure decrease with time derived from the modified exponential relationship given in Eq. 2-14.

Blast Flow vs. LDFF Flow Through an Opening

Fig. 2-11 shows the pressure environment outside openings in two types of structures struck head-on by a long duration blast wave. The pressures rise from zero and stabilize. Fig. 2-12 shows that flow through an opening into a large downstream volume changes from shock induced flow to that induced by pressure differentials across the opening. (As just noted, the constant pressure portions of Fig. 2-11 should be modified by superimposing pressure decreases derived from Eq. 2-14.)

In the LDFF, as soon as the shutters are opened, air begins to flow through the shutter (window) area. If the rear wall of the test room were removed so that downstream conditions in the LDFF were similar to those used to construct Fig. 2-12, after a period of transition, the flow would stabilize into one controlled by the pressure differential across the window. Since the volume of the LDFF compression chamber is finite, its pressure falls according to the relationship given by Eq. 2-11.

$$\Delta p_{5,1}(t) = \Delta p_{5,1}(0)\ [(1-t/t_f)^2] \qquad (2\text{-}11)$$

where $\Delta p_{5,1}(t)$ = the chamber pressure (5) in excess of ambient pressure (1) as a function of time

and t_f = the time the chamber pressure becomes equal to ambient pressure.

Thus, it appears that after initial transition periods, flows through openings caused by blast waves are at least qualitatively similar to that caused by opening the shutters in the LDFF. In both cases, the flow is controlled by the pressure differential across the opening, and in both cases, pressure decrease with time occurs on the high pressure side. If the pressure decreases in the LDFF (from Eq. 2-11) are similar to blast induced pressure decreases (from Eq. 2-14) then flow in the LDFF should be quantitatively as well as qualitatively similar to blast induced flow.

The bracketed terms of these two equations (i.e., the term that determines the fall off of pressure with time from some initial value) are plotted as a function of the time ratios t/t^+ for the blast wave and t/t_f for the LDFF in Fig. 2-13. The two are very similar, especially in the early time, high flow velocity parts.

The comparison between the change with time of LDFF chamber pressures and blast wave reflected pressures (as distinct from incident pressures) is actually even better than that shown in Fig. 2-13. The blast wave curve becomes a bit steeper, bringing it closer to the LDFF curve. The curve for reflected pressure is slightly different for each incident pressure (because peak reflected pressure is an increasing function of incident pressure). A single point is shown for illustrative purposes. At t/t^+ of 0.5, the reflected pressure ratio for an 4 psi incident blast wave is 0.28, compared with a pressure ratio of 0.30 for the incident wave itself, and 0.25 for the LDFF.

It can be concluded, therefore, that LDFF chamber pressures are good simulants of blast wave pressures produced by nuclear weapons.

Flow Conditions Within Rooms

The preceding discussion dealt with situations in which the chamber

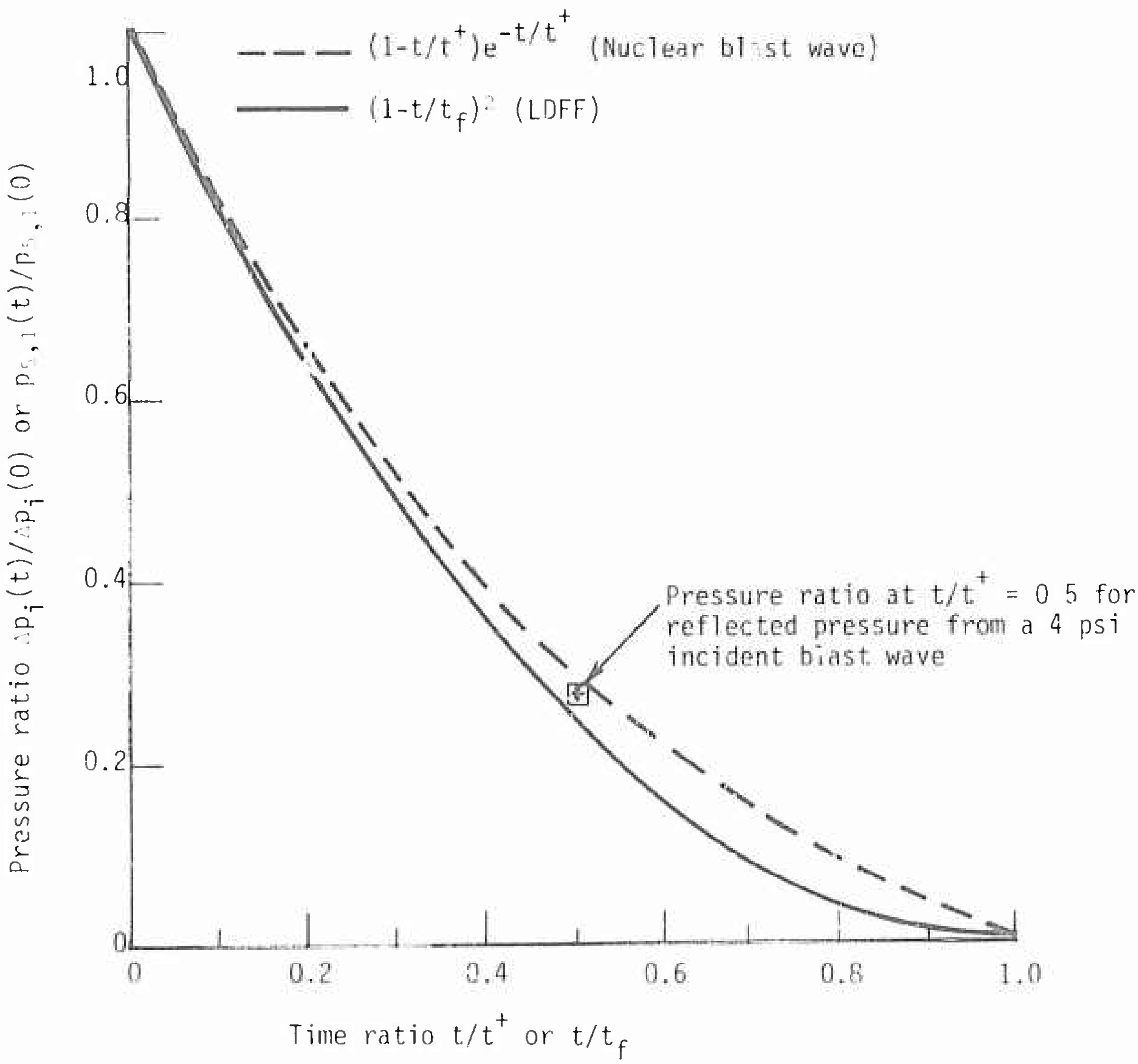


Fig. 2-13. Comparison of Nuclear Blast Wave with LDFF Chamber Pressure Fall-Off With Time.

or room downstream from the opening was large enough that its presence did not affect the flow through the opening. Pressure in the chamber was implicitly assumed to be ambient pressure. A far more common situation, however, is one in which a room's limited size very definitely influences inflow.

In the case of a blast wave striking a building, the shock wave that enters an opening (a window in a room, for example) will spread out (diffract) immediately after passing into the room, and will reflect and re-reflect from the side and back walls of the room, and from its ceiling and floor. The overall effect of these complex interactions is to raise the general pressure in the room (the process is appropriately called "room filling"). If there is another opening in the room, this pressure increase will result in outflow through that opening.

If the blast wave is long enough these complex reflections and refraction processes will dissipate, and a generally steady (or quasi-steady) flow condition will establish itself. Flow will not be uniform in the room, tending to be high near the entrance and exit, low in the corners removed from these openings, and with the possibility of strong eddies forming, but the flow pattern will stabilize.

In the case of the LDFF, similar processes take place, except for the initial effects of the finite time taken for the shutters to be pushed open by the compression chamber pressure. Flow, however, enters the room, and in its own complex way fills it until generally steady (or quasi-steady) conditions are established just as they are from a blast wave.

Thus, air flow in the LDFF test room is similar to the air flow that would be generated by a long duration blast wave after reflections within the room had died out. Some blast wave phenomena -- such as the very high inflow velocities (jets) that are generated by long lasting reflected or stagnation pressures -- manifest themselves most strongly after shock wave reflection processes are well underway. The only way to study the effects of these phenomena is in a facility such as the LDFF that can generate flows similar to those from megaton range weapon.

In earlier blast-fire interaction tests most of the information acquired was on the effect of the shock wave and its accompanying flows.* The test program described in this report was specifically designed to acquire information on the effects of later, high velocity flows, both in blast-fire interaction situations (i.e. in rooms where fires have started), and in other situations -- specifically in an Emergency Operating Center (EOC) -- where the very high velocities themselves can cause damage. It is just these situations that can be examined in the LDFF.

* With a window that occupied only 14% of the wall, there was evidence of a jet formation fairly late in the blast wave pulses (the duration of which were about 0.1 sec). (Ref. 2)

Section 3

TEST PROGRAM

Section 3

TEST PROGRAM

GENERAL TEST DESIGN

A basic element of blast-fire interaction test design is the type of facility to be tested. Previous tests had emphasized residential facilities, with tests being made in simulated living rooms and bedrooms (Ref. 2,3), and additional tests being made using mattresses (Ref 4). For this program, an examination was made of the characteristics of the present inventory of fallout shelter spaces (Ref 7). This examination indicated that NFSS use classes of commercial, educational, and government and public service each accounted for more spaces than did the residential use class. Therefore, in designing this program, greater emphasis was placed on non-residential facilities.

The room configurations decided on included an office, a classroom, a clothing store, a warehouse, and a living room. Additional tests were conducted to investigate extinguishment of confined fuels, and two non blast-fire tests were conducted using typical Emergency Operating Center (EOC) configurations.

For each test (except those of the EOC configurations) furniture and other combustibles in the room were ignited with an array of propane flames that were played on the combustibles for a period of about twenty to sixty seconds. After a time delay equivalent to the delay between the arrival of the thermal and blast pulses from bursts of low megaton range weapons, the shutters were opened. Subsequent phenomena in the room were photographed with the two high speed cameras, one located at the rear of the room and pointed toward the shutters, and a second located in the side wall furthest from the doorway and pointed across the room. A Tyco (strain gauge type) pressure gauge was located on the side wall near the camera port, and a Kistler (piezoelectric) pressure gauge was located in the center of the solid portion of the rear wall. A leaf switch was located near the doorway, and for certain tests, an anemometer was placed in various places in the room. Camera port and gauge locations are shown on Fig. 3-1.

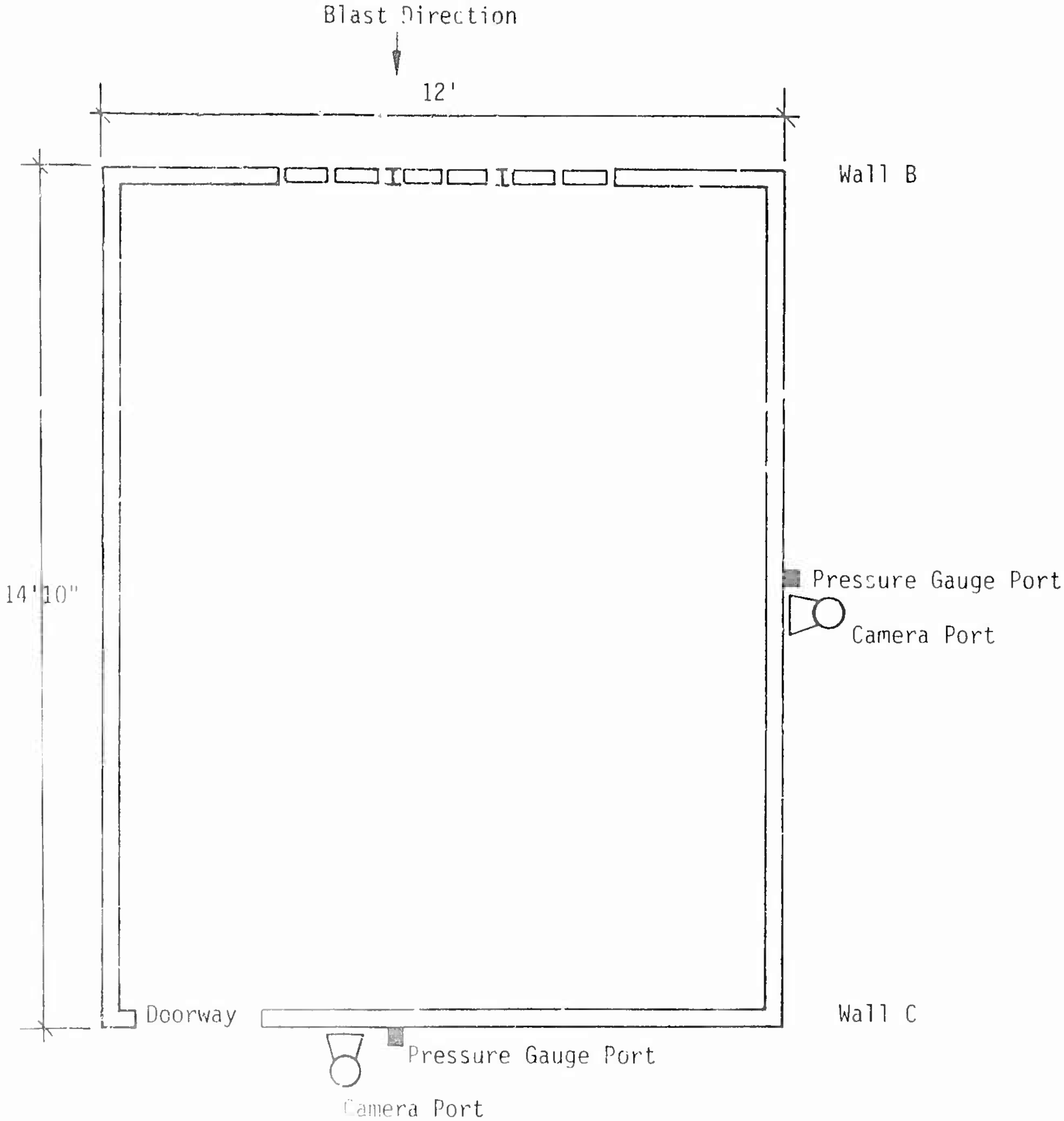


Fig. 3-1. Sketch of Room Geometry.

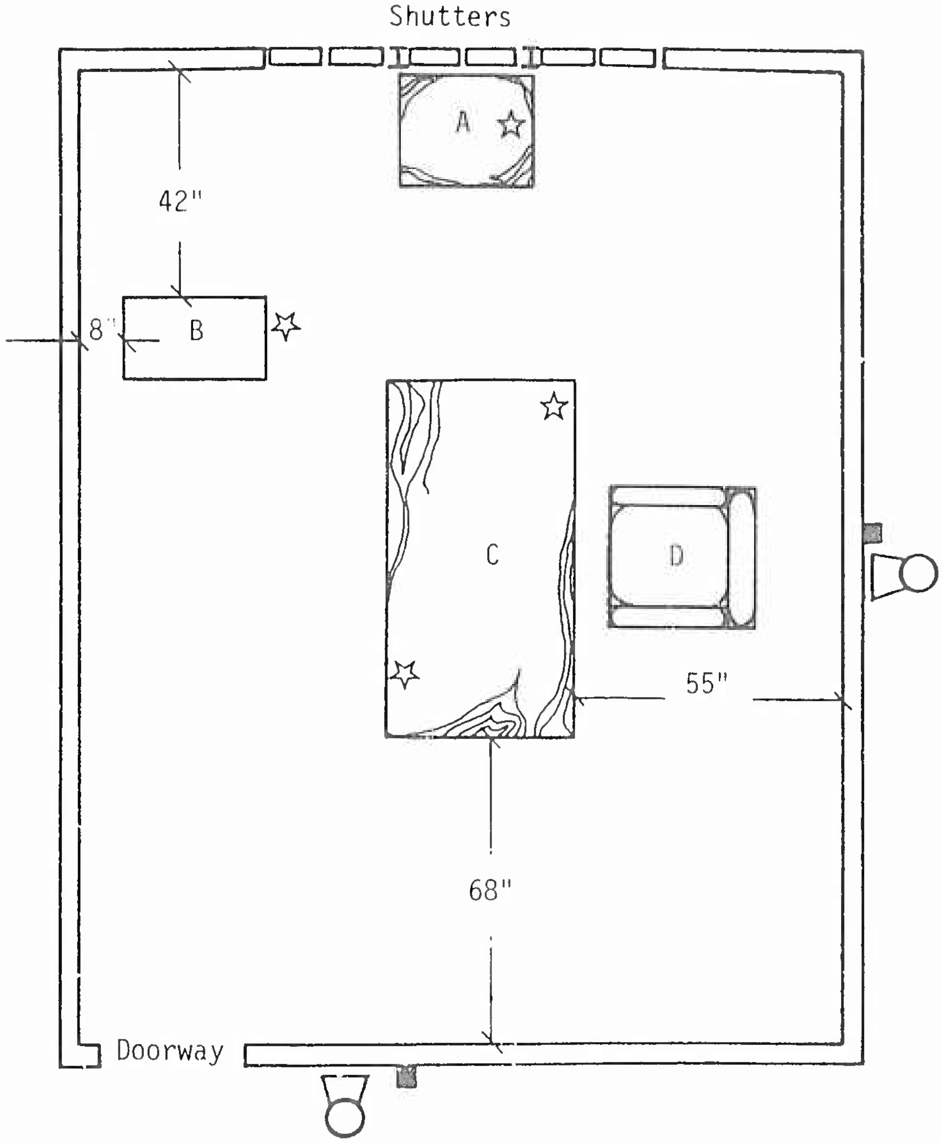
SUMMARY OF TEST RESULTS

Office Geometry Tests

Four tests (Numbers 1 through 4) were conducted with the office geometry shown in Fig. 3-2. Before the tests, papers were scattered about on the desk and in the drawers of the filing cabinet, as shown in Fig. 3-3, and books were placed on the book table. The combustible materials were ignited with ignition sources such as those shown in Fig. 3-3.

Three of the tests had compression chamber pressures of about 2.2 psi and the other a pressure of about 4 psi. Shutter openings were 14 ft^2 and 21 ft^2 for the 2.2 psi tests, and 21 ft^2 for the 4 psi test. With these openings, flow velocities through the front window and rear doorway for the 2.2 psi tests were predicted to be between 340 ft/sec and 400 ft/sec. and for the 4 psi test, about 470 ft/sec.

In all cases, all fires were extinguished. Considerable rearrangement and breakage of the furniture took place, more with the 14 ft^2 opening than with the 21 ft^2 opening, see Fig. 3-4. Some papers were ejected from the room.



A - 24 x 22 in. table with books

B - 26 x 14 in. four drawer file cabinet

C - 34 x 60 in. wood desk

D - chair with steel frame and plastic cushions

☆ Ignition sources

Fig. 3-2. Sketch of Test Geometry, Test Number 3

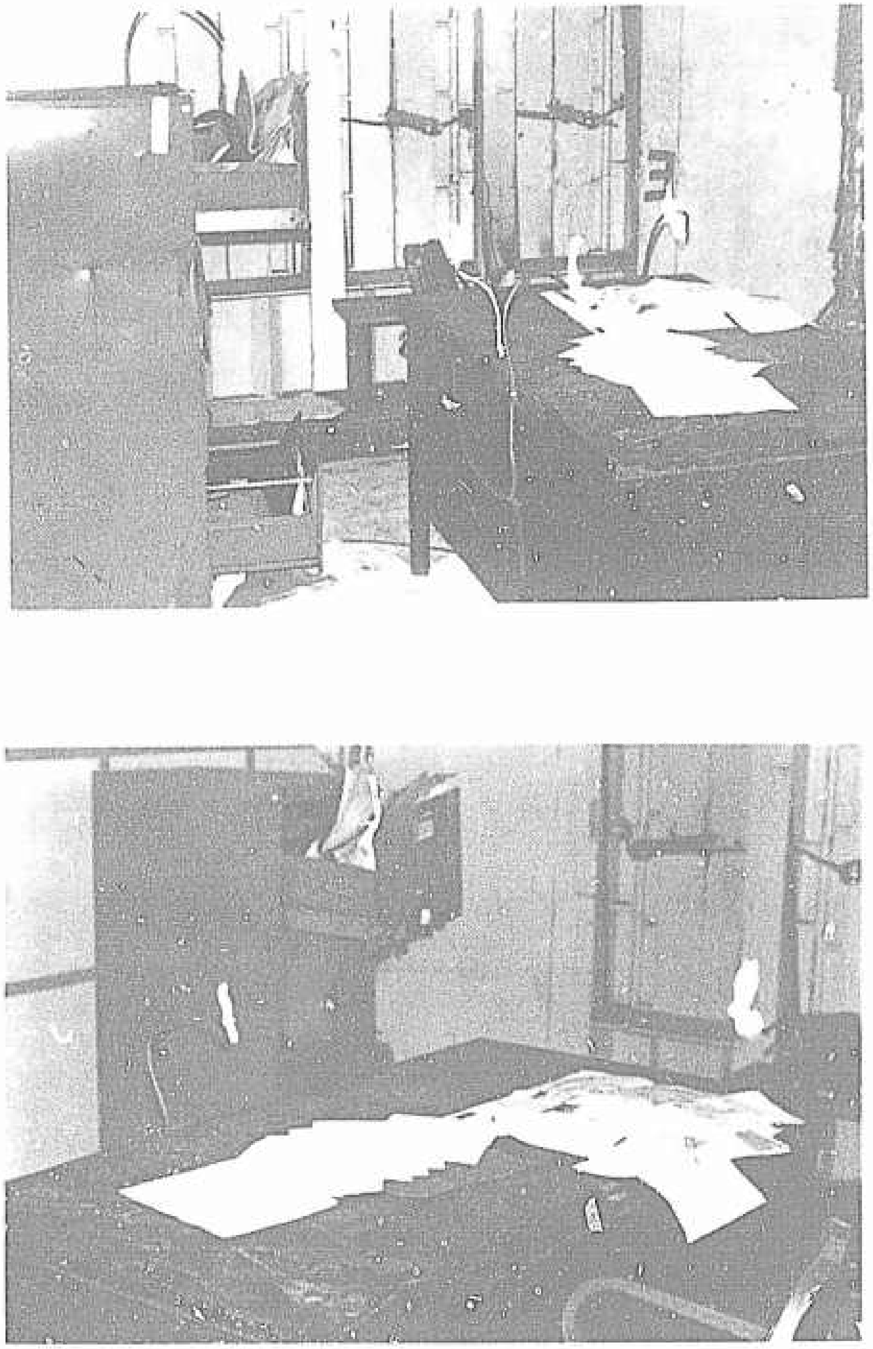
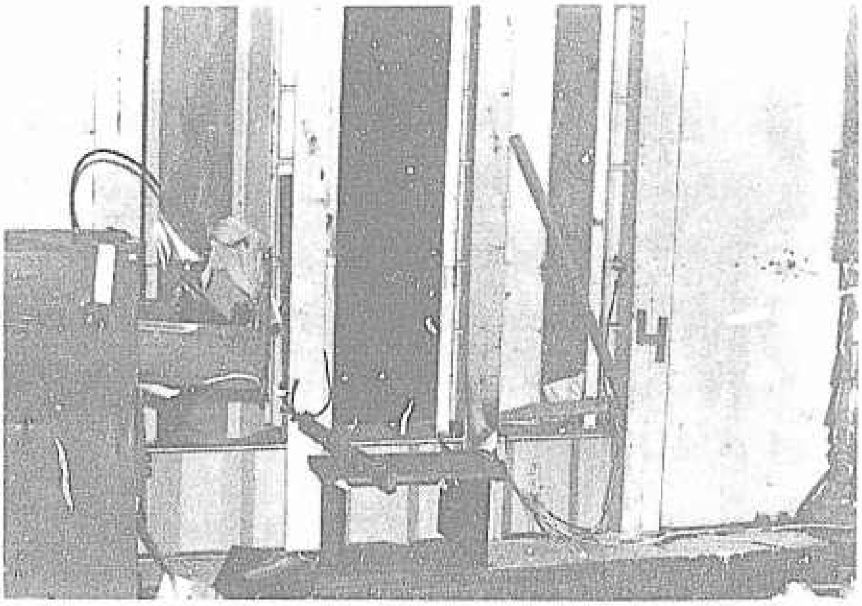


Fig. 3-3. Pretest Photographs, Test Number 3.



A

B

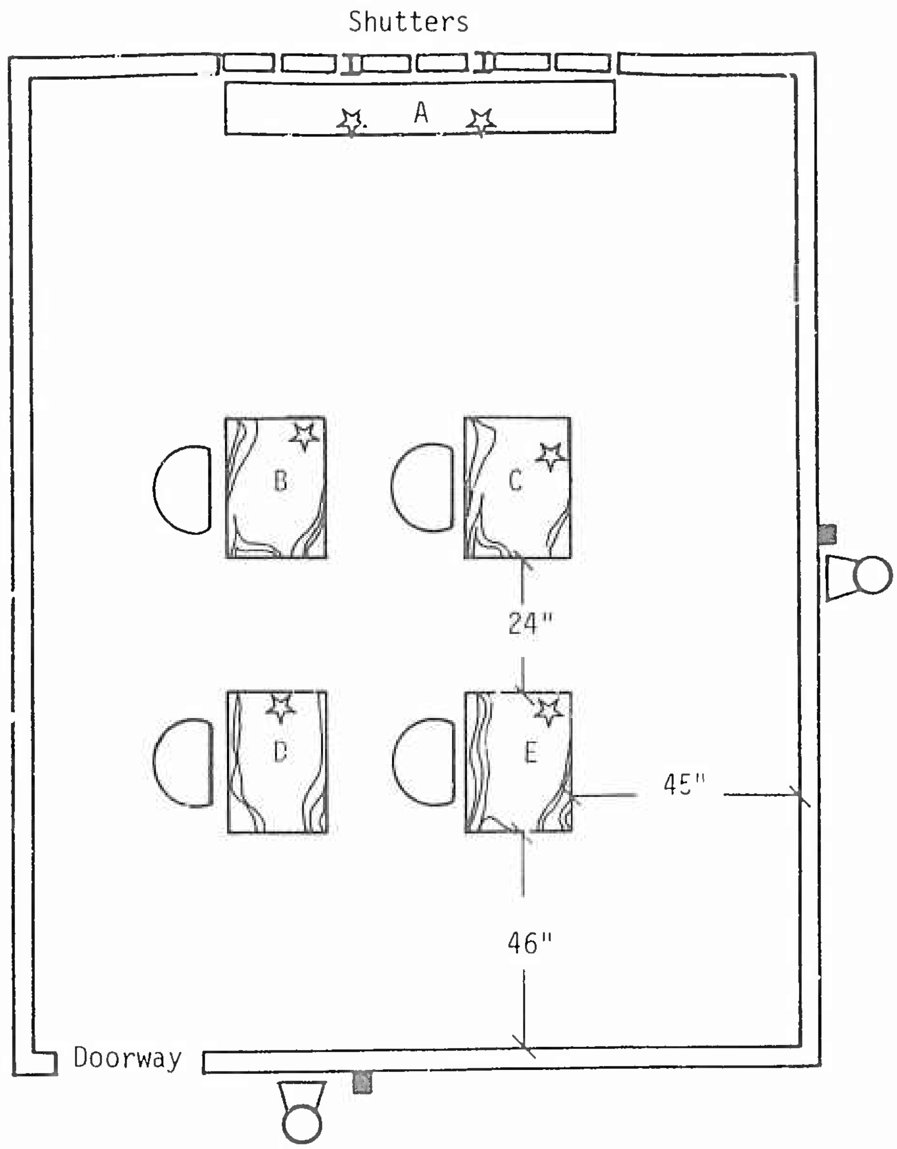
Fig. 3-4. Posttest Photographs, Test Number 4.

Classroom Geometry Tests

Two tests (Numbers 5 and 12) were conducted with geometries similar to that shown in Fig. 3-5. Before the tests, papers were scattered about on the four desks, and an open book was placed on the window sill, as shown in Fig. 3-6. The ignition sources also shown in Fig. 3-6 were used to ignite the papers.

Both tests had an initial compression chamber pressure of about 2 psi, and after a delay time of 54 seconds, all three shutters were opened, which resulted in a window opening of 21 ft^2.

In both cases, all fires were extinguished. One desk tipped over on Test 5, none on Test 12. The desks that did not tip over were moved, but not a great deal, (see Fig. 3-7).

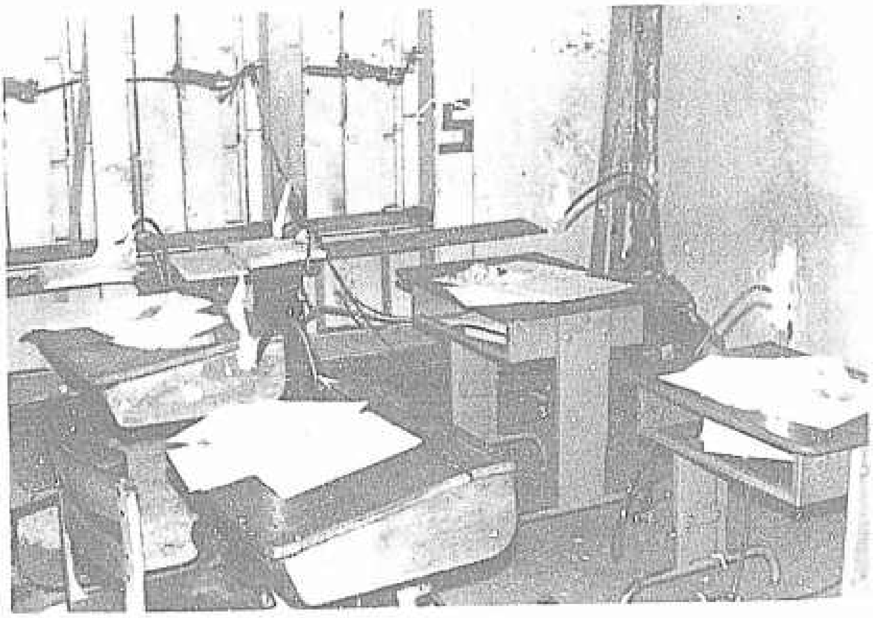


A - 12 x 60 in. shelf

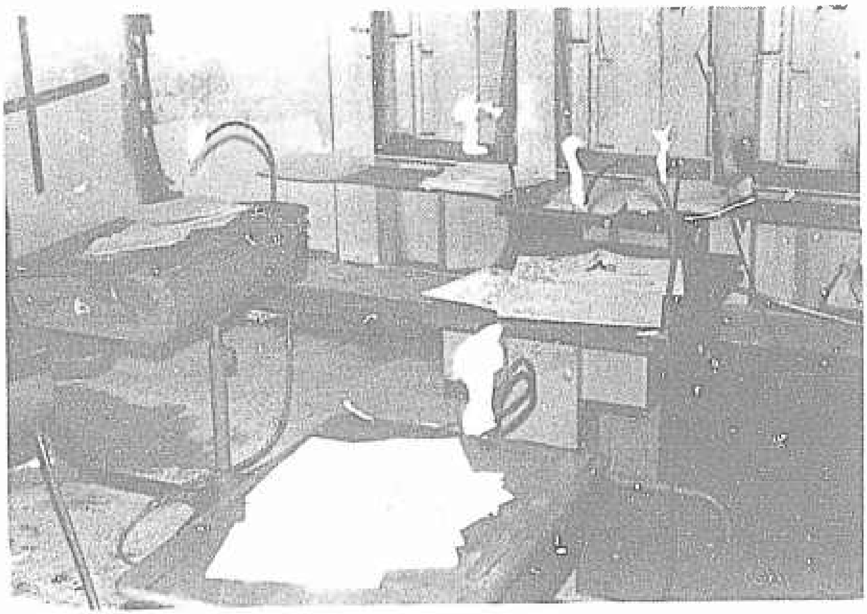
B, C, D, & E - 23 x 18 in. school desks

☆ Ignition sources

Fig. 3-5. Sketch of Test Geometry, Test Number 5

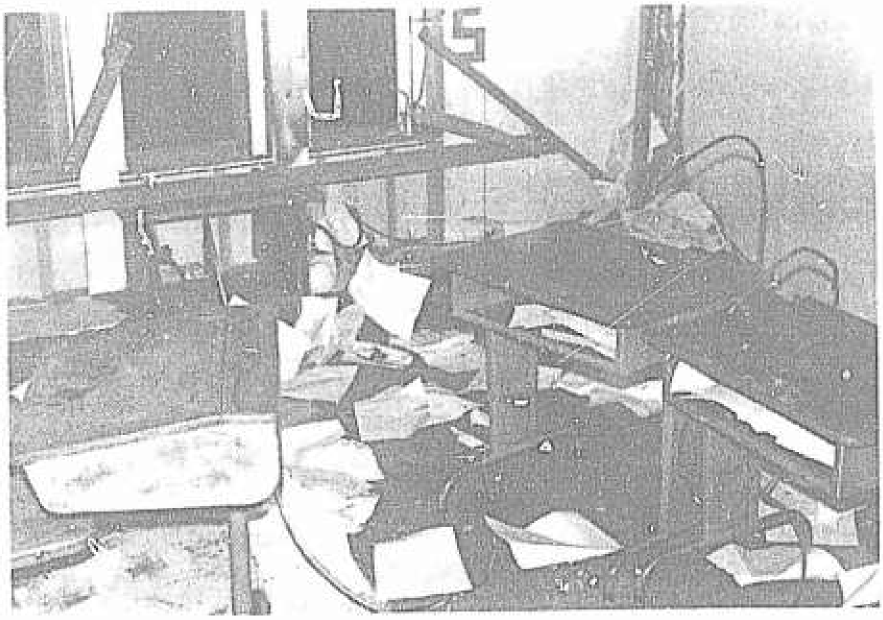


A

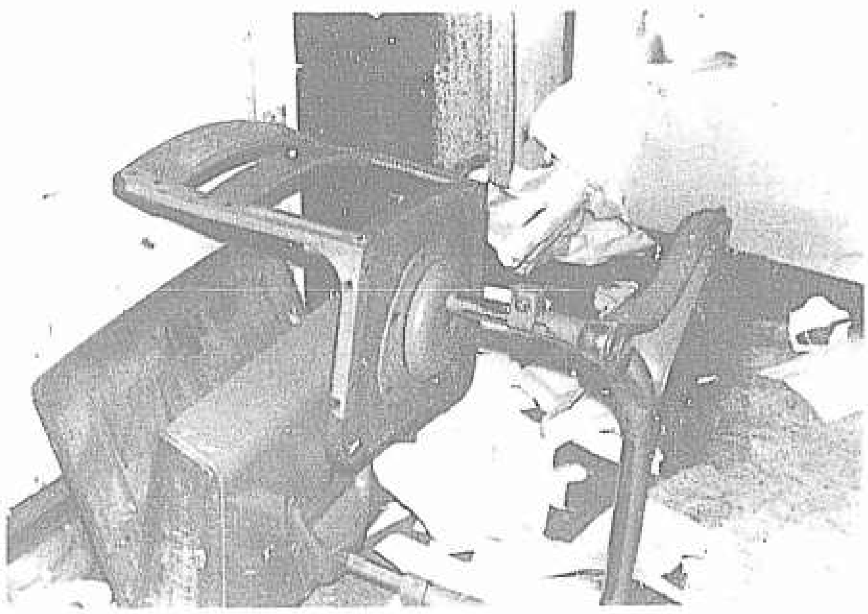


B

Fig. 3-6. Pretest Photographs, Test Number 5.



A



B

Fig. 3-7. Posttest Photographs, Test Number 5.

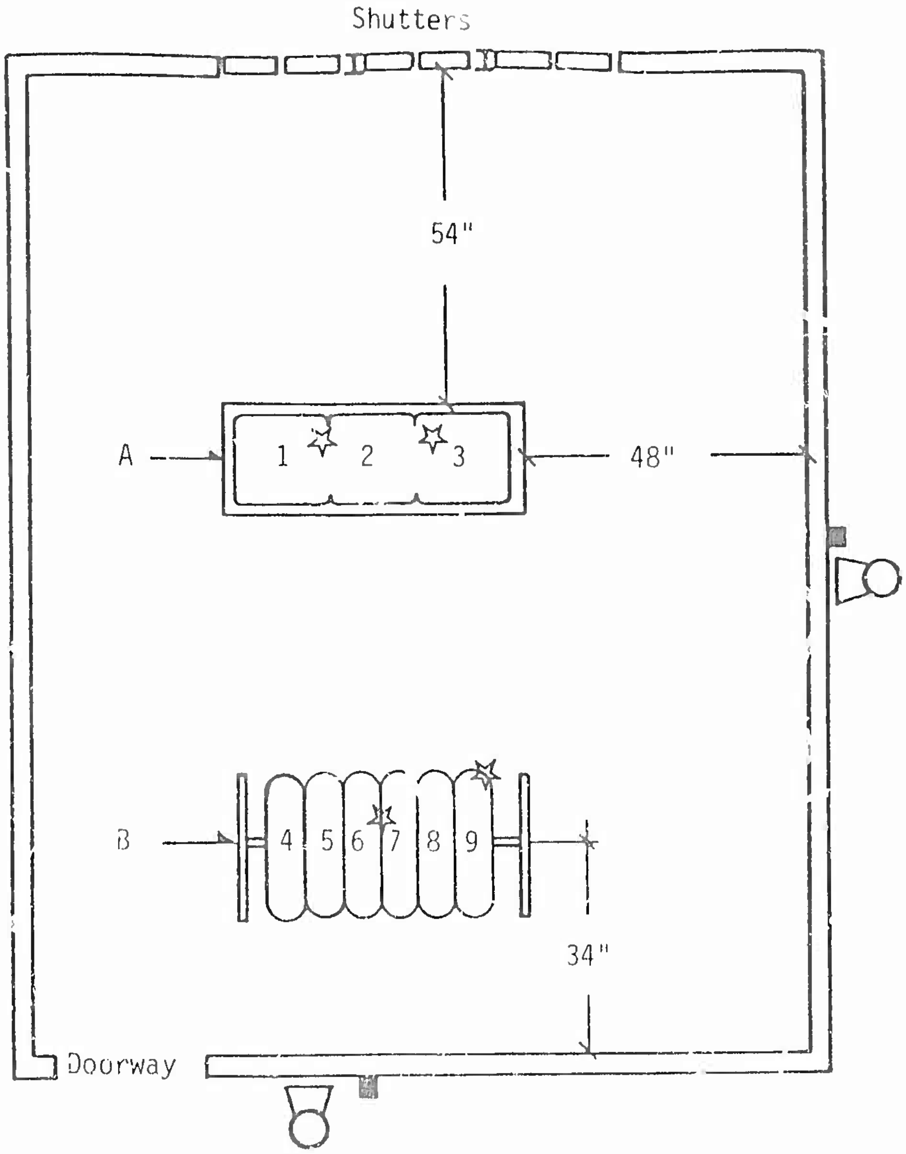
Clothing Store Geometry Tests

Three tests (Numbers 6, 11, and 15) were conducted with geometries similar to that shown in Fig. 3-8. Folded pieces of terry cloth, muslin, denim, and duck were placed on a table upstream from a clothing rack from which pieces of similar cloth were hung. Overall views of one of the simulated stores are shown in Fig. 3-9.

All three shutters were opened for each test (window openings of 21 ft^2). Initial compression chamber pressures were increased from 2 psi, to 4 psi, to 5.75 psi; predicted velocities (through either window or doorway) for these initial conditions were about 350, 470, 570 ft/sec respectively. Delay times for the first two tests were 54 seconds and 27 seconds, respectively, but the third test was fired with no delay time (about 7 seconds was planned) because of shutter closure failure.

In all three tests, most of the cloth material was ejected from the room (Fig. 3-10) and scattered up to 100 ft from the doorway. In the first test, the clothes rack was dismantled and the tables tipped over. In the higher pressure tests, physical damage was great; tables and clothing racks were virtually destroyed, as can be seen in Fig. 3-10.

All flames were extinguished in all three tests, but smouldering combustion continued in some places. After the 2 psi chamber pressure test, a number of pieces of cloth outside the doorway were still smouldering and burst into flame after some 10 minutes had elapsed. After both 4 psi and 6 psi chamber pressure tests both flames <u>and</u> smouldering combustion were extinguished in the pieces of cloth that were ejected from the room (which constituted most of those that were originally in the simulated stores). In each case, however, one still smouldering piece was deposited directly beneath the window opening where after about five minutes it burst into flame.



A - 5- x 18 in. table

B - 49 in. long, 60 in. high clothes rack

1 - terry cloth

2 - denim

3 - mixed duck and muslin

4, 7, & 8 - muslin

5, 6, & 9 - duck

☆ Ignition sources

Fig. 3-8. Sketch of Test Geometry, Test Number 15

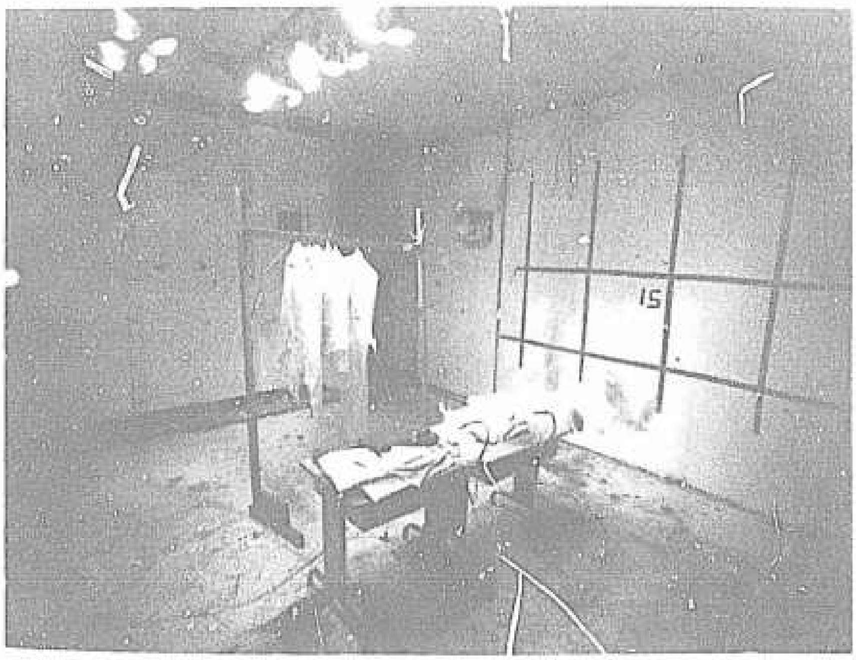


Fig. 3-9. Pretest Photographs, Test Number 15.

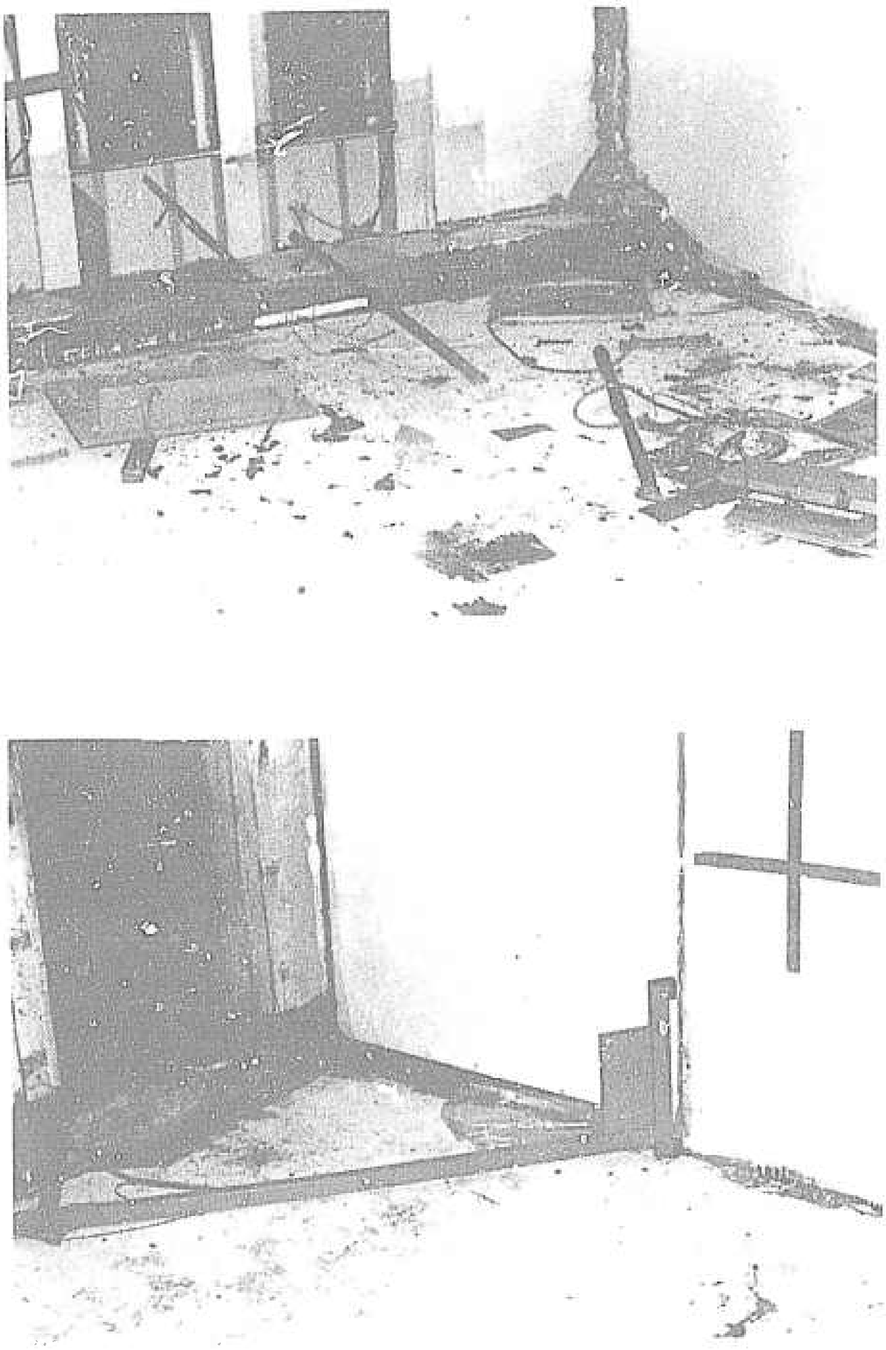


Fig. 3-10. Posttest Photographs, Test Number 11.

Warehouse Geometry Tests

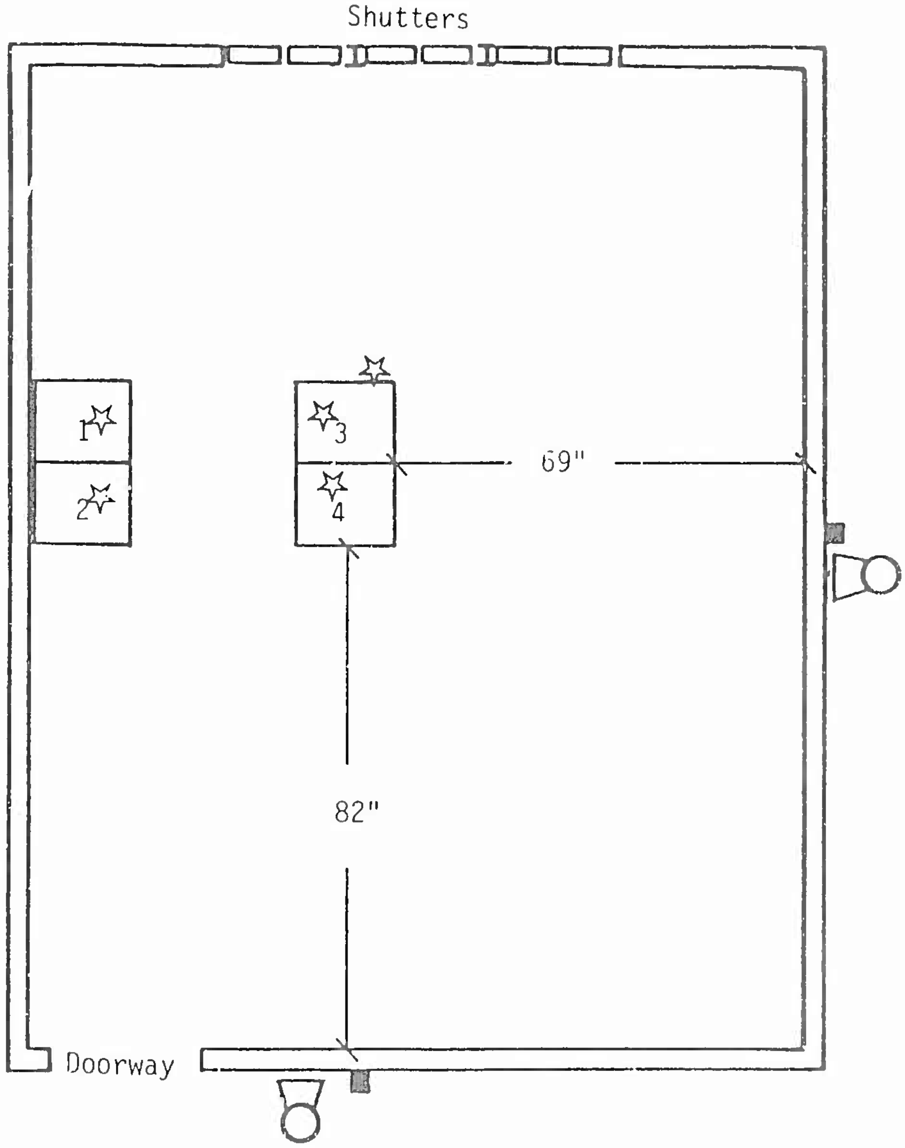
Five tests (Numbers 7, 13, 16, 18, and 20) were conducted in geometries generally similar to that shown in Fig. 3-11, with a stack of unweighted boxes in the center of the room and boxes weighted with lead blocks, along the side wall near the doorway. Both the central stack and a side box are shown in Fig. 3-12. In the last two tests, additional weighted boxes were placed near the other side wall and near the rear wall as well. In the first (low pressure) test, a small amount of crumpled paper was placed in all the boxes. In all the other tests, the top boxes in the central stack and those nearest the window contained large amounts of uncrumpled newspaper, and the boxes near the walls were entirely empty except for the lead weights.

All three shutters were opened for each test. One test was run with a compression chamber pressure of about 2 psi; two (13 and 18) with pressures of about 4 psi; and two (16 and 20) with pressures of about 6 psi. Thus the flow velocities through the window and doorway for these tests varied by almost a factor of two, from about 340 ft/sec to about 600 ft/sec. For the first three tests in the series, no problems were encountered with igniting the material with the propane sources such as those shown in Fig. 3-13. On shot 18, however, all boxes ignited early so that the fires were burning much more vigorously at the time of shock arrival than they were in the three preceding tests, and on the last shot (20) ignition appeared to be incomplete to that the fires were less vigorous than they were on any of the preceding tests.

In all cases, fires in the central stack of boxes were extinguished and remained so. Much of the material from this stack was ejected from the room through the doorway although a fair amount was scattered about the room, and especially in the corners near the front (window) wall as shown in the lower photograph of Fig. 3-13.

In contrast, on two of the tests, (both of those at 4 psi) flames were observed in the weighted boxes along the side wall near the doorway immediately after the shot (within 30 seconds), as can be seen in the upper photograph of Fig. 3- 13. On two of the other tests (Number 7 at 2 psi and Number 16 at 6 psi) flames were extinguished in these boxes, but they were still smouldering immediately after the test, and reignited within 10 minutes. On Test 16, the box near the other side wall was also smouldering immediately after the test, but the smouldering fire itself went out. The box near the rear wall on this test was ejected from the room, and all fires were extinguished.

On the last test of the series (Test 20) all fires were extinguished and none rekindled, but as noted earlier, ignition on this test was not complete, so its results must be discounted.



1 & 2 - 17 x 13 x 13 in. cardboard boxes

3 & 4 - 17 x 13 x 13 in. cardboard boxes (stacked three high)

☆ Ignition sources

Fig. 3-11. Sketch of Test Geometry, Test Number 13

Fig. 3-12. Pretest Photograph, Test Number 7.

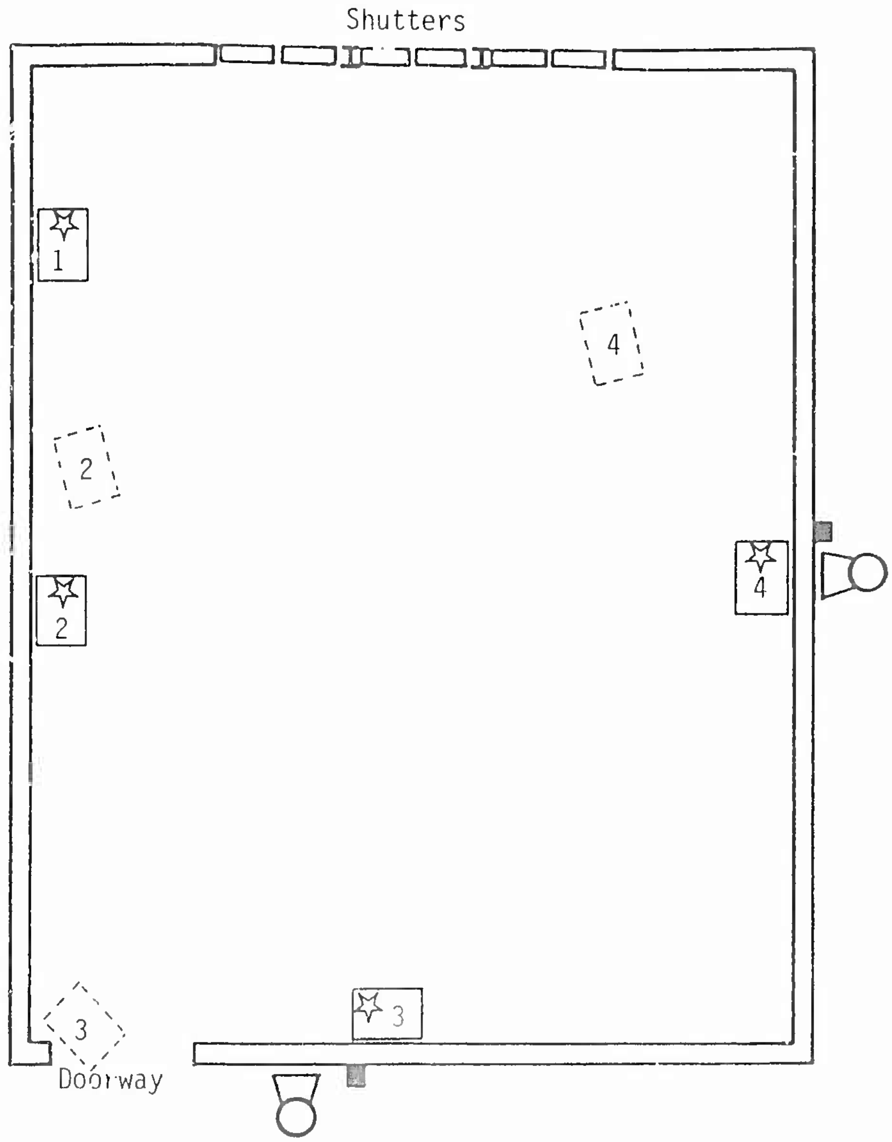
Fig. 3-13. Posttest Photographs, Test Number 16.

Confined Fuels Tests

In these two tests, (19 and 21) run to acquire information on the importance of fuel location on the ability of blast to extinguish fires, paper was placed in four cages placed along the two side walls and the rear wall as is shown in Fig. 3-14 and the photographs of Fig. 3-15, and ignited before blast wave arrival. (A similar, but smaller, cage was placed near the doorway on Test 16, basically a warehouse geometry.)

All three shutters were opened on the tests, and the compression chamber pressures were 2 psi (shot 19) and 5.5 psi (shot 21).

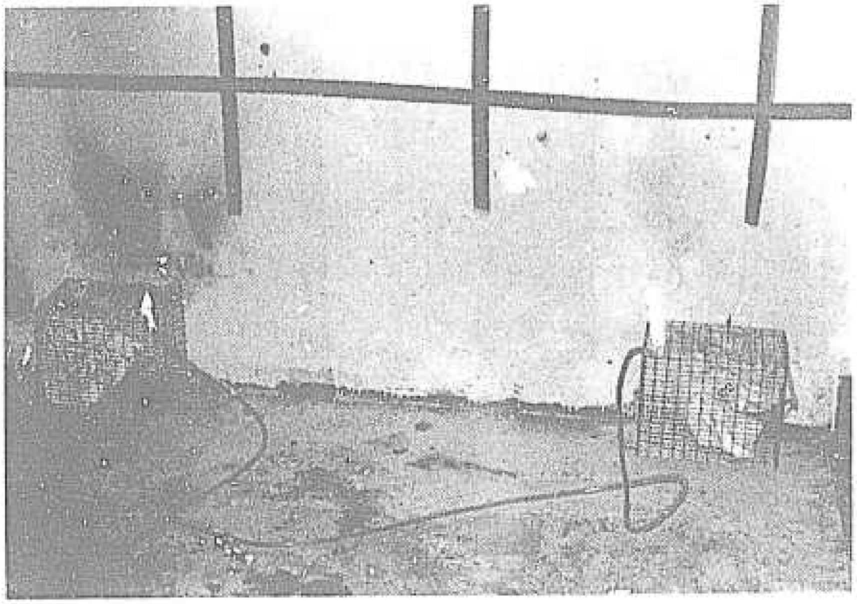
On both tests, the material in the cage nearest to the window along the side wall burned completely, even though flow velocities through the window ranged up to about 550 ft/sec. On Test 19 the material in the other cage near the same wall also burned completely as shown in Fig. 3-16. In all other cases, fires in the cages were extinguished and the cages were moved (see Figs. 3-14 and 3-16), indicating the presence of strong eddies and counter currents.



1, 2, 3, and 4 - 8.5 x 12.5 x 8 in. wire cages containing paper (dotted lines indicate posttest locations)

☆ Ignition sources

Fig. 3-14. Sketch of Test Geometry, Test Number 21



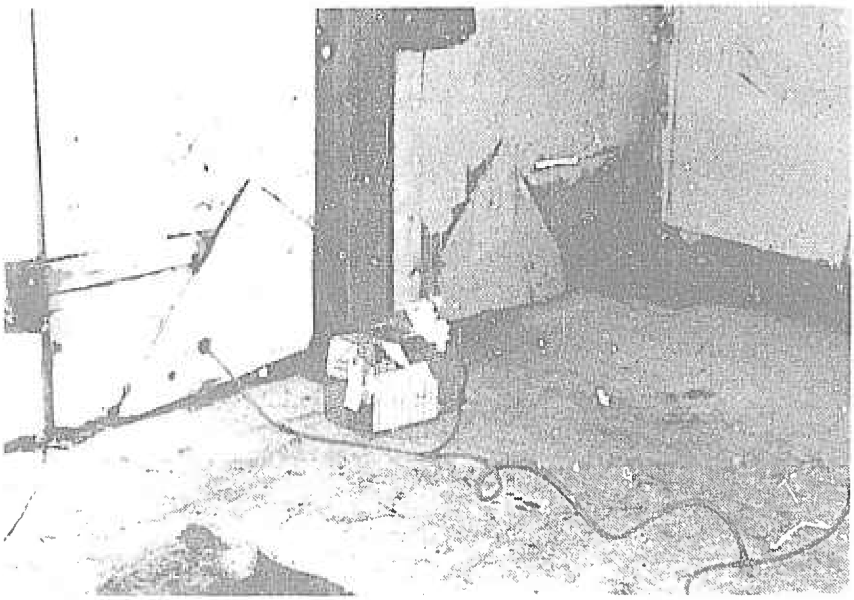


Fig. 3-15. Pretest Photographs, Test Number 19.

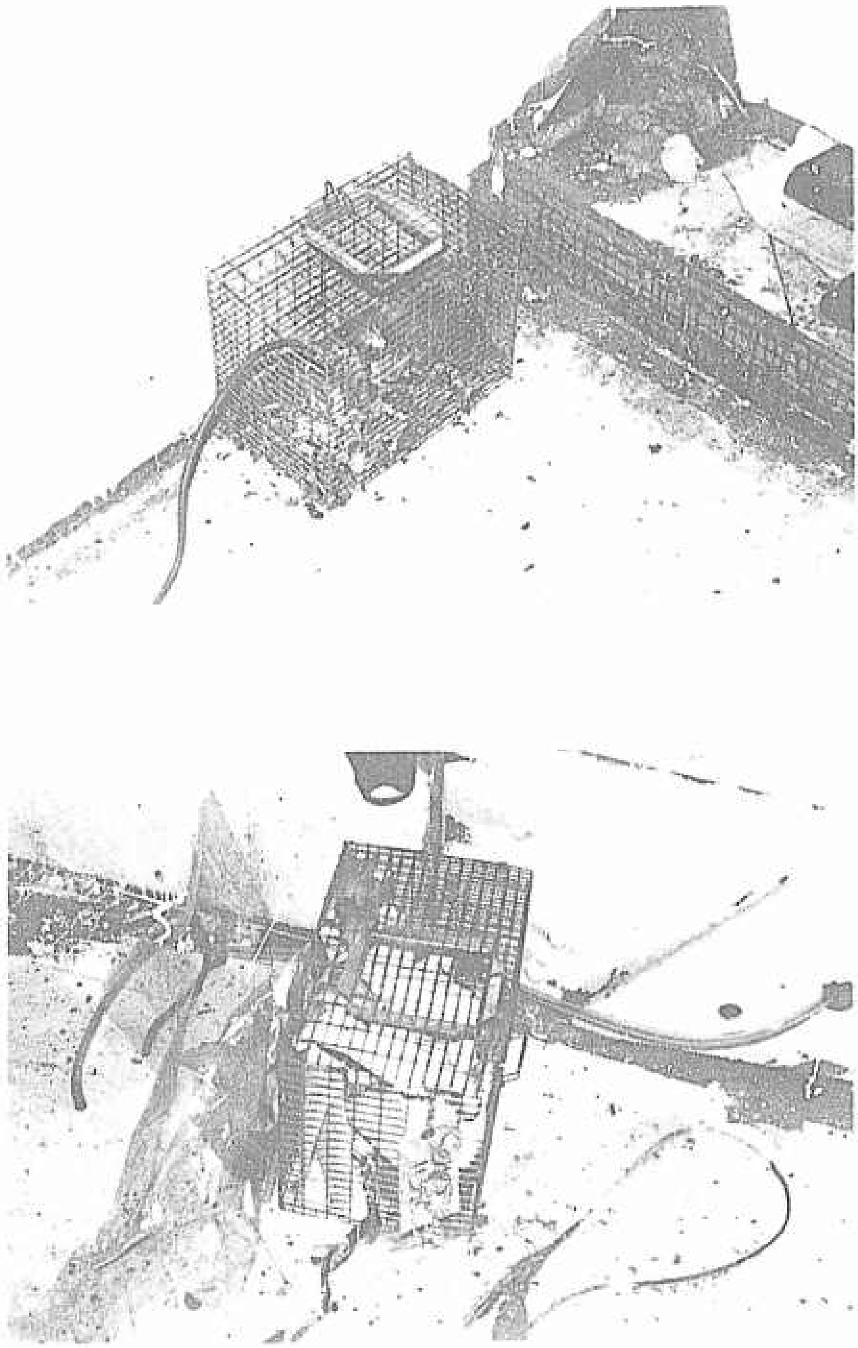


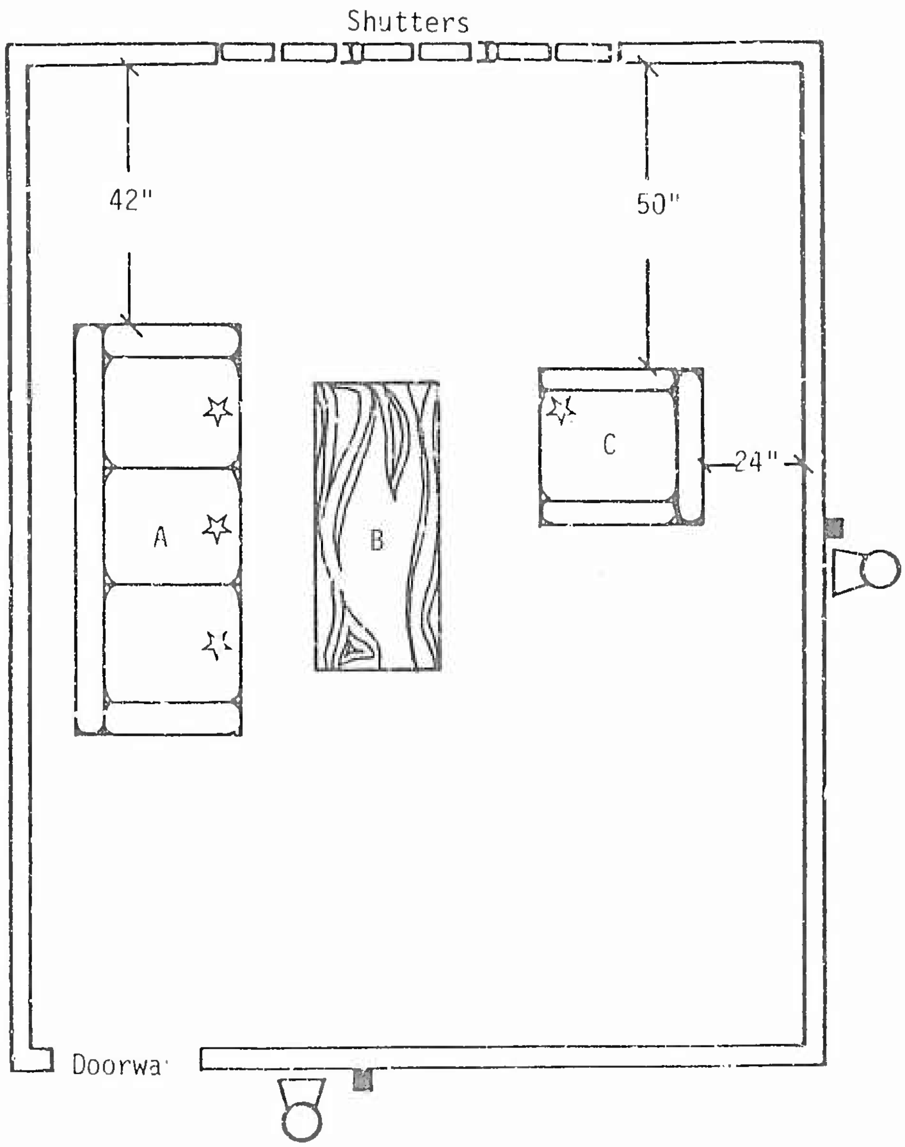
Fig. 3-16. Posttest Photographs, Test Number 19.

Living Room Geometry Tests

Three tests (Numbers 8 through 10) were attempted with living room geometries like those shown in Fig. 3-17, but only one (Number 10) was successful. (In Test 8, with a compression chamber pressure of about 2 psi, fires were not ignited; in Test 9 with a compression chamber pressure of about 4 psi, the shutters did not open, and all materials in the room, except the coffee table burned up.) The test rooms all had a wood frame couch with plastic covered cushions, a wooden coffee table, and a wood frame chair with plastic cushions. A pretest photograph (from Test 8) is shown in Fig. 3-18.

Compression chamber pressure on Test 10 was 3 psi, delay to a premature shutter opening was 27 seconds, and all 3 shutters opened (21 ft^2 window area). The predicted velocity through the room openings was about 400 ft/sec.

All fires were blown out and stayed out. As can be seen in Fig. 3-19, both the chair and table were broken. Most of the cushions were blown outside the room, and the cover and cushioning material were separated on those that were most severely burned.



A - 69 x 28 in. wood frame sofa with plastic cushions

B - 48 x 18 in. wood coffee table

C - 30 x 25 in. wood frame arm chair with plastic cushions

☆ Ignition sources

Fig. 3-17. Sketch of Test Geometry, Test Number 10

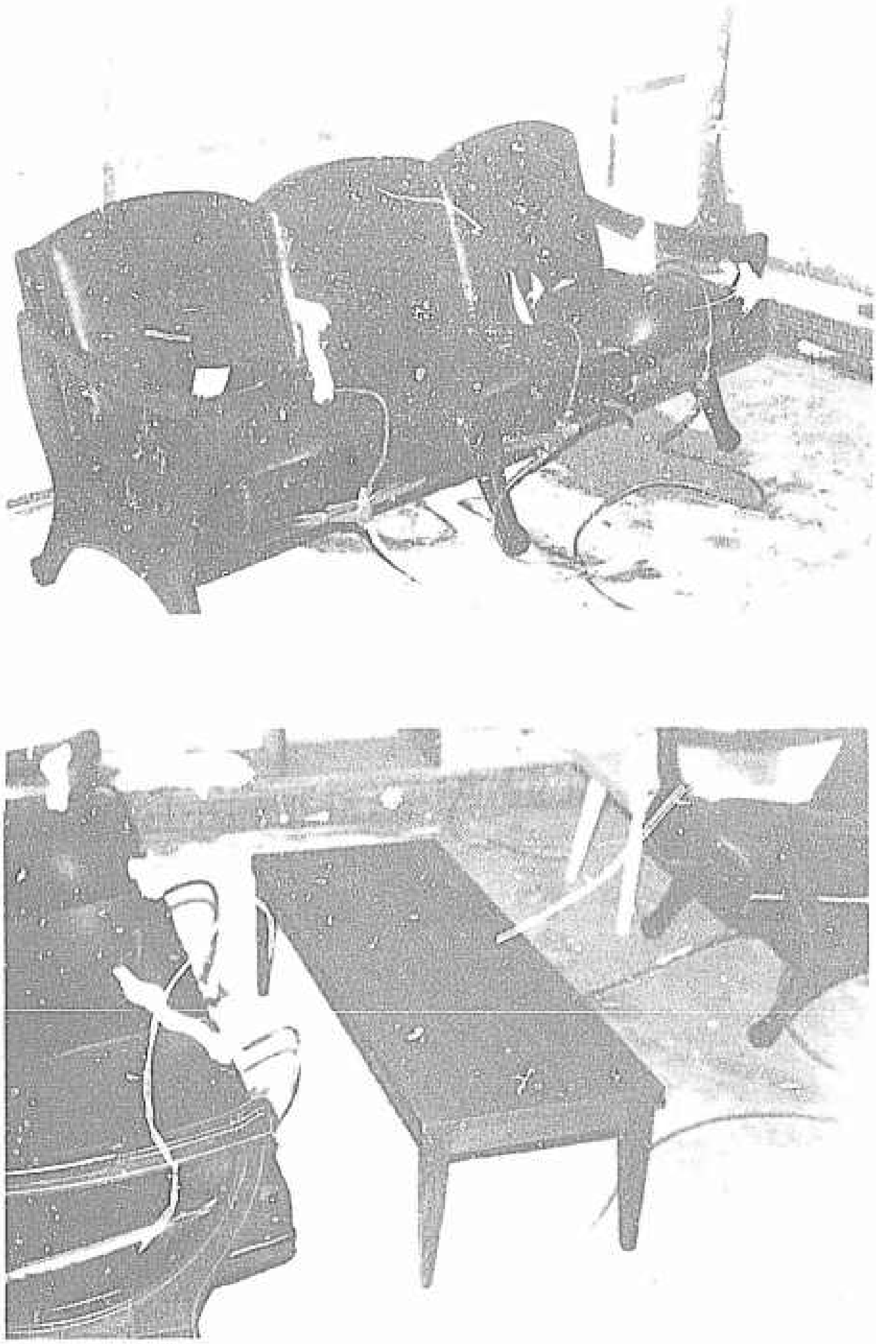


Fig. 3-18. Pretest Photographs, Test Number 8.

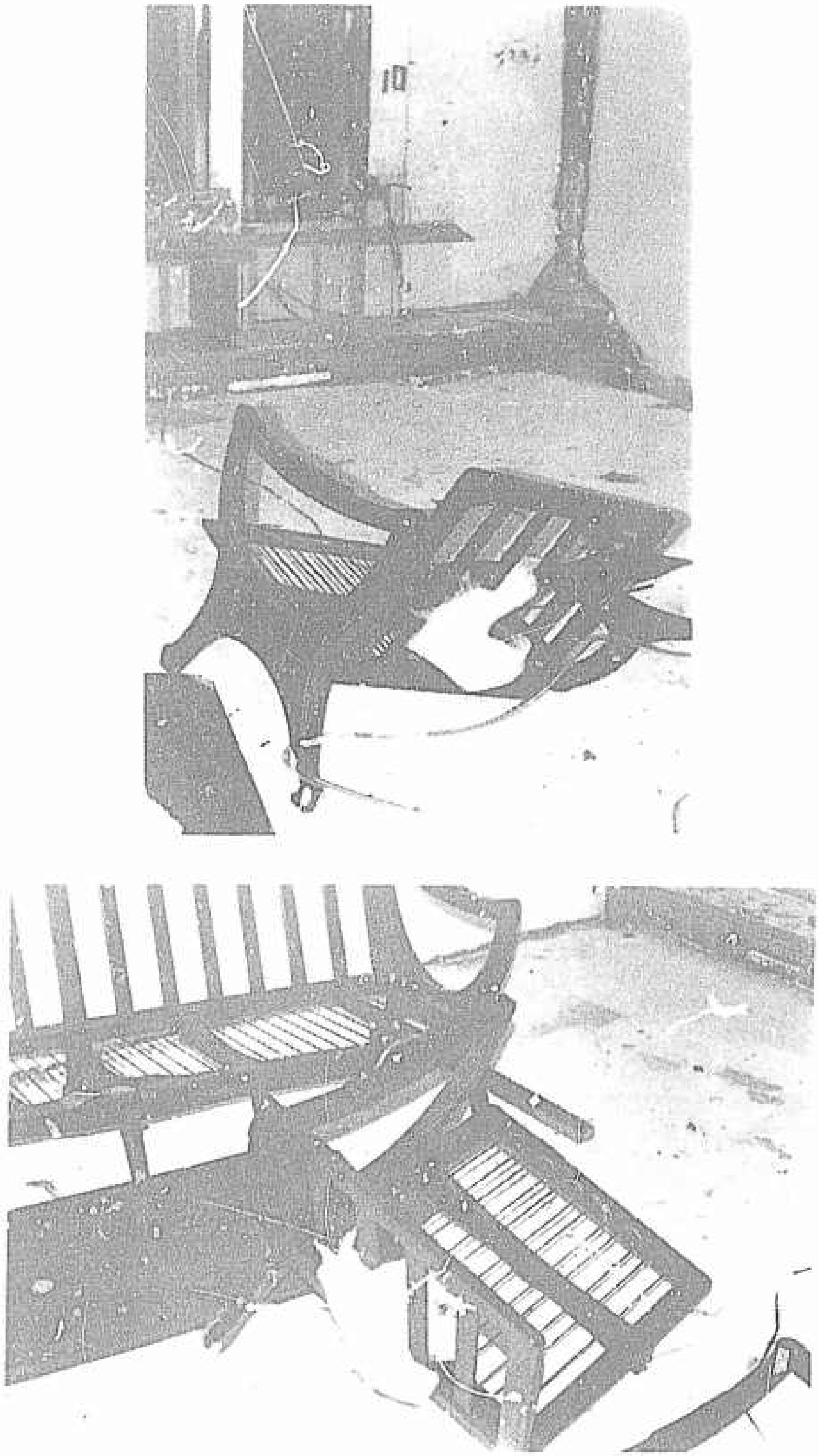
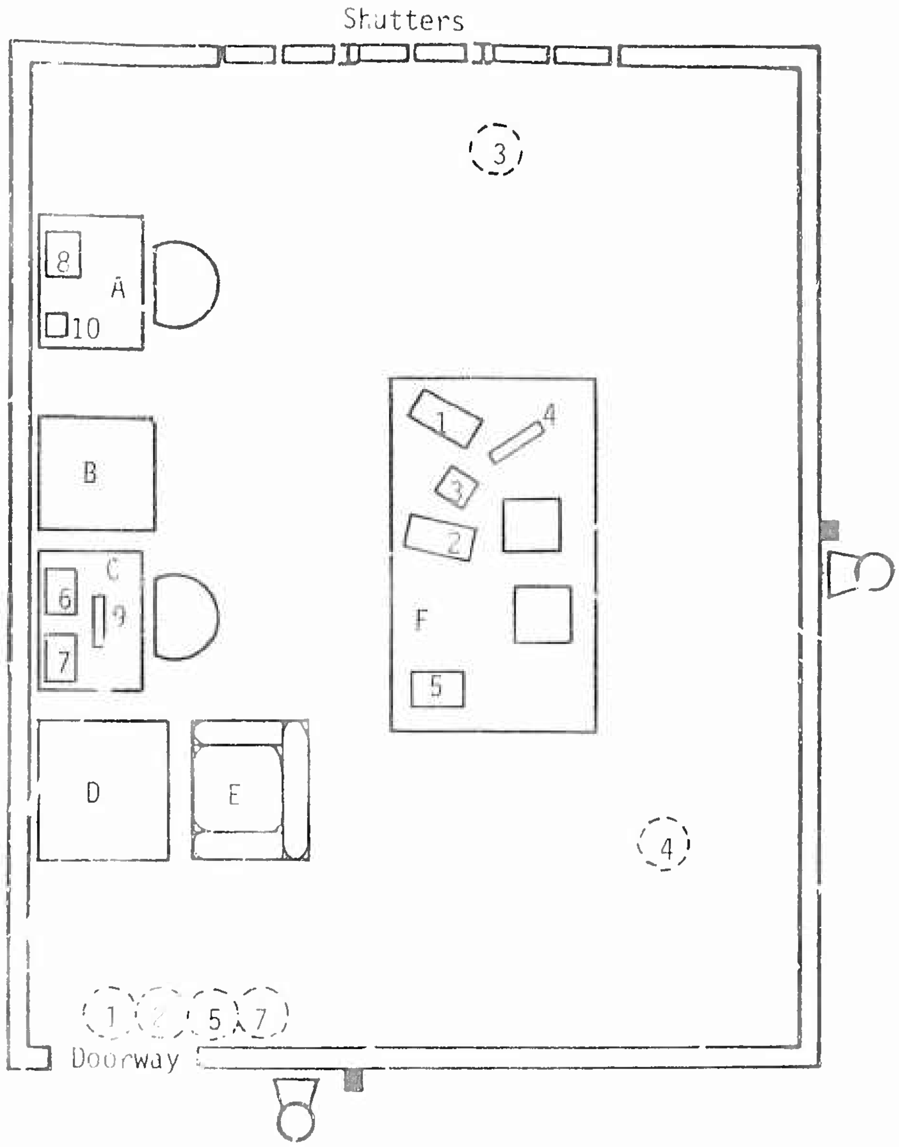


Fig. 3-19. Posttest Photographs, Test Number 10.

EOC Geometry Tests

In these two tests (Numbers 14 and 17) equipment and other materials typical of those in EOC's were placed in the LDFF test room. One of the arrangements adopted is sketched in Fig. 3-20, the other is shown in the photographs of Fig. 3-21. Compression chamber pressure was 4 psi in both cases, but three shutters were opened on Test 14, and two on Test 17. Thus flow velocities through the window were about 450 ft/sec and 550 ft/sec respectively.

While a few items of equipment located along the side wall near the window were undamaged after the first test, all equipment sustained some damage as a result of the second test (only one item was still operable) and much was ejected through the doorway as shown in Fig. 3-22. Refer to the individual test reports for additional information on particular items of equipment.



A & C - 23 x 18 in. school desk

B - 20 x 20 x 84 in. relay rack

D - 2? x 24 x 27 in. teletype

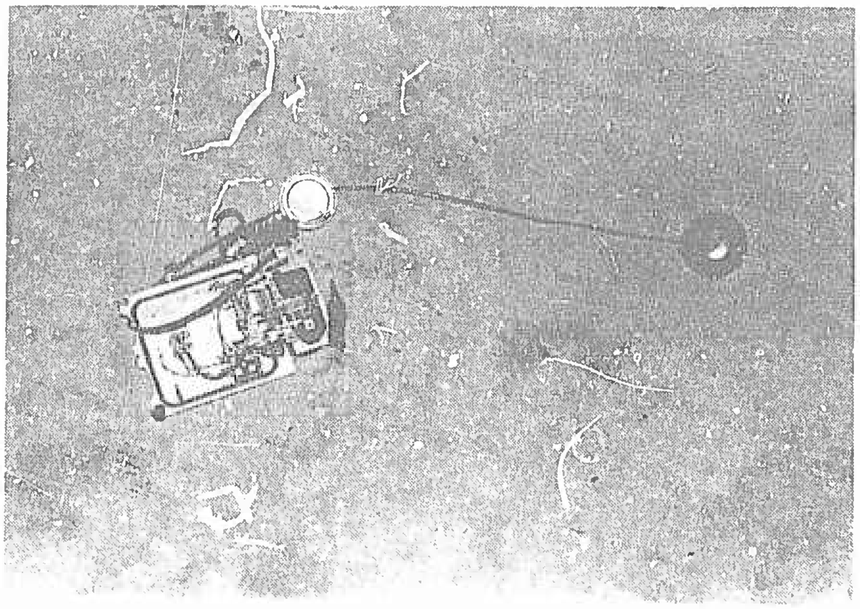
E - steel frame chair with plastic cushions

F - 34 x 60 in. wood desk

Note: For descriptions of equipment 1 through 8 see text of test report. Numbers in dotted circles indicate posttest locations.

Fig. 3-20. Sketch of Test Geometry, Test Number 14

Fig. 3-21. Pretest Photographs, Test Number 17.



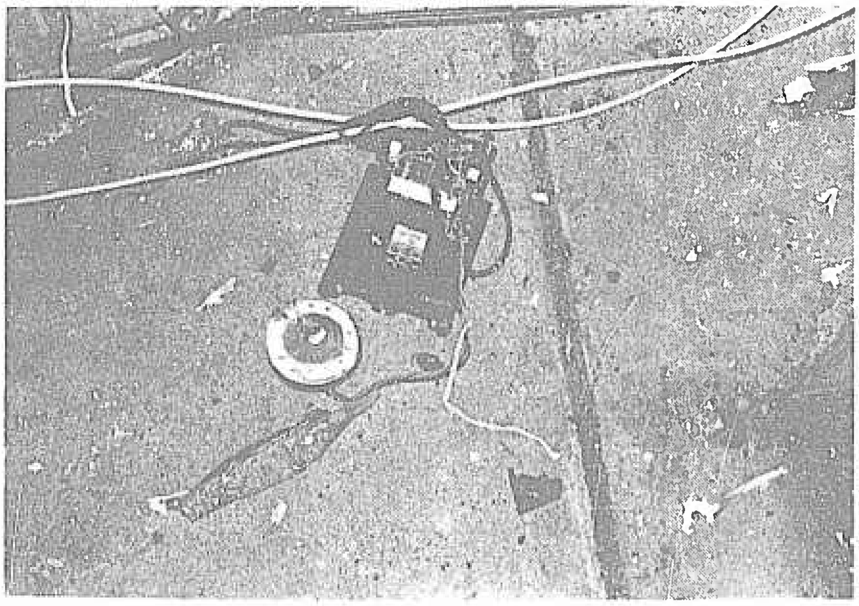


Fig. 3-22. Posttest Photographs, Test Number 17.

ANALYSIS AND CONCLUSIONS FROM BLAST-FIRE TESTS

It is clear from the material in Section 2, that the blast-fire test program in the LDFF is, in essence, an examination of the effect on room fires of the part of a blast wave that controls flow into a room _after_ all effects of the sharp shock front have been dissipated. Air flow caused by the LDFF has no such sharp front; it rises to a quasi-steady value after the shutters are opened. This can be seen in Fig. 2-23, a typical trace of the first part of a pressure vs time signal from the side wall gauge.

In contrast, Goodale's earlier blast-fire tests (Ref. 2, 3, and 4) can be thought of as emphasizing the shock front effects. Although the times between the end of the thermal ignition phase and the arrival of a blast wave in the earlier tests were characteristic of megaton range weapons, the blast pulses themselves had total durations (∿100 msec) similar to those from weapons smaller than about 0.05 kT. Indeed, the total pulse durations in the earlier tests were of the same order as the rise time (∿100 msec) of flow in the LDFF. A typical pulse from the earlier tests has been superimposed on Fig. 3-23.

The two programs thus complement each other, with Goodale's dealing with effects of the "front end" of a blast wave (i.e principally shock wave effects), and the LDFF program dealing with effects of the "back end" of a blast wave. In that sense, the results of the two programs could be thought of as additive, that is, effects observed in the LDFF would take

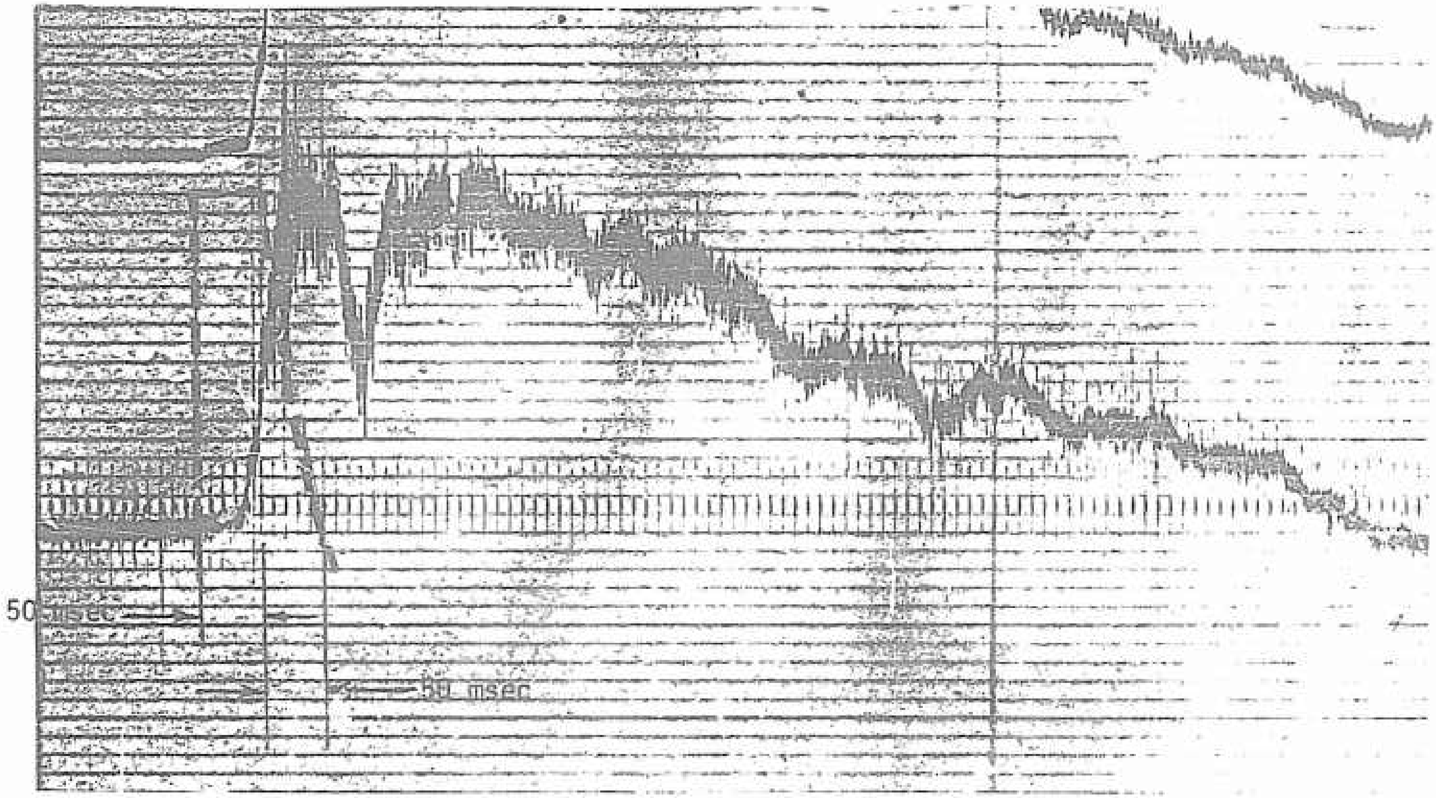


Fig. 3-23. Typical Trace From Sidewall Gauge in LDFF Test Room. Dashed line is typical short duration pulse from earlier blast-fire test program.

place in addition to those observed in the earlier tests, because they would occur later.

With these considerations in mind, the combined results to date of the two programs can be summarized in the following manner.

Goodale found that blast waves with incident overpressures of about 2.5 psi and above extinguished all flames, although substances capable of sustaining smouldering combustion tended to continue to smoulder and could reignite. He also found that, in general, the placement of the burning elements in a room was not especially critical. (This is because a shock wave immediately spreads out after passing through an opening and quickly extends from wall to wall in a room.)

In the LDFF, the test results, summarized in Section 3, indicate that air flow from a compression chamber pressure of 2 psi* extinguished all flames in materials located in regions of high flow velocity (either from direct flow through the room or from strong eddies). In addition, in these regions of high flow velocity, even smouldering combustion was virtually eliminated in the lighter materials (cloth, cardboard, etc.) that could sustain smouldering combustion. (All fires were extinguished in the centrally placed materials in the warehouse geometries, and in the clothing store geometries, only pieces of cloth directly under the window even

* For reasons discussed in Section 2, it is generally conservative to equate LDFF compression chamber pressure to incident blast wave overpressure. Pressures from blast waves outside an opening in a building would frequently be higher than incident pressures and would not be lower.

smouldered.) Smouldering fires in heavier materials (mattress fillings,* intact stacks of paper, etc.) were not extinguished.

The LDFF tests also showed, however, that the location of materials in a room could be critical. Some areas experienced very low flow velocities, so low, in fact, that even flames in crumpled newspapers (as in the confined fuel tests) were not extinguished. These areas tended to be along the side walls of the room, and near the front (window) wall opening.

Thus, for fuels not capable of sustaining smouldering combustion, (minor fuels) the LDFF results tended to confirm and strengthen Goodale's conclusions and lowered the experimentally observed threshold from 2.5 psi to 2 psi. (In his analysis, Goodale assumed the threshold to be 2 psi.) For these fuels, Goodale concluded that all fires would be extinguished by the shock front. The LDFF results indicated that if any escaped such extinguishment there would be high probability that later blast wave flows would complete the job, although some located in very low velocity regions might not be extinguished.

The more important LDFF results, however, relate to materials capable of sustaining smouldering ignition. For these materials, the LDFF results

* It should be noted that current Federal regulations on mattress materials (that have been in effect for over five years) greatly reduce the likelihood of mattress fires. In the LDFF tests with mattresses (Ref. 4) it was very difficult to cause a mattress ignition.

from the clothing store, warehouse, and living room geometries indicate that many will be totally extinguished at overpressures as low as 2 psi, and (with the exception of heavier materials that stay intact) virtually all would be totally extinguished at 5 psi, if the materials are located in high flow areas of the room.

For these major fuels Goodale estimated the probability, p_f, that a sustained room fire would be established (i.e. that flashover would take place) if the fuels were ignited. For incident blast wave overpressures below 2 psi Goodale estimated that p_f would be 1, and for overpressures above 5 psi, that p_f would be ½ (with linear interpolation in between). In effect he postulated that there would be no blast extinguishment of major fuels at 2 psi, and that only one half the major fuel fires would be extinguished at 5 psi.

There has not yet been time to develop quantitative interpretations of the LDFF results, but qualitatively it would seem almost certain that both probabilities would decrease; there would be substantial extinguishment of some of these fuels at below 2 psi, and more than ½ would likely be extinguished at 5 psi. Thus the LDFF results to date suggest that long duration blast flows can reduce sustaining fires to a greater degree than indicated by Goodale.

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Appendix A

Test Reports

Appendix A

TEST REPORTS

This appendix contains detailed reports, including pre- and post-test photographs, on each of the tests, the results of which were summarized in Section 3. The reports are arranged in numerical order; the first number of the pagination refers to the test number. A summary of initial test conditions follows. (See also Table 2-1 for predicted and measured flow values.)

Table A-1

Summary of Initial Test Conditions

Test Number	Room Geometry	Compression Chamber Pressure (psi)	Shutter Opening (% of wall)
1	Office	2.2	21
2	Office	4.2	21
3	Office	2.2	21
4	Office	2.25	14(7)*
5	Classroom	2.1	21
6	Clothing Store	2.1	21
7	Warehouse	2.1	21
8	Living Room	2.0	21
9	Living Room	4.0	-
10	Living Room	3 0	21
11	Clothing Store	4.0	21
12	School Room	2.0	21
13	Warehouse	3.9	21

* Number in parenthesis indicates planned shutter opening.

Table A-1 (cont.)

Summary of Initial Test Conditions

Test Number	Room Geometry	Compression Chamber Pressure (psi)	Shutter Opening (% of wall)
14	EOC	4.0	21
15	Clothing Store	5.75	21
16	Warehouse	6.25	21
17	EOC	4.0	14(7)*
18	Warehouse	4.25	21
19	Confined Fuel	2.0	21
20	Warehouse	6.1	21
21	Confined Fuel	5.5	21

* Number in parenthesis indicates planned shutter opening.

Test Report | Test Number 1

Type-- Office

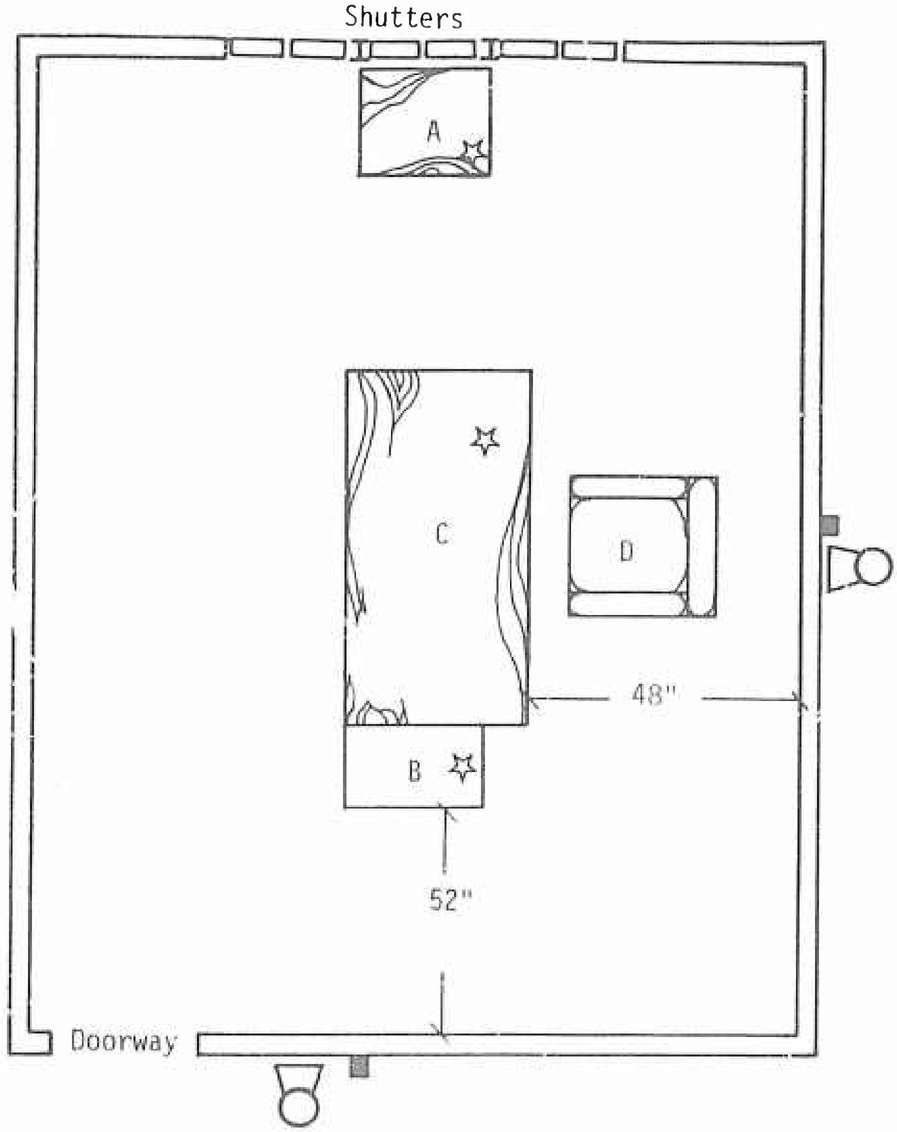
Test Conditions

Compression Chamber Pressure	2.15	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	0.85	(psi)
Positive Phase Duration	0.85	(sec)
Delay (ignition to blast)	27	(sec)

Test Geometry and Results

The simulated office consisted of a desk, chair and four drawer file cabinet, all located in the center of the room and a book table located directly in front of the shutters. Papers were placed on the desk and in the top and bottom drawers of the file cabinet which were left open. Books were placed on the book table.

The blast put out all the fires, moved the file cabinet and desk (slightly damaging the desk) and scattering papers around the room and in the outside hallway.



A - 24 x 22 in. table with books

B - 26 x 14 in. 4 drawer steel file cabinet (top and bottom drawer open containing paper)

C - 34 x 60 in. wood desk (paper scattered on top)

D - chair with steel frame and plastic cushions

☆ Ignition sources

Fig. 1-1. Sketch of Test Geometry, Test Number 1

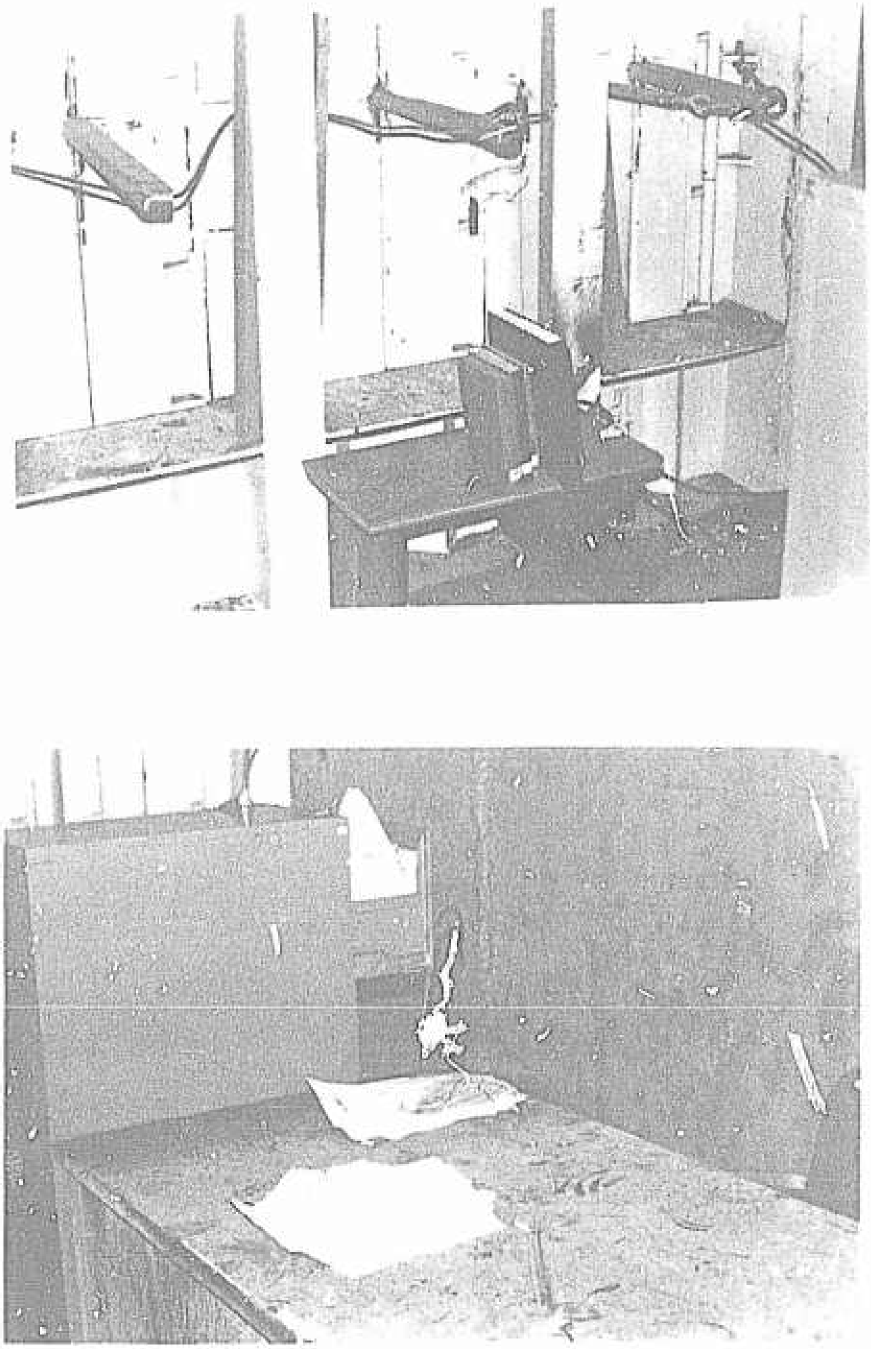


Fig. 1-2. Pretest Photographs, Test Number 1

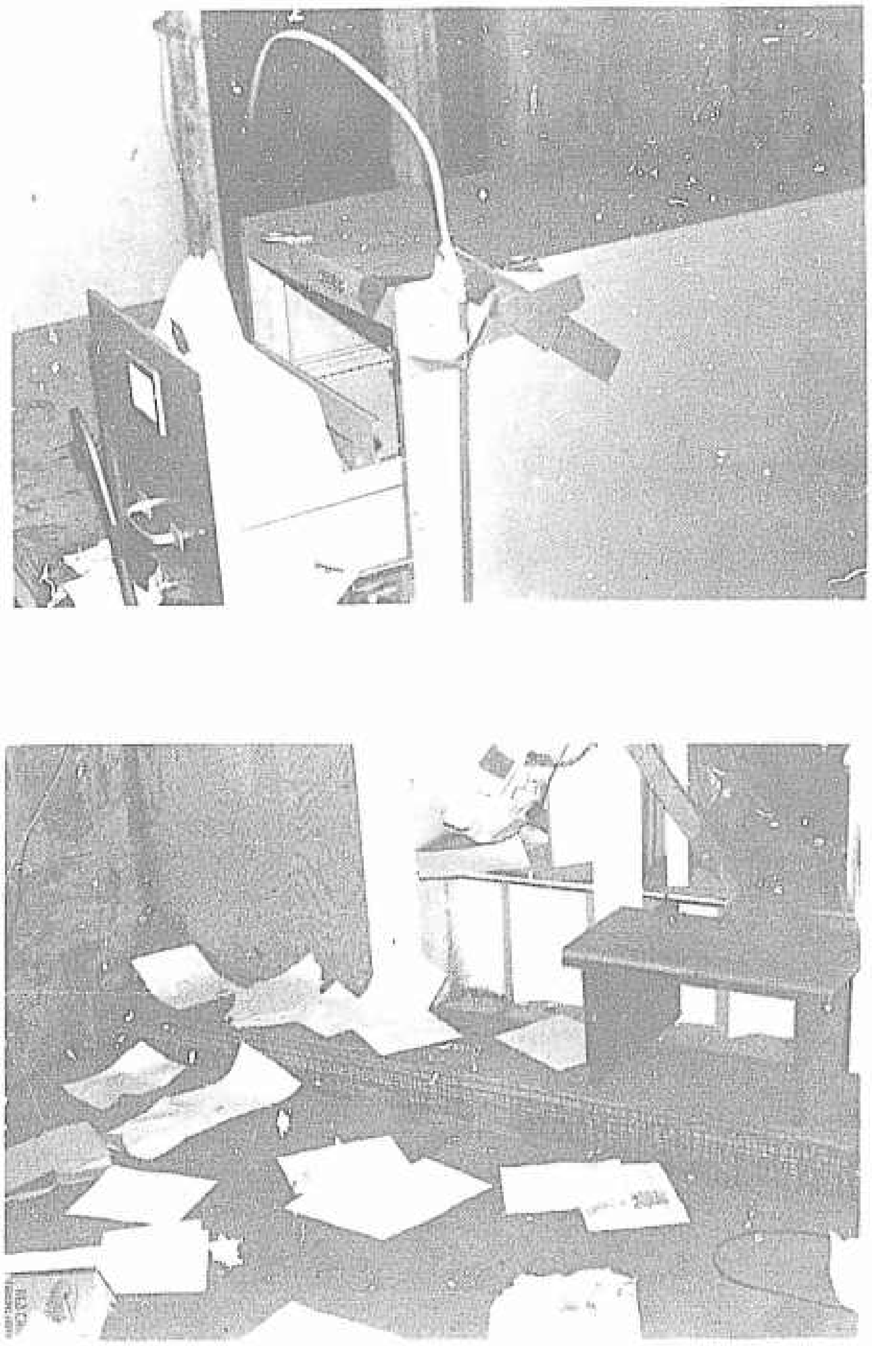


Fig. 1-3. Pre and Posttest Photographs, Test Number 1

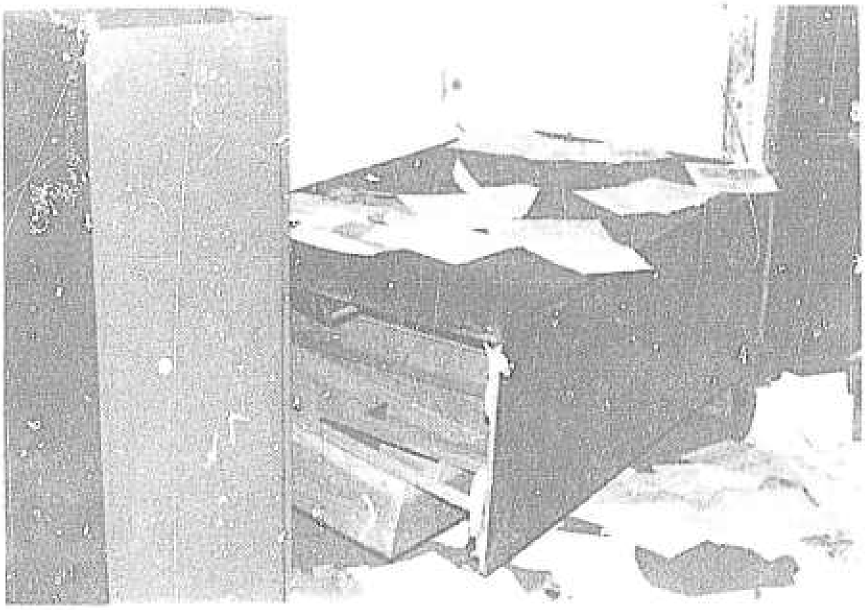


Fig. 1-4. Posttest Photographs, Test Number 1

Test Report Test Number 2

Type-- Office

Test Condition

Compression Chamber Pressure	4.15	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	1.96	(psi)
Positive Phase Duration	1.4	(sec)
Delay (ignition to blast)	14.5	(sec)

Test Geometry and Results

This test was essentially a repeat of test one at a higher pressure. (See Fig. 1-1). The blast put out all of the fires and did considerably more damage. The desk was broken up and was driven part way out the door. The file cabinet was knocked over and ended up on top of the desk. See the posttest photographs Figs. 2-3 and 2-4.

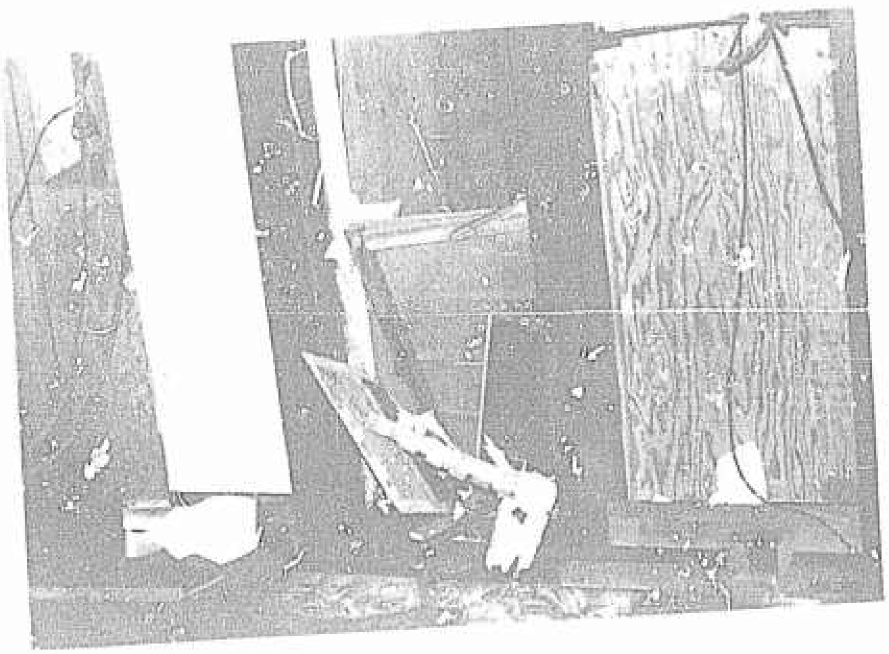
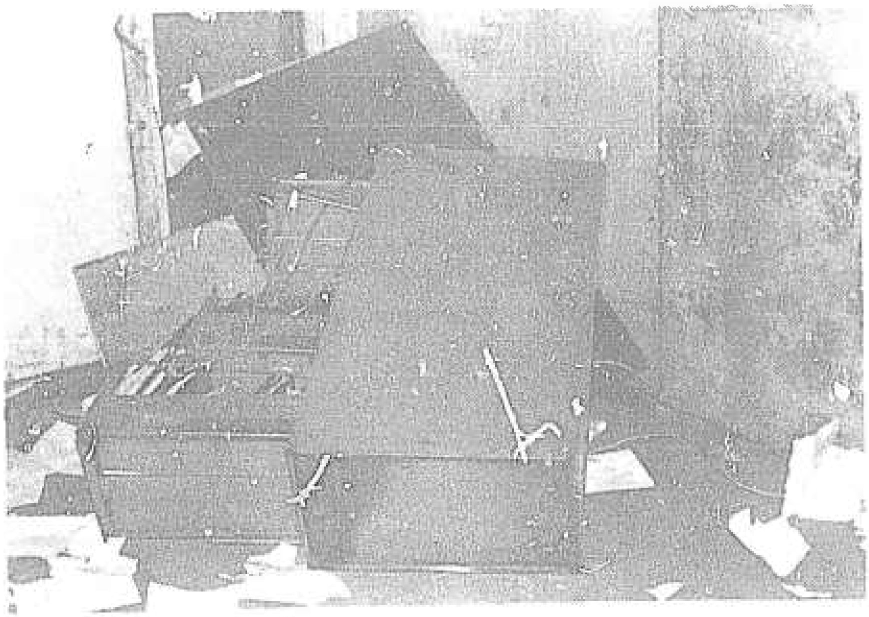


Fig. 2-2. Posttest Photographs, Test Number 2



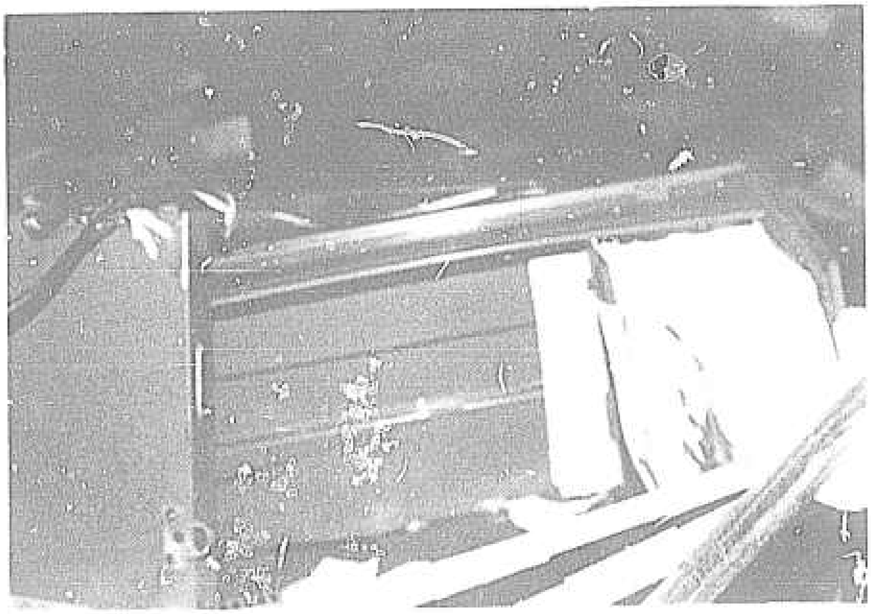


Fig. 2-3. Posttest Photographs, Test Number 2

Test Report Test Number 3

Type-- Office

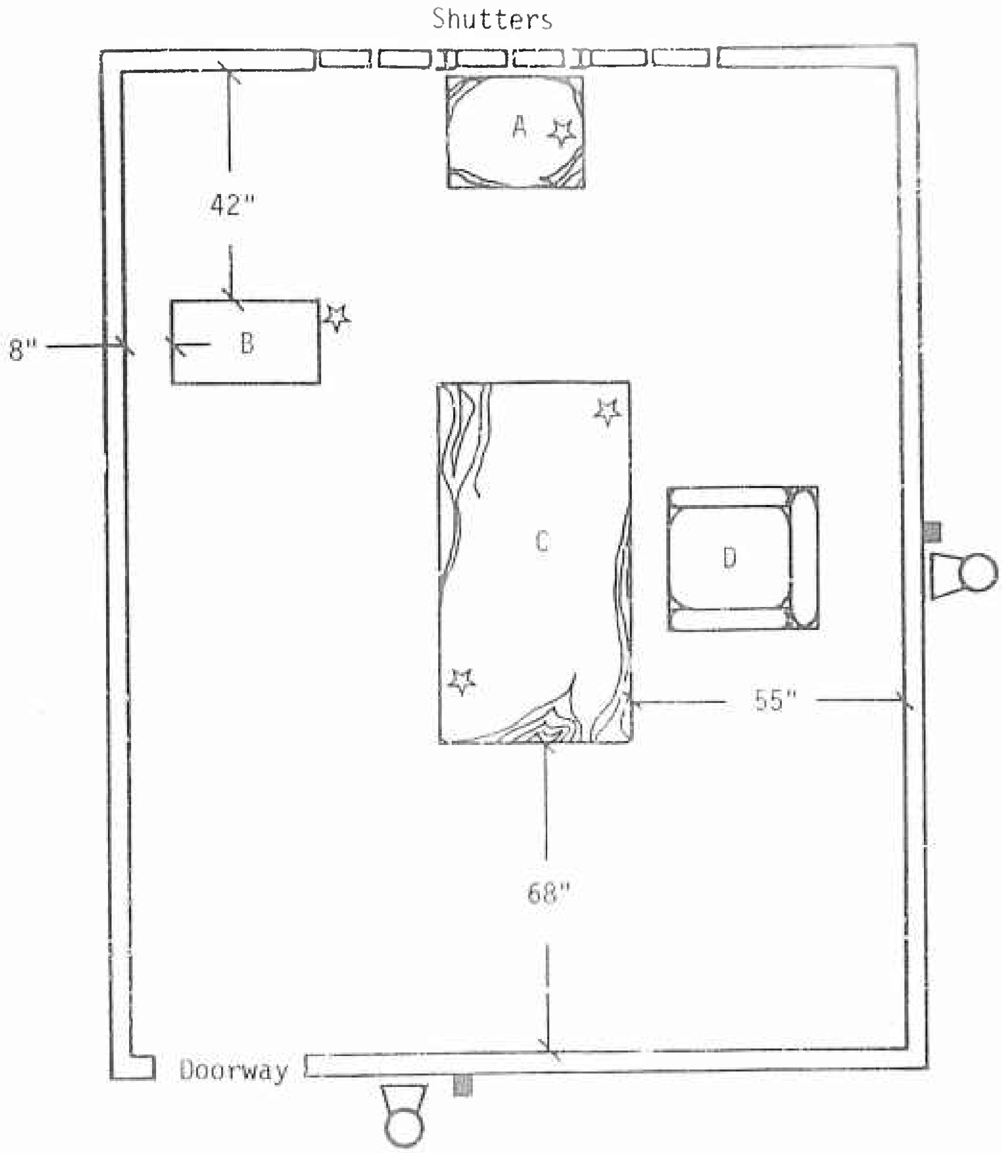
Test Conditions

Compression Chamber Pressure	2.2	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	1.1	(psi)
Positive Phase Duration	0.97	(sec)
Delay (ignition to blast)	54	(sec)

Test Geometry and Results

The simulated office consisted of a desk and chair in the center of the room, a four drawer file cabinet with the top and bottom drawers open, and a book table directly in front of the shutter opening (See sketch in Fig. 3-1). Paper was placed on the desk and in the drawers of the file cabinet, and books were placed on the table. Each location had an ignition source. See photographs in Fig. 3-2A and B.

The blast put out all fires, pushed the desk into the doorway, broke the chair and pushed it against the back wall and tipped over the file cabinet spilling the contents on the floor. See posttest photographs Figs. 3-3 and 3-4.



A - 24 x 22 in. table with books

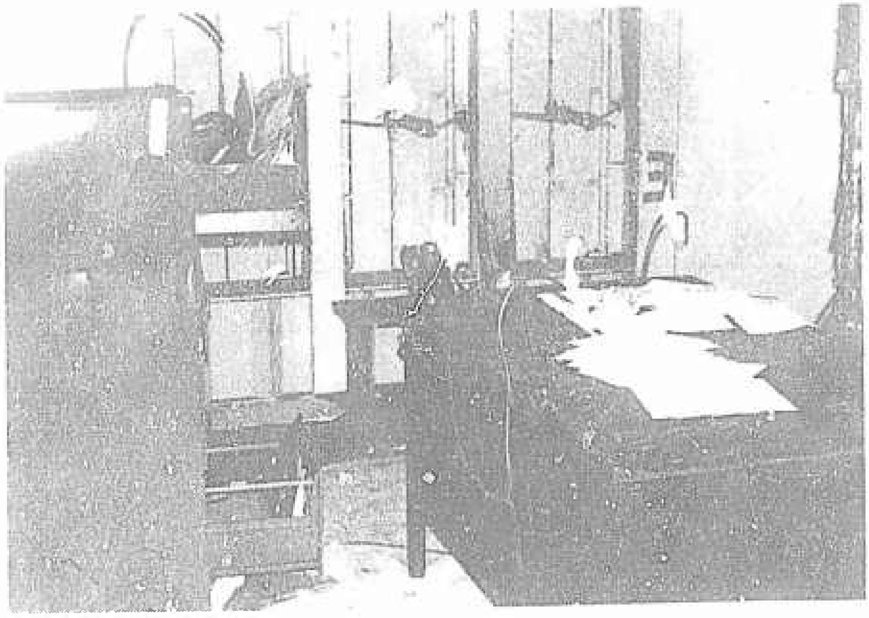
B - 26 x 14 in. four drawer file cabinet

C - 34 x 60 in. wood desk

D - chair with steel frame and plastic cushions

☆ Ignition sources

Fig. 3-1. Sketch of Test Geometry, Test Number 3



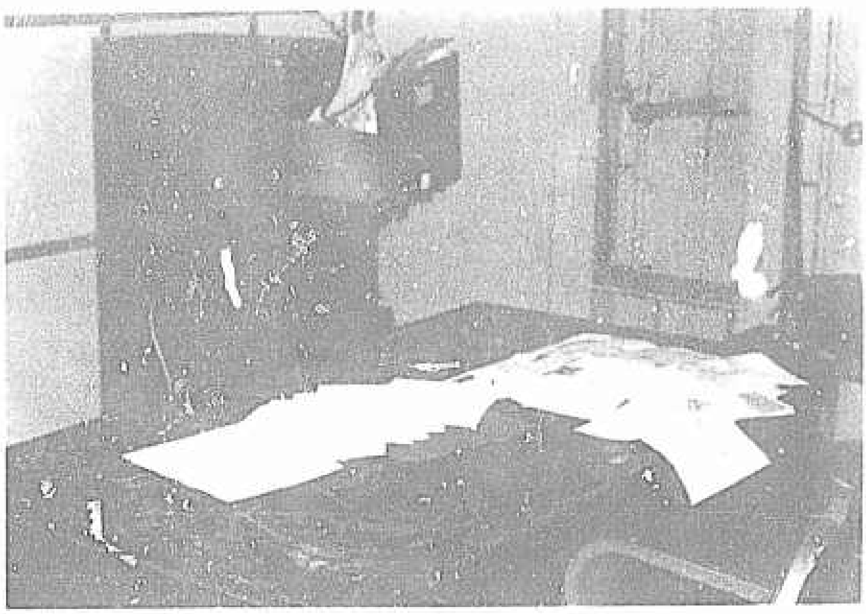


Fig. 3-2. Pretest Pho ographs, Test Number 3.

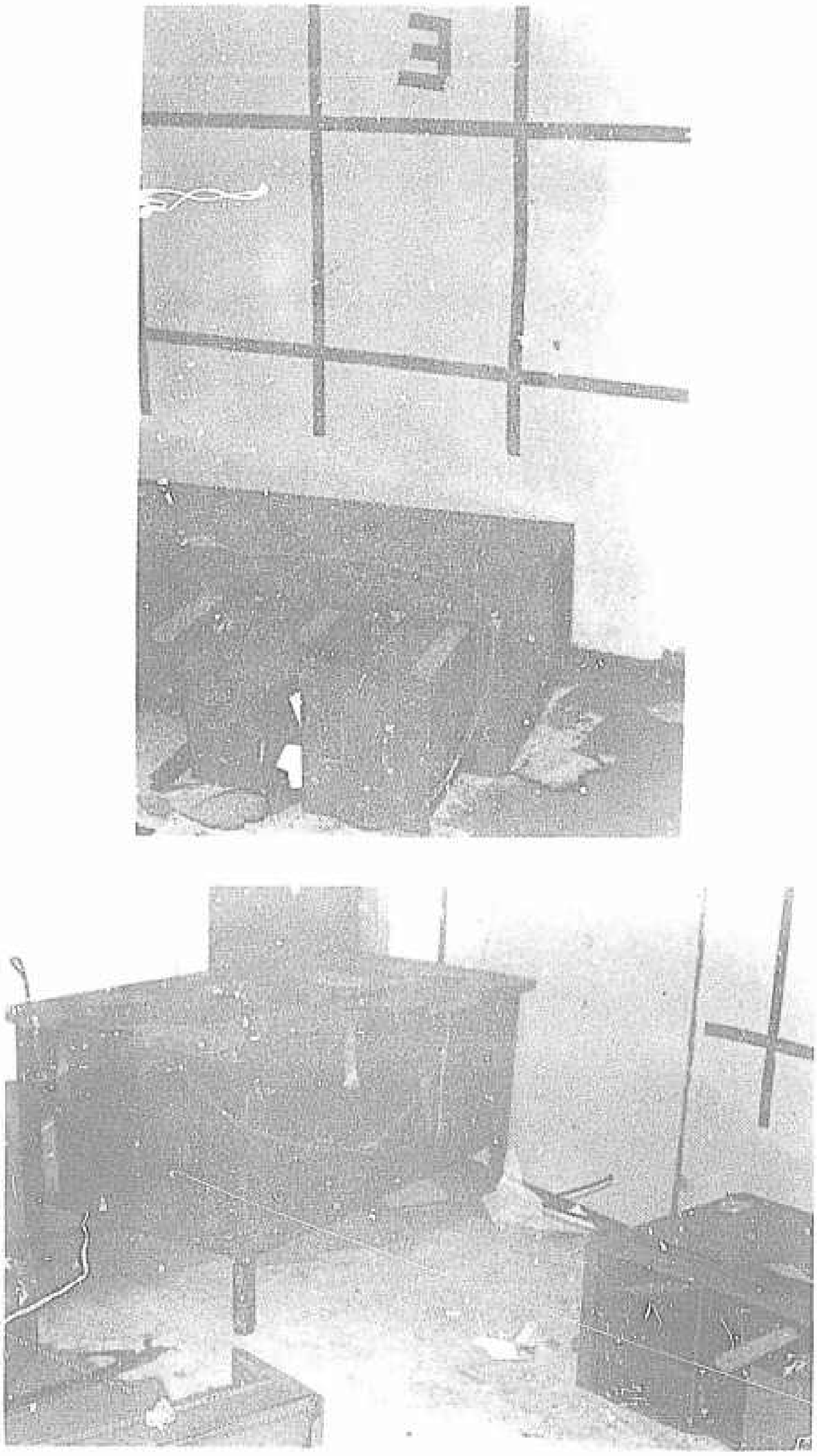


Fig. 3-3. Posttest Photographs, Test Number 3.

Fig. 3-4. Posttest Photograph, Test Number 3.

Test Report

Test Number 4

Type-- Office

Test Conditions

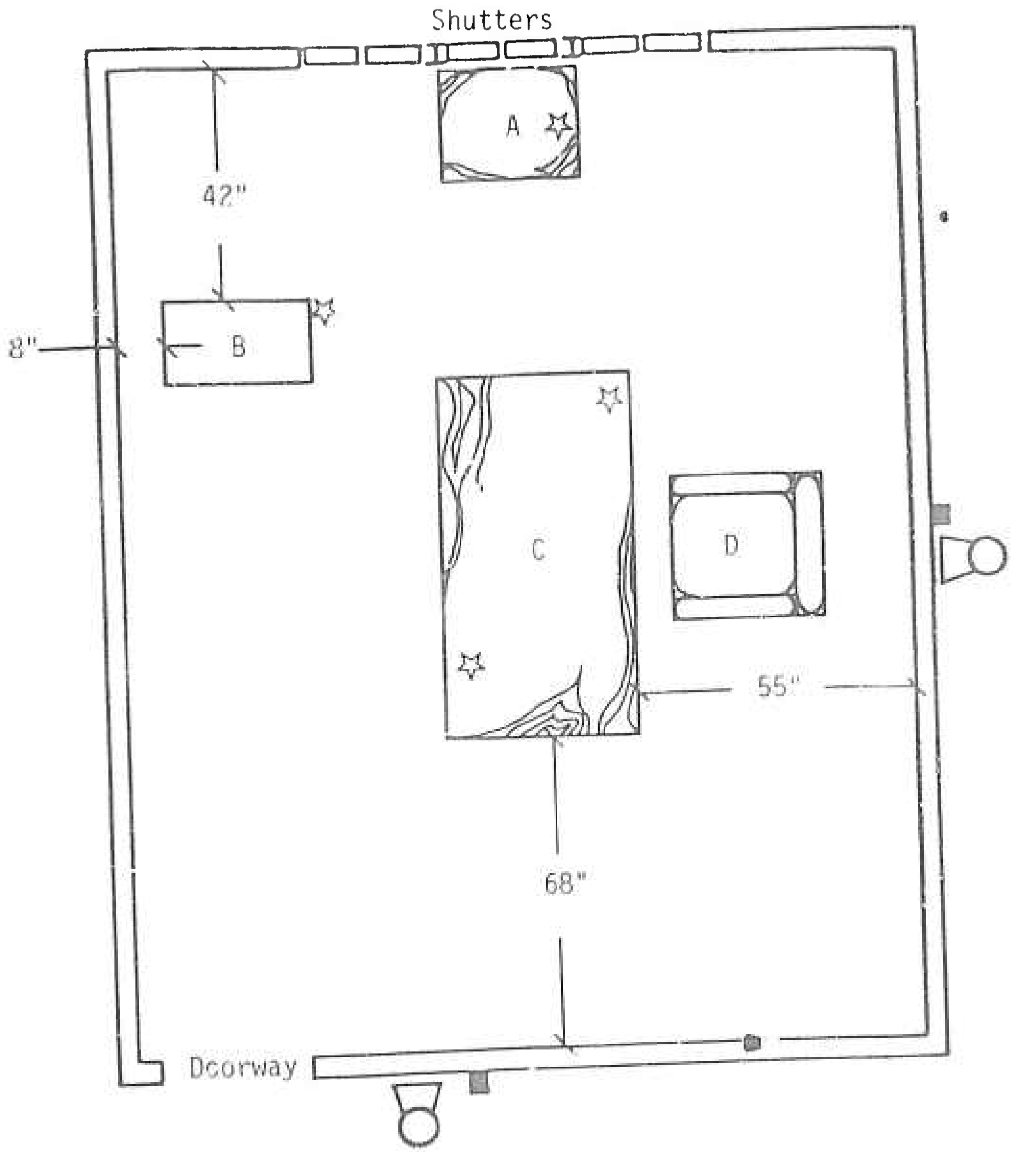
Compression Chamber Pressure	2.25	(psi)
Diaphragm Opening	14*	(%)
Peak Pressure in Room (side wall gauge)	0.5	(psi)
Positive Phase Duration	1.2	(sec)
Delay (ignition to blast)	54	(sec)

Test Geometry and Results

The simulated office consisted of a desk and chair in the center of the test room, a four drawer file cabinet with the top and bottom drawer open, and a book table directly in front of the shutter opening. (See sketch in Fig. 4-1). Paper was placed on the desk and in the file cabinet and books were placed on the table. There was an ignition source for each of the above locations. See pretest photographs in Figs. 4-2 and 4-3.

The blast wave put out all fires and severely damaged the desk, leaving the top on the floor and pushing the remainder part way through the doorway (See photographs Fig. 4-4). The chair was also severely damaged (See Fig. 4-6B), and numerous papers and parts of the desk were scattered along the corridor outside the test room.

* A 7% opening had been planning, but as Fig. 4-5A shows, two shutters opened.



A - 24 x 22 in. table with books

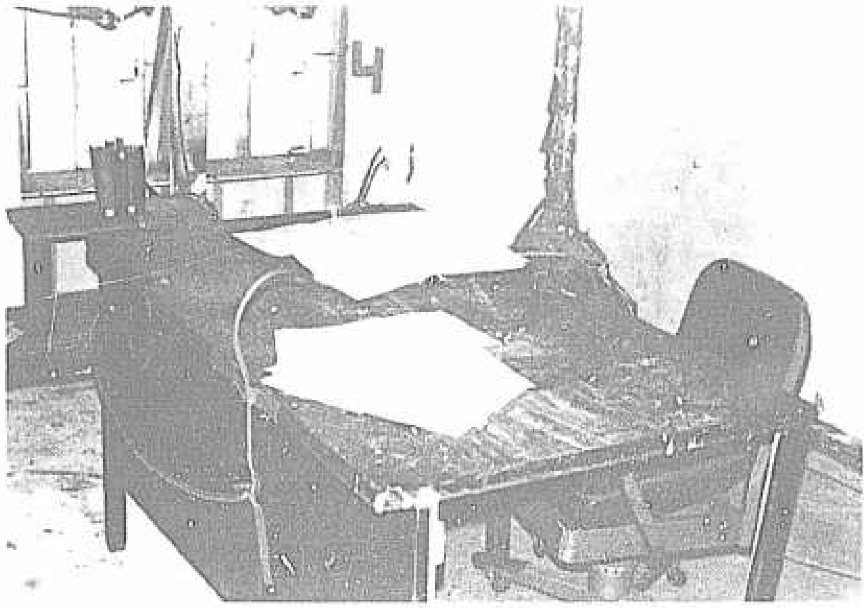
B - 20 x 14 in. four drawer file cabinet

C - 34 x 60 in. wood desk

D - chair with steel frame and plastic cushions

☆ Ignition sources

Fig. 4-1. Sketch of Test Geometry, Test Number 4



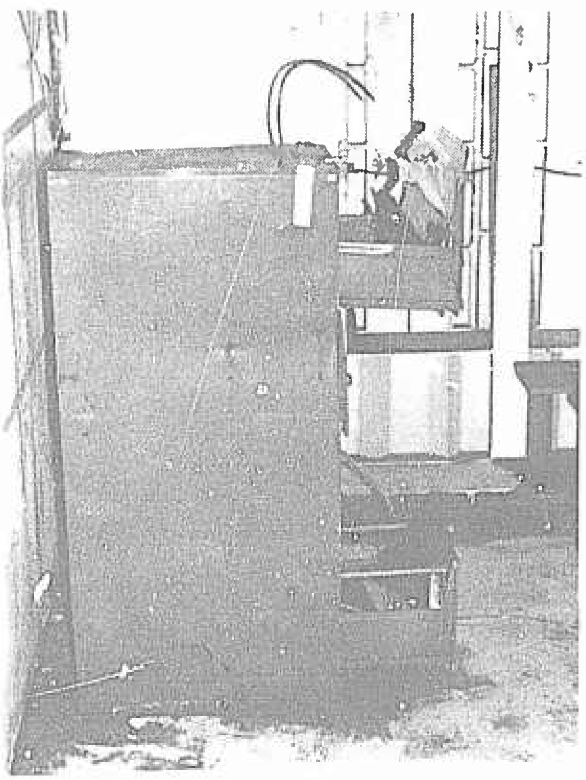


Fig. 4-2 Pretest Photographs, Test Number 4

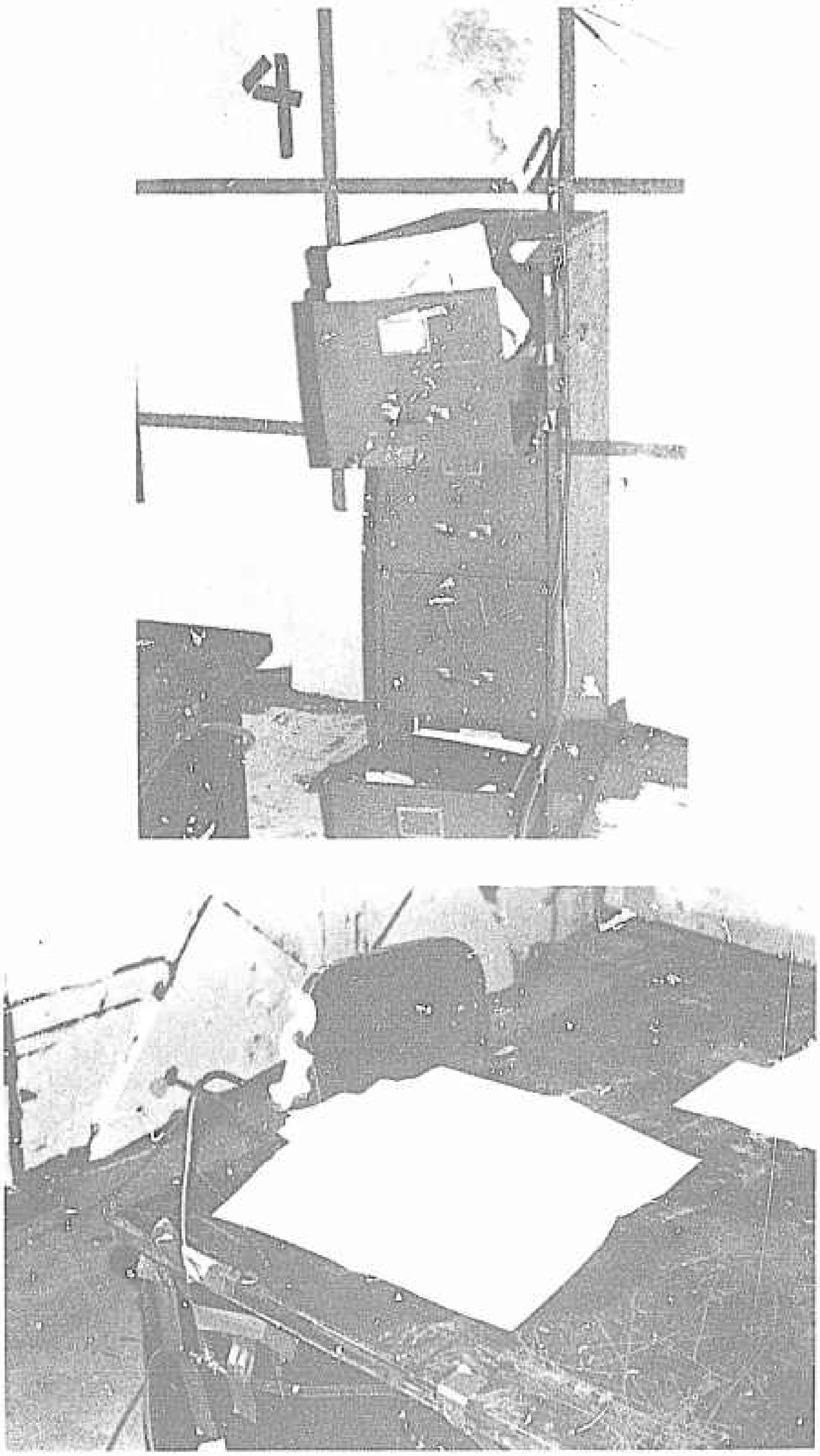


Fig. 4-3. Pretest Photographs, Test Number 4.

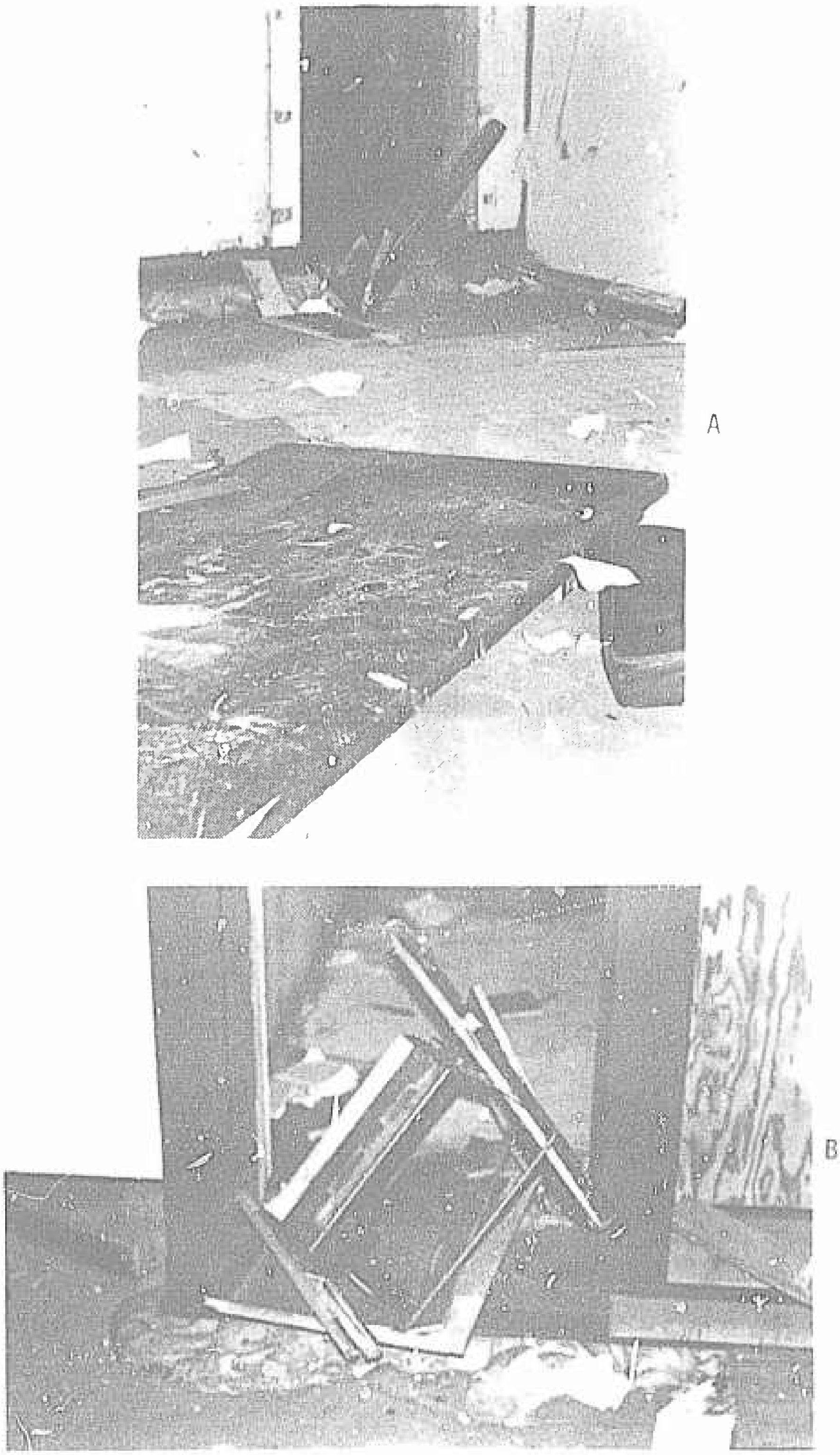
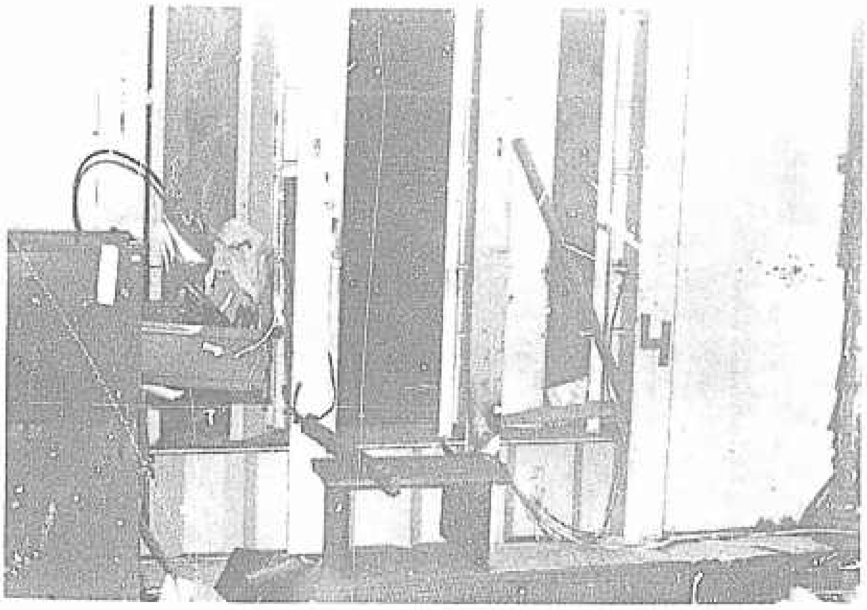
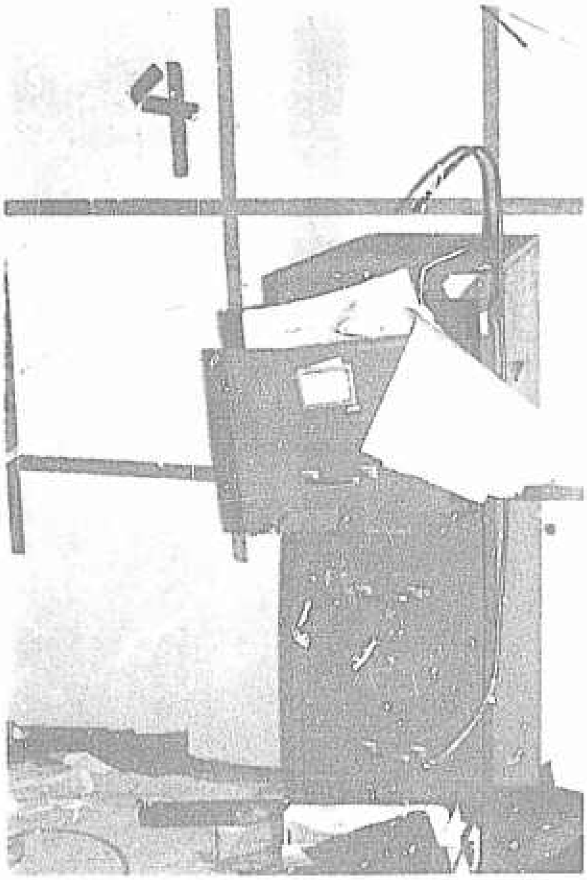


Fig. 4-4. Posttest Photographs, Test Number 4



A



B

Fig. 4-5. Posttest Photographs, Test Number 4.

A

B

Fig. 4-6. Posttest Photographs, Test Number 4.

Test Report Test Number 5

Type-- Classroom

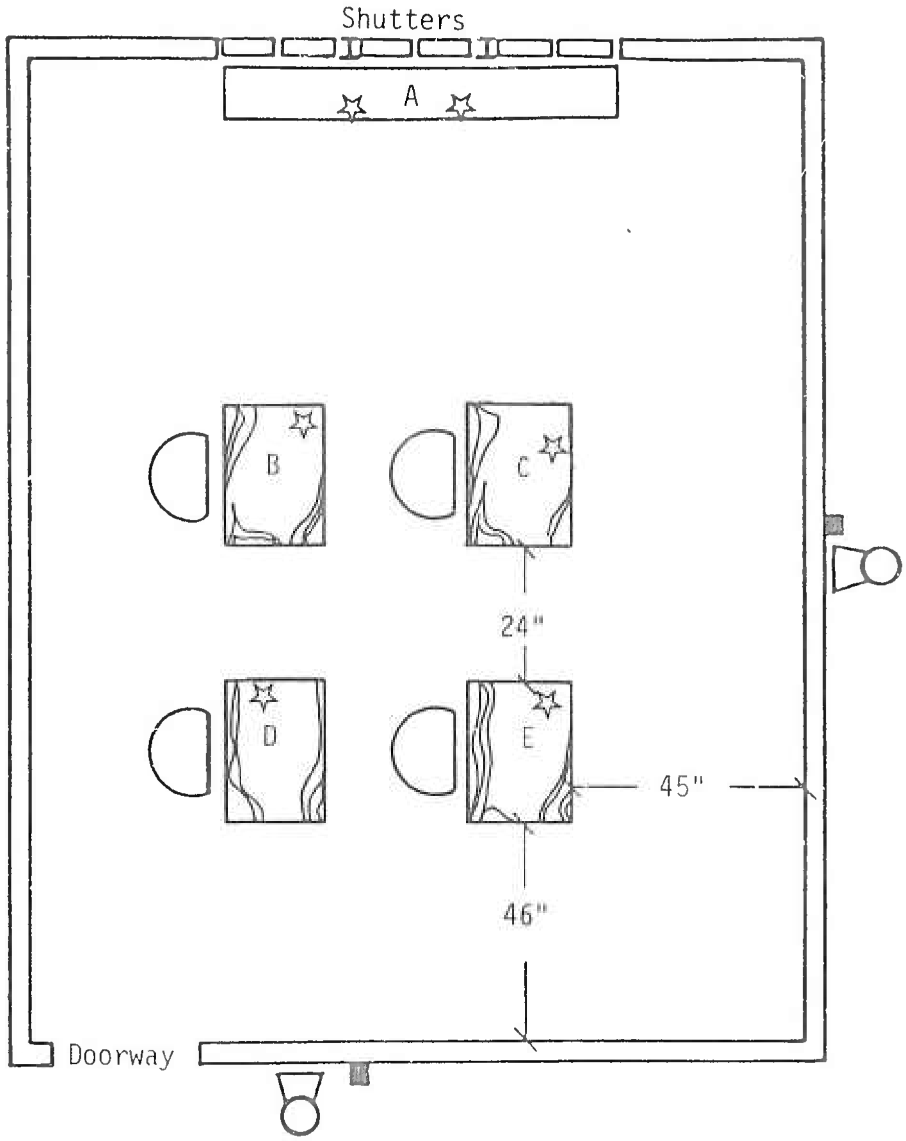
Test Conditions

Compression Chamber Pressure	2.1	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	1.1	(psi)
Positive Phase Duration	1.0	(sec)
Delay (ignition to blast)	54	(sec)

Test Geometry and Results

Four school desks were placed as shown in the sketch in Fig. 5-1. Papers were placed in the desks, on top of the desks and on a shelf directly in front of the shutters. Six ignition sources were used, one on each desk and two on the shelf. See pretest photographs Fig. 5-2.

All sources ignited. Once the shutters opened it appeared that the flames were quickly extinguished. Desk D (See Fig. 5-1) tipped over and ended up against the back wall. Desks B,C, and E moved slightly but remained upright. Papers were spread throughout the room and in the corridor outside the doorway. Posttest photographs of the room are presented in Figs. 5-3 through 5-4.

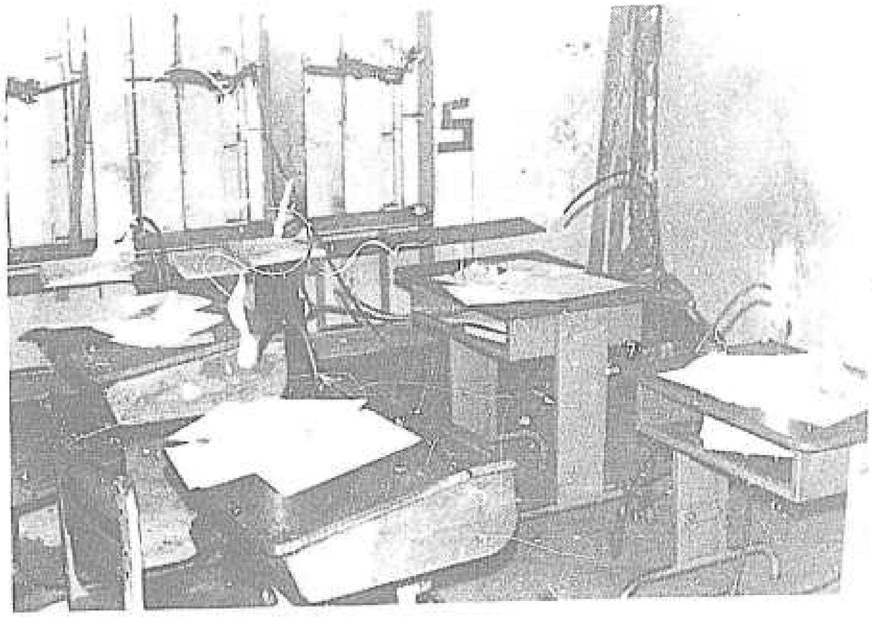


A - 12 x 60 in. shelf

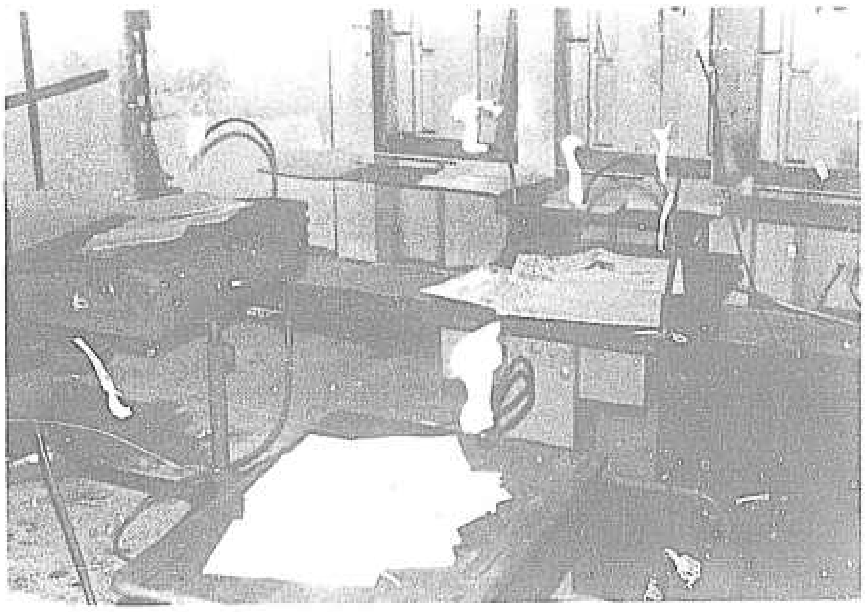
B, C, D, & E - 23 x 18 in. school desks

☆ Ignition sources

Fig. 5-1. Sketch of Test Geometry, Test Number 5

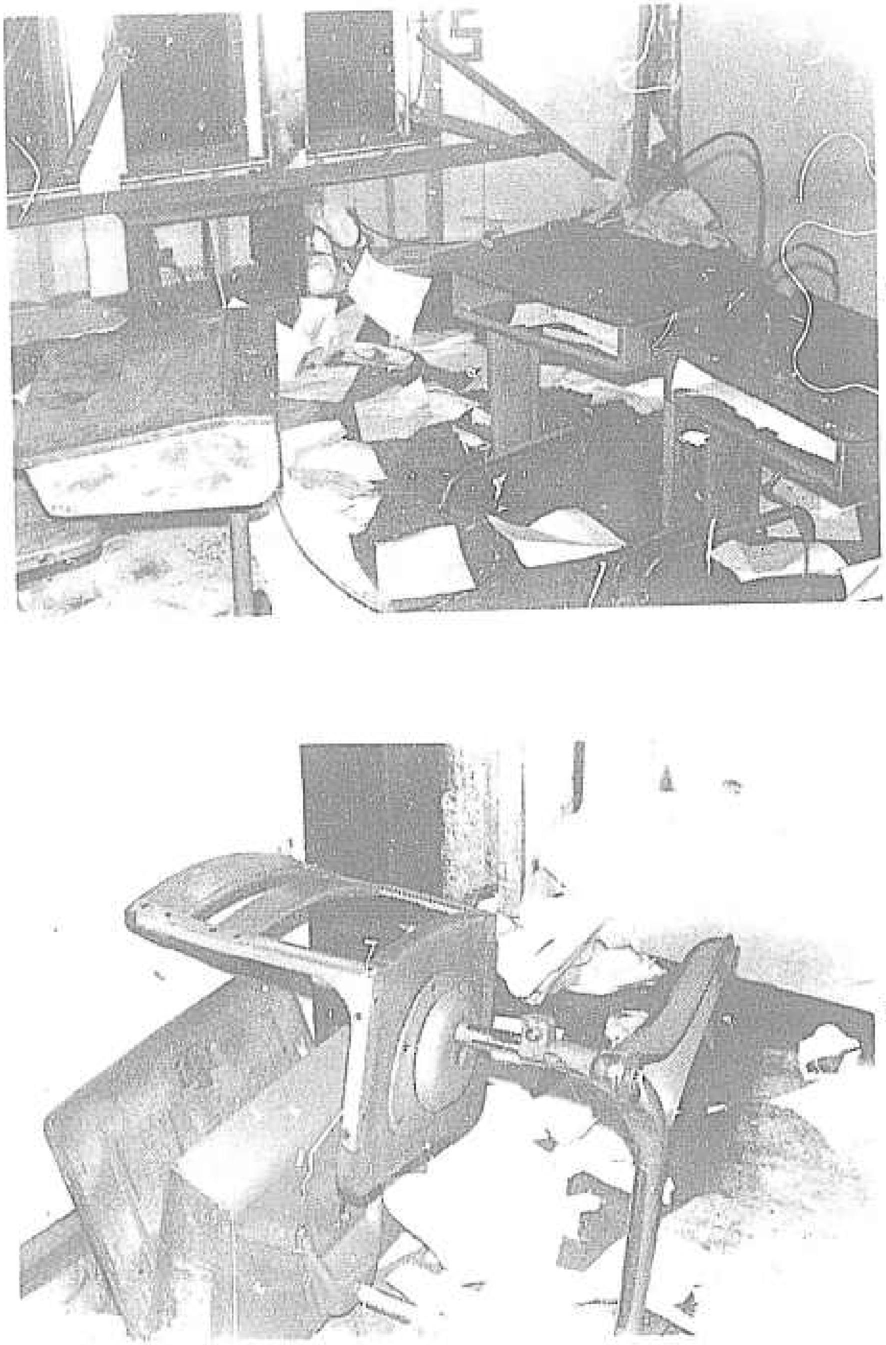


A



B

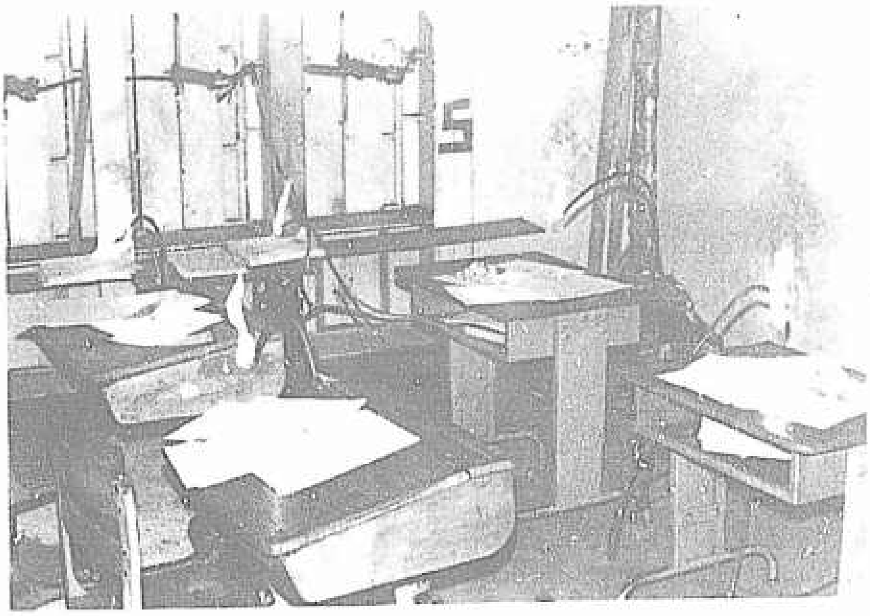
Fig. 5-2. Pretest Photographs, Test Number 5.



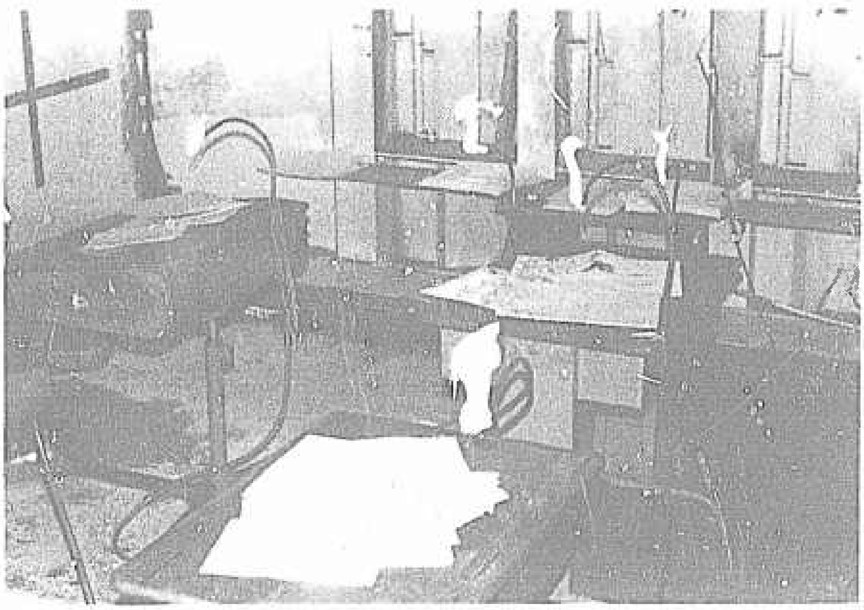
A

B

Fig. 5-3. Posttest Photographs, Test Number 5.

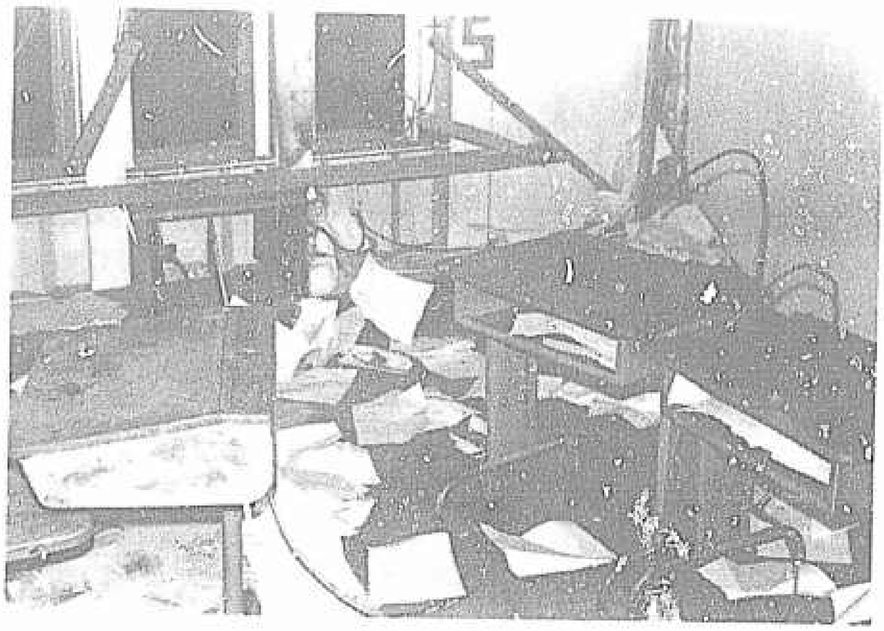


A

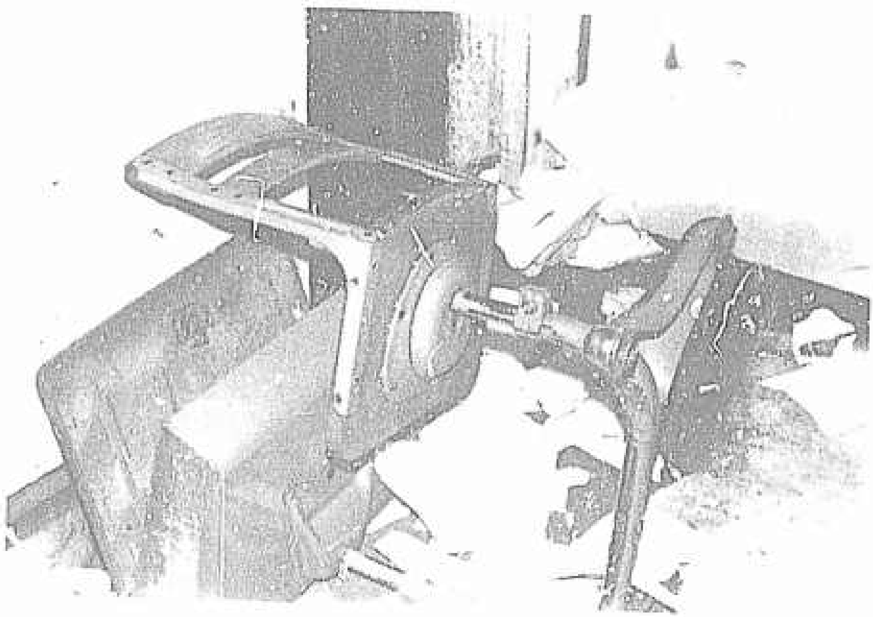


B

Fig. 5-2. Pretest Photographs, Test Number 5.



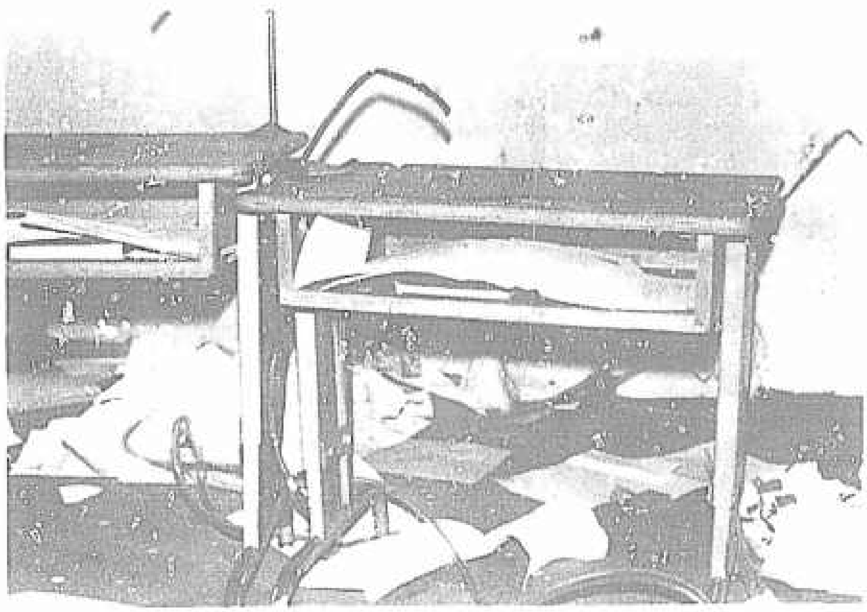
A



B

Fig. 5-3. Posttest Photographs, Test Number 5.

A



B

Fig. 5-4. Posttest Photographs, Test Number 5.

Test Report Test Number 6

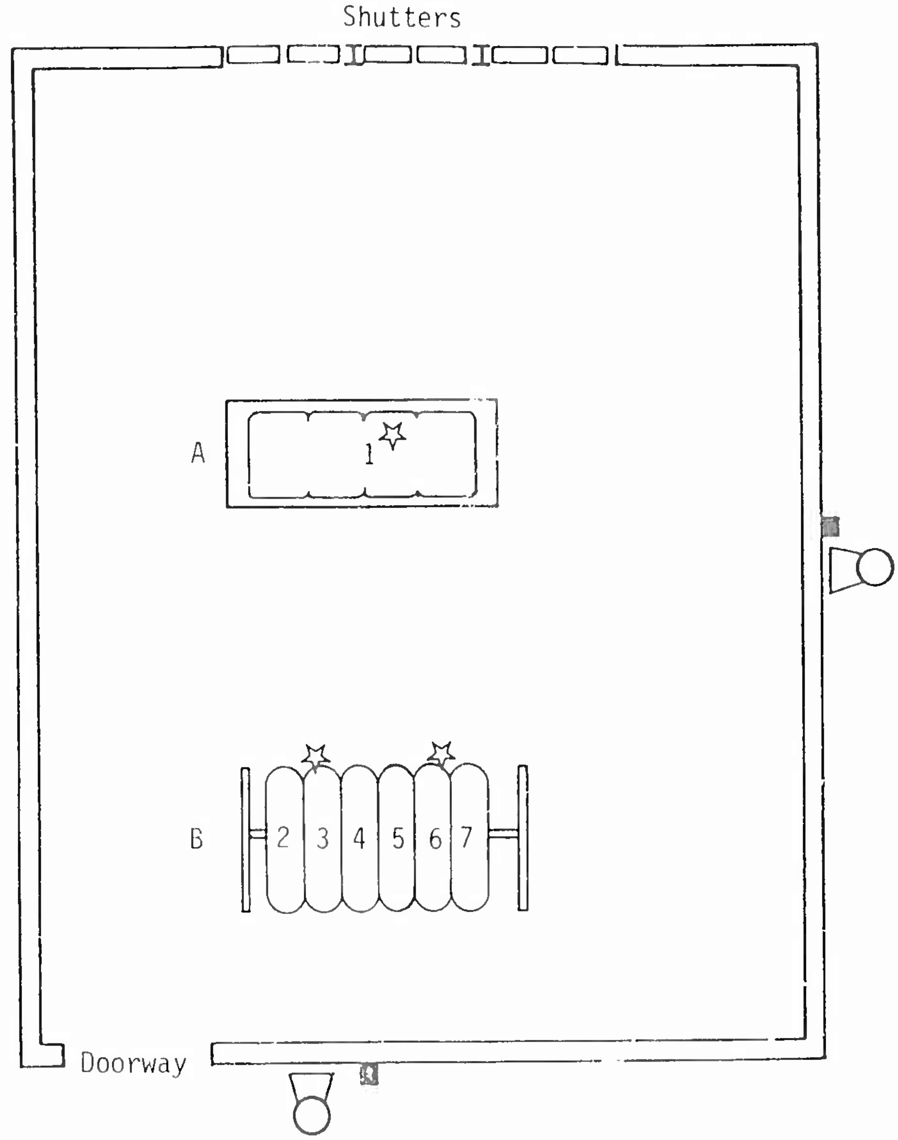
Type-- Clothing Store

Test Conditions

Compression Chamber Pressure	2.1	(psi)
Diaphragm Opening	21	( )
Peak Pressure in Room (side wall gauge)	1.2	(psi)
Positive Phase Duration	0.98	(sec)
Delay (ignition to blast)	54	(sec)

Test Geometry and Results

A simulated clothing store was installed in the center of the test room. A table (made up of two school desks) was placed as shown in Fig. 6-1. On the table were stacked, folded and rumpled piles of denim, drill, terrycloth, and two weights of muslin. Directly behind the table was placed a clothes rack on which coat hangers draped with drill and muslin were placed. See pretest photographs Figs. 6-2A and B, and Fig. 6-3A. Ignition sources were placed on the table and on the coat rack and considerable burning was evident at both locations prior to the blast. The airblast removed all the clothes from the rack and the tables, knocked over the clothes rack and essentially dismantled it (see photograph, Fig. 6-3B). One of the desks (which made up the table) tipped over and ended upside down next to the back wall. The other desk rotated 180^{0} and also ended up near the back wall. (See photograph, Fig.6-4B.) Cloth was scattered a distance of 60 ft outside the doorway. All flames were extinguished, although many pieces were smouldering. One piece (the furthest from the doorway) burst into flame less than 10 minutes after the test. (See Fig. 6-5A and B.) A piece of light weight muslin ignited at 12 minutes and other pieces at later times. Various of these pieces are shown in Figs. 6-6A and B and 6-7. There were also numerous partially burned pieces which were extinguished. (One sucn piece in the edge of the doorway is shown in Fig. 6-4A.)



A - table made up of two 23 x 18 in. school desks

B - clothes rack

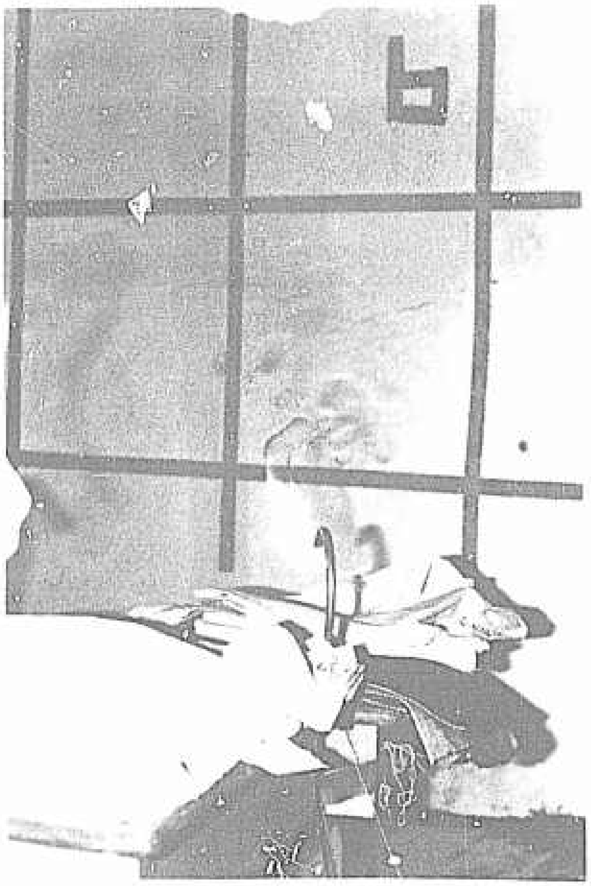
1 - piles of folded drill, denim, terry cloth and muslin

2, 3, & 4 - drill

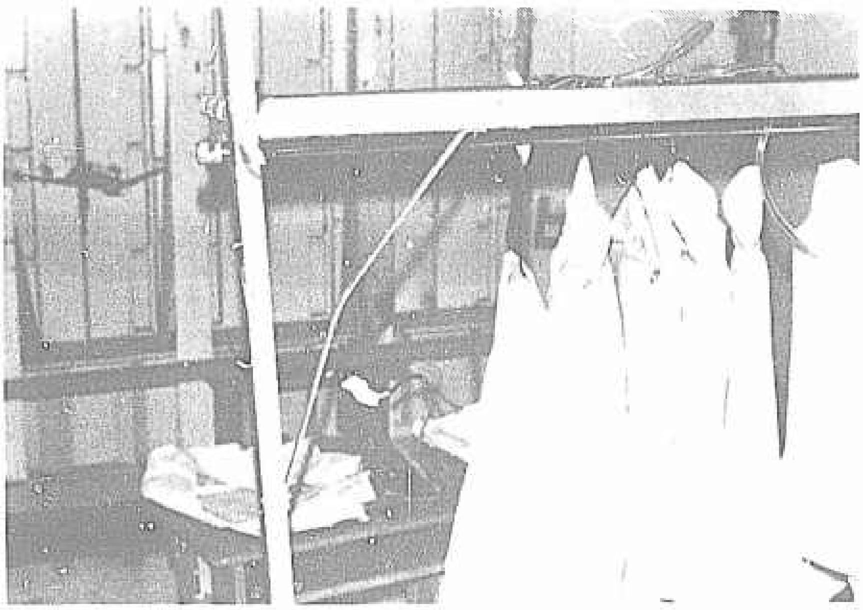
5, 6, & 7 - muslin

☆ Ignition sources

Fig. 6-1. Sketch of Test Geometry, Test Number 6



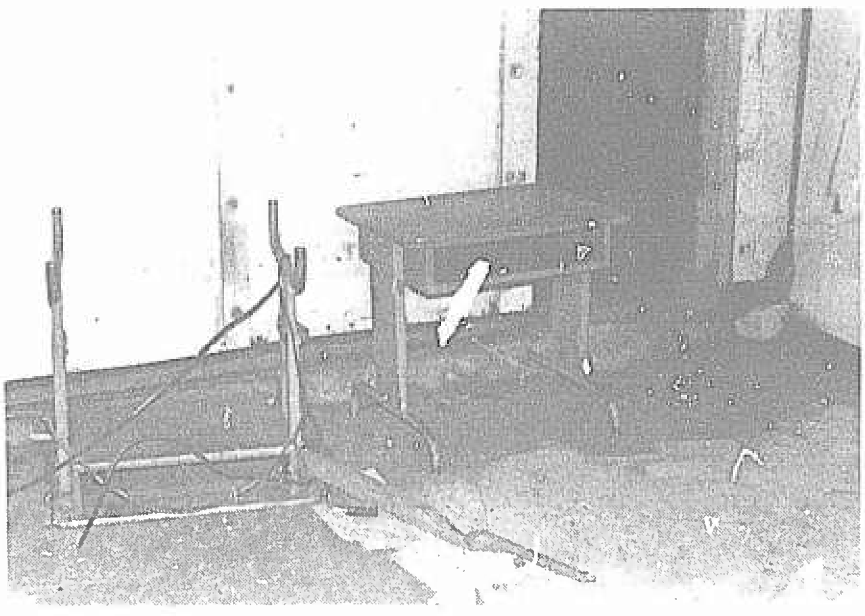
A



B

Fig. 6-2. Pretest Photographs, Test Number 6.

A



B

Fig. 6-4. Posttest Photographs, Test Number 6.

Fig. 6-5. Posttest Photographs, Test Number 6.

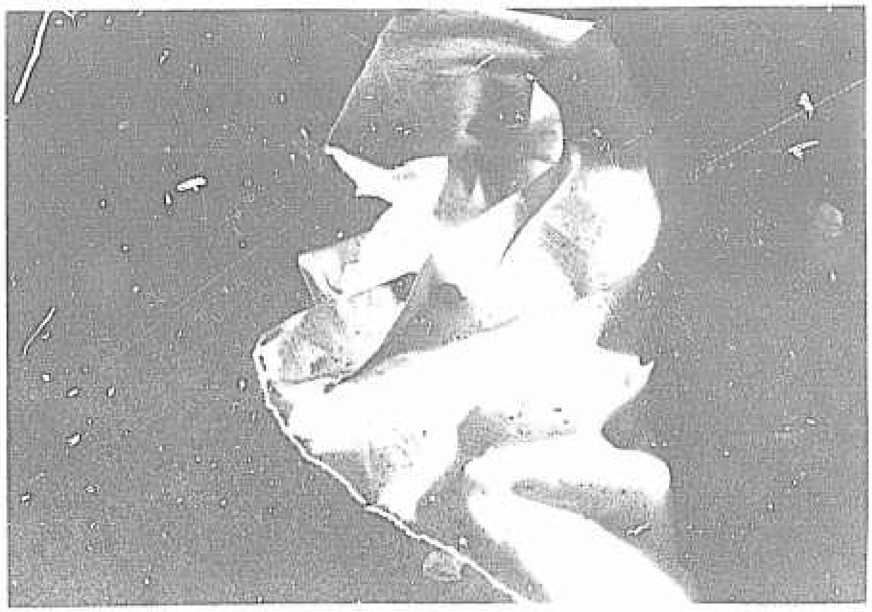


Fig. 6-6. Posttest Photographs, Test Number 6.

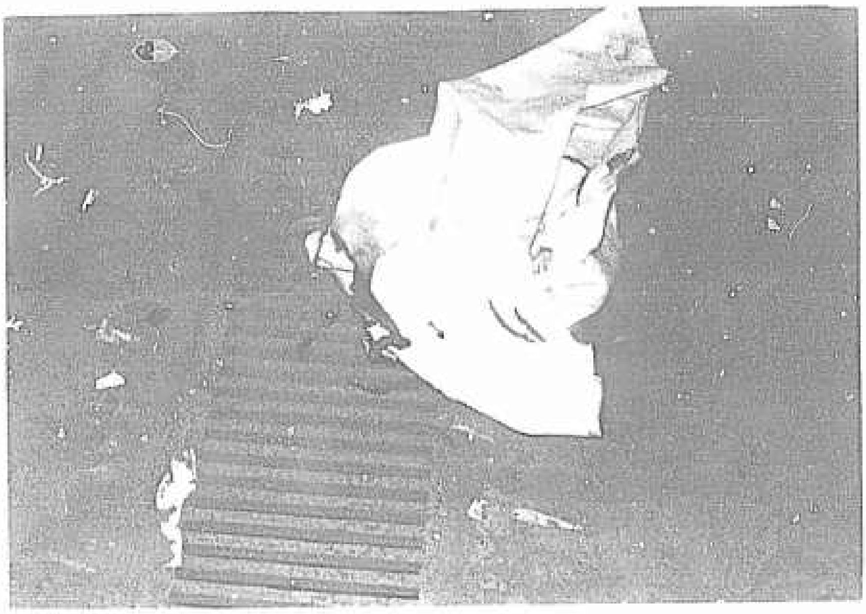


Fig. 6-7. Posttest Photograph, Test Number 6.

Test Report | Test Number 7

Type-- Warehouse

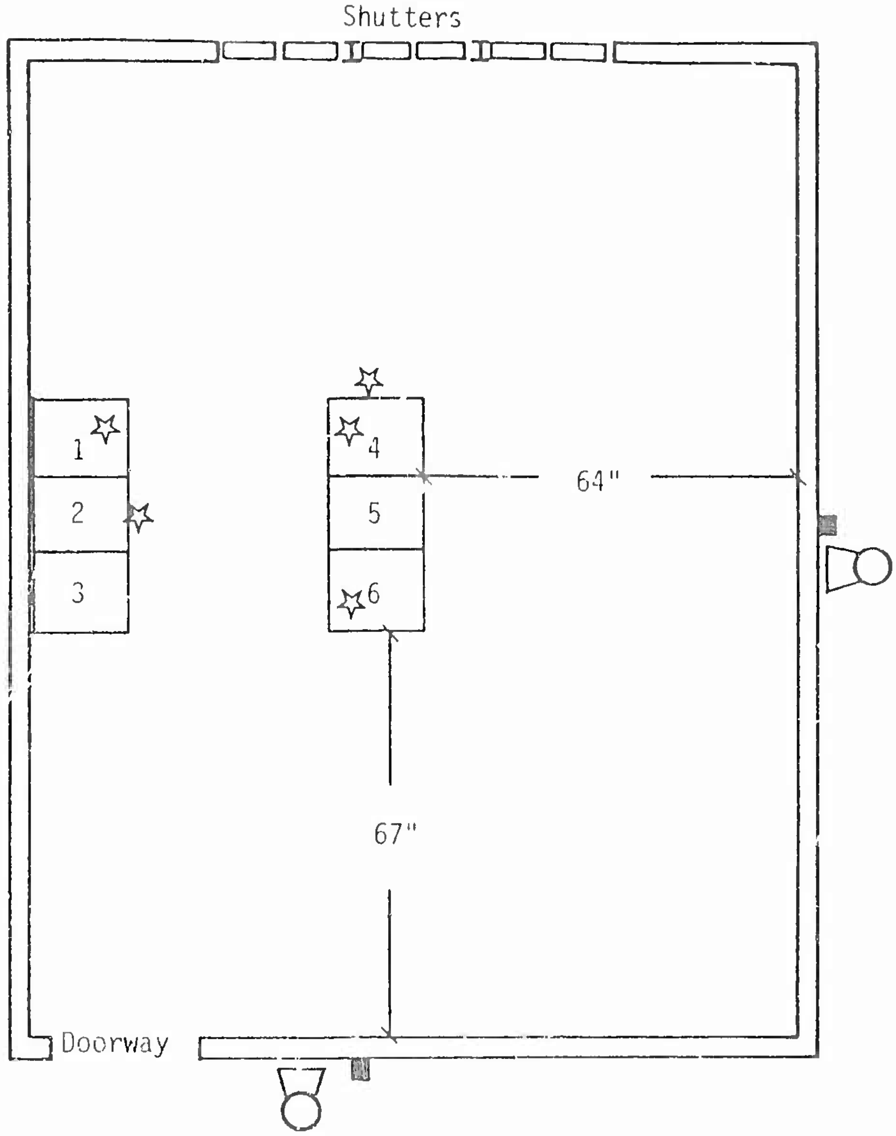
Test Conditions

Compression Chamber Pressure	2.05	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	1.1	(psi)
Positive Phase Duration	0.99	(sec)
Delay (ignition to blast)	54	(sec)

Test Geometry and Results

A simulated warehouse was installed in the test room. Nine storage boxes were stacked in the center of the room and three boxes were placed along the wall as shown in the sketch in Fig. 7-1. The boxes contained packing material (crumpled paper). The three boxes along the wall were weighted down (with lead blocks) and the ones in the center were not. Two of the stacks were ignited on the top and front (toward the shutters). See the pretest photographs Fig. 7-2 and Fig. 7-3

All flames were extinguished. The center stack of boxes ended up either 50 ft outside the room, as shown in Fig. 7-4A, or in the front of the room, as shown in Fig. 7-4B. The weighted boxes along the wall smouldered and burst into flame immediately. One of the boxes outside of the room smouldered and burst into flame 9 minutes, 26 seconds after the test. See photographs in Fig. 7-5A and B.

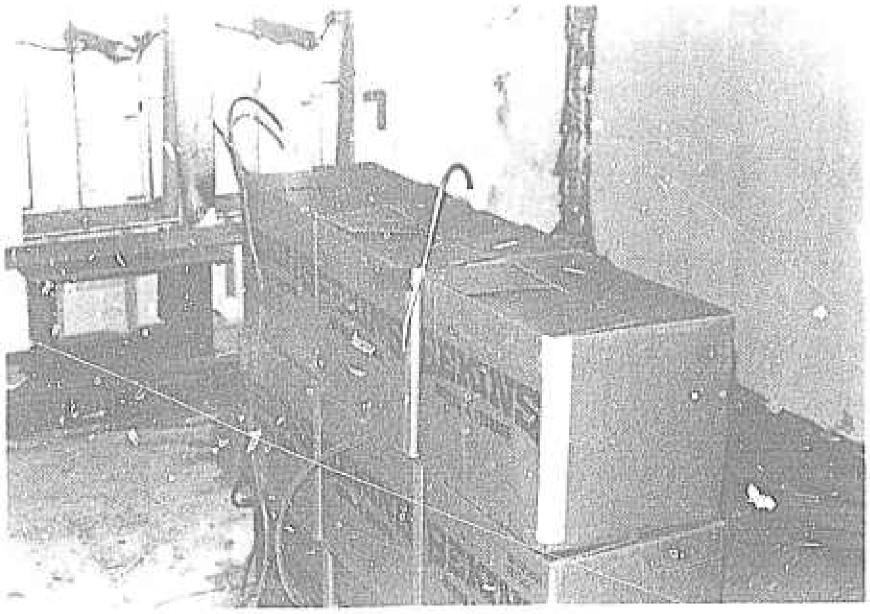


1, 2, & 3 - 17 x 13 x 13 in. cardboard boxes

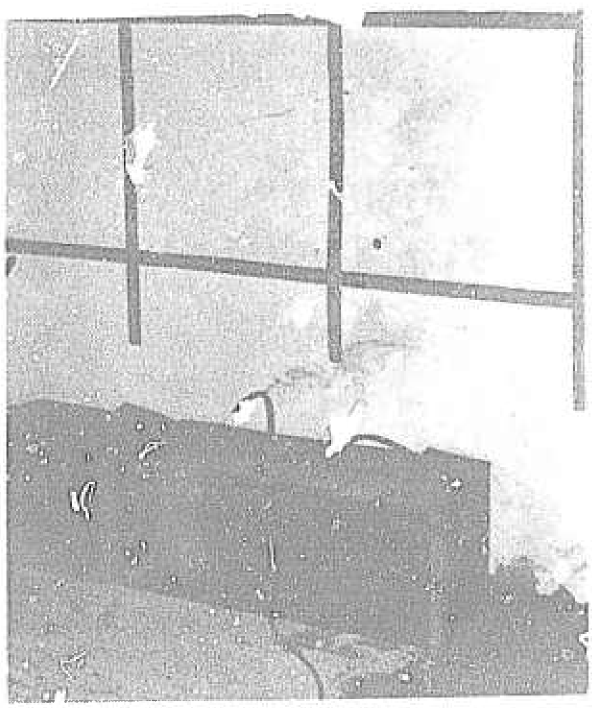
4, 5, & 6 - 17 x 13 x 13 in. cardboard boxes stacked three high

☆ Ignition sources

Fig. 7-1. Sketch of Test Geometry, Test Number 7



A



B

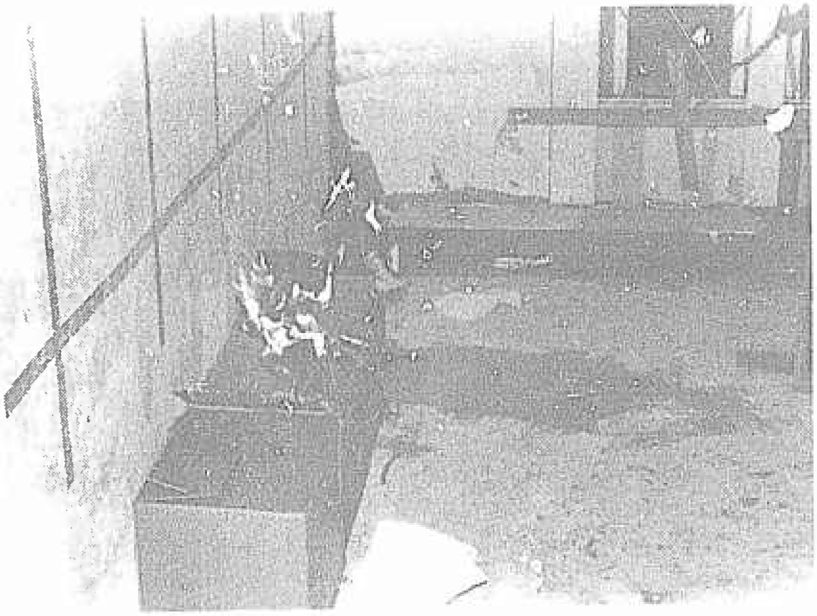
Fig. 7-2. Pretest Photographs, Test Number 7.

Fig. 7-3. Pretest Photograph, Test Number 7

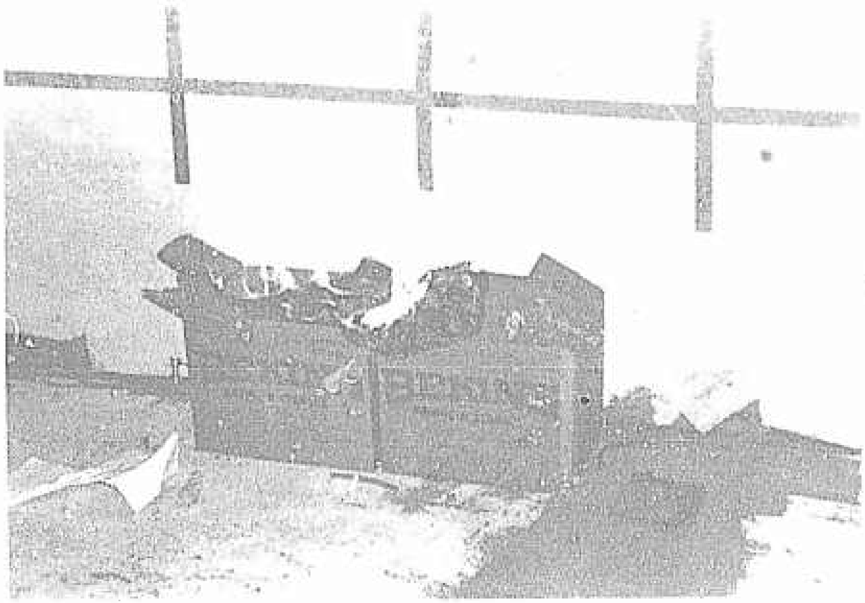
A

B

Fig. 7-4. Posttest Photographs, Test Number 7



A



B

Fig. 7-5. Posttest Photographs, Test Number 7

Test Report | Test Number 8

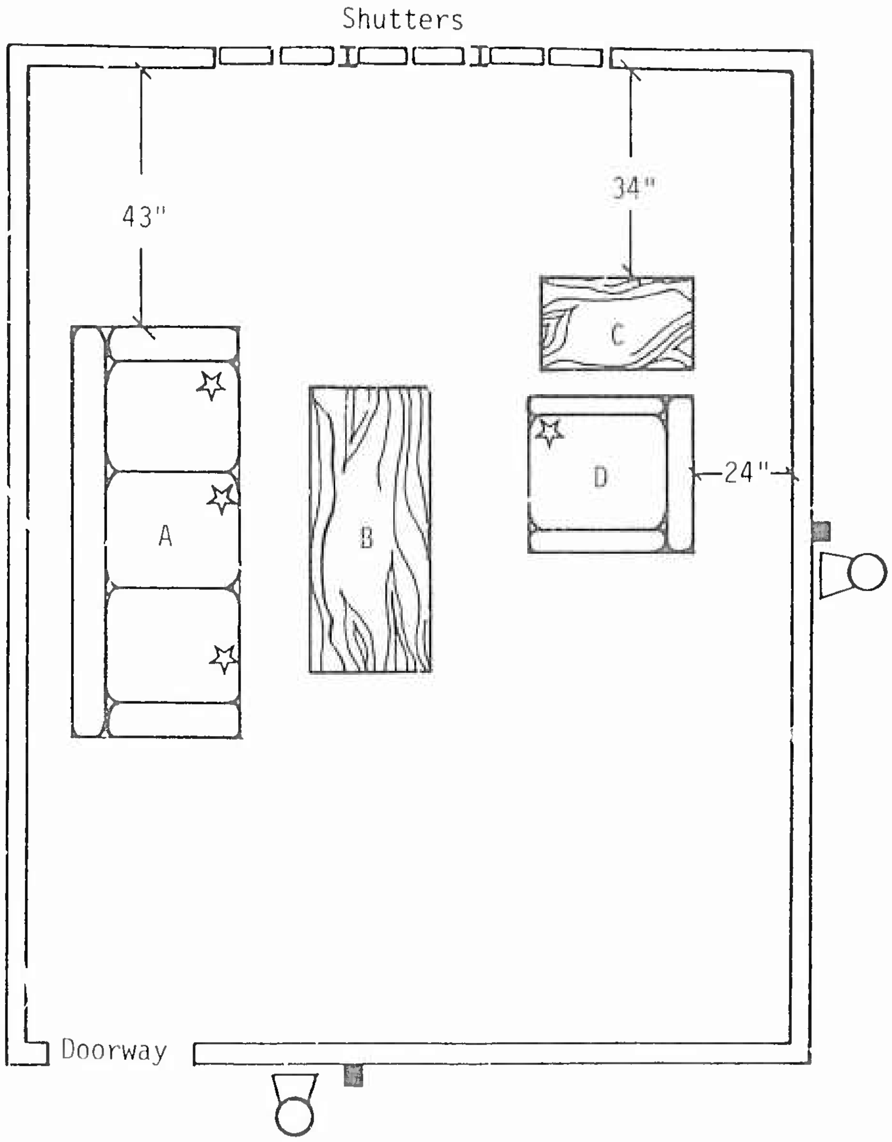
Type-- Living Room

Test Conditions

Compression Chamber Pressure	2.0	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	1.0	(psi)
Positive Phase Duration	0.97	(sec)
Delay (ignition to blast)	---	(sec)

Test Geometry and Results

The room contained a sofa, coffee table, side table and wood frame chair. In this test the shutters opened prior to ignition, thus no blast-fire data was obtained. Furniture was arranged as shown in Fig. 8-1 through 8-4.



A - 69 x 28 in. wood frame sofa with plastic cushions

B - 48 x 18 in. wood coffee table

C - 27 x 16 in. wood side table

D - 30 x 25 in. wood frame arm chair with plastic cushions

☆ Ignition sources

Fig. 8-1. Sketch of Test Geometry, Test Number 8

Fig. 8-2. Pretest Photographs, Test Number 8

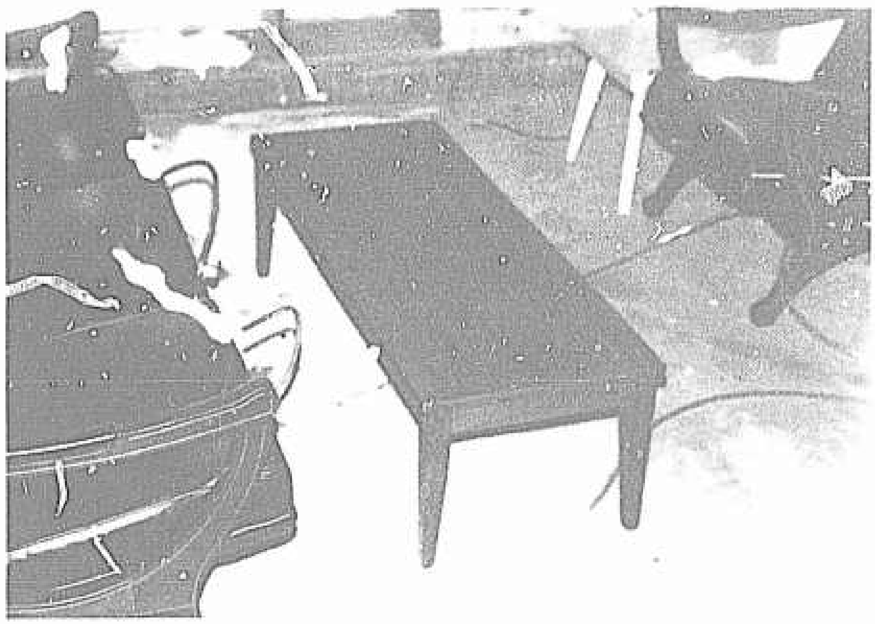
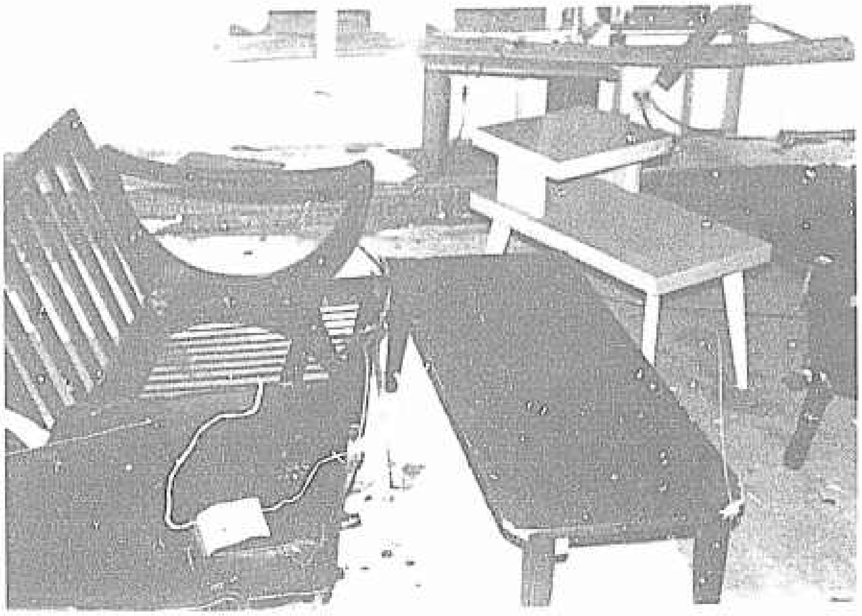


Fig. 8-3. Pretest Photographs, Test Number 8



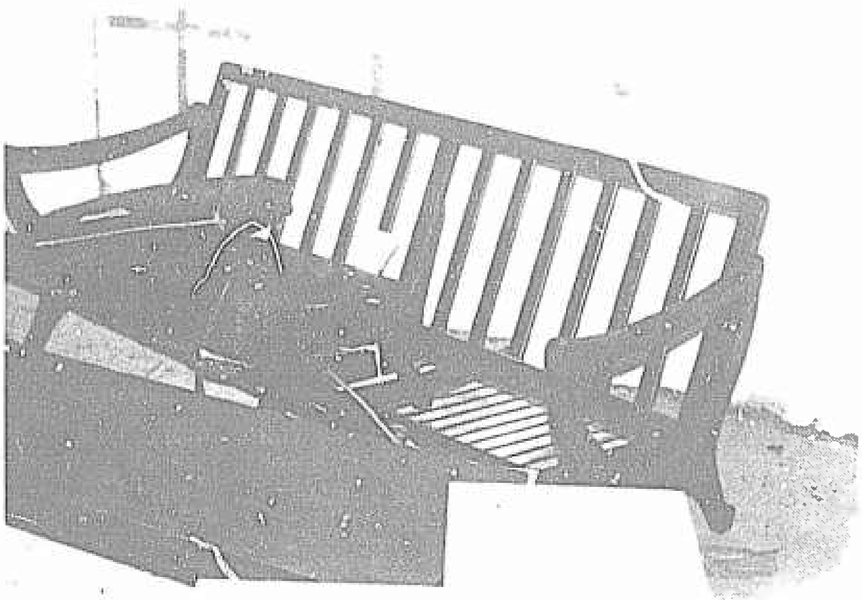


Fig. 8-4. Posttest Photographs, Test Number 8

Test Report Test Number 9

Type-- Living Room

Test Conditions

Compression Chamber Pressure	4.0	(psi)
Diaphragm Opening (planned)	21	( )

Test Geometry and Results

The room arangement was the same as that for test 8 (see Fig. 8-1). In this case the shutters failed to open and the furniture burned as can be seen in Fig. 9-1. No blast-fire interaction data was obtained.

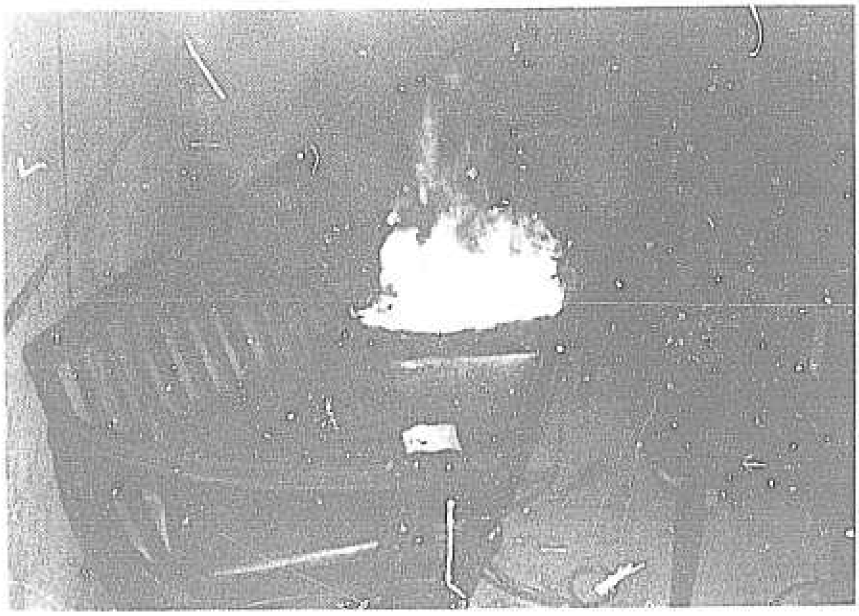


Fig. 9-1. Photograph, Test Number 9

Test Report

Test Number 10

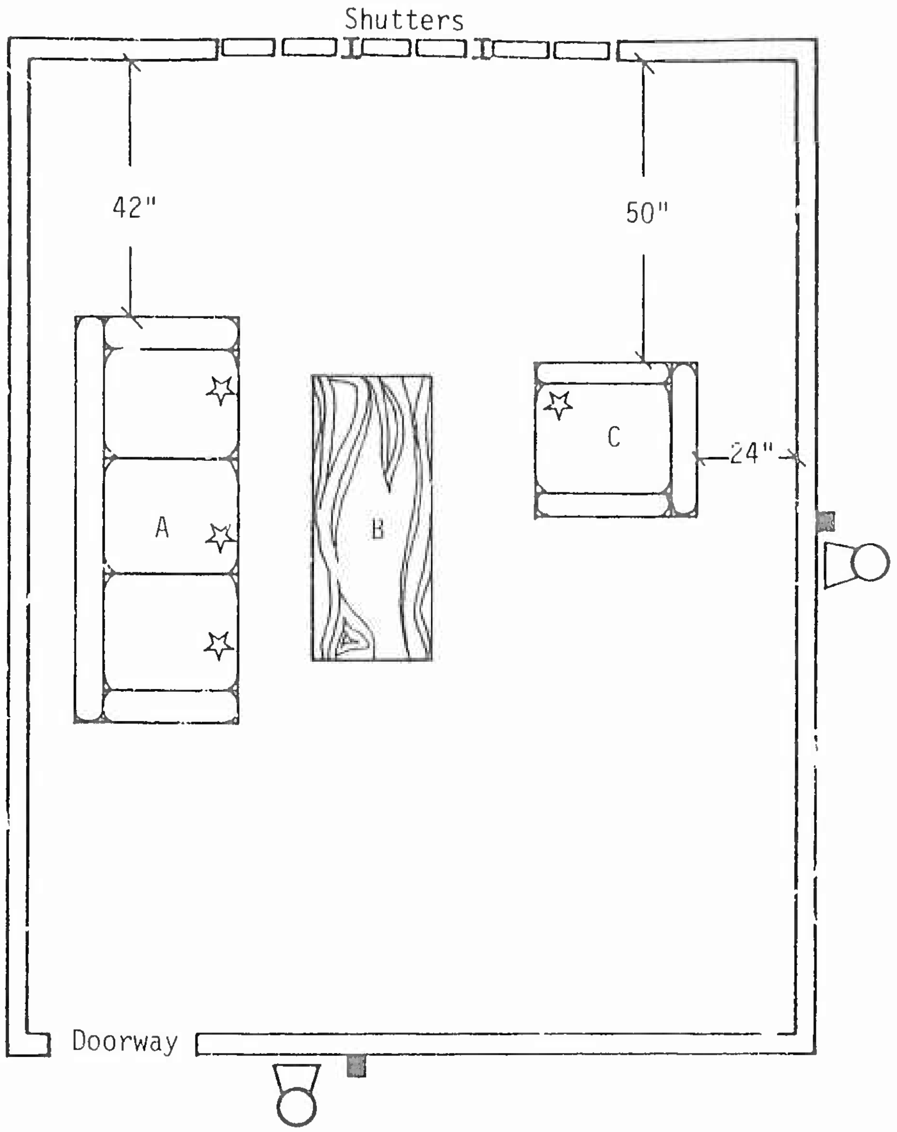
Type-- Living Room

Test Conditions

Compression Chamber Pressure	3.0	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	1.4	(psi)
Positive Phase Duration	0.97	(sec)
Delay (ignition to blast)	27	(sec)

Test Geometry and Results

The room contained a wood-frame sofa with plastic cushions, a wood coffee table, and a wood-frame arm chair with plastic cushions arranged as shown in Fig. 10-1. Both ignition and shutter opening took place as planned. All fires were blown out and stayed out. As can be seen in Fig. 10-3. both the chair and table were broken. Most of the cushions were blown outside the test room. On those that were most severely burned, the foam plastic cushioning material was separated from the plastic covers. See Fig. 10-2 and 10-4.



A - 69 x 28 in. wood frame sofa with plastic cushions

B - 48 x 18 in. wood coffee table

C - 30 x 25 in. wood frame arm chair with plastic cushions

☆ Ignition sources

Fig. 10-1. Sketch of Test Geometry, Test Number 10

Fig. 10-2. Posttest Photographs, Test Number 10

Fig. 10-3. Posttest Photographs, Test Number 10

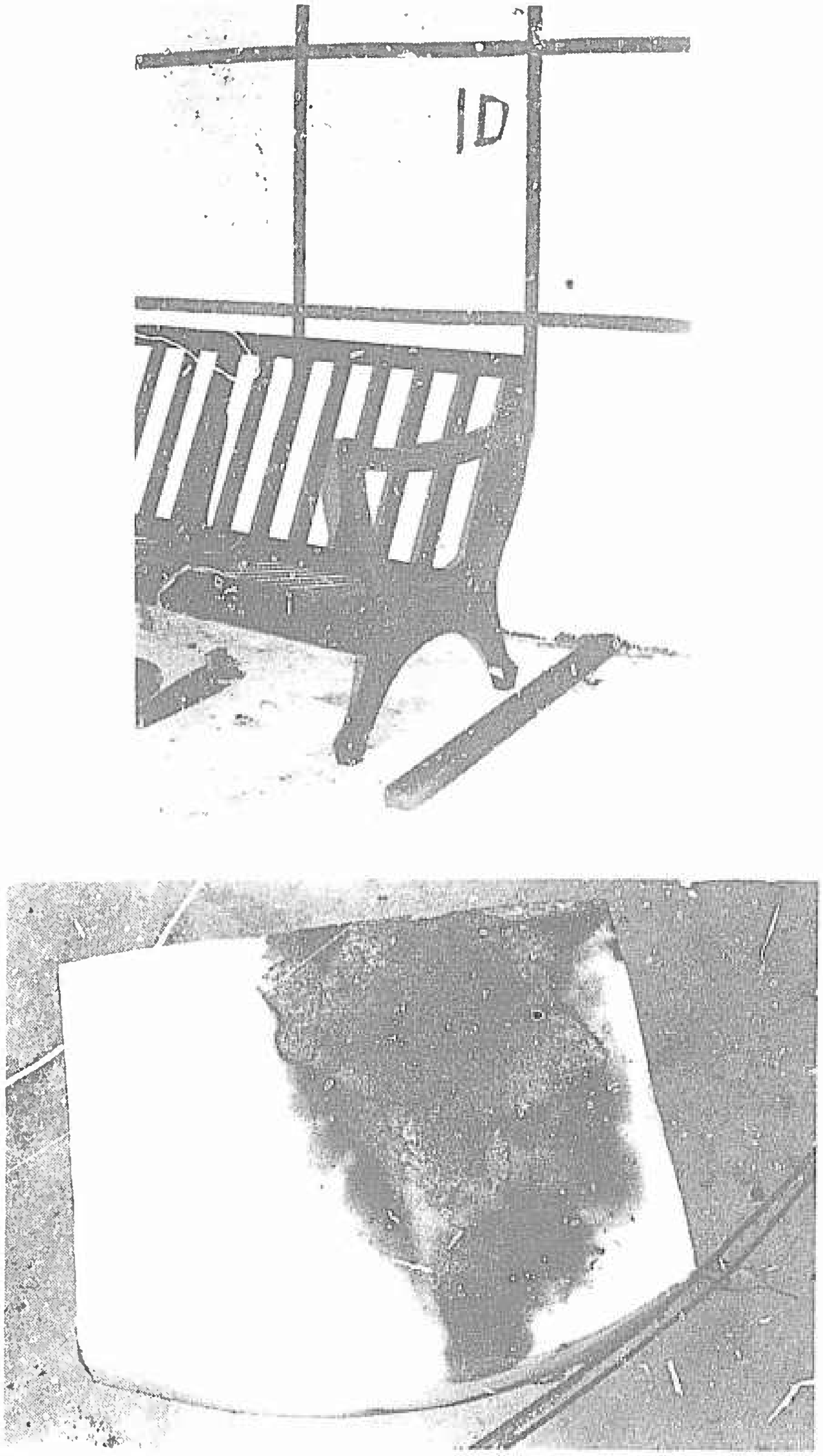


Fig. 10-4. Posttest Photographs, Test Number 10

Fig. 10-5. Posttest Photograph. Test Number 10

Test Report | Test Number 11

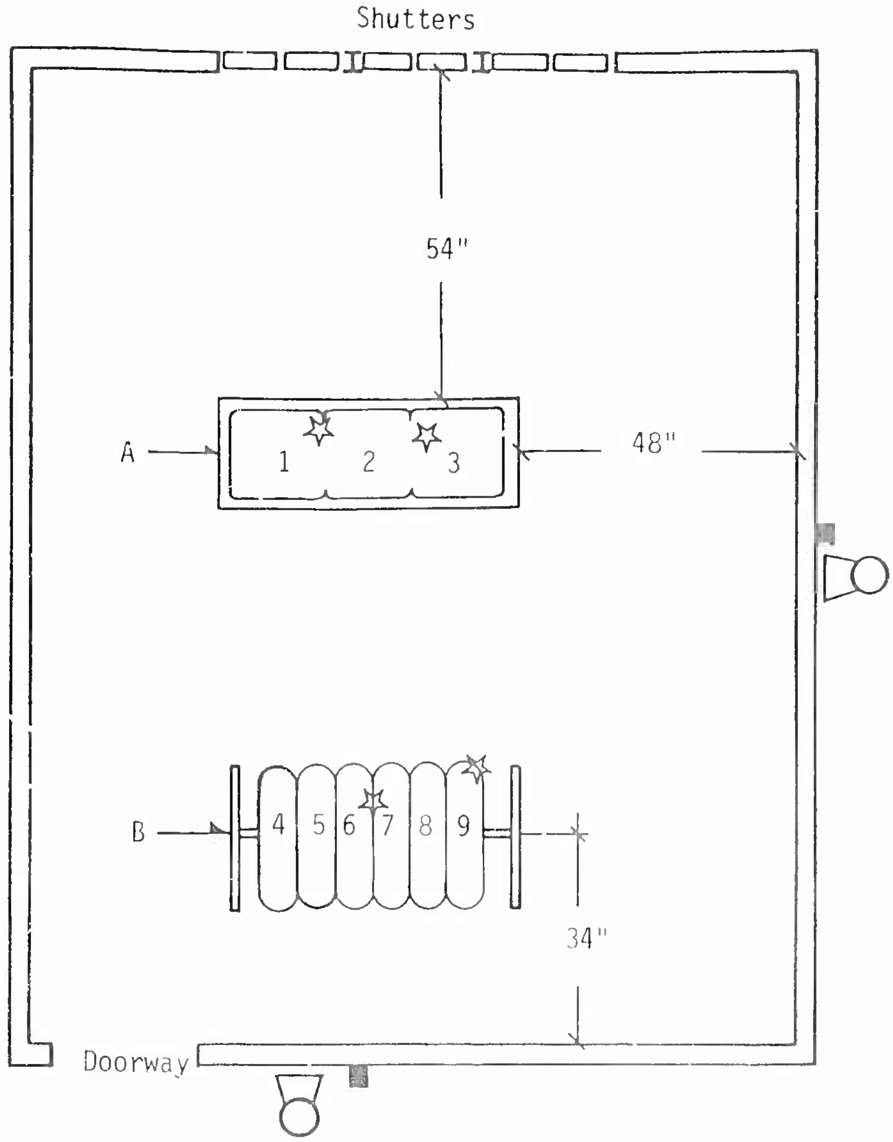
Type-- Clothing Store

Test Conditions

Compression Chamber Pressure	4.0	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	1.8	(psi)
Positive Phase Duration	1.2	(sec)
Delay (ignition to blast)	27	(sec)

Test Geometry and Results

The simulated clothing store arrangement was similar to that in Test 6, with material arrayed on tables placed upstream from a clothing rack. The table contained terry cloth, denim and 3 ft by 4 ft pieces of duck and muslin, all folded once or twice, arrayed as shown in Fig. 11-1. The clothing rack contained hanging pieces of duck and muslin. The piloted ignition flames can be seen in Figs. 11-2 and 11-3. Damage to the rack and tables was far more severe than in test 6. Most of the cloth was blown out of the room and all fires in this material were extinguished. One piece, however, that was deposited under the central shutter opening smouldered vigorously and burst into flame about 3½ minutes after the shutters opened.



A - 50 x 18 in. table

B - 49 in. long, 60 in. high clothes rack

1 - terry cloth

2 - denim

3 - mixed duck and muslin

4, 7, & 8 - muslin

5, 6, & 9 - duck

☆ Ignition sources

Fig. 11-1. Test Geometry, Test Number 11

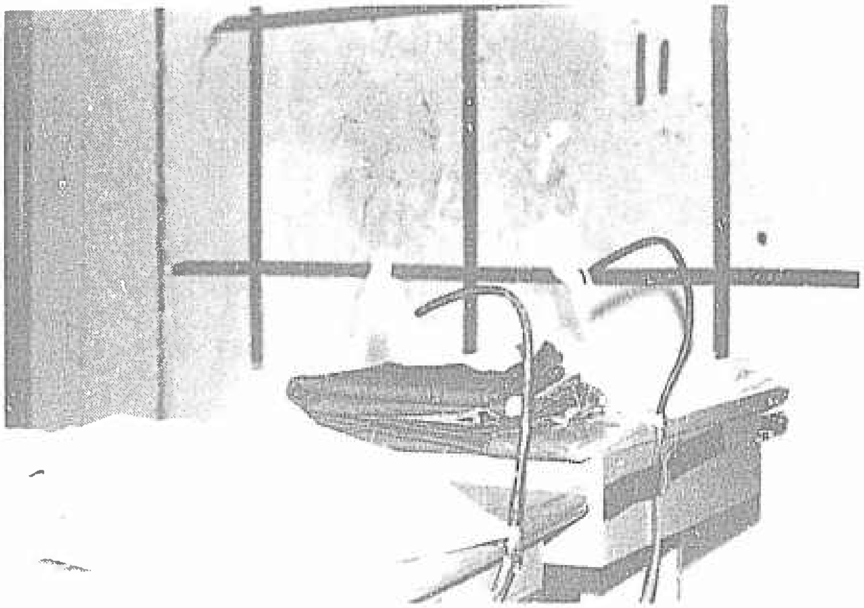


Fig. 11-2. Pretest Photographs, Test Number 11

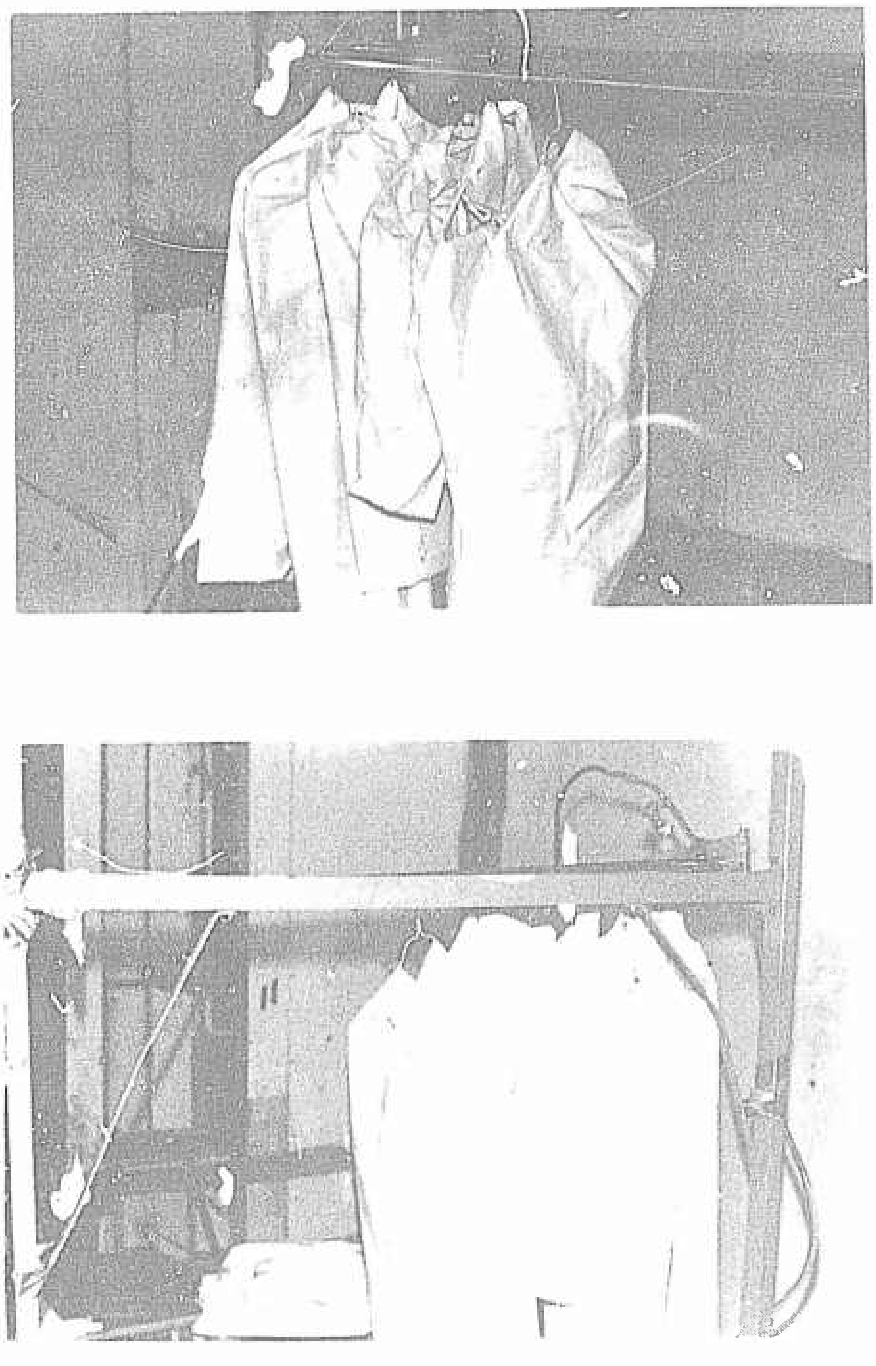
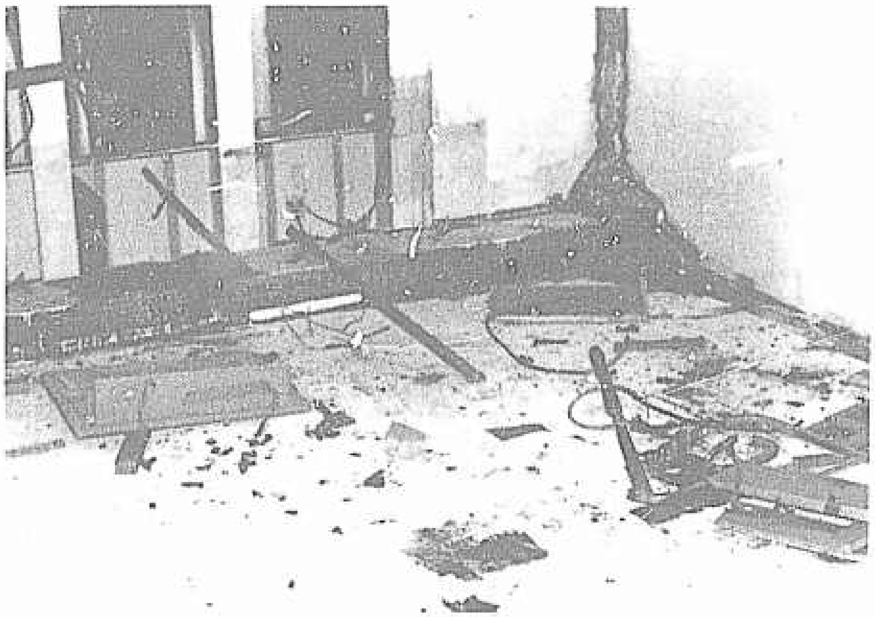


Fig. 11-3. Pretest Photographs, Test Number 11



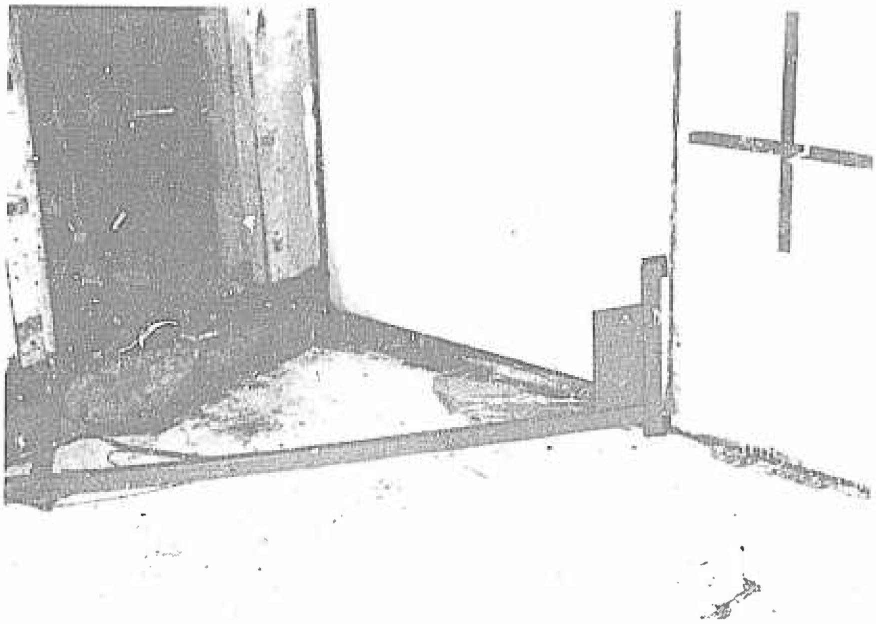


Fig. 11-4. Posttest Photographs, Test Number 11

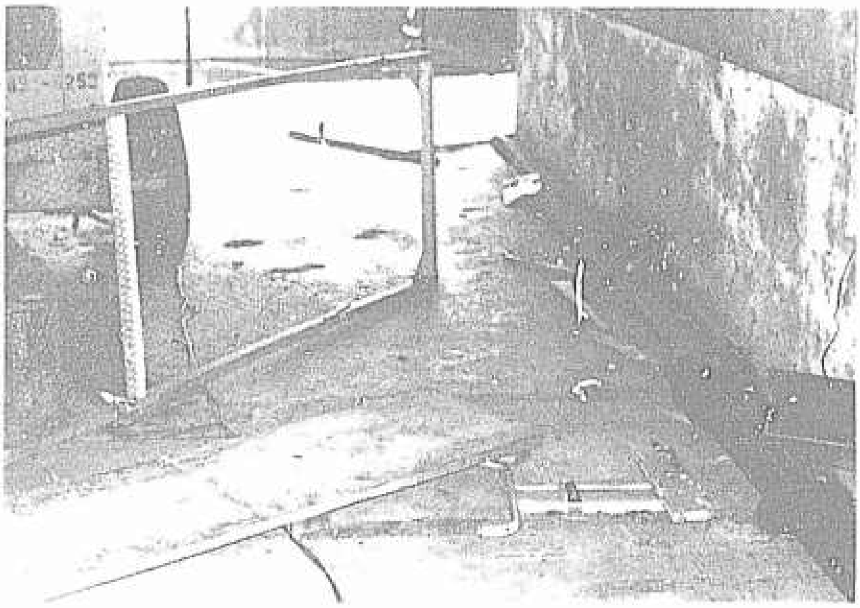


Fig. 11-5. Posttest Photographs, Test Number 11

Test Report   Test Number 12

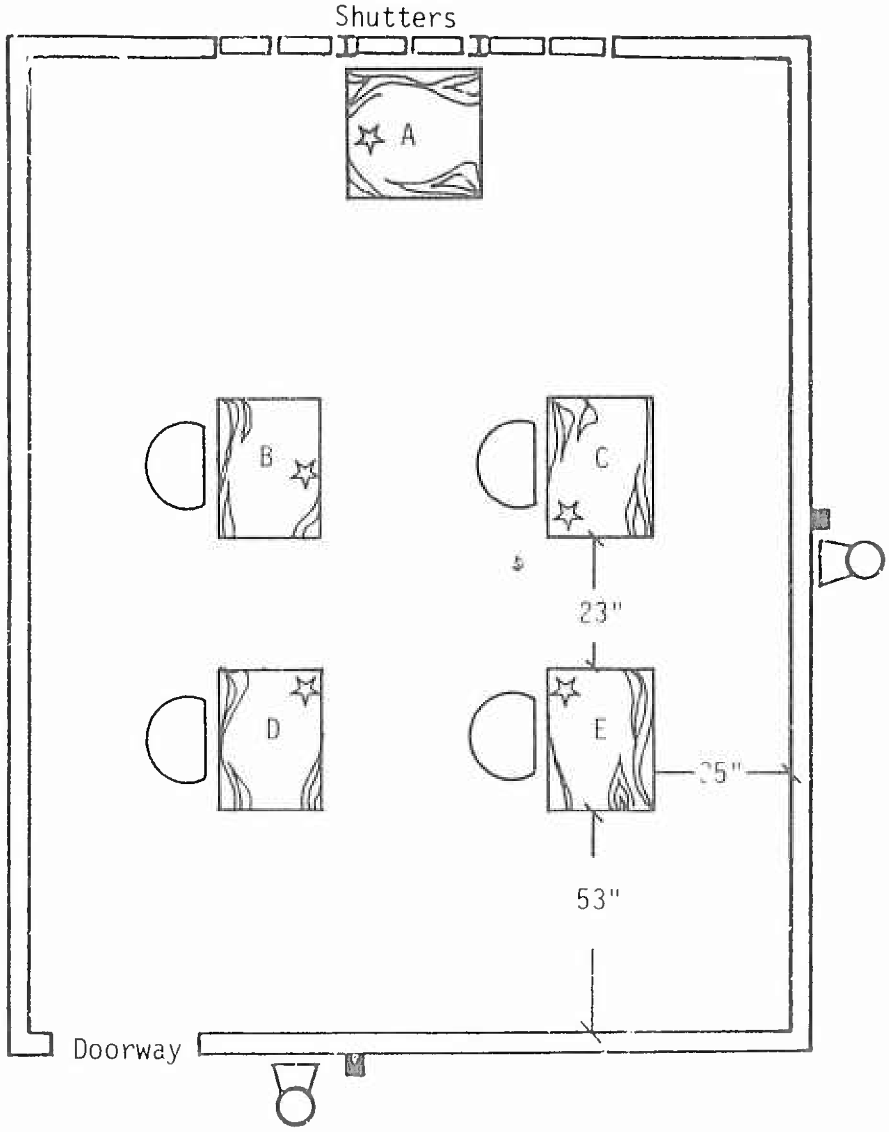
Type--School Room

Test Conditions

Compression Chamber Pressure	2.0	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	1.1	(psi)
Positive Phase Duration	0.97	(sec)
Delay (ignition to blast)	54	(sec)

Test Geometry and Results

This test was essentially a duplicate of Test 5, with a similar arrangement of desks and combustible materials (See Figs. 5-1 and 12-2). Results of the two tests were quite similar; all combustible materials were extinguished and papers were scattered about the room and into the hallway. None of the desks tipped over (one did in test 5) and they were displaced only slightly (See Fig. 12-3 and 12-4).

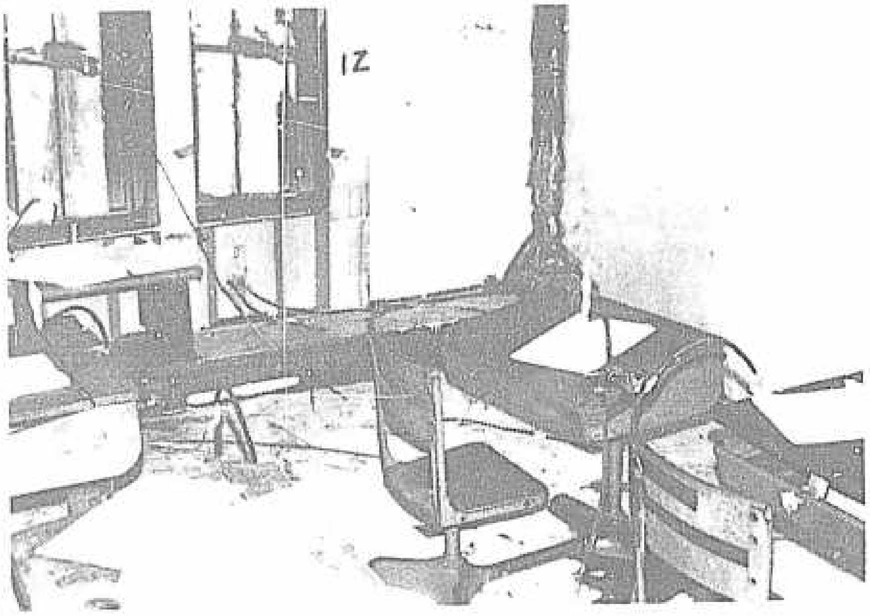


A - 24 x 22 in. wood table

B, C, D, & E - 23 x 18 in. school desk and chair

☆ Ignition sources

Fig. 12-1. Sketch of Test Geometry, Test Number 12



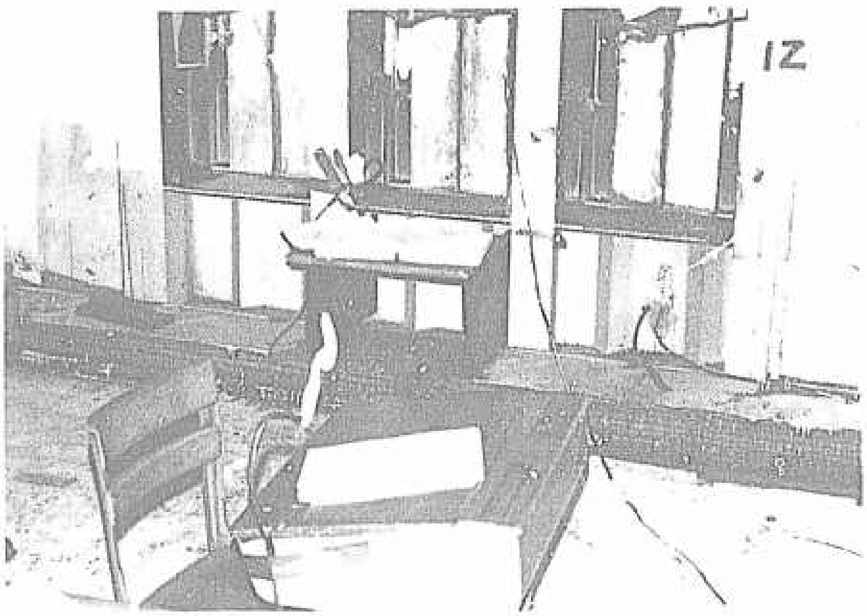


Fig. 12-2. Pretest Photographs, Test Number 12

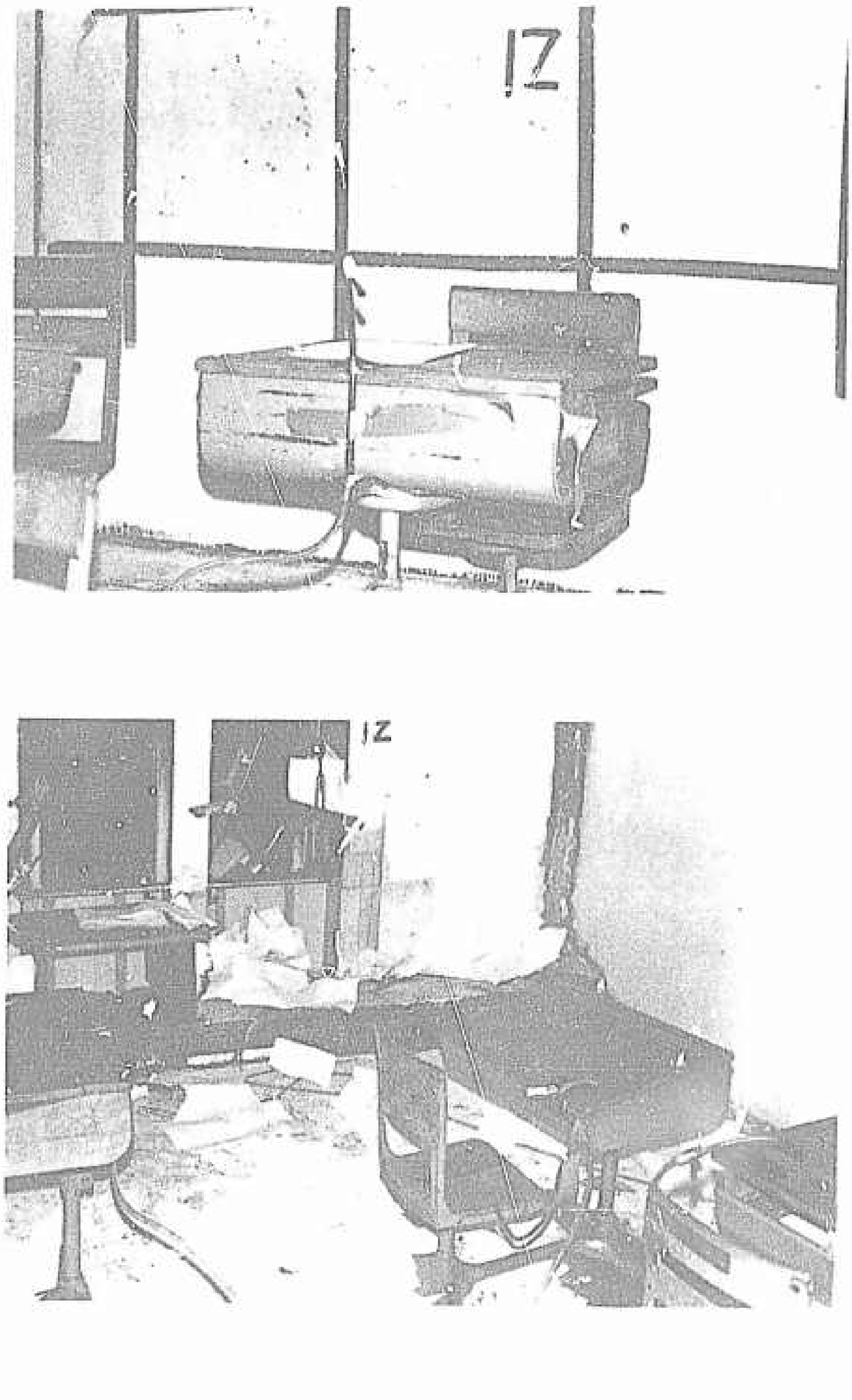
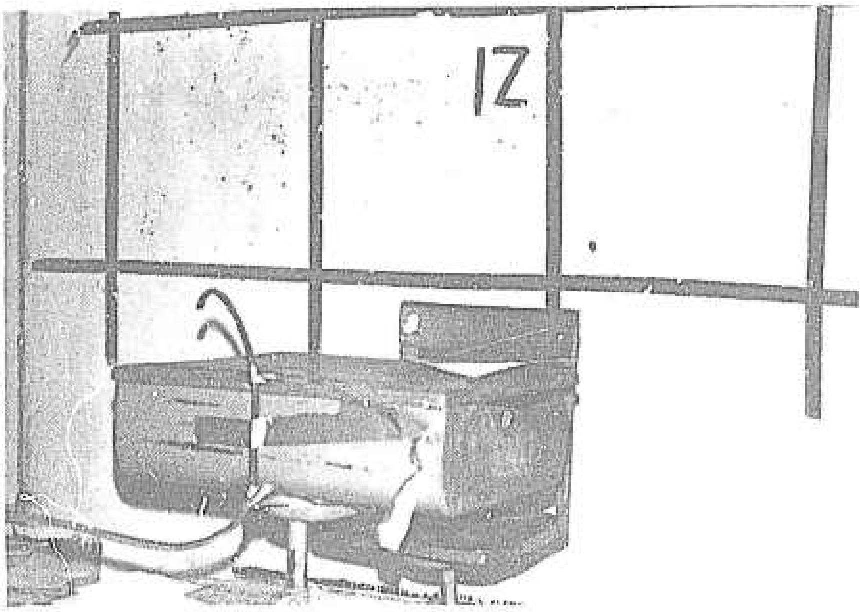


Fig. 12-3. Pre and Posttest Photographs, Test Number 12.



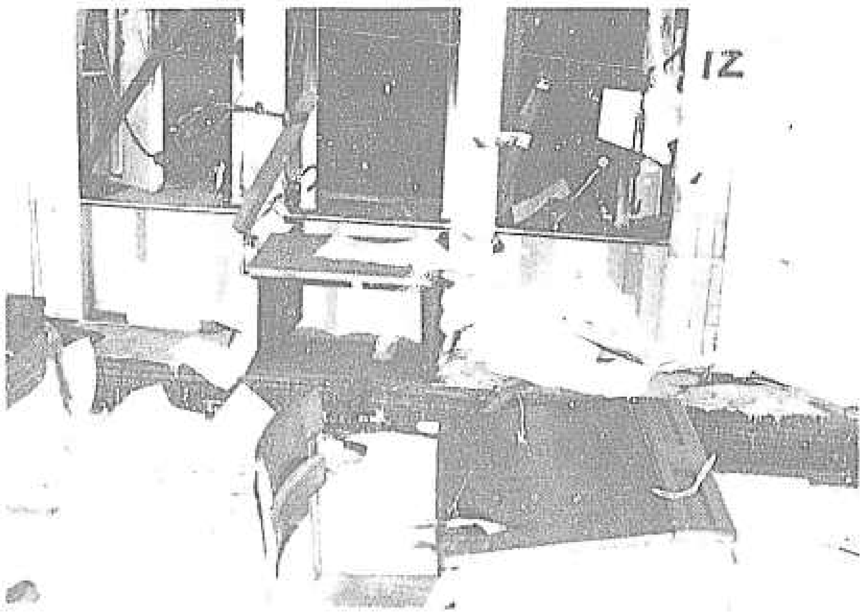


Fig. 12-4. Posttest Photographs, Test Number 12

Test Report | Test Number 13

Type-- Warehouse

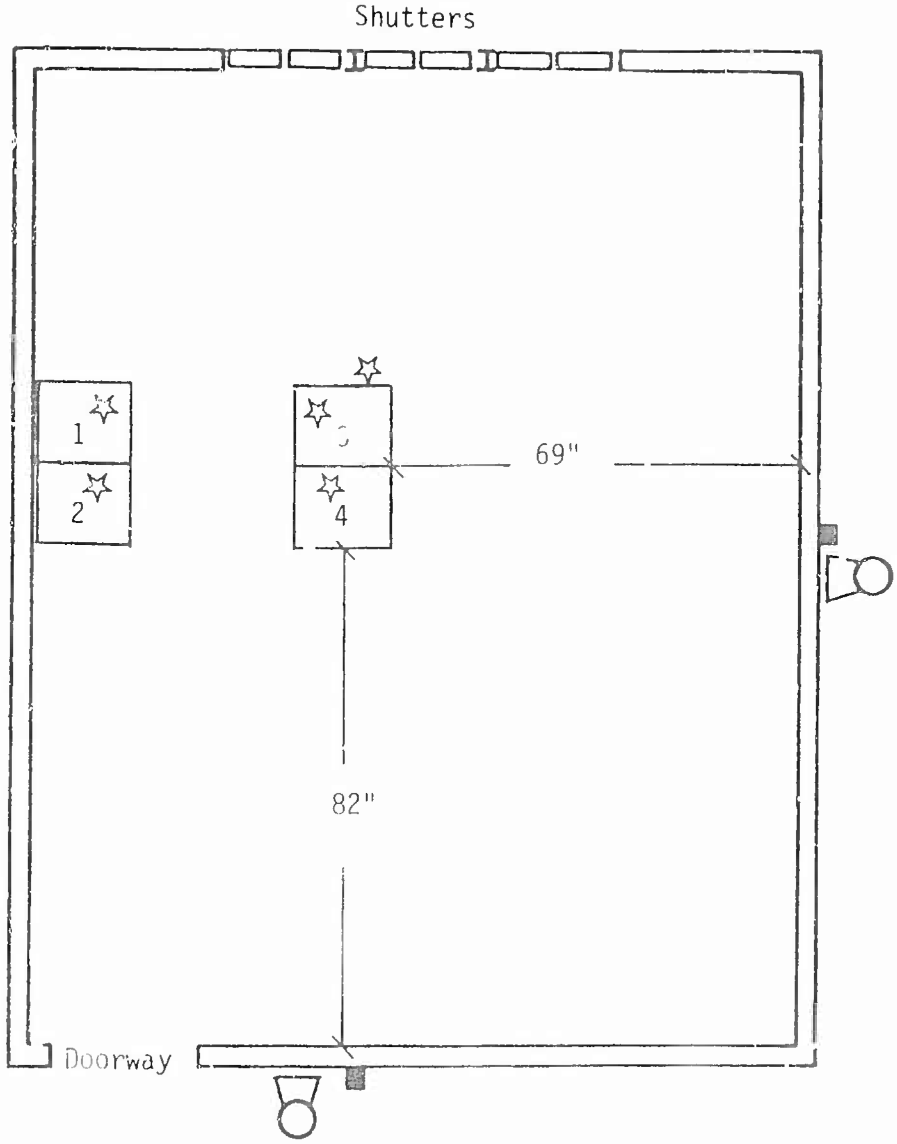
Test Conditions

Compression Chamber Pressure	3.9	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	1.7	(psi)
Positive Phase Duration	1.3	(sec)
Delay (ignition to blast)	27	(sec)

Test Geometry and Results

The overall geometry of this test resembled that of test 7 in that the boxes weighted with lead were arrayed along the side of the room closest to the doorway and the unweighted boxes containing paper were placed near the center of the room. In this test, however, there were two empty weighted boxes along the side wall, where in test 7 there were three boxes containing crumpled paper. Furthermore the central stacks consisted of six boxes (two rows, three boxes high) in this test, as shown in Fig. 13-2, in place of the nine box stack (three rows, three boxes high) of test 7. Additionally, only the front row of boxes (toward the shutters contained paper).

After the test, the side (weighted) boxes were flaming, and about one half the paper content of the central stack was distributed over the entire floor of the test room (See Fig. 13-3 and 13-4). The remainder of the paper was blown out the rear doorway and did not re-ignite.



1 & 2 - 17 x 13 x 13 in. cardboard boxes

3 & 4 - 17 x 13 x 13 in. cardboard boxes (stacked three high)

☆ Ignition sources

Fig. 13-1. Sketch of Test Geometry, Test Number 13

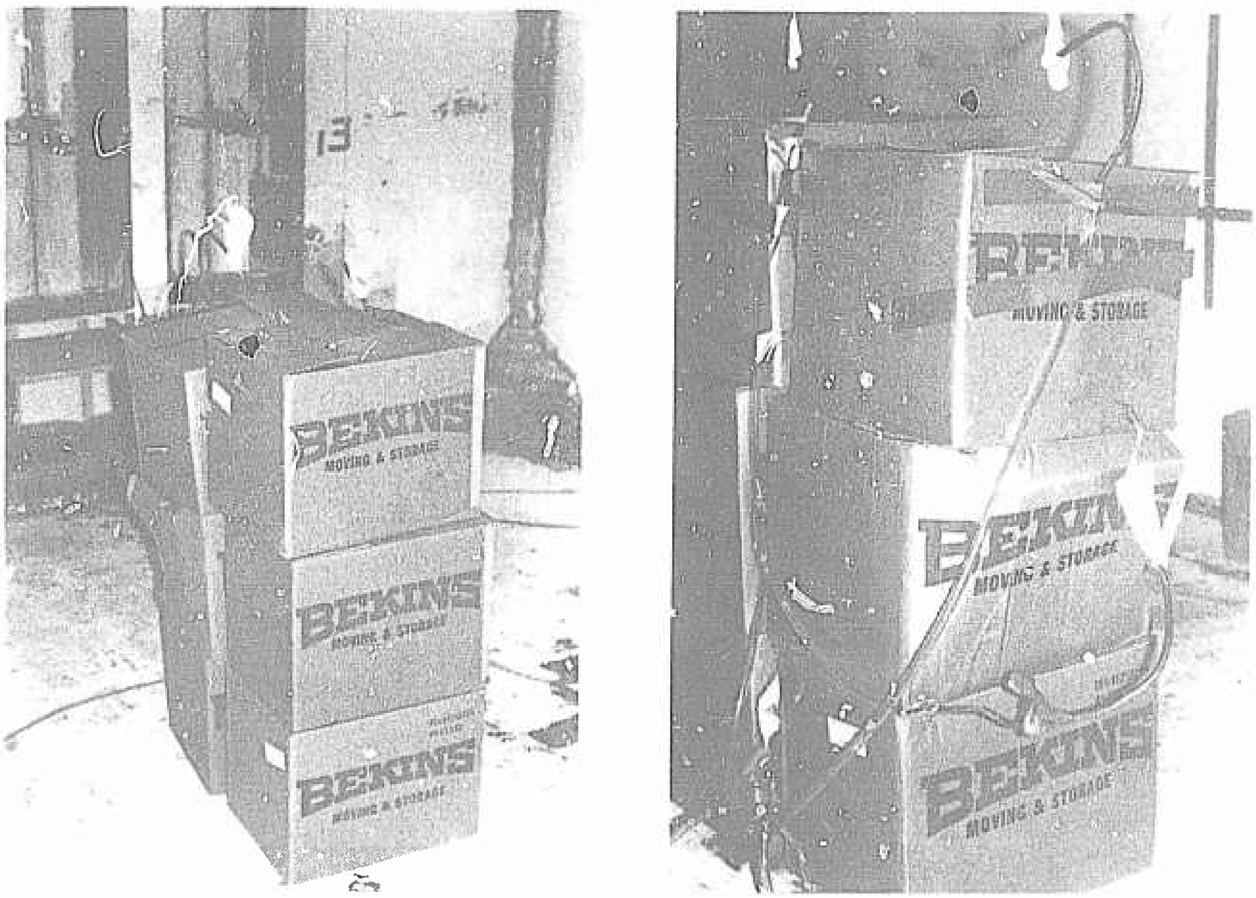


Fig. 13-2. Pretest Photographs, Test Number 13

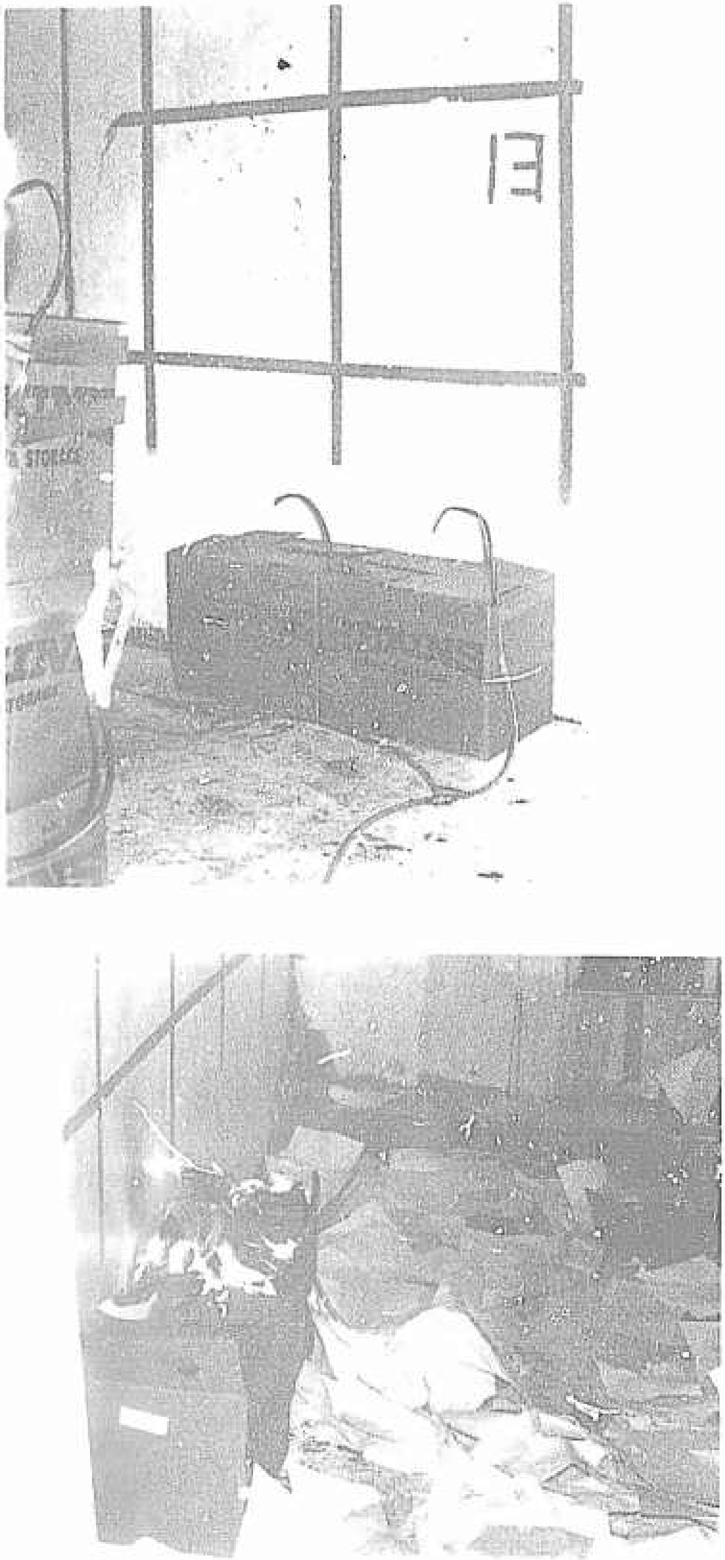


Fig. [illegible] 3. Pre and Posttest Photographs, Test Number 13

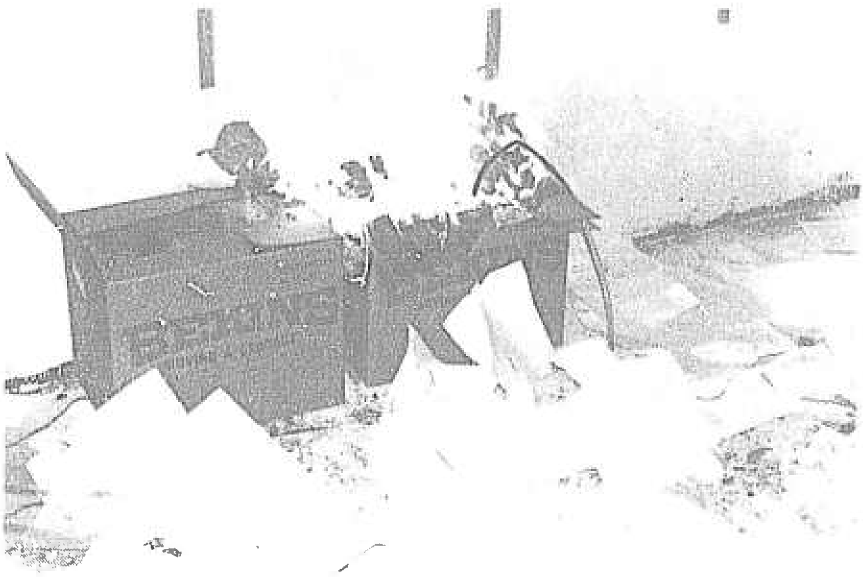


Fig. 13-4. Posttest Photograph, Test Number 13

Test Report Test Number 14

Type-- Emergency Operations Center (EOC)

Test Conditions

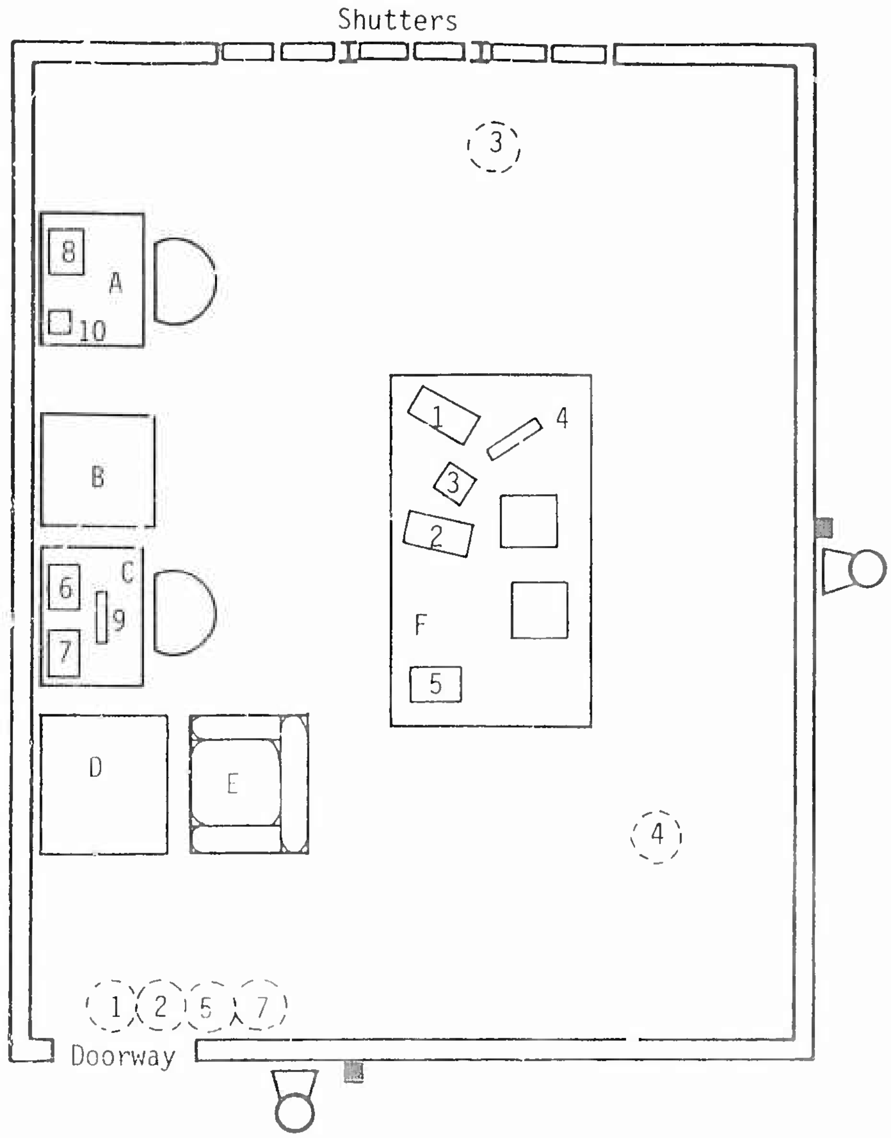
Compression Chamber Pressure	4	(psi)
Diaphragm Opening	21	(%)
Peak Pressure in Room (side wall gauge)	2.1	(psi)
Positive Phase Duration	1.4	(sec)

Test Geometry and Results

The simulated EOC test geometry is sketched in Fig. 14-1. The equipment tested included a large radio rack, teletype, desks, chair and numerous items of radiation equipment. These items were as follows:

Item Number	Item
1	CDV-717 Model 1-1 (94500)
2	CDV-715 Model 1-A (95049)
3	Charger (55918)
4	Dosimeter (0852045)
5	CDV-700 Model 6A (56659)
6	CDV-1A (37641)
7	CDV-6A (28804)
8	CDV (16010)
9	Dosimeter (0829919)
10	Charger (02429)

The pretest arrangement (including the above items of equipment) is shown in Figs. 14-2 through 14-6. The blast severely damaged the desk, originally located in the center of the room. The top was broken in half and was found in front of the doorway. Most of the remainder of the desk was found outside the door in the hallway. The teletype and chair were heavily damaged and were found in the outside corridor. The chair was 17 ft from the doorway and the teletype 38 ft. Items 1, 2, 5, and 7 were found in front of the doorway under the debris from the desk. All were damaged and only two of them showed any response when turned on. Item 4 (dosimeter) was badly damaged and was found near the back wall. All other items were undamaged. Posttest photographs from this test are presented in Figs. 14-7 through 14-14.



A & C - 23 x 18 in. school desks

B - 20 x 20 x 84 in. relay rack

D - 20 x 24 x 27 in. teletype

E - steel frame chair with plastic cushions

F - 34 x 60 in. wood desk

Note: For descriptions of equipment 1 through 8 see text. Numbers in dotted circles indicate posttest locations.

Fig. 14-1. Sketch of Test Geometry, Test Number 14

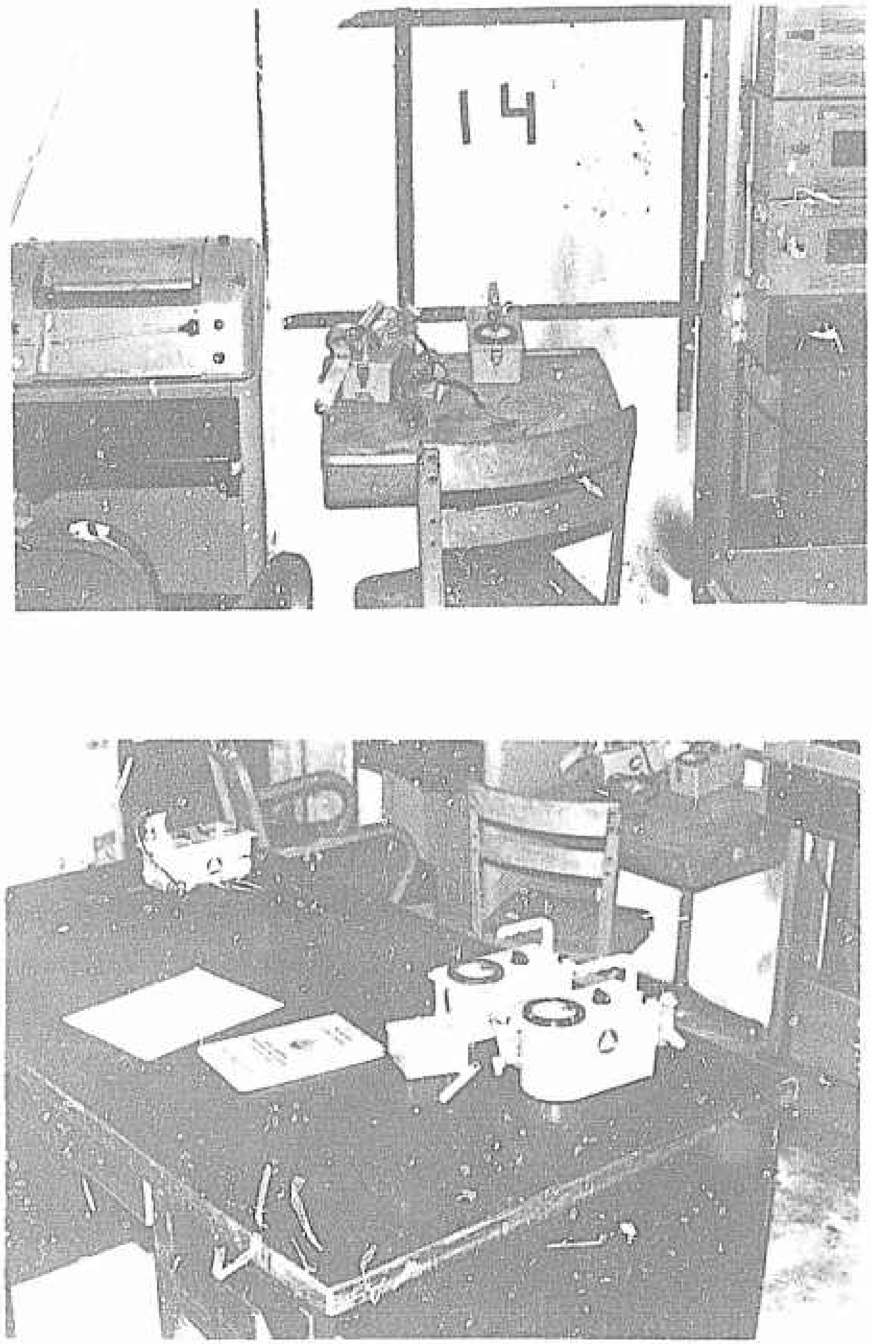


Fig. 14-2. Pretest Photographs, Test Number 14

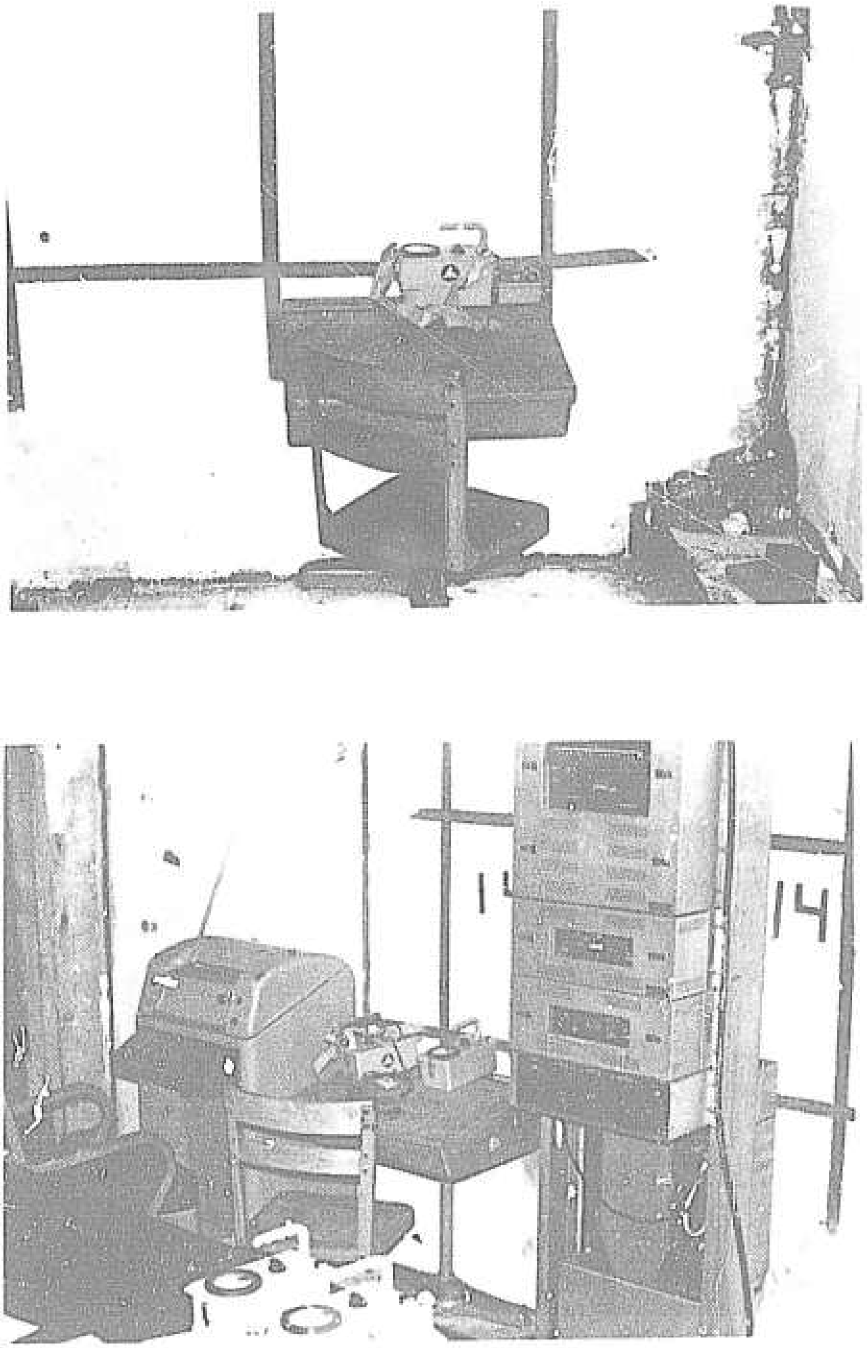
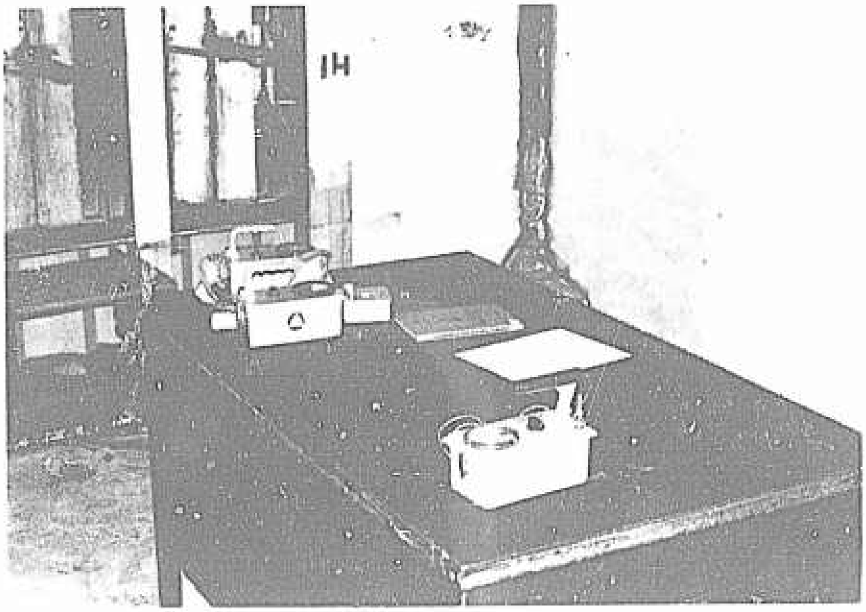


Fig. 14-3. Pretest Photographs, Test Number 14



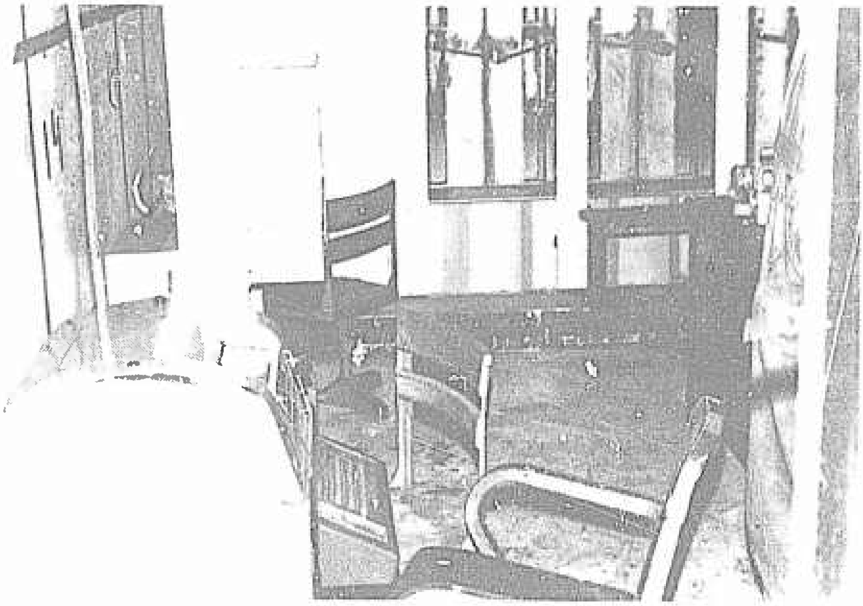
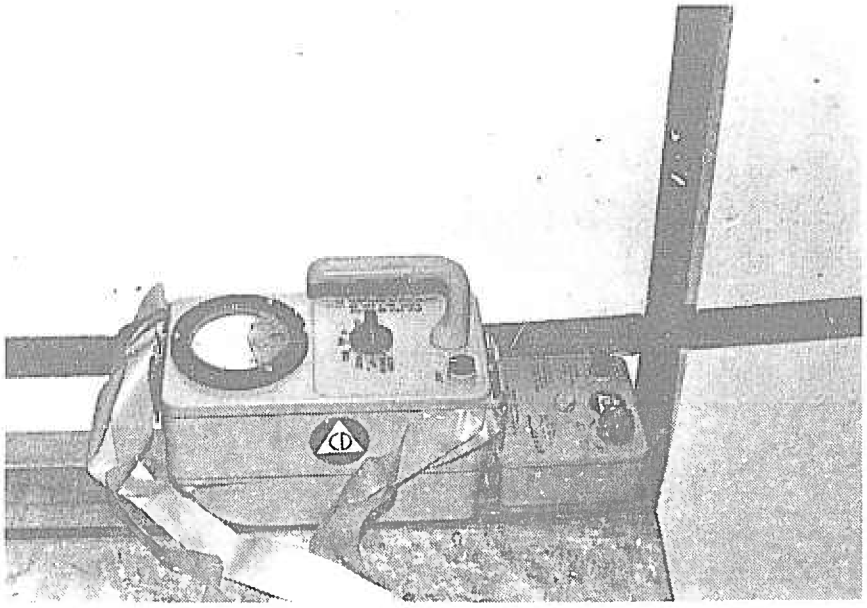


Fig. 14-4. Pretest Photographs, Test Number 14



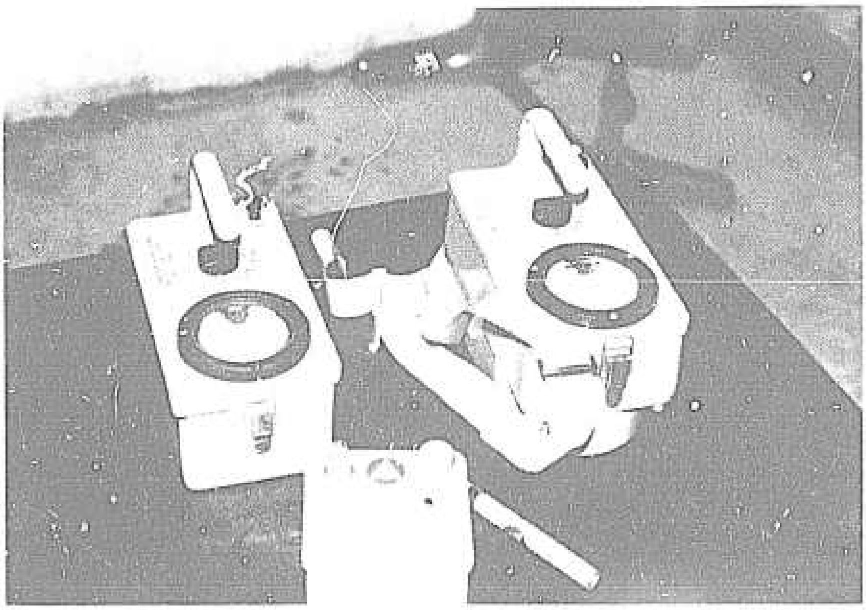
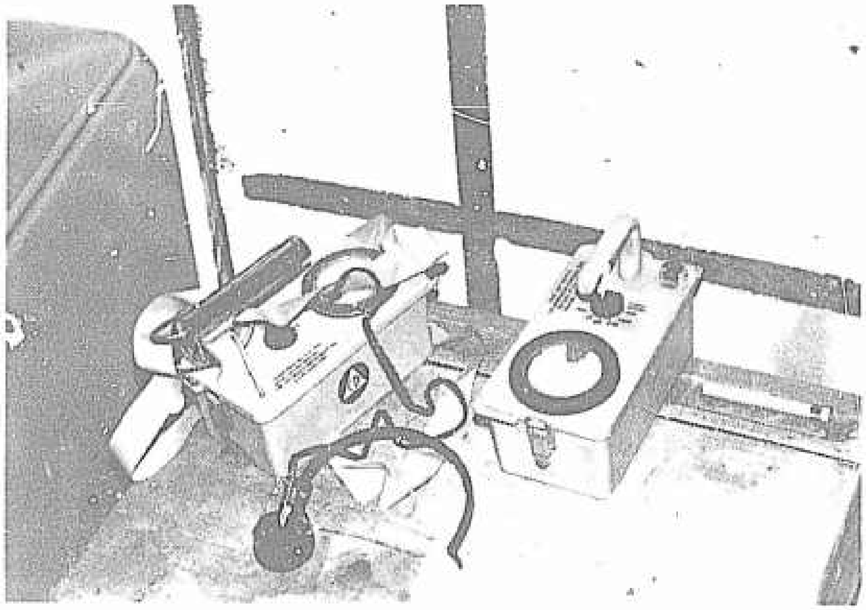


Fig. 14-5. Pretest Photographs, Test Number 14



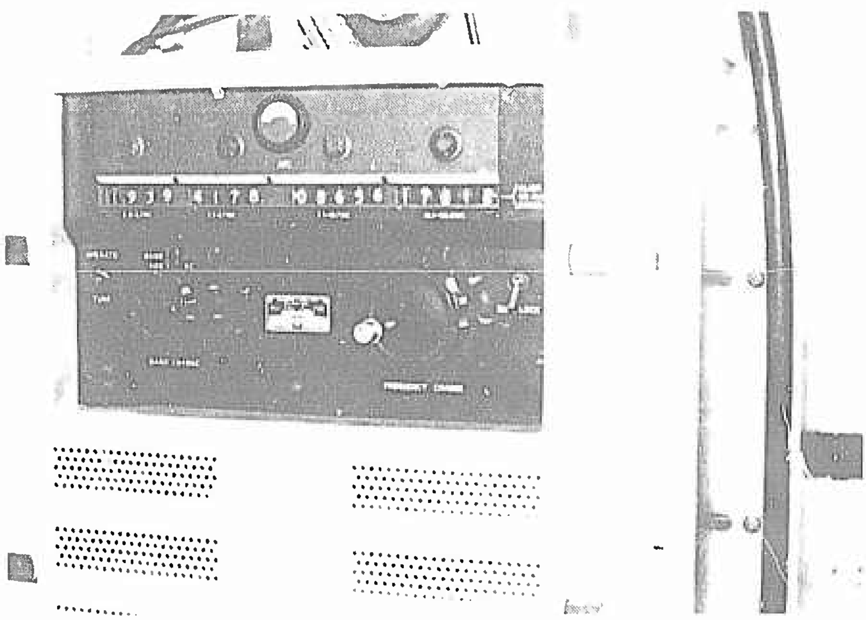


Fig. 14-6. Pretest Photographs, Test Number 14

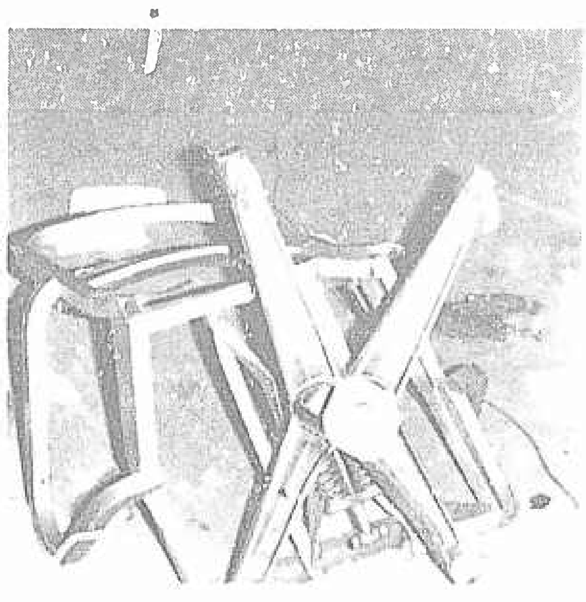


Fig. 14-7. Posttest Photographs, Test Number 14.

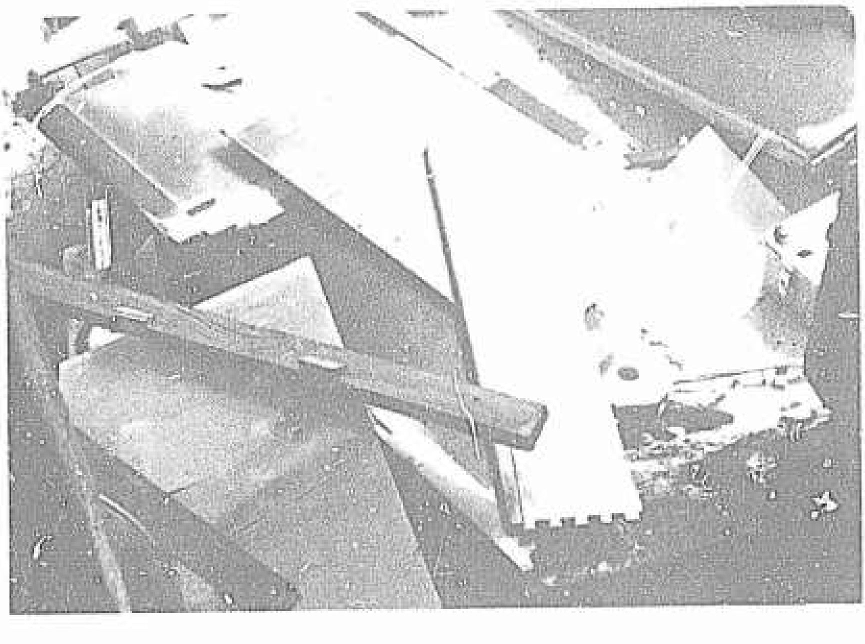


Fig. 14-8. Posttest Photographs, Test Number 14

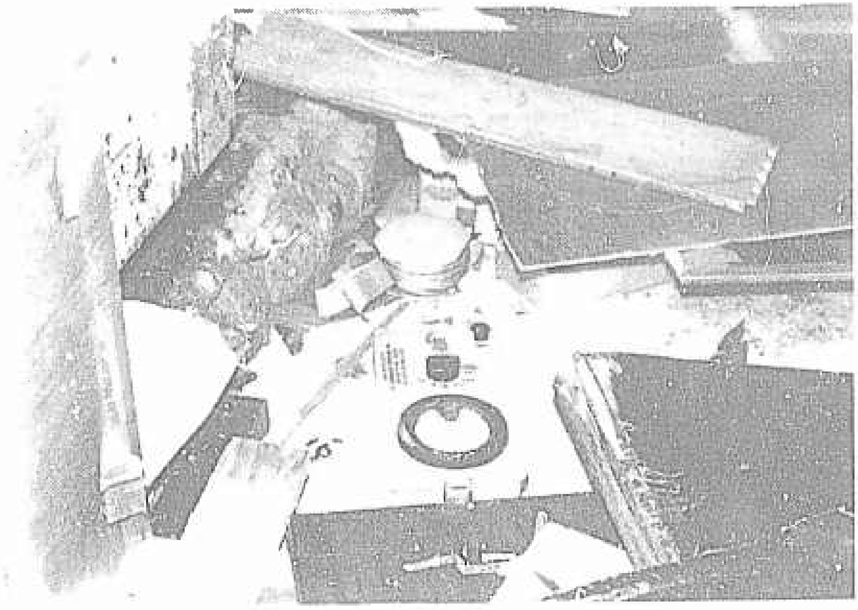


Fig. 14-9. Posttest Photographs, Test Number 14

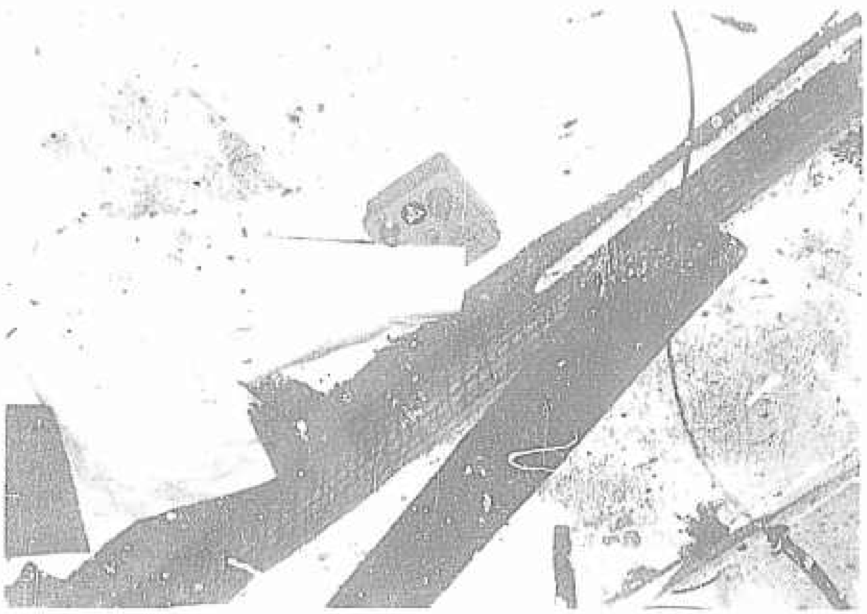


Fig. 14-10. Posttest Photographs, Test Number 14

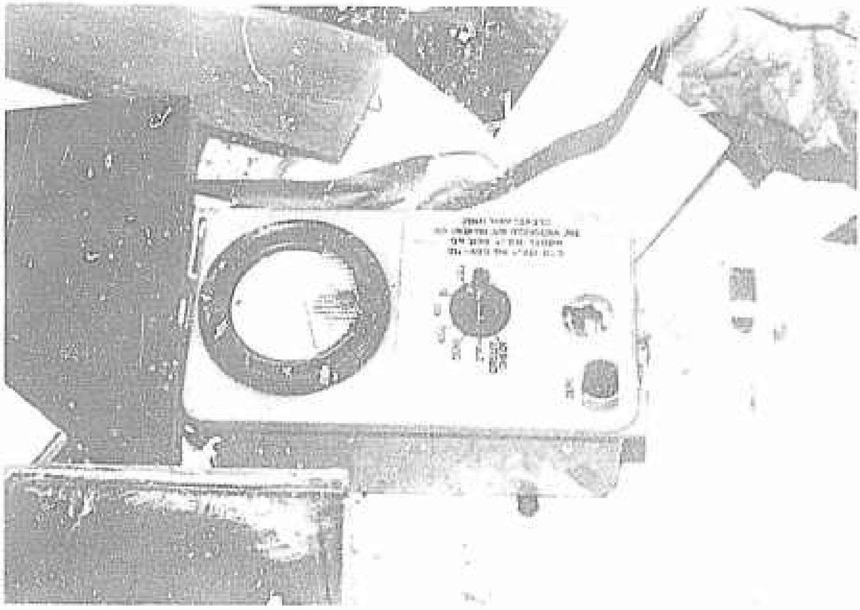
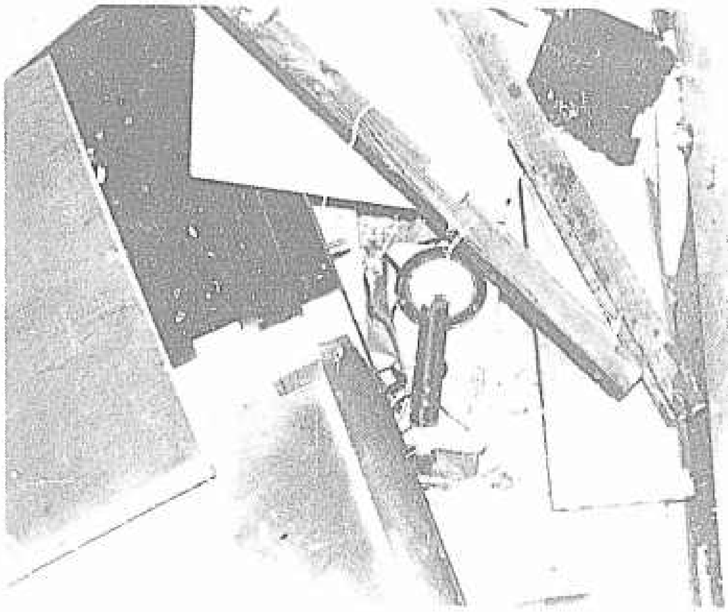


Fig. 14-11. Posttest Photographs, Test Number 14



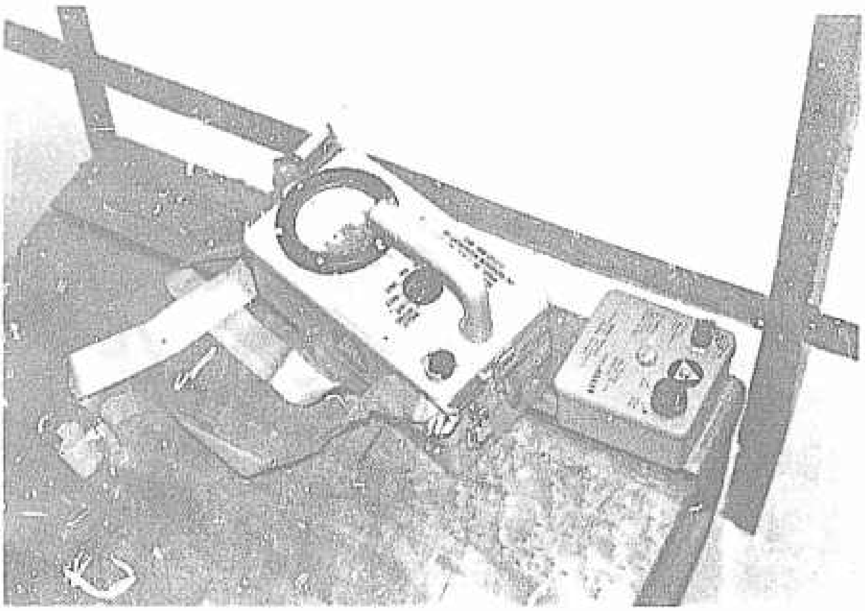


Fig. 14-12. Posttest Photographs, Test Number 14

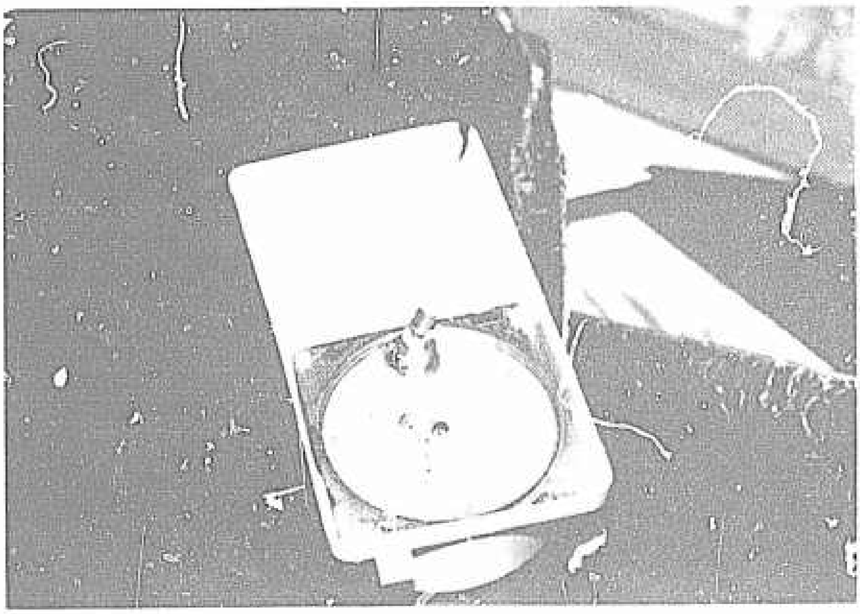


Fig 14-13. Posttest Photographs, Test Number 14

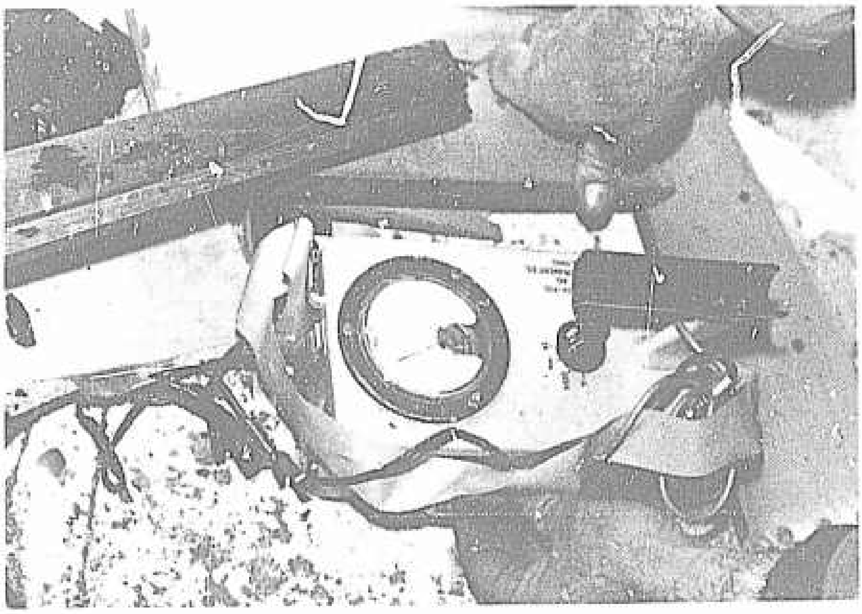


Fig. 14-14. Posttest Photograph, Test Number 14

Test Report | Test Number 15

Type-- Clothing Store

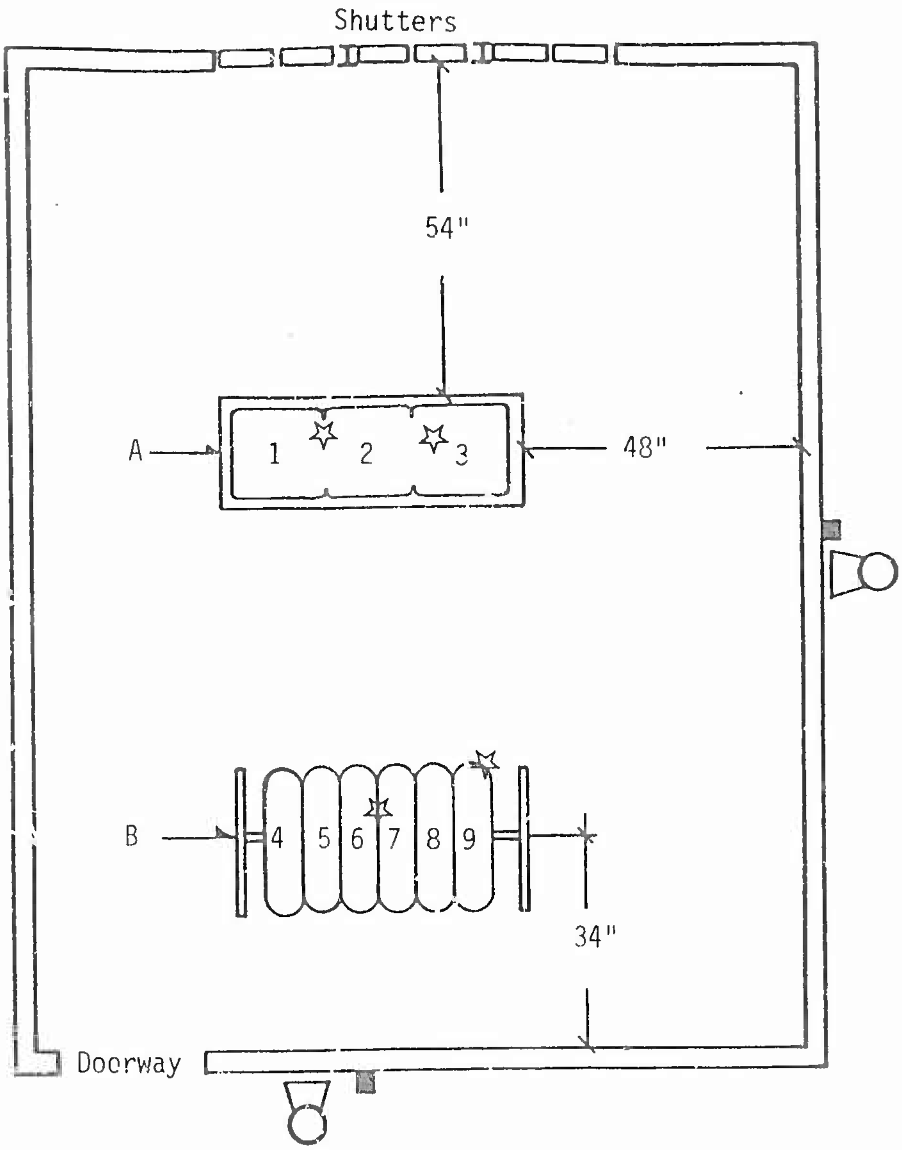
Test Conditions

Compression Chamber Pressure	5.75	(psi)
Diaphragm Opening	21	(%)
Average Pressure in Room	3	(psi)
Positive Phase Duration	1.4	(sec)
Delay (ignition to blast)	Very short	(sec)

Test Geometry and Results

The general contents and arrangement of this simulated clothing store were the same as those used in Tests 6 and 11. As sketched in Fig. 15-1, tables containing folded pieces of terry cloth, muslin, denim, and drill were placed upstream from a rack from which hung pieces of drill and muslin. The photographs of Fig. 15-2 are two pre-test views of the room which show the materials as well as the piloted propane ignition sources.

The tables and rack were virtually destroyed by the air flow following the opening of the shutters, and most of the cloth was thrown out of the room. One piece of drill that was thrown some 60 ft from the doorway smouldered but did not reignite. As with Test 11, one piece of smouldering muslin was deposited under the central shutter, and reignited about five minutes after the shot.



A - 50 x 18 in. table

B - 49 in. long, 60 in. high clothes rack

1 - terry cloth

2 - denim

3 - mixed duck and muslin

4, 7, & 8 - muslin

5, 6, & 9 - duck

☆ Ignition sources

Fig. 15-1. Sketch of Test Geometry, Test Number 15

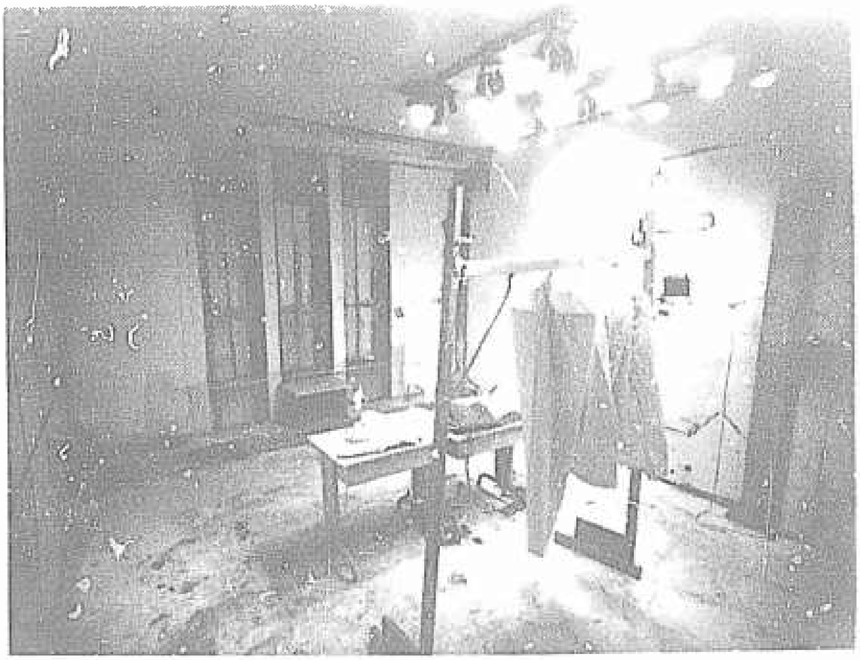


Fig. 15-2. Pretest Photographs, Test Number 15

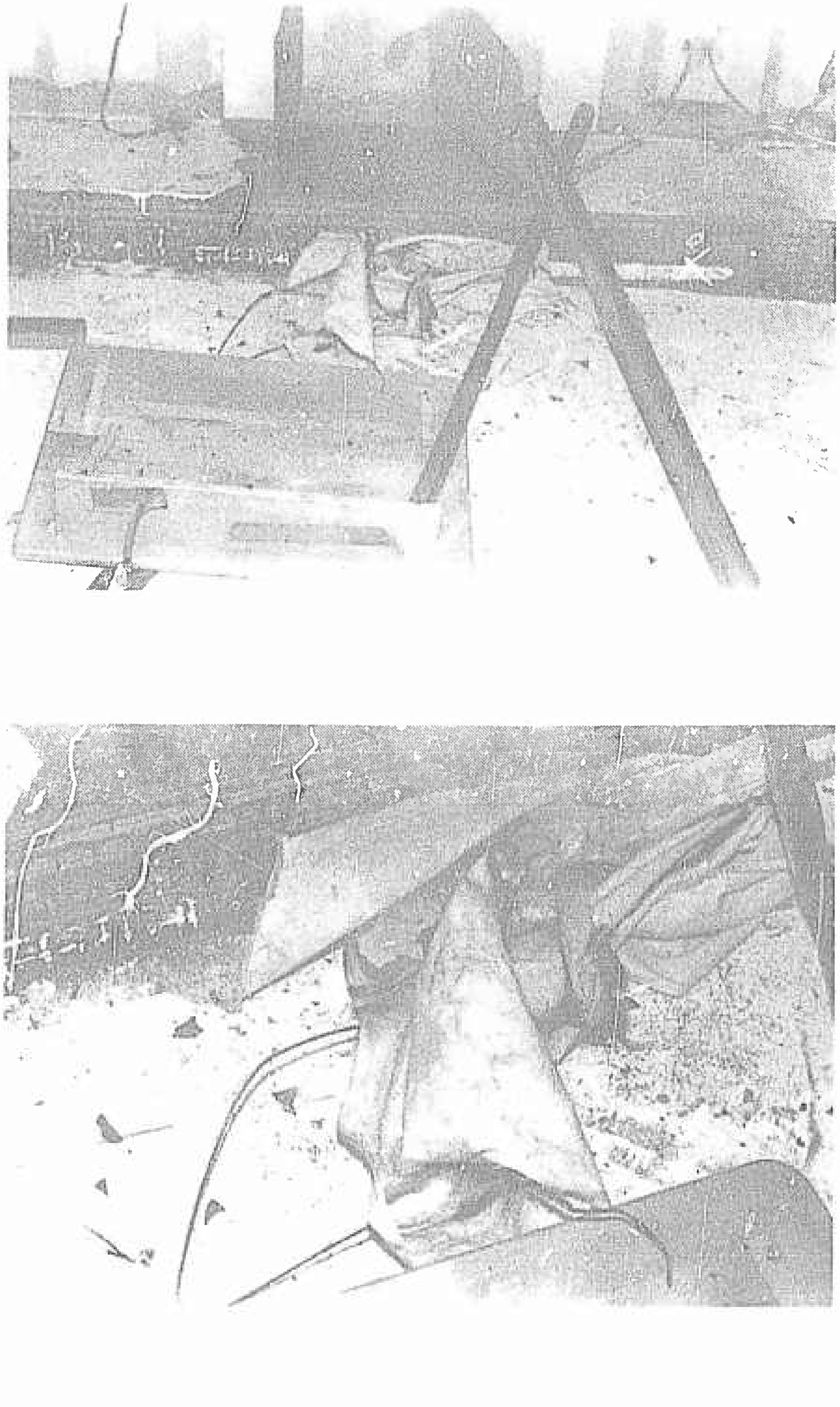


Fig. 15-3. Posttest Photographs, Test Number 15

Test Report

Test Number 16

Type-- Warehouse

Test Conditions

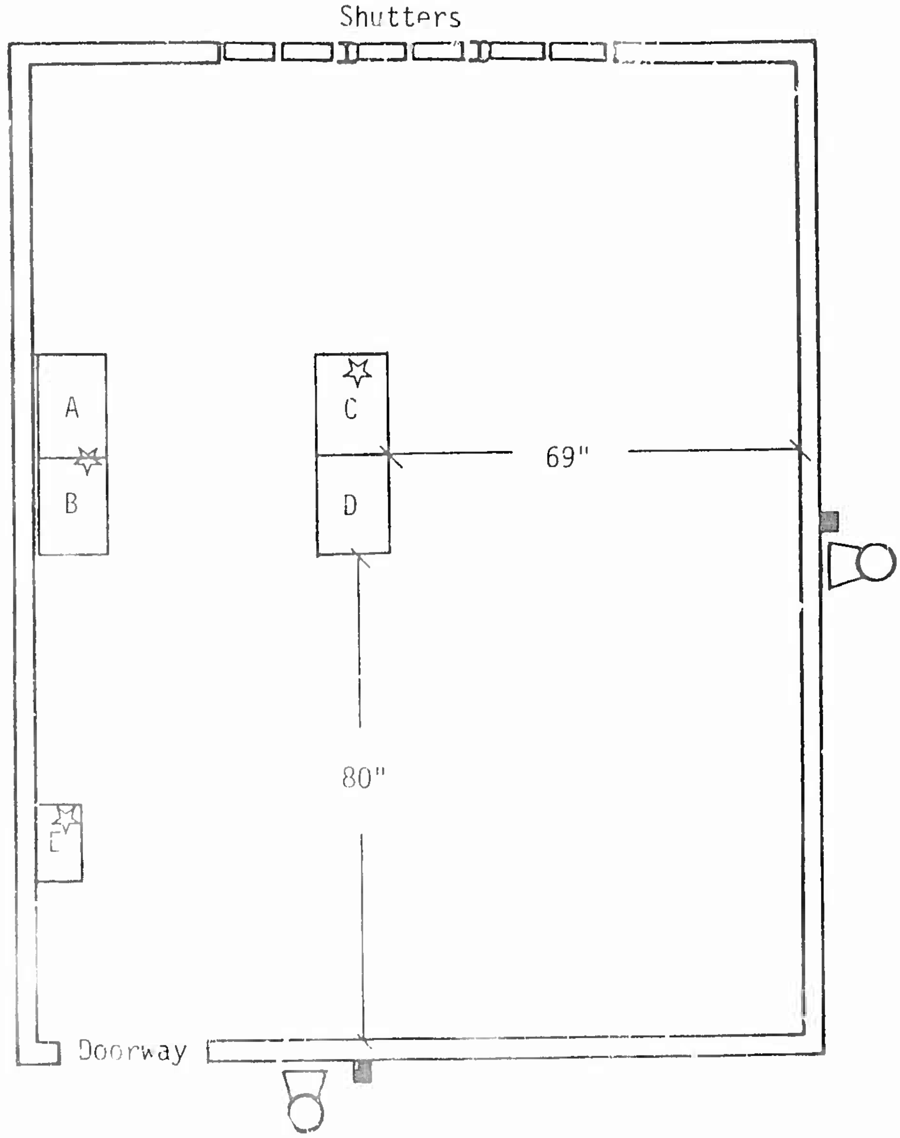
Compression Chamber Pressure	6.25	(psi)
Diaphragm Opening	21	(%)
Average Pressure in Room	3	(psi)
Positive Phase Duration	1.3	(psi)
Delay (ignition to blast)	7	(sec)

Test Geometry and Results

The basic test geometry was very similar to that of Test 13, with two, lead-weighted, empty boxes along the side wall near the rear doorway, and a stack of boxes, two deep and three high, containing fairly large amounts of uncrumpled paper, was placed in the center of the room. One feature added for this test was an 8.5 in. x 12.5 in. x 8 in. wire cage (actually a guinea pig cage) near the doorway in which papers were placed and ignited. This was the first of the "confined fuel" tests designed to investigate the effect of preventing burning elements from being transported out of the test room. Fig. 16-1 is a sketch of the room arrangement; the pretest photographs of Fig. 16-2 show the wire cage in place, and the location of ignition sources.

Results of the test were quite similar to those of the tests conducted at about 1/3 and 2/3 the chamber pressure of this test. (The chamber pressure of Test 7 was about 2 psi, and that of Test 13 about 4 psi.) All burning materials from the center stack were extinguished and large masses of unburnt paper from that stack were distributed about the room, (particularly into the corners, Fig. 16-4) and ejected through the doorway into the corridor behind the room (see Fig. 16-3). Flames were extinguished in the weighted boxes along the side wall, but they continued to smoulder, and rekindled in about 10 minutes as shown in Fig. 16-4.

The material confined in the cages near the doorway was completely extinguished.



A & B - 17 x 13 x 13 in. cardboard box (weighted, no paper)

C - 17 x 13 x 13 in. cardboard boxes stacked three high (containing crumpled paper)

D - 17 x 13 x 13 in. cardboard boxes stacked three high (empty)

E - 8.5 x 12.5 x 8 in. wire cage containing crumpled paper

☆ Ignition sources

Fig. 16-1. Sketch of Test Geometry, Test Number 16

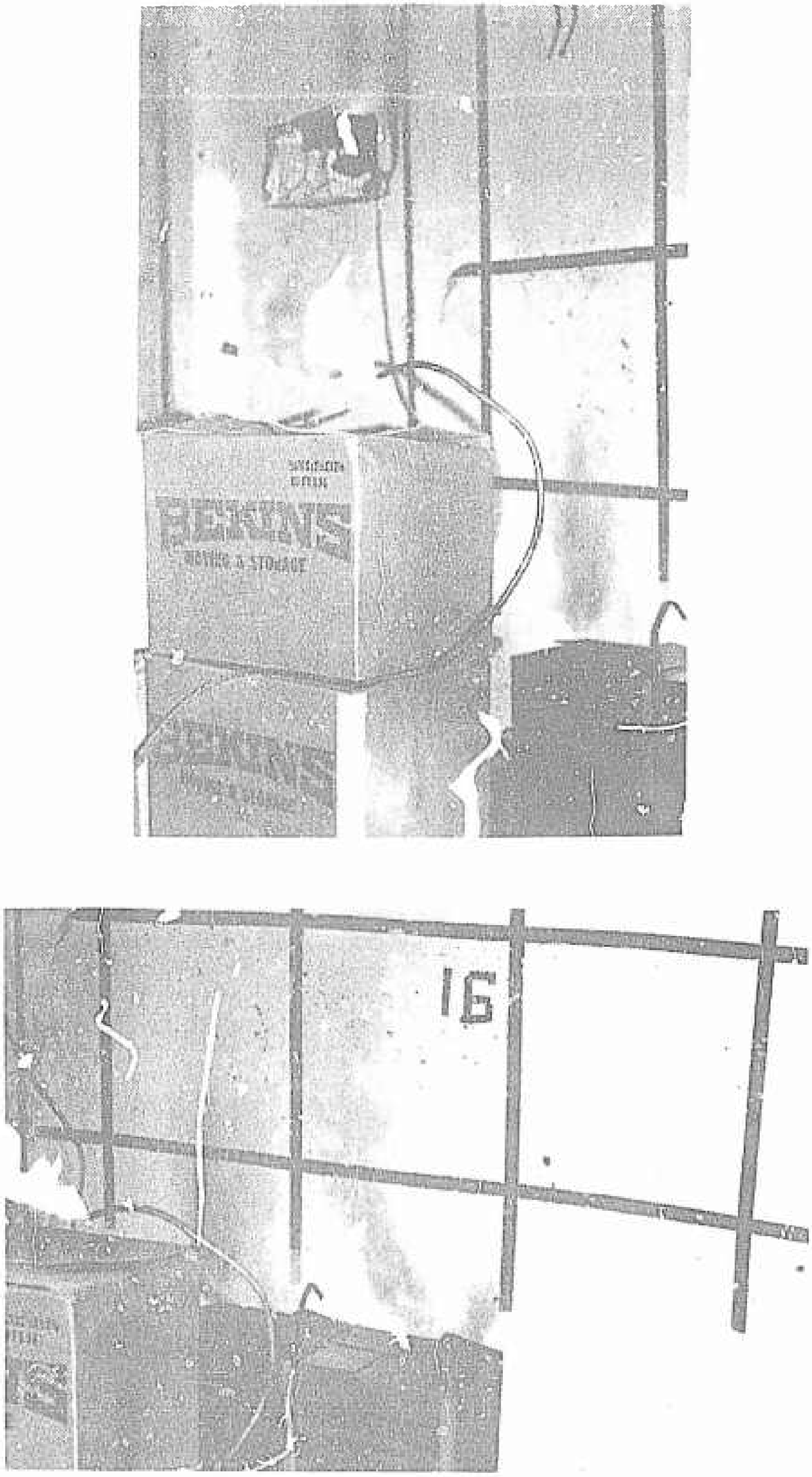


Fig. 16-2. Pretest Photographs, Test Number 16

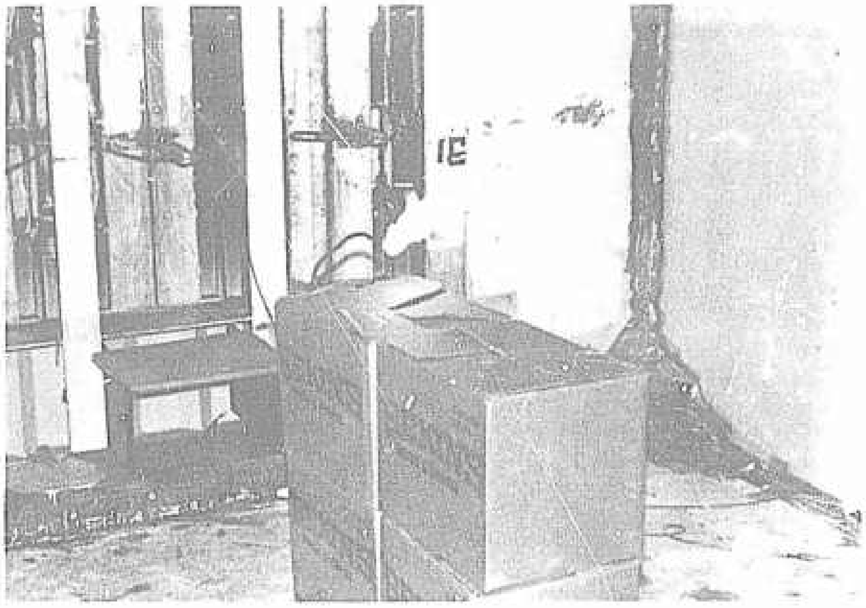


Fig. 16-3. Pre and Posttest Photographs, Test Number 16

Fig. 16-4. Posttest Photographs, Test Number 16

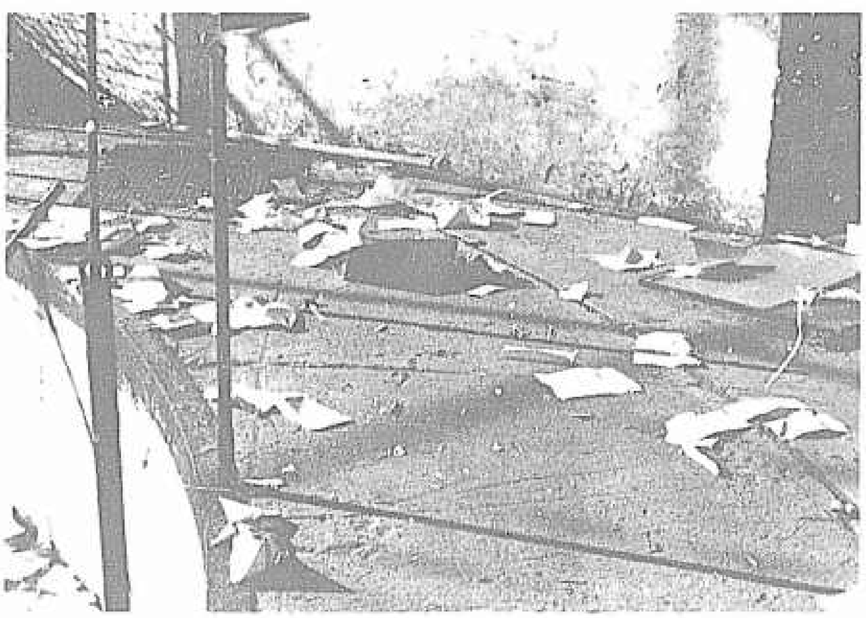


Fig. 16-5. Posttest Photographs, Test Number 16

Fig. 16-6. Posttest Photograph, Test Number 16

Test Report Test Number 17

Type EOC

Test Conditions

Compression Chamber Pressure	4 (psi)
Diaphragm Opening	14* (%)
Average Pressure in Room	0.8 (psi)
Positive Phase Duration	1.9 (sec)

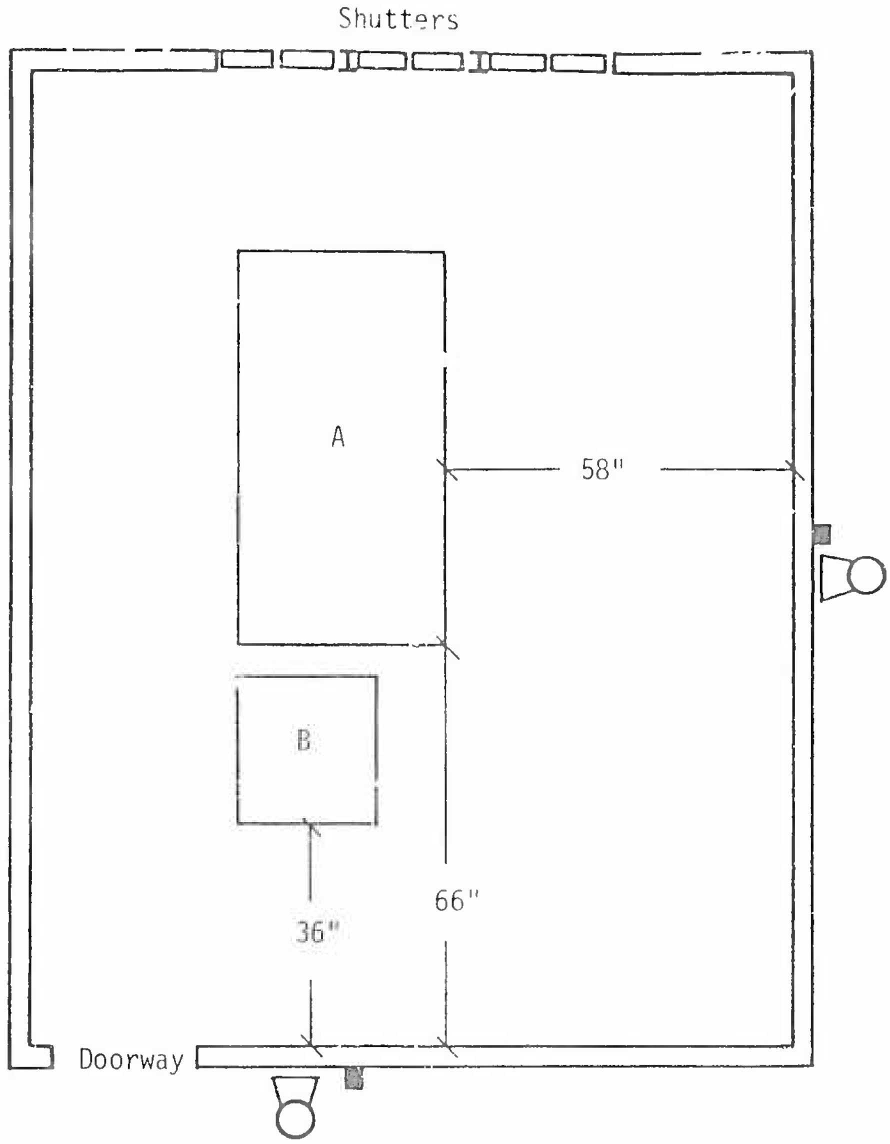
Test Geometry and Results

The simulated EOC test geometry is sketched in Fig. 17-1. The equipment tested included a desk on which was placed three telephones and three small radios. Placed next to the desk was a tall relay rack (previously used in test 14). Photographs of this equipment prior to the test are shown in Figs. 17-3 through 17-5 (lower photograph).

The blast damaged all of the equipment. Pieces of telephones and radios were scattered as far as 50 ft from the doorway (see Fig. 17-8). The relay rack was outside the test room in the corridor about five feet from the doorway and was severely damaged, see Figs. 17-7, 17-9 and 17-10 (lower photograph) and 17-11 (upper photograph).

The desk was broken up and piled in the doorway as shown in Fig. 17-11 (lower photograph).

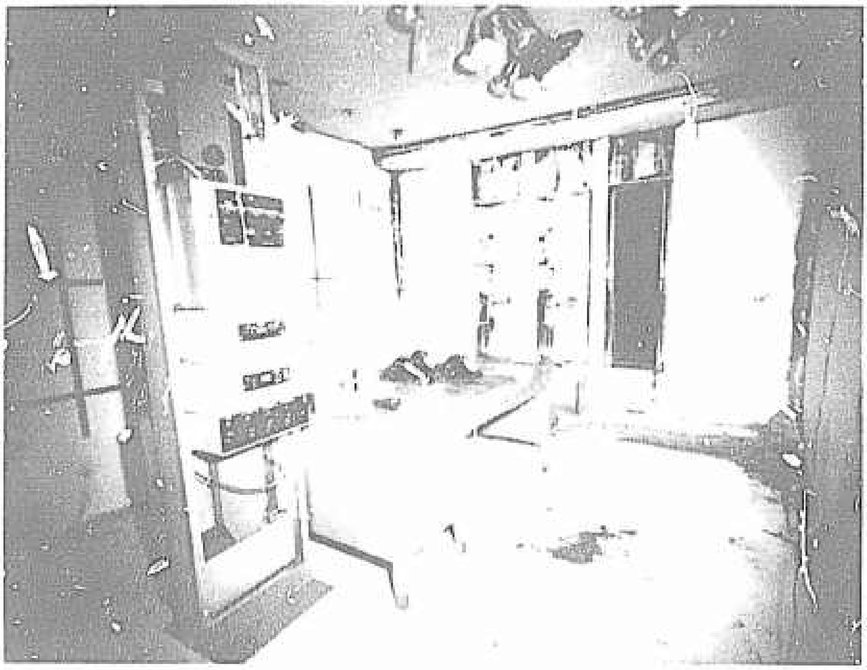
* A 7% opening was planned, but two shutters opened.



A - 36 x 66 in. desk containing three telphones and three radios

B - 24 x 24 in. communications rack

Fig. 17-1. Sketch of Test Geometry, Test Number 17



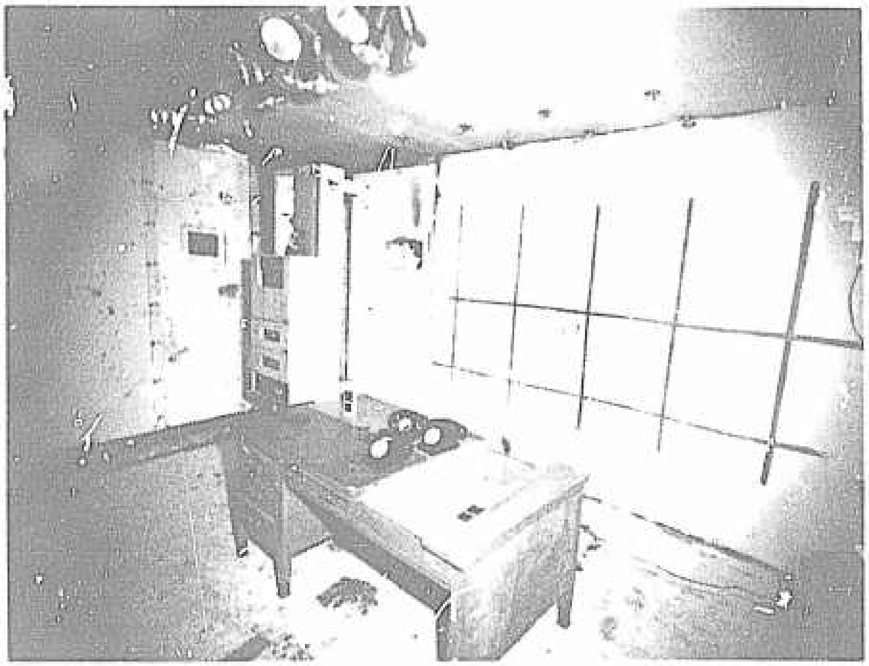
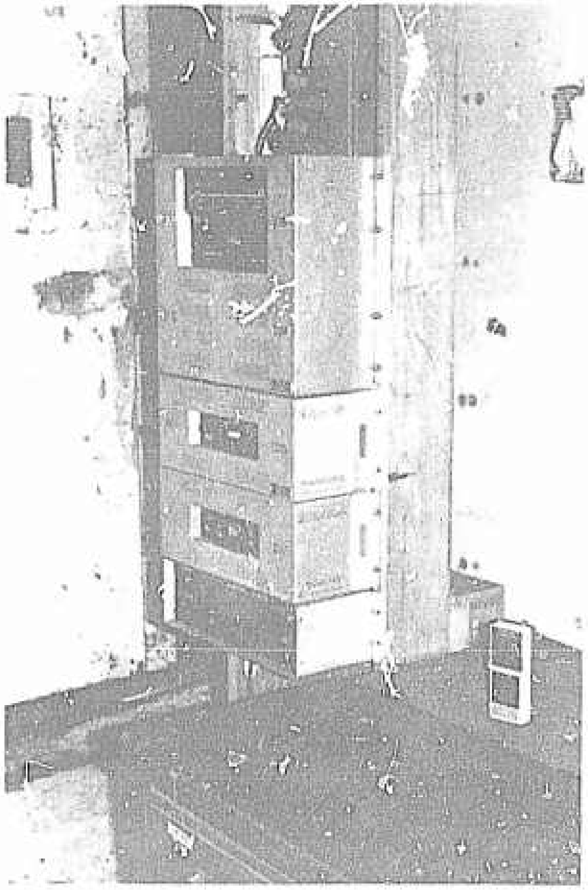


Fig. 17-2. Pretest Photographs, Test Number 17



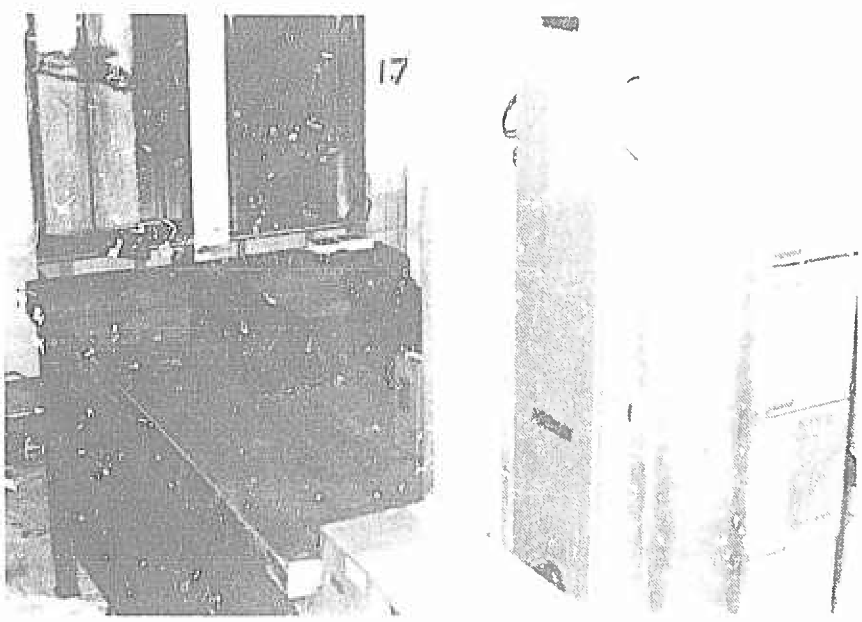
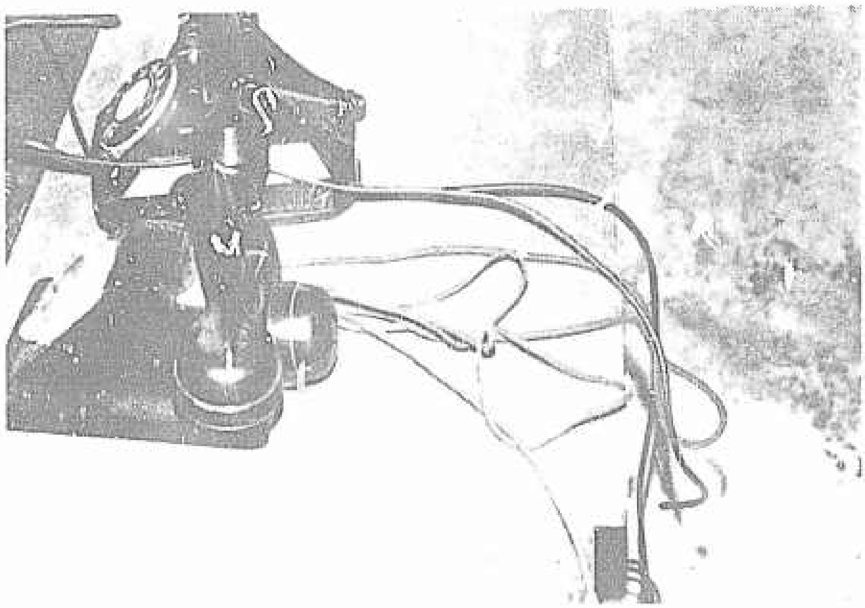


Fig. 17-3. Pretest Photographs, Test Number 17



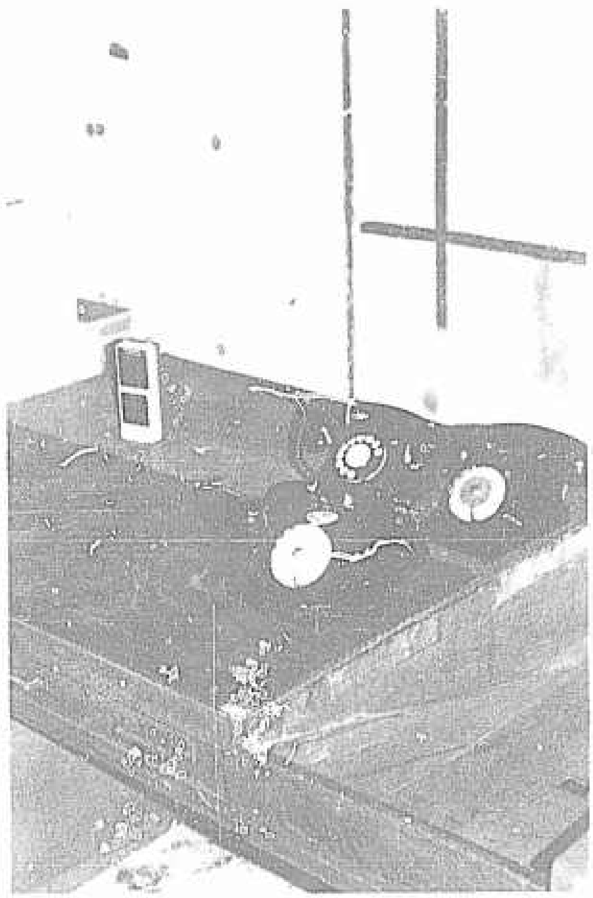
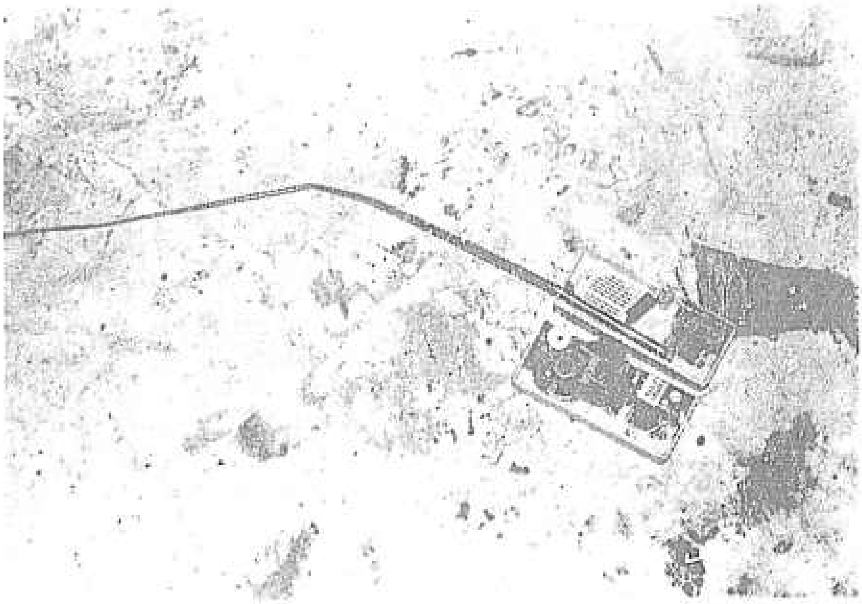


Fig. 17-4. Pretest Photographs, Test Number 17



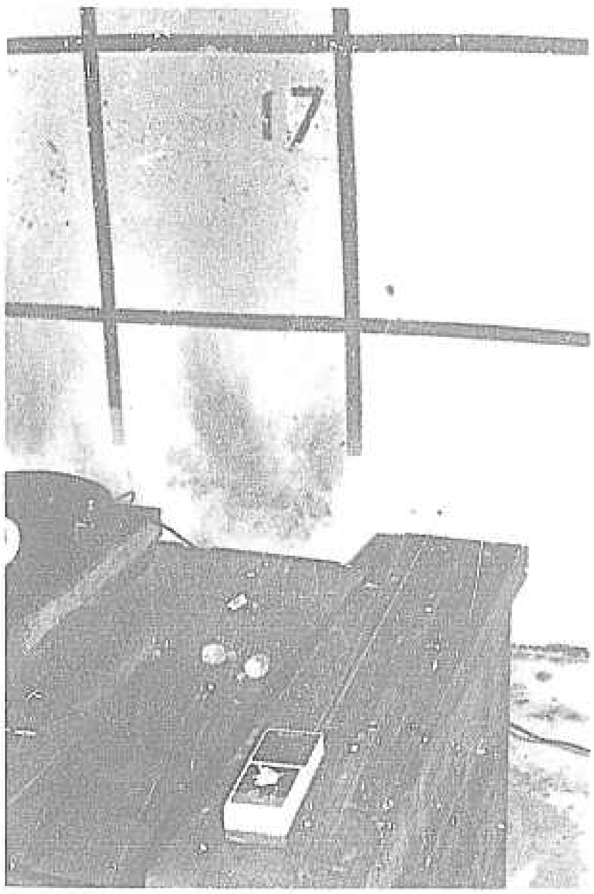
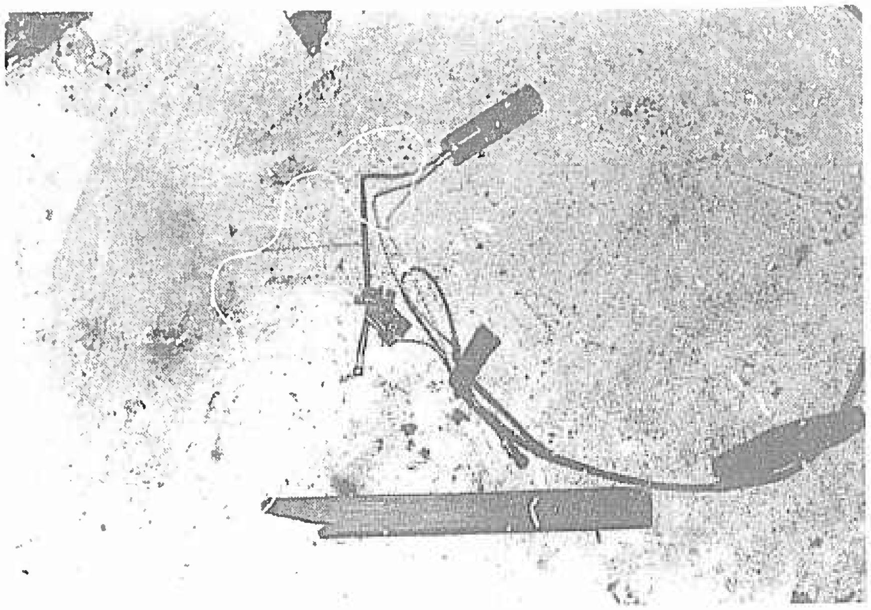


Fig. 17-5. Pre- and Posttest Photographs, Test Number 17.



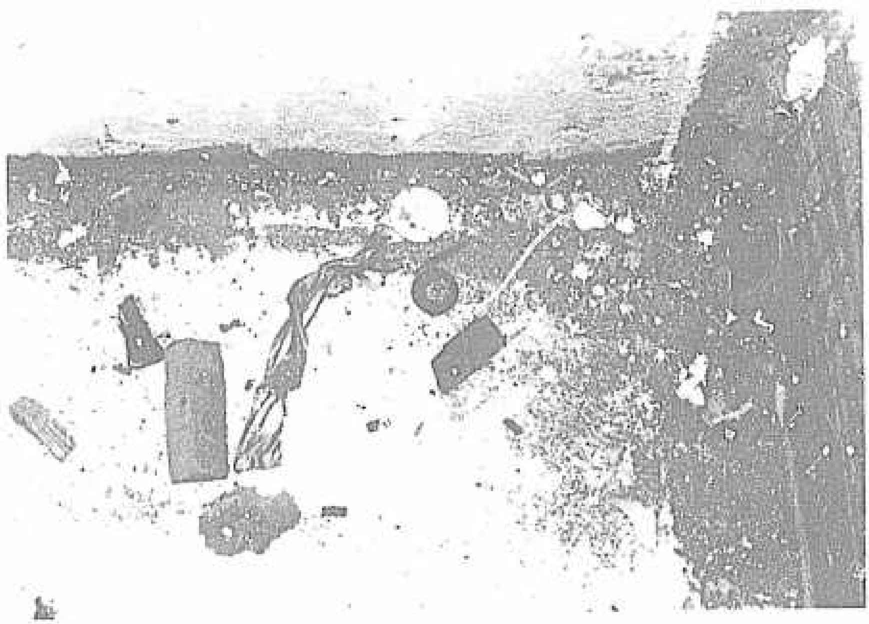


Fig. 17-6. Posttest Photographs, Test Number 17

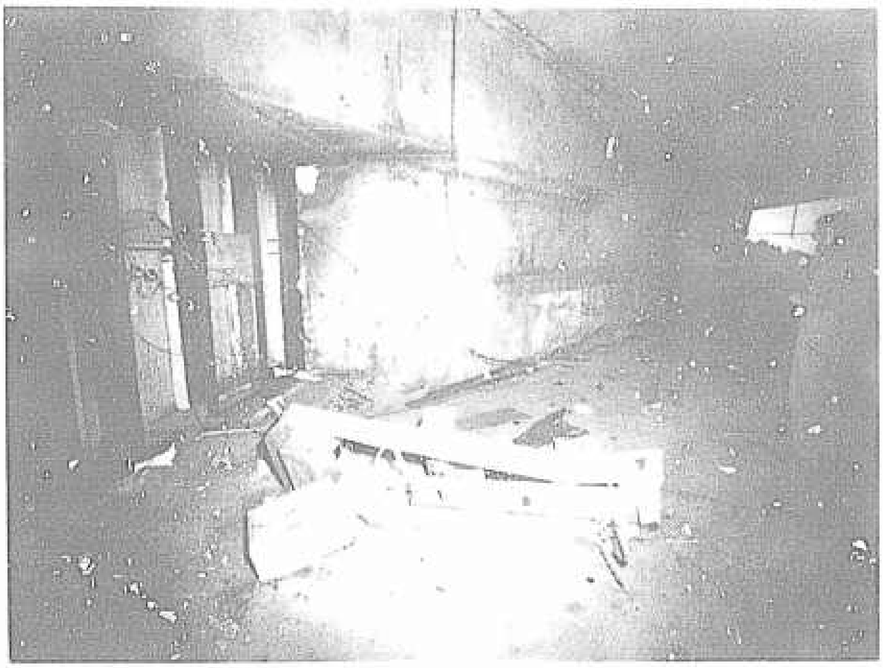
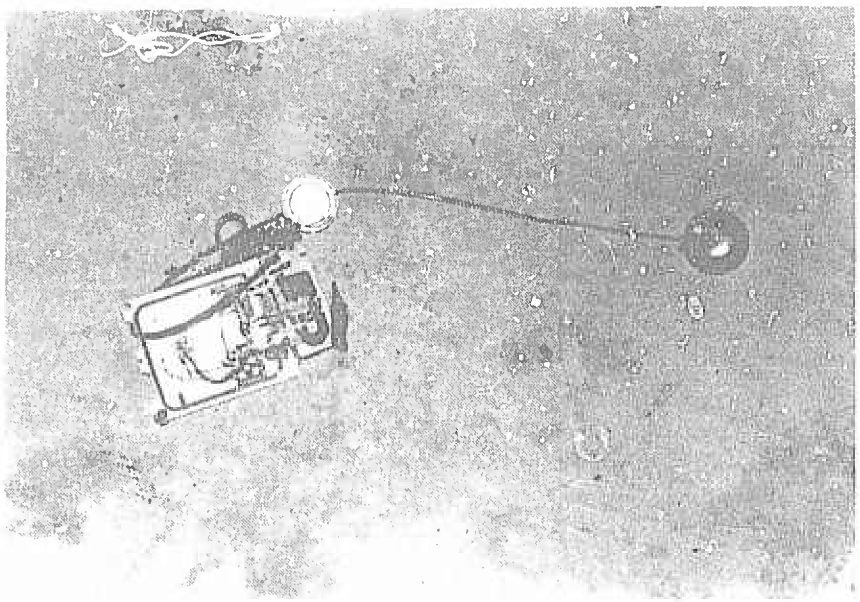


Fig. 17-7. Posttest Photo -aphs, Test Number 17



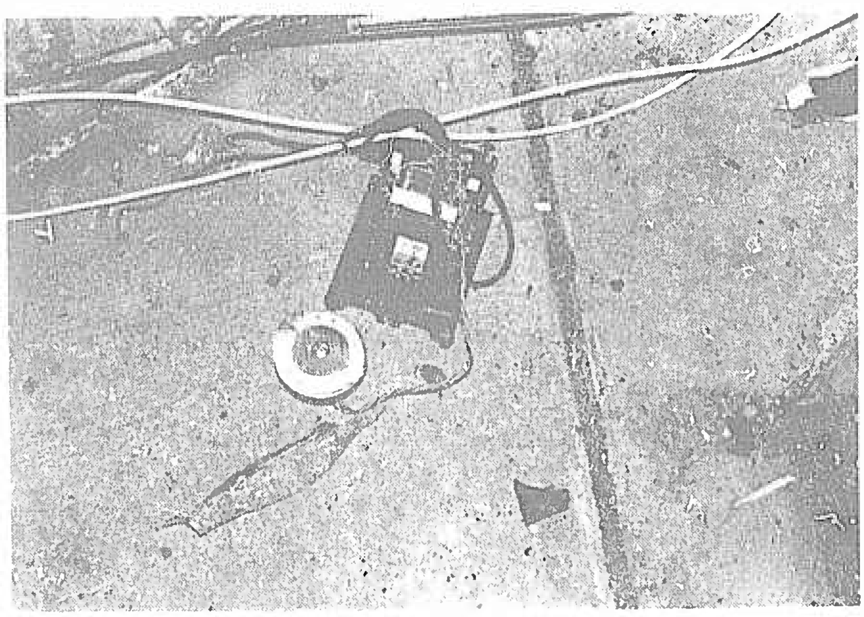
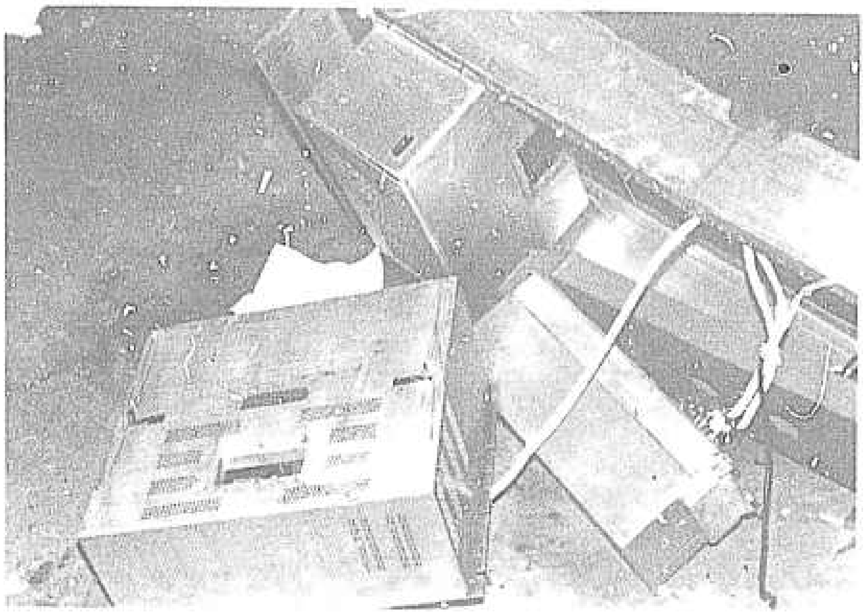


Fig. 17-8. Posttest Photographs, Test Number 17



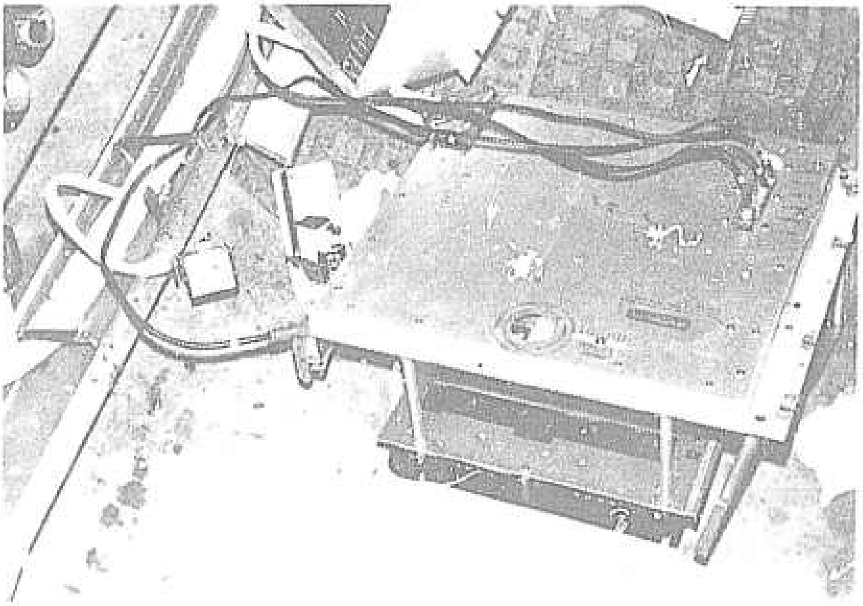


Fig. 17-9. Posttest Photographs, Test Number 17

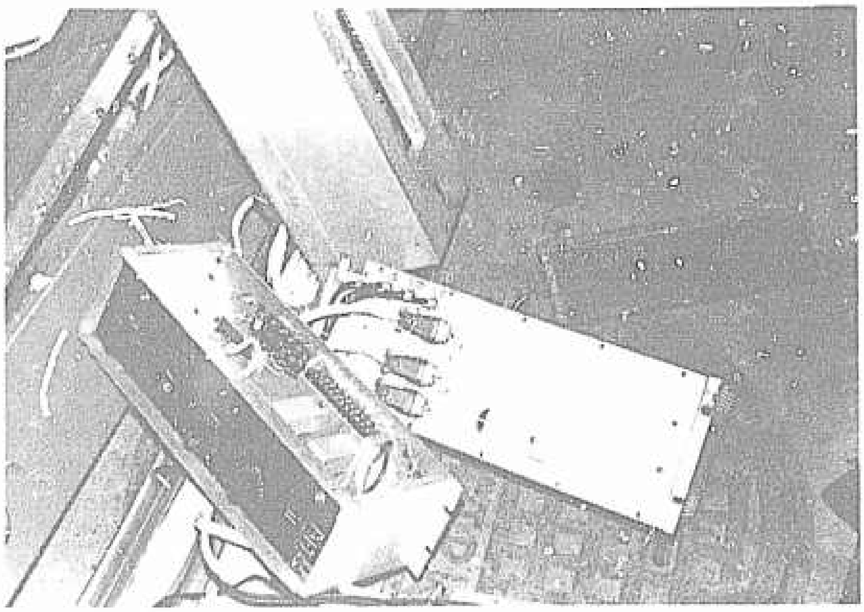
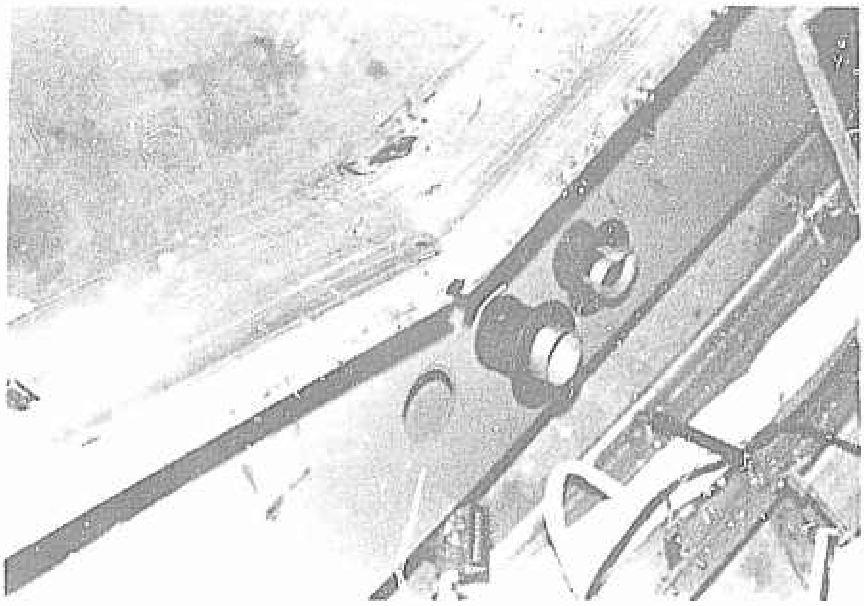


Fig. 17-10. Posttest Photographs, Test Number 17



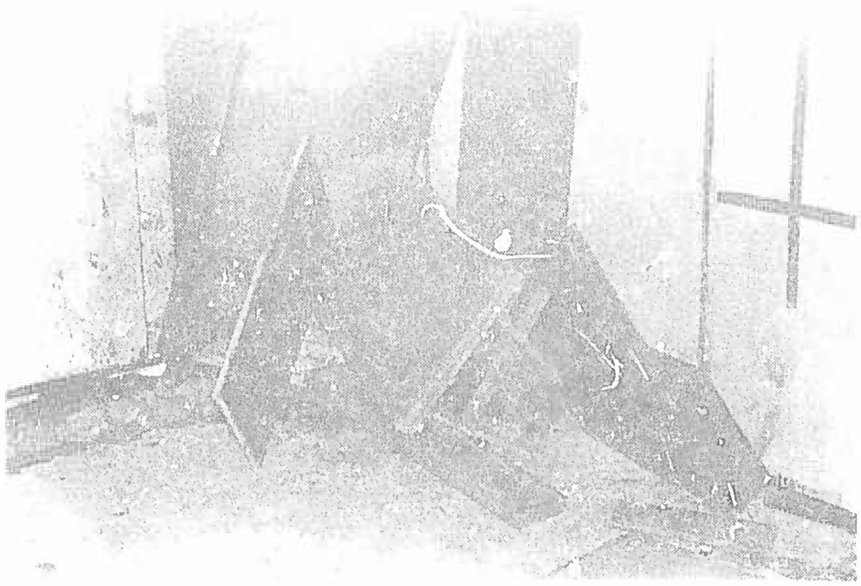


Fig. 17-11. Posttest Photographs, Test Number 17

Test Report Test Number 18

Type-- Warehouse

Test Conditions

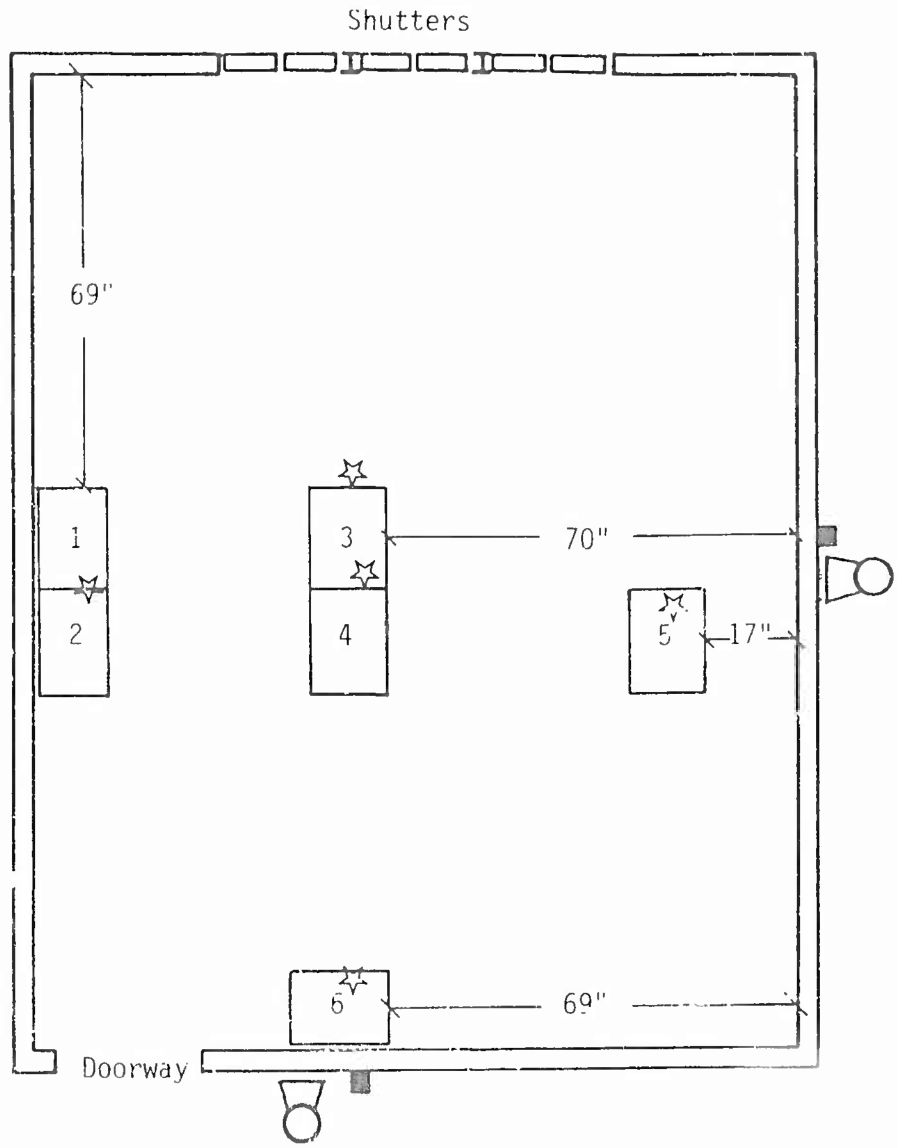
Compression Chamber Pressure	4.25	(psi)
Diaphragm Opening	21	([illegible])
Average Pressure in Room	2.4	(psi)
Positive Phase Duration	1.3	(sec)
Delay (ignition to blast)	27	(sec)

Test Geometry and Results

This test had the same basic warehouse configuration used in the last two tests (13 and 16) with certain additions designed to investigate whether the smouldering fires that occurred in the empty weighted boxes located along the side wall near the doorway and that reignited later could also exist in other areas of the room. The question was whether the cause of these fires was the location of the fuel or the type of fuel. Therefore, in addition to placing the central stack of six boxes containing a large quantity of paper in the center of the room and the two empty weighted boxes along the side wall, an empty weighted box was placed along the rear wall and another between the center stack and the side wall away from the doorway. The configuration is shown in Fig. 18-1 and the photographs of Fig. 18-2.

In this test, it was apparent that the central stack of boxes pre-ignited, that is, they ignited by the pilot light (Fig. 18-3) before the supply of propane was increased to form a long flame that was supposed to ignite the boxes. As a result of this, the fire in the central stack was very well established; its entire top and a good deal of the paper within the top boxes were flaming vigorously at the time of the shot. Despite this, all flames in this material were extinguished, and -- as before -- the contents of the stack were distributed widely throughout the room, and in the corridor behind the rear doorway.

In contrast, all fires in the weighted boxes were not extinguished. The two side boxes (numbers 1 and 2 in Fig. 18-1) were flaming within 30 seconds after the shot and the box near the other side wall (number 5) was smouldering, although the smouldering fire did eventually go out.



1, 2, 5, & 6 - 17 x 13 x 13 in. cardboard boxes (weighted, no paper)

3 - 17 x 13 x 13 in. cardboard boxes stacked three high (full of paper)

4 - 17 x 13 x 13 in. cardboard boxes stacked three high (top full of paper)

☆ Ignition sources

Fig. 18-1. Sketch of Test Geometry, Test Number 18

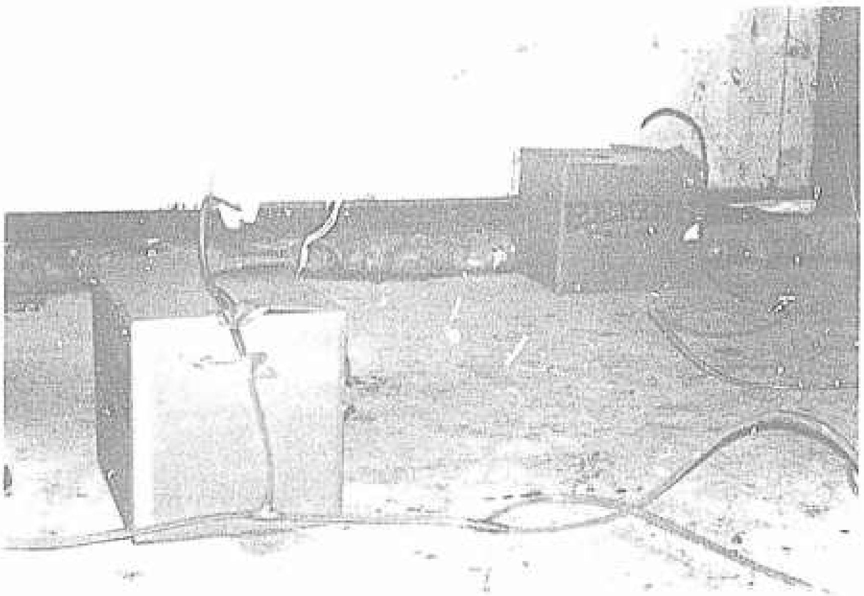
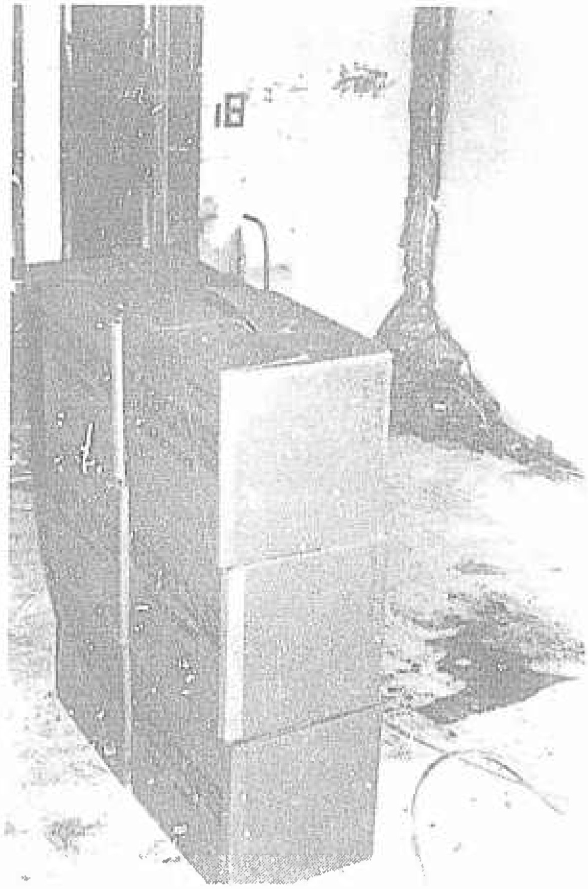


Fig. 18-2. Pretest Photographs, Test Number 18



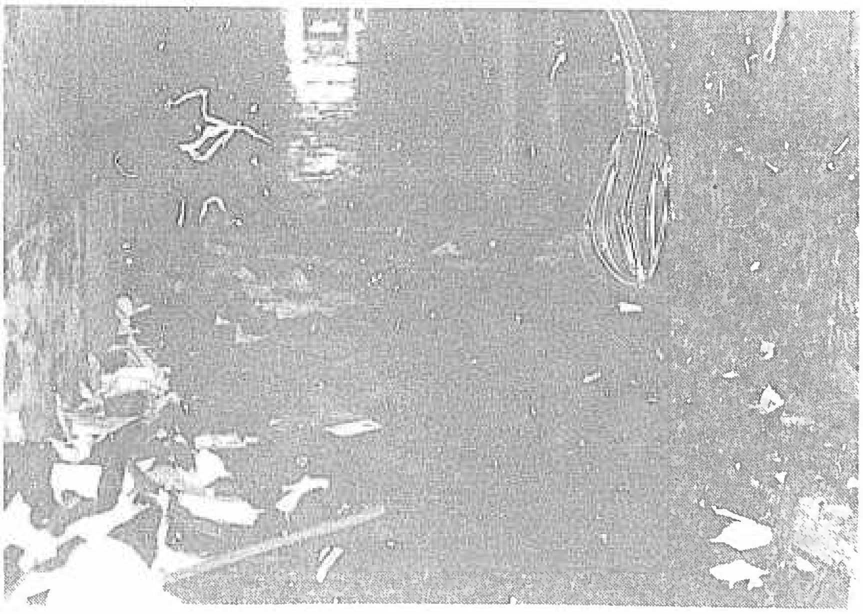


Fig. 18-3. Pre and Posttest Photographs, Test Number 18

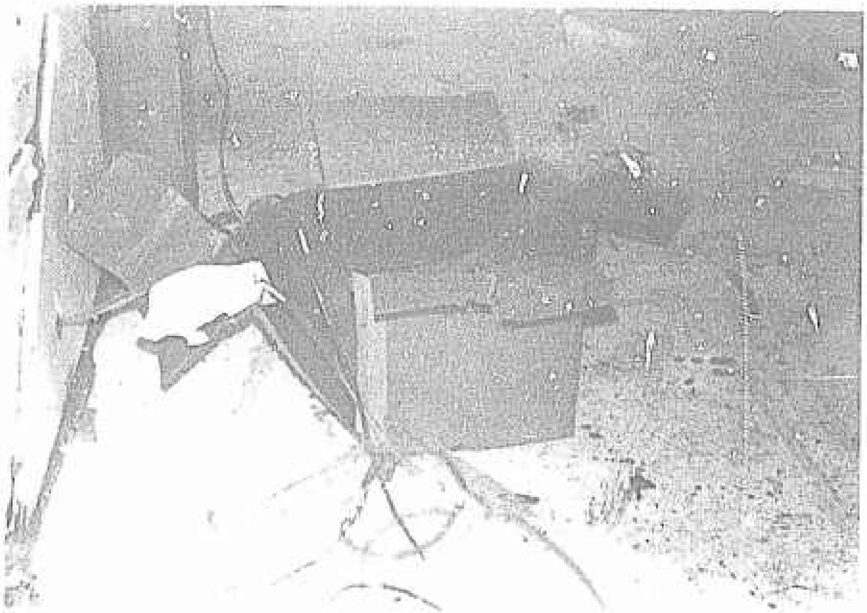


Fig. 18-4. Posttest Photographs, Test Number 18

Fig. 18-5. Posttest Photograph, Test Number 18

Test Report	Test Number 19

Type-- Confined Fuel Test

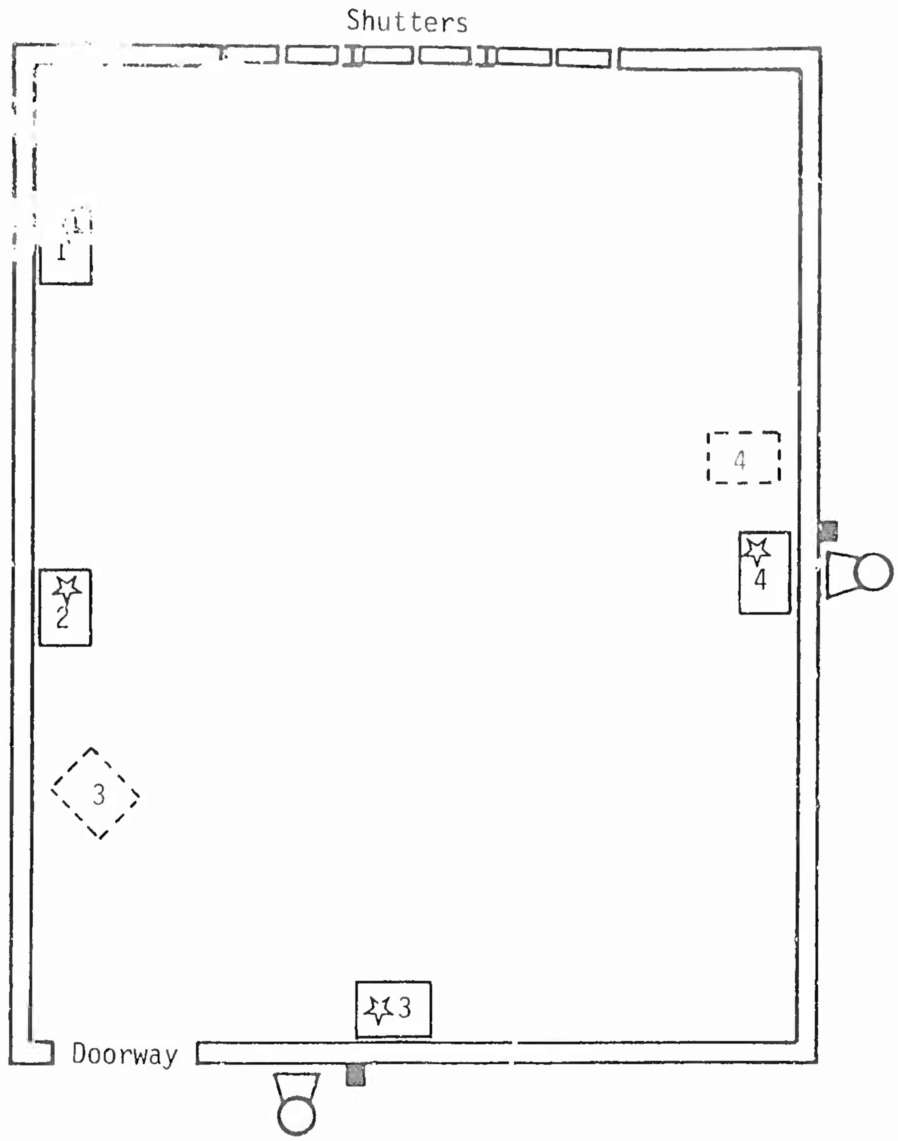
Test Conditions

Compression Chamber Pressure	2	(psi)
Diaphragm Opening	21	(%)
Average Pressure in Room	1.05	(psi)
Positive Phase Duration	0.94	(sec)
Delay (ignition to blast)	54	(sec)

Test Geometry and Results

In this test, all fuel (paper) was confined to four cages similar to the single cage used during Test 16. These were placed: against the side wall nearest the doorway, one fairly close to the shutters (cage 1), the other near the center of the room (cage 2); along the rear wall directly opposite the shutters (cage 3); and near the side wall farthest from the doorway, about halfway between the front and rear walls (cage 4) The configuration adopted is shown in Fig. 19-1. The top part of Fig. 19-2 is a pretest photograph of cages 1 and 2, and the lower part, a photograph of cage 4. Cage 3 is in the top photograph of Fig. 19-3.

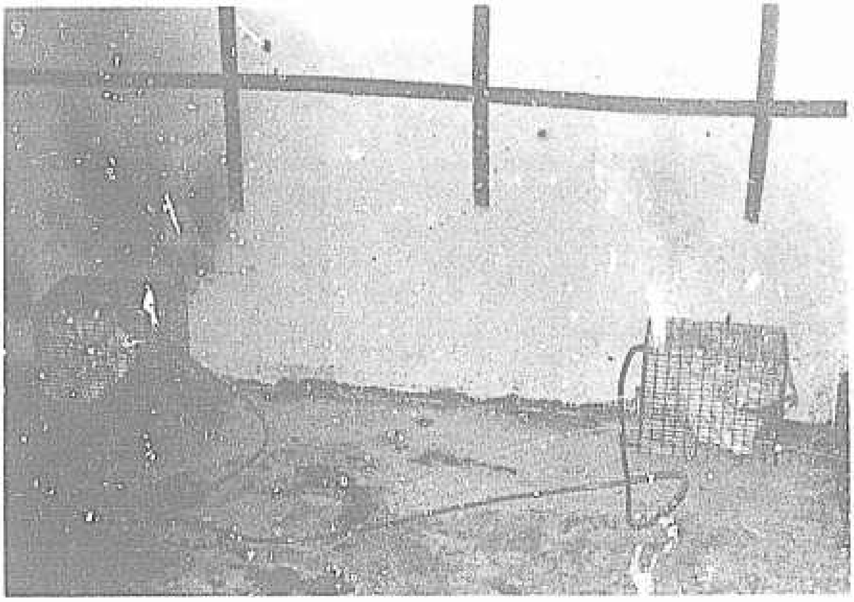
After the shot the contents of cages 1 and 2 were found totally consumed; the fires were extinguished in cages 3 and 4, which were displaced as shown in Fig. 19-1. This suggests that cages 1 and 2 were away from the direct high velocity flow between the window and the doorway, that cage 3 experienced a strong flow directly from the window, and that cage 4 was located in an area in which a high velocity swirl formed. Posttest photographs are shown in Figs. 19-3 through 19-5.



1, 2, 3, & 4 - 8.5 x 12.5 x 8 in. wire cages containing ignited paper. (Dotted lines indicate posttest locations)

☆ Ignition sources

Fig. 19-1. Sketch of Test Geometry, Test Number 19



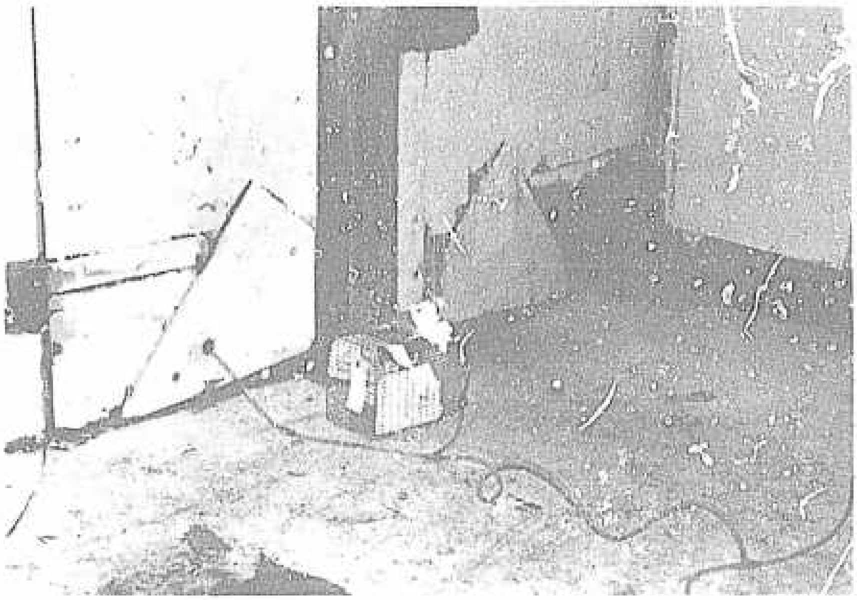


Fig. 19-2. Pretest Photographs, Test Number 19

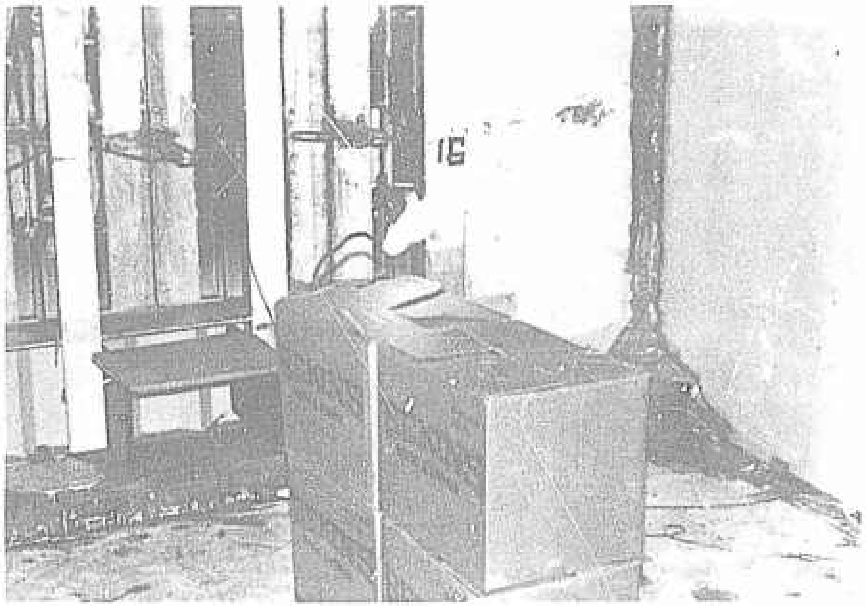


Fig. 16-3. Pre and Posttest Photographs, Test Number 16

Fig. 16-4. Posttest Photographs, Test Number 16

Fig. 16-5. Posttest Photographs, Test Number 16

Fig. 16-6. Posttest Photograph, Test Number 16

Test Report

Test Number 17

Type EOC

Test Conditions

Compression Chamber Pressure	4	(psi)
Diaphragm Opening	14*	(%)
Average Pressure in Room	0.8	(psi)
Positive Phase Duration	1.9	(sec)

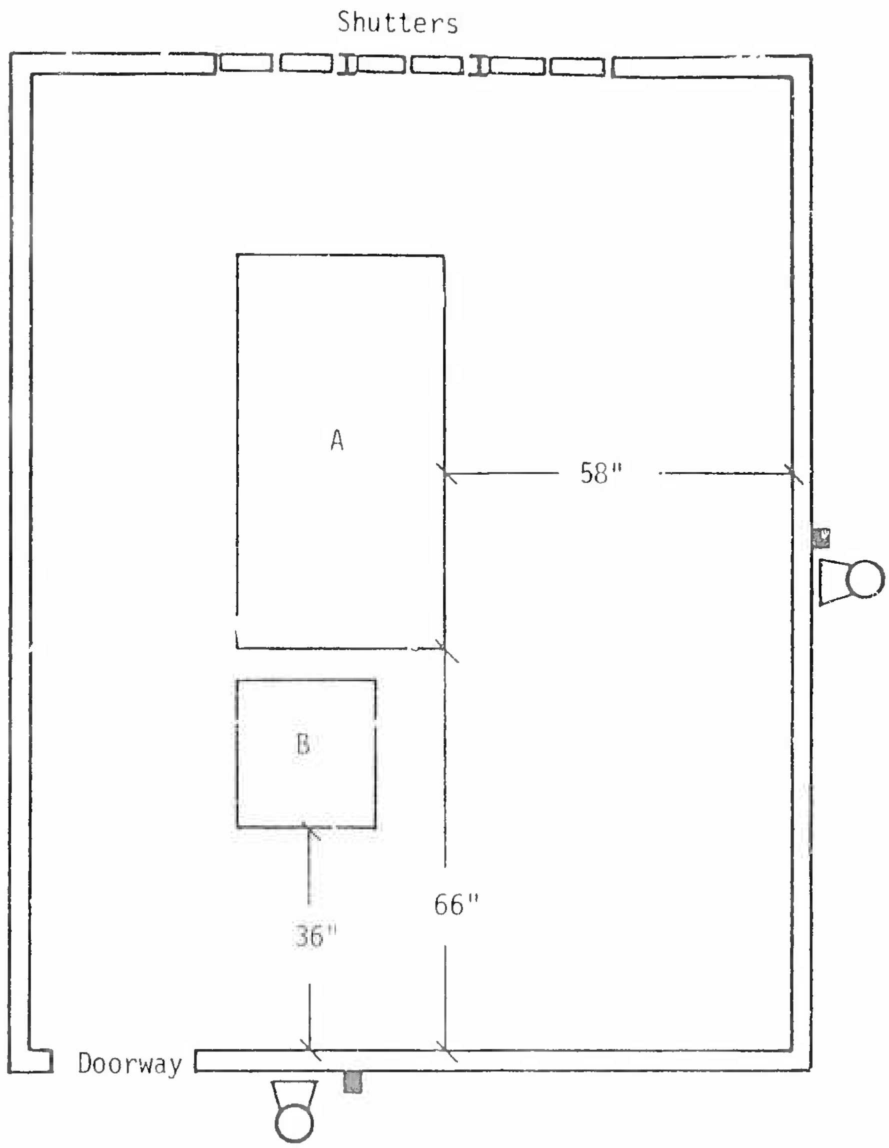
Test Geometry and Results

The simulated EOC test geometry is sketched in Fig. 17-1. The equipment tested included a desk on which was placed three telephones and three small radios. Placed next to the desk was a tall relay rack (previously used in test 14). Photographs of this equipment prior to the test are shown in Figs. 17-3 through 17-5 (lower photograph).

The blast damaged all of the equipment. Pieces of telephones and radios were scattered as far as 50 ft from the doorway (see Fig. 17-8). The relay rack was outside the test room in the corridor about five feet from the doorway and was severely damaged, see Figs. 17-7, 17-9 and 17-10 (lower photograph) and 17-11 (upper photograph).

The desk was broken up and piled in the doorway as shown in Fig. 17-11 (lower photograph).

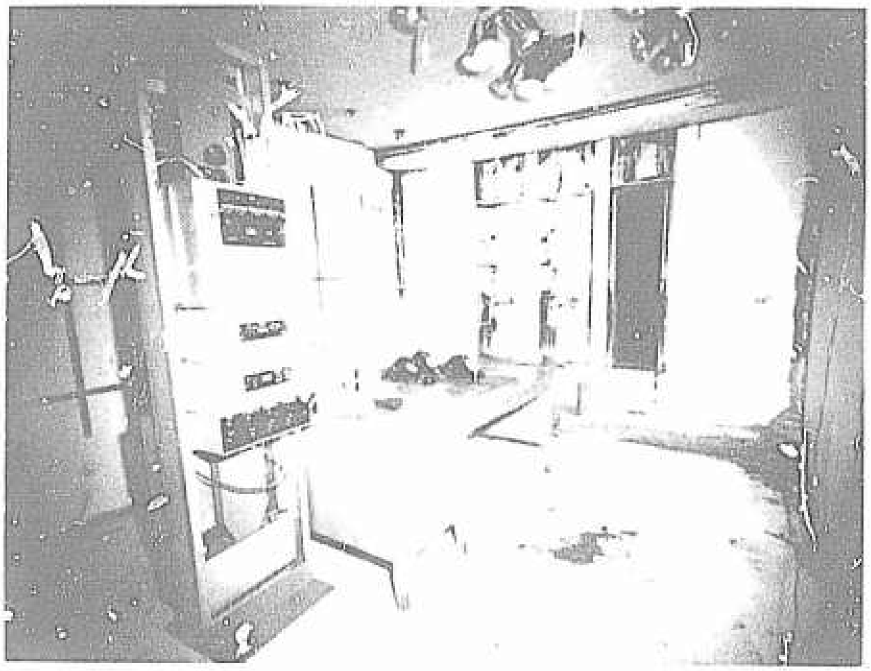
* A 7% opening was planned, but two shutters opened.



A - 36 x 66 in. desk containing three telphones and three radios

B - 24 x 24 in. communications rack

Fig. 17-1. Sketch of Test Geometry, Test Number 17



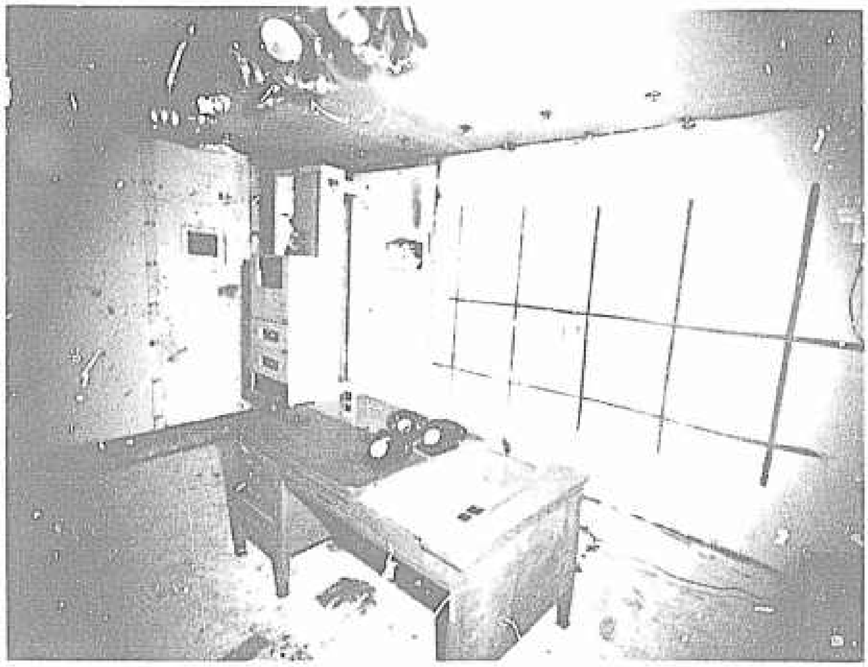


Fig. 17 2. Pretest Photographs, Test Number 17

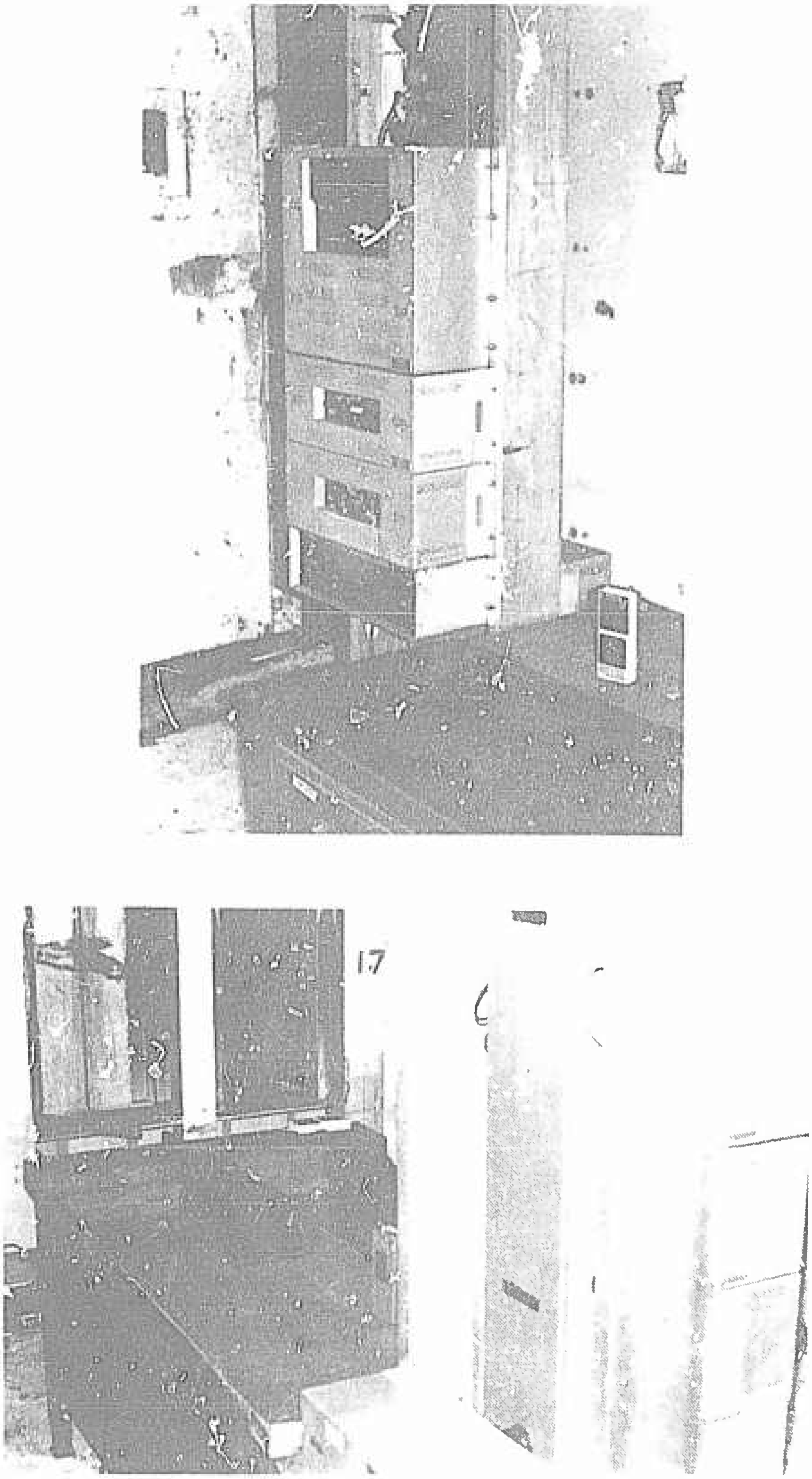
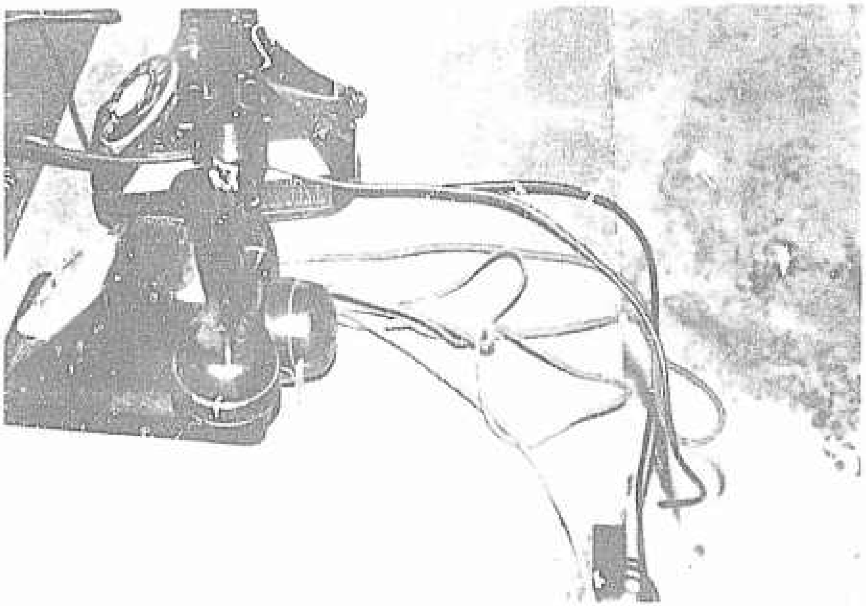


Fig. 17-3. Pretest Photographs, Test Number 17



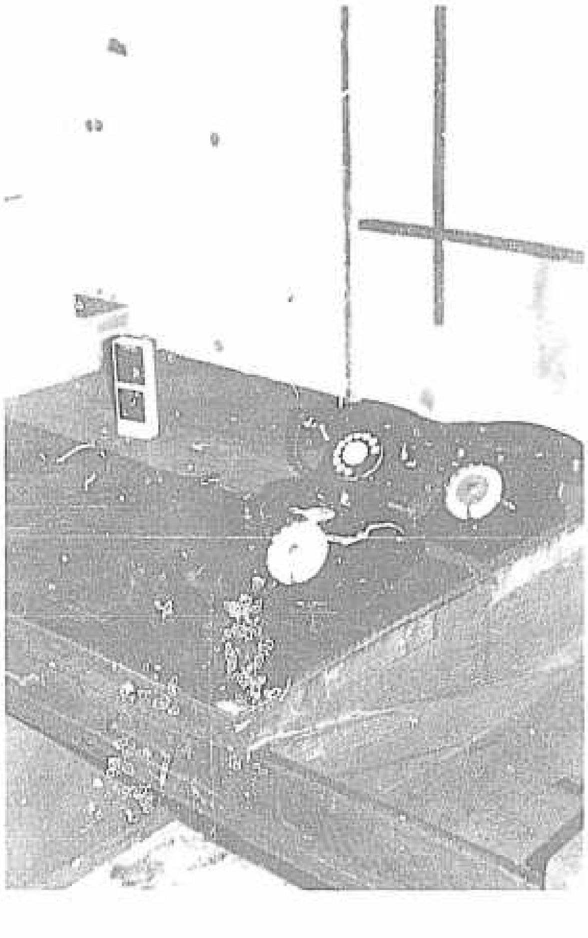


Fig. 17-4. Pretest Photographs, Test Number 17

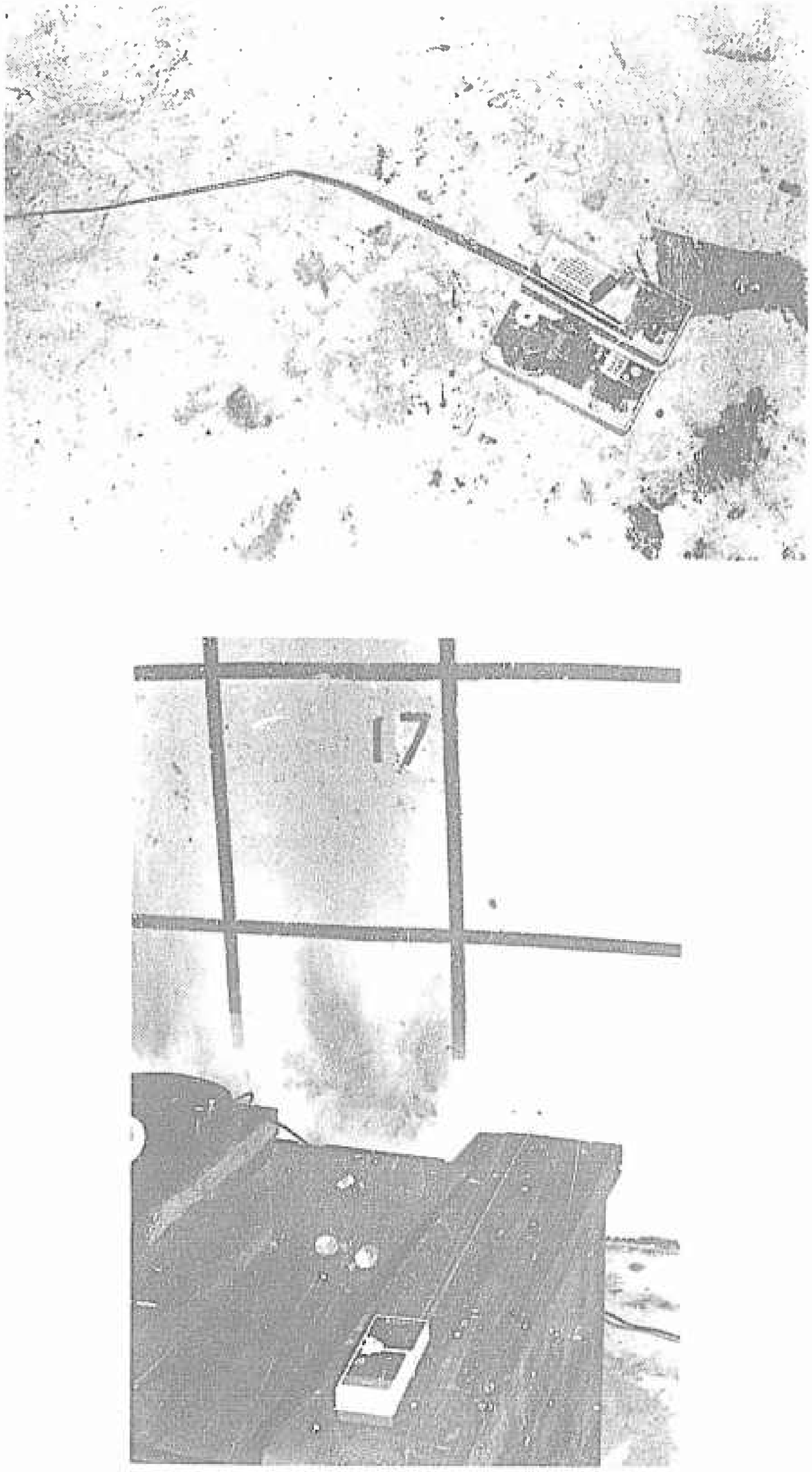


Fig. 17-5. Pre- and Posttest Photographs, Test Number 17.

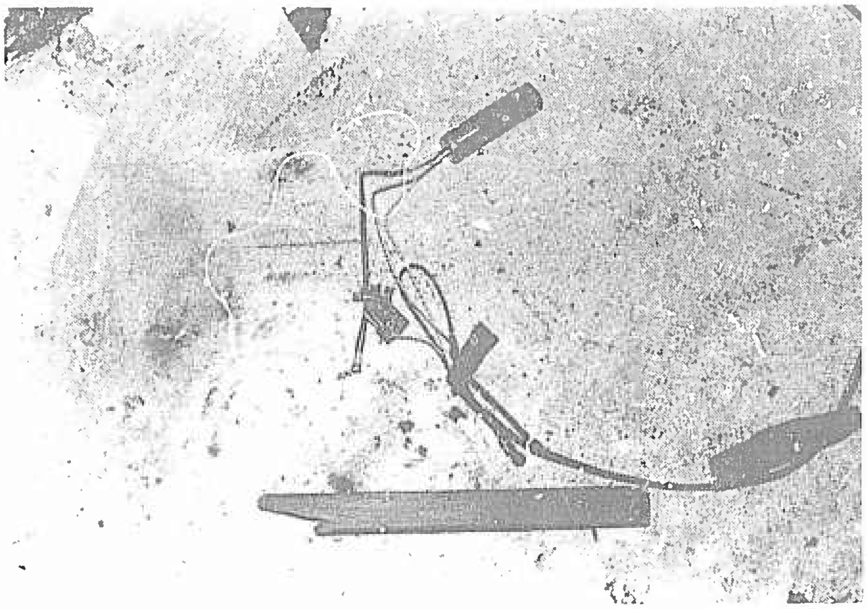


Fig. 17-6. Posttest Photographs, Test Number 17

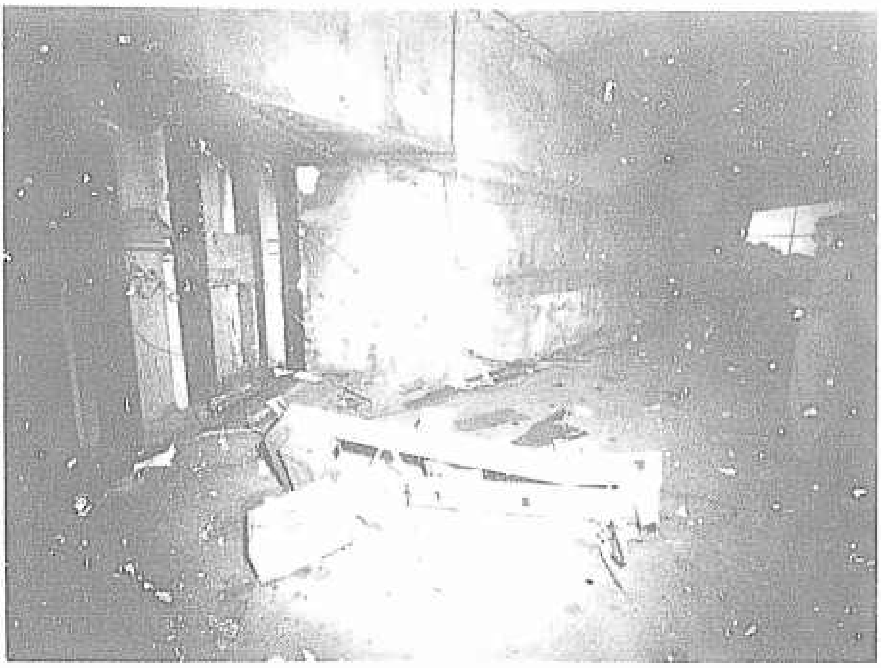
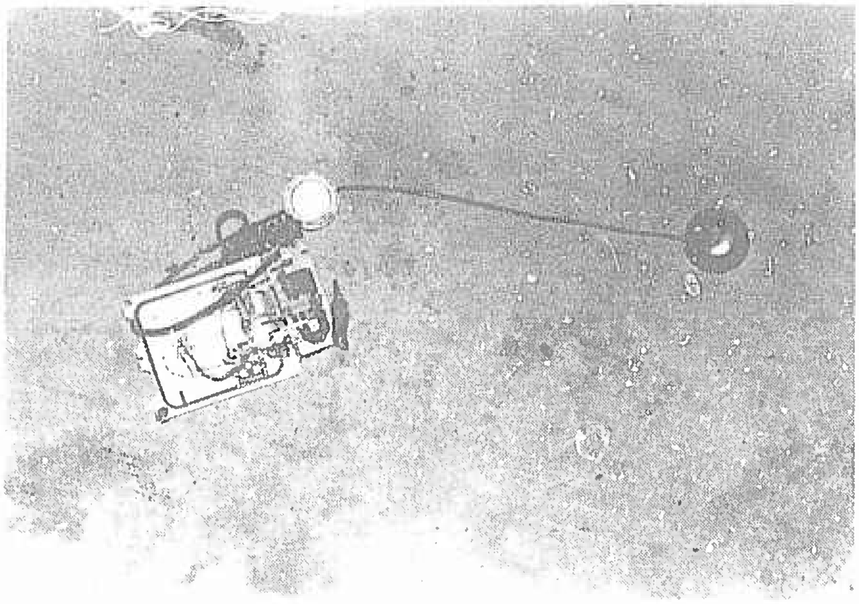


Fig. 17-7. Posttest Photographs, Test Number 17



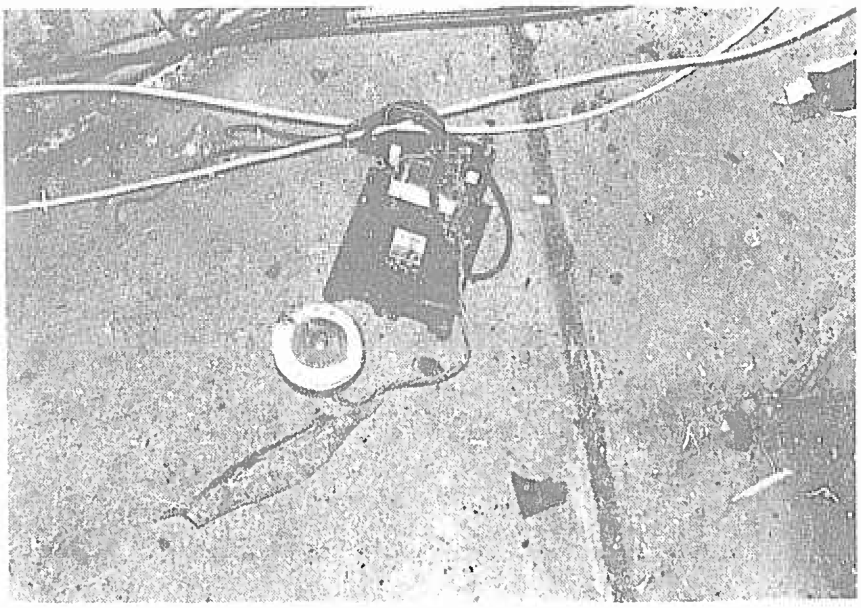


Fig. 17-8. Posttest Photographs, Test Number 17

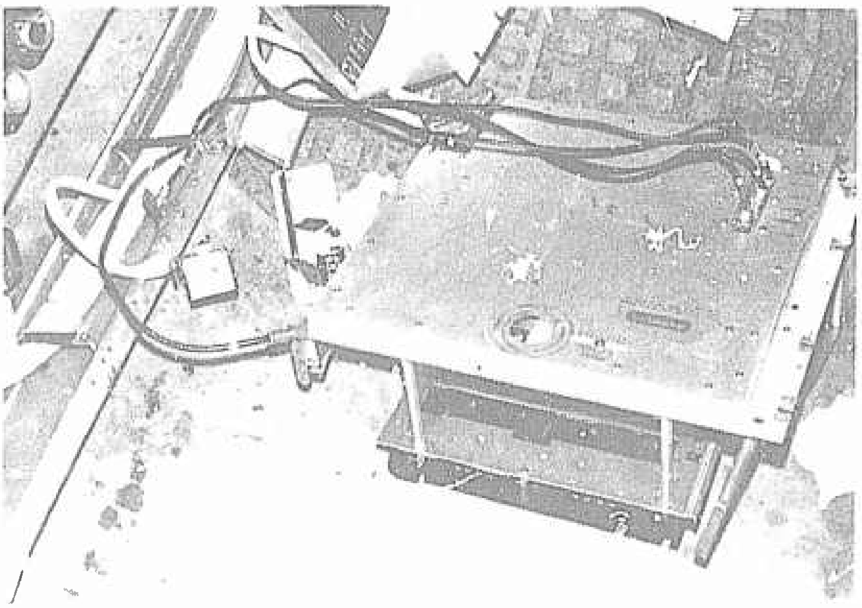


Fig. 17-9. Posttest Photographs, Test Number 17

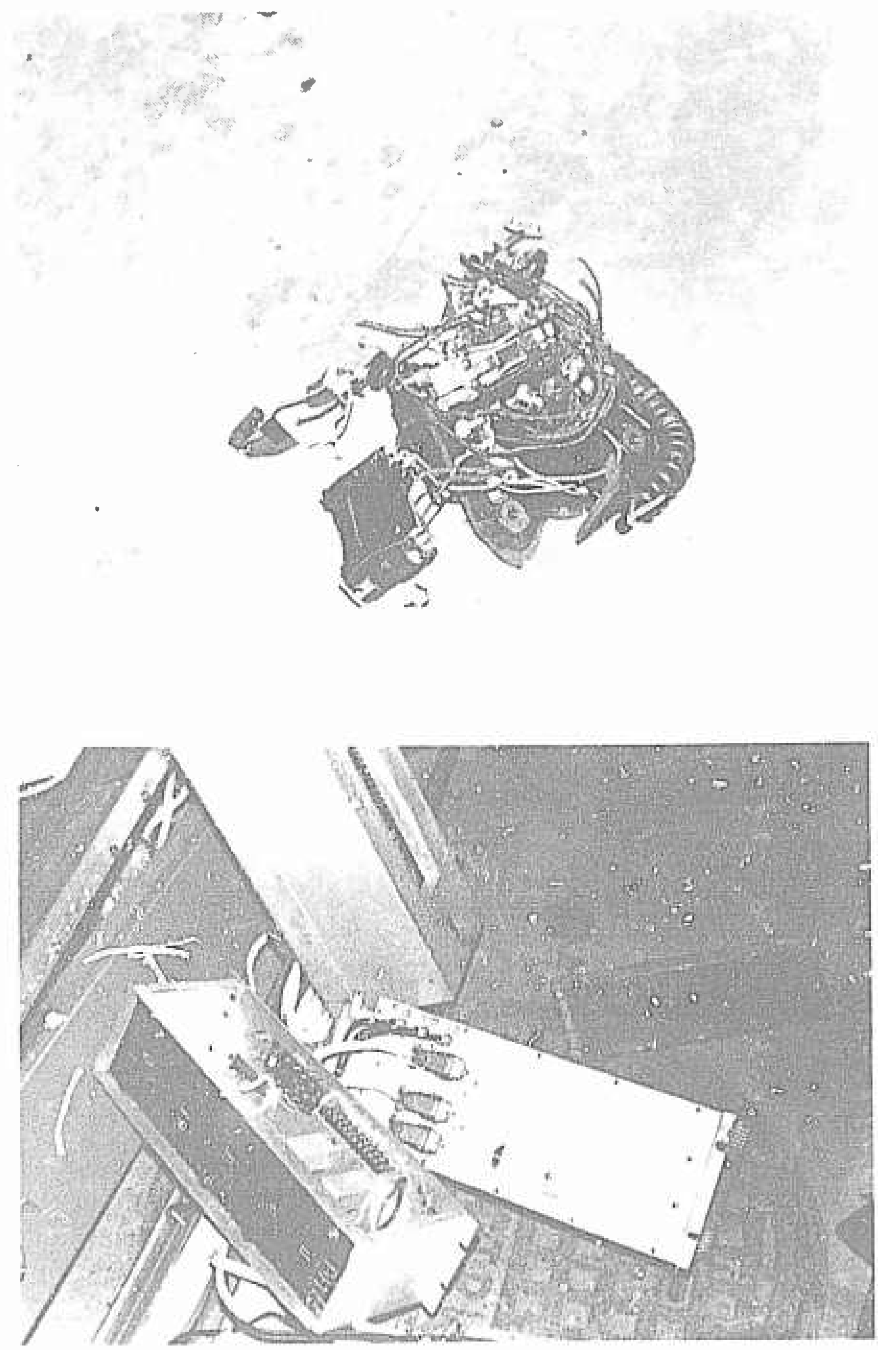


Fig. 17-10. Posttest Photographs, Test Number 17

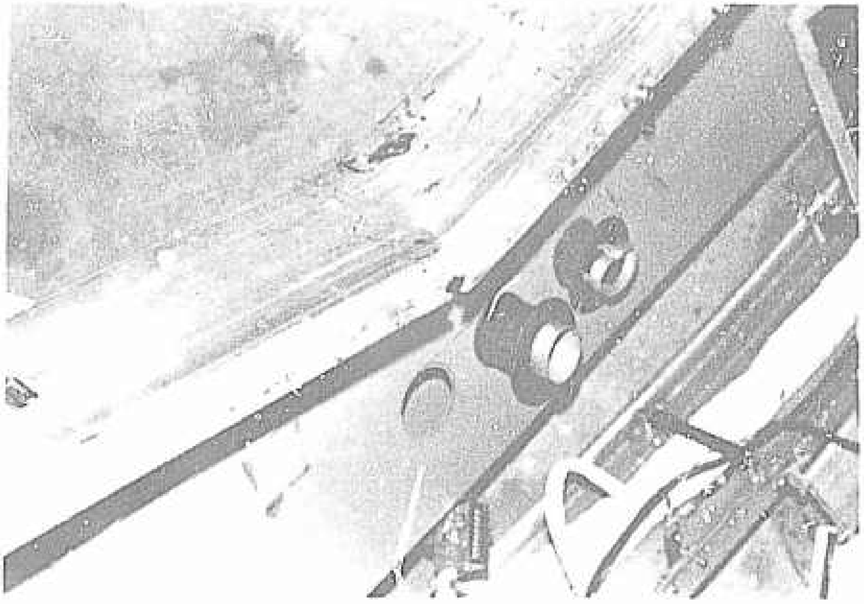


Fig. 17-11. Posttest Photographs, Test Number 17

Test Report — Test Number 18

Type-- Warehouse

Test Conditions

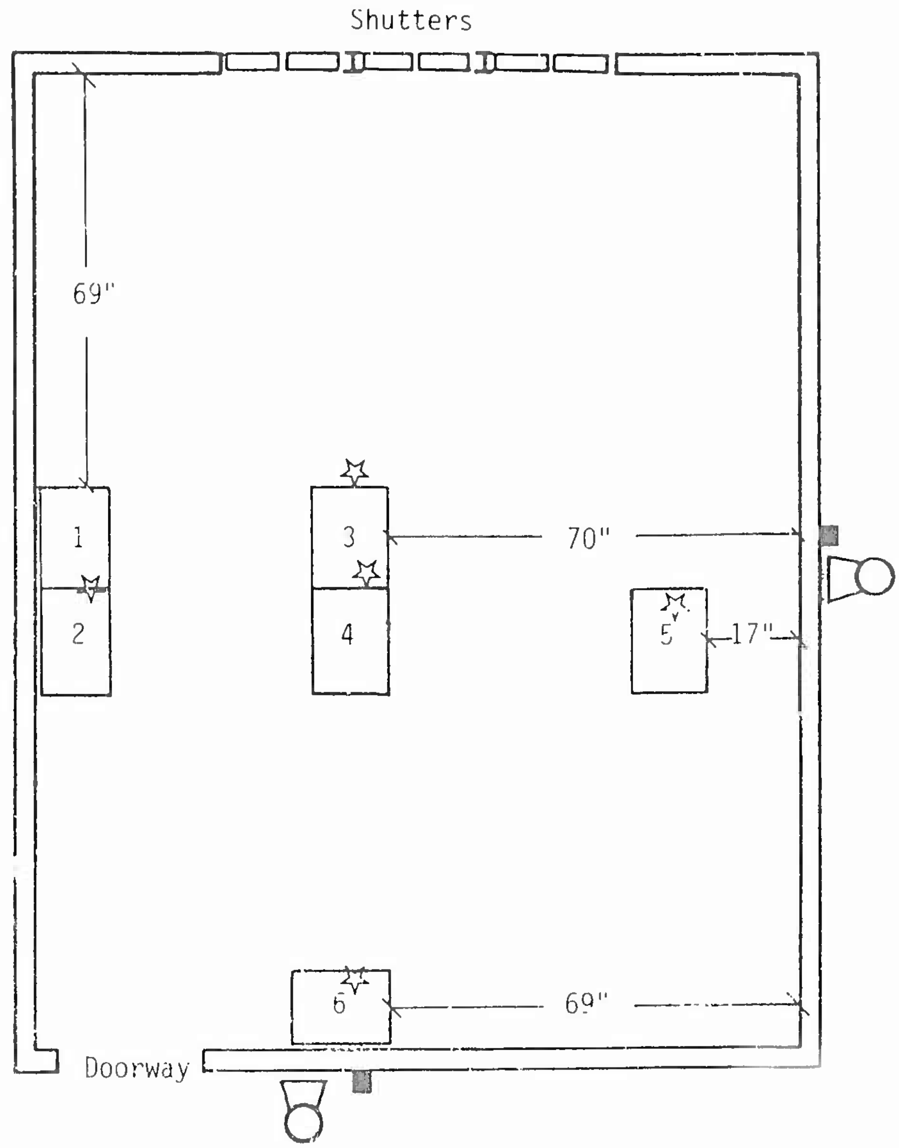
Compression Chamber Pressure	4.25	(psi)
Diaphragm Opening	21	([illegible])
Average Pressure in Room	2.4	(psi)
Positive Phase Duration	1.3	(sec)
Delay (ignition to blast)	27	(sec)

Test Geometry and Results

This test had the same basic warehouse configuration used in the last two tests (13 and 16) with certain additions designed to investigate whether the smouldering fires that occurred in the empty weighted boxes located along the side wall near the doorway and that reignited later could also exist in other areas of the room. The question was whether the cause of these fires was the location of the fuel or the type of fuel. Therefore, in addition to placing the central stack of six boxes containing a large quantity of paper in the center of the room and the two empty weighted boxes along the side wall, an empty weighted box was placed along the rear wall and another between the center stack and the side wall away from the doorway. The configuration is shown in Fig. 18-1 and the photographs of Fig. 18-2.

In this test, it was apparent that the central stack of boxes pre-ignited, that is, they ignited by the pilot light (Fig. 18-3) before the supply of propane was increased to form a long flame that was supposed to ignite the boxes. As a result of this, the fire in the central stack was very well established; its entire top and a good deal of the paper within the top boxes were flaming vigorously at the time of the shot. Despite this, all flames in this material were extinguished, and -- as before -- the contents of the stack were distributed widely throughout the room, and in the corridor behind the rear doorway.

In contrast, all fires in the weighted boxes were not extinguished. The two side boxes (numbers 1 and 2 in Fig. 18-1) were flaming within 30 seconds after the shot and the box near the other side wall (number 5) was smouldering, although the smouldering fire did eventually go out.



1, 2, 5, & 6 - 17 x 13 x 13 in. cardboard boxes (weighted, no paper)

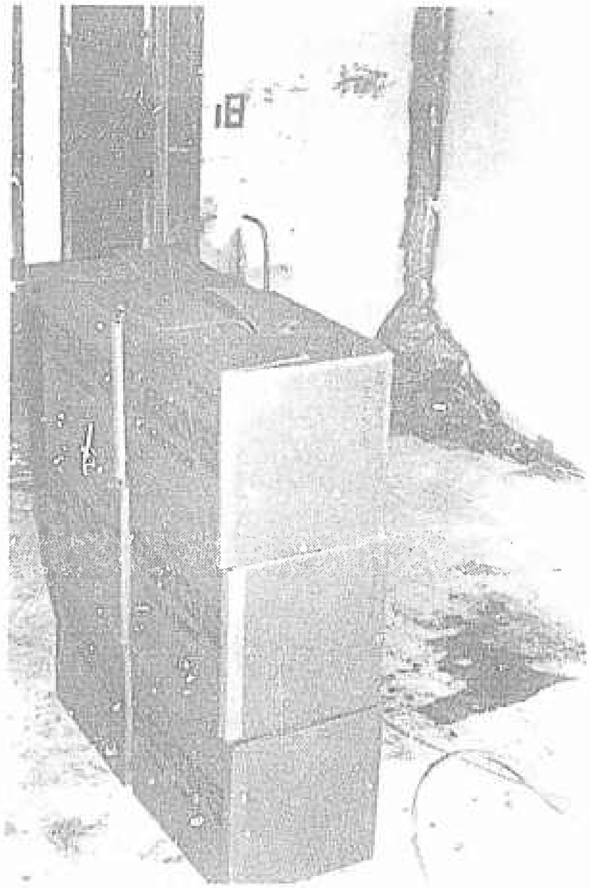
3 - 17 x 13 x 13 in. cardboard boxrs stacked three high (full of paper)

4 - 17 x 13 x 13 in. cardboard boxes stacked three high (top full of paper)

☆ Ignition sources

Fig. 18-1. Sketch of Test Geometry, Test Number 18

Fig. 18-2. Pretest Photographs, Test Number 18



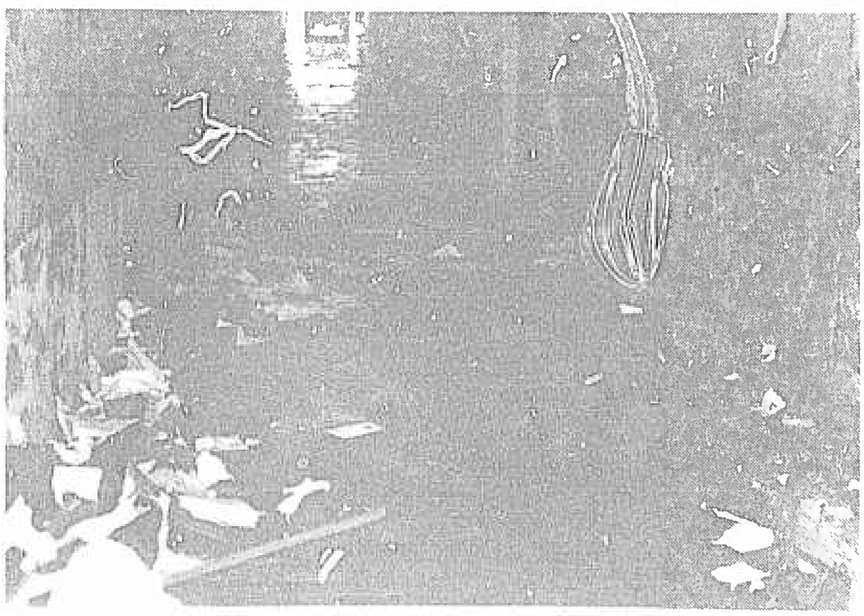


Fig. 18-3. Pre and Posttest Photographs, Test Number 18

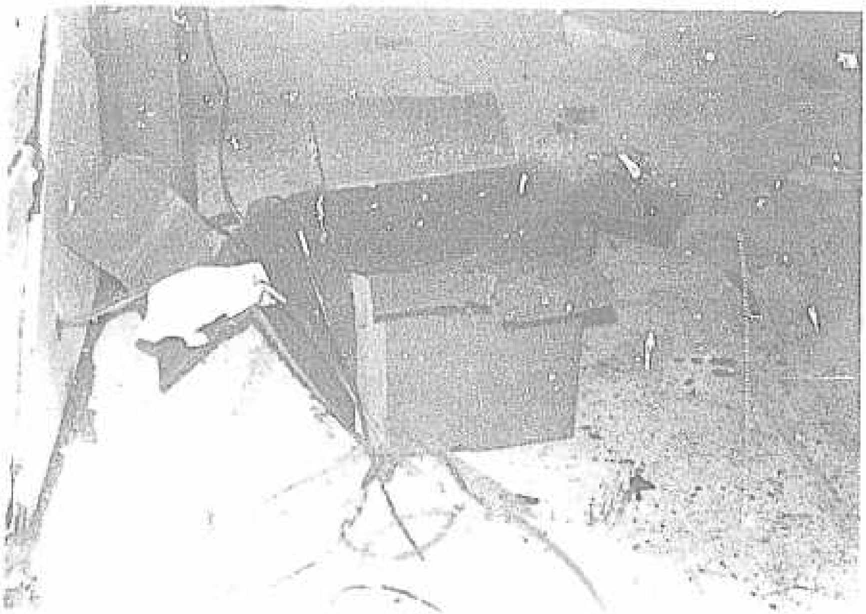


Fig. 18-4. Posttest Photographs, Test Number 18

Fig. 18-5. Posttest Photograph, Test Number 18

Test Report | Test Number 19

Type-- Confined Fuel Test

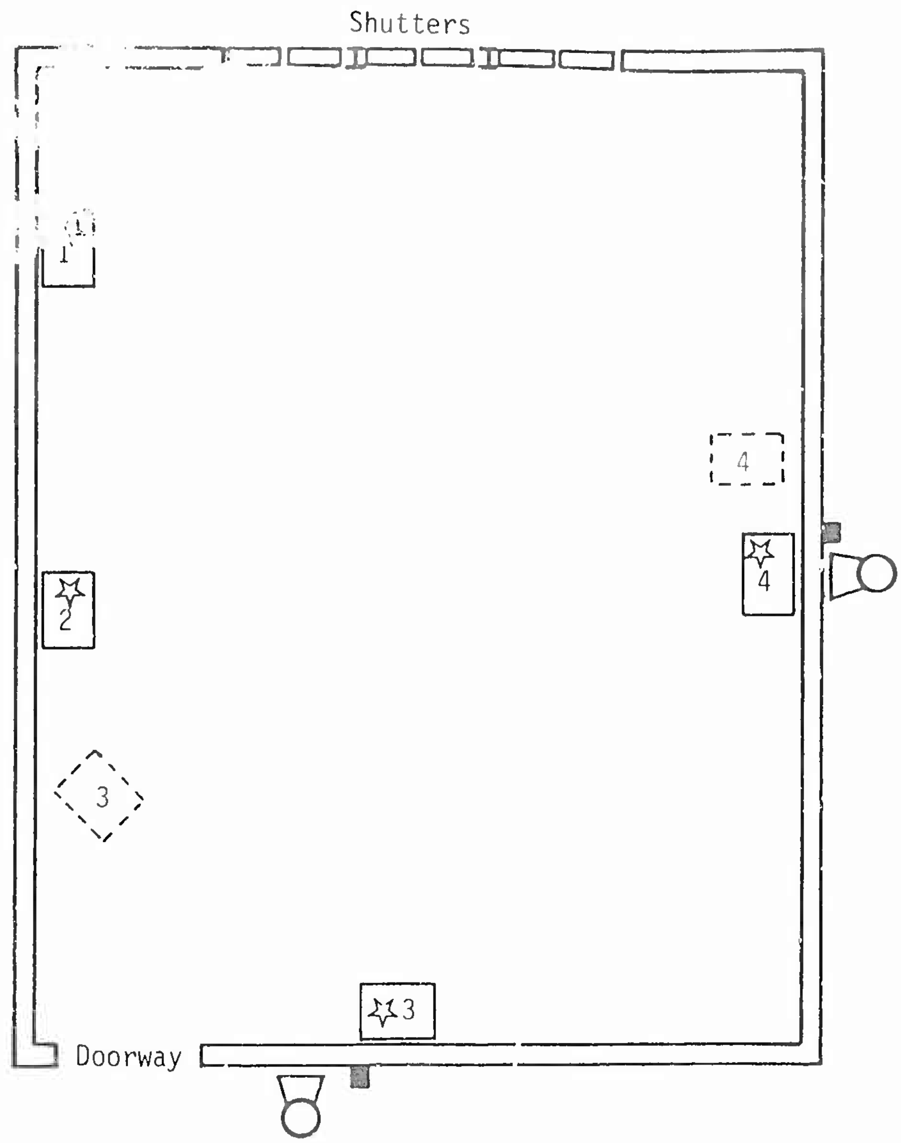
Test Conditions

Compression Chamber Pressure	2	(psi)
Diaphragm Opening	21	(%)
Average Pressure in Room	1.05	(psi)
Positive Phase Duration	0.94	(sec)
Delay (ignition to blast)	54	(sec)

Test Geometry and Results

In this test, all fuel (paper) was confined to four cages similar to the single cage used during Test 16. These were placed: against the side wall nearest the doorway, one fairly close to the shutters (cage 1), the other near the center of the room (cage 2); along the rear wall directly opposite the shutters (cage 3); and near the side wall farthest from the doorway, about halfway between the front and rear walls (cage 4) The configuration adopted is shown in Fig. 19-1. The top part of Fig. 19-2 is a pretest photograph of cages 1 and 2, and the lower part, a photograph of cage 4. Cage 3 is in the top photograph of Fig. 19-3.

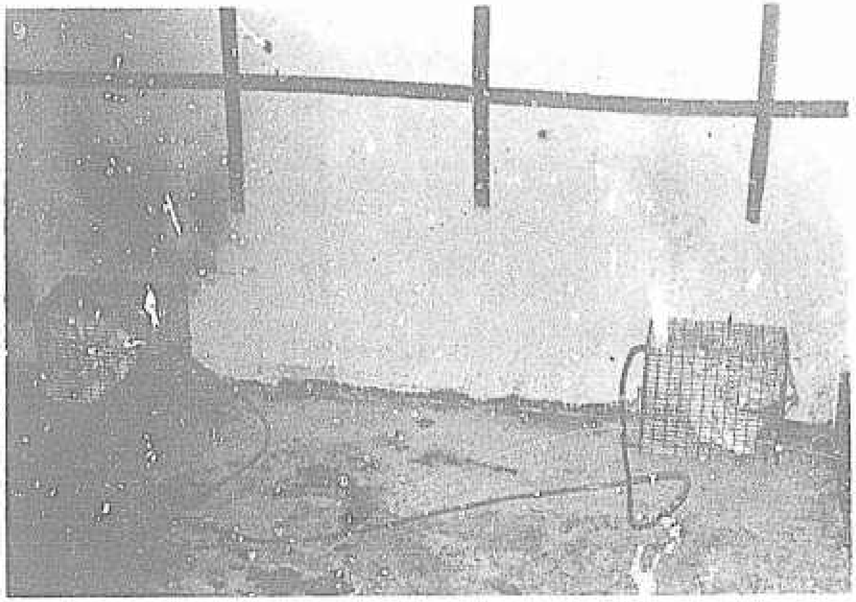
After the shot the contents of cages 1 and 2 were found totally consumed; the fires were extinguished in cages 3 and 4, which were displaced as shown in Fig. 19-1. This suggests that cages 1 and 2 were away from the direct high velocity flow between the window and the doorway, that cage 3 experienced a strong flow directly from the window, and that cage 4 was located in an area in which a high velocity swirl formed. Posttest photographs are shown in Figs. 19-3 through 19-5.



1, 2, 3, & 4 - 8.5 x 12.5 x 8 in. wire cages containing ignited paper. (Dotted lines indicate posttest locations)

☆ Ignition sources

Fig. 19-1. Sketch of Test Geometry, Test Number 19



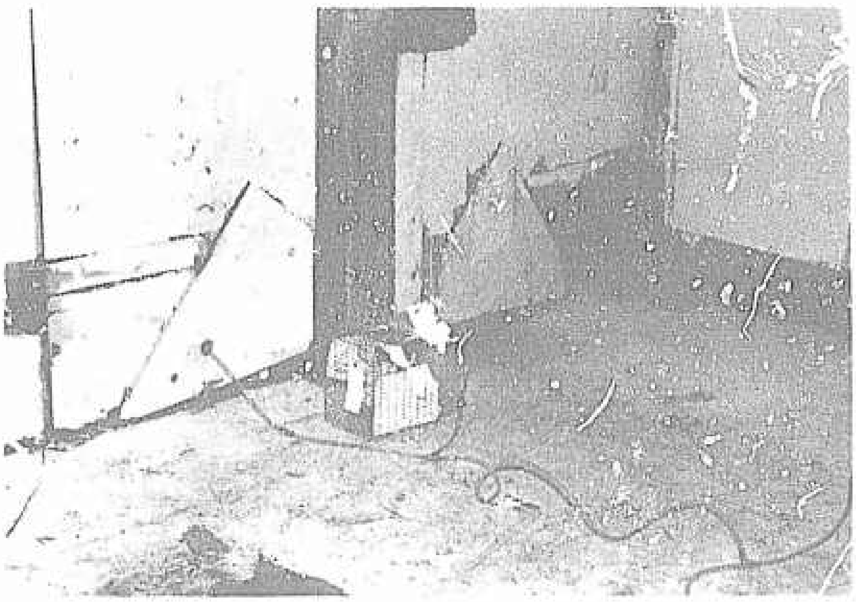


Fig. 19-2. Pretest Photographs, Test Number 19

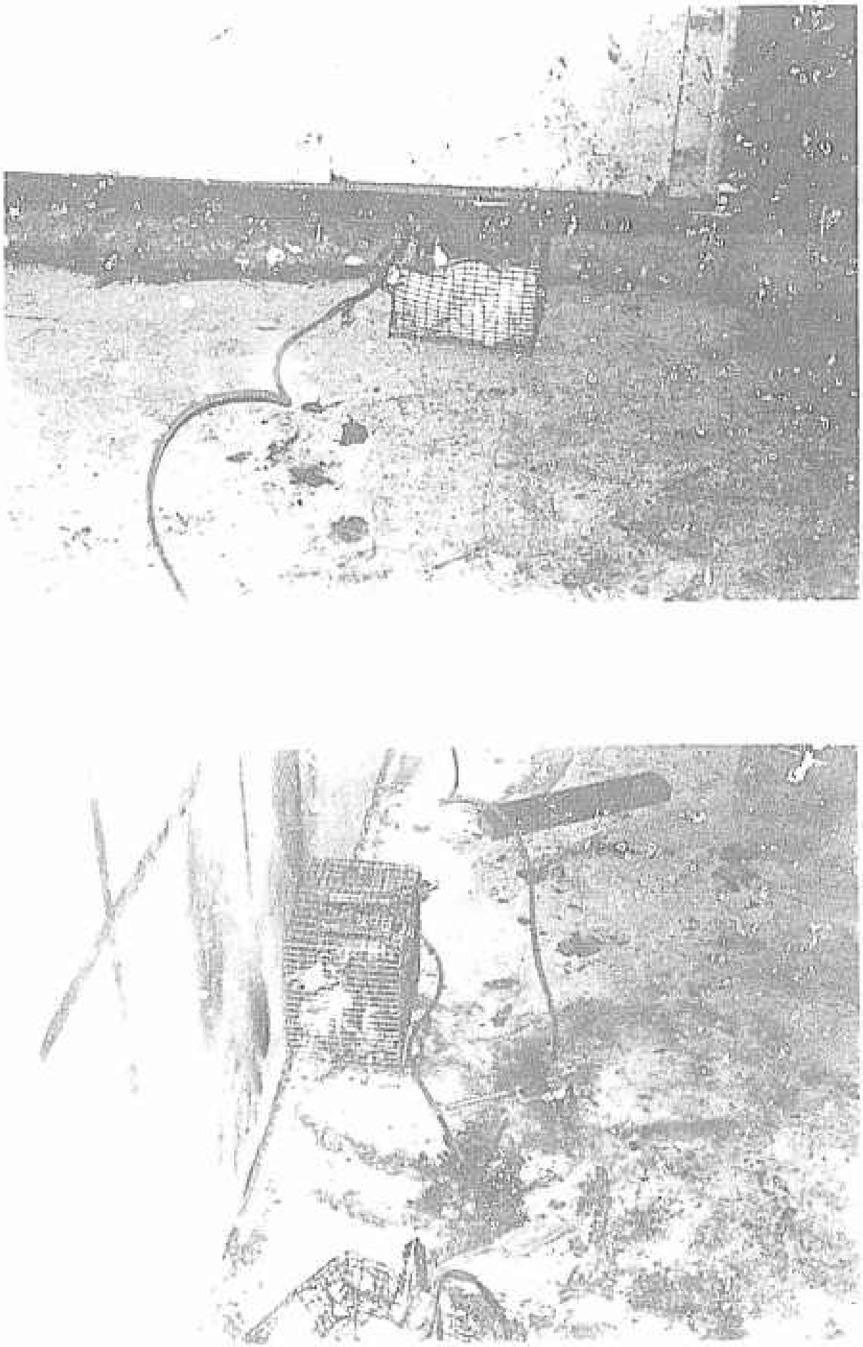
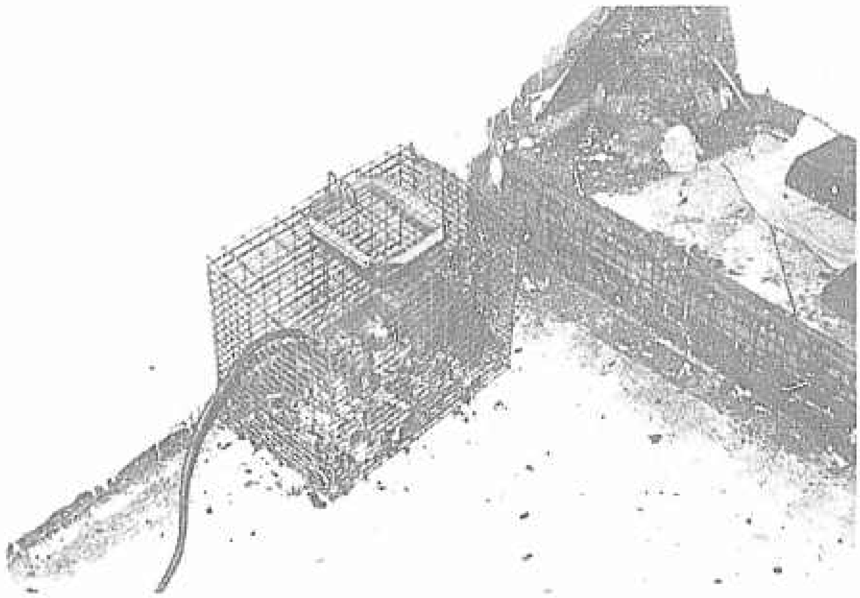


Fig. 19-3. Pre and Posttest Photographs, Test Number 19



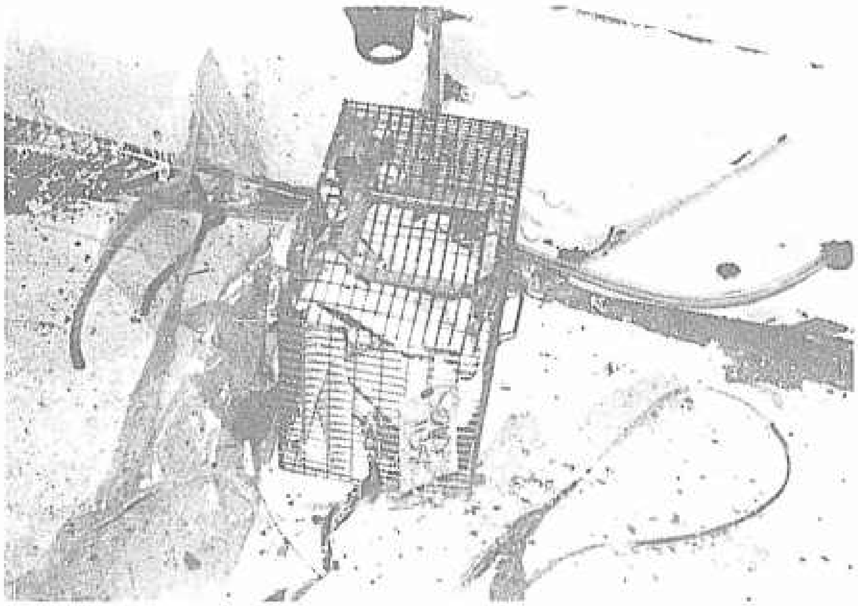


Fig. 19-4. Posttest Photographs, Test Number 19

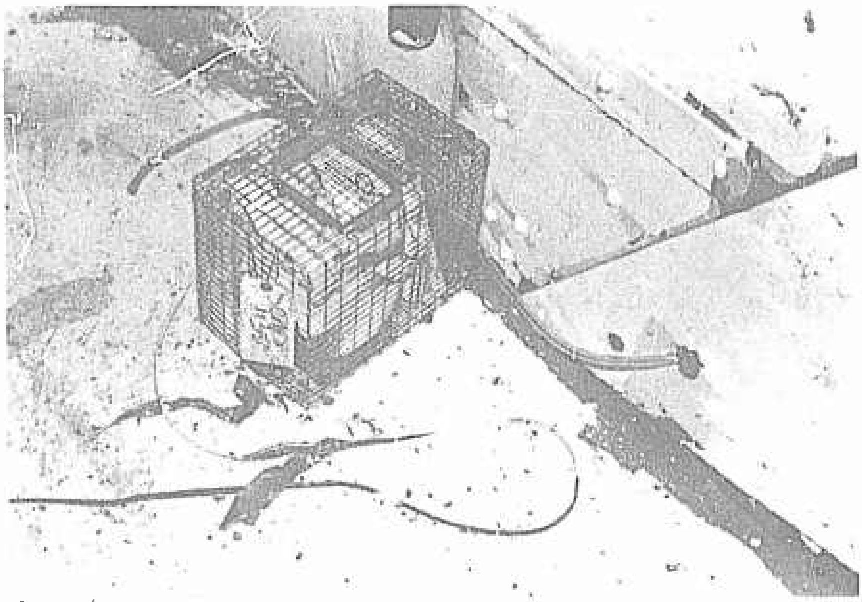


Fig. 19-5. Posttest Photographs, Test Number 19

Test Report Test Number 20

Type-- Warehouse

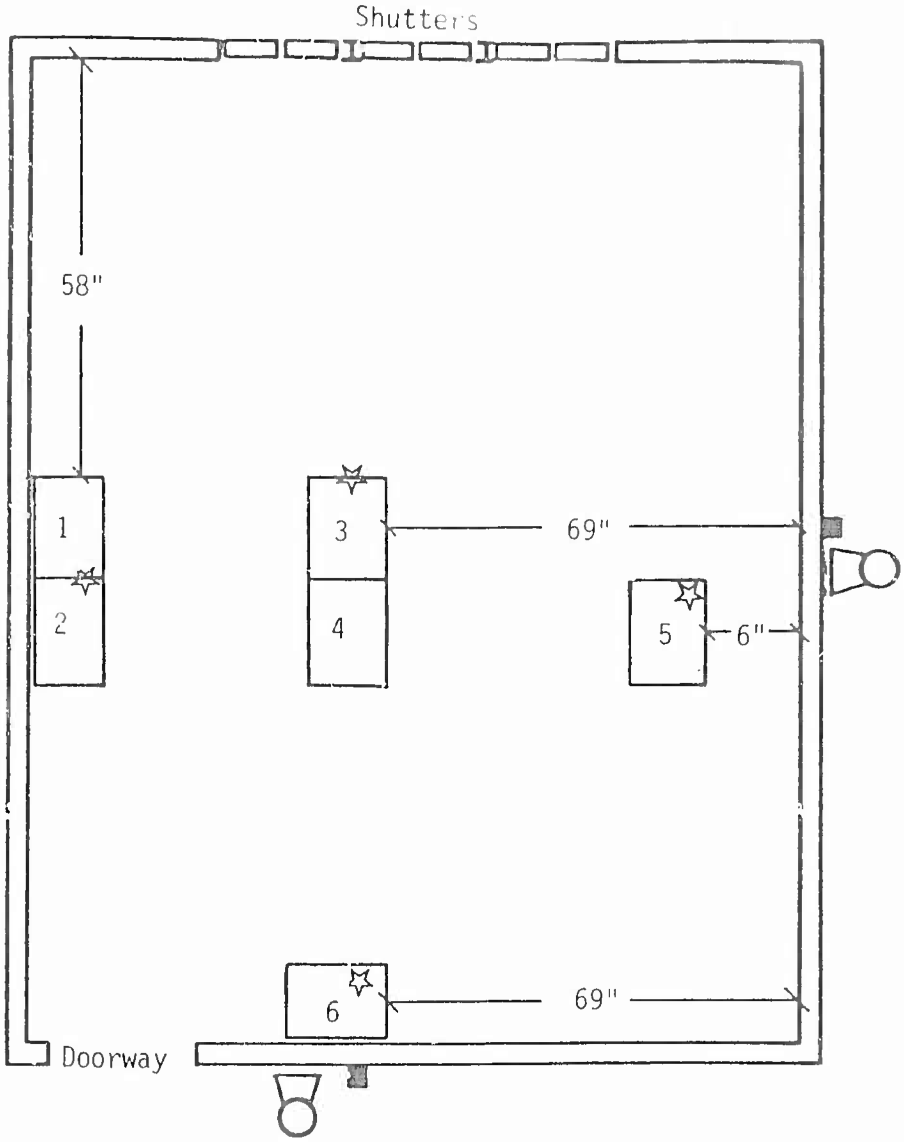
Test Conditions

Compression Chamber Pressure	6.1	(psi)
Diaphragm Opening	21	(%)
Average Pressure in Room	3.0	(psi)
Positive Phase Duration	1.5	(sec)
Delay (ignition to blast)	7	(sec)

Test Geometry and Results

This simulated warehouse room was arranged very much like that of Test 18, with a central stack of 6 boxes containing a good deal of paper, and four weighted but empty boxes placed in various other parts of the room. See Fig. 20-1 and the photographs of Figs. 20-2 through 20-4.

For the first time, all flames were extinguished and none rekindled. More movement of the weighted boxes was evident than before. Those along the side wall nearest the doorway were moved away from the wall and toward the front wall. The one along the opposite side wall moved upstream some 10 ft, coming to rest against one of the shutter openings, suggesting the presence of a strong eddy. Posttest photographs are shown in Figs. 20-4 through 20-7.



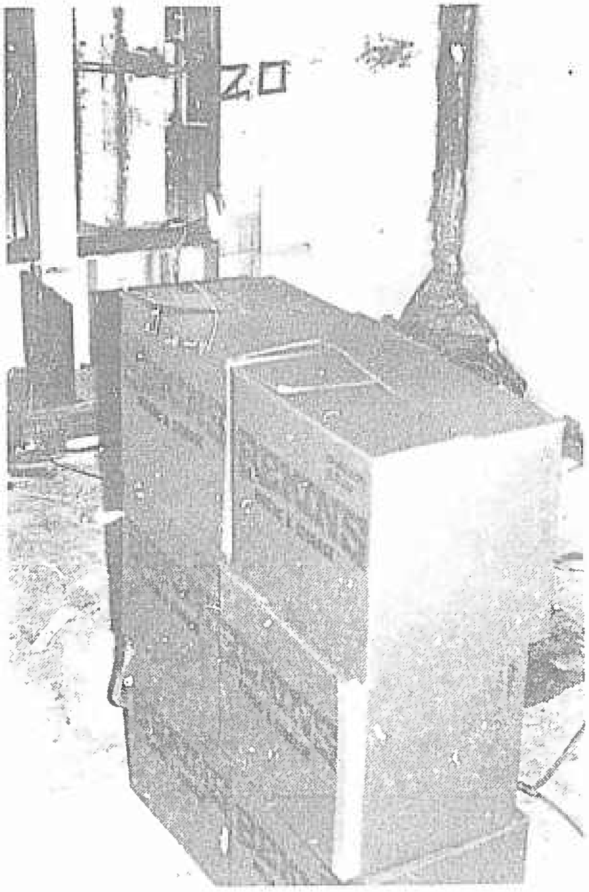
1, 2, 5, & 6 - 17 x 13 x 13 in. cardboard boxes (weighted, no paper)

3 - 17 x 13 x 13 in. cardboard boxes stacked three high (full of paper)

4 - 17 x 13 x 13 in. cardboard boxes stacked three high (top box full of paper)

☆ Ignition sources

Fig. 20-1. Sketch of Test Geometry, Test Number 20



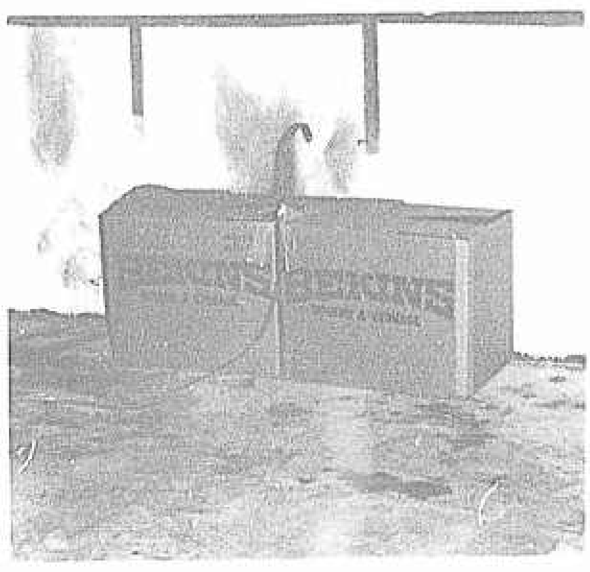


Fig. 20-2. Pretest Photographs, Test Number 20

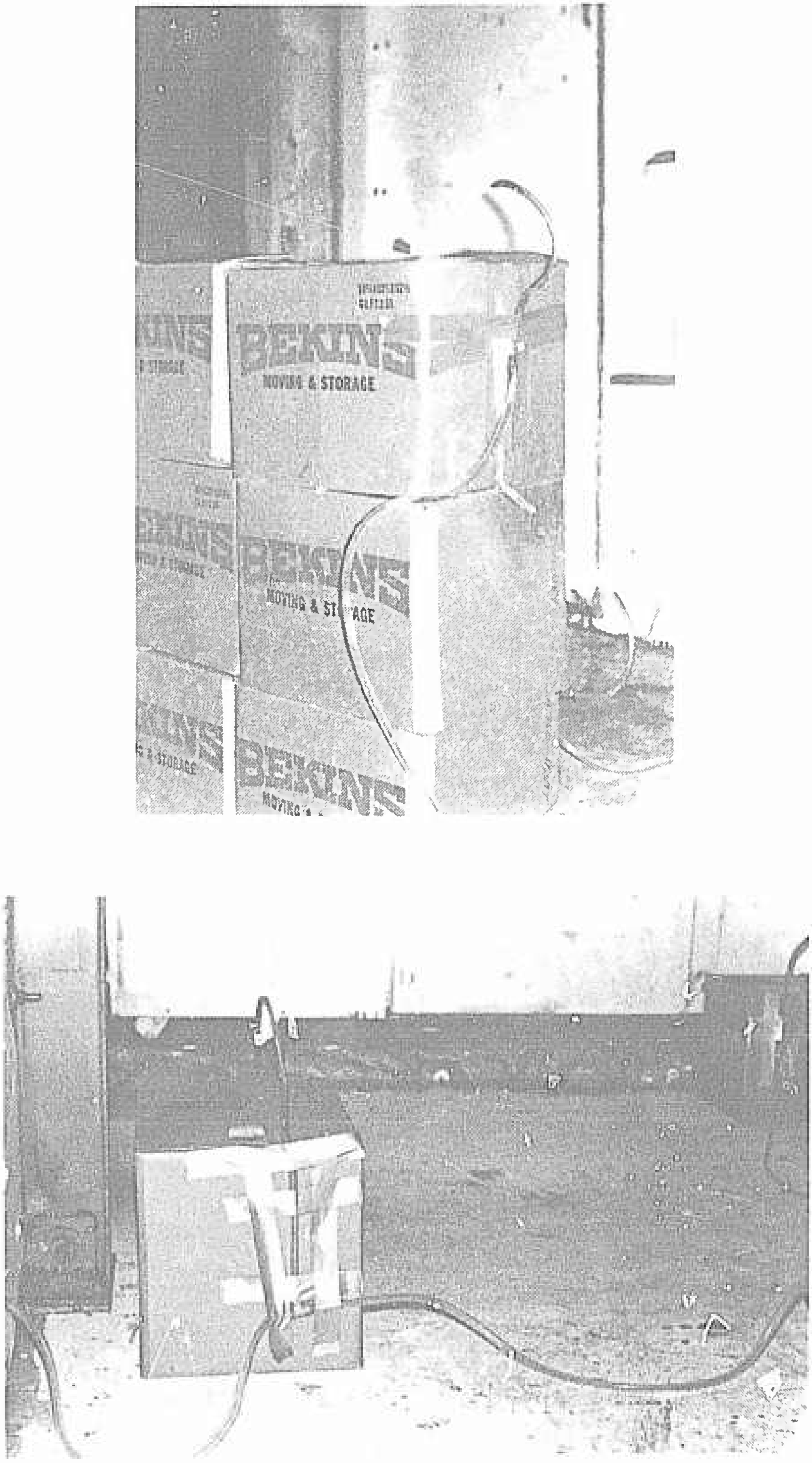


Fig. 20-3. Pretest Photographs, Test Number 20

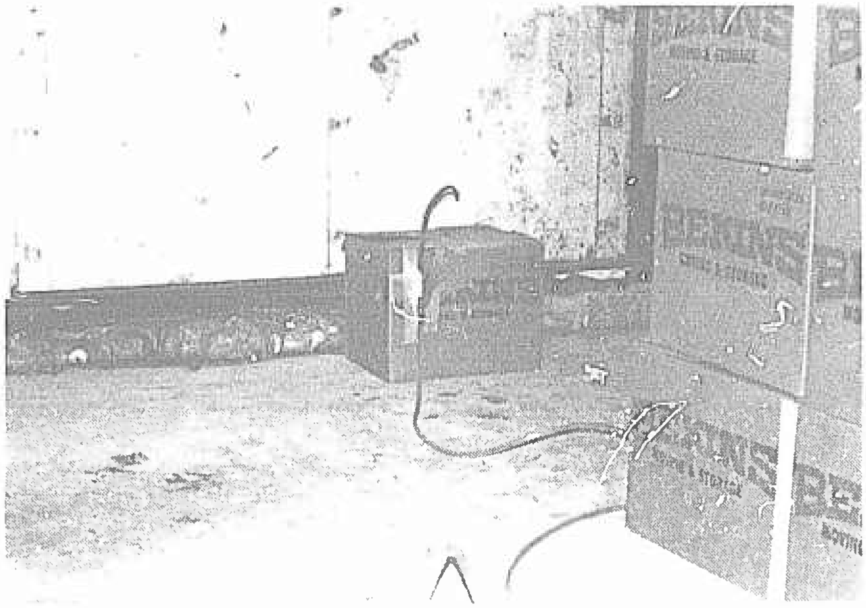


Fig. 20-4. Pre and Posttest Photographs, Test Number 20

Fig. 20-5. Posttest Photographs, Test Number 20

Fig. 20-6. Posttest Photographs, Test Number 20

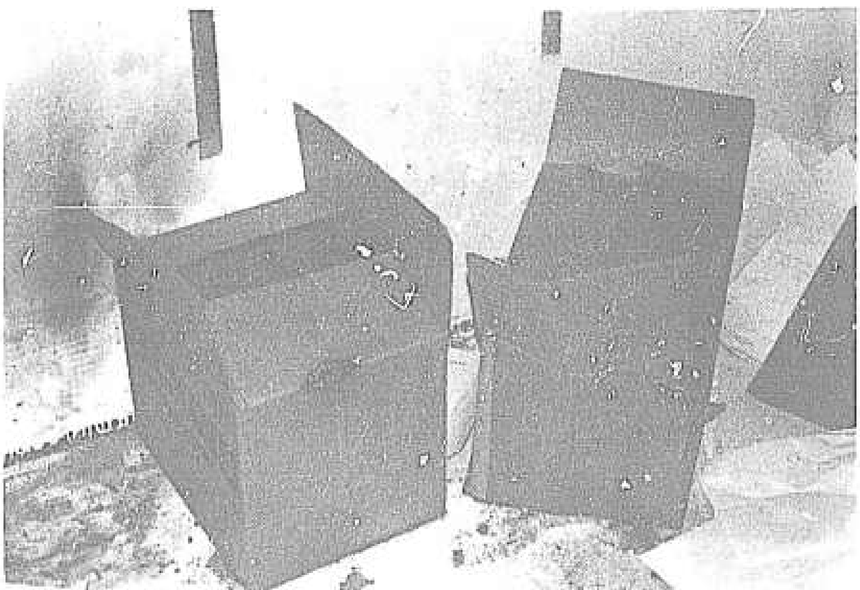


Fig. 20-7. Posttest Photographs, Test Number 20

Test Report Test Number 21

Type-- Confined Fuel Test

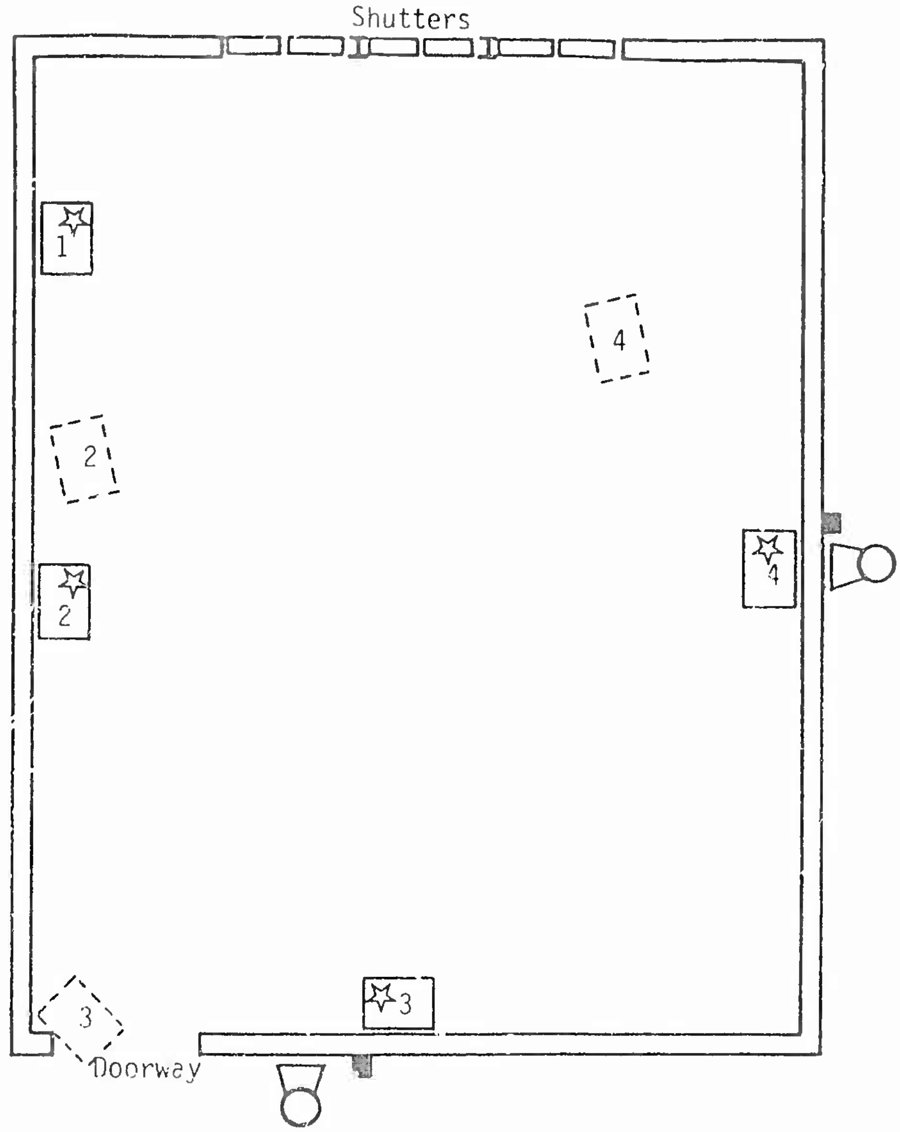
Test Conditions

Compression Chamber Pressure	5.5	(psi)
Diaphragm Opening	21	(%)
Average Pressure in Room	2.8	(psi)
Positive Phase Duration	1.4	(sec)
Delay (ignition to blast)	7	(sec)

Test Geometry and Results

As with Test 19, this was solely a confined fuel test, with paper fuel in four cages at various places in the room. (See Figs. 21-1 through 21-3. The overpressure used in this test was, however, much higher than that of Test 19 (5.5 psi chamber pressure vs. 2 psi).

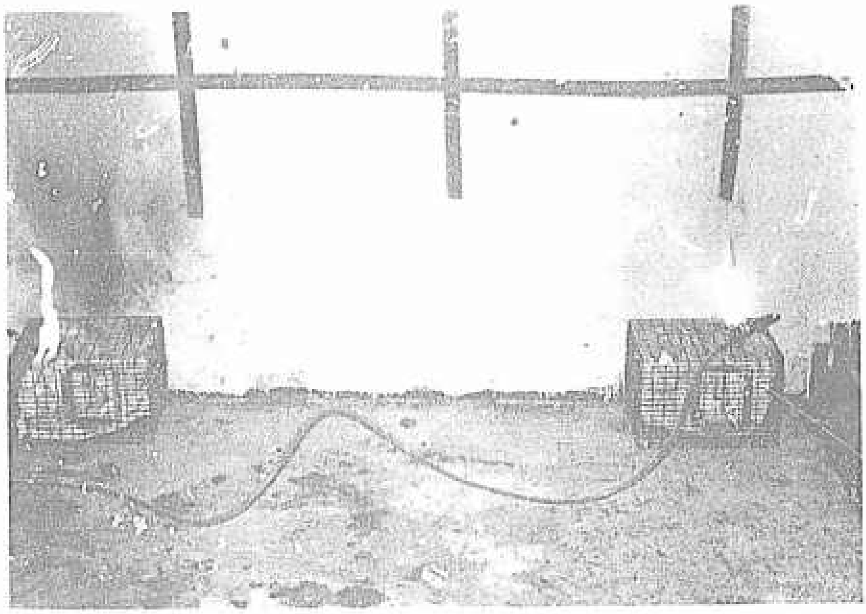
The results of the test were similar to those of Test 19 except that more fires were extinguished. Only fuel in cage number 1 continued to burn. Fires in the other three were extinguished and the cages themselves were translated as shown in Fig. 21-1. These translations give some insight into the flow field that established itself in the room.



1, 2, 3, & 4 - 8.5 x 12.5 x 8 in. wire cages containing paper (dotted lines indicate posttest locations)

☆ Ignition sources

Fig. 21-1. Sketch of Test Geometry, Test Number 21



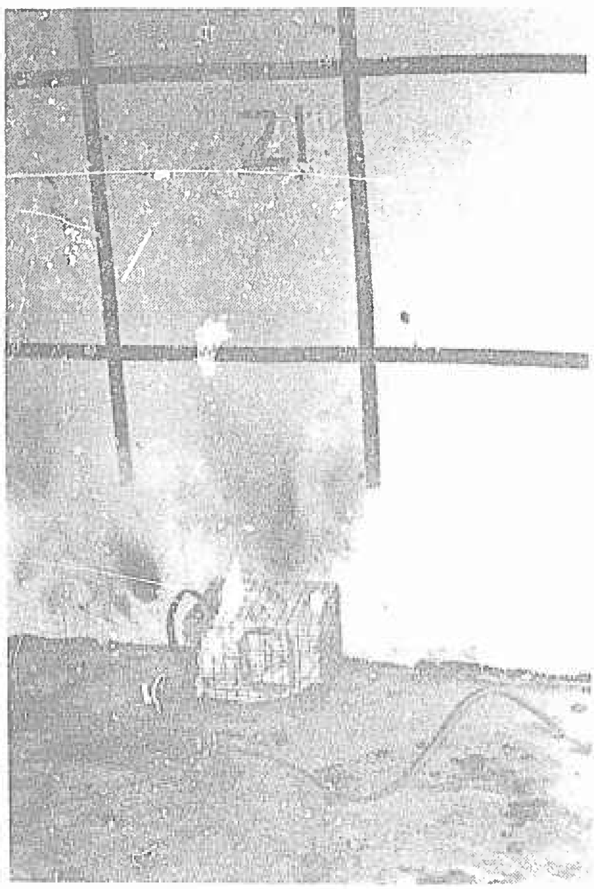


Fig. 21-2. Pretest Photographs, Test Number 21

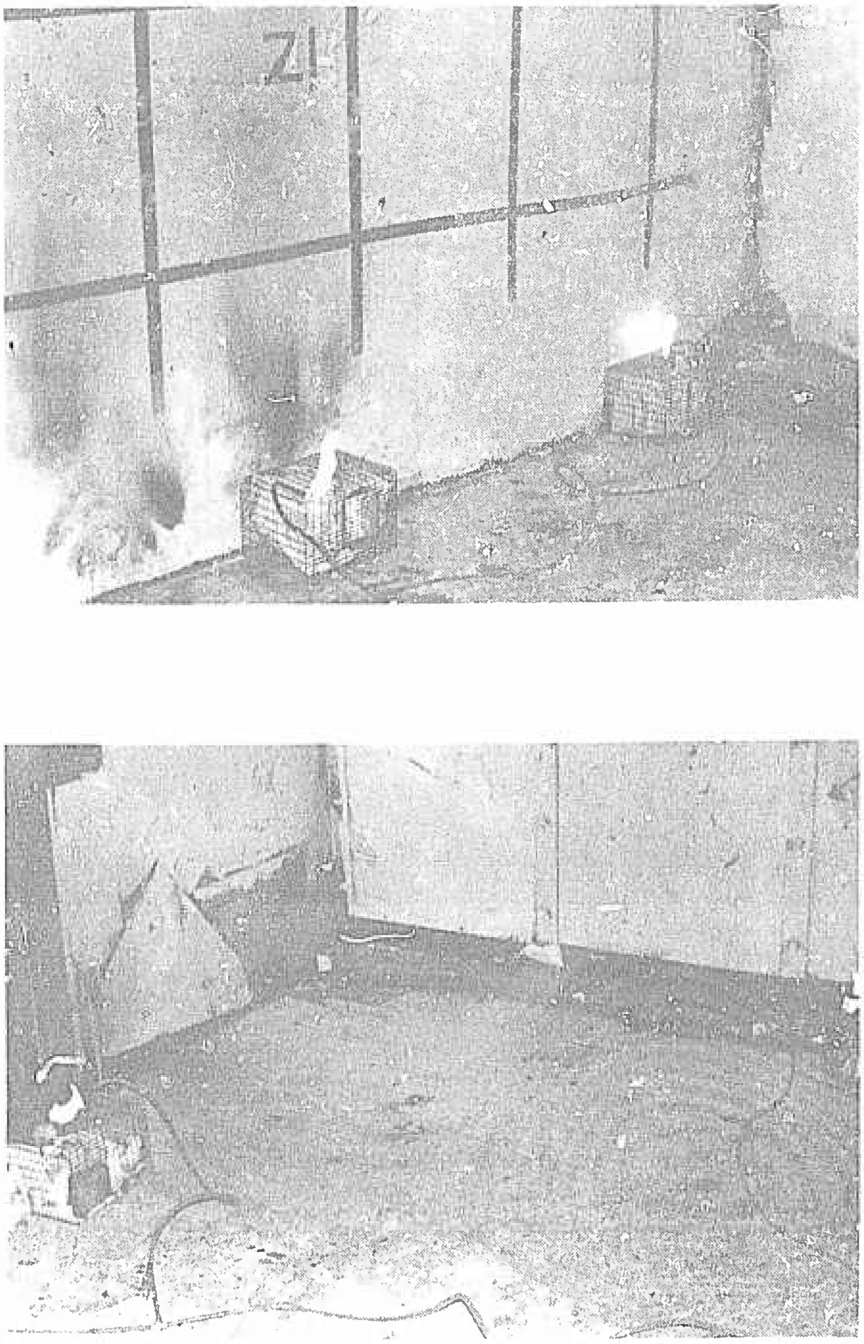
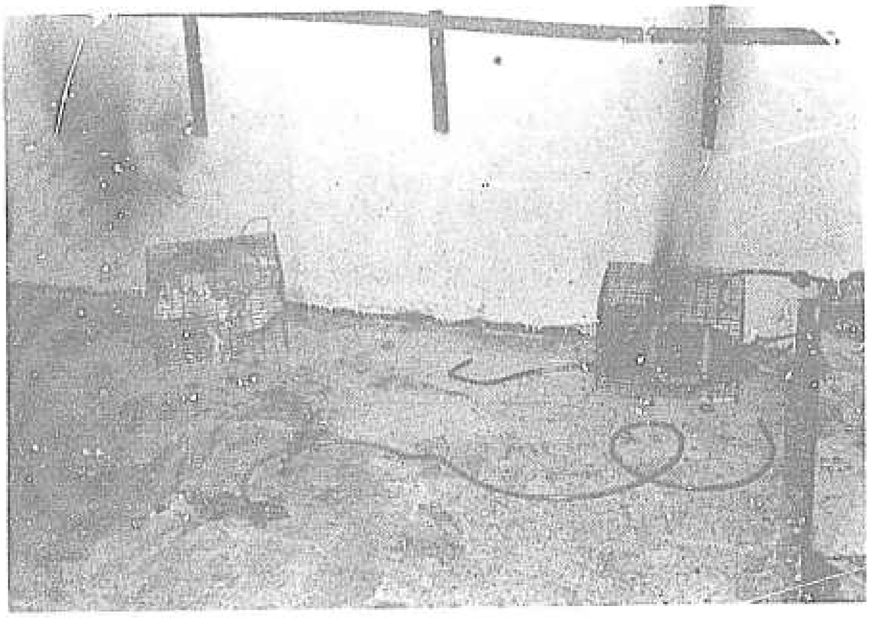


Fig. 21-3. Pretest Photographs, Test Number 21



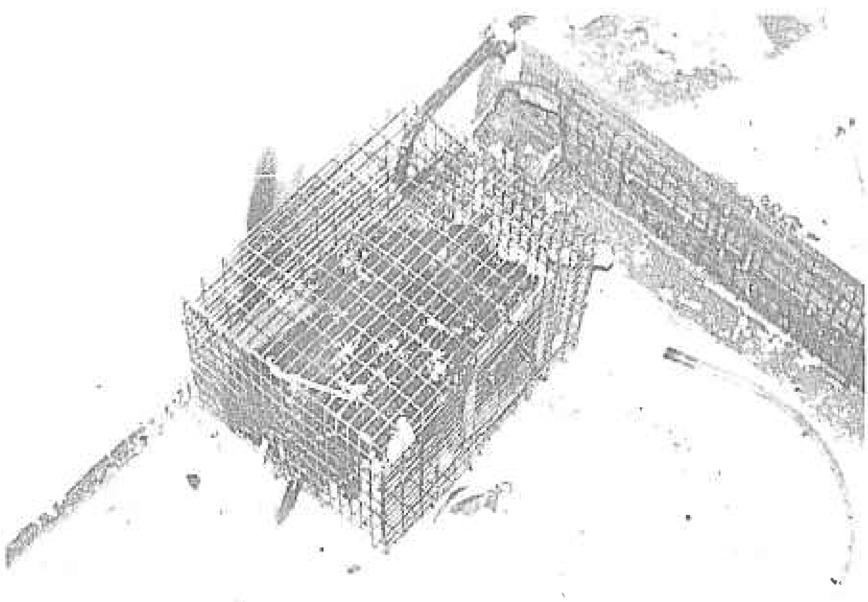


Fig. 21-4. Posttest Photographs, Test Number 21

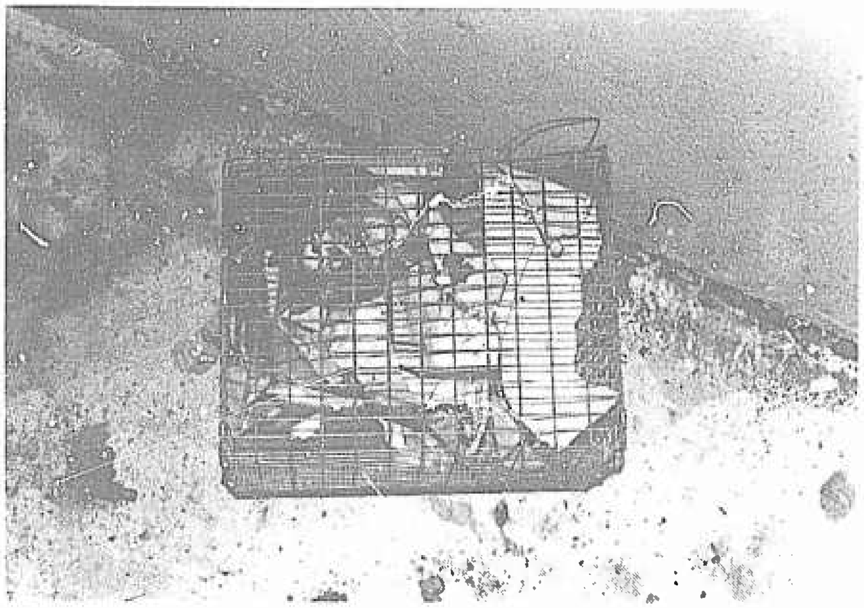


Fig. 21-5. Posttest Photograph, Test Number 21

Appendix B

SUMMARY OF RELATIONSHIPS AMONG BLAST WAVE PARAMETERS

Appendix B

SUMMARY OF RELATIONSHIPS AMONG BLAST WAVE PARAMETERS

In this appendix, expressions relating flow velocity, reflected pressures, and stagnation pressure to incident shock overpressure are given. The notation, values, and units used are as follows:

a_1 = sound velocity in air at ambient conditions = 1130 ft/sec

M_i = the Mach number of the flow (the ratio of flow velocity to sound velocity) behind the incident shock front

p_1 = ambient pressure = 14.7 psi

p_i = total pressure in the incident shock wave (psi)

p_s = total pressure in the stagnation region (psi)

Δp_i = incident shock overpressure (psi)

Δp_r = reflected shock overpressure (psi)

Δp_s = stagnation overpressure (psi)

q_i = dynamic pressure in the incident shock = $(\rho_i u_i)^2/2$ (psi)

u_i = flow velocity behind the incident shock (ft/sec)

ρ_1 = ambient air density = 0.002503 lb sec^2/ft^4

Relationships among these variables, and typical values for various values of p_i follow.

1. Incident shock wave flow velocity, u_i

$$u_i = (a_1)(5\Delta p_i)/\sqrt{7p_1(7p_1 + 6\Delta p_i)}$$

for Δp_i = 2 psi, u_i = 101 ft/sec

for Δp_i = 4 psi, u_i = 190 ft/sec

2. Reflected overpressure, Δp_r after head on reflection of the incident shock wave from a solid wall

$$\Delta p_r = 2\Delta p_i(7p_1 + 4\Delta p_i)/(7p_1 + \Delta p_i)$$

for $\Delta p_i <<$, $\Delta p_r = 2\Delta p_i$

for $\Delta p_i = 2$ psi, $\Delta p_r = 4.2$ psi

for $\Delta p_i = 4$ psi, $\Delta p_r = 8.9$ psi

for $\Delta p_i = 8$ psi, $\Delta p_r = 19.5$ psi

for $\Delta p_i >>$, $\Delta p_r = 8\ \Delta p_i$

3. Mach number of the incident flow, M_i

$$M_i = 5\Delta p_i / \sqrt{7(p_1 + \Delta p_i)(7p_1 + \Delta p_i)}$$

for $\Delta p_i = 2$ psi, $M_i = 0.090$

for $\Delta p_i = 4$ psi, $M_i = 0.17$

4. Dynamic pressure of the incident flow, q_i

$$q_i = 2.5(\Delta p_i)^2/(7p_1 + \Delta p_i)$$

for $\Delta p_i = 2$ psi, $q_i = 0.095$ psi

for $\Delta p_i = 4$ psi, $q_i = 0.37$ psi

5. Stagnation pressure of the incident flow, p_s

$$(p_s - p_i)/q = 1 + M_i^2/4 + M_i^4/40 + \ldots$$

with incident overpressure of 10 psi ($M_i \approx 0.36$) or less, the error is less than about 3% if it is assumed that

$$p_s = p_i + q$$

or

$$\Delta p_s = \Delta p_i + q$$

for $\Delta p_i = 2$ psi, $\Delta p_s \approx 2.1$ psi

for $\Delta p_i = 4$ psi, $\Delta p_s \approx 4.4$ psi

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INTERIM TESTS OF THE EFFECTS OF LONG DURATION
BLAST-TYPE FLOWS ON FIRES IN URBAN INTERIORS
AND CONTENTS OF EMERGENCY OPERATING CENTERS (EOC)
URS 7239-10
URS Research Company, San Mateo, California
October 1975
Contract No. DAHC20-73-C-0195, Work Unit 2563A

UNCLASSIFIED

The objectives of the study were to extend the understanding of the manner in which long-duration air blast (from megaton weapons) interacts with fires ignited by the thermal pulse, it having been postulated that extinguishment would occur, for many materials, when subjected to such long-duration flows. To this end, tests were designed and conducted in the URS Long Duration Flow Facility (LDFF) at Fort Cronkhite, California, under the sponsorship of the Defense Civil Preparedness Agency.

A room (approximately 12 ft x 15 ft x 8.5 ft) in this facility was utilized to place burning materials and subject them to pressures of 1.0 to 3.5 psi, flows of 200 to 600 ft/sec and attendant flow durations of 1 to 2 seconds. The materials tested included, but were not limited to, paper (solid-pack and crumpled), cloth, vinyl, cardboard, and wood. In addition, two tests (without fire) of a simulated EOC (without blast-doors) were performed at 2 psi.

The results indicated that 2 psi (rather than 2.5 psi predicted) is a boundary for extinguishment of lighter materials, such as paper and cardboard. Those materials which readily support smouldering combustion, such as cotton batting and heavy cloth, do not extinguish even at 3.5 psi. The results of the EOC test indicated potentially severe damage to communications equipment, monitoring equipment, and furniture.

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