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EDGEWOOD ARSENAL TECHNICAL REPORT

EM-TR-76001

CATEGORY 5 SUPPRESSIVE SHIELD TEST REPORT

by

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October 1975

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A prototype suppressive shield of modular, prefabricated construction suitable for application in illuminant, propellant, and pyrotechnic production lines was proof tested. The 1000 cubic foot structure was demonstrated to be capable of complete fragment retention from simulated explosive slurry mixing equipment. Blast pressure reductions of 75 to 85 percent were measured external to the enclosure for charge weights from 0.57 to 2.4 lbs. Temperature gradients and heat flux generated by charges of 10 to 50 lbs. of illuminant material were similarly reduced.

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PREFACE

The investigation described in this report was authorized under PA, A 4932, Project No. 5751264, under MIPRs B4075 and B5117. The work was performed at the NASA National Space Technology Laboratories (NSTL) under direction of the Edgewood Arsenal Resident Laboratory (EARL) through NASA-NSTL with the General Electric Company and Global Associates as support contractors. The experimental work was completed May 1975.

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CATEGORY 5 SUPPRESSIVE SHIELD

1.0 INTRODUCTION

1.1 Objective. The objective of this program was to proof test a vented enclosure that would suppress an accidental detonation of an explosive igniter slurry mix, and reduce flame and fireball from deflagration reactions to a tolerable level. The shield was designed so that, in the event of a process accident, maximum operator and facility protection would be provided while retaining facility flexibility at minimum cost.

1.2 Authority. The investigation described in this report was authorized under PA, A 4932, Project No. 5751264, MIPRs B4075 and B5117. The work was performed under the direction of the Edgewood Arsenal Resident Laboratory at the NASA National Space Technology Laboratories (NSTL) with support from the General Electric Company and Global Associates.

1.3 Background. The suppressive shielding program (1) was initiated in 1969 to provide improved, cost-effective, safety-certified explosion suppressive protective structures in the form of homogeneously vented enclosures as an alternative to the use of US Army TM5-1300 walls. Previous tasks have demonstrated the concept feasibility and have shown that blast overpressure, fireball, and fragmentation hazards from an accidental detonation can be significantly reduced or suppressed. Full scale prototype structures have been developed for applications in Chemical Agent Munition Demilitarization Systems (2, 3), white phosphorus munition processing (4), explosive ordnance disposal (5, 6), and 81mm mortar round production lines (7, 8).

In 1973 the program was given increased impetus by US Army authorization to provide, within three years, a sound technological base for the concept. At the direction of the Project Manager, USA Production Base Modernization and Expansion Office and with the cognizance of the Suppressive Shielding Technical Steering Committee, a simultaneous program was initiated to provide proven prototype hardware applicable to seven major categories of hazardous munition production operations. Work is currently in progress on all of the shields, and the testing of a prototype fixture for Category 5 applications is the subject of this report.

In addition to the basic definitions of Category 5, Army Ammunition Plant (AAP) surveys conducted during April 1974 resulted in selection of an igniter slurry mixing operation at the Longhorn AAP as a typical application for this shield. Specific consideration during the program was thus given to the candidate operation, although the shield is applicable to the entire spectrum of Category 5 applications with only minor modifications required to address size restraints.

2.0 TECHNICAL INVESTIGATIONS

2.1 Test Fixture. The design and fabrication of the Category 5 suppressive shield will be published in a separate report. The structure, in various stages of fabrication, is shown in figures 1-5.

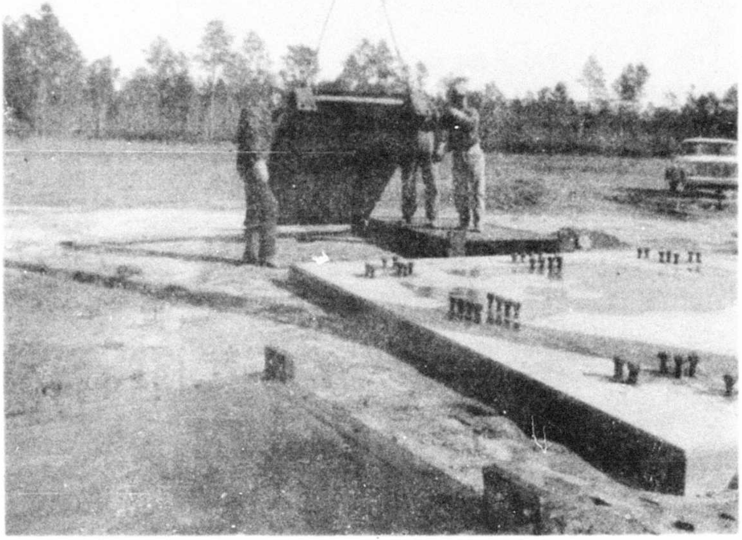

Figure 1. Category 5 Suppressive Shield Wall Section Being Positioned on Concrete Slab

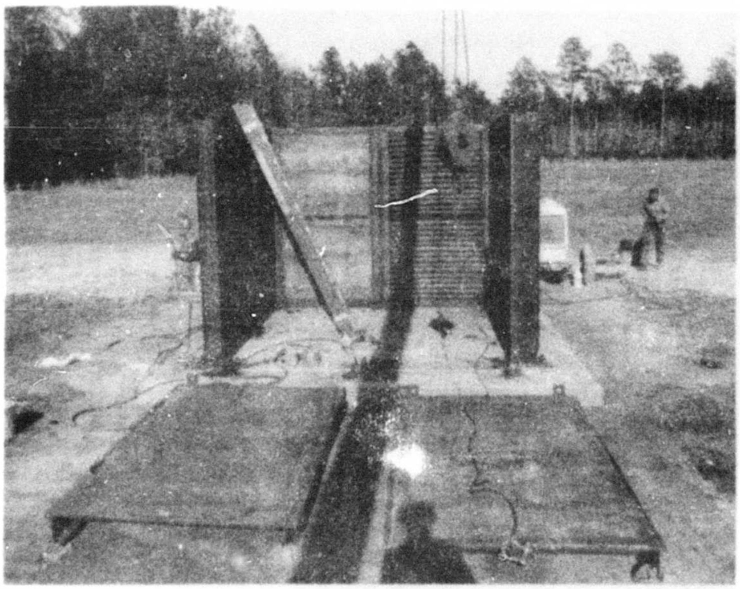

Figure 2. Category 5 Suppressive Shield Showing Six Wall Sections in Place

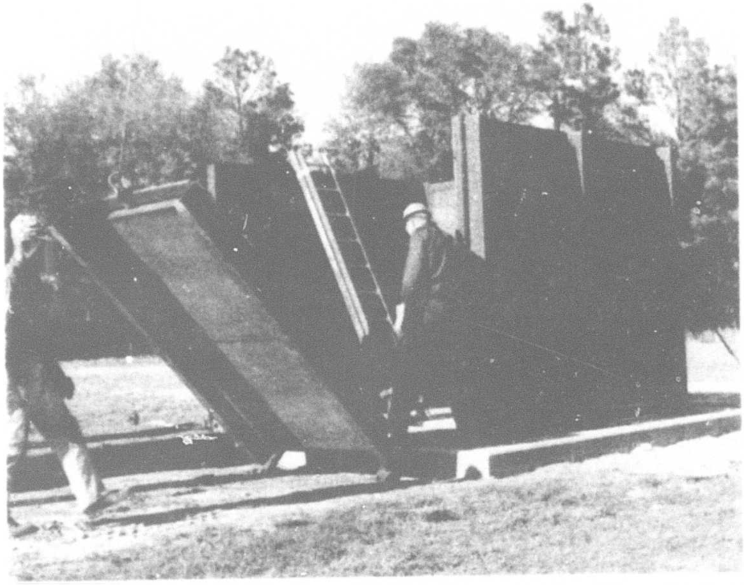

Figure 3. Category 5 Suppressive Shield Wall Section Being Positioned on Studs in Concrete Foundation

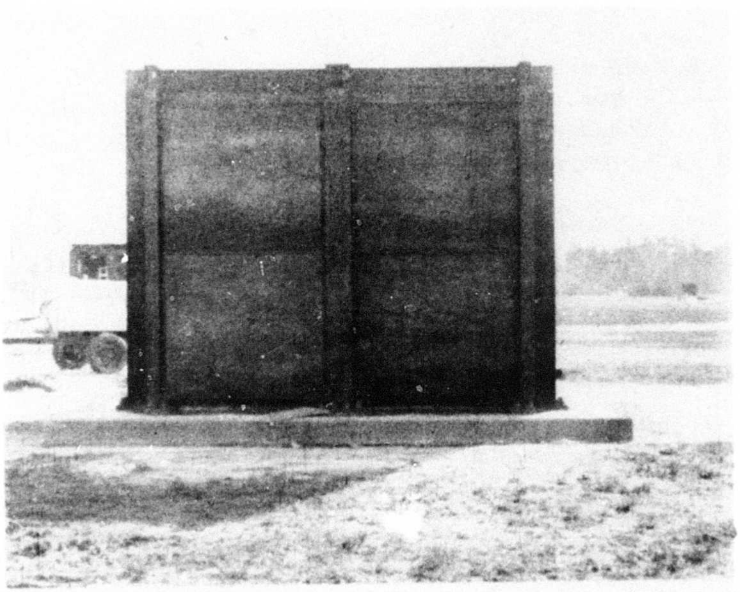

Figure 4. Completed Category 5 Suppressive Shield

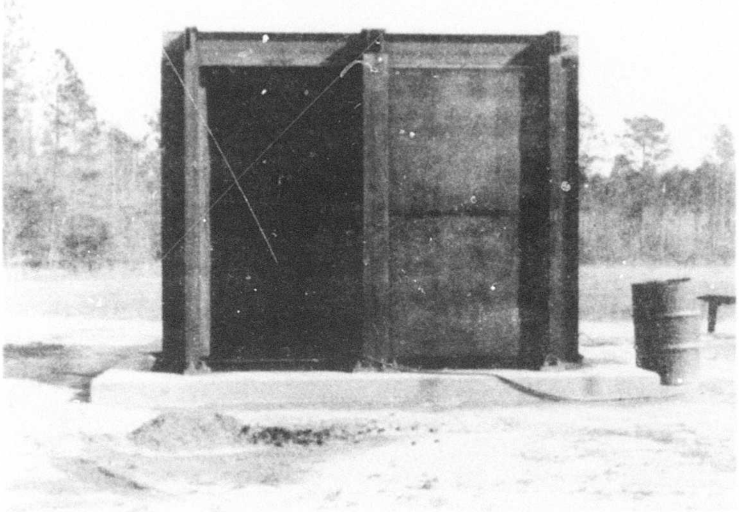

Figure 5. Category 5 Suppressive Shield
Showing Personnel/Equipment Access Door

2.2 Test Program Scope. To evaluate the effectiveness of the suppressive shield design and to provide basic data for empirical input into the Applied Technology Program, a series of tests were performed within the structure as follows:

- Explosive tests were conducted inside the suppressive shield using spherical C-4 charges. The final charge weight (2.44 lbs C-4) provided structural loading of 62.5 psi peak side-on overpressure at the wall and so represents a 25 percent blast pressure overload beyond the design point.

- Fragmentation confinement tests were conducted using simulated processing equipment from the candidate application, with an equivalent charge of high explosive.

- Flame and thermal confinement tests were conducted using an illuminant composition.

All tests were preceeded by appropriate free-air calibrations using equivalent weights of C-4 or illuminant mix.

2.3 Explosive Containment Tests. The response of the structure and the degree of attenuation of explosive force was measured in a series of tests using progressively larger quantities of C-4 explosive. In each case the C-4 was formed into a spherical charge, wrapped with black Velostat plastic, suspended on the horizontal centerline 42 inches above the floor, and detonated with a J-2 blasting cap. Weights of explosive were calculated to generate peak side-on blast overpressures of 20 psi, 30 psi, 50 psi, and 62.5 psi at the closest structural walls, as verified by a series of free-air tests.

Measurements of internal and external blast pressure, internal quasi-static pressure, and reflected pressure were made during all tests in the suppressive shield. A plan view of transducer placement during the tests is shown in figure 6 and details of instrumentation are given in table 1. Pressure transducer mounting schemes are as follows:

- Piezoelectric transducers were used to measure side-on blast pressure external to the shield. Susquehanna Instruments ST-7H transducers with integral ballistic probes were mounted in stands constructed of 2-inch iron pipe such that the probe is horizontal at charge height and oriented toward the direction of the charge. Each probe in an array was staggered a minimum of 1.0 foot from a direct line to the remaining sensors in an array, in order to minimize reflections.

- Piezoelectric transducers were used to measure internal blast reflected pressure at the walls of the shield. Susquehanna Instruments ST-4 transducers were mounted flush with the interior structural frame within 1-1/2-inch diameter cylindrical teflon blocks, such that electrical and some semblance of shock isolation from the structure was afforded. The ST-4 gauge located in the corner was similarly mounted into a 4-inch x 6-inch steel plate facing the charge. All of the face-on measurements were made at charge height (42 inches).

- Susquehanna Instruments ST-2 transducers were used to measure blast pressure external to the shield at ground level. The ST-2 transducers were mounted externally within teflon inserts in a one-foot wide MS12-133 channel, similar to the arrays described in earlier work at BRL (9).

- PCB 101 A02 gauges were used to measure internal quasi-static pressure and were mounted at the interior wall surfaces in isolation chambers similar to that described by Schoemacker (9).

In addition, the structure was instrumented with approximately 40 BLH weldable strain gauges, three piezoelectric accelerometers, and two Southwest Research Institute designed wall displacement gauges; data and analysis of these measurements will be provided in a subsequent report. External motion picture coverage of the explosive tests was provided by two HYCAM Model 41.004 cameras operated at up to 3000 frames per second. A 24-frame per second Mitchell camera provided real time documentary coverage.

2.4 Fragmentation Test. Equipment used in the candidate igniter slurry mix operations was simulated as shown in figures 7 and 8. An explosive charge of 0.970 pounds of C-4 was emplaced in the mixing cup of the simulated equipment during the test. After the test, the mixer simulator and table were found in several pieces. The fragmentation resulting from the test is shown in figure 9. Although both rod-shaped and small chunky fragments were recovered, no penetration of even the first layer of perforated plate was observed. Overall, damage to the structure was so slight as to be considered negligible.

2.5 Fireball and Thermal Containment Tests. A series of tests were performed using 10, 20, 30, and 50 pound charges of a magnesium-sodium nitrate illuminant composition. The materials (55 percent $NaNO_3$/45 percent magnesium granules) were tumble-mixed

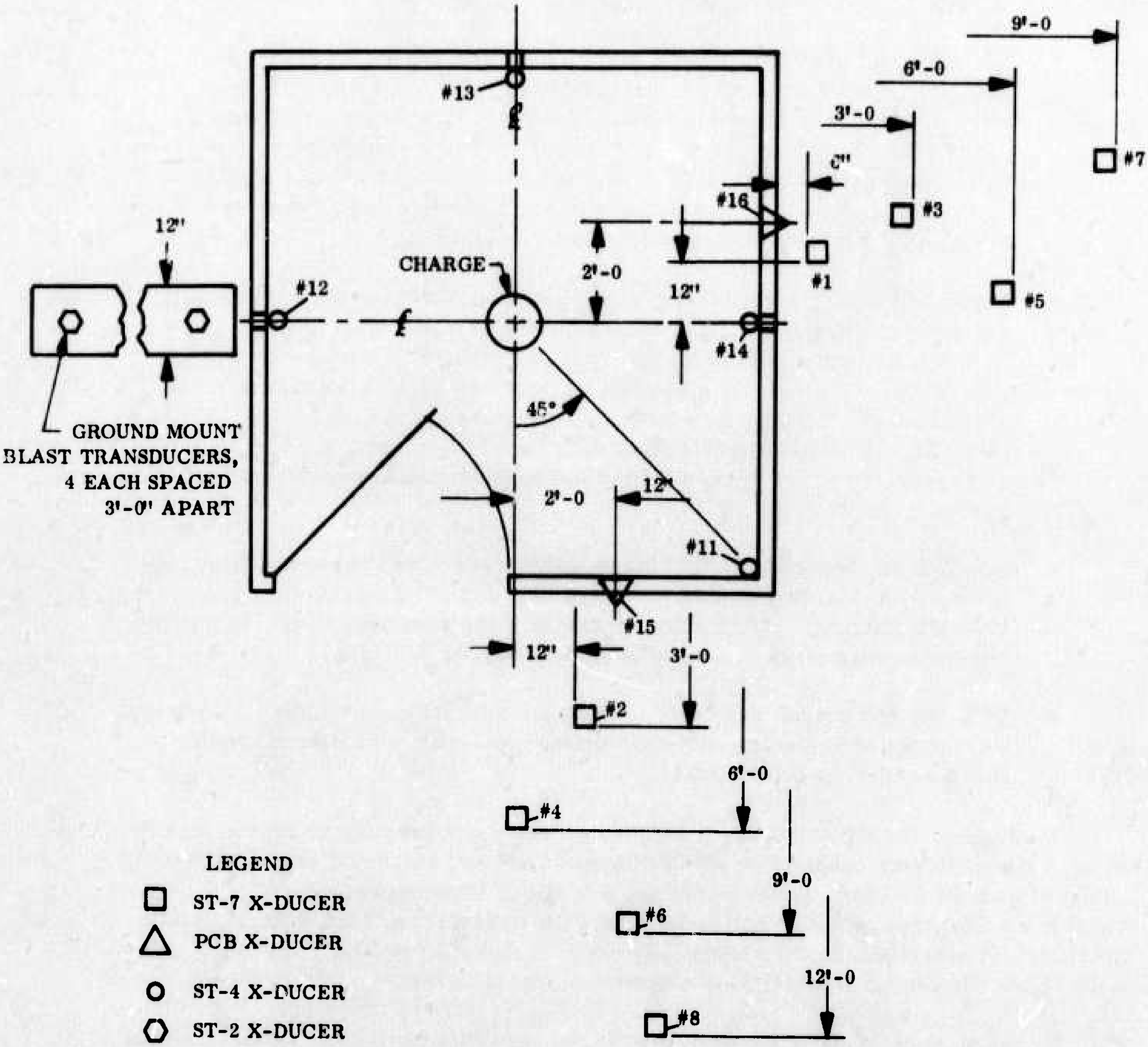

Figure 6. Internal and External Pressure Transducer Array Typical for Five Tests Category 5 S/S

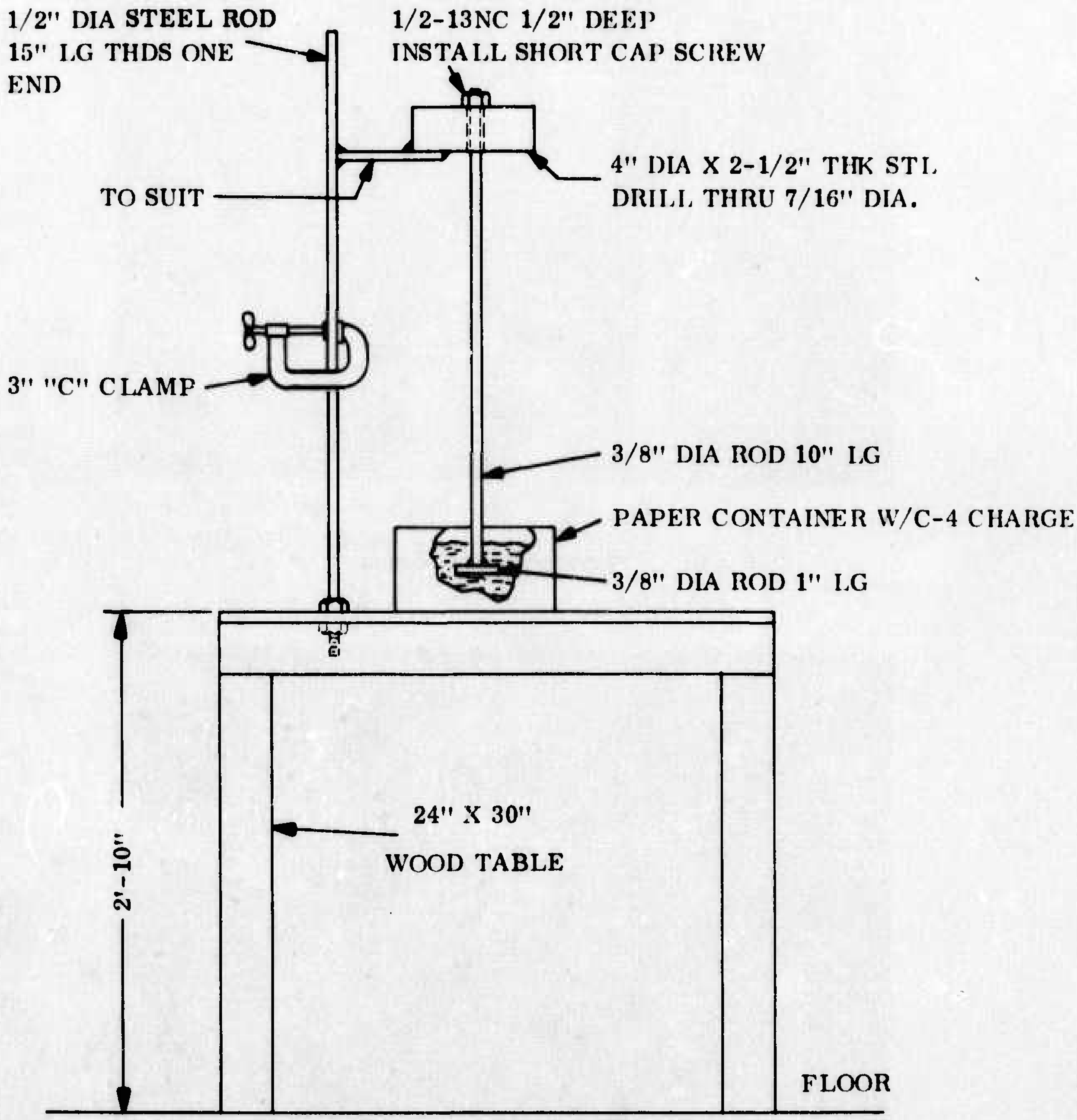

Figure 7. Simulated Application Hardware Category 5

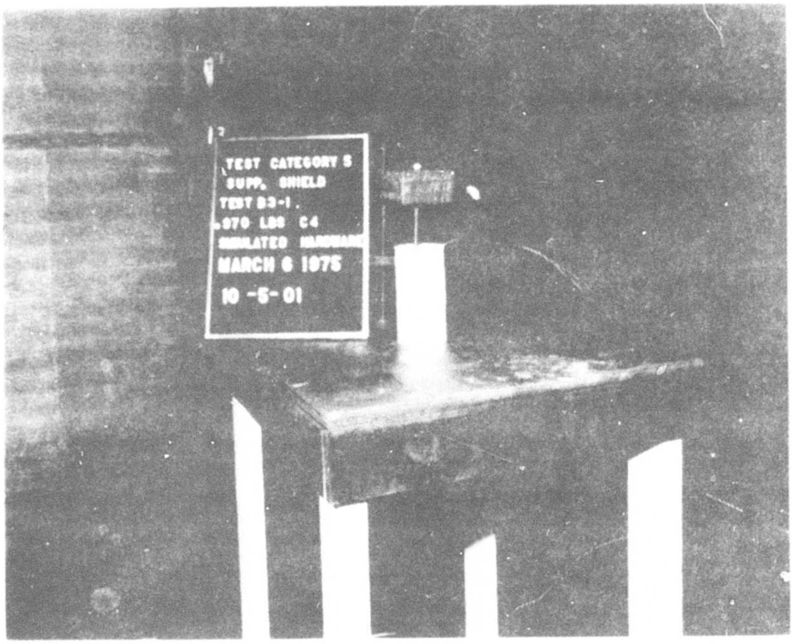

Figure 8. Simulation Test Set-up

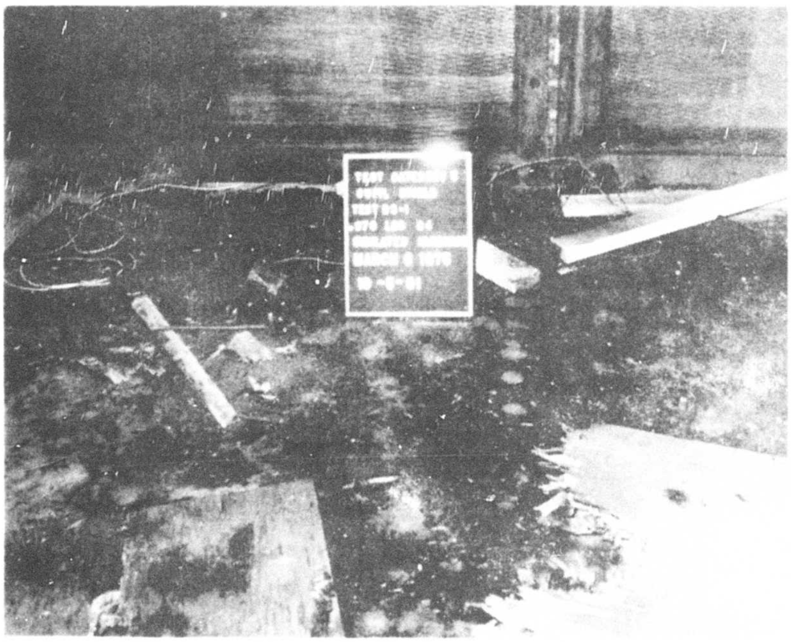

Figure 9. Fragmentation Resulting from Simulation Test

Table 1. Instrumental Details, Category 5 Explosive Containment Tests

Parameter	Transducer	Amplifier	Cable	Recorder	Installed Time Constant
Blast Pressure (side on)	ST-7H (ballistic probe)	PCB 401A11	1100 ft. RG58 C/U Coax	Biomation 610B Honeywell 96	10 sec. 200 msec.
Blast Pressure (side on)	ST-2 ground mount	PCB 401A11	1100 ft. RG58 C/U Coax	Biomation 610B Honeywell 96	10 sec. 200 msec.
Blast Pressure (Refl.)	ST-4 wall mount	PCB 402A02	1100 ft. RG58 C/U Coax	Honeywell 96	200 msec.
Static Pressure	PCB 101A02 in baffle mount	NEFF 109-6	1100 ft. RG58 C/U	Sangamo 4700	10 sec.

immediately prior to testing, placed in a square cardboard box, and ignited with an electric match head boosted by approximately 100 grams of UTC No. 3001 solid rocket propellant. These tests were instrumented with internal temperature, external temperature, heat flux, and fireball duration sensors. Motion picture coverage included 200-1500 frame per second, 24 frame per second real time and 200-1500 frame per second infrared film. Figure 10 shows the test arrangement. Instrumentation for all thermal measurements is detailed in table 2. Similar tests were performed in free air, with the test layout shown in figure 11.

Table 2. Instrumentation for Illuminant Tests, Category 5

Parameter	Transducer	Amplifier	Cable	Recording
Temperature	Chromel-Alumel 30 AWG Thermo-couple w/150°F reference junction	NEFF Model 109-6	1100 ft. shielded 2 conductor 20 AWG	Sangamo 4700
	YSI # 44030 Thermistors	Transdata 2001G with NEFF 109-6	1100 ft. shielded 2 conductor 20 AWG	Honeywell 96
Heat Flux	Keithley 610 with probe	NA	1100 ft. RG58 C/U	Sangamo 4700
Burning Time	Monsanto MT-2 Photocell	Transdata 2001G with NEFF 109-6	1100 ft. shielded 2 conductor 20 AWG	Honeywell 96
Static Pressure	PCB 101A02	NEFF 109-6	1100 ft. RG58 C/U	Honeywell 96

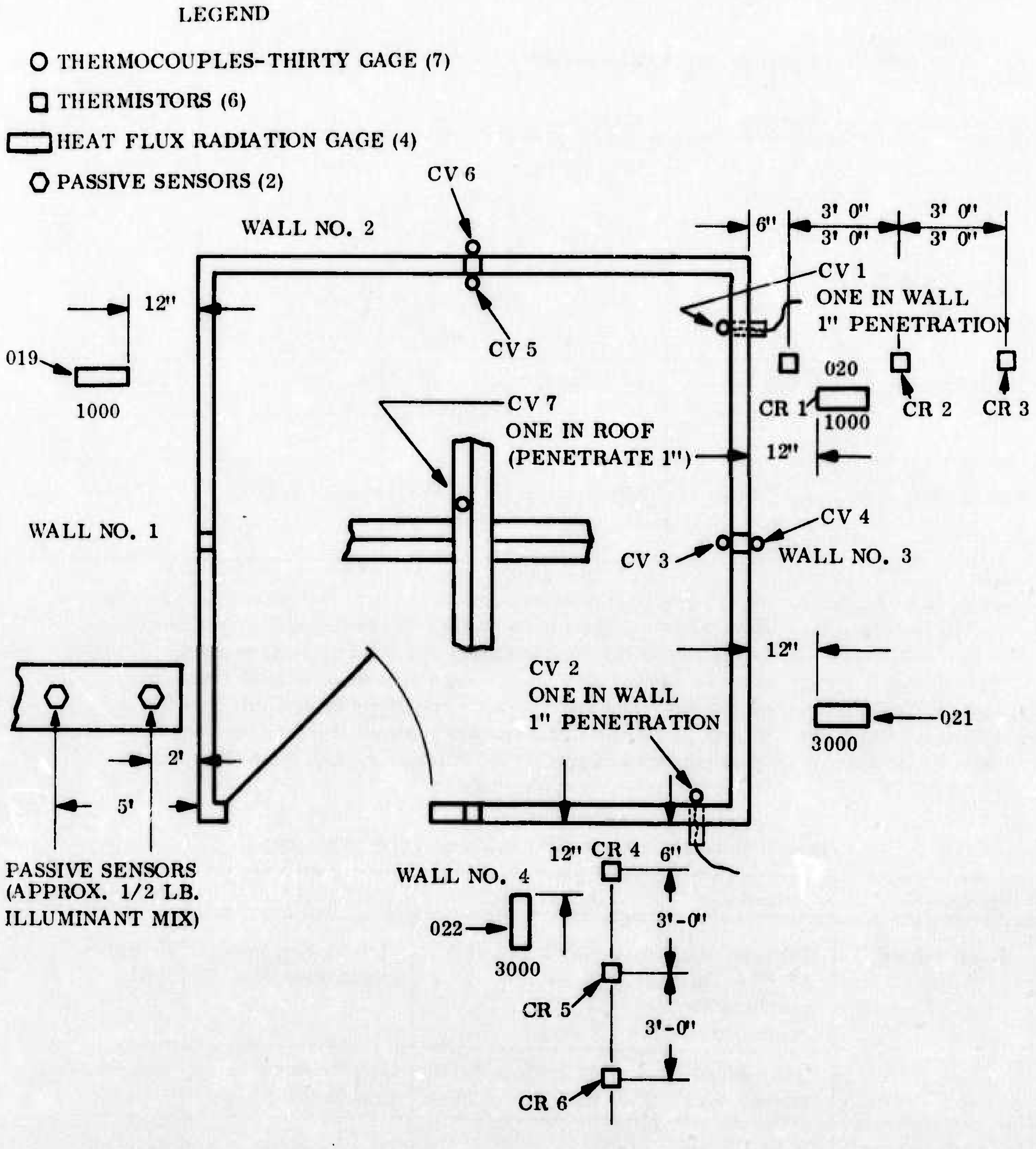

Figure 10. Category 5 Illuminant Test Setup and Instrumentation Locations

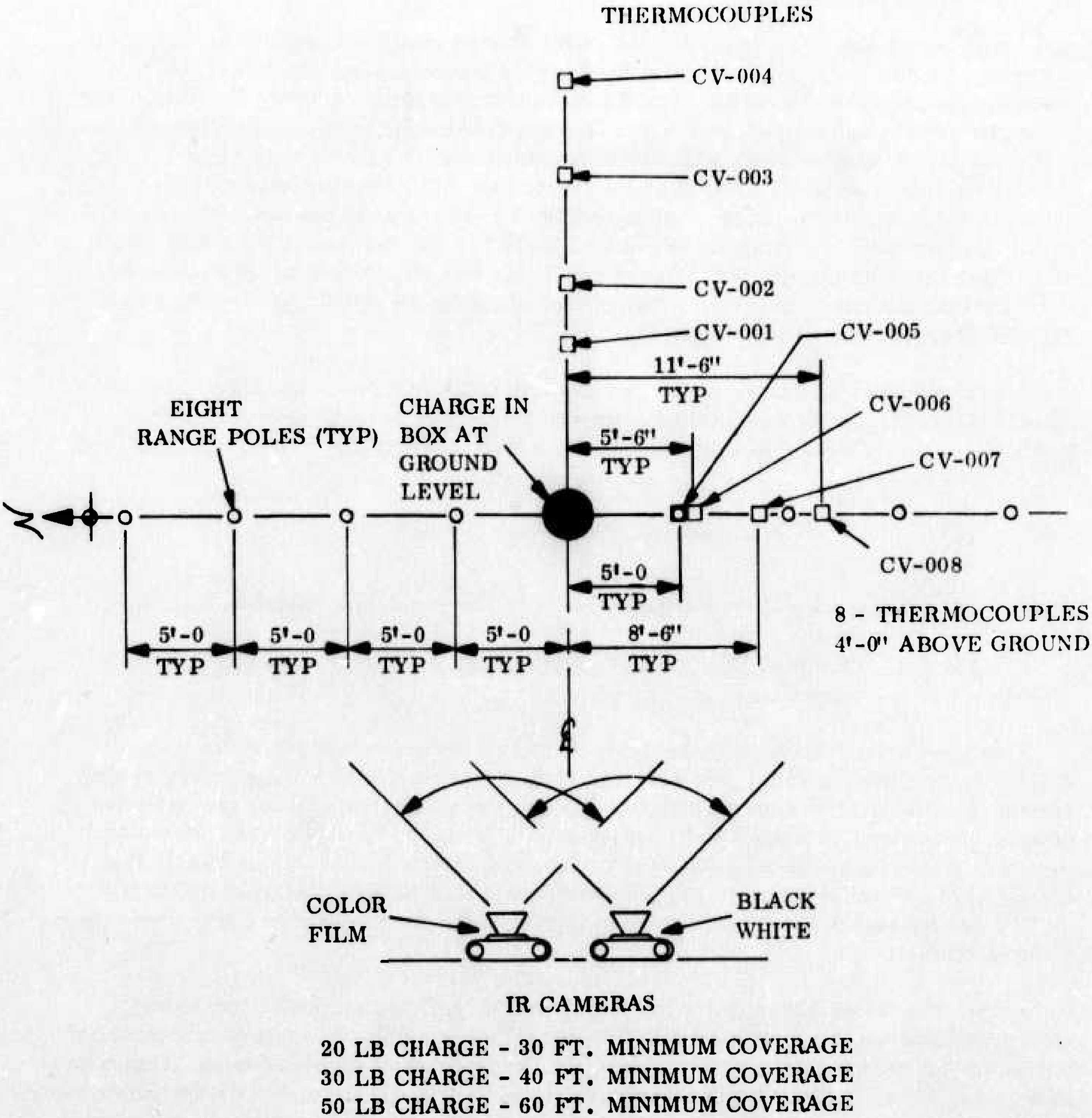

Figure 11. Free Field Illuminant Test Configuration

3.0 RESULTS AND DISCUSSION

3.1 Pressure Measurements

3.1.1 External Pressure. Side-on blast data obtained from the explosive containment tests are summarized in table 3. Graphical presentations of observed side-on blast overpressures are shown in figure 12. For the measurements made with the ST-7H transducers at the charge height, the maximum allowable overpressure for an operator-safe environment (2.3 psi) is attained at distances from the shield wall of zero to six feet for test charges varying from 0.572 lb. to 2.44 lb. In the particular case for which the shield was designed; i.e., a 1.84 lb. charge corresponding to a calculated 50 psi peak side-on overpressure at the wall, the pressure is reduced to the 2.3 psi level at 3.7 feet, which compares favorably with the expected value of 4.9 feet. This comparison and the observed average pressure reduction of 80 $\pm$ 3 percent for all distances and charge weights indicates that the shield performed as anticipated.

It should be noted that the pressure reduction ratios in table 2 are based on actual free-field measurements at equivalent distances rather than upon values taken from Soroka's tables. Thus the percent reduction at a given distance and charge weight is given by

$$\% \text{ reduction} = \frac{P_o - P}{P_o} \times 100$$

where P_o = Observed free-air side-on blast overpressure at distance R from charge.

P = Observed side-on blast overpressure external to shield at distance R from charge.

No significant differences in pressure reduction were observed for various charge weights at the same distance. The corresponding variation with distance was only slightly greater than the estimated uncertainties, although the total range of pressure reduction extended from about 85 percent to 75 percent. This deviation from previously reported observation may be attributed to the small range of Z values inherent in the tests. For example, 70 percent of the measurements were made at Z values between 10 and 18 ft. $lb^{-1/3}$, and all such points lie within that region of the pressure-distance curve where the slope is small.

Since the scaled distances for the shield tests do not vary markedly, the external blast pressures may be correlated with free air values in a different manner by consideration of the increase in effective distance, Z, by the presence of the shield wall. Figure 13 shows plots for all ballistic probe measurements and a free-air curve for similar pressure values. It can be seen from these curves that the effective scaled distance for equivalent pressure levels is decreased by approximately 2.7 over the range of test conditions.

The 2.3 psi side-on overpressure level is generally considered to represent the safe tolerance for operator personnel. Since the presence of the shield decreases the scaled distance at constant pressure by a factor of 2.7, the weight of explosive that can be utilized in the shield without exceeding tolerance limits is about 20 (i.e., 2.7^3) times the weight

Table 3. External Side-on Blast Overpressure Behavior (ST-7 Transducers)

Distance from Charge (ft.)	Charge Weight (lb.)	No. of Measure-ments	Pressure Side-on (Shield) (PSI)	Z	Pressure Side-on (Free Field) (PSI)	Pressure Side-on (Soroka) (PSI)	Pressure Reduction (%)	Avg. Reduc-tion (%)
6.4	0.572	1	19	7.71	14.5	12.68	87	87
8.7	0.572	2	1.2±0.05	10.48	7.5	6.9	84	
	0.970	2	1.65±.05	8.80	11.3	9.66	85	84±1
	1.84	2	2.7±.14	7.10	15.5	15.13	83	
	2.44	2	3.5±.3	6.46	21.2	18.66	83	
11.7	0.572	2	0.92±.02	14.1	5.2	4.13	82	
	0.970	1	1.4	11.8	6.8	5.56	79	80±2
	1.84	2	1.65±.07	9.55	8.7	8.22	81	
	2.44	2	2.4±.25	8.69	10.6	9.90	77	
14.7	0.572	2	.74±.01	17.7	3.5	2.91	79	
	0.970	3	.83±.06	14.8	4.5	3.82	82	79±2
	1.84	2	1.4±.2	12.0	6.3	5.40	78	
	2.44	2	1.68±.15	10.9	7.3	6.41	77	
17.7	0.572	1	.60	21.3	2.8	2.24	79	
	0.970	4	.72±.05	17.9	3.4	2.86	79	
	1.84	2	1.15±.07	14.4	4.7	3.99	76	77.5±2
	2.44	1	1.30	13.1	5.5	4.65	76	
20.7	0.572		-	24.9	2.3	1.82		
	0.970		-	20.9	2.85	2.30		
	1.84	2	1.0±.2	16.9	3.7	3.12	73	73
	2.44		-	15.4	4.3	3.59		

that could be tolerated in free air. Quantity-distance requirements can thus be significantly reduced by application of suppressive structures as enclosures for hazardous operations.

The ST-2 ground plane measurements of external side-on blast overpressure are shown in table 4. It is noted that the pressure levels are somewhat higher than that afforded by the ST-7 transducers at charge height, particularly for the 2.44 lb. test. The differences may be explained by any of several mechanisms:

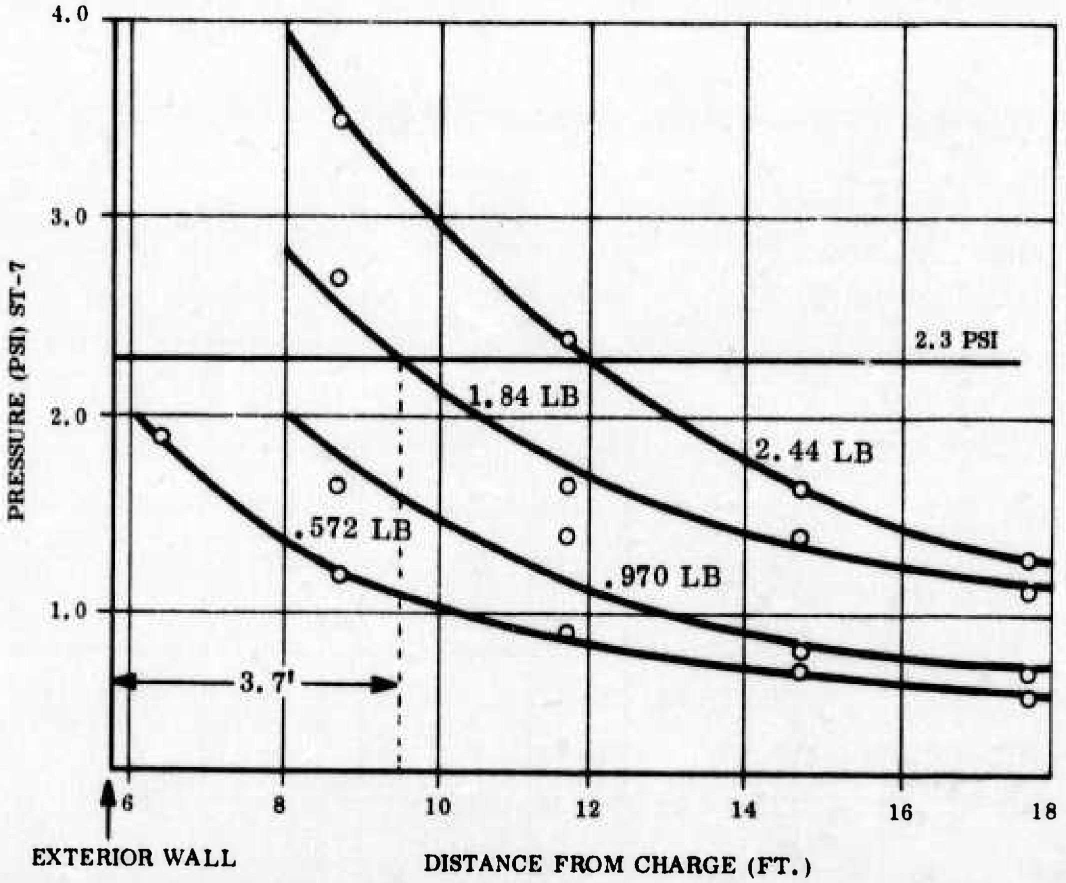

Figure 12. External Side-on Blast Pressure as a Function of Distance from Charge. The design charge weight is 1.84 lb.

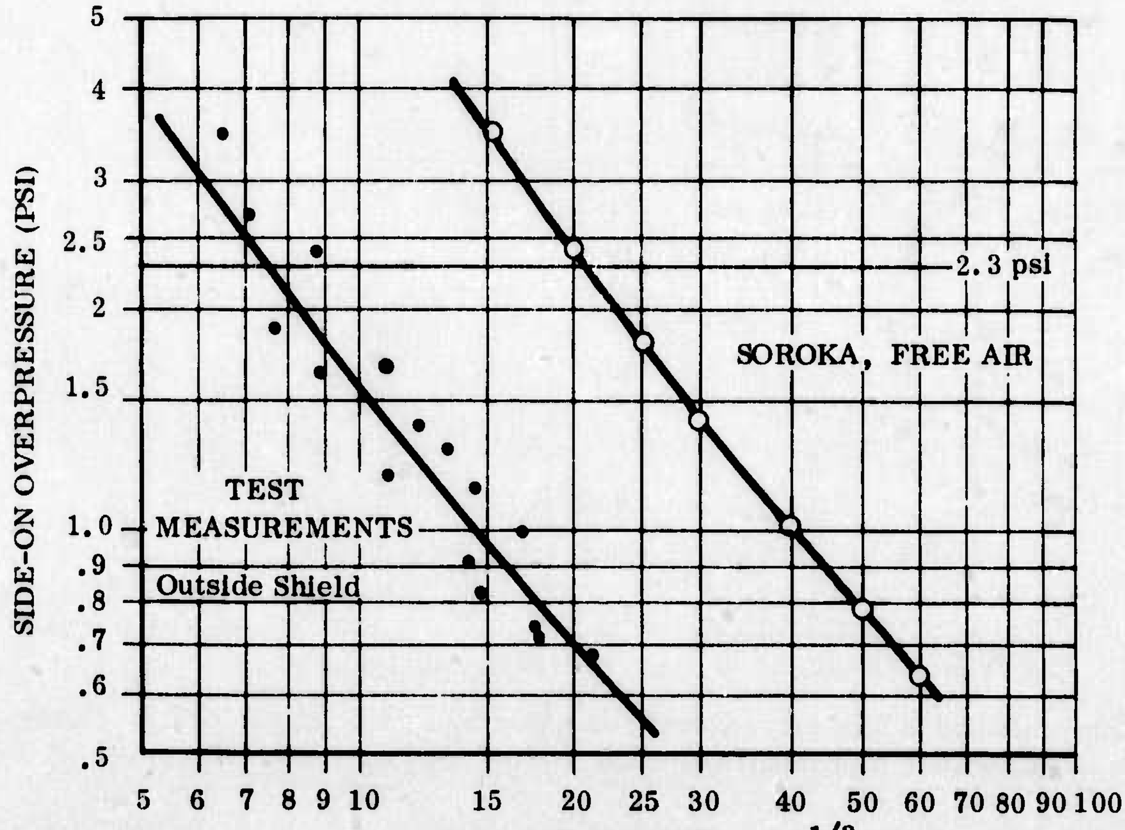

Figure 13. Comparison of External Blast Pressure with Free Air Values

Table 4. External Side-on Blast Overpressure Behavior (ST-2 Transducers)

Distance from Charge (ft.)	Charge Weight (lb.)	No. of Measurements	Side-on Pressure (PSI)
8.7	0.572		
	.970	3	2.0 ± .4
	1.84	1	3.8
	2.44	1	3.3 (3.7)
11.7	.572		
	.970	3	1.9 ± .5
	1.84	1	3.2
	2.44	1	3.5 (3.3)
14.7	.572		
	.970	3	1.5 ± .2
	1.84	1	2.8
	2.44	1	2.2 (3.2)
17.7	.572		
	.970	3	1.2 ± .3
	1.84	1	2.5
	2.44	1	2.4

(a) The probable existence of mach stem reflections at the ground level locations of the ST-2 transducers.

(b) Partial reflected pressure character of the blast measurements in the ST-2 array, occasioned by being placed lower than charge height and mounted perpendicular to the ground plane.

(c) Higher sensitivity, ergo greater accuracy, of the ST-2 transducers at the pressure levels observed, although this factor should have been minimized by the selection of high sensitivity ST-7H probes for the present application. Similarly, the longer installed time constant of the ST-2 transducers affords greater accuracy with respect to essentially static calibrations.

3.1.2 Internal Blast Pressure. Reflected blast pressure measurements taken at interior wall and corner locations nearest the charge are shown in table 5. Tracings typical of the data are shown in figure 14. Parameters of interest in reflected pressure considerations are compared to free-air values at equivalent Z in table 6. With the exception of the lowest charge weight, all tests resulted in significantly higher reflected pressure and impulse levels with correspondingly shorter peak arrival times than predicted on the basis of free-air behavior; the average increase in reflected pressure and impulse at the closest walls was 128 ± 10 percent. Possible explanations for these observations include the following:

(a) Some increase in pressure level is expected since the explosive material used (C-4) has a higher equivalency than the pentolite spheres upon which free-air

Table 5. Reflected Blast Overpressure

Distance from Charge (ft.)	Charge Wt. (lb.)	No. of Measurements	Reflected Pressure* (psi)	Reinforced Pressure Peak (psi)	Z (ft · $lb^{-1/3}$)	Reflected Impulse † (psi · msec)	Arrival Time † (msec)
(wall) 5.2	0.572	2	47±5	-	6.23		
	.970	2	140±15	-	5.22	42±3	1.03±.03
	1.84	3	242±20	-	4.23	54±5	.97±.01
	2.44	2	346±25	-	3.84	68±5	.98±.02
	2.44	1	120±25**	139/188	3.84	65±5	.90 (1.06, 1.17)
(corner) 7.35	.572	1	38±4	35±5	8.85	26	-
	.970	1	63±15	72±15	7.42	61±5	2.32(2.54)
	1.84	1	110±20	117±20	6.06	68±6	1.90(2.07)
	2.44	1	175±20	159±20	5.46	83±6	1.86(2.04)

* Uncertainties from readout noise level, NOT STD. DEVIATION.

** Anomalous - see text † Uncertainties = Std. deviation.

Table 6. Comparison of Internal Reflected Blast Parameters with Free Air Values (Soroka)

Z (ft · $lb^{-1/3}$)	$W^{1/3}$ ($lb^{1/3}$)	Reflected Pressure (Meas.) (psi)	Reflected Pressure (Soroka) (psi)	Reflected Impulse (Meas.) (psi·msec)	Reflected Impulse (Scaled) $\left(\frac{psi \cdot msec}{lb^{1/3}}\right)$	Reflected Impulse (Soroka) $\left(\frac{psi \cdot msec}{lb^{1/3}}\right)$	Arrival Time (Scaled) $\left(msec \cdot lb^{-1/3}\right)$	Arrival Time (Soroka) $\left(msec \cdot lb^{-1/3}\right)$
CORNER								
8.85	.830	38 (35)	24	26	32	15.3		3.75
7.42	.990	63 (72)	37	61	62	18.7	2.34 (2.56)	2.77
6.06	1.225	110 (117)	65	68	55	23.6	1.55 (1.69)	1.93 1.59
5.46	1.346	175 (159)	89	83	62	26.6	1.38 (1.52)	1.59
WALL								
6.23	0.830	47±5	60	15	18	22.8	-	2.03
5.22	0.990	140	102	42	42	28.1	1.04	1.46
4.23	1.225	242	201	54	44	36.1	0.79	0.98
3.84	1.346	346	271	68	51	40.7	0.73	0.81
3.84	1.346	120 (139) (188)	271	65	48	40.7	0.67 (.78) (.87)	0.81

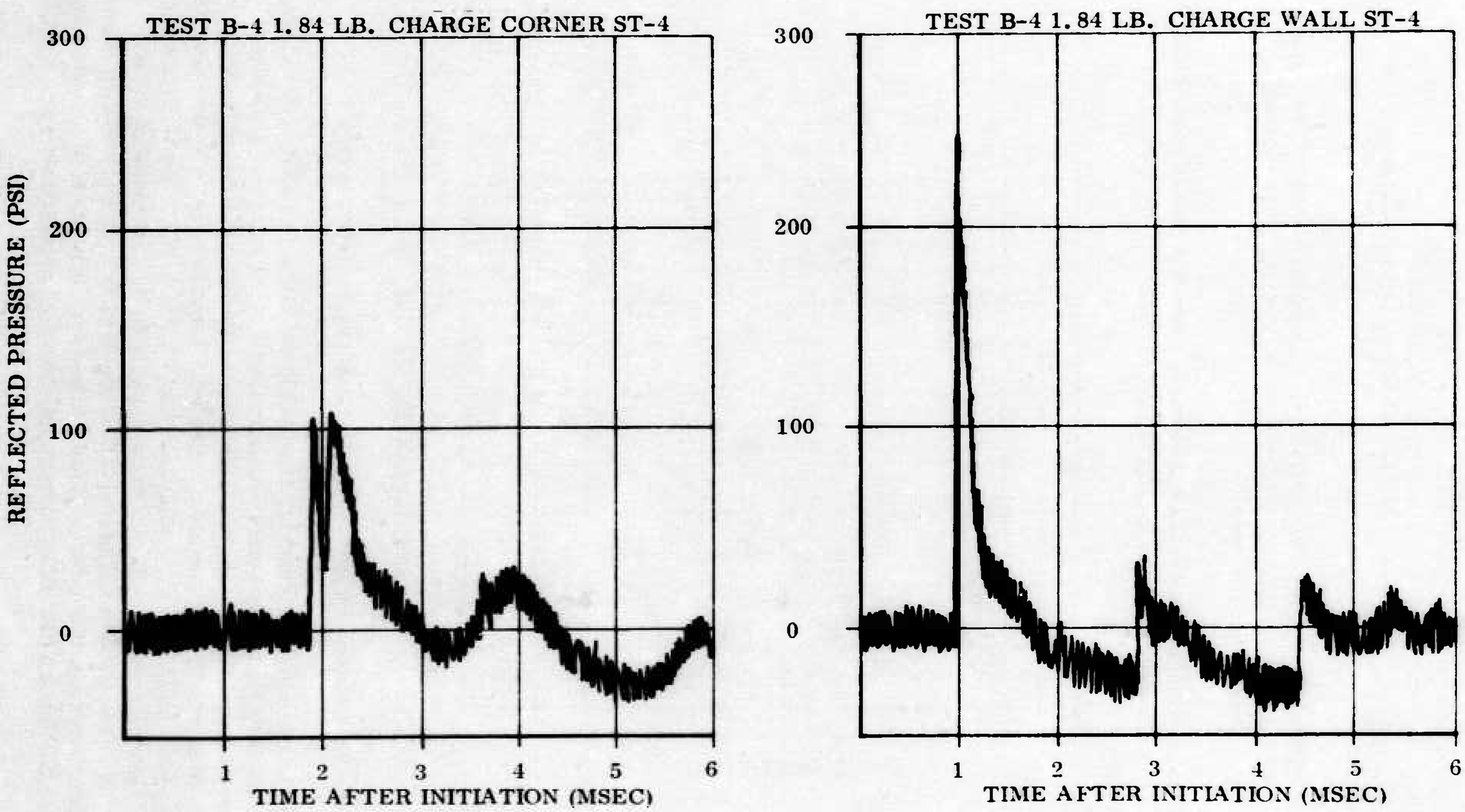

Figure 14. Typical Reflected Pressure Curves

computations are based. This is corroborated by higher side-on overpressures observed during free-field measurements, figure 15. Side-on ballistic measurements made internally during the last test at the wall distance were approximately 10 percent higher than expected free air values.

(b) Exact TNT equivalency of the wrapped C-4 charges, prepared and initiated according to local procedures, is difficult to assess, as is the exact duplicity of same without specific empirical evidence.

(c) The frame locations of the ST-4 transducers are adjacent to panel edges and reinforcement of reflected waves may occur in the shallow valley so provided.

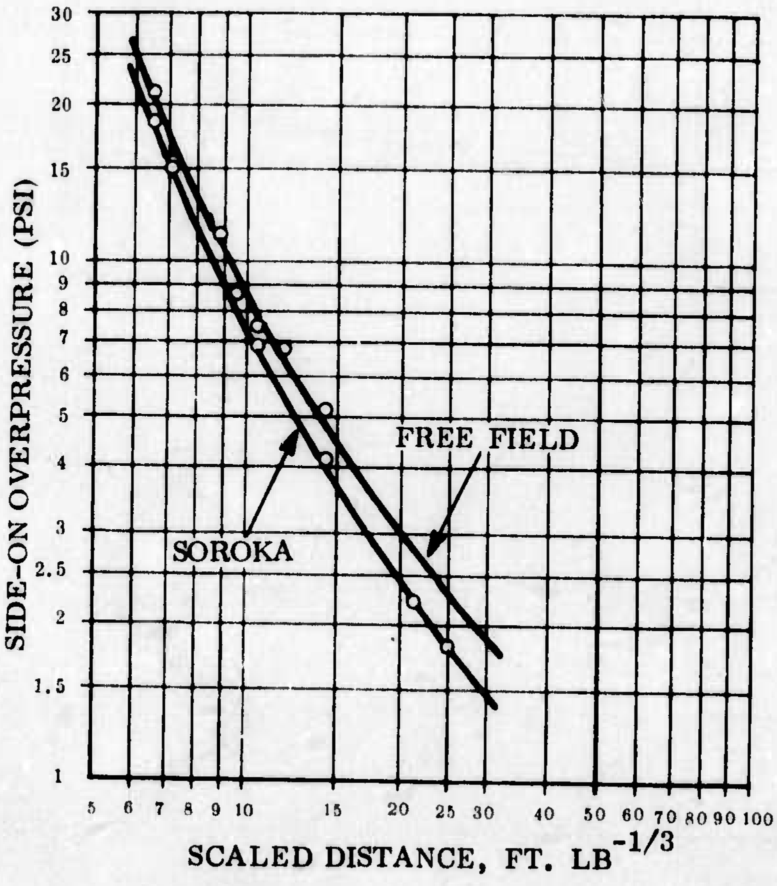

Figure 15. Comparison of Free Field Measurements with Soroka's Curve

The reflected pressure transducers mounted in the corner exhibit expected abnormal waveshapes, indicating that considerable reinforcement occurs at these locations. The initial blast wave arrival times show similar decrease to that observed at the walls, but the peak pressure levels are approximately doubled. Furthermore, a second peak is observed at approximately $170/W^{1/3}$ microseconds $\cdot$ $lb^{-1/3}$, oft times of higher peak pressure than the initial wave. The wavefront velocity in this region of overpressure is on the order of 1700 ft/sec and the calculated difference in path length to yield the observed doublet is 0.082 ft., or about one inch. Since gross linear structural dimensions are 1-2 orders of magnitude larger than this quantity, the observed phenomenon may be attributable to characteristics of the mounted transducer or to localized corner structural details rather than to the actual conformation of reinforced blast waves in the corner of a vented enclosure. The doublet waveshape was not generally observed at the wall-mounted transducers, so asymmetric charge initiation or other characteristics of the explosive may be ruled out as a source of the corner anomaly.

It is observed that the total reflected impulses were much higher in the corners than at the walls of the structure, despite the greater interline distance from the charge and consequent lower peak pressures. The corner impulse values are 130 percent ± 10 percent above those at the walls and 250 percent ± 50 percent of impulses expected on the basis of free-air tables.

A significant variance in reflected pressure and waveshape was observed at one wall location during the last test; the initial overpressure peak at this singular point was approximately 1/3 that of two other corresponding locations, and a closely spaced triplet wave occurred. The total impulse, however, was essentially the same at all equivalent distances. Approximately 10 milliseconds after the initial pulse the transducer signal was interrupted and post-test inspection revealed a cut cable due to shield panel excursions during the test. In the same test, one of the other ST-4 transducers yielded a peculiar wave shape in that a shoulder occurred during the peak pressure decay. Both transducers were located on the same side of the charge, and a possible explanation for the observation would be that the anomaly is the result of unusual charge initiation or reaction during that particular test.

Despite higher than anticipated loadings, the structure successfully withstood blast pressures from all tests without significant damage. The wall reflected pressure level during the 2.44 lb proof test corresponds approximately to 170 percent overload based on charge weight, and to 150 percent of the design side-on overpressure.

3.1.3 Quasi-static Pressure. Pressure levels as measured by the PCB101A02 transducers were in general difficult to ascertain throughout the test series. In the initial tests (0.572 lb., 0.97 lb., 1.84 lb. charge weights), repeated attempts were made to measure interpanel quasi-static pressures; in no cases were signals observed above the background noise levels, indicating less than 0.2 psi above ambient as an upper limit. In all tests, the charge wt/volume ratio that governs static pressure peak value was small compared to the expected peak blast pressures at the internally located pressure transducers. Consequently, the small, slowly decaying static pressure components were difficult to determine from the large signal excursions occasioned by incomplete filtration of the airblast pressure spikes. The interpretation of positive pressure duration was further complicated by the thermal drift of the signals in nearly all cases.

The quasi-static pressure levels obtained from oscillographic tracings of magnetic tape records are given in table 7. For each record, two values for peak quasi-static pressure are herein reported (see figure 16):

(1) A value P_{max}, obtained by exponential extrapolation of the decay curve back to the initial pressure pulse.

(2) A value $P_{average}$, obtained by assuming an exponential pressure rise with a time constant on the order of one millisecond, followed by real-time exponential decay.

Table 7. Quasi-static Pressures from Category 5 Tests

Charge Wt.	P_{max} Calc. (12) (psi)	P_{max} Observed (psi)	$P_{average}$ Observed (psi)	Duration (msec)
0.97 lb	13	9.4 ± 1.6	5.6 ± 1.1	40 ± 6
1.84 lb	24	17.8 ± 1.0	10.9 ± 1	44 ± 2
2.44 lb.	29	33 ± 6	19 ± 2	38 (?)*

*Questionable Measurement

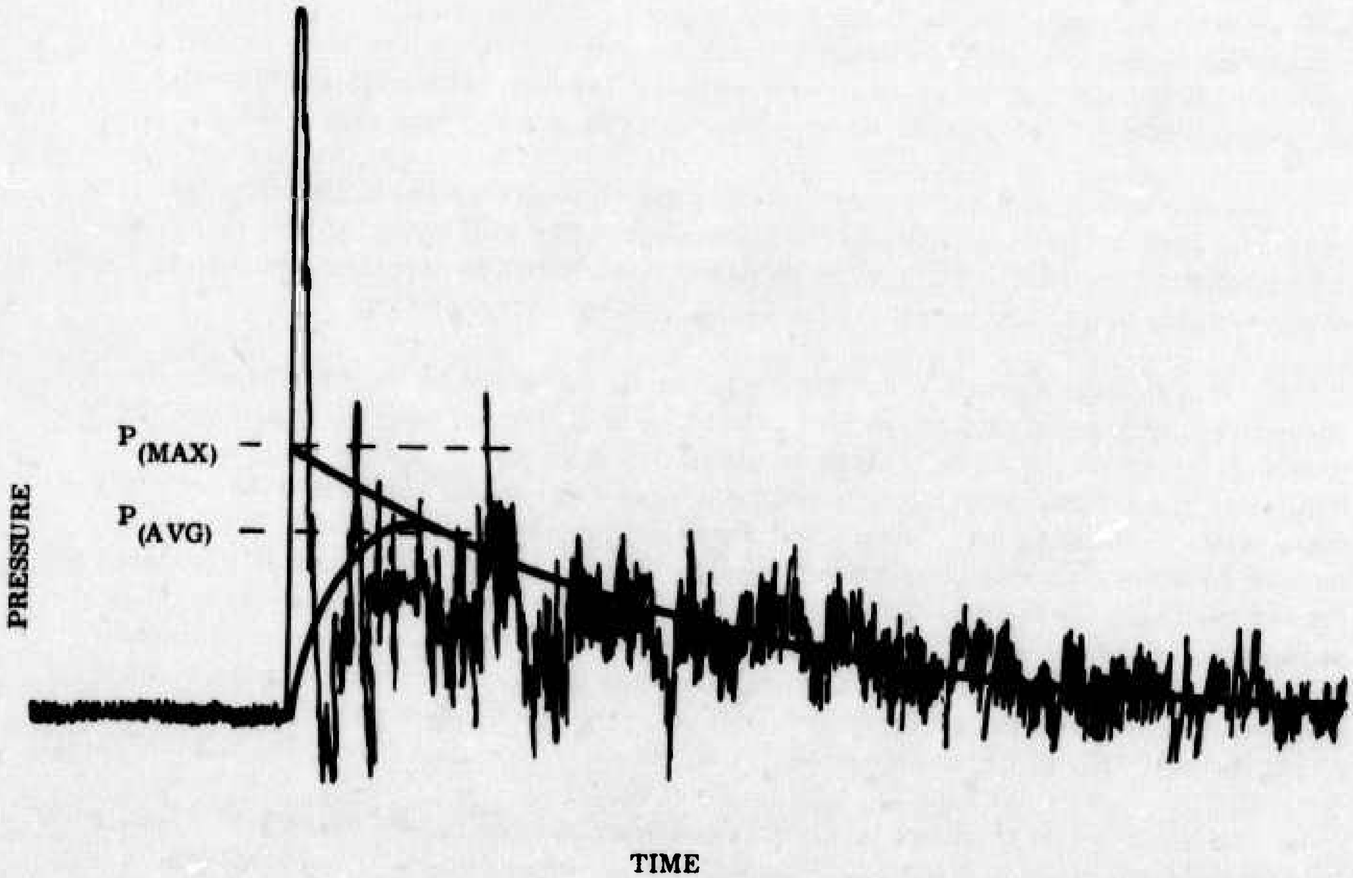

Figure 16. Typical Quasi-static Pressure Tracing

Two features of Table 6 are apparent:

(1) The observed quasi-static pressures P_{max} are in general somewhat less than the corresponding calculated values based on closed-box consideration, (12), the difference averaging approximately 25 percent.

(2) The observed pressure levels $P_{average}$ are approximately 50 percent of the calculated values.

Regardless of which convention is chosen, it may be stated with certainty that observed quasi-static pressures were less than expected, in contrast to the blast pressure behavior described above.

3.2 Thermal Measurements

3.2.1 Fireball Characteristics. Table 8 shows the fireball dimensions and duration for the high explosive charges fired in free field and inside the shield. No fireball was observed to extend beyond the walls of the shield for any of the intershield high explosive tests, although the maximum free field fireball size, i.e., 11.8 ft. diameter x 12.7 ft. high (1.842 lb. charge) and 11.6 ft. diameter x 12.9 ft. high (2.442 lb. charge) would extend beyond dimensions of the shield (11.4 ft. wide x 9 ft. 0 inches high).

Table 8. Fireball Dimensions and Duration High-Explosive Charges

FREE FIELD DATA			SUPPRESSIVE STRUCTURE DATA		
Charge Weight (lb)	Maximum Fireball Dia. x Ht. (ft)	Fireball Duration (sec)	Charge Weight (lb)	Fireball Outside (ft)	Fireball Duration Outside (sec)
.572	7.4 x 6.9	.053	.572	None Observed	N/A
.970	6.9 x 6.4	.070	.970	None Observed	N/A
1.842	11.8 x 12.7	.106	.970	None Observed	N/A
2.442	11.6 x 12.9	.084	1.842	None Observed	N/A
			2.442	None Observed	N/A

Table 9 is a display of fireball dimensions and duration observed during the illuminant tests. For all charge weights, the fireball dimensions in the free field was greater than outside dimensions of the shield. This extension beyond the shield side walls ranged from approximately 3-1/2 feet for the 10 pound charge to 10 feet for the 50 pound charge. The shield attenuated this potential threat beyond the side walls to approximately 1-1/2 feet in the worst case. The duration of this fireball beyond the walls ranged from 0.2 seconds for the 10 pound charge to 0.5 seconds for the 50 pound charge.

Table 9. Fireball Dimensions and Duration - Illuminant Charges

FREE FIELD DATA				SUPPRESSIVE SHIELD DATA	
Charge Weight (lb)	Maximum Fireball Dia. x Ht. (ft)	Time to Maximum (sec)	Total Fireball Duration (sec)	Fireball Dimension (ft)	Observed Duration (sec)
10	18 x 18.5	1.031	3.325	1-2*	.208**
20	16.3 x 15.3	0.855	3.310	No Comparable Test	
30	27.8 x 23.3	0.817	2.650	1-2*	.167**
50	32 x 24	0.600	1.993	1-2*	.504**

* Fireball was observed to extend 1-2 feet outside shield wall for all illuminant tests.
** Total time any flame visible outside shield wall.

Burning particles (fire brands) were observed to be projected 3 to 5 feet from the shield for all charge weights; the quantity and intensity varied directly as the charge weight. The total event time for this phenomena was less than 0.5 seconds.

3.2.2 Panel Configurations. The Category 5 shield panels were all of the same configuration as shown in figure 17 except the northern-most panel in wall number 1. This panel was fabricated with an aluminum basket weave material (Interweave by Harrington and King Perforating Company, Ramsey, New Jersey - 20 gauge aluminum (B&S), 53 percent vent area), which was designed as a fireball, fire brand flame impingement medium (see figure 18). All other panels were fabricated using four layers of standard aluminum, 16 x 16 mesh window screen as the fireball, fire brand, flame impingement medium. The vent area of each layer of screen was 62 percent. The effective venting ratio (α_{eff} for the four layers was then 15.5 percent. The interweave material yields an α_{eff} of 53 percent.

Observation of the high speed motion pictures of the illuminant tests inside the shield showed that the interweave allowed passage of slightly more fireball/fire brand/flame than did the four layers of screening. The interweave withstood the heat much better than did the 16 x 16 mesh aluminum screening. The screening material almost entirely disintegrated during the 30 pound illuminant charge test. The effects of the disintegration was not readily apparent, however, when observing the motion pictures of the subsequent 50 pound illuminant test.

3.2.2 Ten Pound Illuminant Charge Test Data. Table 10 shows the thermal data acquired during the 10 pound illuminant charge test. Of significance in this data comparison is the fact that the thermistors, arrayed at 0.5, 3.5 and 6.5 feet outside the shield wall, indicated virtually ambient temperature. Free air temperatures at similar distances ranged from 92°F at 6.5 ft., to 990°F at 0.5 feet. Of the seven chromel-alumel thermocouples that were inserted one inch deep into the structural steel of the shield, five were on the inside

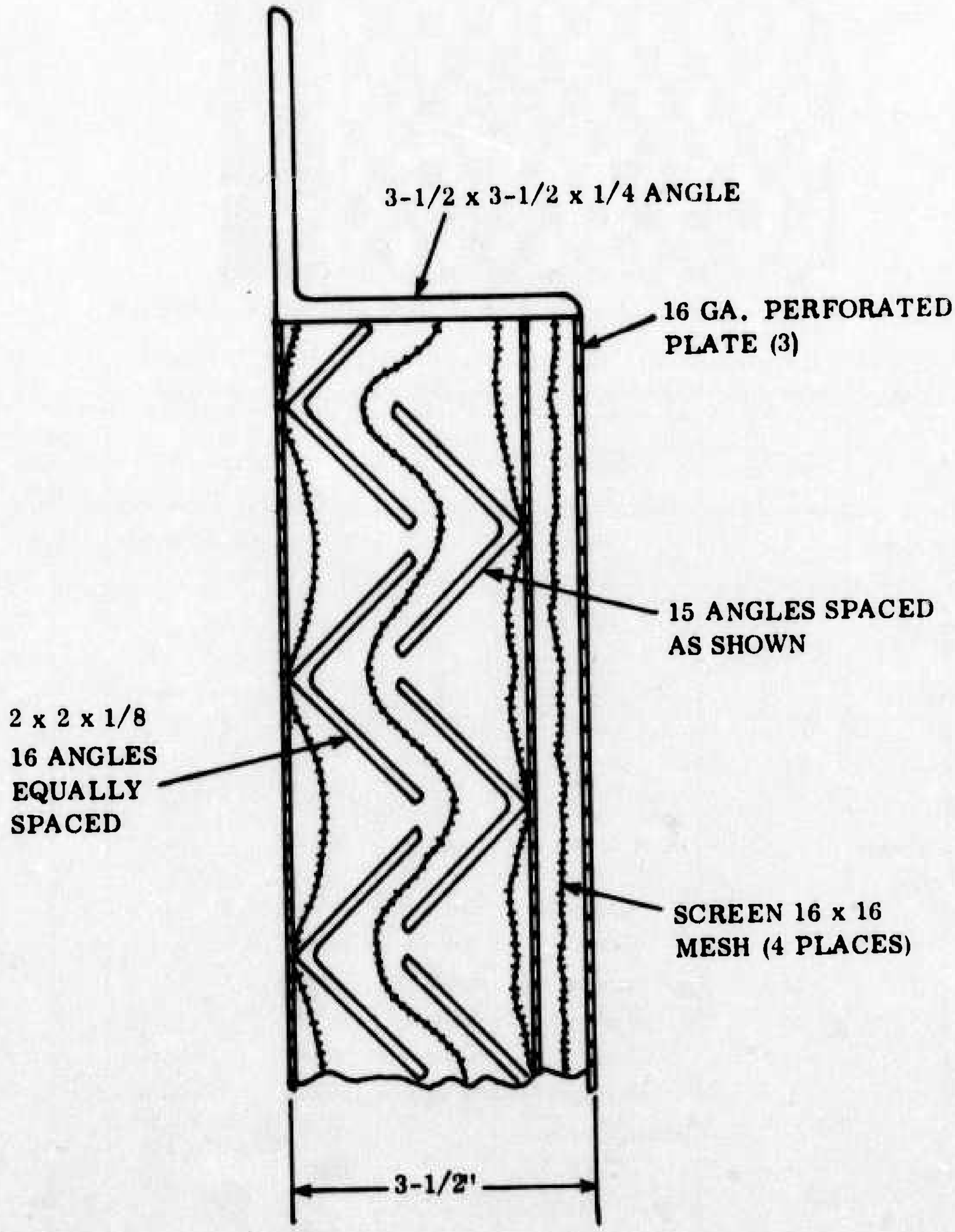

Figure 17. Category 5 Panel Section

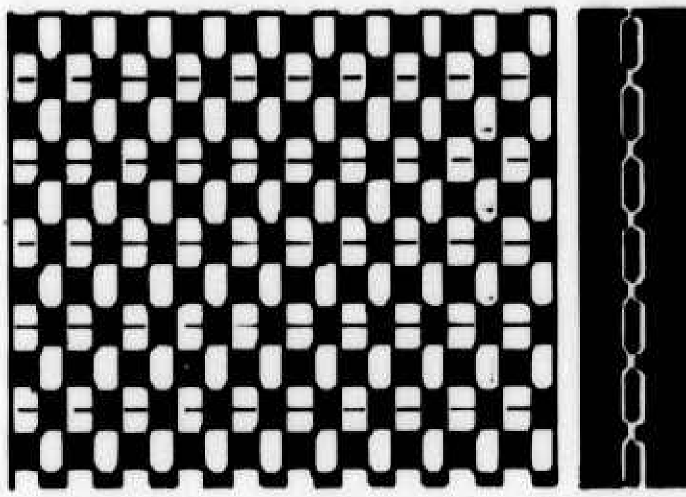

Figure 18. Interweave - Approximately Fifty-Three Percent Open

Table 10. Illuminant Test Thermal Measurements for 10 Pound Charge Weight - Test No. D-1-1 Burning Time .518 Second

Channel No.	Sensor	Distance		Location Wall No.	Measured Values	Equiv. Free Air Values†	△*
		From Chgr. (Feet)	From Wall				
CR-19	Heat Flux Meter	6.7	1.0 ft.	1	Over Range on all meters	N/A	N/A
CR-20		6.7	1.0 ft.	3	" " " " "		
CR-21		6.7	1.0 ft.	3	" " " " "		
CR-22		6.7	1.0 ft.	4	" " " " "		
Q-15	PCB Transducer	5.2	Flush w/inside	1	No Indication of Pressure		
Q-16			"	3	" " " "		
Q-17			"	3	" " " "		
Q-18			"	4	" " " "		
CV-1	Chromel-Alumel Thermocouple	5.2	1" inside	Inside 3	2500+°F		
CV-2		5.2	inside	Inside 4	No data		
CV-3		5.2	inside	Inside 3	161°F		
CV-4		5.7	outside	Outside 3	75°F		
CV-5		5.2	1" inside	Inside 2	123°F		
CV-6		5.7	outside	Outside 2	75°F		
CV-7		8.0	1" inside	Inside 5	No data		
CV-8			Ambient reference		75°F		
CR-1	Thermistor	6.2	0.5 ft.	3	79°F	990°F - 425°F -	911°F 346°F
CR-2		9.2	3.5 ft.	3	75°F	275°F -	200°F
CR-3		12.2	6.5 ft.	3	75°F	92°F -	17°F
CR-4		6.2	0.5 ft.	4	77°F	990°F - 425°F -	911°F 348°F
CR-5		9.2	3.5 ft.	4	75°F	275°F -	200°F
CR-6		12.2	6.5 ft.	4	75°F	92°F -	17°F

*Difference between free air and test values.

†2400 $BTU/HR/FT^2$ extrapolated from 50 ft. radius to 6.7 ft. radius.

and two on the outside. Figure 7 shows the location of these thermocouples and identifies the channel number. The seven chromel-alumel thermocouples were located as shown in table 10 and as described for the 50-pound test, paragraph 3.2.5. Thus CV-3 and CV-5 indicate inside skin temperatures; CV-1, CV-2 and CV-7 indicate inside air temperatures; CV-4 and CV-6 indicate exterior skin temperatures. Two of the channels, CV-2 and CV-7 failed to function during the test. Of significance is that the two thermocouples located in the steel in the outer wall indicated only ambient temperature. The other thermocouples located inside registered temperatures of 123°F (CV-5), 161°F (CV-3) and 2500+°F (CV-1).

No comparable heat flux data was acquired due to an improper calibration range setting on the Keithly Model 860 heat flux meters.

No measurable pressures were observed from any of the four PCB transducers installed in the shield, indicating less than 0.2 psi of quasi-static pressure.

3.2.4 Thirty Pound Illuminant Charge Data. Table 11 shows the thermal data acquired during the 30-pound illuminant charge test. Again, the temperatures at 0.5, 3.5 and 6.5 feet outside the shield were relatively low (75°F to 115°F) while temperatures at similar distances in free field ranged from 2500+°F at 5.0 ft. (approximate inside wall distance) to 850°F at 11.5 ft.

A comparison of peak heat flux in units of cal/cm^2 sec at a distance of one foot outside the shield wall is shown in Table 11. Free field peak heat flux data acquired at a distance of 50 feet from the charge center was extrapolated back to 6.7 feet by application of inverse-square radiant heat flux laws. Thus, the heat flux at 6.7 feet, H_2, was given by:

$$H_2 = H \text{ (peak heat flux at 50 ft.) } \times \frac{(50 \text{ feet})^2}{(6.7)^2}$$

3.2.5 Fifty Pound Illuminant Charge Test. Table 12 displays the thermal data acquired during the 50 pound charge illuminant test. Temperatures at 0.5, 3.5, and 6.5 feet outside the wall ranged from 77°F at 6.5 feet to 181°F at 0.5 feet. At comparable distances in the free field, the temperatures ranged from 2500+°F at 5.0 feet (approximate inside shield wall distance) to 1172°F at 11.5 feet (compared to the 6.5 feet reading with the shield in place).

The three thermocouples located one inch inside the structure (CV-1, CV-2, CV-7) overranged the maximum chromel-alumel temperature (2500+°F). This indicates that the primary fireball essentially completely filled the enclosed volume. Thermocouples CV-3 and CV-5 were attached in contact with the interior panel members and indicated 321°F and 132°F, respectively. Such variation was observed in the other tests and is explained by off-center combustion of the illuminant mix and directional convection of the reaction products. Posttest ash deposits on the floor of the structure at various locations were observed to corroborate the anisotropic thermal measurements. A measure of the shield thermal energy containment characteristics is afforded by exterior thermal sensors. Two thermocouples attached to the exterior frame steel (CV-4 and CV-6) indicated only ambient temperature (74°F). Thus the escaping energy was insufficient, during the measurement time of greater than two seconds, to overcome the thermal inertia of the steel structure.

Table 11. Illuminant Test Thermal Measurements for 30 Pound Charge Weight--Test No. D-2-1 Burning Time .630 Sec.

Channel No.	Sensor	Distance: From Chg.	Distance: From Wall	Location Wall No.	Measured Values	Equil. Free Air Values †	△ *
CR-19	Heat Flux Meter	6.7	1.0 ft.	1	.054 cal/cm^2 sec	10.1 cal/cm^2 sec.	N/A
CR-20	↓	6.7	1.0 ft.	3	.015 "	10.1 "	↓
CR-21	↓	6.7	1.0 ft.	3	.015 "	10.1 "	↓
CR-22	↓	6.7	1.0 ft.	4	.010 "	10.1 "	↓
Q-15	PCB Transducer	5.2	Flush w/ inside	1	No indication of pressure	N/A	↓
Q-16	↓	5.2	↓	3	" " " "	↓	↓
Q-17	↓	5.2	↓	3	" " " "	↓	↓
Q-18	↓	5.2	↓	4	" " " "	↓	↓
CV-1 *	Chromel-Alumel Thermocouple	5.2	1" inside	3	No Data Recorded	None	↓
CV-2	↓	5.2	inside	4	↓	↓	↓
CV-3	↓	5.2	inside	3	↓	↓	↓
CV-4	↓	5.7	outside	3	↓	↓	↓
CV-5	↓	5.2	inside	2	↓	↓	↓
CV-6	↓	5.7	outside	2	↓	↓	↓
CV-7	↓	8.0	1" inside	5	↓	↓	↓
CV-8	↓	Ambient reference			↓	↓	↓
CR-1	Thermistor	6.2	0.5 ft.	3	90°F	2500+°F - 1992+°F -	2410°F 1902°F
CR-2	↓	9.2	3.5 ft.	3	75°F	1285°F -	1210°F
CR-3	↓	12.2	6.5 ft.	3	75°F	852°F -	777°F
CR-4	↓	6.2	0.5 ft.	4	115°F	2500+°F - 1992+°F -	2385°F 1877°F
CR-5	↓	9.2	3.5 ft.	4	108°F	1285°F -	1177°F
CR-6	↓	12.2	6.5 ft.	4	81°F	852°F -	771°F

† 2400 BTU/HR/FT^2 extrapolated from 50 ft. radius to 6.7 ft. radius.

*Difference between free air and test values.

Table 12. Illuminant Test Thermal Measurements for 50 Pound Charge Weight--Test No. D-3-1 Burning Time .504 Sec.

Channel No.	Sensor	Distance From Chg.(Ft.)	Distance From Wall	Location Wall No.	Measured Values	Dist. (Ft.) From Chgr.	Equiv. Peak Free Air Values*	△*
CR-19	Heat Flux Meter	6.7	1.0 ft.	1	.015 cal/cm^2 sec	6.7*	14.1 cal/cm^2 sec	N/A
CR-20	↓	6.7	1.0 ft.	3	.027 "	6.7*	14.1 "	↓
CR-21	↓	6.7	1.0 ft.	3	.11 "	6.7*	14.1 "	↓
CR-22	↓	6.7	1.0 ft.	4	.019 "	6.7*	14.1 "	↓
Q-15	PCB Transducer	5.2	Flush	1	No Pressure Indicated		N/A	N/A
Q-16	↓	5.2	"	3	" " "		↓	↓
Q-17	↓	5.2	"	3	" " "		↓	↓
Q-18	↓	5.2	"	4	" " "		↓	↓
CV-1	Chromel-Alumel Thermocouple	5.2	1" inside	3	2500+°F	N/A	None	↓
CV-2	↓	5.2	inside	4	2500+°F	↓	↓	↓
CV-3	↓	5.7	inside	3	321°F	↓	↓	↓
CV-4	↓	5.7	outside	3	74°F	↓	↓	↓
CV-5	↓	5.2	inside	2	132°F	↓	↓	↓
CV-6	↓	5.7	outside	2	74°F	↓	↓	↓
CV-7	↓	8.0	inside	5	2500+°F	↓	↓	↓
CV-8	↓	Ambient Reference			74°F	↓	↓	↓
CR-1	Thermistor	6.2	0.5 ft.	3	181°F	5.0 5.5	2500+°F - 2140°F -	2319°F 1959°F
CR-2	↓	9.2	3.5 ft.	3	99°F	8.5	1492°F -	1393°F
CR-3	↓	12.2	6.5 ft.	3	79°F	11.5	1172°F -	1093°F
CR-4	↓	6.2	0.5 ft.	4	145°F	5.0	2500+°F - 2140°F -	2355°F 1995°F
CR-5	↓	9.2	3.5 ft.	4	81°F	8.5	1492°F -	1411°F
CR-6	↓	12.2	6.5 ft.	4	77°F	11.5	1172°F -	1095°F

*Heat flux (3350 BTU/HR/FT^2) extrapolated to 50 ft. radius

This information agrees well with computations of total radiant heat loss from the heat flux measurements.

From table 12, it is obvious that the dramatic reduction in peak radiant heat flux observed during the 30 lb. test was repeated in this case.

The radiant heat flux curves for the shield tests are shown in figure 19 compared to the heat flux for the same charge in free field but at 50 ft. radius rather than the 6.7 feet for the shield test. Integration of these curves to show total radiant heat gain with time is shown in figure 20.

Selected photographs showing interior and exterior condition of the shield after completion of all tests are provided as figures 21 through 25. The only evidence of testing having been performed are the deposits of $Mg0/Na_20$ combustion products and the deteriorated interpanel screening.

4.0 CONCLUSIONS

The primary conclusion that can be drawn as a result of reviewing and analyzing the test data is that all design and performance requirements described for the Category 5 suppressive shield were met. Both explosion and deflagration containment exceeded expectations, and the shield structurally withstood all tests.

It can be concluded that the interweave aluminum flame/fireball attenuation panel element (53 percent venting) is just as effective as the four layers of aluminum screen wire. The interweave is more cost effective since it requires only a single installation operation compared to four for the screening material. Furthermore, the interweave material withstands an adverse chemical environment whereas the fine mesh aluminum would have a tendency to deteriorate in a relatively short period of time.

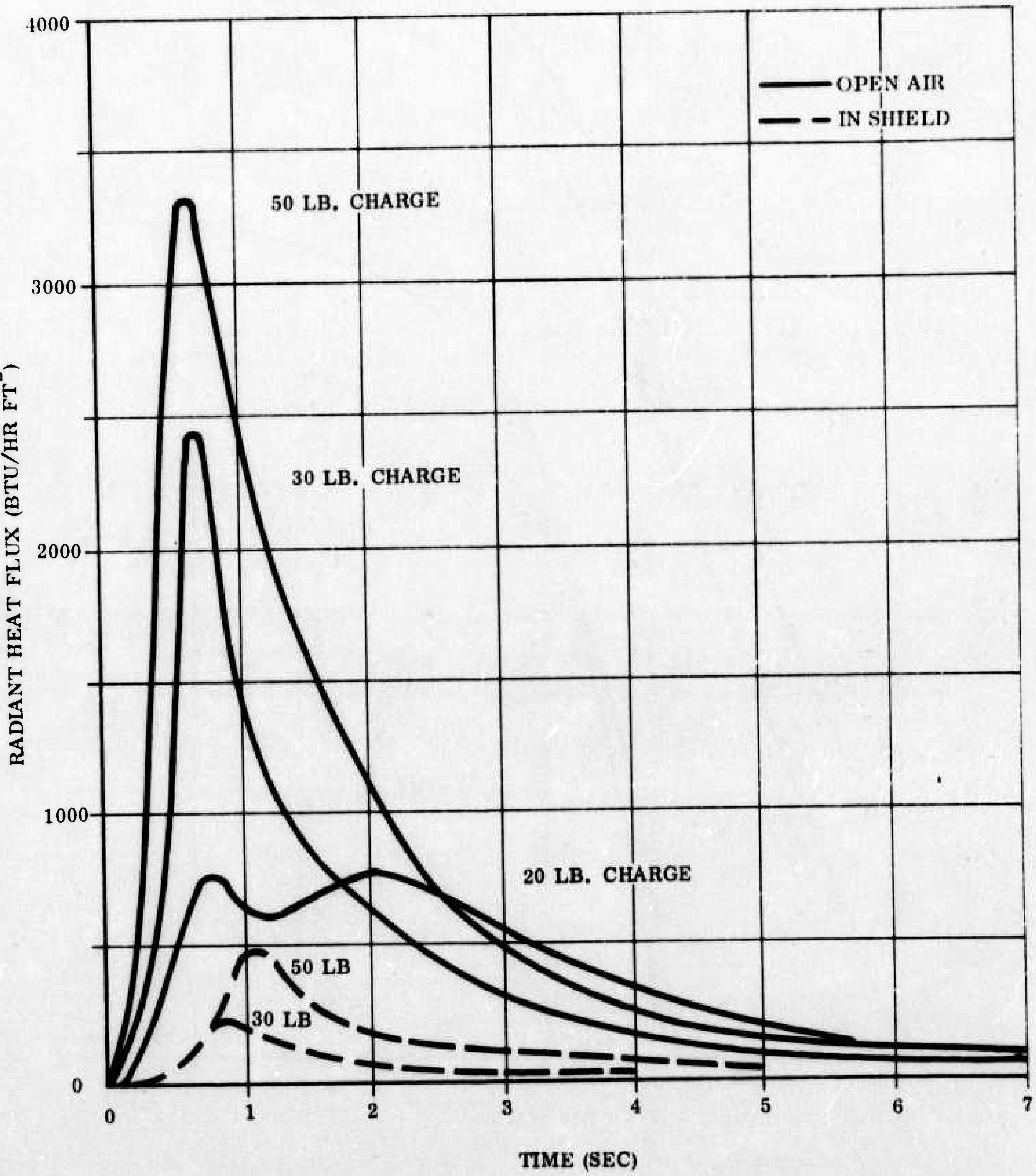

Figure 19. Heat Flux as a Function of Time

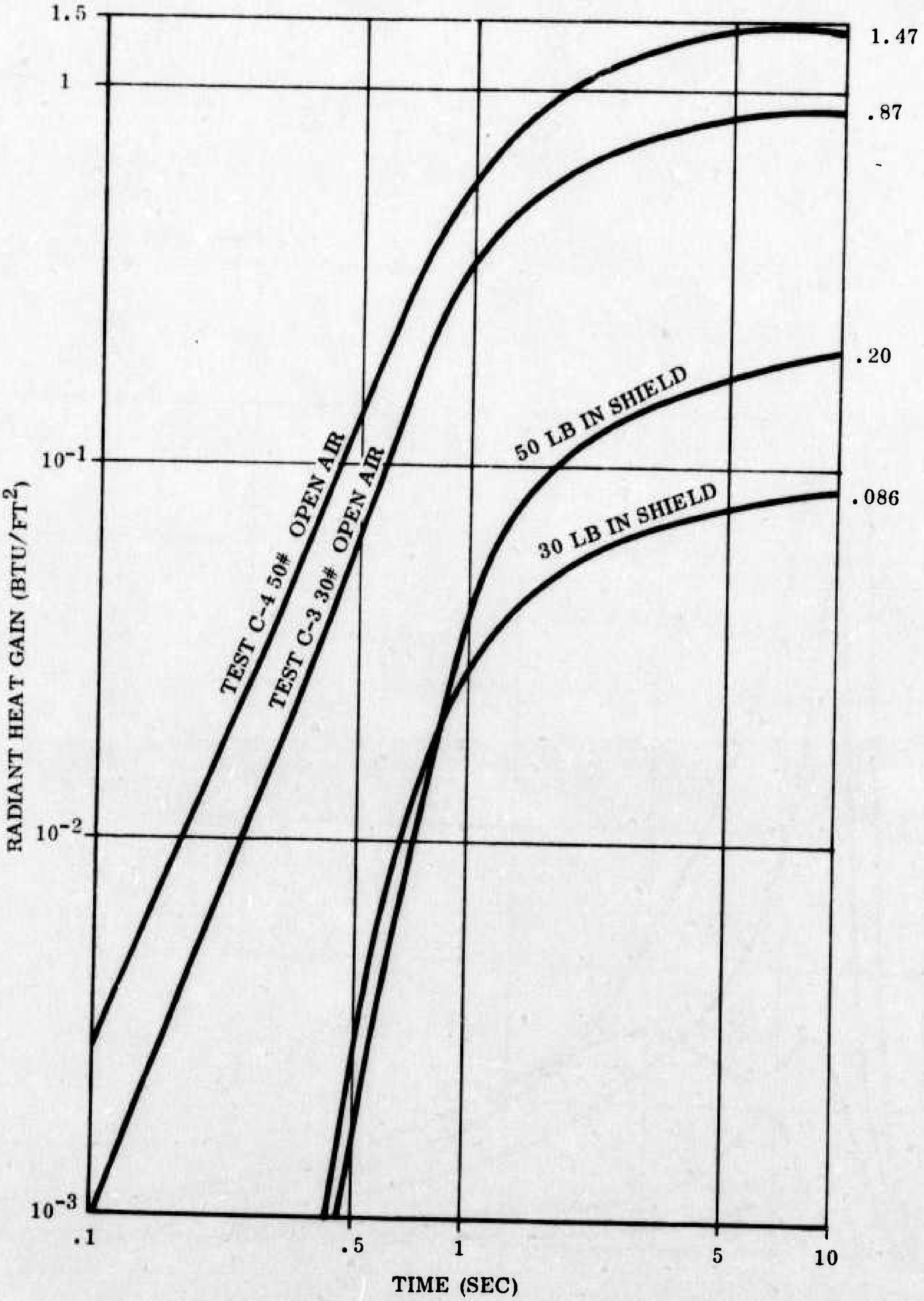

Figure 20. Radiant Heat Gain Versus Time

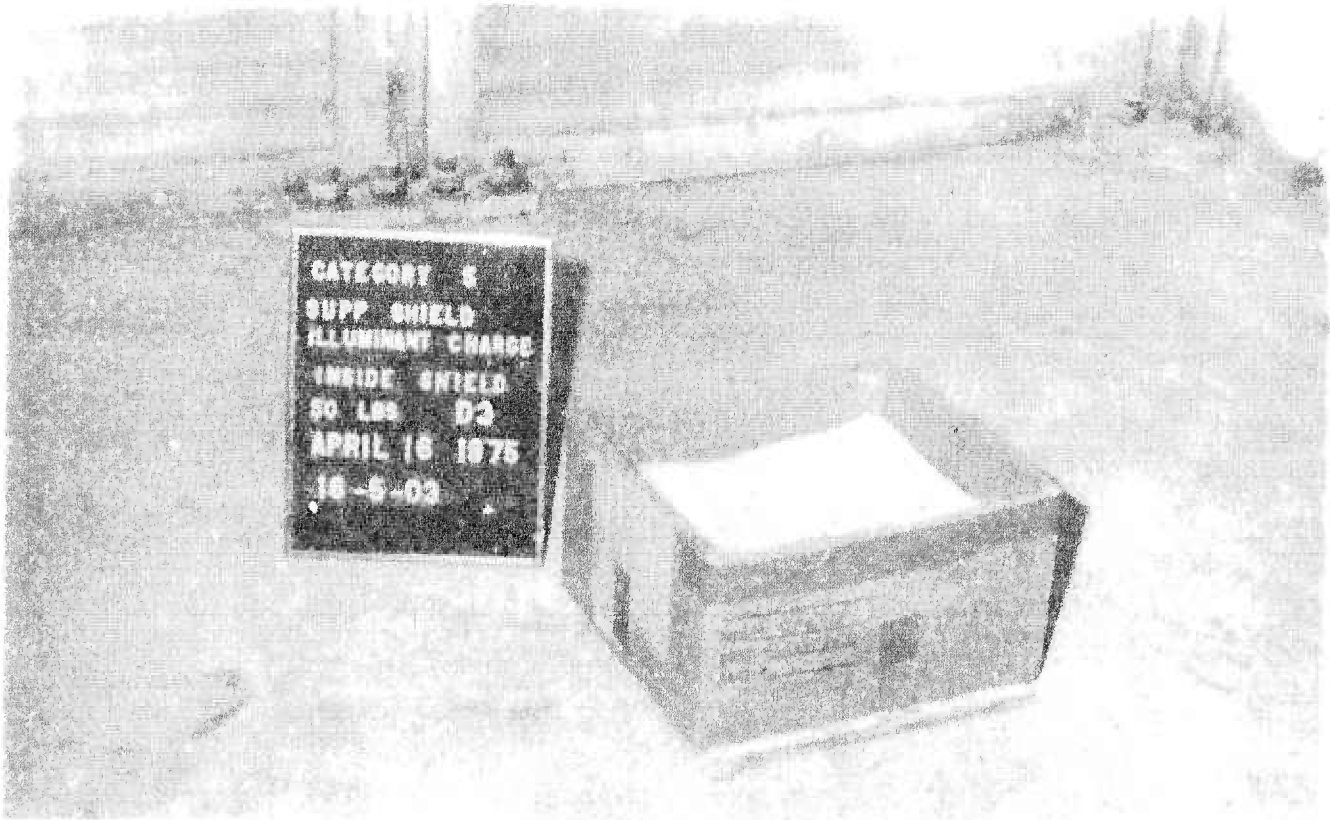

Figure 21. Pretest Configuration, 50 Pound Illuminant Charge

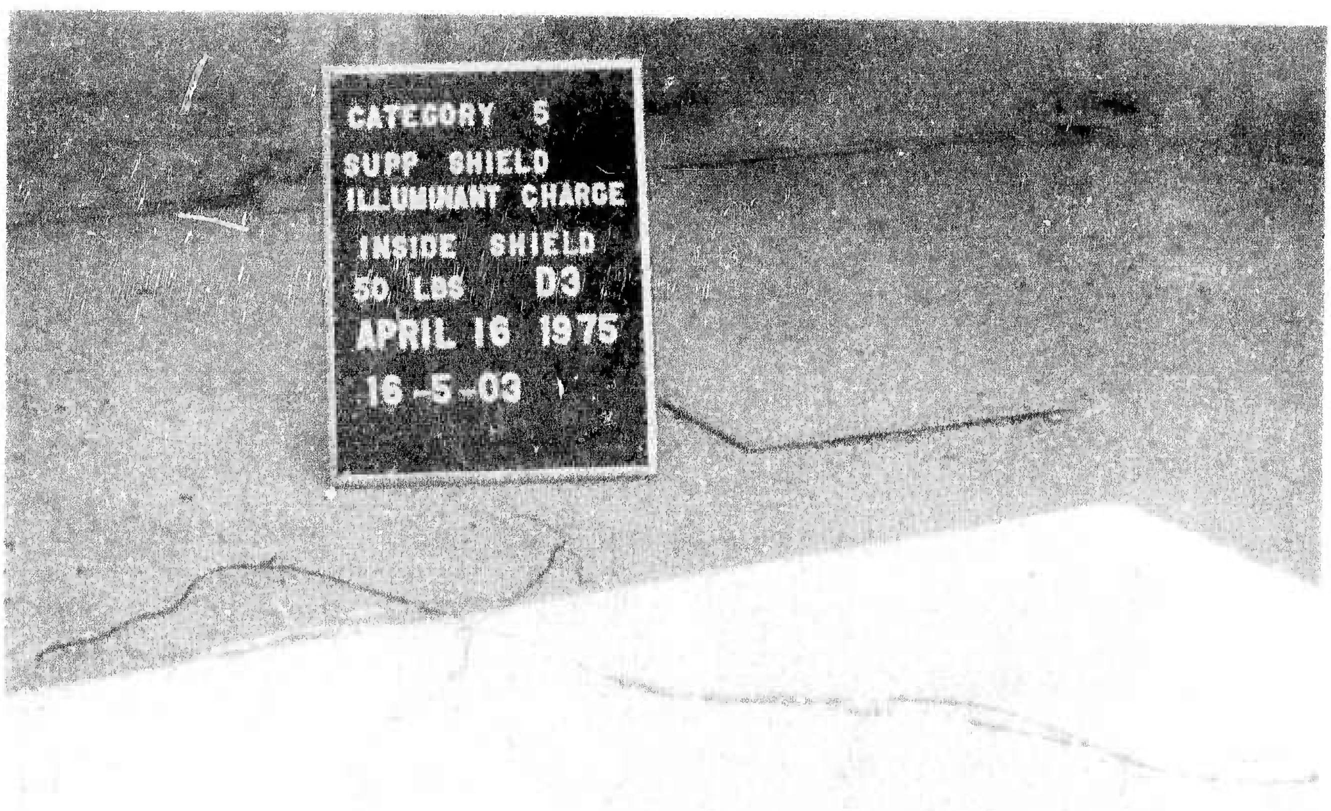

Figure 22. Post Test Interior View

Figure 23. Post Test Exterior Roof View.

Figure 24. Post Test Interior Roof View.

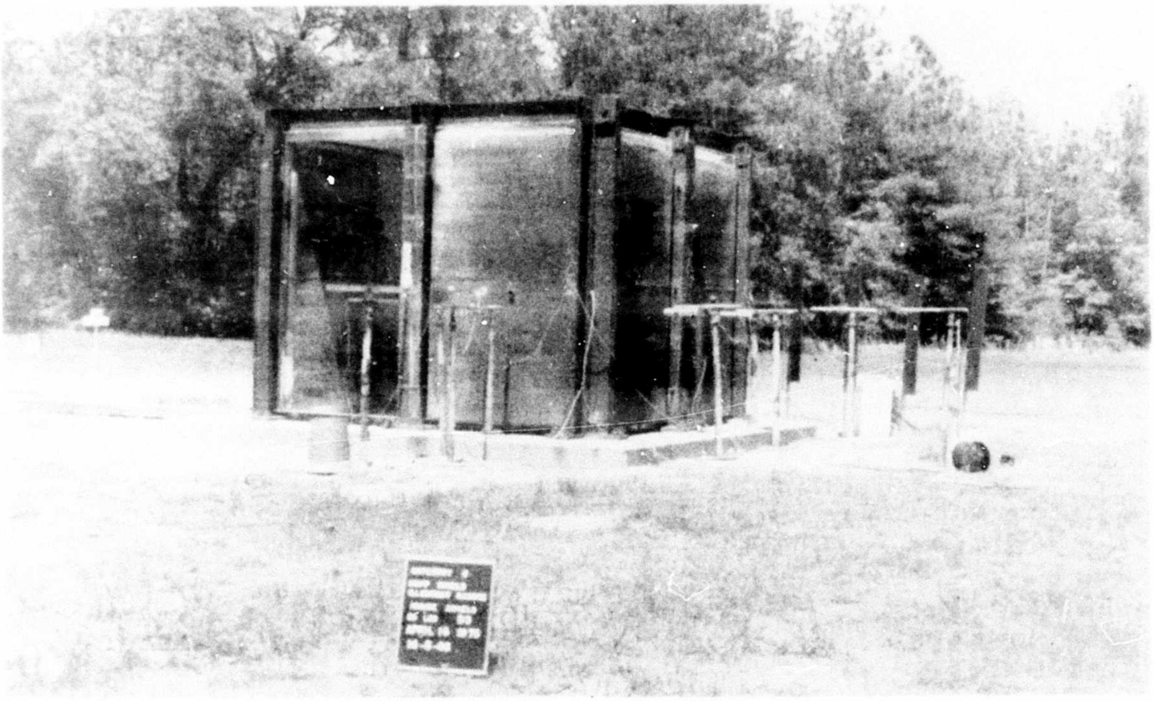

Figure 25. Category 5 Suppressive Shield After Completion of all Testing

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