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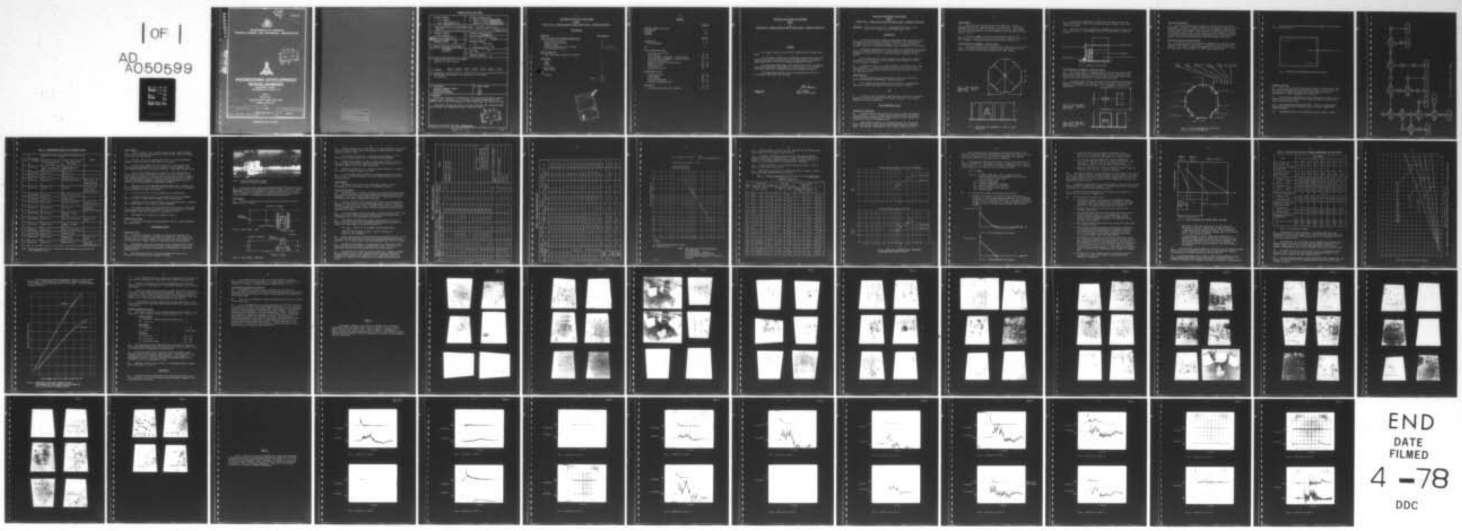

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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANIZATION

ENGINEERING DEVELOPMENT ESTABLISHMENT

MARIBYRNONG, VICTORIA

REPORT

PROJECT P522

REHABILITATION OF RANGE IMPACT AREAS PERSONNEL PROTECTION

BY

T.L. DUELL

PUBLICATION EDE 6/77

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16. ABSTRACT

Trials were conducted to establish the level of protection necessary against fragments from a detonating 5.5 in HE shell; to measure overpressures at the driver's position and the attenuation of these overpressures by a protective cabin.

This report describes the trials, the results obtained and a design procedure used to predict the overpressure within a protective cabin.

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ENGINEERING DEVELOPMENT ESTABLISHMENT

REPORT

ON

PROJECT P522 - REHABILITATION OF RANGE IMPACT AREAS - PERSONNEL PROTECTION

FOREWORD

This report relates to Project P522, Rehabilitation of Range Impact Areas.

In 1975 EDE was tasked with investigating the means of carrying out reseeding and erosion correction work to the impact areas of Puckapunyal Range, where there is the risk of detonating unexploded ordnance.

The Requirement Study Report, EDE Publication No 36/75, recommended that operator protection be provided on a tracked tractor and also that trials be carried out to establish the levels of protection required.

This report describes the trials and investigations carried out to establish these levels of protection.

Maribyrnong
22 Apr 77

(J.C. WISDOM)
Head of Establishment

ENGINEERING DEVELOPMENT ESTABLISHMENT

REPORT

PROJECT P522 - REHABILITATION OF RANGE IMPACT AREAS - PERSONNEL PROTECTION

REFERENCE: EDE Publication No 36/75 - Requirement Study Report on EDL Project P522, Rehabilitation of Range Impact Areas.

INTRODUCTION

1. In 1975 Engineering Development Establishment (EDE) were tasked with studying the means available to carry out restoration and reseeding work on the impact areas of the Puckapunyal Range. The work involves hazards to personnel, the worst of which is considered to be a detonating 5.5 in HE shell.

2. Following an appreciation of this hazard it was considered that operator protection should be provided on a tracked tractor no smaller than group 10. Subsequently a group 30 tractor (Caterpillar D8H) was provided for this project.

3. Plate penetration trials were conducted to establish the thickness of commercially available and readily weldable steel required to afford protection against fragments.

4. Overpressure trials were conducted using 5.5 in HE shell and charge demolition blocks. A thin walled steel cabin was fitted to the tractor to establish the overpressure attenuation that could be expected by the use of a protective cabin.

Acknowledgement

5. The plate penetration and overpressure trials were conducted at Proof and Experimental Establishment, Graytown Victoria.

6. The overpressure measurements were carried out by the Mechanical Laboratories Group of EDE under the direction of Mr J.P. Kipluks.

AIM

7. To detail trials and studies that have been carried out to establish the level of protection required for an operator against 5.5 in HE shell fragments and blast overpressure.

PLATE PENETRATION TRIALS

Selection of Test Plate

8. The plate selected for the trial was steel to Australian Standard 1204, Grade 350. This is a medium tensile structural steel that offers suitable mechanical properties and in particular is readily weldable and available ex stock at a reasonable price.

9. Armour quality steel was not considered because of the probable higher cost, and the likelihood that there would be delays in obtaining plate. Additionally, armour quality steel is more difficult to weld.

Trials Method

10. The trials were carried out with test plates, 0.7 m by 0.9 m, arranged vertically in a pattern around a 5.5 in HE shell. The distance from the centre of the shell to the test plates was 1.5 m. The minimum distance from the ground to the cabin mounted on a D8H Caterpillar Tracked Tractor is 1.6 m.

11. Trials of a number of shells in both vertical and horizontal positions were conducted with the test plates placed tangential to a circle of 3 m diameter. The shell was placed in the centre of the circle.

Plate and Shell Arrangement - Vertical Shell

12. Test plates were placed at eight positions equally spaced around the circle, and where varying plate thicknesses were used in the one trial, plates of the same thickness were located on the same diagonal.

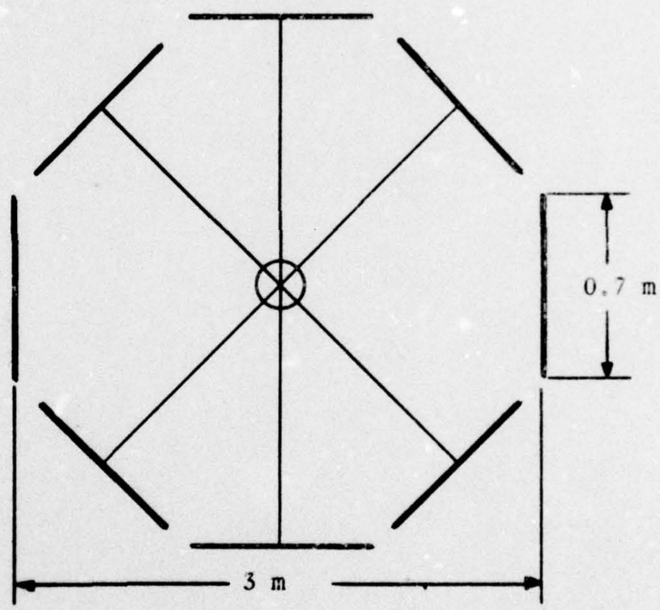


FIG 1 - PLATE AND SHELL ARRANGEMENT - VERTICAL SHELL, PLAN

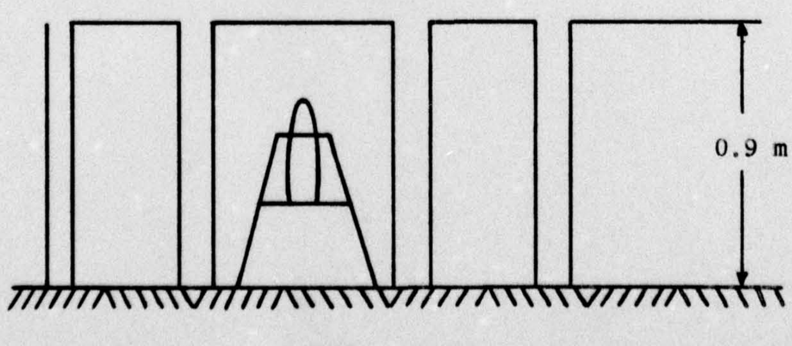


FIG 2 - PLATE AND SHELL ARRANGEMENT - VERTICAL SHELL, ELEVATION

13. The shell was supported in a particle board stand such that the height of the centre of the shell was the same as the height of the centre of the test plates.

14. The test plates were supported by sandbags and concrete blocks, and held in position by a steel banding strap and a wooden stake, as depicted in Fig 3.

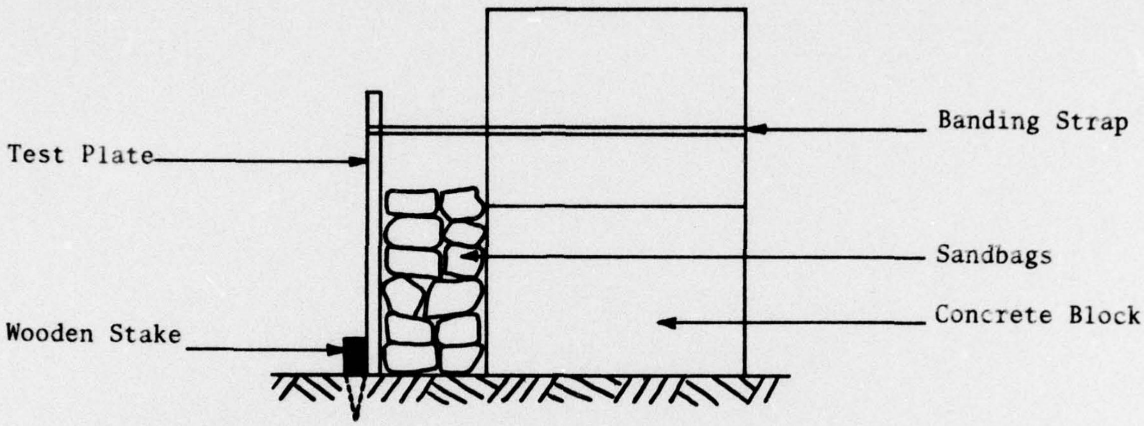


FIG 3 - SUPPORT OF TEST PLATES

Plate and Shell Arrangement - Horizontal Shell

15. To test the effect of fragments from the base and fuze of the shell, plates were arranged normal to the longitudinal axis of a horizontal shell, and centred on the longitudinal axis of the shell. Additional plates were placed at the sides of the shell to obtain side effect data.

16. For these trials the fuze was fitted to the shell which was placed in a particle board support such that the centre of the shell was at the same height as the centre of the test plates. The arrangement is depicted in Fig 4 and 5.

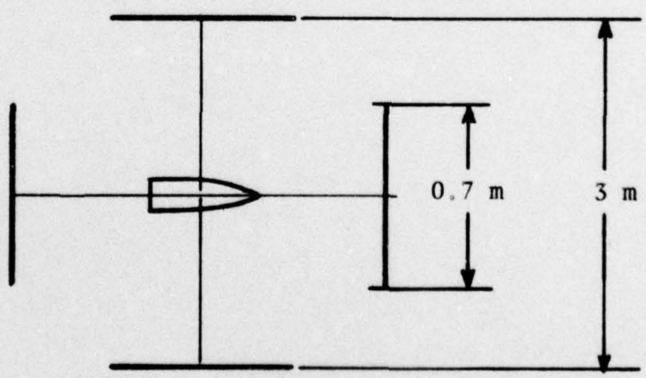


FIG 4 - PLATE AND SHELL ARRANGEMENT - HORIZONTAL SHELL, PLAN

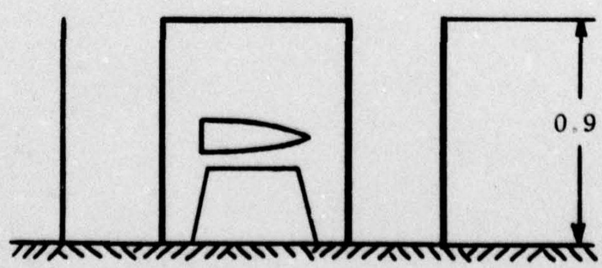


FIG 5 - PLATE AND SHELL ARRANGEMENT - HORIZONTAL SHELL, ELEVATION

Test Plate Thicknesses

17. The test plate used was in nominal ½ in (12 mm) and 3/4 in (20 mm) thicknesses. The total thickness of plate at each position around the circle could be varied from ½ in upwards in ½ and ¼ in increments by combinations of these plates in laminates. Where more than one plate was used to obtain the desired thickness, they were positioned as closely together as possible. The maximum air gap between plates was determined by the rough edge of the plates, resulting from flame cutting, and was estimated to be 1/16 in.

Marking of Plates for Identification

18. All plates used in the trials were stamped on the rear face with an identification code which consisted of a group of four or six letters and numerals. Fig 6 shows a typical arrangement of test plates from ½ in up to 1¼ in thickness, and gives the key to the identification code.

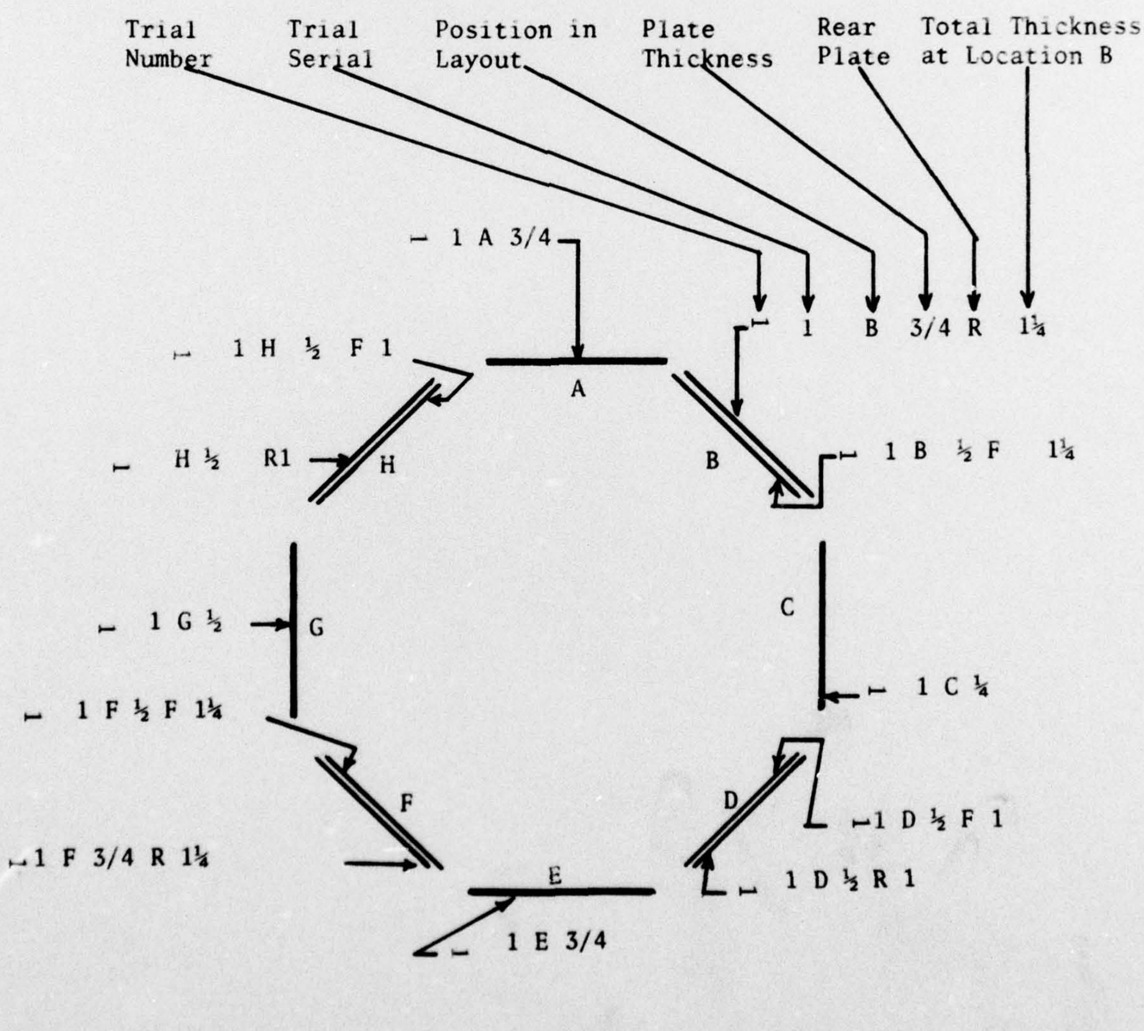


FIG 6 - TYPICAL ARRANGEMENT OF TEST PLATES AND KEY TO IDENTIFICATION CODE

19. The location of the identification code as marked on the test plate is illustrated in Fig 7.

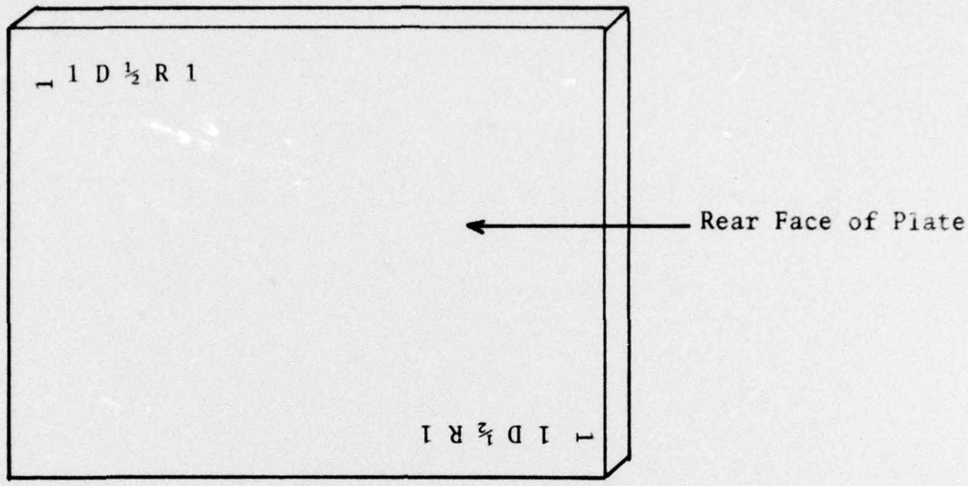


FIG 7 - LOCATION OF IDENTIFICATION CODE ON TEST PLATE

Sequence of Trials

20. Each trial consisted of one or more serials. If the thickest test plate for a particular trial was penetrated on the first serial, the trial was considered complete and a new trial using different test plate thicknesses, or, shell arrangement was carried out.

21. If there was no penetration of the test plate on the first serial, further serials were carried out until either the plate was penetrated or three serials had been fired.

22. New plates were used for each serial. Fig 8 is a logic diagram showing the possible paths through the series of trials, depending on results obtained.

23. Comprehensive detail of all possible trials is given in Table 1.

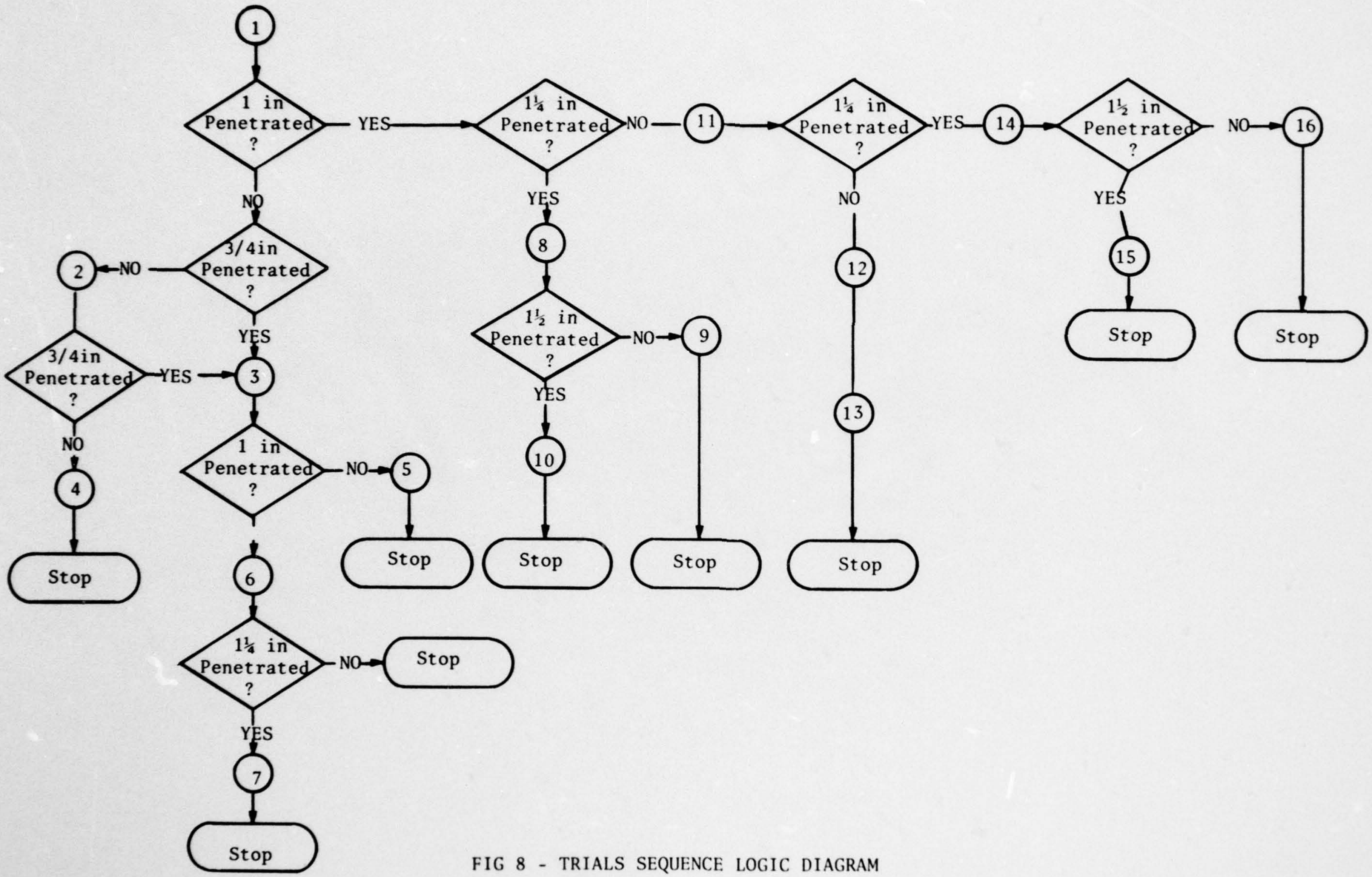


FIG 8 - TRIALS SEQUENCE LOGIC DIAGRAM

TABLE 1 - COMPREHENSIVE DETAIL OF ALL POSSIBLE TRIALS

Trial No	Arrangement of Shell	Number of Plates and (nominal) Thickness (in) of		Comment
		Plate to be Trialed per Serial	Total Plate Usage for Trial	
1	Vertical	Two ½ in, Two 3/4 in Two 1 in, Two 1¼ in.	Twenty Four ½ in, Twelve 3.4 in.	
2	Horizontal	Two 3.4 in	Six 3.4 in	
3	Horizontal	Two 1 in	Twelve ½ in	
4	Vertical	Eight 3/4 in	Twenty four 3/4 in	3/4 in OK. Use up 3/4 in for additional data.
5	Vertical	Three 1 in	Six ½ in	1 in OK. Use up 1 in for additional data.
6	Horizontal	Two 1¼ in	Six 3/4 in Six ½ in	
7	Horizontal	Two 1½ in	Twelve 3/4 in	
8	Horizontal	Four 1½ in	Twenty four 3/4 in	End and side effects on 1½ in.
9	Vertical	Three 1½ in	Six 3/4 in	1½ in OK, additional data.
10	Horizontal	Two 13/4 in	Twelve ½ in Six 3/4 in	
11	Horizontal	Two 1¼ in	Six 3/4 in Six ½ in	As for Trial No 6
12	Vertical	Eight 1¼ in	Eight ½ in Eight 3/4 in	
13	Vertical	Four 1¼ in	Four ½ in Four 3/4 in	
14	Horizontal	Two 1½ in	Twelve 3/4 in	
15	Horizontal	Two 13/4 in	Twelve ½ in Six 3/4 in	As for Trial No 10
16	Vertical	Six 1½ in	Twelve 3/4 in	1½ in OK, additional data.

Note: Plates available for trial. Forty two 12 mm (nominal ½ in) and Forty two 20 mm (nominal 3/4 in).

Trials Results

24. Trial 1, using ½, 3/4, 1 and 1¼ in plate to check radial fragments from a vertical shell was completed on the first serial. Both 1¼ in plates in the array were penetrated.

25. The next trial in the sequence was Trial 8, to check longitudinal fragments from a horizontal shell, against 1½ in plates.

26. The trial was stopped after two serials as it was apparent that the longitudinal fragments were not as serious as radial fragments, and the result from each serial was almost identical. There were no penetrations.

27. The trial was stopped after two serials to enable enough plate to be available to conduct a further two serials with a full array of 1½ in plates and vertical shells, to ensure that the more serious radial fragments were adequately proven against 1½ in plate, and the near identical results from the longitudinal fragments, indicated with high confidence that 1½ in plate would not be penetrated by longitudinal fragments.

28. The next trial in the sequence would have been Trial 9, however due to the completion of Trial 8 after two serials, the next trial was designated Trial 16, modified to eight 1½ in plates.

29. Two serials of Trial 16 were conducted with no penetrations.

30. A total of twenty 1½ in plates were subjected to radial fragments; four 1½ in plates to longitudinal fragments with no penetrations.

31. Examination of the strikes on these plates indicated results consistent with the penetration of 1¼ in plate by radial fragments.

32. The number of strikes without penetration of 1½ in plate is sufficient to have high confidence that 1½ in plate will not be penetrated by 5.5 in HE shell fragments when struck normally at a distance of 1.5 m.

33. Photographs of all plates are included at Annex A.

Penetration Criteria

34. A plate was considered to be penetrated if the rear surface exhibited any visible cracks.

OVERPRESSURE TRIALS

Purpose of Trials

35. An analytical method is available to calculate the pressure rise within a structure subjected to external blast pressures. The calculations are based upon the internal volume of the structure, the area of openings in the structure and a leakage coefficient based upon data from experiments.

36. Overpressure trials were carried out using a Caterpillar D8H Tracked Tractor fitted with a protective steel cabin to establish the internal and external pressures resulting from detonation of known masses of explosive at known distances.

37. The cabin used in these trials was fabricated for use on this tractor for anti personnel mine clearing in Vietnam.

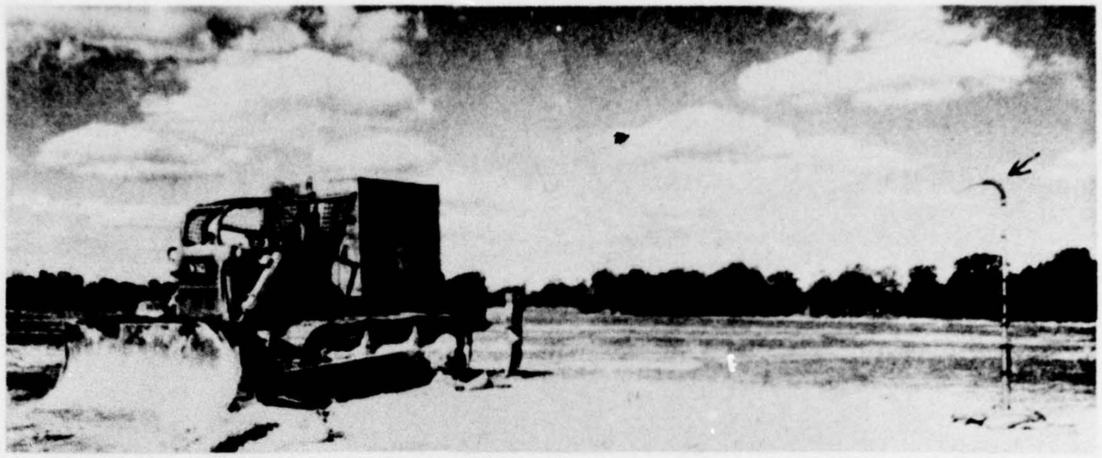


FIG 9 - VIEW OF TRACTOR USED IN TRIALS
(External Transducer Arrowed)

38. These trials were aimed at providing data which could ensure that the analytical methods reliably predicted the real situation, and also to obtain measurements of blast overpressures at varying distances from a 5.5 in HE shell to establish the magnitude of overpressures that could be expected if a 5.5 in HE shell is detonated during range clearing operations.

Trial Method

39. Pressure transducers were located inside and outside the cabin as shown in Fig 9, 10 and 11.

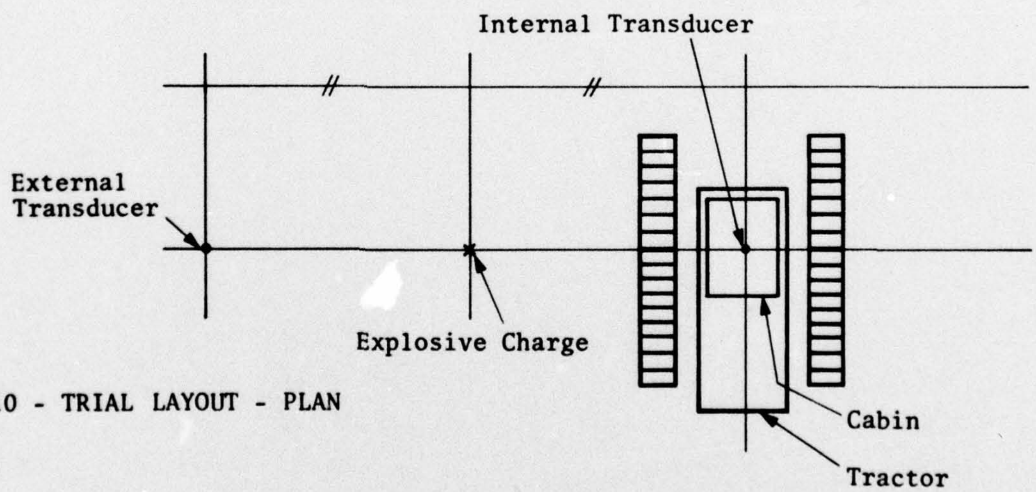


FIG 10 - TRIAL LAYOUT - PLAN

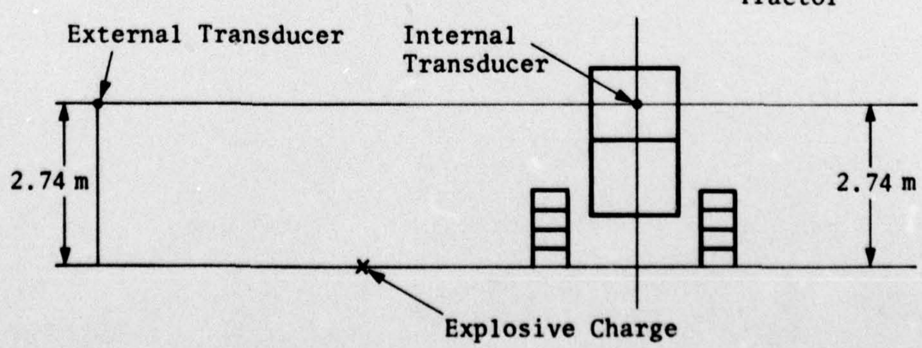


FIG 11 - TRIAL LAYOUT - ELEVATION

40. Charge demolition blocks (RDX-TNT, 60-40) were detonated on the ground surface at known distances from the transducer, using CE primers and Caps, Blasting, Electric, L2A1.

41. The pressure time history, as detected by the transducers, was recorded on a storage cathode ray oscilloscope and photographed.

42. Charges were detonated at the rear and at the side of the tractor, with the charge and external transducer located on the longitudinal and transverse centre line of the cabin respectively.

43. Demolition blocks of 1.25, 5 and 10 lbs were detonated at distances of 1 m and 4.5 m from the edge of the cabin.

44. 5.5 in HE shells were detonated on the ground surface at distances of 4.5 m and 7.6 m from transducers set at the height above ground as for the cabin trials.

Trials Results

45. The results of the trials are tabulated in Table 2, and the photographs of the oscilloscope traces are included at Annex B.

Prediction of Results

46. The methods used to predict external blast overpressures and pressure rise within the cabin were based upon information and data presented in US Department of the Army, Technical Manual TM 5-1300, 'Structures to Resist the Effects of Accidental Explosions', June 1969.

47. The data presented in this manual (TM 5-1300) is for TNT explosive, whereas the trials were carried out with Composition B Explosive (RDX 60% - TNT 40%), requiring the mass of RDX - TNT used in the trials to be adjusted to an equivalent mass of TNT to allow the TM 5-1300 data to be used in the analysis of the results.

48. It was found that a mass of TNT equal to 80% of the mass of RDX - TNT used in the trial, with data from TM 5-1300, predicted the peak external overpressures with a very good degree of correlation.

49. The measured and predicted external overpressures are listed in Table 3, and Fig 12 shows the relationship between measured and predicted values when plotted against the scaled distance ZG:

($ZG = \frac{D}{M^{1/3}}$. Where D is the straight line distance between explosive and transducer in feet; and M is the mass of explosive, TNT in pounds.)

50. It was also found that the peak external overpressures produced by the 5.5 in HE Shell correlate very well with the overpressures produced by the detonation, at the same distance from the measurement point, of 6.3 lb of TNT.

51. Although the adjustment to an equivalent mass of TNT gives reliable predictions for the peak external overpressures, it does not predict the duration of the positive pressure phase with sufficient accuracy.

52. The duration of the positive pressure phase has a significant effect on the pressure rise that can be expected within a structure subjected to external blast pressure as the magnitude of the overpressure within the structure is a function of the impulse (the area under the pressure-time curve).

TABLE 2 - OVERPRESSURE TRIALS RESULTS

Blast No	Mass of Charge RDX/TNT (lb)	Maximum Pressures		Duration of Positive Pulse		Side or Rear of Tractor	Distance to Edge of Cabin (m)	Tractor Present Yes/No	Comment
		External (psi)	Internal (psi)	External (ms)	Internal (ms)				
1	10	18.4	-	5	-	SIDE	4.5	YES	TRANSDUCER IN NOSE CONE
5	5	12.8	-	4	-	SIDE	4.5	"	TRANSDUCER IN LEAD DISC
6	5	9.2	-	5	-	SIDE	4.5	"	"
7	5	10.7	0.94	5	17	SIDE	4.5	"	"
8	10	12.2	1.30	5.5	17.2	SIDE	4.5	"	"
9	10	12.2	1.38	5.6	15.5	SIDE	4.5	"	"
10	1.25	4.6	-	3.5	-	SIDE	4.5	"	"
11	1.25	4.6	-	3.7	-	SIDE	4.5	"	"
12	1.25	4.1	0.63	4.0	15	REAR	4.5	"	"
13	5	8.7	1.84	5.0	17	REAR	4.5	"	"
14	1.25	-	1.21	-	12	REAR	1.0	"	"
15	1.25	-	0.96	-	15	SIDE	1.0	"	"
16	1.25	11.5	0.92	2.7	14.6	SIDE	1.0	"	"
17	1.25	3.6	-	3.2	-	-	5.5	NO	PLAN DISTANCE TO TRANSDUCER INSTRUMENT CHECK
18	5.5 HE	6.1	-	4.1	-	-	7.6	NO	PLAN DISTANCE TO TRANSDUCER
19	1.25	3.7	-	3.2	-	-	5.5	NO	AS FOR 17
20	5.5 HE	8.0	-	4.8	-	-	4.5	NO	AS PER 18
		5.8	-	5.0	-	-	7.6	NO	"

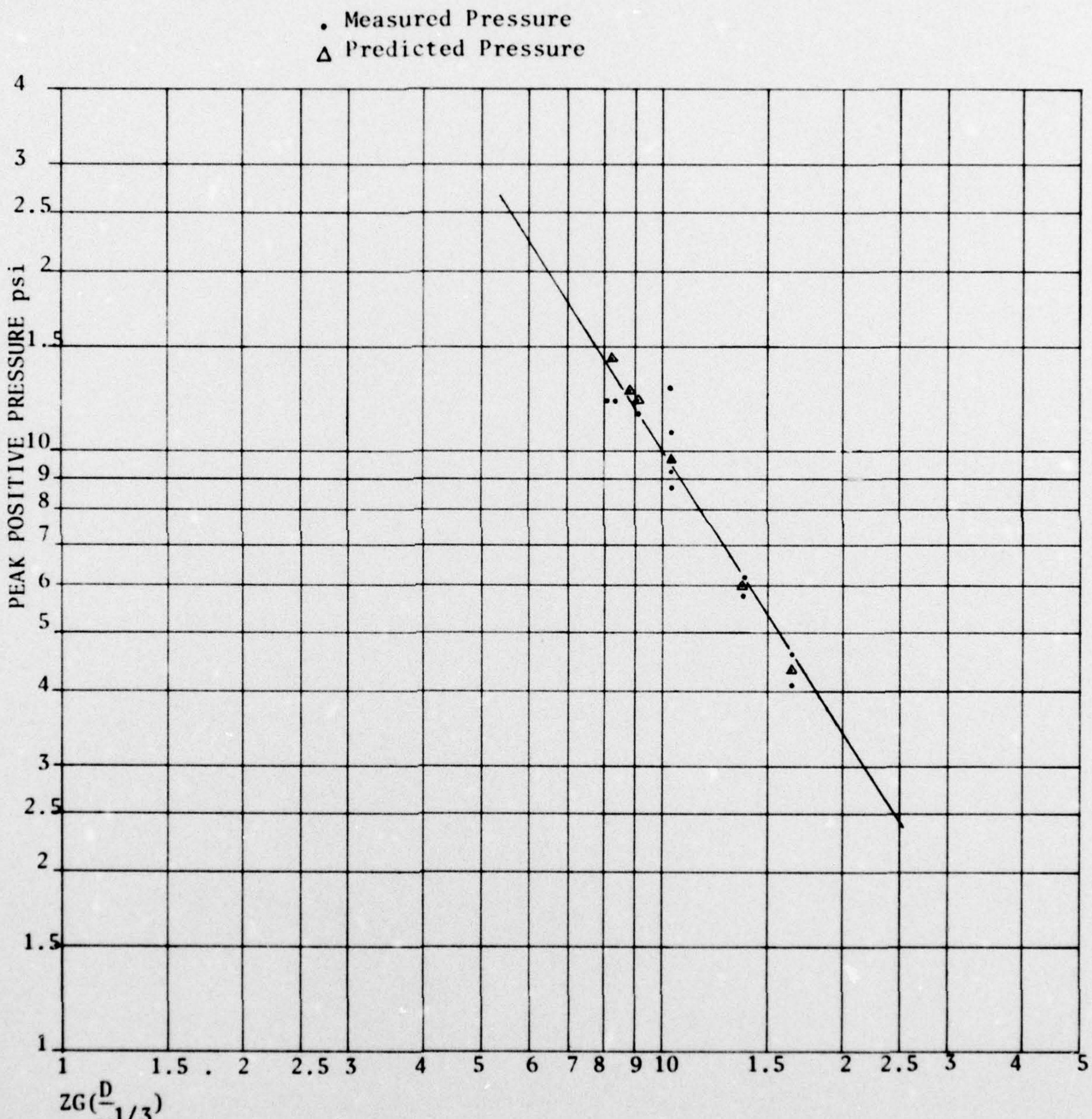
Note
Because the Transducer was calibrated in psi (lb/in^2) this unit has been used in this table.

TABLE 3 - EXTERNAL PRESSURE PREDICTIONS

Blast No	Charge Mass		Plan Distance		True Distance (ft)	Pressure		Positive Pulse		ZG
	RDX/TNT (lb)	TNT (lb)	(m)	(ft)		Measured (psi)	Predicted (psi)	Measured (ms)	Predicted (ms)	
1	10	8	4.5	14.76	17.28	18.4	14.45	5	3.82	8.13
5	5	4	4.5	14.76	17.28	12.8	9.65	4	3.79	10.24
6	5	4	4.5	14.76	17.28	9.2	9.65	5	3.79	10.24
7	5	4	4.5	14.76	17.28	10.7	9.65	5	3.79	10.24
8	10	8	4.5	14.76	17.28	12.2	14.45	5.5	3.82	8.13
9	10	8	4.5	14.76	17.28	12.2	14.45	5.6	3.82	8.13
10	1.25	1	4.5	14.76	17.28	4.6	4.30	3.5	3.14	16.26
11	1.25	1	4.5	14.76	17.28	4.6	4.30	3.7	3.14	16.26
12	1.25	1	4.5	14.76	17.28	4.1	4.30	4.0	3.14	16.26
13	5	4	4.5	14.76	17.28	8.7	9.65	5.0	3.79	10.24
14	1.25	1	1	3.28	9.57	-	12.08	-	2.111	9.00
15	1.25	1	1	3.28	9.57	-	12.08	-	2.111	9.00
16	1.25	1	1	3.28	9.57	11.5	12.08	2.7	2.111	9.00
17	1.25	1	5.5	18.04	20.16	3.6	3.29	3.2	3.45	18.97
18	5.5 HE SHELL	6.3	7.6	24.93	26.5	6.1	5.95	4.1	5.2	13.50
19	1.25	1	5.5	18.04	20.16	3.7	3.29	3.2	3.45	18.97
20	5.5 HE SHELL	6.3	4.5	14.76	17.28	8.0	12.57	4.8	3.81	8.80
	5.5 HE SHELL	6.3	7.6	24.93	26.5	5.8	5.95	5.0	5.2	13.50

'Least squares' fit press. = $\frac{369}{ZG^{1.578}}$ using measured data.

Correlation coefficient = 0.96



D = Distance from explosion (feet)
M = Mass of TNT, lb

NOTE: Pressures predicted using method in TM 5-1300 and
0.8 RDX/TNT Mass = TNT Mass
Pressures measured using RDX/TNT
6.3 lb TNT used to predict 5.5 in HE shell pressures.

FIG 12

53. This discrepancy is due to the fact that RDX-TNT and TNT have both differing pressure and impulse characteristics.

54. To achieve a reasonable correlation with the measured positive pressure durations, the scaled distance - ZG was increased by 10% for the purpose of obtaining an adjusted scaled duration, $t_o/M^{1/3}$ (where t_o is duration in milliseconds and M is the mass of TNT in pounds).

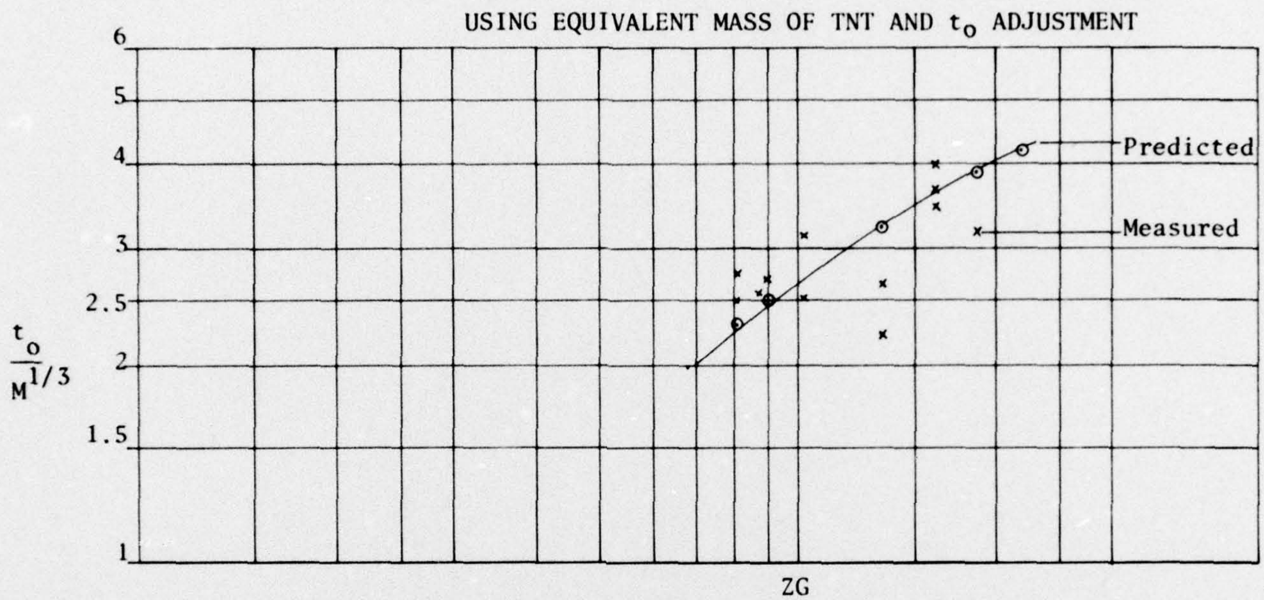
55. The resulting time - t_o was further adjusted by using $1.1\ M^{1/3}$ to obtain t_o from the scaled duration.

56. Adjusted values of positive pressure duration are listed in Table 4, and plotted against measured values in Fig 13.

TABLE 4 - EXTERNAL PRESSURE AND POSITIVE PULSE DURATION PREDICTIONS

ADJUSTED VALUES OF t_o

Blast No	Charge Mass		True Distance	Pressure		Positive Pulse Duration		ZG
	RDX/TNT (lb)	TNT (lb)		Measured (psi)	Predicted (psi)	Measured (ms)	Predicted (ms)	
1	10	8	17.28	18.4	14.5	5	4.6	8.13
5	5	4	17.28	12.8	9.65	4	4.41	10.24
6	5	4	17.28	9.2	9.65	5	4.41	10.24
7	5	4	17.28	10.7	9.65	5	4.41	10.24
8	10	8	17.28	12.2	14.45	5.5	5.6	8.13
9	10	8	17.28	12.2	14.45	5.6	4.6	8.13
10	1.25	1	17.28	4.6	4.30	3.5	3.66	16.26
11	1.25	1	17.28	4.6	4.30	3.7	3.66	16.26
12	1.25	1	17.28	4.1	4.30	4.0	3.66	16.26
13	5	4	17.28	8.7	9.65	5.0	4.41	10.24
14	1.25	1	9.57	-	12.08	-	2.55	9.00
16	1.25	1	9.57	11.5	12.08	2.7	2.55	9.00
17	1.25	1	20.16	3.6	3.29	3.2	3.95	18.97
18	5.5 HE	6.3	26.5	6.1	5.95	4.1	6.05	13.50
19	1.25	1	20.16	3.7	3.29	3.2	3.95	18.97
20	5.5 HE	6.3	17.28	8.0	12.57	4.8	4.6	8.8
20	5.5 HE	6.3	26.5	5.8	5.95	5.0	6.05	13.5



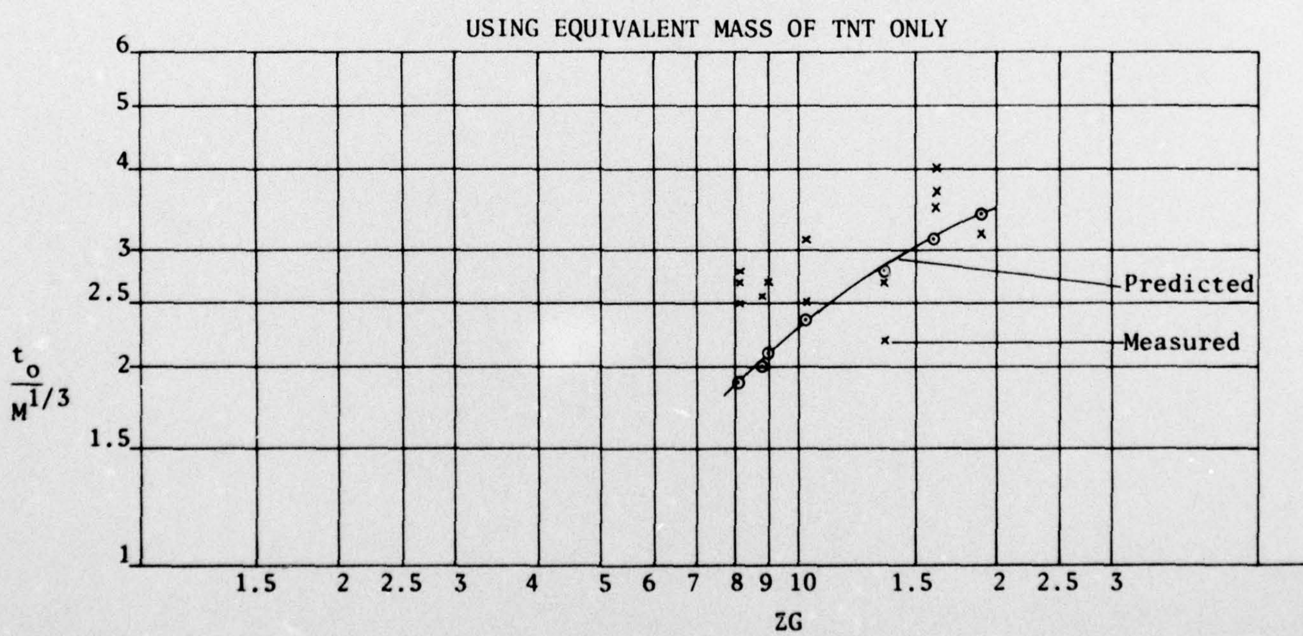


FIG 13 - DURATION OF PRESSURE PULSE, COMPARISON OF MEASURED AND PREDICTED VALUES

57. This approach gives a reasonably reliable method to predict the external blast overpressures and the positive pressure duration, and is the basis for the prediction of the internal overpressures that might be experienced within the cabin under various conditions.

58. The approach presented in TM 5-1300 to calculate the pressure rise within a structure is: the change in internal overpressure, ΔPi, within a time interval, Δt, is a function of the pressure difference at the openings in the structure, P-Pi, and the area to volume ratio Ao/Vo,

$$\Delta Pi = C_L \left(\frac{Ao}{Vo}\right)\Delta t$$

Where C_L = leakage co-efficient, and is a function of the pressure difference at the openings in the structure, P-Pi (from Fig 4-72 TM 5-1300)

P = external overpressure

Pi = internal overpressure

ΔPi = internal overpressure increment

Ao = area of openings in the structure

Vo = internal volume of the structure

Δt = time increment

59. To calculate the internal over pressure-time history:

a. determine the pressure time history of the applied blast, P, acting on the surface surrounding the opening. For the purpose of calculation the external overpressure is assumed to decrease linearly to zero in the time t_o. A typical pressure-time history is shown at Fig 14, and the assumed pressure-time history at Fig 15.

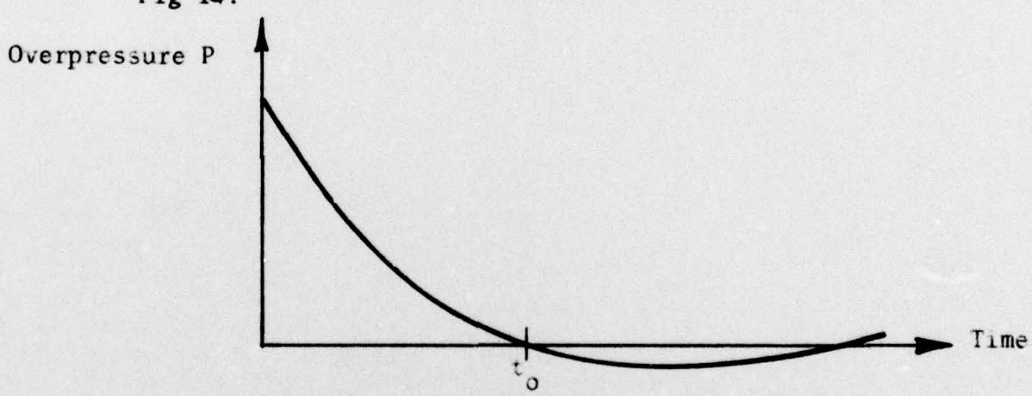


FIG 14 - TYPICAL PRESSURE-TIME HISTORY

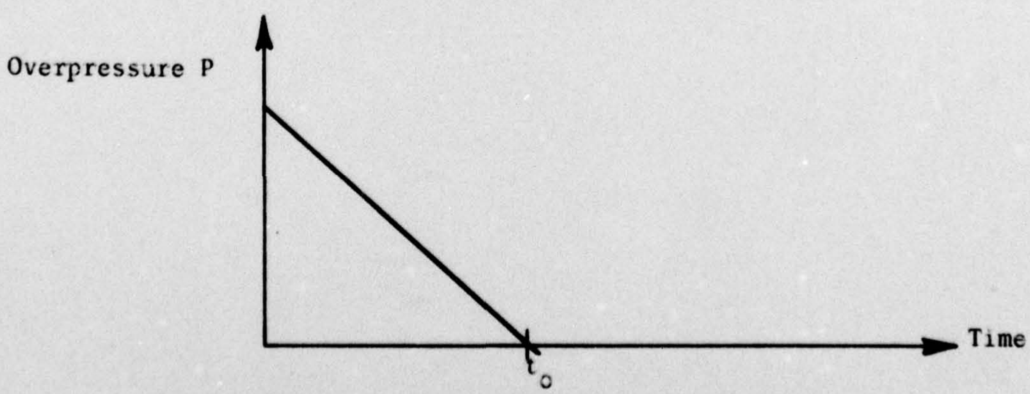


FIG 15 - ASSUMED PRESSURE-TIME HISTORY

b. Divide the duration of the applied overpressure into n intervals, Δt, each being from $t_o/10$ to $t_o/20$ and determine the value of the external overpressure P, at each interval.

c. For each time interval compute the pressure differential P-Pi, and determine the value of C_L, then calculate ΔPi using Ao/Vo and Δt. Add ΔPi to Pi for each interval being considered to obtain a new value of Pi for the next interval.

d. Repeat for each interval. Note that when P-Pi becomes negative, the value of C_L must also be taken as negative.

60. This approach proved to be too simplistic to predict the results of the trials. The reason being that the model assumes that the leakage is confined to a single opening in one face of the structure, whereas the test cabin had many leakage areas on all faces, and hence a more comprehensive approach was required to account for this.

61. A method of accounting for the size and location of the various leakage areas consisted of lumping areas together at distances which were the mean of the distances to centres of the individual areas.

62. Two and three area models were tried using various approaches to allocate discrete areas to a lumped area.

63. The calculations carried out were:

a. Determine the pressure-time history of the applied external overpressure acting at distances D1, D2 (and D3 for the three area model) where the distances D are the distances from the explosive to the lumped leakage areas A1, A2 (and A3).

b. Calculate the time of arrival of the shock front at the various leakage areas.

c. Note that the shock front will have differing characteristics at the different distances to the leakage areas. As the distance from the explosive increases, the peak pressure decreases with a consequent increase in the duration of the positive pressure phase.

d. The external pressure-time history for a three area model would be as shown in Fig 16.

e. Only the positive pressure phase of the external overpressure is considered since the magnitude of the negative pressures are considerably less than the positive pressures and have very little influence on the internal pressure-time history for the area-volume ratios under consideration.

f. The difference in the arrival times of the shock front at the first and second leakage areas is considered to be the time that the external pressure acts on leakage area A1, and similarly the difference in arrival times at areas A2 and A3 is considered to be the time for area A2. For the final area, the duration of the positive pressure phast t_o, is the time that the external pressure influences the internal pressure through this leakage area.

g. As before the time of application of the external pressure is divided into n steps of Δt and ΔPi calculated using the appropriate leakage area.

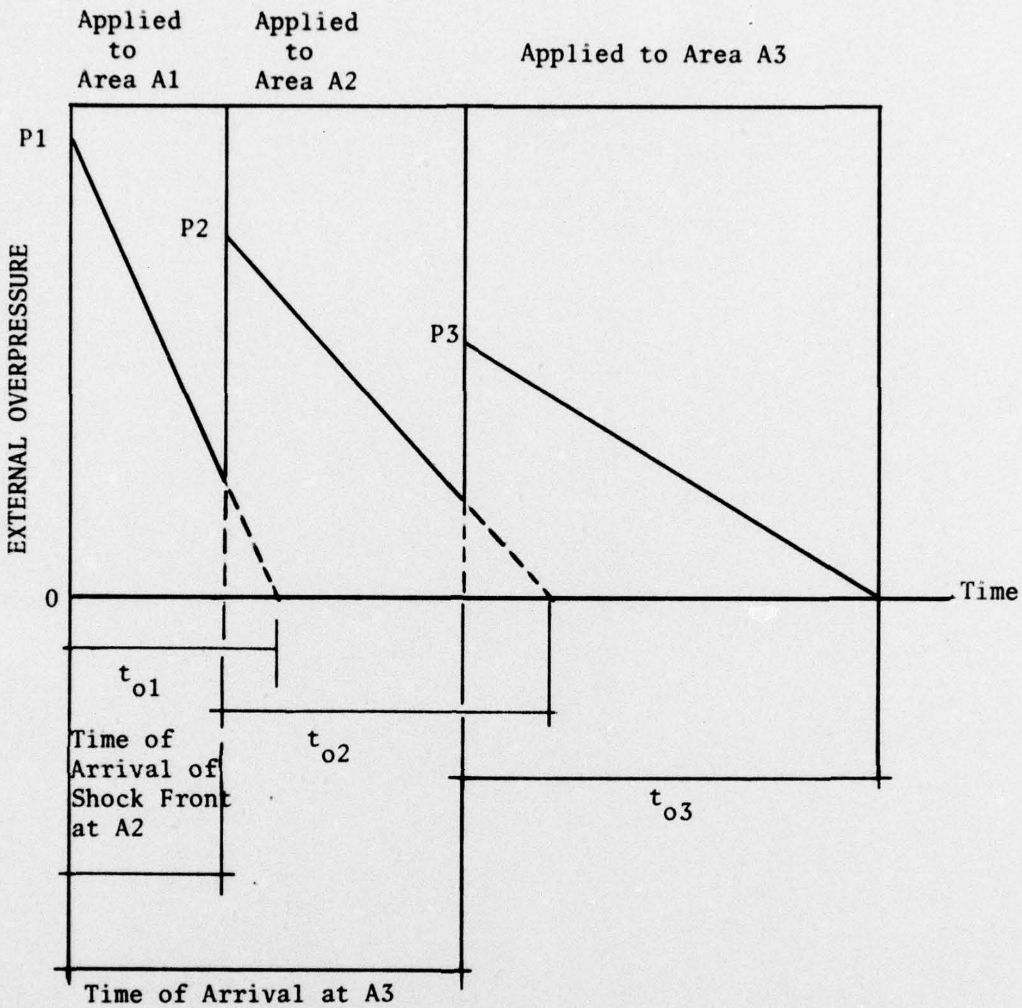


FIG 16 - TYPICAL PRESSURE-TIME HISTORY THREE AREA MODEL

h. When these n steps have been carried out the conditions prevailing at the next leakage area are applied again over n steps but using the internal pressure Pi as calculated at the n^{th} interval for the previous leakage area as the starting point for the internal pressure.

i. If the difference in arrival times of the shock front at consequent leakage areas is greater than the duration of the positive pressure phase for the first area in question, then the external pressure is set to zero for the remainder of the intervals greater than the duration t_o for that series of calculations.

64. A two-area model using distances to centres of area was found to predict results closer to the measured results than any other approach attempted. The measured and predicted results are listed in Table 5.

65. Although the model used to achieve these results predicted internal overpressures within 10% for some trials there is a variation in the accuracy of prediction with changes in distance and location of the explosive.

TABLE 5 - MEASURED AND PREDICTED INTERNAL OVERPRESSURES TWO AREA METHOD

Item	BLAST NUMBER							
	7	8	9	12	13	14	15	16
Mass of TNT (lb)	4	8	8	1	4	1	1	1
Plan Distance to Edge of Cabin (m)	4.5	4.5	4.5	4.5	4.5	1	1	1
Location: Side or Rear of Cabin	Side	Side	Side	Rear	Rear	Rear	Side	Side
Distance 1 (ft)	15.66	15.66	15.66	17.72	17.72	7.64	7.18	7.18
Area 1 (ft^2)	0.802	0.802	0.802	5.04	5.04	5.04	2.3	2.3
Distance 2 (ft)	19.88	19.88	19.88	21.92	21.92	12.58	11.33	11.33
Area 2 (ft^2)	5.43	5.43	5.43	1.707	1.707	1.707	3.95	3.95
Internal Overpressure: Measured (psi)	0.94	1.30	1.38	0.63	1.84 (1)	1.21	0.96	0.92
Predicted (psi)	1.06	1.55	1.55	0.5	1.1	0.89	0.83	0.83
Duration of Positive Pressure Internal: Measured (ms)	17	17.2	15.5	15	17	12	15	14.6
Predicted (ms)	15.8	15.8	15.8	15.2	15.6	13.4	12.3	12.3
Predicted Value as % of Measured: Pi	113	119	112	79	60	73	86	90
t_o	93	92	102	101	92	112	82	84

Note 1. This value is suspect.

66. Considering the overall results, it is expected that the actual overpressures will be in the range +37% to -16% of the predicted values, and the duration of the positive pressure phase will be in the range of +22% to -2% of the predicted values.

67. The effect of a 5.5 in HE shell can be estimated within these limits, using the method described, by calculating the internal overpressure for various leakage areas of the new cabin and plotting the results against internal overpressure at the centre of thecabin if the cabin were not present.

68. The worst case for a 5.5 in HE shell is if it is detonated directly under the cabin, in which case the external overpressure measured at the location of the centre of the cabin would be 52 psi.

69. The relationship between internal overpressure cabin leakage area, and external overpressure that would be experienced at the centre of the cabin is shown in Fig 17.

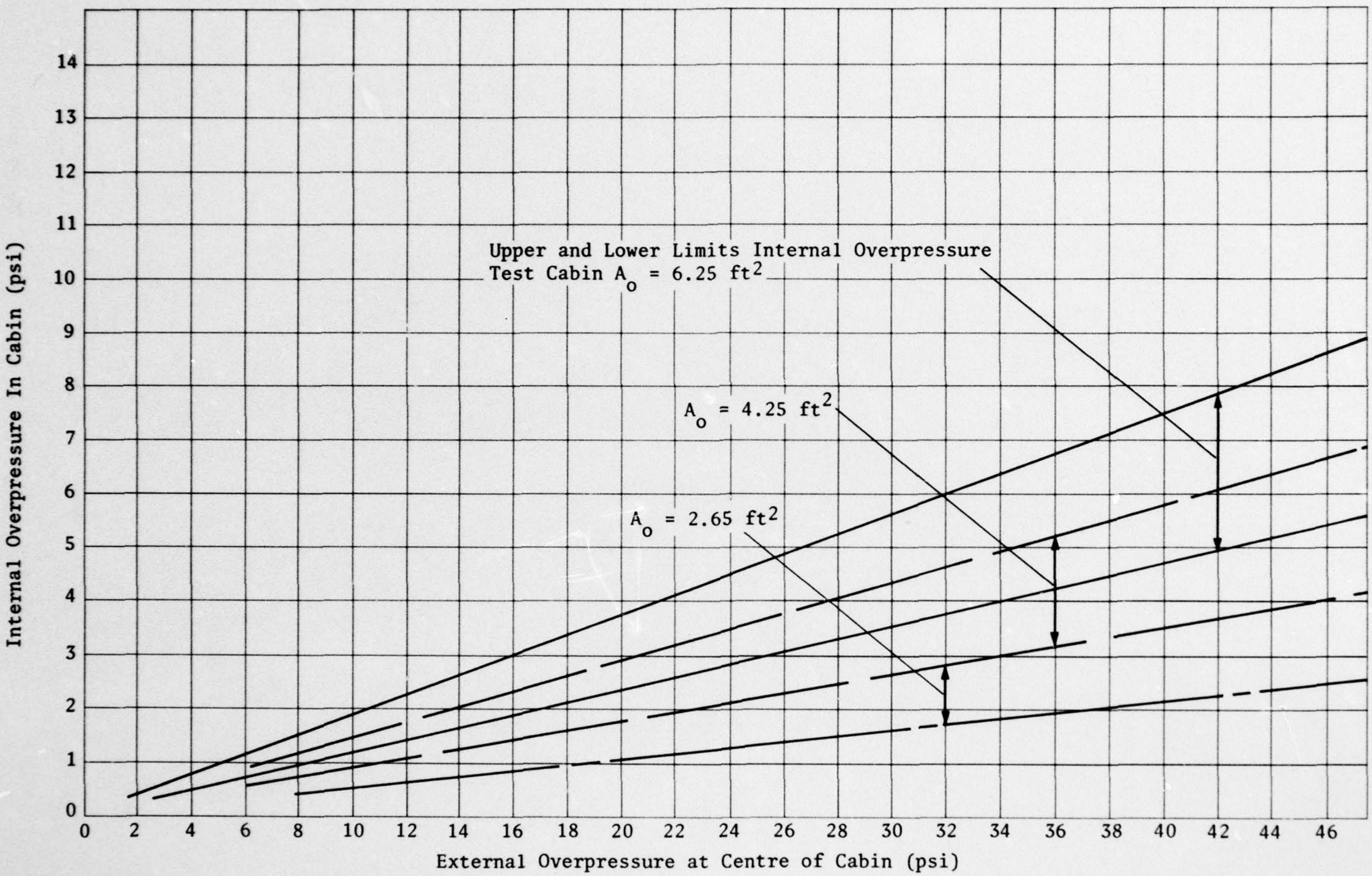


FIG 17 - APPROX RELATIONSHIP BETWEEN INTERNAL OVERPRESSURE CABIN LEAKAGE AREA AND EXTERNAL OVERPRESSURE

70. By extracting the internal overpressure limits at 52 psi external overpressure, a relationship can be obtained for internal overpressure versus leakage area for the worst cast 5.5 in HE shell. This relationship is shown in Fig 18.

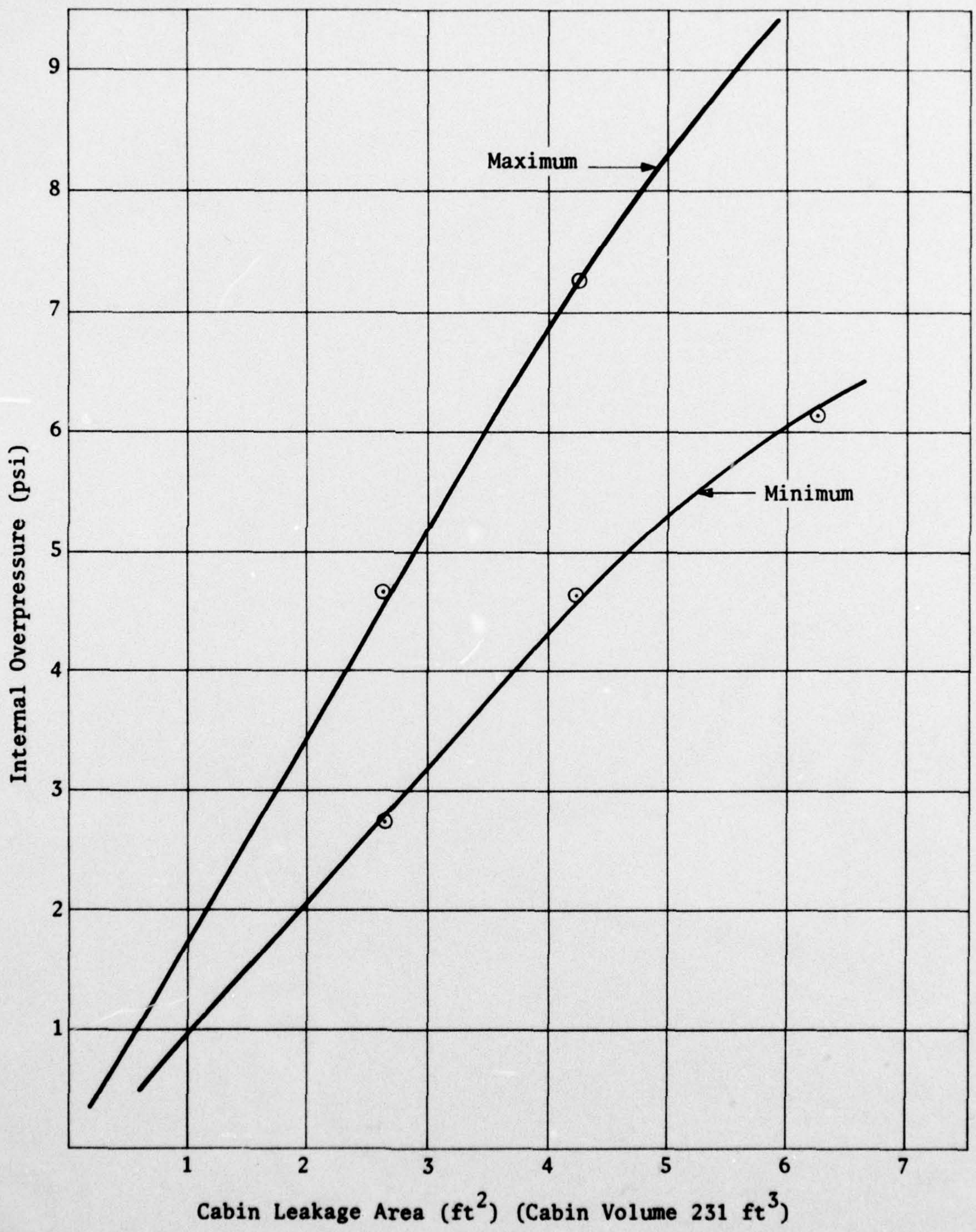


FIG 18 - APPROXIMATE RELATIONSHIP BETWEEN INTERNAL OVERPRESSURE AND CABIN LEAKAGE AREA FOR DETONATION OF 5.5 in HE SHELL AT MINIMUM DISTANCE

71. Fig 17 allows decisions to be made on the upper limit of leakage area that could be considered for a particular limit of internal overpressure.

72. Clearly, the prediction of internal overpressures for conditions differing from the trials conditions, by the method described is not entirely satisfactory.

73. Due to the model being structured to predict the trials results, its accuracy for other conditions cannot be guaranteed. However, it provides the only means available, apart from lengthy trials that would cause extensive damage to the tractor, of obtaining an estimate of the conditions within the cabin if a 5.5 in HE shell were detonated close to the tractor.

74. These estimates provide a design basis for the cabin closer to the required solution than could have been possible without the criteria provided by the model.

Internal Overpressure Limit

75. The criteria presented in TM 5-1300 for primary blast effects in man, applicable to fast rising air blasts of short duration (ie, 3 - 5 ms) is:

a. Eardrum Rupture		
(1) Threshold.	Maximal effective pressure (psi)	5
(2) 50 per cent	" " "	15
b. Lung Damage		
(1) Threshold	" " "	30 - 40
(2) Severe	" " "	80 and above
c. Lethality		
(1) Threshold	" " "	100 - 200
(2) 50 per cent	" " "	130 - 180
(3) Near 100 per cent	" "	200 - 250

76. For long duration blast loads TM 5-1300 states that the threshold levels may be approximately one-third that for short duration, however, there is no statement of the magnitude of long durations.

77. Advice was sought from the National Acoustics Laboratory (NAL) regarding criteria for durations longer than 5 ms. NAL advised that there is some evidence that the effects of overpressure on the eardrum is independent of duration, and that rupture of the eardrum could occur in susceptible ear at an overpressure of 2 psi.

78. Applying a limit of 2 psi to Fig 17, the maximum allowable leakage area for the cabin is 1.15 ft^2.

CONCLUSIONS

79. A protective cabin manufactured from AS1204 grade 350 steel plate of 40 mm thickness will provide adequate protection against fragments from a detonating 5.5 in HE shell.

80. The leakage areas of the cabin are to be such that an internal overpressure of 2 psi is not exceeded. If a cabin volume of 231 ft^3 can be obtained, this implies a maximum allowable leakage area of 1.15 ft^2.

Action Resulting from Trials Results

81. A wooden mock up cabin is being constructed on the tractor to determine construction detail necessary to achieve the protection requirements. Upon completion the mock up will be used as the pattern for the construction of the steel cabin.

82. Trials will be conducted to prove the overpressure protection afforded by the steel cabin.

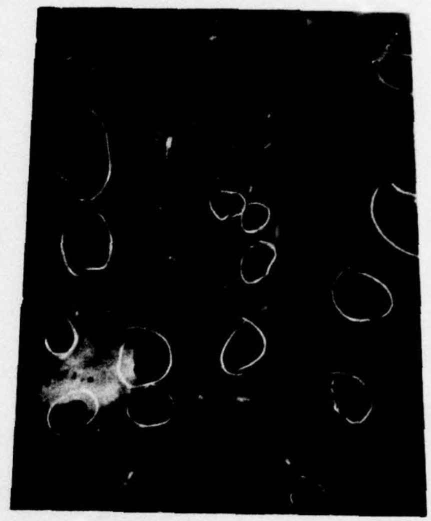
83. It is not proposed at this stage to detonate 5.5 in HE shell adjacent to the tractor and cabin to prove the fragment protection. It is considered that the results of the tests reported can be used with sufficient confidence to predict the performance of the enclosure in this respect. Furthermore because the infinite number of possible combinations of shell location and attitude makes it impossible to predict the worst case with any confidence, many shells would need to be detonated to provide convincing results. Each test would require some repair of the tractor and replacement of some of the steel plates to ensure that any penetration was not the result of reduced protection due to previous strikes. If after completion of the enclosure it is assessed that there are areas of doubtful integrity then it may be necessary to carry out some limited trial.

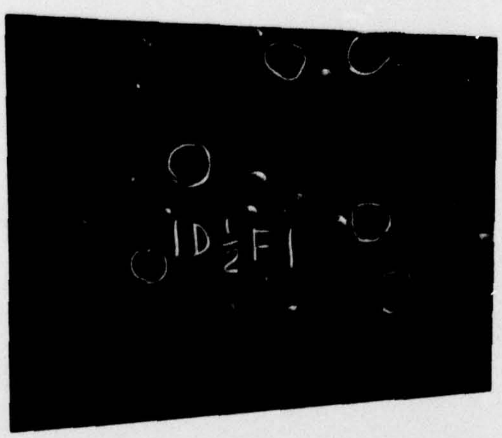
ANNEX A

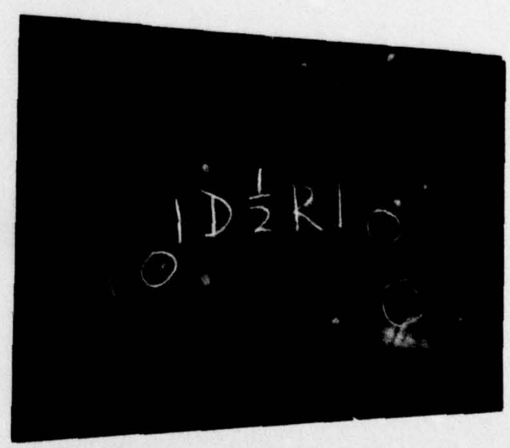
The figures included in this annex are reproductions of polaroid, photographs of the test plates used in Trial 1, Serial 1, Trial 8, Serial 1 and 2; and Trial 16, Serial 1 and 2. Also included is a photograph of each site layout with the exception of Trial 1, Serial 1, and Trial 8, Serial 2. Captions have been omitted as the plate markings etc visible in the photographs are self explanatory.

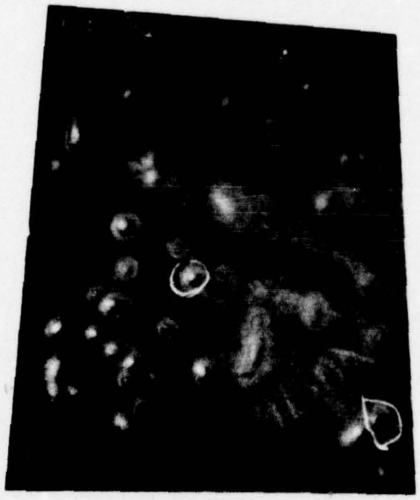

1B½F0¼

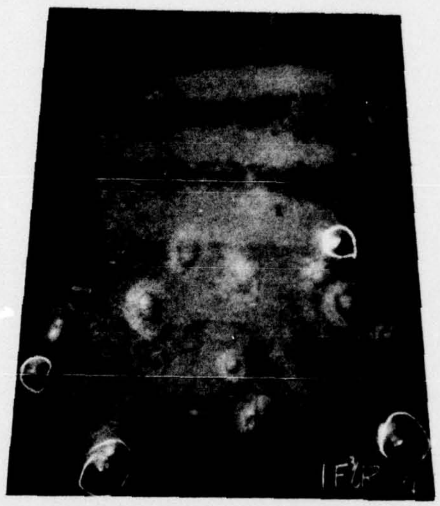

1B¾R1¼

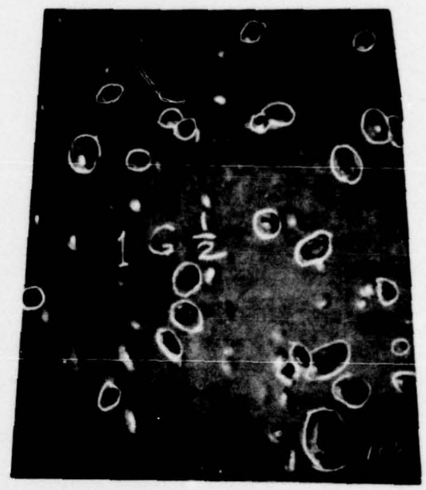



1D½F1


1D½R1

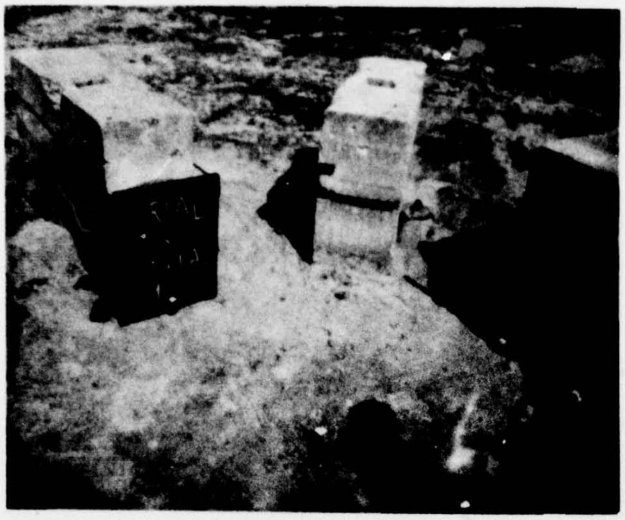


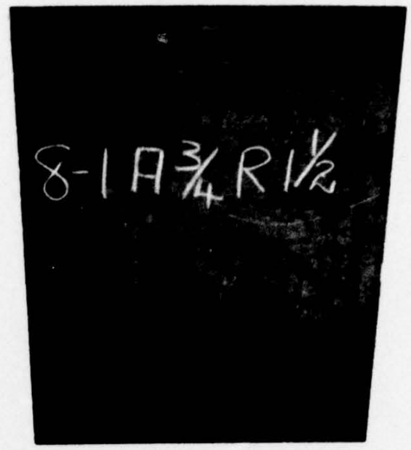


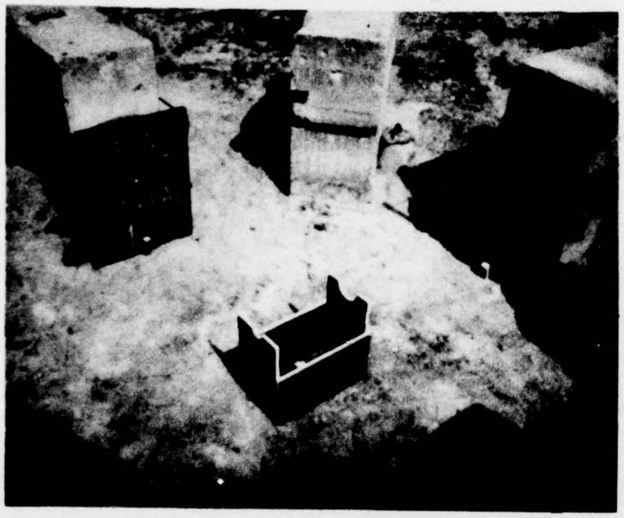

1 G $\frac{1}{2}$


1H $\frac{1}{2}$ F 1

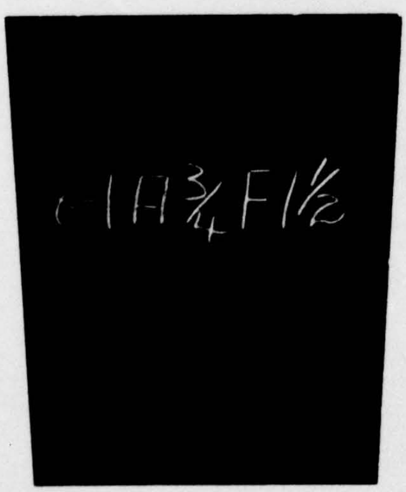

1 H $\frac{1}{2}$ R 1




8-1A¾R1½




8-1C¾F1½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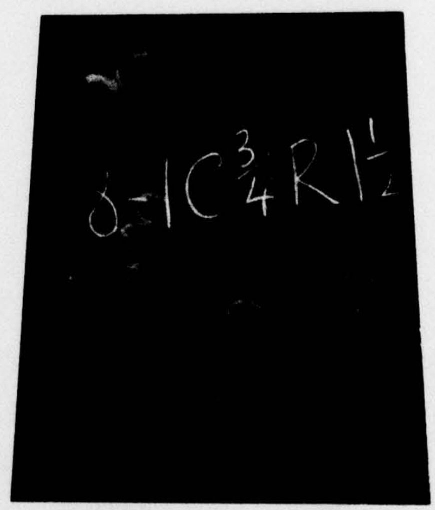
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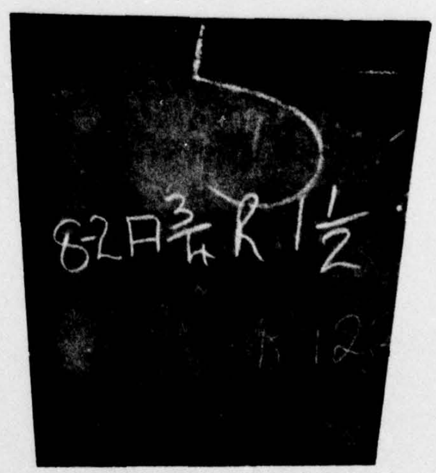
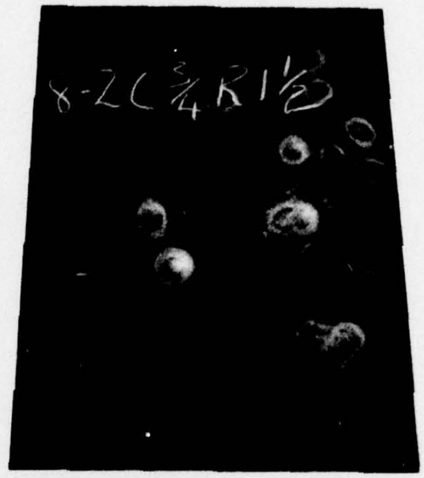


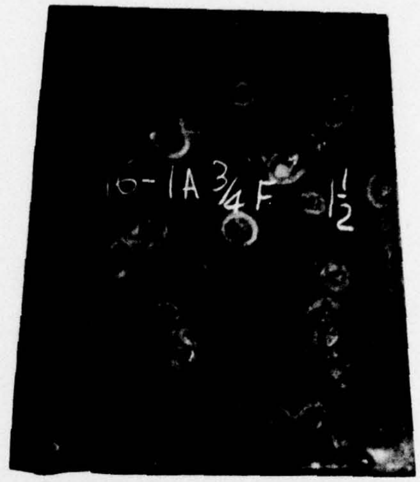

C 3/4 F 1/2


8-2C 3/4 R 1/2


E 3/4 F 1/2


8-2E 3/4 R 1/2

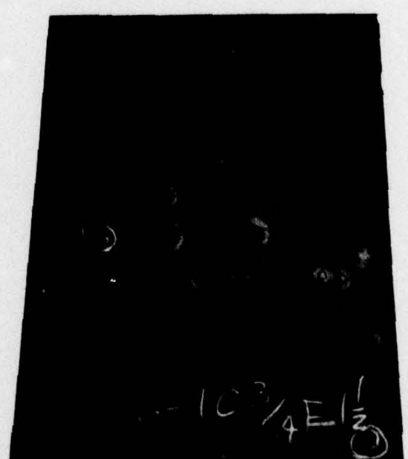

8-2G 3/4 F 1/2


16-1A 3/4 F 1 1/2

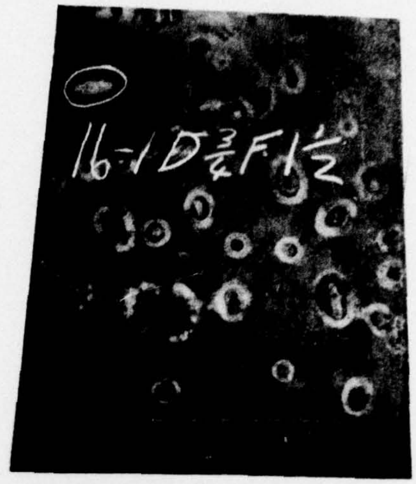

16-1A 3/4 R 1 1/2


16-1B 3/4 F 1 1/2

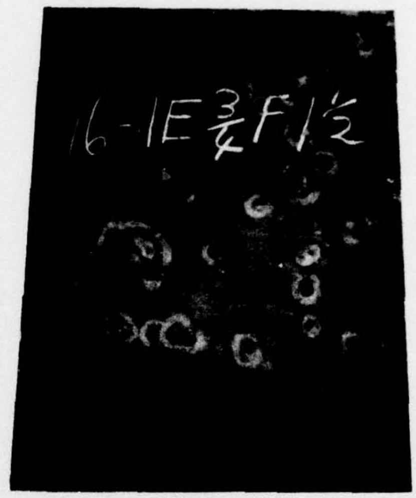

16-1B 3/4 R 1 1/2


-1C 3/4 E 1 1/2


16-1C3/4R 1 1/2


16-1D 3/4 F 1 1/2


16-1D 3/4 R 1 1/2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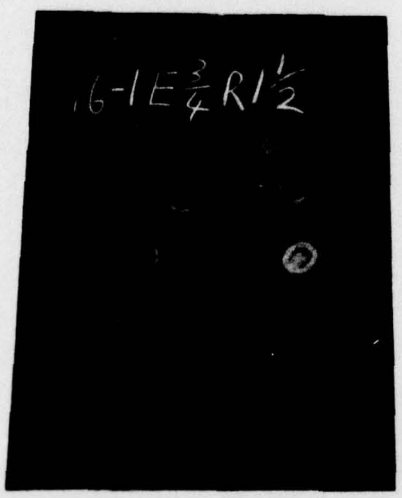
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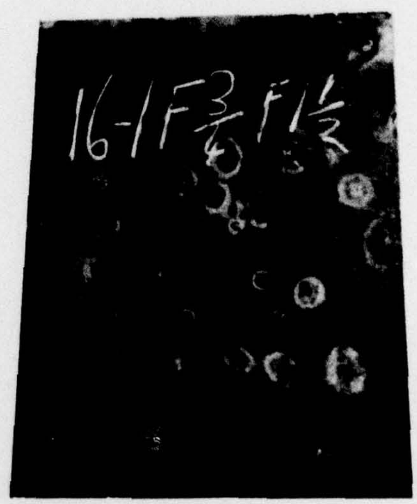
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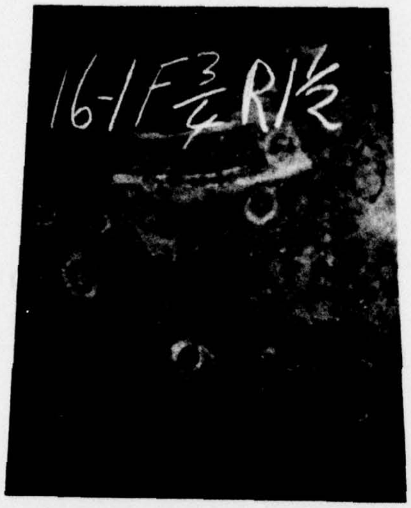
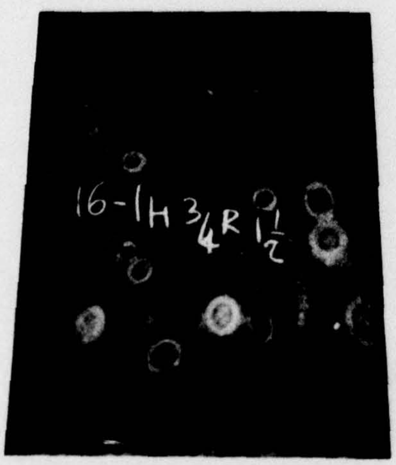
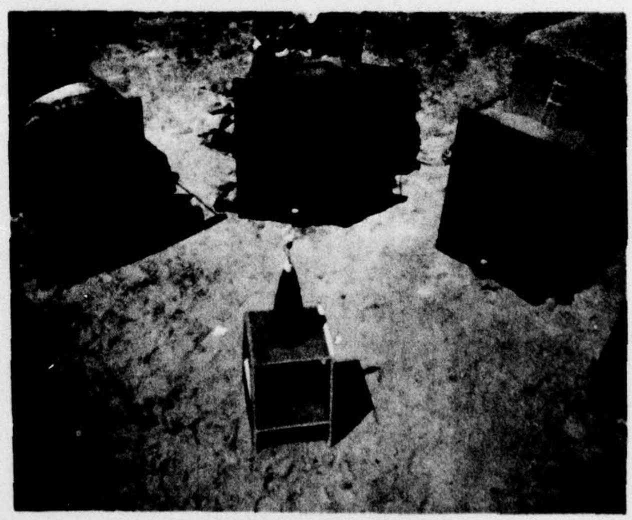

16-1F 3/4 R 1/2


16-1G 3/4 F 1 1/2


16-1G 3/4 R 1


16-1H 3/4 F 1 1/2


16-1H 3/4 R 1 1/2




16-2A ½ F 1½


16-2A ½ M 1½

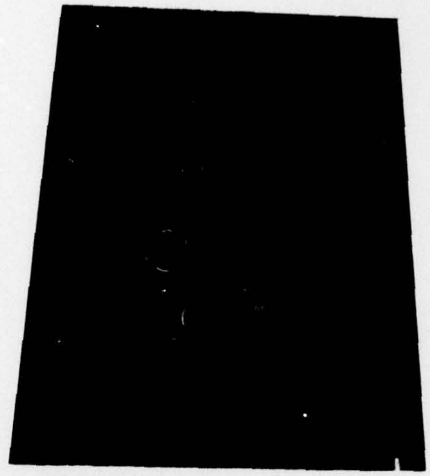

16-2A ½ R 1½

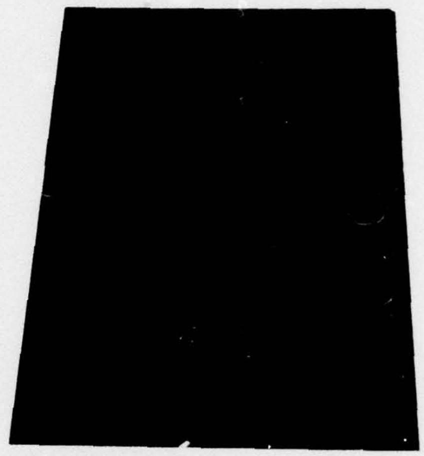

16-2B ½ F 1½

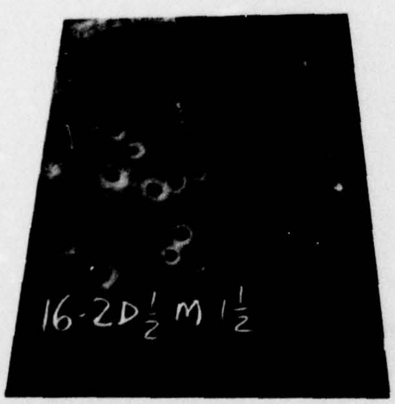

16-2B ½ M 1½


16-2B ½ R 1½


16-2C ½ F 1½



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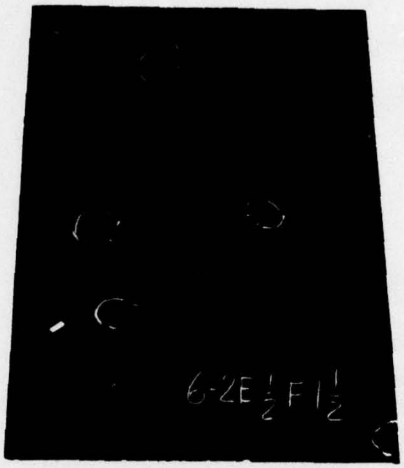
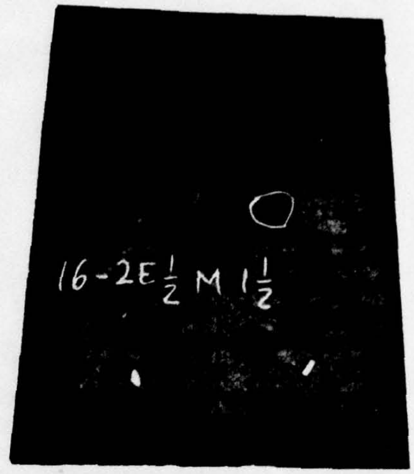
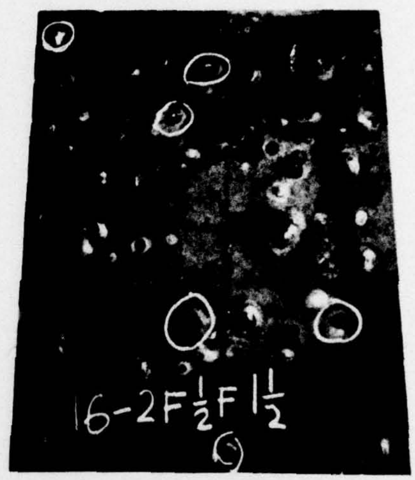
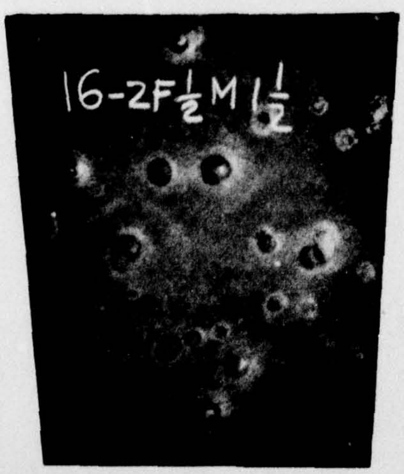
16-2D ½ R 1½

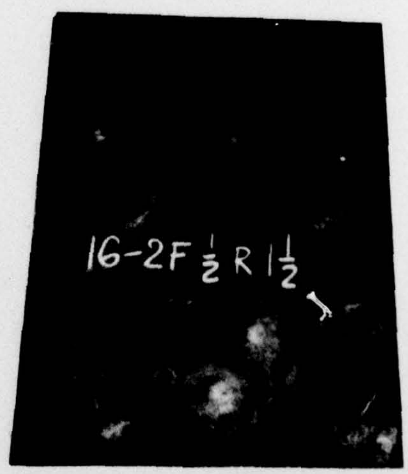

6-2E 1/2 F 1 1/2

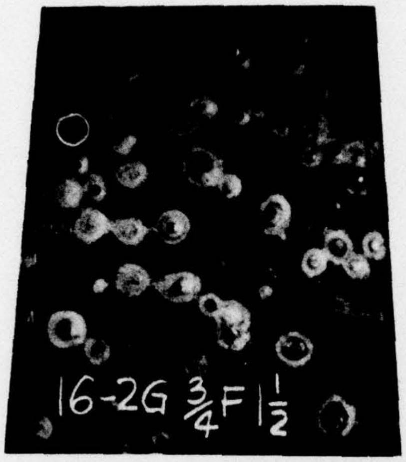

16-2E 1/2 M 1 1/2


16-2E 1/2 R 1 1/2


16-2F 1/2 F 1 1/2


16-2F 1/2 M 1 1/2


16-2F 1/2 R 1 1/2


16-2G 3/4 F 1 1/2


16-2G R 1 1/2


16-2H 3/4 F 1 1/2


16-2H 3/4 R 1 1/2

ANNEX B

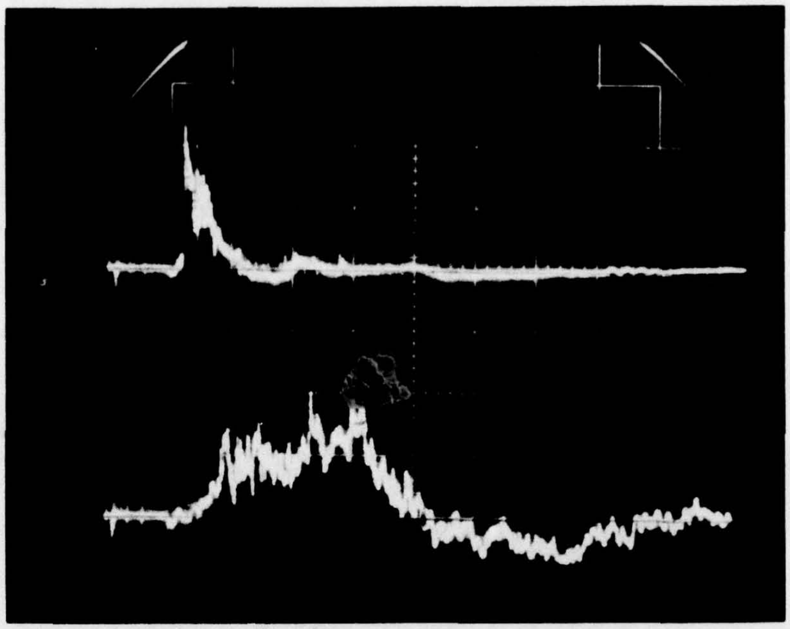
Fig 1 to 20 of this annex are reproductions of polaroid photographs of oscilloscope traces of the pressure-time history of Blast No 1 to 20 as recorded on a storage cathode ray oscilloscope. For Blast No 1 to 16 (Fig 1 to 16) inclusive, Channel 1 (CH1) is the record of external overpressure and Channel 2 (CH2) of internal overpressure. Blast No 17 to 20 (Fig 17 to 20) are all records of external overpressure.

CH1

10 psi/cm

1 psi/cm

CH2



5 ms/cm

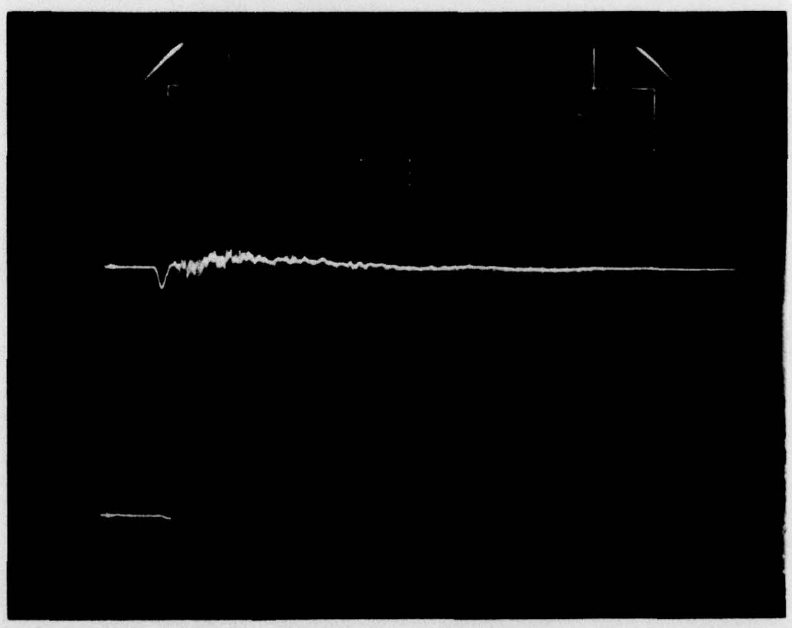
FIG 1 - BLAST NO 1 15 SEP 76

CH1

10 psi/cm

1 psi/cm

CH2



5 ms/cm

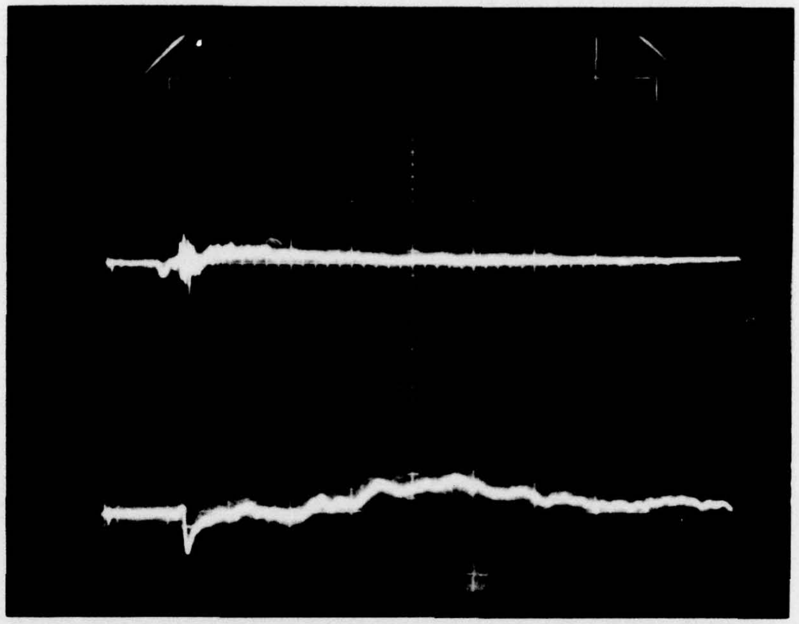
FIG 2 - BLAST NO 2 15 SEP 76

CH 1

10 psi/cm

1 psi/cm

CH 2



5 ms/cm

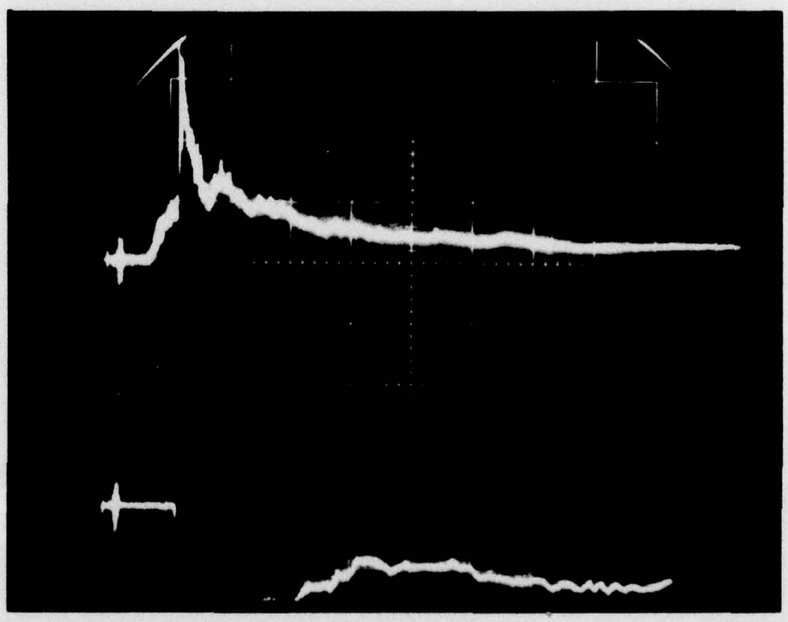
FIG 3 - BLAST NO 3 15 SEP 76

CH 1

10 psi/cm

1 psi/cm

CH2



5 ms/cm

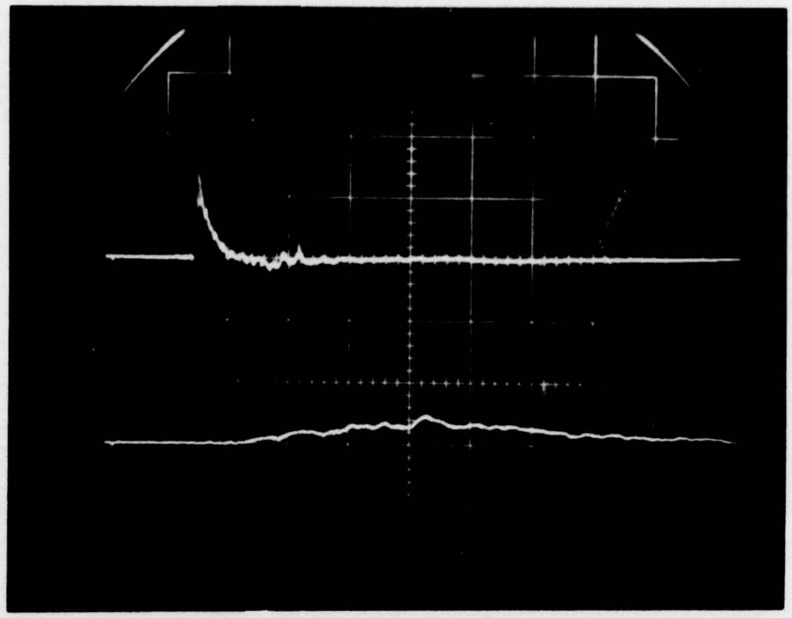
FIG 4 - BLAST NO 4 15 SEP 76

CH1

10 psi/cm

1 psi/cm

CH 2



5 ms/cm

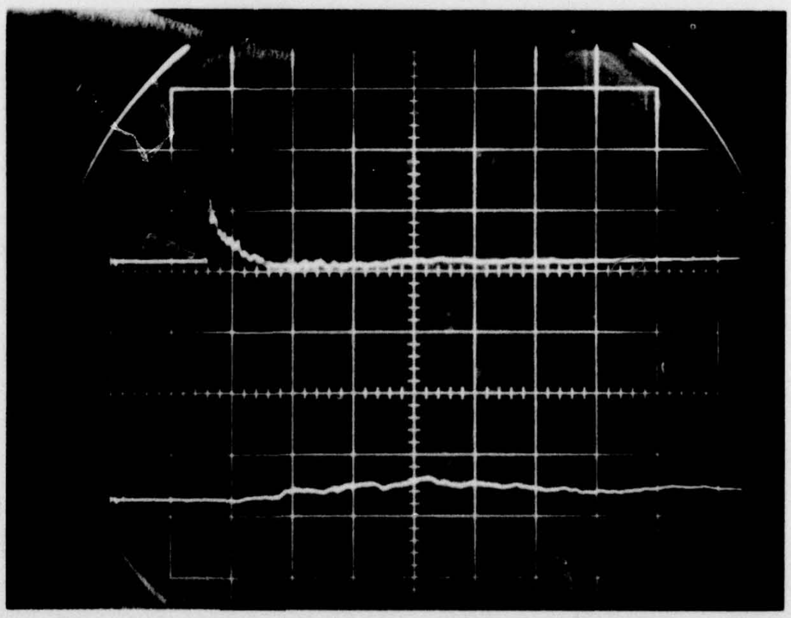
FIG 5 - BLAST NO 5 15 SEP 76

CH1

10 psi/cm

1 psi/cm

CH2

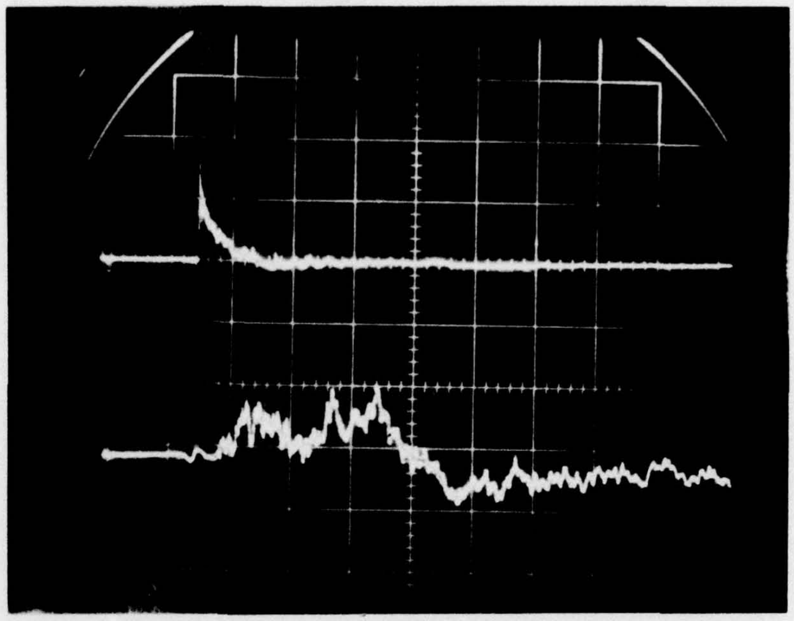


5 ms/cm

FIG 6 - BLAST NO 6 15 SEP 76

10 psi/cm CH1

1 psi/cm CH2

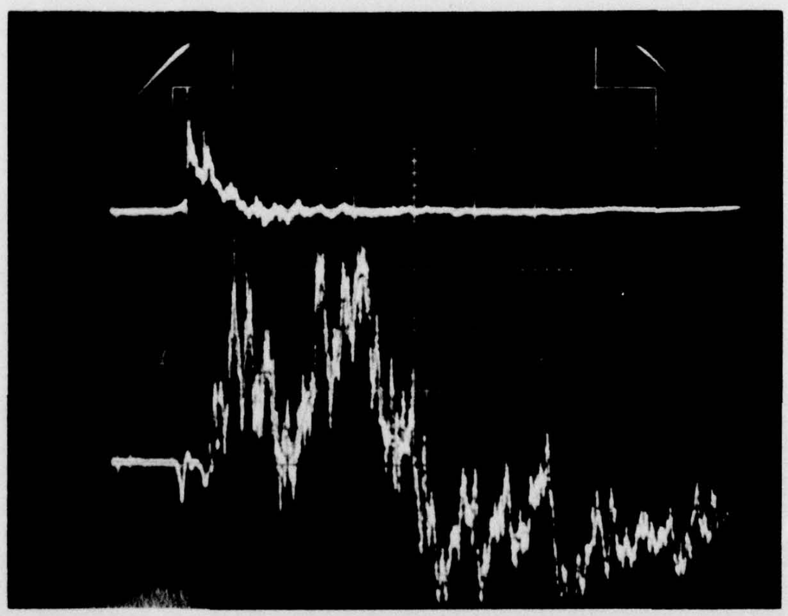


5 ms/cm

FIG 7 - BLAST NO 7 16 SEP 76

10 psi/cm CH1

0.4 psi/cm CH2



5 ms/cm

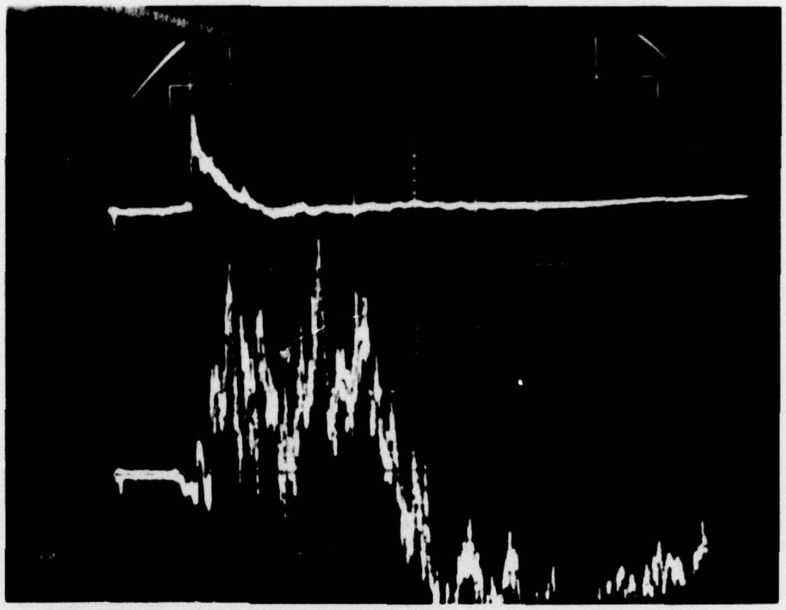
FIG 8 - BLAST NO 8 16 SEP 76

CH1

10 psi/cm

0.4 psi/cm

CH2

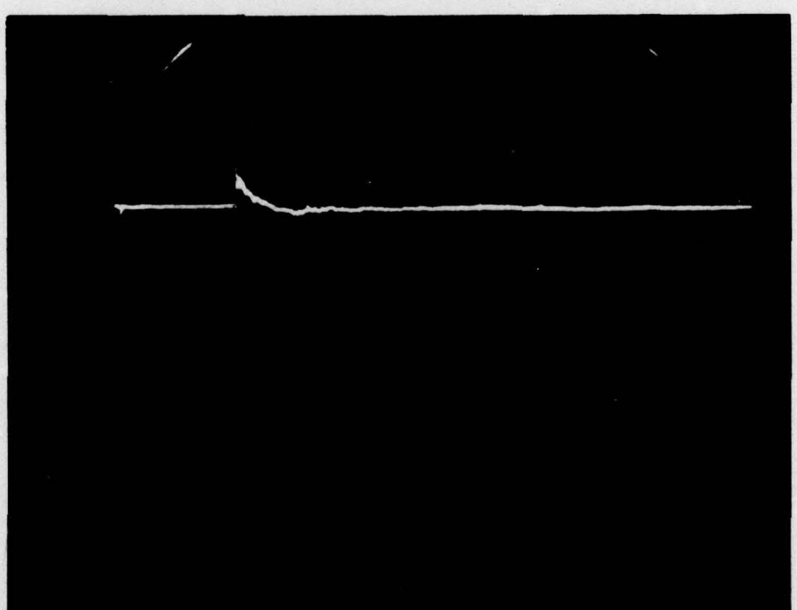


5 ms/cm

FIG 9 - BLAST NO 9 16 SEP 76

CH1

10 psi/cm



5 ms/cm

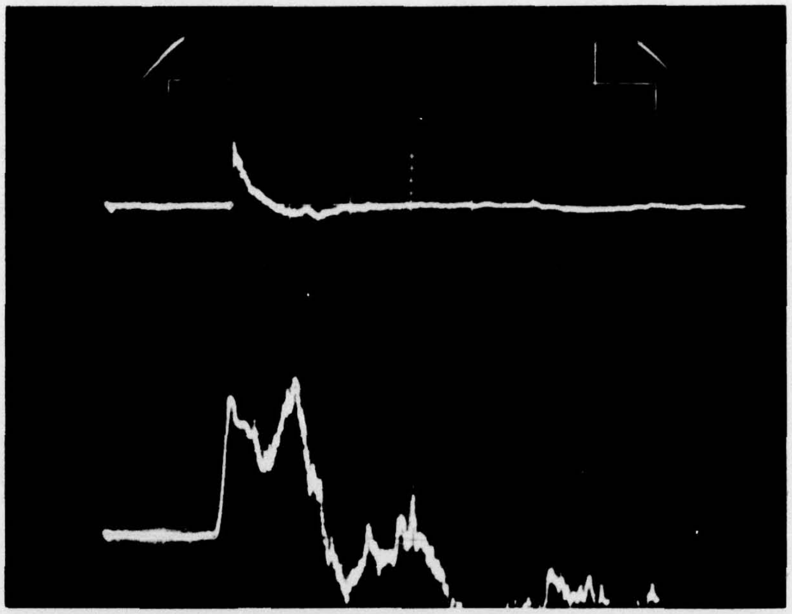
FIG 10 - BLAST NO 10 16 SEP 76

CH1

5 psi/cm

0.4 psi/cm

CH2



5 ms/cm

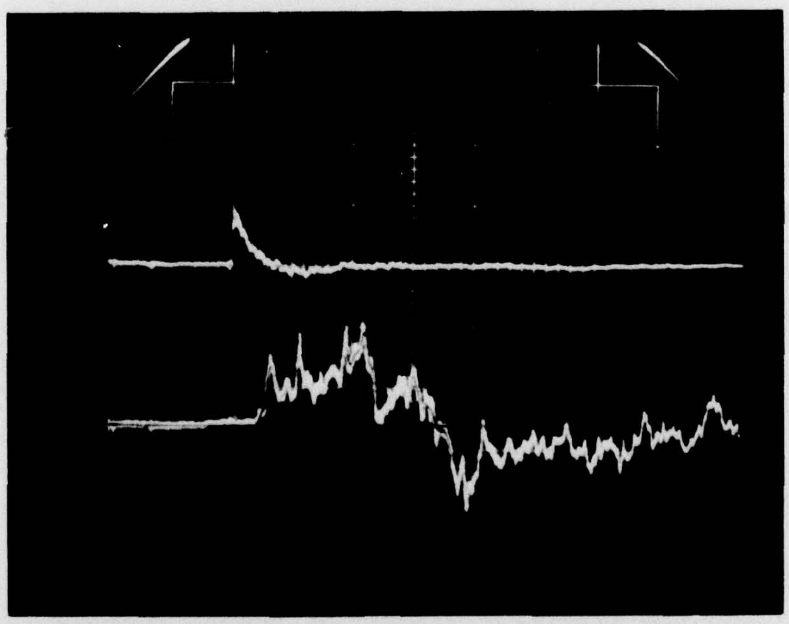
FIG 11 - BLAST NO 11 16 SEP 76

CH1

5 psi/cm

0.4 psi/cm

CH2



5 ms/cm

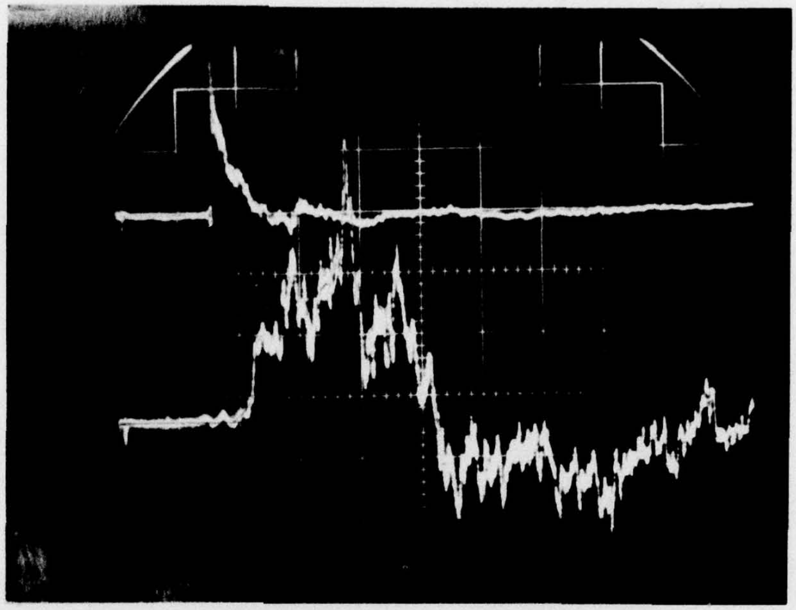
FIG 12 - BLAST NO 12 16 SEP 76

CH1

5 psi/cm

0.4 psi/cm

CH2



5 ms/cm

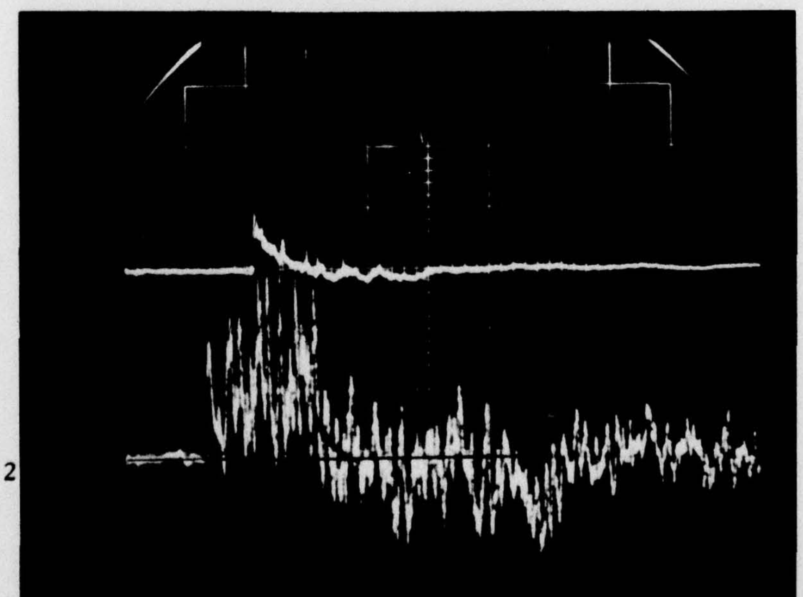
FIG 13 - BLAST NO 13 16 SEP 76

CH1

5 psi/cm

0.4 psi/cm

CH 2



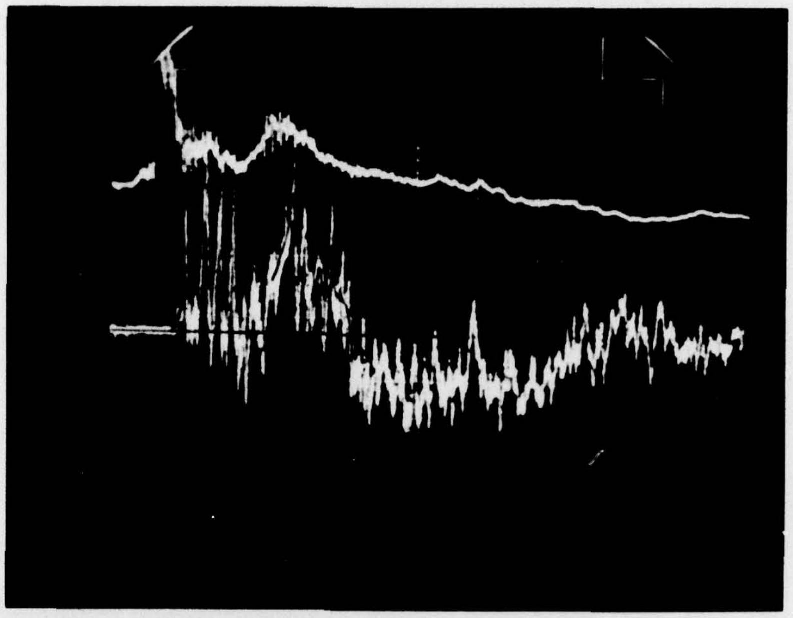
Disc 4.5 m
From Charge

5 ms/cm

FIG 14 - BLAST NO 14 16 SEP 76

CH1
5 psi/cm

0.4 psi/cm
CH2

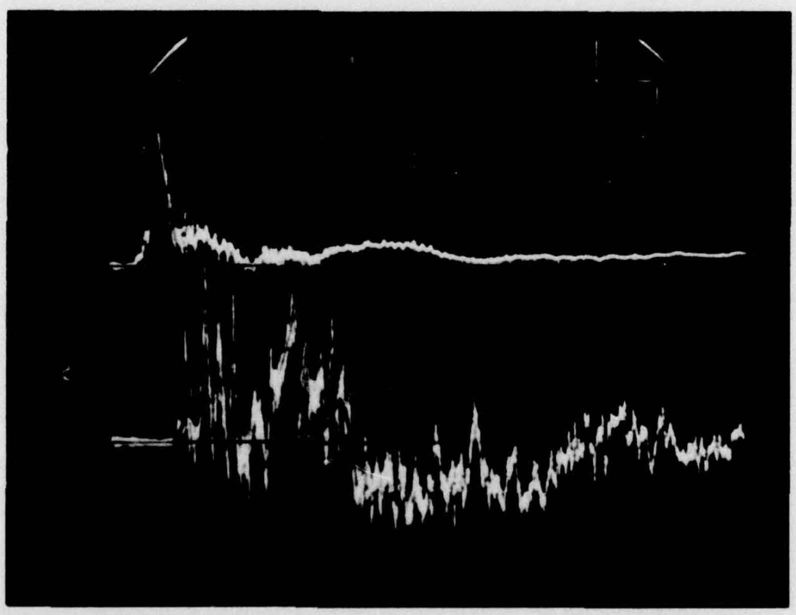


5 ms/cm

FIG 15 - BLAST NO 15 16 SEP 76

CH1
5 psi/cm

0.4 psi/cm
CH2



5 ms/cm

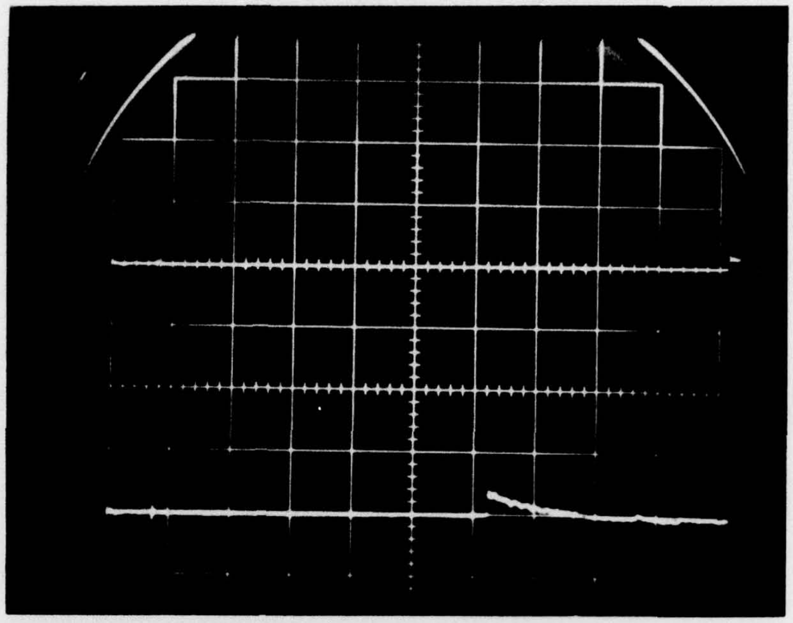
FIG 16 - BLAST NO 16 16 SEP 76

CH1

10 psi/cm

10 psi/cm

CH2



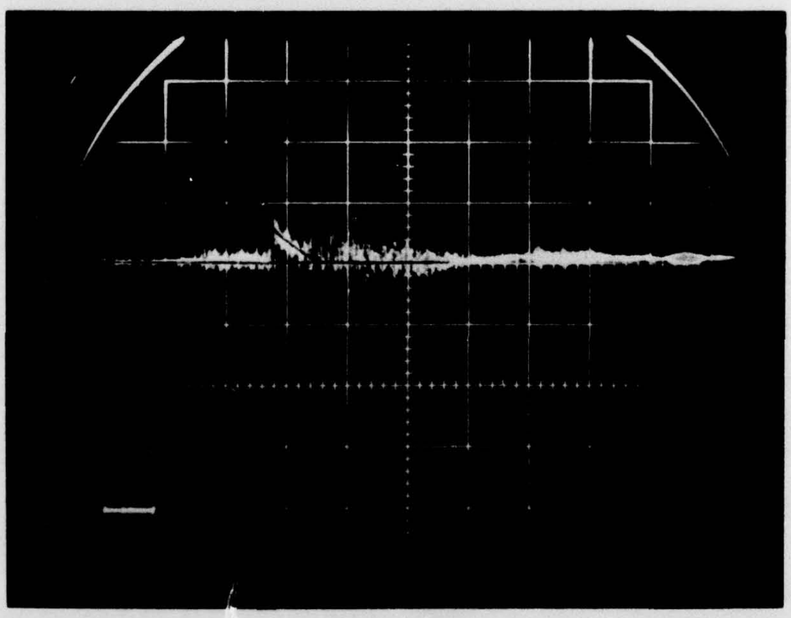
2 ms/cm

FIG 17 - BLAST NO 17 17 SEP 76

CH1

10 psi/cm

CH2



5 ms/cm

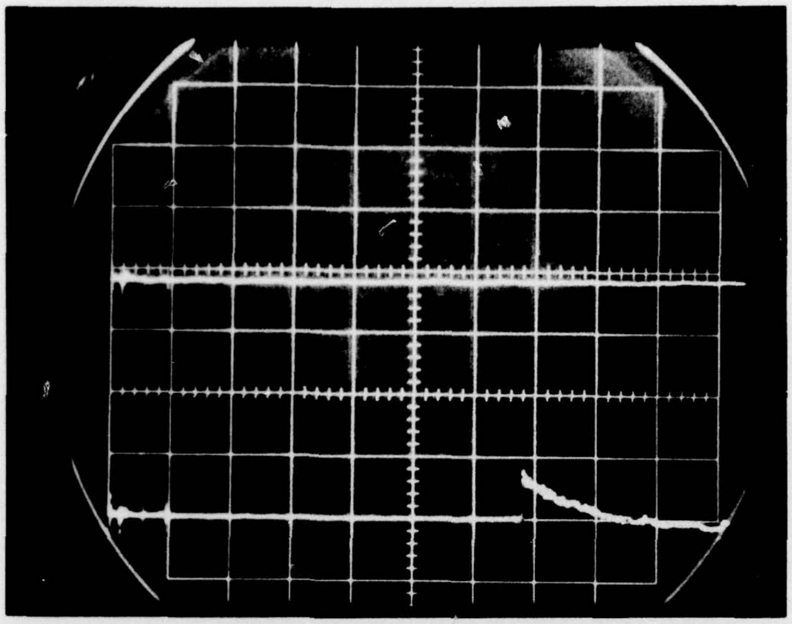
FIG 18 - BLAST NO 18 17 SEP 76

CH1

5 psi/cm

5 psi/cm

CH2



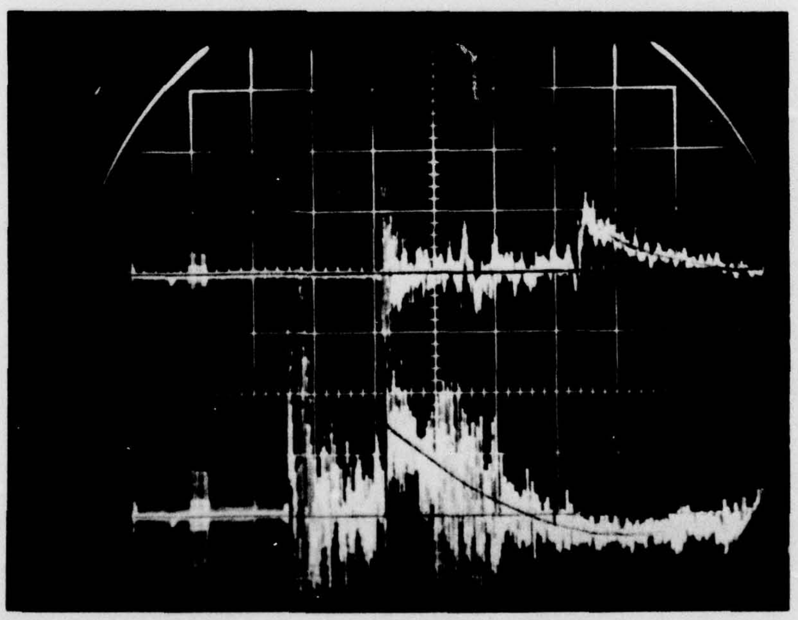
2 ms/cm

FIG 19 - BLAST NO 19 17 SEP 76

CH1

5 psi/cm

CH2



2 ms/cm

FIG 20 - BLAST NO 20 17 SEP 76