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HAZARD CLASSIFICATION TEST OF COMPLETE ROUND 155-mm PALLETS

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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To determine the Quantity-Distance restrictions associated with the storage of complete round pallets of 155-mm ammunition requires that the potential contribution of the propellant to blast overpressures be known or estimated if the projectiles detonate en masse. This report presents the results of tests that were conducted to compare pressure profiles generated when the HE projectiles on a complete round pallet detonate en masse. The pallets were designed to transport and store 16 155-mm HE projectiles, propelling charges, and fuzes. One, four, and eight pallet arrays were tested using live and inert propelling charges.

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TABLE OF CONTENTS

I. INTRODUCTION

The Ballistic Research Laboratory (BRL) in support of DEA-A-74-TN-1182 with the Dutch Government designed a series of tests to evaluate the storage hazards associated with the use of a complete round pallet designed to transport and store 16 rounds (HE projectiles, propelling charges, primers and fuzes) of 155-mm ammunition. This effort was funded by the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME). Tests were conducted by the TERA Group at the New Mexico Institute of Mining and Technology.

A. Objectives

The objectives of this effort were to (1) determine the contribution of the propelling charges to blast overpressures when the HE projectiles on the complete round pallet detonate en masse, and (2) expand the data base that can be used to resolve similar problems analytically. To determine the contribution of the propelling charges to blast overpressures experimentally, field tests were conducted wherein selected HE projectiles on one, four, and eight pallet arrays (with and without propelling charges) were statically detonated. Air blast parameters measured at selected distances from the pallet(s) were then used to estimate the TNT weight equivalency of each test.

B. Background

The time required to issue ammunition to artillery units at forward area supply points can be critical in the event of a combat emergency. One means of reducing the issue time is to incorporate into the logistic system complete round palletization of separate-loading artillery ammunition (projectiles, propelling charges, primers and fuzes).

Unfortunately, storing the HE projectiles (Hazard Division 1.1) and the propelling charges (Hazard Division 1.2) in the same magazine could result in an increase in the number of magazines required to store a given number of rounds. This is a consequence of mixed Hazard Division storage regulations[1] which require that the explosive filler weight and the propellant weight be combined and the total weight be considered as Hazard Division 1.1 in determining Quantity-Distance restrictions at a storage site.

The Quantity-Distance restrictions define the minimum permissible distance between a potential explosion site containing a given quantity of explosives and inhabited buildings, public traffic routes, etc.

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[1] *Manual on NATO Safety Principles for the Storage of Ammunition and Explosives, 1977.*

When the total explosive weight at a storage site is known and all the explosives detonate en masse, then the air blast parameters (peak overpressure, impulse and duration of the shock wave) at known distances from the site can be calculated using standard techniques[2,3] that have been in use for many years. Conversely, measured air blast parameters at selected distances from a detonation can be used to estimate the total explosive weight.

II. SCOPE OF STUDY AND TEST PROCEDURES

A total of eight pallet tests and five calibration tests were conducted in support of this effort. The overpressure versus time history of the shock wave was recorded at 12 distances for each test.

A. Description of Pallets

In practice the 16 complete rounds will be secured to a special pallet, see Figure 1. For test purposes the pallets were omitted in the one and four pallet simulation tests. However, pallets were used in the eight pallet tests where the pallets were stacked two high, see Figure 2. In the one and four pallet tests, see Figure 3 and 4, the projectiles and propelling charge cans were placed on a large steel plate and arranged so that geometric relationship between them was the same as if they were palletized.

All tests were conducted using M107 HE (6.985 kg Comp B) projectiles and propelling charge cans containing either four M4A1 (6.078 kg M1) propelling charges or an equal volume of inert propellant. Fuzes and primers were not required to satisfy the test objectives and were omitted.

Selected projectiles on each pallet were primed by filling their fuze wells with composition C-4 and inserting the knotted end of a length of Primacord. All Primacord leads were of equal length and were tied together at a junction point as shown in Figures 3 and 4. The junction point was connected, by a long length of Primacord, to a remotely located mechanical-electrical safety block.

In the first single pallet test only one projectile was statically detonated. In the remaining tests a multiple point initiation scheme was employed by detonating one projectile in each vertical and horizontal row. The multiple point scheme was used to minimize directional effects.

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[2] *C.N. Kingery, "Air Blast Parameters Versus Distance for Hemispherical TNT Surface Bursts," Ballistic Research Laboratory Report No. 1344, September 1966 (AD811673).*

[3] *H.J. Goodman, "Compiled Free-Air Blast Data on Bare Spherical Pentolite," Ballistic Research Laboratory Report No. 1092, February 1960 (AD235278).*

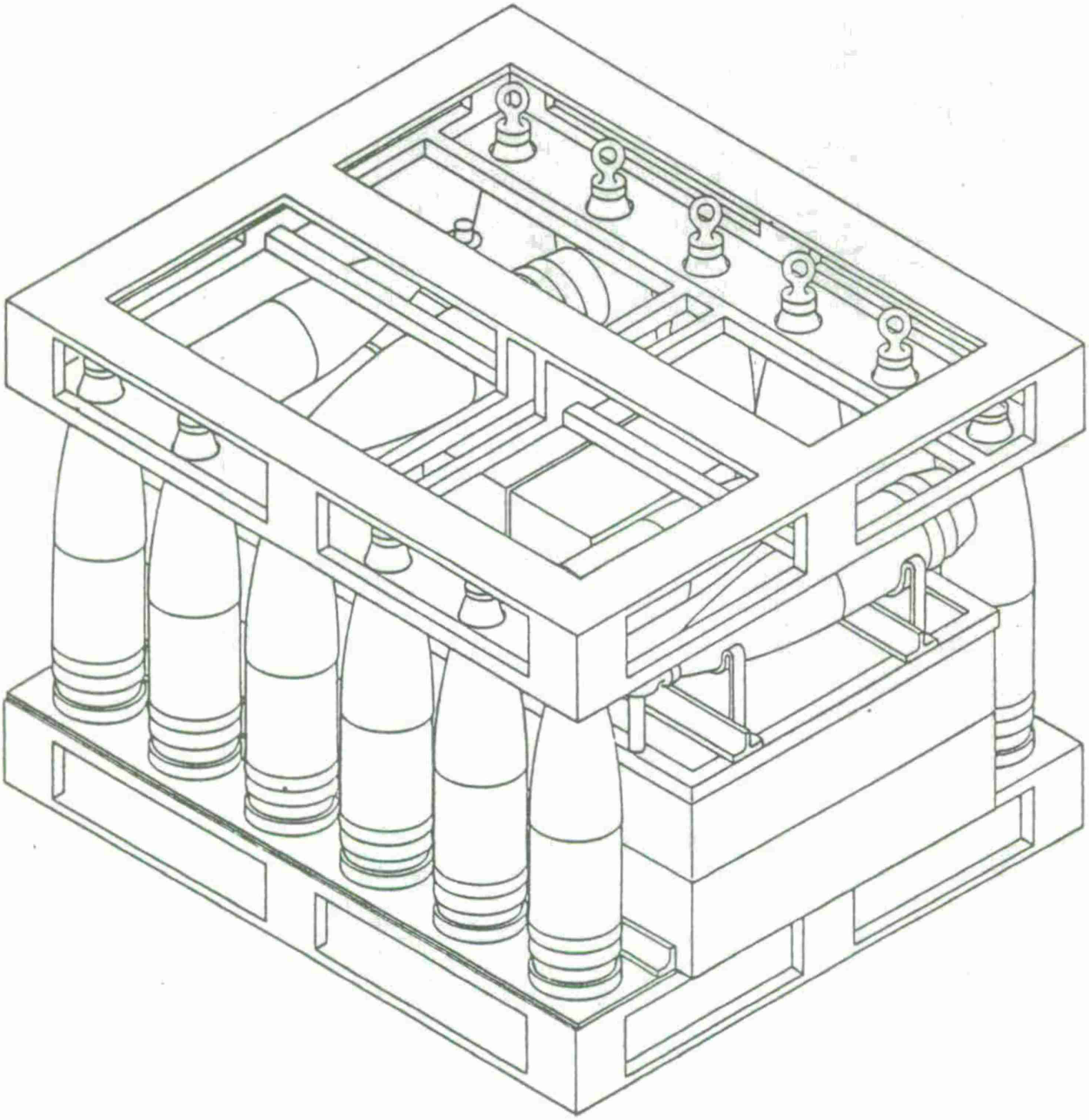
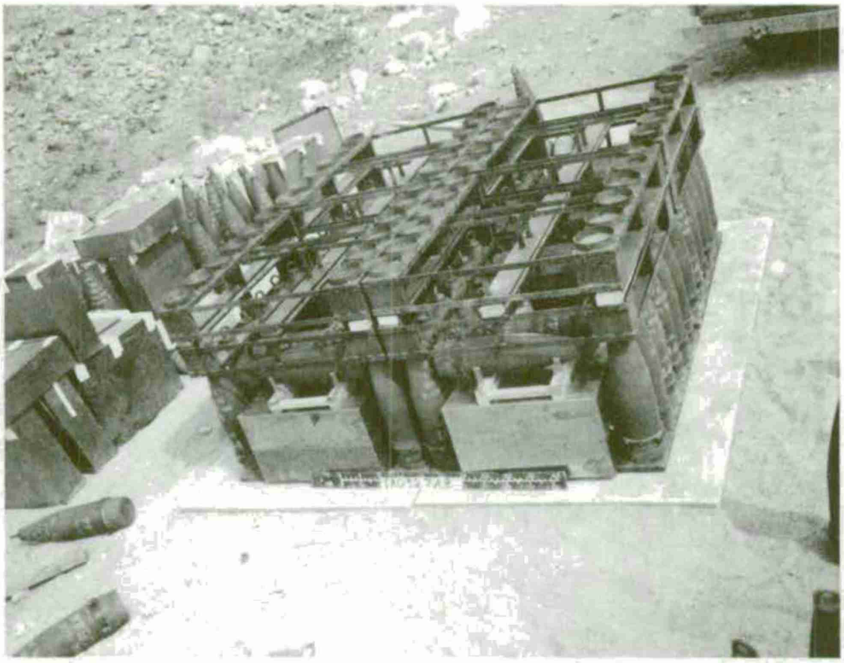


Figure 1. Complete Round Pallet for 155-mm Ammunition



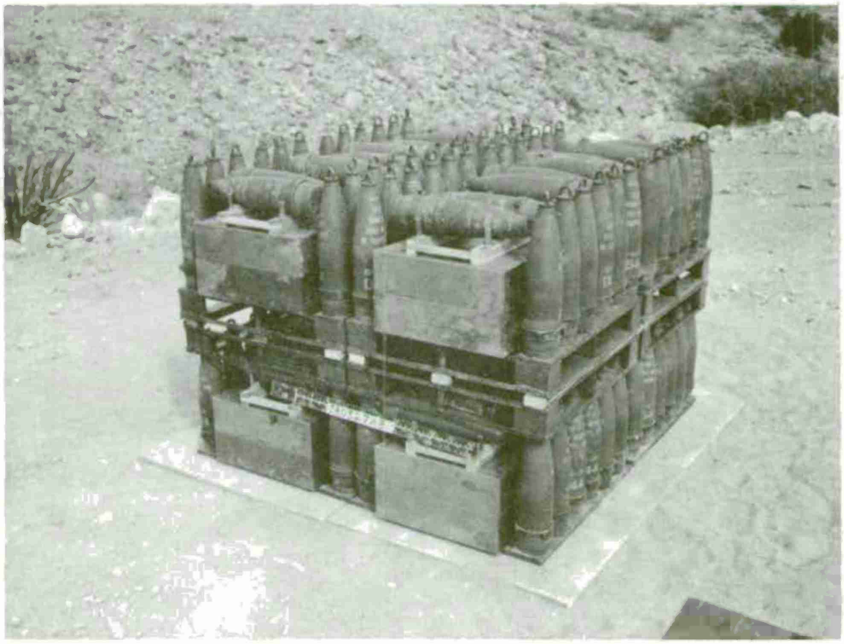


Figure 2. Eight Pallet Array

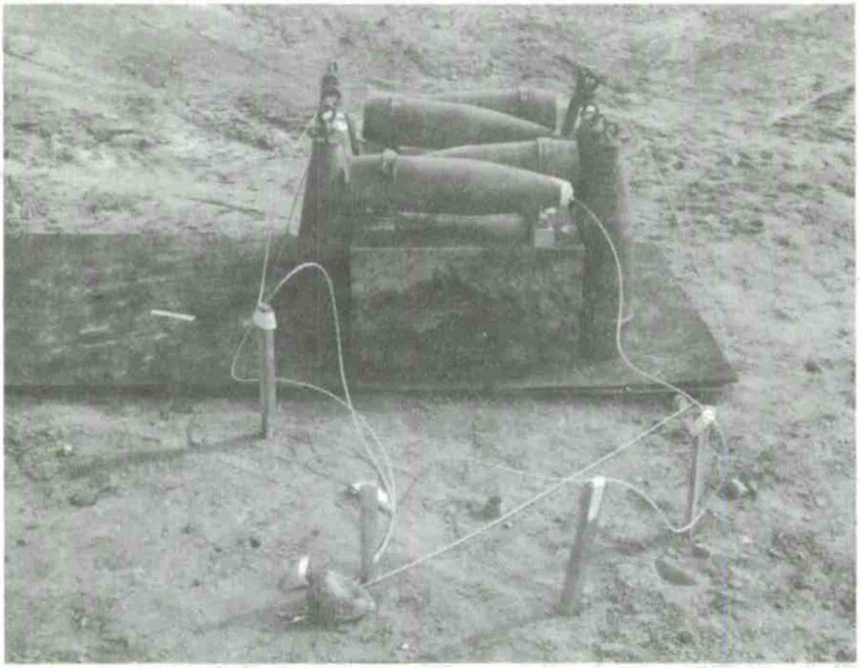


Figure 3. Single Pallet Array

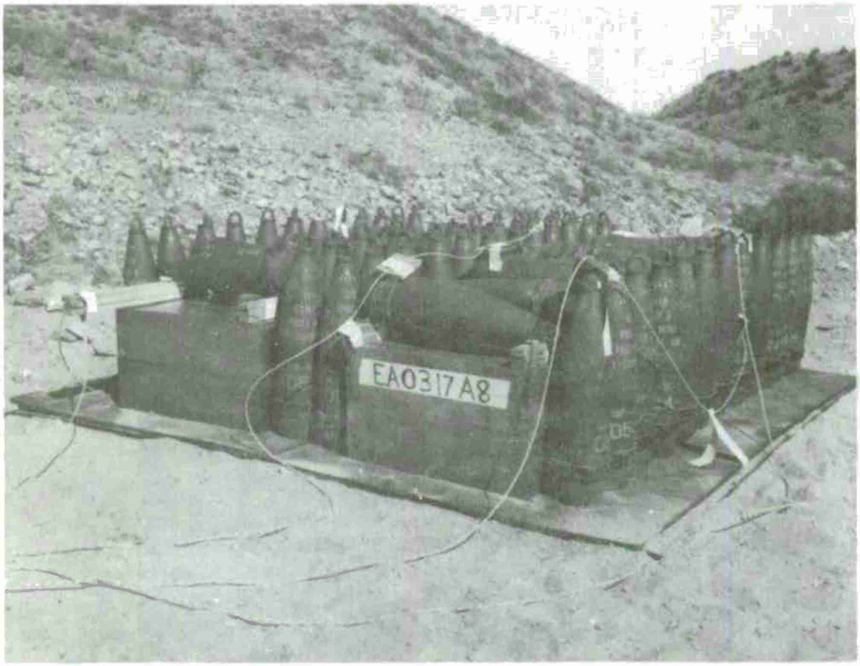


Figure 4. Four Pallet Array

B. Test Set-Up

Two test sites were used. At each site the air blast parameters were recorded at 12 stations as shown in Figure 5. At test location "A" the distance from ground zero to the stations was kept relatively constant while the pallet parameters were varied. At location "B" the distance from ground zero to the stations was varied from test to test in an attempt to monitor similar pressures as a function of distance and the total explosive and propellant weight for each array.

C. Instrumentation

The KSP Industries Model PT-309-2 pressure transducer was used in all tests. It contains a piezo-electric sensing element which has a nominal charge sensitivity of 610 pico-coulombs per psi, and a natural frequency greater than 120 KHz.

The signals were amplified and recorded on a Consolidated Electrodynamics Corporation Model 3300 magnetic tape recorder. The system provided a data bandpass of from near zero to 20 KHz.

The tapes containing the analog data recordings were digitized at a sampling rate of 100 KHz (real time) in preparation for computer processing and plotting of pressure versus time histories.

To minimize ground shock effects, the pressure transducers were flush mounted, via a Teflon collar, to aluminum blocks. The aluminum blocks were then positioned in the ground, at selected distances, and insulated from the hard rock-filled terrain by several inches of sand.

III. RESULTS AND OBSERVATIONS

The air blast parameters recorded at each station were used to estimate a TNT equivalent weight factor (EWF)* for each test configuration. The final data form is a ratio (R) of the EWF of pallets with live propelling charges to the EWF of pallets with inert propelling charges.

A. Air Blast Parameters

The peak overpressure (P_m), arrival time (t_a), positive duration (t_+) and positive pressure impulse (I) histories of an explosive event can all be used to estimate an EWF. However, in this series of tests only the peak overpressure and arrival time data were used. The measured air blast parameters for each test are presented in tabular form in Table I.

*****_The EWF in this effort is defined as the weight of a hemispherical TNT charge, detonated on the surface of the earth, required to produce the same air blast parameters that were observed for each pallet(s) configuration._

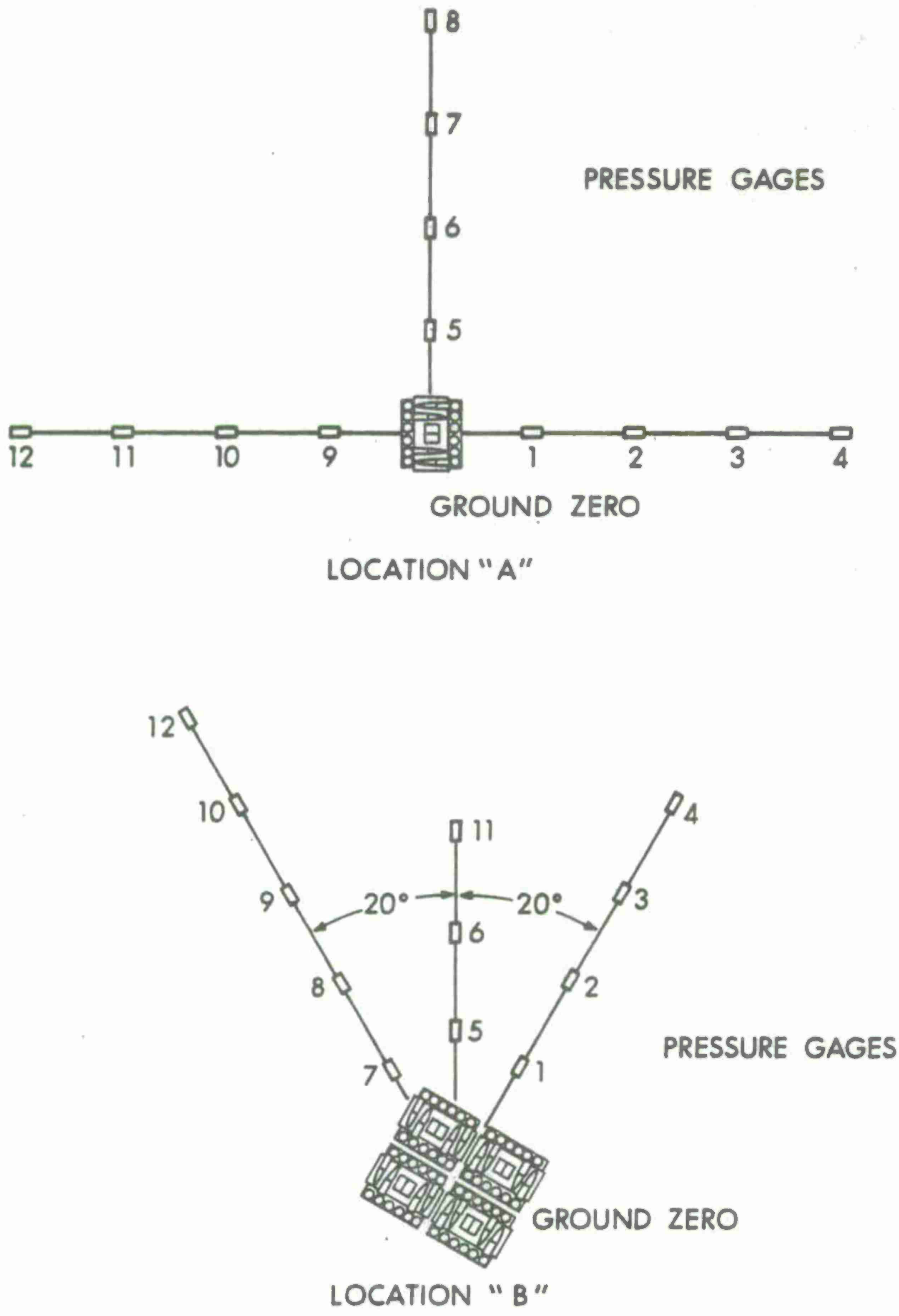


Figure 5. Field Test Set-Up

Table I. Test Results - Measured Blast Parameters

		Distance		Pressure		EWF$_p$ *		t_a	EWF$_{ta}$ **		t_+
Test No.	Gage No.	m	(ft)	kPa	(psi)	Kg	(lbs)	ms	kg	(lbs)	ms
	5B	13.5	44.2	151.7	22.0	131	289				9.4
	9C	13.4	44.8	186.2	27.0	168	371				10.5
	2A	17.4	57.0	110.3	16.0	181	398				9.4
1	6B	16.9	55.5	117.2	17.0	181	398				5.6
One Pallet	10C	17.3	56.9	106.9	15.5	170	375				16.7
With Propellant	3A	24.4	80.2	44.8	6.5	129	284				16.5
	7B	24.5	80.5	44.8	6.5	130	287				4.0
	11C	24.2	79.3	55.2	8.0	170	375				18.0
	4A	34.0	111.4	33.1	4.8	181	398				4.4
	8B	33.9	111.3	31.0	4.5	178	393				12.9
					Average Values	162	357				
	1A	13.4	44.0	172.4	25.0	158	349	14.0	144	317	9.4
	5B	13.4	44.0	151.7	22.0	128	283	10.5	384	847	8.9
	9C	13.4	44.0	206.8	30.0	209	460	14.0	144	317	10.0
	2A	17.1	56.0	103.4	15.0	156	343	21.3	150	330	9.4
2	6B	17.1	56.0	124.1	18.0	205	451	17.0	351	773	6.1
One Pallet	10C	17.1	56.0	117.2	17.0	189	416	21.0	158	349	10.6
With Propellant	3A	24.4	80.0	53.8	7.8	165	364	37.0	177	390	
	11C	24.4	80.0	79.3	11.5	308	679	37.5	170	374	13.3
	4A	34.0	111.5	26.2	3.8	128	282	61.0	186	411	3.9
	8B	34.0	111.5	22.8	3.3	97	213	59.8	206	455	17.6
	12C	34.0	111.5	24.8	3.6	115	254	62.0	166	365	4.4
					Average Values	169	372		203	448	

* EWF$_p$: TNT Equivalent Weight Factor based on peak overpressures.

** EWF$_{ta}$: TNT Equivalent Weight Factor based on time of arrival.

Table I. Test Results - Measured Blast Parameters (Continued)

		Distance		Pressure		EWF_p		t_a	EWF_{ta}		t_+
Test No.	Gage No.	m	(ft)	kPa	(psi)	Kg	(lbs)	ms	kg	(lbs)	ms
	1A	13.4	44	110.3	16.0	83	183				10.0
	5B	13.4	44	60.7	8.8	34	74				16.5
	9C	13.4	44	75.8	11.0	49	108				8.9
3	2A	17.1	56	46.9	6.8	46	102	23.5	99	218	10.6
One Pallet	6B	17.1	56	51.0	7.4	52	115	24.5	81	178	6.1
Without Propellant	10C	17.1	56	51.0	7.4	52	115	24.0	90	198	10.0
	3A	24.4	80	34.5	5.0	81	179				11.1
	7B	24.4	80	31.7	4.6	68	149				4.0
	11C	24.4	80	44.1	6.4	119	262				10.5
	8B	34.0	111.5	17.2	2.5	52	114	70.0	61	134	14.5
	12C	34.0	111.5	17.9	2.6	59	130	69.0	70	154	4.7
				Average Values		63	139		80	176	
4	3A	24.4	80.0	106.9	15.5	471	1038	29.0	529	1166	16.6
Four Pallets	7B	24.6	80.8	131.0	19.0	615	1358	20.5	1973	4349	3.5
With Propellant	11C	24.1	79.2	144.8	21.0	686	1513	29.0	494	1088	16.6
	2A	33.9	111.2	55.2	8.0	475	1047	49.0	624	1375	
	4A	33.9	111.2	51.0	7.4	444	978	49.0	624	1375	4.4
	6B	34.0	111.4					40.0	1486	3277	6.7
	8B	34.0	111.4					39.5	1550	3417	
	12C	34.0	111.5	64.8	9.4	610	1345	50.0	605	1326	7.8
				Average Values		550	1213		980	2171	

Table I. Test Results - Measured Blast Parameters (Continued)

		Distance		Pressure		EWF_p		t_a	EWF_{ta}		t_+
Test No.	Gage No.	m	(ft)	kPa	(psi)	Kg	(lbs)	ms	kg	(lbs)	ms
	1A	12.4	40.8	281.3	42.0	246	543	10.0	299	660	8.8
	2A	13.4	43.8	248.2	36.0	256	564	11.0	324	714	14.4
	5B	12.8	42.0	227.5	33.0	203	447	12.0	191	420	
5	6B	13.7	45.0					13.0	227	500	6.7
Four Pallets	8C	15.4	50.5	125.5	18.2	150	331	16.0	223	491	13.3
Without Propellant	3A	24.9	81.6	68.9	10.0	266	586	34.0	322	709	17.6
	9C	26.5	86.9	86.2	12.5	445	980	41.0	212	467	16.0
	4A	30.4	99.6	23.4	3.4	74	164	48.0	273	601	10.0
	10C	31.9	104.7	41.4	6.0	243	535	52.0	273	602	17.7
				Average Values		235	527		260	574	
	5B	14.3	46.9	468.8	68.0	704	1552	13.0	289	637	10.5
	6B	15.2	49.9	434.4	63.0	788	1738	14.0	335	739	11.0
6	7C	14.1	46.2	296.5	43.0	369	813	9.0	905	1995	6.5
Four Pallets	8C	15.0	49.2	303.4	44.0	459	1012	10.0	962	2120	11.0
With Propellant	9C	29.6	97.1	89.6	13.0	650	1439	38.0	658	1450	14.0
	3A	30.8	101.0	68.9	10.0	504	1112	42.0	600	1323	19.0
	10C	36.3	119.0	35.9	5.2	282	621	54.0	660	1455	-
	4A	37.8	124.1	58.6	8.5	708	1560	59.0	585	1290	4.0
	12C	59.1	193.9	27.6	4.0	736	1623	112.0	673	1483	-
	11B	59.9	196.4	41.4	6.0	1601	3529	114.0	670	1476	11.0
				Average Values		680	1500		634	1397	

Table I. Test Results - Measured Blast Parameters (Continued)

		Distance		Pressure		EWF_p		t_a	EWF_{ta}		t_+
Test No.	Gage No.	m	(ft)	kPa	(psi)	Kg	(lbs)	ms	kg	(lbs)	ms
	1A	15.5	51	330.9	48.0	578	1275	11.5	757	1668	13.3
	5B	15.5	51	268.9	39.0	447	985	12.5	561	1237	8.3
	7C	15.5	51	358.6	52.0	626	1381	11.0	905	1995	6.5
7	8C	16.5	54	268.9	39.0	531	1170	11.5	1080	2380	8.9
Eight Pallets	6B	16.5	54					14.0	555	1223	-
Without Propellant	3A	31.1	102	68.9	10.0	519	1145	41.0	682	1504	25.0
	9C	31.1	102	91.0	13.2	784	1728	40.0	816	1798	14.0
	4A	38.1	125	48.3	7.0	538	1186	56.5	776	1710	15.0
	10C	38.1	125	41.4	6.0	407	897	55.5	844	1860	16.6
	11B	61.0	200	38.6	5.6	1517	3345	114.0	813	1792	16.6
					Average Values	661	1457		779	1718	
	2A	20.4	67	386.1	56.0	1601	3530	14.8	1836	4048	-
	5B	19.5	64	317.2	46.0	1075	2370	14.0	1677	3697	9.0
8	7C	19.5	64	372.3	54.0	1314	2896	13.0	2135	4707	7.2
Eight Pallets	8C	20.4	67	317.2	46.0	1234	2720	14.5	1979	4364	17.6
With Propellant	6B	20.4	67					15.0	1777	3918	-
	3A	32.6	107	127.6	18.5	1446	3188	36.0	1693	3733	22.0
	4A	39.6	130	106.9	15.5	2041	4500	51.0	1685	3714	10.0
	9C	39.6	130	62.1	9.0	1059	2334	50.0	1884	4154	19.0
	10C	48.5	159	68.9	10.0	1960	4320	70.0	1833	4042	28.0
	11B	62.8	206	55.2	8.0	2980	6569	107.0	1620	3572	8.9
	12C	77.7	255	27.6	4.0	1666	3674	142.0	2098	4626	-
					Average Values	1637	3610		1838	4052	

1. Peak Overpressure. The pressure versus time histories for each test were examined for quality. Approximately 15% of the records were of poor quality and rejected due to ground shock effects and fragment/debris impacts on the aluminum blocks housing the transducers. The remaining pressure time histories were used to determine the peak overpressure at each station and generate EWF's using the cube root scaling laws and the "Blast Parameters Versus Scaled Distance" Table in Reference 2. The average EWF based on the peak overpressures are listed in Table II together with ratios showing the contribution of the propelling charges to blast over pressures in terms of changes in the EWF (R_p). Tests 1 and 4 were unique and not used in forming the EWF ratios.

2. Arrival Time. The pressure versus time histories were also used to measure arrival times. An EWF based on the arrival time was then calculated using the method described in Reference 4 for each station. This method involves (a) forming a ratio of the measured distance to the measured arrival time, (b) forming a ratio of the scaled distance to the scaled arrival time using the "Blast Parameters Versus Scaled Distance" Table in Reference 2, (c) determine the scaled distance when the two ratios are equal and (d) use cube root scaling laws to determine an EWF. The average EWF for each test are listed in Table II together with ratios showing the contribution of the propelling charges to arrival time (R_{ta}).

3. Positive Duration and Impulse. The quality of the pressure versus time histories deteriorated with time in many cases due to noise, ground shock, fragment/debris impact, and what appeared to be thermal drifting. Therefore, no effort was made to estimate EWF's based on positive duration or impulse test results.

B. Observations

In general, the EWF's based on arrival times were greater than the EWF's based on peak overpressures. The relatively poor agreement between the average values in Test 4 can be attributed to differences in the data base. In Test 4 a total of six data points were used in calculating EWF_p in contrast to eight data points for EWF_{ta}. The two additional points used in the EWF_{ta} solution were relatively high, 1588 kg versus an average value of 1052 kg and are probably the result of focusing.

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[4] *C.N. Kingery and W.F. Jackson, "Blast Screening Tests for the Alternate Explosive Fill Program," Ballistic Research Laboratory Memo Report No. 2336, October 1972 (AD 907354).*

The results of Test 1 show that the detonation of only one projectile can lead to the en masse detonation of all the projectiles.

If it is assumed that propellant and TNT are equally effective on a weight basis in producing blast overpressures, then the equivalent weight of a pallet, in lbs. of TNT, with and without propellant can be calculated using the following formula from Reference 5:

$$W_{pallet} = W_{HE}\, KF + W_{prop}$$

Where

W_{HE} = total explosive filler weight of all 16 projectiles.

K = conversion factor, Comp B to TNT.

F = factor given by the modified Fanno formula to account for the energy expended in projectile breakup (0.635 for the 155-mm projectile).

W_{prop} = total weight of all 16 propelling charges.

This technique yields EWF's for a pallet with and without propelling charges of 175 kg and 78 kg respectively. These calculated values from a ratio of 2.24 compared to an overall average ratio value of 2.56 from the test data. The average empirically derived EWF for each test configuration together with predicted values are presented in Figure 6.

A comparison of the predicted and measured values in Figure 6 validates the assumption that propellant and TNT are equally effective, on a weight basis, in producing blast overpressures.

IV. CONCLUSIONS

The contribution of the propelling charges to blast overpressure can be equated to TNT, on an equal weight basis, when assessing the storage hazards associated with the use of the pallet evaluated in this study.

The detonation of only one projectile in a group of pallets can result in the en masse detonation of the remaining projectiles.

No additional testing is required.

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[5] *F.H. Weals, "ESKIMO 1 Magazine Separation Test," Naval Weapons Center TP 5430, April 1972.*

TABLE II. TEST RESULTS - AVERAGE EQUIVALENT WEIGHT FACTORS

TEST	TEST SITE	NO OF PALLETS	PROPELLANTS NO	PROPELLANTS YES	EWF_p (kg)	R_p Ratio	EWF_{ta} (kg)	R_{ta}	REMARKS
1	A	1		X	162				Single Point initiation test.
2	A	1	X		63		80		
3	A	1		X	169	2.68	203	2.54	Ratios formed from Tests 2 and 3.
4	A	4		X	550		980		
5	B	4	X		235		260		
6	B	4		X	680	2.88	634	2.44	Ratios formed from Tests 5 and 6.
7	B	8	X		661		779		
8	B	8			1637	2.48	1838	2.36	Ratios formed from Tests 7 and 8.

EWF_p : TNT Equivalent Weight Factor based on peak overpressure averages.

EWF_{ta} : TNT Equivalent Weight Factor based on arrival time averages.

$$R_p : \frac{EWF_p \text{ (With Propellant)}}{EWF_p \text{ (W/O Propellant)}} , \quad R_{ta} : \frac{EWF_{ta} \text{ (With Propellant)}}{EWF_{ta} \text{ (W/O Propellant)}}$$

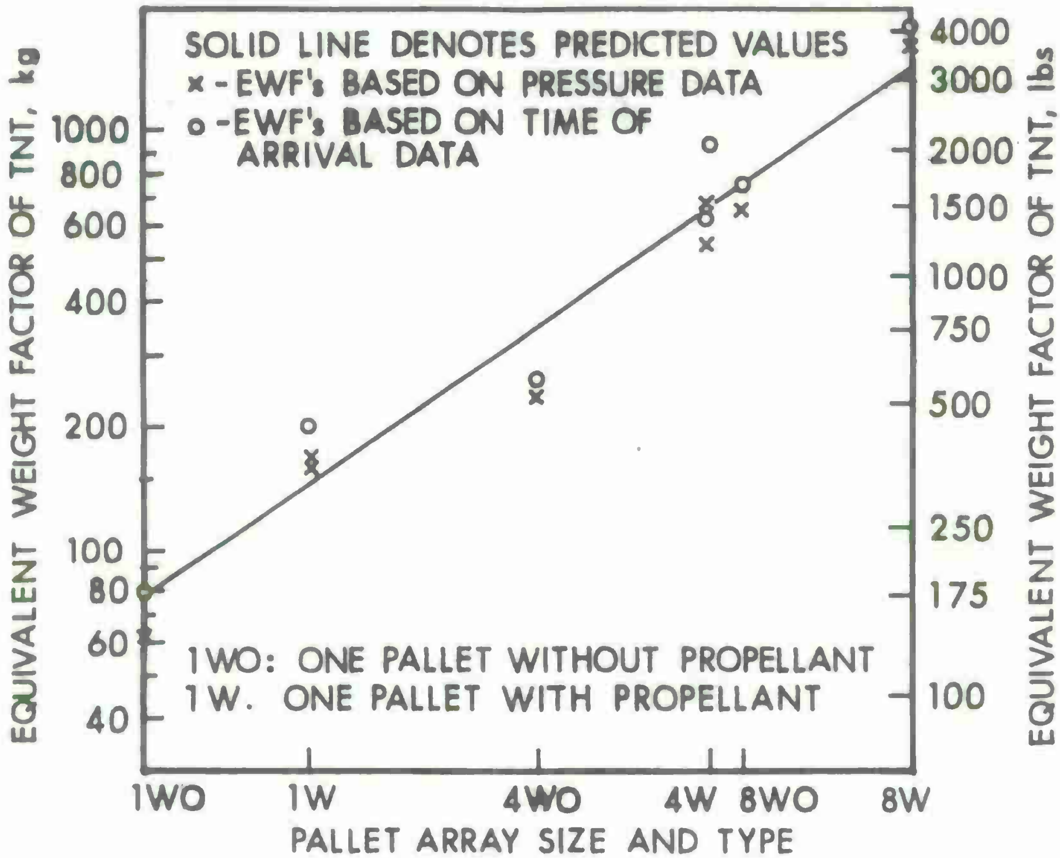

FIGURE 6. MEASURED AND PREDICTED EQUIVALENT WEIGHTS FOR ONE, FOUR AND EIGHT PALLET ARRAYS, WITH AND WITHOUT LIVE PROPELLANT CHARGES.

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