Jimmie C. Oxley,[1] *Ph.D.; James L. Smith,*[1] *Ph.D.; and Elmo Resende,*[1] *M.S.*

Determining Explosivity Part II: Comparison of Small-Scale Cartridge Tests to Actual Pipe Bombs*

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ABSTRACT: The small-scale explosivity device (SSED) has been used to assess the explosive power of a number of low explosives—smokeless powders (WC-870, Red Dot, Bullseye, Winchester Action Pistol, and IMR-PB), Pyrodex, black powder, and an improvised explosive (TATP). The device requires 2 g of energetic material, a heavy-walled containment vessel, and a standard blast shield to permit use in most laboratories. The data from the SSED are compared with the fragmentation of pipe bombs which contained 300 to 700 g of powder. The SSED provided the same relative ordering of explosivity as suggested by the fragmentation of the real devices. In addition, the SSED was used to evaluate the chemical residue remaining after an explosion. Issues in using the device such as optimal detonators and restricted reaction volume were probed using three high explosives—TNT, Tetryl, and RDX.

KEYWORDS: forensic science, pipe bomb, improvised explosive, fragmentation, smokeless powder, black powder, small-scale explosivity device, post blast, explosive, TATP

In the study of explosives, it is neither cheap, fast, nor safe to study every problem at full scale. As part of an on-going effort to find laboratory tests that adequately reflect real-world devices, we previously reported (1) the adaption of the British Cartridge test (2–4) for use as a small-scale explosivity tester. The set-up employs sufficiently small amounts of explosive that it is possible to use it in a laboratory fume hood. The only additional protection required are a blast shield and a heavy walled containment vessel. The test, as originally designed, initiates 2 g of energetic material in a British .303 brass cartridge using a #8 detonator and a 1-L, 1 in. thick, stainless steel containment vessel. Explosive power (explosivity) is assessed from the amount of cartridge casing remaining attached to its base after detonation.

We have found it convenient to use the small-scale explosivity device (SSED) not only for evaluation of explosive power but also to determine the chemical residue remaining postblast. The ability to create and collect post-blast residue in the laboratory has several potential applications. First it may allow quantification of the fraction of explosive remaining. Second it allows identification of the chemicals produced by the blast. In our lab, the latter application has been applied to environmental concerns. In law enforcement, such information should allow relating blast residue to an unknown found at a suspect's dwelling. The SSED can be employed to prove the unknown creates the same type of residue as that found at the blast site. To examine explosive residue, the firing chamber must be thoroughly cleaned. Furthermore, after detonation a chromatograph with the appropriate detector makes the analysis more complex than the simple determination of the fraction of the cartridge remaining on the original base required to assess explosivity. In both applications, explosivity rating and residue analysis, a number of issues arose which we address herein: the effect of the initiator; the effect of restricted reaction volume; and the comparison to real data. This study compares the results of the SSED test with field studies of pipe bombs.

Experimental Section

Double-base (WC-870, Red Dot, Bullseye and Winchester Action Pistol) and single-base (IMR-PB) smokeless powders, Pyrodex, and black powder were purchased. Triacetone triperoxide (TATP) was synthesized in our laboratory from acetone and hydrogen peroxide; details will be reported elsewhere (Oxley/Smith manuscript in preparation). 2,4,6-Trinitrotoluene (TNT), 2,4,6-trinitrophenylmethylnitramine (Tetryl) and 1,3,5-trinitro-1,3,5-triazocyclohexane (RDX) were provided by government agencies. A detailed description of the SSED can be found in Ref 1. The containment vessel was a 1-L, thick-walled, bolted-closure, vented metal cylinder (Fig. 1). The energetic material to be tested was loosely packed in a preweighed British .303 cartridge. The brass cartridge was about 55 mm in length; the base, about 13 mm in diameter, had a single hole; the cartridge diameter tapered to ~7 mm in diameter at the mouth. The depth of the energetic material below the cartridge mouth was measured (typically 2 cm) to determine relative volume; the detonator was inserted directly touching the energetic material and taped in place. The entire assembly was placed in the containment vessel. Following detonator initiation, the remains of the cartridge base were collected, washed in water, rinsed in acetone, dried, and weighed. The explosive power was correlated to the fraction of the cartridge remaining attached to the base.

Modifications to the previous protocol for the study reported herein are as follows. Instead of using strictly #8 detonators, some tests employed exploding bridgewire (EBW) detonators—RP-2 or RP-3—donated by Reynolds Industry System, Inc. The dimensions and compositions of these detonators are shown in Table 1. For the

[1] Chemistry Department, University of Rhode Island, Kingston, RI.

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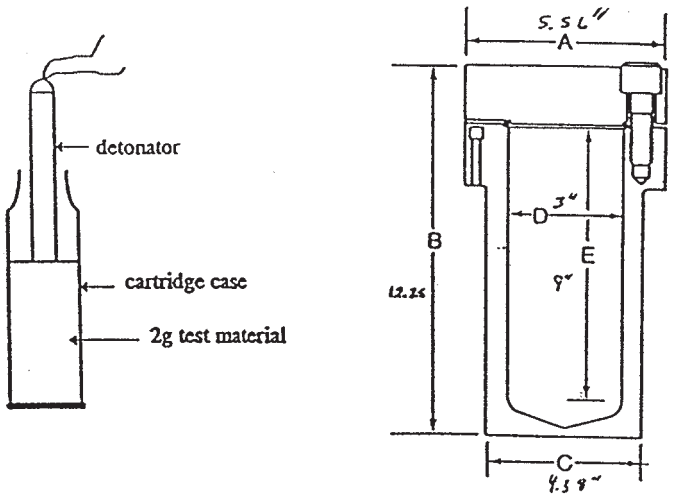

FIG. 1—*Small-scale explosivity device and sample holder.*

TABLE 1—*Initiators.*

	#8	RP-3	RP-2
Dimensions	(2 in. × 0.25 in.)	(0.506 in. × 0.130 in.)	(0.465 in. × 0.202 in.)
PETN (mg)	450	29	32
Other energetics (mg)	Pb azide (11)		RDX (18)
	Pb cresol (190)		binder
Detonation Product observed by GC/ECD for initiator only (no charge)			
	PETN	PETN	PETN RDX
Detonation Products from initiators in three firings, respectively, of*			
	TNT	RDX	Tetryl
Benzoic acid			S,S,S
Naphthalene	S,S,S	M,_,S	M,S,S
$C_{10}H_{22}$	S,S,S		
Acenaphthylene	S,S,S	M,_,S	M,S,S
Naphthlenecarbonitrile		S,_,S	S,S,_
Phenanthrene/anthracene	_,S,S	S,_,S	S,S,S
Fluoranthene	S,S,S	S,S,_	S,S,_
Pyrene	_,S,S	S,S,_	S,S,_
Hexanedioic acid esters	M		
Ethlyhexyl or other phthalates	S		

* Products assigned by match of 90% of better to GC/MS library. Main charge was also observed in most cases. Small (S) and medium (M) indicate relative peak size.

low-density smokeless powders, we found it impossible to fit 2 g of energetic material into the cartridge. For that reason we filled the cartridge to about the same volume (same height) it was filled by 2 g of high explosive. Table 2 shows the weight of filler and its depth below the cartridge rim detonator. This offset was typically 2 cm but even reducing it to 1.4 cm, only allowed 1.4 g of Red Dot to fit in the cartridge. A similar question—fill to same weight or same volume—was encountered in the pipe bomb studies. We chose to fill the 2 in. by 12 in. steel pipes (same volume); but the total weight of energetic material varied from 300 to 700 g.

Details of the pipe bomb tests have been published (5). In that study steel, butt-end welded pipes (2 in. by 12 in.) were initiated in 55 gallon steel drums filled with sand or Grit-o-Cob® to protect and capture the thrown pipe fragments. The sand or ground cob only touched the bottom end cap of the pipe. The rest of the pipe was isolated from the sand/cob by a 12 in. cylindrical cardboard sleeve 8 in. in diameter. The pipe bombs were initiated with either #12 detonators or electric squibs. Following initiation, a sieve and magnet were used to collect pipe fragments; collection efficiency averaged 87%. The steel fragments were cleaned, counted, and weighed. The appearance of the fragments was described and photographed. Data were plotted in fragment weight distribution maps (FWDM). FWDM plots account for fragment number and size without requiring complete recovery. It compensates for the fact that total pipe weight or recovery of pipe will vary from pipe to pipe by using a percentage of fragment weight over total recovered pipe weight instead of using absolute fragment weight directly (5). The axes of the FWDM plot are shown below:

$$X = [\text{weight of a single fragment } (m_x)\}/[\text{total weight of all fragments } (M_r)]$$

$$Y = \log\{[100*(\text{weight fragments as heavy or heavier than } m_x)]/(\text{total weight all fragments } M_r)\}$$

$$= \log\{[\text{sum } (m_1 + m_2 + m_3 \ldots + m_x)]/(M_r)\}$$

Dividing both the individual fragment weight (x axis) and the sum of all fragments as large or larger (y axis) by the total recovered fragment weight means that plots can be used to compare pipes of unequal weight, size, or collection efficiencies. FWDM were found to be reproducible and relatively insensitive to percentage recovery. When recovery is incomplete, it tends to be the small fragments that are lost. Since small fragments end up being plotted near the origin of the graph, they do not have the effect on the slope that larger fragments do. The larger fragments tend to dictate the slope, and it is the slope of the FWDM plots which differentiates the magnitude of the blast. High or medium-power events, which produced many small fragments, were recognizable by steep slopes, while low-power events, which formed few fragments, plotted shallow slopes (Fig. 2).

Results and Discussion

The results for the small-scale cartridge tests are shown in Table 2. The explosive power is correlated with the amount of cartridge remaining. The smaller the "average fraction remaining," the more powerful the charge. It has been suggested that it would be more "intuitive" if a high number meant a more powerful explosive; therefore, a column "average fraction shattered" (1.000 *minus* the average fraction remaining) is also presented.

Effect of Initiators

Three different initiators were examined: #8 detonators and exploding bridge wire detonators RP-2 and RP-3. PETN is the main charge in each but in amounts varying from 29 to 450 mg (Table 1). Table 3 shows the fraction cartridge remaining when these initiators were used with high explosives (TNT, RDX, and Tetryl) and two inert materials [salt (NaCl) and sand]. The inert materials show what might be considered the logical difference between an initiator with 450 mg PETN (#8) and one with 29 mg PETN (RP-3). With #8 caps in NaCl, 40% of the case was shattered; in fact, even an empty brass cartridge was fragmented. This was a concern raised during our previous SSED study—the "zero" was too far from zero so that the range of responses was limited. With the

Table 2: Summary of Small-Scale Explosivity Device Results.

Test #	303 Brass wt (g)	Tested Material	Type of Detonator	Sample Weight (g)	Depth (cm)	Base wt (g) Remaining	Fraction Base Remaining	Ave *	Avg. Fract. Remaining	Avg. Fract. Shattered
1	10.947	NaCl	# 8	2.000	3.3	6.543	0.60			
2	10.999	NaCl	# 8	2.000	3.3	6.428	0.58			
3	10.815	NaCl	# 8	2.029	3.2	6.589	0.61		0.597	0.403
87	11.030	TNT	# 8	2.0001	2.3	3.305	0.30	*		
88	10.997	TNT	RP-2	2.0000	2.2	3.334	0.30	*		
89	10.996	TNT	RP-3	2.0002	2.1	3.976	0.36			
98	10.980	TNT	RP-3	2.0002	2.2	4.154	0.38		0.370	0.630
90	10.991	Tetryl	# 8	2.0001	2.2	2.281	0.21	*		
91	10.959	Tetryl	RP-2	2.0011	2.1	2.621	0.24	*		
92	10.948	Tetryl	RP-3	2.0001	2.2	3.842	0.35		0.350	0.650
93	11.076	RDX	# 8	2.0005	2.7	2.420	0.22			
94	11.040	RDX	RP-2	2.0003	2.8	2.440	0.22			
95	11.039	RDX	RP-3	2.0008	2.8	2.518	0.23		0.223	0.777
99	10.960	TATP	RP-3	1.2042	1.7	4.428	0.40			
100	10.985	TATP	RP-3	1.1923	1.5	4.683	0.43			
101	11.000	TATP	RP-3	1.1489	1.6	4.646	0.42		0.418	0.582
27	11.110	Pyrodex	# 8	2.008	1.6	4.880	0.44			
28	11.079	Pyrodex	# 8	2.005	1.6	4.725	0.43			
29	10.940	Pyrodex	# 8	2.008	1.6	4.756	0.43		0.433	0.567
106	10.955	Black Powder	RP-3	2.0007	2.85	10.966	1.00			
107	11.043	Black Powder	RP-3	2.0011	2.8	11.042	1.00		1.000	0.000
108	11.048	WC-870	RP-3	2.0016	2.55	11.050	1.00			
109	10.952	WC-870	RP-3	2.0008	2.5	10.918	1.00		0.999	0.001
110	10.922	IMR-PB	RP-3	1.7753	1.45	4.554	0.42			
111	11.068	IMR-PB	RP-3	1.6949	1.55	4.674	0.42		0.420	0.580
112	11.031	Red Dot	RP-3	1.3998	1.45	4.701	0.43			
113	10.964	Red Dot	RP-3	1.3987	1.4	4.585	0.42		0.422	0.578
20	11.011	Bullseye	# 8	2.0016	1.6	3.278	0.30			
21	10.953	Bullseye	# 8	2.0030	1.5	2.678	0.24			
22	10.979	Bullseye	# 8	2.0011	1.6	2.841	0.26			
23	11.014	Bullseye	# 8	2.0066	1.4	3.674	0.33			
24	11.034	Bullseye	# 8	2.0052	1.5	2.590	0.23			
25	11.020	Bullseye	# 8	2.0014	1.5	2.940	0.27			
26	11.019	Bullseye	# 8	2.0091	1.5	2.873	0.26		0.271	0.729
114	10.958	Bullseye	RP-3	1.4006	2.45	4.680	0.43			
115	11.023	Bullseye	RP-3	1.3998	2.55	4.671	0.42		0.425	0.575
116	10.870	Winchester	RP-3	1.8232	2.45	6.072	0.56			
117	10.961	Winchester	RP-3	1.8217	2.45	7.191	0.66	*		
118	10.919	Winchester	RP-3	1.8223	2.55	6.028	0.55		0.555	0.445
119	10.966	sand	RP-3	2.0021	3.65	10.959	1.00			
120	10.937	sand	RP-3	1.9955	3.65	10.943	1.00			
121	10.968	sand	RP-3	2.0029	3.65	10.978	1.00		1.000	0.000

* Not used in calculation of average fraction cartridge remaining.

smaller initiators (RP-3), we found a true zero; "initiated" sand left the cartridge case intact or with a small hole. In contrast, RDX, the most powerful explosive used in this study, showed no difference in cartridge fragmentation regardless of the size of the detonator. However, both the other high explosives, TNT and Tetryl, show slightly less shattering when the smaller initiator was employed. This suggested that the smaller detonator had difficulty initiating response in the less powerful fillers. Thus, the smaller detonators solved one problem and presented another. The amount of explosive they contain is small enough that the detonator itself is not responsible for shattering the brass cartridge; however, that amount of explosive may be insufficient to initiate any response in a relatively weak formulation. For example, Pyrodex, a black powder substitute, is not considered dramatically more powerful than black

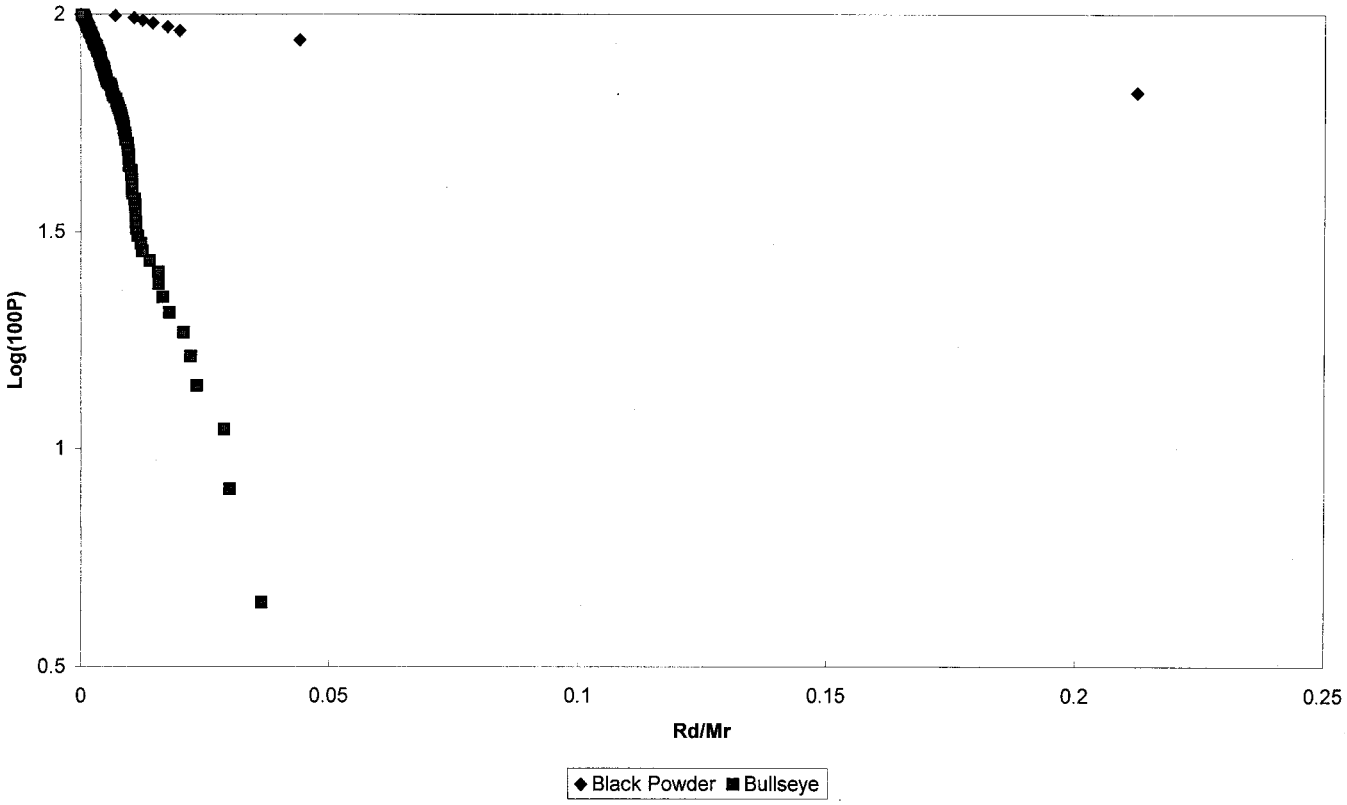

FIG. 2—*Fragment weight distribution map (FWDM) for Bullseye and for black powder.*

TABLE 3—*The effect of the initiator.*

Test #	.303 Brass wt (g)	Tested Material	Type of Detonator	Base wt (g) Remaining	Depth (cm)	Fraction Base Remaining	Fraction Base Shattered
1	10.947	NaCl	#8	6.543	3.3	0.60	0.40
2	10.999	NaCl	#8	6.428	3.3	0.58	0.42
3	10.815	NaCl	#8	6.589	3.2	0.61	0.39
119	10.966	sand	RP-3	10.959	3.65	1.00	0.00
120	10.937	sand	RP-3	10.943	3.65	1.00	0.00
121	10.968	sand	RP-3	10.978	3.65	1.00	0.00
87	11.0301	TNT	#8	3.305	2.3	0.30	0.70
88	10.9969	TNT	RP-2	3.334	2.2	0.30	0.70
89	10.9961	TNT	RP-3	3.976	2.1	0.36	0.64
98	10.9798	TNT	RP-3	4.154	2.2	0.38	0.62
90	10.9912	Tetryl	#8	2.281	2.2	0.21	0.79
91	10.9587	Tetryl	RP-2	2.621	2.1	0.24	0.76
92	10.9476	Tetryl	RP-3	3.842	2.2	0.35	0.65
93	11.0757	RDX	#8	2.420	2.7	0.22	0.78
94	11.0403	RDX	RP-2	2.440	2.8	0.22	0.78
95	11.0394	RDX	RP-3	2.518	2.8	0.23	0.77

NOTE: All samples weighed 2.000 g.

powder. However, when a #8 cap was used to initiate Pyrodex, 57% of the cartridge was shattered, whereas, black powder, initiated with an RP-3, left the cartridge broken but unfragmented. We conclude that if one is testing a suspected explosive one should first use a small initiator; if there is no response, the test should be repeated with a larger initiator. The large initiator should be benchmarked against a suitable inert material.

In order to use the SSED to identify post-blast residue, it was necessary to examine the residue produced by the initiators. Accordingly, we examined the residue from three initiators (#8, RP-2, RP-3) alone and when initiating 2 g of TNT, RDX, or Tetryl. The results are included in Table 1. Compounds were identified by GC/MS using a spectral library; only matches of reliability 90% or better are reported. Although the explosive filler was detected, the

other products were generally the same, regardless of the charge initiated. Therefore, we concluded the products were produced by the initiator. Phthalates are thought to arise from the wire insulation of the detonator, while the condensed-ring products could come from the wire or soot of the explosives. In terms of identifying residue from the main 2 g charge, it was notable that residue from the main charge was not generally observed when the large detonator (#8) was employed. TNT and Tetryl were observed with the two EBW initiators, but RDX was only tentatively identified. Therefore, chemical analysis tests should be performed primarily with small detonators, such as the RP-3 EBW.

Effects of Restricted Reaction Volume

A major concern in using small-scale tests is that some artifact of the smaller test would distort the results. Obviously, small-scale tests must be carefully bench-marked against the scenario they are meant to model. The 2-g detonation tests allow for testing in the laboratory, but there were questions whether the post-blast residue from a confined 2-g blast was representative of that from a larger detonation. In a separate study examining post-blast residue of TNT, we quantified the amount of TNT remaining post-blast and found up to ten times more TNT remaining after "initiation" of a 2-g charge in the SSED as compared with a 75 g charge in a 55-gallon barrel. (Quantification of remaining TNT in the SSED was accomplished by extraction of the vessel with acetonitrile, and comparison of the acetonitrile extracts against standard TNT solutions using a gas chromatograph equipped with a DB-5 capillary column and an electron capture detector. The amount of TNT residue in the 55-gallon barrel was calculated from similar extractions and analyses of witness plates contained in the barrel; details of the 75 g tests can be found in an Oxley/Smith manuscript presently in preparation.) With an oxygen-deficient explosive such as TNT, we speculated that the small (1 L) container used in the SSED restricted after-burning of TNT which can occur in free-field detonation. To determine if there was significant after-burning, the 2-g tests, which were normally performed in air, were performed under oxygen and under nitrogen. Results are shown in Table 4. In both cases the TNT used, flaked TNT, performed poorly compared with powdered TNT. About 89% of the 303 brass cartridge remained attached to the base after detonation of the flaked TNT as compared with 30% using powdered TNT. However, the purpose of these tests, under nitrogen or under oxygen, was to analyze for the amount of TNT remaining. There was a factor of ten less TNT remaining when the TNT was initiated under oxygen instead of nitrogen (Table 5). This result implies that after-burning is of major importance at the 2-g scale for TNT. Furthermore, the results are in good agreement with theoretical calculations. If the detonation of TNT is written as shown below, then

$$C_7H_5N_3O_6 \rightarrow 7\ CO_2 + 2.5\ H_2O + 1.5\ N_2$$

complete oxidation to CO_2 requires 16.5 moles of oxygen atoms. TNT, itself, only supplies 6 moles, so that the other 10.5 moles of oxygen atoms must come from the environment. For 2 g (0.00881 moles) of TNT, the moles of O_2 required are calculated as 0.0463 moles:

$$(10.5 \text{ mole O/mole TNT} * 0.00881 \text{ mole TNT})/$$

$$(2 \text{ atom O/mole } O_2) = 0.0463 \text{ moles } O_2$$

If standard atmospheric conditions are assumed (i.e., 22.4 L/mole), then this quantity of O_2 would take up the volume of 1.04 L. Since the volume of the SSED is approximately 1 L, it is reasonable that

TABLE 4—*Detonation of TNT in nitrogen versus oxygen in SSED.*

	Sample 2 g TNT Flake	TNT (g)	Initiator	Cartridge Weight (g)		Fraction Cartridge		TNT	% TNT
				Start	End	Remaining	Shattered		
122	Sample 1 N_2	2.0011	RP-3	10.944	9.708	0.887	0.113	0.503	25%
123	Sample 2 N_2	2.0002	RP-3	11.051	9.854	0.892	0.108	0.954	48%
124	Sample 3 O_2	2.0044	RP-3	10.993	10.874	0.989	0.011	0.034	2%
125	Sample 4 O_2	2.0066	RP-3	10.922	9.703	0.888	0.112	0.046	2%
	2 g TNT Powder								
87	TNT in air	2.0001	#8	11.030	3.305	0.300	0.700	not determined	
88	TNT in air	2.0000	RP-2	10.997	3.334	0.303	0.697	not determined	
89	TNT in air	2.0002	RP-3	10.996	3.976	0.362	0.638	not determined	
98	TNT in air	2.0002	RP-3	10.980	4.154	0.378	0.622	not determined	

TABLE 5—*Comparison of SSED to Pipe Bombs.*

Energetic Material	Small-Scale Explosivity Device			Steel Pipe Bombs (2 in. × 12 in).				
	% Base Remaining	% Base Shattered	Wt. Filler (g)	Wt. Filler (g)	Number of Pipe Fragments (D*)	Slope of the FWDM	Number of Pipe Fragments (S*)	Slope of the FWDM
Bullseye	43	58	1.4	430	221,258	31,45	122,145	6
IMR-PB	42	58	1.7	390	185	28	133	7
Red Dot	42	58	1.4	320	118,191,210	27	119,119	9
Winchester	56	45	1.8	550	815	56		
Black Powder	100	0	2.0	680	9,22	1.5	15,17	1.3
WC-870	100	0	2.0	660	4,11	0.2	12,15	0.9

* D denotes initiation with #12 detonator; S, with electric squib. Multiple entries means repeat tests.

under an oxygen atmosphere only 2% of the TNT is found in the post-blast residue. Without further tests we cannot speculate whether less oxygen deficient explosives would be as affected as TNT. What is clear is that while after-burning affects the amount of TNT residue remaining it does not affect its explosive performance.

Comparison of SSED Results to Real Devices

To benchmark SSED results to the real world, we compared the SSED results for black and smokeless powders to the fragmentation of pipe bombs with the same fillers. Excluding flammable liquids, about 60% of illegal explosive devices used in the U.S. are pipe bombs (6,7). They are usually made using commercial smokeless powders. In a separately reported study we prepared and fired 56 pipe bombs and rated the explosivity of the energetic filler by plotting the number and size of the pipe fragments (5). We termed the plot a fragment weight distribution map (FWDM) and rated the power of the filler using the slope. As indicated in Table 5, the high-power fillers are sensitive to the type of initiation. A detonator (#12) applied to Bullseye initiated a detonation, while a squib initiated only a deflagration (5). For this reason data for pipe bombs is differentiated as to the type of initiation (Table 5). Table 5 also compares the FWDM slope that we considered indicative of the power of the explosive filler to the fraction of the cartridge shattered, which is the indication of explosivity provided by the SSED.

At the bottom of Table 5, we note that the SSED clearly differentiates between the low-power and high-power fillers. In the companion pipe bomb study we found the low-power fillers produced FWDM slopes of less than 2. With the SSED, using RP-3 detonators, these same fillers produce no shattering. While this is helpful for the purpose of ordering them among other energetic fillers, it does not distinguish them from inert materials. Clearly, if a suspect material is being tested to determine if it is energetic, a "zero" result achieved with a small detonator must be followed by a second test with a larger initiating device. At the top of Table 5, we note that the SSED distinguishes the high-power fillers but does not differentiate among them. The pipe bomb study suggests Bullseye is more energetic than IMR-PB and Red Dot which are about equally energetic, at least this is the results from the pipe bomb study when a detonator is used to initiate the fillers. When a squib was used in the pipe bomb study we observed the same lack of differentiation in the FWDM slope as we observed in the SSED results. We conclude that the SSED is not allowing the initiation of full detonation, and this is not surprising considering the small scale of the device. The one piece of data from the SSED that does not track with the pipe bomb data is that achieved with Winchester Action Pistol. In this case we believe the SSED is showing the true ordering more clearly than the pipe bomb test. This is based on our understanding of the chemistry of the fillers (Winchester Action Pistol is a slower burning powder than Bullseye) and on the fact that only one pipe of Winchester was shot.

Conclusions

The small-scale explosivity device (SSED) provides a good relative ordering of the power of explosives. However, in choosing initiators, one must consider that a detonator, containing large amounts of explosive, such as a #8 cap, will make even an inert material appear energetic, i.e., it will blast away some of the cartridge. On the other hand, a smaller detonator, such as a RP-3 EBW, will not differentiate low energy fillers from inert substances. The SSED is an excellent device for testing whether a suspect material is energetic. However, given the caveat above, it is necessary to perform the first test with a small detonator and a second test with a larger one. In any case, any detonator used should be benchmarked against a known explosive and an inert. The SSED has also been found to be useful in determining explosive residue. However, in terms of quantifying post-blast residue, we have found with TNT the values obtained by SSED are abnormally high due to the restricted volume of the container. In a larger container or in free-field undetonated TNT that is thrown from the charge burns in the vast-volume of oxygen around it and, thus, is not found in the post-blast debris.

Acknowledgments

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Additional information and reprint requests:
Jimmie C. Oxley
Chemistry Department, University of Rhode Island
Kingston, RI 02881
(Phone/fax) (401) 874-2103
Email: joxley@chm.uri.edu