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DEVELOPMENT OF RAPID-BURNING INCAPACITATING PYROTECHNIC MIXTURES

by

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The object of the study was to develop a rapid-burning incapacitating pyrotechnic mixture that would satisfy a 5- to 10-second emission time requirement. The results of the study follow:

1. A fast-burning incapacitating pyrotechnic mixture was devised which, when loaded into the 73-cc volume wedge-shaped submunition, satisfies the 5- to 10-second emission time requirement. The mixture must be granulated to an average particle size of 2500μ and pressed at 1.61×10^3 kg/cm^2.

2. The burning rate is a function of stoichiometry, loading pressure, and particle size.

3. The mixture has a vaporization efficiency of 70%.

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PREFACE

The work described in this report was authorized under Project/Task 1W663614DE7303, Incapacitating Chemical Material, Projectile, 155-mm, Howitzer, Incapacitating Agent XM723. The initial work was started in September 1971 and was completed December 1973. The experimental data are contained in notebooks 3028, 3609, and 8652.

SUMMARY

The object of this investigation was to develop a rapid-burning incapacitating pyrotechnic mixture that would satisfy a 5- to 10-second emission time requirement.

The subject areas included:

1. Burning characteristics such as emission time, yield, vaporization efficiency, and exhaust gas temperature.

2. Sensitivity such as electrostatic, friction, impact, and temperature.

3. Parameters for increasing the burning rate: catalysis, burning pressure, particle size, pressing pressure, and stoichiometry.

The results of this study show that:

1. A fast-burning incapacitating pyrotechnic mixture was devised which, when loaded into the 73-cc volume wedge-shaped submunition, satisfies the 5- to 10-second emission time requirement. The mixture, which must be granulated to an average particle size of 2500μ and pressed at 1.61×10^3 kg/cm^2, has the following composition:

Material	Percent
EA 3834A	55
$KClO_3$	25
EBS	17
Nitrocellulose	3

2. The burning rate is a function of stoichiometry, loading pressure, and particle size.

3. The mixture has a vaporization efficiency of 70%.

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DEVELOPMENT OF RAPID-BURNING INCAPACITATING PYROTECHNIC MIXTURES

I. INTRODUCTION.

Theoretical considerations indicate that rapid dissemination of inhalation effective chemical agents provides improved casualty effects against personnel having protective gear available. The concept being that mean masking time is 15 seconds. During that time, personnel exposed to the aerosolized chemical agent could breathe it and become casualties. After that time, no additional agent exposure would be expected.

To illustrate the above concept, figure 1 is presented to show the relationship of the percentage of target area covered with an effective dosage versus the emission time per source for a constant number of sources. For this relationship the following parameters hold true:

Constant source of agent - 25 grams
Number of agent sources - 576
ICt50 of agent - 100 mg min/m^3
Masking time - 15 seconds
Windspeed at neutral atmospheric stability - 5 mph
Target area - 150 square meters
Distribution of agent sources - uniform random

The domain from a 10- to 20-second emission time per source represents conventional agent pyrotechnic mixture system. The domain from a 1- to 10-second emission time per source represents the rapid-burning agent pyrotechnic mixture system. This relationship shows that a conventional pyrotechnic mixture system covers 17% to 32% of the target area with an IC50, whereas rapid-burning agent pyrotechnic mixture system covers from 33% to 42% of the same area.

The major objectives of this investigation were to devise an efficient, safe, fast-burning (5 to 10 seconds) incapacitating agent – pyrotechnic mixture suitable for loading into an optimized submunition shape, the wedge.

II. MATERIALS AND EQUIPMENT.

Pyrotechnic materials used in this study along with their specifications are listed below:

Potassium chlorate, Grade B, Class V (Specification Mil-P-150)
Nitrocellulose, Technical (TT-N-3500, February 1963)
EA 3834A (Manufacturing Technology Directorate) Edgewood Arsenal, Aberdeen Proving Ground, MD
Ethylene bis (isothiosemicarbazide) (EBS) (Ash Stephens Company)

Test devices used in this study are shown in figure 2. Volume and surface area (of fill) of wedge submunitions are given below:

Large - volume 73 cc, surface area 4.74 cm^2
Medium - volume 53cc, surface area 4.74 cm^2
Small - volume 35 cc, surface area 4.13 cm^2

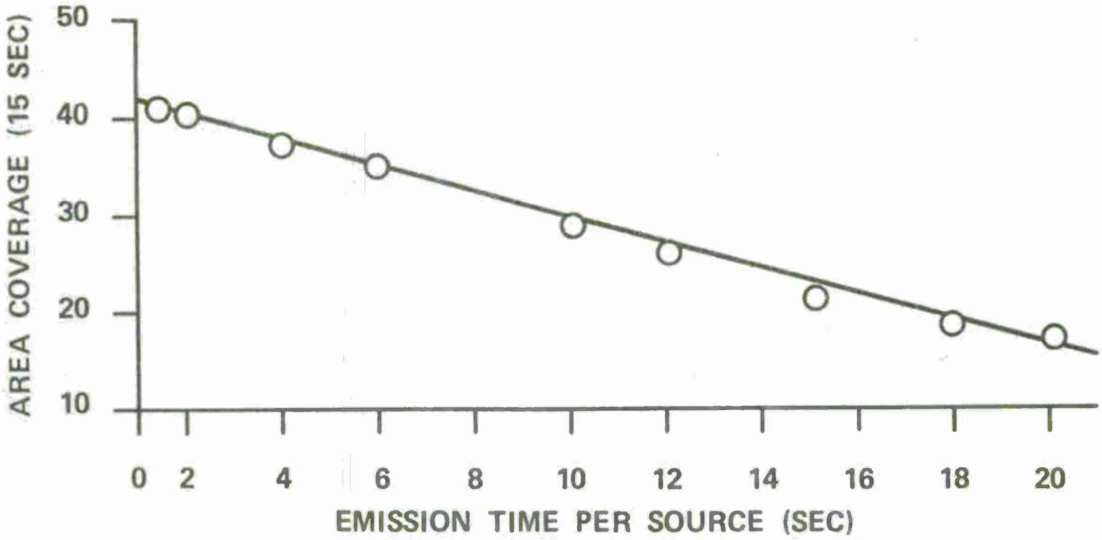

Figure 1. Area Coverage Versus Emission Time Per Source (Seconds)

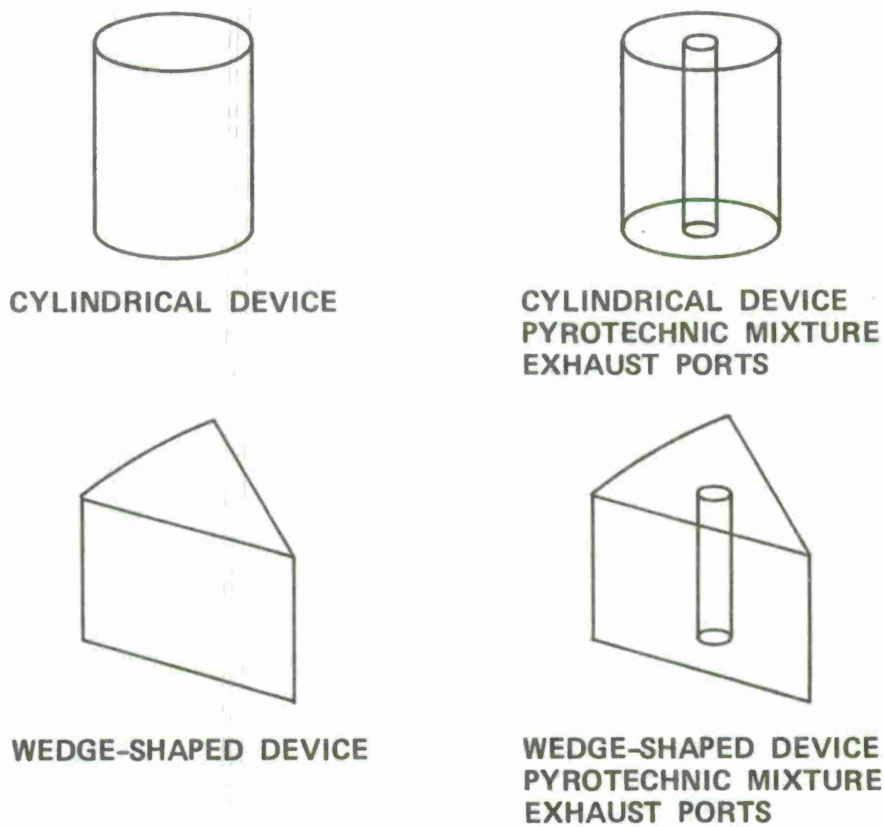

Figure 2. Test Devices

III. EXPERIMENTAL PROCEDURES AND RESULTS.

A. Catalysis Study.

The object of the first study was to determine the effect of known catalysts on the burning rate and functioning characteristics of an optimized conventional agent pyrotechnic mixture.[1] Each mixture formulated was pressed into a cylindrical test device with a conical frustrum center cone configuration (.635 cm) (.794 cm diameter) at 3.7×10^2 kg/cm^2 pressure. The test device was 6.35 cm in length and 3.175 cm in diameter.

The burning characteristics and mixture formulation are shown in table 1. The averages of agent fill weight, yield, vaporization efficiency, and emission time were evaluated for each of the four catalysts mixtures studied as well for as the reference conventional mixture. A T-test, at a signifiance level of 0.05, for comparing group averages was performed on the data.[2] The T-test indicated that the difference in emission time was significant. It also indicated that there was no significant difference in yield or vaporization efficiency.

The four burning catalysts lowered the emission time from 20% to 30% without significant change in yield.

B. Pressure Study.

Secondly, the effect of burning pressure on emission time was observed by varying the exhaust port diameter on the test device. For this experiment, small wedge-shaped submunitions with agent fill of 16.5 grams were used. The reference incapacitating pyrotechnic mixture previously described was pressed at a pressure of 7.6×10^2 kg/cm^2. Figure 3 shows a plot of emission time versus exhaust port diameter. The relationship is linear; the equation of the line being $y = -.3215 + 2.475X$. Starting with an exhaust port diameter of .635 cm (emission time 12.5 seconds) and decreasing the exhaust port diameter to .437 cm (7.6 seconds), the emission time was reduced 39.2%. The yield of agent (shown in grams at each point in parentheses) does not show any strong dependence on burning pressure. Further experimentation with smaller exhaust port diameter (less than .437 cm) resulted in rupturing of the test device through development of excessive internal pressure.

C. Stoichiometry Study.

Thirdly, the emission time was studied as a function of the oxidizer to fuel ratio. For this study, the mixtures were pressed at 3.7×10^2 kg/cm^2 into cylindrical test devices 6.35 cm long and 3.17 cm in diameter having a conical frustrum center cone configuration of 0.635 to 2.794 cm. Three mixtures were used for this study; the ozidizer to fuel ratio varied from 1/1 to 2.4/1; the agent fill weight was 22 grams. The mixtures contained the following pyrotechnic ingredients.

	Oxidizer/Fuel Ratio		
Pyrotechnic	1.1	1.6	2.4
ingredient	90	90	90
$KC10_3$	25	30	29
EBS	25	20	12
EA 3834A	50	50	59

The standard oxidizer fuel ratio 1.25:1 determined the experimental area. The percent agent change in the 2.4/1 oxidizer/fuel ratio mixture was to desensitize the mixture for loading and pressing operations.

Figure 4 shows the linear relationship, the equation of the line line being $y = 22.151 - 5.081X$. Varying the oxidizer to fuel ratio from 1/1 to 2.4/1 reduces the emission time 40%, from 17.3 to 10.1 seconds. There is no significant change in yield of agent (in grams is shown at each point) with variation in oxidizer/fuel ratio over the range of conditions studied.

Table 1. Catalysis Effect

Catalyst	Weight of agent fill	Vaporization efficiency*	Yield**	Emission time
	gm	%	gm	sec
Reference X	21.2	72	15.2	10.1
	20.2	70	14.2	10.3
	20.2	73	14.6	10.4
	20.5	74	15.6	10.3
	19.8	71	14.0	10.4
Average	20.4	72.0	14.6	10.3
Standard deviation	0.52	1.58	0.51	0.12
Ferric acetyl acetonate	20.9	69	14.4	7.1
	21.1	68	14.3	7.3
	21.1	72	15.4	7.4
	21.2	72	15.3	7.2
	21.1	67	14.9	7.1
Average	21.1	69.6	14.9	7.2
Standard deviation	0.11	2.3	0.5	0.13
Ferric sulfide	21.2	71	15.0	8.0
	21.1	72	15.2	8.2
	21.1	71	15.0	8.4
	21.2	77	16.0	8.3
	21.2	70	14.7	8.2
Average	21.2	72.2	15.2	8.2
Standard deviation	.05	2.77	0.49	0.15
Ferric oxide	21.1	66	13.9	7.1
	21.2	68	14.4	7.3
	21.7	67	14.6	7.4
	21.2	70	14.7	7.2
	21.2	68	14.3	7.1
Average	21.3	67.8	14.3	7.2
Standard deviation	0.24	1.48	0.31	0.13
Cupric chloride	21.6	67	14.6	7.0
	21.6	71	15.3	7.3
	21.0	73	15.3	7.2
	21.2	72	15.0	7.1
	21.1	70	14.7	7.4
Average	21.3	70.6	15.98	7.2
Standard deviation	0.28	2.30	0.33	0.16

Pyrotechnic ingredients	Weight Percent	
	Modified	Reference
EBS	19	20
$KClO_3$	24	25
EA 3834A	55	55
Catalyst	2	0

$$\text{*Vaporization efficiency} = \frac{\text{Weight agent aerosolized}}{\text{Weight agent contained}} \times 100$$

**Yield = Weight agent aerosolized

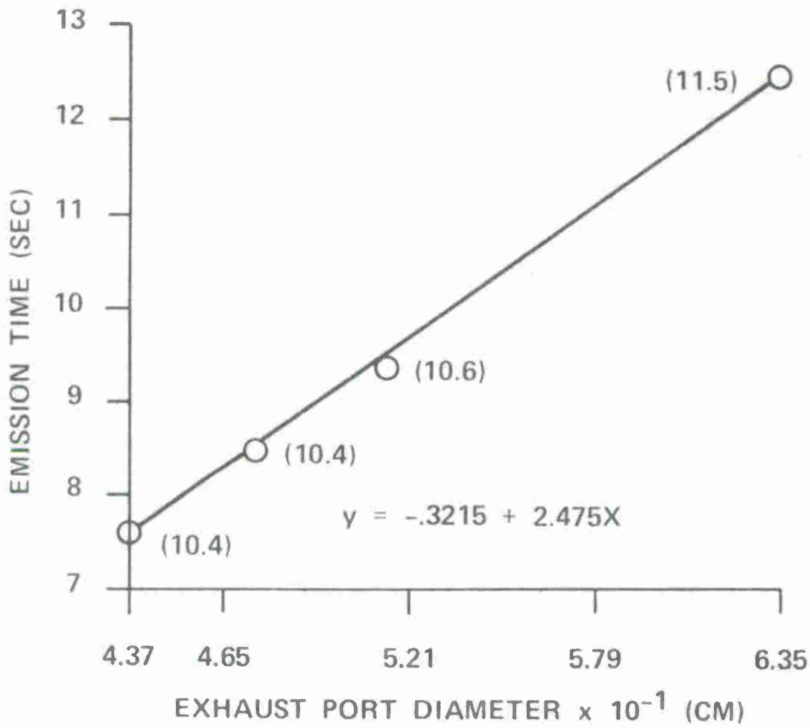

Figure 3. Emission Time Versus Exhaust Port Diameter

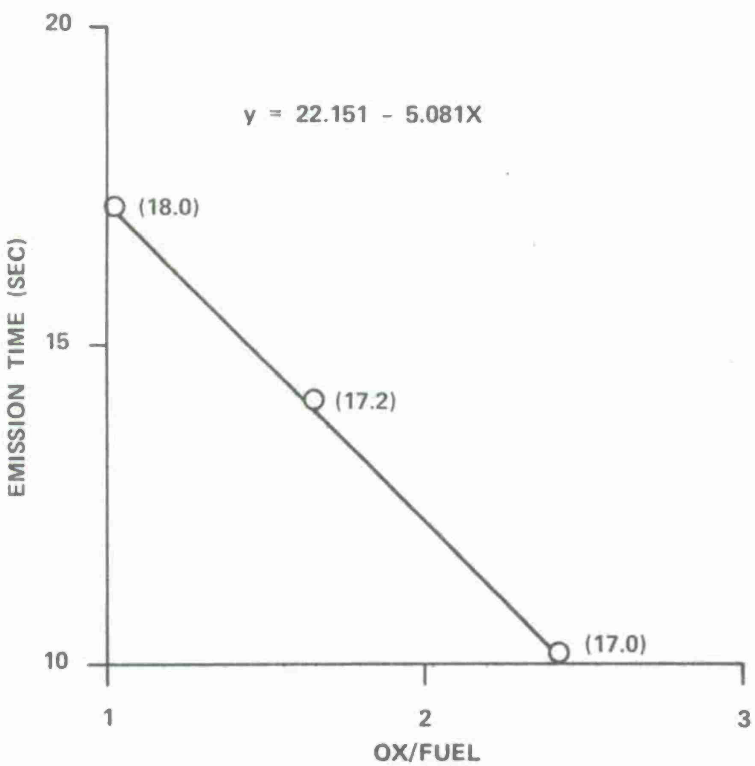

Figure 4. Emission Time Versus Oxidizer/Fuel

D. Particle Size Study.

The object of the next study was to determine the effect of mixture particle size on emission time. Three mixtures were used for this experiment; and their average granular sizes were 44μ, 250μ, and 2500μ respectively. The 44μ mixture is the reference powder mixture. Larger size mixture particles (250μ and 2500μ) were obtained by granulating the reference mixture with nitrocellulose (NC) binder (parts by weight: 55, EA 3834A; 17, EBS; 3 nitrocellulose; 25, $KClO_3$).

Small wedge-shaped submunitions were used as test devices.

The mixture was pressed with a conical frustrum center cone configuration (1.27 to 1.40 cm) at a pressure 1.13×10^3 kg/cm^2. Figure 5 shows a plot of emission time versus particle size. The relationship is exponential; with the equation of the line being $y = 19.587X - 0.173$. Varying the particle size from 44μ to 2500μ decreases the emission time by 50%, from 10 to 5 seconds.

The agent fill weight used for these experiments was 24.8 grams, and the yield of the agent is shown at each point in parenthesis. There is no significant change in yield with variation in particle size.

E. Consolidation Pressure Study.

The effect of consolidation load pressure on emission time was determined. The granulated incapacitating agent mixture (previously described) was pressed into large wedge-shaped submunitions at a pressure of 3.9×10^3 kg/cm^2. The mixture was pressed with a conical frustrum center cone configuration (cone diameter 1.27 to 1.40 cm). Figure 6 shows a plot of emission time versus consolidation pressure. The plot indicates a change of 80% in the emission time, from 10.3 to 2 seconds. But, the yield of agent decreased 60%, from 20.5 grams at a pressure of 3.9×10^3 kg/cm^2 to 8 grams at zero loading pressure.

The yield of agent in grams is shown at each point. This significant decrease in yield at lower loading pressure is due to both a lower loading efficiency and a lessened vaporization efficiency.

F. Fill Weight Study.

The object of the next experiments was to evaluate the response variables (emission time, yield, and load force) as a function of the control variable fill weight. These series of experiments would aid processors who prefer to press to a stop instead of a set pressure. For such a procedure, fill weight becomes the control variable.

For this experiment, 40 large wedge-shaped submunitions were pressed to a stop (.3175 cm from the top surface of the wedge) in one and two increments. The mixture was pressed with a conical frustrum center core configuration (1.27 to 1.40 cm); it consisted of the previously described granulated pyrotechnic ingredients. The data from these tests are shown in tables 2 through 4 and figures 7 through 10. From the tabular and graphical data presented, the following conclusions can be deduced.

1. There is a linear relationship between fill weight and emission time for one- and two-increment loadings.

a. For one- and two-increment loadings, there is a 99% confidence that a linear relationship exists between emission time and fill weight.

b. The standard deviation of emission time for one increment loading at any given fill weight is 1.65 seconds.

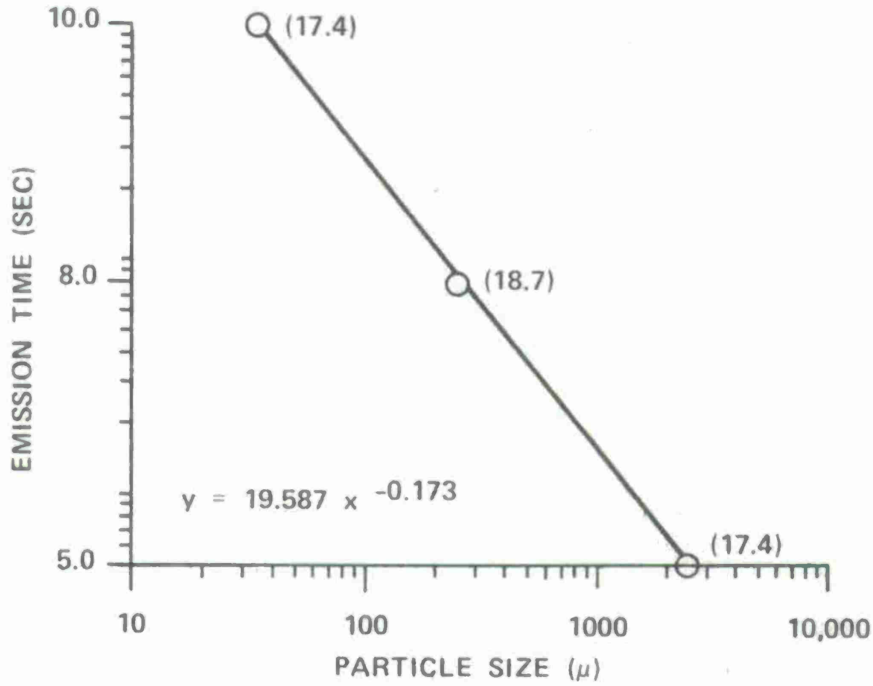

Figure 5. Emission Time Versus Particle Size

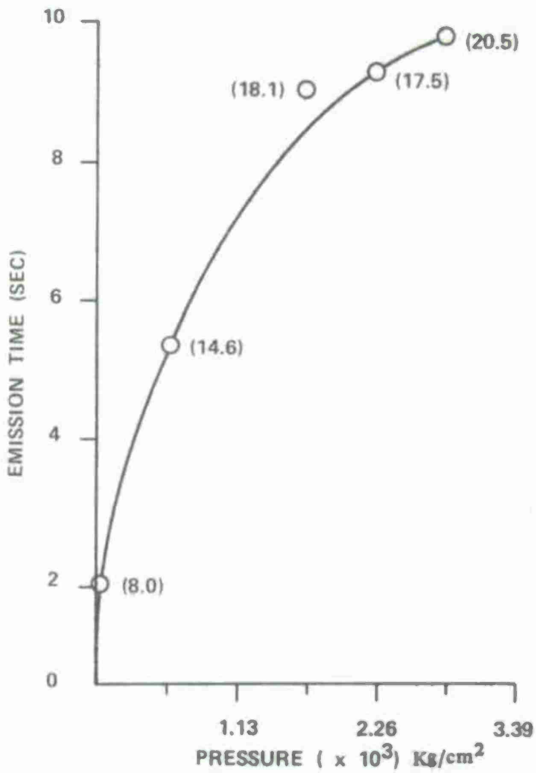

Figure 6. Emission Time Versus Loading Pressure

Table 2. Fill Weight Versus Response Variables

Unit No.	Number of increments	Pressure	Fill weight	Emission time	Yield	Vaporization efficiency
		kg/cm^2	gm	sec	gm	%
511	1	9.7×10^2	62	5.9	23.4	
512	1	9.6	62.5	5.6	Flamed	Flamed
513	1	9.6	61.5	4.8	25.9	73
514	1	12.6	61.7	4.8	25.0	70
515	1	12.6	62.1	4.4	24.9	68
521	2	13.0	64.1	6.1	23.4	67
522	2	13.0	64.3	7.3	Flamed	Flamed
523	2	12.2	64.9	9.2	25.9	73
524	2	13.0	64.6	8.3	25.0	70
525	2	13.0	65.7	8.9	24.9	68
Average	1	10.8×10^2	61.9	5.1	23.1	68
Average	2	12.8×10^2	64.7	8.0	24.8	70
Standard deviation	1	1.6×10^2	0.39	0.624	0.987	2.645
Standard deviation	2	3.5×10^1	0.38	1.262	1.036	2.870

Table 3. Fill Weight Versus Response Variables

Unit No.	Number of increments	Pressure	Fill weight	Emission time	Yield	Vaporization efficiency
		kg/cm^2	gm	sec	gm	%
1011	1	32.6×10^2	69.4	10.0	26.0	68
1012	1	32.6	73.0	9.4	28.1	70
1013	1	32.6	66.0	11.1	28.1	77
1014	1	29.3	67.7	8.1	25.6	69
1015	1	29.3	70.0	11.0	27.2	71
1021	2	28.5	72.9	12.5	30.5	76
1022	2	28.5	73.2	12.0	31.7	79
1023	2	30.0	73.6	11.5	28.3	70
1024	2	31.4	73.0	10.6	25.2	63
1025	2	30.1	74.0	13.0	31.2	77
Average	1	31.3×10^2	69.2	9.92	27.0	71
Average	2	29.7×10^2	73.3	11.9	29.4	73
Standard deviation	1	3.128×10^2	2.63	1.239	1.164	3.535
Standard deviation	2	1.09×10^2	0.46	0.926	2.654	6.519

Table 4. Fill Weight Versus Response Variables

Unit No.	Number of increments	Pressure	Fill weight	Emission time	Yield	Vaporization efficiency
		kg/cm^2	gm	sec	gm	%
1511	1	47.3 X 10^2	71.1	11.1	Flamed	Flamed
1512	1	52.2	77.7	10.4	27.6	65
1513	1	57.0	72.2	13.0	30.8	77
1514	1	48.9	71.8	9.6	Flamed	Flamed
1515	1	53.0	69.5	13.3	28.6	77
1521	2	48.9	78.9	12.5	33.9	78
1522	2	47.3	76.4	12.1	30.0	72
1523	2	46.5	76.3	12.5	31.4	75
1524	2	46.4	76.6	11.7	30.7	73
1525	2	39.9	76.1	12.0	31.9	76
Average	1	51.6 X 10^2	72.5	11.5	29.0	73
Average	2	45.8 X 10^2	76.9	12.2	31.6	75
Standard deviation	1	3.8 X 10^2	3.11	1.617	1.637	6.928
Standard deviation	2	3.4 X 10^2	1.15	0.3435	1.482	2.387

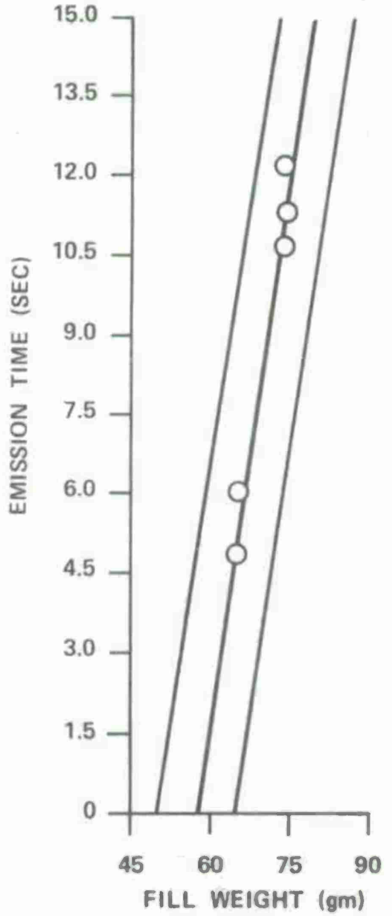

Figure 7. Emission Time Versus Fill Weight (gm) Two Increments

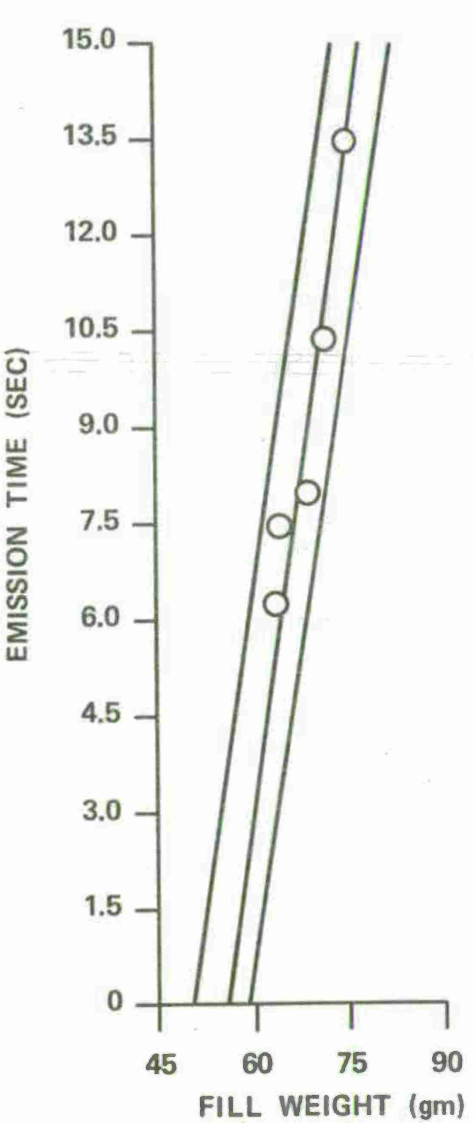

Figure 8. Emission Time Versus Fill Weight (gm) One Increment

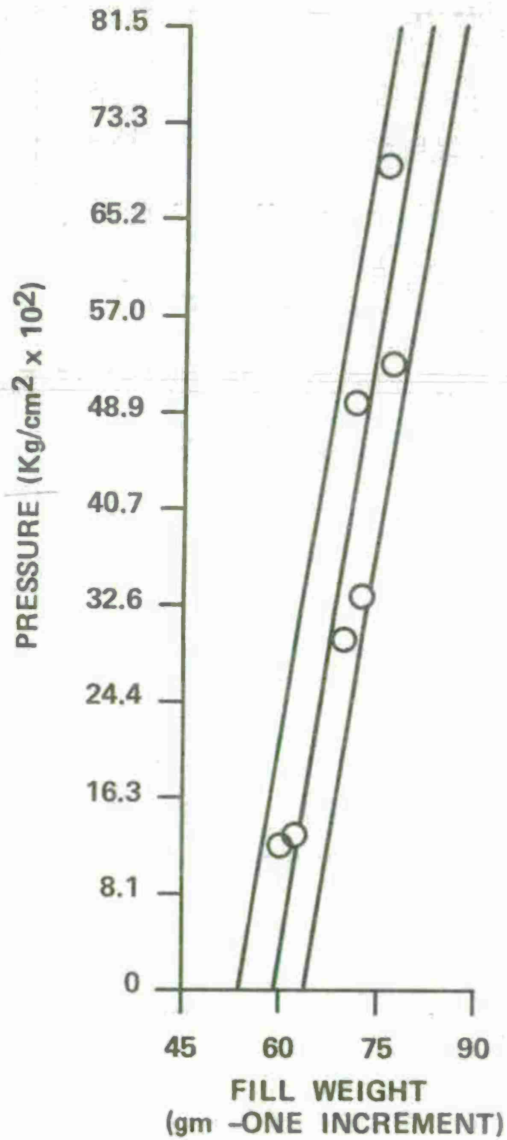

Figure 9. Pressure Versus Fill Weight (gm) One Increment

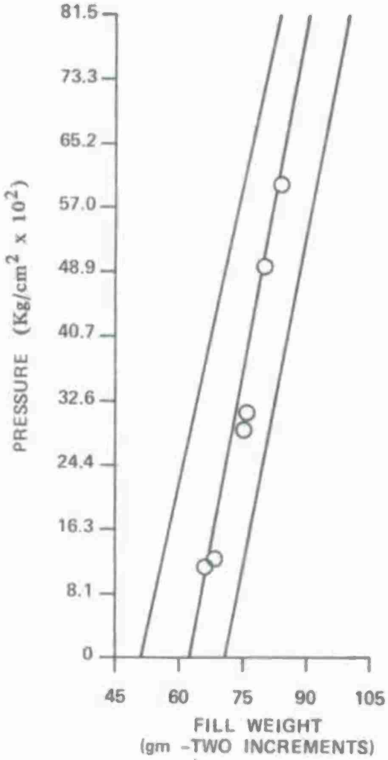

Figure 10. Pressure Versus Fill Weight (gm)

c. From the equation of the line for this relationship (one increment loading), a fill weight of 58.0 grams would generate an emission time of 5- to 10-seconds (7.5-second average).

d. The 95% limit for emission time (one increment) is ±3.3 seconds; i.e., future observations are expected between these lines (figure 7) 95% of the time.

e. The standard deviation of emission time for two increment loadings at any given fill weight is 2.4 seconds.

f. From the equation of the line of this relationship (two increment loadings), a fill weight of 62.4 grams would generate an emission time of 7.5 seconds (average between 5- and 10-seconds).

g. The 95% limit for emission time (two increment loadings) is ±5.1 seconds, i.e., future observations are expected to fall between lines shown on figure 8, 95% of the time.

h. The rate at which EA 3834A is generated from the granulated incapacitating mixture is greater at shorter emission times than at longer emission times.

2. There is a 99.9% confidence that a linear relationship exists between load force and fill weight for one increment loadings.

3. The standard deviation of loading pressure at any given fill weight is estimated to be 4.6×10^2 kg/cm^2 for one increment loadings.

4. The 95% limits for pressure are $\pm 9.7 \times 10^2$ kg/cm^2; i.e., future observation are expected to fall between the lines shown on figure 9, 95% of the time.

5. There is a 98% confidence that a relationship exists between loading pressure and fill weight at two increment loadings. The standard deviation of the loading pressure at two increments at any given fill weight is 7.6×10^2 kg/cm^2. The 95% limits for loading pressure as shown in figure 10 are $\pm 1.6 \times 10^3$ kg/cm^2.

G. Match Variability Study.

A batch experiment was conducted to estimate the variation to be expected in average emission time and yield between batches of the EA 3834A intimate pyrotechnic mixture. Four batches of EA 3834A granulated mixture (parts by weight of ingredients: 25 $KClO_3$; 17 EBS; 3 NC; and 55 EA 3834A) were prepared and pressed into 20 medium wedge-shaped submunitions. The mixture was pressed in two increments at a loading pressure of 3.1×10^3 kg/cm^2 per increment. The average mixture fill weight in each test device was 53 grams. Data from this experiment are shown in table 5.

By applying a T-test at a significant level of 0.05, it was determined that there was no significant difference of emission times and yields between batches of mixtures.

H. Burning Temperature and Pressure Study.

The physical properties of exhaust gas temperature and burning pressure of the EA 3834A intimate pyrotechnic granulated mixture were measured using a chromel alumel thermocouple and a Stratham pressure transducer. Ten wedge-shaped submunitions (volume 73 cc) were used as test devices for the exhaust gas temperature measurements. Pressure measurements were made in wedge-shaped test devices (volume 53 cc).

Tables 6 and 7 show the results of these tests. The average exhaust gas temperature of the mixture as shown in table 6 was 398°C ±34.5; the average burning pressure was 5.126×10^{-2} kg/cm^2.

I. Sensitivity Study.

The rapid-burning EA 3834A pyrotechnic mixture sensitivity to impact, friction, and electrostatic charge was determined using standard methods and standard techniques. Results of sensitivity tests (shown in tabulation, below) are not considered to demonstrate any unusual hazard.

Sensitivity of EA 3834A Pyrotechnic Mix

Ignition temperature	50% Probability of ignition on impact*	Static spark**	Friction sensitivity (DuPont method)
°C	cm	joules	
	Method		
193.1 ±9.64	Bruceton 334	.095	
	Max 283		8/20

* 10 kg drop weight.
** Minimum energy at which ignition occurs.

J. Position Experiment Study.

An experiment was performed to study the burning characteristics of nine wedge-shaped submunitions functioned on the chamber floor. The wedges were placed with one exhaust port facing the floor to simulate a possible functioning position of the submunition which might interfere with satisfactory operation. In order to compare the burning characteristics of these with submunitions functioned from the normal clamped

Table 5. Batch Experiment

Batch	Unit No.	Emission time	Yield	Vaporization efficiency
		sec	gm	%
B	1	9.5	17.9	62
B	2	10.5	22.8	76
B	3	8.5	21.6	71
B	4	10.0	17.3	61
B	5	10.5	21.6	72
Average		9.80	20.4	68.4
Variance		0.700	6.093	43.30
Standard deviation		0.836	2.468	6.580
C	1	12.5	20.8	69.0
C	2	12.5	18.0	60.0
C	3	8.0	19.2	67.0
C	4	7.5	17.7	60.0
C	5	7.0	16.0	55.0
Average		9.50	18.3	62.0
Variance		7.625	3.198	32.7
Standard deviation		2.761	1.788	5.718
D	1	7.5	17.3	58
D	3	9.5	22.2	73
D	4	11.0	21.2	70
D	5	10.0	22.5	75
Average		9.50	20.8	69
Variance		2.166	5.753	58.00
Standard deviation		1.472	2.398	7.615
E	1	10.0	18.1	65
E	2	8.0	19.4	65
E	3	9.0	18.8	64
E	4	8.0	20.1	67
E	5	10.5	16.0	55
Average		9.10	18.5	63.2
Variance		1.300	2.467	22.2
Standard deviation		1.140	1.571	4.711

Table 6. Exhaust Gas Temperature

Unit No.	Mixture fill weight	Pressure	Emission time	Rate*	Temperature**
	gm	kg/cm^2	sec		oc
1A	68.4	1.74×10^3	7.5	7.2	400
2A	69.6	1.82×10^3	8.0	7.0	380
3A	69.5	1.78×10^3	8.0	6.9	400
4A	69.2	1.63×10^3	8.0	7.0	330
5A	69.6	1.82×10^3	7.8	7.1	450
6A	69.5	1.67×10^3	7.5	6.4	390
7A	69.7	1.94×10^3	8.8	6.4	400
8A	69.2	1.89×10^3	9.0	6.1	380
9A	69.4	1.89×10^3	8.0	7.1	450
10A	69.4	1.82×10^3	8.5	6.6	400
Average	69.35	1.80×10^3	8.11	6.78	398
Standard deviation	0.372	98.21	0.507	0.377	34.5

* Rate of weight loss - mixture.

** Exhaust gas temperature.

Table 7. Exhaust Burning Pressure

Unit No.	Maximum pressure*	Emission time
	kg/cm^2	sec
2	6.34×10^{-2}	10.0
3	5.85×10^{-2}	10.6
4	4.09×10^{-2}	10.6
5	4.79×10^{-2}	13.0
Average	5.268×10^{-2}	11.05
Standard deviation	1.017×10^{-2}	1.33

*Exhaust port diameter, 0.9525 cm

position (about 15 cm from the floor), nine controls were included in the study. All submunitions used in this experiments were filled with 53 grams of the fast-burning agent pyrotechnic mixture at a loading pressure of 3.1×10^3 kg/cm^2 dead load. Both exhaust ports were .953 cm in diameter. The results of these tests are shown in table 8.

Table 8. Functioning Position Effect

Unit No.	Functioning position	Time	Yield	Vaporization efficiency
		sec	gm	%
1	Clamped	8.0	14.9	58
2	↓	9.0	17.7	64
3		10.0	16.5	57
4		9.5	18.7	62
5		8.0	18.7	61
6		10.0	18.9	63
7		10.0	18.0	62
8		8.0	18.2	64
9		8.0	18.3	63
Average		8.9	17.8	62
Standard deviation		0.9502	1.2932	2.5056
1	Floor	8.0	18.9	64
2	↓	9.0	16.2	54
3		9.0	14.8	51
4		9.0	16.0	54
5		10.0	18.9	64
6		9.0	14.5	50
7		8.0	15.8	55
8		8.0	15.4	53
9		8.0	14.6	50
Average		8.6	16.1	55
Standard deviation		0.7017	1.6872	5.4083

A T-test at a significant level of 0.05 was performed on the data in table 8. The results of the T-test indicated the following:

1. The average yield and vaporization efficiency of the mixture in the submunitions functioned on the chamber floor were less than those functioned from submunitions in the clamped position.

2. The average emission time of the mixtures in submunitions functioned on the chamber floor was found to be less than the mixture functioned from submunitions in the clamped position. However, all differences were small and did not significantly change the overall munition efficiency.

K. Open-Flame Test.

The object of the following experiment was to determine the amount of EA 3834A aerosol cloud destroyed by a propane flame. This experiment was designed to simulate conditions under which the test device would prematurely function due to exposure to a fire.

For these experiments, cylindrical test devices (8.89 X 3.81 cm diameter) were used.

The granulated mixture was loaded into the test devices in one increment at 2×10^{-2} kg/m^2.

Experimental procedures consisted of placing a propane flame near the exhaust port of the test device and igniting the agent pyromixture remotely. The resultant agent aerosol cloud was collected on filter samplers for chemical analysis. To evaluate the amount of agent destroyed, test devices were also functioned without the presence of the propane flame.

The results of the open-flame tests are shown in table 9. Unit numbers 1 through 5 represent the control devices; unit numbers 8 through 11 represent the test devices. A T-test for comparing the difference at a 0.05 level of significance indicated that a difference exists between the emission times of agent generated from the control devices and the agent generated from test devices. The reason for this acceleration is considered to be the heating of the test device by the open flame. Heated pyrotechnic mixtures are known to function faster.

Table 9. Open-Flame Test

Unit No.	Weight of agent fill	Emission time	Yield	Vaporization efficiency
gm	gm	sec	gm	%
Control devices				
1	27	6.8	20.3	76
3	26.3	6.2	17.8	68
4	26.3	6.8	22.1	85
5	27.0	6.5	23.8	90
Average	26.65	6.58	21.00	79.75
Standard deviation	0.4041	0.2872	2.56	9.74
Variance	0.1633	0.025	6.59	94.92
Test devices				
8	26.7	6.3	0.5	2
9	26.6	6.2	0.5	2
10	26.5	6.1	0.5	2
11	26.7	5.8	1.1	4
Average	26.55	6.10	0.6500	2.50
Standard deviation	0.1288	0.2158	0.3000	1.00
Variance	0.0166	0.0466	0.0900	1.00

During exposure to the flame, 97% of the agent aerosol cloud is decomposed.

The above data analysis indicate that if the XM 723 submunitions were part of a catastrophe in which a fire results, the yield of agent would be reduced 97%.

L. Computer Prediction of Exhaust Products.

Also, a computer program was used to predict the combustion products from the reaction of $KClO_3$ and EBS. The same thermodynamic measurements and faction ratios of these constituents that describe the rapid-burning mixture were programmed into the computer with following data input and combustion product output:

Input Data

Pressure of burning gas	Temperature of burning gas
1 A+M.	700°K

Ratio of oxidizer/fuel
1.4706

Output Data

Product	Mole fraction
N_2	0.2051
KCl (S)	0.17101
$H_\alpha S$	0.1363
CO_2	0.1714
H_2O	0.1629
((S))	.0654
H	.0508

M. Optimum Mixture.

From the prior experimental procedures and results, a rapid-burning incapacitating pyrotechnic mixture has been devised. This mixture, when loaded into the large wedge-shaped submunition, satisfies the 5- to 10-second emission time requirement and presents no unusual hazard in laboratory preparation. The mixture has the following composition:

Components	Percent
EA 3834A	55
$KClO_3$	25
EBS	17
Nitrocellulose	3

and must be granulated to an average particle size of 2500μ and pressed at an average pressure of 1.61×10^3 kg/cm^2.

The emission rate of the mixture is a function of stoichiometry, loading pressure, and particle size.

The loading pressure for the mixture is a function of the theoretically calculated setback forces, associated with ejecting the wedge-shaped submunitions from the XM 723 projectile.

The functioning characteristics of the optimized mixture in the large wedge-shaped submunition is shown in table 10.

Table 10. Functioning Characteristics of Optimized Mixture

Unit No.	Weight of agent fill	Pressure	Emission time	Yield	Vaporization efficiency
	gm	kg/cm^2	sec	gm	
1A	38.1	1.6×10^3	8.8	25.2	67
2A	28.2	1.3×10^3	8.8	27.8	74
3A	39.1	1.8×10^3	8.8	24.8	64
4A	38.9	1.8×10^3	8.8	24.8	65
5A	38.9	1.9×10^3	8.8	28.1	73
6A	38.9	1.9×10^3	9.3	28.8	75
7A	38.9	1.8×10^3	9.4	26.5	69
8A	38.8	1.8×10^3	9.0	28.0	73
9A	39.7	2.0×10^3	10.7	28.9	74
Average	38.8	1.6×10^3	9.16	26.9	70
Standard deviation	0.472	5.9×10^2	±0.625	1.69	4.25

IV. CONCLUSIONS.

1. A rapid-burning incapacitating pyrotechnic mixture has been devised which, when loaded into the 73 cc wedge-shaped submunition, satisfies the 5- to 10-second emission time requirement. The mixture, its composition listed below, must be granulated to an average particle size of 2500μ and pressed at 1.61×10^3 kg/cm^2.

Mixture	Percent
EA 3834A	55
$KC10_3$	25
EBS	17
Nitrocellulose	3

2. The burning rate is a function of stoichiometry, loading pressure, and particle size.

3. The optimum mixture has a vaporization efficiency of 70%.

LITERATURE CITED

1. Hassell, Cecil D. Dissemination Studies of EA 3834A and EA 3834B from Pyrotechnic Mixtures p 9-16, EATR 4346. February 1970. CONFIDENTIAL Report.

2. ORDP Pamphlet 20-110. Section 20-110. Section I. Engineering Design Handbook, p 3-40. Office of the Chief of Ordnance, Washington, DC 20315.

SELECTED REFERENCE

Hinchen, J. D., Practical Statistics For Chemical Research p 7-48, Methuen and Co. LTD., London, England, 1969.

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