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**All-Secondary Explosive Hot-Wire Devices**

University of California



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# All-Secondary Explosive Hot-Wire Devices

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# ALL-SECONDARY EXPLOSIVE HOT-WIRE DEVICES

by

Robert H. Dinegar and Daniel T. Varley III

## ABSTRACT

The explosives PETN, HMX, HNS-1, and RDX can be ignited by a hot wire at low-current levels. When deflagrated under confinement, PETN and HMX generate sufficient gas pressures to actuate a valve or cutting mechanism. Under proper conditions, deflagrations in small charges of PETN or HMX will build up to detonation. Deflagrating charges can also be used to shear and accelerate a flying plate, which initiates detonation in an acceptor explosive upon impact.

## I. INTRODUCTION

This report describes: (1) the hot-wire, low-voltage ignition of the explosives PETN, HMX, HNS-1, and RDX, (2) the gas pressures generated by PETN and HMX during deflagration, (3) the deflagration-to-detonation transition (DDT) in PETN and HMX, and (4) the use of PETN and HMX as donor charges in flying-plate detonators.

PETN\* is purified by recrystallizing it from acetone by the addition of water. Different particle sizes are produced by varying the rate of mixing the water with the PETN/acetone solutions. For comparison, we prepared one PETN sample by ball-milling the larger particles with porcelain balls. HMX\*\* is the beta ( $\beta$ ) polymorph material. RDX,\*\* as received, was 99.8% pure and had a specific surface ( $S_p$ ) of 1400 cm<sup>2</sup>/g. We prepared various particle sizes of HMX and RDX by wet-grinding large-sized material. HNS-1† is a fine-particle material.

\*Manufactured by the Trojan Powder Company, 17 North 7th, Allentown, PA 18101.

\*\*Manufactured by the Holston Defense Corporation, P.O. Box 749, Kingsport, TN 37662.

†Synthesized by Mason and Hanger, Silas Mason Co., Inc., Pantex Plant, P.O. Box 30020, Amarillo, TX 79177.

In this report, "ignition" denotes a self-sustaining deflagration of a confined explosive charge started by a hot wire. The reaction products are used to do work on the test devices to demonstrate that ignition occurred and that the deflagration was sustained.

## II. IGNITION OF PETN, HMX, AND RDX IN SE-1 ASSEMBLIES

This report centers on the ignition of pure secondary explosives. The threshold ignition currents for mixtures of potassium picrate and PETN or HMX are given in Ref. 1.

Confinement of the ignition charge is absolutely necessary in order to achieve a self-sustaining deflagration. Confinement prevents expansion cooling of the initial product gases.

The SE-1 mechanical assembly shown in Fig. 1 was the first of two test assemblies used for the ignition experiments. The housing walls are 1.2-mm-thick brass. The 0.05-mm-diam bridgewire is Nichrome V (80% nickel and 20% chromium). It is soldered between electrodes that are 1 mm apart in an asbestos-filled diallylphthalate plastic head. The electrical resistance of the assembly is 0.6  $\Omega$ . The

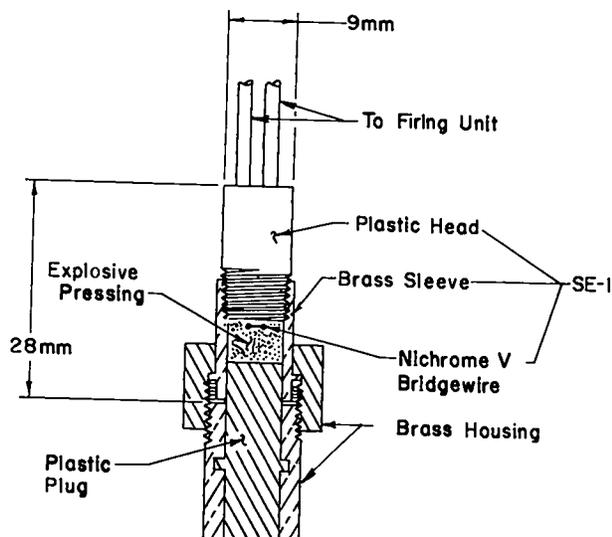


Fig. 1.  
SE-1 mechanical assembly.

plastic head screws into the brass housing, and the explosive pressing is loaded into the cavity over the bridgewire. A plastic plug confines the pressing. The threshold ignition currents for the SE-1 assembly are shown in Table I.

At a high PETN pressing density of 1.6 g/cm<sup>3</sup>, where there is low porosity or small free volume in the assembly of particles, the threshold current goes through a minimum of 1 A as the S<sub>p</sub><sup>o</sup> is changed from 3450 to 17 100 cm<sup>2</sup>/g. The lowest value appears at a permeability (resistance to fluid flow) that is characteristic of particles with S<sub>p</sub><sup>o</sup> values of about 7000-9000 cm<sup>2</sup>/g. At a pressing density of 1.4 g/cm<sup>3</sup>, the threshold current is constant at 0.8 A for S<sub>p</sub><sup>o</sup> values between 3000 and 9000 cm<sup>2</sup>/g, but increases when the S<sub>p</sub><sup>o</sup> value becomes large. One experiment using PETN with a density of 1.2 g/cm<sup>3</sup> failed to ignite even with a current of about 50 A.

HMX must be pressed to a high density for ignition at reasonable current levels. At 1.6-g/cm<sup>3</sup> pressing density, the S<sub>p</sub><sup>o</sup> of HMX has no observable effect

TABLE I

THRESHOLD IGNITION CURRENTS IN SE-1 TEST ASSEMBLY

Nichrome V Bridgewire: Diameter = 0.05 mm, Length = 1.0 mm, Resistance = 0.6 Ω

PETN			HMX <sup>b</sup>			RDX <sup>b</sup>		
Density (g/cm <sup>3</sup> )	S <sub>p</sub> <sup>o</sup> (cm <sup>2</sup> /g)	Current (A)	Density (g/cm <sup>3</sup> )	S <sub>p</sub> <sup>o</sup> (cm <sup>2</sup> /g)	Current (A)	Density (g/cm <sup>3</sup> )	S <sub>p</sub> <sup>o</sup> (cm <sup>2</sup> /g)	Current (A)
			1.2	3 500	>60			
				8 300	55			
				18 600	10			
1.4	3 450	0.8	1.4	3 500	50	1.4	2 250	12
	6 950 <sup>a</sup>	0.8		8 300	2.5		6 650	1.9
	8 400	0.8		18 600	1.3		14 200	0.8
	18 600	3.5						
1.6	3 450	10.0	1.6	3 500	1.3	1.6	2 250	0.8
	6 950 <sup>a</sup>	1.0		8 300	1.3			
	8 400	1.0		18 600	1.3			
	17 100	2.0						

<sup>a</sup>Ball-milled sample; others precipitated.

<sup>b</sup>All ball-milled.

on the threshold current value. The threshold current for  $S_0^2$  values between 3500 and 18 600  $\text{cm}^2/\text{g}$  is 1.3 A. However, for 1.2- and 1.4- $\text{g}/\text{cm}^3$  HMX pressing densities, the lower  $S_0^2$  values require firing currents of about 50 A.

Only a few tests were made with RDX. The same trend appears that was observed in the HMX data. That is, the threshold decreases with an increase in  $S_0^2$  and charge density.

### III. IGNITION OF SECONDARY EXPLOSIVES IN ER-321 ASSEMBLIES

The second test assembly used was the ER-321, a Los Alamos Scientific Laboratory hot-wire device based on the Sandia Laboratory MC-3095 flying-plate detonator. The ER-321 (see Fig. 2) provides a high degree of confinement of the explosive pressing.

Threshold currents for HMX and HNS-1 in the ER-321 are given in Table II. The threshold of 1.0 A for 1.7  $\text{g}/\text{cm}^3$  HMX at  $-54^\circ\text{C}$  indicates that high-density HMX can function at low temperatures with low-current levels. The HNS-1 threshold is higher (2.0 A), but it also functions at low temperatures.

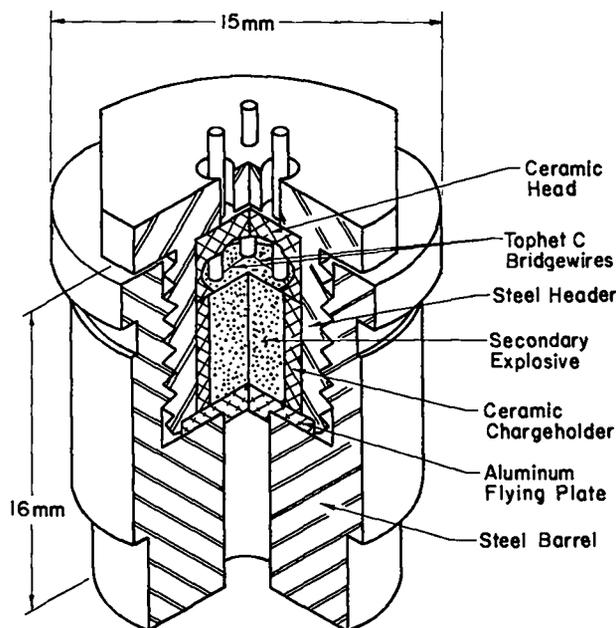


Fig. 2.  
ER-321 assembly.

HNS-1- and HMX-loaded assemblies were also thermal-cycled before threshold testing. The threshold in the HMX assemblies increased by 0.5 A, whereas the HNS-1 assemblies failed to ignite at 25 A.

The effect of HMX density on ignition at low temperatures is also shown in Table II. Densities from 1.6 to 1.7  $\text{g}/\text{cm}^3$  functioned from ambient to  $-54^\circ\text{C}$ . The range of densities that function narrows as the temperature is decreased.

At ambient conditions, ER-321 assemblies loaded with 1.4, 1.6, and 1.7  $\text{g}/\text{cm}^3$  PETN functioned at 3.4 A, whereas densities of 1.0 and 1.2  $\text{g}/\text{cm}^3$  failed. HNS-1 at densities of 1.4 and 1.7  $\text{g}/\text{cm}^3$  also functioned at 3.4 A at ambient conditions. RDX at densities of 1.4 to 1.6  $\text{g}/\text{cm}^3$  ignited at 3.0 A ambient temperature. Densities other than those listed were not evaluated.

### IV. GAS PRESSURE GENERATION

The gas pressures generated by ignited PETN and HMX were first measured in a standard SE-1 mechanical assembly that was confined as shown in Fig. 3. The forward end of the pressing is contained by a 0.64-mm-thick aluminum disk which is held in place by a cylindrical barrel. On the aft end of the pressing is the SE-1 plastic head and brass housing. The assembly is clamped together in a steel outer housing by a steel screw cap. A similar arrangement was used with the ER-321 test assembly. In this assembly, the pressing is contained by an 0.8-mm-thick aluminum disk.

The pressure detector was a Kistler 30-kpsi transducer. The pressure signal received by the transducer as a function of time was transmitted to an oscilloscope as a voltage vs time output. The transducer output was calibrated using known static pressures. The total volume in which the pressure was measured is the original charge volume and the volume between the charge and the pressure transducer.

Table III shows the results of the pressure generation experiment with PETN and HMX. Using the SE-1 assembly, we measured a peak pressure of 0.05 GPa (7.1 kpsi) in a total volume of 1.15  $\text{cm}^3$  for 371 mg of PETN at a density of 1.6  $\text{g}/\text{cm}^3$ . For HMX, we measured a peak pressure of 0.05 GPa (7.3 kpsi) in a

TABLE II

IGNITION STUDIES IN ER-321 TEST ASSEMBLY

Tophet C Bridgewire: Diameter = 0.044 mm, Length = 1.3 mm, Resistance = 1.0  $\Omega$

Effect of Thermal Cycling

Firing Temperature =  $-54^{\circ}\text{C}$       Density =  $1.7 \text{ g/cm}^3$   
 Thermal Cycle = 11 cycles from  $120^{\circ}\text{C}$  to  $-30^{\circ}\text{C}$  and back;  
 25 min at each temperature

		<u>Number Tested</u>	<u>Current (A)</u>	<u>Standard Deviation (A)</u>
HMX ( $S_p = 8300 \text{ cm}^2/\text{g}$ )	Control	20	1.04	0.07
	Thermal cycled	20	1.53	0.10
HNS-1 ( $S_p = 18\,000 \text{ cm}^2/\text{g}$ )	Control	10	2.0	0.17
	Thermal cycled	10	>60	--- <sup>a</sup>

Effect of Density and Firing Temperature

HMX ( $S_p = 8300 \text{ cm}^2/\text{g}$ )      Firing Current = 3.4 A

<u>Density (<math>\text{g/cm}^3</math>)</u>	<u>Firing Temperature</u>		
	<u><math>-54^{\circ}\text{C}</math></u>	<u><math>-30^{\circ}\text{C}</math></u>	<u>Ambient</u>
1.70	F <sup>b</sup>	F	F
1.65	F	F	---
1.60	F	F	F
1.55	NF <sup>c</sup>	F	---
1.50	NF	F	F
1.45	NF	F	---
1.40	NF	NF	F
1.35	---	---	---
1.30	---	NF	NF

<sup>a</sup>.. = Not tried.

<sup>b</sup> F = Fire.

<sup>c</sup>NF = No fire.

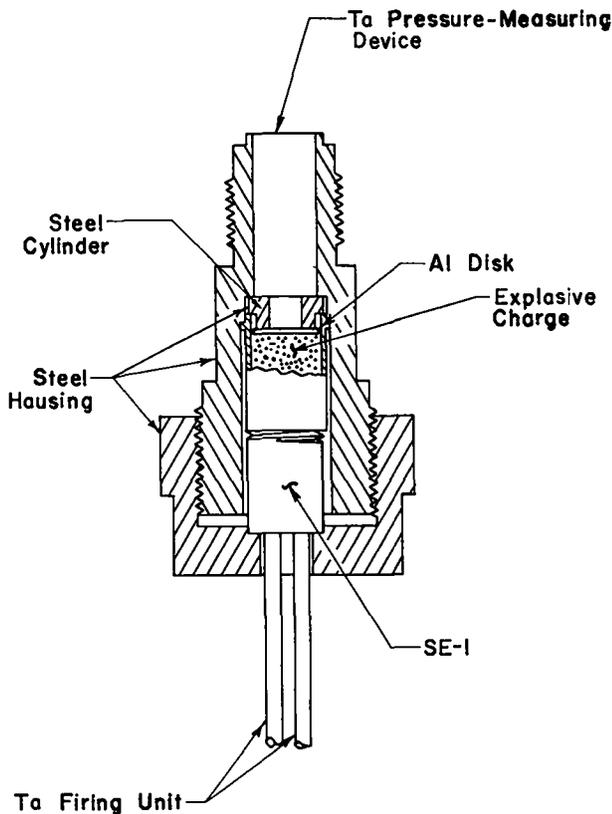


Fig. 3.  
SE-1 pressure generator.

total volume of 1.23 cm<sup>3</sup> for 454 mg of explosive at a density of 1.44 g/cm<sup>3</sup>. Using the ER-321 assembly, we measured a peak pressure of 0.03 GPa (4.4 kpsi) in a total volume of 3.38 cm<sup>3</sup> for 98 mg of HMX at a density of 1.55 g/cm<sup>3</sup>.

The lower pressures observed with the SE-1 assembly (when mass of explosive and volume are considered) result from a lack of confinement at high pressure. The SE-1 will not reliably shear a 1.27-mm-thick disk whereas the ER-321 will.

The pressure profile from each reacting explosive displayed a sharp rise. The time from start of pressure rise to the peak is about 0.5 ms. After reaching a maximum value, the pressure decays over the next several milliseconds.

TABLE III  
GAS PRESSURE GENERATION

SE-1 Test Assembly				
Explosive	Density (g/cm <sup>3</sup> )	Mass (mg)	Total Volume (cm <sup>3</sup> )	Peak Pressure (GPa/kpsi)
PETN	1.4	162	1.03	0.014/1.96
	1.6	185	1.03	0.017/2.52
	1.6	371	1.15	0.049/7.11
HMX	1.40	162	1.03	0.009/1.34
	1.40	243	1.09	0.025/3.59
	1.40	325	1.14	0.026/3.76
	1.44	454	1.23	0.053/7.72
ER-321 Test Assembly				
HMX	1.55	98	3.38	0.030/4.36
	1.55	97	3.38	0.026/3.82
	1.55	96	3.38	0.025/3.61
	1.55	97	3.38	0.028/4.07
	1.55	99	3.38	0.026/3.75

## V. PETN AND HMX AS DONOR CHARGES IN DETONATORS

### A. Deflagration-to-Detonation Transition (DDT)

Figure 4 shows the SE-1 type DDT assembly used. Its construction allows for variations in the length of the donor charge and in the diameter and length of the transition charge. The bridgewire is the same as that in the ignition and pressure-generation experiments. The booster charges were high-density PETN pellets. The criterion of detonation was a dent in an 18-mm-thick 2024 Dural witness plate placed against the face of the booster pellet.

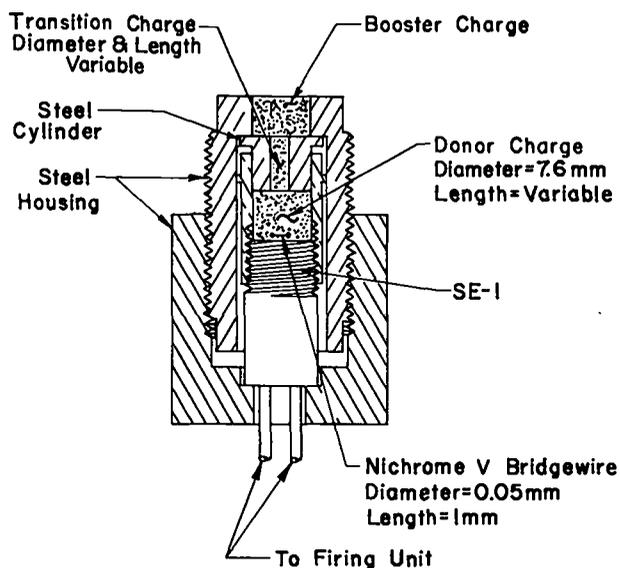


Fig. 4.  
DDT assembly.

Table IV shows the effects of donor density and transition charge variations (diameter, length, powder density, and  $S_0^p$ ) on the likelihood of a DDT reaction occurring in PETN. We consider these data preliminary. Each data point represents a maximum of three shots. Our results indicate that a DDT reaction is obtained most often in small-diameter, long-length transition charges containing relatively loose-packed, coarse explosive powder.

A similar study was made with HMX in the SE-1 assembly. DDT was obtained when transition charges were 12.8-mm long and loading density was 1.0 g/cm<sup>3</sup> or less. The powder  $S_0^p$  was less than 8500 cm<sup>2</sup>/g.

## B. Flying-Plate Detonators

The assembly used in the flying-plate initiation<sup>2</sup> experiments is similar to that used in the DDT experiments. It differs from the DDT assembly in that it contains a 6061-T6 aluminum disk that is sheared by the reacting-donor-charge gas pressure to form a 2.5-mm-diam by 0.64-mm-thick flying plate that travels down a barrel and initiates an explosive acceptor charge upon impact. The SE-1 flying-plate assembly is shown in Fig. 5.

TABLE IV  
DDT IN PETN

SE-1 Test Assembly at Ambient Temperature

Transition Charge			Donor Charge <sup>a</sup>			
$S_0^p$ = same as donor			$S_0^p$ (cm <sup>2</sup> /g)			
Diameter (mm)	Length (mm)	Density (g/cm <sup>3</sup> )	Density 1.4 g/cm <sup>3</sup>		Density 1.6 g/cm <sup>3</sup>	
			3500	8400	3500	8400
2.5	6.4	0.8	D <sup>b</sup>	ND	D	D
		1.0	D	D	D	ND
		1.2	D	ND	ND	ND
		1.4	D	ND	ND	ND
		1.6	ND <sup>c</sup>	ND	ND	ND
2.3	12.8	0.8	D	D	D	D
		1.0	D	D	D	D
		1.2	D	D	D	D
		1.4	D	ND	D	ND
		1.6	ND	ND	ND	ND
4.1	6.4	0.8	D	D	ND	ND
		1.0	D	D	D	ND
		1.2	D	ND	ND	ND
		1.4	ND	D	ND	ND
		1.6	... <sup>d</sup>	...	ND	ND
4.1	12.8	0.8	D	D	D	ND
		1.0	D	D	D	ND
		1.2	D	D	D	D
		1.4	D	ND	D	D
		1.6	ND	...	ND	ND

<sup>a</sup>Diameter = 7.6 mm; Length = 7.0 mm.

<sup>b</sup>D = Detonation.

<sup>c</sup>ND = No detonation.

<sup>d</sup> = Not tried.

The successful all-PETN systems consisted of 1.6-g/cm<sup>3</sup> donor charges between 2.5 and 7.0 mm long. The acceptor charge densities varied from 0.8 to 1.2 g/cm<sup>3</sup>. The acceptor charges were 2.1 and 2.5 mm in diameter and 6.4 mm long. The  $S_0^p$  of the PETN samples used for donor and acceptor charges ranged from 3000 to 19 000 cm<sup>2</sup>/g.

The successful all-HMX systems consisted of 1.4- and 1.6-g/cm<sup>3</sup> donor charges between 2.5 and 7.0 mm long. The acceptor charge densities varied from 0.8 to 1.4 g/cm<sup>3</sup>. The acceptor charge diameters were 2.5 and 4.1 mm and the charge lengths were 6.4 mm. The HMX was ball-milled to an  $S_0^p$  of 8300 cm<sup>2</sup>/g.

Both the HMX and the PETN systems used a booster pellet of high-density PETN or plastic-bonded RDX and a 2024 Dural witness plate.

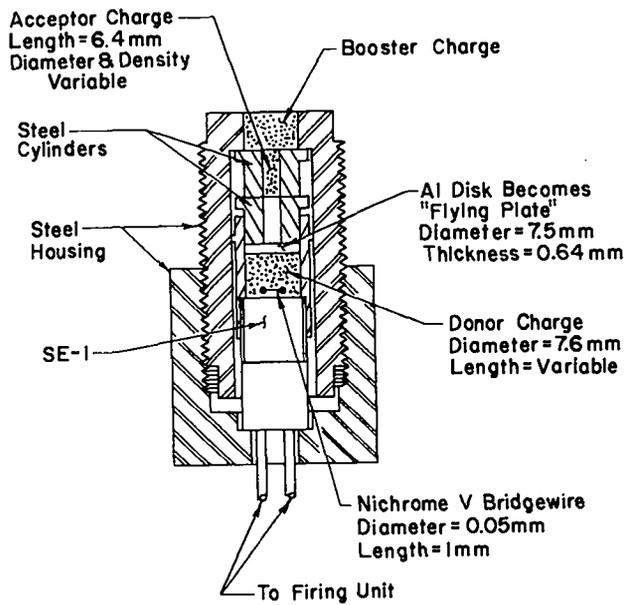


Fig. 5.  
Flying-plate assembly.

The ER-321 assembly is a flying-plate detonator by design. Assemblies loaded with  $1.7 \text{ g/cm}^3$  HMX and  $1.50 \text{ g/cm}^3$  RDX were used to detonate  $1.6 \text{ g/cm}^3$  PETN and  $1.6 \text{ g/cm}^3$  HMX booster pellets.

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