LA-7358-MS

Informal Report

c.3

The Ignition and Initiation of Potassium Picrate and Potassium Picrate/Explosives Mixtures: Nonprimary, Hot-Wire Detonators

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

LA-7358-MS
Informal Report

UC-45
Issued: August 1978

The Ignition and Initiation of Potassium Picrate and Potassium Picrate/Explosives Mixtures: Nonprimary, Hot-Wire Detonators

Robert H. Dinegar

THE IGNITION AND INITIATION OF POTASSIUM PICRATE AND POTASSIUM PICRATE/EXPLOSIVES MIXTURES: NONPRIMARY, HOT-WIRE DETONATORS

by

Robert H. Dinegar

ABSTRACT

Potassium picrate (KP) and KP blended with the explosives PETN or HMX can be ignited by a hot wire. Maximum gas pressure generation occurs in several milliseconds and is about 0.3 GPa in a volume of 0.3 cm^3. The shock from detonating PETN initiates small, brass-confined pressings of KP to steady detonation velocities of 3.5 to 5.5 km/s in the density range 1.0 to 1.6 Mg/m^3. KP mixes can be employed as deflagrating donor mixtures in two types of electric detonators. In one the high-pressure deflagration drives a stress wave into an explosive in which the deflagration is transformed into a detonation. In the other the high pressure accelerates a flying plate, which initiates detonation in an acceptor explosive upon impact.

I. INTRODUCTION

Salts of picric acid are crystalline substances that can be exploded by heat and shock. Most, however, possess inherent drawbacks to their use. For example: (1) the performance of the heavy metal salts (lead, barium, iron, and nickel) is erratic and unreliable; (2) lithium and sodium picrates form hydrates that decrease their sensitivity to ignition; and (3) ammonium picrate occurs in two forms at room temperature, the stable yellow and metastable red.[1]

The potassium salt of picric acid - potassium picrate (KP) - does not form a hydrate and normal preparation gives only one form. It also possesses a high crystal density as well as low drop-weight impact and spark sensitivities.

This report discusses: (1) the hot-wire, low-voltage ignition of KP; (2) the shock initiation to detonation of KP; (3) the hot-wire, low-voltage ignition of KP mixed with common secondary explosives; and (4), two schemes in which rapidly burning KP mixes may be used to bring about detonation of explosives.

II. IGNITION OF KP

The test vehicle for the ignition experiments is shown in Fig. 1. The ignition wire is Nichrome V, 80% Ni and 20% Cr. It is soldered between two electrodes 1 mm apart. The wire diameter was a parameter in these experiments and ranged between 0.038 and 0.508 mm.

The KP used as the ignition charge was obtained as a powder 99.5% pure. The particles had a permeametrically determined specific surface (S_o^p) of less than 100 m^2/kg. Most of our experiments were

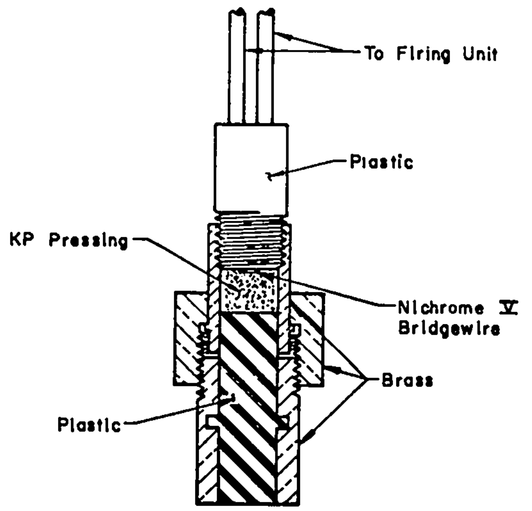

Fig. 1.
Hot-wire ignition-threshold assembly.

performed using this large-particle powder comminuted by grinding with porcelain balls to an S_0^P value of ~250 m^2/kg. The mass of the charge varied between 300 and 525 mg; the charge diameter was 7.6 mm; the length, 6.8 mm. The loading densities were between 1.0 and 1.6 Mg/m^3.

The wires were heated rapidly by passing direct current through the circuit from an external source. The voltages at which the devices fired were recorded. The voltage/current relationships in the bridgewires were measured to establish the values of the electrical parameters of the system.

Table I shows, as functions of wire diameter, the threshold (minimum) ignition voltage, current, and power required to ignite KP to burning. The data lead to several conclusions: (1) both coarse and ground KP have the same threshold of ignition; (2) the threshold is independent of loading density; and (3) the wire diameter determines the values of the threshold minima. Since there is probably a fixed ignition temperature for KP, the rough linearity of power versus the square of the wire diameter simply reflects that the more massive wires require more energy.

All loading densities of KP have approximately the same ignition threshold, for a given wire size. This does not mean that the ignition results were the same in all cases. Low-density (1.0 Mg/m^3) pressings were only marginally ignited and the reaction was quite weak. The brisance of the ignited material increased with charge density.

The threshold values of Table I are for prompt reaction (essentially instantaneous) of KP pressings. Delayed ignitions were also observed. They were most common with large wire diameters.

TABLE I

THRESHOLD IGNITION VOLTAGE,
CURRENT, AND POWER OF KP
S_0^P = <100 and 240 m^2/kg
Densities = 1.0; 1.4; 1.6 Mg/m^3

Nichrome V Bridgewire Diameter (mm)	Initial Bridgewire Resistance (Ω)	Voltage (V)	Current (A)	Power (W)
0.038	1.15	1.2	0.5	0.6
0.050	0.60	1.3	0.8	1.0
0.127	0.10	1.3	2.5	3.3
0.203	0.05	2.0	8.5	17
0.508	0.02	3.2	27	86

III. GAS PRESSURE GENERATION IN DEFLAGRATING KP

The development of the deflagration of ignition KP depends upon many factors; e.g., the specific surface of the material, the porosity of the pressing, as well as the degree of confinement of the charge. Most of our pressure measurements were made with large-particle KP and KP comminuted to a surface per unit mass of 240 - 250 m²/kg by grinding and at a porosity of slightly less than 0.2. Hot-wire, ignition-threshold assemblies (without brass/plastic plug and brass coupling ring) loaded with the powder were confined in steel bodies which, in turn, fitted into a pressure-measuring and recording setup. The assembly is shown schematically in Fig. 2. The pressure detector was a Kistler 216 MPa (30-kpsi) quartz transducer. The pressure signal received by the transducer as a function of time was transmitted to a recording system as a voltage/time output, digitized and plotted as a pressure/time graph using a previously obtained pressure-transducer calibration.

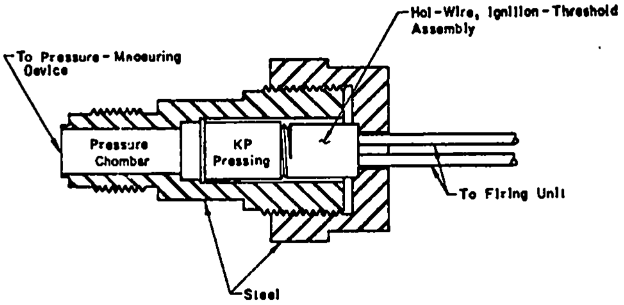

Fig. 2.
Gas pressure measurement assembly.

The data of Table II reveal that deflagrating KP generates pressure maxima of about 0.3 GPa in the test device. The values of pressure maxima seem to be relatively unaffected by a change in particle-specific surface or the diameter of the igniting wire. The time to ignition of the KP (t_{ign}), as indicated by a pressure rise, is on the order of milliseconds and does depend upon the diameter of the hot wire and the KP specific surface. The same statement can be made of the times associated with pressure maxima (t_{max}). The differences in time between the t_{ign} and t_{max} are small and constant at 0.3 and 0.4 ms. The fast rise in pressure is shown in Fig. 3, a representative trace.

TABLE II

PRESSURE (P)/TIME (t) DATA FOR IGNITED KP
Density = 1.6 Mg/m³
Ignition Voltage = 2.5 V

Material	S_0^P (m²/kg)	Nichrome V Bridgewire Diameter (mm)	t_{ign} (ms)	t_{max} (ms)	P_{max} (GPa)
KP	<100	0.038	4.2	4.5	0.2
KP	<100	0.050	2.8	3.1	0.3
KP	<100	0.127	7.8	8.1	0.3
KP-6	240	0.038	3.1	3.4	0.2
KP-7	250	0.050	1.7	2.1	0.3
KP-6	240	0.127	11.9	12.2	0.2

Notes:
t_{ign} = Total time to KP ignition.
t_{max} = Total time to maximum pressure.
P_{max} = Maximum pressure generated in test device.

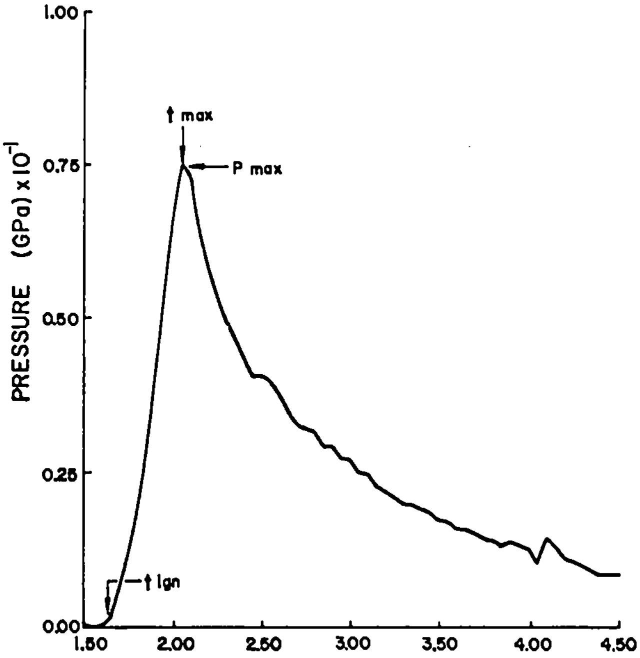

Fig. 3.
Gas pressure generation from ignited KP versus time.

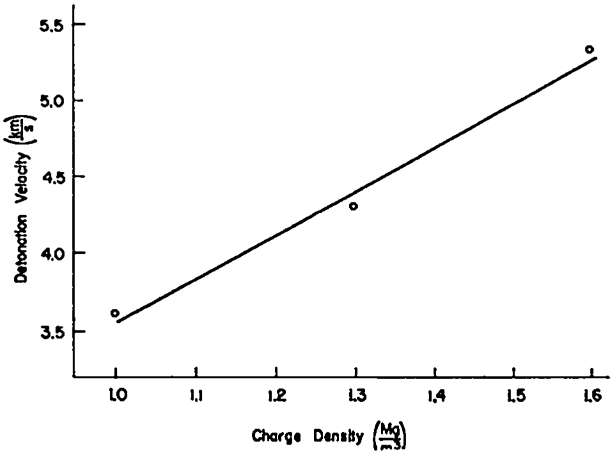

Fig. 4.
Detonation velocity of KP versus charge density.

The t_{ign} and t_{max} values appear to go through minima at 0.050-mm wire diam. We strongly suspect that the longer times with larger wires again simply reflect an increased time of wire heating. The slight increase in ignition time with the wire having the smallest diameter could be associated with poorer heat transfer to the KP crystals.

IV. INITIATION OF KP TO DETONATION

KP can be initiated to detonation by a strong shock such as emanates from the face of a detonating explosive.

Cylindrical pressings with diameter and length = 12.7 mm and loading density = 1.0 Mg/m^3, in Micarta holders (wall thickness = 0.64 mm), were initiated by the detonation from a 9407 PBX pellet (ρ = 1.6 Mg/m^3). Steady state detonation was established in the KP within 1 mm of charge length. The stable velocity was 3.8 km/s.

The variation of the detonation velocity with loading density is shown in Fig. 4. In this experiment the pressings were 7.62-mm diam by 5.16 mm long and were pressed in brass sleeves 2 mm thick. The KP particles had a specific surface of 240 m^2/kg. The KP was initiated by the shock from detonating PETN of three different densities - 0.85, 0.90, and 0.95 Mg/m^3. All three initiated KP to detonation with little delay. Significant delay times in 1.3 Mg/m^3 KP begin to occur with PETN densities of 0.8 Mg/m^3. This sets the minimum PETN detonation velocity for prompt initiation of KP as around 4 km/s. Scaling the data of Dobratz,[2] this corresponds to a Chapman-Jouget pressure (P_{CJ}) of about 3 GPa in PETN.

The plot of the detonation velocity (D) versus reciprocal of charge radius (r) for two pressing diameters at two densities is shown in Fig. 5. An extrapolation of these data gives 4.1 km/s and 4.8 km/s for the infinite-diameter detonation velocities of KP at 1.0 and 1.3 Mg/m^3. The calculated values[3] are 4.5 and 5.3 km/s. This is considered good agreement - it is about as close as is found for PETN, for example. The Eyring reaction zone lengths, "a," are 0.9 and 0.8 mm, calculated from the equation[4]

$$D_r = D_{r=\infty} - \frac{aD_{r=\infty}}{2r} .$$

The depth of a dent in a metal plate is a rough measure of the detonation pressure developed in an explosive. The average depth of the dent generated

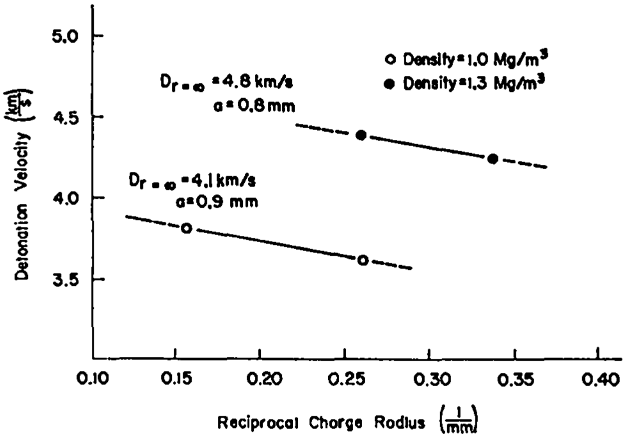

Fig. 5.
Detonation velocity of KP versus reciprocal of charge radius.

by detonating KP and detonating PETN as a function of the loading density have been measured using a "witness" plate of 20/24 Dural, 18 mm thick.

All pressings were 7.62-mm diam by 5.16 mm long; the S_o^p values were 225 m²/kg for KP and 320 for PETN. P_{CJ} for PETN is known. The P_{CJ} for KP was estimated from the following relationship.[5]

$$\left[\text{depth}_{KP} \Big/ \text{depth}_{PETN}\right] P_{CJ}^{PETN}$$

Density (Mg/m³)	**P_{CJ}^{KP} (GPa)**
1.0	5.5
1.3	11.0
1.6	18.8

The values at densities of 1.0 and 1.6 Mg/m³ are in reasonable agreement with the calculated[8] ones of 5.3 and 15.3 GPa.

V. IGNITION OF KP MIXED WITH SECONDARY EXPLOSIVES

KP mixed with secondary explosives provides material that combines good features of both components. The presence of KP permits the mixture to be ignited at low voltage levels with moderate confinement whereas the addition of the secondary explosive provides additional brisance.

KP mixed with PETN and with HMX have been studied. Table III presents the ignition data collected. A comparison of this table with Table I shows that the threshold ignition value of voltage, current, and power are essentially the same for the mixes as for pure KP. This constancy extends over a wide range of mix composition for both secondary explosives.

VI. GAS PRESSURE GENERATION IN IGNITED KP MIXES

The pressure-generation characteristics of KP/PETN and KP/HMX mixes were measured in the same manner as for pure KP. One igniter wire diameter and a single loading density were used with various compositions of mixes. Table IV shows the data collected.

The KP/PETN mixes gave t_{ign} and t_{max} that appear to become smaller with increasing amounts of PETN. KP/PETN mixes of 10/90 composition gave time values that are a little over one-half those for pure KP. P_{max} increases significantly as the per cent of KP in the mixture is reduced from 90 to 10. P_{max} for KP/PETN mix of 10/90 composition is 1-1/2 times that for pure KP.

The results with KP/HMX are not so clear-cut. The ignition times show an erratic dependance on percentage of fine-particle HMX. The pressures generated are about the same as with KP/PETN mixes, higher than with pure KP.

VII. USE OF KP AND KP MIXES AS DONOR CHARGES IN DETONATORS

We have investigated two ways in which deflagrating KP and KP mixes function successfully as donor charges in detonators. In the first, "deflagration-to-detonation-transition" (DDT) initiation, the deflagrating donor charge is coupled directly to a confined secondary explosive charge. This transition charge must be of such type, density, and size that the deflagration will change into a detonation. The second, labeled "flying-plate" (FP) initiation, involves an indirect process. The donor is ignited and the resulting pressure is used to shear a metal disk, which moves across an air gap impinging on an acceptor explosive. The acceptor explosive

TABLE III

THRESHOLD IGNITION VOLTAGE, CURRENT, AND POWER OF KP MIXES

KP	PETN	S_o^p	KP	HMX	S_o^p
(% by mass)		(m²/kg)	(% by mass)		(m²/kg)
100	---	250	50	50	580
90	10	250	25	75	740
50	50	275	10	90	850
25	75	290			
10	90	290			

Densities = 1.4 and 1.6 Mg/m³

Nichrome V Bridgewire Diameter (mm)	Initial Bridgewire Resistance (Ω)	Voltage (V)	Current (A)	Power (W)
0.050	0.6	1.4	1.0	1.4
0.127	0.1	1.4	3.0	4.2

TABLE IV

PRESSURE (P)/TIME (t) DATA FOR IGNITED KP/SECONDARY EXPLOSIVE MIXES

Nichrome V Bridgewire Diameter = 0.05 mm
Ignition Voltage = 2.5 V
KP S_o^p = 910 m²/kg PETN S_o^p = 330 m²kg
HMX S_o^p = 910 m²/kg Density = 1.6 Mg/m³

Material	KP	PETN	S_o^p	t_{ign}	t_{max}	P_{max}
	(% by mass)		(m²/kg)	(ms)	(ms)	(GPa)
KP: Mix-1	90	10	250	2.6	2.9	0.2
KP: Mix-2	50	50	275	1.7	2.0	0.3
KP: Mix-4	25	75	290	2.0	2.2	0.4
KP: Mix-3-2	10	90	310	1.5	1.7	0.5
		HMX				
KP: Mix-7	50	50	580	2.4	2.7	0.3
KP: Mix-6	25	75	740	2.0	3.3	0.3
KP: Mix-5	10	90	850	4.2	4.5	0.4

Notes:

t_{ign} = Total time to mix ignition.

t_{max} = Total time to maximum pressure.

P_{max} = Maximum pressure generated in test device.

must be of such type, density, and physical dimensions that it is shock-initiated to detonation by the impacting flying plate.

A. Deflagration-to-Detonation-Transition Initiation

Figure 6 is a diagram of the device used in DDT initiation experiments. The igniter wire is Nichrome V, 0.05-mm diam and 1 mm long. The donor charge is 7.6-mm diam and 6.8 mm long. The principal feature is the small explosive transition charge between the donor and acceptor pressings. The small diameter of the transition barrel relative to the donor charge seems to provide an interaction region, which enhances the transition to detonation.

Table V shows data we have collected using KP/PETN 10/90 (% by mass) mix as the donor charge. Both PETN and KP/PETN have been used extensively at different densities as the transition charge. Data from other experiments indicate that HMX, RDX, and HNAB also can be used. The acceptor pellet was high-density PETN of 7.6-mm diam and 5.0-mm length. The criterion for achievement of detonation in this pellet was the production of a dent in a 20/24 Dural "witness" plate (18 mm thick) placed across the face of the acceptor charge.

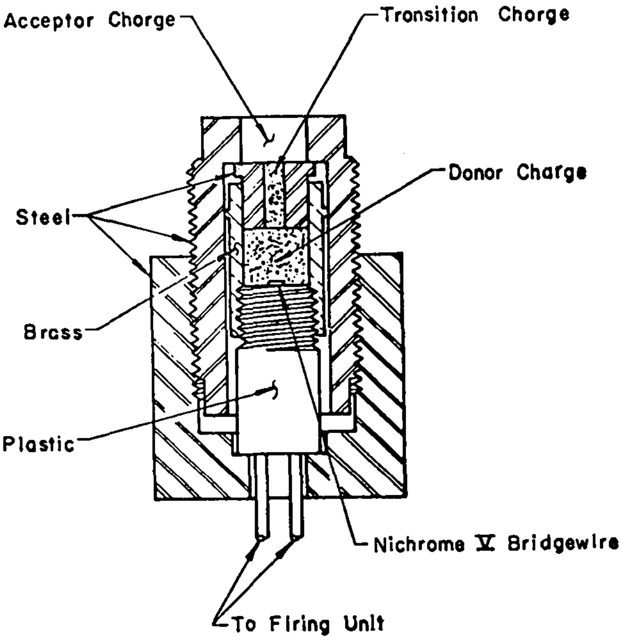

Fig. 6.
Deflagration-to-detonation-transition (DDT) assembly: small-diameter transition charge.

Apparently, there is a maximum density of the transition charge that will build up to detonation. This is not inconsistent with the picture of the DDT mechanism given by Sulimov, one aspect of which is combustion products penetrating through pores into unreacted explosive, preheating the material and helping initiation of a low-velocity detonation.[6]

The abrupt change in charge diameter between the donor and the transition pressing could cause the shearing effect shown by Campbell in 1976 to be necessary for the transition from burning to detonation in the high-density propellant FKM.[7] In our system this latter would be helpful but appears not to be absolutely necessary for the DDT reaction. KP/PETN 10/90 mixes of 1.2 Mg/m^3 density gave two detonations in four experiments when the transition charge was the same diameter and density as the donor charge, but with a length of 5 mm. The failures that occurred appeared to be caused by incomplete burning of the donor pressings. From this latter we conclude that the DDT that occurs when there is no charge-diameter discontinuity is very close to failure conditions. With a small-diameter transition pressing we have experienced no difficulty and infer that there is a reasonable margin over threshold conditions.

The length of the KP/PETN 10/90 mix donor pressing required to detonate KP/PETN 10/90 mix small-diameter transition charges also has been investigated. With low-density (1.2 Mg/m^3) pressings the donor length cannot be decreased significantly below 7 mm without failure to ignite. If the donor denstiy is 1.6 Mg/m^3, the pressing length may be decreased to slightly below 4 mm.

KP/HMX 10/90 (% by mass) mix also has been employed successfully as a donor charge. The only loading density we have found to ignite satisfactorily is 1.6 Mg/m^3. Table VI shows the data for these donors with PETN of four different densities as the transition charge. High-density PETN again was the acceptor pellet.

B. Flying-Plate Initiation of Acceptor Charge

The assembly used in flying-plate initiation experiments is shown in Fig. 7. The donor charge and

TABLE V

EFFECT OF TRANSITION CHARGE EXPLOSIVE TYPE AND DENSITY ON DETONATION OF PETN ACCEPTOR PELLET

Donor Charge	**Transition Charge**	**Acceptor Charge**
KP/PETN = 10/90% by mass	Diameter = 2.5 mm	PETN[a]
KP S_o^p = 250 m^2/kg	Length = 6.4 mm	Density = 1.6 Mg/m^3
PETN S_o^p = 330 m^2/kg		
Ignition Voltage = 2.5 V		

Donor Charge	**Transition Charge**		**Acceptor**
Density (Mg/m^3)	**Explosive**	**Density (Mg/m^3)**	
1.6	PETN[a]	0.6	Detonation
1.6	PETN[a]	0.8	Detonation
1.6	PETN[a]	1.0	Detonation
1.6	PETN[a]	1.2	Detonation and no detonation
1.6	KP/PETN 10/90	1.1	Detonation
1.6	KP/PETN 10/90	1.4	No detonation
1.2	KP/PETN 10/90	1.2	Detonation[b,c]

---

[a] PETN: Reprecipitated from acetone with water; S_o^p = 330 m^2/kg.

[b] Ignition Voltage: 40 V.

[c] Dent observed in Al slug used in place of acceptor pellet.

igniter wire have the same dimensions as in the DDT initiation assembly. In this system an aluminum disk is sheared by the pressure generated in the reacting-donor chamber, forming a "flying plate", which travels down the barrel and impacts the acceptor charge.

With large (7.6-mm diam by 5.0 mm long) acceptor pellets, pure KP did not work satisfactorily in this fixture. Only the thinnest of aluminum disks could be sheared and these did not initiate any of the acceptor explosives that were tried.

KP/PETN mixes of 50/50 composition or more PETN at loading densities 1.2 Mg/m^3 or above, all drove flying plates that did initiate high-density PETN pellets. Only limited success was achieved with KP/HMX mixes impacting large-diameter acceptor pellets. Data obtained using KP/HMX 10/90 mix donors and acceptor pellets (pressings) equal in diameter to the flying plate are shown in Table VII. Evidently, at least HMX and HNAB acceptors - at several loading densities - can be used to initiate large (7.6-mm by 5.0-mm) high-density 9407 PBX booster pellets.

Small-diameter (~1-mm) lead-sheathed, high-density PETN and aluminum-sheathed, high-density HNS mild detonating fuse (MDF) explosives also have been initiated to detonation by KP/PETN-driven flying plates. These, in turn, detonate 9407 PBX.

KP/HMX 25/75 and 10/90 mixes will bring about flying-plate initiation of PETN MDF with small-diameter igniter wires, high-density donors, and with quite thin aluminum flyers.

TABLE VI

EFFECT OF TRANSITION CHARGE DENSITY ON DETONATION OF PETN ACCEPTOR CHARGE

Donor Charge	Transition Charge	Acceptor Charge
KP/HMX = 10.90% by mass KP $S_o^p = 220\ m^2/kg$ HMX $S_o^p = 350\ m^2/kg$	PETN[a] Diameter = 2.5 mm Length = 6.4 mm	PETN[a] Density = $1.6\ Mg/m^3$

Donor Charge Density (Mg/m^3)	Transition Density (Mg/m^3)	Acceptor
1.6	0.6	Detonation[b]
1.6	0.8	Detonation[c]
1.6	1.0	Detonation[c] and no detonation[b]
1.6	1.2	No detonation[b]

---

[a] PETN: Reprecipitated from acetone with water; $S_o^p = 330\ m^2/kg$.

[b] Ignition Voltage = 40 V.

[c] Ignition Voltage = 2.5 V and 40 V.

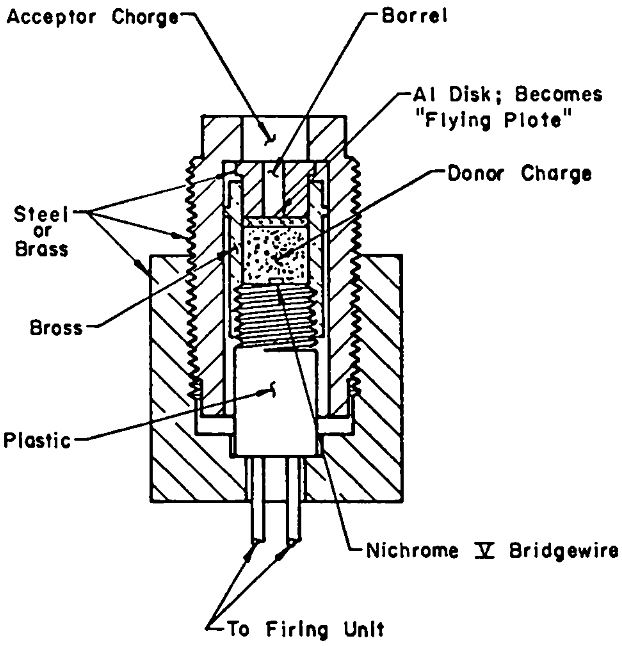

Fig. 7.
Flying-plate initiation assembly.

ACKNOWLEDGMENTS

The author wishes to thank the following persons: G. E. Seay and W. H. Meyers, as well as J. Kirkham (Atomic Weapons Research Establishment, Aldermaston, England) for many helpful discussions and suggestions; C. Mader for BKW calculations; M. Stammler and T. E. Larson for data on KP; M. Manes and R. DeWitt for the pressure measurements; and M. Mirabal and W. Patterson for skillful experimental assistance.

TABLE VII

EFFECT OF ACCEPTOR EXPLOSIVE TYPE AND DENSITY ON DETONATION OF BOOSTER CHARGE

Donor Charge	Acceptor Charge	Booster Charge
KP/HMX = 10/90% by mass	Diameter = 2.5 mm	9407 PBX
Densities = 1.4 & 1.6 Mg/m^3	Length = 6.4 mm	Density = 1.6 Mg/m^3
KP S_0^P = 220 m^2/kg		
HMX S_0^P = 360 m^2/kg		
Ignition Voltage = 2.5 V		

Flying Plate

Flyer Material: 6061-T6 Al, 0.64 mm thick
Flyer Barrel: Diameter = 2.5 mm
Flyer Barrel: Length = 6.4 mm

Acceptor Charge			Booster
Type	S_0^P (m^2/kg)	Density	D = Detonation
HMX	360	0.8	D
HMX	360	1.0	D
HMX	360	1.2	D
HMX	360	1.4	D
HNAB	<100	0.8	D
HNAB	<100	1.0	D
HNAB	<100	1.2	D
HNAB	<100	1.4	D

REFERENCES

1. Los Alamos Scientific Laboratory Group WX-2, unpublished data.

2. B. M. Dobratz, Ed., "Properties of Chemical Explosives and Explosive Simulants," Lawrence Livermore Laboratory report UCRL-5139 Rev. 1 (July 1974).

3. C. Mader, Los Alamos Scientific Laboratory Group T-14, unpublished data, 1977.

4. H. Eyring, R. E. Powell, G. H. Duffey, and R. B. Parlin, "The Stability of Detonation," Chem. Rev. 45, 69 (1948).

5. M. J. Urizar, Los Alamos Scientific Laboratory Group WX-2, unpublished data, 1977.

6. A. A. Sulimov, B. S. Ermolaev, A. A. Borisov, A. I. Korotkov, B. A. Khasainov, and V. E. Khrapovsky, "On the Mechanism of Deflagration to Detonation Transition in Gas-Permeable High Explosive," in *Proc. 6th Symp. (International) on Detonation*, Coronado, California, 24-27 August 1976 (ONR-Dept. Navy, Arlington, Virginia, 1977, ACR-221), p. 250.

7. W.Campbell, Los Alamos Scientific Laboratory Group M-3, unpublished data, 1976.

Printed in the United States of America. Available from
National Technical Information Service
US Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Microfiche $3.00

001-025	4.00	126-150	7.25	251-275	10.75	376-400	13.00	501-525	15.25
026-050	4.50	151-175	8.00	276-300	11.00	401-425	13.25	526-550	15.50
051-075	5.25	176-200	9.00	301-325	11.75	426-450	14.00	551-575	16.25
076-100	6.00	201-225	9.25	326-350	12.00	451-475	14.50	576-600	16.50
101-125	6.50	226-250	9.50	351-375	12.50	476-500	15.00	601-up	

Note: Add $2.50 for each additional 100-page increment from 601 pages up.