

CHAPTER 6

INITIATION SYSTEMS

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6 INITIATION SYSTEMS

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6.1 AWARENESS SUMMARY

6.1.1 Explosive Trains

Modern ammunition is required to be virtually 100 % reliable, because of the expensive and possibly dire consequences of a malfunction. Even more importantly, it is required to be 100 % safe to the user, in view of the high cost of accidents to personnel and equipment and because of the general lowering of morale which would result from lack of confidence in Service materiel. Munitions designers meet these requirements of safety and reliability by the use of an explosive train.

An explosive train is a sequential arrangement of explosive components with the fundamentals being an easily initiated primary explosive (initiator), a booster sensitive enough to be reliably initiated by the modest output of the initiator but also providing much higher output to initiate the relatively insensitive main charge. Figure 6-1 shows examples of both igniferous and detonating explosive trains (see 6.1.3). The burning train shows the initiation of gun propellant charge, the booster being fine grain propellant or black powder in a primer tube. The detonating train for a high explosive shell has an initiator that has a detonation shock output that detonates the booster, which in turn detonates the main charge. For detonating trains that use a sensitive primary explosive a physical arming mechanism is required to prevent inadvertent initiation of the main charge if the primary explosive is accidentally initiated such as if the munition is dropped.

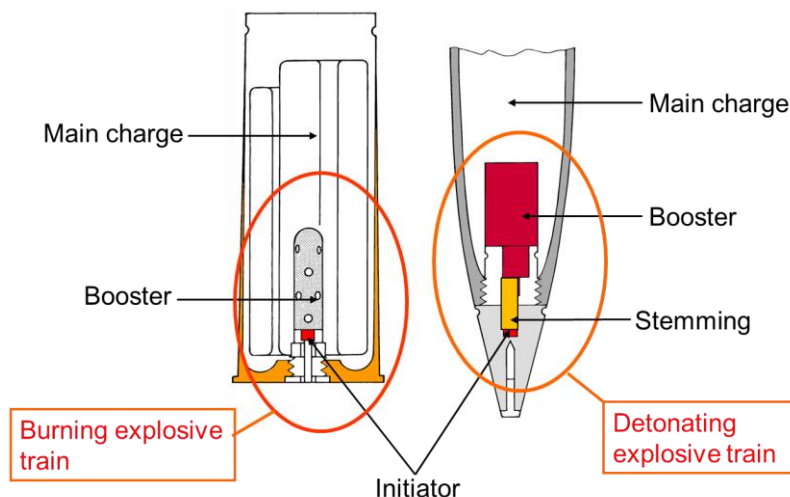


Figure 6-1 Examples of burning (gun propellant) and detonating (HE shell) explosive trains

6.1.2 In-line and Out-of-line Detonating Explosive Trains

To protect against accidental detonation of a main high explosive charge in a munition the concept of a safety and arming mechanism is employed with an out-of-line explosive train. In virtually all cases this involves the physical movement of the initiator held in a shutter that either slides or rotates to bring the initiator in line with the booster. Figure 6-2 demonstrates this concept where the primary explosive (initiator) cannot be struck by the striker while in this, the out-of-line, position. For this to arm the shutter must move and bring the initiator in line with both the striker and the booster charge. Where possible the munition should experience two independent stimuli that will then allow the shutter to move. As an example, an artillery shell fuze must experience both the g-force of launch (set-back) and rotational acceleration (spin) together before it will arm.

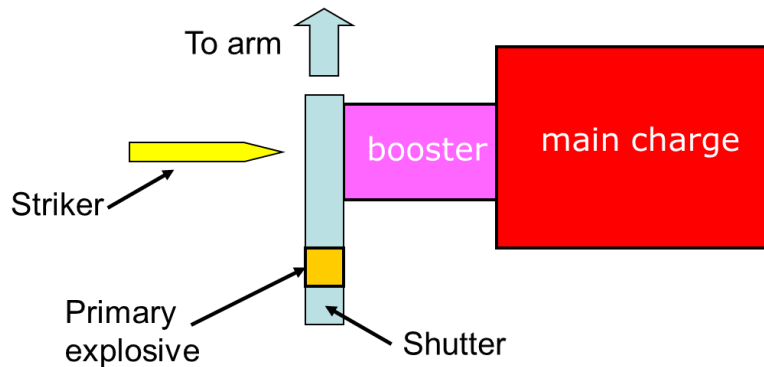


Figure 6-2 Safety and arming in the out-of-line position (not to scale)

An in-line detonating explosive train is one where all of the explosive components including the initiator are in a configuration such that if the initiator fires the explosive train will detonate. For this to provide the necessary safety against accidental detonation of the booster and main charge the initiator must not contain sensitive primary explosive. To achieve this, Exploding Bridgewire (see 6.3.4.7) and Exploding Foil Initiator (see 6.3.4.8) type detonators are employed. These contain only secondary explosive and are initiated to detonation by an electrical pulse that cannot be produced accidentally. Even then it is usual to have a safety and arming mechanism within the firing circuit for additional safety.

6.1.3 Igniferous and Disruptive Trains

All explosives burn or detonate, but undesirable forms of both processes can occur including transitions from one process to another. Explosive trains are designed to ensure that the main charge is effectively initiated to one mode or the other without risk of anomalous or inferior performance. A train intended to cause the deflagration of a propellant charge, or the combustion of a pyrotechnic charge, is called an igniferous train. Igniferous means, literally, 'fire-carrying'. A train intended to bring about detonation in a high explosive (HE) main charge is called a disruptive train. An igniferous train consists entirely of

components which burn, though some of them do so with explosive violence. A disruptive train, on the other hand, commences in nearly every case with an ignition and converts to detonation at some subsequent point in the train. This fact, however, may not be immediately obvious, even to the user of the system; the system may be so miniaturised and its effect so rapid and violent that the process appears outwardly to be entirely detonative, e.g. the UK Service L1A2 and L2A2 Demolition, detonators.

The first component of the train is designed to be triggered by some external influence a positive human action, the acceleration of the launch, an impact against a target, a change of ambient pressure or an electronic timing device. This releases a mechanical, electrical or chemical effect to act on the explosive filling of the first component of the train. This component is known as an initiator. Once the initiator functions, it acts on the next component of the train and so on until the main explosive payload is initiated by either a burning or shock stimulus.

In military explosive trains the common means of initiation are percussion, stabbing, electrical energy or friction. Friction devices are not common in British service but are widely used in foreign ammunition. The output of the initiator may be one of two general types. The first is a flash or longer-lasting flame, perhaps accompanied by a pressure pulse and/or hot particles. The other type is a detonation shock wave, usually accompanied by high-velocity metal fragments.

Each component of the train is so designed that it is reliably sensitive to the means of input and has adequate output to activate the next component. In disruptive explosive chains once detonation has been achieved then the next component must be shock sensitive enough to 'accept' the shock output from the previous 'donor' component. With igniferous explosive chains it is essential to ensure that each component is chosen to reliably accept the stimulus (e.g. hot particle or hot gas) from the previous component otherwise failure of the train will occur at the interfaces of the components. Once the ignition stimulus has been transferred to the next component in the chain reliable propagation will only continue if the heat generated by the reaction zone is sufficient to raise the next layer of unreacted composition to its ignition temperature and compensate for any radial heat losses.

The number of components in the train is the minimum consistent with the reliable and effective initiation of the main charge, whether it is HE, propellant or pyrotechnic. The number of components in and the complexity of explosive trains can vary greatly with the type of munitions. For example, hand grenades have relatively simple trains whereas modern guided weapons have very complex explosive trains which also involve simultaneous initiation of several components at different locations on the weapon system.

Another important principle of explosive trains is that the first one or two components of the train, which are intrinsically very sensitive to one or more types of stimulus, are designed in a minimum size. Succeeding components are

larger, of greater output but less sensitive. The reasons for the small size of initiators are:

1. They can be more easily shielded from external causes of accidental initiation.
2. The consequences of accidental initiations in manufacture, assembly and use are minimised.
3. The initiators can be conveniently incorporated in fail-safe mechanical devices whereby they are physically separated not only from the means of their own initiation but also from the next component.
4. Primary explosives are expensive.

Examples of igniferous (smoke grenade and propelling charge) and disruptive (warhead) explosive trains are shown below (Figure 6-3). The examples for the smoke grenade and warhead show how it is usual to have additional elements in the explosive train. The delay composition in the smoke grenade controls timing between the initiator and the booster priming composition and the stemming in the warhead transfers the detonation produced by the stab detonator to the booster. One of the main safety features of the disruptive explosive train shown below would be to incorporate the stab detonator in a fail-safe mechanical device (see 6.1.2). The high explosive and pyrotechnic compositions used in these trains are covered in the specific chapters on these types of explosive. The initiatory components in these trains contain several primary explosives and these compositions and their components are discussed in the next sections of this chapter.

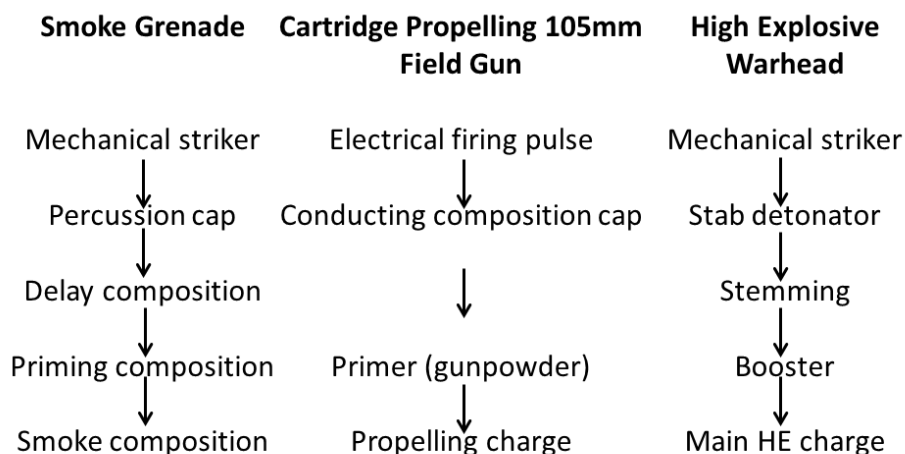


Figure 6-3 Examples of explosive trains

6.1.4 Initiators

The first component in a military explosive train is an initiator. Initiators are divided into two types, namely igniters and detonators. Igniters, or more strictly their fillings, burn when initiated by an appropriate stimulus. They produce a

flash or longer-lasting flame and thereby impart an igniferous effect to the next component.

Detonators themselves undergo detonation, though not necessarily instantaneously upon initiation, and impart a detonation shock wave to the next component in the train. All disruptive trains contain a detonator, or an equivalent component, at some point in the system.

Disruptive trains are less easy to define than igniferous ones, for several reasons. Firstly, in many cases it is necessary that the train does not function at detonation speed throughout its entire length. In many explosive trains there are requirements for pyrotechnic delays to burn between the time of initiation of the train and the required time of detonation of the main charge. Secondly, a detonation process is usually set up by burning to detonation.

This process may take place within the first component, and be completed within tens of microseconds of the initiating stimulus. Alternatively, the burning process may be designed to occupy a much longer time, perhaps seconds, before converting to detonation. Irrespective of the time which elapses between the first initiation of the train and its conversion to detonation, and irrespective of the number of igniferous stages before the conversion takes place, the component which brings about the conversion to detonation is always the detonator. A detonator can often be considered as a device for causing deflagration to detonation transition (DDT) in an explosive train, although there are detonator types where the detonation is created by very high pressure impact in EBWs and EFIs.

In general, therefore, disruptive trains commence either with an almost instantaneous detonation process brought about by a detonator, or with a burning process of appreciable duration started by an igniter and converted at a later stage to detonation via a detonator. The combination of an igniter and detonator, with or without igniferous components interposed, is common in military explosive trains.

6.1.5 Igniters and Detonators

The initiating stimuli applied to igniters can be either mechanical or electrical. The mechanical stimuli are stabbing and percussion. Electrical stimuli are provided by the use of hot-wire devices, sparking systems or the high resistance of conductive explosives. Some igniters are referred to as caps, a cap being defined in 1986 by the Ordnance Board as 'a small metal container fitted with a flame-producing explosive composition'. Although this definition covers numerous types of igniter, only the percussion and conducting explosive types are usually referred to as caps. These have in common the fact that they are often obturating (gas-sealing) components in gas-producing systems, but otherwise the differentiation between caps and other kinds of igniter is not clear.

Because detonators, unlike igniters, are not always the first component in a train, the stimuli by which they are designated are not completely identical to those used in igniter nomenclature. The mechanical method is by stabbing,

there being few requirements for percussion detonators. Electrical stimuli are provided by; for example, hot-wire devices, high-resistance conducting explosive compositions, exploding bridgewire (EBW) (see 6.3.4.7) and exploding foil initiator (EFI) (see 6.3.4.8) detonators. Detonators can also be initiated by the output of igniters or delay columns, as in the case of flash-receptive detonators.

6.1.5.1 Mechanically initiated explosive devices

Mechanically initiated igniters and detonators respond to some type of mechanical force such as percussion to activate an explosive contained in the device.

6.1.5.2 Electrically initiated explosive devices

Electro-explosive devices (EEDs) are pyrotechnic or explosive containing devices designed to be initiated by electrical means. EEDs are termed as igniters if they have an igniferous output or detonators for a detonative output and can be classified as either low voltage or high voltage types. They may be classed as single or double pole devices. Double pole devices can be initiated either by discharge directly between the poles (pin to pin discharge) or by discharge between the pins and the case via the explosive filling (pin to case discharge).

Electric detonators/igniters are often referred to as electro-explosive devices (EEDs), these include hot-wire detonators/igniters, Semi-Conductor Bridge (SCB) devices, Exploding Bridge Wire (EBW) devices and Exploding Foil Initiators (EFIs). All of these devices require the application of voltage stored in a discharging device until the voltage reaches a level that will cause the violent destruction of some component to release the energy into the explosive.

Low voltage igniters and detonators include, hot-wire, fusehead, conducting composition and Semi-Conductor Bridge (SCB) devices whilst high voltage detonators include Exploding Bridge Wire (EBW) and Exploding Foil Initiator. Both low and high voltage devices are detailed in Sections 6.2.2 (igniters) and 6.3.4 (detonators).

6.2 IGNITERS

6.2.1 Primary Explosives Used in Initiators

In contrast to conventional explosives which are materials capable of very rapid reaction, attended by the sudden liberation of a large amount of heat energy and the simultaneous formation of a large volume of gas, primary explosives are energetic materials that possess exceptionally high initiation sensitiveness (see 20.2.1) to impact, friction, electrostatic discharge, heat, and shock. The assessment of a boundary between primary and secondary explosives is a matter on which there could be considerable argument depending on the criteria

considered, but it is convenient for this purpose to take mechanical sensitiveness as the principal criteria and to classify any material with a Figure of Insensitiveness (F of I) (see 20.10.2.1) below 30 as a primary explosive, for example, lead azide (15–25), lead styphnate (18) and VH2/VH4 compositions (10).

Primary explosives are further classified according to the rate of explosive decomposition. Initiators with low rates of explosive decomposition (igniferous/deflagrating) decompose by normal chemical reactions to produce high temperatures and flames and these are used to ignite primers, propellants or pyrotechnics. Examples of igniferous/deflagrating primary explosives are the lead styphnate based percussion primer cap compositions, VH2 and VH4. Materials which detonate produce a shock wave, supersonic in the medium of the explosive which decomposes the substance instantaneously as it passes through the substance liberating energy to maintain the shock wave. The shock wave produced by the primary explosive is used to initiate the detonation of booster or main charge high explosives. Examples of detonative primary explosives are lead azide and silver azide.

The selection of an explosive for use in an igniter or detonator depends on the type of initiating stimulus to be applied, the nature of the output required and on considerations of safety, reliability and cost. The explosives used are mostly of the primary type, that is, those which are readily ignited by a small mechanical, electrical or other thermal stimulus. For use in initiators, the main requirements for primary explosives are:

1. Sufficiently sensitive to explode reliably under the designed stimulus and yet be sufficiently stable to permit manufacture, filling and normal handling in service to be carried out safely.
2. High output of flash for igniters or rapid burning to detonation for detonators.
3. Consistency of reaction time.
4. A long storage life, entailing good chemical and thermal stability and also compatibility with the materials of which initiators are commonly made.

Primary explosives may be single compounds or mixtures (compositions) of several ingredients. The number of single chemical compounds having the above requirements and which can be made easily and cheaply is fairly small with British service initiators relying mainly on the following primary explosive compounds, either in the pure state or in mixtures:

- Lead styphnate (lead 2,4,6-trinitroresorcinate)
- Barium styphnate (barium 2,4,6-trinitroresorcinate)
- Lead dinitroresorcinate (lead 2,4-dinitroresorcinate)
- Lead mononitroresorcinate
- Lead trinitrophenylglucinate
- Lead azide

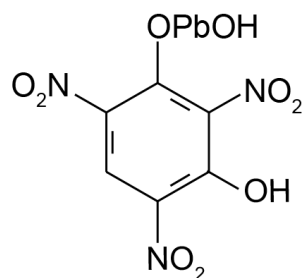
- Silver azide
- Tetrazene
- Potassium picrate

Of these compounds, the azides are essentially disruptive in nature and are used only in detonators. The others are less violent and more versatile. Other compounds used include potassium chlorate and barium nitrate, which are not explosive in the unmixed state but are useful oxidants in explosive mixtures, also antimony sulphide and calcium silicide which are fuels in such mixtures. Many of the primary explosive compounds used in British service initiators are allotted code numbers from the RD1300 series, which historically were the responsibility of the Propellants, Explosives and Rocket Motor Establishment (PERME), Waltham Abbey. Another set of code numbers is the RD1600 series (mixtures), which for many years was the responsibility of the Royal Armament Research Development Establishment (RARDE), Fort Halstead. In both cases the initials derive from the former Research Department, the forerunner of both PERME and RARDE. Following privatisation of the Royal Ordnance in 1987, Royal Ordnance Plc and latterly BAE Systems owned the rights to the RD formulations and in many instances adopted their own designations. The main igniferous and detonative primary explosive compounds and mixtures used in initiators and the devices employed are detailed in the following sections.

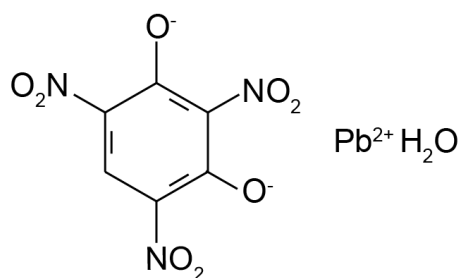
The methods of manufacture of primary explosives are detailed in Chapter 10.

6.2.1.1 Lead styphnate

Lead styphnate (lead 2,4,6-trinitroresorcinate) the lead salt of styphnic acid (2,4,6-trinitroresorcinol) has been of particular use as an initiator material. There are two forms of the salt; the Basic salt (β -form) where the crystals tend to be needle like in appearance and give rise to a powdery product and the Normal salt (α -form) which contains one molecule of water of crystallisation, the single crystal is rhombic varying from granular to prism form with a tendency to widely varying aggregation according to the conditions of its formation. The formulae for the basic and normal salts are shown in Figure 6-4.



Monobasic lead styphnate



Normal lead styphnate
(lead 2,4,6-trinitroresorecinate monohydrate)

Figure 6-4 Basic and normal lead styphnate

Lead styphnate is very sensitive to mechanical shock, friction, heat (flash) and static electricity and when dry, it can be readily ignited by static discharges from the human body. The longer and narrower the crystals, the more susceptible the material is to static electricity.

Lead styphnate is manufactured in the form of microscopic orange-brown crystals which are insoluble in water and in most organic solvents. The crystal density is 3.09 g cm^{-3} . At this density the velocity of detonation is 5200 m s^{-1} , at a density of 2.6 g cm^{-3} it is 4900 ms^{-1} and at a density of 0.93 g cm^{-3} it is 2100 m s^{-1} . Lead styphnate has an ignition temperature of 260°C and is readily ignited by flame and particularly so by electric sparks. Its F of I (see 20.10.2.1) is 20. It should be noted that in addition to F of I used to characterise the sensitiveness (see 20.2.1) of a material, the friction, thermal and electrostatic sensitiveness shall also be considered. Like all heavy metal derivative explosives, lead styphnate has a low heat of explosion ($Q=1885 \text{ J g}^{-1}$) and low power index as RD1303, (lead block = 41). It is not sufficiently brisant to be used alone in detonators, but is used for such in admixture for example with lead azide and aluminium powder in ASA (Lead Azide/Lead Styphnate/Aluminium) mixture used in the flash sensitive demolition detonators, L1A2 and L2A2. In mixtures, lead styphnate is widely used in igniters of various kinds, including percussion caps. When mixed with graphite, lead styphnate forms a “conducting composition” (CC) which is used in a number of CC igniters.

There are several different forms of lead styphnate used in British service, namely; RD1302, α -normal monohydrate which has been superseded by RD1303 which is similar to RD1302 but has a special crystal size and habit and is less susceptible to ESD. RD1303 is used as an ingredient for percussion cap composition VH4 and is mixed with powdered graphite for use in electric cap and igniter compositions. RD1346 is a free flowing form of β -monobasic lead styphnate and is used as an ingredient for priming compositions, bridgewire compositions and fast delay compositions. RD1349, β -monobasic lead styphnate is similar to RD1346 but has a modified particle size and shape to RD1336 and is used as an ingredient of priming compositions and fusehead compositions. RD1367 an α -normal lead styphnate is manufactured using a commercial process which is more economic for the manufacture of percussion cap composition, VH2. It should be noted that as all normal lead styphnate salts contain one molecule of water of crystallisation, they are unsuitable for use in stores which may be subjected to temperatures above 130°C . For this purpose, use is made of monobasic lead styphnate.

6.2.1.1.1 Properties of lead styphnates

The properties of lead styphnate, RD1303, RD1346, RD1349 and RD1367 as defined in UK Military Explosive Safety Certificates No's SC1523 (RD1303, RD1367) and Safety Certificate No SC1529 (RD1346 and RD1349) and relevant UK Defence Standards are detailed in Appendix A Table A-1

6.2.1.2 Barium styphnate

Normal barium styphnate (2,4,6-trinitroresorcinate), the barium salt of 2,4,6-trinitroresorcinol (styphnic acid) contains one molecule of water of crystallisation. It is made for British service in four different crystalline forms, RD1320, RD1320A, RD1320B and RD1340. All forms are relatively insensitive having F of Is (see 20.10.2.1) of approximately 40 - 50 and are difficult to ignite by electric spark. RD1320 is used in fuze delay compositions, RD1320A is used as a gas producer in Igniter Electric Bridgewire (IEBW) igniters, RD1320B is used as a priming composition in electric bridgewire applications. RD1340 is used as an ingredient in composition RD1652 (RD1340/potassium chlorate/antimony sulphide) an igniferous composition used in flash sensitive cap composition, an ingredient for delay compositions and an ingredient for stab sensitive and igniferous detonator and cap compositions. It should be noted that all barium styphnate salts are incompatible with sulphur, sulphides, lead and lead compounds

The formula for normal barium styphnate (barium 2,4,6-trinitroressorcinate monohydrate) is shown in Figure 6-5.

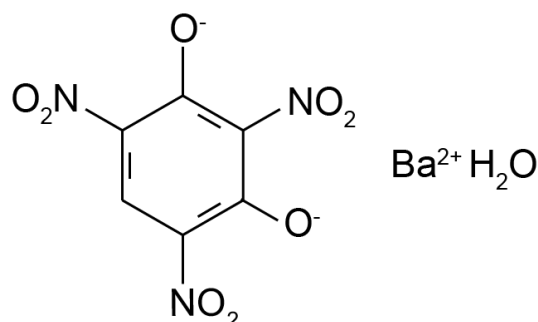


Figure 6-5 Normal barium styphnate

6.2.1.2.1 Properties of barium styphnate

The properties of barium styphnate, RD1320, RD1320A, RD1320B and RD1340 as defined in UK Military Explosive Safety Certificate Nos SC1596A (RD1320, RD1320A, RD1320B) and Safety Certificate No SC1597 (RD1340) and relevant UK Defence Standards are detailed in Appendix A Table A-2.

6.2.1.3 Lead dinitroresorcinate

Lead dinitroresorcinate (LDNR) has one less nitro-group than lead styphnate, and therefore has a lower oxygen balance and is a less violent explosive, but it is more sensitive to impact. Two structural isomers of the compound have been manufactured, usually referred to as 2,4-LDNR (RD1337) and 4,6-LDNR (RD1308) respectively. Their formulae are shown in Figure 6-6.

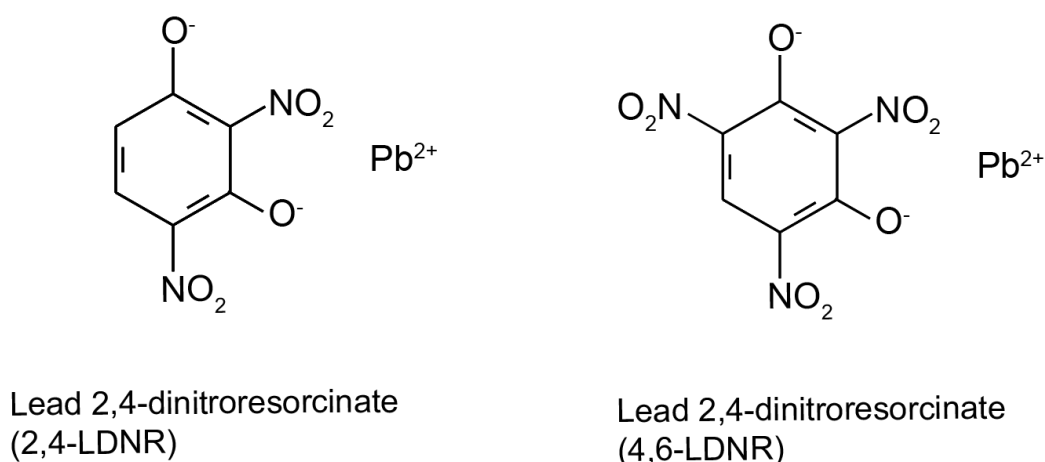


Figure 6-6 Structural isomers of lead dinitroresorcinate

The first to enter British service was 4,6-LDNR, which in monobasic form is known as RD1308 and contains carboxymethylcellulose as a granulating agent. It was used unsuccessfully in World War II as a delay for small-calibre shells but now has little or no use in military applications. Improvements to manufacturing processes resulted in the production of RD1353 which has found use as a priming and delay composition used in some bridgewire igniters, for example in composition RD1655, an igniferous, flash sensitive composition. Further refinements produced a low lead type material, RD1358 which has been used in fusehead compositions and as a gas producer.

The 2,4-isomer of LDNR was also first used in British service in World War II, originally to replace RD1308. The first version was called RD1305, and this was followed by an improvement to the manufacturing process to give a better product called RD1337, otherwise known as 'R Composition'. RD1337 is now the most important version of LDNR. It is easily and reliably initiated by percussion (F of I = 10), stabbing or by flash. It is used in admixture with barium nitrate and tetrazene in composition RD1651, commonly known as "L mixture", which is the most common filling in British service stab igniters and is also used as a priming layer in flash-receptive detonators such as RZY detonators. It conforms to the requirements of high-temperature stability since it contains no water of crystallisation.

6.2.1.4 Properties of lead dinitroresorcinate

The properties of lead dinitroresorcinate, RD1308 and RD1337 as defined in UK Military Explosive Safety Certificate No's SC832 and SC1530 (RD1308 and RD1337 respectively) and relevant UK Defence Standards are detailed in Appendix A Table A-3.

6.2.1.5 Lead trinitrophenylglucinate

Lead trinitrophenylglucinate has the formula shown in Figure 6-7. Its explosive properties are similar to those of lead styphnate and it performs better at low temperatures. Moreover, it has the advantage over normal lead styphnate of

containing no water of crystallisation and so is more resistant to high temperature conditions. It is known as RD1359 and has been used in applications where its advantages outweigh its high cost.

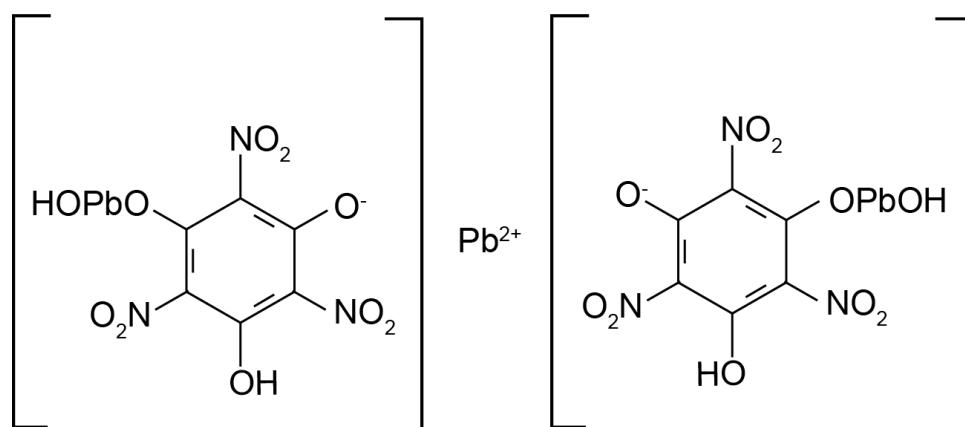


Figure 6-7 Lead trinitrophenylglucuronate

6.2.1.6 Tetrazene

Tetrazene is an organic primary explosive which, unlike those described in the foregoing paragraphs, contains no metallic elements. It is not used alone, or as a major ingredient on a weight basis, but it is an excellent sensitiser for both igniferous and disruptive mixtures, such as in VH2 and VH4 mixtures used in primer percussion caps. Tetrazene has the chemical name 1-amino-1(1H-tetrazol-5-yl)-azo-guanidine monohydrate. Its chemical formula is shown in Figure 6-8.

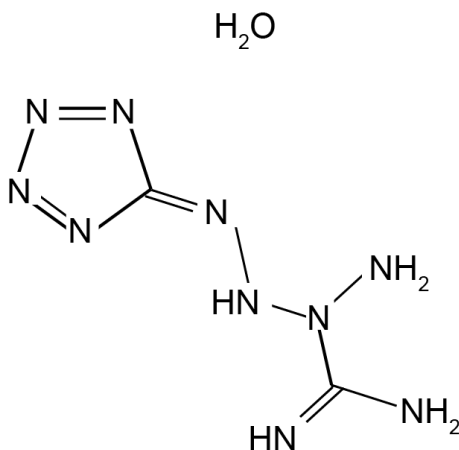


Figure 6-8 Tetrazene

It is a white or pale yellow fluffy crystalline material which can be in one of two polymorphic forms. It is not readily soluble in any common solvent and so cannot, in practice, be either purified or physically modified by recrystallisation.

Tetrazene was first used in the British service about the time of World War II. As manufactured by the original method it was an extremely difficult substance to process, but an improved method was developed which provided tetrazene of micro granular, free-flowing form and of better stability, this was designated RD1357A. Its bulk density is 0.6 g cm^{-3} and this can be increased to 1.05 g cm^{-3} by pressing at 6.9 MPa. The latter fact is, however, not relevant since tetrazene is not used alone.

The F of I (see 20.10.2.1) of tetrazene is 10, denoting a highly sensitive material. It has remarkable properties as a sensitiser of other primary explosive compounds and mixtures. When added to lead azide in quite small proportions, between 2 % w/w and 5 % w/w, it reduces the F of I considerably, but larger additions do not further increase the sensitisation. Tetrazene is also used in small proportions to sensitise stab or percussion igniter compositions based on lead styphnate or on lead dinitroresorcinate (LDNR). The omission of tetrazene in percussion cap compositions often results in unreliable ignition and in some instances failure of the caps to function.

It is believed that the sensitising effect of tetrazene in mixtures is due to the abrasion, upon stabbing or percussion, of the soft tetrazene crystals by the harder crystals of the other constituents, e.g. lead azide or barium nitrate, calcium silicide, antimony sulphide etc. This friction produces 'hot spots' too which tetrazene, with its low ignition temperature of 160°C , is particularly susceptible. The ignition of the tetrazene then initiates the whole mixture.

Tetrazene has low thermal and hydrolytic stability and will readily decompose at around 90°C and is destroyed by the addition of boiling water. As a result of this research has been undertaken by Pacific Scientific Energetic Material Co, USA in conjunction with the Office of Naval Research, USA, to find tetrazene replacements with enhanced stability⁽¹⁾.

6.2.1.6.1 Properties of tetrazene

The properties of tetrazene, RD1357A as defined in UK Military Explosive Safety Certificate No's SC802 and relevant UK Defence Standards are detailed in Appendix A Table A-4.

6.2.1.7 UK manufactured igniferous primary explosives

Examples of igniferous primary explosive compounds and compositions presently manufactured in the UK along with their use in military stores are detailed briefly in Table 6-1.

Table 6-1 Igniferous Primary Explosive Compounds/Composition and Their Use

Primary Explosive	Designation	Use
Lead Styphnate	RD1303	Composition RD1303/Graphite
	RD1349	Fuseheads, IEBW213
	RD1367	Composition ASA
Barium Styphnate	RD1320	Protractor DR2037
	RD1320A	IEBW222
	RD1340	Composition RD1652
Lead 2,4 dinitroresorcinat (LDNR)	RD1337	Composition RD1651
Potassium Picrate	RD1369M	Cap Electric 30 mm (Aden)
Tetrazene	RD1357A	Composition RD1651

6.2.2 Types of Igniter

6.2.2.1 Igniferous mixtures

It is not always possible to find a material, which meets all the requirements for a particular service use. It is therefore, often necessary to prepare mixtures of several ingredients tailored to meet the specific service requirement. Lead styphnate and LDNR, in their various chemical and crystalline forms, are used in igniters, either unmixed or mixed with other ingredients to modify their sensitivity and/or their igniferous output. These mixtures commonly contain an inorganic salt as oxidant and other materials which act as fuels or sensitisers or both. Some commonly used ingredients for initiator mixtures and their function are given in Table 6-2.

Table 6-2 Examples of Ingredients for Initiator Mixtures

Function	Ingredient
Explosive	lead styphnate, lead 2,4-dinitroresorcinat (LDNR)
Oxidant	nitrate, perchlorate, peroxide
Sensitisers	tetrazene, sulphur, ground glass
Heat Producers	calcium silicide, aluminium
Conducting Materials	graphite

A common igniferous composition of this type is RD1651, otherwise known as L Mixture consisting of the following ingredients:

- 2,4-LDNR, (RD1337) 50 % w/w
- Barium nitrate 45 % w/w

- Tetrazene 5 % w/w

This mixture is easily and reliably initiated by percussion (F of I = 15), stabbing or by flash, and can therefore, be used as either the first, or as a subsequent filling in an igniferous explosive train. Its output of flash is highly effective. It has excellent thermal stability and has a predicted Service life of 20 years. L Mixture is the most common filling in British service stab igniters. It is also used in numerous flash-receptive detonators. Other igniferous compositions, approximately formulated on similar lines include; RD1652, RD1655 and RD1658. Details of the compositions, F of I's (see 20.10.2.1) and examples of their UK service use are detailed in Table 6-3.

Some igniferous compositions are used in stores which are ultimately self-destroying and therefore the chemical nature of the products of combustion is not important, even if, like the solid chlorides deposited by chlorate and perchlorate compositions, those products are corrosive to metals. In cap compositions for the ignition of propellants in small arms, however, it is essential that the products are not corrosive to the bore of the weapon. The percussion caps used in the Service for this purpose, still contain the complex mixtures patented by von Herz in the 1920s and which are designated by his initials plus a number. Examples are the VH2 and VH4 compositions, detailed in

Table 6-4.

Table 6-3 Igniferous Primary Explosive Compositions

Primary Explosive Composition	Designation	Use	F of I
Barium Styphnate (RD1340) Potassium Chlorate Antimony Sulphide	RD1652	TVE L4A2, LMDE N2/N12, CERU 200/400 Range	20
Aluminium Lead Styphnate (RD1367) Lead Azide (Dextrinated)	ASA	Demolition detonators L1A2/L2A2	15
Lead Styphnate (RD1303) Graphite	RD1303 Graphite	TVE L4A2, CC Cap Electric (30 mm Aden)	35
Lead 2, 4 DNR (RD1337) Barium Nitrate Tetrazene	RD1651 (L Mixture)	Detonator 6.5 grn LZY, Stab Igniter 2.1 grn L (1 grain (grn) = 64.799 mg)	15
Potassium Picrate Potassium Perchlorate	RD1658	Cap Electric 2.3 grn (30 mm Aden)	30

Aluminium		(1 grain (grn) = 64.799 mg)	
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Table 6-4 Igniferous Primary Explosive Percussion Cap Compositions

Composition Designation	Ingredients (w/w)	F of I	Use
VH2	Lead styphnate (RD1367) 38 % Barium nitrate 39 % Tetrazene 2 % Antimony sulphide 5 % Calcium silicide 11 % Lead dioxide 5 %	10	Percussion caps (7.62 mm, 5.56 mm SAA) Artillery Primers Grenade Fuzes Thermal Batteries
VH4	Lead styphnate (RD1303) 27 % Barium nitrate 44 % Tetrazene 2 % Antimony sulphide 27 %	10	Mortar Bomb Primary Cartridges, PYTHON

VH2 and VH4 compositions are largely non corrosive and are used extensively as percussion cap compositions used in a wide range of small arms ammunition (SAA) including both 7.62 mm and 5.56 mm SAA respectively. Many USA primers also contain secondary explosives such as PETN which is added to increase explosive output whilst powdered aluminium may also be added to increase flame temperature. The compositions are manufactured by dry mixing of the composition ingredients. A safer and more convenient 'Eleyprime' process was developed during the 1970s. This process involved the mixing of non-explosive precursor chemicals and filling them into SAA caps. The reaction to produce the active explosives was initiated in the cap itself by adding a drop of water. However, this process was not adopted for the manufacture of British SAA caps, although the process is presently used for the manufacture of "rimfire" type caps used in commercial shot gun cartridges. As a result, the process of the dry mixing of ingredients adopted for the manufacture of compositions VH2 and VH4 continues to be used today. The manufacture of 'Eleyprime' is detailed briefly in Chapter 10.

Primer percussion L21A1 containing a percussion cap "SINOXID" composition is the trademark used for traditional primer compositions of DYNAMIT NOBEL

AG which consist of identical ingredients as VH2 composition however, ingredient ratios are not known.

6.2.2.2 Composite igniters

The number of single compounds suitable for use alone in igniters is very small, because of the requirement that the compound must not burn to detonation within the confinement of the initiator. Only lead styphnate, LDNR and to a lesser extent barium styphnate and lead trinitrophenylglucinate, are candidates for use in an unmixed state. There are two ways of enlarging the range of possible fillings. One is by employing mixtures which modify the properties of the base ingredient. Some examples of this, as applied to lead and barium styphnate and LDNR, have been described earlier. The other way is to combine two complementary fillings in one initiator, pressed in separate but contiguous layers.

One layer supplies the required sensitivity and the other provides the required output. A third layer may also be present. The principle is applied both to igniters and detonators, and they are called 'composite' types.

The contents of Service composite initiator igniters are denoted by a simple code which combines the recognised abbreviations (shown below) or other designations of the layered fillings:

L	=	L Mixture (RD1651)
P	=	Gunpowder G20
R	=	R Composition (RD 337)
SR112	=	tetranitrocarbazole (40 % w/w), potassium nitrate (60 % w/w)

An example of this nomenclature is the L/SR 112 igniter. If the letters are single the solidus is omitted, e.g. LP.

6.2.2.3 Stab igniters

Stab igniters are used to initiate flash-receptive detonators or pyrotechnic delay trains. A typical stab igniter is shown in Figure 6-9.

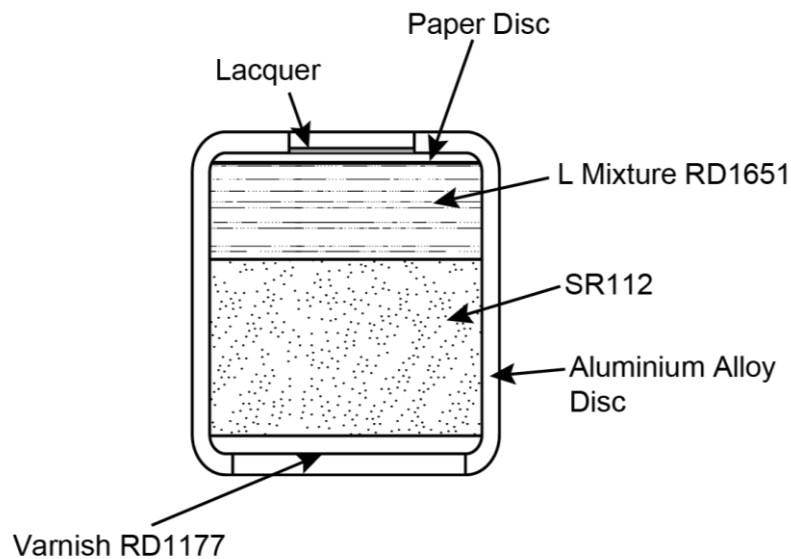


Figure 6-9 Typical stab igniter 1.5 grn L/SR 112

They are employed mainly in fuzes for shell, bombs and some pyrotechnic marker smoke stores and consist of a cup made of copper, aluminium or aluminium alloy and the filling which must be compatible with the material used. The cup is small, typically 4 mm - 5 mm in length and diameter, with a hole at both ends. The input hole is closed with a paper disc and lacquered. The output hole is closed with a thin metal disc and similarly sealed. The total filling weight varies between 0.55 grain (0.036 g) and 4.1 grain (0.27 g). Most Service stab igniters have filling weights of less than 2.0 grains (0.13 g).

If the flash component of the output is the main requirement a stab igniter is usually filled with L Mixture only. Alternatively, if the flash output needs prolonging for up to, say, 20 milliseconds a pyrotechnic layer is pressed in as a base charge and topped with L Mixture. Typical base charges are SR112 and gunpowder G20, giving fillings designated L/SR112 and LP respectively.

Stab igniters are initiated by the action of a steel striker needle, which is tapered at about 30° from parallel and has a minute flat area forming the tip. The sensitivity of stab igniters depends not only on the nature of the filling, but also on the pressing load: the greater the compaction the less striker energy is needed. The material of the input closure is also important, and a varnished or lacquered paper disc is usual for this. The overall functioning time is approximately inversely proportional to the striker velocity. Typically, the time between strike impact and output closure rupture is about 0.5 milliseconds. An example of a stab igniter-flash receptive detonator system is shown in Figure 6-10.

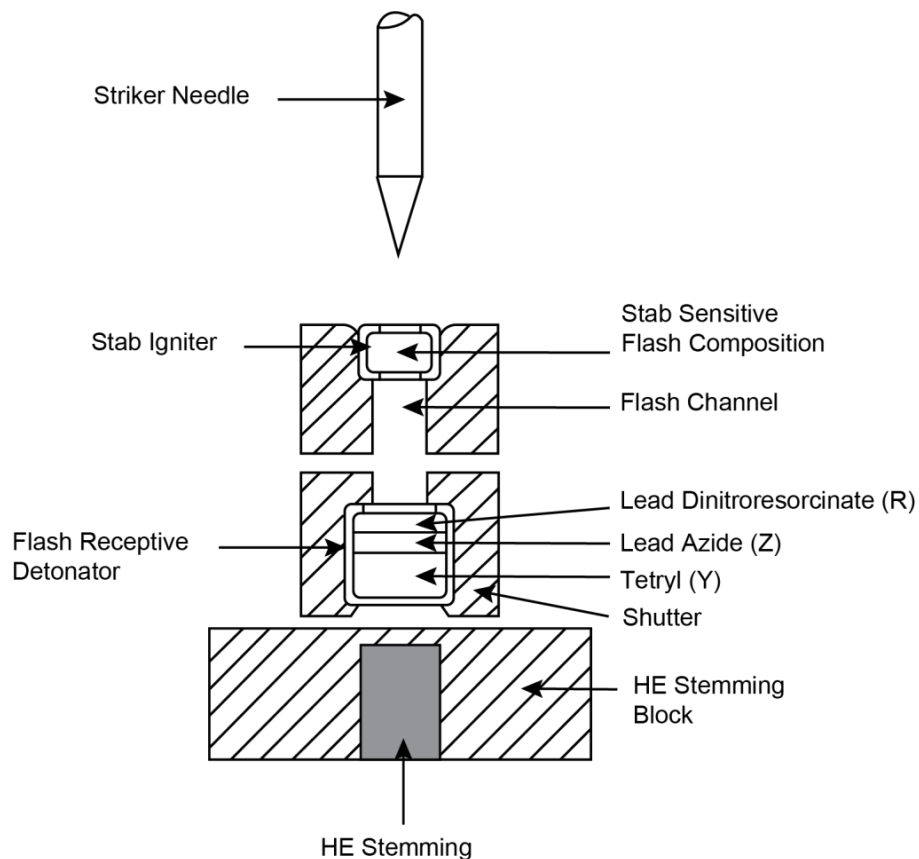


Figure 6-10 Example of a stab igniter – flash receptive detonator system

6.2.2.4 Percussion caps

Percussion caps constitute a class of igniter which are used in the Services for a variety of stores, including small arms cartridges, mortar bomb primary cartridges, some cannon and artillery primers, grenade fuzes, pyrotechnic stores and thermal batteries, also seat ejection and canopy jettison systems for aircraft. There are three types of percussion cap, namely; “Berdan”, “Boxer” and “Rimfire”. The main differences between Berdan and Boxer caps lie in the location of the anvil. In the Berdan cap the anvil is an integral part of the cap chamber (cartridge) whilst in the Boxer cap the anvil is a separate stirrup piece that sits inverted in the primer cup whereas the Rimfire dispenses with the need for an anvil. Each type is discussed below:

6.2.2.4.1 Berdan

The Berdan initiation system features an anvil that is an integral part of the cartridge case, formed by a projection of the cartridge case into the centre of the cap chamber, as shown in Figure 6-11. A cap chamber is formed in the base of the cartridge case and connected to the interior of the cartridge case by two fire holes. Some modified forms of the Berdan initiation system exist: The French modified Berdan has a narrow strip of metal forced up from the floor of the cap chamber to form a mound with a gap in the cap chamber floor underneath. The mound acts as the anvil and the gap becomes the fire hole.

The Chinese modified Berdan has a central, triangular fire hole in the floor of the cap chamber, into which is forced a small metal ball. This ball is too large to pass through the fire hole, and instead is retained in the fire hole, projecting into the cap chamber to act as the anvil, with the gaps around the metal ball allowing the flame to pass into the cartridge case cavity.

Berdan Caps are now manufactured from drawn cartridge brass. However, in the past, copper alloy and cupro-nickel were used extensively in their manufacture. The ideal metal should expand easily to provide efficient obturation while being strong enough to withstand the striker blow without being pierced and withstand the pressures generated by the initiation of the priming composition. Modern, brass, Berdan caps are manufactured as a parallel-sided cup shape, see Figure 6-12, and then varnished internally. A cap composition (or primer composition) is pressed into the cup and covered by a paper disc; this may be pressed in with the cap composition or separately. After filling, the cap is sealed with varnish. This type of percussion cap is usually only encountered in Land Service use with the NATO 7.62 mm family of munitions

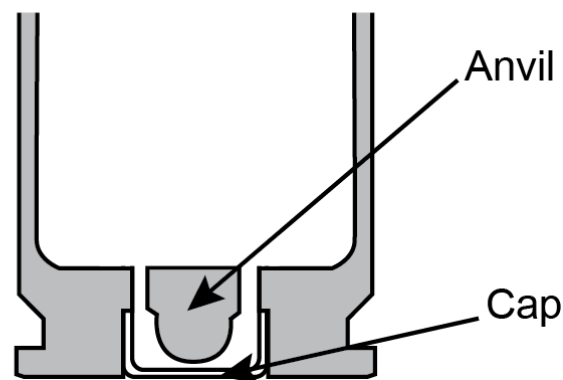


Figure 6-11 Berdan type percussion cap fitted in small arms cartridge

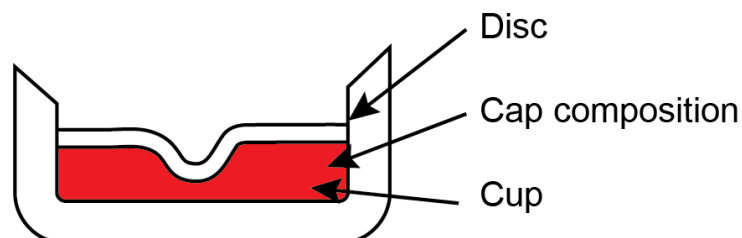


Figure 6-12 Berdan percussion cap

6.2.2.4.2 Boxer

The Boxer initiation system is in common use within most natures of Land Service SAA natures, with the exception of the 0.22 inch munitions. The Anvil is an integral component of the percussion cap. It is usually made from brass and has three holes or gaps machined into it to allow passage of the flame on firing, see Figure 6-13. The cap chamber has one central fire hole connecting to the interior cavity of the cartridge case. Boxer caps are manufactured in a similar fashion to Berdan caps, though the inclusion of the anvil necessitates an additional step of assembly to fit the anvil into the cap after pressing the paper disc into the Cap. The assembly, including anvil, are then varnished.

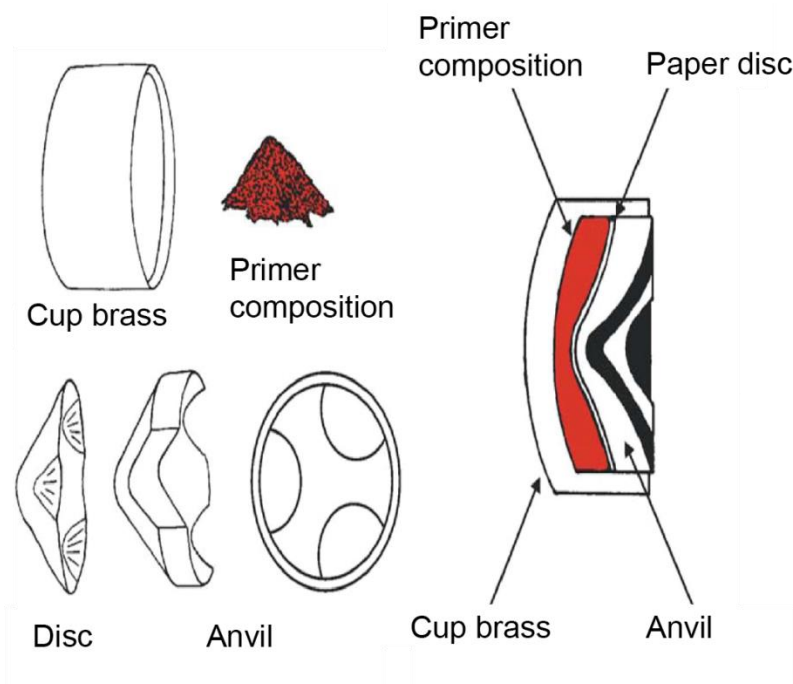


Figure 6-13 Boxer percussion cap

6.2.2.4.3 Rimfire

The Rimfire Case initiation system, shown in Figure 6-14, is used mainly in the 0.22 inch family of munitions. It dispenses with the percussion cap and anvil, in favour of locating the priming composition in a hollow rim formed internally in the base of the cartridge case. The priming composition is initiated by the off-centre firing pin crushing a part of the rim of the cartridge case, rather than crushing a cup against a central anvil.

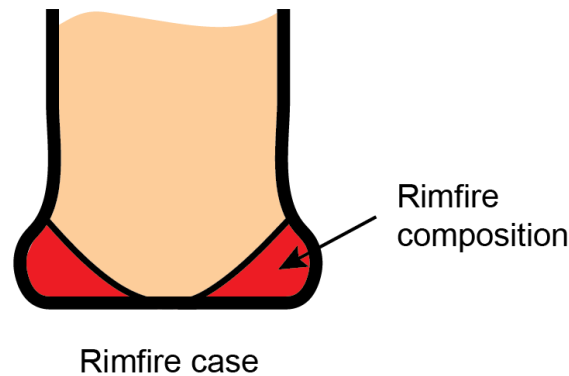


Figure 6-14 Rimfire percussion system

Both Berdan and Boxer percussion caps are classified as centre fire caps and in both cases the type of explosive filling is generally similar (i.e. VH2 or VH4 lead styphnate based compositions) whereas the Rimfire type system use Eleyprime composition.

When comparing stab igniters and percussion caps, the igniferous output required of the explosive filling is similar. However, the mechanism of initiation of a centre fire percussion cap is somewhat different from that of a stab igniter in that a cap filling rests against a metal anvil and the impact of the hemispherical-tipped firing pin on the cap causes the filling to be nipped between the deformed cap and the anvil. Initiation is therefore by impact and not by a combination of impact and friction as in a stab igniter. Also, in a cap there is ample space next to the filling for the gas to escape via the firehole(s).

An important difference between stab igniters and percussion caps is that the latter form part of an obturation (gas-sealing) system. On firing, the system has to contain a quantity of gas at high pressure for an appreciable fraction of a second, or even seconds. It is therefore vitally important that the cap does not become perforated or dislodged from its seating by the violence of its own discharge; otherwise a serious failure of the system will occur. This constraint limits both the weight of the filling and its brisance. In practice, percussion cap fillings are very small, typically between 0.025g and 0.16g. Another fairly stringent requirement is the sensitiveness (see 20.2.1) to impact which, in terms of F of I, is between 7 and 13. The requirement of non-corrosive primary explosive compositions for SAA caps has already been mentioned.

Lead styphnate is the favoured base ingredients for Service cap compositions. Lead styphnate itself is a primary high explosive which under confinement can detonate with considerable brisance. There is therefore, an upper limit of about 45% to the lead styphnate content of a cap filling; above this, mass explosion of the filling can occur, causing cap blowback and obturation failure.

Of the British service cap compositions, VH2 is the most violent and is used in SAA to give the rapid ignition on which a small propellant charge relies for its ballistic regularity. It is also used in aircraft seat ejection cartridges and canopy

jettison systems. VH4 is less violent and is used in 51 mm and 81 mm mortar bomb primary cartridges, aircraft practice bombs and flares, and in hand grenades.

6.2.2.5 Conducting composition igniters

The simplest way to employ an electric current to initiate a primary explosive is the conducting composition (CC) method. The explosive is rendered conducting by the addition of graphite, but its resistivity is kept high. If an electric current, even of low voltage, is then passed through a small charge of the composition, the heating effect will rapidly ignite it. High voltage pulses are even more effective. The conducting composition principle is more reliable than the bridgewire system, in that it employs no fragile resistance wire which can break or corrode. It also permits cheaper manufacture of ammunition. A number of non-obturator CC igniters are used in the Service for fuzes in aircraft bombs and in guided weapons. The basic features of a conducting composition igniter are shown in Figure 6-15.

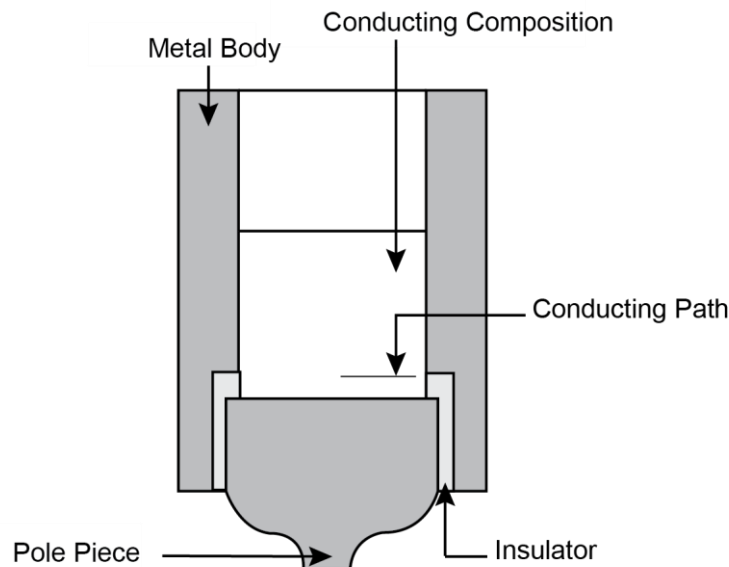


Figure 6-15 Basic features of a conducting composition igniter

The CC system is much used in the Service and can be adapted to caps in gun ammunition (i.e. CC Cap Electric, 30 mm Aden) and other, non-obturator igniters and detonators. The cap conducting cap composition was originally developed as a component of a Naval primer which must fire in a circuit with an applied voltage of 220 V with a 4 Ω series resistance. In theory they can be used for any size of gun system to which electrical power can be supplied, but in practice are used in higher calibres. Service conducting caps are made of brass. They are larger than SAA percussion caps, being typically about 11 mm in diameter and about 4 mm in length. The base of the cap is formed by the pole piece, which is insulated from the brass forming the rest of the cap. The conducting filling, roughly equal in weight to that in a percussion cap, rests on

the pole piece and is surrounded by an annular distance piece. An electric current applied to the pole piece via the firing pin of the gun must pass through the composition in order to reach the distance piece and return via the body of the cartridge and the gun. The conducting filling is RD1654, composed of lead styphnate, RD1303, with a proportion of graphite in the range 4%-6%. The firing voltage can be wide ranging, varying from 5V dc to the 115V ac supplied to the 30 mm Aden gun. An Aden conducting cap composition cap is shown in Figure 6-16.

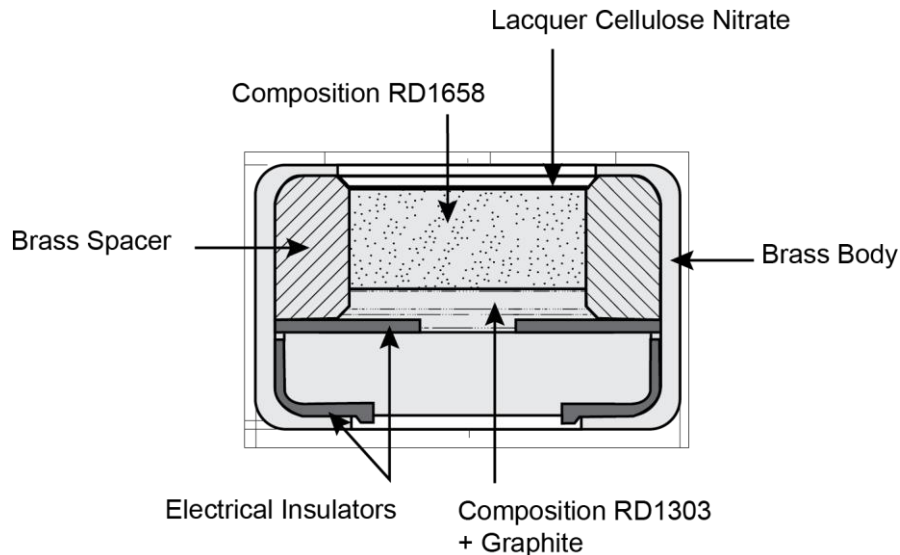


Figure 6-16 Aden conducting composition cap

6.2.2.6 Bridgewire igniters

Bridgewire igniters, often referred to as “Hot-Wire” igniters or Igniters Electric Bridgewire (IEBW), are an alternative to CC igniters, where a low voltage supply is available. These low voltage EEDs consist of a resistive wire bridge in close thermal contact with an explosive material. They are initiated by passing a current through the wire to produce a temperature rise in the explosive sufficient to cause a self-sustaining thermal reaction, leading to explosion. Thin metal bridgewires are commonly used to ignite explosive materials such as pyrotechnics, propellants and primary or secondary explosive powders. A low current, typically 3-5A, passing through the bridge wire heats it to approximately 900 K. This starts a reaction in the explosive material, usually an ignition or deflagration, which then increases to a useful output. The time between application of the current pulse and the peak output is the functioning time of the device. A wide range of ordnance applications make use of such electro-explosive devices (EEDs) including igniters, actuators and detonators. Hot-wire devices usually have a resistance of 1 Ω for electrostatic safety. A 1 Ω hot-wire device is a compromise between the energy required to ignite the energetic material and the energy dissipated by the bridge when subjected to electrostatic discharge (ESD).

They are divided into two types; bridgewire types and fusehead types. Both types contain a bridgewire, but the difference lies in the design of the insulating support for the bridgewire and in the way the primary explosive is placed against the bridgewire. In the so-called bridgewire type igniter, Figure 6-17, the wire is secured to one face of a plug of insulating material through which the lead wires are inserted to connect with the bridgewire. This assembly occupies the major part of the interior of a brass, aluminium or stainless steel sleeve. A charge of powdered primary explosive is then pressed into the remaining space, covering the bridgewire. Finally, the surface of the filling is sealed, approximately flush with the output end of the sleeve. This design is employed in a wide variety of Service uses. It can also be used as the igniting portion of an electric detonator. Bridgewire igniters are very small, some only 10 mm - 20 mm in length. Those which form part of an obturating system for a gun cartridge are known as bridgewire caps, analogously to CC caps.

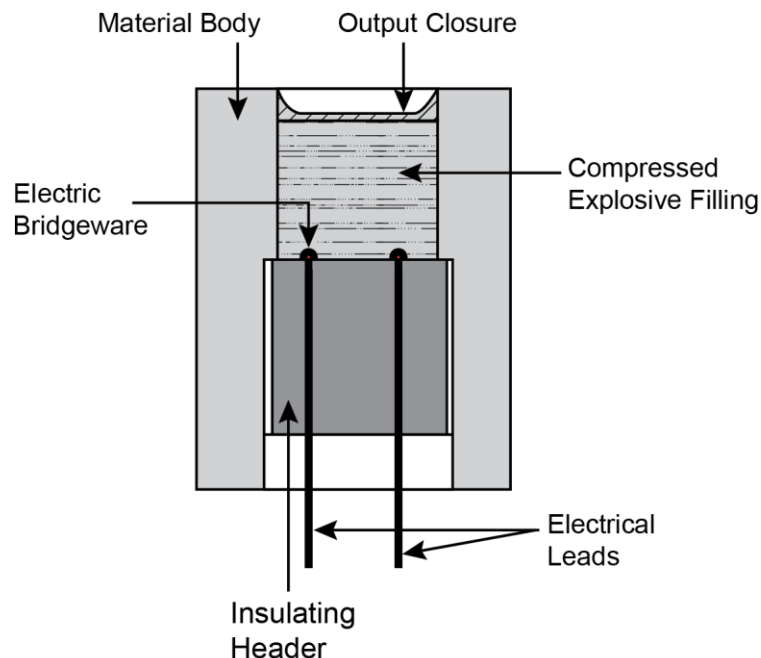


Figure 6-17 Basic features of a bridgewire igniter

The various explosive fillings of Igniters Electric Bridgewire (IEBW) include the following:

- RD1320A Barium styphnate
- RD1349 β -monobasic lead styphnate

Bridgewire igniters have found use in such stores used in Frangible Pillar Assemblies, flash-receptive detonators, Cartridge Ejector Release Units (CERU), Thermal Batteries, GW SAUs, etc.

6.2.2.7 Fusehead igniters

A fusehead, Figure 6-18, consists of a bridgewire, two lead wires and an insulating support, all of which are contained in a miniaturised, self-contained

unit compared with the relatively bulky support in a bridgewire igniter. Fuseheads are made from a laminate consisting of an insulating material sandwiched between two pieces of copper foil. A small strip of this laminate forms the support. The bridgewire is soldered across the tip, joining the two pieces of copper foil, and lead wires are soldered to the other ends of the two pieces of foil. The bridgewire is then dipped in a quick-drying liquid initiating composition. When this coating has dried a coating of a flash composition is similarly applied. These and possibly additional coatings form an explosive match-head on the wire. The assembly acts as a versatile igniting device which can be used for igniting gun cartridge primers or providing the igniferous part of electric demolition detonators. The civil version of the demolition detonator, manufactured in very large numbers for commercial blasting, also relies on a fusehead, which is secured in the open end of a detonator tube by a thermoplastic plug.

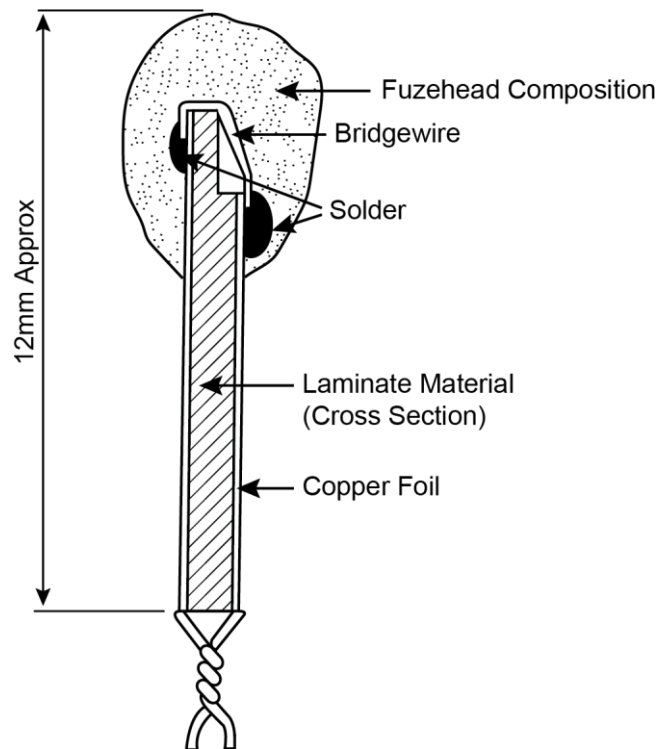


Figure 6-18 Basic features of an electric fusehead

The initiating compositions for Service fusehead igniters include mixtures of potassium chlorate with either lead mononitroresorcinate or charcoal. Other fuseheads employ normal lead styphnate or monobasic lead styphnate, RD1349. The flash composition forming the outer coating may be potassium chlorate/charcoal, cerium/red lead, 2,4-dinitroresorcinate (LDNR), normal lead styphnate or 88% tribasic lead styphnate/12% Boron (RD1361B). The liquid matrix for the initiating and flash compositions is either nitrocellulose or ethyl cellulose. Fusehead igniters are used in several military stores including for example, electric detonator demolition (L2A2) and thermal batteries.

6.2.2.8 Pyrofuse igniters

The pyrofuse igniter is an electrically initiated thermite reaction device used in the Naval service for igniting small rocket motors. It consists of a coil of pyrofuse wire wound on a bobbin and supplied with electrical power. The wire has a core of aluminium and an outer layer of palladium. When a current is passed through it, the wire undergoes resistive heating. An exothermic alloying process occurs between the two metals. This rapidly heats the wire to above its boiling point and it disintegrates in a burst of hot particles and vapour. The device has also been used in a 3 inch rocket motor.

6.2.2.9 High voltage igniters

An electric igniter which can be initiated only by a high voltage source is safer than the bridgewire and CC types, which can be initiated accidentally by stray low voltage currents. The bridgeless high-voltage squib (BHVS) utilises the conducting pyrotechnic composition SR72C consisting of copper (II) oxide (67%), aluminium (33%). This thermite-type mixture is ignited by the passage of a current from a 0.5 pF capacitor charged to 2000V. The BHVS is used in certain rocket motor igniters where the necessary high voltage is available. Further to the BHVS, high voltage exploding bridgewire (EBW) initiators have been employed for the ignition of certain large rocket motors.

6.3 DETONATORS

The Service definition of a detonator is “a device containing a sensitive explosive intended to produce a detonation wave”. Most but not all detonators are devices designed to convert burning to detonation. The range of timescales in which different kinds of detonator combine the two processes is very wide, from a few microseconds in the more advanced types to a designed delay of several seconds in some commercial blasting detonators. Irrespective of the means by which the detonator is designed to be initiated, the preliminary burning process generally involves fillings of the types discussed in the proceeding paragraphs and occupies the major portion of the total functioning time. The ultimate detonation process, with only a very small filling of high explosive to be consumed, occupies only about 1 μ s.

Service detonators can be divided into fuze detonators and demolition detonators. A fuze is a device to control the initiation of a main charge. The role of a fuze detonator is to initiate the main charge of a high explosive munition or sub-munition. Generally, it does so through a disruptive explosive train, and in most cases the fuze detonator itself is a miniature explosive train.

A demolition detonator is the first disruptive initiator in a hand-placed explosive train for the purpose of a demolition. A Service demolition detonator is considerably larger than a fuze detonator, partly because the explosive filling is larger but mainly because it contains its own igniter in the form of an electric fusehead. In another respect, a demolition detonator is comparable to a fuze detonator in that they both contain a miniature disruptive train within a metal

container. There is little to distinguish the Service detonators, L1A2 and L2A2 Detonator Demolition from their nearest civil counterparts, the high-strength, so-called 'instantaneous' electric blasting detonator, but the latter has many variants in terms of different manufacturers, strengths, delay times and means of initiation.

6.3.1 Primary Explosives Used in Detonators

Detonator fillings comprise both primary and secondary high explosives and most of them are much more brisant than the most violent of the primary igniferous types, such as lead styphnate. The igniferous types are included in detonator fillings only to provide sensitivity to input and to assist the process of burning to detonation. Detonative primary explosives used and typical devices are detailed in the following sections. The methods of manufacture of primary explosives are detailed in Chapter 10.

6.3.1.1 Lead azide

Lead azide was discovered by Curtius who first prepared and characterised its explosive properties in 1891. Lead (II) azide is a primary high explosive which has been the mainstay of Service detonator fillings since the early to mid-20th century. Like all other primary explosives, it does not completely meet the ideal requirements, but its safety, reliability and performance are all acceptable when it is manufactured and used in the light of accumulated knowledge and experience. Lead azide (PbN_6) is the lead salt of hydrazoic acid (HN_3) and has the structural formula shown in **Figure 6-19**.

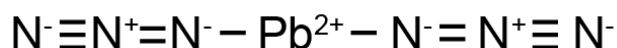


Figure 6-19 Lead azide

It is manufactured in the form of microscopic white crystals which have an absolute density of 4.8 gcm^{-3} . The crystals do not melt on heating but detonate violently at $320^\circ\text{C} - 360^\circ\text{C}$ depending on the rate of heating. Lead azide has good thermal stability at moderately elevated temperatures.

Lead azide, unlike most other practical explosives, contains no carbon, hydrogen or oxygen. Its explosion products comprise only nitrogen and lead vapour; therefore its calculated heat of explosion is low, being simply its heat of formation with the sign changed. For the same reason its gas volume, usually calculated as the nitrogen volume only, is one-third of that of a CHNO explosive. The calculated power index (see Table 4.6) is only 13 but in the lead block test the practical result is 37. These properties are unexceptional for a primary explosive, but the advantages of lead azide lie elsewhere. Its simple mode of decomposition enables it to burn instantly to detonation even in milligram quantities. It has high density, and moreover can be compressed nearly to its absolute density without loss of sensitivity, a phenomenon known

as 'dead-pressing' where sensitiveness (see 20.2.1) is reduced at high densities. It therefore has a high detonation velocity for a primary explosive and high brisance. The consequent ability of lead azide to induce detonation in secondary explosives is almost unrivalled in its class. This has enabled the size of detonator fillings to be reduced to conveniently small dimensions, an immense benefit in the design of military explosive trains. Lead azide is not, however, sufficiently sensitive for either flash or stabbing to be used in Service detonators without an appropriate topping of a more sensitive explosive such as RD1651 (L mixture).

Lead azide has four polymorphic forms, α , β , γ , δ which differ in their sensitiveness (see 20.2.1) to impact and friction. The manufacture of lead azide suitable for loading into detonators was subject of interest and concern to both military and commercial operators since the replacement of mercury fulminate began in the 1920s and 1930s. Preparation of lead azide was associated with difficulties brought about by the extreme sensitiveness of the material, in part due to polymorphic modification. Under certain conditions lead azide will spontaneously explode.

Lead azide is hydrolytically unstable and can degrade in the presence of moisture, carbon dioxide and certain vapours given off by some synthetic polymers, to produce hydrazoic acid a highly sensitive explosive and extremely toxic compound. This acid in turn will attack copper and any copper rich alloys present in ammunition or fuzes to produce the extremely sensitive copper azide. Lead azides are compatible with lead styphnate and with tetrazene. There are several manufactured forms of lead azide as discussed below.

6.3.1.2 Service lead azide (SLA)

Service lead azide (α -form) consists of small rhombic crystals and must not contain dust, needle shaped crystals or large crystals, as these may be super sensitive. The material is not sufficiently sensitive to pricking by a needle to allow it to be used in stab-sensitive detonators without a sensitiser or a top increment of a stab-sensitive composition such as RD1651 (L mixture) containing RD1337 (lead 2,4-dinitroresorcinate, barium nitrate and tetrazene).

Service lead azide suffers from several disadvantages. It is especially sensitive to ignition by friction in the presence of grit. Over the years there have been many instances of ignitions during filling operations generally attributed to this. Also, because of its hard crystalline nature Service lead azide does not have good binding properties when consolidated into narrow channels for fuzes where high resistance to break-up forces is an essential safety requirement. This has resulted in the development and production of new types of lead azide processes and products which have advantages in processing, loading and functioning.

The main application of Service lead azide was the main filling for a wide range of service detonators including 2.3 grn LZY, 6.5 grn LZY, 2.6 grn LZ, 3.5 grn LZ, 6 grn ZY, 2 grn RZY, 1.5 grn RZY, Table 6-5.

6.3.1.3 Pure lead azide, RD1339

The purest of the lead azides, RD1339, is the α -form, and is of controlled crystal size. It has an F of I of 30 and a detonation velocity of 4550 m s^{-1} at a pressed density of 3.8 g cm^{-3} . The crystallisation of lead azide in the presence of non-ionic surface active agents was studied with the objective of developing a safe and reproducible method of preparation of pure lead azide suitable for technical applications where highest output was required. As a result, pure lead azide designated RD1339 was developed for mixing with powdered graphite without segregation for application to conducting composition detonators⁽²⁾. No existing lead azide composition could meet this requirement.

The main application of pure lead azide, RD1339 is a conducting composition (RD1339/graphite) for use in electric detonators (i.e. detonator electric CC No1 and No2, Mk1, detonator electric NBC 170mg, 2.6 grn).

6.3.1.4 Colloidal co-precipitated lead azide, RD1343

The other lead azide composition in Service use is RD1343. This is originated from the early discovery that the occasional spontaneous detonations of lead azide which occurred during manufacture can be avoided altogether by adding hydrophilic colloids to the precipitating solutions. Further to this a demand for lead azide of greater purity and initiating efficiency, weight for weight than the dextrinated type (see RD1352) and to obtain a form of lead azide suitable for pressing into open ended sleeves without the danger of flaking on the surface, resulted in the development of RD1343, a “phelgmatised lead azide” so called as it contained a small proportion of a cellulose substance, (sodium carboxymethylcellulose) that desensitises the azide and helps to bind the pressed crystals. RD1343 was designed to give the best combination of a simple process, high azide value and optimum physical properties. Its natural moisture content is very low and it is non-hygroscopic. The material consists of white, discrete free flowing crystals which give a material of increased bulk density and reduced hygroscopicity. The product is free from small particles but has excellent pressing properties.

Note: RD1343 is an improved version of lead azide RD1333, having improved flow properties for automatic loading systems.

The main application of, colloidal co-precipitated lead azide, RD1343 is the filling for detonators excluding CC types and includes 1.5 grn RZY, 2.3 grn LZY, 2.6 grn LZ, 2 g RZY, 5.5 grn LZ, Table 6-5.

6.3.1.5 Dextrinated lead azide, RD1352

Dextrin (a form of starch) is a favoured additive in the preparation of lead azide. It suppresses the formation of the undesired β -polymorph, acts as a desensitiser, albeit at the expense of performance and tends to give white “dumb-bell” shaped or well-rounded crystals which are free from large single crystals and large aggregates. The product designated RD1352, has consistent

chemical and physical characteristics, including higher azide content and higher bulk density. These benefits result from the use during the precipitation stage of an ionic surfactant (dispersing agent) in addition to the dextrin.

The uniformity and good flowing properties of dextrinated lead azide, RD1352 and colloidal co-precipitated lead azide, RD1343 make them both very suitable for use in automatic loading machines.

The main application of dextrinated lead azide, RD1352 is use in NATO or USA detonator types (i.e. Relay detonators M7, M17; Stab detonators M22, M24; M215 detonator non-electric etc.). In UK Service stores RD1352 is used in Detonator demolition L1A2 and L2A2.

6.3.1.6 Lead azide GAM

Lead azide GAM developed and introduced in 1967 consists of a mixture of Gelatin, Lead Azide and Molybdenum disulphide. Molybdenum disulphide was added to overcome the poor cohesive properties of Gelatin/Lead azide mixture. The electrical properties of the GAM product are excellent; however, the bulk density and power of GAM lead azide are lower than those of Dextrinated lead azide. The main application of lead azide GAM, is use in the DR series of detonators, as shown in Table 6-5.

6.3.1.7 Basic lead azide

It has been reported⁽³⁾ that the High Energy Materials Research Laboratory (HEMRL), Pune, India, has undertaken research studies on primary explosives with a view to synthesising a series of new lead azides, which are safer, powerful and free from the drawbacks of current lead azide. It has been reported that HEMRL has successfully synthesised and developed a new and safer lead azide called basic lead azide (BLA) which has been assigned the empirical formula $[3\text{Pb}(\text{N}_3)_2 \cdot 2\text{PbO}]$. The material is reported to be a crystalline free flowing and non-hygroscopic material having a bulk density of $2.0 \pm 0.2 \text{ g cm}^{-3}$, which detonates high explosives efficiently and has a better thermal and hydrolytic stability compared to other lead azides. Further to this the material has better compatibility with copper than service lead azide (SLA) and is less sensitive to impact and friction than SLA having a F of I = 65-72 (see 20.10.2.1) compared to a F of I = 20 – 30 for SLA. BLA has been made sensitive to flash pick up by the addition of trinitrophenylglucitol (TNPG) during manufacture and therefore, requires a smaller quantity of lead styphnate in detonating compositions such as ASA (Lead Azide/Lead Styphnate/Aluminium). Based on the characteristics of ASA composition and the properties of BLA, a composition using BLA, designated as BLASA, was formulated (BLA/LS/Aluminium powder: 80/19/1 % w/w) and compared to ASA (65.0/32.5/2.5 % w/w). The sensitiveness to impact and friction of ASA and BLASA (F of I = 15 and 64 for ASA and BLASA respectively) showing that the BLASA composition to be much less sensitive than the ASA composition. BLASA compositions are now used instead of ASA composition in a range of

tubular and closed detonators manufactured in India but to date have not found service in the UK.

6.3.1.8 Properties of lead azides

The properties of Service lead azide (SLA), RD1339, RD1343, RD1352 and Lead azide GAM, as defined in UK Military Explosive Safety Certificate No's SC120B, SC1514, SC1585, SC1501 (SLA, RD1339, RD1343, RD1352 respectively and relevant UK Defence Standards) are detailed in Appendix A Table A-5.

6.3.1.9 Silver Azide

Silver(I) azide was first prepared by Curtius in 1890 and is the silver salt of hydrazoic acid and has the structural formula AgN_3 shown in

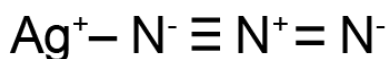


Figure 6-20.

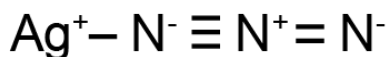


Figure 6-20 Silver azide

Its white microscopic crystals, which darken on exposure to light, have a density of 4.81 g cm^{-3} . There is only one crystal form at ordinary temperatures. Silver azide does not melt on heating but detonates at 273°C , which is a considerably lower temperature than that of the lead salt. Its thermal stability at intermediate temperatures is even better than that of lead azide. Silver azide has an F of I of 25, a lower detonation velocity than lead azide and about the same capacity to initiate secondary explosives to detonation. Like lead azide, when used in detonators it needs to be initiated by a more sensitive explosive.

The chief advantage of silver azide over lead azide is that it is not subject to hydrolysis by moisture; therefore, it is used as a replacement for the lead salt in certain detonators exposed to humid environments. Silver azide has its own disadvantages; like lead azide, it is incompatible with copper, but unlike lead azide it is also incompatible with tetrazene which precludes its use in RD1651 (L mixture) which contains tetrazene. Furthermore, it is incompatible with sulphur compounds including antimony sulphide. There are two Service silver azides having the designations RD1336 and RD1374.

6.3.1.10 Silver azide, RD1336

RD1336 consists of a free flowing material consisting of aggregates of orthorhombic shaped crystals. Difficulties in applying this material to automated detonator filling, "fortress filling" resulted in the development of a modified silver azide, designated RD1374.

The main application of silver azide, RD1336 was in composite detonators (of the flash receptive type) to replace lead azide when the environmental conditions may cause deterioration of the lead azide. (i.e. 2.25 g RWY, 2.1 g RWY, 1.45 g RWY).

6.3.1.11 Silver azide, RD1374

RD1374 has a smaller particle size to RD1336 giving a material of higher bulk density (1.4 g cm^{-3}) compared to RD1336 (0.75 g cm^{-3}) which is better for automated detonator filling processes such as “fortress filling”. The main application of silver azide, RD1374 is as a direct replacement for RD1336 used in the 2.25 grn RWY detonator for Fuze L106.

6.3.1.12 Properties of silver azides

The properties of silver azide, RD1336 and RD1374 as defined in UK Military Explosive Safety Certificate No SC1584A and relevant UK Defence Standards are detailed in Appendix A Table A-6.

6.3.2 UK manufactured detonative primary explosives

Examples of detonative primary explosive compounds and compositions presently manufactured in the UK along with their use in military stores are detailed briefly Table 6-5.

Table 6-5 Detonative Primary Explosive Compounds/Compositions and Their Use

Primary Explosive	Designation	Use
Lead Azide GAM	Lead Azide GAM	Detonators DR7004, DR7009, DR7046, DR7047, DR7050, DR7052, DR7054 (long tube fusehead initiated detonators)
Dextrinated Lead Azide	RD1352	Detonator demolition L1A1, L2A2 (ASA composition)
Service Lead Azide	SLA	Detonator 6.5 grn LZY, Depth Charge MII MoD 3-Detonator 2.3 grn LZY Base Percussion L56A1 (120 mm HESH & WP) Detonator 2.3 grn LZY,
Colloidal Lead Azide	CLA	Detonator DR7025 (SAUs)
Silver Azide	RD1374	Detonator 2.25 grn RWY (Rapier)

6.3.3 Types of Detonator

6.3.3.1 Disruptive mixtures

In the same way that igniferous mixtures are used in igniters, some mixtures used in detonators combine the useful properties of two or three ingredients. Lead azide can be sensitised to impact by the addition of tetrazene, and alternatively can be made into a conducting composition by the inclusion of

graphite. Service detonators Detonator Demolition L1A2 and L2A2 contain the flash-sensitive A.S.A. Mixture, comprising, Lead Azide (68 % w/w), Lead Styphnate (29 % w/w), Aluminium (3 % w/w). This mixture readily burns to detonation. The inclusion of aluminium is twofold, firstly it improves its free-flowing capability and secondly it prevents the mixture building up on the punches during pressing. However, the inclusion of aluminium has a sensitising effect on the composition. The F of I of A.S.A. mixture is 15, an indication of the danger attending any maltreatment of demolition detonators.

6.3.3.2 Composite detonators

In general, the output required of Service detonators is obtained more by composite arrangements of single explosive compounds than by mixtures. The most common igniferous layers are L Mixture (RD1651), employed for its sensitivity to stabbing, and R Composition (2,4-LDNR) which is flash-sensitive. The igniferous layer is followed in most cases by lead azide in the form of RD1339 or RD1343, replaced in a few instances by silver azide, RD1374.

Fuze detonators, though necessarily small in size, are required to have sufficient detonation pressure to transmit a shock wave across an air gap and through a metal septum to the boosting explosive. To achieve this reliably, many fuze detonators contain a layer of secondary boosting explosive adjacent the azide layer. This base charge has for many decades been of tetryl, but is currently being replaced by the other types of secondary high explosives such as RDX or PETN.

As with igniters, the fillings of composite detonators are often designated by initial letters, as follows:

L	=	L Mixture, RD1651
R	=	2,4-lead dinitroresorcinate (LDNR), RD1337
RDX	=	RDX, RD1347
W	=	Silver azide, RD1374
Y	=	Tetryl (CE)
Z	=	Lead azide, RD1343.

The ways of combining these letters are the same as for composite igniters.

A composite flash receptive detonator, 2.1 grn RZY (2,4 LDNR, Service lead azide, tetryl) is shown in Figure 6-21.

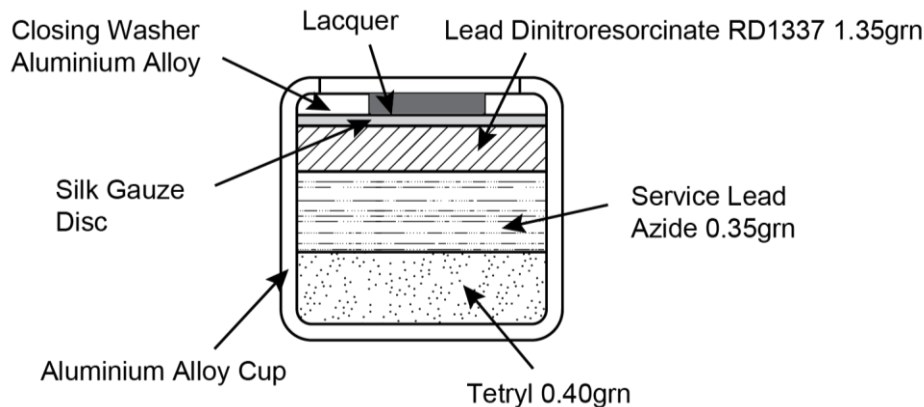


Figure 6-21 2.1 grain RZY composite detonator

6.3.3.3 Stab detonators

Stab detonators are similar to stab igniters in respect of their means of initiation, cup material (aluminium, aluminium alloy or tinned copper), the initiating layer (L Mixture) and typical weight of filling (2 grains - 3 grains, 0.1 g - 0.2 g). They are mostly of the LZ, LZY, or LZ/RDX categories. The majority of them are filled and pressed from the input (open) end, leaving the base of the cup intact; this is known as direct loading (DL). Some are filled by indirect loading, that is, the output end of the cup is perforated and the layers are filled and pressed from that end, after which the hole is closed by an aluminium disc. Indirect-loaded (IL) stab detonators have a lower performance than direct-loaded (DL) ones as measured by the thickness of metal septum through which they can initiate a booster charge. Also they are less tolerant than DL detonators to variation of the thickness of the cup base; the IL type needs a very small (0.13 mm) and critical thickness of the closing disc for its effectiveness.

The functioning time for a stab detonator, from striker contact to base rupture, is of the order of 0.3 milliseconds, which is not very different from the total time of an igniter/flash-receptive detonator combination. It would appear, therefore, that most of the functioning time is taken up by the process of the L Mixture igniting from the effect of the stab, and that the process of the azide layer burning to detonation takes comparatively little time. To put the functioning time into perspective, it should be remembered that some time must be added for the acceleration of a spring-loaded striker to a speed of 1 ms^{-1} - 2 ms^{-1} . Stab detonators have been widely applied in fuzes following the format example shown in Figure 6-22.

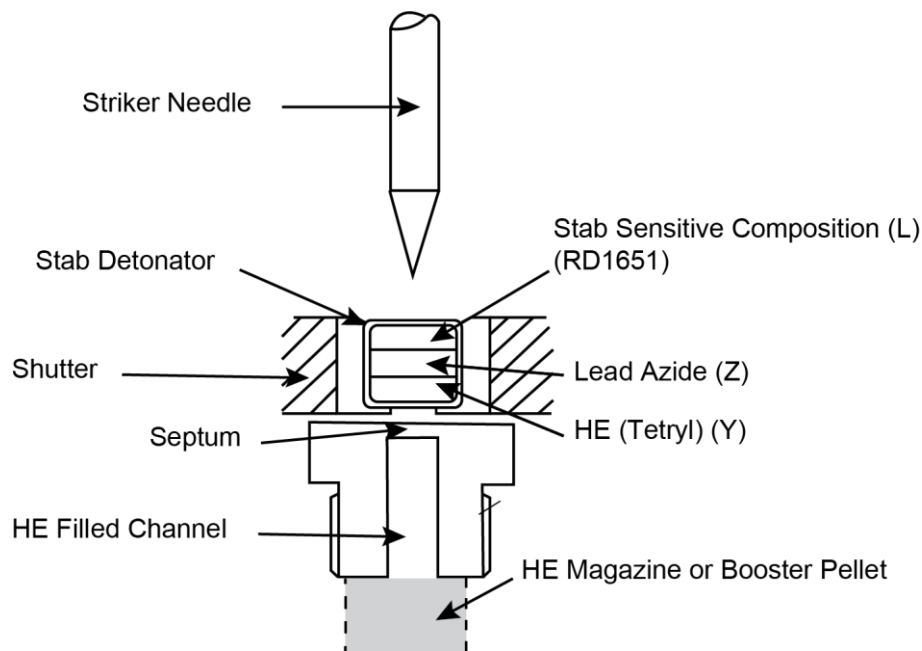


Figure 6-22 Example of (LZY) stab detonator initiation system

The stemmed channel provides a small localised region where the detonative impulse from the detonator can be accepted, built up and passed to the HE magazine. The output from the stemmed channel is not very powerful so it is necessary to use a magazine or booster pellet to transmit the detonation effectively to the next part of the system. Stab detonators include the 2.3 grn and 6.5 grn LZY (RD1651, Lead azide, Tetryl) detonators which have found use in a wide range of Fuzes and Depth Charge Mk 11 MOD3.

6.3.3.4 Flash-receptive detonators

Flash-receptive detonators are a common form of fuze detonator used in a wide range of weapons systems ranging from grenades to Guided Weapon safety and arming units (SAUs). This type of detonator can be initiated by a stab or an electrical igniter, either directly, Figure 6-23, or via a delay column. As in the case of a stab detonator, the disruptive output of a flash-receptive detonator is directed at a booster explosive via a metal septum. Most Service flash-receptive detonators have aluminium alloy cups. The fillings have total weights in the range 1.45 grains - 2.5 grains (0.094 g - 0.16 g) and they are mostly of the RZY, RWY, or R/W/RDX categories. As with stab detonators they can be either direct or indirect-loaded. Flash-receptive detonators have found use in a range of SAUs and Fuzes such as Fuze, Torpedo.

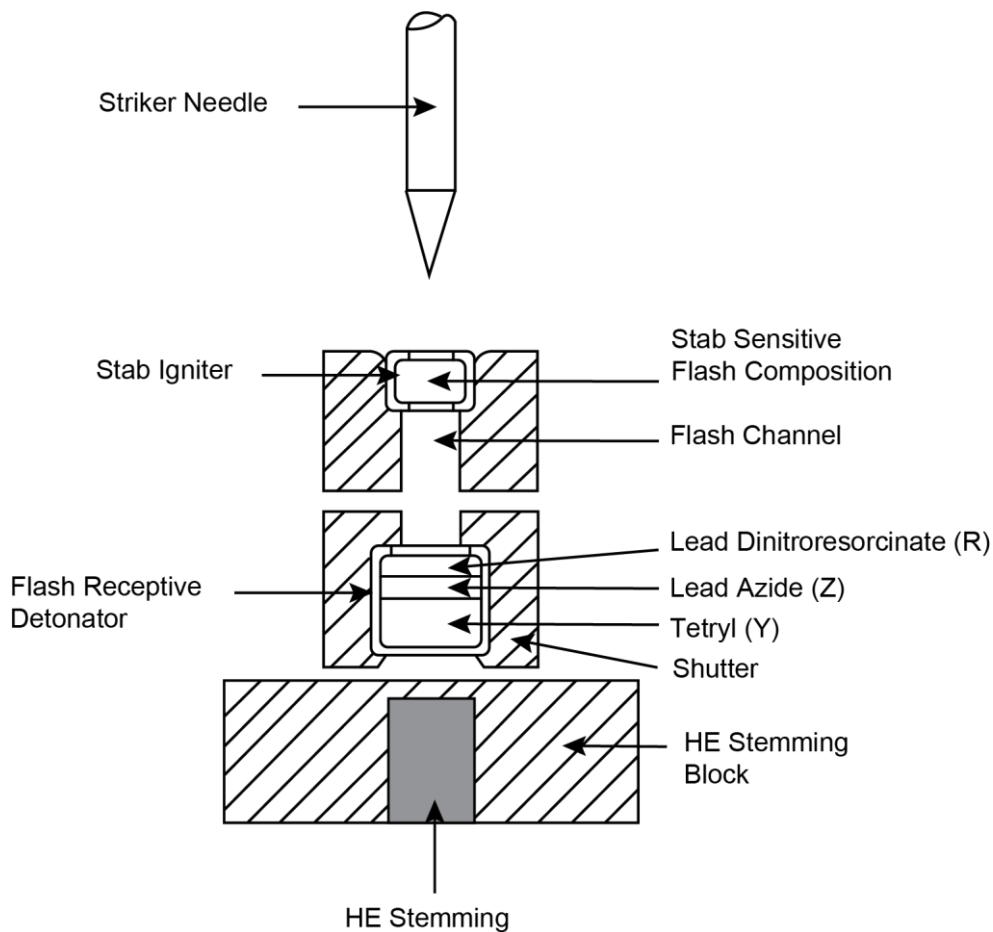


Figure 6-23 Example of stab igniter-flash receptive detonator system

6.3.3.5 Conducting Composition (CC) detonators

Conducting composition detonators are low energy input, fast response explosive devices with a detonative output. They are small enough to be housed in a shutter, moving from shorting terminals in the unarmed position to firing terminals in the armed position. CC detonators are based on the same principle as CC igniters and are of about the same size as other types of fuze detonator. However, they do not employ the lead styphnate/graphite mixture as do CC igniters, but instead lead azide RD1339 with about 3 % w/w graphite added, or, in some cases lead azotetrazole (LAT)/graphite with azide as the next layer. Current types have RDX as the secondary explosive. The detonator cup is usually of brass, plated with gold or silver. CC detonators have previously been used in a number of fuze applications, including BL755 bomblets and LAW 80. An example of a CC detonator is shown in Figure 6-24 and an example of its use within an initiation system is shown in Figure 6-25.

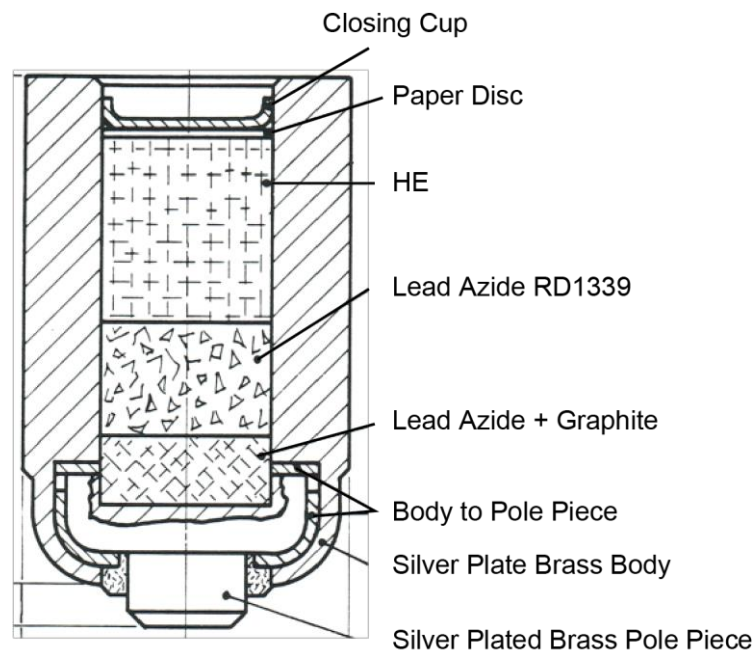


Figure 6-24 Example of an electric conducting composition detonator

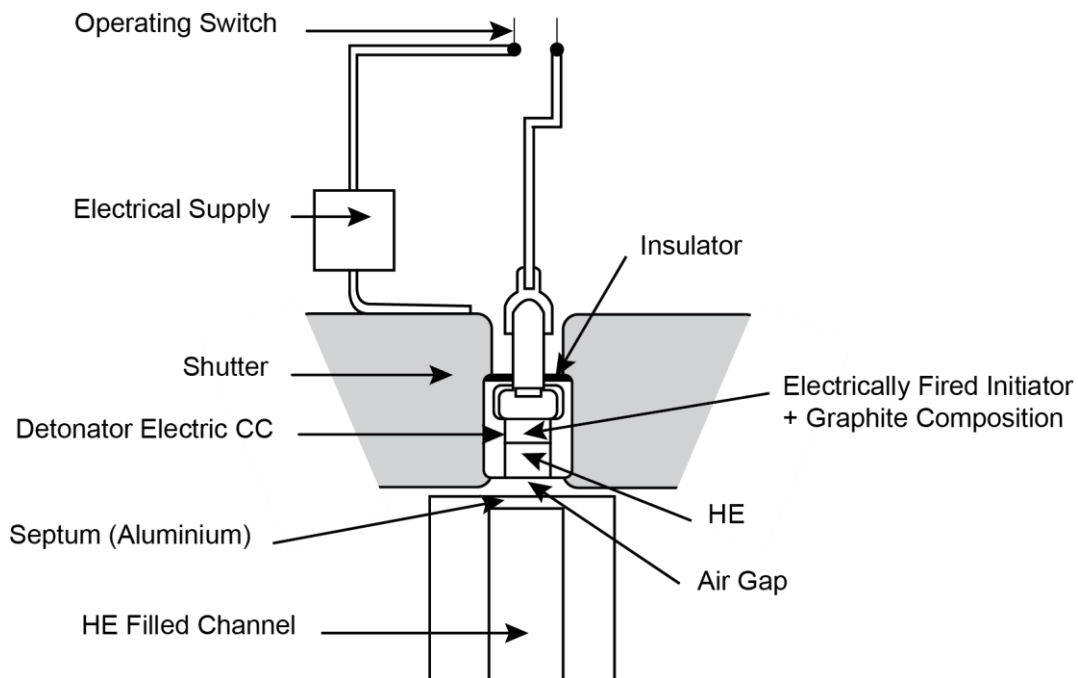


Figure 6-25 Example of an electric conducting composition detonator initiation system

6.3.3.6 Bridgewire detonators

Bridgewire detonators contain a disruptive filling which is initiated by a fusehead or other bridgewire device included in the same container, usually an aluminium tube. Detonator N16, a special purpose long tube device based on a 200/400 series igniter, was designed for use in explosive bolts and was used in Fuze Electric Boost Separation in the Sea Dart missile. Fusehead detonators include

the Service Detonator Demolition L2A2. These detonators are considerably larger than other detonators, consisting of a 60 mm long x 6.4 mm diameter aluminium tube. The initiating composition for the L2A2 detonator is ASA mixture (see 6.3.4.1) and this is followed by a base output charge of PETN. Initiation of the ASA mixture is achieved using an electrically initiated Type E fusehead which is crimped into the open end of the detonator, Figure 6-26. A non-electric detonator (L1A2), Figure 6-27, is identical to the L2A2 but is initiated by Safety Fuse rather than by an electrically initiated fusehead.

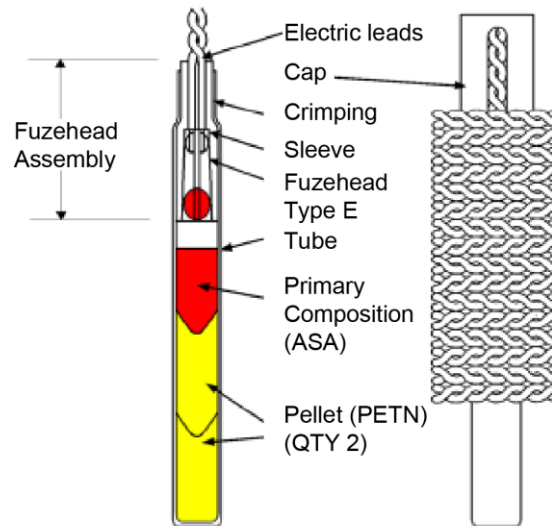


Figure 6-26 Detonator Demolition Electric L2A2

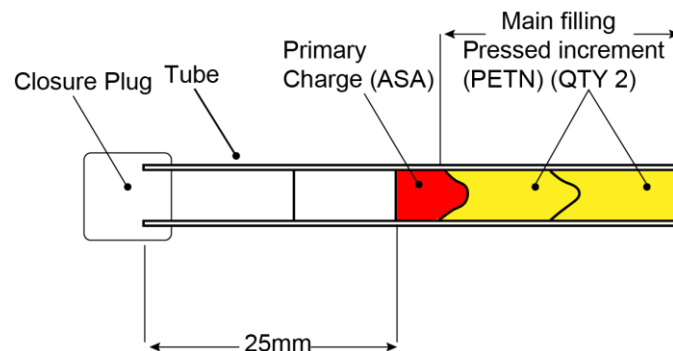


Figure 6-27 Detonator Demolition Non-Electric L1A2

6.3.3.7 Exploding bridgewire detonators

All the igniters and detonators described thus far in this chapter contain primary explosives, which can be easily initiated by physical mishaps or by stray electric currents even of low magnitude. Although protection against accidental functioning is provided as far as possible, no explosive train containing primary explosives is as safe as one which contains only secondary explosives. Moreover, an electric circuit which is designed to initiate a train only when

powered by a high voltage is clearly safer than one intended to operate from a low-power source. An initiator which provides both of these safety features is the exploding bridgewire (EBW) detonator. EBWs are high voltage devices which consist of a low resistance bridgewire in intimate contact with a low density secondary explosive. To activate, a large amount of energy is dissipated into the bridgewire in a small time interval (typically less than 1 μ s). The resultant high power causes the bridge wire to explode and detonate the explosive.

In contrast to the hot-wire initiator, the exploding bridgewire (EBW) device uses shock to initiate a reaction. The shock wave produced by the explosion of the bridgewire initiates detonation directly in a secondary explosive. Because of this, primary explosives are not required. When the initiation characteristics of secondary explosives are considered, only pentaerythritoltetranitrate (PETN) pressed at low densities can be initiated by the relatively low shock output of an EBW. Therefore, PETN is the current explosive used in EBWs. EBW initiation of other secondary explosives can be achieved but the energy input requirements necessitate relatively large firing systems.

The EBW detonator which has been commonly used in UK Service is the N1 Mk2, Figure 6-28. This is a small device, 17.4 mm long, with a moulded thermoplastic body. The bridgewire is of gold, approximately 0.9 mm long and 0.4 mm in diameter. The bridgewire is secured to the insulating body of the detonator and spot welded at each end to a nickel wire contact pin in a similar way to that in a low-tension bridgewire detonator. A filling of low-density PETN is in contact with the wire, and another layer of PETN, pressed to a higher density, is contiguous with the first layer. To initiate the detonator a pulsed current is passed from a 6.5 pF capacitor charged to 2000 V. The current which can rise to more than 700 A heats the bridgewire through the melting, boiling and vaporisation phases. A rapid explosive reaction is initiated which builds up to full detonation throughout the length of the low density filling. Detonation is transferred to the high density pellet, which results in a very powerful output providing reliable detonation of the secondary explosive stemming.

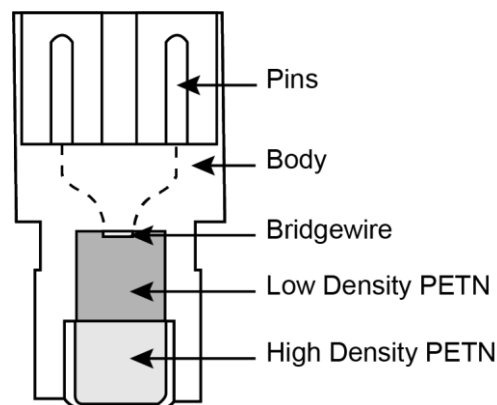


Figure 6-28 Exploding bridgewire detonator N1 Mk2

The EBW detonator is safe from initiation by low currents applied accidentally but is prone to “dudding” if a discharge raises the temperature of the explosive

in contact with the wire to a level which modifies its physical condition or melts the bridgewire. EBW detonators can be used in any weapon system in which a high voltage source is available, and have found use in Guided Weapon systems. Since an EBW detonator contains no primary explosive it can be incorporated in an 'in-line' fuze where there is no requirement to physically move a component of the explosive train to arm the device. The functioning time of an EBW detonator, being a few microseconds, is far faster than that of any other electrical type except the exploding foil initiator (EFI) detonator and faster than that of any mechanical type. The drawbacks of EBWs are generally due to the thermal stability properties of the PETN, which has a melting point 141.3 °C. However, it is not sufficiently stable above 71 °C limiting the temperature at which EBWs can be used for military requirements, to the range -50 °C to +71 °C. HNS cannot be initiated in EBWs at practical firing energies and therefore the safety advantages conferred by this material are unavailable for EBW applications. However, EBWs can be initiated with longer firing pulses than EFIs and control of fireset inductance is less stringent.

6.3.3.8 Exploding foil initiator detonators

Exploding foil initiator (EFI) detonators often referred to as "Slapper" detonators are safe and reliable high voltage detonators, which can replace Exploding bridgewire (EBW) detonators in explosive trains. They were first devised by J Stroud at Lawrence Livermore National laboratory in the USA in the early 1970's. Since that time their development has continued in the USA and Europe and they are now used as in-line detonators for use in electronic safety and arming units (ESAUs) in several UK Service munitions including Sea Wolf missiles and the Spearfish and Sting Ray torpedoes. The EFI detonator like the EBW, depends upon direct shock initiation of secondary explosives.

The EFI, Figure 6-29, contains a thin film metal bridge, usually copper deposited on a thin film of polyimide plastic, creating a foil/flyer assembly which is in turn attached to a thin stripline firing cable with copper conductors and to a barrel which consists of an annulus of plastic about 0.25 mm thick. The firing cable, foil/flyer and barrel are laminated together to form a single assembly just a few millimetres thick. This assembly is offered up to a high explosive pellet of either HNS or PETN to form a complete detonator. Because of the space saving method of stripline construction and the simple, reproducible functioning mechanism, EFI detonators are smaller than EBW detonators and give better timing simultaneously between detonators. Firing times are much less affected by variations in fireset parameters. An EFI detonator-stripline assembly is shown in Figure 6-30.

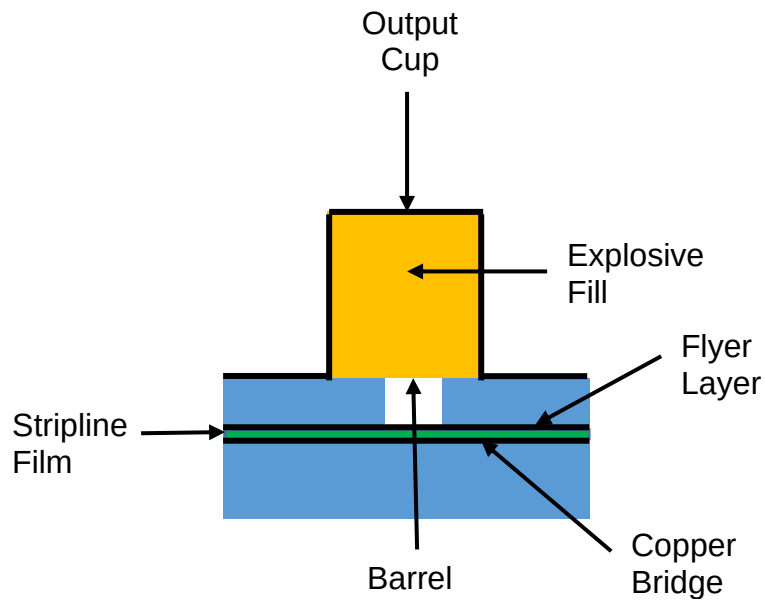


Figure 6-29 EFI detonator



Figure 6-30 EFI detonator-stripline assembly

The device is activated by rapidly delivering a fast rising high current pulse of 2000 V to 3000 V from a capacitor discharge fireset circuit into the bridge. The bridge explodes and accelerates the plastic flyer down a barrel onto a high density pellet of the secondary explosive. The velocity of the flyer is sufficient ($>3000 \text{ m s}^{-1}$) to cause shock initiation of the explosive pellet. Both HNS and PETN are very sensitive to short pulse shock initiation. HNS is the most favoured material as it has a high melting point (318°C) a high temperature of ignition (324°C) and is considered to be sufficiently insensitive for in-line

initiation system use. PETN however, has a relatively low melting point (141 °C), low temperature of ignition (181-182 °C) and demonstrates high explosiveness (see 20.2.1).

There are two types of EFI, namely narrow barrel and wide barrel with the latter often referred to as an infinite barrel type. If the diameter of the barrel is the same as the length of the bridge foil, the design is called a narrow barrel. If the diameter of the barrel is more than twice the bridge foil length, the design is called a wide barrel. A narrow barrel needs to be accurately aligned and the flyer may break off unevenly around the edge of the barrel with loss of bridge energy giving variable shaped fliers which may give variable initiation performance. There are no barrel/bridge alignment problems with the wide barrel type of EFI. Barrels can be several millimetres in diameter and are typically around 0.3 mm in length. The barrel length needs to be short since if the flyer bubble bursts it decelerates and it could fail to initiate the explosive pellet.

The constructional techniques used for EFI detonators can be exploited to design multiple EFI systems which are light and economical in their use of space. An array of copper foil bridges can be etched in the desired geometry. Similarly, a network of firing current conductors can be etched on a single length of plastic which extends to the fireset, and a matrix of barrel holes can be cut into a thin sheet of plastic. These components can be laminated together to form a single thin strip which aligns with a matrix of HNS pellets in a suitable metal or plastic sheet. This arrangement lends itself to easy incorporation into large array initiation systems and has the potential for achieving high levels of reproducibility. The main advantage of using EFIs over EBWs is that these devices will detonate the relatively insensitive secondary explosive HNS. Further advantages include:

- The metal bridge is completely separated from the explosive by an insulating film and an air gap, providing the electrical isolation of the explosive filling.
- Very high current rise time (di/dt) is required to make an EFI function.
- They have a high no-fire threshold.
- The explosive can be pressed to a high (near crystal) density, which provides maximum shock energy output.
- HNS is thermally stable.
- EFI design is relatively simple and easily fabricated. There is only one high density explosive pellet and three to four inert components.
- EFIs can function with superior firing reproducibility than EBWs.
- The EFI filled with HNS is suitable for the initiation of in line explosive trains.
- The major disadvantage with EFIs is that because of impedance limits for the explosion of the driving foil, cable lengths are limited to less than 1 metre and only then using special flat low-impedance cables. However, it may be possible to use greater lengths of cable by changing fireset operating parameters and increasing the overall firing energy.

6.3.3.8.1 Low-Energy EFI (LEEFI) detonators

In recent years the desire to reduce the size, cost and mass of the fireset has driven the investigation of lower-energy EFI initiators which can reliably, safely and precisely operate at reduced firing voltages. The 2000V - 3000V operating voltage range of conventional EFI fireset technology has been constrained by operational requirements and also by the availability of suitably-rated components (which must survive the extreme requirements associated with munition and borehole operating environments). Recent development of low-energy EFI technology has been carried out at Teledyne - e2v Technologies (UK) ⁽⁴⁾ and has resulted in the reduction of the all-fire threshold of the exploding foil bridge structure, to enable initiators and compact firesets that will reliably operate at firing levels of around 1200V or less with STANAG 4187 requirements currently mandating that the no-fire level to be at 500V (or more). Typical no-fire threshold (NFT) and all-fire threshold (AFT) characteristics for LEEFI and a standard EFI for comparison are shown in Table 6-6.

Table 6-6 No Fire and All Fire Thresholds for LEEFI and Standard EFI⁽⁴⁾

EFI	Hot (+85 °C)		Cold (-54 °C)	
	AFT (V)	NFT (V)	AFT (V)	NFT (V)
LEEFI	1189	702	1227	1010
Standard EFI	1794	1398	1824	1568

LEEFI based firesets can now operate at in the region 1200V to 1400V with the result that it is possible to reduce both the physical size and mass of the fireset components. An advantage of this being that integrated Safety and Arming Units (SAUs) can be significantly reduced in size and mass, (nominal 40 mm diameter/250 g compared with 100 mm diameter/1kg of a conventional EFI fireset).

Advantages of LEEFIs include, reduced operating voltages, component miniaturisation and improved system integration with the potential for integration into a SAUs for a range of Complex Weapons.

6.3.3.8.2 EFI takeover onto pyrotechnic material

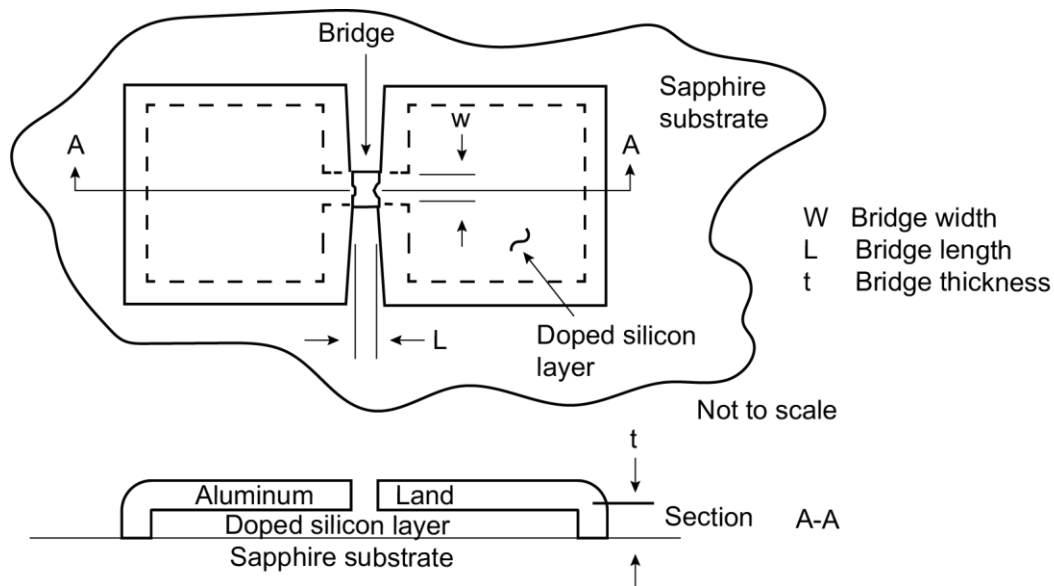
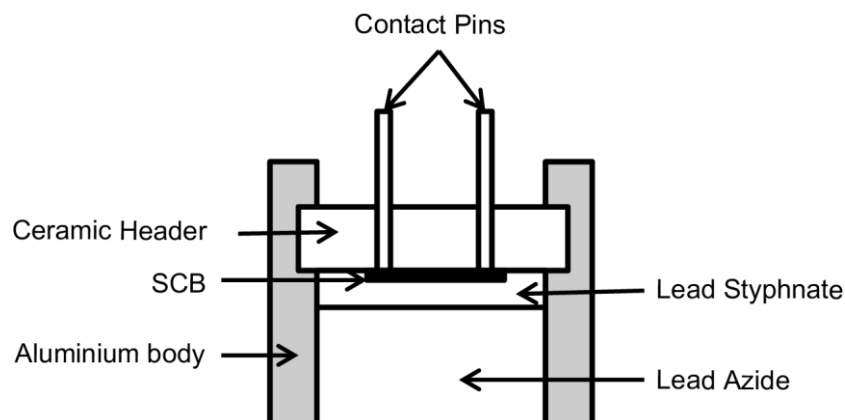
Further to the above, it has been shown that an EFI can be modified to produce the reliable direct ignition of a pyrotechnic composition (B/KNO₃). This has enabled the development of a small direct ignition Electronic Ignition Safety Device. By simplifying the energetic chain, the explosive material required in a Through Bulkhead Initiator (TBI) has been eliminated thereby removing mechanical shock generated during ignition. Based on EFI technology an EFI in-line Ignition Safety Device (ISD) for the Fuzing of Solid Fuel Motors by the direct initiation of a B/KNO₃ pyrotechnic pellet has been developed⁽⁴⁾.

6.3.3.9 Semiconductor bridges (SCBs)

Electrical initiated explosive devices (EIEDs) use electrical conducting composition, hot bridge wires, exploding bridgewire, semiconductor bridge (SCB) or thin metal film bridge as electrical conducting element. Explosive igniters which used electrical conducting composition required few micro joules of energy for initiation. But they are prone to accidental initiation due to electrostatic discharge or radio frequency interference. Hot bridgewire explosive devices require a few mJ of energy for initiation but are unsafe. Exploding bridgewire based explosive devices are safe but are unsuitable for use in electronic fuses due to high voltage required for their operation. As a result of the short comings there was a need to develop a low energy, reliable, safe initiator for use in fuses. It was reported in 1985⁽⁵⁾ that a Semiconductor Bridge (SCB) could be used in place of the bridgewire for initiation of explosive. Bridgewire device function delay is in milliseconds with the no fire and all fire current levels often being dependent upon the energetic material and the physical construction of the explosive device.

SCBs are finding increased use as initiators for both explosive and pyrotechnic devices. They offer advantages in reduced voltage and energy requirements, coupled with enhanced safety features. The advantages afforded by SCBs include; high safety, rapid response, low input energy, high reliability and consistency. The no fire level of devices can be changed by altering the area of the bridge without greatly affecting the all fire energy. SCBs are explosively safe and highly resistive to ESD. The current pulse required to function SCBs is a unique signal preventing their accidental functioning. SCBs are compatible with micro electronic circuitry and can be applied into micro-electromechanical systems (MEMS). A SCB comprises a substrate of non-electrically conductive material, a doped semiconductor layer on the substrate, as well as first and second metal lands forming ohmic contacts on the doped semiconductor layer. An explosive charge bridges the gap between the metal lands across the doped layer, Figure 6-31 with an example of a SCB detonator shown in Figure 6-32.

When fast rising current pulse is applied on the SCB the SCB generates hot plasma for ignition of the explosive powder pressed against the bridge. Ignition is via micro-convection heat transfer process and not just by thermal conductive heat transfer as with hot-wires.

**Figure 6-31 SCB schematic****Figure 6-32 SCB detonator schematic**

SCB devices have been used to ignite materials including thermites (aluminium/copper oxide), gas generators (actuators), rocket motor igniters based on a mixture of titanium sub hydride and potassium perchlorate pressed against the SCB and copper oxide/aluminium thermite. A further application lies in the use of SCB igniters for the activation of thermal batteries using a mixture of titanium sub hydride and potassium perchlorate. SCBs will not initiate secondary explosives but will initiate a Deflagration to Detonation (DDT) transition with PETN and tetraamine-cis-bis(5-nitro-2H-tetrazolato-N²) cobalt(III) perchlorate (BNCP). Research into the development of prototype BNCP detonators incorporating a semiconductor bridge has and continues to be carried out in the USA⁽⁶⁾. Typical operating characteristics of SCBs, EBWs, EFIs and hot-wires are given in

Table 6-7.

Table 6-7 Typical Operating Characteristics of Hot-Wire, SCB, EBW and EFI

Operating Characteristic	Device			
	Hot-Wire	SCB	EBW	EFI
Firing Current (A):				
Threshold	1	>1.5	200	2000
Operating	5	20	>500	3000
Threshold Firing Voltage (V)*	20	30	500	1500
Threshold Firing Energy (J)	0.02	0.005	0.2	0.2
Threshold Power (W)	<0.1	100	100,000	3,000,000
Typical Function Time (μ s)	1000	10-50	2	0.1

Note*: The threshold firing voltage is the voltage required to fire 50 % of the samples. The values listed are nominal and detonators have been fired with lower energy and power requirements. For the EBW values assume a 1 μ F capacitor while 0.15 μ F is assumed for the EFI.

6.3.3.10 Micro-electromechanical systems (MEMS)

Micro Electro Mechanical Systems often referred to as MEMS are based on fabrication technology for creating mechanical devices on a micron (μ m) scale. Individual features of MEMS are on the micron (μ m) scale but systems can be several millimetres in size. It is an emerging technology which is used in many commercial applications and has an increasing use, mainly as sensors, for military weapons. Components based on MEMS technology having been widely used since the early 2000s.

With the increasing move towards smarter, smaller munitions this creates a problem of decreasing space within weapons to accommodate all the necessary components including the guidance and navigation system, fuze and explosives. In order to reduce the size of initiation systems employed in weapons there is a growing interest in the miniaturisation of fuze components. Research in the USA and Europe is presently being undertaken into the miniaturisation of initiation systems using MEMS which includes actuators, igniters, detonators and safety arming units (SAUs). MEMS initiators would provide reduced quantities of sensitive primary explosive in each weapon. Space savings could be utilised for a range of systems (i.e. on-board guidance and control systems). A further advantage of MEMS devices would be the possible integration with electronic safety and arming units.

The practical implementation of MEMS technology is extremely challenging but will enable the reduction in the quantities of sensitive primary explosives used in initiatory devices used in weapons. From a manufactures and environmental perspective, the development of MEMS initiators will considerably reduce the use of toxic heavy metals and waste products and will increase the safety of weapon production by reducing the need for handling bulk quantities of primary explosives.

Recent USA research into MEMS initiators to name but a few includes; igniters for rocket motors, detonators, EFIs, actuators and an ignition safety device utilising a SCB. In the UK, research addressing the problems associated with the incorporation of very small amounts of primary explosives in detonators and actuators has been carried out. The patented MEMS design uses a capillary micro-chamber filled with an explosive material, which precipitates into a second chamber, through micro-cavities with an igniter substance that's detonated when an electric current passes through a simple thermal wire⁽⁷⁾.

6.4 LEAD FREE PRIMARY EXPLOSIVES

Virtually all low voltage and mechanical initiation systems in UK service use primary explosive compounds and compositions based on lead and other heavy metals. Concerns over the hazards to health of using lead containing primary explosives, both in their manufacture and use has led to numerous investigations, worldwide, to identify suitable compounds, either known or novel and free from lead and other heavy metals, which could be used as replacements.

In Europe, current EC legislation⁽⁸⁾; Registration, Evaluation, Authorisation and Restriction of CHemicals (REACH) (see 1.3.2.4.6), will severely limit, and may prohibit the future use of lead and heavy metal containing primary explosives or at least make their availability uncertain. Several USA and UK research programmes have been and continue to be carried out to identify suitable lead free materials. Any proposed lead replacements must retain energetic properties upon exposure to the atmosphere and must be; insensitive to light; sensitive to detonation but not too sensitive to handle and transport; thermally stable to at least 200 °C, chemically stable for extended periods; devoid of toxic metals such as lead, mercury, silver, barium, or antimony. In the USA replacement materials must be free of perchlorate, which may be a possible teratogen and has adverse effects on thyroid function however, to-date the use of perchlorate in both the UK and Europe is not an issue.

A major advantage of lead containing primer compositions (i.e. VH2, VH4 primer compositions) is that they deposit metallic lead onto the gun barrel surface during functioning. The thin film coating acts as a lubricant for the barrel and protects it from corrosion. Lead free primers may generate more abrasive oxides causing greater barrel wear especially with high powered rounds. A number of lead free materials do not meet service requirements as they are

unstable, have excessive sensitiveness (see 20.2.1) or they are not environmentally benign.

Several lead free compounds have been used as replacements for lead styphnate and lead azide. These include, 2-diazo-4,6-dinitrophenol (DDNP), Figure 6-33, which has been used as an initiating explosive in stab detonators and percussion primers, and potassium 4,6-dinitrobenzofuroxan (KDNBF), Figure 6-34, which has been used in percussion initiated primer compositions. DDNP was first prepared in the mid-1800s by Griess. Its temperature of ignition (see 20.10.2.3) is reported to be between 161-188 °C depending on material purity and mode of preparation. DDNP has found applications in several initiating devices including stab detonators and percussion primers. DENEL RSA in 1994 carried out investigations and developed percussion cap primer compositions based on DDNP⁽⁹⁾ whilst DYNAMIT NOBEL AG developed a range of lead free primer compositions, commonly known as SINTOX Primer Composition, based on DDNP. DDNP is virtually the only readily available replacement for lead styphnate in present percussion cap priming compositions. However, despite this, DDNP does exhibit a number of disadvantages, it is light sensitive which can reduce its ignition temperature, it is incompatible with lead azide, it causes allergic reaction in workers, it can be dead pressed and has low density (reported to be 1.63 - 1.72 g cm⁻³) thereby requiring a relatively large volume which could reduce its usefulness for some applications. Further to this, production processes produce large volumes of waste water; it has a high electrostatic sensitiveness (see 20.10.2.6) and has reported questionable shelf life and reliability issues⁽¹⁰⁾. However, in the USA, DDNP is considered to be satisfactory and safe to use in both commercial and military applications.

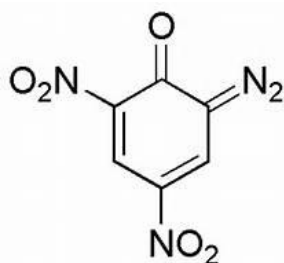


Figure 6-33 Diazodinitrophenol (DDNP)

KDNBF (Figure 6-34) was first prepared by Drost in 1899. Further to this in 1953, Costain⁽¹¹⁾ investigated several meta salts of dinitrobenzofuroxan (DNBF) with KDNBF having low solubility, good stability up to 70 °C chosen for further studies in the development of graphite bridge igniters. There was little interest in KDNBF in the UK until the early 1970s when Thomas (PERME Waltham Abbey, UK) investigated the preparation of the material in a form suitable for fusehead applications⁽¹²⁾. Further to this in 1978 a material was developed to meet a Service requirement for a gas producing composition for use in a miniature explosive cutting system⁽¹³⁾. This KDNBF was known as RD1372.

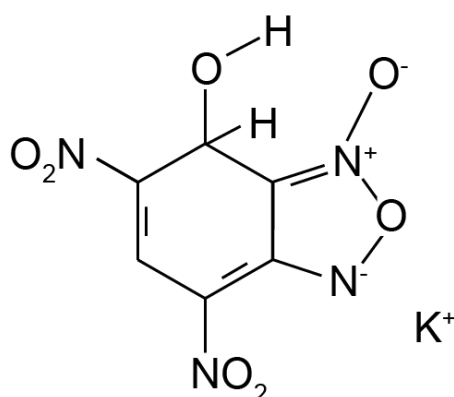


Figure 6-34 Potassium 4,6-dinitrobenzofuroxan (KDNBF)

In the UK in the mid-1990s, Royal Ordnance PLC, Chorley developed a range of low toxicity lead free primer compositions suitable for the replacement of the lead styphnate containing VH2 and VH4 percussion primer compositions used in a range of small arms ammunition. These lead free compositions were based on KDNBF and typically contained potassium or strontium nitrate (oxidiser), tetrazene (sensitiser) and calcium silicide (frictioner). However, these compositions are no longer produced in the UK. A major problem with the manufacture of KDNBF lies with the low product yield and relatively low product volumes which impacted on the commercial viability of the production of KDNBF on a commercial scale.

Other lead free compounds include the thermally stable coordination complexes, (2-(5-cyanotetrazolato)pentaamminecobalt(III) perchlorate) (CP), Figure 6-35, and tetramine-cis-bis(5-nitro-2H-tetrazolato-N²) cobalt(III) perchlorate (BNCP), Figure 6-36, which has been used in prototype SCB detonators. However, the perchlorate content of both CP and BNCP makes them unacceptable for future use.

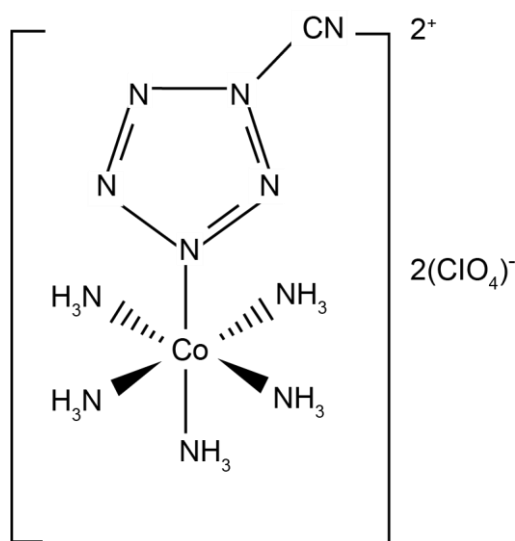


Figure 6-35 Pentamine (5-cyano-H-tetrazolato-N²) cobalt III perchlorate (CP)

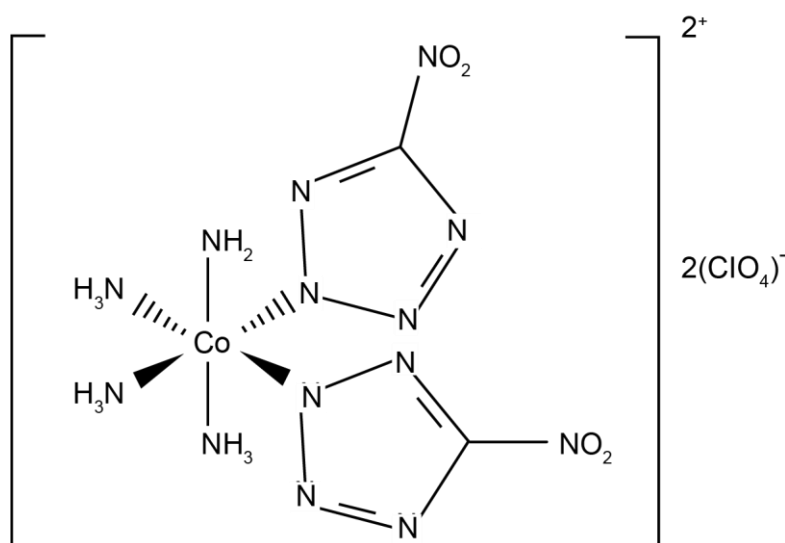


Figure 6-36 Tetraamine-cis-bis (5-nitro-2H-tetrazolato-N2) cobalt III perchlorate (BNCP)

Further to the previously mentioned materials, mixtures of aluminium nanoparticles and heavy metal oxides known as Metastable Intramolecular Composites (MICs) are known to have appropriate sensitivity. However, instability toward atmospheric oxygen and moisture, safety concerns during large scale production, and residual heavy metal contaminations has prevented their adoption as lead salt replacements.

Silver (I) azide has long been considered a possible replacement for lead azide in detonators. Unlike lead azide it is not subject to hydrolysis and is presently used as a lead azide replacement in certain detonators such as the UK Service detonator 2.25 grn RWY. However, silver azide does have some disadvantages namely; like lead azide it is incompatible with copper, but unlike lead azide it is incompatible with tetrazene and sulphur containing compounds such as rubbers and antimony sulphide. This incompatibility precludes its use as a lead azide replacement in several initiator devices containing tetrazene like RD1651-L mixture.

At the present time the most promising replacements for lead azide and lead styphnate are the copper(I) salt of 5-nitrotetrazolate known as DBX-1, Figure 6-37, and the potassium salt of 7-hydroxy-4,6-dinitrobenzofuroxan (KDNP), Figure 6-38. Both materials have been extensively investigated at Pacific Scientific Energetic Materials Co, USA^(14,15,16).

DBX-1 has been patented^(17,18) as a potentially green direct drop-in lead azide replacement. The material has demonstrated superior explosive output and high thermal stability. Unlike lead azide it is stable under humid conditions and does not react with copper and other metals and is compatible with a range of secondary explosives including RDX, HMX and CL20. In addition, it has sensitivity and output characteristics which are equivalent to or exceed lead azide and it does not show any tendency to dead press even at high loading pressures (275.8 MPa). DBX-1 is known to slowly decompose when stored in

water however, due to its positive qualities; it is being sought as a replacement for lead based primary explosives. The material has been submitted for qualification as a primary explosive in weapons development to the Department of Naval Sea Systems Command (USA) and seems to be a suitable drop in replacement for the lead azide and lead styphnate based stab detonator mixture NOL-130 (basic lead styphnate 40 % w/w, dextrinated lead azide 20 % w/w, barium nitrate 20 % w/w, antimony sulphide 15 % w/w, tetrazene 5 % w/w) for use in the M55 stab detonators. KDNP, Figure 6-38, has a very similar chemical structure to KDNBF, Figure 6-34, but the physical properties differ markedly. KDNBF exists as a Jackson-Meisenheimer adduct having a relatively low thermal stability. However, KDNP is a true ionic salt and has high thermal stability. The impact, friction and electrostatic sensitiveness of KDNP are better than that of lead styphnate making it safer to handle. KDNP is a suitable replacement for lead styphnate used either alone or as an ingredient in compositions. It has found use in several applications including impulse cartridge-bridgewire mix, TOW missile initiator units-pressed onto bridgewires and percussion initiated primers (sensitised with tetrazene) and has been qualified as a primary explosive for US Service use by the Department Naval Sea Systems Command.

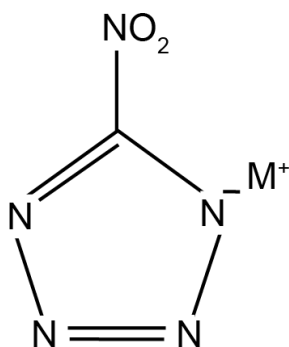


Figure 6-37 Copper(I) 5-nitrotetrazolate (DBX-1)

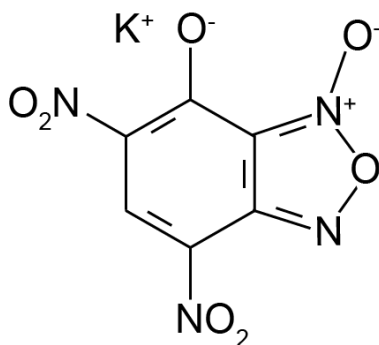


Figure 6-38 Potassium salt of 7-hydroxy-4,6-dinitrobenzofuroxan (KDNP)

The methods of manufacture of DDNP, KDNBF, DBX-1 and KDNP are detailed in Chapter 10.

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APPENDIX A PROPERTIES OF PRIMARY EXPLOSIVES**Table A-1 Properties of Lead Styphnates**

Parameter	α -Normal Salt		β -Monobasic Salt	
	RD1303	RD1367	RD1346	RD1349
Density	3.07 g cm ⁻³	Not Specified	4.06 g cm ⁻³	4.06 g cm ⁻³
Bulk Density	0.80-1.36 g cm ⁻³	1.5 $\pm$ 0.15 g cm ⁻³	1.15 $\pm$ 0.25 g cm ⁻³	1.30 g cm ⁻³
F of I	20	20	30	20
Temperature of Ignition	257 °C (Explodes)	255 °C (Explodes)	240 °C (Explodes)	234 °C (Explodes)
Ignition by Electric Spark (M/M min energy)	25 μ J @ 520 pF	15 μ J @ 520 pF	4.5 μ J @ 520 pF	36 μ J @ 520 pF
Ignition by Electric Spark (R/M min energy)	15 μ J @ 60 pF	<0.3 μ J	5.5 μ J @ 35 pF	8 μ J @ 40 pF

Table A-2 Properties of Barium Styphnates

Parameter	RD1320	RD1320A	RD1320B	RD1340
Density	2.56 g cm ⁻³	2.56 g cm ⁻³	2.56 g cm ⁻³	2.56 g cm ⁻³
Bulk Density	1.49 g cm ⁻³	1.00 g cm ⁻³	1.04 g cm ⁻³	1.10 g cm ⁻³
F of I	50	50	40	40
Temperature of Ignition	310 °C (Explodes)	310 °C (Explodes)	310 °C (Explodes)	318 °C (Explodes)
Ignition by Electric Spark (R/M min energy)	1250 μ J @ 2000 pF	1300 μ J @ 2000 pF	2900 μ J @ 2000 pF	1430 μ J @ 520 pF

Table A-3 Properties of Lead Dinitroresorcinate

Parameter	RD1308	RD1337
Density	3.95 g cm ⁻³	3.17 g cm ⁻³
Bulk Density	0.70 ± 0.10 g cm ⁻³	0.60 g cm ⁻³ (min)
F of I	17	10
Temperature of Ignition	242 °C (Explodes)	242 °C (Explodes)
Ignition by Electric Spark (M/M min energy)	15 µJ @ 76 pF	21 µJ @ 520 pF
Ignition by Electric Spark (R/M min energy)	16 µJ @ 100 pF	160 µJ @ 100 pF

Table A-4 Properties of Tetrazene

Parameter	RD1357A
Density	1.70 g cm ⁻³
Bulk Density	0.50 – 0.75 g cm ⁻³
F of I	10
Temperature of Ignition	135 °C (Explodes)
Ignition by Electric Spark (M/M min energy)	2 µJ @ 520 pF
Ignition by Electric Spark (R/M min energy)	225 µJ @ 1200 pF

Table A-5 Properties of Lead Azides

Parameter	SLA	RD1339	RD1343	RD1352	Lead Azide GAM
Density	4.78 g cm ⁻³	4.68 g cm ⁻³	4.68 g cm ⁻³	4.38 g cm ⁻³	Not Specified
Bulk Density	2.0 g cm ⁻³	0.6 g cm ⁻³	1.4 g cm ⁻³	2.2 g cm ⁻³	1.35 g cm ⁻³
F of I	30	23	30	20	Not Specified
Temp. of Ignition	>300 °C (Detonates)	>300 °C (Detonates)	319 °C (Detonates)	300 °C (Detonates)	Not Specified
Ignition by Electric Spark (M/M min energy)	2 µJ @ 520 pF	8 µJ @ 255-520 pF	2 µJ @ 520 pF	Not Specified	Not Specified
Ignition by Electric Spark (R/M min energy)	225 µJ @ 1200 pF	800 µJ @ 759 pF	Not Specified	Not Specified	Not Specified

Table A-6 Properties of Silver Azides

Parameter	RD1336	RD1374
Density	5.0 g cm ⁻³	5.0 g cm ⁻³
Bulk Density	0.75 g cm ⁻³	1.4 g cm ⁻³
F of I	30	23
Temperature of Ignition	362 °C (Detonates)	385 °C (Detonates)
Ignition by Electric Spark (M/M min energy)	2.5 µJ @ 520 pF	0.45 µJ @ 20 pF
Ignition by Electric Spark (R/M min energy)	400 µJ @ 1200 pF	4.9µJ @ 20 pF