Review Article

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Forensic Investigation of Explosions: A Review

Gurvinder Singh Sodhi[1], **Jasjeet Kaur**[2]

Author Affiliation: [1]Associate Professor and Coordinator, Forensic Science Unit, S.G.T.B. Khalsa College, University of Delhi, Delhi 110007, India. [2]Associate Professor, Department of Chemistry, Shaheed Rajguru College of Applied Sciences for Women (University of Delhi), Vasundhara Enclave, Delhi 110096, India.

Corresponding Author: Gurvinder Singh Sodhi, Associate Professor and Coordinator, Forensic Science Unit, S.G.T.B. Khalsa College, University of Delhi, Delhi 110007, India.

E-mail: gssodhi@sgtbkhalsa.du.ac.in

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Abstract

An explosion is defined as a violent, shattering action caused by a bomb. The main chemical ingredient of a bomb is the explosive – an endothermic substance which serves as a storehouse of energy. When this energy is suddenly released, in the confined space of the bomb, it causes a devastating effect, resulting in loss of lives and property. As compared to conventional crime scenes, explosion sites are more difficult to process. In many cases a building may have collapsed and the crime scene evidence may have become buried beneath the debris. A vital aspect of forensic investigation of bomb blasts is to establish the explosion seat. Equally important is to identify the type of chemical explosives used to commit the crime. This communication highlights the complications encountered in the management of explosion sites and the difficulties experienced in processing the evidence collected there from. The types of injuries which the victims of explosion suffer are also briefly described.

Keywords: Blast waves; Blasting caps; Booster; Deflagration; Detonation; Explosive; Explosive charge; Explosive train; Initiator.

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Introduction

An explosive is a substance or a mixture of substances which, when raised above a threshold temperature, whether by direct heating, friction, impact or shock from another explosive, undergoes a violent and spontaneous chemical transformation with the evolution of a large amount of heat, light and sound, as well as with release of a large volume of gases.[1] The gases, so released, exert a high pressure on the surrounding media.[2] The amount of material required to cause an explosion is called *explosive charge*. The explosive charge stores a great amount of potential energy which, at the moment of explosion, is released as chemical energy, a part of which dissipates as heat, light and sound.[3]

An eruption of explosive has two similarities with an incidence of fire. Firstly, both are combustion reactions. Secondly, both require a fuel and an oxidizing agent. However, whereas in fire, the combustion reaction proceeds smoothly, at a slow rate, in an explosion it occurs at a phenomenal rate, causing violent physical disruption of the surrounding area. Moreover, in arson, aerial oxygen acts as the oxidizing agent, but in explosives, an oxygen-rich functional group is the oxidant.[4]

Mechanism of Explosions

Depending on the pathway of the explosion reaction, the explosives are categorized into two types: composite explosives and molecular explosives.[5] A *composite explosive* is one in which the fuel and the oxidizing agent are separate chemical entities. *Gun powder*, also called *black powder* is an example of a composite explosive.[6] It is a mixture of potassium nitrate (75%), charcoal (15%) and sulphur (10%). Potassium nitrate acts as an oxidant, charcoal as fuel and sulphur lowers the threshold of ignition and is thus a sensitizer. When gun powder is heated, the following chemical reaction takes place.

$$2KNO_3 + 3C + S \longrightarrow K_2S + 3CO_2 + N_2$$

The high pressure produced due to the release of large volumes of carbon dioxide and nitrogen causes the explosion. Another example of a composite explosive is ammonium nitrate – fuel oil, commonly abbreviated as ANFO. In this formulation, ammonium nitrate is the oxidant for fuel oil.[7]

It is also possible that the oxidant and the fuel are a part of the same molecule. Such an explosive is called a *molecular explosive*. Examples of molecular explosives include nitroglycerine, trinitrotoluene (TNT), pentaerythritol tetranitrate (PETN), nitrocellulose and cyclorite (RDX) [8]. Their structures are depicted in Fig. 1. In these compounds, the functional groups act as oxidants, while the carbon chain acts as the fuel.

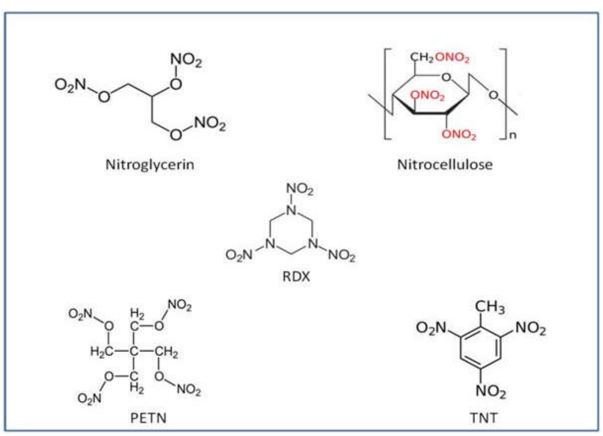

Fig. 1: Common molecular explosives

For example, the explosion reaction of trinitrotoluene may be written as follows.

$$2C_7H_5(NO_2)_3 \longrightarrow 7C + 5H_2O + 7CO + 3N_2$$

Since carbon is one of the products of the reaction, a black cloud appears at the site of TNT explosion.[5]

Classification of Explosives

Explosives are broadly classified into two types: low explosives and high explosives (Fig. 2).[9] Low explosives are those which decompose with a rate lower than the velocity of sound. It is generally within the range 0.20-300 ms^{-1}. As a result, their eruption is not very violent and is termed as *deflagration*. The latter does not initiate from within the main body of charge, but proceeds from the surface, consuming the inner layers step by step. The action is therefore only mildly shattering. Low explosives are also called propellants, implying that these are mainly used to push the ammunition out of the firearm. Gun powder, which is commonly used to propel the bullets from a rifle, is an example of a low explosive. Smokeless powder, the main ingredient of which is nitrocellulose, is yet another example of a low explosive.

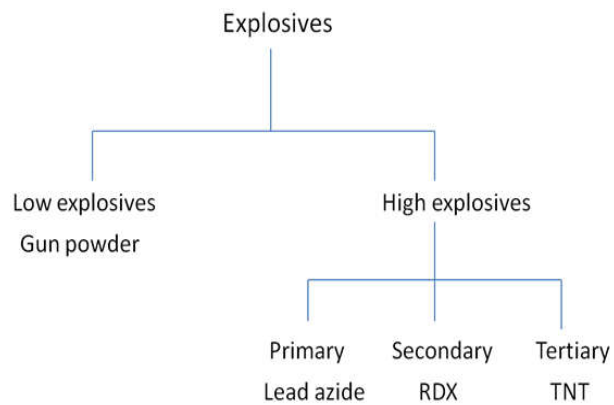

Fig. 2: Classification of explosives

High explosives are those whose rate of decomposition is of the order of 1000–9000 ms^{-1}. The explosive action originates from within the main body of charge and results in a powerful mechanical effect called *detonation*.[4,9] High explosives are sub-classified into three types: primary, secondary and tertiary.[1]

A *primary high explosive* is one which is extremely sensitive to shock, friction or mild heat.[11] Examples include lead azide and mercury(II) fulminate. Such explosives are difficult to handle and transport. These are mainly used to initiate the detonation of a secondary high explosive and hence are also referred to as *initiators* or *detonators*.[4]

Secondary high explosives are insensitive to impact or heat. These are quite stable and can be handled and transported relatively easily. Only when subjected to shock waves, do these explode.

The shock wave is provided by a primary high explosive (Fig. 3). Thus lead azide is a commonly used detonator for secondary explosives like PETN or RDX.[1]

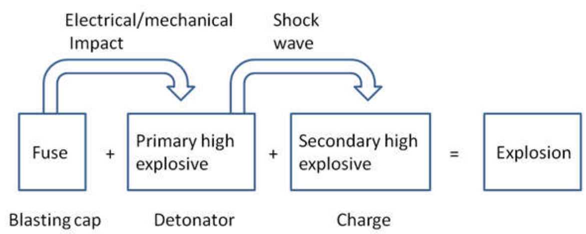

Fig. 3: Eruption of a secondary high explosive

In order to enhance the shattering effect, the primary and secondary high explosives are packed together in tubes made of copper or aluminium. Such tubes are called *blasting caps.*[1] These are usually 5 mm in diameter and 25-75 mm in length. One variety is shown in Figure 4.

Fig. 4: A blasting cap

The blasting caps are endowed with a fuse which operates either electrically or mechanically to explode the primary high explosive, generating the shock wave to erupt the secondary high explosive.

A *tertiary high explosive* has an enormously high shattering power but, paradoxically, a high stability as well.[3] Once a tertiary high explosive erupts, the devastation will be phenomenal, but for initiating its explosion, a detonator in form of a primary high explosive is not enough. Rather a combination of a primary high explosive and a secondary high explosive is needed to blast a tertiary high explosive.

The primary high explosive first detonates the secondary high explosive and the high-order shock wave, so generated, triggers the eruption of tertiary high explosive. The intermediate, secondary high explosive, which amplifies the shock wave of the primary high explosive is called *booster.*[5] For example, RDX is a booster for the teritiary high explosive like nitroglycerine. The sequence of explosion of a tertiary high explosive is symbolically shown in Figure 5.

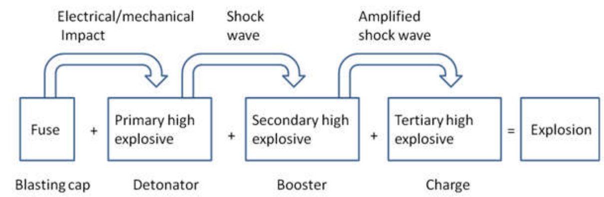

Fig. 5: Eruption of a tertiary high explosive

The series of operations, initiating with the fuse and culminating in an explosion, as shown in Figs. 3 and 5, are called *explosive trains.*[12]

Management of Explosion Site

The objectives of explosion scene management are twofold: firstly to collect evidence and secondly to redeem the area or the infrastructure at the earliest. Before resorting to bomb scene management, emergency measures such as providing medical aid to the injured and extinguishing fire should be pressed into service. Whereas in a conventional crime scene, a single cordon is sufficient, a bomb site ought to be secured by two barrier tapes. The inner cordon covers the area immediately surrounding the bomb seat, while the outer cordon is deployed a few meters away. The area enclosed by the inner cordon is restricted to experts in the field of explosives and evidence collection. The space between the inner and outer cordons is used for keeping technical and documenting tools at hand should these be requisitioned by the experts.[13]

Those entering the inner area ought to wear protective clothing, helmets, gloves and shoe covers. They should also wear masks to avoid inhaling toxic fumes and fine dust particles. The road traffic immediately beyond the outer cordon should be diverted. A metro station, if in vicinity, should be closed. An area for press briefing should be designated outside the second cordon.[13,14]

The area within the inner cordon is the one where most of the crime scene evidence would be found. The first order of business for the investigators is to conduct a walk through of this area so as to acquire an overview of the incident. During this exercise, they should establish the entry and exit pathways for the experts who would subsequently join in the investigation. They should also divide the area within the inner cordon into a suitable number of zones. Each zone is then methodically scanned for plausible evidence. Once the first zone has been thoroughly probed, investigators should move to the second zone, and so on.

The zone where the bomb actually explodes warrants the most painstaking search.[15] At the bomb seat a crater is invariably formed. The dimensions of the crater are recorded and thereafter it is further excavated to a depth of about 0.3 meter so as to extract the evidence buried therein. All loose soil and debris is removed from the interior of the crater and screened through wire mesh to sift out the paraphernalia used in detonation, such as wires fuses, nails and shells. The soil too is preserved for extraction and subsequent analysis of explosive residues which may have become mixed up with debris. Explosive residues are also commonly found adsorbed on items like door panels, window sills and glass pieces that were shattered due to the bomb blast. Volatile residues may be found absorbed in porous items like wood, carpets, curtains and rags. A set of evidence may be blown away from the bomb seat under the impact of blast waves. These will be found in zones away from the crater.

All pieces of evidence should be picked up by disposable scoops, scrapers, dustpans and brushes. If vacuum collection is warranted, the vacuum cleaner should be endowed with disposable accessories. Cotton swabs may also be used as picking aids either in dry state or after moistening with a suitable solvent.

All the collected items should be packed in air tight metal containers. Soil and debris collected from different zones should be packed in separate containers. The type of evidence and the zone number from which it was picked up should be clearly marked on the container.[16] Plastic bags should not be used for packaging explosion evidence since the residues interact with and degrade the polymeric materials. Moreover, sharp edged objects like wires and nails may pierce through the plastic bags and fall off. Paper envelops too are unsuitable since the volatile explosive residues are likely to ooze out of the container.

The investigators should prepare written scene documentation for permanent record. The date on which the explosion occurred, the time at which the information received and the time of arrival at the scene should be indicated in the report. The location, physical measurements and environmental conditions too should be stated. The interviews of witnesses should be incorporated in the report. A rough sketch of the scene, clearly marking the crater, visible evidence and dead bodies should be drawn at the site itself. It should be subsequently fine-tuned either manually or better by making use of computer aided drawing software. The overview of the scene should be photographed, followed by photographing each zone separately. The bomb seat should be photographed from all possible angles. A mid-range photo log showing relative location of two or more evidence should be prepared. In addition, a close-up photograph of each evidence should be taken. Photography and videography of the assembled crowd should also be carried out. This assists in identifying witnesses, and in some cases, the suspects as well.[15,17]

Analysis of Explosion Evidence

Every item from the bomb blast site is first examined with the aid of a microscope to detect particles of unconsumed explosive.[12] These are more likely to be found adhering to the detonator parts than in the embedded debris. If ammonium nitrate is suspected to be the explosive, the evidence is rinsed with water. For other explosives, the evidence is rinsed with acetone. A preliminary examination may be performed by carrying out spot tests with diphenylamine and Griess reagents on the water or acetone extracts.[18] As shown in Table 1, these reagents give characteristic colored spots with all common explosives except trinitrotoluene. The latter, nevertheless, gives a red spot when treated with alcoholic potassium hydroxide.[1,12]

Table 1: Spot tests for common explosives

Explosive	Griess reagent	Diphenylamine reagent	Alcoholic KOH
Nitrate	Pink	Blue	No color
PETN	Pink	Blue	No color
RDX	Pink	Blue	No color
Nitroglycerine	Pink	Blue	No color
TNT	No color	No color	Red

For final confirmation, the washings from water or acetone are concentrated and analyzed with the aid of thin layer chromatography or high performance liquid chromatography.[19,20] Gas chromatography is not routinely used since it operates at high temperatures – and this may prove unsafe while analyzing explosives.

Another device which separates the compounds present in an explosive residue is the ion mobility spectrometer.[1] This hand-held instrument uses vacuum to collect explosive residues from suspect surfaces. Once inside the ion mobility spectrometer, the residues are vaporized by using a heat source. The vapors are exposed to β-rays (electron beam) emitted by radioactive nickel. The chemical entities are converted into electrically charged particles which are then allowed to move in a tube under the influence of an electric field. The preliminary identification of the residue components can be made by noting the time taken by these to move through the tube. The speed depends on their size and structure. The segregated components are finally analyzed by a chromatographic technique.[21]

Blast Waves

A blast wave refers to the flow of hot, compressed gases liberated as fallout of an explosion. The gases are pushed by the large amount of energy released in a limited space of a bomb shell. The wave expands rapidly as it moves away from the bomb seat and, in consequence, compresses the surrounding air. In fact, blast wave is a propagating disturbance that shatters anything that gets in its way. Debris, common utilities, components of detonator and sometimes even people get swept away by it. As the wave moves forward with supersonic speed, it creates a partial vacuum immediately behind it due to displacement of air. To fill up the vacuum, the hot gases of the wave take a U-turn and rush back towards the bomb seat. This causes another blast effect called *negative pressure phase*. The latter is not as devastating as the positive blast phase, but is capable of causing additional damage to the objects that have already been damaged. It may also trigger additional injuries to the victims who survived the direct blast waves.[22] The physical trauma suffered by the victims who come in the line of blast waves are classified into four types: primary, secondary, tertiary and quaternary.[23]

Primary blast injuries are caused to a person who happens to be close to the bomb seat at the time of explosion. The trauma results due to combined effect of pressure and shock embodied in the blast wave and affects internal organs like ear drums, lungs and gastrointestinal tract.

Secondary blast injuries are caused by components of the detonator, such as nails and glass fragments which are propelled outwards during the explosion. These may cause both internal and external injuries to a person who need not only be close to the bomb seat, but may be at a remote location.

Tertiary blast injuries appear in form of bone fractures, blunt trauma and tissue rupture to a person who is lifted by the blast wave to strike a hard object. Children are more prone to such injuries.

Quaternary blast injuries encompass disorders not covered under the aforementioned three classifications. These include burns, amputation of limbs, blinding and nerve damage. Post-trauma psychic disorders may also appear in those persons who may have escaped physical injuries but had witnessed the scene of disaster.[24]

Conclusion

The forensic investigation of explosions entails the following steps.

- Identification of the bomb seat
- Collection and analysis of explosive residues
- Identification of explosive or mixture of explosives used to commit the crime.
- Examining the damage caused by blast waves.

The complexities and difficulties associated with processing of explosion scenes may be negated if the aforementioned steps are carried out scientifically and methodically.

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