Nederlands Forensisch Instituut
Ministerie van Justitie en Veiligheid

Factsheet

Danger assessment of shells

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1. Factsheet in general

The Netherlands Forensic Institute (NFI) conducts a wide variety of investigations. An investigation report from the NFI may be accompanied by a factsheet. This serves as (additional) background information and is of an informative character.

2. Introduction

The expert area of Explosions and Explosives at the NFI frequently receives questions about the dangers of fireworks. A dangerous firework article that frequently appears in the Netherlands is the shell. This firework article and its effects have been investigated by the NFI. This factsheet summarizes the research results with the aim of providing a general overview of the dangers of an exploding shell.

3. Description of shells

3.1. External characteristics

Shells are typically spherical, "onion"-shaped, or cylindrical in form and made of cardboard or plastic. Photos 1 and 2 show two common types of shells. There are also shells in circulation that look different. In case of doubt, you can contact your forensic explosives expert.

Photo 1. Examples of "onion"-shaped cardboard shells.
Photo 2. Examples of cylindrical plastic shells.

The size of common shells varies greatly, from dimensions comparable to a ping-pong ball up to the size of a basketball. However, they can be even larger. For certain events and record attempts, very large shells have been made abroad with diameters of up to nearly 1.5 meters.
The size of a shell is indicated by its "caliber" in inches ["]. Common calibers range from 1.5" to 12", which correspond to diameters of approximately 4.0 to 30 centimeters.

A distinctive physical characteristic that most shells have is a long, broad paper fuse. This type of fuse is called a quick fuse or a tubed fuse. Quick fuses come in various colors and have extremely high burning speeds. This means that when a fuse is ignited, the flame front travels through the fuse and almost immediately reaches the shell's lift charge, causing it to ignite. To prevent this, a piece of green firework fuse (safety fuse) can be attached to the quick fuse.

3.2. Internal structure

A shell is a pyrotechnic article[1]. In the construction of a standard shell, there are always two distinctive components (see Figure 3), namely: component **1** with the lift charge and component **2** with the effect and/or burst charge.

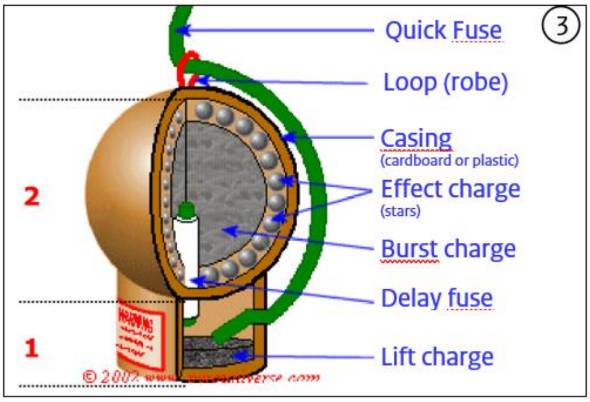

Figure 3. Example of a schematic construction of a shell.

Component 1 typically has a smaller wall thickness than component 2. This is related to the function of the lift charge, which is to lift component 2 into the air. The wall thickness of component 2 must be strong enough to remain intact during the explosive combustion of the lift charge. Additionally, the ignition of the lift charge should not cause a simultaneous reaction with the charge in component 2, which could result in premature detonation. As the shell’s caliber increases, the wall thickness and the average amounts of charges in the shell also increase.

The construction of component 2 with effect and/or burst charge can vary from shell to shell, ranging from a sphere or cylinder completely filled with burst charge to one with multiple filled layers and/or subunits. This difference is not visible from the outside. The construction of the shell determines the effects upon ignition. These effects can vary from a loud, 'tangible' bang (when only a burst charge is present) to a light show with multiple colors (when multiple layers of effect charge are present). Shells

[1] A pyrotechnic article is a device containing a pyrotechnic charge. A pyrotechnic charge is a single substance or - in almost all cases - a mixture of two or more substances which together form an (explosive) flammable material. Pyrotechnic mixtures can for example be used in fireworks and firearms. Mixtures of this kind comprise at least one substance which serves as fuel (reductor) and one substance that serves as oxygen supplier (oxidizer).

with a burst charge as the main effect are also referred to as "report" or "salute" shells. Shells with color or decorative charges as the main effect are often called "color" shells.

The lift charge of a shell always consists of black powder[2]. The burst and effect charges may consist of black powder, but can also be made from other pyrotechnic compositions. For burst charges in "report" or "salute" shells, flash powder[3] is often used. For burst charges in "color" shells, black powder (or a material similar to black powder), or chaff (plant material) coated with a flash powder-like mixture is used. Other compositions or forms are also possible. Various pyrotechnic mixtures are used for decorative effects, depending on the desired effect. For example, for different colors of light, metal salts are commonly used.

In a study conducted by TNO following the Fireworks Disaster in Enschede (May 2000), 33 different shells of calibers 3, 4, 6, 8, 10, and 12” were examined[4]. The TNO study revealed that the total amount of charge varied between 35% and 90% of the total mass of the shell.

3.3. Firing shells from mortars

The burst charge of a shell is supposed to detonate high in the air. To accomplish this, a shell must be fired upwards from a suitable tube. This tube is known as a mortar.

A mortar is a tube that is closed at the bottom. Such a tube is typically made of cardboard, steel, high-density polyethylene (HDPE), or glass fiber-reinforced polyester. Mortars are usually placed in a rack (see photo 4).

Photo 4. Example of a rack with 21 mortars.

The shell is placed on the bottom of the mortar with the lift charge facing down.. The long fuse protrudes from the top of the mortar. The internal diameter of a suitable mortar is equal to the external diameter of the shell, meaning they must be of the same caliber. If a mortar is too small, the shell will get stuck in the case. If a mortar is too large, there will be insufficient pressure build up under the shell during the explosion of the lift charge. In either case, the shell will not be launched into the air, creating a dangerous situation on the ground.

3.4. Legal aspects in the Netherlands

Shells are factory-produced as commercial fireworks. The definition of fireworks according to the Dutch Fireworks Decree is: "pyrotechnic articles for entertainment." In short, a pyrotechnic article, such as a shell, can only be called fireworks if it is used for entertainment purposes. Whether a shell meets this definition depends on the specific situation and circumstances of a case. This is up to the court to determine. Depending on the user's apparent intended use, the NFI can, upon request, conduct a review against the Dutch Fireworks Decree and the RAC[5] or, for example, the Dutch Weapons and Ammunition Act.

Under the assumption that the shell is a firework, it is always considered a professional firework according to the Dutch Fireworks Decree[6]. Shells of any caliber are intended exclusively for use by persons with specialized knowledge (in accordance with the Dutch Fireworks Decree, Article 1.1.2a). Shells must therefore never be made available for the general public.

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[2] Black powder is a pyrotechnic mixture consisting of sodium- or potassiumnitrate and charcoal with or without sulfur (mostly with).

[3] Flash powder is a pyrotechnic mixture consisting of a (per)chlorate- or nitrate-salt (oxidizer) with a metal powder, mostly aluminum and/or magnesium (fuel) which may or may not be mixed with sulphur.

[4] Classificatieonderzoek evenementenvuurwerk SE-Fireworks. Deel 3: Analyse en extrapolatie van classificatieresultaten, TNOrapport PML 2001-C30, E.G. de Jong en R. Eerligh, februari 2001.

[5] RAC = RAC = Regulation on the Designation of Consumer Fireworks pursuant to Article 1.1.1 and Article 2.1.1 of the Dutch Fireworks Decree.

[6] Upon request, the NFI can provide full substantiation in the form of an assessment according to the Dutch Fireworks Decree.

4. Danger assessment of shells

4.1. Functioning and effects

The intended functioning of a shell is as follows: the fuse is lit and ignites the lift charge made up of black powder. The black powder explodes in the mortar[7], causing the shell to shoot out of the mortar and high into the air. Simultaneously, the internal fuse between the lift charge and the burst charge (see figure 3) is ignited. After 3 to 4 seconds, the flame front of this fuse reaches the burst charge, which explodes and creates a blast whose size depends on the quantity and type of burst charge. The exploding burst charge ignites any decorative effects (such as stars) and propels them outward. The decorative effects burn during their flight and produce a light show.

If a shell is not fired from a mortar but is instead ignited while lying on the ground, the same effects occur. However, the explosion of the lift charge will now be clearly visible (see photo 5). This results in heat, fire effects, and a shock wave. After 3 to 4 seconds, the burst charge explodes, usually with a larger explosion. Again, heat, fire effects, and a shock wave occur during this second explosion, ripping the shell apart, with hot cardboard or plastic fragments being scattered. Any burning decorative effects will also be propelled tens to hundreds of meters from the explosion (see photo 6), depending on the shell's caliber (see table 1).[8]

Caliber Shell (inch)	Estimated maximum distance that decorative effects can travel [meters].
2	27
3	43
4	59
5	75
6	91
7	107
8	123
10	155
12	187

Table 1. Spreading of burning effects per caliber.

4.2. Dangers when firing shells from a mortar

There are at least two situations in which a shell ignited in a mortar can lead to life-threatening circumstances. The first is when a person is in the line of fire of the mortar when the shell is launched. The second is when the shell does not release from the mortar and the shell's burst charge explodes within the mortar. Both situations are discussed consecutively in this section.

Person in the line of fire

It almost annually occurs in the Netherlands that a person 'without specialized knowledge' ignites a shell in a mortar directly at the quick fuse while having a body part in front of the opening of the mortar. Due to the very high burning speed of a quick fuse, the lift charge explodes almost immediately. The shell is launched directly and forcefully out of the mortar, which can cause bone fractures for the person in the line of fire. If a person is struck in the head, it can result in fatal injuries[9].

Explosion of a shell in a mortar

It can happen that a shell becomes stuck in the mortar during ignition. Possible causes might be that the shell and mortar sizes are not properly matched, one of them has a defect, or the mortar is very dirty on the inside. The burst charge of the shell then explodes in the mortar.

Several factors determine the hazards posed by the explosion of a shell's burst charge in a mortar. These factors include the type of material and wall thickness of the mortar, and the caliber and type of shell (explosive or decorative effect). International literature shows that particularly shells with only explosive effects can fragment a steel mortar[10]. Depending on factors including those previously mentioned, the fragments of the mortar and shell are propelled tens to hundreds of meters from the explosion. Mortars made of weeker materials such as cardboard or fiber-reinforced PVC tend to fragment sooner than steel mortars. Fragments of these materials are lighter and therefore generally don't travel as far as they lose their speed faster durinog flight. However, PVC fragments can be sharp and pointed. HDPE mortars typically do not fragment, but tear.

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[7] A good functioning mortar will not damage due to the explosion of the black powder lift charge.

[8] TNO, Effectafstanden voor het bezigen van professioneel vuurwerk, drs. W. Colpa, ir. W. Karthaus, ir. R.M.M. van Wees, april 2002, pag. 22.

[9] The Explosives and Explosions department at the NFI uses the following series for the level of injury (in ascending order):

- Physical injury: minor injuries requiring doctor's treatment and/or reversible injuries (ears – no deafness, eyes – no blindness)
- Severe physical injury: irreversible injuries (in the case of ears - deafness, eyes – blindness) or injuries which will have serious consequences if untreated.
- Very severe physical injury: permanent disfigurements which could lead to death, if untreated.
- Fatal injury: injury which results in almost instantaneous death.

[10] Recent fireworks mortars research in the UK and the implications for safety guidance, S.G. Myatt and A.W. Train, 4th international symposium on fireworks, 9-13 October 1998, Halifax, Nova Scotia, Canada.

The speed in conjunction with the weight and shape of the fragments determines the risk of injury to individuals within the range of the flying fragments. Depending on the distance from the explosion and the location of impact on the body, the injuries can be fatal[9]. The literature describes various incidents involving shells and mortars where (fatal) injuries have occurred.[11] [12]

4.3. Dangers of firing without a mortar

Photo 5. The explosion of the lift charge of a 4-inch shell.
Photo 6. The explosion of the burst charge of a 4-inch shell.

A shell is not intended to explode while lying on the ground. If this happens, two consecutive explosions occur (see photos 5 and 6). First, the lift charge explodes, and 3 to 4 seconds later, the burst charge explodes, which is meant to produce a sound effect (loud bang) and/or color effects. The burst charge is usually much more powerful and therefore more dangerous than the lift charge, but both explosions pose a risk of damage to property and injuries to bystanders.

Many people are unaware that a shell ignited on the ground (without a mortar) results in two consecutive explosions. This makes the situation especially dangerous, as people are often unprepared for the second, more powerful explosion. They do not cover their ears anymore (increasing the risk of hearing damage) during the second explosion and might even approach the shell, standing closer when the second detonation occurs.

When a shell explodes directly against an object, the object will almost always be damaged by the heat and shock wave. At a greater distance, there is a risk of fire damage to objects due to the spread of hot and burning parts of the exploded shell.

The level of injuries of the explosions for individuals depends on the distance of the shell from the body part, the location of impact, and the shell's caliber and type. The greatest danger from an exploding shell occurs when the explosion of the shell's burst charge happens very close (a few centimeters) or directly against the body of an unprotected person. Regardless of the shell's caliber, the explosion will cause the skin to rupture and damage underlying tissues. If vital areas are severely damaged, this can lead to death. Shells containing more than 100 grams of flash powder also pose a risk of lung damage from the shock wave, a risk that increases with the amount of flash powder.

Regardless of the type of shell, there will always be severe to very severe bodily injury[9] occurring from an explosion against the unprotected body. If the explosion occurs near the head, neck, or torso, the injuries can be fatal. However, a 'report' (explosive effect) shell generally leads to more severe injuries than a 'color' (color effect) shell under the same conditions (including the same caliber).

For unprotected individuals at greater distances (in the order of meters) from an exploding shell, there is a significant risk of injuries such as burns, eye damage, and (possibly permanent) hearing damage due to the heat and shock wave from both the lift charge and burst charge explosions. The spread of burning decorative effects (such as stars) and other burning parts can still cause burns and eye damage many meters away from the explosions (see also table 1). Additionally, there remains a risk of (possibly permanent) hearing damage over many meters. The occurrence and severity of hearing damage depend on specific environmental factors and the condition of the individuals involved.[12]

[11] Arbeidsveiligheid bij het toepassen van groot vuurwerk, M. van der Plas, RIVM-rapport 620810001/2005.

[12] Entitlement eligibility guidelines, hearing loss, MPC 00646, ICD-9 389.1 (Sensorineural Hearing Loss), 389.0 (Conductive Hearing Loss), veterans affairs Canada, April 2006.

Additional danger can arise if loose materials or materials that can fragment are present in the immediate vicinity of an exploding shell. This releases shards and fragments at high speed. If these shards and fragments are made of hard materials such as glass, metal, or stone, they can cause bodily injury over many meters (in an open path). The severity of the injury is related to the shape, weight, and speed of a shard or piece of fragment. All forms of injury are possible. [9] The chance of being hit is directly dependent on the number of shards and fragments released during an explosion and can vary significantly due to specific local conditions.

For the specific scenario in which a shell is thrown at professional emergency responders and law enforcements officers, the above-mentioned dangers apply too, if they are not wearing protective clothing or hearing protection and/or are hit on an unprotected part of their body. The NFI cannot comment on the effect of an exploding shell on individuals wearing protective clothing without further investigation, due to the significant variability in the properties of protective gear. Previous research by TNO has shown that in certain cases, the explosion of a 3-inch (report) shell can puncture protective clothing and hence lead to injury in those instances.[13]

4.4. Mass explosivity

Pyrotechnic articles containing flash powder can exhibit mass explosive behavior under certain conditions. Particularly, shells with an explosive effect (the 'report' or 'salute' shell) are often mass explosive. This means that such a shell can detonate simultaneously with one or more other flash powder-containing articles when they are located very close to each other. In this case, the flash powder in the other articles ignites not because a fuse is lit, but because another shell explodes. Additionally, another sufficiently powerful explosion in the direct vicinity of one or more mass explosive shells can cause them to detonate simultaneously. This aspect of mass explosivity contributes to a greater hazard potential and is relevant in situations where there is more than one shell present or a shell located near other flash powder-containing articles (for example, in a storage location or a backpack).

4.5. Epilogue

The hazards presented by an exploding shell depend on numerous factors[14]. It is not possible to cover all scenarios in this factsheet. This factsheet only describes the general hazards for several common scenarios. If more specific information is needed (in a criminal case), you can contact the NFI (only available to Dutch law enforcement). This is also recommended when dealing with more than one shell or a shell in combination with other fireworks (see also §4.4), or if modifications have been made to the shell (such as the addition of a spray can, nails, or a gasoline bottle).

[13] TNO-rapport: TNO 2017 R10577 | 2, Onderzoek naar de impact van illegaal vuurwerk. Opdrachtgever: Politie, Staf Korpsleiding, Directie Operatiën, Den Haag.

[14] Generally, hazards are only described in broad terms given that a specific description of the location where an explosive device is to be found is usually not provided. Other environmental materials present at the location can contribute to more or less danger to bystanders. The position of a person's body is not taken into account either (upright or squatting, for instance), nor the height at which the explosive device detonates, in relation to that person (eye or foot height, for example). The number and the position of bystanders at the location also play a role in determining hazard exposure. As a rule, more tests must be performed in order to precisely determine the danger at one specifically described location.

For general questions, you can contact the NFI by telephone (070) 888 68 88.

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