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Law and Order Aspects of the Impact of an Explosion on the Human Body

In my study, I summarise the adverse effects that can occur during the execution of a blasting task and that can affect the person carrying out the blasting and those in the immediate vicinity of the blasting. I summarise the hazards that may occur during the preparation of a blasting task in the area of operation and the safety cornerstones required during its execution to ensure the health of the blaster and his/her unit. I will present the demolition activities of personnel performing special tasks in the law enforcement area and the challenges of their execution, focusing on the area of the greatest risks.

Keywords: *demolition tasks, hatches, challenges, risks, law enforcement*

Introduction

Around the world, many elite law enforcement and counter-terrorism units employ specialists to open doors by blowing them open. In many cases, the use of this capability is explicitly justified and has proved its worth in a number of cases. In some cases, the speed with which conventional manual or mechanical opening devices can be used is not in line with the dynamics of the task. In some cases – secluded perpetrators, hostage situations – professional requirements do not allow for the loss of time. The fact that the AK–47 automatic machine gun used by terrorists and other criminal circles has a theoretical rate of fire of 600 rounds per minute is thought-provoking. I believe that if this type of perpetrator were to take control of a shopping centre or a school, it would not be possible to open the doors for long seconds, which would otherwise be considered fast. In anticipation of such incidents, more and more units have included in their repertoire the displacement and opening of doors, windows, walls and other objects with explosives. However, before I go any further on my topic, I would like to introduce some basic concepts for ease of understanding.

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An explosion is the very rapid disintegration of a material system when it is accompanied by the release of large amounts of energy.[2] Depending on the type of explosion, we distinguish between physical, chemical and nuclear explosions.

In a physical explosion, the chemical composition of the material remains unchanged, but its physical state changes. During the explosion process, mechanical energy is released explosively. Examples of this type of process include: boiler explosions and explosive volcanic eruptions.

In a chemical explosion, the chemical composition of the material system is changed, resulting in the formation of heat and gas at high velocities. The force of the explosion depends on the speed of the transformation, the amount of heat released and the amount of gas formed. Depending on the rate of chemical transformation, we can speak of deflagration, flash, explosion and detonation. The severity of adverse effects on the human body depends on the rate of transformation.

A nuclear fission/nuclear explosion can occur as a result of nuclear fission or nuclear fusion, which creates a change in the atomic structure of matter.

One could say that the combustion, explosion or detonation of an explosive is called an explosion process. The destructive effect of an explosion is due to the shock wave and the shrapnel effect. As a kinetic interpretation of the well-known Boyle–Mariotte law, we know that for ideal gases, the pressure doubles when the volume is halved, and vice versa.[3]

During the explosion process, the air is compressed at the beginning of the pressure wave, and during the first – or positive – phase of its propagation, a high overpressure is generated, which is called a shock wave. In the second – or negative – phase of the process, the pressure drops below atmospheric pressure and the air flows back, in effect creating a suction effect. These phenomena are particularly significant when it is not possible to maintain sufficient distance from the blast site. These cases will be discussed later in my paper in the section on the definition of blast safety.[4]

Explosion in a confined environment

In the case of explosions in confined spaces, the devastating effects of detonation may be greater than in an outdoor environment. The explanation lies in the reflective properties of shock waves. The waves reflecting from boundary surfaces create extremely rapidly varying internal ejection pressure build-ups. In some interference bands, the magnitude of the pressure increase can be several times the maximum value of the wave considered as the dominant one. It can result in the destruction of the object and its occupants. Of course, this depends significantly on the type of explosive, the net explosive mass and its location in space.

2 Lukács 2017: 20–21.
3 Beda et al. 2023: 25.
4 Daruka–Bunyitai 2023: 137–139.

From a law enforcement perspective, blasting in a confined space – even opening a front door – requires considerable professionalism on the part of law enforcement officers. On the one hand, it depends on the way the explosives are used, the quality of the preliminary technical reconnaissance – determining the door's defensive capabilities – and the proper evaluation of the data obtained from the preliminary forensic information. On the basis of the information obtained in advance at the scene of the operation, the means and technique used to forcibly open the door, even by blasting the door, can be selected, but this method is a double-edged sword. Opening the hatch in a momentary manner will in most cases guarantee the success of the operation, as the harmful – but still acceptable – side effects of the blast will paralyse the action, but the primary, secondary and tertiary effects can result in serious, even fatal, injuries on both sides. Not to mention the phenomenon of superposition resulting from the concatenation of shock waves.[5]

Confined space explosions were carried out under laboratory conditions, and the practical conclusions were as follows:

- From both preliminary instrumental measurements and computer simulation, it can be concluded that in confined spaces, the presence and accumulation of reflected shock waves results in a pressure level significantly higher than the maximum pressure of the primary pulses.
- For long-lived pulses with long wavelengths, this effect can extend over the entire blast area, while for short waves the build-up is localised in sharp overpressure zones.
- Boundary surfaces and corners are always critical locations, where overstressing inevitably occurs and the intensity or frequency of the shock wave only affects the extent of the overstressed bands.
- Obviously, special pressure peaks are to be expected at all locations where the geometry of the boundary surfaces induces the focusing of shock waves.
- In the case of a slit-shaped blast-field, the position of the critical zones is primarily determined by the arrangement of the charge: they always appear parallel to the walls and along sharp fault lines from the corners.[6]

Health hazards found during the preparation of a blasting exercise

Toxic effects of explosives

"An explosive is a compound or mixture that, when ignited or detonated, undergoes an extremely rapid, violent chemical reaction, producing large quantities of gas and heat, accompanied by light, sound and a high-pressure shock wave."[7]

[5] Susánszki 1992: 1–2.
[6] Susánszki 1992: 3.
[7] Hernád 2010: 311.

During preparation for blasting operations, contamination by a hazardous substance can be done through the lungs in the form of dust, by eating or smoking with contaminated hands, or through the skin. Ingestion of the explosive may occur mainly through ingestion during preparation or through previous skin lesions.

When performing blasting drills and tasks, the safety requirement is to wear safety goggles, ear protection, protective clothing (gloves) and helmets to reduce the potential for hazards.

Symptoms usually appear a few weeks or months after the adverse external effect. The human body's spontaneous ability to recover from such adverse effects and the chances of recovery are high, but permanent lesions may develop in the case of repeated poisoning. The first thing to do is to prevent the possibility of further poisoning, after which further medical treatment should be arranged if necessary. There is no specific antidote for poisoning by the components concerned, except for the treatment of poisoning by the nitrate component, in which case high doses of vitamin C and methylene blue are administered to the patient.[8]

Table 1: Health effects of explosives used in law enforcement

Explosives	Target	Organ diseases
Nitropenta	cardiovascular system red blood cell skin mucosa conjunctival	hypotomy methemoglobinaemia irritation
Trinitrotoluol[9]	haematopoietic system liver cardiovascular system kidney eye skin, mucous membranes	methemoglobinaemia, haemolysis, liver failure aplastic anaemia hypotonia, degeneration cataracts yellow discolouration, irritation

Source: compiled by the author based on Hernád 2010

Wearing the right protective clothing is a way to protect against absorption through the skin. When blasting, protective gloves, goggles, helmet and hearing protection are essential equipment. It is necessary to clean up after explosive activities and to treat any injuries as soon as possible. Smoking is strictly prohibited during charge installation.[10]

It is also prohibited to use the tools used to assemble or cut explosives for any other purpose. Respiratory protection must be provided by means of a respirator with FFP3P3 protection capabilities.[11]

8 Hernád 2008: 45–46.

9 TNT, or Trinitrotoluene is a group of chemical compounds covering a total of six constitutive isomers. Of these, 2,4,6-trinitrotoluene (also known as TNT or trotyl) is produced in significant quantities and is widely used as both an industrial and military explosive.

10 Daruka–Szalkai 2023: 106–107.

11 Hernád 2007: 191–198.

Harmful physical effects of explosions during law enforcement operations

In a chemical explosion, the sudden increase in gas volume causes the released gases to compress. The resulting increase in gas volume can be up to a thousand times the volume of the explosive. As an illustrative example, the explosion of 270 g of gunpowder, with a volume of 0.18 litres, produces 746 litres of gas in just 0.24 ms.[12]

The overpressure creates a shock wave which causes the primary damage to the human body. This phenomenon is called the primary effect, it is the direct effect of the explosion and it is also the cause of the damage to the surface of the body.

The secondary effect is caused by shrapnel, metal and other fragments of material accelerated by the explosion.

In the tertiary impact, injuries are caused by objects set in motion by explosive pressure. Metallic melts and other combustible materials generated by the thermal effect trigger a further increase in the shrapnel effect.

Shrapnel effect

The shrapnel effect, destructive impact around the head and neck, is responsible for a significant number of serious injuries and 66% of fatal injuries. The surface of the eye has only half the resistance and tensile strength of the skin. Damage: in mild cases, the cornea may rupture, in severe cases, the optic nerve or retina may be damaged, leading to blindness.

Shrapnel injuries to the chest and lower body can both cause serious damage to organs in the body. Injuries to the heart, aorta, spinal cord, oesophagus, lungs can cause mainly irreversible processes.

Explosion overpressure

Explosion overpressure is responsible for damage to air-containing or sensitive organs. The shock wave generated during an explosion suddenly compresses, compresses and expands the air in organs of different densities in the body, to which the tissues of different densities react at different rates. The shearing force between them causes damage to the organs that are sensitive to it.

Tinnitus

The overpressure caused by tinnitus[13] causes hearing loss. In the event of an explosion, shocks and impulsive[14] and impact noises[15] can cause permanent hearing loss.

[12] Lukács 2012: 413.
[13] Gust: a change in air pressure consisting of a wave, which may be accompanied by a high intensity sound effect.
[14] Impulsive noise: noise with a duration of less than 500 ms.
[15] Impact noise: a noise effect lasting less than 35 ms.

In the case of overpressure, the probability of eardrum rupture is 50% at 1 bar pressure damage and up to 85% at 2 bar pressure rises.

The sensitivity of the eardrum may depend on age, hearing diseases and the distance from the epicentre of the explosion. Injuries to the middle ear can usually be successfully treated, but injuries to the inner ear can cause hearing loss or deafness.

The development of internal bleeding can be observed in 3 bar overpressure cases. In these cases, part of the pressure wave enters the body and compresses the air in the 0.2-micron thick alveoli in the lungs, damaging the surrounding membranes and vessel walls. This process causes internal bleeding, air embolism, and later watery and oedematous conditions.

Acceleration

Acceleration is when the shock wave of an explosion sets the body in motion by sudden acceleration.

The subsequent sudden deceleration occurs following impact against some rigid surface. The resulting injuries can range from minor bruises and contusions to severe trauma to limbs and internal organs.

The effect of heat

Burn injuries can occur as a result of direct flame effects during an explosion, contact burns following an explosion, and detonation fireballs. Inhalation of hot air leads to respiratory burns.[16]

Toxic gases – respiratory protection during penetration

Organic explosives are basically composed of carbon, hydrogen, oxygen, nitrogen and other elements. During an explosion, the explosion products contain gaseous and solid compounds.

The oxygen balance is determined by the ratio between the combustible elements in the explosive and the oxygen content.

If the oxygen balance (OB) is 0, in such cases mainly CO_2, water vapour and N_2 are produced. The explosion is followed by a light grey or white smoke, the closest being nitroglycerine (OB +3.5) and ammonium nitrate (OB = +20.0).

When using an explosive with a positive oxygen balance, there is an excess of oxygen and the explosion produces nitrous gases, in which case the smoke is rust red or yellow.

In the case of a negative oxygen balance, there is a lack of oxygen. Most explosives used as law enforcement or military ordnance have a negative oxygen balance. Examples of such explosives are TNT, hexogen, and PENT. When detonated, a dark grey smoke is produced. To improve the oxygen balance, oxygen carrier compounds (sodium nitrate, sodium perchlorate) can be used.

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16 Andrejev–Beljajev 1965.

The following description shows that the toxic gases produced are extremely harmful to health because of the quantity produced during the explosion. Of the gases produced in the explosion, carbon monoxide is the most significant for the operational groups. Carbon monoxide belongs to the group of chemical-type choking gases. It is a colourless, odourless, flammable gas with a lower specific gravity than air. It is formed by the incomplete combustion of organic matter.

It enters the body only through the lungs. Carbon monoxide has 300 times the affinity for haemoglobin, which causes it to inhibit the delivery of oxygen from the blood to the tissues.

The toxicity depends on:

- sensitivity to carbon monoxide (higher in young people)
- the time of exposure
- the CO content of the air inhaled
- the metabolic status of the body (e.g. muscle work)
- blood haemoglobin content (e.g. anaemia)

Symptoms:

- Acute poisoning: dizziness, headache, grogginess, a state similar to drunkenness, followed by unconsciousness and then death. Severe muscle weakness often makes escape impossible.
- Symptoms of chronic poisoning: dizziness, headache, cardiovascular disturbances, reduced mental performance, memory impairment, insomnia, stomach and heart pain, sleep disturbances, reduced work performance, irritability, emotional instability.

In the case of poisoning, the first priority is to rescue the poisoned person, treat them symptomatically and breathe oxygen into the body. In all cases, hospital observation is recommended by experts to prevent late complications.

The explosion process produces large quantities of gases containing toxic and less toxic components. Following the explosion of the hatch, the unit must enter the area of operation and search the blast site in order to apprehend the perpetrator. In such cases, the process can take up to half an hour. The amount of harmful substance inhaled during this time can greatly affect or even sabotage performance. Knowledge of basic poisoning symptoms can contribute significantly to the success of the operation, even survival. It is very important that the "rescue personnel" wear appropriate protective equipment when rescuing a possible poisoned person after an explosion, as he or she can easily become poisoned, and care must be taken to ensure the safety of the breathing of the rescued person, as carbon monoxide poisoning can occur in even higher concentrations in a heightened state of excitement.

Options for the field treatment of blast injuries in practice

Generally speaking, during an explosive event, several parts of the body are almost always affected, with the face, chest and abdomen being the most commonly injured. In the case of damage to the limbs, shrapnel flying at high velocity often causes bone fractures, and in addition, the condition of the external skin and soft tissues may be affected and damaged. In most cases, the damage is more extensive than is primarily visible. In addition to mechanical and thermal damage, such cases are also characterised by extreme oedema.

After an explosive event, the first priority is to get the casualty to safety and to immobilise him or her, without which the team will be taking additional risks, and then to start treating the casualty. The general cABCDE (critical bleeding – Airways – Breathing – Circulation – Disability – Exposure) algorithm is used. The casualty should be placed in a supine position, as the blast may damage several organs, causing severe internal bleeding and loss of consciousness.[17] In case of external bleeding, immediate direct pressure, in case of rectal bleeding, Tourniquet[18] should be applied.

After the initial triage, the ambulance service should be notified immediately. The airway should be secured as a first priority, followed by monitoring of breathing and circulation. Following this check, treatment of visible external injuries can begin. These tasks can be carried out by any member of an operational unit, who will receive training in the theory and physics of battlefield casualty care activities. The on-site treatment of airway injuries is beyond the remit of the operational casualty clearing officer and falls within the medical competence of oximetry, tactical medicine and combat medicine.[19] The definitive treatment of trauma to the ears is a hospital task. In the field, only external injuries visible to the naked eye can be treated.

It should be noted here that experience has shown that it is also necessary to be prepared for the possibility of a second explosion/explosion during a post-explosion activity at the site, either deliberate or accidental. In theory, of course, criminal intent cannot be ruled out, but several factors reduce the risk of this happening. First and foremost, there is a protocol that anyone entering a site with such a threat should only do so after an EOD (Explosive Ordnance Disposal) man has screened the area or building. Thus, the greatest risk rests on the shoulders of the EOD man or soldier.[20]

External surface and respiratory burns can occur during contact with fire. During an explosion, the core temperature can reach thousands of °C, which varies depending on the type of explosive.

The Wallace rule of nine is commonly used to measure external damage to the body surface. It divides the body surface area into 9%, so that the head and arms separately are 9–9%, the chest and abdomen 18%, and the whole back 18%. The lower limbs account for 18–18%. The area around the neck and genitalia is considered to be 1%.[21] To define the injured area, the surface area of the patient's palm can be used as a unit of measurement and is considered to be 1%.

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17 Faggyas 2023: 16–17.

18 A tourniquet is a device used to apply pressure to a limb to induce ischaemia – a restriction of blood supply to any tissue, muscle group or organ of the body – or to stop blood flow. It can be used in emergencies, surgery or post-operative rehabilitation, and its use by the military and law enforcement is common in cases of blast injuries.

19 Hernád 2013: 140.

20 Ember 2021: 34.

21 Pető 2017: 32.

Medical care of the injured, on the spot

As a basic rule, the safety of the injured and the caregiver is paramount, and therefore only an area free from immediate danger is suitable for primary interventions. In addition, it is important that the casualty should only be moved to the extent necessary.

The assessment of the casualty's condition can then be started along the principles of assessment. With a stable respiratory circulation, burn care can be started. An important indication to the care provider is soot around the airway, burnt skin, scorched hairs, which are signs of a respiratory burn. Therefore, definitive, isolated airway management of burn patients may be time critical. It is therefore advisable to perform consistent airway management prior to the development of oedema or obstruction. This intervention is already at the medical level, as the patient should be anaesthetised and intubated immediately with muscle relaxants. As the care needs of burn patients are different from other trauma, patients with airway burns should be transported to a burn centre.

During treatment, the affected body surface should be covered with a sterile dressing, iodine complex should only be used in aqueous (saline) solution in high dilution. This liquid is suitable for cooling the injured area, but continuous cooling of the whole body may lead to hypothermia. If burn gels are available (e.g. Water-Jel), they are also suitable for professional treatment. The casualty may also require large amounts of intravenous fluids and narcotic analgesics during treatment. The 2-10-20 rule of thumb for cooling can be used, whereby the injured area should be cooled preferably within 2 minutes, for 10 minutes and with a flowing fluid of about 20 degrees Celsius of pure water.[22]

Determination of safety distance

A key element in the execution of blasting tasks is the fragmentation, physical location and built-up nature of the environment. Factors affecting the safety distance:

- The explosive mass used increases in proportion to the explosive power, so that the damage can be calculated in proportion to the explosive mass used, and therefore a greater safety distance is required when calculating a larger detonation.
- The amount of explosive to be used is a function of the estimated level of resistance, the safety rating of the hatch. In addition, the structure, material composition, location and condition of the property may also be decisive.

In the case of explosions carried out inside buildings, particular attention should be paid to the harmful effects of the explosion, which, in addition to the secondary shrapnel effect, are the harmful effects on the human body of the combustion products released during the explosion.[23]

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[22] Based on the official care protocol used by Róbert Szántó Operations Ambulance Officer.

[23] Susánszki 1992.

- In addition to personal protective equipment, a ballistic blanket or a ballistic shield may be used to protect against the harmful effects of the resulting shrapnel.
- During any blasting operation, efforts should be made to use physical cover for the area. This could be the stairwell of a condominium or the corner of a building. If these are not available, easily deployable devices should be used.
- Wind, rain, temperature and humidity usually have a negligible effect on the performance of the task.

Determining the safety distance

Three main cases can be distinguished for determining the safety distance.

- Open-air explosion with personal protective equipment on, under cover, in the open air: this is the case where we can be closest to the explosion.
  In this case, the penetrator is located outside the safety distance of the blast, but within the safety distance of the shrapnel, protected from the shrapnel effect. In this case the value of "K" is 0.714. The "K" factor is NEM (NRT in Hungary) – net explosive mass = mass of explosive used × tertiles equivalent + explosive mass × tertiles equivalent.
- Open-air blast without the use of protective equipment, hearing protection or cover: In such cases, a significantly greater safety distance should be maintained to avoid injury. Value of "K": 13.
- Blasting of openings with maximum use of protective equipment and facilities, in confined spaces (indoors): when determining the safety distance, multiply the final result by two compared to case 1. For operational demolition tasks, this is the applicable calculation value.

The formula used to determine the safety distance is SD (BT in Hungary) = K × NEM $^3\surd$

- SD – safety distance in metres
- K – constant factor dependent on the mass of the explosive; proportional to the Net Explosive Mass and expressing the change in pressure due to the propagating shock wave
- NEM – the Net Explosive Mass is the sum of the mass of the charge prepared and the mass of the propellant, converted to the trotile equivalent, expressed in grams.
  The amount of explosive mass used in an arrow explosion can be significantly affected by the explosive content of the primer and the explosive content of the firing charge

Conclusions

Blasting is a highly professional task in any walk of life. Blasting hatch openings used in support of operational procedures are particularly risky activities. In the case of conventional demolitions, it is essential that the participants are located as far away from the area of the demolition as possible, but in the context of law enforcement or the military, they should want to be as close as possible. This is because the capture of the target can only be guaranteed under such conditions.

In the case of an open-air explosion, the physical resistance of the open-air window is proportional to the weight of the explosive to be used, which guarantees the safety of the operational unit and the person or persons to be subjected to the operation, in addition to the achievement of the desired objective. The aim of law enforcement is to ensure the ability of the State to act in its interests.

To avoid injury, the worker must wear or use all protective equipment intended to protect his life and health. To the extent that the requirements relating to the determination of the safety distance have been complied with during the operational activity, it is safe to assume that the task has been carried out without injury.

Good task planning may not necessarily lead to perfect execution, because no matter how prepared the unit is, it is still a variable. These are the pre-deployed surprise mines for which professional personnel can never be adequately prepared. I think there can be attacks, damaging incursions, even for well-trained personnel, which act as so-called booby traps. There is no need for any member of the force to make a mistake and start an irreversible process. In such cases, only well-applied protective equipment and professional medical care can be relied upon.

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