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Explosive Threats and Target Hardening Understanding Explosive Forces, It's Impact on Infrastructure and the Human Body

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ABSTRACT

Explosives and explosive materials can be used for good purposes such as quarrying, tunneling, mining, and removal of obstacles. Explosives can also be used for nefarious purposes. The following groups have all used explosives with the intent to kill, maim, or destroy, White Supremacists/Anti Government Extremists, Terrorists, Disgruntled Employees, Disgruntled Consumers, Criminals (Drug or Financially Motivated), Emotionally Disturbed Persons, and Eco Terrorists. Their motivations can be classified into several primary areas: experimentation, vandalism, excitement, revenge, ideology, criminal enterprise, diversion/distraction, mentally disordered, and finally mixed motives. Most professionals have a limited knowledge of explosives, explosive forces, and the related damage and injuries which can occur in an event where explosives have been utilized. This presentation will inform you of the different types of explosives, related blast dynamics, and the medical issues related to a blast event.

KEYWORDS: Explosives, Blast, Medical Response, Blast Wave, Over Pressure, Emergency Response

CONVERSION FACTORS

PSI to kPa multiply by 6.8948
Pound to Kilograms multiply by .4536
Feet to Meters multiply by .3048

BACKGROUND

This paper provides a discussion of explosive concepts, explosive forces the resulting blast pressures, and emergent medical issues. Knowledge of this information leads to better design, emergency response, and contingency planning.

Explosives 101

Before you can start to study these events and digest the design, construct, and methods chosen by terrorists, it is most important to understand the basics of explosives, explosive forces, and how they work. This ensures we are speaking a common language. This paper does not intend to make you an explosives expert or a "Bomb Technician." Both of these fields require significant initial and ongoing training in highly technical subject matter. What we intend here is to give you a basic concept of explosives, explosive forces, and how they work. There are many other texts and works which contain much greater detail on explosives and explosive devices.

Relative Effectiveness

One concept which I want to present early on is a term known as Relative Effectiveness Factor or RE Factor. One of the oldest known explosives compositions is Trinitrotoluene (TNT). TNT is probably one of the most studied explosives in the world. For that reason TNT is considered a baseline measurement and every other explosive is compared to the effectiveness of TNT. For example Composition C4 (Plastic Explosive) has a relative effectiveness factor of 1.34 that means that 1 pound of C4 is equal to 1.34 pounds of TNT.

What are Explosives?

Explosives are substances which, through chemical reaction, rapidly and violently change to gas, accompanied by high temperatures, extreme shock and a loud noise. An explosion is the process of the substance transforming into the gaseous state.

High and Low Explosives

Explosives are classified as low or high according to the detonating velocity or speed at which this change takes place and other pertinent characteristics such as their shattering effect or sudden release of explosive energy. This is also referred to as brisance which comes from the French word (brisant) to break. Shattering explosives are most often used for cutting steel, timber, or concrete. An arbitrary figure of 3,300 feet per second (fps) is used to distinguish between burning/ deflagration (low explosive) and detonation (high explosive).

Types of Explosions

There are three types of explosions: atomic, mechanical (characterized by a gradual build-up of pressure in a container until it overcomes the structural resistance of the container and an explosion occurs such as a pipe bomb), and chemical - the rapid conversion of a solid or liquid explosive compound into gasses having much greater volume than the substances from which they are generated (e.g. a pop bottle bomb). The entire conversion takes place in only a fraction of a second and is accompanied by shock, heat, light and a loud noise. In all chemical explosions, the changes that occur are the result of combustion or burning.

Combustion (of any type) produces several well-known effects: heat, light, and release of gas. The burning of a log in a fireplace and the detonation of a stick of dynamite are similar because each changes its form and chemical make-up, in doing so, produces the same effects through combustion. The difference between a burning log and the detonating dynamite stick is the rate of the combustion process.

There are three rates of combustion; (1) ordinary combustion, (2) explosion (Rapid Combustion), and (3) detonation. Detonation can be defined as instantaneous combustion, although there is actually a time interval where combustion passes from one particle of explosive compound to the next. When an explosive is detonated, the block or stick of chemical explosive material is instantaneously converted from a solid into a rapidly expanding mass of gasses.

The velocity of instantaneous combustion has been measured for most explosives and is referred to as the detonation velocity of the explosive. Detonation velocities of high

explosives range from approximately 3,300 feet per second (fps) to over 29,900 fps. To bring this speed down to our terms – if we took a five-mile length of garden hose and filled it with a high explosive and then detonated one end of the hose, it would only take one second for the chemical reaction to reach the other end.

In a detonation, the chemical reaction moves through the explosive material at a velocity greater than that of sound through the same material. The characteristic of this chemical reaction is that it is initiated by and, in turn, supports a supersonic shock wave proceeding through the explosive.”

In a deflagration, the chemical reaction moves rapidly through the explosive material and releases heat or flames vigorously. The reaction moves too slowly to produce shock waves.”

There are two types of Explosives they are (1) Low Explosives and (2) High Explosives. Low explosives are said to burn or deflagrate rather than to detonate or explode. The burning gives off a gas which, when properly confined, will cause an explosion. Most low explosives are mechanical mixtures or a mechanical blending of the individual ingredients making up the low explosives.

High Explosives do not require confinement to shatter and destroy. It must generally be initiated by a shock wave of considerable force. This is usually provided by a detonator, blasting cap, or booster in what is known as a “firing train”.

High explosives can vary significantly in their sensitivity to the factors that cause them to detonate. Often, small quantities of more sensitive explosives (detonator or blasting cap) are used to detonate larger amounts of less sensitive explosive material, using a configuration known as an “explosive train.”

A blasting cap, or detonator, is usually the smallest part of the explosive train, and contains sensitive high explosive materials. The detonation of a blasting cap can initiate specific types of high explosives such as dynamite, TNT, commercial, and military explosives, in large or small quantities. Other high explosives, including some forms of ammonium nitrate, require more external energy input than a blasting cap can provide. A three-stage explosive train can be used, where the blasting cap causes the detonation of a “booster,” which, in turn, supplies enough energy to detonate the insensitive high explosive main charge.

The varying velocities of explosives and configuration have a direct relationship to the type of work they can perform. The difference in velocities determines the type of power exerted by high or low explosives. Low explosives have pushing or heaving power and high explosives have shattering power (Brisance).

A high order detonation is a complete detonation of the explosive at its highest possible velocity. A low order detonation is either an incomplete detonation or a complete detonation at lower than maximum velocity.

Explosive Effects

Explosives have several effects. Blast pressure effect is the most powerful of all explosive effects. When the explosion occurs, very hot (between 3,000 and 7000 Fahrenheit) expanding gases are formed in a period of approximately 1/10,000 of a second. These gases exert pressures of about 700 tons per square inch on the atmosphere surrounding the point of detonation at velocities of up to 13,000 miles per hour or 29,900

fps. The expanding gas rolls out from the point of detonation like a ripple in the water and is known as the blast pressure wave.

This wave has two distinct phases positive and negative. Positive: the blast pressure wave moves outward from the point of detonation and delivers violent force to everything in its path. It lasts a relatively short period of time and delivers the highest pressures and velocity.

Negative: more descriptively known as the suction phase. It is three times longer in duration but of less intensity than the positive phase. It is formed as the out rushing air is compressed and forms a vacuum at the point of detonation. The vacuum causes the displaced air to reverse its movements and return to the point of detonation. This accounts for much of the debris that is found at the seat of the explosion and nearby.

Fragmentation Effect: missiles are produced by the explosive container, objects around the detonation point and the intended target. Fragmentation can come from surrounding glass, rocks, pieces of metal, and in the case of improvised explosive devices, nails, nuts, and bolts are often used. Fragmentation adds to the destructive force of the explosive device.

Fragments can travel at velocities up to 2,700 fps.

Incendiary Thermal Effect usually seen as a bright flash or fireball at the moment of detonation can vary greatly from one explosive to another. In general, low explosives will produce longer incendiary thermal effects than will high explosives. A high explosive will produce higher temperatures but for a shorter time. The low explosive fireball is more likely to cause a secondary fire than a high explosive detonation.

Ancillary explosive effects are secondary blast pressure effects (reflected); created by blast waves that are shattered, reflected or shielded by reflective surfaces. The reflective blast wave reflected off of surfaces surrounding it may actually reinforce the original wave by overlapping it in some places (i.e. corners of a room). Certain unusual effects may be noted at a crime scene that can be attributed to the secondary blast pressure effects. This is known as peak overpressure where overlapping pressure waves converge at the point of detonation.

Ground and Water Shock

Ground and Water shock: occur when an explosive is initiated while buried in the earth or submerged under water. Both earth and water are less compressible than air and tend to propagate a shock wave further and with more force than air. Therefore, structural damage may be substantially greater under those circumstances where earth and water are involved.

Water cannot be compressed at all and, therefore, will transmit energy much faster and farther than any other medium including when explosives have been packed (tamping) into that medium.

Explosive Forces

If explosive materials are unrestrained the force of the detonation will travel equally in all directions. In fact explosives are very lazy. Explosive forces will always seek the path of least resistance. Alternatively, if we contain an explosive we can increase its force and the resulting damage. Consider a firecracker. If you take a firecracker and place it on

your open palm and light it you might get a slight burn. If take that same scenario and wrap your closed fist around the firecracker you will cause an injury to your hand.

This notion becomes extremely important when we consider explosive devices used for terrorist or criminal purposes. In these cases tunnels, parking garages, porticos, built-up areas of cities and other confined spaces become locations where explosive forces, if contained and directed, can create huge amounts of damage beyond the capabilities of the explosive itself. During recent years in Israel, London, and Spain; buses, bus stations, and trains have been selected by terrorists as preferred targets for bomb attacks. Explosions in a bus or train create a large number of casualties due to the confined space both from the highly populous nature of these sites, but also from the explosive effects.

As a point of reference the 8 July 2005, London Bus bombing devices weighed about 10 pounds and the 11 March 2004, Madrid, Spain Train bombing explosive weight approximately 22 pounds.

Overpressure

Overpressure is the transient pressure, usually expressed in pound per square inch (PSI), exceeding the ambient pressure, manifested in the shock wave from an explosion. There are different types of overpressure including Incident Overpressure: a result of the explosive pressure wave itself; Reflective Overpressure: a result of the explosive pressure wave hitting a solid surface such as a car, wall, or building and rebounding, thereby increasing the overpressure value; and Peak Overpressure: the maximum amount of overpressure, either incident or reflected, experienced at a particular point during a specified amount of time, in other words, the point where the outbound shockwave and the reflected shockwave meet at the point of initiation.

The effect of overpressure on the human body varies depending on: distance from explosion, nature of surroundings, and the age and physical condition of the individual.

The following charts demonstrate pressure versus range for fifty pounds of explosives and five hundred pounds of explosives. These charts reinforce the concept that explosive forces significantly dissipate over distance. While pressures are very high ten feet from the blast, there is a significant decrease in pressure at forty feet.

Keep in mind these charts reference commercial explosives in the open, they do not take into account reflected pressure and impulse pressure. The charts make reference to a hemispherical burst, this means the charge detonates in contact with the ground and the blast wave propagates with a hemispherical wave front. Examples of this would be a Vehicle Borne Explosive Device (VBIED) or military munitions fused to detonate on impact with the ground.

Chart courtesy of Mr. Ed Conrath, P.E. Senior Principal Engineer, Protection Engineering Consultants Chart courtesy of Mr. Ed Conrath, P.E. Senior Principal Engineer, Protection Engineering Consultants

Overpressure in PSI Effect

- 1-2 Frame house destroyed
- 3-5 Typical commercial construction destroyed
- 5 Tympanic membrane rupture
- 15 Tympanic membrane rupture in 50% of patients
- 30-40 Possible lung injury

40 Reinforced concrete construction destroyed
75 Lung injury in 50% of patients
100 Possible fatal injuries
200 Death most likely
Charles Stewart MD, FACEP, FAAEM (MD 2006)

Blast Injuries and Destructive Capabilities

Previously we discussed the concepts of blast, blast wave, overpressure, and peak overpressure. These forces have significant impact on the human body. The human body contains many gas filled structures that are susceptible to blast injury. By gas filled structures we are speaking of lungs, stomach, intestines, etc.

Concept of Walking Wounded

This is important. In a post blast environment there is a potential for “walking wounded.” These are individuals who present no outward signs of injury but may have significant internal injuries of which they are not aware. This is important for first responders and incident managers to know as all persons within the blast site should be examined before being released.

At the same time as the wounded need to be treated, there are many competing priorities such as law enforcement intervention, fire fighters wanting to put out fires, and investigators seeking post-blast forensic materials.

Significant consideration should be given to the possibility of secondary or tertiary devices which are designed to target first responders. We will discuss this concept in more detail in Chapter 9, Response.

In regards to blast injury, when allowing for your response, consider the old adage “*The Greatest Good for the Greatest Number.*” This is critical as important decisions will need to be made based on the following criterion. Serious consideration should be given to area medical personnel and their abilities to deal with a mass casualty situation. This is a specific skill set that demands a high level of training and preparation. Security Directors, Chief Security Officers, and Building Managers are not trained as medical first responders.

However they must be capable of preparing operational plans and coordinating the response effort. The following information should give you some context on what to expect and what to consider in your planning. Standard texts of triage are normally used to identify proper triage categories. The standard NATO categories are immediate, delayed, minimal, or expectant. The descriptions of the four categories are as follows. Mass casualty triage involves sorting of patients into categories based on urgency of need for treatment using the concept of doing the greatest good for the greatest number of patients. Immediate: these persons have life-threatening or moderately severe injuries that are treatable with a minimum amount of time, personnel, and supplies. These persons also have a good chance of recovery.

Delayed: treatment of these patients can be delayed without significant changes in outcome.

Minimal: these patients require only minor treatment and are generally ambulatory.

Expectant: these patients have injuries requiring extensive treatment that exceeds the medical resources available. In other words, they are expected to die and "care-for-comfort" is indicated.

The following information is provided courtesy of the Department of Health and Human Services Centers for Disease Control and Prevention.

Note: some of the information presented here is specifically intended for medical personnel.

This paper is intended as a Manager's resource. In that light, the following information is provided for the purpose of preparing and coordinating a response effort.

As the author, I have edited out some of the highly technical medical expressions in this chapter. I retained information that a manager or planner would need to speak coherently with local medical professionals and medical first responders.

Explosive devices and high-velocity firearms are the terrorists' weapons of choice. The devastation wrought in two European capitals, Madrid and London, demonstrates the impact that can be achieved by detonating explosives among densely packed civilians. In an instant, an explosion can wreak havoc—producing numerous casualties with complex, technically challenging injuries not commonly seen after natural disasters such as floods, tornadoes, or hurricanes. Because many patients self-evacuate after a terrorist attack, and pre-hospital care may be difficult to coordinate, hospitals near the scene can expect to receive a large influx—or *surge*—of victims after a terrorist strike. This rapid surge of victims typically occurs within minutes, exemplified by the Madrid bombings where the closest hospital received 272 patients in 2.5 hours. In addition, injuries to workers involved in recovery procedures can lead to a secondary wave in surge.

Some key concepts to consider:

- Bombs and explosions can cause unique patterns of injury seldom seen outside combat.
- Expect half of all initial casualties to seek medical care over a one-hour period.
- Most severely injured arrive after the less injured, who bypass EMS triage and go directly to the closest hospitals.
- Predominant injuries involve multiple penetrating injuries and blunt trauma.
- Explosions in confined spaces (buildings, large vehicles, mines) and/or structural collapse are associated with greater morbidity and mortality.
- Primary blast injuries in survivors are predominantly seen in confined space explosions.
- Repeatedly examine and assess patients exposed to a blast.
- All bomb events have the potential for chemical and/or radiological contamination.
- Triage and life saving procedures should never be delayed because of the possibility of radioactive contamination of the victim; the risk of exposure to caregivers is small.
- Universal precautions effectively protect against radiological secondary contamination of first responders and first receivers.

Blast Injuries

The four basic mechanisms of blast injury are termed as: primary, secondary, tertiary, and

quaternary. “Blast Wave” (primary) refers to the intense over-pressurization impulse created by a detonated high explosive (HE). Blast injuries are characterized by anatomical and physiological changes from the direct or reflective over-pressurization force impacting the body’s surface. The HE “blast wave” (over-pressure component) should be distinguished from “blast wind” (forced super-heated air flow). The latter may be encountered with both High Explosives and Low Explosives.

Low Explosives are classified differently because they lack the self-defining High Explosive over-pressurization wave. Low Explosives mechanisms of injuries are characterized as due from ballistics (fragmentation), blast wind (not blast wave), and thermal. There is some overlap between Low Explosives descriptive mechanisms and High Explosive’s Secondary, Tertiary, and Quaternary mechanisms.

Note: Up to 10% of all blast survivors have significant eye injuries. These injuries involve perforations from high-velocity projectiles, can occur with minimal initial discomfort, and present for care days, weeks, or months after the event. Symptoms include eye pain or irritation, foreign body sensation, altered vision, periorbital swelling or contusions.

Selected Blast Injuries

Lung Injury

“Blast lung” is a direct consequence of the High Explosive over-pressurization wave. It is the most common fatal primary blast injury among initial survivors. Signs of blast lung are usually present at the time of initial evaluation, but they have been reported as late as 48 hours after the explosion. Blast lung produces a characteristic “butterfly” pattern on chest Xray.

A chest X-ray is recommended for all exposed persons and a prophylactic chest tube (thoracostomy) is recommended before general anesthesia or air transport is indicated if blast lung is suspected.

Ear Injury

Primary blast injuries of the auditory system cause significant morbidity, but are easily overlooked. Injury is dependent on the orientation of the ear to the blast. Tympanic Membrane perforation is the most common injury to the middle ear. Signs of ear injury are usually present at time of initial evaluation and should be suspected for anyone presenting with hearing loss, tinnitus, otalgia, vertigo, bleeding from the external canal. All patients exposed to blast should have an otologic assessment and audiometry.

Abdominal Injury

Gas-containing sections of the GI tract are most vulnerable to primary blast effect. This can cause immediate bowel perforation, hemorrhage shear injuries, solid organ lacerations, and testicular rupture. Blast abdominal injury should be suspected in anyone exposed to an explosion with abdominal pain, nausea, vomiting, vomiting of blood, painful gastrointestinal symptoms, rectal pain, testicular pain, unexplained decreased

blood volume, or any findings suggestive of an acute abdomen. Clinical findings may be absent until the onset of complications.

Brain Injury

Primary blast waves can cause concussions or mild traumatic brain injury (MTBI) without a direct blow to the head. Consider the proximity of the victim to the blast particularly when given complaints of headache, fatigue, poor concentration, lethargy, depression, anxiety, insomnia, or other constitutional symptoms. The symptoms of concussion and post traumatic stress disorder can be similar.

Emergency Management Options

Follow your hospital's and regional disaster system's plan. Expect an "upside-down" triage - the most severely injured arrive after the less injured, who by-pass EMS triage and go directly to the closest hospitals. For a rough prediction of total "first wave" of casualties use a Mass Casualties Predictor.

Mass Casualties Predictor

In the confusion that often follows a mass casualty event, managing a hospital can be challenging, past mass casualty events show patterns of hospital use. It is possible to estimate initial casualty volume and pattern after a mass casualty event. Public health professionals and hospital administrators can use this information to handle resource and staffing issues during a mass casualty event.

Patterns of Hospital Use

Within 90 minutes following an event, 50-80% of the acute casualties will likely arrive at the closest medical facilities. Other hospitals outside the area usually receive few or no casualties. The less-injured casualties often leave the scene under their own power and go to the nearest hospital. As a result: They are not triaged at the scene by Emergency Medical Services (EMS). They may arrive to the hospital before the most injured. On average, it takes 3-6 hours for casualties to be treated in the emergency department (ED) before they are admitted to the hospital or released.

Casualty Predictor

When trying to determine how many casualties a hospital can expect after a mass casualty event, it is important to remember that casualties present quickly and that approximately half of all casualties will arrive at the hospital within a 1-hour window. This 1-hour window begins when the first casualty arrives at the hospital. To predict the total number of casualties your hospital can expect, double the number of casualties the hospital receives in the first hour.

Casualty Predictor

Total Expected Casualties = (Number of casualties arriving in one hour window) x 2.

Note: The total expected number of casualties will be an estimate. There are many factors that may affect the accuracy of this prediction such as: transportation difficulties and delays, security issues that may hinder access to victims, and multiple explosions or secondary effects of explosion (such as a building collapse).

Obtain and record details about the nature of the explosion, potential toxic exposures and environmental hazards, and casualty location from police, fire, EMS, ICS Commander, regional EMA, health department, and reliable news sources.

If structural collapse occurs, expect increased severity and delayed arrival of casualties. Communications and instructions may need to be written because of tinnitus and sudden temporary or permanent deafness. *For more information, visit CDC on the Web at: www.emergency.cdc.gov/BlastInjuries*

LESSONS LEARNED

Explosives and explosive forces are not complex. By understanding their principles and capabilities we can plan for explosives related events whether they are manmade or technologic. This permits us to design adequate protective measures pre-event by not allowing the introduction of explosive materials into our facilities through adequate design of physical security systems, detection technologies, and response mechanisms. By understanding the outcomes of an explosives related event we can prepare and train emergency first responders to rapidly respond to, mitigate, and recover from an explosives related event.

Lastly the farther you are away from the device the better your chances are of survivability so DISTANCE=LIFE SAFETY. Also if you find yourself in the area of a blast any barrier is better than no barrier and can provide you protection. Walls, parked vehicles, even a curbing will provide protection to your body from blast trauma.