

## Introduction

An explosion is a sudden release of a large amount of energy in a destructive manner.<sup>1</sup> Explosions can be associated with tremendous heat, property damage, shrapnel, and shock waves; as well as the potential to harm people.

The risk of explosion is one of the undesirable side effects of today's society. Even such harmless places as playing fields can be hazardous. In the US, some playing fields have been placed over used landfill sites, where there can be a problem with methane gas leaking from the underground rubbish. It may be no surprise then, to read about, *"a soccer mom went after a stray ball that had fallen into an eroded hole around a light pole. To see in the shadows, she pulled out a pocket lighter. An exploding fireball threw her several feet back from the methane-filled hole. Fortunately, she suffered little more than minor burns and a bad case of the shakes."*<sup>2</sup>

## Possible causes of explosions

Modern explosives are widely used for many applications: from mining, to space exploration, demolition, ammunition, to many types of military weapons including land mines.

Explosions are not limited to explosives however. Compressed gas cylinders and boilers can rupture explosively, while certain chemical reactions can runaway leading to an explosive situation.

Flammable liquids can give off vapors leading to fuel-air explosions, while liquefied, flammable gases can cause Boiling Liquid Expanding Vapour Explosions (or BLEVE's).

Combustible dusts can explode under certain conditions explosions. In particular they present a hazard during bulk handling, where even innocuous materials, such as grain and flour, can cause a dust explosion. Even smoke under certain conditions can explode.<sup>3</sup>

The reasons for explosions are many and varied, and it would be beyond the scope of this article to discuss them all. Instead it will be limited to the common factor of all explosions, and that is the release of pressure. It is this form of energy release which drives most of the destructive forces associated with explosions.

## Pressure

Pressure is defined as a force spread over an area. Atmospheric pressure corresponds to 101.325 kPa. This might not mean much but if we convert the units to kg/m<sup>2</sup>, this corresponds to 10,332 kg/m<sup>2</sup>. This is the consequence of living under 30 kms of atmosphere that is pushing down on us from all directions.

It is something we live with everyday and don't take too much notice of. However, if all that weight was coming at us from one direction (up to 10 tonnes/m<sup>2</sup>) over your body area it has the potential to make a BIG difference.

This might give you some appreciation of the potential power of explosions.

## Where pressure comes from

Pressure is caused by the countless number of collisions of air molecules upon a given surface. Air molecules are in constant motion with each molecule moving at about 450 metres/sec, and colliding about 370,000,000 (or 370 million) times each second and travelling about 0.0001 millimetres between each collision.

When they collide with a solid surface, they give it a little "push," as they rebound in the opposite direction. It becomes pressure a 'zillions' of molecules are colliding and rebounding over a given surface area.

Air molecules at any given pressure are in equilibrium with each other in terms of collisions, molecular velocity and separation from each other. An increasing pressure as in a car tyre, simply means air molecules are forced closer together, so that there are far more collisions and therefore a greater overall force is applied. On the other hand, an increase in temperature causes air molecules to move faster and therefore there are more powerful and frequent collisions, so the net effect is again an increase in pressure.

## Kinds of overpressure

Overpressure occurs when air pressure at a local point is above air pressure. That overpressure will quickly disperse in all directions to enable the whole to return to equilibrium. The following are examples of over pressure.

**1. Sound.** Air is an elastic medium, and it always seeks to maintain equilibrium at atmospheric pressure. Any pressure above atmospheric is known as overpressure, and may be created for example, by somebody speaking. The voice box produces many variations in air pressure, creating variable pressure waves with overpressures of the order of 2 to 20 millionths above atmospheric pressure (0.00002 – 0.00002 kPa). These pressure waves travel at the speed of sound at 331.4 m/s.

This property of air is an essential component in being able to speak, to hear and to communicate with other people.

**2. Sonic Booms.** Another kind of pressure wave with an associated overpressure is the sonic boom. The air cannot move away quickly enough when aircraft are flying at speeds greater than the speed of sound, and so it is forced into a shock wave, which in turn quickly degrades into a sound wave known as a sonic boom.

Sonic booms associated with a pressure wave with an overpressure of about 0.07 kPa (some 7,000 times the ordinary noise level) at ground level create sufficient noise in which a "public reaction can be expected".<sup>4</sup>

Aircraft flying at altitudes less than 30 metres have created sonic booms up to 6.9 kPa.

**3. Wind.** Wind blowing from one direction is another way to think of overpressure, although it is not strictly considered as such. This time the important factor is the surface area facing the wind, since pressure under these circumstances is a force being applied in a single direction.

A cyclonic wind of 140 kms/hour from a category 3 cyclone would apply a pressure on a person of my build of about 0.93 kPa, or corresponding to a total force of about 55 kilograms. I'm told you cannot stand upright in a wind like that!

If a wind could blow at the speed of sound, then the pressure would be equivalent to atmospheric pressure (about 101 kPa) and the total force would be about 6,000 kgs. It is well known that people have been sent flying when in close proximity to an explosion. Maybe these figures will provide an appreciation why, with some of the forces that may be unleashed in an explosion.

### **Detonation & deflagration**

So how does pressure translate into the effects of an explosion? Both TNT and gunpowder are well known examples of explosive materials, since they both contain both fuel and oxidizer within their make up.

These two materials react in different ways when they explode; by detonation and deflagration respectively.

### **Detonation**

TNT explodes by detonation, which means the explosion reaction proceeds through the material at a speed greater than the speed of sound. In practical terms, it is instantaneous, so that when a tonne of TNT, which occupies a volume of about 600 litres, detonates, the same volume is now occupied with about 500,000 litres of gaseous products. The fireball may reach 2,000 deg C, producing overpressures of the order of 200,000 to 400,000 atmospheres, with an initial pressure wave moving out at speeds up to 9,200 m/s. This is about 30 times the speed of sound.

At these kinds of pressures everything gives way, even the ground beneath, to form a crater up to 60 m<sup>3</sup>. At the shock front there will be an instantaneous pressure rise, and if it hits anything solid, it will be immediately bent, buckled, shattered or torn into shrapnel.

This supersonic wave rapidly slows down as it loses energy to degrade into a sound wave. This sound wave continues to lose energy where close in it will be heard as a very loud "bang," but further out as a drawn-out softer "boom."

### **Deflagration**

Gunpowder on the other hand usually reacts by deflagration in which the reaction proceeds at a rate slower than the speed of sound. Deflagration therefore does not produce shock waves, and for this reason gunpowder can be used in such things as skyrockets as a propellant, since it burns slowly enough to send the rocket into the air. That would never happen with TNT!

It is still an effective explosive however, since sufficient pressures can be generated to have the desired shattering or rupturing effects when the gunpowder is confined. This can sometimes be seen on TV, where the hero (or villain!) lays a trail of gunpowder that rapidly burns after lighting, until it hits the powder keg. Once inside the keg, the burning front continues to produce such a large volume of gaseous combustion products that the 'instant' pressure rise will cause an explosion.

Other explosions that occur largely by this means are dust, gas and flammable vapour explosions. They can be just as destructive inside buildings, because of the volume of gases produced from the reaction, will create such a rapid build-up of pressure and the building is unable to vent quickly enough. It can lift the roof, blow out walls and windows, and the effect can be just as devastating as TNT.

Deflagration therefore only causes explosions when the material is confined, so that there is pressure build-up sufficient to produce a 'bang.'

### **Overpressure & People**

The human frame, compared with rigid structures such as buildings, is quite resistant to the direct effect of overpressure from an explosion (see tables 1 & 2).<sup>5</sup> This may be a dubious advantage however, since rigid structures can collapse or turn into shrapnel, so that people may be trapped or crushed inside fallen buildings, or hit by shrapnel.

They can be turned into missiles themselves, so they are thrown at something to cause injury.

On the other hand such are totally random nature of explosions, that seeming miracles have occurred where people have emerged unscathed.

Injury to People	Overpressure (kPa)
100% lethality	500 – 800
50% lethality	350 – 500
Threshold lethality	200 – 300
Severe lung injury	130 – 200
50% Eardrum rupture	200 – 233 (under 20 yrs)
50% Eardrum rupture	100 – 133 (over 20 yrs)

**Table 1 - Overpressure & injury to people**

Degree of Damage to Buildings	Overpressure (kPa)
Almost complete destruction	70
Damage so severe as to necessitate demolition	33
Not feasible to render it habitable during war	25
90% Window damage	4
50% Window damage	2
5% Window damage	0.5

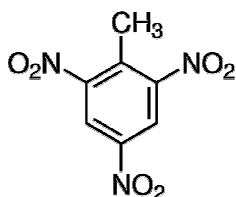
**Table 2 – Overpressure & building damage**

In major cities with tall buildings, blast waves from bombs have often been directed along streets by a process called funneling, or they have been reflected off other buildings, so that the overpressure tends to drop more slowly. In these situations, buildings and people can still be at risk, at distances that would be normally considered safe, if the same event had occurred in an open space.<sup>6</sup>

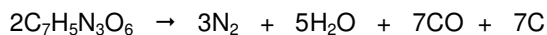
### TNT Equivalence

Explosive forces are of interest to a wide variety of people for various reasons: forensics, accident investigation, mining, demolition, military to name a few. To try to find way to compare the different types of explosions, the impact of a given explosion are sometimes converted to the impact of an equivalent amount of TNT.

This can only be at best an estimate and is based on consideration of such factors as crater formation, the size, shape and spread of shrapnel, and degree of demolition.



TNT or 2,4,6-trinitrotoluene (CAS 118-96-7) is a yellow solid. It is relatively insensitive to shock and can be easily poured as molten liquid (melts 80 C) into shaped charges or combined with other explosives. An explosion involving TNT produces a lot of free carbon and is therefore very sooty. The equation is:



TNT is quite toxic and turns the skin a bright yellow-orange colour.

### Incidents

Incidents involving explosions continue to occur around the world due to human factors, reasons unknown and so called acts of God. Some of the more relevant include:<sup>7,8</sup>

1. Thailand, February 1991. A tractor-trailer transporting dynamite overturned in a stone quarry, where a large crowd gathered and began looting. After about one hour the whole load detonated killing 122, leaving another 99 seriously injured, and 50 homes destroyed. Believed due to fallen cigarette butt.
2. A fisherman pulled up a sidewinder missile with a net in Lake Michigan, and left it on the shore. After 8 days someone recognized what it was; it was also found to be armed and ready to go.
3. Fire fighters intending to add realism to a drill activated what they thought was a smoke grenade. It was an explosive device.
4. Argentina, November 1995. Explosion at an arms factory rained shells and shrapnel over town for 4 days, 15,000 evacuated, 200 unaccounted for. Cause, human error.
5. USA, October 1994. Driver illegally cut in front of petrol tanker on underpass of freeway. Tanker was carrying 31,000 litres petrol, it rolled and exploded. Car driver killed.
6. USA, August 1994. Worker cut into old fuel tank of bus. Explosion threw his body 70 metres.
7. South Africa, 1987. Lightning strike on an explosives factory during a storm resulted in a massive explosion involving 8 tonnes dynamite, producing a crater the size of a football field.
8. Algeria, 1993. Woman and three children killed by explosion when they drove over a gas line that was leaking.
9. Canada, 1935. Three workers given the job of decontaminating a factory using detonators. They identified a spot where a leakage of nitroglycerine was suspected, and before setting off a detonator, they hid behind a

building some 25 metres away. The blast was equivalent to 8 tonnes TNT, and left a crater 10 metres deep and 50 metres wide.

### The Situation in WA

The possible reasons for explosion in WA cover the whole gamut found world-wide, and could include explosives, detonators, World War II souvenirs, ammunition, BLEVE's, flammable vapours, combustible dusts, gas cylinders, boilers, ammonium nitrate and uncontrolled chemical reactions.

The only advice that applies for these situations are BIG steps the other way, because explosions always travel a lot faster than you can. Protective gear such as full gas suits are available for toxic or corrosive materials, but there is nothing that will protect against an explosion. Explosive materials are therefore best left for others to recover. However, all fire fighting personnel must remain alert to situations where an explosion may occur.

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<sup>1</sup> Tokle G, "Hazardous Materials Response Handbook," 1993, NFPA, Quincy, Massachusetts

<sup>2</sup> Snyder Sachs J, "At Play in a Field," Discover, 18(No 6)1997, 54-59

<sup>3</sup> Sutherland BJ, "Smoke Explosions," March 1999, Fire Engineering Report 99/17, School of Engineering, University of Canterbury, NZ

<sup>4</sup> NASA Dryden Flight Research Centre, November, 1994

<sup>5</sup> Marshall VC, "Major Chemical Hazards," 1987, Ellis Horwood Ltd, England

<sup>6</sup> Mays GC & Smith PD, "Blast Effects on Buildings," 1995, Thomas Telford, London

<sup>7</sup> Bowen JE, "Emergency Management of Hazardous Materials Incidents," 1995, NFPA, Quincy, 1995

<sup>8</sup> MIHDAS database, SilverPlatter, Norwood, MA, US

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