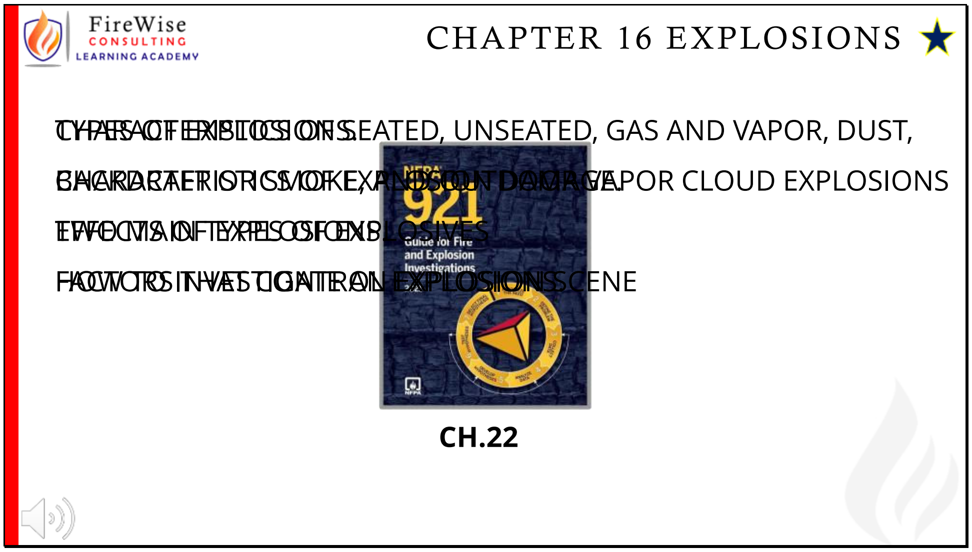
Slide 1



Welcome to Chapter **16** Explosions. If you are following us in NFPA 921, 2021 we are covering Chapter 22.

In this chapter we will discuss:

- the types of explosions.
- the characteristics of explosion damage.
- the effects of explosions.
- the factors that control explosions.
- the characteristics of seated, unseated, gas and vapor, dust, backdraft or smoke, and outdoor vapor cloud explosions.
- the two main types of explosives.

And

- Explain how to investigate an explosion scene.

Slide 2

This chapter covers an introduction to explosions. It will assist investigators charged with investigating and analyzing explosion incidents and rendering opinions as to the cause, responsibility, or prevention of such incidents, and the damage and injuries which arise from these events. As these types of events are fairly rare, investigators should remain within their level of expertise and call for assistance from more qualified and experienced investigators when needed.

Slide 3

The main focus of this chapter is the investigation of diffused fuels (not concentrated) in lightweight construction structures which are the most common events encountered by fire investigators.

Explosions are gas dynamic meaning, for example, that explosions caused by hydrostatic pressure of a non-compressible liquid such as water, are not explosions. So destruction caused by a water hammer is not classified as an explosion.

The chapter does not cover explosions caused by high explosives such as from an Improvised Explosive Device (IED) or Improvised Incendiary Device (IID)), nuclear explosions, or illegal drug laboratories. If you suspect one of these types of explosions call an expert from the applicable authority having jurisdiction.

The photograph in this slide shows the aftermath of a propane vapor explosion. The home owner intentionally leaked propane into the basement of the home and ignited it. He was found sitting in a chair in the basement with a bible in his hands. The house was originally located where the firefighters are standing. The magnitude of the damage approaches the high end of a vapor explosion.

Slide 4

The term explosion is difficult to define precisely and may vary for the type of event. The type of explosion is determined by the evidence. Evidence includes damage or changes to structures or objects, or injury to persons.

For purposes of fire investigation an explosion is defined as the sudden conversion of potential energy, either mechanical or chemical, to kinetic energy. Kinetic energy is energy in motion. The conversion into kinetic energy produces and releases gas or gases under pressure which then causes mechanical damage to materials or people. Although there is usually a loud noise associated with an explosion it is not an element of primary concern.

Factors controlling explosion effects and damages include the type, configuration and amount of fuel, as well as the size, shape and material of the container or construction, and the type and amount of venting present.

Overpressure is simply atmospheric pressure above ambient pressure. This photograph shows the damage to the house next door to the one in the previous slide.

Slide 5

The two major types of explosions routinely involving fire investigators are mechanical and chemical. Each has subtypes which are differentiated by the source or mechanism by which the overpressure is produced.

A mechanical explosion is strictly a physical process in that it doesn't involve any change to the basic chemical composition of the substance in the container. It is the rupture of a closed vessel or container such as a boiler, tank, cylinder, building or other container resulting in the release of pressurized liquid gas or vapor.

A chemical explosion is one in which an exothermic chemical reaction is the source of the high-pressure gas and the fundamental chemical nature of the fuel is changed.

Slide 6

BLEVE

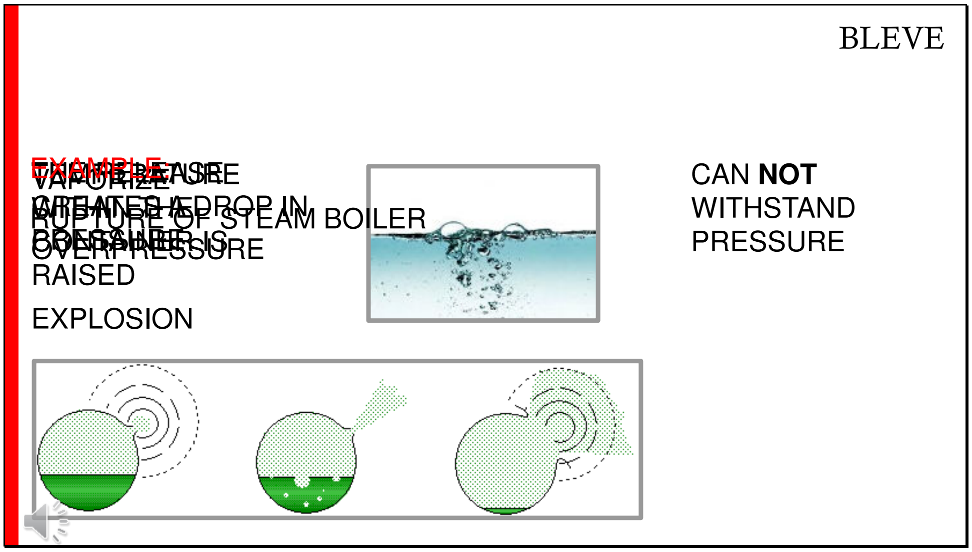
BOILING LIQUID EXPANDING
VAPOR EXPLOSION

CONTAINER OF LIQUID UNDER
PRESSURE AT HIGH TEMPERATURE

A frequent subtype of mechanical explosion encountered by fire investigators is the boiling liquid expanding vapor explosion, commonly referred to as a BLEVE. A BLEVE is an explosion involving a container of liquid under pressure at temperatures above its atmospheric boiling point. The containers may range in size from a small aerosol like that in this photograph to a much larger container like the one shown in the following video.

Slide 7

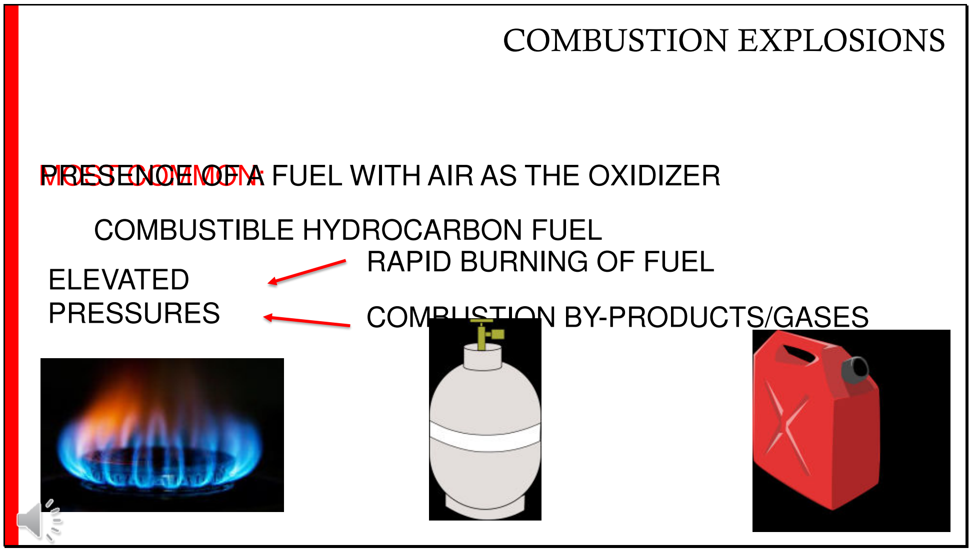
Slide 8



A BLEVE may result when the temperature of the liquid and vapor within the container is raised to the point where the container can no longer withstand the pressure and the vessel ruptures. The release of the pressurized liquid creates a sudden drop in pressure allowing it to vaporize almost instantaneously contributing to the overpressure and explosion. The ignition of the vapor usually occurs from the original heat that caused the BLEVE or from another electrical or mechanical source that comes into contact with an expanding cloud of gas or vapor.

An example of a BLEVE that does not involve an ignitable liquid is the rupture of a steam boiler where the energy source is the pressurized steam. Steam explosions won't be accompanied by a flame front and rarely result in a fire.

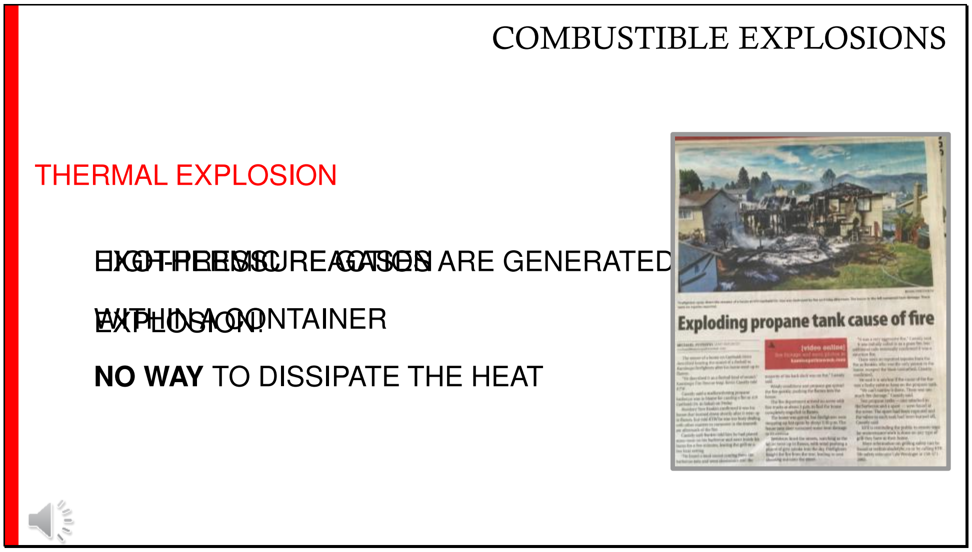
Slide 9



The most common explosions fire investigators encounter are caused by the burning of a combustible hydrocarbon fuel like natural gas, propane or gasoline. A combustion explosion is characterized by the presence of a fuel with air as the oxidizer. Elevated pressures are created by the rapid burning of the fuel and production of combustion by-products and gases. The reaction can accelerate to the point where an explosion occurs.

Uniform reactions occur more or less equally throughout the material. Propagating reactions initiate at a specific point in the material and spread through the unburned material.

Slide 10



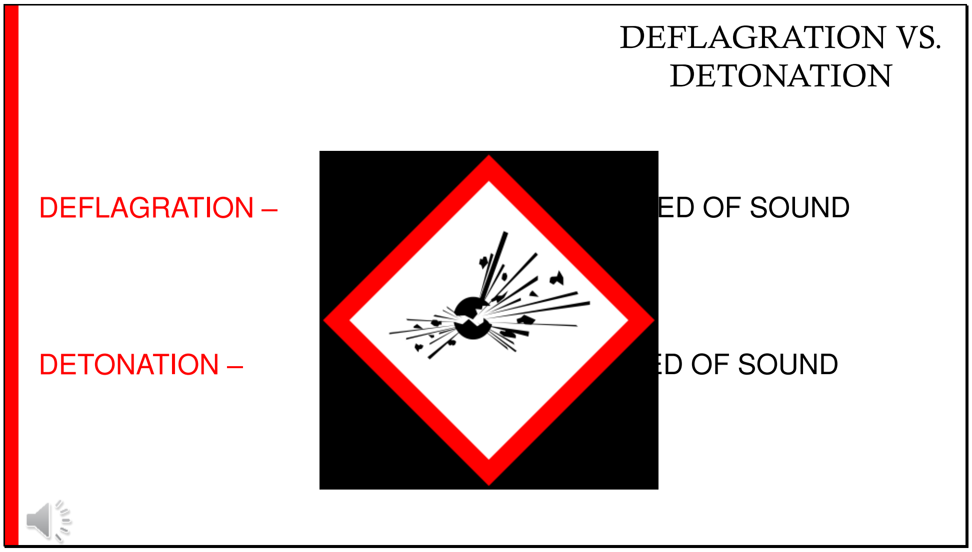
A thermal explosion is the result of an exothermic reaction occurring within a container without provisions for dissipating the heat of the reaction. This can accelerate to the point at which high-pressure gases are generated and an explosion occurs. Propane containers are a good example; they are equipped with a pressure relief valve that is designed to vent the cylinder if the pressure inside the cylinder exceeds a given pressure. If the relief valve fails or can't release the pressure quickly enough an explosion will take place.

Slide 11

In this case, the propane tank was placed beside the rear driver's side tire on the outside of the pickup truck. The owner had just had the propane tank filled and was having an afternoon nap in a camper mounted in the bed of the truck. It was a hot summer day and the sun was shining directly onto the propane tank. The owner woke up and, as was his usual habit, lit a cigarette as he got out of the bed which was over the cab of the truck. He told the investigator that there was a loud bang and the camper just seemed to disappear. He survived the incident probably because he was in close proximity to the ignition source, otherwise known as the epicentre of the explosion.

The investigator believes that the propane tank was overfilled and the gas expanded from the heat of the sun shining directly onto the tank. This caused gas Vapors to vent into the camper which were ignited by the open flame used to light the cigarette. The owner did not smell the gas probably because his olfactory system was overloaded by exposure to the odorant.

Slide 12



Combustion explosions are classified as either deflagrations or detonations, depending on the propagation of the flame front through the fuel-air mixture. Propagation simple means spreading and in the case of a combustion explosion the speed of the flame front.

A deflagration is reaction front that travels through the mixture at less than the speed of sound. Deflagration is self-sustaining as long as the mixture is correct. Deflagrations travel at subsonic speed that can be vented successfully.

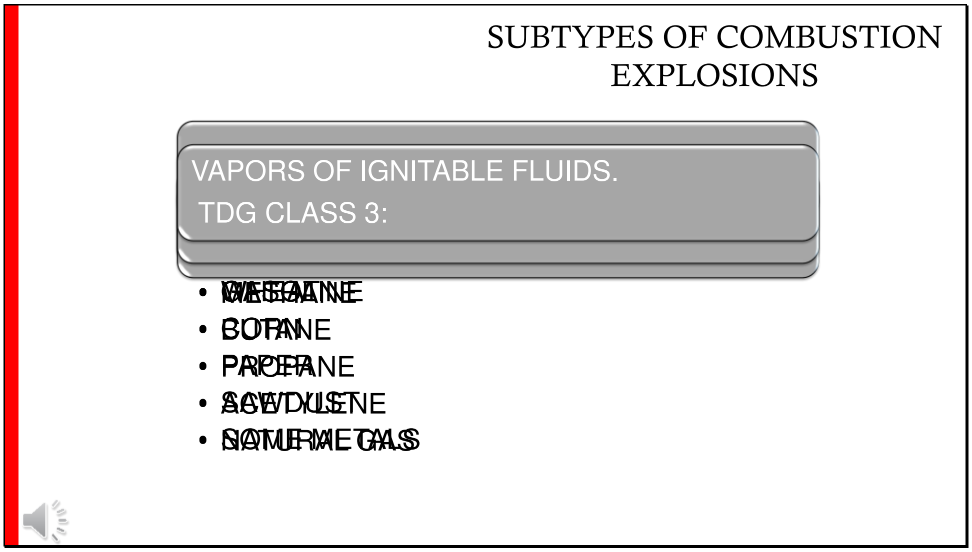
A detonation, on the other hand, is a combustion reaction in which the velocity of the reaction is faster than the speed of sound forming a shock wave that leads the flame front. Detonations are self-sustaining processes not requiring other driving mechanisms.

The difference between deflagration and detonation is the magnitude of the pressure versus time for the system involved in the combustion reaction.   The detonation is much faster and cannot be vented because of the extreme speed of the reaction.

Slide 13

DeHaan video #33 Dr. DeHaan: Deflagration vs. Detonation

Slide 14



Subtypes of combustion explosions are:

- Flammable gases that fall under Transportation of Dangerous Goods Class 2.1, for example, methane, butane, propane, acetylene, or natural gas
- Vapours of ignitable liquids that fall under TDG Class 3, for example, gasoline
- Combustible dusts such as wheat, sugar, corn, paper, sawdust and some metals
- Smoke and flammable products of incomplete combustion which can cause a backdraft explosion

And

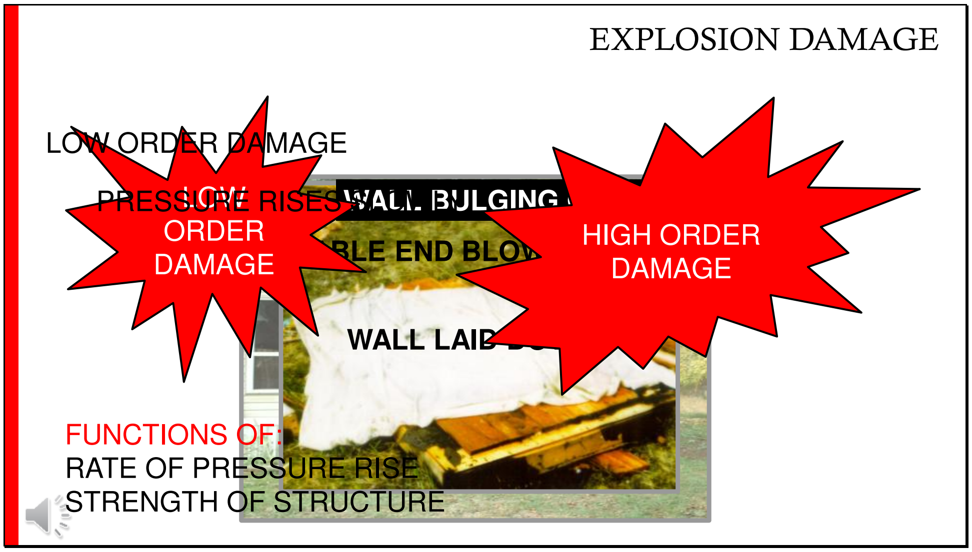
- Aerosols

***Change this slide for U.S. version. JT**

Slide 15

Electrical explosions
High-energy electrical arcs may also generate sufficient heat to cause an explosion. The rapid heating of surrounding gases may result in a mechanical explosion that may or may not cause a fire.   A clap of thunder accompanying lightning is an example of an electrical explosion effect. Electrical explosions are the extremely rapid expansion of gases heated by the passage of the current. High-energy electrical arcs require high voltage, therefore, special expertise is required to investigate these events as they are not covered by this course nor NFPA 921.

Slide 16

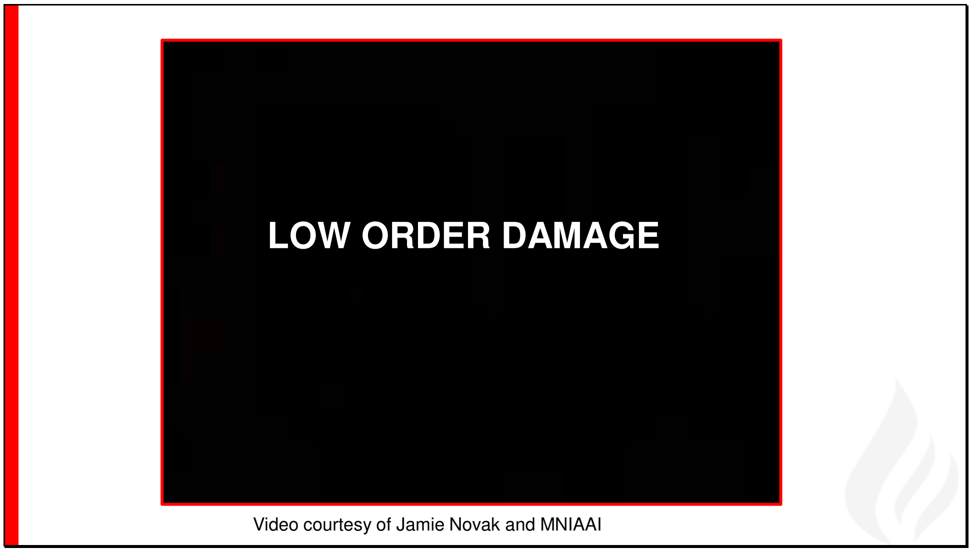


Investigators use the terms high-order damage and low-order damage to characterize explosion damage. Understanding the terms will reduce confusion with similar terms used to describe the energy release from explosives. The differences between the two damage descriptions are more functions of rate of pressure rise and the strength of the confining vessel or structure than of the maximum pressure reached. Sometimes the use of the terms may not be appropriate as the site may contain evidence spanning both terms.

Low-order damage results when the explosion pressure rises slowly. It is produced when the blast load is enough to cause large surfaces, such as walls or roofs, to fail but insufficient to break up larger surfaces and accelerate debris to significant velocities. The characteristics of low-order damage include walls bulged out or laid down, roofs lifted slightly, windows dislodged with the glass intact, and thrown-out debris that is generally large and found within a short distance from the structure.

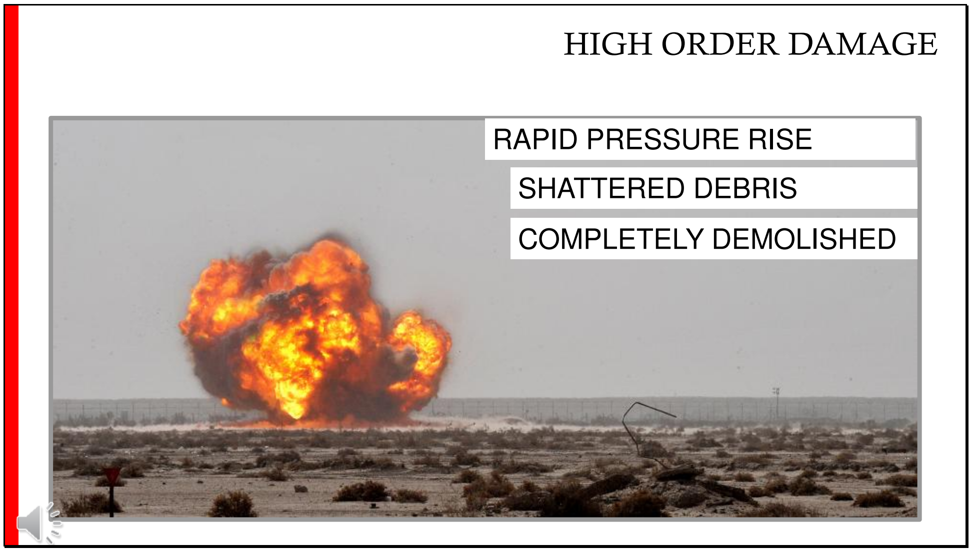
Typical low order damage can be seen in the following video. The windows and doors will blow out providing venting of the pressure built up by the explosion and the building will shift on the foundation.

Slide 17



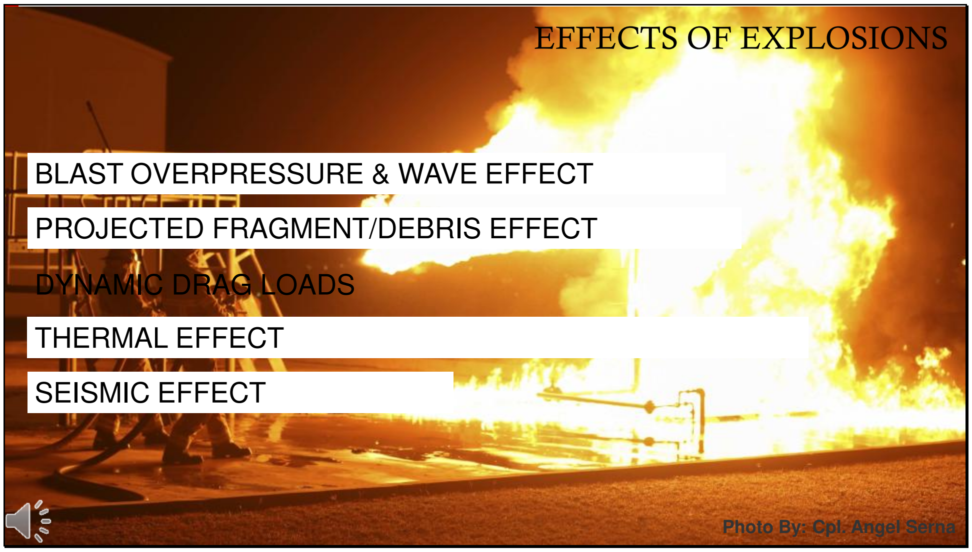
Copied from Email:
Bob,
Not a problem. As long as Jamie Novak and the chapter are credited properly it isn't a problem.
James Iammatteo
Chief Investigator
Minnesota State Fire Marshal Division
445 Minnesota Street, Suite 145
St. Paul, MN. 55101-5145

Slide 18



High-order damage results from relatively high blast loads specifically from a rapid rate of pressure rise. The characteristics of high-order damage include shattered walls, roofs and structural members. The building may be completely demolished. Small pulverized debris is often thrown over considerable distances, possibly a hundred or more metres.

Slide 19



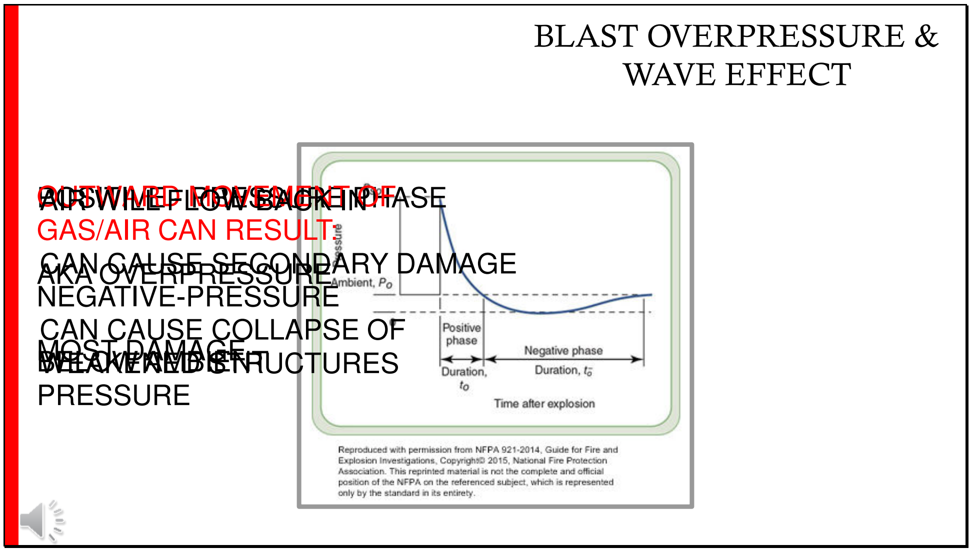
An explosion is a gas dynamic effect that, under ideal conditions, will manifest in an expanding spherical heat and pressure wave front which produces the damage characteristics of explosions. There are five major effects of explosions.

- Blast overpressure and wave effect
- Projected fragment or debris effect
- Dynamic drag loads (the wind effect from the expanding blast wave after the shock wave has moved through. Its effect is felt on thin structures such as power poles)
- Thermal effect

and

- Seismic effect which causes vibrations through the ground

Slide 20

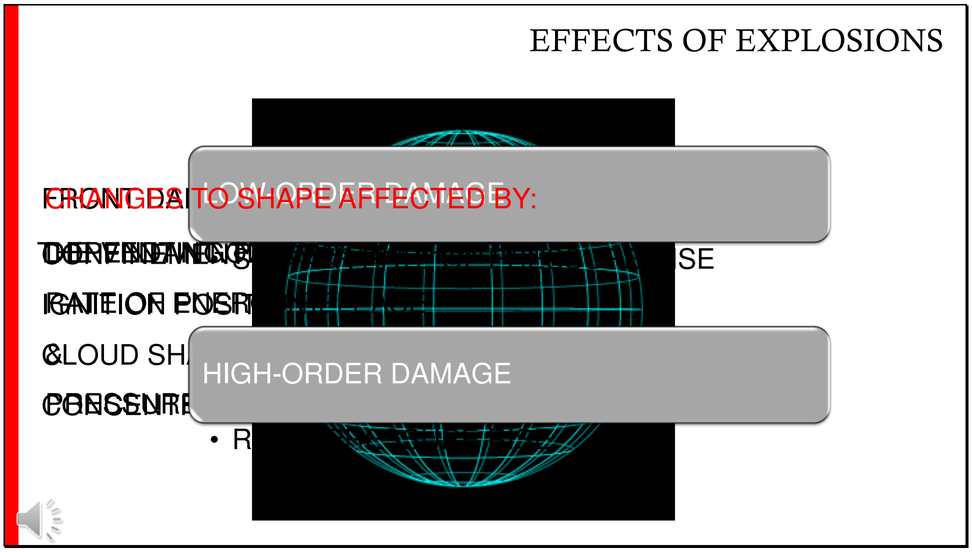


The blast overpressure and wave effect is a result of large quantities of gas being produced by the explosion of the material. The gases move outward at high speed. This is the positive-pressure phase which is also known as overpressure. Most of the damage is caused by this phase. The outward movement of the gas/air can result in a vacuum or negative-pressure (below ambient pressure) zone which causes air to flow back in to bring the pressure back up to ambient. It may appear that a second explosion has blown debris back toward the seat of the explosion but this could also be from the negative pressure of the explosion.

This negative pressure can cause secondary damage and movement of debris which may conceal the point of origin. Although of generally less power than the positive-pressure phase the negative pressure may be of sufficient strength to cause collapse of structural features weakened by the positive phase. This may be difficult to detect in diffuse gas/vapor explosions.

NEED figure 21-5 from J&B pressure time curve Page 308 4th edition
IS this the graph needed ? JT

Slide 21



An idealized explosion would be spherical, expanding evenly in all directions from the epicentre but changes to direction, shape and force of the front may be affected by confinement and obstruction, ignition position, cloud shape, or concentration distribution at the source of the blast pressure wave. Confinement changes the shape and force of the front. The direction of the front may be changed by the venting path or redirection when the front is reflected off a solid object such as a building.

Explosion blast pressure front damage is not only a product of the total amount of energy but is also, and sometimes more significantly, dependent on the rate of energy release and the resulting rate of pressure rise. Damage from slower rates of pressure rise is characterized by low-order damage. Damage from rapid pressure rise is characterized by high-order damage.

The following videos show typical low order damage. Ten pounds of propane was ignited in a room in nearest corner of the basement. The first video is at regular speed and the second is in slow motion.

Slide 22

Slide 23

Note the fire starts in the basement room on the Alpha Delta corner. The pressure front takes the siding off the house in large pieces which is typical of low order damage. The flame front moves through the basement and main floor but goes out.

Slide 24

THERMAL EFFECT

FLAME FRONTS

MOMENTARY JETS OF FLAME

FIREBRANDS

HOT/BURNING FRAGMENTS

Thermal effects may occur from the release of energy that can ignite nearby combustibles. Flame fronts which may be momentary jets of flame, during or after an explosion, and firebrands which are hot or burning fragments propelled from the explosion, are possible thermal effects, especially from flammable Vapors. Secondary fires caused by the flame front may increase the damage as well as injuries from the explosion but may also burn out where there's insufficient fuel to keep the flame front expanding.

The following video is a graphic representation of a flame front traveling through a structure.

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Jamie Novak – Minnesota Chapter IAAI?

Slide 26

DeHaan video –What Determines the speed of development of the flame front.

Slide 27

This is a mobile home where a deflagration occurred. Note the damage to the roof. The explosion lifted the roof but was not powerful enough to remove it. The rear of the trailer contained a bedroom and the blast pressure pushed the rear wall out. The flame front went through the trailer leaving burn marks on the walls but self extinguished as the flame front vented through the rear wall and dissipated. Most of the walls were singed and changed colour. When firefighters arrived at the scene the only fire they found was a pair of socks burning in the dresser drawer.

At the time of the explosion a man and wife were in the bed in the bedroom. He was wearing only his underpants and was lying on top of the bedcovers. The wife was lying under the bedcovers. He was killed by inhalation of hot gases and she survived unharmed.

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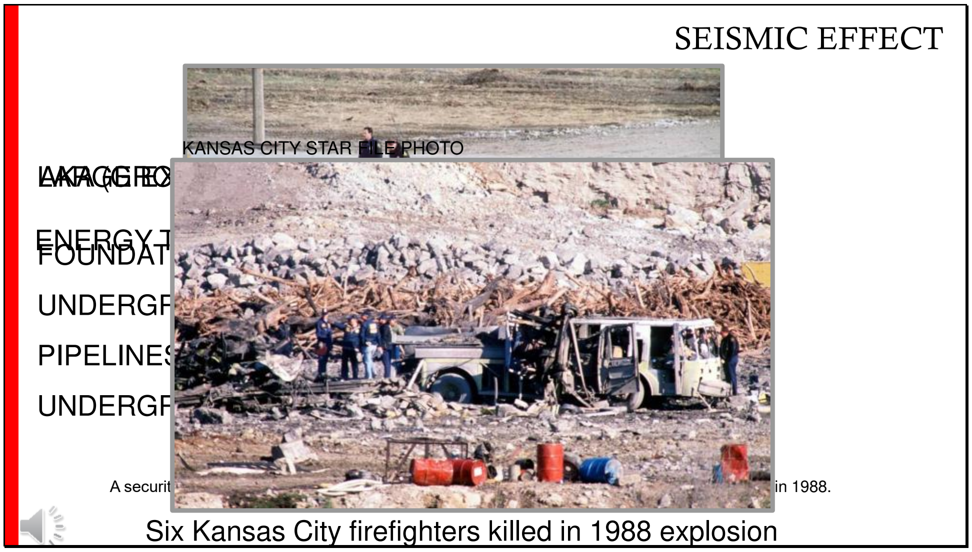
THERMAL EFFECT

EXPLOSION TYPE	EFFECT
COMBUSTION	• RELEASES HEAT ENERGY • CAN CAUSE SECONDARY FIRES
CHEMICAL	• RELEASES GREAT QUANTITIES OF HEAT
DETONATING	• PRODUCES EXTREMELY HIGH TEMPERATURES OF SHORT DURATION
DEFLAGRATION	• PRODUCES LOWER TEMPERATURES OF LONGER DURATION

The thermal damage from a chemical explosion depends not only on the nature of the explosive fuel but also on the duration of the high temperature. The table shown here provides an analysis of explosion type and resulting thermal effect. Fires may be ignited some distance from the explosion center so they should be investigated to determine the reason for them so as to prevent misleading the investigation.

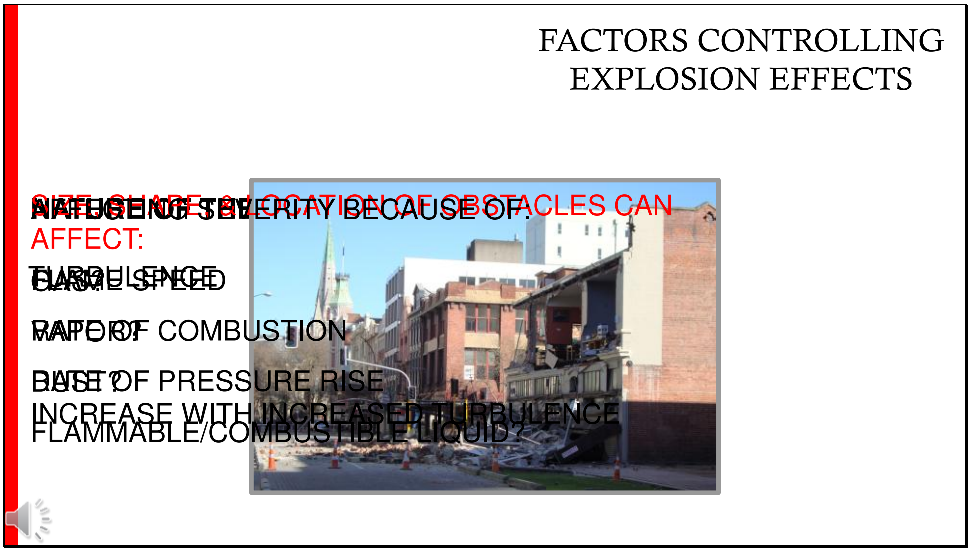
Slide 29



The Seismic effect is usually negligible for small explosions, diffuse fuel explosions and deflagrations. For seismic effect, or ground shock to occur, the explosion must transmit energy into the ground or localized kinetic energy is transmitted into the ground. For example a seismic effect can be caused by the collapse of a structure onto the ground. Large explosions, usually associated with detonations, can create craters and major seismic effects causing damage to building foundations, underground utilities, pipelines and underground tanks.

Six Kansas City firefighters were killed in an explosion in 1988. . Two semi trailers loaded with 50,000 pounds of ammonium nitrate, fuel oil and aluminum pellets exploded. News reports said, “Tens of thousands of sleepers across the metropolitan area awoke, wondering what happened. People heard it 50 miles away.” At least two explosions occurred creating craters 80 to 100 feet in diameter and 8 feet deep. More information is available in the additional learning section of this Chapter or you can Google “Six Kansas City firefighters killed in 1988 explosion” if you would like to learn more about this event.

Slide 30



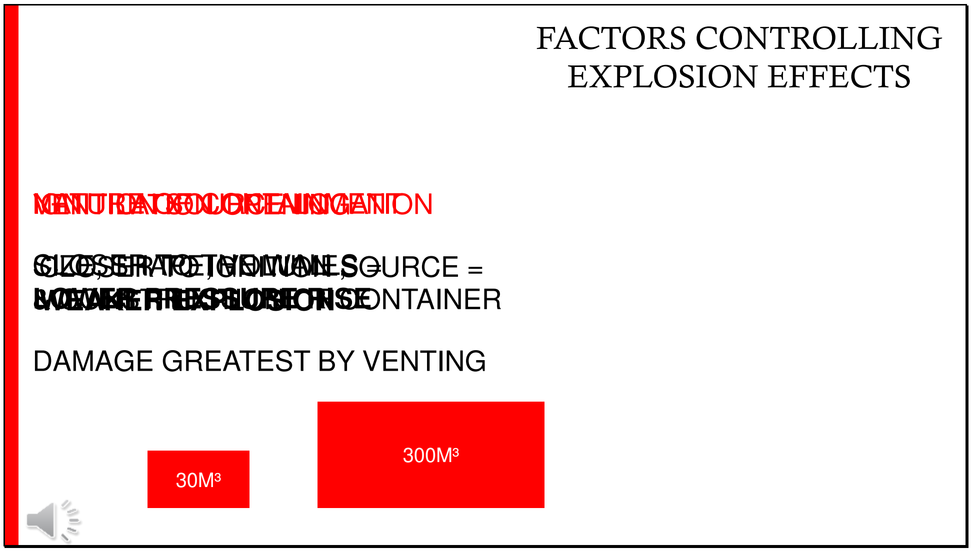
There are a number of factors which can control the effects of an explosion. The nature of these factors and their various combinations in any one explosion incident can produce a wide variety of physical effects with which the investigator will be confronted.

The **nature of the fuel**, whether it is a gas, vapor, dust, or flammable or combustible liquid, will significantly impact upon the effects that the explosion will produce.

The size, shape and location of obstacles within the confining vessel can affect the nature of the turbulence thus affecting the severity of the explosion because flame speed, rate of combustion and rate of pressure rise all increase with increased turbulence.

Photo from:
https://www.google.ca/search?q=seismic+damage+from+explosion&hl=en&authuser=0&tbm=isch&source=lnt&tbs=sur:fc&sa=X&ved=0ahUKEwiz1OGTvJ7aAhVN62MKHXPyCVEQpwUIIA&biw=1280&bih=590&dpr=1.5#imgrc=0DbPcok0F42A_M:

Slide 31



The nature of containment such as size, shape, volume, and construction of the container will change the effects of an explosion. For example, a specific amount of natural gas will produce a different rate-of-pressure rise if it is contained in a 30 m^3 room versus a 300 m^3 room. The larger the space the less damage given the same volume of product.

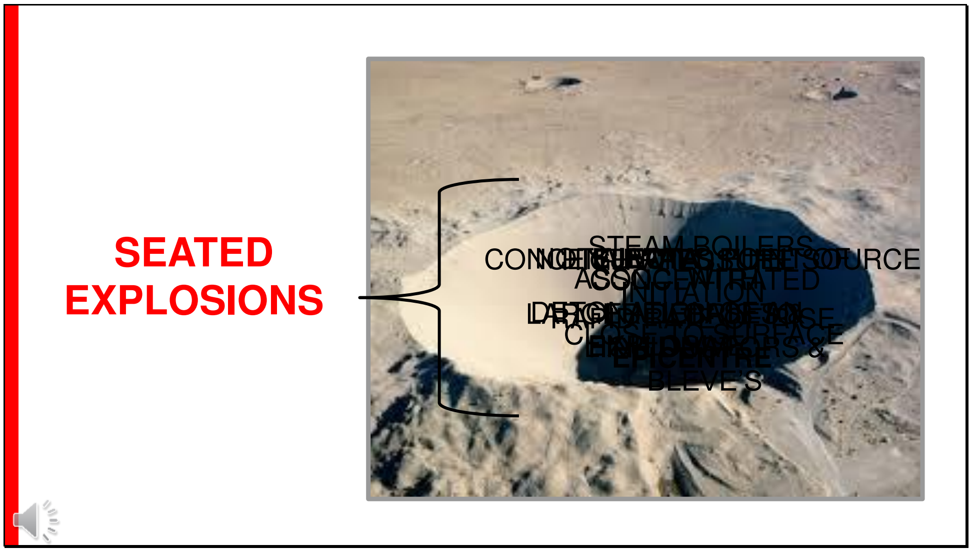
The highest rate of pressure rise will occur if the ignition source is in the centre of the confining structure. The closer the ignition source is to the walls of the confining structure the sooner the flame front will reach the wall and extinguish which leads to lower pressure rise and a smaller explosion.

The higher the venting and the closer the ventilation is to the ignition source the weaker the explosion. A weaker explosion creates less damage but the damage will be greatest in the path of the venting, for example, a window or door. Typical venting of a deflagration with low order damage can be seen in the following video.

Slide 32

Watch the following video again, this time, note the typical venting of a deflagration with low order damage.

Slide 33



The seat of an explosion is the crater or concentrated area of greatest damage, frequently roughly circular or spheroid in shape. It may not always be located at the point of initiation which is often referred to as the epicentre. Material may be thrown out of the crater. This material is known as ejecta which may range from larger pieces of shattered debris to fine dust. The presence of a seat indicates the explosion of a concentrated fuel source in contact with, or in close proximity to the surface. The seated explosion is generally characterized by high pressure and rapid rates of pressure rise. The seat can be of any size depending on the size and strength of the explosive material involved. Seated explosions are normally associated with the detonation of an explosive, but can also be caused by steam boilers, highly concentrated fuel gases and liquid fuel Vapors, and BLEVEs in small containers.

Photo location:
https://www.google.ca/search?q=explosion+crater&hl=en&authuser=0&tbm=isch&source=lnt&tbs=sur:fc&sa=X&ved=0ahUKEwjk9ffcvp7aAhUM52MKHbL5BtsQpwUIIA&biw=1280&bih=590&dpr=1.5

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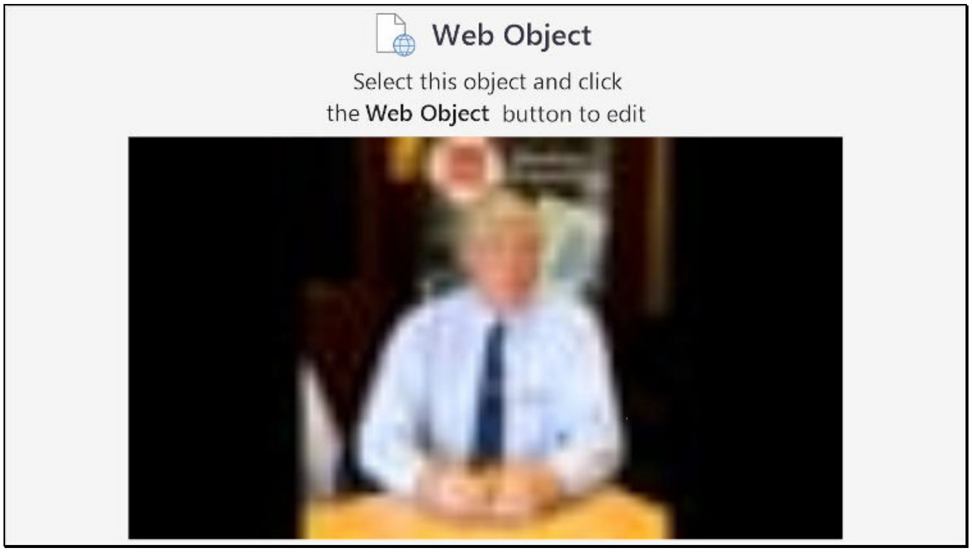
Fire investigators are more likely to be involved with non-seated explosions than seated ones. A nonseated explosion occurs when fuels are dispersed or diffused and mixed with air at the time of the explosion. These explosions will normally be deflagrations demonstrating moderate rates of pressure rise and subsonic explosive velocities. Fuel gases, such as natural gas and liquefied petroleum (LP) usually produce non-seated explosions because of the confinement of the gases in large containers such as rooms.

Normally the non-seated explosion will result in low order damage, pushing and heaving similar to that shown in this photograph. The windows may be blown out as well.

Explosions from the Vapors of flammable or combustible liquids are usually non-seated explosions because they occur at subsonic explosion speed and the large area that they cover means that small, high-damage seats will not occur.

Slide 35

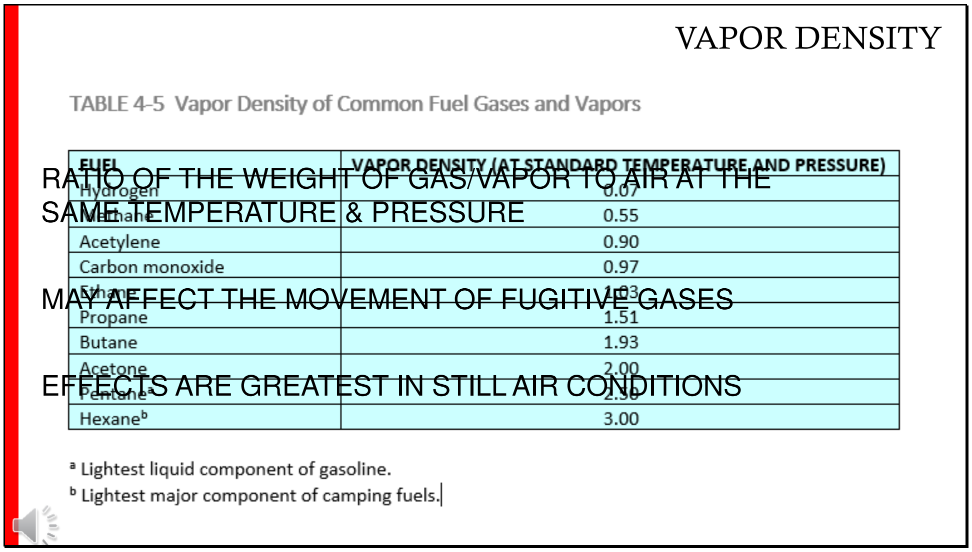


Dehaan video #31 Dr. DeHaan: Seated vs. Non-seated Explosions

Slide 36

Fuel gases and the vapors of ignitable liquids are the most commonly encountered explosions that fire investigators will be involved with. Lighter-than-air gases produce more violent explosions but are less frequently encountered than gases or vapors with vapor density greater than 1.0. Gaseous fuel-air mixtures are easily ignited because all they require is an ignition source resulting in the explosion. A mixture slightly above or richer than stoichiometric will produce the most violent explosion results.

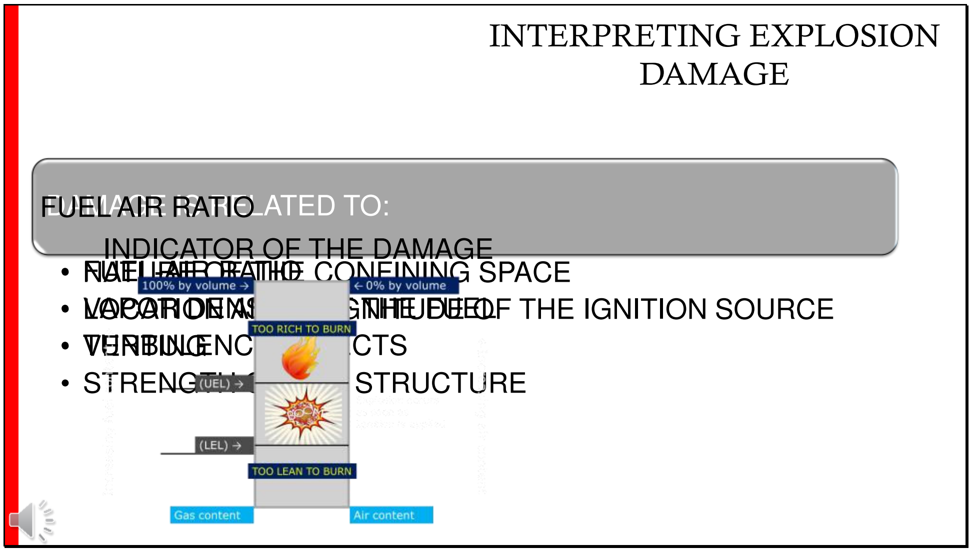
Slide 37



FUEL	VAPOR DENSITY (AT STANDARD TEMPERATURE AND PRESSURE)
Hydrogen	0.07
Methane	0.55
Acetylene	0.90
Carbon monoxide	0.97
Ethane	1.03
Propane	1.51
Butane	1.93
Acetone	2.00
Pentane[a]	2.50
Hexane[b]	3.00

Vapour density is the ratio of the average molecular weight of a given volume of gas or vapor to that of air at the same temperature and pressure and is also referred to as specific gravity. The vapor density of the gas or vapor may affect the movement of fugitive gas as it escapes from its container or system. Vapour density effects are the greatest in still air conditions. The vapor densities of various products can be seen in this chart taken from Kirks Fire Investigation 7th edition page 100.

Slide 38



The explosion damage to structures, whether low-order damage or high-order damage, is related to the following factors

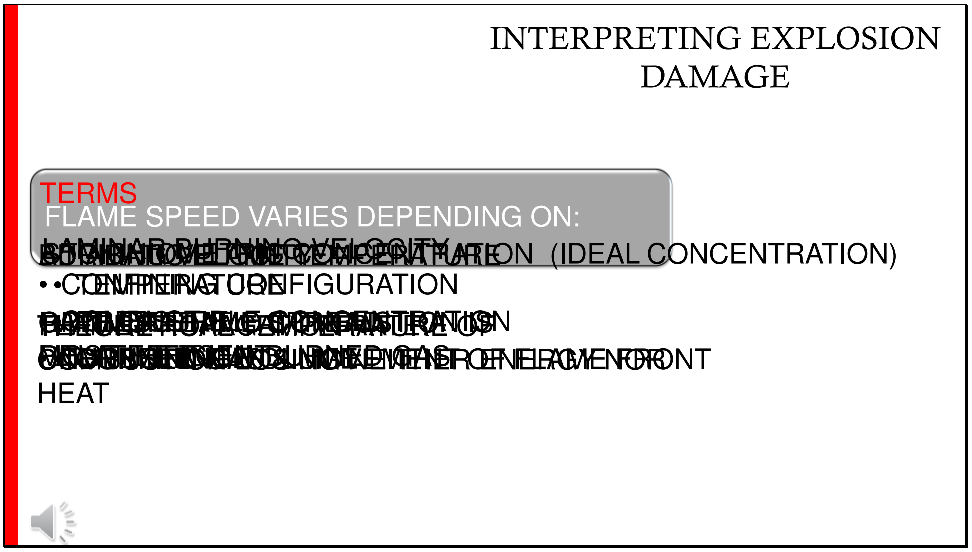
- ***The fuel-air ratio***
- The vapor density of the fuel
- turbulence effects
- The nature of the confining space
- The location and magnitude of the ignition source
- Available venting

And

- The strength of the structure

The **fuel-air ratio** at the time of ignition can be an indicator of the damage to the confining structure.
Mixtures at or near the upper or lower explosive limits usually produce less violent explosions. The entire volume of the container need not be occupied by a flammable mixture of gas and air for there to be an explosion. Relatively small volumes of explosive mixtures capable of causing damage may result from gases or Vapors collecting in a given area.

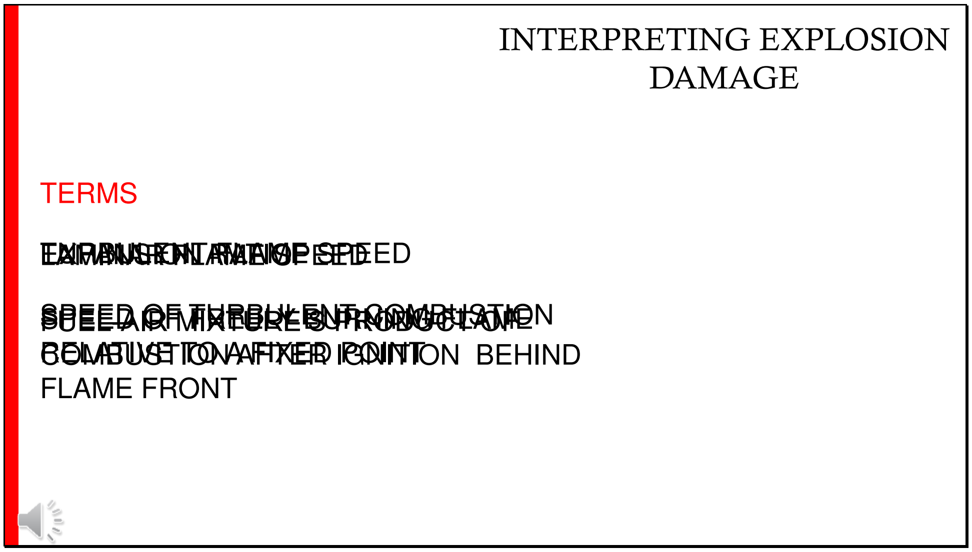
Slide 39



Flame speed may vary widely depending on temperature, pressure, confining volume, confining configuration, combustible concentration and turbulence.   Some terms that will take further study for complete understanding include:

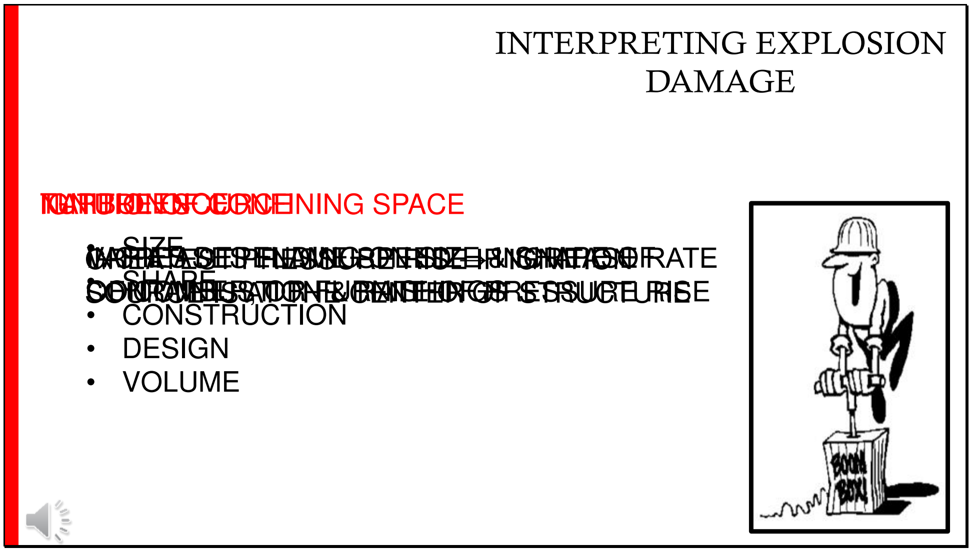
- Stoichiometric concentration (sometimes called ideal concentration): is the optimum ratio at which point combustion will be most efficient. In the combustion process, oxygen reacts with the fuel, and the point where all the oxygen and all the fuel burned is defined as the stoichiometric concentration.
- Burning velocity: is the rate of flame propagation or spread relative to velocity of unburned gas ahead of it
- Adiabatic flame temperature: is the theoretical temperature of a complete combustion process that loses neither energy nor heat to its outside environment
- Laminar burning velocity: is the flame propagation rate relative to the unburned gas and the movement of the flame front into the unburned gas as it chemically combines the fuel and oxidizer into a combustible mixture.

Slide 40



- Expansion ratio: is the rate of expansion of a fuel-air mixture's products of combustion after ignition behind the expanding flame front
- Laminar flame speed: is the speed of a freely burning flame relative to a fixed point without turbulent effects
- Turbulent flame speed: is the speed of a turbulent combustion, which is generally relevant to a real explosion.

Slide 41

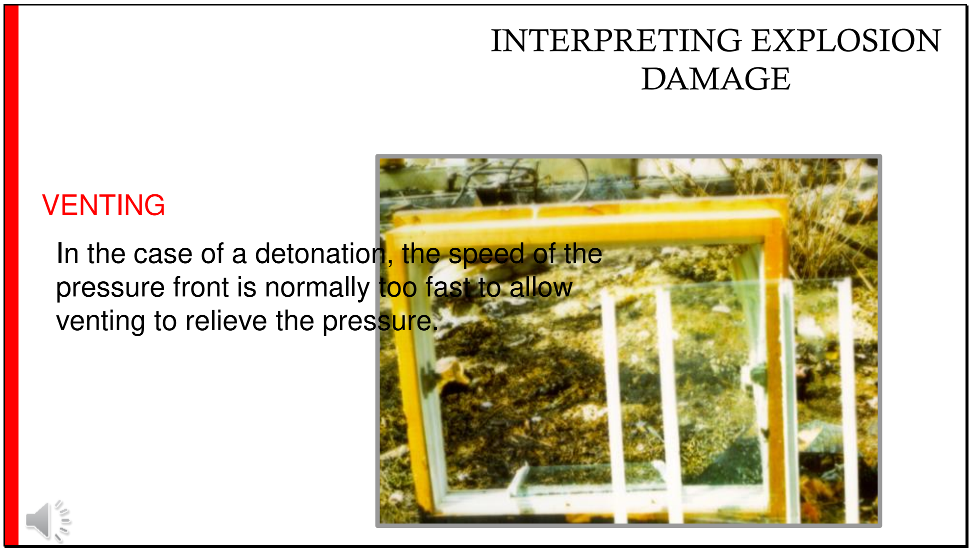


Turbulence within the fuel-air mixture increases the flame speed and thus increases the rate of combustion and the rate of pressure rise. Turbulence may vary depending on the size, shape of the container, or furnishings within the container. Investigators must be aware of any natural or forced air ventilation that can create turbulence.

Nature of confining space: The size, shape, construction, design and volume of the confining space greatly affects the nature of the explosion damage. A smaller confining space, for the same amount of fuel, will increase the rate of pressure rise greatly.

Location and magnitude of the ignition source: The greatest pressure rise will occur if the ignition source is in the centre of the containing structure. Although the energy of the ignition source has minimal effect on the course of the explosion unusually large ignition sources can significantly increase the speed of pressure development and thereby cause deflagration to detonation transition (DDT).

Slide 42



The nature of **the venting** of the containment has varying effects on explosion damage. A length of pipe may rupture in the centre allowing the gas to vent.

A room may experience destruction or merely movement of the walls and ceiling depending on the number, size and location of doors and windows. In many cases of deflagration, the windows will blow out allowing the blast pressure to vent. The windows may come out intact and not break, or break only on impact with solids like the ground, trees or other structures. In this case the window blew out intact and did not break even on impact with the ground.

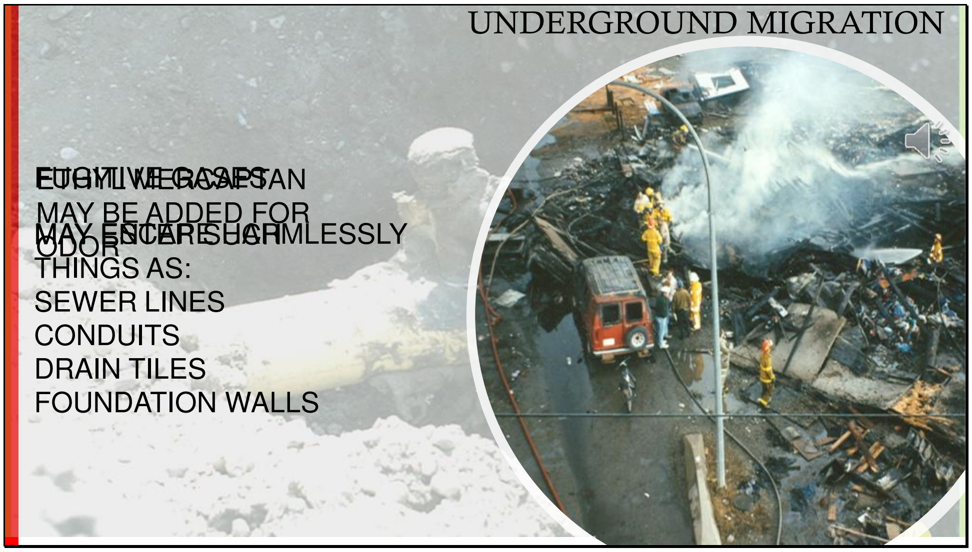
In the case of a detonation the speed of the pressure front is normally too fast to allow venting to relieve the pressure.

Slide 43

The **strength of the structure** also affects the damage caused by an explosion. For the purpose of this chapter a structure is anything that can be used to contain anything else. The strength of the structure depends on what type of structure it is and what it is made of. For example, an explosion in a simple structure such as a travel trailer would react differently from an explosion in a high rise building.

In both cases, these were intentional acts where propane gas was used as the fuel. The travel trailer on the right was destroyed while the apartment building received modest structural damage.

Slide 44



Underground fuel gases either lighter or heavier-than-air have escaped from underground piping systems, entered structures and fueled fires or explosions. Lighter than air fugitive gases may permeate the soil and migrate upward to dissipate harmlessly or enter structures through any openings such as sewer lines, electrical and telephone conduits, drain tiles or foundation walls. In some cases the migration of fuel gases permeating up through garden soils can kill surface plants giving advance warning that something is wrong.

Note that some gases such as natural gas and propane have no odours of their own so foul-smelling compounds such as ethyl mercaptan are added. Odorant verification should be part of the investigation. Gas detectors may be helpful in locating sources of gas leaks.

Note: Get DeHaan to tell story on video

Slide 45

In this case six people were killed in a natural gas explosion. The incident happened around 10:00 AM. in an occupied second hand store. There was a natural gas line running in front of the store with a branch line running off to a nearby subdivision. The joint between the main line and the branch line was compromised allowing fugitive gas to escape under the paved parking lot outside the second hand store. Natural gas being lighter than air travelled upward but was blocked by the pavement in the parking lot. The gas spread and found an opening in the foundation wall of the second hand store. Investigators did not determine the source of ignition. The odorant in the gas was scrubbed out as the gas traveled through the ground so the people in the store probably did not smell anything prior to the explosion.

Slide 46

DeHaan video - Warning signs of fuel leaking in soil

Slide 47

MULTIPLE EXPLOSIONS

SECONDARY OR CASCADE EXPLOSIONS

SUBSEQUENT EXPLOSION IN ADJOINING AREAS

PHYSICAL EVIDENCE MAY INDICATE

MORE THAN 1 EXPLOSION

EXPLOSIONS DEPENDENT ON AIR-FUEL MIXTURE IN THAT AREA

A migration and pocketing effect can produce multiple explosions referred to as secondary or cascade explosions. Therefore when ignition or explosion occurs in one story or room subsequent explosions may occur in adjoining areas or stories. The migration or pocketing of fuel may produce areas with different fuel-air mixtures resulting in a series of explosions depending on the ratio of the air-fuel mixture in each area. Multiple explosions are a common occurrence. Sometimes they occur so rapidly that witnesses may report hearing only one explosion but the physical evidence, such as multiple epicentres, indicates more than one explosion occurred.

Slide 48

This is a photo of the remains of a sawmill after a deadly dust explosion claimed the lives of two workers in 2012.

Some witnesses reported they heard two or more explosions. This is often the case with dust explosions where the first event loosens other dust particles and secondary explosions, sometimes worse that the primary explosion, occur.

Violent and destructive explosions can be fueled by dust that is suspended in the air. The dust may even be from materials that are not normally considered to be combustible such as aspirin, aluminum, sugar and milk products. A wide variety of materials such as grain dusts, sawdust, metals, chemicals, pigments, and coal and charcoal may result in dust explosions. Influencing factors include particle size, concentration, turbulence, moisture and sources of ignition.

Slide 49

This is a minor dust explosion that occurred when firefighters were trying to extinguish a fire in a hopper at a saw mill. There were no injuries but it is a graphic example of why personal protective equipment must be worn at all times. Imagine if the firefighters were not wearing breathing apparatus.

Slide 50

Dust caused this deadly sugar mill explosion in Georgia which killed 14 workers at a sugar plant in 2008.

Particle size plays a part in the energy produced by the explosion. Generally, the finer the dust particles the more violent the explosion. The combustion reaction is a surface phenomenon and the rate of pressure rise is dependent on the surface area of the dust particles. Finer dusts have greater surface area. In general, the hazard exists when the dust particles are 500 microns or less in diameter.

Concentration: The minimum explosives concentration (MEC) may vary with the specific dust but unlike gases and Vapors there is generally no reliable maximum limit. MEC is usually measured in milligrams per cubic meter.

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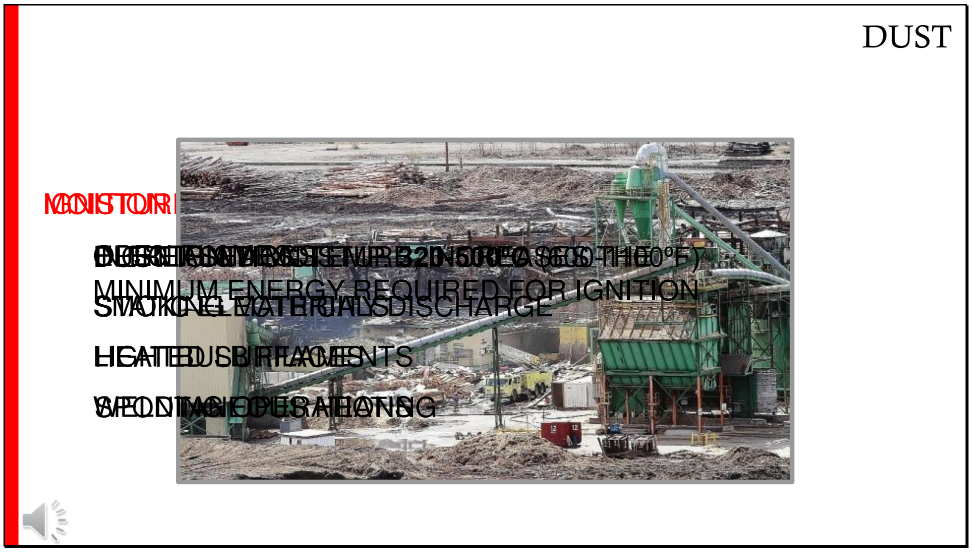


Also in 2012, another deadly sawdust explosion occurred in this sawmill which again claimed the lives of two workers.

Moisture is another factor that investigators must consider. Increasing the moisture content of the dust particles increases the minimum energy required for ignition but once ignition occurs ambient moisture content has little impact. There are some metals, however, that react with moisture and will burn rapidly with moderate moisture content levels.

Sources of ignition: The actual ignition temperature for most dusts range from 320 to 500 degrees Celsius (600 to 1100 degrees Fahrenheit). Sources of ignition include open flames, smoking materials, lightbulb filaments, welding operations, electric arcs, static electricity discharge, heated surfaces and spontaneous heating. Identifying the ignition source may be difficult because there are often multiple possibilities.

Slide 52

It is common for fires in rooms or other containers to become oxygen depleted which results in the generation of flammable gases due to incomplete combustion. The opening of a door or window allows air to be mixed with the gases. The gases then ignite and burn sufficiently fast to produce low-order damage. This is termed backdraft or smoke explosion. A good example of a smoke explosion can be seen in the following video.

Slide 53

Dehaan Backdraft or smoke Explosion

Slide 54

Another concern is the use of shipping containers or Sea-Cans for storage. In 2011 a Canadian fire officer was fatally injured as the result of an explosion in a metal storage container which was being used to store a limited number of gasoline-fuelled tools. The locked container was exposed to direct fire impingement and radiant heat caused by a wood frame building burning directly onto three sides of the container. The resulting heat transferred to the container caused combustible material inside the storage unit to ignite and fuel tanks on some of the gas powered tools to fail allowing gasoline vapours to escape to the atmosphere. At some point after that, the gasoline-to-air mixture reached the explosive range and ignited. The explosion caused the container to catastrophically fail, severing both doors and throwing them over 40 meters away from the storage container. One of the doors struck the fire officer causing fatal injuries.

The explosion occurred an estimated 2 hours after the arrival of the fire department. Inadequate ventilation of the sea-can was identified as a major contributing factor. The standard vents built into shipping containers ARE NOT ACCEPTABLE as ventilation openings for land-based storage applications. These were designed for air movement based upon atmospheric weather changes only and do not provide adequate air flow for the storage of combustible or flammable materials.

Slide 55

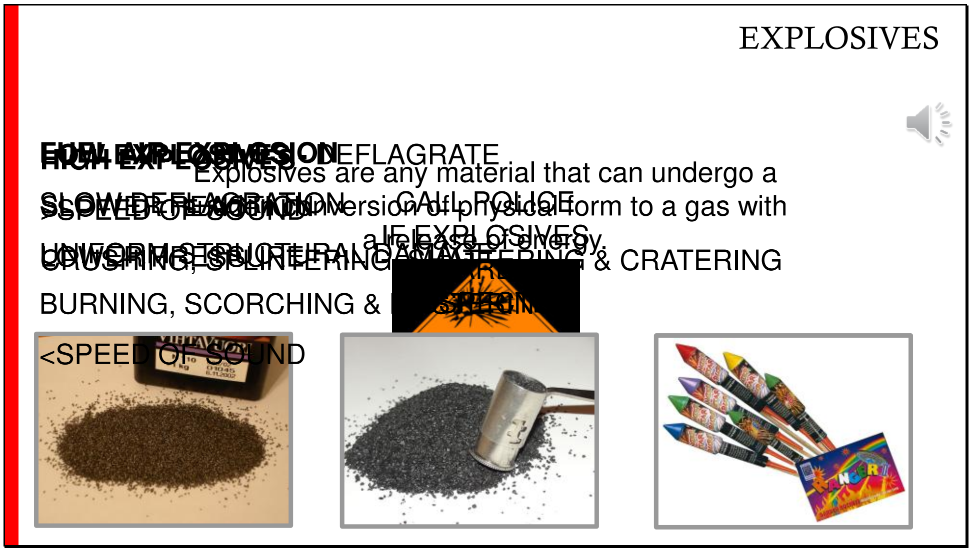
OUTDOOR VAPOR CLOUD EXPLOSION

UNCONFINED VAPOR-AIR EXPLOSION

AKA UNCONFINED VAPOR CLOUD EXPLOSION (UVCE)

The release of gas, vapor or mist into the atmosphere may result in a cloud forming within the fuel's flammable limits and any subsequent ignition may result in an outdoor vapor cloud explosion. The phenomenon is referred to as unconfined vapor-air explosion or unconfined vapor cloud explosion. It is frequently related to catastrophic failure of vessels or tankers which release large amounts of fuel possibly into low-lying areas. The outdoor vapor cloud explosion usually needs natural or man-made obstacles to provide partial confinement. In this case a propane tanker has rolled over and containment is provided by the low-lying area. All that is required is a leak in the tank and an ignition source to initiate the vapor explosion.

Slide 56

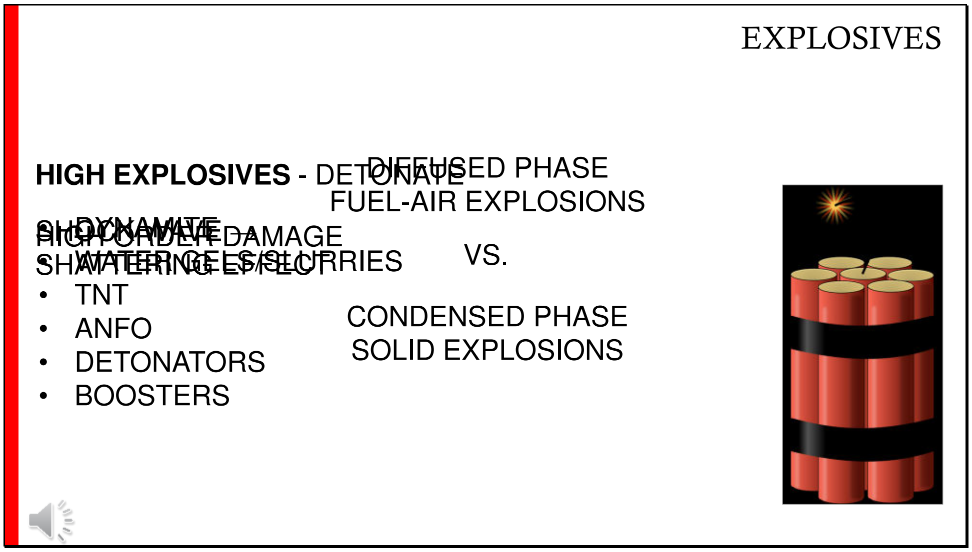


Explosives are any material that can undergo a sudden conversion of physical form to a gas with a release of energy. If the investigator suspects that the explosion was the result of an explosive the police or other agency having jurisdiction for explosives should be called immediately.

Low explosives deflagrate having a relatively slow rate of reaction and the development of relatively low pressure. This means that they work by pushing or heaving causing low-order damage. Common low explosives are smokeless powder, black powder and fireworks.

A fuel-air explosion is most often a slow deflagration resulting in structural damage that is uniform and omnidirectional with relatively widespread evidence of burning, scorching and blistering. Rate of combustion of a low explosive is less than the speed of sound. The velocity of a detonation of a high explosive is much higher than the speed of sound and the location of the explosion is evidenced by crushing, splintering, shattering and cratering.

Slide 57



High explosives detonate which produces a shock wave resulting in a shattering effect causing high-order damage. Common high explosives are dynamites, water gels or slurries, TNT, ANFO, detonators, boosters.

When high explosives are properly initiated the result is a high-order detonation – it has reached its designed velocity of detonation. If high explosives aren't properly initiated they may still detonate but at a lower velocity resulting in a low-order detonation.

The effects produced by diffuse phase, fuel-air explosions and condensed phase, solid explosives, are quite different. Low explosives generally produce low-order damage and high explosives produce high-order damage.

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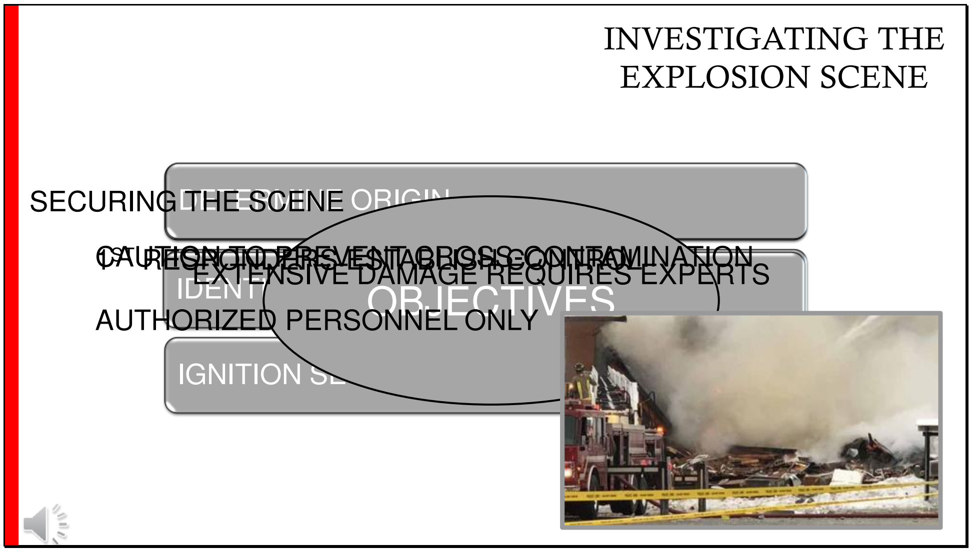

The general objectives of the explosion scene investigation are no different from those for a regular fire investigation: determine the origin, identify the fuel and ignition source, describe the ignition sequence, determine the cause, and establish the responsibility for the incident. **A preplanned systematic approach is important.** The following investigative procedures should be followed for both large and small incidents. Extensive damage would require the coordination of additional experts such as explosion and structural engineers.

Securing the scene – The first duty of the investigator is to ensure that the scene of the explosion has been secured. First responders to the scene should establish and maintain physical control of the structure and surrounding areas. No unauthorized person should be allowed to enter the scene or touch blast debris even remote from the scene. **Authorized personnel, including investigators, should log in and out of the scene through the perimeter.** Authorized personnel should use caution to prevent cross-contamination of the scene, for example, explosive residue that may be on footwear from the firing range.

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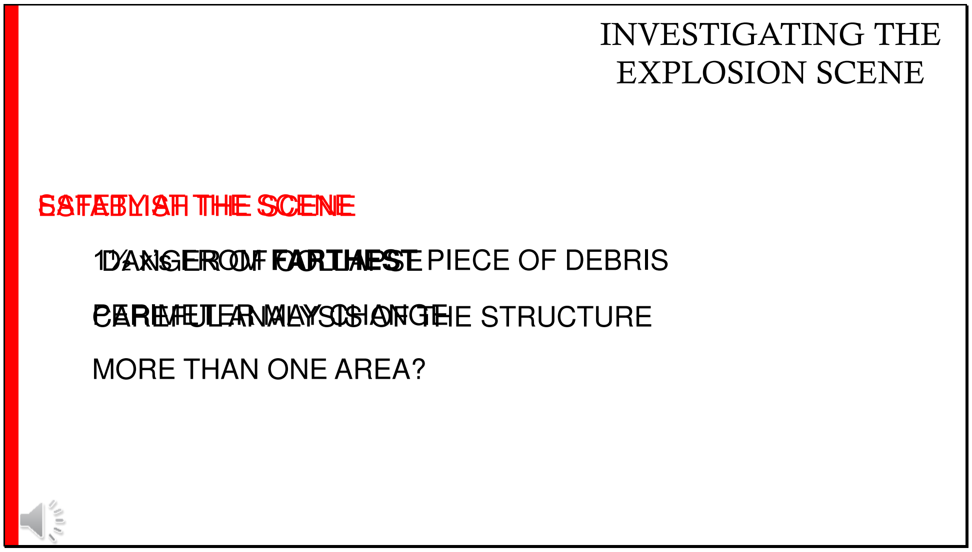
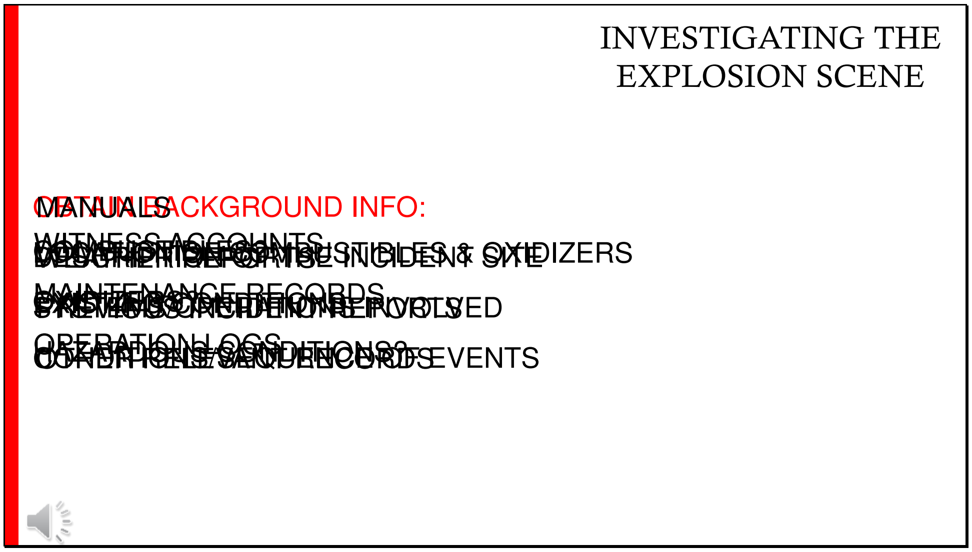


Establish the scene – The outer perimeter of the incident scene should be established at one and one-half times the distance of the farthest piece of debris found. The perimeter may change several times as other pieces of debris are found. The perimeter may expand or contract as the investigation proceeds. It may be practical to secure several areas rather than one bigger area but this should only be done after the initial scene evaluation has been completed and only as directed by the lead investigator or incident commander.

Safety at the scene – Structures that have been involved in an explosion are often more structurally damaged than those involved in a fire without explosion. The danger of collapse of the building or parts of the building is high. Careful analysis of the structure stability must be performed and may initiate the involvement of a structural engineer or other expert. All of the fire investigation safety recommendations, identified in Chapter 11, also apply to the investigation of explosion scenes.

Slide 60



The investigator should obtain as much background information as possible before beginning the scene examination. This information should include: a description of the incident site, systems and operations involved, and conditions and sequence of events that led to the incident. The investigator must identify the locations of any combustibles and oxidizers that were present and the conditions existing at the time of the incident as well as what combustibles, oxidizers and hazardous conditions currently exist. Investigators should examine witness accounts, maintenance records, operations logs, manuals, weather reports, previous incident reports and any other relevant records.

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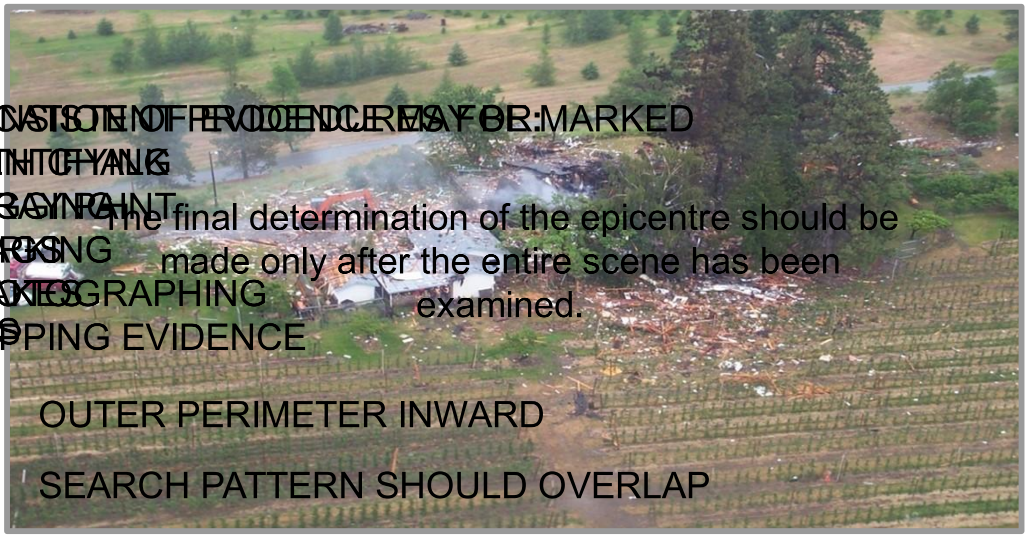
SEARCH PATTERNS



When establishing search patterns the scene should be searched from the outer perimeter inward toward the area of greatest damage. The search pattern may be spiral, circular, grid shaped or a combination thereof. The search patterns should overlap so that no evidence is lost at the edges of the pattern.

The number of searchers depends on the size and complexity of the scene. Consistent procedures for identifying, logging, marking, photographing and mapping of evidence must be maintained. The location of evidence may be marked with chalk, spray paint, flags, stakes or any other means of marking. GPS technology can also be used to accurately identify the position of evidence.

The final determination of the epicentre should be made only after the entire scene has been examined.

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In this case, the single family home that exploded was originally located inside the red circle. The debris field stretched over hundreds of metres including several well used roads. The areas on both sides of the roads were secured and debris on the roads was thoroughly examined and then the roads were re-opened to traffic.

A grid system was established and a 4X8', 2X4" frame was constructed and used to determine the boundaries of the grid. Each grid was outlined using spray paint, photographed before the debris was examined and GPS was used to determine exact locations where evidence was found.

As part of the debris field was in an orchard the rows between the plants were also used as part of the grid.

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SEARCH PATTERNS

THE 4 R's

RECOGNITION - RECOVERY - REASSEMBLY - RECONSTRUCTION

LOCATION & INTENSITY, DIRECTION

TRAINING & EXPERIENCE OF EXAMINERS IS CRITICAL

PHYSICAL EVIDENCE

The scene search can be thought of as the first step in the investigation process, which may be remembered as the Four R's: Recognition, Recovery, Reassembly and Reconstruction.

Recognition at the scene includes assessment of the blast damage (location, intensity, direction) as well as recognition of the pieces of physical evidence to be used in the later stages of the investigation. Physical evidence of an accidental situation or mechanism that brought about an explosion can be just as important as the evidence of a deliberate act or bombing. The training and experience of the examiners or searchers is critical to the investigation, because important evidence can be small and appear inconsequential. Such evidence is easily overlooked by untrained searchers.

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SEARCH PATTERNS

THE 4 R’s

RECOVERY

REASSEMBLY

RECONSTRUCTION

COLLECTING EVIDENCE

DOCUMENTATION

PRESERVATION

EXPLOSIONS PRODUCE BLAST, PRESSURE, FRAGMENTATION, AND THERMAL EFFECTS.

PIECING THE DEVICE TOGETHER

WHAT WAS PRESENT?

WHO WAS PRESENT?

Recovery involves not only the physical process of collecting evidence but its documentation and preservation as well. The process must take into account the fact that explosions produce blast, pressure, fragmentation, and thermal effects.

Reassembly of the device or mechanism entails piecing the device or mechanism together. It may take place within the laboratory or at the scene but is a necessary test to see whether the entire chain of circumstances is accounted for. Finally, the scenario must be ***reconstructed.*** What was present? Who was present? For example, it may entail drawing a picture of the scenario of the explosion.

Re-assembly and reconstruction applies to accidental explosions as well.

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INITIAL SCENE ASSESSMENT

IF AN EXPLOSIVE OR EXPLOSIVE DEVICE IS SUSPECTED:

DISCONTINUE INVESTIGATION

SECURE THE SCENE

CONTACT POLICE

FIRE?

EXPLOSION?

BOTH?

WHICH CAME FIRST?

LOOK FOR OVERPRESSURE

ANALYZE HEAT DAMAGE

DOCUMENT THE DAMAGE

HIGH-ORDER?

LOW-ORDER?

SEATED?

UNSEATED?

INITIAL ASSESSMENT

The investigator should make an initial assessment of the scene to determine what type of incident occurred. Do not proceed if there are any questions or concerns about site safety.

If the investigator suspects or determines that the explosion was caused by explosives or an explosive device they should discontinue the scene investigation, secure the area, and contact the police or other agency responsible for explosives.

Determine whether the incident was a fire, explosion or both, and if both, which came first. Look for signs of overpressure such as displaced or bulging walls, floors, and/or ceilings. Analyze the extent of heat damage to the structure and its components.

Document the damage before the scene is disturbed. Determine if the damage indicates high-order or low-order-damage. Was the explosion seated or unseated?

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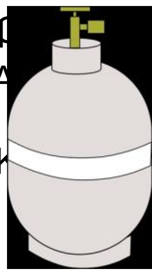
INITIAL SCENE ASSESSMENT



The type of explosion should be identified as soon as possible. Was it a mechanical explosion such as a BLEVE or a chemical combustion explosion? Analyze the nature of the damage patterns to determine if a detonation or deflagration occurred.

Identify the fuel types that were available at the scene such as fuel gases, dusts and other potential fuel sources that could initiate an explosion.

Attempt to establish the origin of the explosion. The origin is usually identified as the area of most damage. For a seated explosion it is the crater or localized area of severe damage. For a diffuse fuel-air explosion the origin is consistent with the confining volume or room of origin.

Attempt to identify the ignition source by looking for potential sources including hot surfaces, electrical arcing, static electricity, open flames, or sparks. When a gas explosion is under consideration the investigator should locate all possible ignition sources keeping in mind that through gas migration the ignition may not have occurred in the area with the most explosion damage.

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DETAILED SCENE ASSESSMENT

AFTER INITIAL SCENE ASSESSMENT -

DEBRIS EXAMINATION:

DAMAGED ARTICLES IDENTIFIED:

SHATTERED?

HIGH ORDER DAMAGE (DETONATION)

BLAST PRESSURE WAVE – NEGATIVE PHASE

BENT/BROKEN?

(DEFLAGRATION)

DETAILED STUDY

After an initial scene assessment has provided general information a more detailed study of the blast damage and debris is needed.

A detailed analysis of the explosion damage should be made and properly recorded. Damaged articles should be identified as having been affected by one or more explosion forces such as blast pressure wave – positive phase, blast pressure wave – negative phase, shrapnel impact, thermal energy, and/or seismic energy. The debris should be examined to see if it was shattered into small pieces or is bent and/or broken into larger pieces.

Shattering of debris is indicative of a high order damage that is usually associated with a detonation while bending, pushing, heaving and breaking into larger pieces is more consistent with a deflagration. Even with a detonation, materials that were located further away from the epicentre may display damage that resembles a deflagration.

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DETAILED SCENE ASSESSMENT

DEBRIS FIELD DRAWINGS & PHOTOS:

FIRE & HEAT DAMAGE

UTILITY EQUIPMENT

MATERIAL

DIRECTION

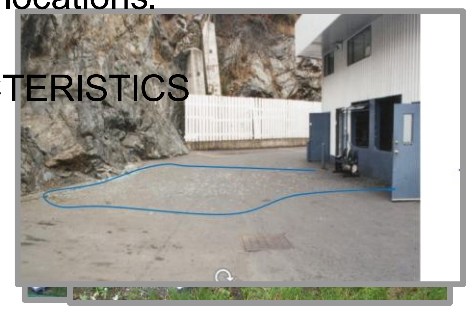
Significant pieces of evidence may be found in a wide variety of locations.

SIZE

TRAVEL DISTANCE

MASS

PHYSICAL CHARACTERISTICS



A detailed recording of the debris field, through drawings and photographs, should be made showing the material, size, mass, direction, travel distance, physical characteristics and anything that could aid in identifying the origin of the explosion. Significant pieces of evidence may be found in a wide variety of locations such as outside the exploded structure or imbedded in structural members. The condition and position of utility equipment such as gas meters should also be examined and recorded. This process assists in identifying and recording the force of the explosion.

Fire and heat damage should be identified as having been caused by a pre-existing fire or by the thermal effect of the explosion. Debris propelled from the point of origin that is burned may be an indicator that fire preceded the explosion.

In this case the glass from the explosion was clean and free of smoke indicating that it broke as a result of the blast pressure and there was no pre-existing fire.

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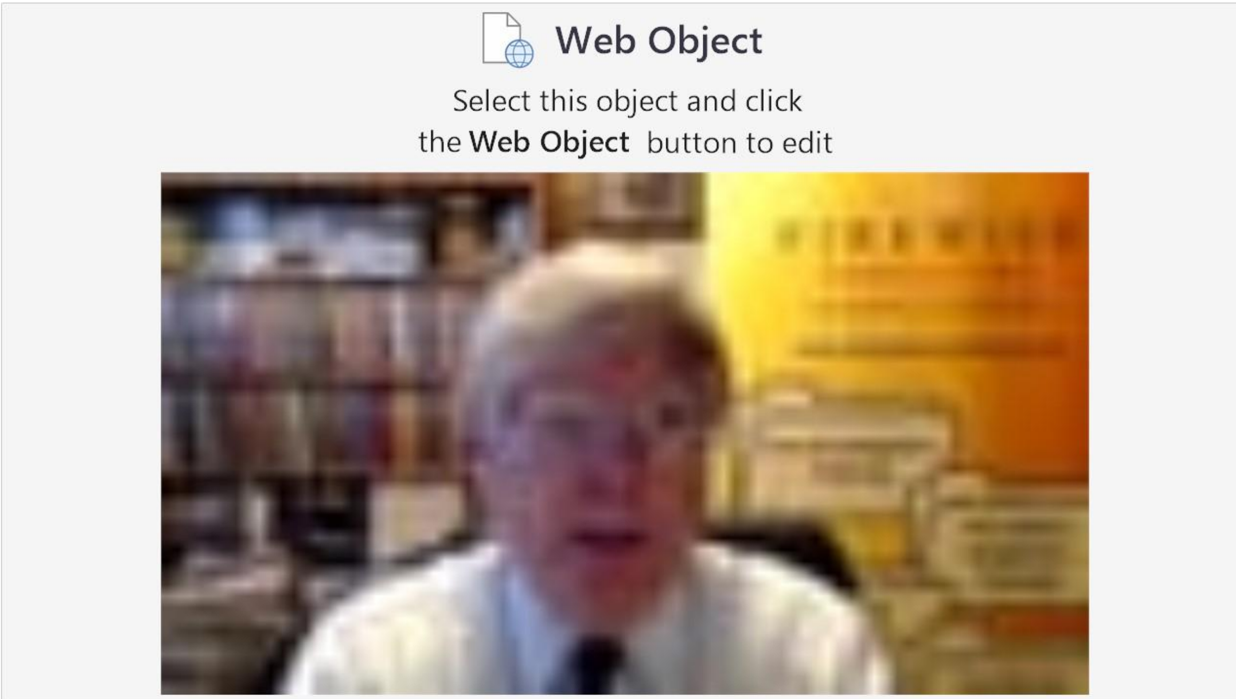
Web Object
Select this object and click
the Web Object button to edit

DETAILED SCENE ASSESSMENT

NEXT: DETERMINE MEANS OF IGNITION

FACTORS:

Next, after the areas of ignition and fuel have been identified, the means of ignition should be determined. Factors to consider include: minimum ignition energy of the fuel, ignition energy of the potential ignition source, ignition temperature of the fuel, temperature of the ignition source, location of the ignition source relative to the fuel, presence of both fuel and ignition source at the time of ignition along with witness accounts of conditions prior to and at the time of the explosion.

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DETAILED SCENE ASSESSMENT

ANALYSIS

- TIMELINE ANALYSIS
- PATTERN/DEBRIS ANALYSIS
- CORRELATION: BLAST FIELD - DAMAGE
- ANALYSIS OF ITEMS & STRUCTURE
- CORRELATION: THERMAL EFFECTS

For an analysis to determine the simultaneous presence of fuel and ignition source the following techniques may be used:

- Timeline analysis – with the information gathered a sequence of events should be tabulated for the time prior to the explosion and during the explosion
- Damage pattern and debris analysis – is the documentation of debris and structural damage
- Correlation of blast yield with damage incurred – to determine if the damage and projectile distances correlate with the type and amount of fuel.
- Analysis of damaged items and structure –the relation of the type of fuel and the damage caused may require specialized assistance
- Correlation of thermal effects – heat damage may be evidence of a fireball or fire during the event and may assist in the identification of the type of explosion and the fuel.

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DETAILED SCENE ASSESSMENT

IDENTIFY FUEL

TRAJECTORIES TO TRACE BACKWARDS

ODOR VERIFICATION

Explosion dynamics analysis uses force vectors or trajectories to trace backward from the least to most damaged areas to aid in identifying the origin or epicenter of the explosion.

Once the origin or epicenter has been established the investigator should determine the fuel. All available fuel sources should be considered and then limited to one fuel source that meets all the physical damage criteria. Chemical analysis of debris, soot, soil and air may assist in identifying the fuel. Once the fuel has been identified the investigator can then determine the source. All gas piping should be examined and leak tested. Odour verification should be part of an investigation involving flammable gas.

In this case, a plastic natural gas pipe was hit by lightning. The copper trace wire used to identify the location of the plastic pipe was taped to the gas line. The electrical charge from the lightning travelled through the copper trace wire and at each location where the wire was taped to the plastic line a hole was burned through the gas line. The fuel migrated into the basement of the home and exploded killing the two occupants.

DEBRIS FIELD & INJURIES

DIAGRAM

PHOTOS:

INJURIES CAN BE FROM:

PRE-BLAST DAMAGE?

MATERIAL

CLOTHING

DIRECTION

THERMAL EFFECT,

SIZE

HARD HATS

DISTANCE

BLAST PRESSURE

POST-BLAST DAMAGE?

MASS

BOOTS

PHYSICAL CHARACTERISTICS

The investigator needs to distinguish between pre-blast and post-blast damage. A detailed diagram of the debris field should be made showing the material, size, mass, direction, distance, physical characteristics and anything that could aid in identifying the article of origin. This process assists in identifying the force vectors of the artifacts.

Post blast injuries to people can range from slight to fatal. The thermal energy can vary causing minor to severe burns and damage to the lungs and other internal organs. Blast pressure Injuries can be caused by shrapnel fragments being thrown away from the epicentre and also be internal organ damage. Photographs must be taken of injuries to victims and any materials removed from victims such as clothing, hardhats, and boots by the force of the explosion or first responders. Clothing of victims may contain physical and chemical residues and should be carefully preserved for laboratory analysis after documentation.

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CHAPTER REVIEW

POTENTIAL ENERGY INTO KINETIC ENERGY

TWO TYPES OF EXPLOSIONS MECHANICAL & CHEMICAL

LOW ORDER & HIGH ORDER DAMAGE

EXPLOSION EFFECTS:

- BLAST PRESSURE FRONT EFFECT
- SHRAPNEL EFFECT
- THERMAL EFFECT
- SEISMIC EFFECT

FACTORS:

NATURE, SIZE, VOLUME, & SHAPE OF CONTAINER

RATE OF PRESSURE RISE

In this chapter we discussed:

That an explosion is a sudden conversion of potential energy, either chemical or mechanical, into kinetic energy (the energy possessed by a system or object as a result of its motion).

The two major types of explosions are mechanical and chemical and are differentiated by the source and mechanism that produce them.

The characteristics of explosion damage are low-order and high-order damage.

The effects of an explosion include blast pressure front effect, shrapnel effect, thermal effect, and seismic effect.

Factors controlling the explosion effects are type and shape of fuel; nature, size, volume, and shape of containment vehicle; venting of the containment vessel; relative maximum pressure achieved; and rate of pressure rise.

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CHAPTER REVIEW

FUEL GASES & IGNITABLE LIQUID VAPORS

DUST EXPLOSIONS

TRACE FROM LEAST DAMAGE TO MOST DAMAGE

- AGRICULTURAL PRODUCTS
- CARBONACEOUS MATERIALS
- METALS
- CHEMICALS
- PLASTICS
- RESIN

Analyzing the scene and evidence to establish the origin of the explosion. This is done through determining whether the explosion was seated or non-seated, the area of most damage, and the potential fuel.

An explosion dynamics analysis is conducted to trace backward from the least to the most damaged area.

Fuel gases or the vapors of ignitable liquids are the most commonly encountered explosions.

Dust explosions may occur from the following materials: agricultural products, carbonaceous materials, chemicals, dyes and pigments, metals, plastics, and resin.

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CHAPTER REVIEW

EXPLOSION INVESTIGATION OBJECTIVES

VAPOR CLOUD EXPLOSIONS

LOW EXPLOSIVES & HIGH EXPLOSIVES

BACKDRAFT OR SMOKE EXPLOSIONS

- DETERMINE ORIGIN
- IDENTIFY FUEL/IGNITION SOURCE
- DETERMINE CAUSE
- ESTABLISH RESPONSIBILITY

It is common for fires in airtight rooms to become oxygen depleted. This results in the generation of flammable gases due to incomplete combustion and, if air is introduced, the potential for backdrafts and smoke explosions.

The release of gas, vapor, or mist into the atmosphere may result in a cloud forming within the fuel’s flammable limits and, subsequently, ignition, culminating in an outdoor vapor cloud explosion.

Explosives are categorized into two main types: low explosives and high explosives, which should not be confused with low-order and high-order damage.

The objectives of an explosion scene investigation are no different from those of a fire investigation: Determine the origin, identify the fuel and ignition source, determine the cause, and establish the responsibility for the incident.

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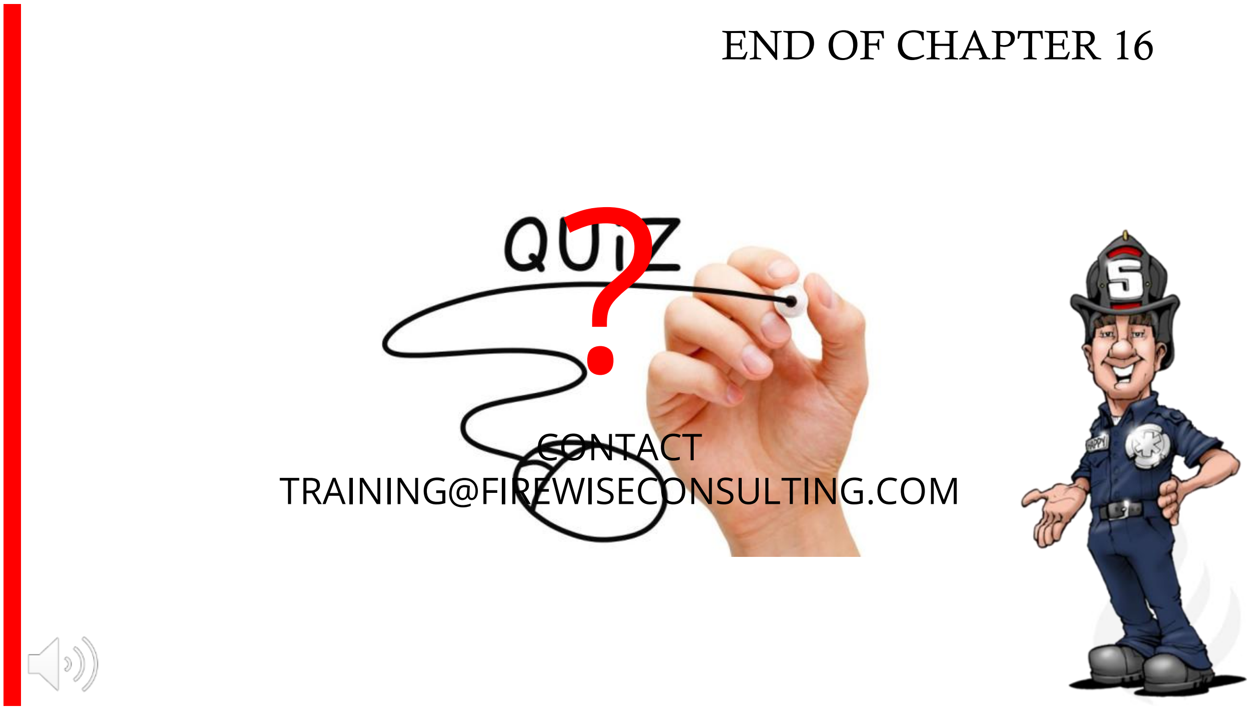

That’s the end of Chapter **16** Explosions. You are now ready to move on to **Chapter 17 Part 1** which deals with **Automobile Fires**, but please complete the quiz for Chapter **16** first.

If you have any questions now is a good time to contact your teacher.