Explosion Investigation and Analysis

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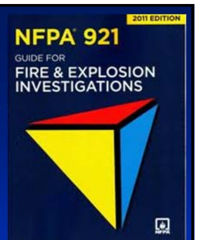
TRACE Fire Protection and Safety
Richmond, Kentucky

References



- NFPA-921 Chapter 21
- Explosion Investigation and Analysis, Kennedy
- Gas Explosions in Buildings and Heating Plants, Harris
- Gas Explosion Handbook, GexCon
- Dust Explosions in the Process Industries, 3RD Edition, Eckhoff
- Practical Bomb Scene Investigation, Thurman
- Explosives Engineering; Copper
- Introduction to the Technology of Explosives; Cooper
- Blasters' Handbook, 16th Edition, DuPont

I. Introduction

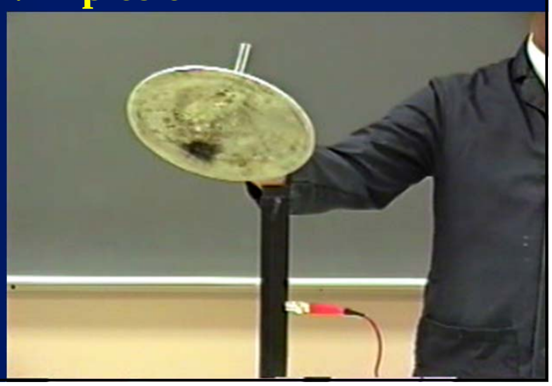
Foundation

Pay attention to details the large pieces will come in to place.

Scientific Method

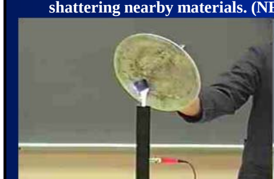
A. Definitions

1. Explosion



1. Explosion

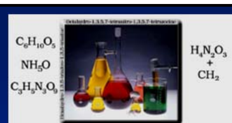
The sudden conversion of potential energy (chemical or mechanical) into kinetic energy with the production and release of gases under pressure, or the release of gas under pressure. These high pressure gases then do mechanical work such as moving, changing, or shattering nearby materials. (NFPA-921)



Elements of an Explosion

- Rapid Increase in Gas Pressure (Gas Dynamic)
- Confinement of the Pressure
- Rapid release of that Pressure
- Damage or Change to the confining structure or the vessel
- Noise is not an element (Not required)

2. Explosives



The term "explosives", generally is used in reference to a wide range of energetic materials that can react chemically to produce heat, light, and gas.

3. Combustion Explosion

The rapid combustion of a fuel in a confined area.

- Fuel Gases
- Industrial Gases
- Dust

4. Deflagration

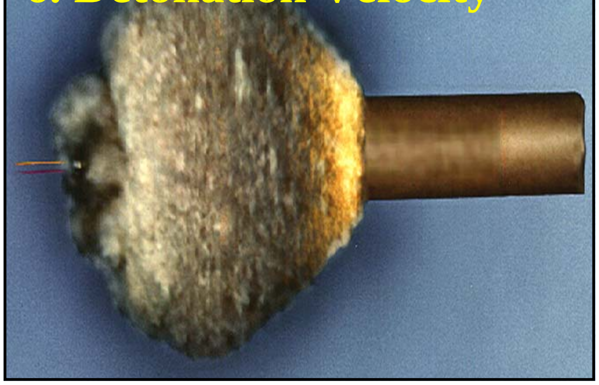
Rapid burning.

Deflagration is a rapid chemical reaction in which the output of heat is enough to enable the reaction to proceed and (depending on the ambient conditions of the fuel) be accelerated without input of heat from another source. (Subsonic Reaction)

5. Detonation

Instantaneous combustion or conversion of a solid, liquid or gas into larger quantities of expanding gases accompanied by heat, shock and most often a noise. (Supersonic Reaction)

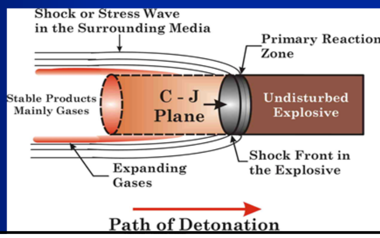
6. Detonation Velocity



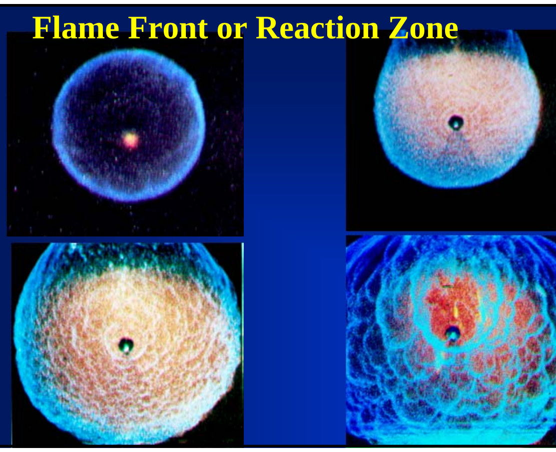
a. Detonation Wave

A detonation wave is a shock wave in a reacting (explosive or fuel) material where the chemical reaction is carried out in the shock front.

Example is an explosive material. However, in a diffuse fuel the flame front or reaction zone is also present.



Flame Front or Reaction Zone



7. Deflagration to Detonation Transition (DDT)

Once a self-sustaining reaction has begun, it propagates through the adjacent material at a rate determined by either porosity, particle size, density, pressure, heat, and distance.

Deflagration(Subsonic) transitions to Detonation (Supersonic) reaction rate.

B. Types Of Explosions


1. Mechanical Explosion

Nature of the fuel does not change.


1. Mechanical Explosion

2. Chemical Explosion

Nature of the fuel changes.

Explosives, no oxidizer required


2. Chemical Explosion

Nature of the fuel changes

Combustion, Oxidizer Required

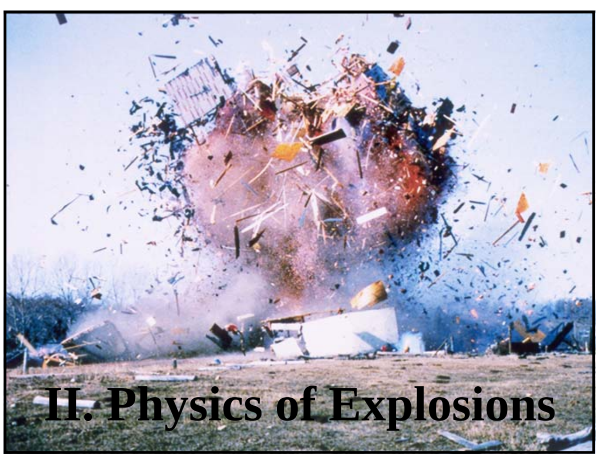
3. Electrical Explosion

An electrical explosion is caused by a high-energy electrical arc which generates sufficient heat to cause failure of the containing component.

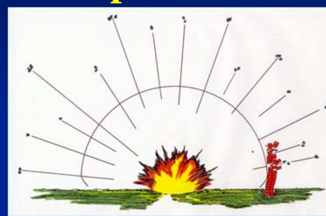

3. Electrical Explosion

4. Nuclear Explosion

An atomic explosion is induced by either fission or fusion.

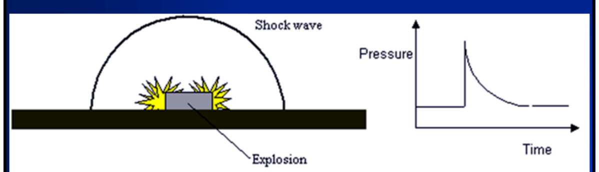


A. Effects of an Explosion

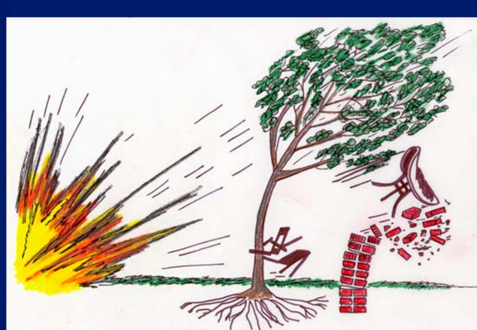


- Blast Pressure
- Fragmentation
- Thermal or Incendiary
- Ancillary Effects

1. Blast Pressure Effects

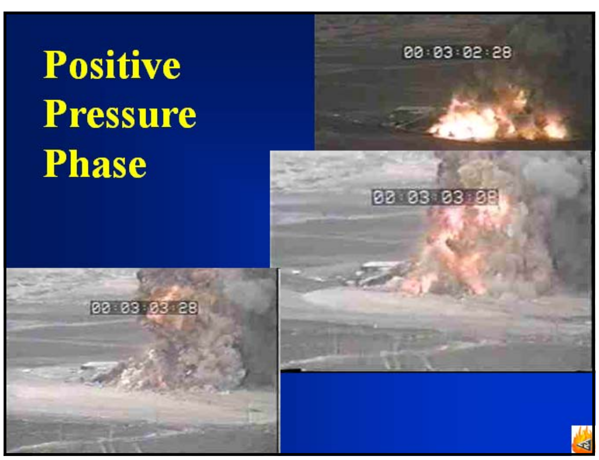


a. Positive Pressure Phase




Positive Pressure Phase

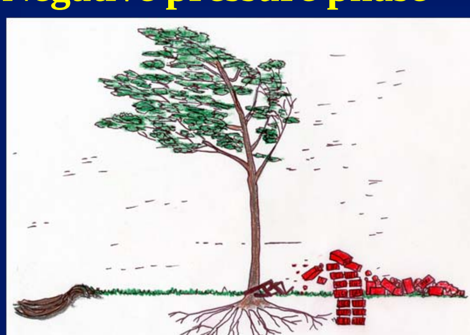

Positive Pressure Phase


Positive Pressure Phase
00:03:02:28

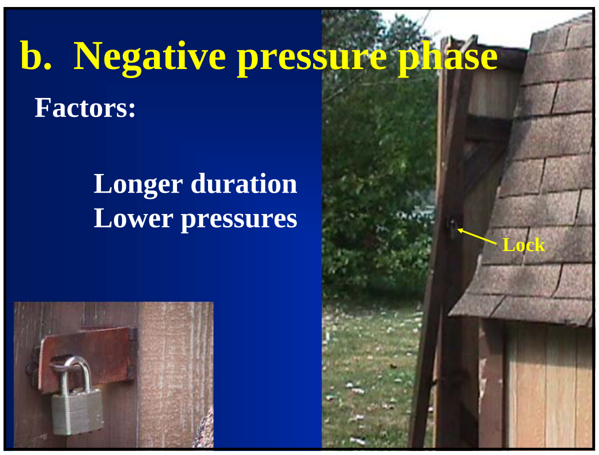
Positive Pressure Phase

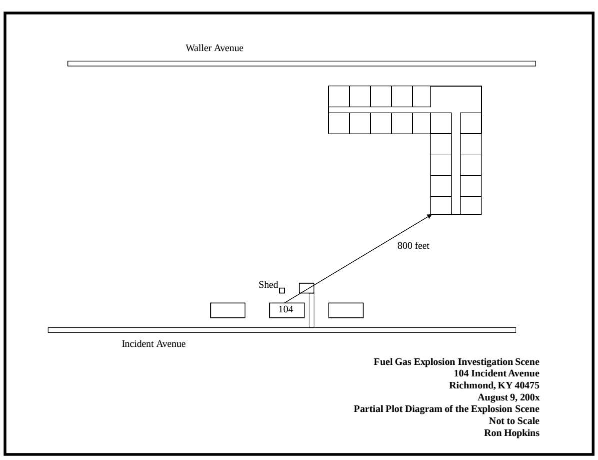
PEPCON Rocket Fuel
Fire and Explosion, 1988

b. Negative pressure phase




b. Negative pressure phase
Factors:
Longer duration
Lock

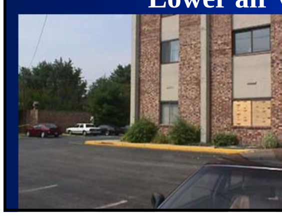

b. Negative pressure phase
Factors:
Longer duration
Lower pressures
Lock


Waller Avenue
800 feet
Shed
104
Incident Avenue
Fuel Gas Explosion Investigation Scene
104 Incident Avenue
Richmond, KY 40475
August 9, 200x
Partial Plot Diagram of the Explosion Scene
Not to Scale
Ron Hopkins

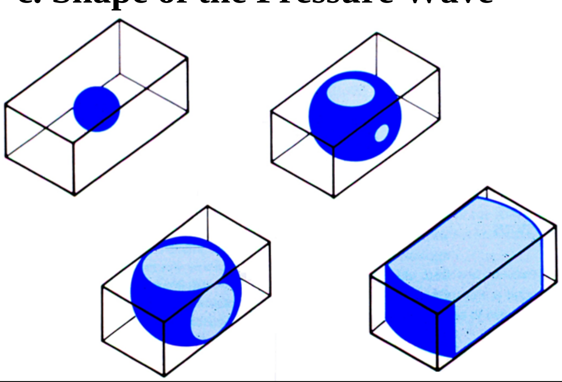
b. Negative pressure phase

Factors:

- **Longer duration**
- **Lower pressures**
- **Lower air velocity**



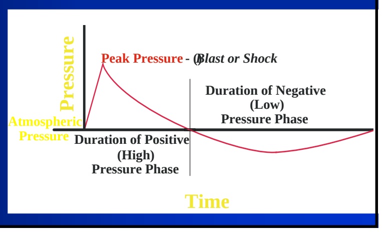
c. Shape of the Pressure Wave



d. Rate of Pressure Rise

v.

Maximum Pressure



2. Fragmentation Effect

Fragments
Shrapnel

2. Fragmentation Effect

Fragments
Shrapnel

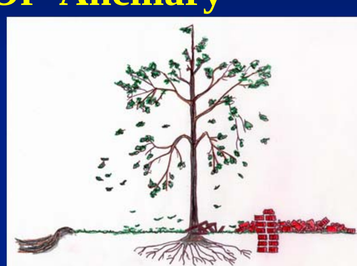
3. Thermal Effect - Incendiary

Example temperatures: 3000 – 7000 degrees F.

High Density and Low Density Fuels

4. Secondary Blast Pressure Or Ancillary Effects

a. Reflection

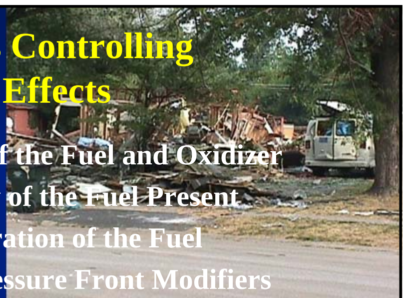


4. Secondary Blast Pressure Or Ancillary Effects

a. Reflection

b. Earth, Water Shock, and Ceiling

D. Factors Controlling Explosion Effects



1. Nature of the Fuel and Oxidizer
2. Quantity of the Fuel Present
3. Configuration of the Fuel
4. Blast Pressure Front Modifiers
4. Containment Vessel
5. Initiation Source and Location
6. Venting

F. Seated Explosion

The "seat" of an explosion is defined as the crater or area of greatest damage located at the point of initiation (epicenter) of an explosion.

a. Condensed Phase Fuel

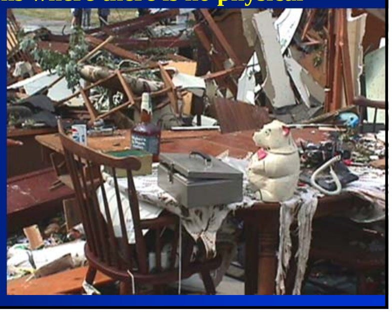
An explosive material in the form of a solid or liquid rather than a gas or vapor.

b. Mechanical Explosion

Boiling
Liquid
Expanding
Vapor
Explosion

G. Non-Seated Explosion

Those explosions where there is no physical evidence of a single location where the explosion originated.



Diffuse Phase Fuel

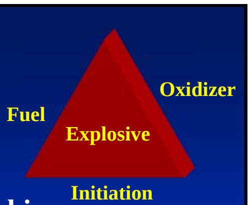
a. Diffuse Phase Fuel, Gases and Vapors

A general category of combustion explosions that occur as a result of the ignition of fuel gases (i.e. Natural Gas, LPG), Industrial Gases, Sewer Gases, and vapors of pooled liquids (i.e. gasoline vapors, lacquer thinner, MEK).

b. Dust Explosion

Ignition of solid materials such as dusts and fines.

III. Explosives

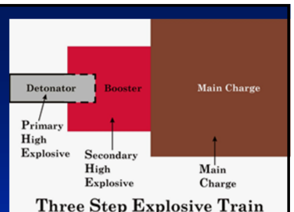


A. General

Fuel Oxidizer Relationships

Explosive
- Fuel
- Oxidizer - Oxygen Balance
- Special Fuel or Sensitizer

1. Definitions



a. Firing Train

A sequence of events required to initiate a single or final event.

b. High Order Detonation

Complete burning of the explosive material or initiation of the material at maximum velocity.

c. Low Order Detonation

Incomplete burning of the explosive material or initiation of the material at less than maximum velocity.

Reaction at less than maximum velocity

2. Low Explosives

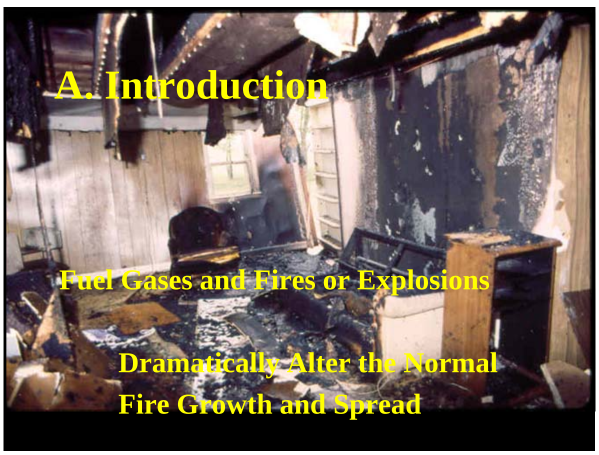
a. Deflagrates
b. Material is a mixture
c. Initiated by heat.
d. Confinement required for explosion
e. VOE below 3000 ft/sec

Examples: Black powder, smokeless powder

3. High Explosives

a. Material undergoes detonation without confinement.
b. Material is a compound
c. Initiated by shock or heat
d. Supersonic reaction in the product.
e. High brisance
f. VOD above 3300 ft/sec

Examples: Dynamite, ANFO, PETN



NFPA 54
National Fuel Gas Code

From the "point of delivery" to the connections with each gas utilization device

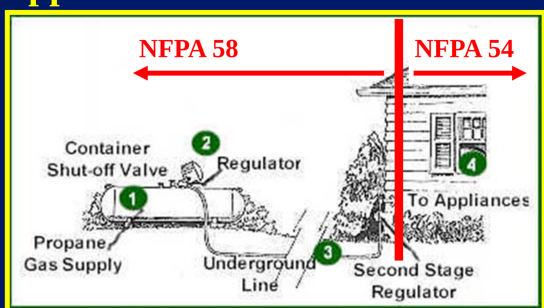
The *"point of delivery"* shall be considered the outlet of the service meter assembly or the outlet of the service regulator or service shutoff valve where no meter is provided.

NFPA 58
Liquefied Petroleum Gas Code

Containers, piping, and associated equipment, when delivering LP-Gas to a building for use as a fuel gas.

Including tanks, cylinders, and piping up to the second stage regulator

Application of the NFPA Codes



B. Fuel Gases

Fuel gases by definition:

- **Natural Gas (Commercial)**
- **Liquefied Petroleum Gas (in the vapor phase only)**
- **Liquefied Petroleum Gas–Air mixtures**
- **Manufactured Gases**
- **Mixtures of these gases**

Most commonly encountered by the fire and explosion investigator will be natural gas and commercial propane.

1. Odorization

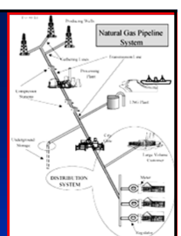
- **LP-Gas and natural gas have little or no identifiable odor in their natural state**
- **Odorant containing t-butyl mercaptan, thiophane, ethyl mercaptan or other mercaptans are added by law**
  - **Natural Gas - 49 CFR 129.625**
  - **LP gas NFPA 58 Section 4.2.1**
- **Must be noticeable "at concentration in air of one-fifth of the lower explosive limit"**

1. Odorization

- **Natural gas odorant is added by the local distribution company prior to the introduction of the gas into the distribution Pipelines (mains).**
  - **Natural gas in long-distance transmission pipelines is usually not odorized.**
- **LP-Gas odorant is added by the gas supplier prior to delivery to an LP-Gas distributor's bulk plant.**

2. Fuel Gas System Components

a. Natural Gas Systems



Typically piped directly to the consumers' buildings from centralized production and storage facilities via:

- **Transmission Pipelines.**
- **Distribution Pipelines (Mains)**

b. Fuel Gas System Components

Natural Gas Systems

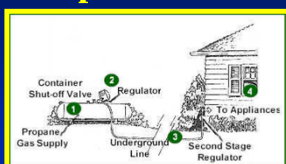
Service Lines (House Lines)

- Piping
- Pressure regulation
- Metering
- Valving
- Utilization equipment

Fuel Gas System Components

b. LPG Systems

- Storage Tank or Cylinder
- Piping
- Pressure regulation
- Metering
- Valving
- Utilization equipment



(1.) LP-Gas Storage Containers

ASME Tanks (>120 Gallons)

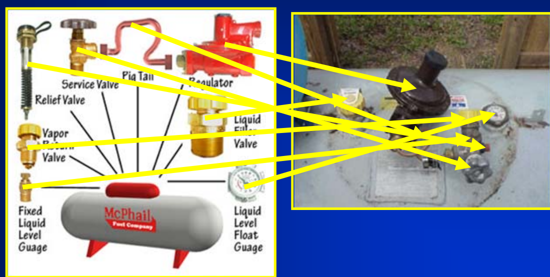
ASME Boiler and Pressure Vessel Code

DOT Cylinders (<120 Gallons)

49 CFR - Transportation

(2.) Container Appurtenances

(Tanks)



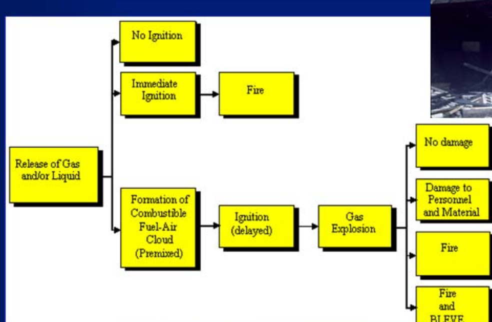
c. Normal Working Pressures

Natural Gas	8" W.C. (~ 0.3 PSI)
Propane	11" W.C. (~0.4 PSI)

Some appliances have additional regulators to lower working pressures to about 3.5" W.C. (~0.13 PSI)

1 psi = 27.7" W.C.

3. Fuel Gas Explosions



Gas Migration Ignition Study, Minnesota Chapter IAAI

To much gasoline!

Flash fire or unconfined combustion explosion?

4. Characterization of Explosion Damage


a. High Order Damage


Characteristics

- Small Debris Pieces
- Long Missile Distances
- Fast Rate of Pressure Rise
- Negative Pressure Phase is powerful

Fuel - Air Relationship

- Optimum Mixture
- Near or just above stoichiometric
- Most efficient burning
- Little following fire

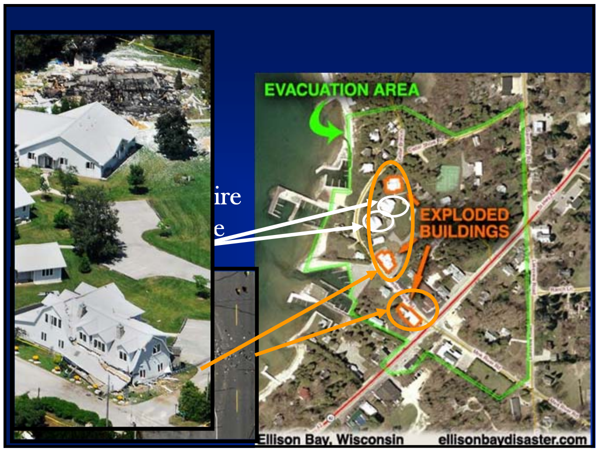
Characteristics

- Large Debris Pieces
- Short Missile Distances
- Slower Rate of Pressure Rise
- Pushing or Heaving

Fuel - Air Relationship

- Near LEL or UEL
- Inefficient burning
- Low rate of pressure rise
- Low speed pressure wave
- Near LEL, little following fire
- Near UEL, greater potential for following fire

Damage Characterization



c. Vapor Density and Damage



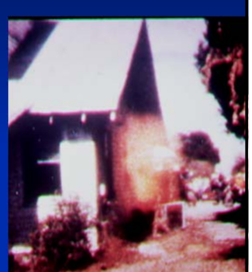
Relationship of Gas in Compartment?
Why?

Lighter-than-air gases

- **Collect in upper areas**
- **Pocketing at ceilings**
- **Migrate through openings**

Heavier-than-air gases

- **Collect in lower areas**
- **Burns at high levels when ignited**
- **Low pocketing is unusual**



c. Location of damage is not indicative of vapor density

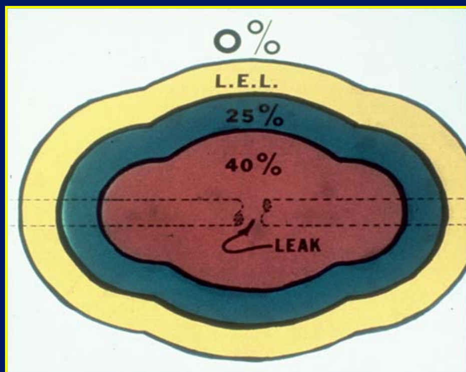
A common misconception

- More a function of wall strength or,
- Height of explosive range

d. Minimum Ignition Energy

- Most easily ignitable fuels
- Ignition Temperatures
  - 700 - 1100 F
- Ignition Energies 0.20 - 0.25 millijoules
  - Examples would include:
  - Static Electricity,
  - Operation of Motors, Switch

e. Underground Migration *Fuel Gases*



Gas Line Bar Hole Survey

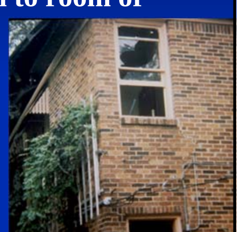
f. Multiple ("Cascade") Explosions

a. Multiple pockets of gas

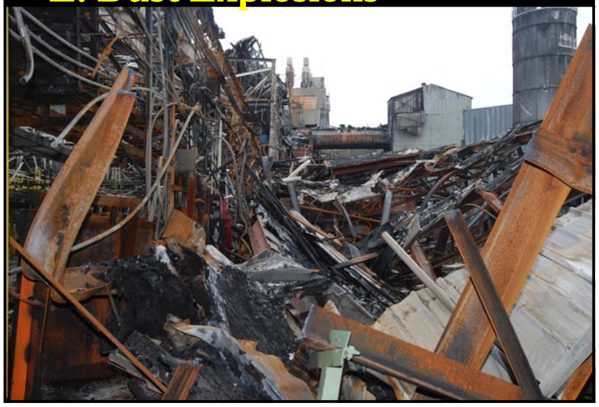
b. "Cascade" from room to room or floor to floor

c. Aeration of pockets over the UEL

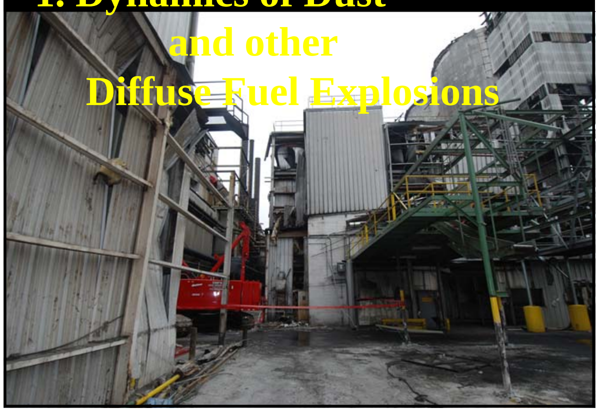
d. Multiple explosions are very common



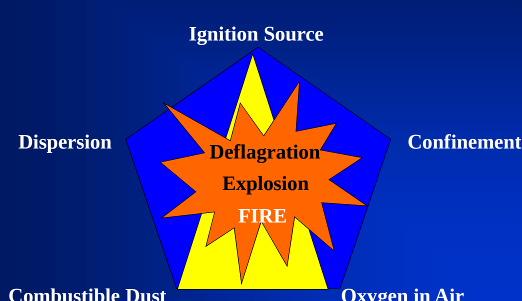
E. Dust Explosions



1. Dynamics of Dust and other Diffuse Fuel Explosions



a. 5 Elements Required for a Dust or other Diffuse Fuel Explosion



b. Diffuse Phase Fuels, Dust

b. Wide variety of materials

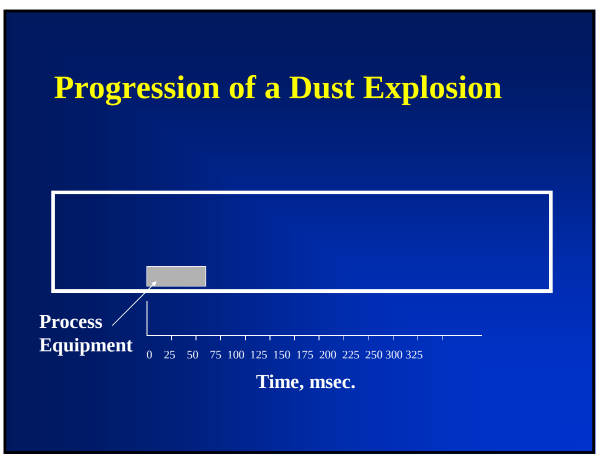
Combustible and Non-Combustible

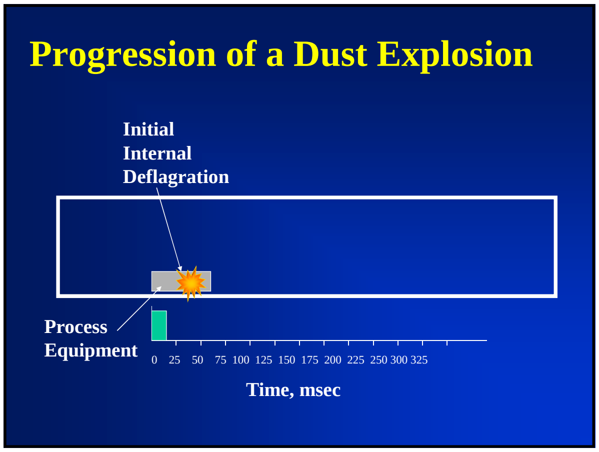
c. Controlling Factors

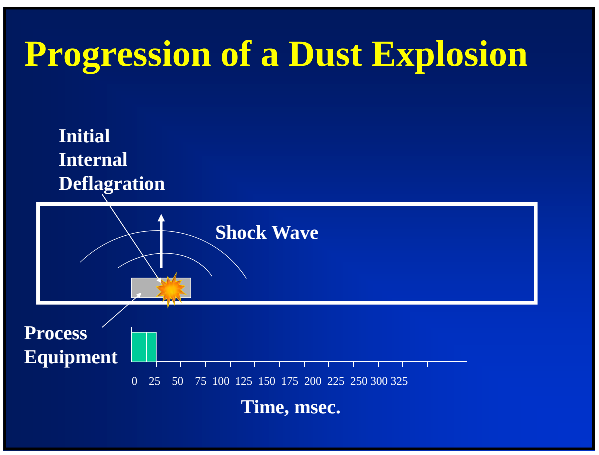
- Suspended or Layered
- Particle Size
- Concentration
- Turbulence
- Moisture

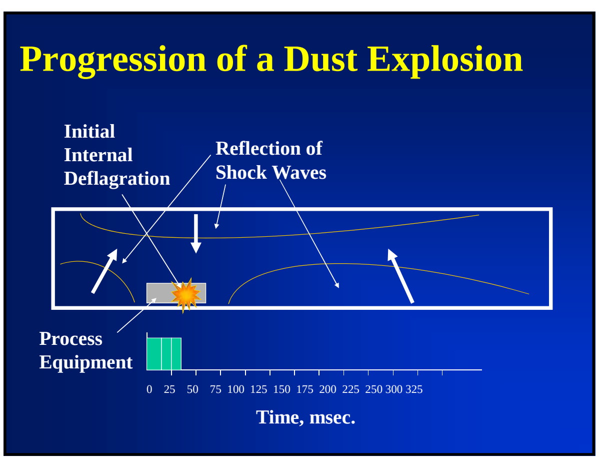

2. Progression of Dust Explosions
a. Usually occur in series
b. Initial explosions usually less violent than subsequent
c. Subsequent explosions are fueled by additional dust put into suspension

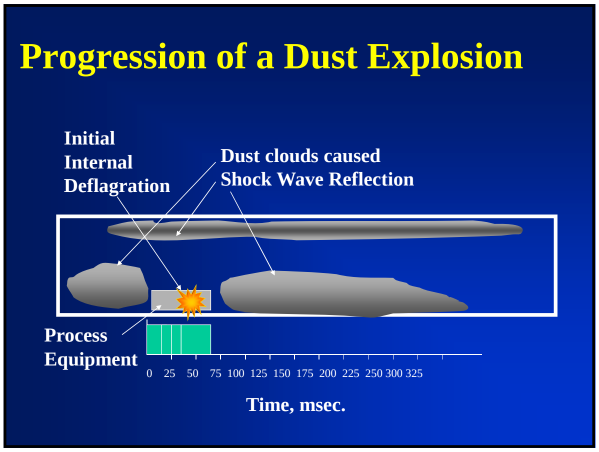

3. Typical Dust Explosion Event

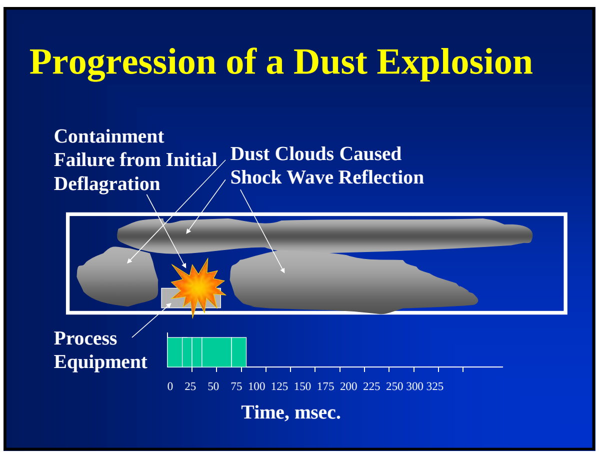

Progression of a Dust Explosion
Process Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.

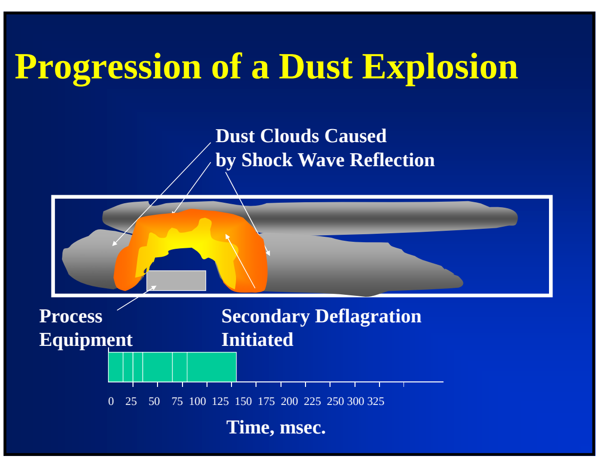

Progression of a Dust Explosion
Initial
Internal
Deflagration
Process
Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec

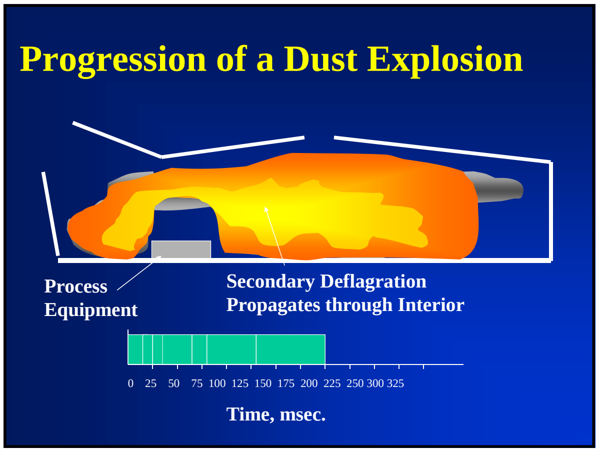

Progression of a Dust Explosion
Initial
Internal
Deflagration
Shock Wave
Process
Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.

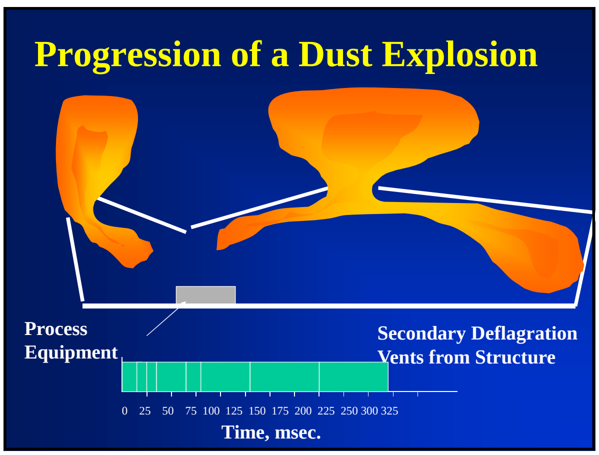

Progression of a Dust Explosion
Initial
Internal
Deflagration
Reflection of
Shock Waves
Process
Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.

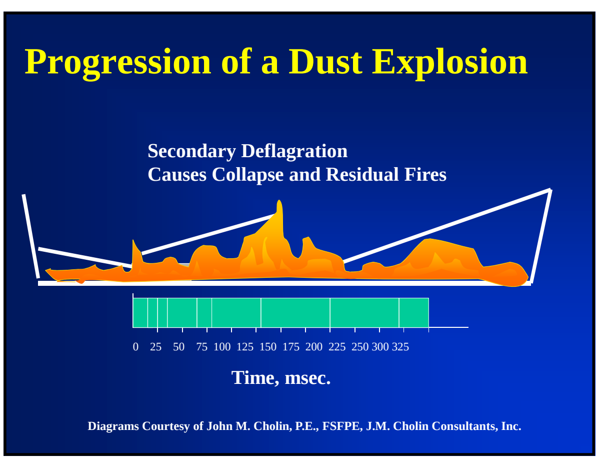

Progression of a Dust Explosion
Initial
Internal
Deflagration
Dust clouds caused
Shock Wave Reflection
Process
Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.


Progression of a Dust Explosion
Containment
Failure from Initial
Deflagration
Dust Clouds Caused
Shock Wave Reflection
Process
Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.


Progression of a Dust Explosion
Dust Clouds Caused
by Shock Wave Reflection
Process
Equipment
Secondary Deflagration
Initiated
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.


Progression of a Dust Explosion
Process Equipment
Secondary Deflagration Propagates through Interior
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.


Progression of a Dust Explosion
Process Equipment
Secondary Deflagration Vents from Structure
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.


Progression of a Dust Explosion
Secondary Deflagration Causes Collapse and Residual Fires
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.
Diagrams Courtesy of John M. Cholin, P.E., FSFPE, J.M. Cholin Consultants, Inc.

CSB Model of the Imperial Sugar Plant Explosion

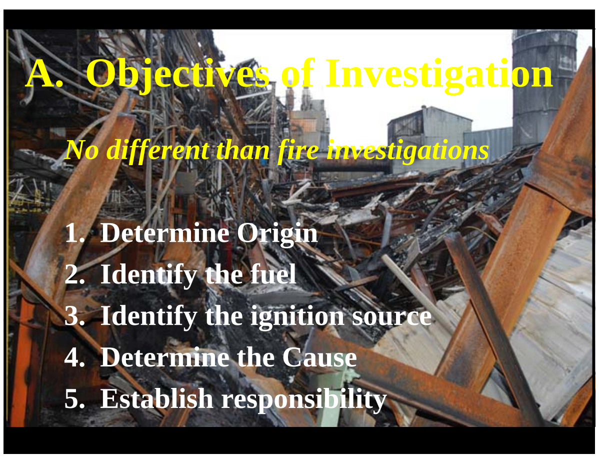
G. Backdraft Explosions

1. **Ventilation Controlled Fires**

   Post Flashover Conditions


3. Ventilation
Introduction of fresh air (oxygen) allows rapid combustion of the fuel.


IV. Investigating the Explosion Scene


A. Objectives of Investigation
No different than fire investigations
1. Determine Origin
2. Identify the fuel
3. Identify the ignition source
4. Determine the Cause
5. Establish responsibility

B. Systematic Approach is Even More Important

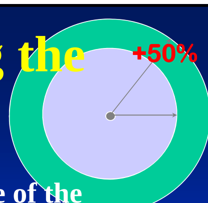
1. Scenes are usually larger than simpler fires
2. Scenes are usually more disturbed than fires

C. Secure the Scene

Establish and maintain control of the scene and area

Prevent unauthorized persons from entering

D. Establishing the Scene



1. 1 1/2 times the distance of the furthest piece of debris
2. Debris may have been propelled great distances into adjacent buildings or vehicles
3. As additional debris is found, the scene is widened

E. Scene Search

1. Outer perimeter inward towards epicenter

2. Briefing and Control of Search Teams

Identifying evidence

Photographing evidence

Mapping evidence

3. Safety at the Explosion Scene

a. Structures are unsound

b. Secondary explosions are possible

c. In bombings, secondary devices, unexploded devices or undetonated explosives are possible

d. Special Scene Hazards

F. Incident Assessment

- Incident
  - Fire
  - Explosion
    - Seated
      - Explosives
      - BLEVE
    - Non-Seated
      - Fuel Gas
      - Dust

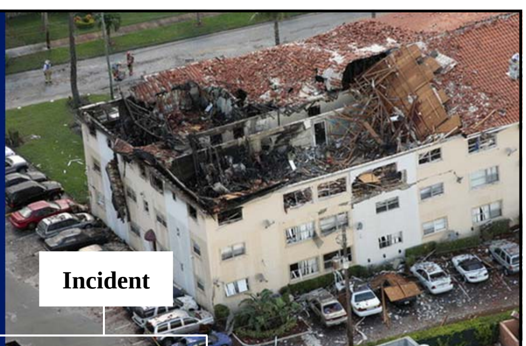
1. Initial Incident Assessment

Identify Explosion or Fire

Burning or Heat Treatment

Overpressure

- Incident
  - Fire
  - Explosion



- Incident
  - Fire
  - Explosion

a. Low or High Order Damage

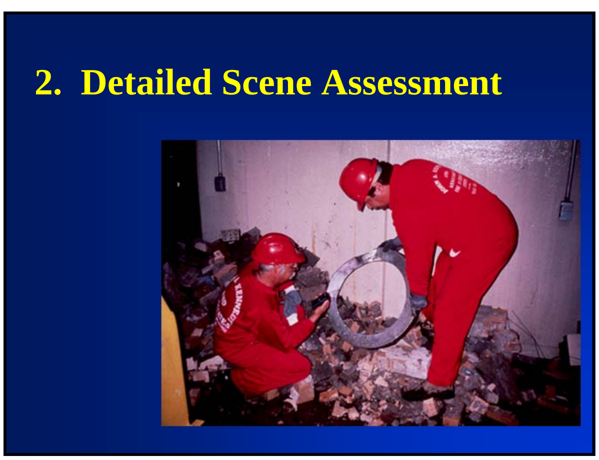
b. Seated or Non-Seated

c. Type of Explosion

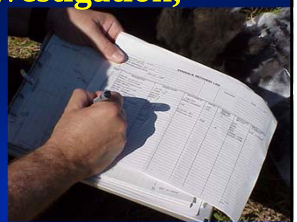
- Mechanical
- Chemical
- Combustion
- BLEVE
- Electrical


d. Type of Fuel
a. Fuels Available
b. Condition of Systems
c. Compare Damage

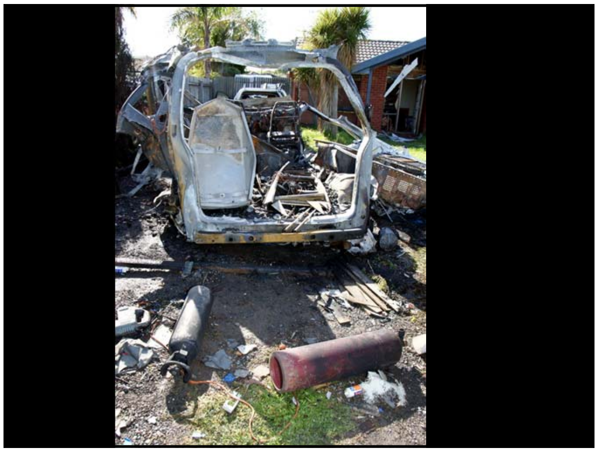

d. Type of Fuel
a. Fuels Available
b. Condition of Systems
c. Compare Damage

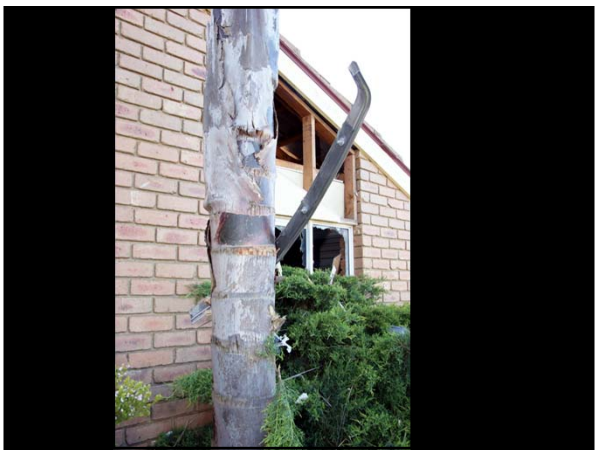

2. Detailed Scene Assessment

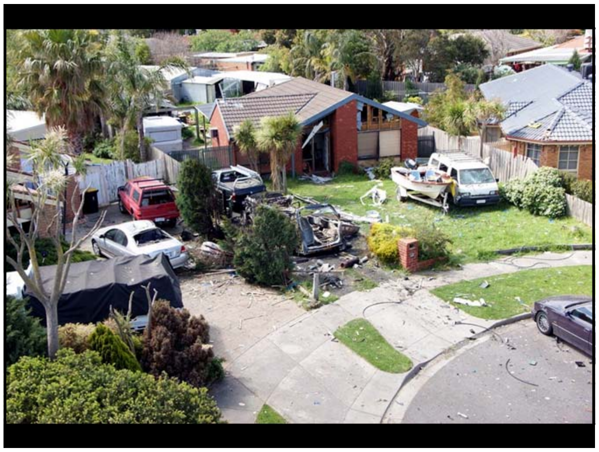
a. Record the Investigation, Evidence and Findings

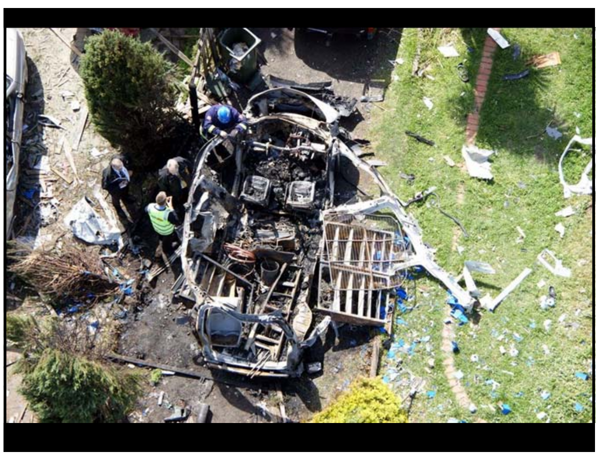


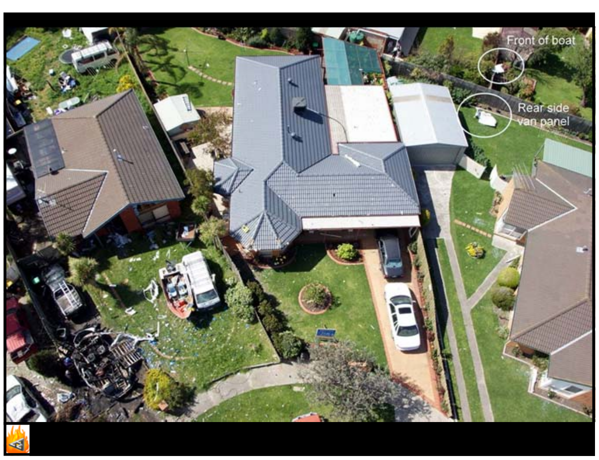
- Notetaking
- Diagramming and Mapping
- Photography
- Proper Evidence Collection and Preservation









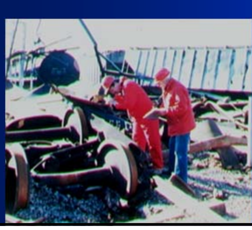

Front of boat
Rear side van panel

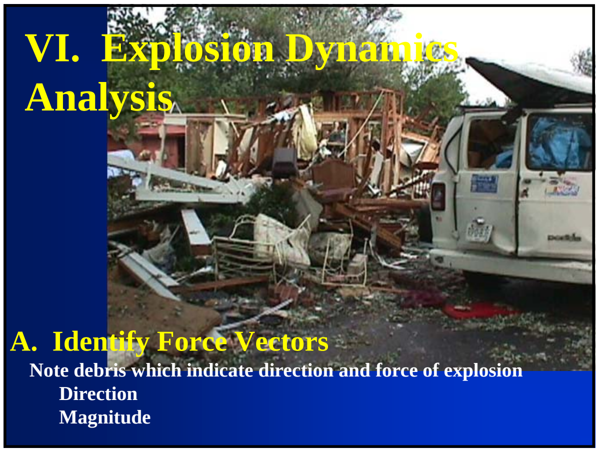
c. Identify Pre-Blast and Post-Blast Fire Damage

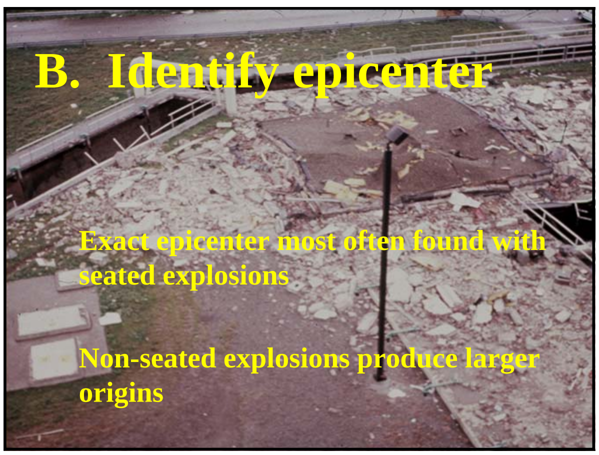
Propelled Debris may be burned or unburned

d. Locate, Identify and Record Articles of Evidence

Evidence may have been propelled into a variety of locations




VI. Explosion Dynamics Analysis
A. Identify Force Vectors
Note debris which indicate direction and force of explosion
Direction
Magnitude


B. Identify epicenter
Exact epicenter most often found with seated explosions
Non-seated explosions produce larger origins


C. Analyze Origin (Epicenter)
1. Explosion Dynamics Analysis
Trace Force Vectors
Least to Most Damage

2. Construct Explosion Dynamics

Vector Diagram

Direction of debris movement

Relative force of debris movement

Both large scale and small scale diagrams may be necessary

D. Analyze Fuel Source

1. Compare nature of damage to available fuels

2. All available fuels must be considered and eliminated

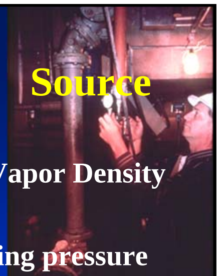
3. Samples

4. Physical Evidence Samples

a. Residues
- Ignitable Liquids
- Explosives

b. Fuel Containers/ Appliances/ Equipment

5. Determine Fuel Source



Source may be related to Vapor Density

All gas appliances and piping pressure tested

Any leaks discovered must be identified as pre- or post-blast

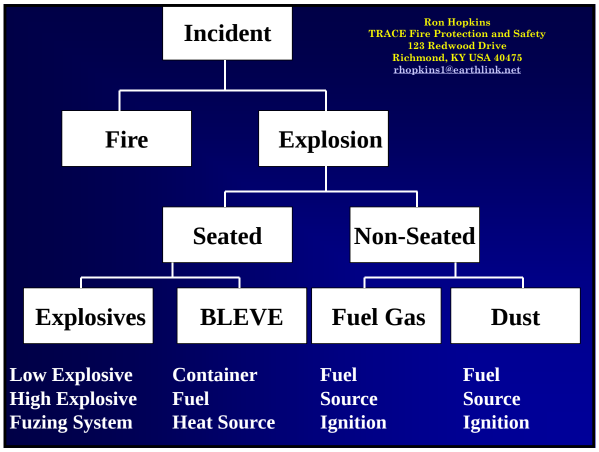
E. Analyze Ignition Source

1. Often most difficult

2. Multiple possible ignition sources often present

3. Consider all available information

- Minimum Ignition Energy of Fuel
- Ignition Energy of Ignition Source
- Ignition Temperature of Fuel
- Temperature of Ignition Source
- Location of Ignition Source in Relation to Fuel
- Contemporaneous presence of Fuel and Ignition Source
- Witness Accounts



Explosion Dynamics Analysis

Questions?

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