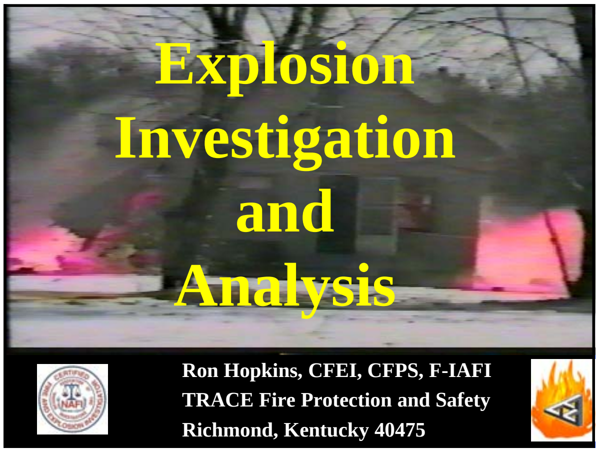
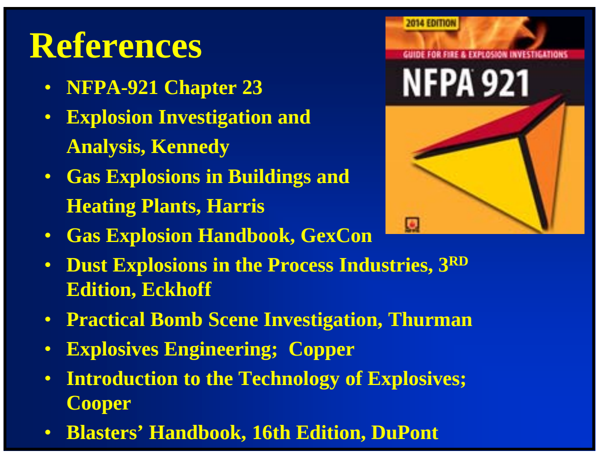

Explosion Investigation and Analysis
Ron Hopkins, CFEI, CFPS, F-IAFI
TRACE Fire Protection and Safety
Richmond, Kentucky 40475


References
• NFPA-921 Chapter 23
• 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
2014 EDITION
GUIDE FOR FIRE & EXPLOSION INVESTIGATIONS
NFPA 921


I. Introduction
Foundation
Pay attention to details the large pieces will come in to place.
Scientific Method

Monday, May 6, 2013: A division of the California Public Utilities Commission recommended that the agency levy a $2.25-billion penalty against Pacific Gas and Electric Company for the deadly 2010 explosion in San Bruno, CA, USA.

A. Definitions

1. Explosion

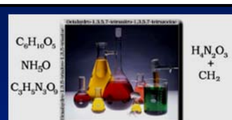
1. Explosion

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

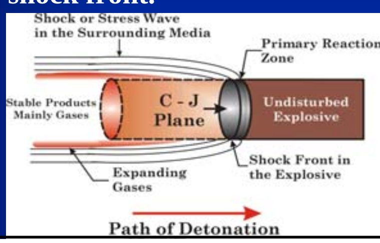
Instantaneous combustion or conversion of a solid, liquid or gas into larger quantities of expanding gases accompanied by heat, shock and most often a noise. (Supersonic Reaction)

6. Detonation Velocity

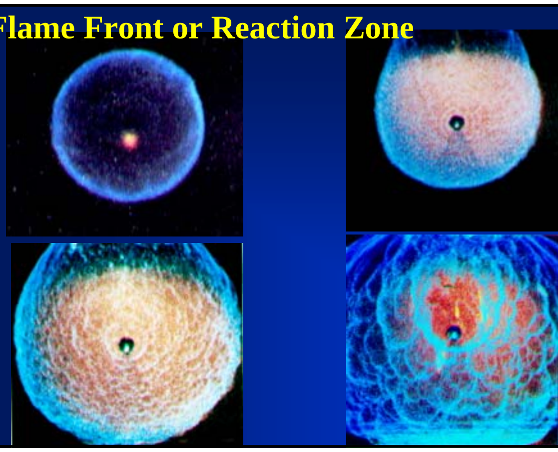
a. Detonation Wave

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

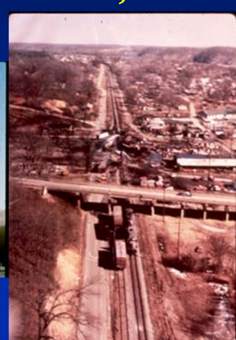


7. Deflagration to Detonation Transition (DDT)

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, 23.2



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

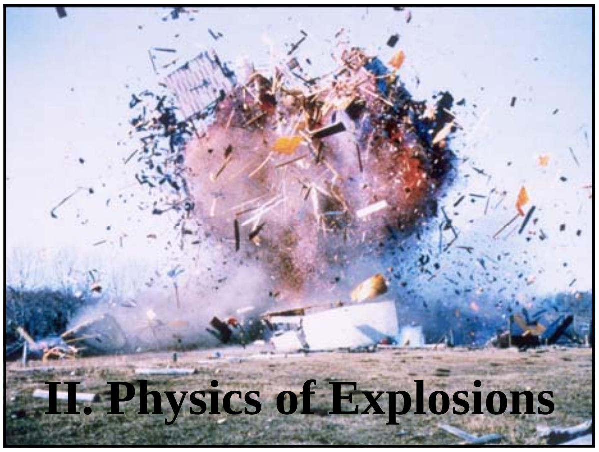
3. Electrical Explosion

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.

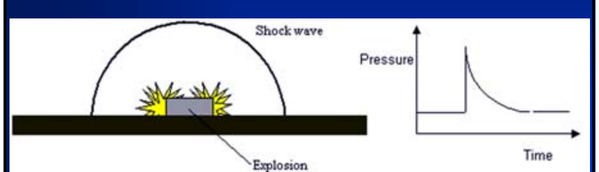


II. Physics of Explosions

A. Effects of an Explosion, 23.4

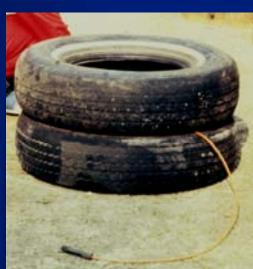
- Blast Pressure
- Fragmentation
- Thermal or Incendiary
- Ancillary Effects

1. Blast Pressure Effects



a. Positive Pressure Phase

Positive Pressure Phase

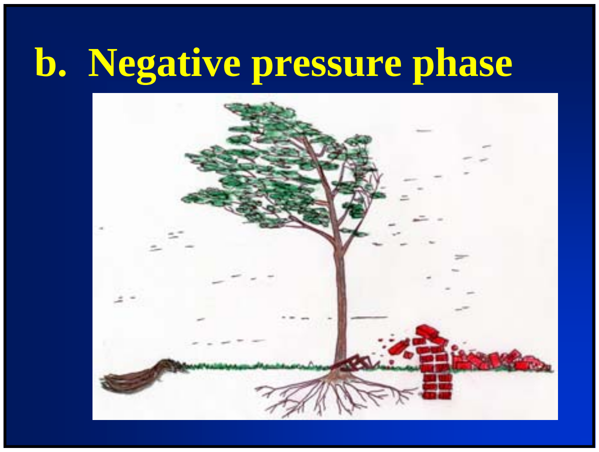


Positive Pressure Phase

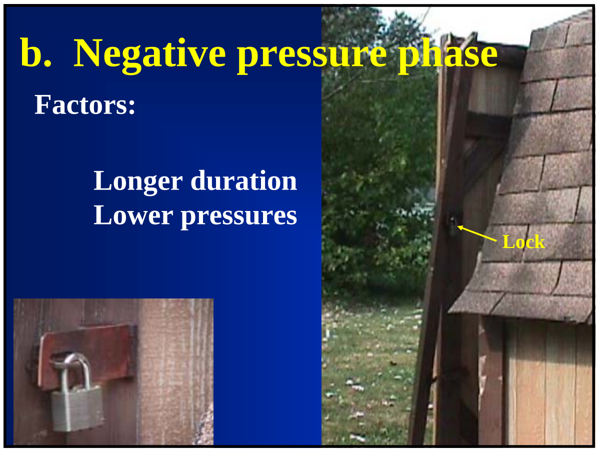
Positive Pressure Phase

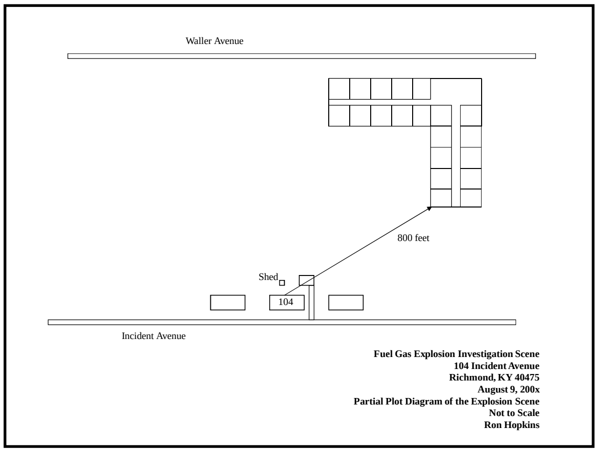
Positive Pressure Phase

PEPCON Rocket Fuel
Fire and Explosion, 1988


b. Negative pressure phase


b. Negative pressure phase
Factors:
Longer duration
Lock

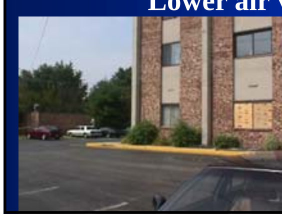

b. Negative pressure phase
Factors:
Longer duration
Lower pressures
Lock

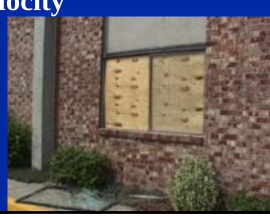


b. Negative pressure phase

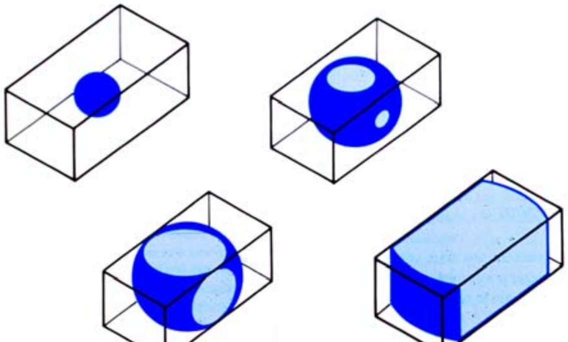
Factors:

- Longer duration
- Lower pressures
- Lower air velocity



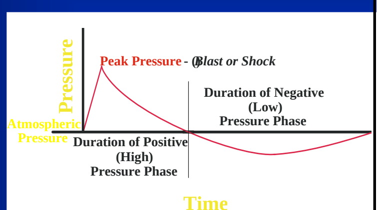


c. Shape of the Pressure Wave



See FIGURE 23.4.1.4(b)

d. Rate of Pressure Rise v. Maximum Pressure



2. Fragmentation Effect

Fragments
Shrapnel

2. Fragmentation Effect

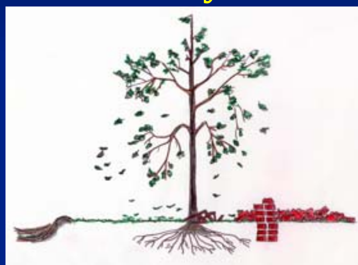
Fragments
Shrapnel

3. Thermal Effect - Incendiary

Example temperatures: 3000 – 7000 degrees F.

High Density and Low Density Fuels

4. Secondary Blast Pressure Or Ancillary Effects



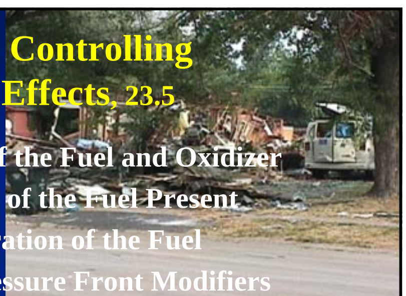
a. Reflection

4. Secondary Blast Pressure Or Ancillary Effects

a. Reflection

b. Earth, Water Shock, and Ceiling

D. Factors Controlling Explosion Effects, 23.5



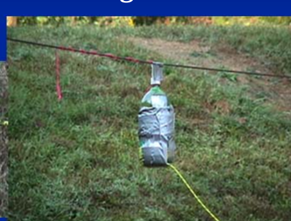
1. Nature of the Fuel and Oxidizer
2. Quantity of the Fuel Present
3. Configuration of the Fuel
4. Blast Pressure Front Modifiers
4. Containment Vessel
5. Initiation Source and Location
6. Venting

E. Seated Explosion, 23.6

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

F. Non-Seated Explosion, 23.7

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

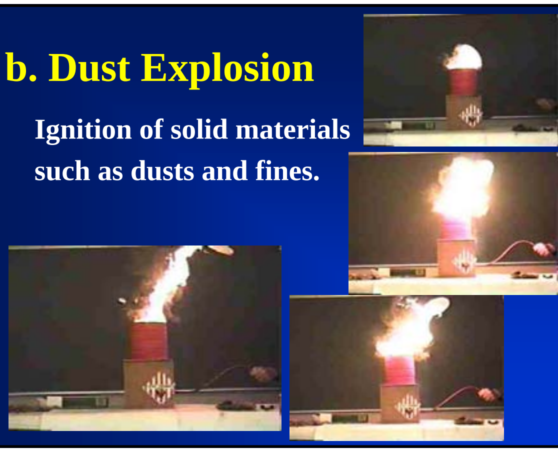
Diffuse Phase Fuel

a. Diffuse Phase Fuel, Gases and Vapors

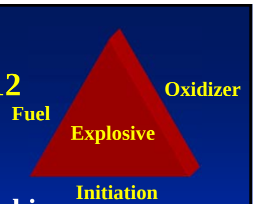
A general category of combustion explosions that occur as a result of the ignition of fuel gases (i.e. Natural Gas, LPG), Industrial Gases, Sewer Gases, and vapors of pooled liquids (i.e. gasoline vapors, lacquer thinner, MEK).

b. Dust Explosion

Ignition of solid materials such as dusts and fines.



III. Explosives, 23.12

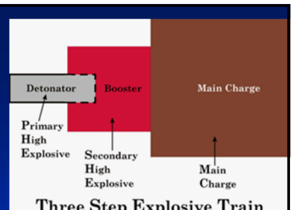


A. General

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

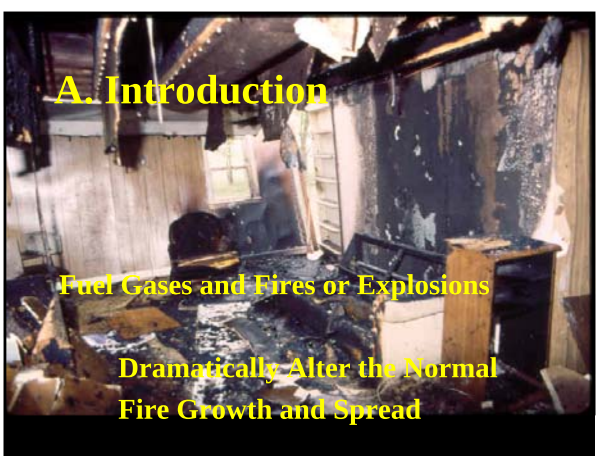
a. Deflagrates
b. Material is a mixture
c. Initiated by heat.
d. Confinement required for explosion
e. VOE below 3000 ft/sec

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

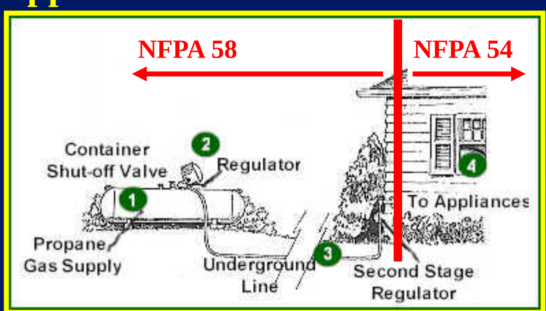
The *"point of delivery"* shall be considered the outlet of the service meter assembly or the outlet of the service regulator or service shutoff valve where no meter is provided.

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, 23.8

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

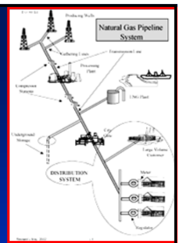
- LP-Gas and natural gas have little or no identifiable odor in their natural state
- Odorant containing t-butyl mercaptan, thiophane, ethyl mercaptan or other mercaptans are added by law
  - Natural Gas - 49 CFR 192.625
  - LP gas NFPA 58 Section 4.2.1
- Must be noticeable "at concentration in air of 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)

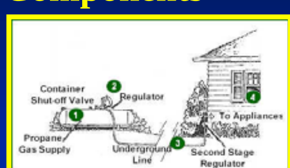
b. Fuel Gas System Components

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

c. Normal Working Pressures

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

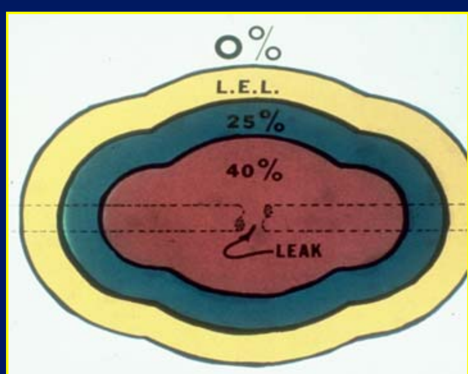
Some appliances have additional regulators to lower working pressures to about 3.5” W.C. (~0.13 PSI)

1 psi = 27.7” W.C.

3. 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

4. Underground Migration *Fuel Gases*



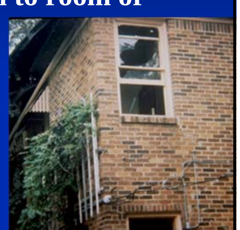
5. Multiple ("Cascade") Explosions

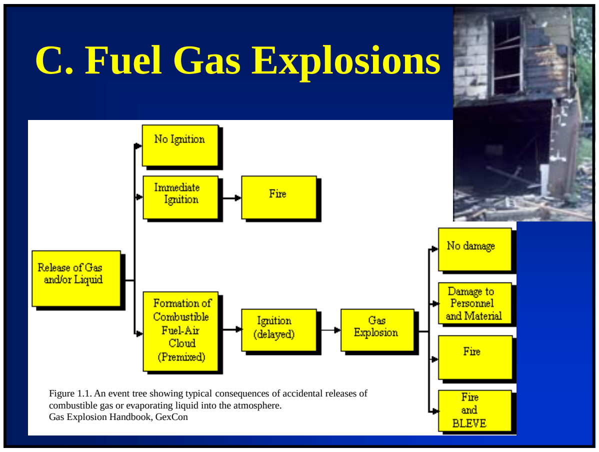
a. Multiple pockets of gas

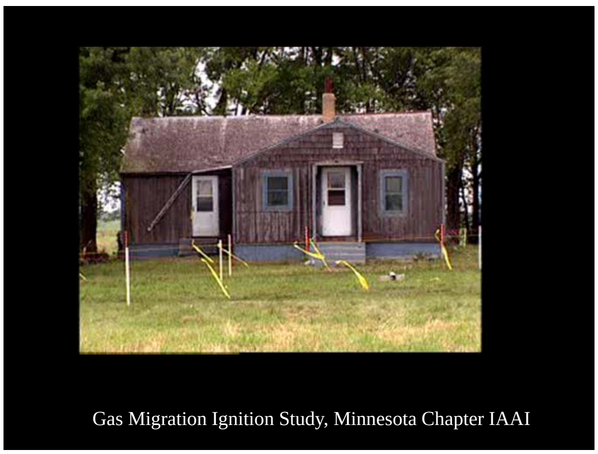
b. "Cascade" from room to room or floor to floor

c. Aeration of pockets over the UEL

d. Multiple explosions are very common




C. Fuel Gas Explosions
Release of Gas and/or Liquid
No Ignition
Immediate Ignition
Fire
Formation of Combustible Fuel-Air Cloud (Premixed)
Ignition (delayed)
Gas Explosion
No damage
Damage to Personnel and Material
Fire
Fire and BLEVE
Figure 1.1. An event tree showing typical consequences of accidental releases of combustible gas or evaporating liquid into the atmosphere.
Gas Explosion Handbook, GexCon


Gas Migration Ignition Study, Minnesota Chapter IAAI

To much gasoline!

Flash fire or unconfined combustion explosion?

D. Characterization of Explosion Damage, 23.3

1. 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

2. Low Order Damage

Characteristics

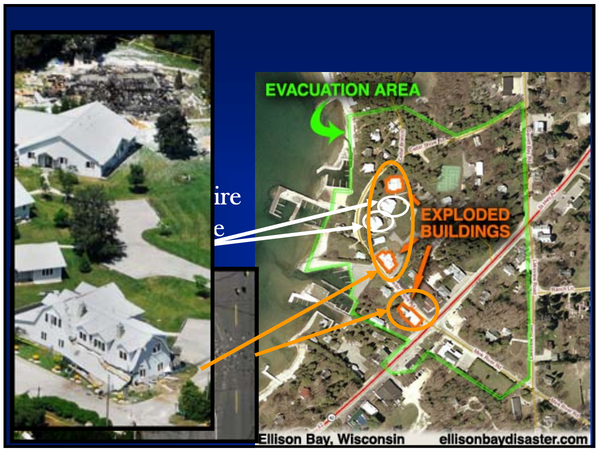
- Large Debris Pieces
- Short Missile Distances

- Slower Rate of Pressure Rise
- Pushing or Heaving

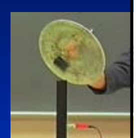
Fuel - Air Relationship

- 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



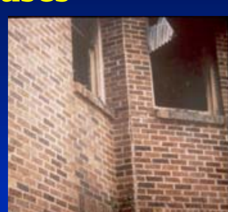
D. Vapor Density and Damage



Relationship of Gas in Compartment?
Why?

Lighter-than-air gases

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



Heavier-than-air gases

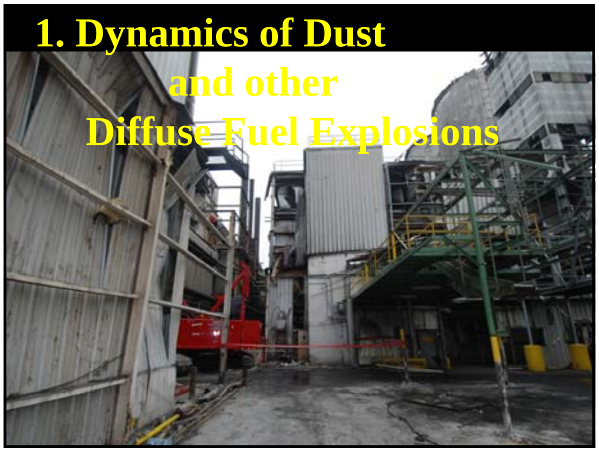
- Collect in lower areas
- Burns at high levels when ignited
- Low pocketing is unusual

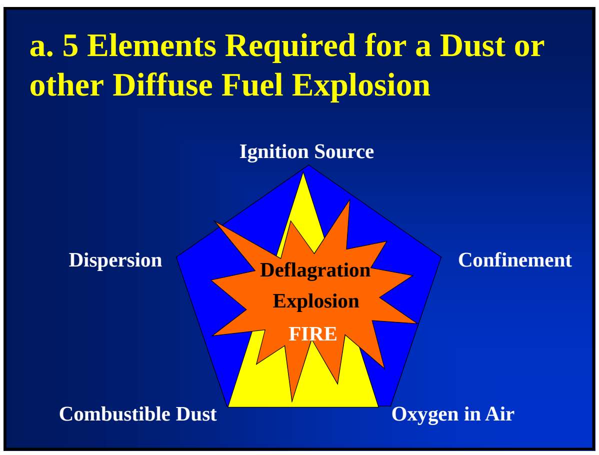
Location of damage is not indicative of vapor density

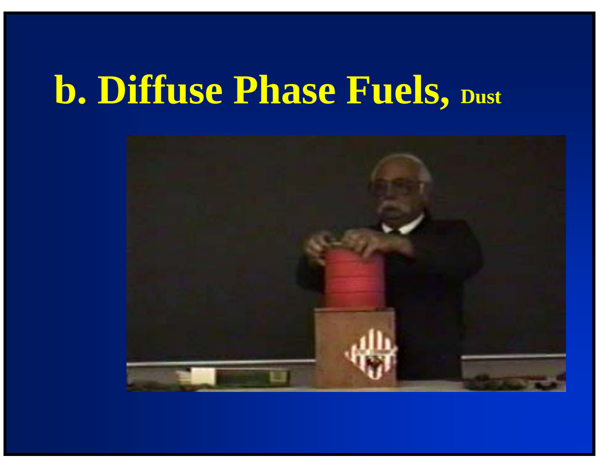
A common misconception

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


E. Dust Explosions, 23.9


1. Dynamics of Dust
and other
Diffuse Fuel Explosions


a. 5 Elements Required for a Dust or other Diffuse Fuel Explosion
Ignition Source
Dispersion
Confinement
Deflagration
Explosion
FIRE
Combustible Dust
Oxygen in Air


b. Diffuse Phase Fuels, Dust

b. Wide variety of materials

Combustible and Non-Combustible

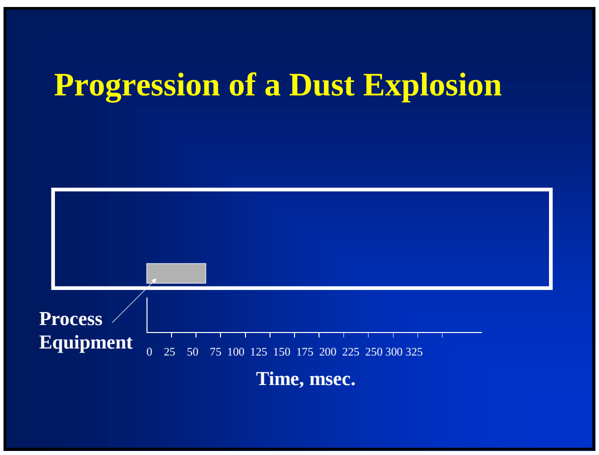
c. Controlling Factors

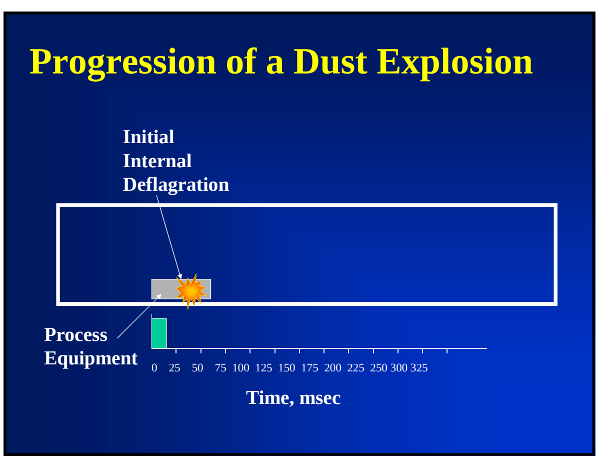
- Suspended or Layered
- Particle Size
- Concentration
- Turbulence
- Moisture

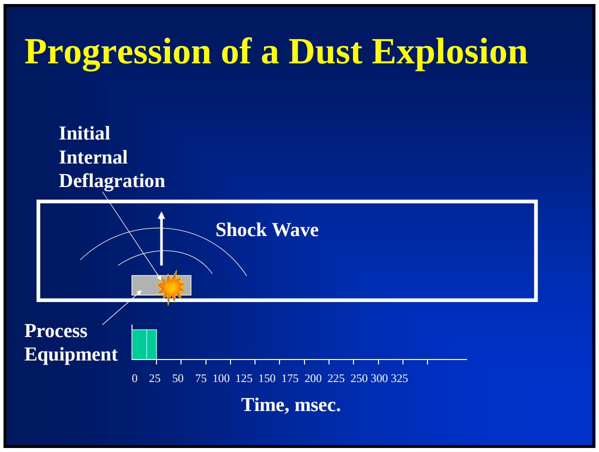
2. Progression of Dust Explosions

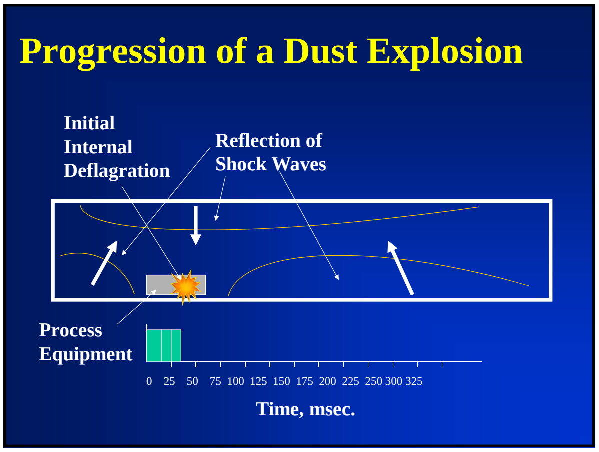
a. Usually occur in series
b. Initial explosions usually less violent than subsequent
c. Subsequent explosions are fueled by additional dust put into suspension

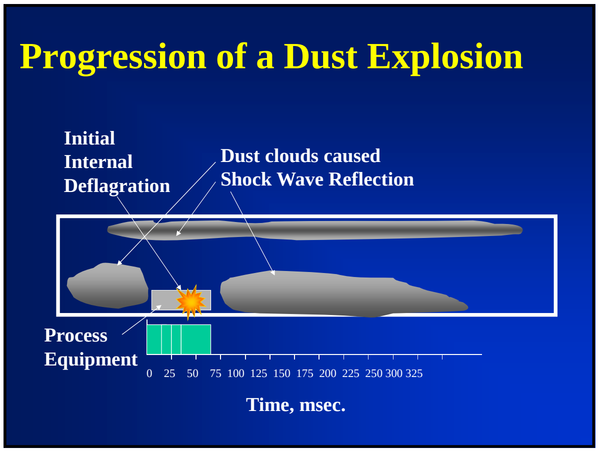

3. Typical Dust Explosion Event

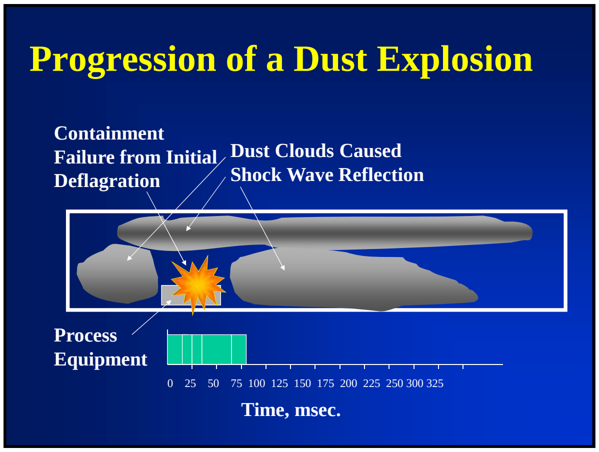

Progression of a Dust Explosion
Process Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.

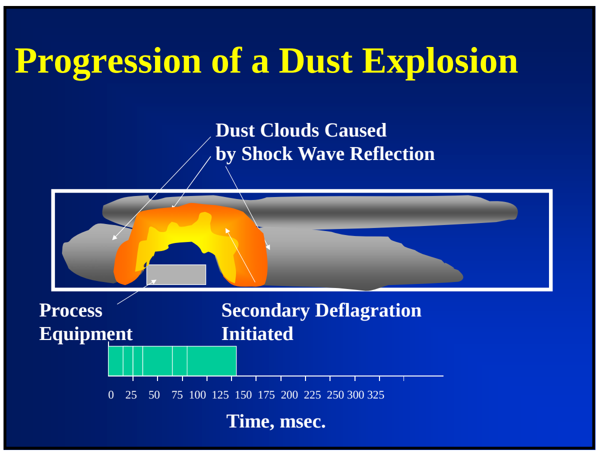

Progression of a Dust Explosion
Initial Internal Deflagration
Process Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec

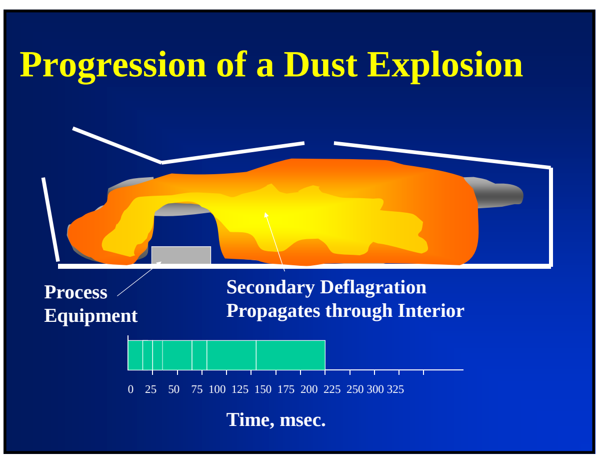

Progression of a Dust Explosion
Initial Internal Deflagration
Shock Wave
Process Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.

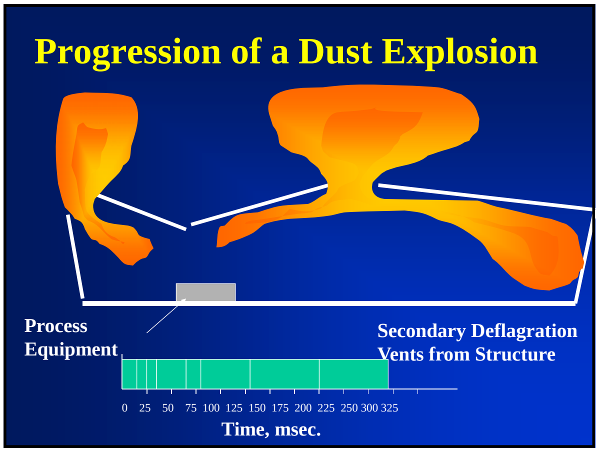

Progression of a Dust Explosion
Initial Internal Deflagration
Reflection of Shock Waves
Process Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.

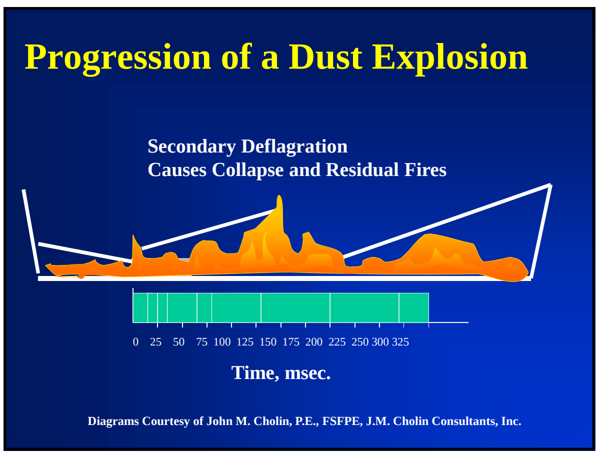

Progression of a Dust Explosion
Initial Internal Deflagration
Dust clouds caused Shock Wave Reflection
Process Equipment
0 25 50 75 100 125 150 175 200 225 250 300 325
Time, msec.


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

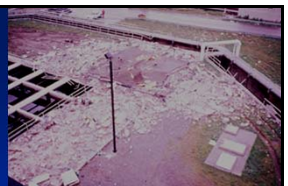
F. Backdraft Explosions, 23.10

1. Ventilation Controlled Fires
   Post Flashover Conditions

V. Investigating the Explosion Scene, 23.14

A study of the Methodology

Systematic Approach is Even More Important



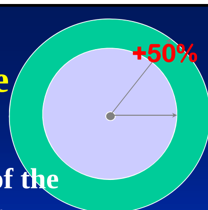
1. Dramatic Event
2. Scenes are usually larger than fires
3. Scenes are usually more disturbed than fires
4. Fatalities and Injuries
5. People want answers, Now!

A. Secure the Scene

- Establish and maintain control of the scene and area
- Prevent unauthorized persons from entering

Minimize Entry

Establishing the Scene



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

B. Diffuse Fuel Explosion Event

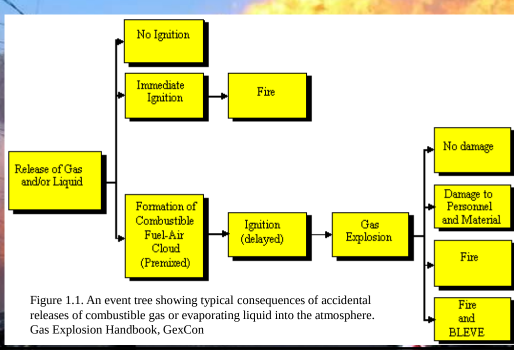


Figure 1.1. An event tree showing typical consequences of accidental releases of combustible gas or evaporating liquid into the atmosphere. Gas Explosion Handbook, GexCon

Objectives of an Explosion Investigation

No different than a fire investigation

1. Determine Origin
2. Identify the fuel
3. Identify the ignition source
4. Determine the Cause
5. Establish responsibility

NFPA 921 (2011) 21.14.1 General.

Scientific Method

NFPA 921 Chapter 4

Basic Methodology

- Recognize the Need
- Define the Problem
- Collect Data
- Analyze the Data
- Develop a Hypothesis
- Test the Hypothesis
- Select Final Hypothesis

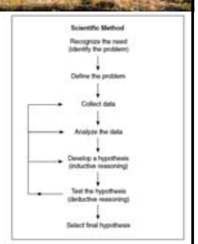


FIGURE 4.3 Use of the Scientific Method.

E. Determine the Origin

Initial Scene Inspection,
NFPA 921 23.14.3

Without a preplanned, systematic approach, explosion investigations become even more difficult or impossible to conduct effectively.

1. Tools to Determine the Explosion Origin

Witness Information. The analysis of observations reported by persons who witnessed the fire or were aware of conditions present at the time of the fire.

Explosion Dynamics. The analysis of the explosion dynamics, (NFPA 921 23.1 – 21.12)

Surveillance Video (Witness Information?)

Natural Gas Explosion
JJ's Restaurant
Kansas City, Missouri
February 19, 2013

Detailed Analysis

Does this tell you
Why or What?

Utilize Fire Investigation Technology Concepts

- Safety
- Sources of Information
- Planning the Investigation
- Documentation of the Investigation
- Physical Evidence
- Origin Determination
- Fire Cause Determination
- Analyzing the Incident for Cause and Responsibility
- Failure Analysis and Analytical Tools

Origin Determination

NFPA 921 Chapter 18
Origin Determination

NFPA 921 23.14
Investigating the Explosion Scene.

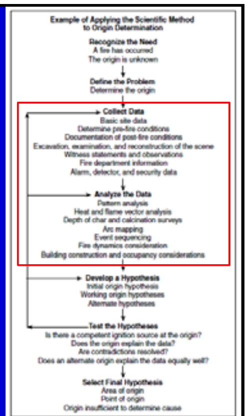


FIGURE 18.2 An Example of Applying the Scientific Method to Origin Determination.

Collect Data

- Basic site data
- Determine pre-explosion conditions
- Documentation of post-explosion conditions
- Excavation, examination, and reconstruction of the scene
- Witness statements and observations
- Fire department information
- Alarm, detector, and security data

Analyze The Data, Origin Determination

Tools to Utilize

- Identify Damage Effects of the Explosion
- Explosion Dynamics Vector Diagrams
- Event Sequencing
- Construction and Occupancy Considerations
- Computer Modeling

2. Explosion Scene Safety

a. Structures are unsound

b. Secondary explosions are possible

c. Bombings, secondary devices, unexploded devices or undetonated explosives are possible

d. Special Scene Hazards

3. Searching the Scene

- Outer perimeter inwards towards the epicenter.

Briefing and Control of Search Teams

- Safety Briefing
- Identifying evidence
- Photographing evidence
- Mapping evidence

4. Initial Assessment

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

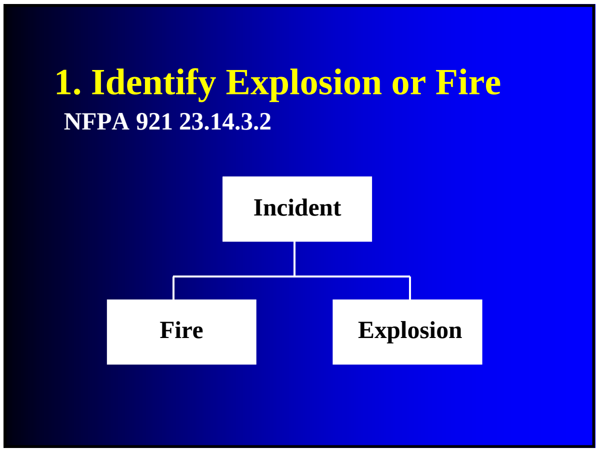
a. Initial Incident Assessment

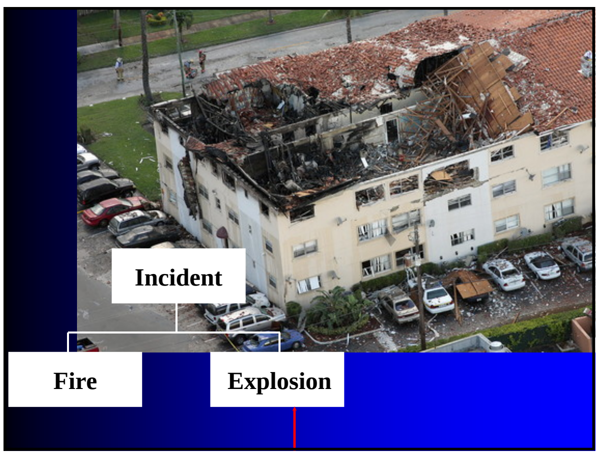
Identify Explosion or Fire?

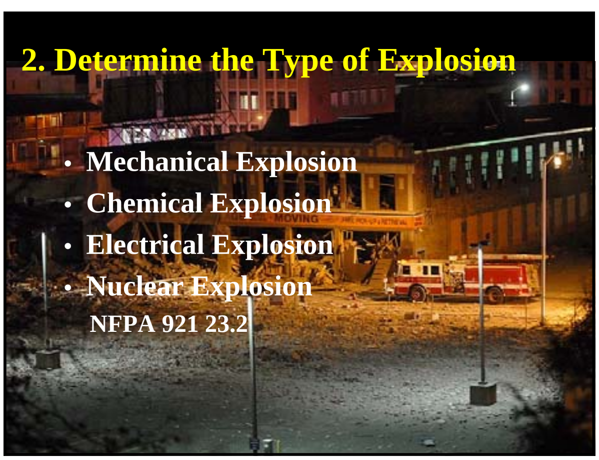
Burning or Heat Treatment

Overpressure

- Incident
  - Fire
  - Explosion


1. Identify Explosion or Fire
NFPA 921 23.14.3.2
Incident
Fire
Explosion


Incident
Fire
Explosion


2. Determine the Type of Explosion
• Mechanical Explosion
• Chemical Explosion
• Electrical Explosion
• Nuclear Explosion
NFPA 921 23.2

Type of Explosion

- Mechanical
- Chemical
- Electrical
- Nuclear

3. Determine if the Explosion is Seated or Non-Seated

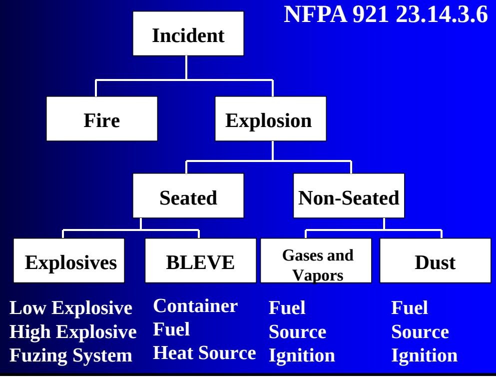
Incident
- Fire
- Explosion
  - Seated
  - Non-Seated

NFPA 921 23.14.3.4

Seated or Non-Seated

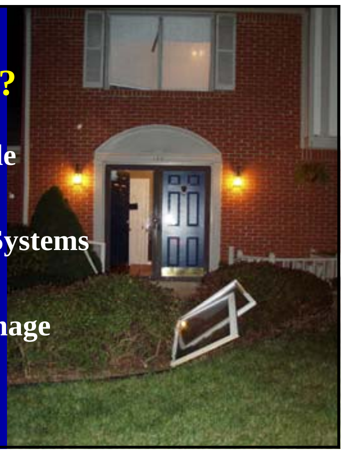
4. Identify Potential General Fuel Type

NFPA 921 23.14.3.6



Type of Fuel?

- Fuels Available
- Condition of Systems
- Compare Damage



Available Fuels

Identify Potential General Fuel Type

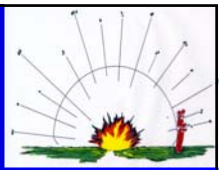
NFPA 921 23.14.3.6

Identify Potential General Fuel Type

NFPA 921 23.14.3.6

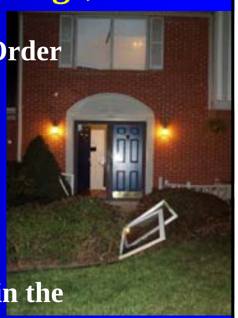
Type of Fuel?

5. Identify Damage Effects of the Explosion



- Blast Overpressure and Wave - Positive Phase
- Blast Pressure and Wave - Negative Phase
- Fragment impact
- Thermal energy
- Ground shock
- Dynamic drag loads

Characterize the Damage, 23.3



Low Order and High Order Damage

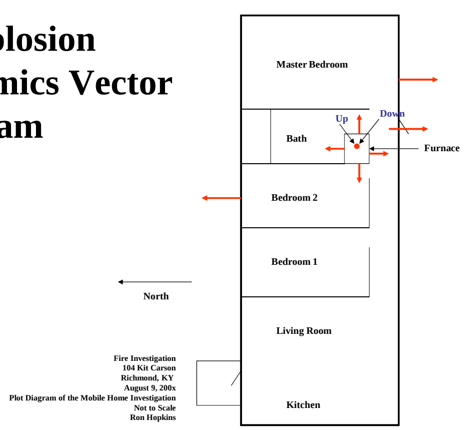
- Shattered
- Bent
- Broken
- Flattened
- Look for Changes in the Nature of Damage

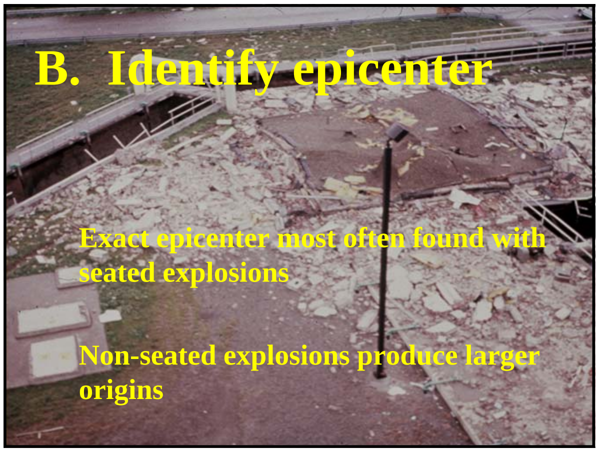
Type of Damage?

6. Construct Explosion Dynamics, 23.14.4.4
Vector Diagram

- Direction of debris movement
- Relative force of debris movement
- Both large scale and small scale diagrams may be necessary

6. Explosion Dynamics Vector Diagram





8. Construction and Occupancy Considerations

- Explosion Venting
- Glass Exterior
- Process Information
- Type of Storage
- Blast Front Modifiers

9. Computer Modeling

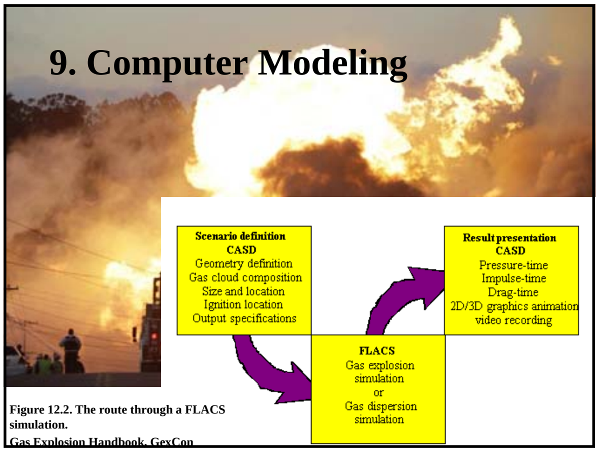


Figure 12.2. The route through a FLACS simulation.
Gas Explosion Handbook, GexCon

Establish the Origin.

NFPA 921 23.14.3.7

Select Final Hypothesis

- Area of Origin
- Point of Origin
- Origin insufficient to determine cause

If you do not determine the correct Explosion Origin, then you cannot determine the Explosion Cause.

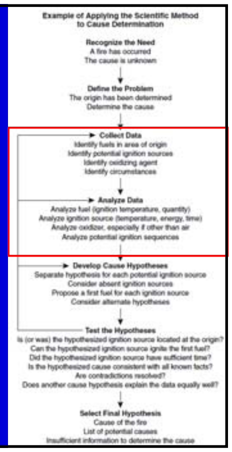
FIGURE 18.2 An Example of Applying the Scientific Method to Origin Determination.

Explosion Dynamics Analysis

F. Determine the Cause

- Detailed Scene Assessment

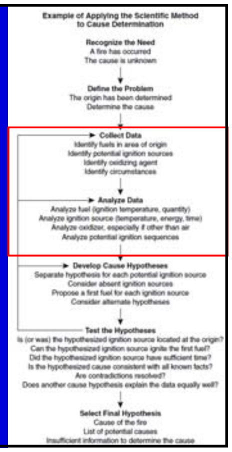
NFPA 921 Figure 19.2 An Example of Applying the Scientific Method to Cause Determination.



Collect Data

- Identify fuels in area of origin
- Identify potential ignition sources
- Identify oxidizing agent
- Identify circumstances

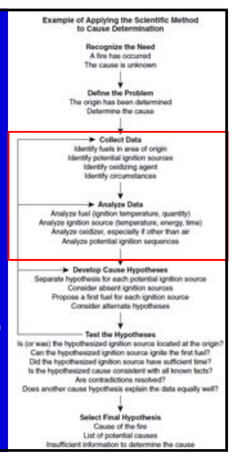
NFPA 921 Figure 19.2



Analyze Data

- Analyze fuel (ignition temperature, quantity)
- Analyze ignition source (temperature, energy, time)
- Analyze oxidizer, especially if other than air
- Analyze potential ignition sequences

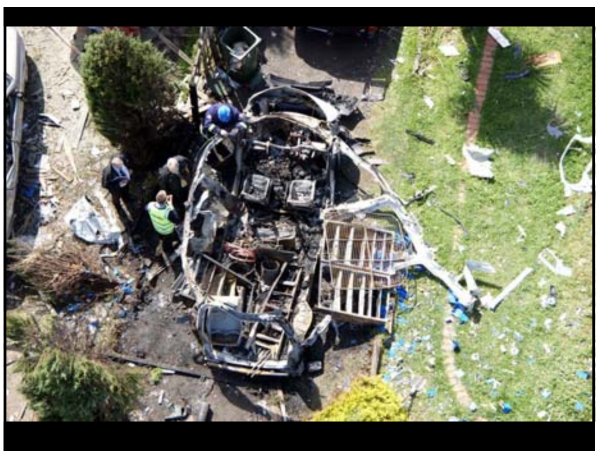
NFPA 921 Figure 19.2



Continue to Utilize Investigation Technology Concepts

- Scientific Method
- Systematic Approach
- Pay Attention to Details

- Scene Safety
- Documentation of the Investigation
- Proper Collection of Physical Evidence
- Failure Analysis and Analytical Tools



b. Identify Pre and Post Blast Damage

- Propelled Debris may be burned or unburned

c. Locate, Identify, and Record Articles of Evidence

- Evidence may have been propelled into a variety of locations

d. Physical Evidence Samples

Residues

- Ignitable Liquids
- Explosives

Fuel Containers, Appliances or Equipment

e. Analyze Fuel Source, NFPA 921 21.16

- Knowledge, Authority, and Equipment to complete non destructive and destructive testing.
- Notification of Interested Parties

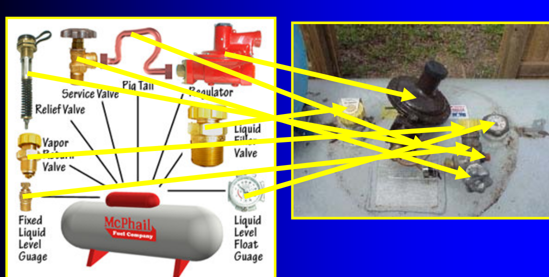
e. Analyze Fuel Source, NFPA 921 23.16

- All gas appliances and piping pressure tested
- Any leaks discovered must be identified as pre- or post-blast

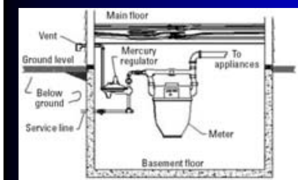
Consider all available information

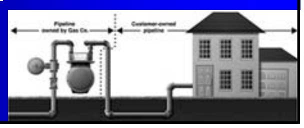
- Minimum Ignition Energy of Fuel
- Ignition Energy of Ignition Source
- Ignition Temperature of Fuel
- Temperature of Ignition Source
- Location of Ignition Source in Relation to Fuel
- Contemporaneous presence of Fuel and Ignition Source
- Witness Accounts

Container Appurtenances, (Tanks)



Residential NG Regulator and Meter





Gas Line Bar Hole Survey

JJ's Restaurant, Kansas City, MO

February 19, 2013

Site Excavation

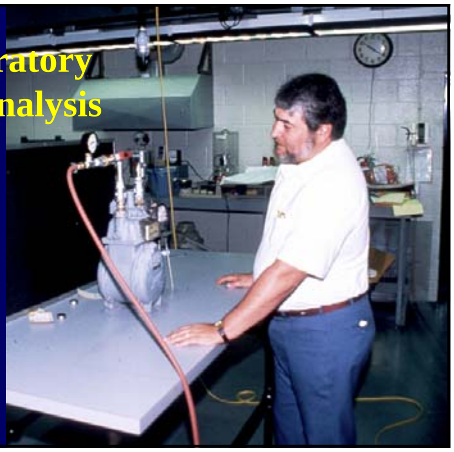
- JJ's Restaurant, Kansas City, MO


LIGHTNING POWDER
1-800-852-0300


Evidence Inspection

Laboratory Analysis

Laboratory Analysis



f. Establish Ignition Source

Diffuse Phase Fuels

(Gases, Vapors, Dusts)

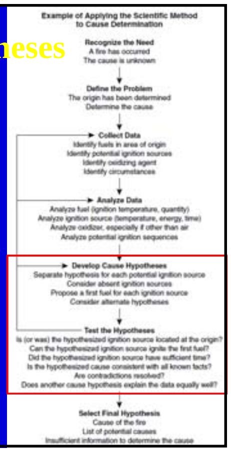
Analyze Ignition Source(s)

- Often most difficult
- Multiple possible ignition sources often present

g. Develop Cause Hypotheses

- Separate hypothesis for each potential ignition source
- Consider absent ignition sources
- Propose a first fuel for each ignition source
- Consider alternate hypotheses

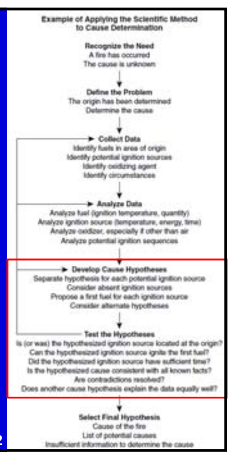
NFPA 921 Figure 19.2



Test the Hypotheses

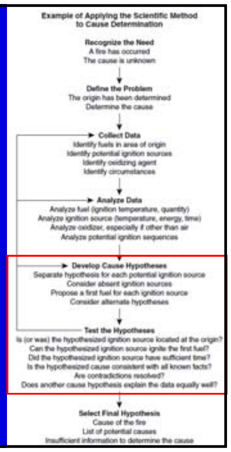
- Is (or was) the hypothesized ignition source located at the origin?
- Can the hypothesized ignition source ignite the first fuel?
- Did the hypothesized ignition source have sufficient time?

NFPA 921 Figure 19.2



Test the Hypotheses

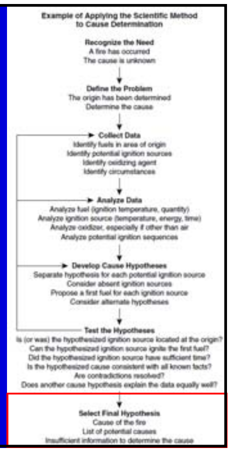
- Is the hypothesized cause consistent with all known facts?
- Are contradictions resolved?
- Does another cause hypothesis explain the data equally well?



NFPA 921 Figure 19.2

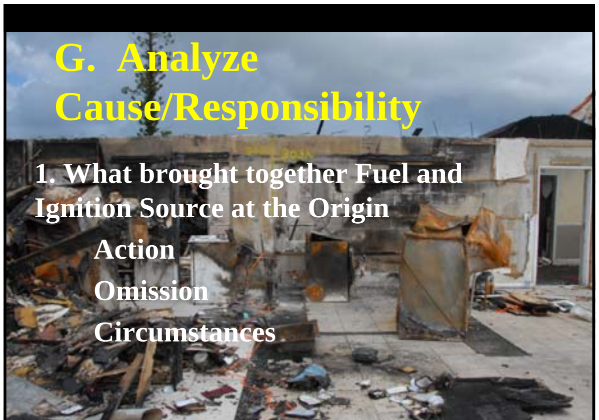
Select Final Hypothesis

- Cause of the Explosion
- List of potential causes
- Insufficient information to determine the cause



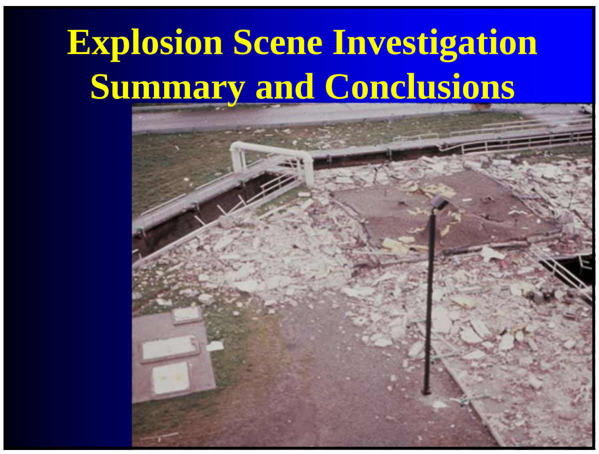
NFPA 921 Figure 19.2

G. Analyze Cause/Responsibility



1. What brought together Fuel and Ignition Source at the Origin
   - Action
   - Omission
   - Circumstances

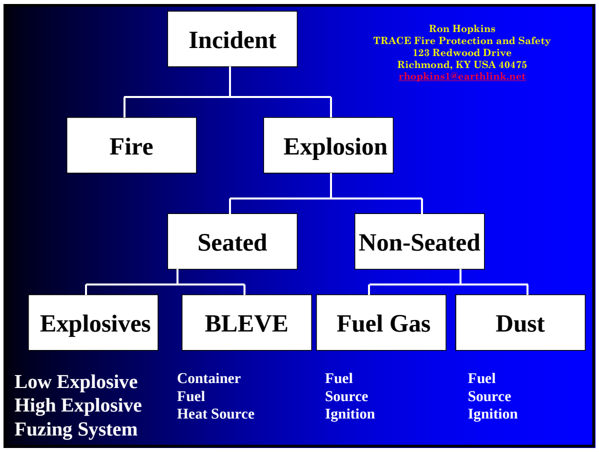

2. What could have prevented the Explosion
• Compliance to Codes
• Compliance to Standards
• Compliance to Good Practice
• Proper Industrial Engineering


Explosion Scene Investigation
Summary and Conclusions


Objectives of the 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

Utilize Investigation Technology Concepts

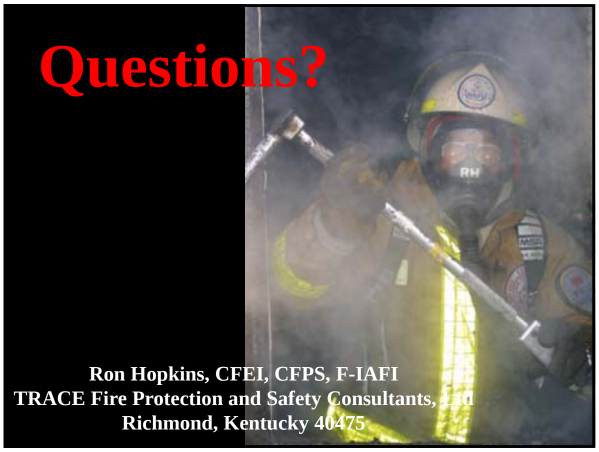
- Safety
- Sources of Information
- Planning the Investigation
- Documentation of the Investigation
- Physical Evidence
- Origin Determination
- Fire Cause Determination
- Analyzing the Incident for Cause and Responsibility
- Failure Analysis and Analytical Tools



Pay Attention to Details

and the

Big Pieces will Fall into Place



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