FIRES, EXPLOSIONS, AND COMBUSTIBLE DUST HAZARDS

Morgan Worsfold & Paul Amyotte

Dalhousie University, Halifax, NS, Canada

Manny Marta

NOVA Chemicals, Sarnia, ON, Canada

DALHOUSIE UNIVERSITY *Inspiring Minds*

MINERVA Safety Management Education

NOVA Chemicals®

Module Basics

- Scope
  - Fires, explosions, and combustible dust hazards
- Motivation
  - While these incidents and hazards are prevalent in the process industries, practitioner knowledge gaps exist
- Objective
  - Achievement of specific learning objectives by the target audience of undergraduate engineering students

Learning Objectives

- Remembering
  - Define combustible dust
  - Identify the three elements of the fire triangle and the five elements of the explosion pentagon
- Understanding
  - Explain how gaseous, liquid and solid fuels burn
  - Describe the fundamentals of a dust explosion according to the explosion pentagon
- Applying
  - Calculate the airborne concentration resulting from the dispersion of a dust, given its bulk density, layer thickness and enclosure height

Learning Objectives (Continued)

- Analyzing
  - Identify combustible dust hazards in a given example
- Evaluating
  - Determine appropriate prevention and mitigation strategies for a specific case study and explain reasoning
- Creating
  - Formulate a dust explosion prevention plan for a given scenario, taking into account each element of the explosion pentagon

Module Outline

- Basic Fire Principles
- Basic Explosion Principles
- Dust Explosion Fundamentals
- Fuel
- Ignition Source
- Oxidant
- Mixing
- Confinement
- Dust Layer Fires
- Prevention and Mitigation
- Case Studies
- Resources
- Evaluation

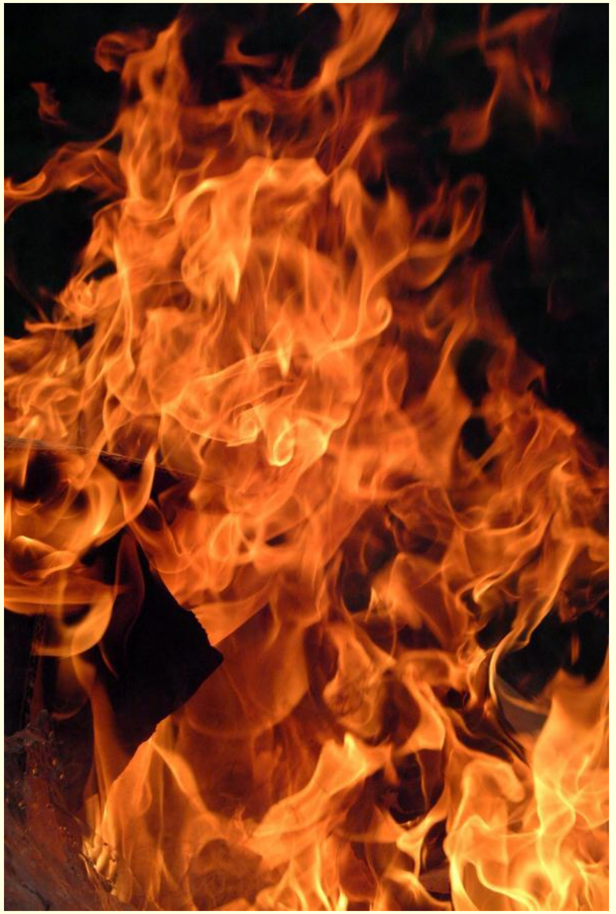
Basic Fire Principles

Fire triangle elements

- Fire definitions
  - Chemical reaction (combustion) in which a substance combines with an oxidant and releases energy, part of which is used to sustain the reaction
  - Process of combustion characterized by heat, smoke, flame or any combination thereof
- Fuel – gas, liquid, solid
- Oxidant – gas, liquid, solid
- Ignition source – many types widely found in industry

Flammability parameters

- Flash point: FP
- Vapour pressure: p^{sat}
- Lower flammability limit: LFL
- Upper flammability limit: UFL
- Flammability range: LFL → UFL
- Minimum ignition energy: MIE
- Autoignition temperature: AIT



Fire consequences

- Flame
- Heat
- Smoke

One Side of the Chevron Richmond Refinery Fire

The Other Side

Fire types

- Pool fire
- Jet fire
- Fireball
- Flash fire
- Dust layer fire

Pool Fire

Jet Fire

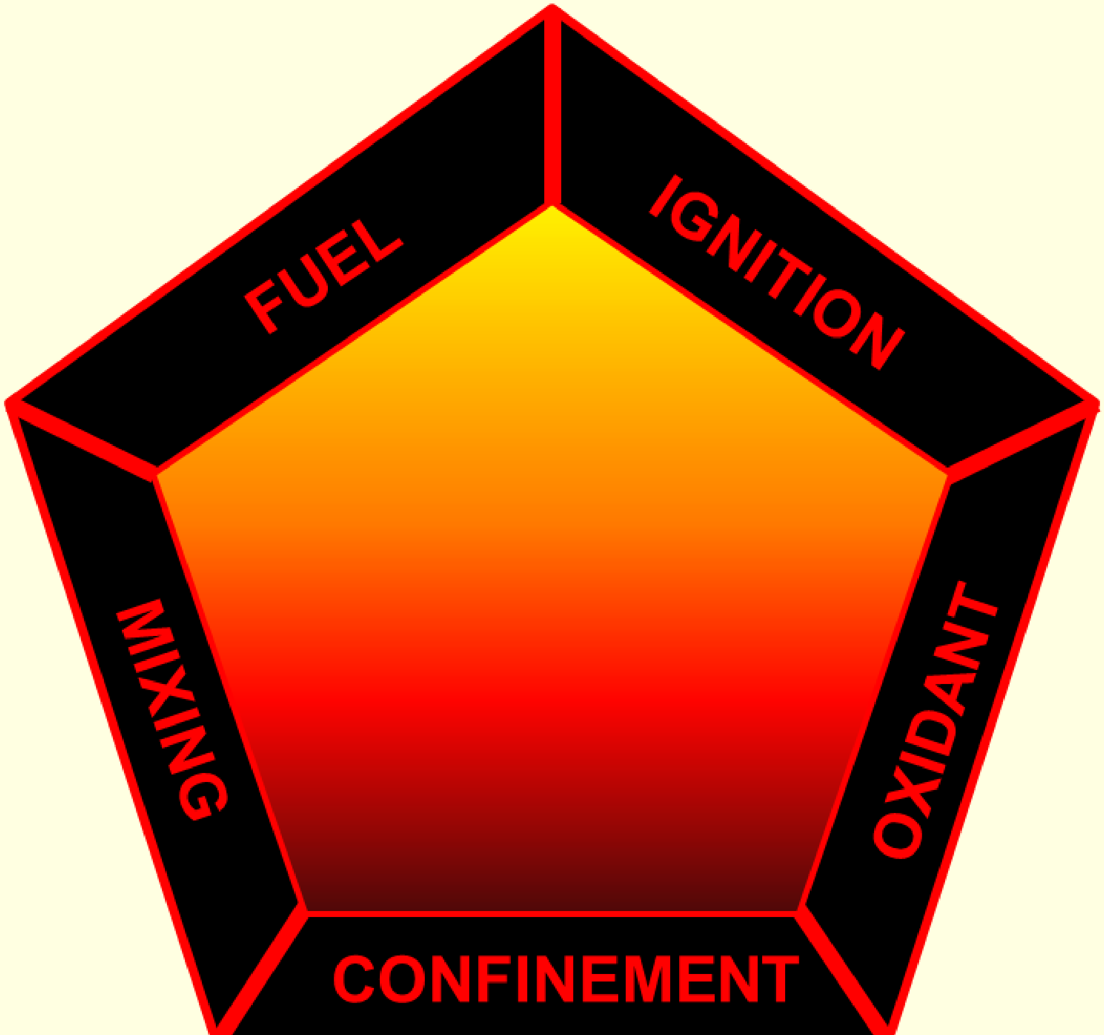
Fire examples

Piper Alpha

Buncefield

Deepwater Horizon

Basic Explosion Principles

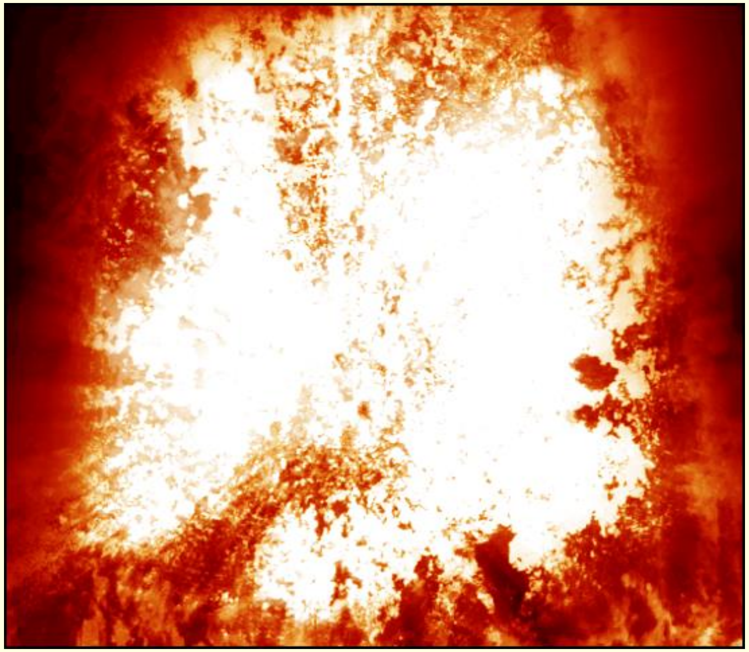


Explosion pentagon elements

- Explosion definition
  - Rapid expansion of gases resulting in rapidly moving pressure or shock wave
  - Expansion can be mechanical (e.g., rupture of pressurized cylinder) or result of rapid chemical reaction
  - Explosion damage caused by pressure or shock wave that does work on its surroundings
- Fuel – as per fire triangle
- Oxidant – as per fire triangle
- Ignition source – as per fire triangle
- Mixing – of fuel and oxidant
- Confinement – for overpressure development

Explosibility parameters

- Maximum explosion pressure: P_{max}
- Maximum rate of pressure rise: $(dP/dt)_{max}$
- Volume normalized maximum rate of pressure rise: K_G for gases and K_{St} for dusts



Explosion consequences

- Overpressure
- Missile fragments

Heat Exchanger Rupture

Support Column Sheared Off Baseplate

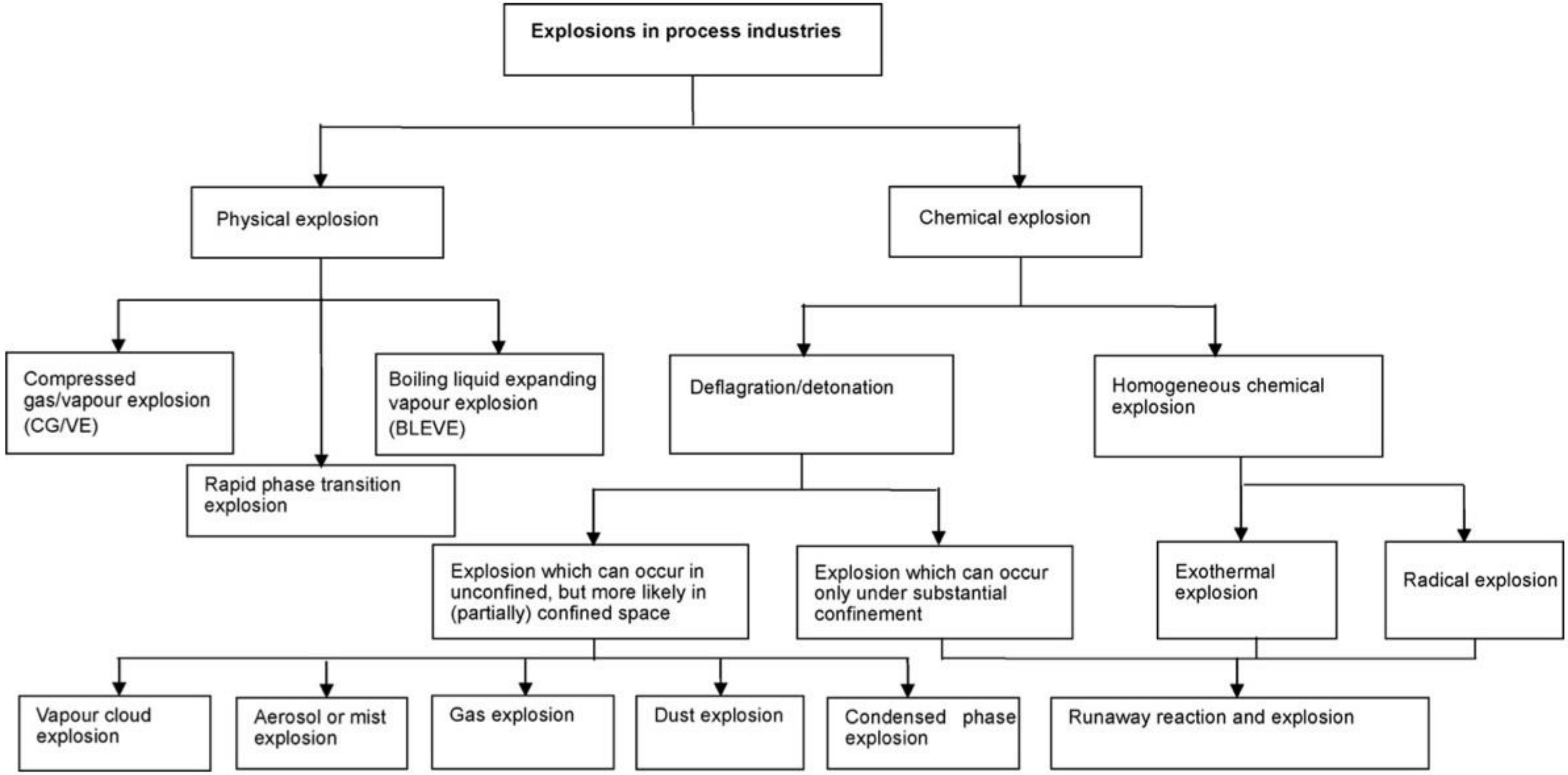
Explosion types

- General categories
  - Physical
  - Chemical

BLEVE

- Speed of reaction front
  - Deflagration
  - Detonation

Explosion types



Explosion examples

Flixborough

Toulouse AZF

BP Texas City

Fires ↔ explosions

The major distinction between fires and explosions is the rate of energy release. Fires release energy slowly, whereas explosions release energy rapidly.

Fires can also result from explosions, and explosions can result from fires.

A good example of how the energy release rate affects the consequences of an accident is a standard automobile tire. The compressed air within the tire contains energy. If the energy is released slowly through the nozzle, the tire is harmlessly deflated. If the tire ruptures suddenly and all the energy within the compressed tire releases rapidly, the result is a dangerous explosion.

Domino effects

Primary Scenario	Escalation Vector	Expected Secondary Scenario[a]
Pool fire	Heat radiation, fire impingement	Jet fire, pool fire, BLEVE, toxic release
Jet fire	Heat radiation, fire impingement	Jet fire, pool fire, BLEVE, toxic release
Fireball	Heat radiation, fire impingement	Tank fire
Flash fire	Fire impingement	Tank fire
Mechanical explosion[b]	Fragments, overpressure	All[c]
Confined explosion[b]	Overpressure	All[c]
BLEVE (boiling liquid expanding vapour explosion)[b]	Fragments, overpressure	All[c]
VCE (vapour cloud explosion)	Overpressure, fire impingement	All[c]
Toxic release	–	–

[a]Expected scenarios also depend on the hazards of the target vessel inventory.
[b]Following primary vessel failure, further scenarios may occur (e.g., pool fire, fireball, toxic release).
[c]Any of the scenarios listed in the first column (primary scenario) may be triggered by the escalation vector.

Dust Explosion Fundamentals

Play Video

Dust can explode!

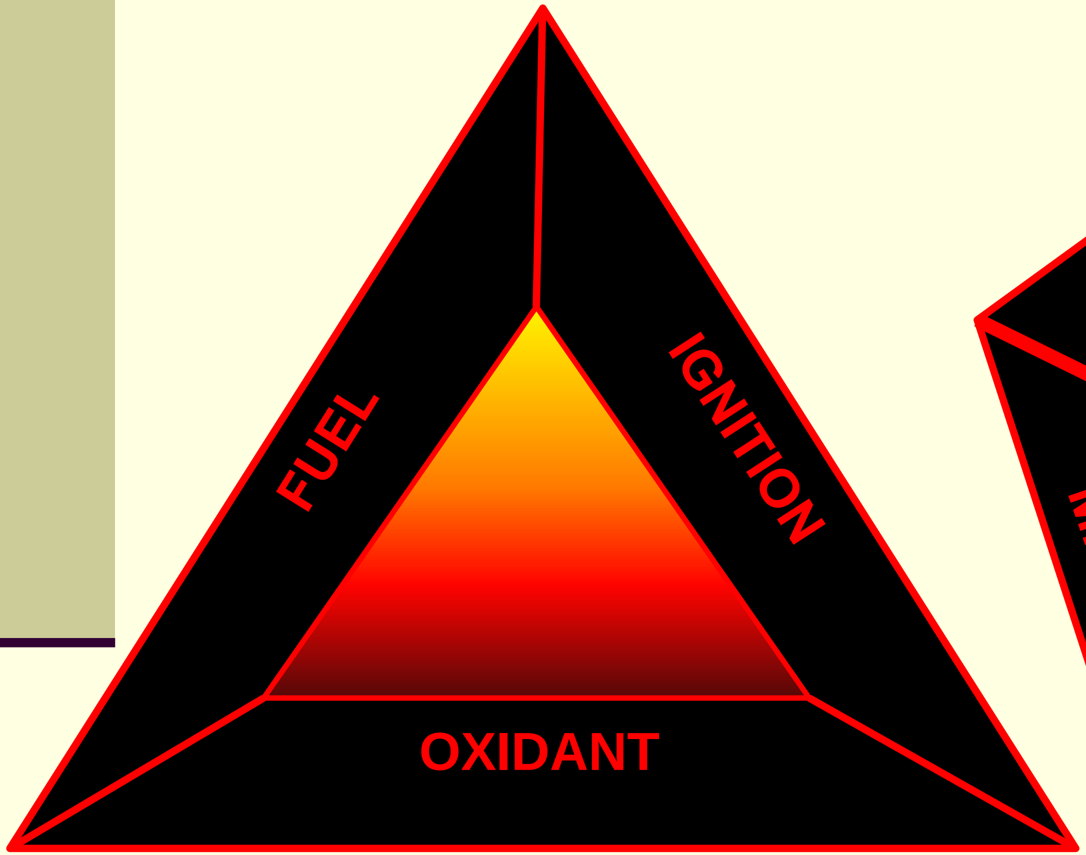
Methane-triggered coal dust explosion - Westray Coal Mine (26 fatalities)

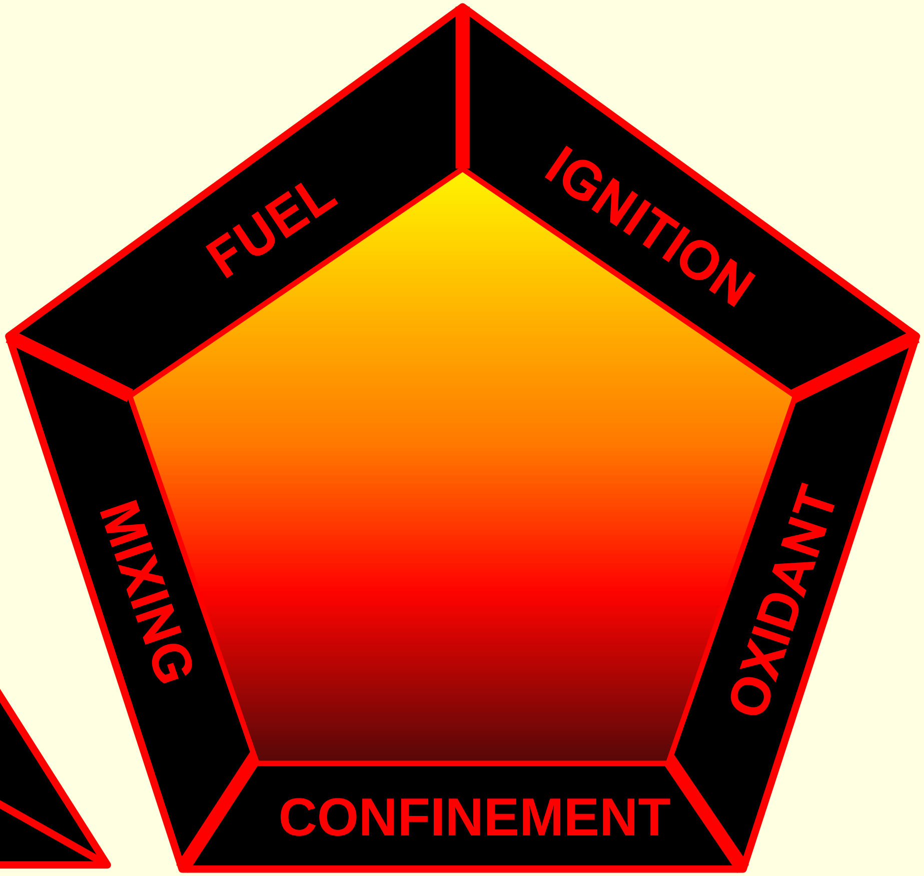
Aluminum dust explosion - Hayes Lemmerz International - Huntington (1 fatality)

Polyethylene dust explosion - West Pharmaceuticals (6 fatalities)

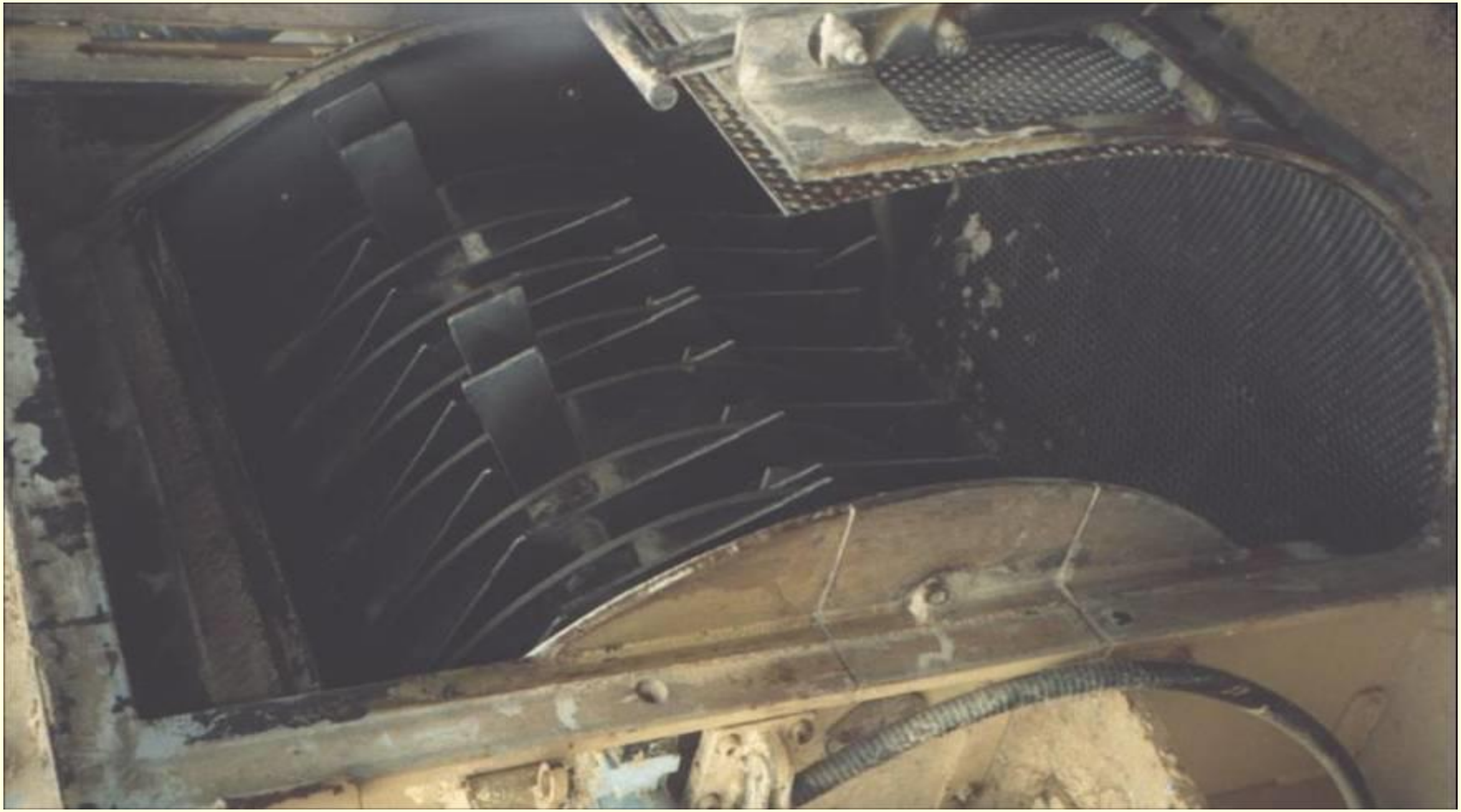
Sugar dust explosion - Imperial Sugar Company (14 fatalities)

Fire triangle and explosion pentagon





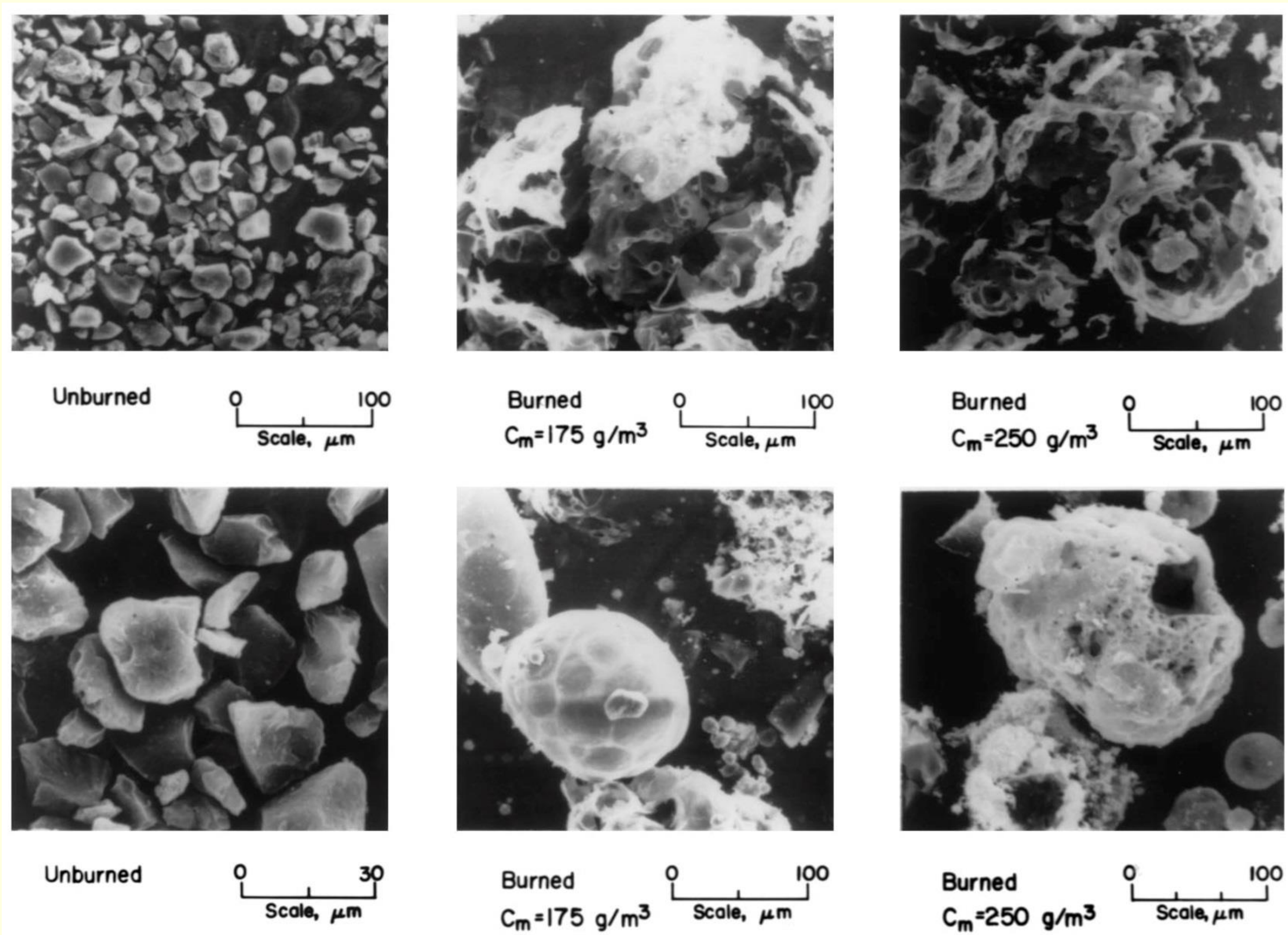
Hammermill – pentagon in practice



How dusts explode

- Chemical explosion
  - Propagating combustion reaction
- Reaction mechanism
  - Dust/air mixture heterogeneous; reaction may be heterogeneous (few) or homogenous (most)
  - Most dusts explode as gas explosions
    - Volatiles from solid material
- Explosion: **FUEL** (dust) and **OXIDANT** are **MIXED**, ignited by **IGNITION SOURCE**, and sufficient **CONFINEMENT** results in overpressure development

How coal dust explodes



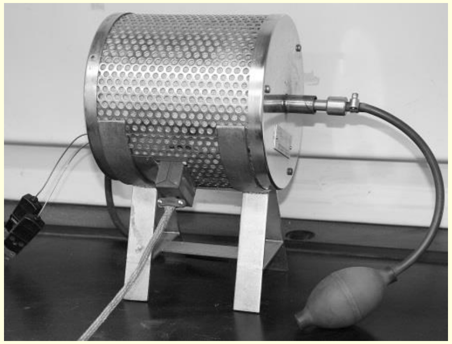
Dust explosion parameters

- Laboratory-scale testing can determine dust explosion parameters for hazard/risk determination
- Likelihood of occurrence
  - MEC: Minimum Explosible Concentration
  - MIE: Minimum Ignition Energy
  - MIT: Minimum Ignition Temperature
  - LOC: Limiting Oxygen Concentration
- Severity of consequences
  - P_{max}: Maximum explosion pressure
  - $(dP/dt)_{max}$: Maximum rate of pressure rise
  - $K_{St} = (dP/dt)_{max} \cdot V^{1/3}$

Testing standards and equipment

- ASTM E1226-12a: Standard Test Method for Explosibility of Dust Clouds
- ASTM E1515-07: Standard Test Method for Minimum Explosible Concentration of Combustible Dusts
- ASTM E2019-03 (2013): Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air
- ASTM E1491-06 (2012): Standard Test Method for Minimum Autoignition Temperature of Dust Clouds

20-L Apparatus



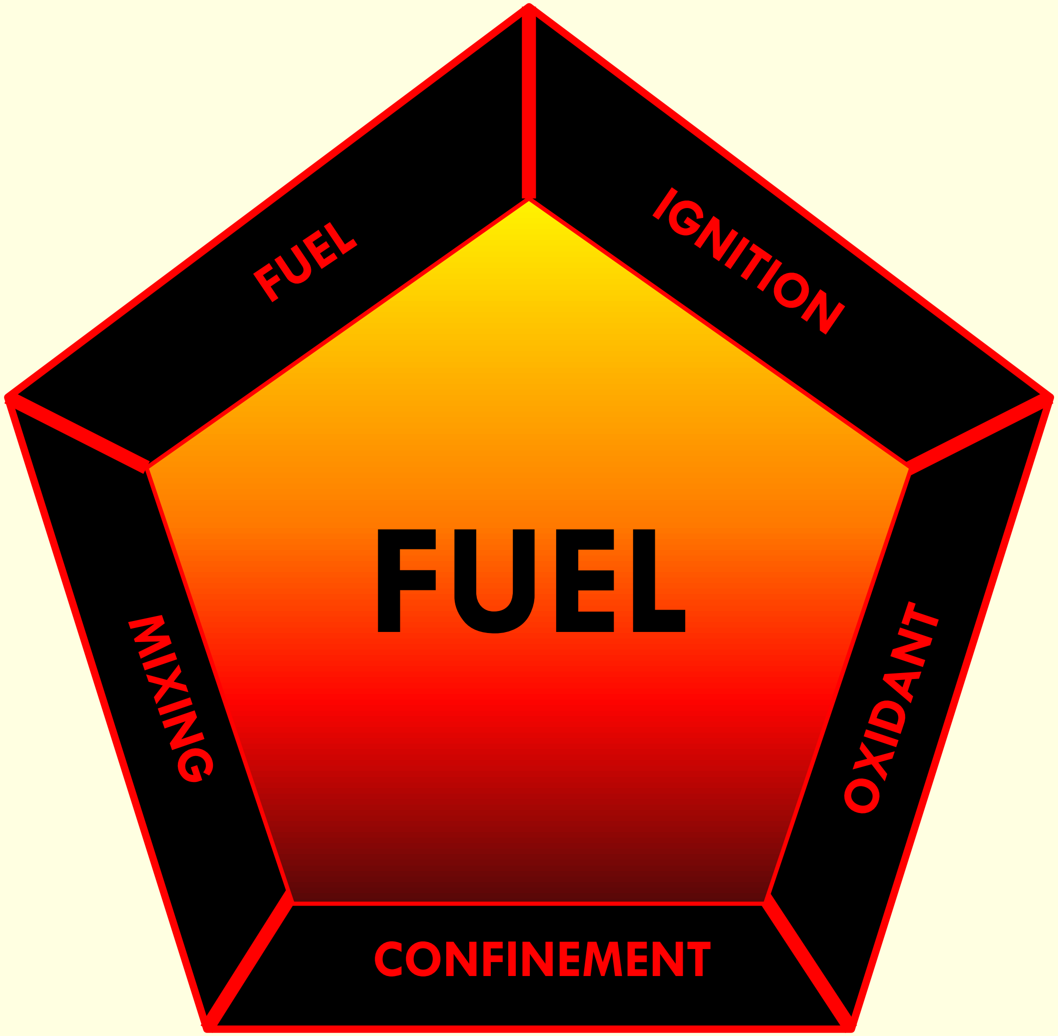
BAM Oven

MIKE3 Apparatus

Risk control standards

- NFPA 61 – Agriculture and Food Industries
- NFPA 68 – Deflagration Venting
- NFPA 69 – Prevention Systems
- NFPA 120 – Coal Mines
- NFPA 484 – Combustible Metals
- NFPA 499 – Electrical Installations
- NFPA 654 – Manufacturing, Processing and Handling Dusts
- NFPA 664 – Wood Processing

Element 1 of 5 – Fuel

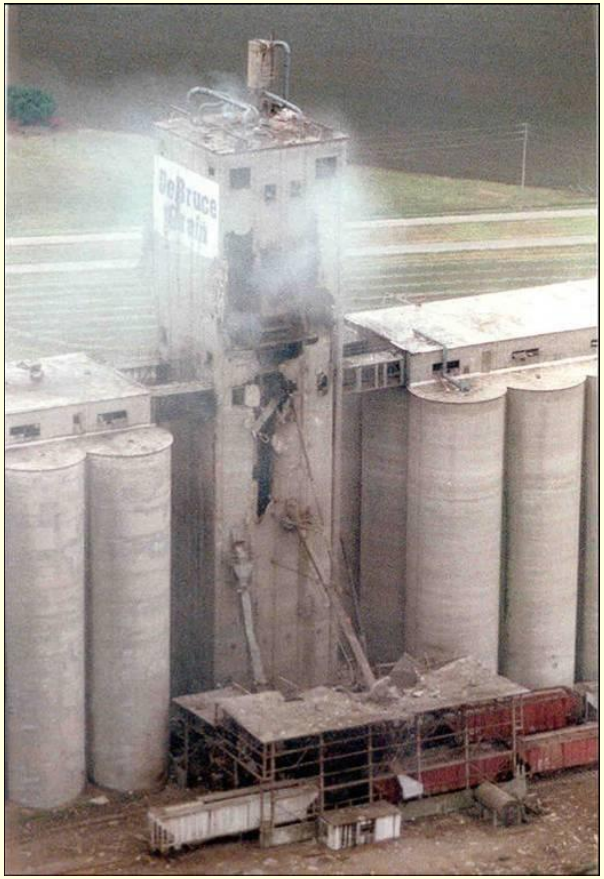


Dust and combustible dust

- NFPA definition of dust
  - Any finely divided solid, 500 µm or less in diameter
- NFPA definition of combustible dust
  - A combustible particulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape.

Examples of combustible dusts

- Coal and coal products
- Food products
- Metals and alloys
- Rubber and plastics
- Wood products
- Textiles
- Pharmaceuticals
- Pesticides



DeBruce Grain Elevator Explosion

Examples of process units

- Silos
- Hoppers
- Dust collectors
- Grinders
- Dryers
- Furnaces
- Mixers
- Pulverizing units
- Conveying systems

Bucket Elevator

How much layered dust is too much?

Sugar dust accumulation on steel belt drive motor

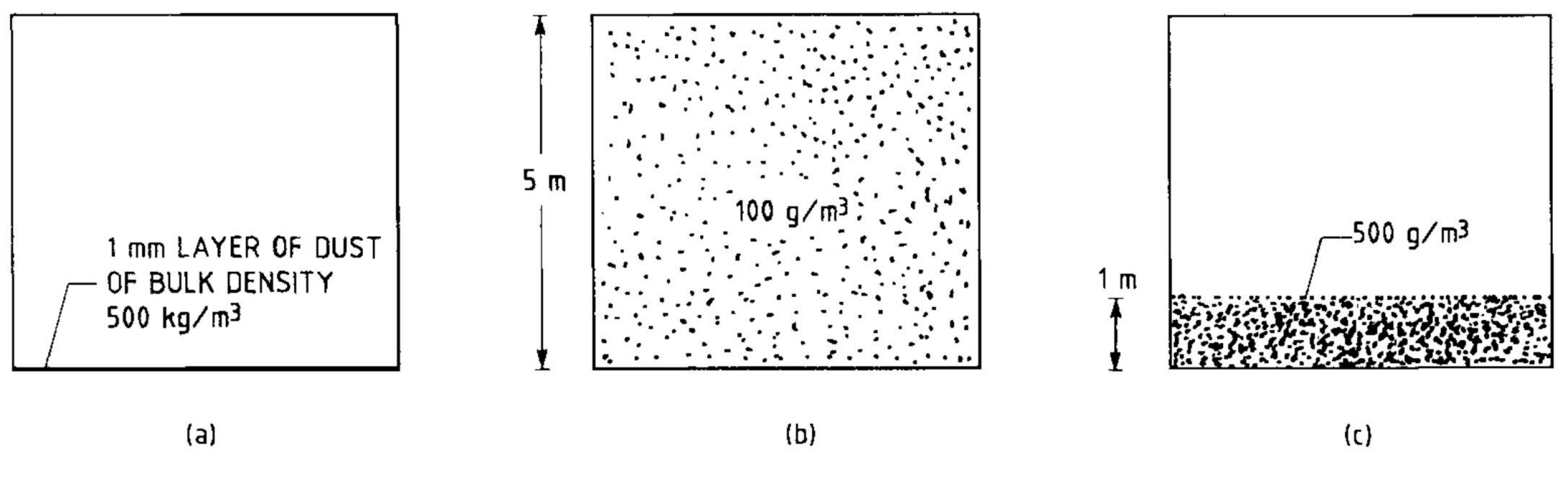
Cornstarch accumulation under cornstarch silo

Calculation of dust concentration

$$C = \rho_{bulk} \, (h/H)$$

- C = dust concentration
- ρ_{bulk} = bulk density of dust layer
- h = thickness of dust layer
- H = height of dust cloud produced from dust layer

Example: $C = \rho_{bulk} (h/H)$



h = 1 mm	H = 5 m	H = 1 m
ρ_{bulk} = 500 kg/m^3	C = 100 g/m^3	C = 500 g/m^3

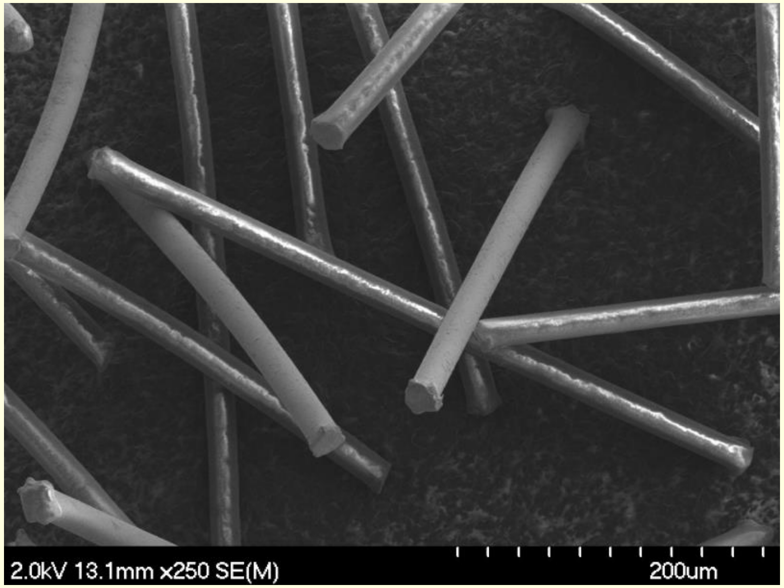
Particle size

- In general, as particle size of a given dust decreases, there is an increase in both explosion severity and likelihood
  - P_{max} increases
  - K_{St} increases (potentially significantly)
  - MEC, MIE and MIT all decrease
  - Smaller particle → larger surface area → higher reactivity
- For nanomaterials, testing to date indicates an increase in explosion likelihood but no significant increase in severity
  - Limited severity effect likely caused by particle agglomeration during dispersion

Particle shape

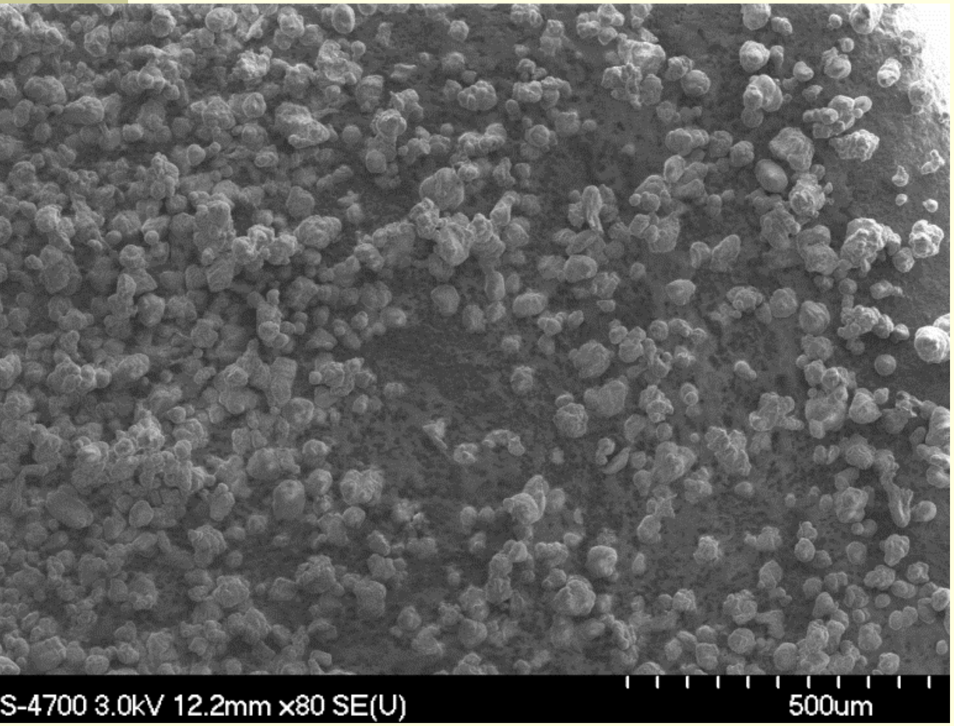
- Non-spherical particles can be combustible
  - Flake-like particles
  - Flocculent particles (fibers with L/D ratio)

Wood Fibers

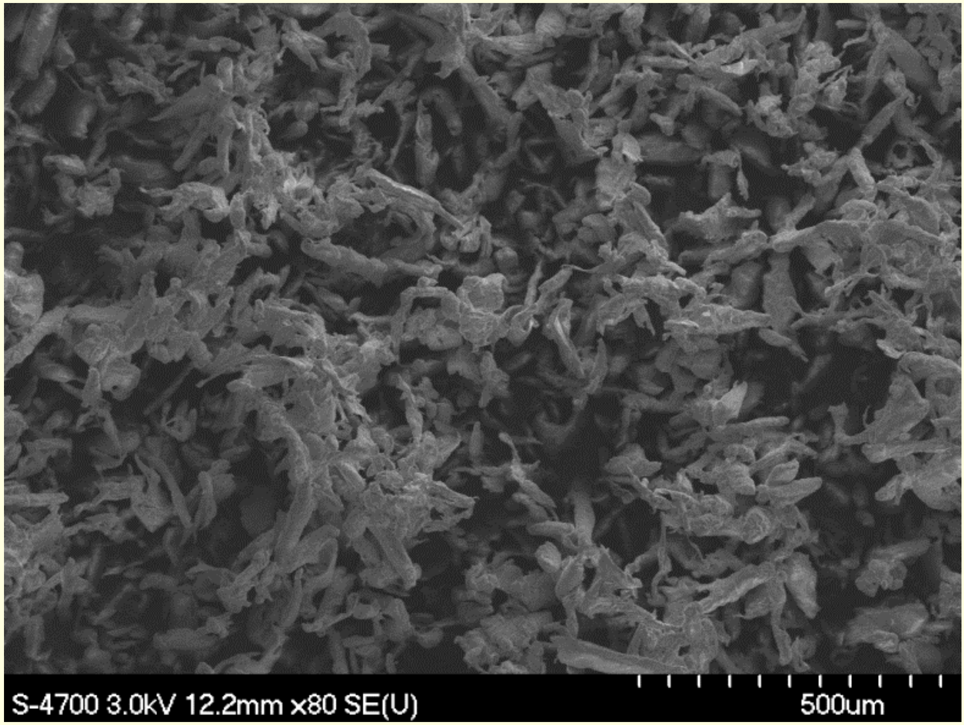


Nylon Flock

Both of these dusts are combustible



Spherical Polyethylene

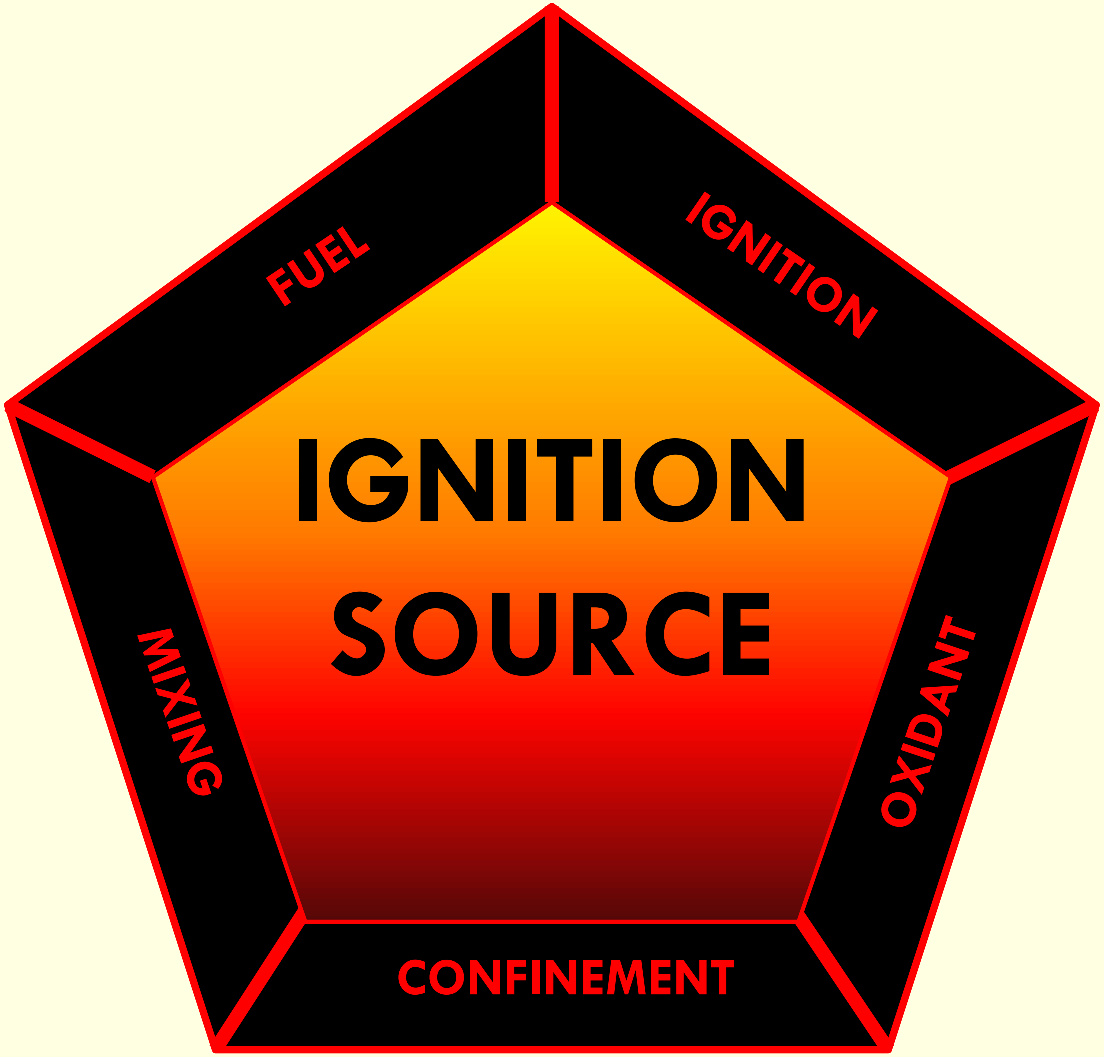


Fibrous Polyethylene

Hybrid mixtures

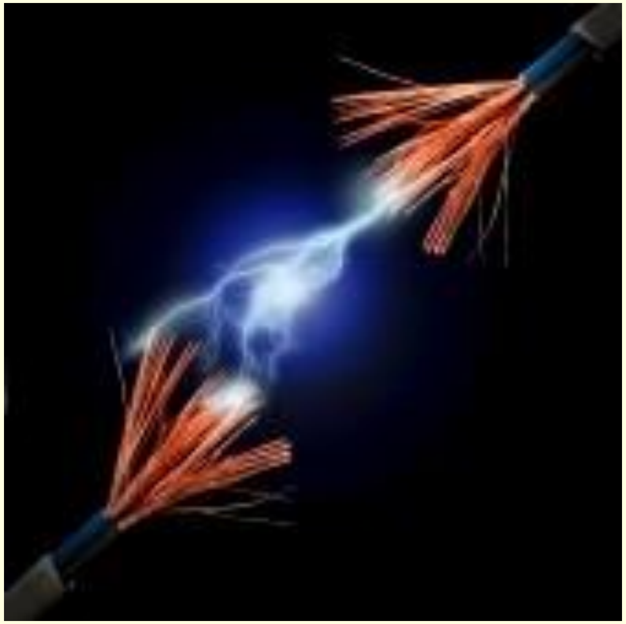
- Flammable gas and combustible dust
  - May each be present in concentrations less than their individual LFL (gas) and MEC (dust), and still be explosible
- Result in increased explosion severity and likelihood
- Examples
  - Methane gas and coal dust
  - Natural gas and fly ash
  - Hydrocarbon gases and resins

Element 2 of 5 – Ignition Source



Examples of ignition sources

- Flames and direct heat
- Hot work
- Incandescent materials
- Hot surfaces
- Electrostatic sparks
- Electrical sparks
- Friction sparks
- Impact sparks
- Self-heating
- Static electricity
- Lightning
- Shock waves



MIE and MIT testing

- MIE and MIT testing can be conducted to better identify potential ignition source hazards
- MIE and MIT test results are applicable to efforts aimed at dust explosion prevention
  - Removal of ignition sources
  - Grounding and bonding
  - Control of process/surface temperatures

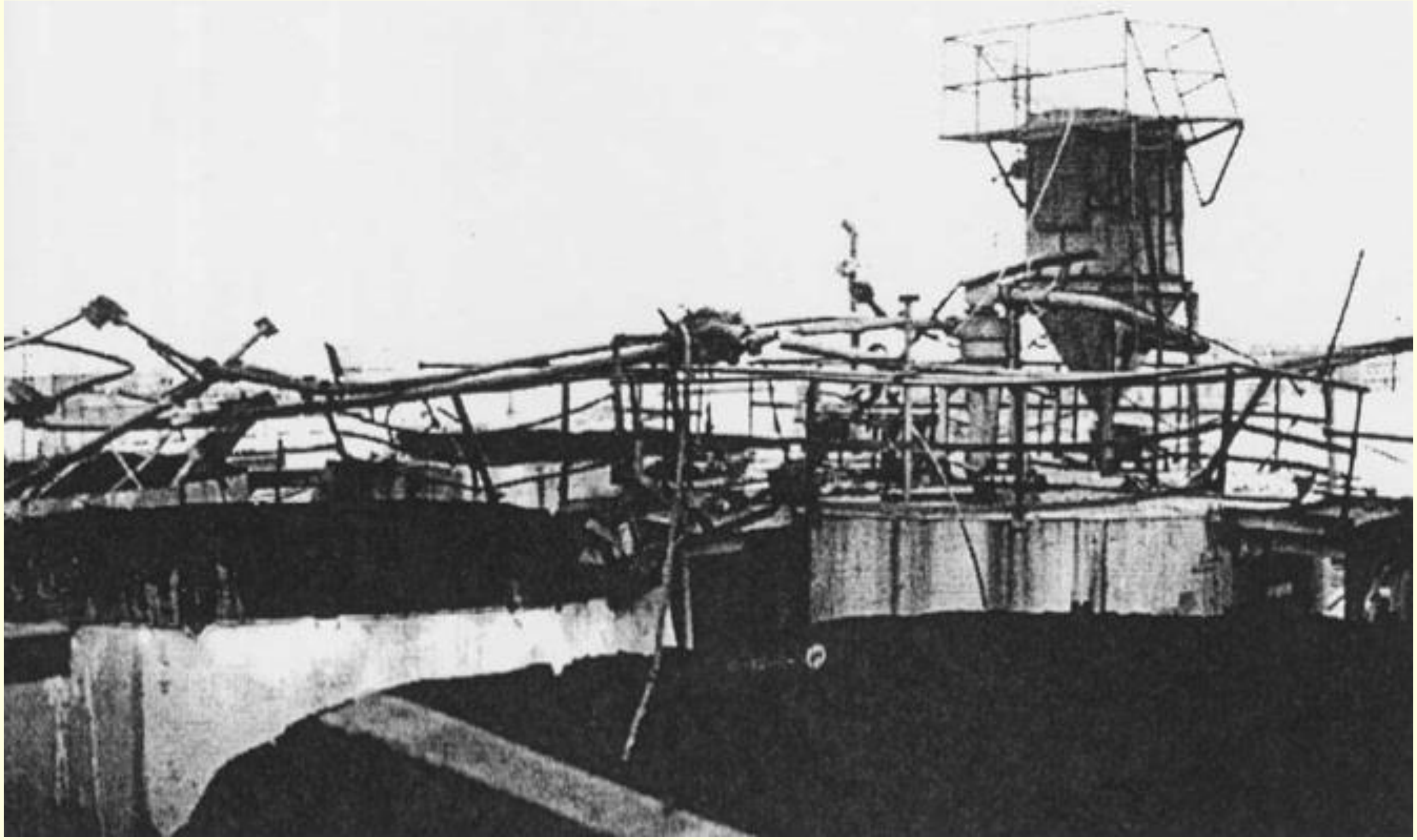
MIE values of some dusts

Material	MIE with inductance [mJ]	MIE without inductance [mJ]
Epoxy coating powder	1.7	2.5
Polyester coating powder	2.9	15
Polyamide coating powder	4	19
Magnesium granulate	25	200
Flock	69-98	1300-1600

Ignition of titanium dust

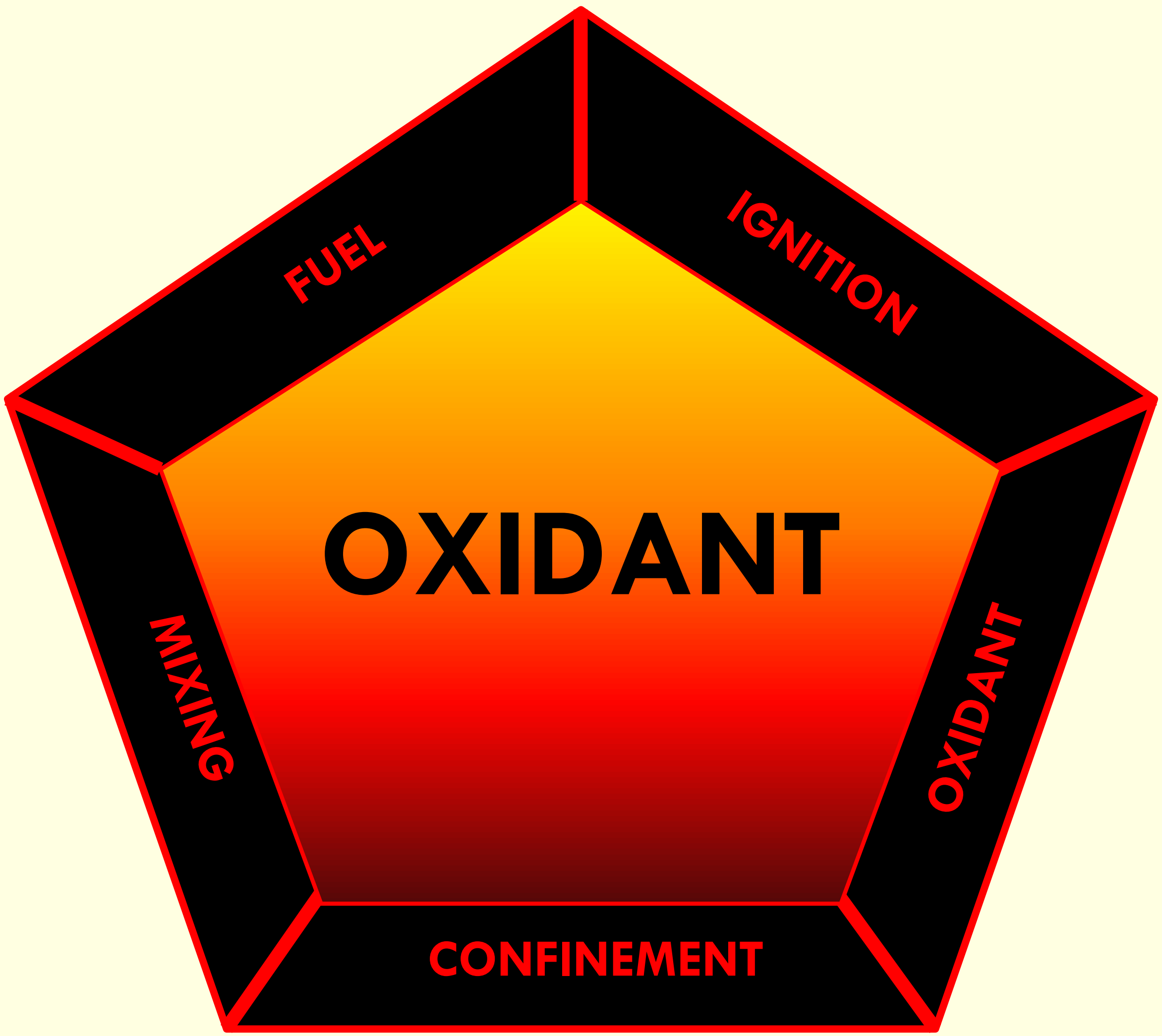
	MIE [mJ]		
Size	**With inductance**	**Without inductance**	**MIT [°C]**
<150 µm	10-30	1-3	>590
<45 µm	1-3	1-3	460
≤20 µm	<1	<1	460
150 nm	Not determined	<1	250
60-80 nm	Not determined	<1	240
40-60 nm	Not determined	<1	250

Destruction at 10 mJ



ABS (Acrylonitrile-Butadiene-Styrene) Plant

Element 3 of 5 – Oxidant



Limiting oxygen concentration

- Oxygen is the most common oxidant
- Does not have to be completely removed to prevent a dust explosion
- Limiting oxygen concentration (LOC)
  - Highest oxygen concentration in a dust/air/inert gas mixture at which an explosion fails to occur
  - Value for a given dust depends on inert gas used
  - Industry application – inerting

Use of inert gas

- Inert gas examples – carbon dioxide, nitrogen argon, helium, steam, flue gas
- Inerting can introduce new hazards
  - Asphyxiation from reduced oxygen levels in air
  - Reaction of inert gas with dust
  - Electrostatic discharge when CO_2 is drawn from high-pressure or cryogenic tanks
  - Leakage of inert gas in systems under pressure
  - Introduction of ignition sources from inerting equipment such as vacuum pumps

LOC values of some dusts

Material	**LOC with nitrogen [volume %]**
Pea flour	15.5
Calcium stearate	12.0
Wheat flour	11.0
High-density polyethylene	10.0
Sulfur	7.0
Aluminum	5.0

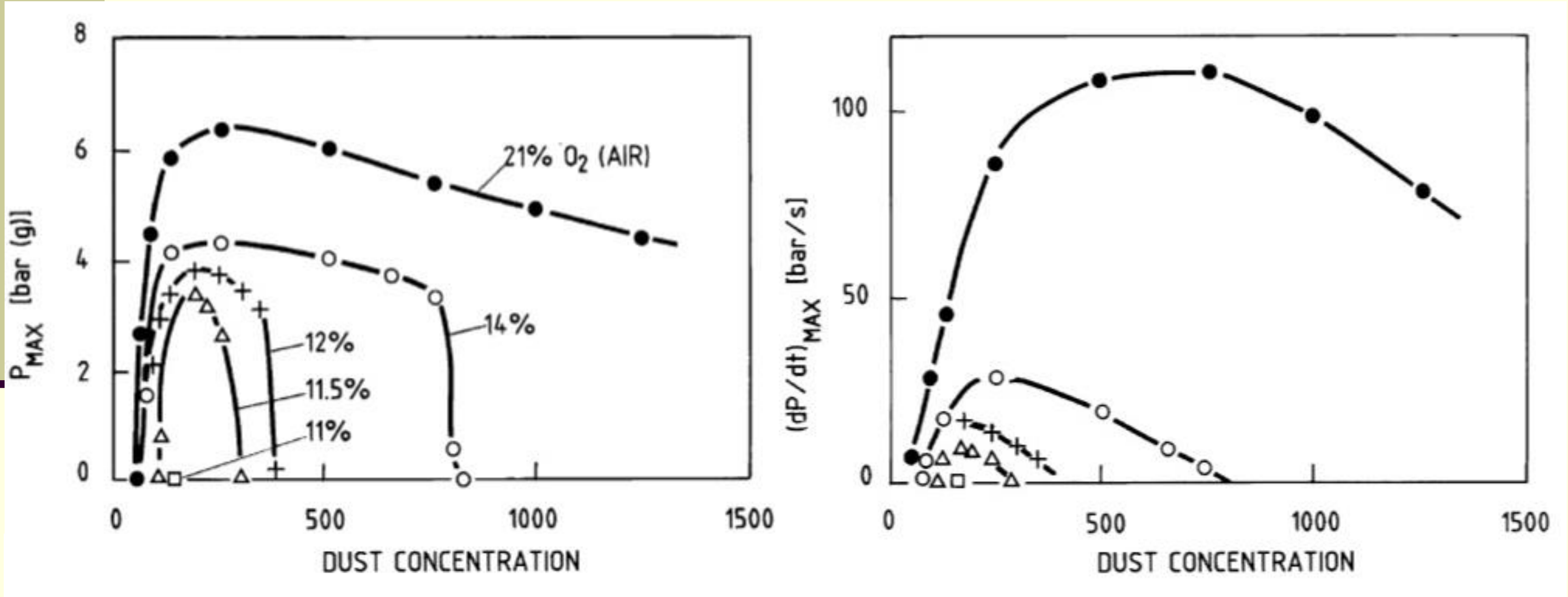
Inert gas effectiveness

Magnesium Dust

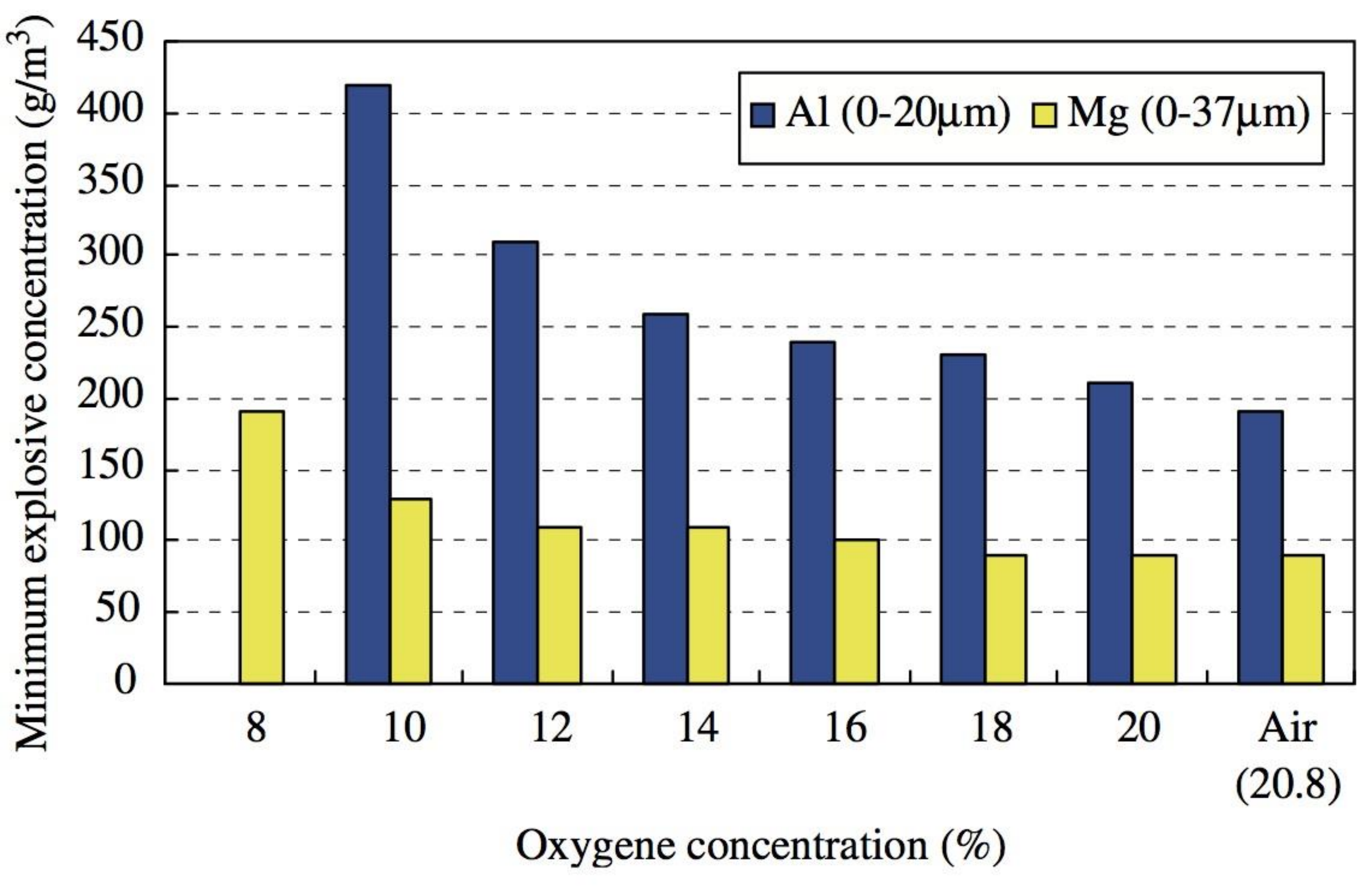
Inert Gas	LOC [volume %]
Nitrogen (diatomic)	6.8
Carbon dioxide (triatomic)	5.5
Argon (monatomic)	4.0

Effect on P_{max} and $(dP/dt)_{max}$

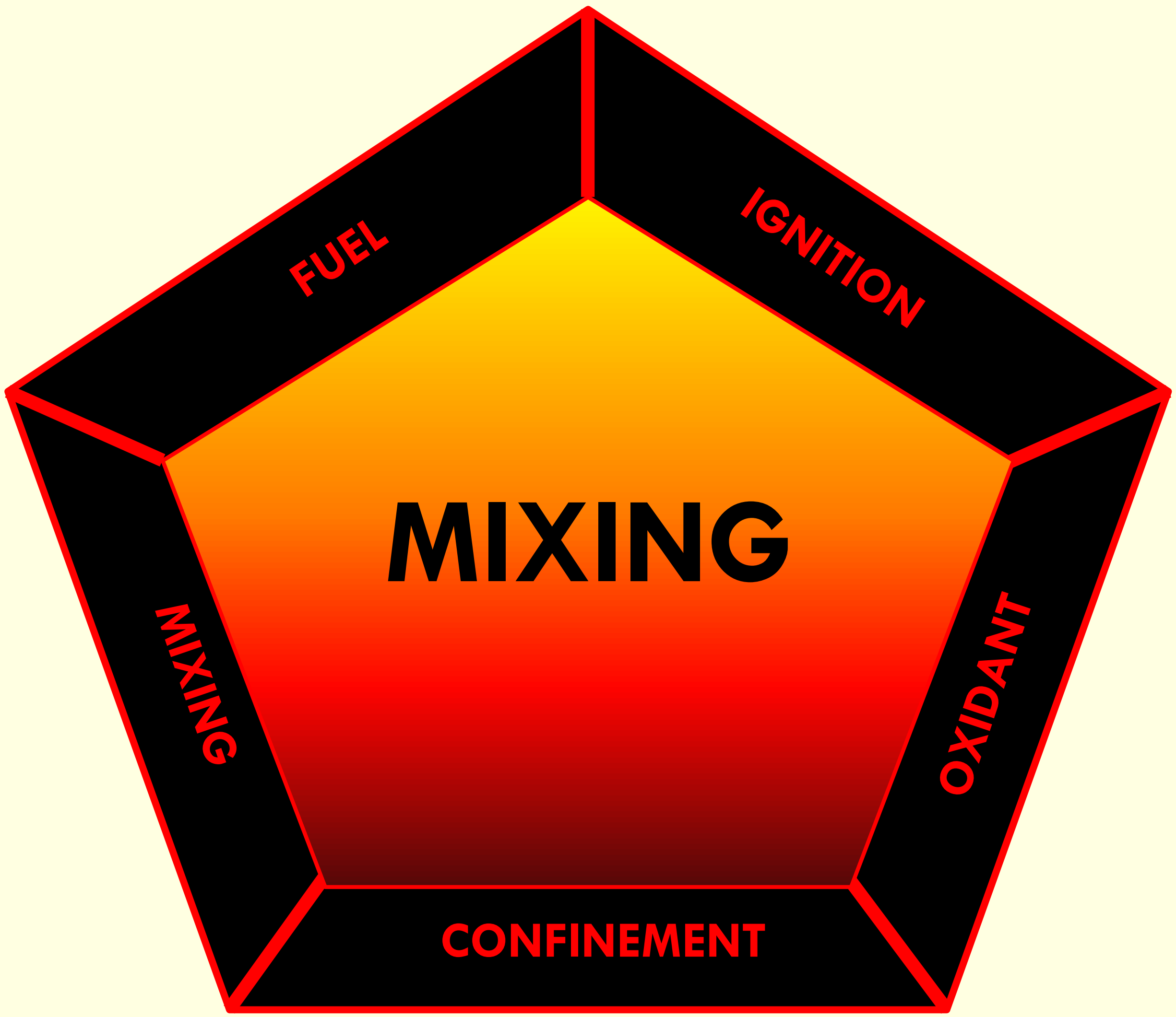
Brown Coal Dust/Air/Nitrogen



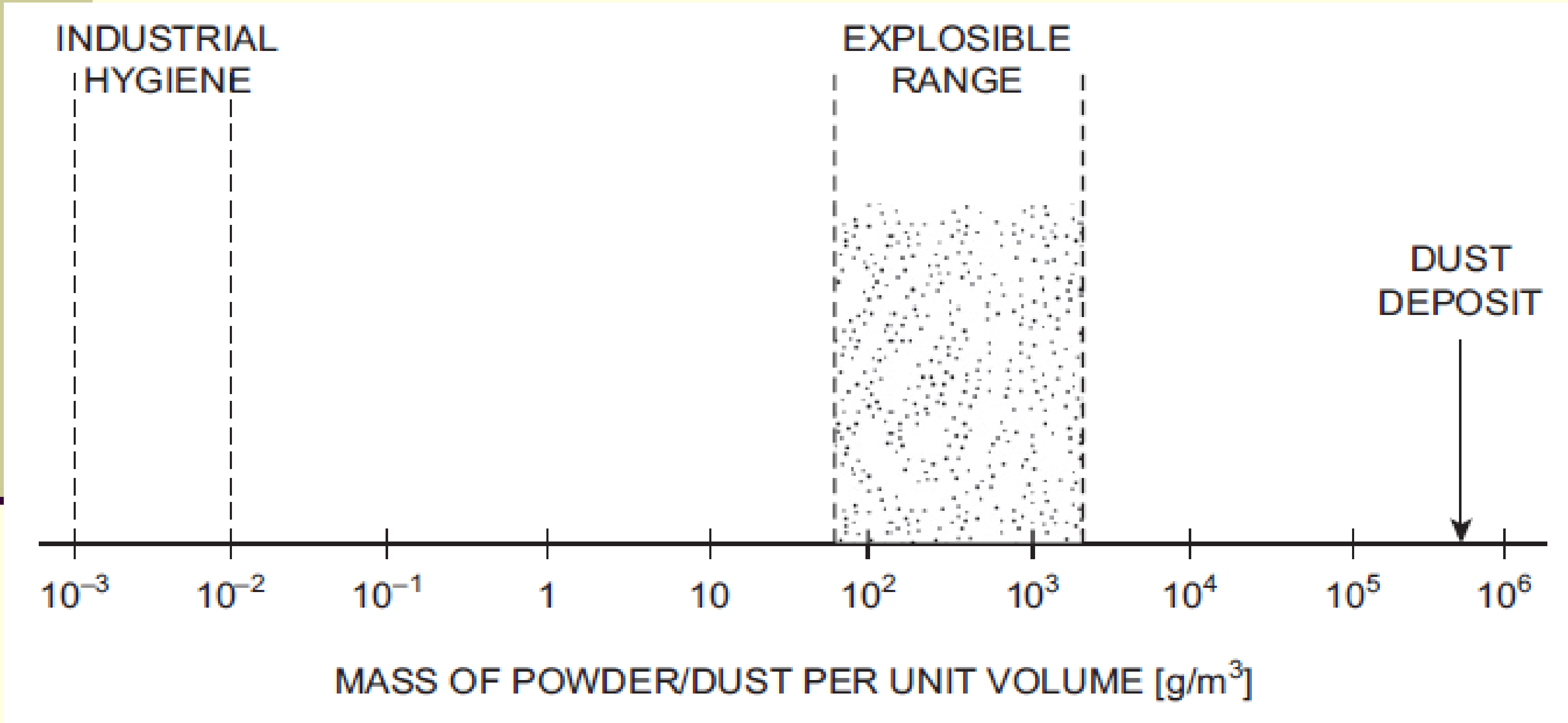
Effect on MEC (nitrogen)



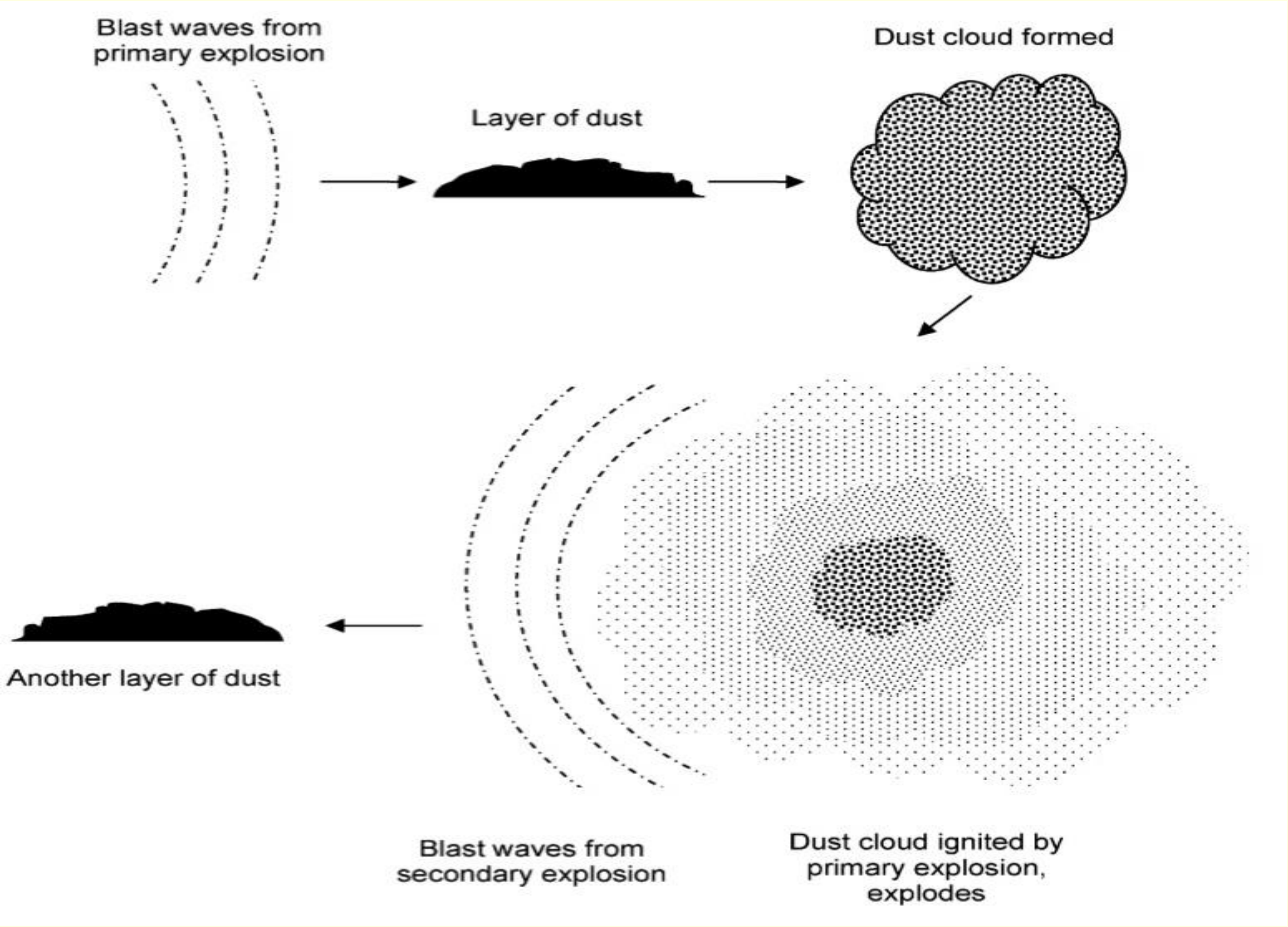
Element 4 of 5 – Mixing



Primary dust explosions



Secondary dust explosions



Primary/secondary dust explosions

- Primary dust explosions generally occur inside process vessels and units
  - Mills, grinders, dryers, etc.
- Secondary dust explosions are caused by dispersion of dust layers by an energetic disturbance
  - Upset conditions/poor housekeeping practices
    - Vigorous sweeping; cleaning with compressed air
  - Blast wave from primary explosion
    - Gas or dust explosion; other explosion types

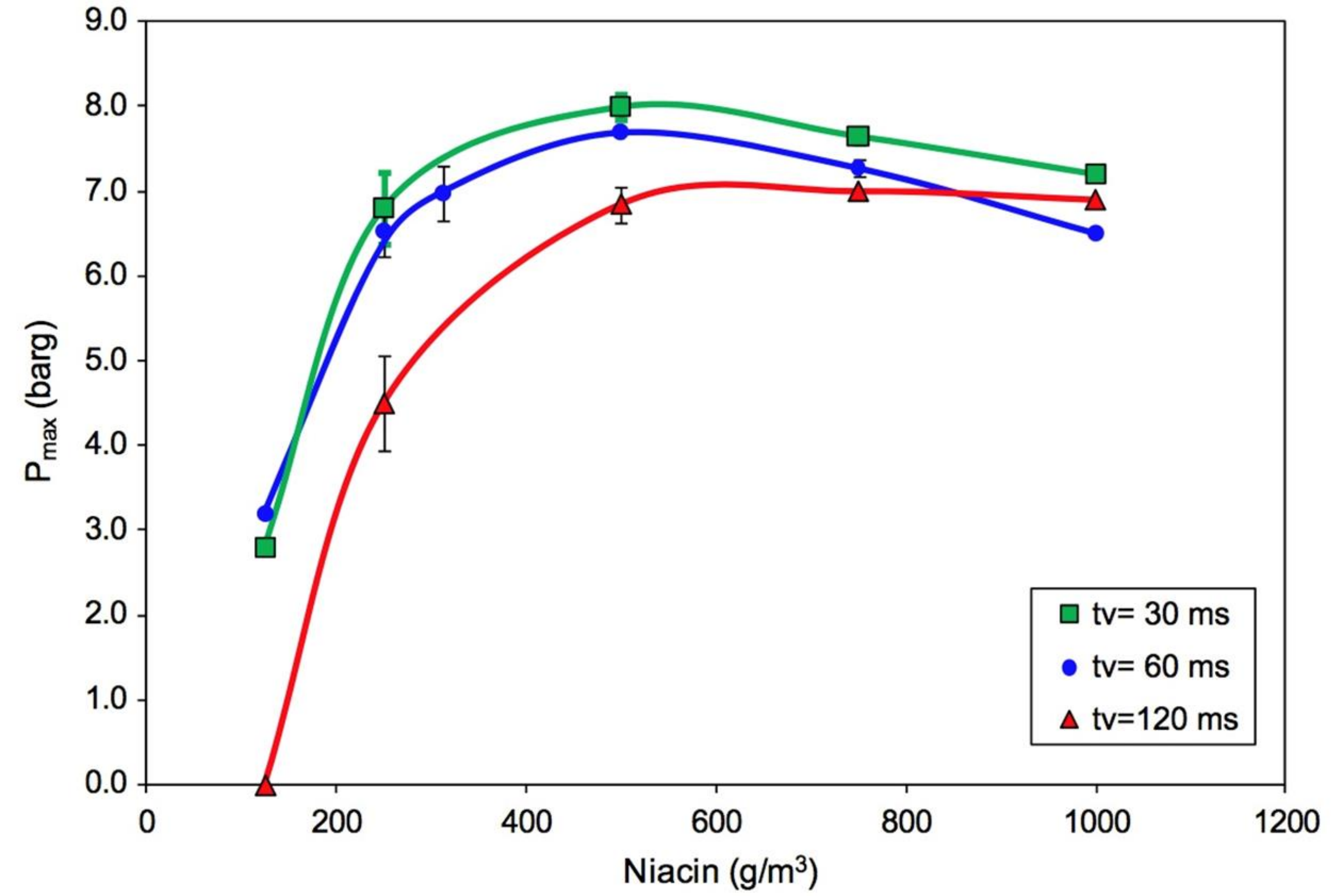
Dustiness/dispersibility

Characteristic	Influence on Dispersion
Particle size	Larger diameter → higher settling velocity
Particle specific surface area	Larger specific surface area → lower settling rate
Dust moisture content	Higher moisture content → reduced dispersibility
Dust density	Higher density → higher settling velocity
Particle shape	Asymmetry and roughness → lower settling velocity
Agglomeration processes	Impact effective particle diameter

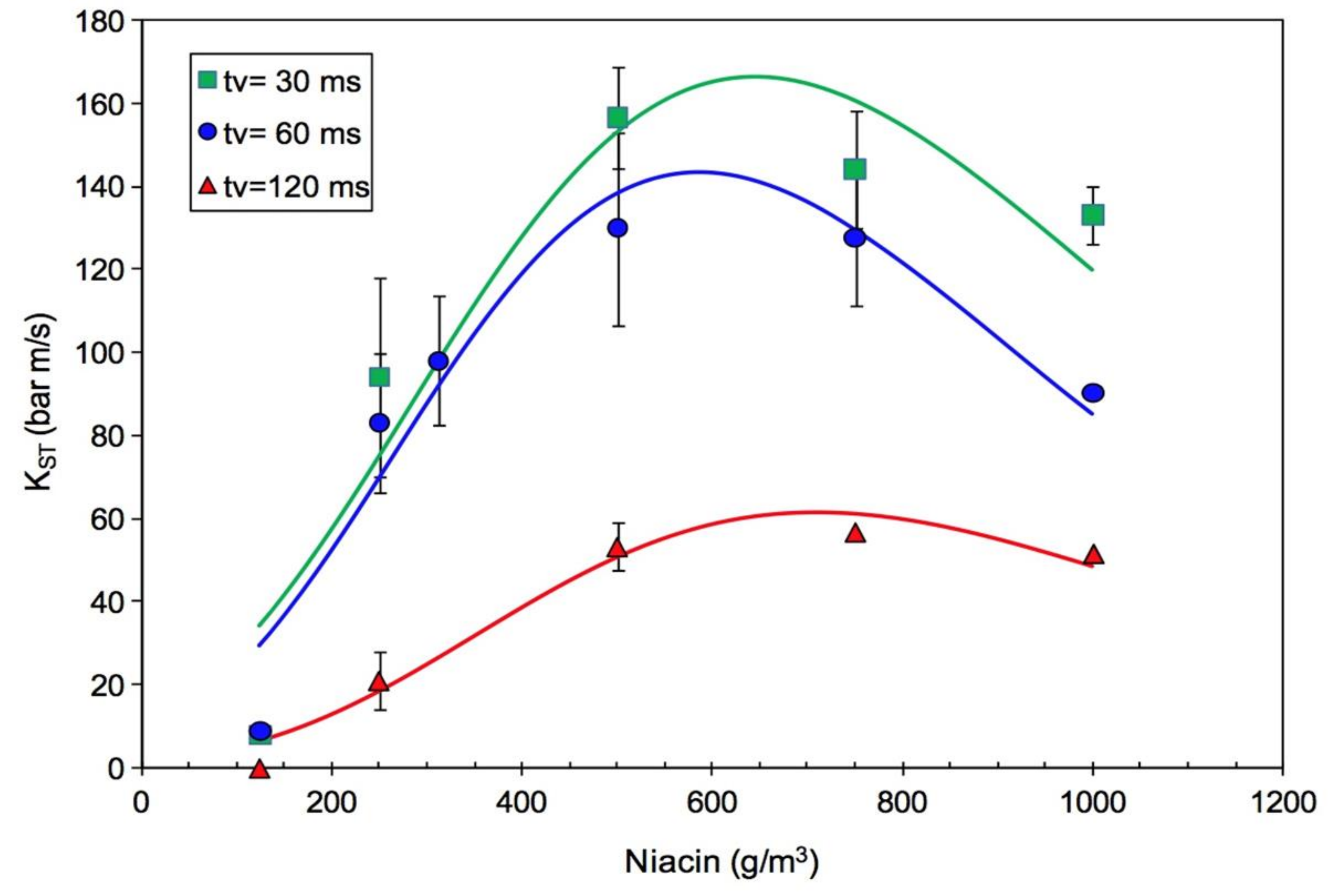
Turbulence

- Some degree of turbulence will always exist in a dust cloud
  - No such thing as a quiescent dust cloud within the confines of the earth's gravitational field
- Effects of turbulence
  - Increased ignition requirements
    - Highly turbulent dust clouds are harder to ignite
  - Heightened combustion rates
    - Once ignited, highly turbulent dust clouds yield more severe consequences

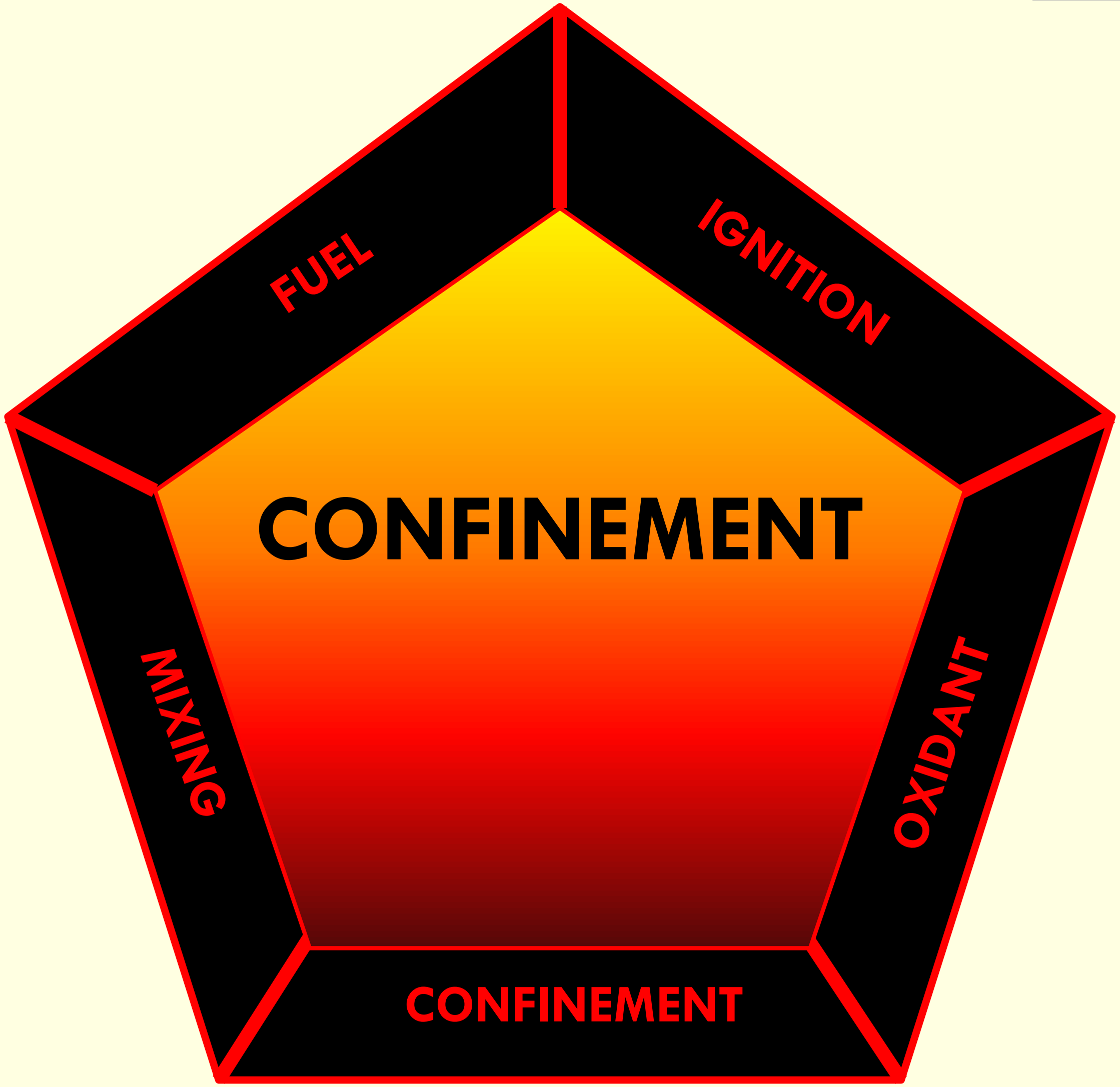
Turbulence and overpressure



Turbulence and rate of pressure rise



Element 5 of 5 – Confinement



Role of confinement

- Confinement allows for overpressure development

$$PV = nRT \xRightarrow{fixed\,V,\,R=const,\,n\approx const} \uparrow T \rightarrow \uparrow P$$

- Confinement does not need to be total for a dust explosion to occur
  - Semi-confined spaces
  - Unconfined spaces with high blockage ratio (congestion) and subsequent turbulence generation

Degree of confinement

- No confinement/low confinement
  - Flash fire
  - Dust explosion rare occurrence
- Partial confinement
  - Fireball with limited pressure rise and flame propagation
  - Explosion development possible
- Complete confinement
  - Full overpressure development

Partial confinement





Methane-triggered coal dust explosion
with fireball emerging from mine portal
Bruceton Experimental Mine
Pittsburgh, PA

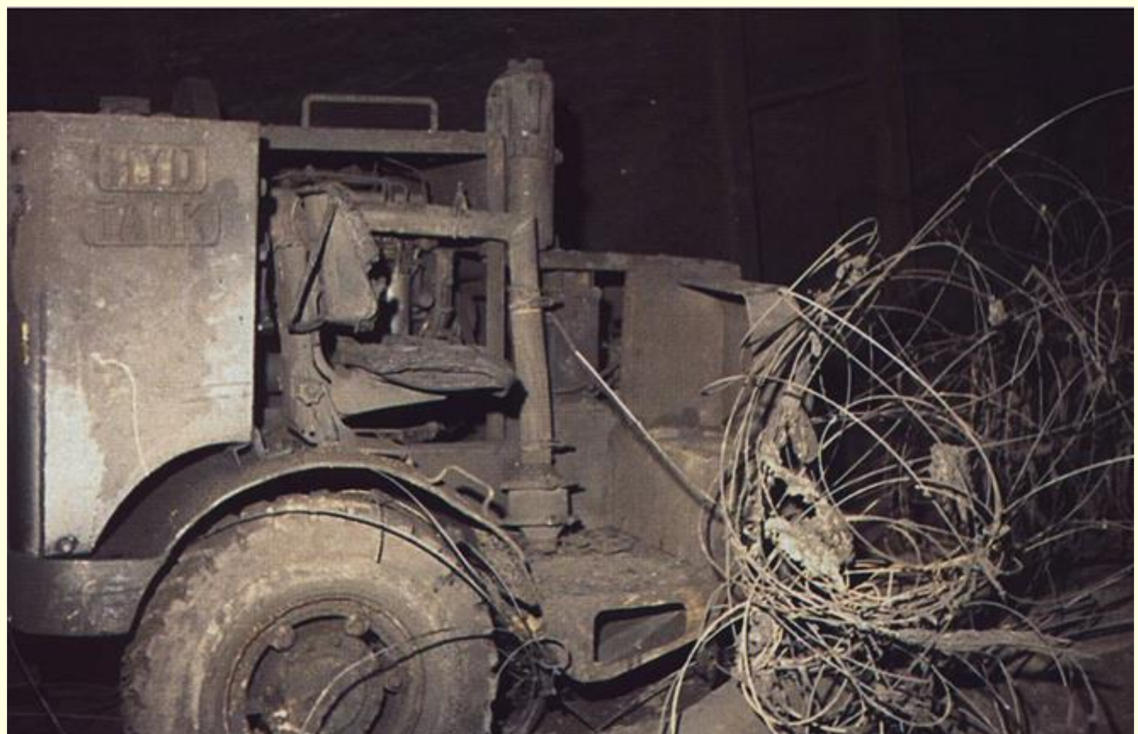
Partial confinement

- Underground mine workings
- Approximate mine gallery as a corridor with one end open, ignition occurring at opposite end
- Explosion development and flame propagation follows corridor
- Burned gases expand behind flame front and push unburned fuel/air mixture toward open end of corridor, generating turbulence
- Flame front accelerates as it reaches turbulent flow field
- Self-accelerating feedback mechanism

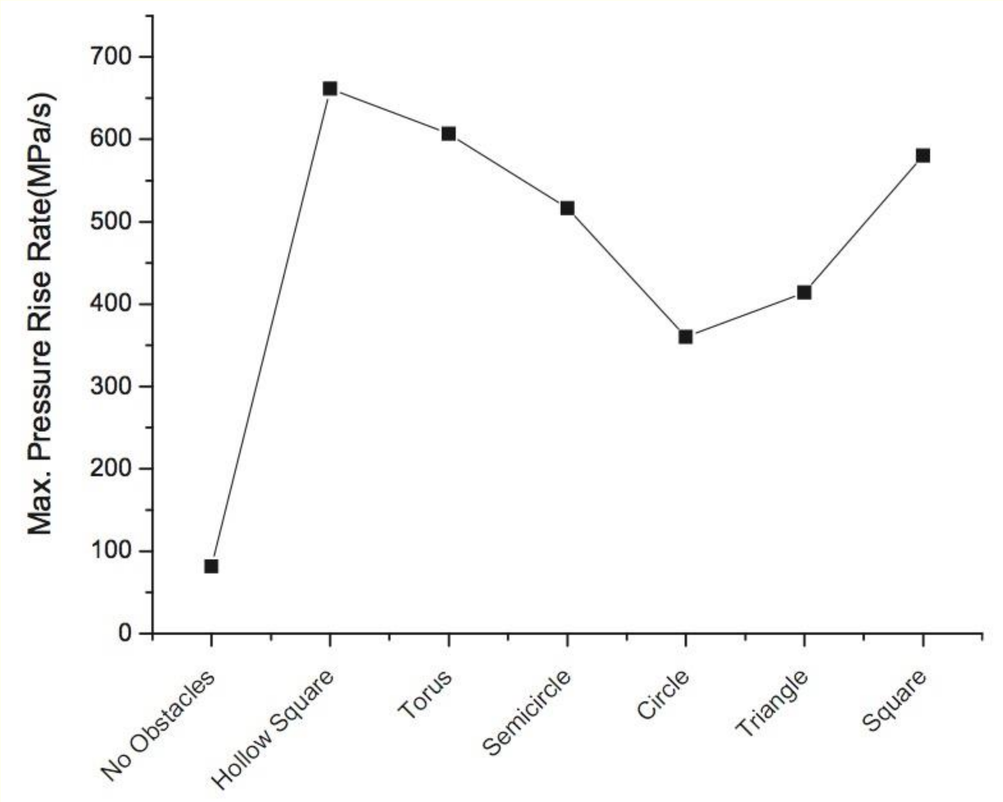
Congestion

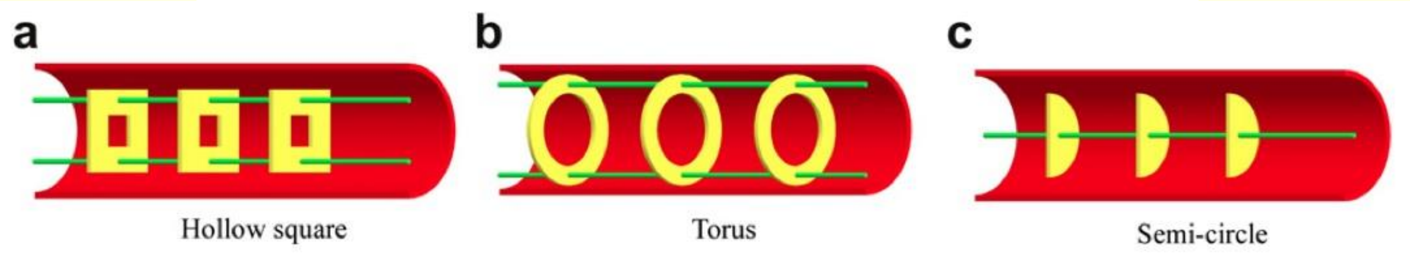
- Obstacles can create congestion (blockage) and generate significant post-ignition turbulence

Boom Truck
Westray



Influence of obstacle type





Explosion relief venting

- Dust explosion mitigation
  - Overpressure is reduced by relieving confinement

Corn Flour Explosion with Relief Venting

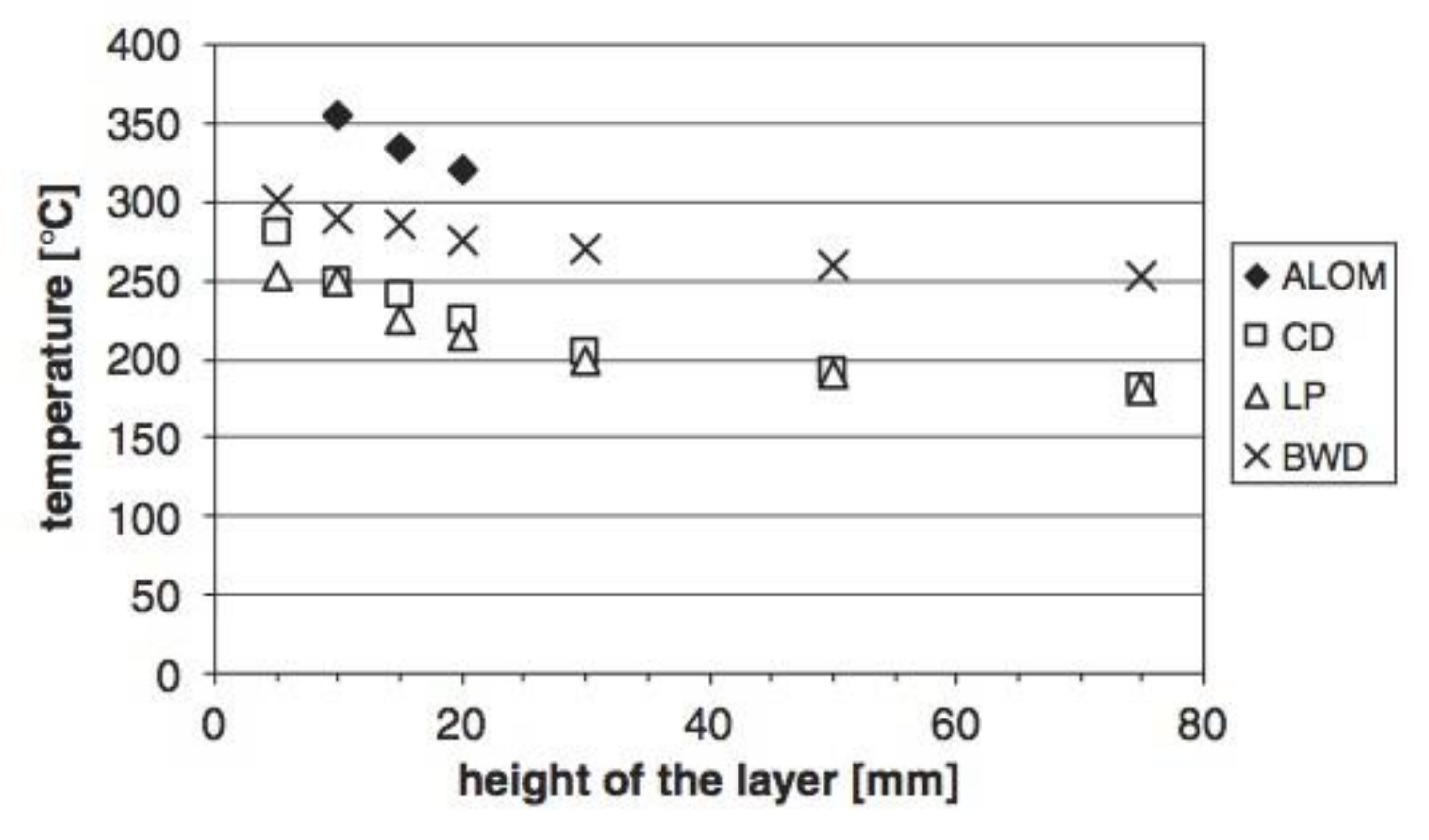
Dust Layer Fires

Magnesium
Dust Layer Fire

Ignition of dust layers

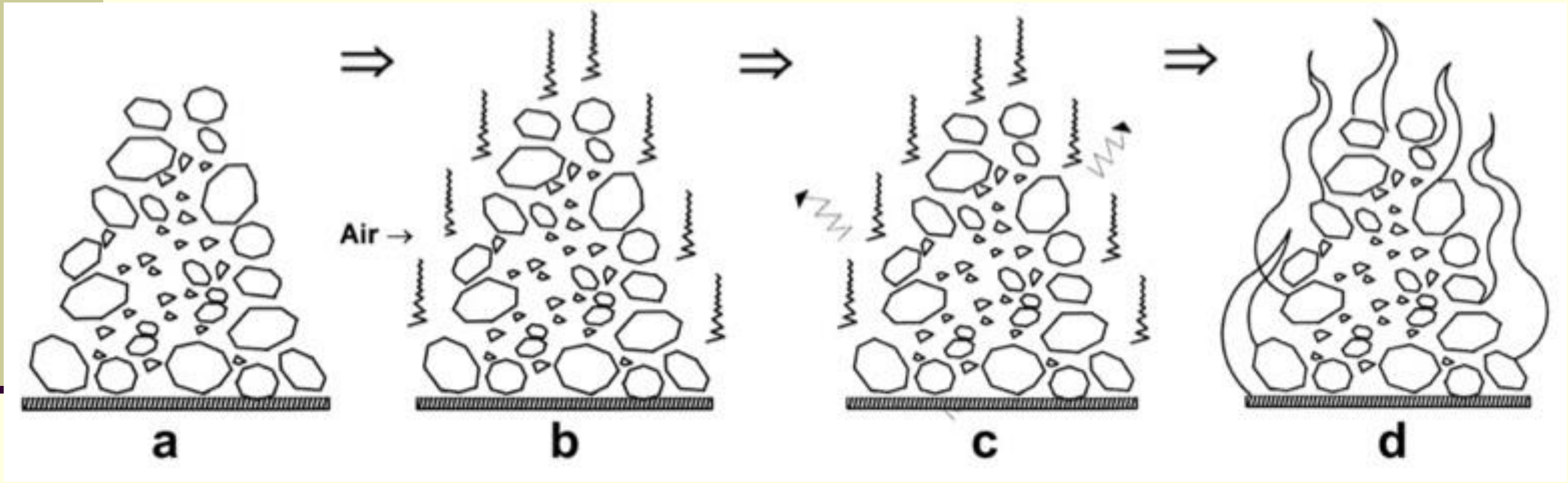
- Self-heating (self-ignition)
- External heat source
  - Pieces of metal
    - Nut or bolt (heated by repeated contact with equipment surfaces)
  - Overheated surface
    - Bearing or motor
- Layer Ignition Temperature (LIT)
  - Minimum temperature required to ignite a layer of dust of a certain thickness

Effect of layer thickness



ALOM = Aluminum Oxide; CD = Coal Dust; LP = Lycopodium; BWD = Beechwood Dust

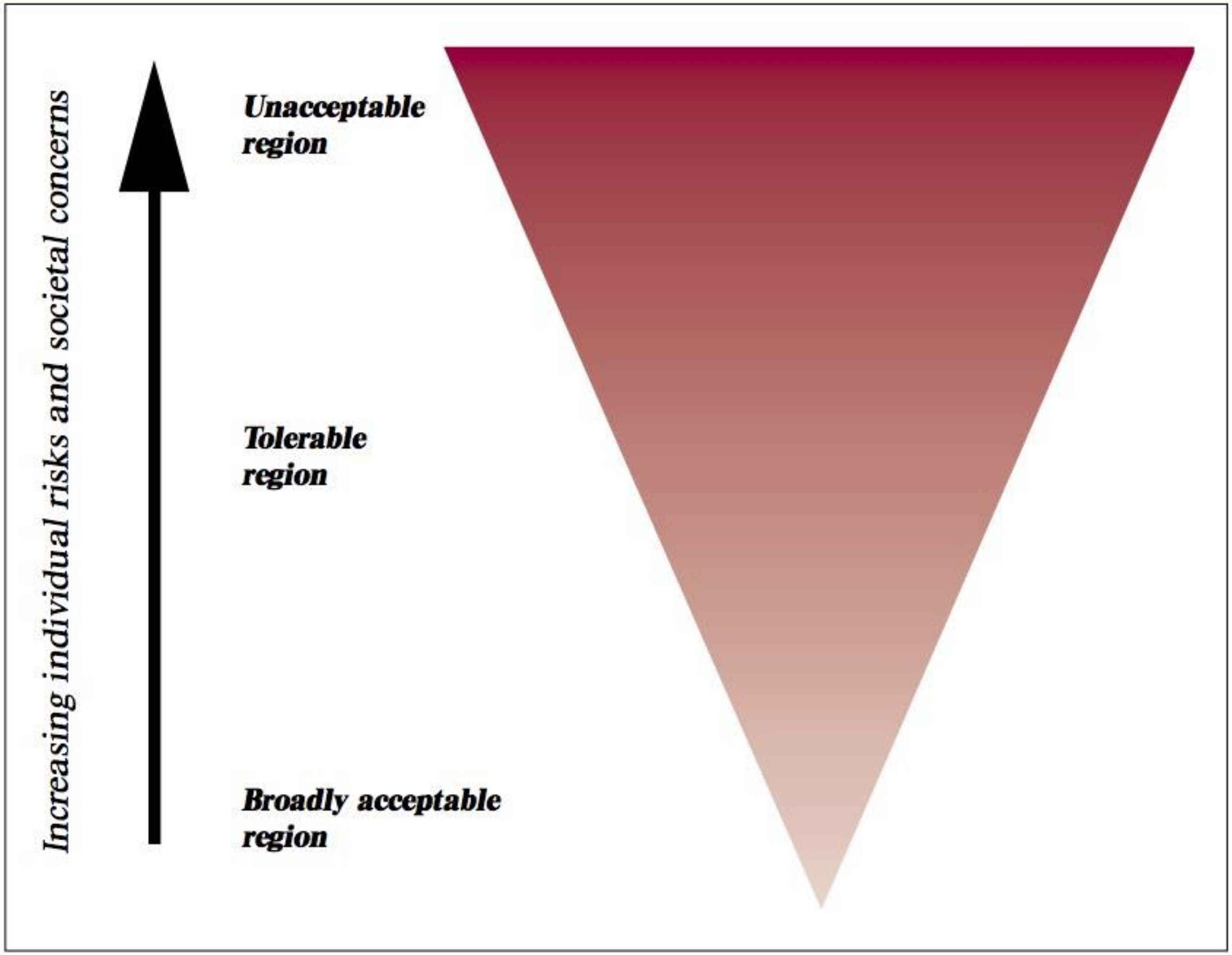
Self-ignition



Normalization of deviance

- Dust fires are sometimes ignored or normalized
  - Accepting as normal (and then ignoring) negative events
  - Culture of risk-denial
  - Counter to concept of safety culture
- Evidence that something is not right in the workplace
  - Nothing normal about an unintentional dust fire

Prevention and Mitigation



ALARP

Hierarchy of controls

INHERENT SAFETY

PASSIVE ENGINEERED SAFETY

ACTIVE ENGINEERED SAFETY

PROCEDURAL SAFETY

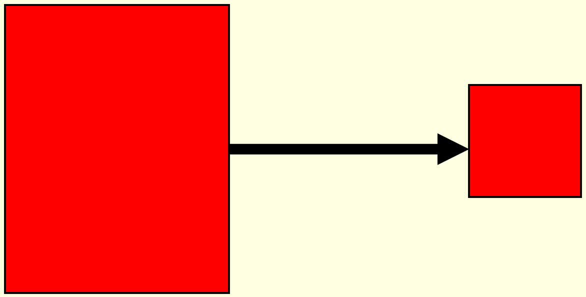
Hierarchy as a continuum

Inherent safety

- Proactive approach to reduce reliance on engineered or add-on safety devices (both passive and active) and procedural measures
- Four basic principles
  - Minimization
  - Substitution
  - Moderation
  - Simplification

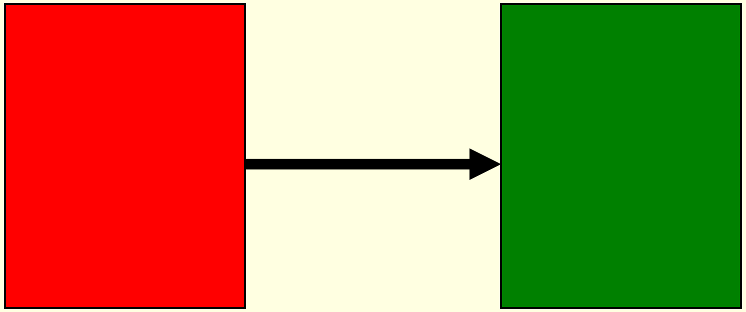
Minimization

Minimize amount of hazardous material in use (when use of such materials cannot be avoided – i.e. elimination)



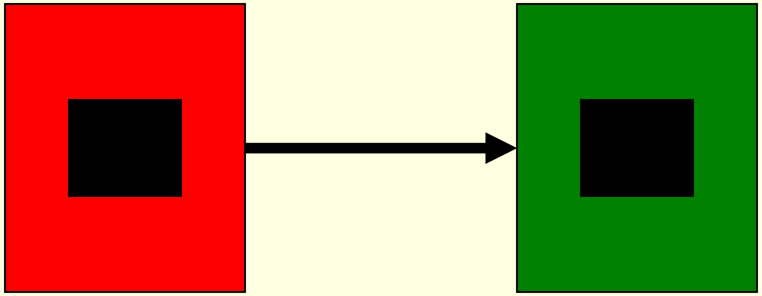
Substitution

Replace substance with less hazardous material; replace process route with one involving less hazardous materials



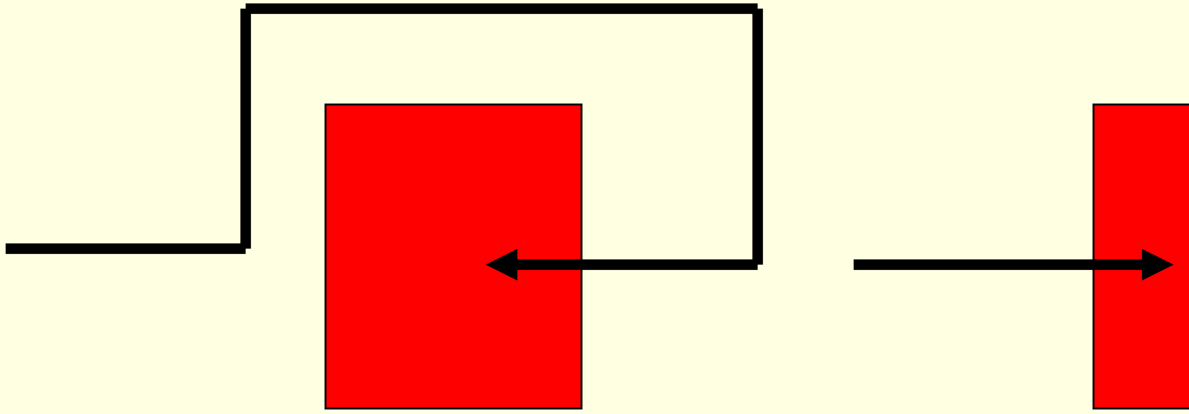
Moderation

Use hazardous materials in least hazardous forms; run process equipment with less severe operating conditions

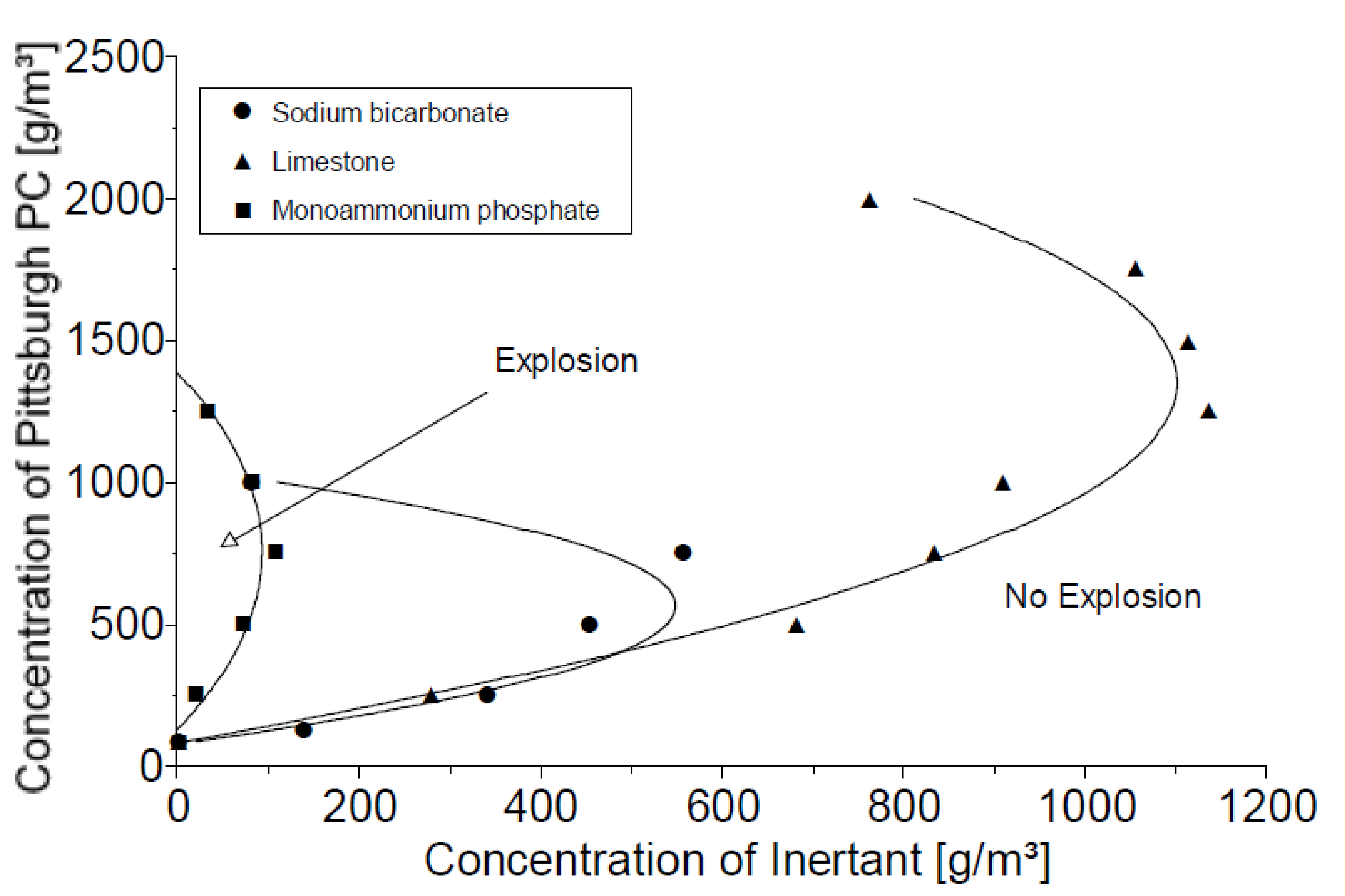


Simplification

Simplify equipment and processes that are used; avoid complexities; make equipment robust; eliminate opportunities for error



Minimum inerting concentration



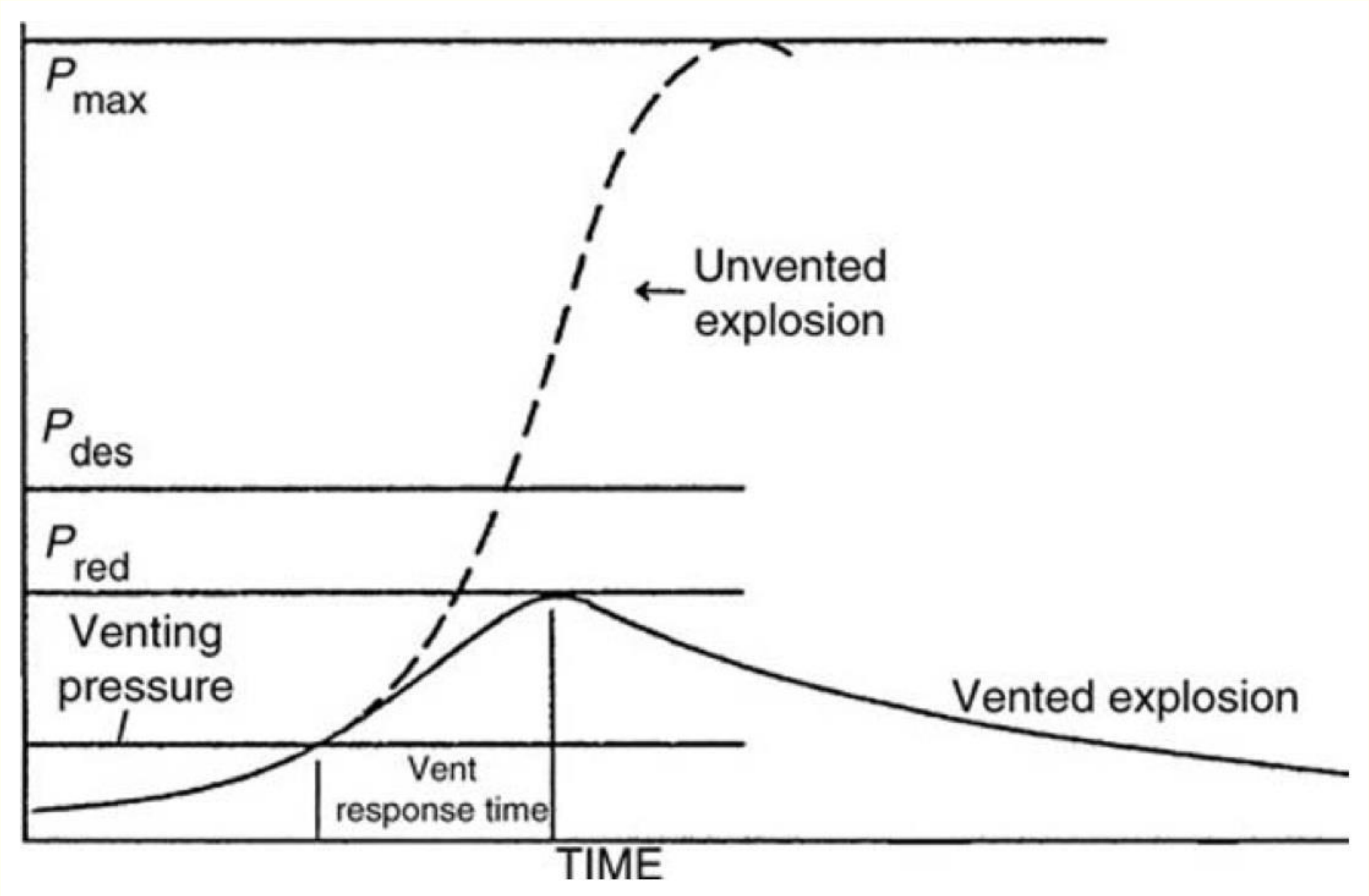
Passive engineered safety

- Add-on safety devices
  - Explosion relief vents
  - Physical barriers
- Have no function other than to act when called upon to mitigate consequences of an explosion
- Do not require event detection or device activation
- More reliable than active devices

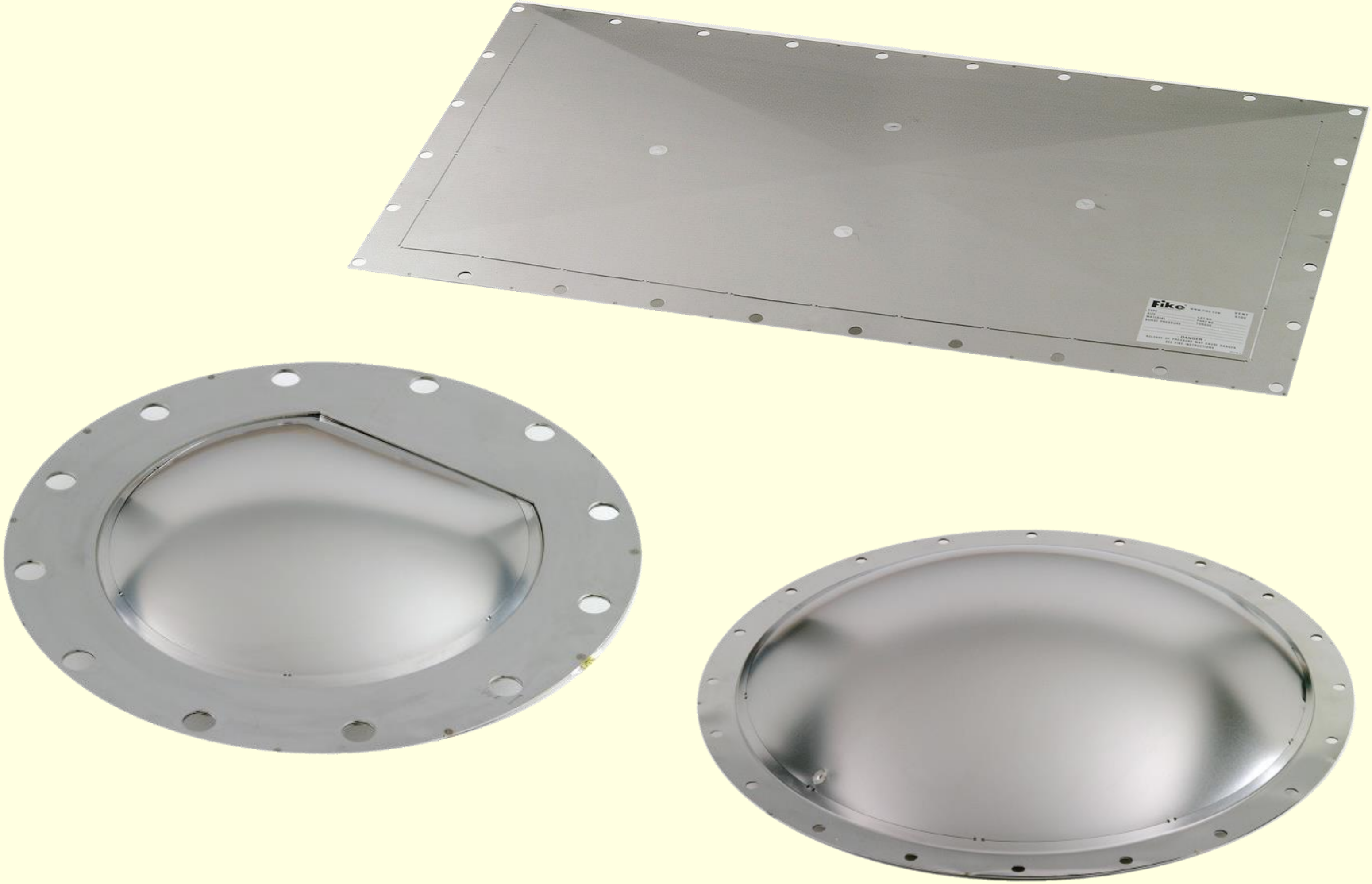
Venting

Corn Flour Explosion with Relief Venting

Venting process



Relief panels and rupture disks



Flameless venting

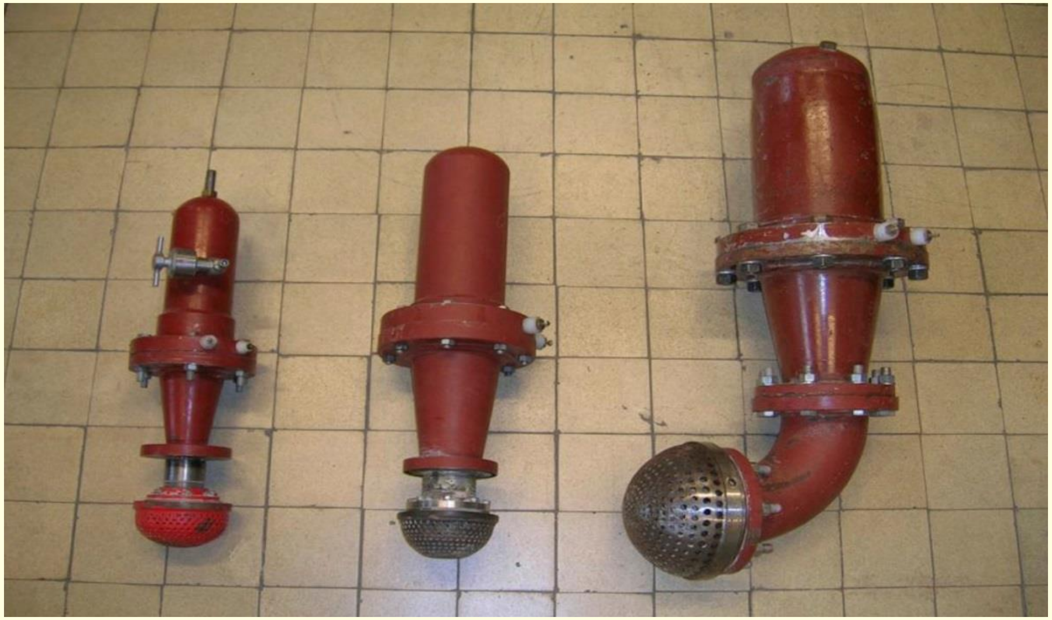
Corn Flour Explosion with Flameless Venting

Flame quenching devices

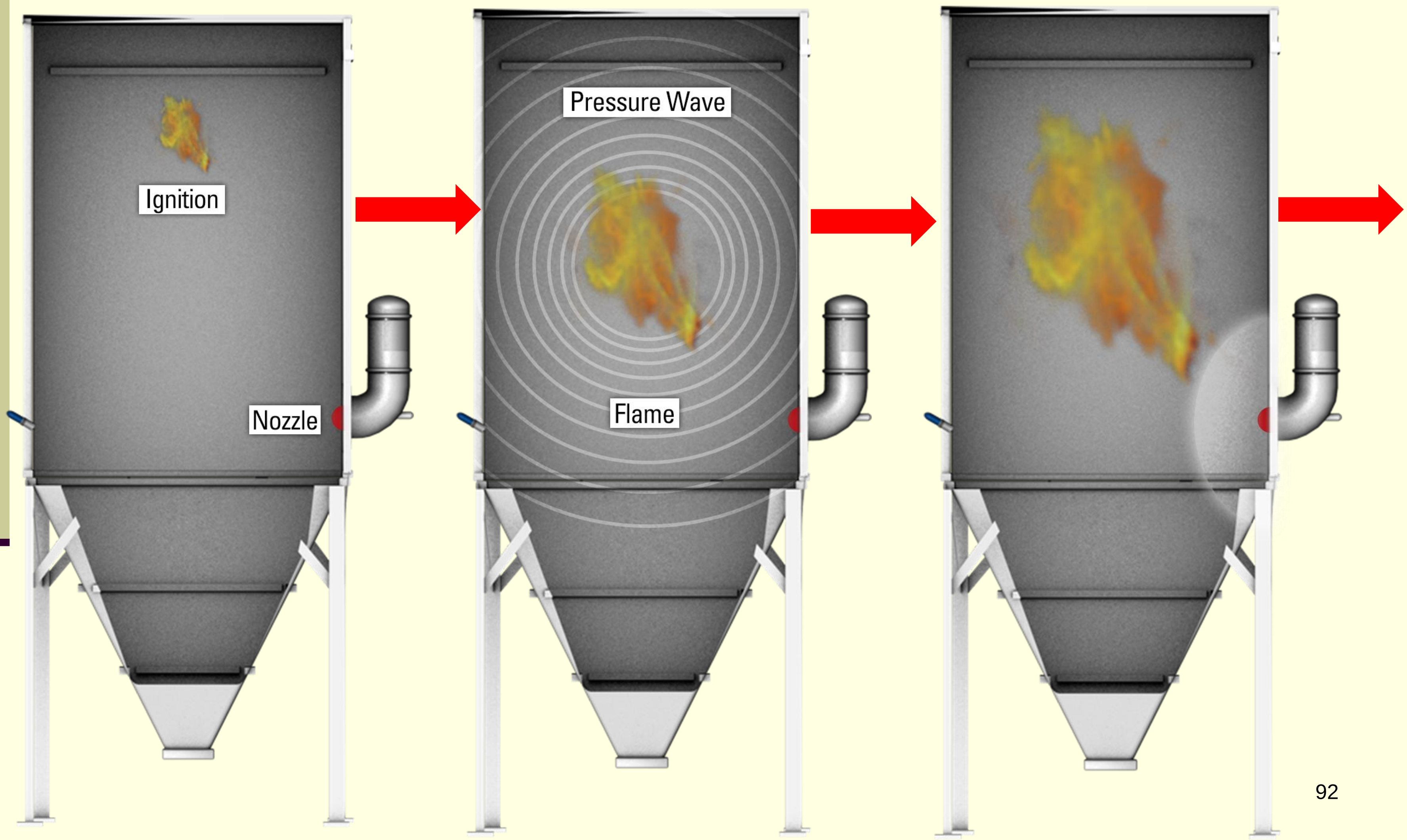
Active engineered safety

- Add-on safety devices
  - Inerting (gas) systems
  - Automatic explosion suppression
  - Explosion isolation valves
- Have no function other than to act when called upon to mitigate consequences of an explosion
- Require event detection and device activation
- Less reliable than passive devices

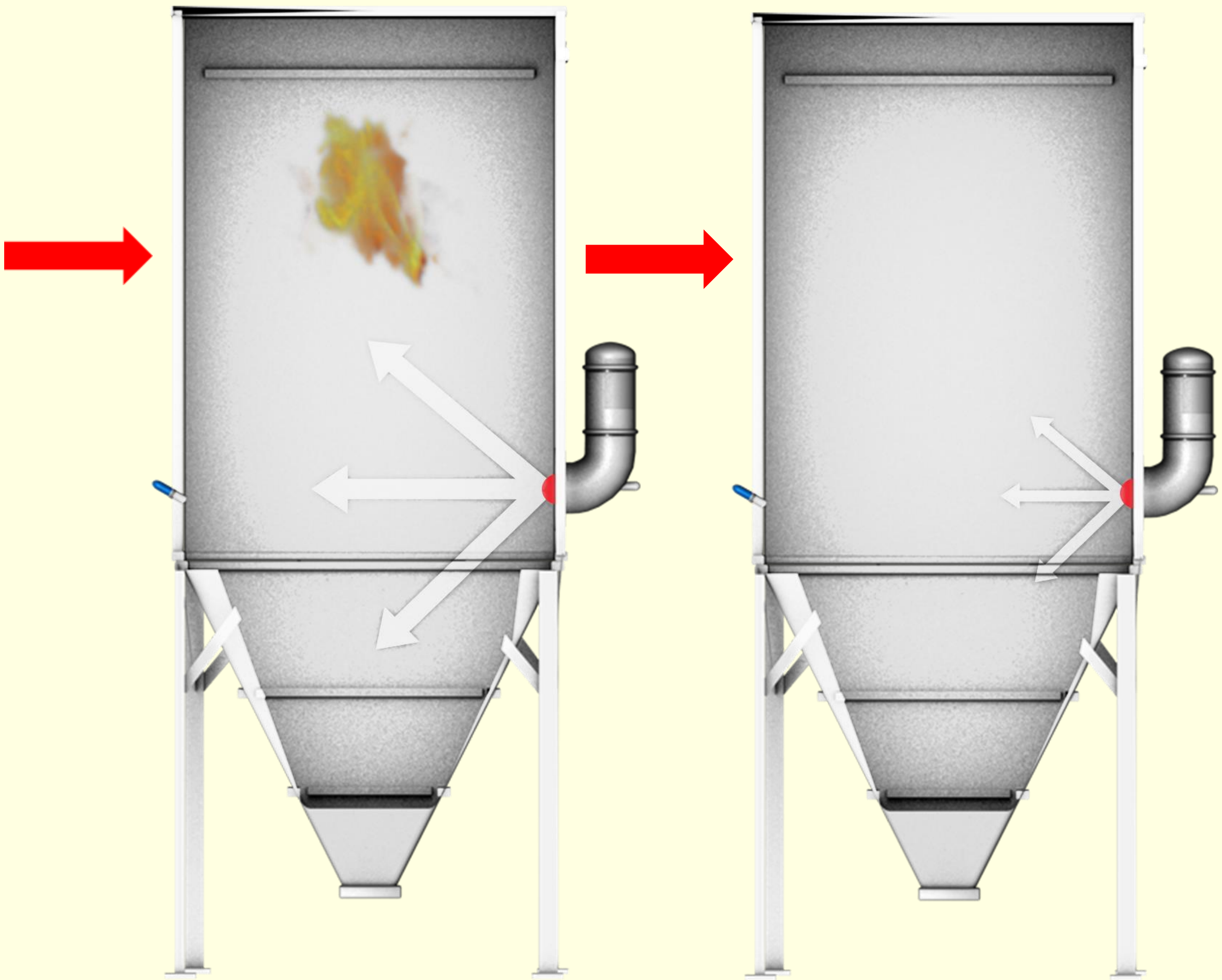
Suppression – HRD canisters



Suppression sequence



Suppression sequence (continued)



Isolation valves

Procedural safety

- Safe work practices and procedures
  - Grounding and bonding
  - Hot-work permitting
  - Permit-to-work system
  - Housekeeping
- Directly involves people
  - Human error possible
  - Training essential
- Least effective category in hierarchy

Housekeeping

- Primary line of defence against dust explosions
- Design
  - Eliminate cleaning
  - Make cleaning easier
  - Scheduling
  - All surfaces cleaned
  - Performed safely

Dust Collection to Measure Accumulation

Safety management systems

- Accountability: Objectives and Goals
- Process Knowledge and Documentation
- Capital Project Review and Design Procedures
- Process Risk Management
- Management of Change
- Process and Equipment Integrity
- Human Factors
- Training and Performance
- Incident Investigation
- Company Standards, Codes and Regulations
- Audits and Corrective Actions
- Enhancement of Process Safety Knowledge

Safety culture

- Provides the link between an organization’s beliefs and prevention and mitigation strategies
- Safety culture
  - Reporting culture
  - Just culture
  - Learning culture
  - Flexible culture
- Collective mindfulness
- Risk awareness

Keys to success

- Hierarchy of controls
  - Inherent safety
  - Passive engineered safety
  - Active engineered safety
  - Procedural safety
- Safety management system
- Safety culture

Case Studies

- *To paraphrase G. Santayana, one learns from history or one is doomed to repeat it*
- Westray
  - Coal mine
  - Methane-triggered coal dust explosion
- Hoeganaes
  - Atomized iron production facility
  - Iron dust flash fires
- Imperial Sugar
  - Sugar refinery
  - Sugar dust explosion

Westray: what happened

Methane-triggered coal dust explosion

Plymouth, NS

May 9, 1992

26 fatalities

Westray: why

- Substandard practices
  - Poor housekeeping with respect to coal dust
  - Inadequate rock dusting
  - Continuation of mining in spite of inoperable methane detection devices
  - Storage of fuel and re-fueling of vehicles underground
- Substandard conditions
  - Inadequate ventilation system design and capability
  - Thick layers of coal dust with unacceptably high levels of combustible matter
  - Inadequate system to warn of high methane levels

Westray: lessons learned

- Poor safety culture
  - Lack of management commitment and accountability to safety matters
  - Fear of reprisal on part of workers
- Ineffective safety management system
  - Human factors
  - Training
  - Poor compliance to best industry practices and legislated safety requirements

Westray: lessons learned

Hoeganaes: what happened

Iron dust flash fires

Gallatin, TN

Jan 31, 2011

    2 fatalities

March 29, 2011

    1 injury

May 27, 2011

    3 fatalities,

    2 injuries

Hoeganaes: why

- No employee training
- Accumulations of iron dust
  - Inadequate housekeeping
  - Elevated surfaces

Hoeganaes: lessons learned

Safety Culture

- Ignoring known hazards
- Reporting culture
  - Frequent minor flash fires not reported
- Learning culture
  - Repetition of similar incidents
- Flexible culture
  - Decision-making flawed

Hoeganaes: lessons learned

Imperial Sugar: what happened

Sugar dust explosion

Port Wentworth, GA

Feb 7, 2008

14 fatalities

36 injuries

Imperial Sugar: why

- Conveyor belt: no dust removal system or explosion vents
- Inadequate housekeeping
- Inadequate evacuation plan

Imperial Sugar: lessons learned

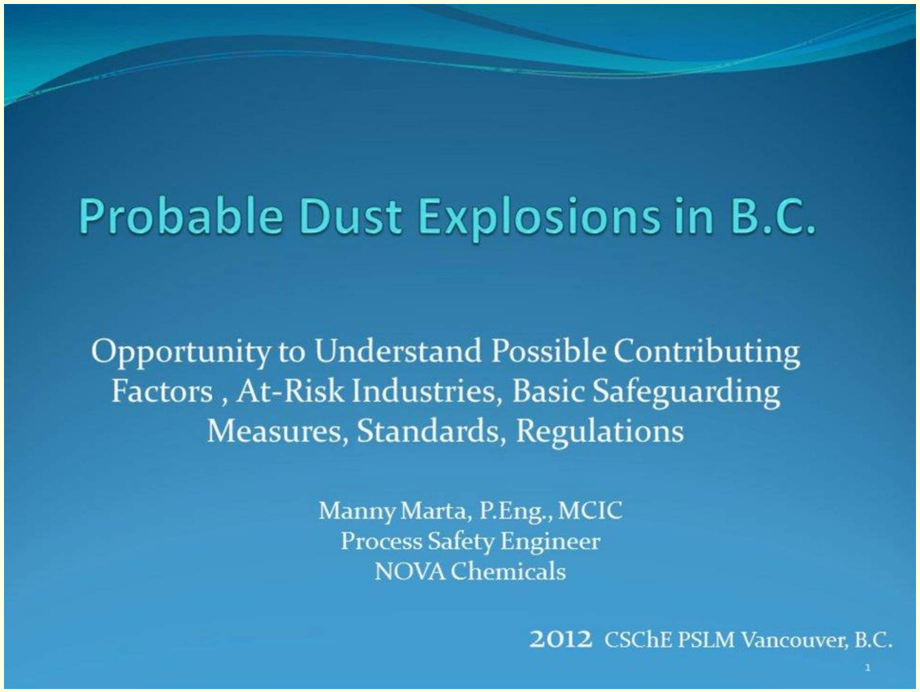
Imperial Sugar: lessons learned

- Previous fires and near-misses
- Management knew about hazards

Resources

- Videos
- Reports
- Data Bases
- Standards
- Papers
- Books

Videos, reports, data bases



CSB
U.S. CHEMICAL SAFETY BOARD

IFA
Institut für Arbeitsschutz der
Deutschen Gesetzlichen Unfallversicherung

Standards

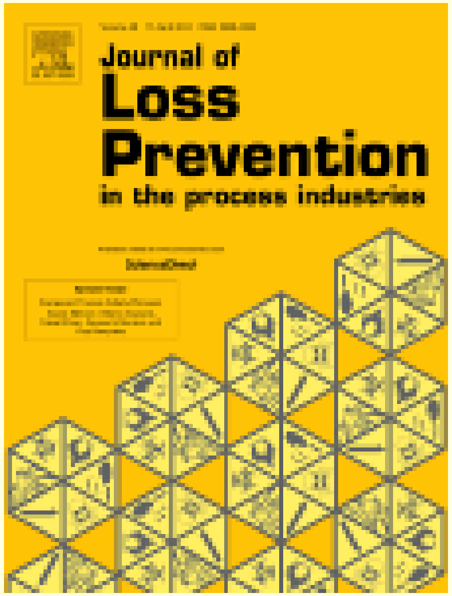
ASTM INTERNATIONAL

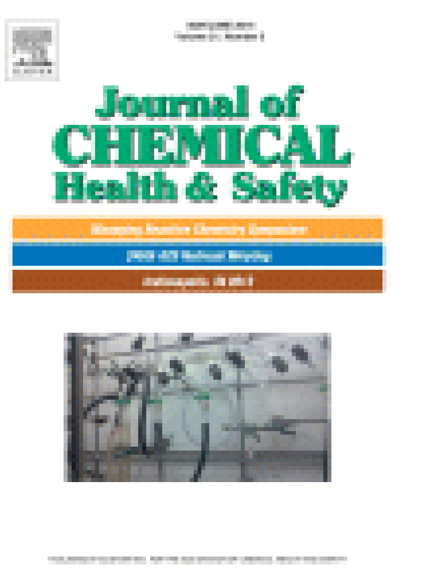
Standards Worldwide

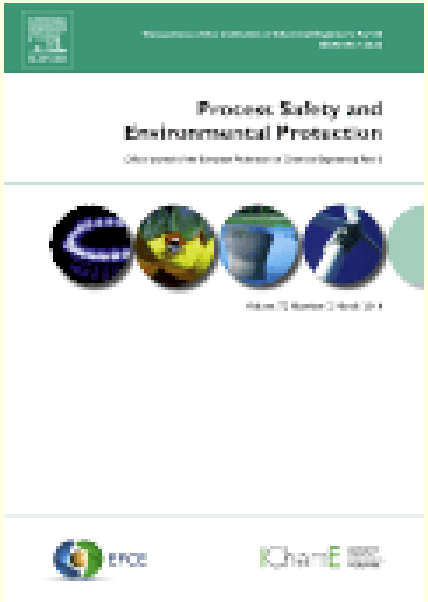
NFPA®

Papers

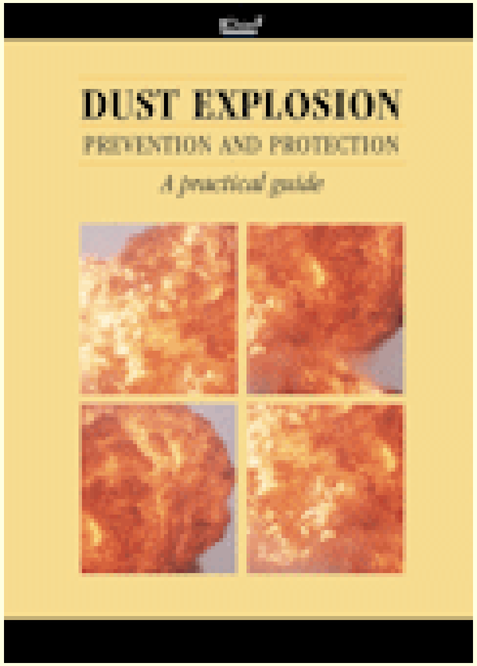

HAZARDOUS
MATERIALS

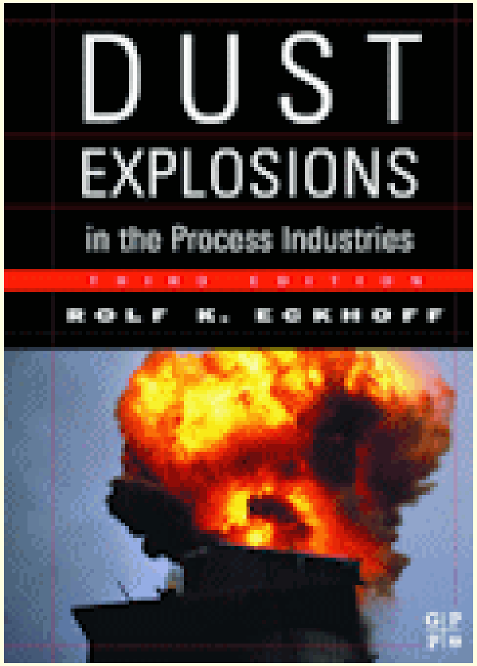

Journal of
Loss
Prevention
in the process industries

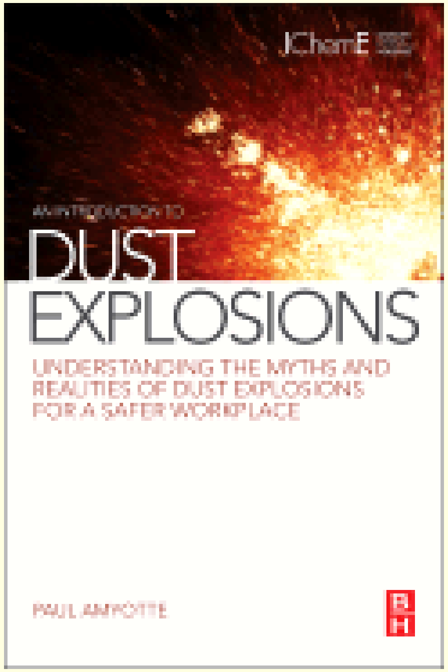

Journal of
CHEMICAL
Health & Safety


Process Safety and
Environmental Protection

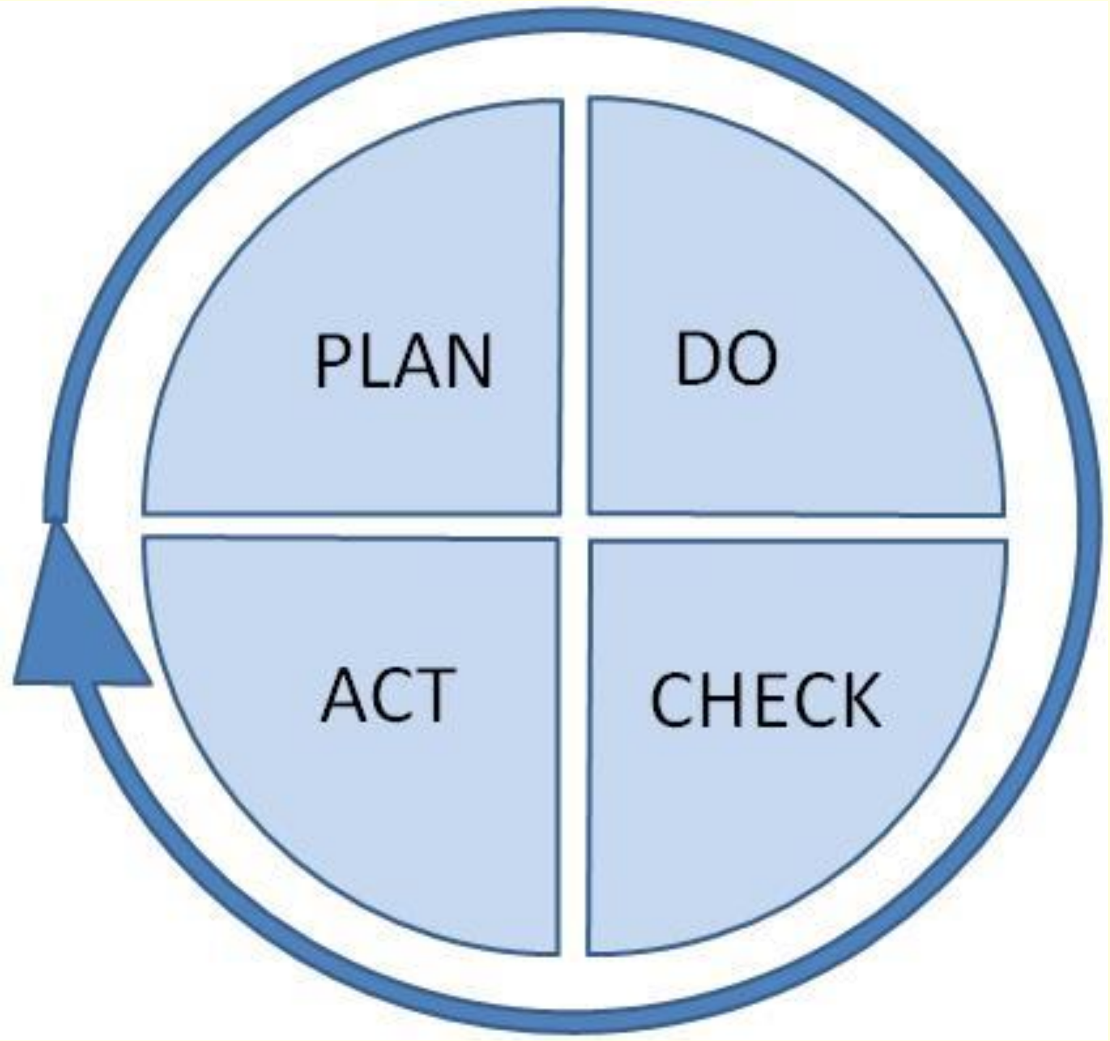
Books


DUST EXPLOSION
PREVENTION AND PROTECTION
A practical guide


DUST
EXPLOSIONS
in the Process Industries
ROLF K. ECKHOFF


AN INTRODUCTION TO
DUST
EXPLOSIONS
UNDERSTANDING THE MYTHS AND
REALITIES OF DUST EXPLOSIONS
FOR A SAFER WORKPLACE
PAUL AMYOTTE

Evaluation



Remembering

Define what is meant by a "combustible dust".

Identify all of the elements of the fire triangle and the explosion pentagon.

Understanding

Explain how a gaseous, liquid or solid fuel actually burns. (What is the physical state of the reacting fuel?)

Describe the fundamentals of a dust explosion according to the explosion pentagon.

Applying

Calculate the airborne concentration in an enclosure with a height of 5 m resulting from the dispersion of a 0.8-mm thick layer of corn flour having a bulk density of 0.82 g/cm^3.

Analyzing

Identify the possible fuel sources that could have been involved in the explosion at the Babine Forest Products facility in Burns Lake, BC on January 20, 2012. Discuss which of these involved combustible dust hazards.

Note: This incident was investigated by WorkSafeBC; the investigation report is available on their web site: www.worksafebc.com.

Evaluating

Determine several strategies that might have been helpful in preventing and mitigating the polyethylene dust explosion at the West Pharmaceuticals facility in Kinston, NC on January 29, 2003. Be sure to justify your choices.

Note: This incident was investigated by the US Chemical Safety Board; the investigation report is available on their web site: www.csb.gov.

Creating

Formulate a dust explosion prevention plan for the scenario described below. Be sure to account for each element of the explosion pentagon.

A fine aluminum powder is being processed at a facility involving numerous physical operations such as grinding, pulverizing and sieving. Workers are largely unaware of combustible dust hazards and plant management has not shown itself to be very supportive of loss prevention efforts.