Exponent®

Dust Explosions

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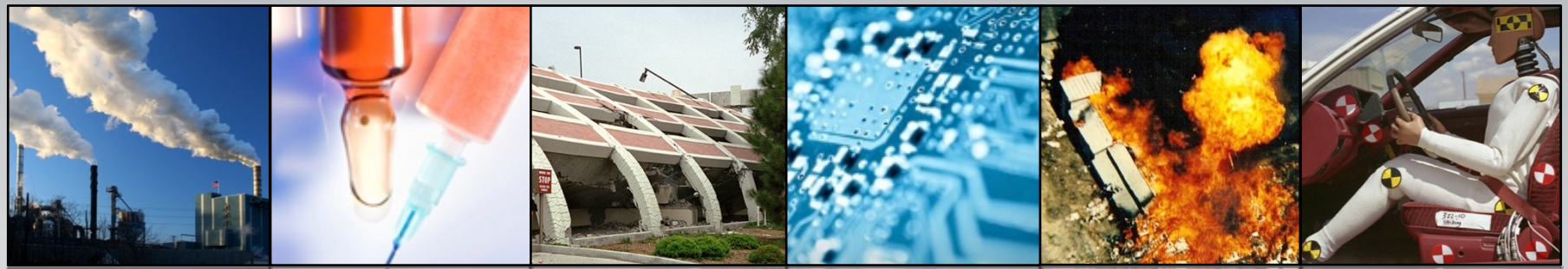
Outline

- Combustible Dust Background
- Hazard Identification
- Dust Hazard Analysis
- Hazard Mitigation

Combustible Dust Background

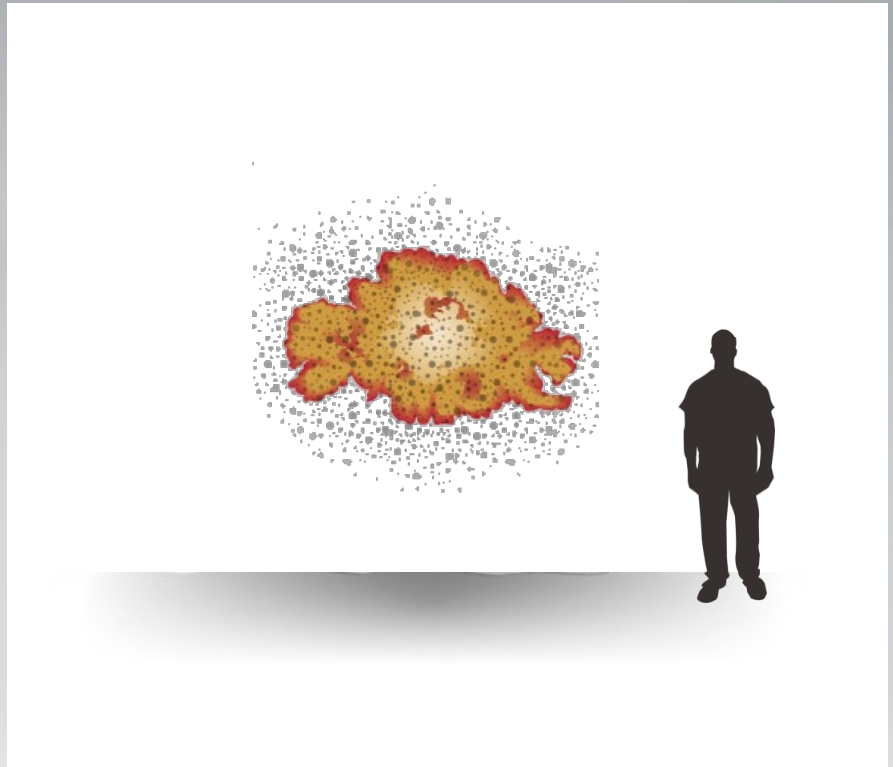


Combustible Dusts - Effect of Particle Size

Source: After Eckhoff, “Dust Explosions in the Process Industries” (2003).

Elements of a Flash Fire

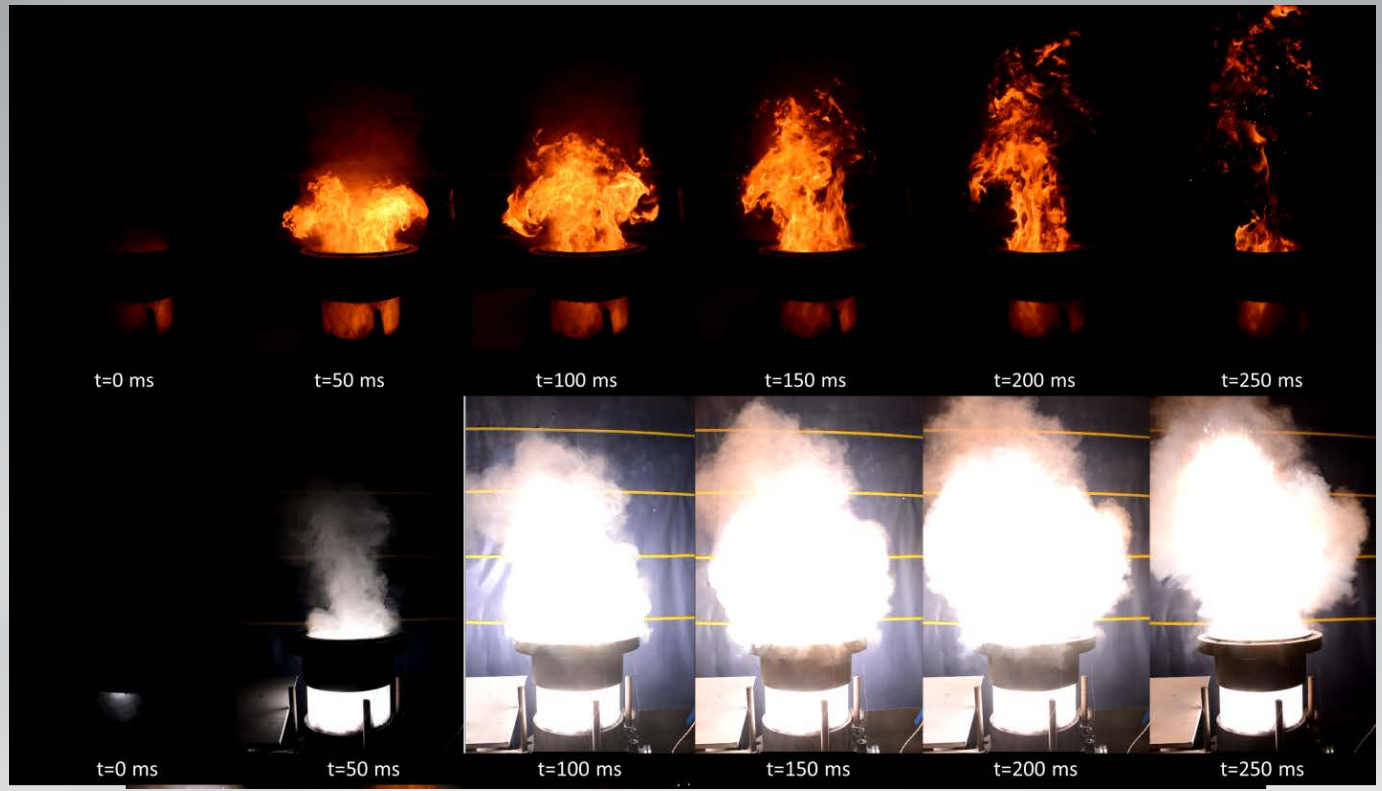
- Combustible dust
  - Small particle size
  - Oxidizable
- Oxidizer (e.g. air)
- Ignition source
- Dispersion of dust



Organic and Metal Dust Flash Fires

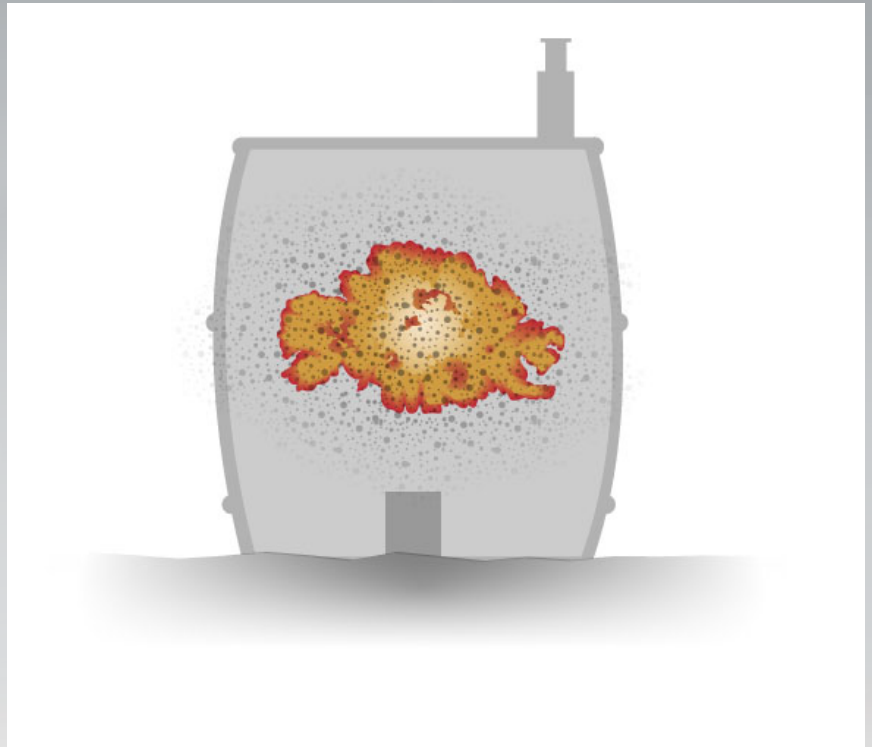
Organic Dust

Metal Dust



Elements of a Dust Explosion

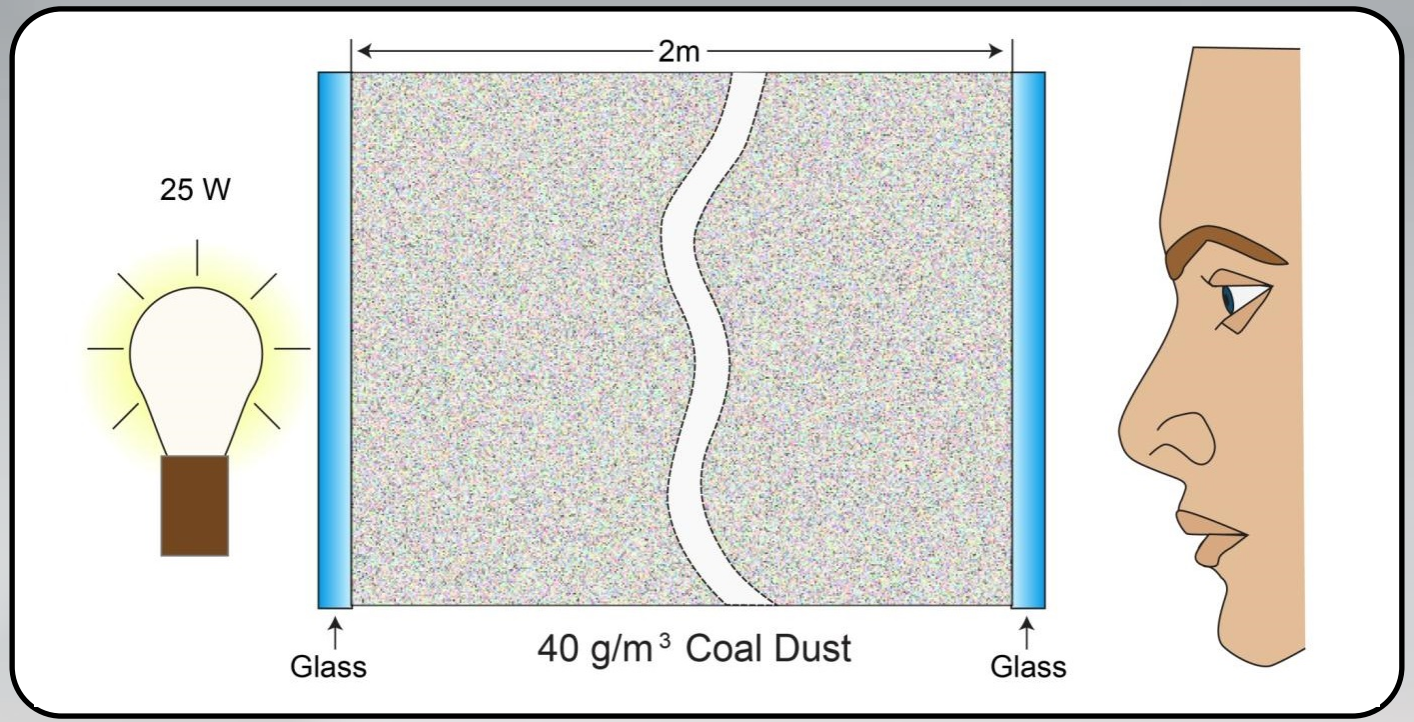
- Combustible dust
  - Small particle size
  - Oxidizable
- Oxidizer (e.g. air)
- Ignition source
- Dispersion of dust
- Confinement



Flash Fire vs. Explosion

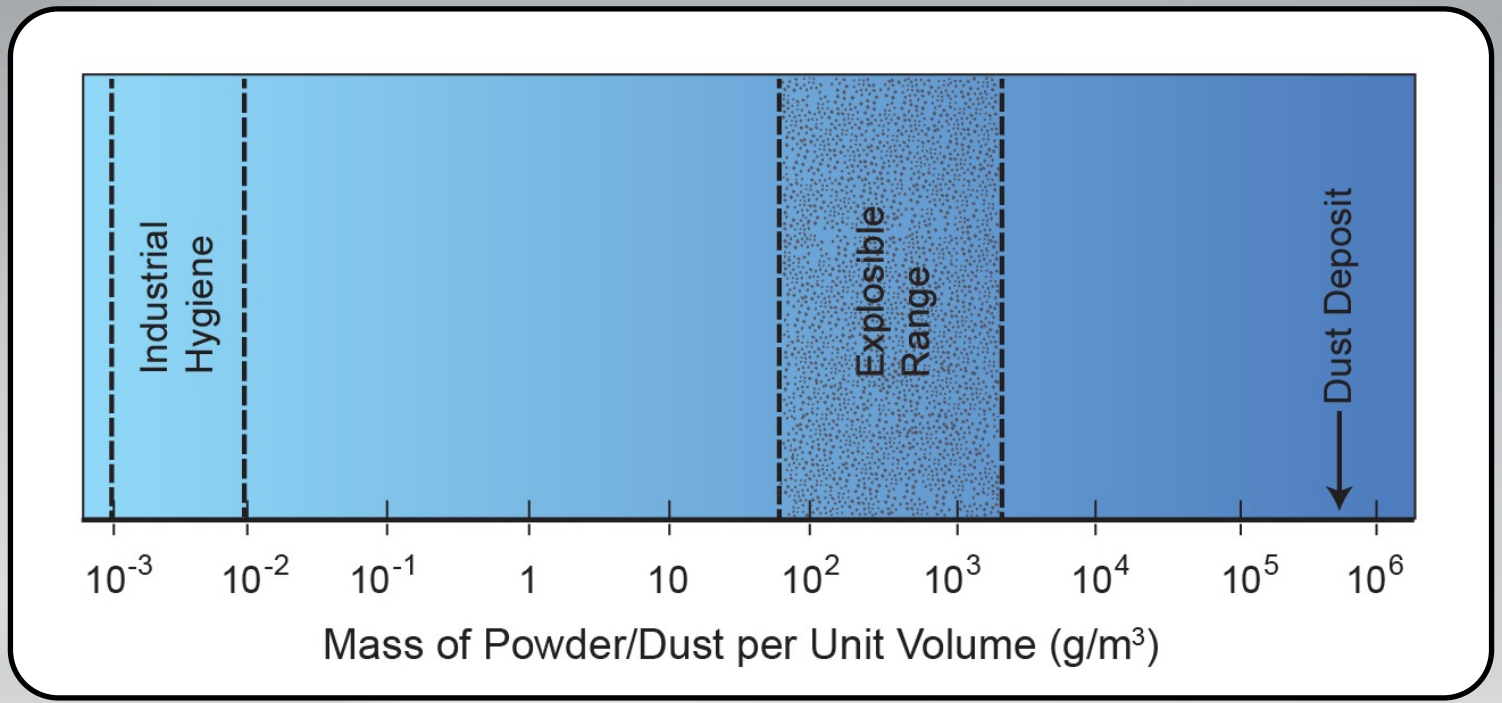
Demonstration – FM Global

Dust Concentration for Explosion Regime



Source: After Eckhoff, Dust Explosions in the Process Industries (2003).

Dust Concentration Regimes

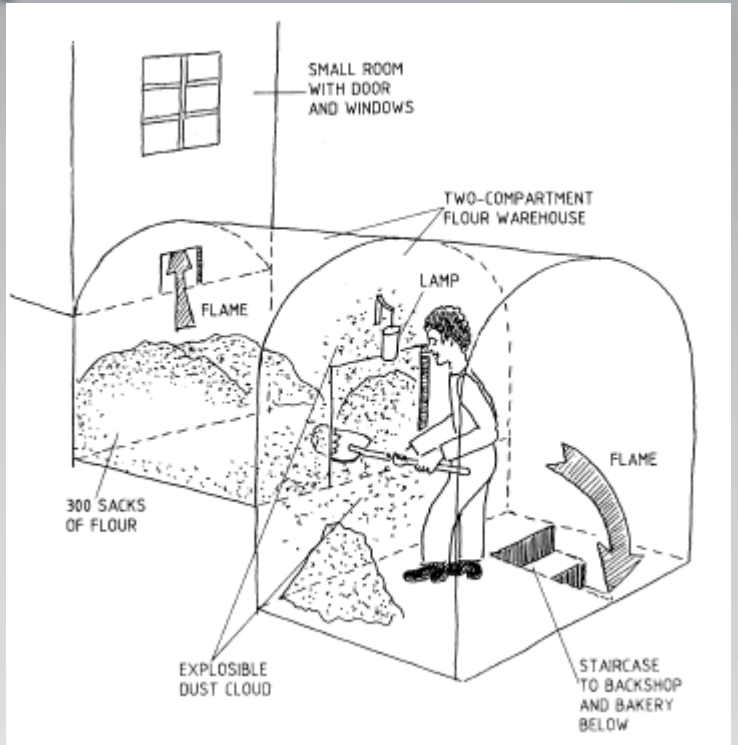


Source: After Eckhoff, Dust Explosions in the Process Industries (2003).

History of Dust Explosions and Current Emphasis

First Reported Dust Explosion

- Mr. Giacomelli's Bakery
- Turin, Italy
- December 14, 1785
- 2 injuries
- Blew out windows and window frames
- Reported cause: grain flour dust ignited by lamp



Source: Eckhoff, Dust Explosions in the Process Industries (2003).

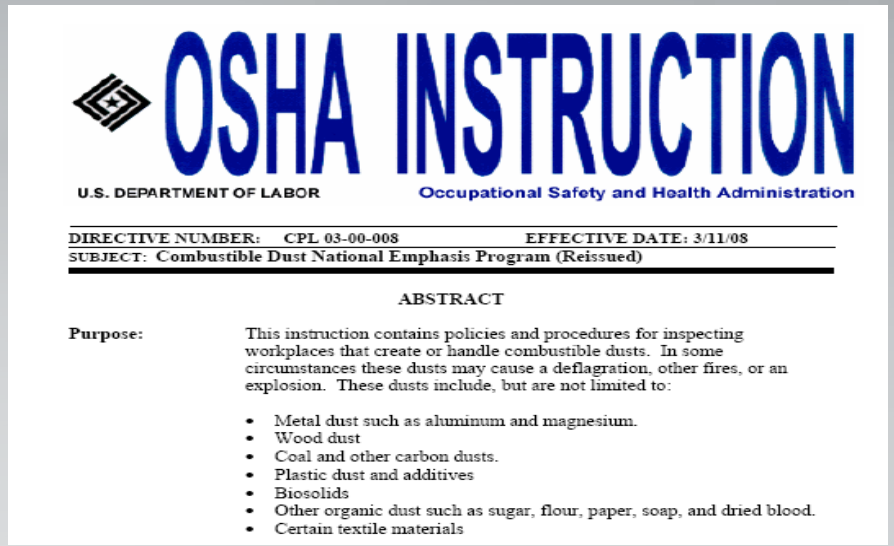

Two missing, 22 hurt in factory blast
LONDON, Kentucky (CNN) -- An explosion and fire at a plastics factory Thursday morning injured 22 workers and left at least two others unaccounted for, a state emergency official said.
Jahn Foundry
Massachusetts 1999
News
Firefighters douse blaze at rubber-recycling plant
By Sam Knowlton
Staff writer
Local News
E-mail this story to a friend.
Printer
2 dead, 3 missing in plant explosion
By Jason Spencer and Sandy Walls
The Free Press
At least two people were killed and three remained missing
after a massive explosion destroyed a pharmaceuticals factory
Kinston.
CTA Acoustics,
Corbin, KY, 2003
Rouse Polymerics,
Vicksburg, MS, 2002
West Pharmaceuticals, Kinston, NC, 2003

Recent U.S. Combustible Dust Incidents

Year	Facility	State	Dust	Fatalities
1999	Gray Iron Casting Foundry	MA	Phenolic Resin	3
2002	Rubber Recycling Facility	MS	Scrap Tire Grindings	5
2003	Rubber Drug Delivery Products	NC	Polyethylene Dust	6
2003	Fiberglass Insulation Plant	KY	Phenolic Resin	7
2003	Automotive Wheel Foundry	IN	Aluminum Dust	1
2008	Sugar Refinery	GA	Sugar	14
2011	Metal Powder Manufacturer	TN	Iron Dust	5?

Combustible Dust National Emphasis Program

- Effective October 18, 2007
  - Reissued March 11, 2008
- Outreach
- Targeted inspections
- NEP and other documents have listed OSHA regulations and NFPA Standards believed to apply to dust explosions



OSHA INSTRUCTION

U.S. DEPARTMENT OF LABOR — Occupational Safety and Health Administration

DIRECTIVE NUMBER: CPL 03-00-008 EFFECTIVE DATE: 3/11/08

SUBJECT: Combustible Dust National Emphasis Program (Reissued)

ABSTRACT

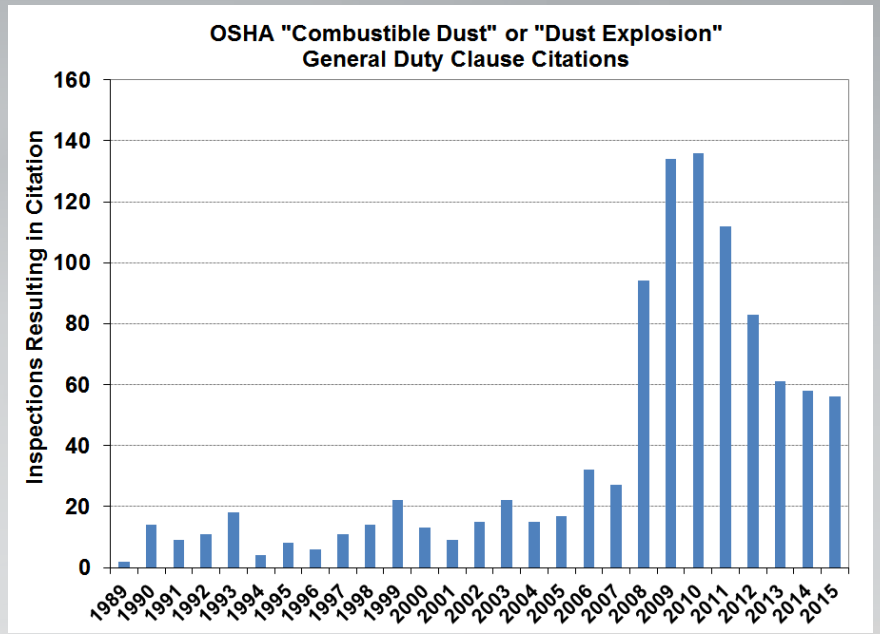
Purpose: This instruction contains policies and procedures for inspecting workplaces that create or handle combustible dusts. In some circumstances these dusts may cause a deflagration, other fires, or an explosion. These dusts include, but are not limited to:

- Metal dust such as aluminum and magnesium.
- Wood dust
- Coal and other carbon dusts.
- Plastic dust and additives
- Biosolids
- Other organic dust such as sugar, flour, paper, soap, and dried blood.
- Certain textile materials

OSHA Combustible Dust NEP Results

Appendix A
NFPA Publications Relevant to Combustible Dust Hazard Controls

NFPA Number	Title	Current Edition
61	Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities	2008
68	Guide for Venting of Deflagrations	2007
69	Standard on Explosion Prevention Systems	2008
70	National Electrical Code	2008
77	Recommended Practice on Static Electricity	2007
85	Boiler and Combustion Systems Hazards Code	2007
86	Standard for Ovens and Furnaces	2007
91	Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Noncombustible Particulate Solids	2004
484	Standard for Combustible Metals	2006
499	Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas	2008
654	Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids	2006
655	Standard for Prevention of Sulfur Fires and Explosions	2007
664	Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities	2007



Hazard Identification – Test Methods

Testing Required by Standards – NFPA 652

"5.1 Responsibility. The owner/operator of a facility with potentially combustible dusts shall be responsible for determining whether the materials are combustible or explosible, and, if so, for characterizing their properties as required to support the DHA."

Testing Required by Standards – NFPA 652

"5.2 Screening for Combustibility or Explosibility.*

5.2.1 The determination of combustibility or explosibility shall be permitted to be based upon either of the following:

(1) Historical facility data or published data that are deemed to be ***representative*** *of current materials and process conditions*

(2) Analysis of ***representative*** *samples in accordance with the requirements of 5.4.1 and 5.4.3"*

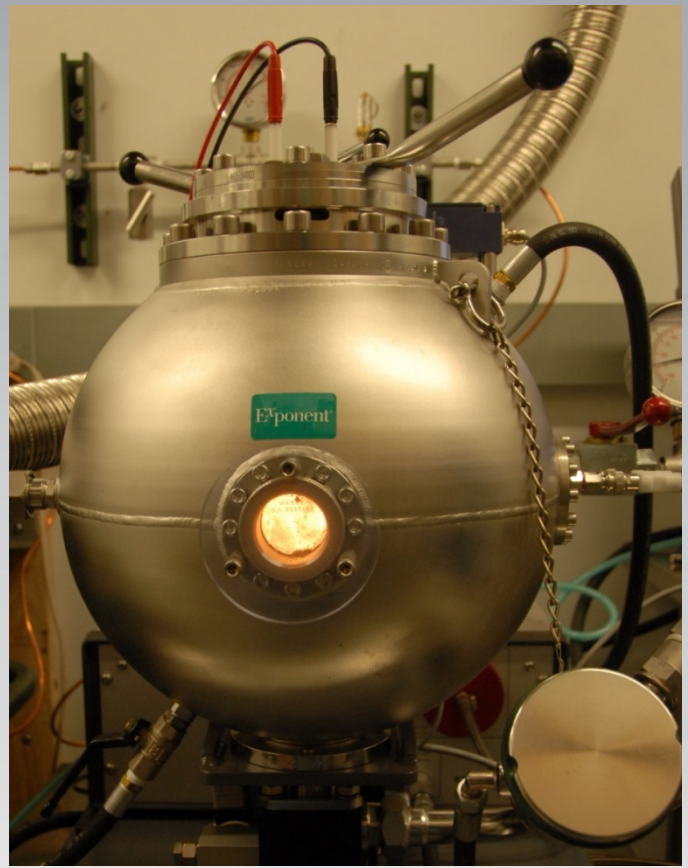
Trough Test – Is the Sample Combustible as a Dust Layer?

- Flame held to one end of powder train
- Material “combustible” if flame propagates past heated zone
- In practice only some samples that are “explosible” are also “combustible”

Go/No-Go Test – Is the Sample Explosible as a Dust Cloud

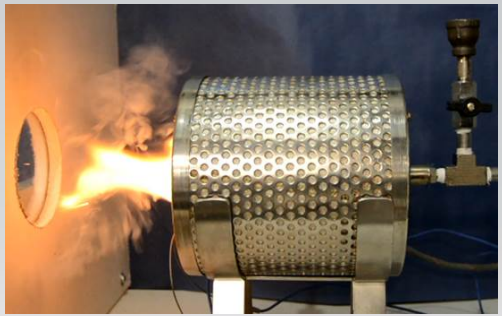
- Explosion pressure measured in closed volume
- 2.5-kJ to 10-kJ chemical igniters typically used
- Material explosible if the pressure ratio (PR) is greater than 2

$$PR = \frac{P_{ex} - \Delta P_{igniter}}{P_{ignition}}$$



Additional Common Test Methods

ASTM Method	Title	Results
E1226	Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts	P_{max}, K_{St}
E1515	Standard Test Method for Minimum Explosible Concentration of Combustible Dusts	MEC
E2019	Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air	MIE
E1491	Standard Test Method for Minimum Autoignition Temperature of Dust Clouds	MAIT
E2931	Standard Test Method for Limiting Oxygen (Oxidant) Concentration of Combustible Dust Clouds	LOC



Dust Hazard Analysis

Dust Hazard Analysis (DHA)

- NFPA 652 requires retroactive DHA for existing facilities within 3-year time period of the effective date of standard
  - Some commodity specific standards using 5-year time period
  - Next edition of 652 may extend time period
- Chapter 7 Provides details on DHA Methodology
  - Material Evaluation
  - Process Systems
  - Building or Building Compartments
- NFPA 652 App. B, NFPA 651 App. F include an example DHAs

Chapter 7 Dust Hazards Analysis (DHA)

7.1* General Requirements.

7.1.1 Responsibility. The owner/operator of a facility where materials that have been determined to be combustible or explosible in accordance with Chapter 5 are present in an enclosure shall be responsible to ensure a DHA is completed in accordance with the requirements of this chapter.

7.1.2* The requirements of Chapter 7 shall apply retroactively in accordance with 7.1.2.1 through 7.1.2.3.

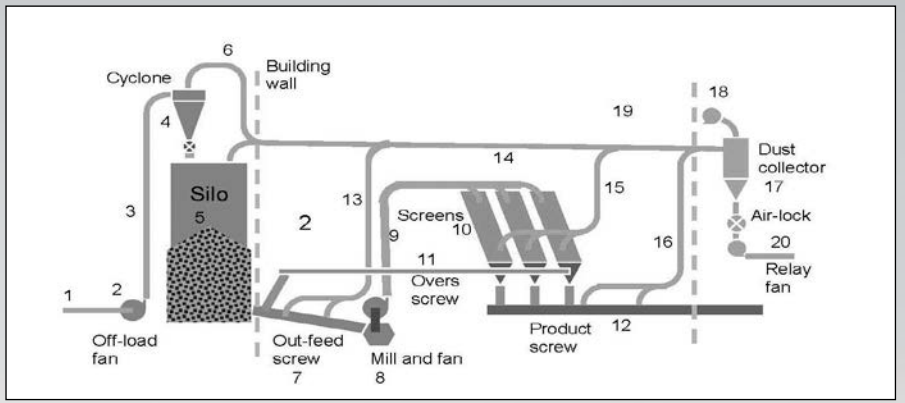
7.1.2.1 For existing processes and facility compartments that are undergoing material modification, the owner/operator shall complete DHAs as part of the project.

7.1.2.2* For existing processes and facility compartments that are not undergoing material modification, the owner/operator shall schedule and complete DHAs of existing processes and facility compartments within a 3-year period from the effective date of the standard. The owner/operator shall demonstrate reasonable progress in each of the 3 years.

7.1.2.3 For the purposes of applying the provisions of 7.1.2, material modification shall include modifications or maintenance and repair activities that exceed 25 percent of the original cost.

Dust Hazard Analysis (DHA)

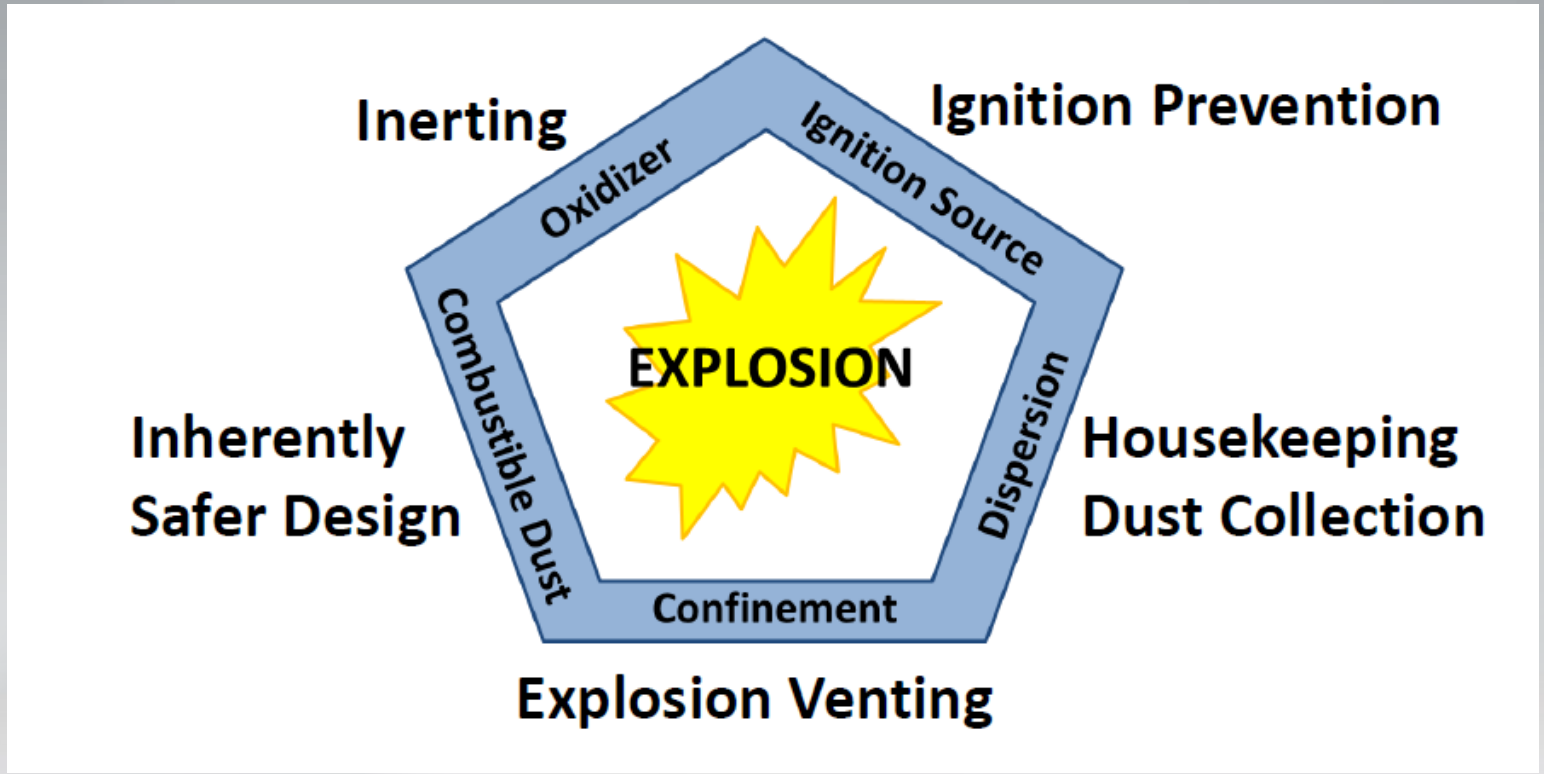
- Multiple methodologies can be used
  - Checklist, What-if, FMEA, HazOp, etc.
- Not intended to require PSM for all dusts



Source: NFPA 652

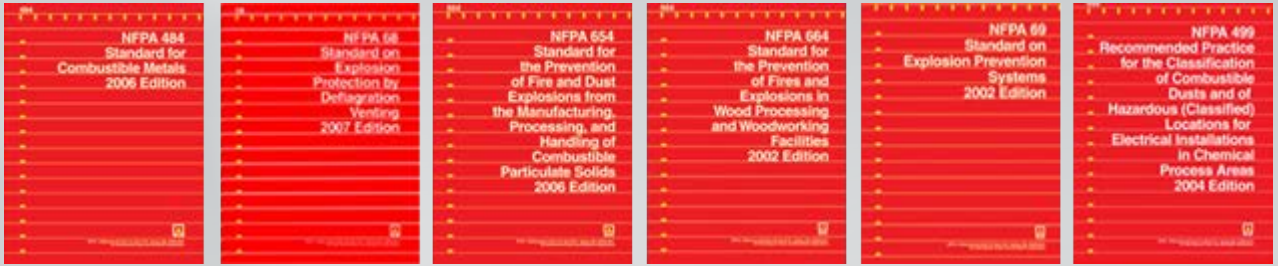
Mitigation Strategies

Eliminating Sides of the Pentagon



NFPA Standards

- OSHA citations and many building codes reference NFPA Standards.
- NFPA Standards include both prescriptive requirements and performance-based equivalent options
- Mitigation options need to be determined on a process by process basis. Standards require formal dust hazard analysis.



www.nfpa.org/??? i.e., www.nfpa.org/652

NFPA Standards for the Prevention of Dust Fires and Explosions

- NFPA 61 *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*
- NFPA 120 *Standard for Fire Prevention and Control in Coal Mines*
- NFPA 484 *Standard for Combustible Metals*
- NFPA 652 *Standard on Fundamentals of Combustible Dust*
- NFPA 654 *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*
- NFPA 655 *Standard for the Prevention of Sulfur Fires and Explosions*
- NFPA 664 *Standard of Fires and Explosions in Wood Processing and Woodworking Facilities*

Related NFPA Standards and Practices

- NFPA *68 Standard on Explosion Protection by Deflagration Venting*
- NFPA 69 *Standard on Explosion Prevention Systems*
- NFPA 70 *National Electric Code*
- NFPA 499 *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*
- NFPA 505 *Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations*

Other US Standards and Practices

- FM Global Data Sheets
  - 7-17 Explosion Protection Systems
  - 7-73 Dust Collectors and Collection System
  - 7-76 Prevention And Mitigation Of Combustible Dust Explosions And Fire
  - Industry Specific Standards
- Building and Fire Codes

NFPA 652 *Standard on the Fundamentals of Combustible Dust*

- New Standard - effective date September 7, 2015
- Intended to cover fundamental topics that apply to all types of dusts
- Applies in addition to commodity specific standards

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Relationship to Commodity Specific Standards

- Can follow commodity specific standard where it also covers requirement in 652
- Requirements in 652 that are prohibited by commodity specific standard are prohibited
- Where a commodity specific standard does not address requirement, must follow 652

1.4 Conflicts.

1.4.1* For the purposes of this standard, the industry- or commodity-specific NFPA standards shall include the following:

(1) NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*
(2) NFPA 484, *Standard for Combustible Metals*
(3) NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*
(4) NFPA 655, *Standard for Prevention of Sulfure Fires and Explosions*
(5) NFPA 664, *Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities*

1.4.2 Where a requirement in an industry- or commodity-specific NFPA standard differs from the requirement specified in this standard, the requirement in the industry- or commodity-specific NFPA standard shall be permitted to be used.

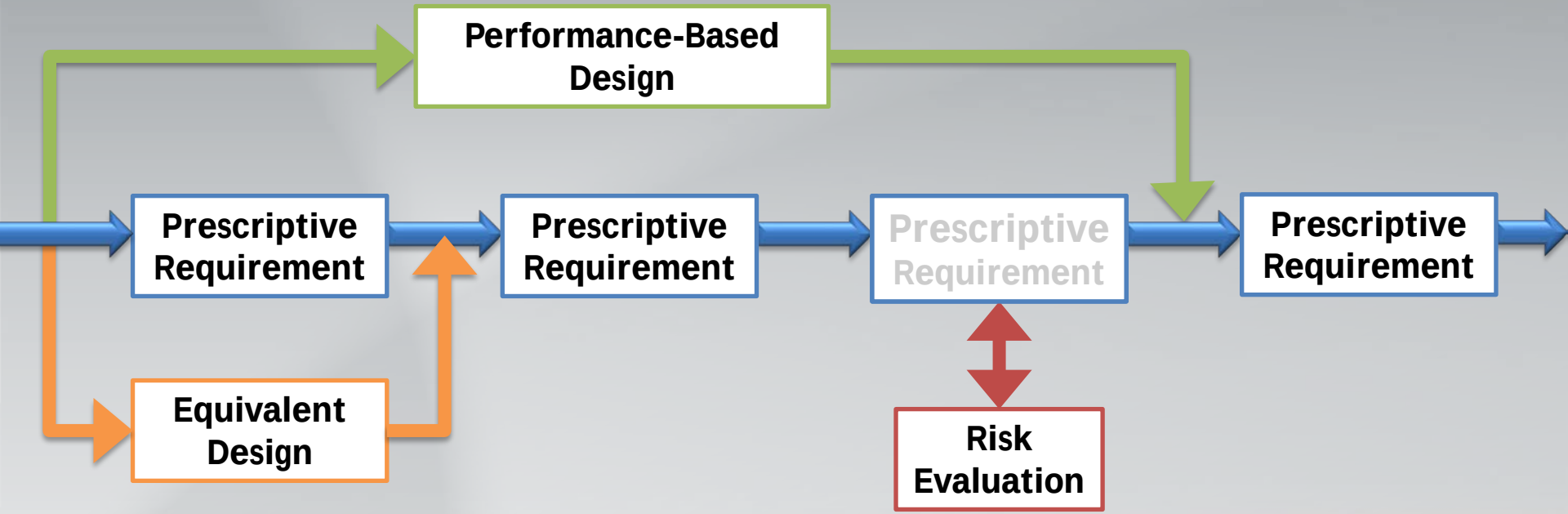
1.4.3 Where an industry- or commodity-specific NFPA standard specifically prohibits a requirement specified in this standard, the prohibition in the industry- or commodity-specific NFPA standard shall be applied.

1.4.4 Where an industry- or commodity-specific NFPA standard neither prohibits nor provides a requirement, the requirement in this standard shall be applied.

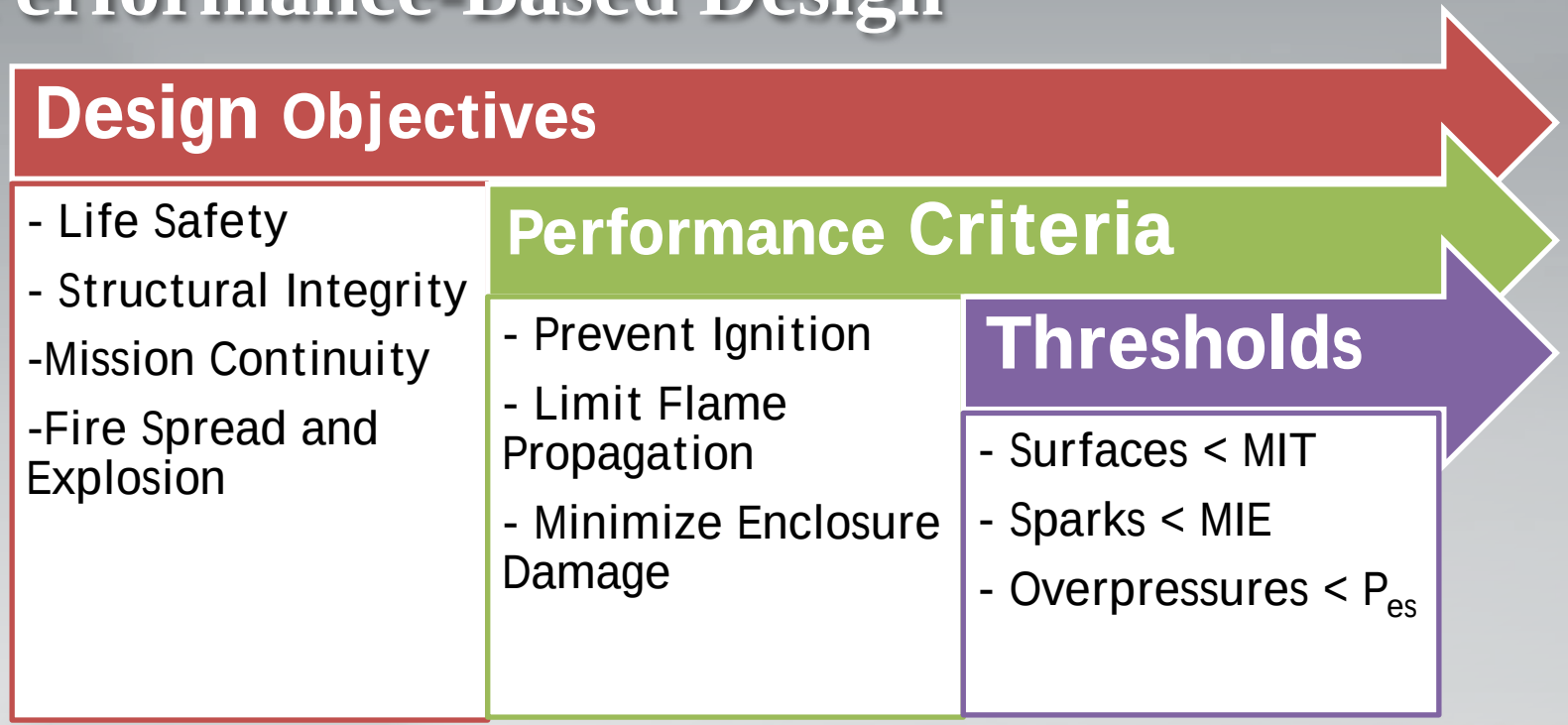
1.4.5 Where a conflict between a general requirement of this standard and a specific requirement of this standard exists, the specific requirement shall apply.

Alternate Protection Strategies

Alternate Protection Strategies



Performance-Based Design



Prescriptive Protection Methods

Areas of Guidance in NFPA Standards

- Dust Hazard Analysis
- Building construction
- Building explosion venting
- Equipment explosion protection
- Equipment isolation
- Bulk storage
- Material transfer systems
- Size reduction operations
- Segregation, separation, or detachment of hazard areas
- Particle size separation
- Mixers and blenders
- Dryers
- Dust collection equipment
- Fire protection
- **Housekeeping**
- **Management of change**
- **Control of ignition sources**
- **Employee training, inspection, and maintenance**

Items in bold apply retroactively

Minimizing Dust Accumulations

- Dust accumulations can allow small event to become catastrophic
- Minimize escape of dust from equipment
  - Operate equipment at negative pressure
  - Maintain equipment seals
- Use dust collection systems in dust generation areas
- Frequent housekeeping to remove dust accumulations before they reach hazardous levels
- Do not neglect elevated surfaces or other difficult to reach areas

Combustible Dust Accumulation Thresholds

Standard	Combustible Dust Accumulation Threshold
NFPA 484 (Metal)	Color of underlying surfaces not discernible
NFPA 654 (General)	1/32” over 5% or 1000 ft^2
NFPA 664 (Wood)	1/8”
NFPA 499 (Electrical Classification Class II Division 1)	1/8”
NFPA 499 (Electrical Classification Class II Division 2)	Color of underlying surfaces not discernible

Dust Layer Accumulation Threshold Evaluation Methods in NFPA 654

6.1.1.3* Dust flash fire or dust explosion hazard areas shall additionally be determined in accordance with any one of the following four methods:

(1) Layer depth criterion method in 6.1.3
(2) Mass method A in 6.1.4
(3) Mass method B in 6.1.5
(4) Risk evaluation method in 6.1.6

Housekeeping

- Establish regular cleaning frequencies to maintain dust accumulations below hazard thresholds
  - Consider quantifying material cleaned
- Using cleaning methods that minimize generation of clouds
  - Vacuuming with vacuums approved for combustible dust and classified area
  - Gentle sweeping
- Vigorous sweeping, blow down or steam should only be used after vacuuming and
  - Elimination of ignition sources
  - Use low supply pressure (<15 psig)

Ignition Source Control

- Sparks (friction, electrical, static electricity)
  - Proper grounding, bonding
- Hot surfaces
- Hot work
- Open flames
- Heating systems
- Slipping belts
- Bearings
- Electrical Equipment (NFPA 499, 70)

Electrical Classification – NFPA 499

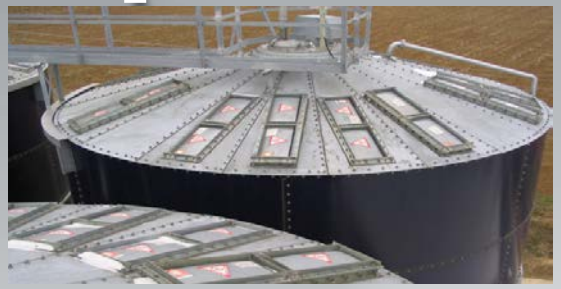
- Areas with combustible dust may be classified as Class II (dust) Division 1 or 2 by OSHA and NFPA 499 and 70
  - Classified electrical equipment should be used (NFPA 70 – NEC)
  - Classified industrial trucks (fork lifts) should be used (NFPA 505)
- Good housekeeping, prevention of dust releases and partitions, can reduce extent of classified areas

Unclassified Areas – NFPA 499 Chapter 6

Electrical Classification	Ignitable Dust Presence
Class II, Division 1 or Zone 20/21	Dust clouds during normal conditions or > 1/8” accumulation
Class II, Division 2 or Zone 22	Dust clouds during abnormal conditions or color of underlying surfaces not discernible
Unclassified	No visual dust clouds Color of underlying surfaces discernible

- The term *normal* does not necessarily mean the situation that prevails when everything is working properly.
- The term *abnormal* is used here in a limited sense and does not include a major catastrophe.

Explosion Protection



7.1.4 Explosion Protection for Equipment.

7.1.4.1 The design of explosion protection for equipment shall incorporate one or more of the following methods of protection:

(1) Oxidant concentration reduction in accordance with NFPA 69, *Standard on Explosion Prevention Systems*
   (a) Where oxygen monitoring is used, it shall be installed in accordance with ISA 84.00.01, *Functional Safety: Application of Safety Instrumented Systems for the Process Industry Sector.*
   (b) *Where the chemical properties of the material being conveyed require a minimum concentration of oxygen to control pyrophoricity, that level of concentration shall be maintained.

(2) *Deflagration venting in accordance with NFPA 68, *Standard on Explosion Protection by Deflagration Venting*

(3) Deflagration pressure containment in accordance with NFPA 69, *Standard on Explosion Prevention Systems*

(4) Deflagration suppression systems in accordance with NFPA 69, *Standard on Explosion Prevention Systems*

(5) *Dilution with a noncombustible dust to render the mixture noncombustible *(See 7.1.4.2.)*

(6) *Deflagration venting through a listed dust retention and flame-arresting device

No Protection

Source: Rembe

Deflagration (Explosion) Vents

- NFPA 68 provides equations for determining required explosion vent areas
- Vent reduces maximum overpressure
- Typically lower cost than explosion suppression systems
- Must vent to restricted outdoor area
- Flame Arresting and Particulate Retention (Flameless) vents can be used indoors

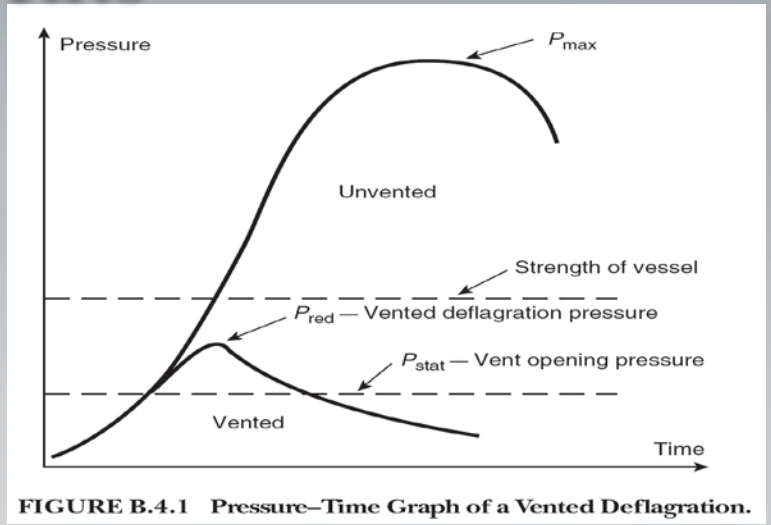
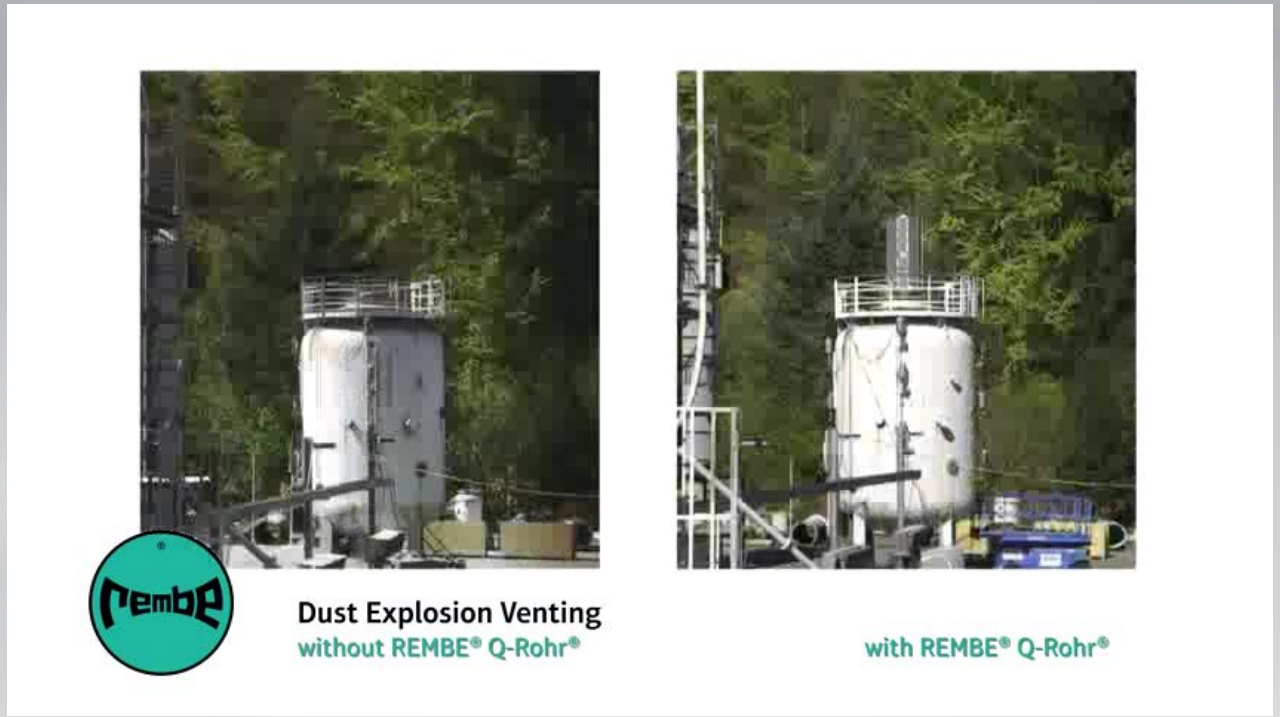


FIGURE B.4.1 Pressure–Time Graph of a Vented Deflagration.

Undersized Vent

Source: Rembe

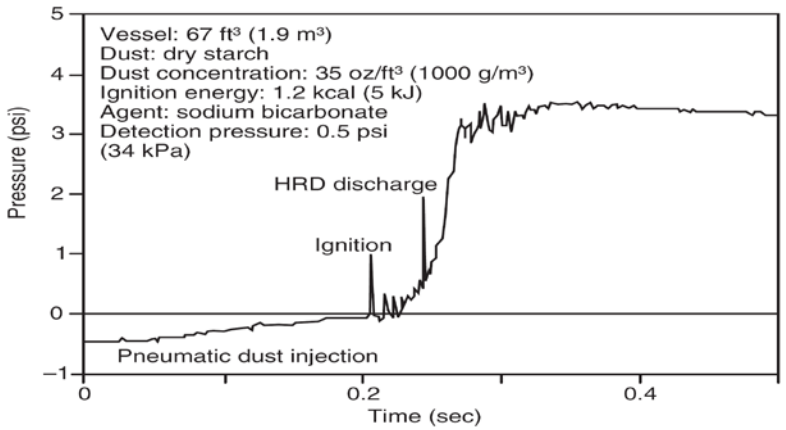
Explosion Venting



Source: Rembe

Deflagration Suppression – NFPA 69

- Detection of explosion
  - Pressure rise
  - Spark/flame detection
- Suppression
  - Fast injection of chemical suppressants
- Can typically minimize explosion overpressure to a few psi
- Often used when explosion venting is not feasible
- Typically more expensive than venting



Note: Pressures are gauge pressures.

FIGURE B.5.1(b) Pressure Versus Time in a Suppressed Deflagration.

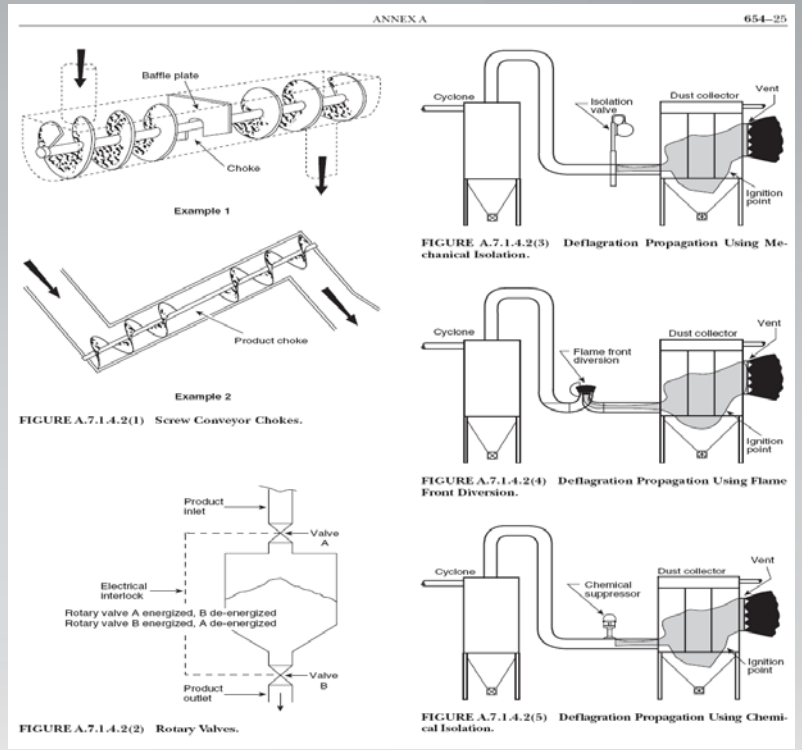
Source: Plot from NFPA 654-2006

Deflagration Suppression – Slow Motion

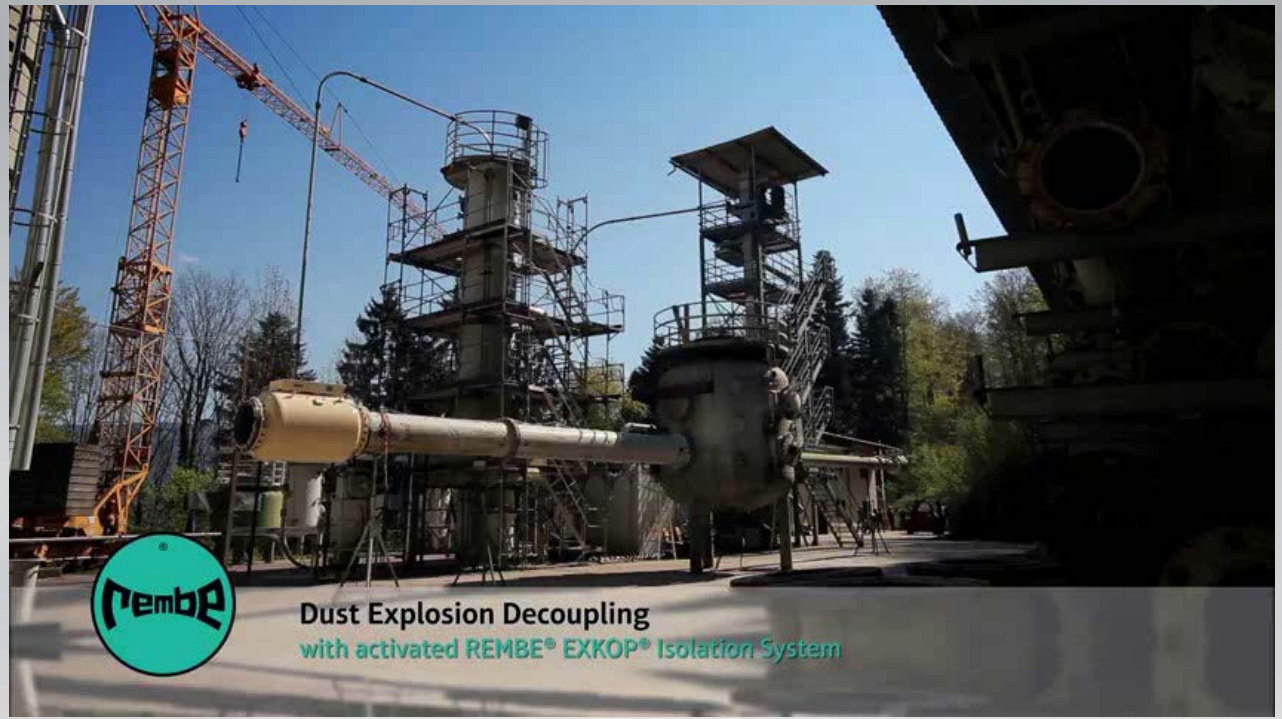
Source: Fike Corporation

Equipment Isolation – NFPA 654

- Prevent propagation of fire or deflagration between connected equipment
- Mechanical chokes
- Rotary valves
- Fast acting valves
- Flame front diverters
- Chemical suppressors



Explosion Isolation



Source: Rembe

Summary

- Catastrophic dust explosions have placed an increased emphasis on the prevention and mitigation of dust explosions.
- Standards and guidelines provide guidance for the prevention and mitigation of dust fires and explosions.
- NFPA guidelines for preventing and mitigating explosions focus on:
  - Hazard Identification
  - Dust Hazard Analysis
  - Mitigation Methods
  - Housekeeping and dust collection
  - Removal of ignition sources
  - Explosion protection of equipment
  - Maintenance and training

Exponent®

Dust Explosions

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