Combustible Dust – Understanding Hazard Analysis, Mitigation, and the Current Industry Standard of Care

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Presentation Agenda

Fundamentals of Combustible Dust

- Review lost history and fundamentals of fire, flash fire, and explosion hazards

Current Regulatory Framework

- Present current and upcoming code requirements and NFPA standards

------Break------

Dust Hazard Analysis (DHA)

- Introduce DHAs and discuss what must be included
- DHA examples and case studies

------Break------

Hazard Management

- Discuss methods for prevention and mitigation

Questions and Interactive Discussion

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Fundamentals of Combustible Dust

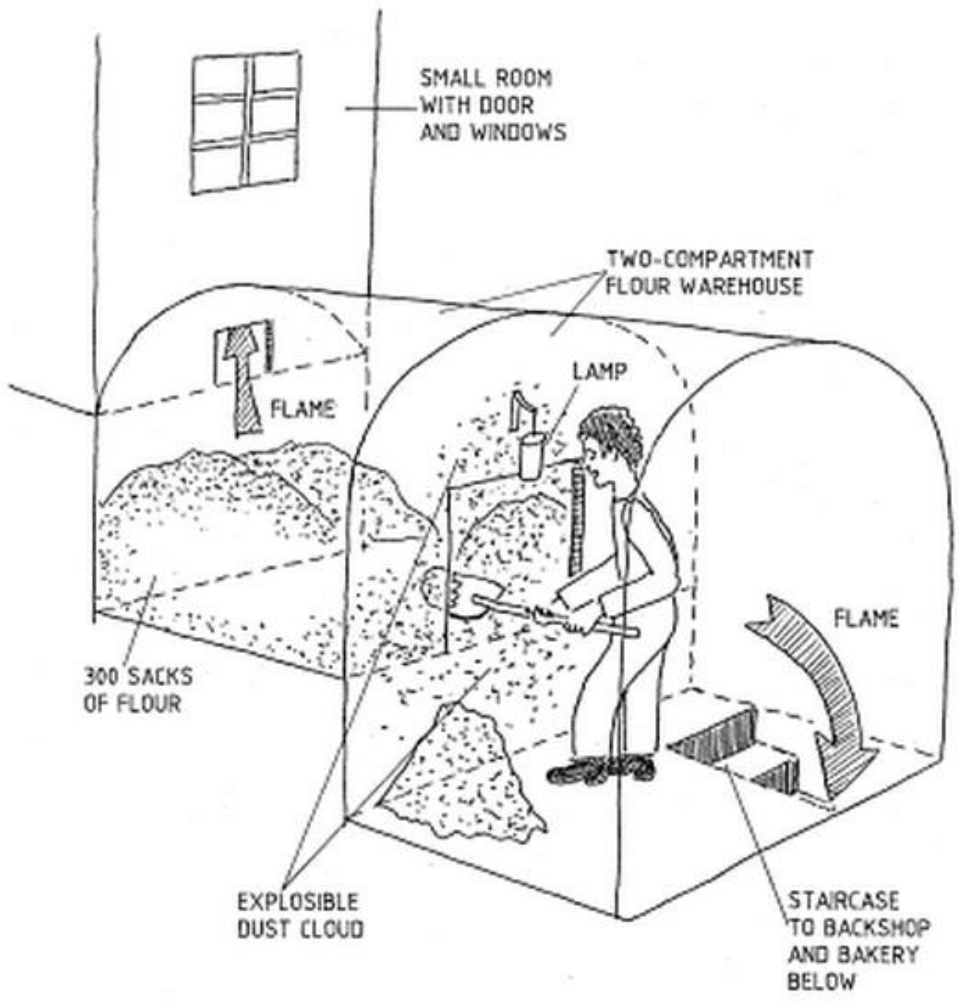
What industries generate and handle combustible dust?

Fundamentals of Combustible Dust

What's the risk? A review of loss history.

Explosion in a flour warehouse, Turin Italy, 1785

- Early documented combustible dust explosion
- Long period of dry weather
- Worker shoveling flour to chamber below warehouse
- Large volume of flour fell and was ignited by lamp
- Secondary explosion occurred in warehouse causing bakery windows to blow out
- Owner of bakery familiar with similar incidents



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Fundamentals of Combustible Dust

What's the risk? A review of loss history.

Imperial Sugar, Georgia, 2008

- Killed 14 workers and injured 36 others
- Fire explosion occurred in an enclosed conveyor located beneath sugar silos
  - Likely due to overheated bearing
- Primary explosion dislodged dust that had accumulated on surfaces causing secondary explosions throughout the complex

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Fundamentals of Combustible Dust

What's the risk? A review of loss history.

New Taipei Water Park Deflagration, Taiwan, 2015

- Colored corn starch sprayed into the crowd using blowers and compressed air canisters
- Dust cloud ignited near stage, possibly from lighting or smoking materials
- Aftermath resulted in 15 deaths and 496 injuries

Fundamentals of Combustible Dust

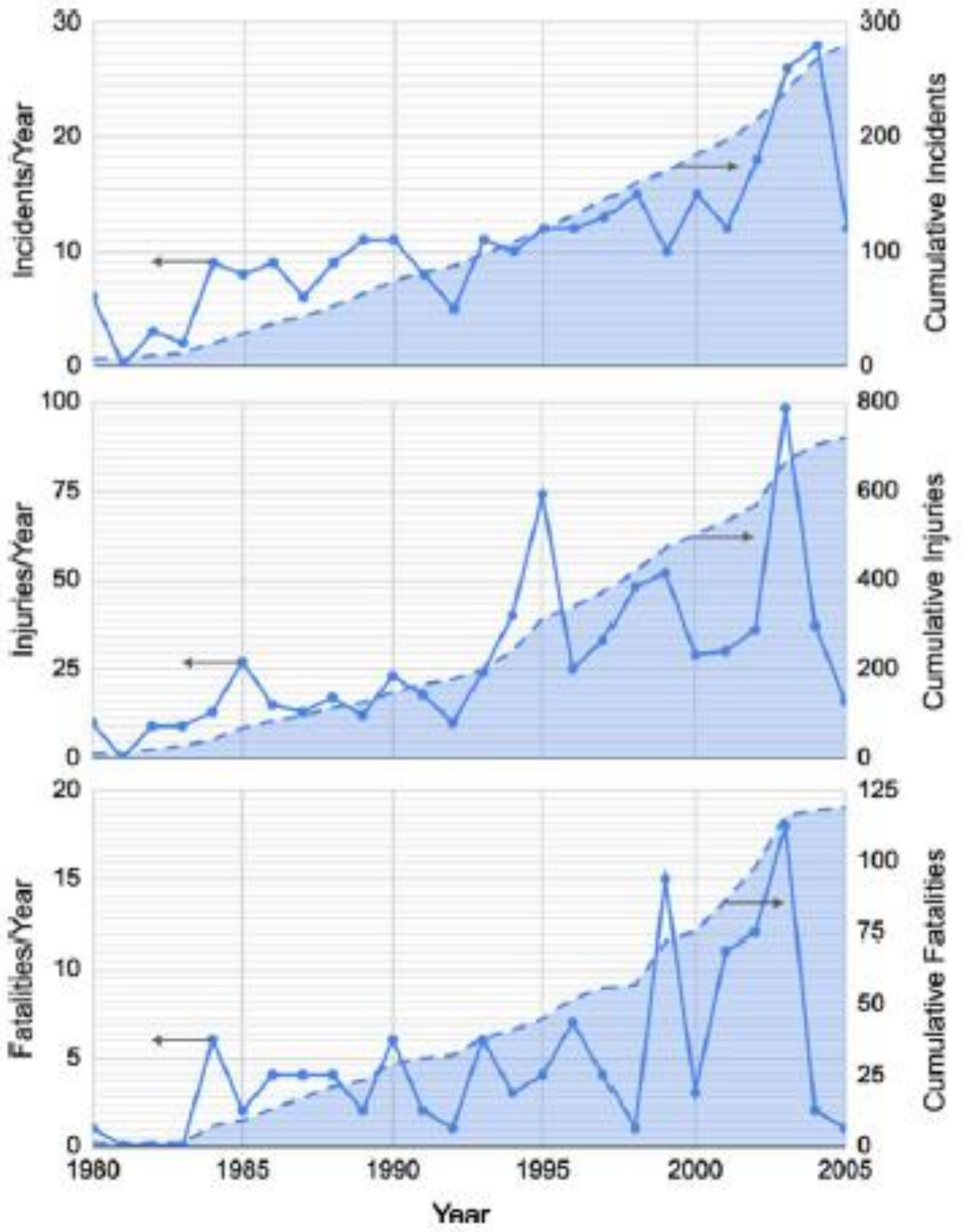
What's the risk? A review of loss history.

Didion Milling Company Explosion and Fire, Wisconsin, 2017

- Explosion occurred in dry corn milling facility
- Primary explosion likely originated in milling equipment and was followed by several secondary explosions
- Five fatalities and 14 injuries

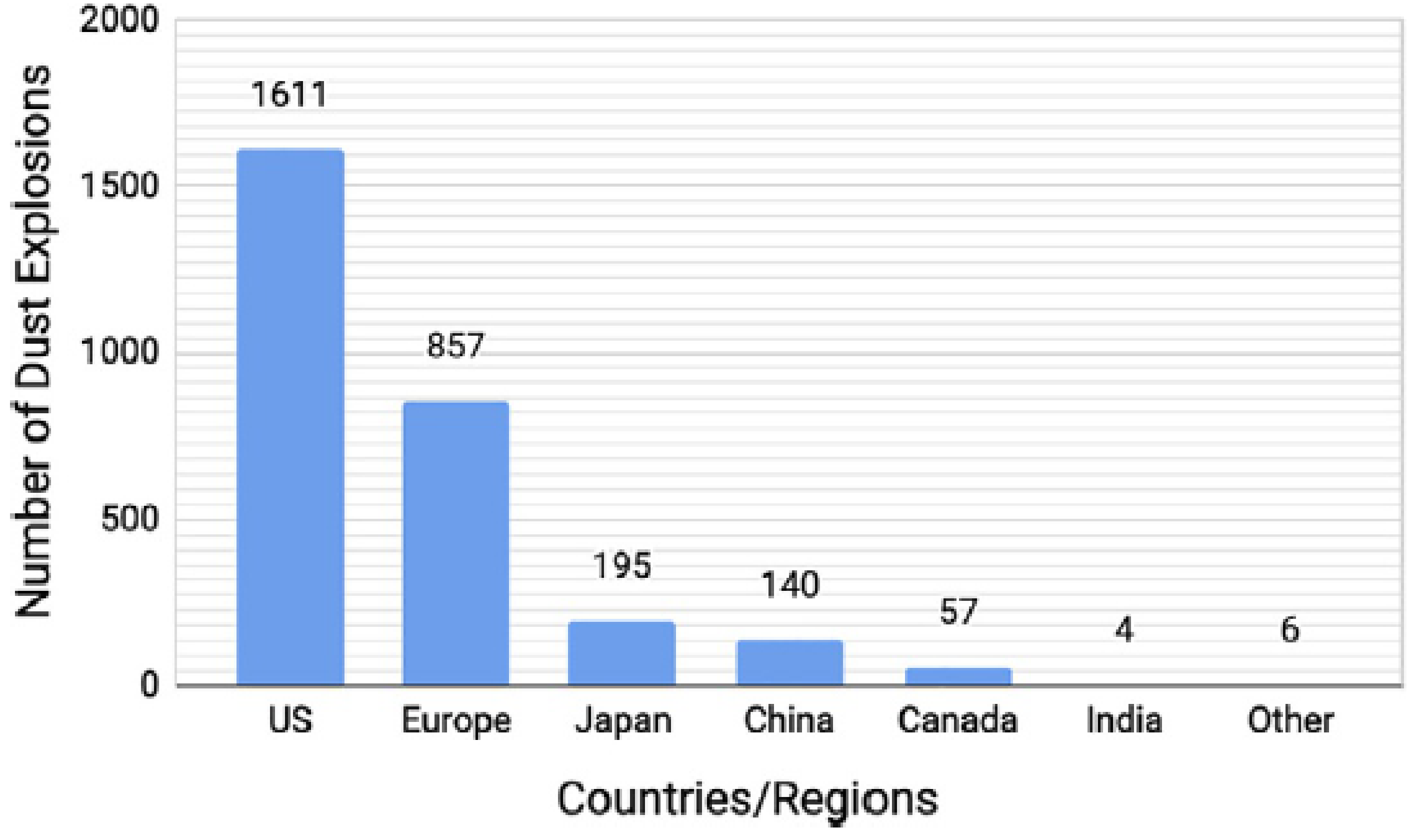
Fundamentals of Combustible Dust

What's the risk? A review of loss history.



Dust explosion incidents documented by the CSB between 1980 and 2005: *Methods in Chemical Process Safety – Volume 3 Dust Explosions*

Reported dust explosions from 1785 to 2012 from: *Methods in Chemical Process Safety – Volume 3 Dust Explosions*



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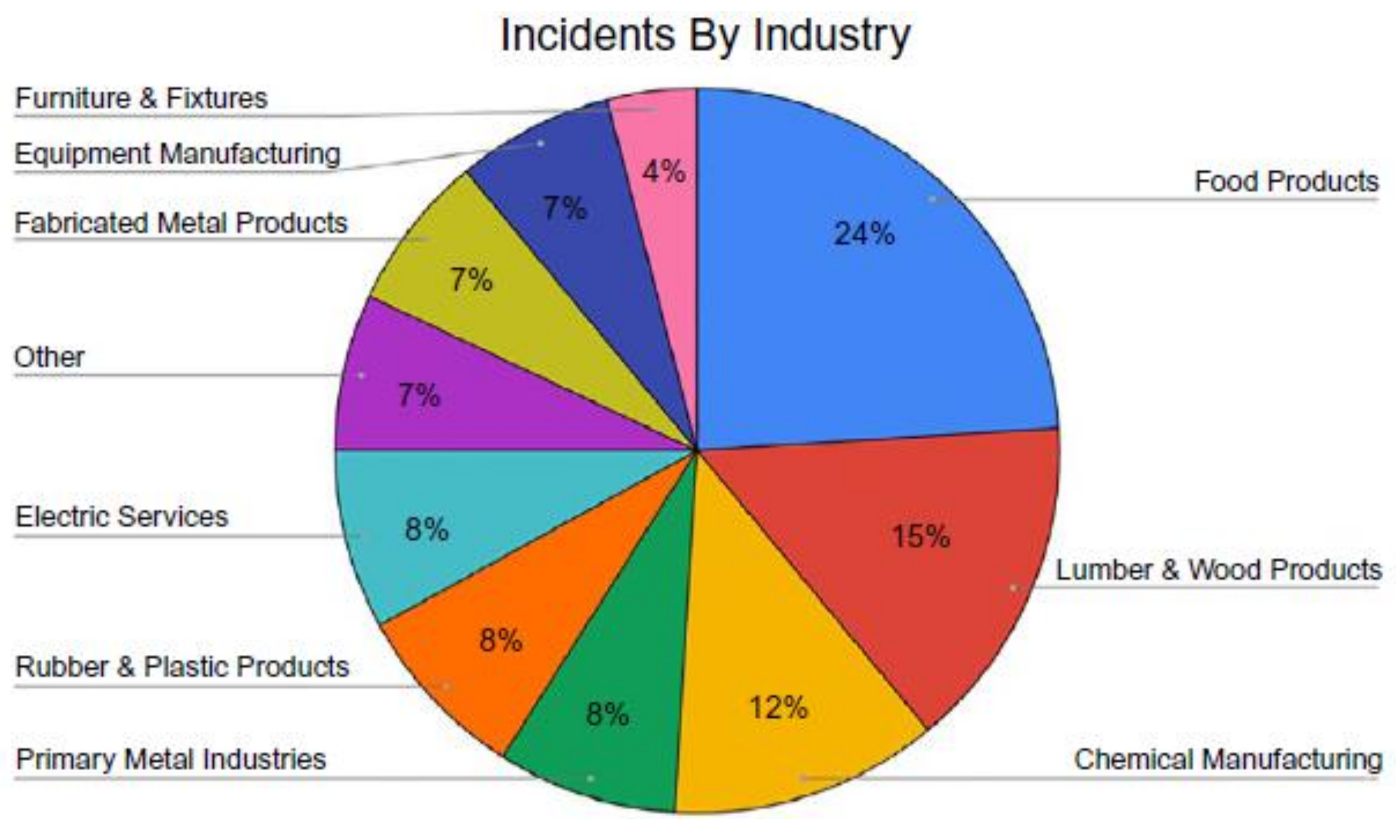

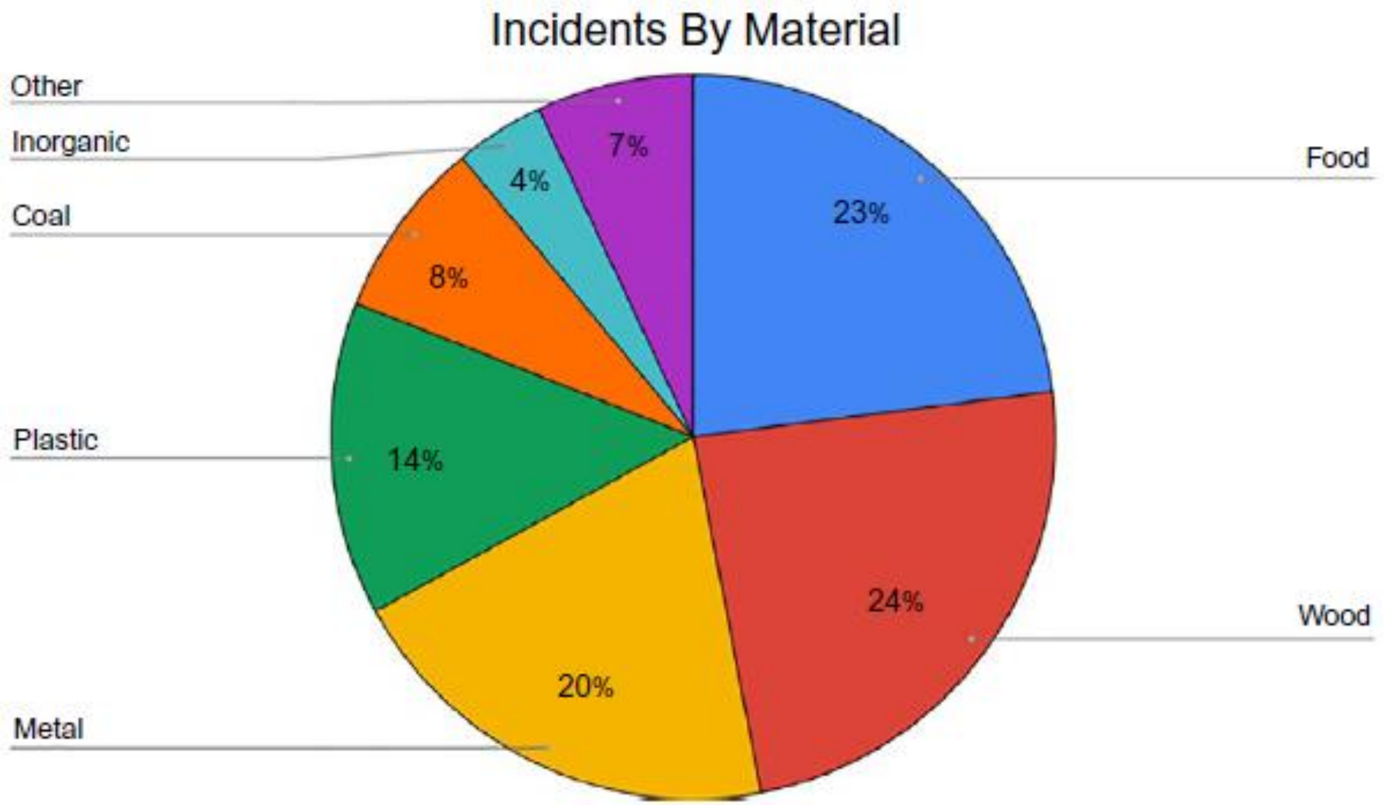

Breakdown of dust explosion incidents between 1980 and 2005:
Methods in Chemical Process Safety – Volume 3 Dust Explosions

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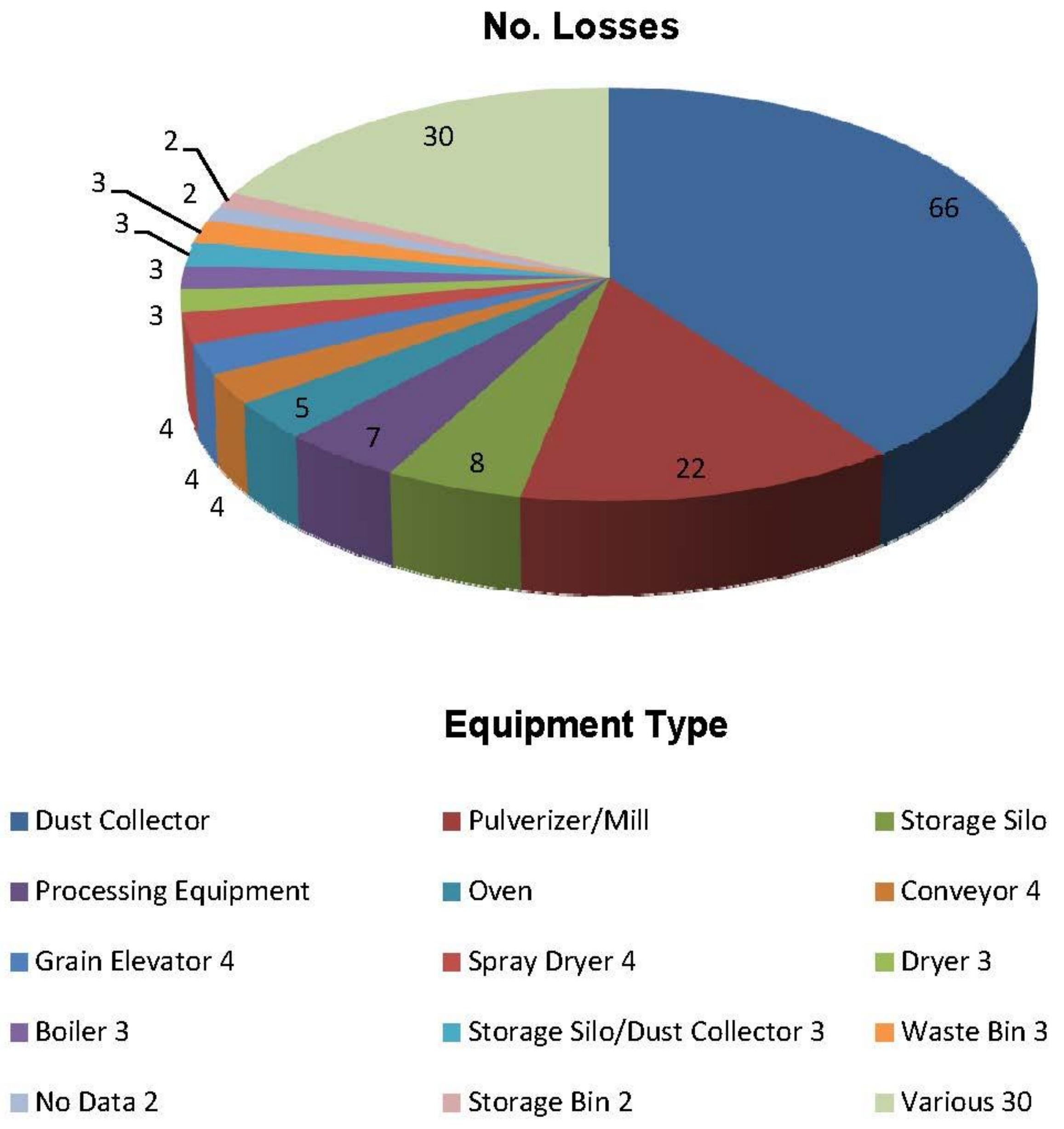
What's the risk? A review of loss history.



Breakdown of equipment involved in dust explosions from 1983 and 2006: FM Data Sheet 7-76, "Table 6. Losses by Equipment Type," *FM Global Property Loss Prevention Data Sheets*, Factory Mutual Insurance Company, January 2012, pg. 38.

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Fundamentals of Combustible Dust

Conditions Necessary for an Explosion

Combustible dust (fuel)

- Finely divided combustible particulate that propagates a deflagration

Oxygen

- Present in air

Dispersion

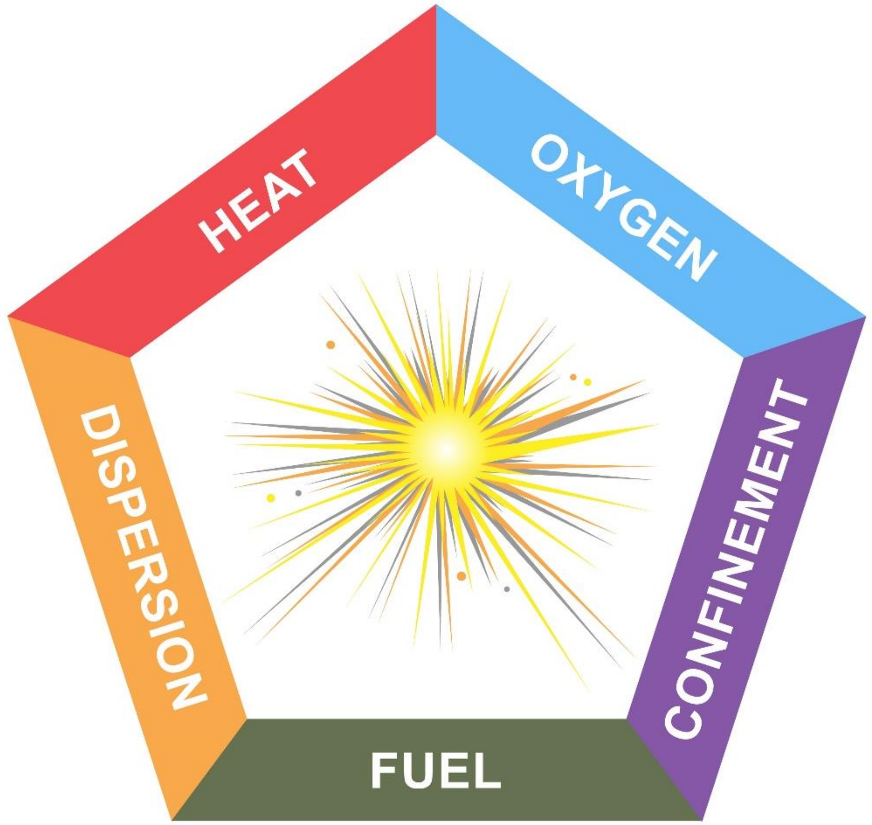
- Dust dispersed in air above in sufficient concentration

Ignition Source

- Ignition source has enough energy to ignite dust

Confinement

- Compartment / vessel ruptures due to overpressure



Explosion Pentagon

Fuel + Oxygen + Ignition = Fire

Fuel + Oxygen + Ignition + Dispersion = Flash Fire

Fuel + Oxygen + Ignition + Dispersion + Confinement = Explosion

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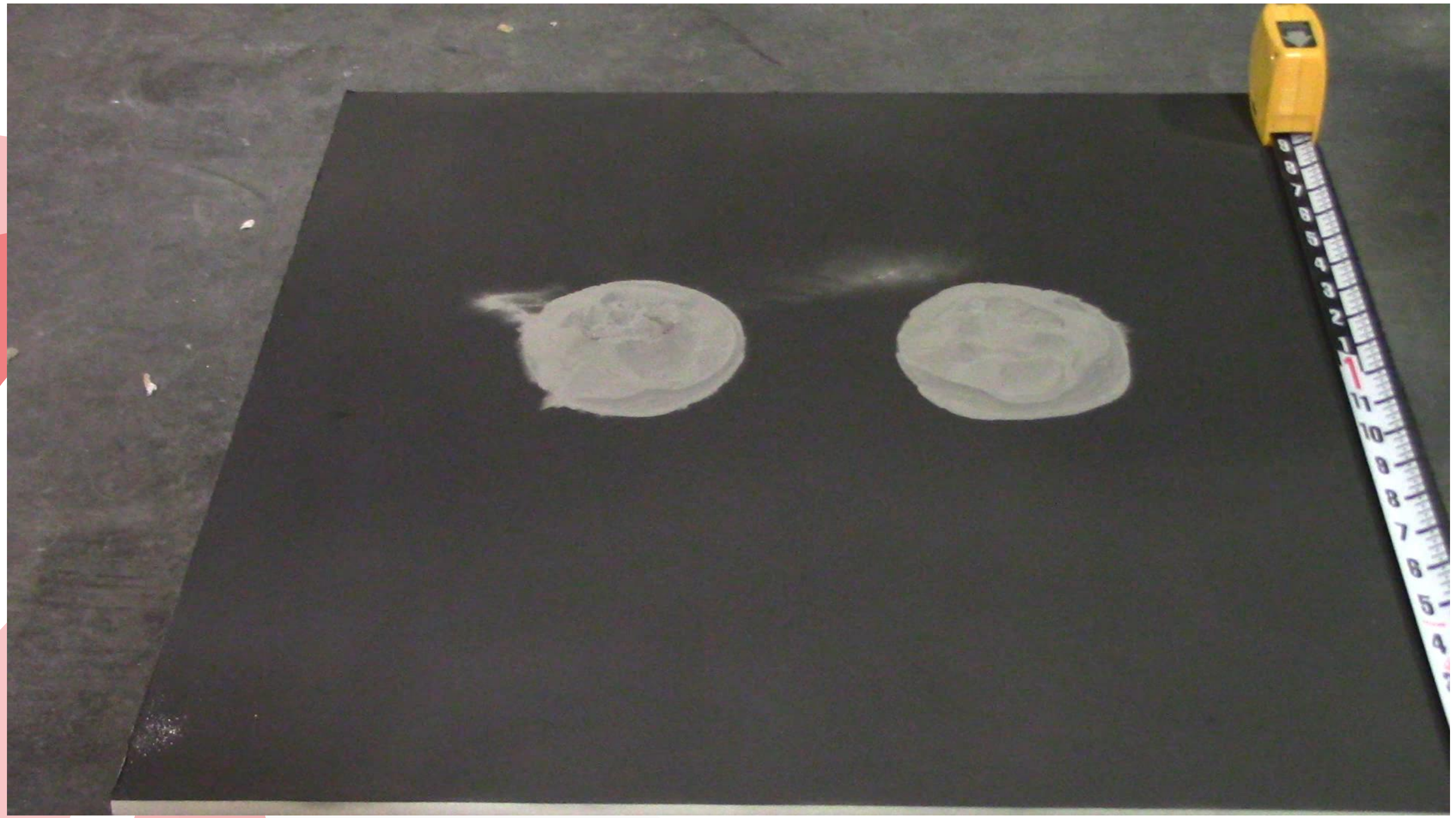
Fundamentals of Combustible Dust

Dust Fire

Titanium dust, ¼ inch thick



MDF wood fiber, ¼ inch thick

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Fundamentals of Combustible Dust

Dust Deflagration (Flash Fire)

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Fundamentals of Combustible Dust

Dust Explosion

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Fundamentals of Combustible Dust

Combustible Particulate Solids (CPS)

- Any combustible solid material composed of distinct particles or pieces regardless of size, shape, or chemical composition
  - Dusts, fines, fibers, flakes, chips, chunks, or mixtures of these
- Whenever CPS are produced, processed, handled, or conveyed, fine particles will break off
- All CPS should be expected to contain some amount of combustible dust
  - Fines generally do not remain mixed with course particulate




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Fundamentals of Combustible Dust

Particulate Size

Rate of combustion depends on particle size

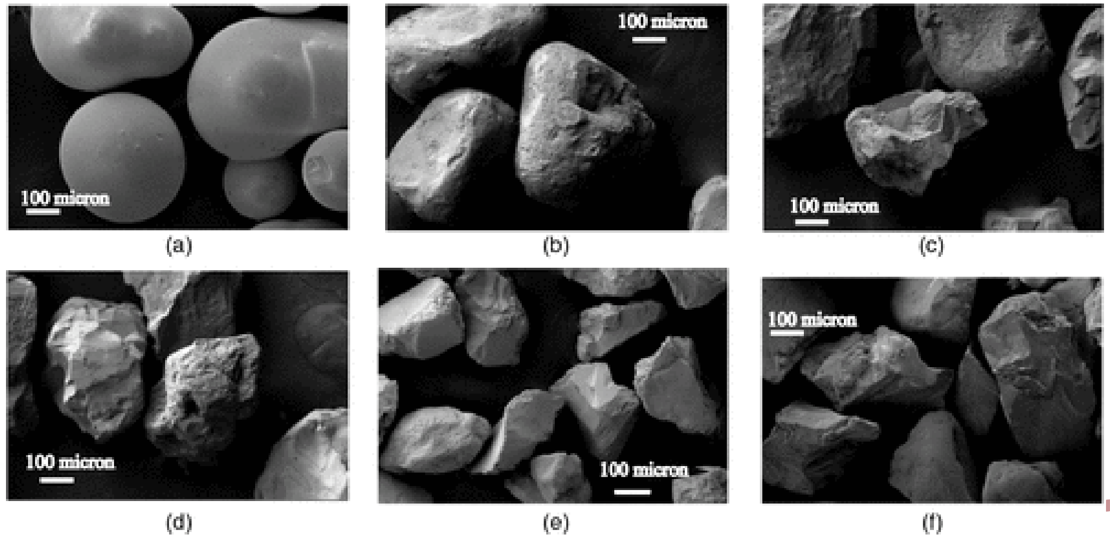
- Distribution of particle size, particle morphology

When the average particle size is small enough, flame propagation can occur

- Traditionally defined as 420 microns or smaller (US No. 40 standard sieve)
- Ordinary granulated sugar is 75% sub 420 micron

New definitions focus on testing versus particle size alone

- Dust determined to be explosible / deflagrable via testing
- Median particle size of 500 microns or higher may be explosible in some cases



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Fundamentals of Combustible Dust

Standardized Dust Testing

Table 1: Dust explosibility parameters.

Parameter	Apparatus	Description	Test method
P_{max}	20-L Siwek	Maximum explosion pressure in a constant-volume explosion	ASTM E1226
$(dP/dt)_{max}$	20-L Siwek	Maximum rate of pressure rise in a constant-volume deflagration	ASTM E1226
K_{St}	20-L Siwek	Volume-normalized (standardized) maximum rate of pressure rise in a constant-volume deflagration	ASTM E1226
MEC	20-L Siwek	Minimum explosible (or explosive) dust concentration	ASTM E1515
MIE	Modified Hartmann	Minimum ignition energy of a dust cloud (electric spark)	ASTM E2019
MIT	Godbert-Greenwald furnace	Minimum ignition temperature of a dust cloud	ASTM E1491
LIT	Hot plate	Minimum ignition temperature of a dust layer or dust deposit	ASTM E2021
LOC	20-L Siwek	Limiting oxygen concentration in the atmosphere for flame propagation in a dust cloud	ASTM E2931
Volume resistivity	Charge decay test unit	DC resistance or conductance of insulating materials	ASTM D257

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Fundamentals of Combustible Dust

Standardized Dust Testing

Parameter	Description (unit)	Typical Application
P_{max}	Maximum explosion pressure (bar)	Design of explosion protection systems and consequence analysis. $K_{St} > 0$ indicates a potential flash fire and/or explosion hazard.[1]
K_{St}	Deflagration index (bar-m/s)	
MEC	Minimum explosible concentration (g/m^3)	Dust hazard analysis and forensic analysis of flash fires and explosions.
MIE	Minimum ignition energy (mJ)	Measure of ignition sensitivity most relevant to electrostatic discharge and other types of sparks.
MIT	Minimum dust cloud ignition temperature	Measure of ignition sensitivity most relevant to large heated surfaces, elevated process temperatures, and mechanical sparks. Also applied to determine thresholds for equipment temperatures in hazardous areas.
LIT	Dust layer ignition temperature	Evaluating surface temperature limits to prevent dust layer ignition. Applied to determine thresholds for equipment temperatures in hazardous areas.
SIT	Self-ignition temperature	Evaluating the propensity for self-heating leading to spontaneous ignition. Applied for evaluation of bulk storage enclosures.

[1.] Testing low K_{St} / P_{max} dusts in the cubic meter apparatus may indicate dusts are non-explosible.

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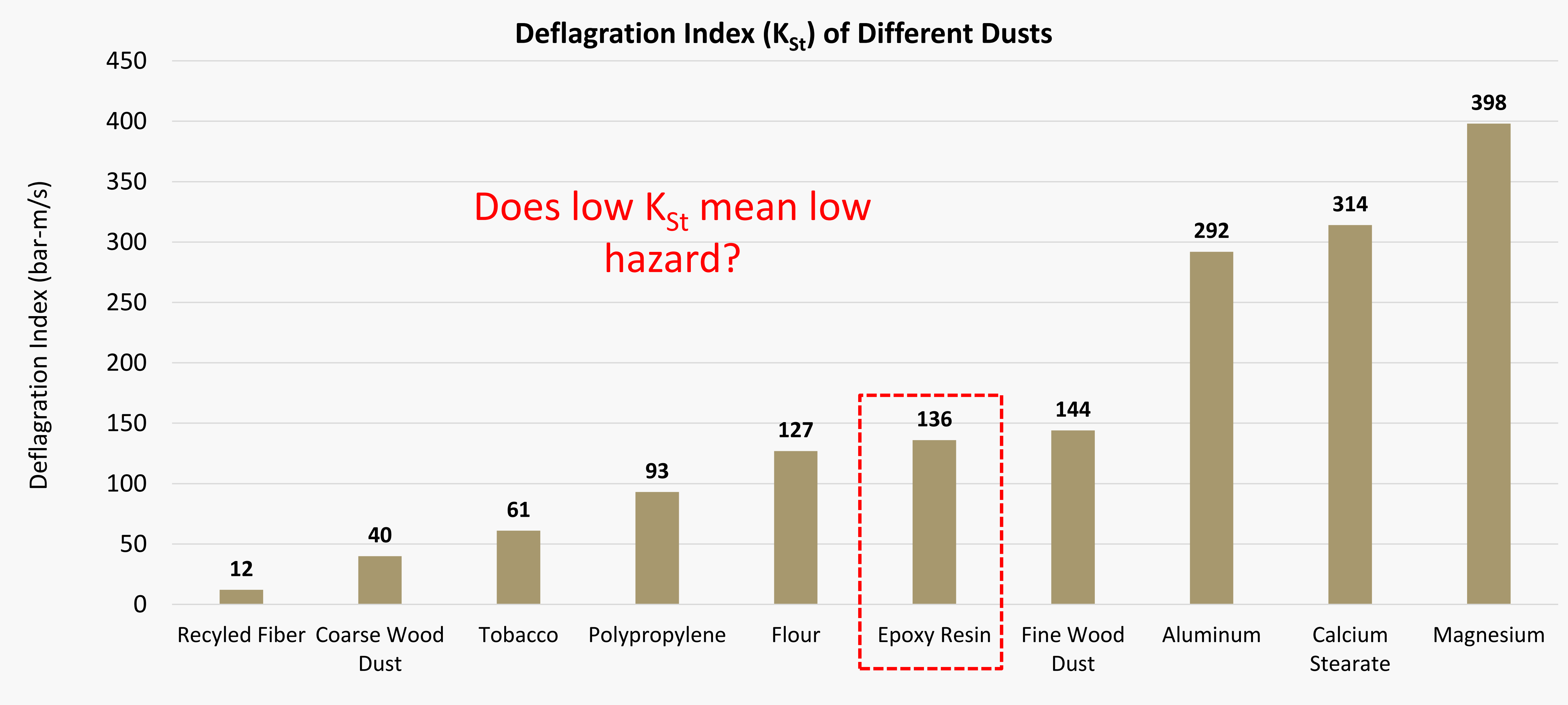
Standardized Dust Testing

Example properties taken from GESTIS Database: https://staubex.ifa.dguv.de/explosuche.aspx?lang=e



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Fundamentals of Combustible Dust

Standardized Dust Testing

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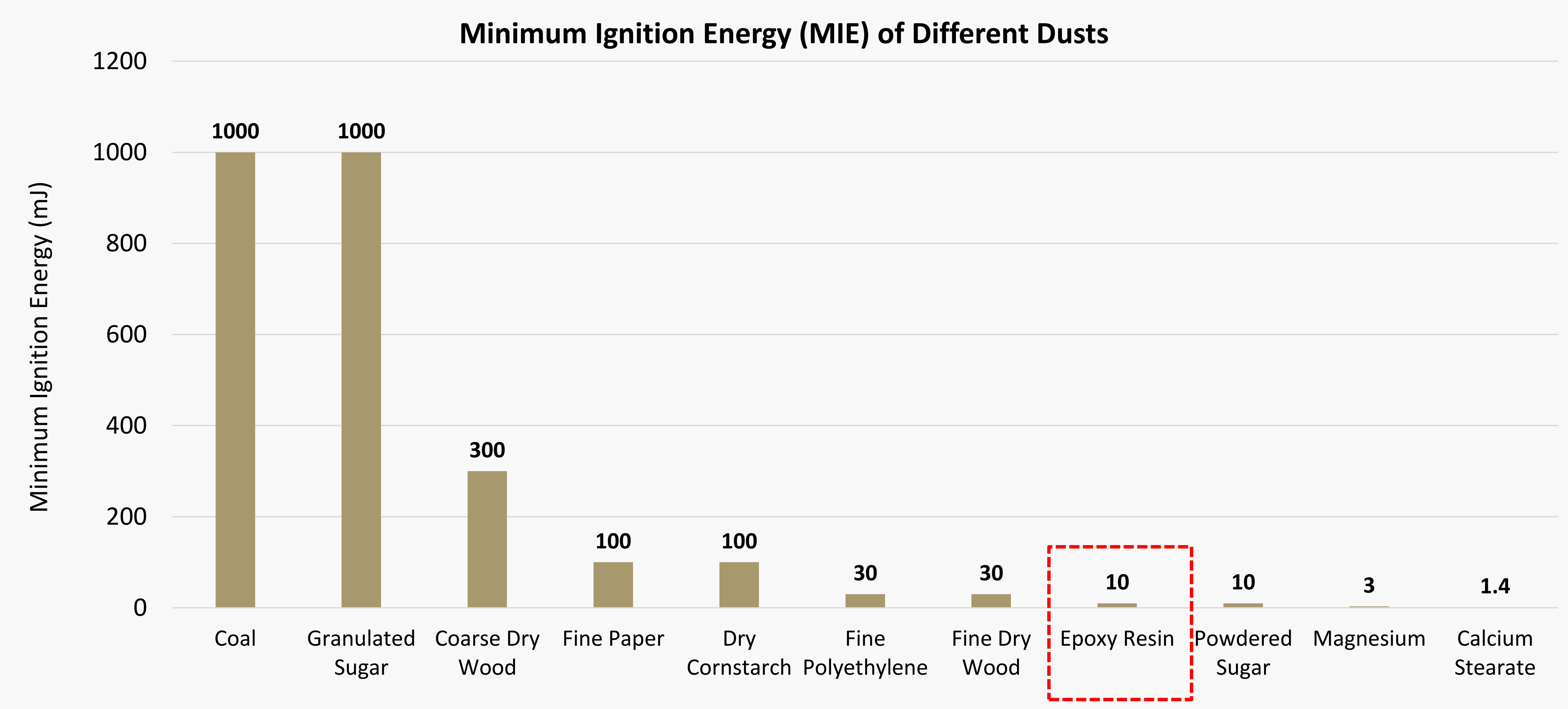

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Fundamentals of Combustible Dust

Example Dust Testing Results

Table 1: Summary of explosibility screening test results.

Sample	Moisture content (wt.%)	Concentration (g/m^3)	Explosible
Corn starch	5.30	1000	Yes

Table 2: Summary of dust explosibility parameters.

	Explosion severity			Ignition sensitivity		
Sample	P_{max} (bar g)	$(dP/dt)_{max}$ (bar/s)	K_{St} (bar · m/s)	MEC (g/m^3)	MIT (°C)	MIE^a (mJ)
Corn starch	8.4	459	125	60	300	300 – 500

Notes
(a) MIE testing was performed without inductance.

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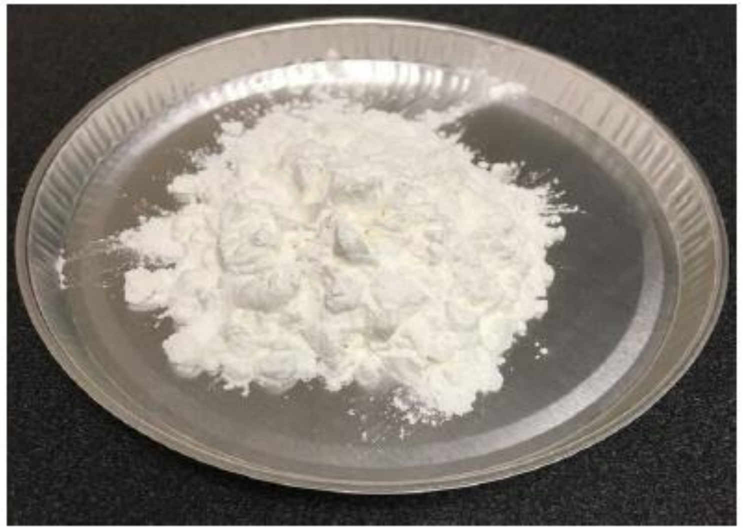
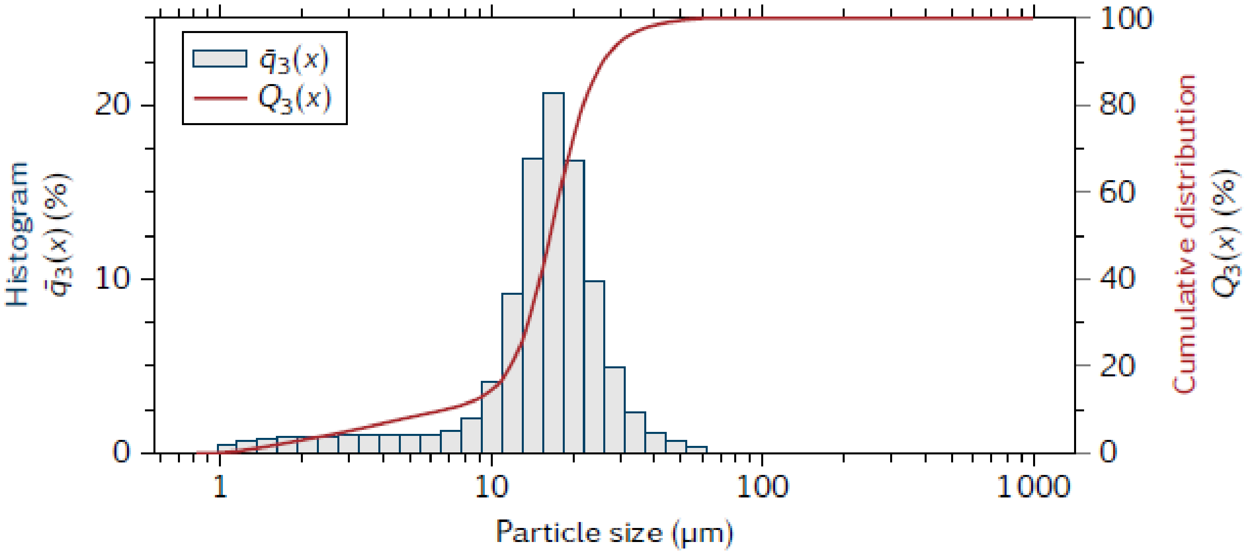
Fundamentals of Combustible Dust

Example Dust Testing Results

Table 3: Dust sample particle size analyses.

Dust sample	Median diameter (µm)	Sauter mean diameter, d_{32} (µm)	% Particle distribution < 75 µm
Corn starch	16.5	10.6	100.0





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Regulations and Standards

Regulations and Standards

Regulatory Framework

NFPA 652

NFPA 68, 69, 70 etc.

ASTM

OSHA NEP

FIRE CODES

NFPA 61

NFPA 484

NFPA 664

NFPA 654

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Regulations and Standards

NFPA Combustible Dust Standards

Standard	Industry / Commodity	Current Edition	Scope
652	All combustible dust producing facilities	2019	Fundamentals for identifying and managing hazards
61	Agricultural and food facilities	2020	Identifying and managing industry or commodity specific combustible dust hazards. Some standards (e.g., NFPA 484 and 664) address fire hazards associated with other industry-specific processes.
484	Combustible metals	2019	
654	Dusts not covered by other standards (e.g., paper, plastics, chemicals, pharmaceutical)	2020	
655	Sulphur	2017	
664	Woodworking and forest products	2020	
68	All industries	2018	Explosion venting
69	All industries	2019	Explosion prevention and explosion isolation
70	All industries	2020	Article 500 addresses requirements for hazardous (classified) areas

Regulations and Standards

NFPA Combustible Dust Standards

Standard	Industry / Commodity	Current Edition	Scope
505	All industries	2018	Standard for powered industrial trucks in hazardous (classified) areas
2112	All industries	2018	Performance requirements for flame-resistant garments
2113	All industries	2020	Selection, care, and use of flame-resistant garments
77	All industries	2019	Recommended practice on identifying and managing electrostatic ignition hazards
499	All industries	2017	Recommended practice for the classification of combustible dusts and of hazardous (classified) locations

Regulations and Standards

NFPA Combustible Dust Standards

NFPA combustible dust standards are rapidly changing

- Considerable efforts in recent editions to align with NFPA 652
- All commodity-specific standards now include retroactive DHA requirement
- Standards assign "deadline" of September 7, 2020 to complete DHAs

Many requirements are retroactive

- DHA and hazard management plan
- Ignition source control
- Management systems (e.g. housekeeping, Management of Change, etc.)

Upcoming changes to future editions

- Merging NFPA 652 and commodity-specific standards
- NFPA 660 will be new, all-encompassing combustible dust standard

Regulations and Standards

OSHA National Emphasis Program on Combustible Dust

Directive CPL 03-00-008 issued on March 11, 2008

- Issued following Imperial Sugar explosion
- Increase inspection and enforcement activities
- Applies NFPA combustible dust standards as industry standard of care
  - Most recent editions can be enforced

Citations issued in several ways:

- General Duty Clause
- 29 CFR 1910.272 (grain handling facilities)
- 29 CFR 1910.22 (housekeeping)
- 29 CFR 1910.307 (hazardous (classified) areas)

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Regulations and Standards

International Fire Code

2015 and prior editions

- Chapter 22 – Combustible Dust-Producing Operations
  - General requirements for controlling ignition sources and housekeeping
  - Fire code official *is authorized* to enforce applicable provisions of referenced NFPA standards

2018 Edition

- Chapter 22 – Combustible Dust-Producing Operations
  - Owner responsible for compliance with the IFC and NFPA 62
  - NFPA 652 applies to new and existing facilities and operations
  - Existing facilities *shall* have a DHA completed within 3 years of the adoption of the 2018 code
  - Industry- or commodity-specific standards *shall be complied with* based on the DHA (hazard management plan)

2021 Edition

- Available October, 2020
- New requirements specific to additive manufacturing

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Regulations and Standards

2018 International Fire Code

CHAPTER 22

COMBUSTIBLE DUST-PRODUCING OPERATIONS

User note:

About this chapter: *Chapter 22 provides requirements that seek to reduce the likelihood of dust explosions by managing the hazards of ignitable suspensions of combustible dusts associated with a variety of operations including woodworking, mining, food processing, agricultural commodity storage and handling and pharmaceutical manufacturing, among others. Ignition source control and good housekeeping practices in occupancies containing dust-producing operations are emphasized. Appropriate standards are referenced to deal with the specific dust hazards.*

SECTION 2201 GENERAL

2201.1 Scope. The equipment, processes and operations involving dust explosion hazards shall comply with the provisions of this code and NFPA 652.

2201.2 Permits. Permits shall be required for *combustible dust*-producing operations as set forth in Section 105.6.

SECTION 2202 DEFINITION

2202.1 Definition. The following term is defined in Chapter 2:

COMBUSTIBLE DUST.

SECTION 2203 PRECAUTIONS

2203.1 Owner responsibility. The owner or operator of a facility with operations that manufacture, process, blend, convey, repackage, generate or handle potentially combustible dust or combustible particulate solids shall be responsible for compliance with the provisions of this code and NFPA 652.

2203.2 Dust hazard analysis (DHA). The requirements of NFPA 652 apply to all new and existing facilities and operations with combustible dust hazard. Existing facilities shall have a dust hazard analysis (DHA) completed in accordance with Section 7.1.2 of NFPA 652.

The fire code official shall be authorized to order a dust hazard analysis to occur sooner if a combustible dust hazard has been identified in a facility that has not previously performed an analysis.

2203.3 Sources of ignition. Smoking, the use of heating or other devices employing an open flame, or the use of spark-producing equipment is prohibited in areas where *combustible dust* is generated, stored, manufactured, processed or handled.

2203.4 Housekeeping. Accumulation of *combustible dust* shall be kept to a minimum in the interior of buildings. Accumulated *combustible dust* shall be collected by vacuum cleaning or other means that will not place *combustible dust* into suspension in air. Forced air or similar methods shall not be used to remove dust from surfaces.

SECTION 2204 ADDITIONAL REQUIREMENTS

2204.1 Specific hazards standards. The industry- or commodity-specific codes and standards listed in Table 2204.1 shall be complied with based on the identification and evaluation of the specific fire and deflagration hazards that exist at a facility.

TABLE 2204.1 SPECIFIC HAZARDS STANDARDS

STANDARD	SUBJECT
NFPA 61	Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities
NFPA 69	Standard on Explosion Prevention Systems
NFPA 70	National Electrical Code
NFPA 85	Boiler and Combustion System Hazards Code
NFPA 120	Standard for Fire Prevention and Control in Coal Mines
NFPA 484	Standard for Combustible Metals
NFPA 654	Standard for 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 for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities

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Regulations and Standards

International Building Code

2018 IBC Requirements for Occupancy Classification and Explosion Control

TABLE 307.1(1)
MAXIMUM ALLOWABLE QUANTITY PER CONTROL AREA OF HAZARDOUS MATERIALS POSING A PHYSICAL HAZARD[a, j, m, n, p]

MATERIAL	CLASS	GROUP WHEN THE MAXIMUM ALLOWABLE QUANTITY IS EXCEEDED	STORAGE[b]			USE-CLOSED SYSTEMS[b]			USE-OPEN SYSTEMS[b]	
			Solid pounds (cubic feet)	Liquid gallons (pounds)	Gas cubic feet at NTP	Solid pounds (cubic feet)	Liquid gallons (pounds)	Gas cubic feet at NTP	Solid pounds (cubic feet)	Liquid gallons (pounds)
Combustible dust	NA	H-2	See Note q	NA	NA	See Note q	NA	NA	See Note q	NA

Note q applies where conditions create a fire or explosion hazard

- Conditions must be evaluated, and a report submitted to the building official (§414.1.3)
    - Determine the degree of hazard and recommended safeguards, including the appropriate occupancy classification
    - DHA addresses this requirement
- Requirements for explosion control (§414.5.1) should also be evaluated in DHA

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Regulations and Standards

Industry Feedback on Combustible Dust Regulations

Chemical Safety Board (CSB)

- Recently issued “Dust Hazard Learning Review” https://www.csb.gov/assets/1/6/dust_hazard_review.pdf

Barriers to improvement

- Complacency
- Normalization of risk

Controls

- Lack of risk awareness
- Difficulty removing all dust
- Difficulty finding “qualified” companies / experts for dust control and explosion protection
- One-size-fits-all approach not applicable across industry or even same facility
- Cost versus perceived benefit

Compliance

- Inconsistent enforcement
- Mandatory directives not necessarily followed – “not worried about it”
- Where followed, often out of fear of punishment by regulators

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Dust Hazard Analysis

Let’s take a quick break…

Dust Hazard Analysis

What is a DHA?

Hazards

- Fire
- Flash Fire
- Explosion

Material Hazards

- Develop dust sampling and test strategy
- Perform “Go/No-go” explosibility screening tests (first pass)
- Evaluate potential explosion severity and ignition sensitivity

Equipment Hazards

- Identify potential deflagration or explosion hazards
- Evaluate incident scenarios for credibility
- Compare existing safeguards with industry best practice
- Develop practicable, cost-effective recommendations to close gaps

Building Hazards

- Identify potential flash fire and explosion hazards
- Evaluate hazards
- Provide recommendations and guidelines for hazard prevention and mitigation

Dust Hazard Analysis

Typical DHA Process

1. Conduct dust testing / evaluate representative data
2. Gather facility and process information
3. Conduct a site inspection (existing facilities) or design review (new facilities)
4. Identify where fire, flash fire, and explosion hazards exist
5. Develop recommendations to manage hazards (hazard management plan)

Dust Hazard Analysis

Common DHA Methodologies

Methodology	Description	Benefits	Weaknesses
Checklist	Audit using checklists prepared based on prescriptive NFPA requirements.	• Quick and low-cost method • Systematic check for prescriptive compliance	• Lacks detail to understand hazards and conditions • May over-specify protection
Traditional (NFPA-style)	Analysis and documented report prepared by qualified individual. The process is systematically evaluated against NFPA requirements.	• Documentation of the process, hazards, and gaps in protection	• Requires more effort and documentation • May over-specify protection
Engineering Analysis (often called performance-based)	**Systematic documented analysis, applying test data, calculations / measurements, and research to identify credible hazards and applicable recommendations.**	• **Thorough documentation of the process, hazards, and gaps in protection** • **Protection is applied to credible hazards**	• **Requires more effort and documentation** • **More time required to complete analysis**
PHA / HAZOP	Systematic evaluation using PHA methodology (e.g., HAZOP) and team approach.	• Structured assessment with diverse team of participants • Effective in identifying and addressing upset conditions	• Outcome depends on the experience of the team • Desktop exercises may not identify hazards in the field
Risk-based	Qualitative or semi-quantitative risk analysis applied to one of the methods above.	• Prioritizes action items • Identifies protection beyond NFPA standards	• Items incorrectly deemed "low risk" may not be addressed • Acceptable risk defined by user

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Dust Hazard Analysis

Hazard Management Compliance Options

Prescriptive compliance

- Applicable NFPA 652 requirements
  - Preventative measures, mitigating barriers, management systems
- Commodity-specific requirements

Performance-based option

- Evaluate design against performance goals, objectives, and criteria
- Documented performance-based design report
- **Requires Authority Having Jurisdiction (AHJ) approval**

Risk analysis

- Design achieves acceptable level of risk
- Documented risk analysis
- **Requires Authority Having Jurisdiction (AHJ) approval**

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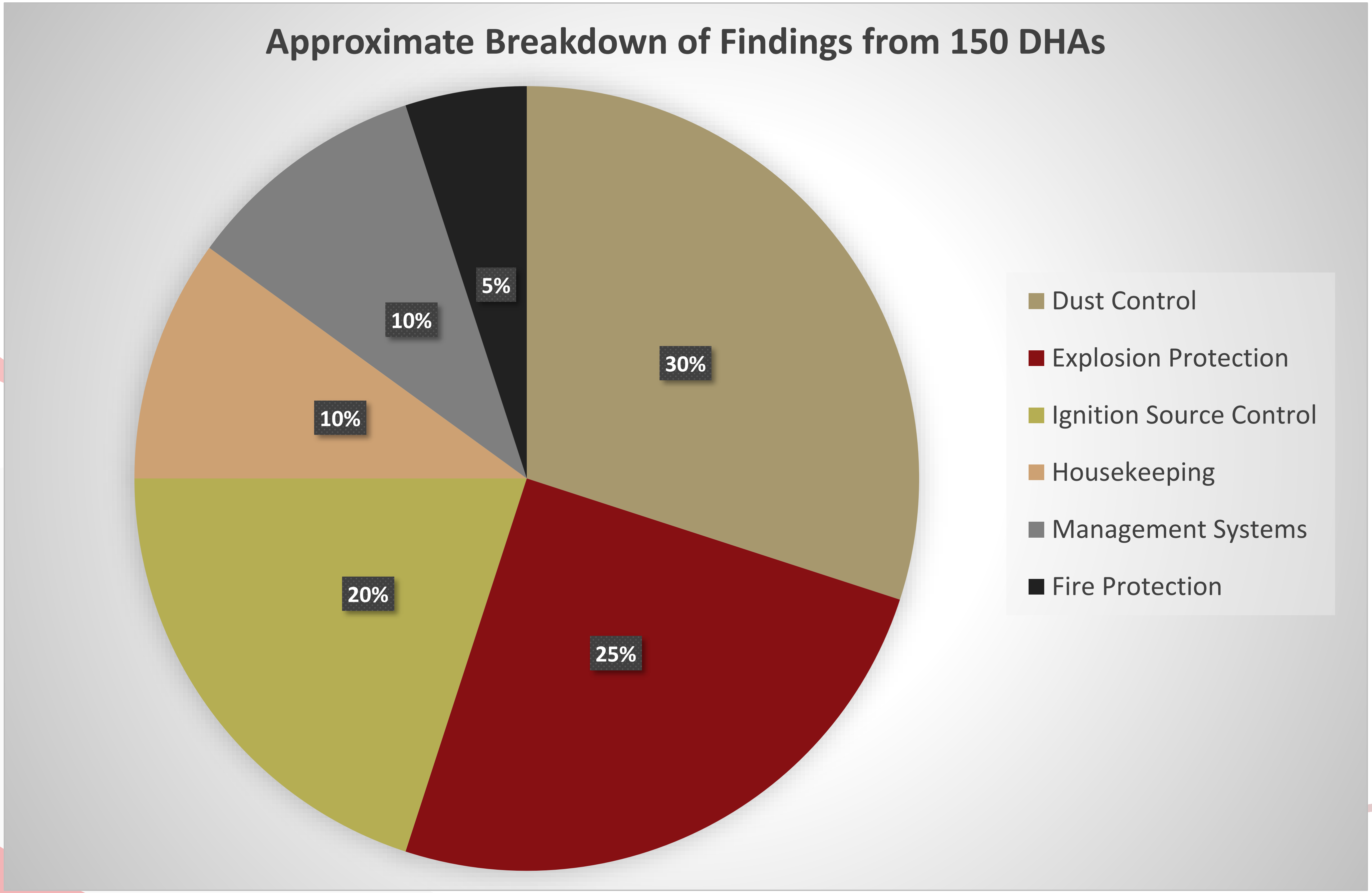
Dust Hazard Analysis

Initial (Reactive) and Design-phase (Proactive) DHAs



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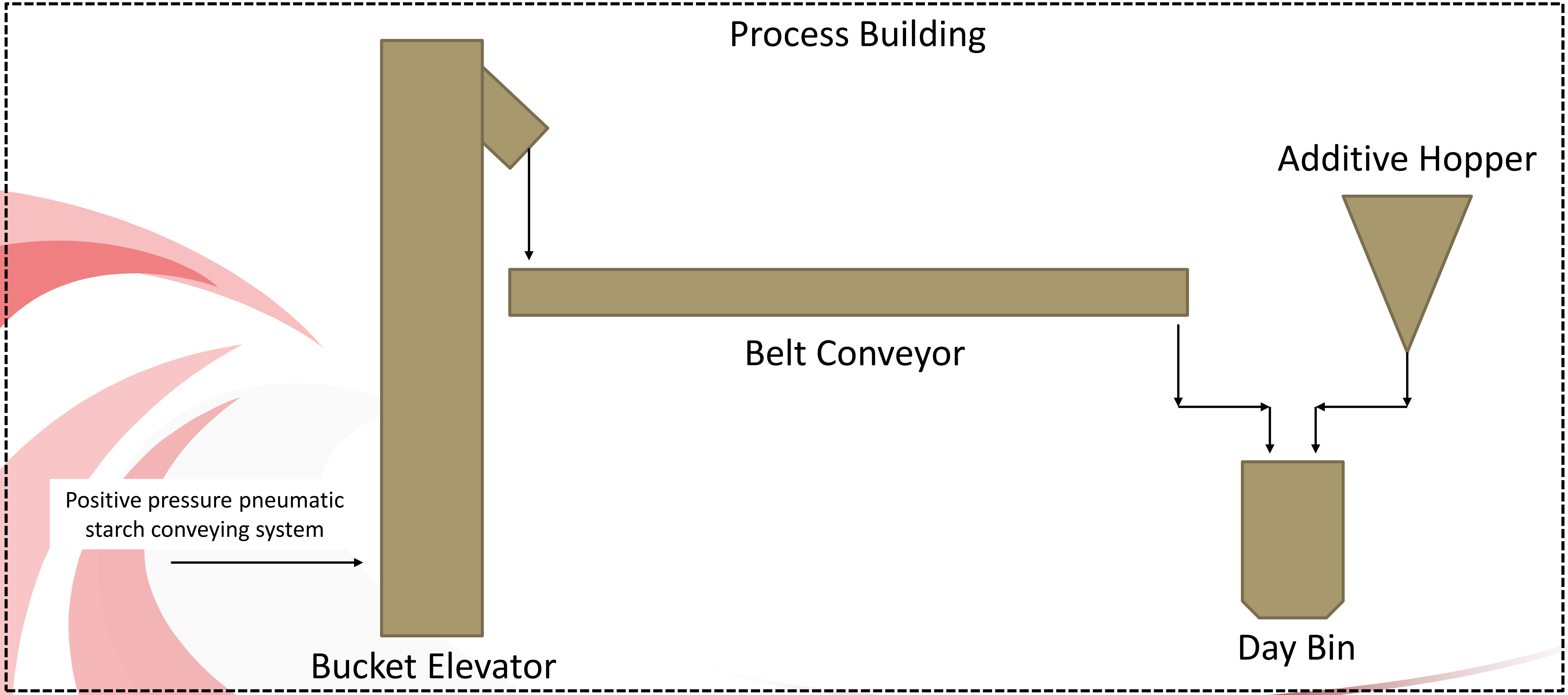
Dust Hazard Analysis

DHA Example – Starch and Additive Process



Dust Hazard Analysis

DHA Example – Material Hazard Analysis

Material	Median Diameter (µm)	P_{max} (bar)	K_{St} (bar-m/s)	MEC (g/m³)	MIT (°C)	LIT (°C)	MIE (mJ)
Corn Starch	16.5	8.4	125	60	300	400	300 – 500
Additive	63	8.5	152	45	400	Melts	10

- Both dusts are explosible, hazard class St-1 dusts
  - K_{St} and P_{max} similar to many organic dusts such as wood, flour, etc.
- MEC values of 60 g/m³ and 45 g/m³
  - Optically thick dust cloud (e.g., can't see light through ~10 ft)
  - Plausible in equipment and in the event of large spill / dispersion event
- MIT and LIT values relatively low
- Both dusts are susceptible to ignition by various forms of sparking and electrostatic discharge

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Dust Hazard Analysis

DHA Example – Material Hazard Analysis

Ignition Sources

Potential Ignition Source	Energy (mJ) or Temperature (°C)	Capable of Igniting Starch Dust?	Capable of Igniting Additive Dust?
Electrostatic discharge from a person	~30 mJ	No	Yes
Electrostatic discharge from ungrounded dust handling equipment	~1000 mJ	Yes	Yes
Electrical arcing (e.g., from energized components)	>>1000 mJ	Yes	Yes
Surfaces of motors and lighting	< 180°C	No	No
Surfaces that feel "hot to the touch"	< 90°C	No	No
Visible sparks / burning embers	> 500°C	Yes	Yes
Open flame	> 500°C	Yes	Yes
Welding slag	> 1500°C	Yes	Yes

Note: data in table is approximate and for illustrative purposes only.

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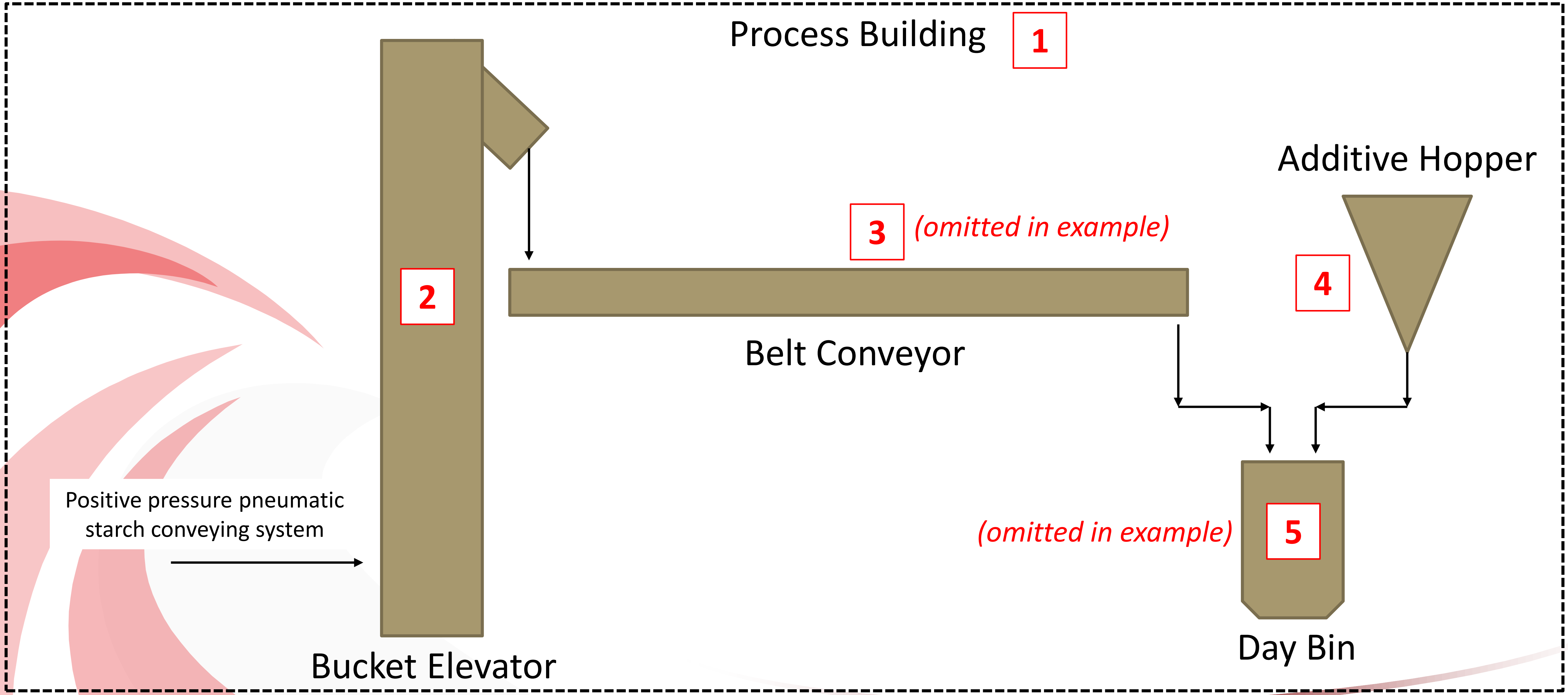
Dust Hazard Analysis

DHA Example – Starch and Additive Process



Dust Hazard Analysis

DHA Example – Building Hazard Analysis

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Dust Hazard Analysis

DHA Example – Building Hazard Analysis

How much dust is too much?

- NFPA 654 defines threshold of about 1/16 of an inch for flash fire and explosion hazard
  - Based on 1/32 of an inch threshold adjusted for starch bulk density

Combustible dust hazards

- Fire hazard
- Flash fire hazard (potential for building-wide deflagration)
- Explosion hazard

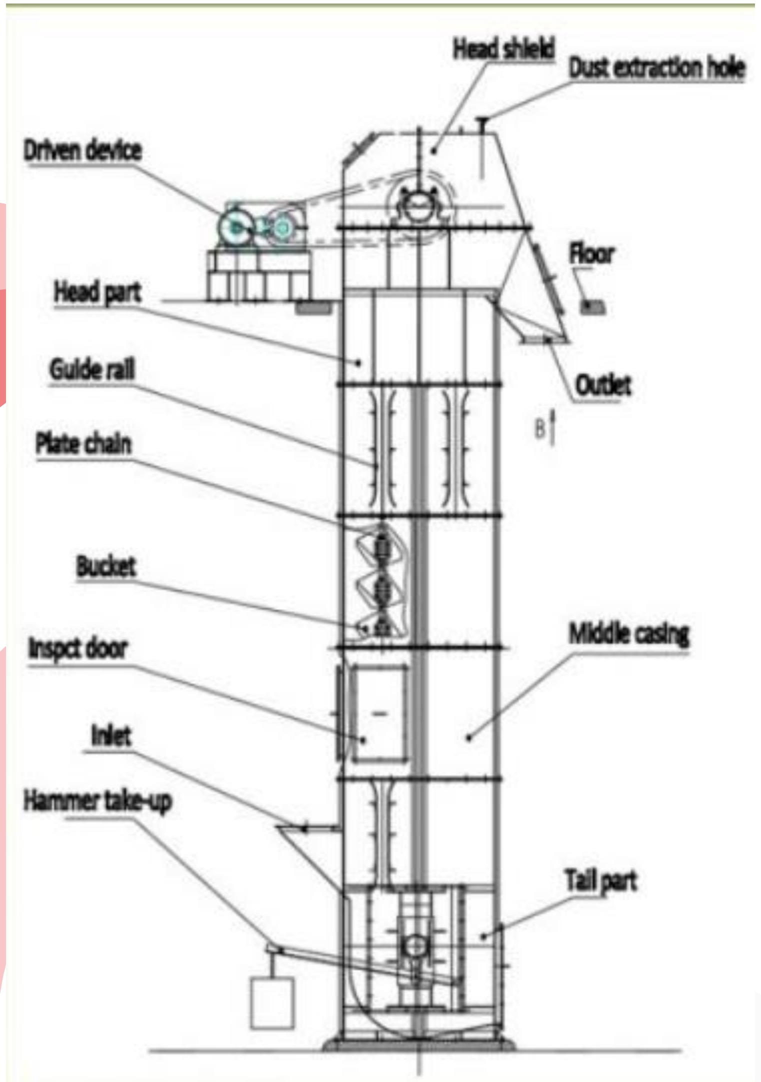
Recommendations for hazard management

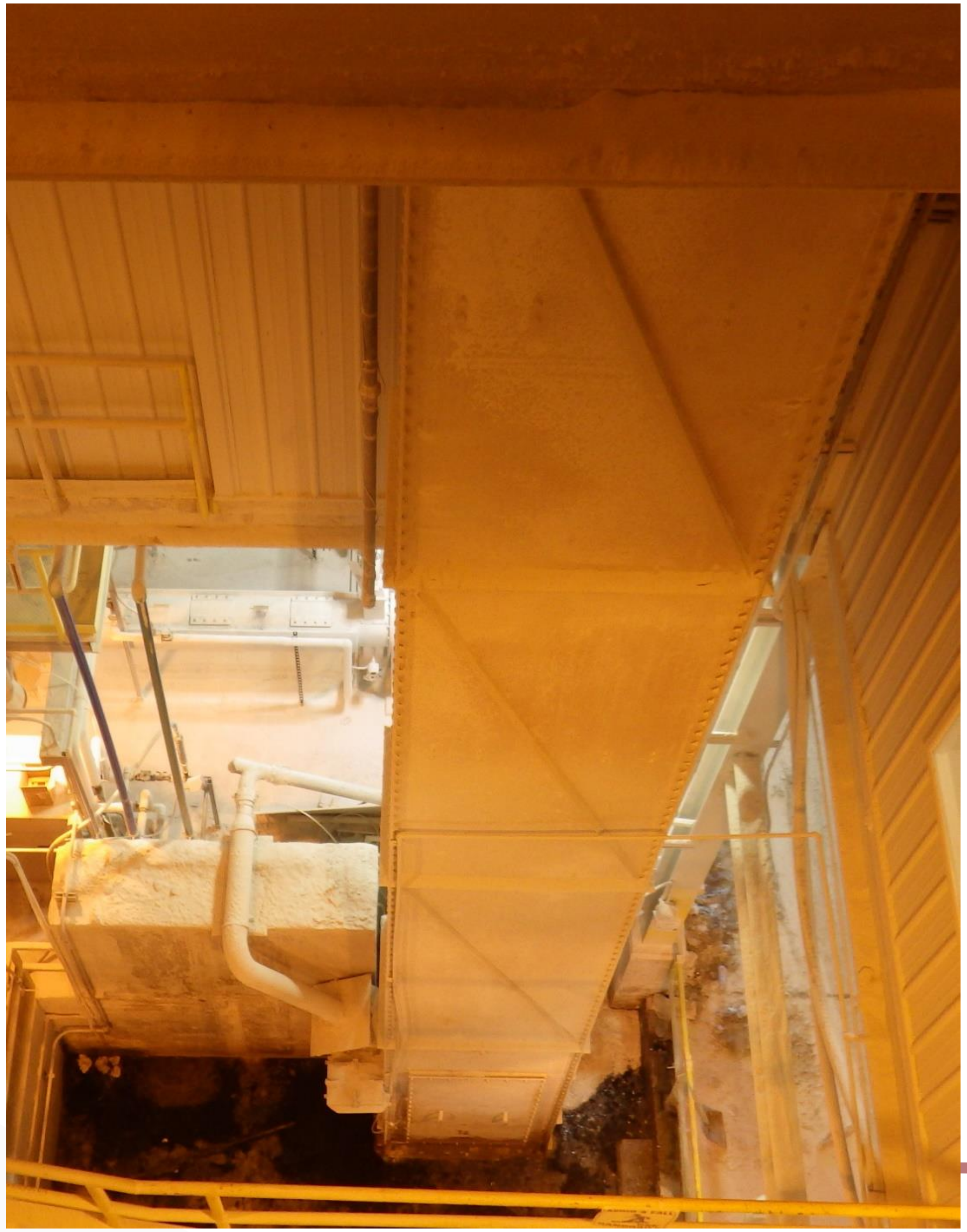
- Process redesign and replacement (best long-term option)
- Control dust – seal equipment and repair dust collectors
- Restrict personnel access during pneumatic loading
- Increase inspections and housekeeping
- Install protected central vacuum system
- Class II, Division 1 and 2, Group G electrical equipment

Dust Hazard Analysis

DHA Example – Equipment Hazard Analysis

Bucket Elevator





Dust Hazard Analysis

DHA Example – Equipment Hazard Analysis

Hazard analysis

- Suspended dust – pneumatic conveying and bucket motion
- High-frequency, high energy ignition mechanisms
- Located indoors in building with hazardous amounts of fugitive dust
  - No protection, presents high risk for secondary explosion

Combustible dust hazards

- Fire hazard
- Explosion hazard

Recommendations

- Process redesign and replacement
  - Pneumatically convey directly to protected interior bin
- Monitor bearing temperature, belt alignment, and belt speed / amperage
- Install chemical explosion suppression and isolation
- Restrict personnel access during pneumatic loading

FIRE & RISK ALLIANCE

Dust Hazard Analysis

DHA Example – Equipment Hazard Analysis

Additive Hopper

Dust Hazard Analysis

DHA Example – Equipment Hazard Analysis

Hazard analysis

- Dust suspended during manual pouring
- Concentration may briefly exceed the MEC
- Dust is very sensitive to ignition
  - General purpose electrical equipment and electrostatic discharge may ignite dust
- The hopper is open (not confined)

Combustible dust hazards

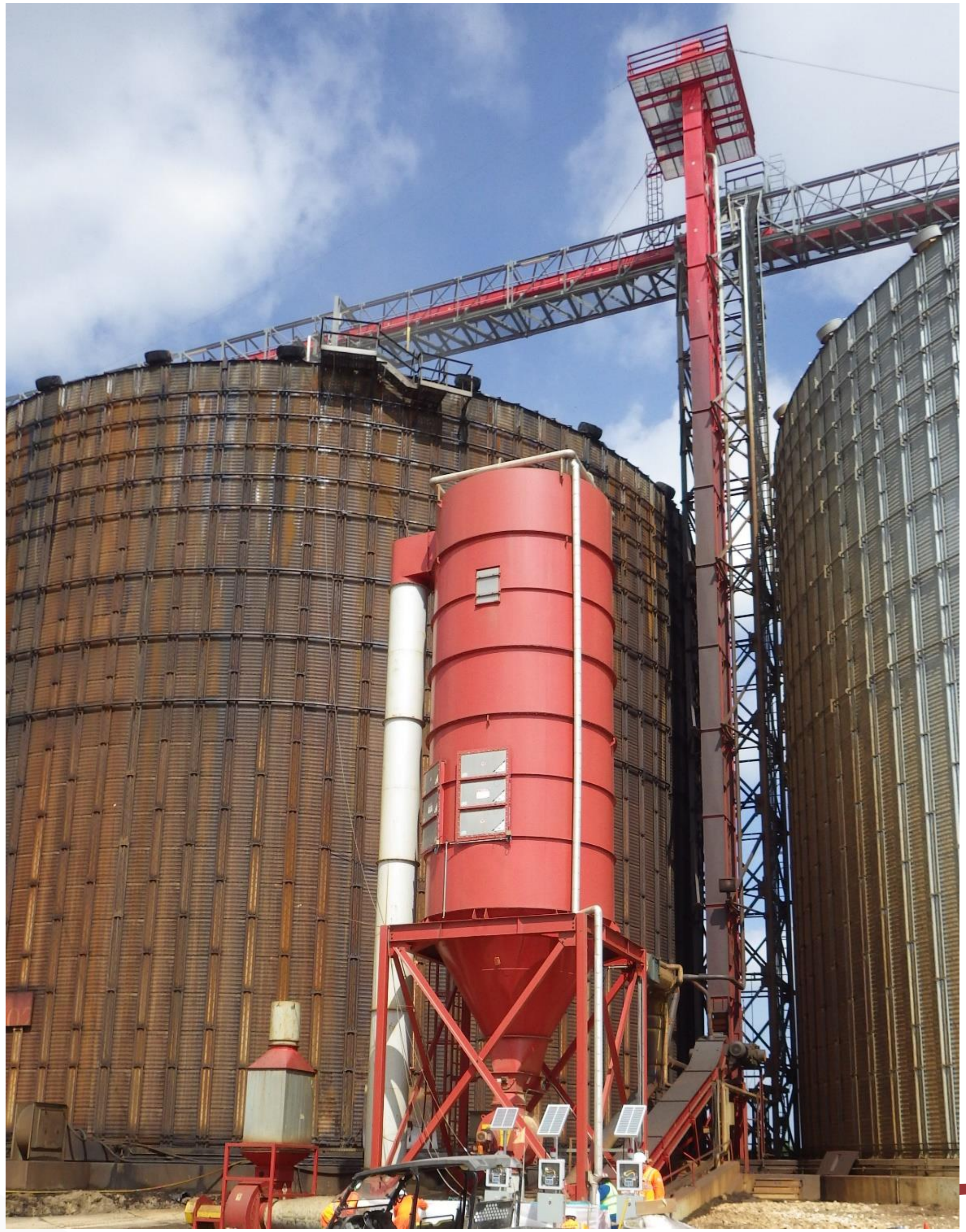
- Fire hazard (area around hopper)
- Flash fire hazard

Recommendations

- Bond and ground equipment and operator
- Class II, Division 2, Group G electrical equipment (with improved housekeeping)
- Provide dust collection hood routed to protected dust collector
- Increase frequency of inspection and housekeeping
- Install close-clearance rotary valve at base of hopper
- Provide NFPA 2112 flame-resistant clothing for the worker

Dust Hazard Analysis

Case Study – Wood Pellet Storage Facility



FIRE & RISK ALLIANCE

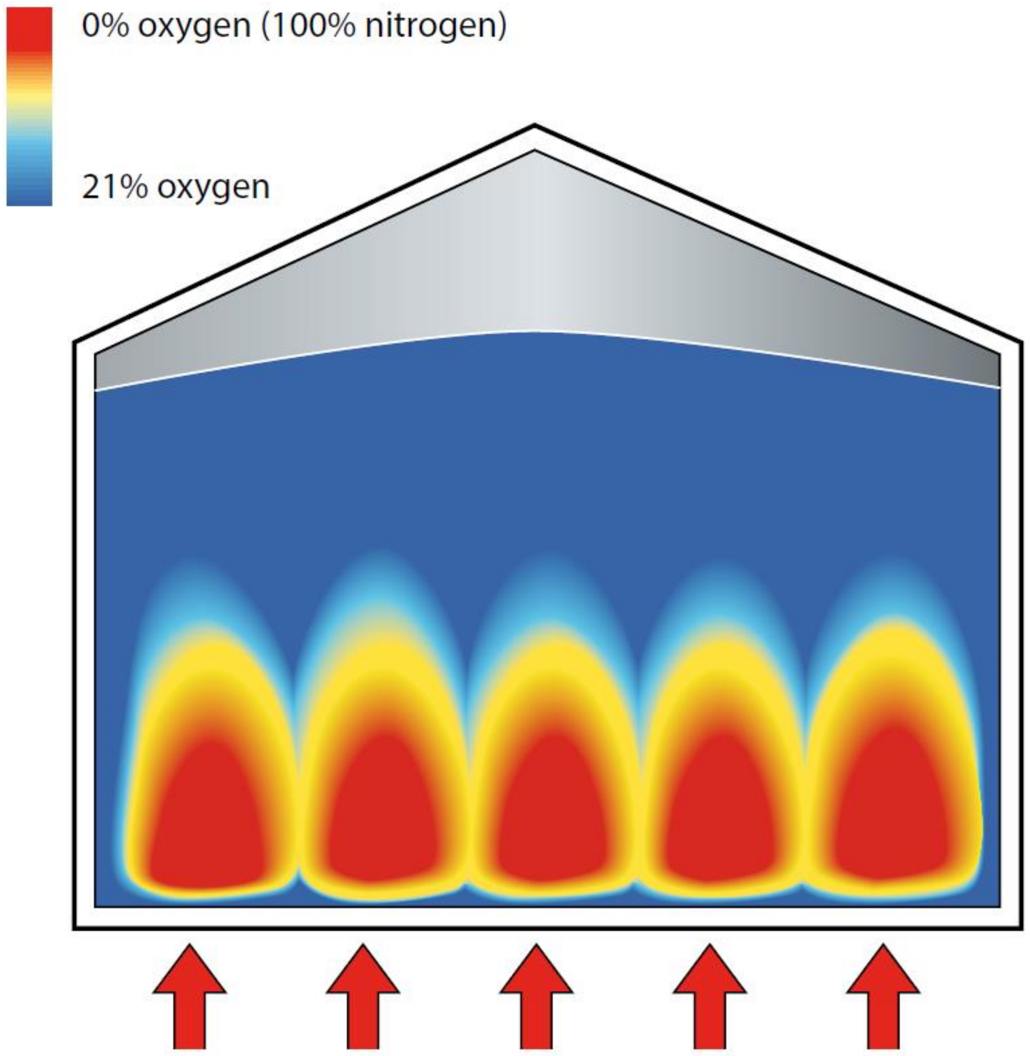
Dust Hazard Analysis

Case Study – Wood Pellet Storage Facility

- Key findings
  - Initial dust explosion led to chain of undesirable events
  - Applicable fire code did not clearly establish required protection
  - Unique process and hazards required DHA
  - Numerous deficiencies identified
    - Pellet storage protocols, detection, and suppression
    - Ignition source control
    - Explosion protection
    - Training
    - Emergency planning and response
- Key recommendations
  - Retrofit storage silos for proper detection and suppression
  - Install additional monitoring on conveying equipment
  - Redesign and protect dust collection to current industry standards
  - Implement rigorous employee training
  - Develop emergency response plan in collaboration with responding fire departments

Dust Hazard Analysis

Case Study – Wood Pellet Storage Facility



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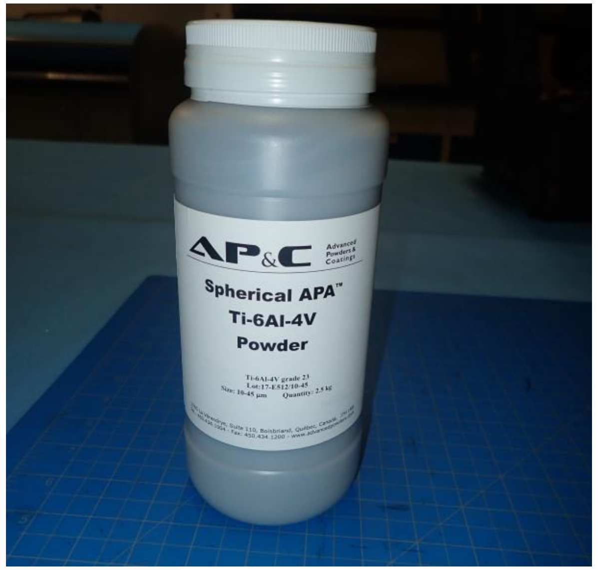
Dust Hazard Analysis

Case Study – Titanium Additive Manufacturing



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Dust Hazard Analysis

Case Study – Titanium Additive Manufacturing

- Jurisdiction concerns
  - Titanium perceived as unique, severe hazard
  - Water reactivity and appropriate suppression
  - Explosion venting
  - Electrical classification

Property	Titanium Value	Similar Material(s)
Deflagration Index, K_{St}	60 bar-m/s	Sawdust, paper dust
Maximum explosion pressure, P_{max}	6.1 bar	Sawdust, paper dust
Minimum explosible concentration, MEC	50 g/m3	Flour, cornstarch
Minimum ignition energy, MIE	3 – 10 mJ	Powdered sugar

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Dust Hazard Analysis

Case Study – Titanium Additive Manufacturing

- Key findings
  - Primary risk associated with explosion / flash fire
    - Fire and water reactivity present far less risk
  - Argon suppression system introduced more risk than it mitigated
    - Appropriate suppression achieved by manual application of Met-L-X powder
  - Credible building explosion hazard did not exist
- Key recommendations
  - Dust control, housekeeping, and protected electrical equipment was necessary
  - Safe storage and handling of powders
  - Employee and fire department training
  - Coordinated emergency response plan

Dust Hazard Analysis

Case Study – Engineered Wood Fiber

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Dust Hazard Analysis

Case Study – Engineered Wood Fiber

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Dust Hazard Analysis

Case Study – Engineered Wood Fiber

- Key findings
  - High value process and plant was at high risk for dust explosions and flash fires
  - Low K_{St} perceived to mean “no risk”
  - Process equipment located indoors without explosion protection
  - Significant fugitive dust issue due primarily to “blow-down” approach
  - Multiple design deficiencies in existing dust collection systems
- Key recommendations
  - Immediately implement training to “recalibrate” mindset of risk presented by combustible dust
  - Install explosion protection on indoor equipment
  - Install protected central vacuum system(s) for cleaning and stop blow-downs
  - Address design deficiencies in existing dust collection systems

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Dust Hazard Analysis

Summary of Key Takeaways

- All DHAs must provide a systematic analysis of material, building, and equipment hazards
- The individual(s) performing the DHA must be qualified
- Material hazards must be evaluated based on representative data
  - Testing typically provides the best data
  - Literature data is acceptable if used appropriately
  - Not all dust is equal, the DHA must address specific hazards
- Building and equipment hazard analysis must address all dust handling equipment and areas
  - Knowledge of the equipment and associated hazards is important
  - Where possible, field inspections should be conducted
  - Team participation provides the best insight into upset conditions
  - Details matter – many incidents involve multiple, obscure failures
- The DHA must clearly identify fire, flash fire, and explosion hazards
- Recommendations for managing hazards must be made
  - Administrative and engineering controls

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Hazard Management

Let's take a quick break…

Hazard Management

Hierarchy of Controls – Inherently Safer Design

Minimization	• Use smaller quantities of hazardous material • Perform a hazardous procedure as few times as possible
Substitution	• Replace a substance with a less hazardous material • Replace processing route with one that does involve hazardous material
Moderation	• Use hazardous materials in their least hazardous form
Simplification	• Design processes, equipment, and procedures to eliminate opportunities for errors • Eliminate excessive use of add-on safety features and protective devices

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Hazard Management

NFPA 652 Requirements

Wholistic approach to hazard management

- Engineering controls, administrative controls, PPE
- Prevention and mitigation

Management Systems (administrative controls, PPE) – Chapter 8

- Operating procedures and practices
- Housekeeping
- Hot work
- PPE
- Inspection, testing, and maintenance
- Training and hazard awareness
- Emergency planning and response
- Incident investigation
- Management of Change

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Hazard Management

NFPA 652 Requirements

Mitigation and Prevention – Chapter 9

- Building design
- Equipment design
- Ignition source control
- Dust control
- Explosion prevention / protection
- Fire protection

Focus of the following discussion is on explosion prevention / protection

Hazard Management

Explosion Protection Methods

Explosion venting

- NFPA 68

Explosion suppression

- NFPA 69, Chapter 10

Explosion isolation

- Active isolation – NFPA 69, Chapter 11
- Passive isolation – NFPA 69, Chapter 12

Other methods

- Oxidant reduction – NFPA 69, Chapter 7
- Combustible reduction – NFPA 69, Chapter 8
- Detection and ignition control – NFPA 69, Chapter 9
- Pressure containment – NFPA 69, Chapter 13

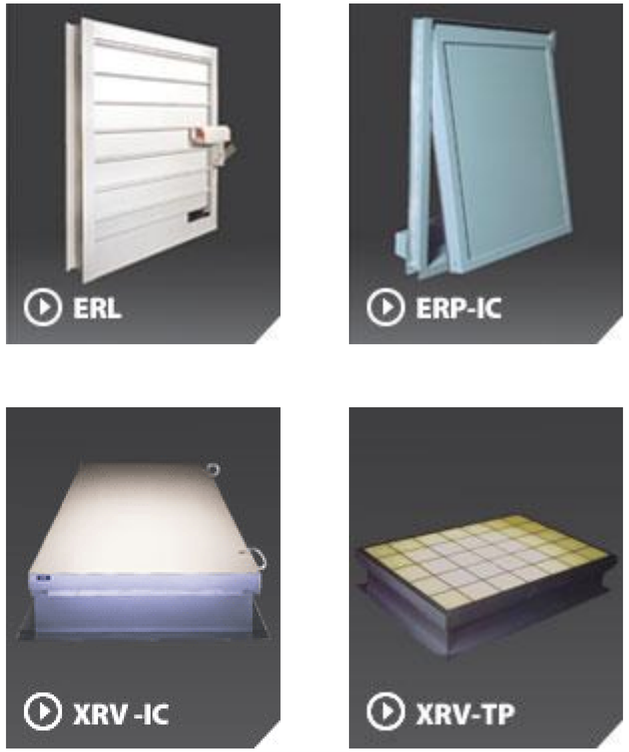
Hazard Management

Explosion Venting Overview

Hazard Management

Explosion Venting Equipment

Wall and roof panels



Hazard Management

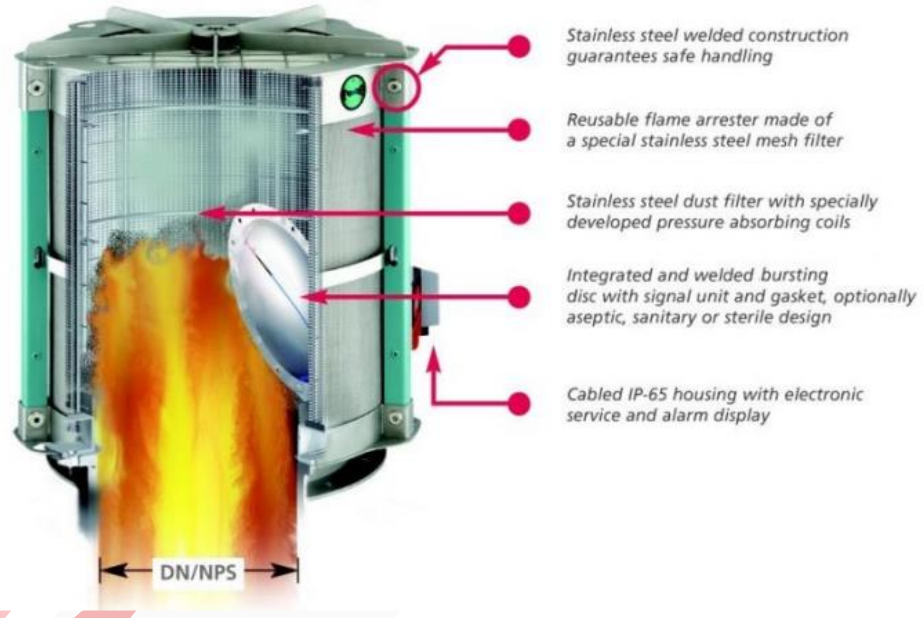
Explosion Venting Equipment

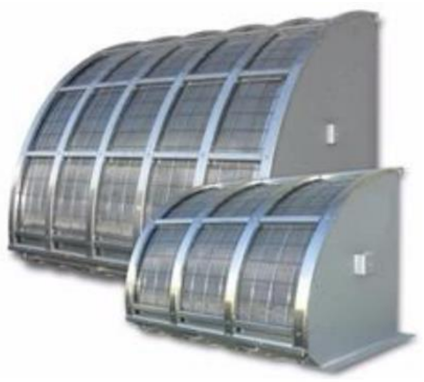
Vent (rupture) panels

Hazard Management

Explosion Venting Equipment

Flame arresting and particulate retention devices





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Hazard Management

Consequences of a Vented Explosion

Design must address:

- Dust collector strength
- Dust collector and process parameters
- Dust properties
- Fireball and pressure effects
- Thrust force
- Weather effects

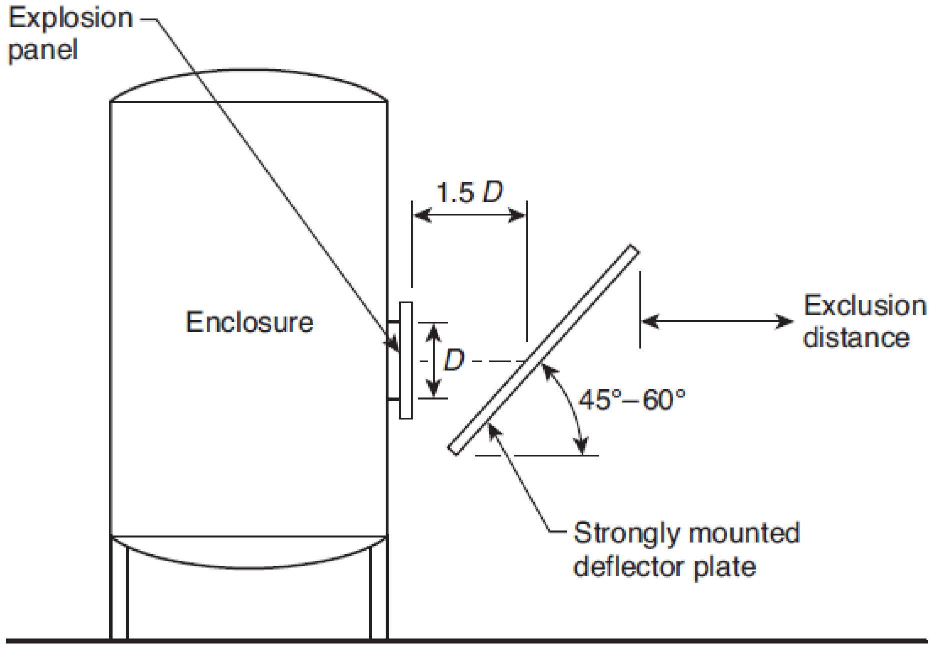

FIGURE 6.6.2.4 Design for an Installation of a Blast Deflector Plate.

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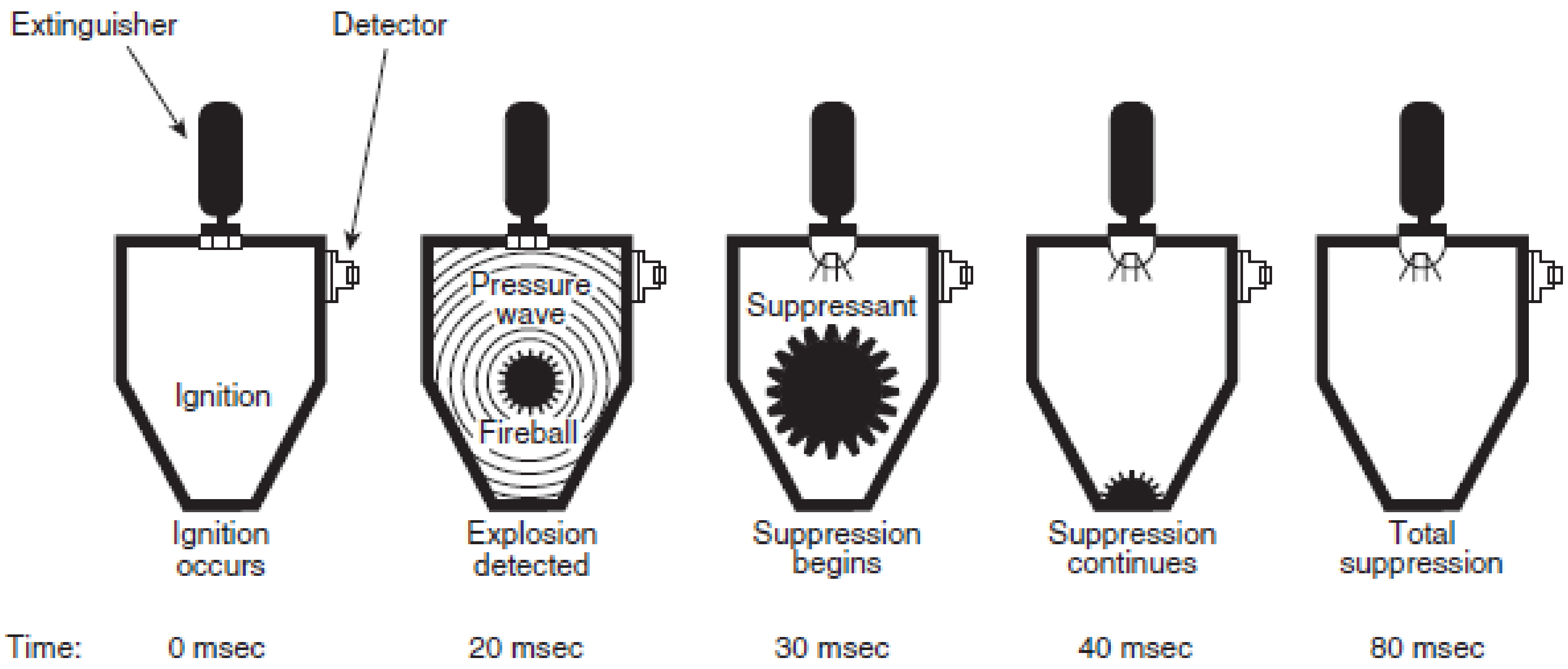
Hazard Management

Deflagration Suppression Overview



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Hazard Management

Deflagration Suppression Equipment

Detectors

Suppression canisters

Control panels

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Hazard Management

Explosion Isolation

Active isolation

- Relies on detection and activation of device

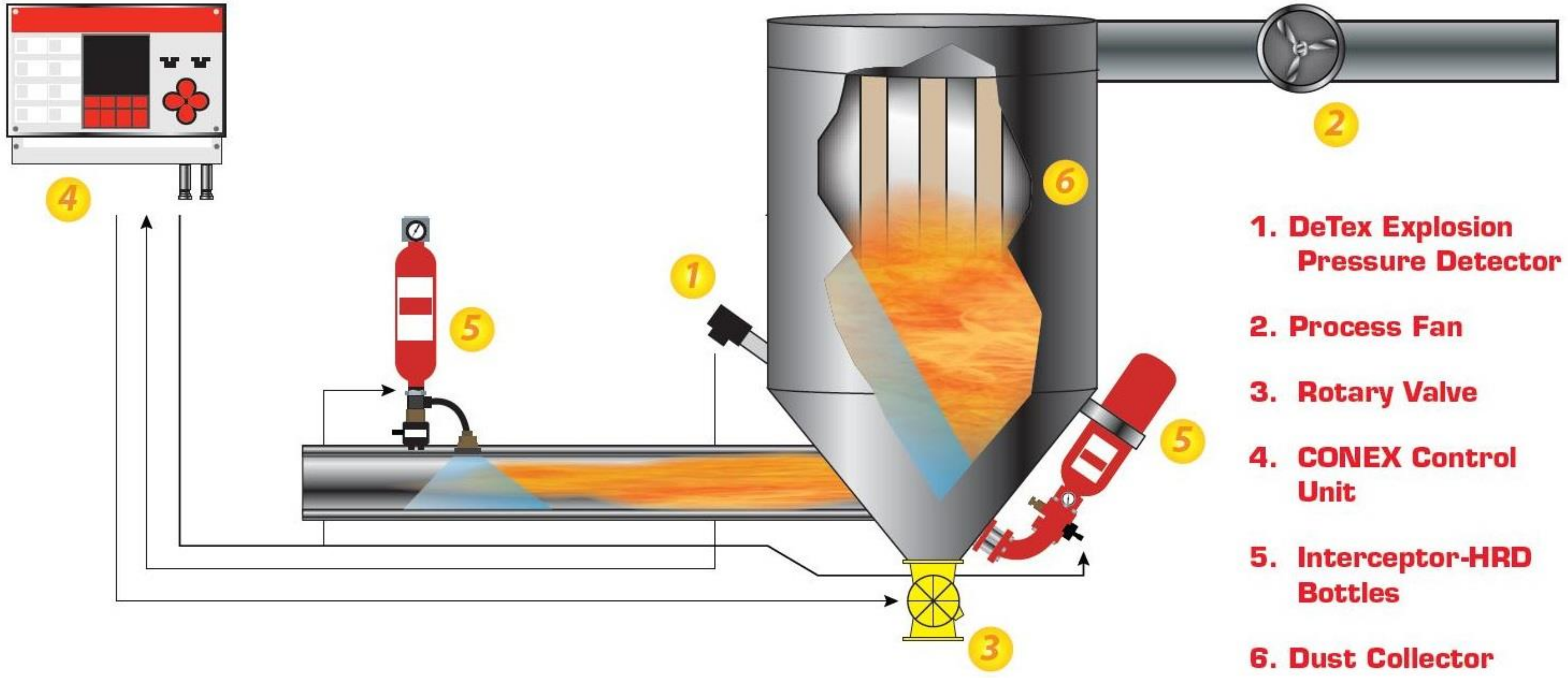
Types of active isolation used in combustible dust applications

- Chemical isolation
- Fast-acting mechanical valve
- Actuated pinch valve
- Externally actuated float valve

Hazard Management

Explosion Isolation

Chemical isolation



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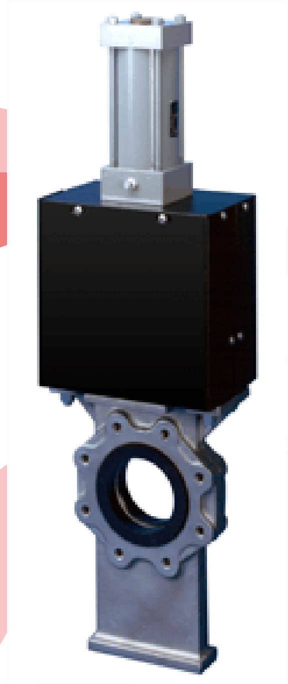
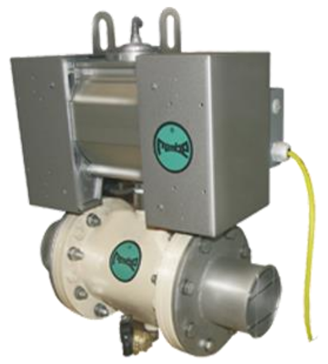
Hazard Management

Explosion Isolation

Fast-acting mechanical valves



Actuated pinch valves



Hazard Management

Explosion Isolation

Passive isolation

- Does not require detectors or actuated

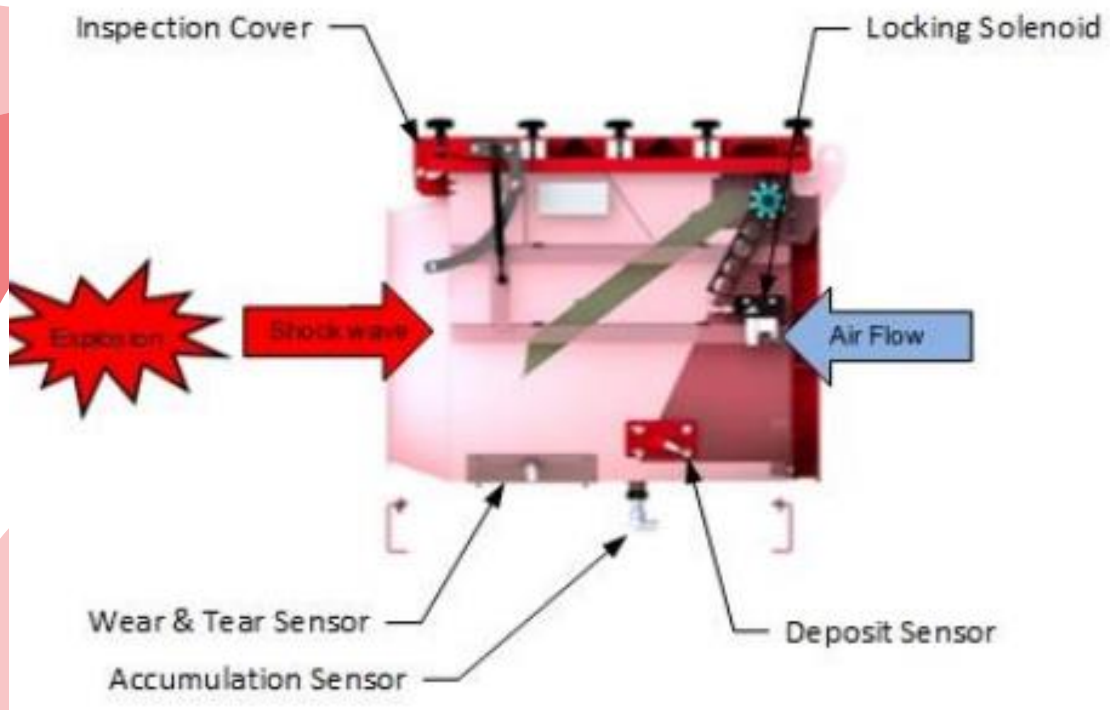
Types of active isolation used in combustible dust applications

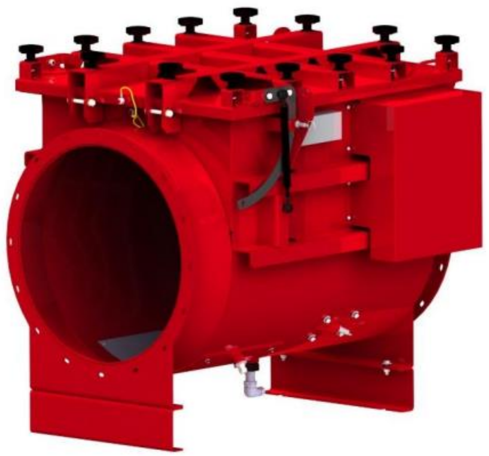
- Passive flap valves
- Material chokes (rotary valves)

Hazard Management

Explosion Isolation

Passive flap valves

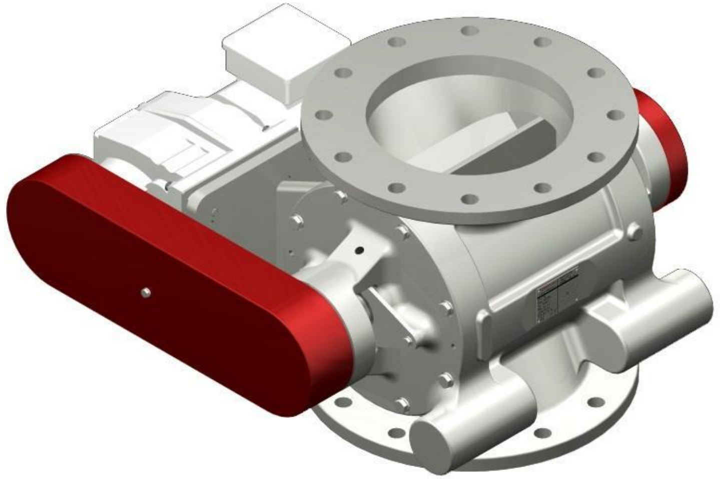




Hazard Management

Explosion Isolation

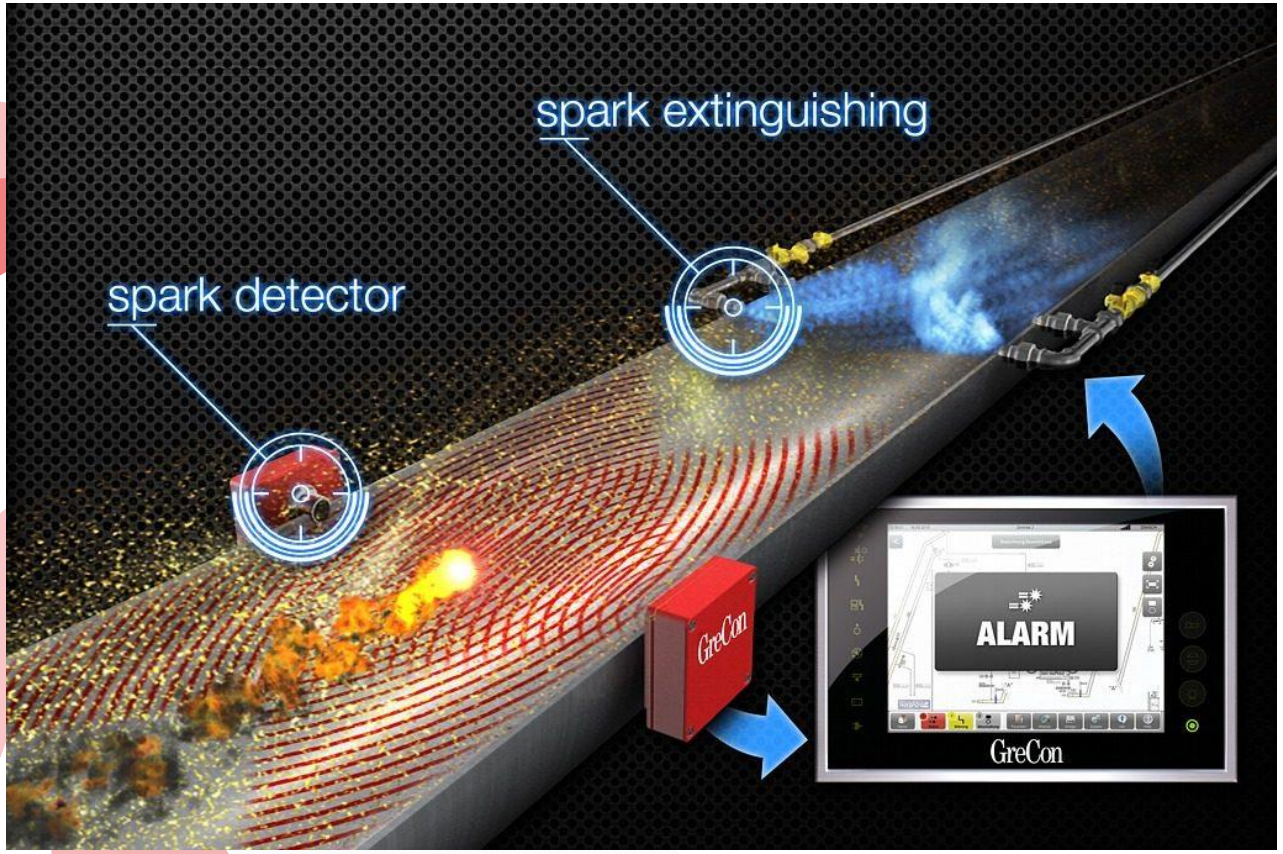
Material chokes (rotary valves)

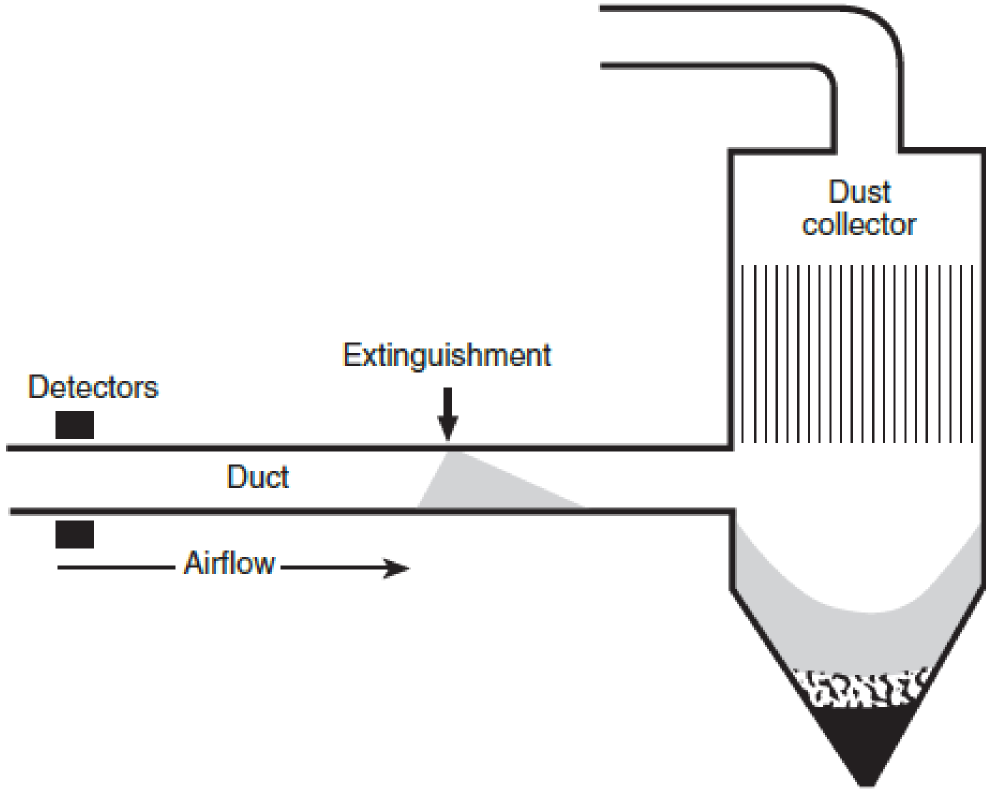


Hazard Management

Ignition Prevention (Likelihood Reduction)

Spark Detection and Suppression





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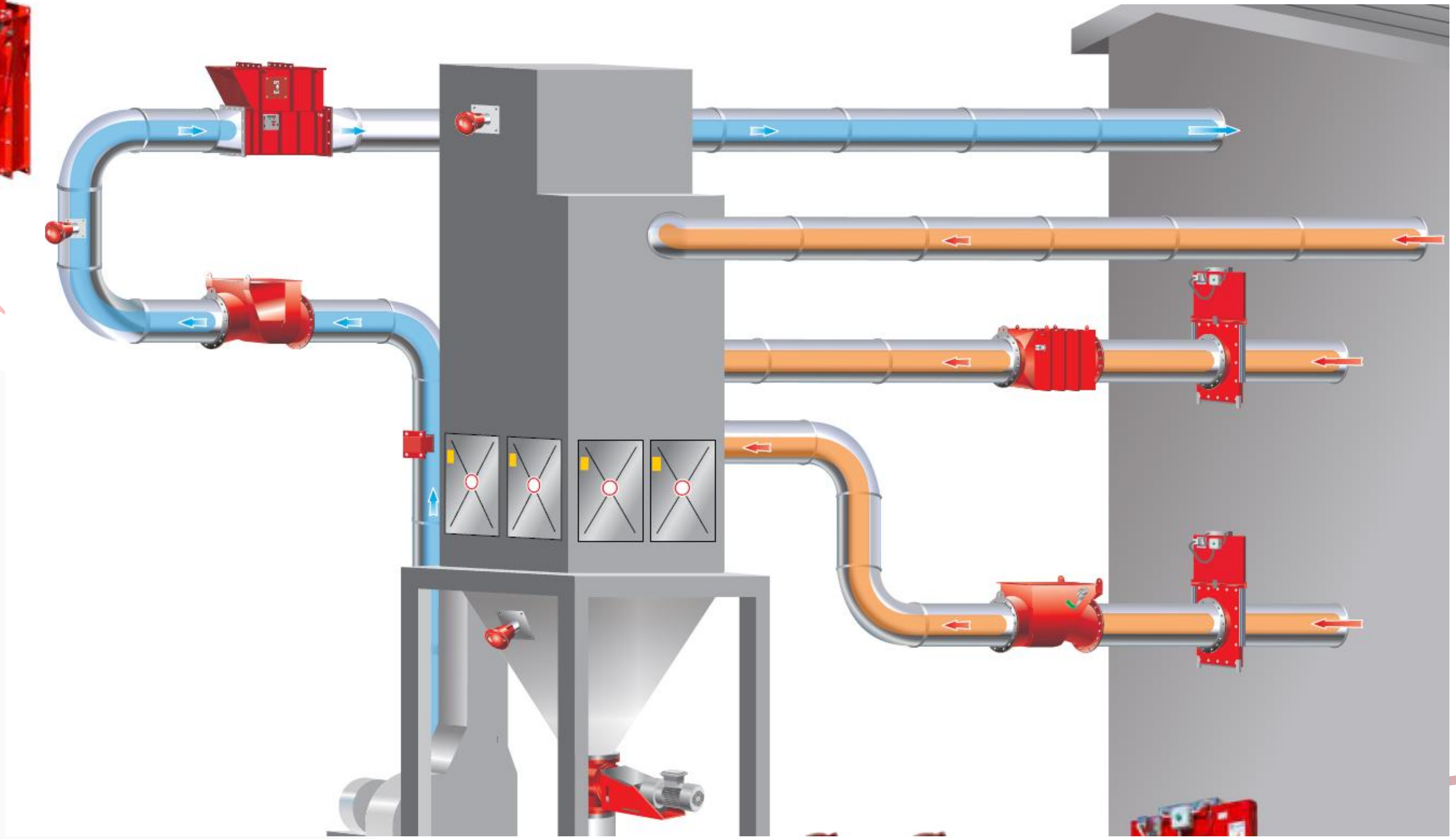
Hazard Management

Preventing Ember, Flame, and Smoke Transmission

Abort Gates and Fire Shutters



Hazard Management

Explosion Protection Design

DHA establishes:

- Where hazards exist
- Conceptual recommendations for appropriate hazard management

Explosion protection design is typically separate phase

- Proper design equally important as other aspects of fire protection
- NFPA 68 and 69 require documented design
  - Representative dust properties
  - Equipment and process details
  - Engineering calculations
  - Analysis of explosion consequences (for venting)
- Explosion protection systems often interface with other systems
  - Fire alarm system (NFPA 72 requires monitoring)
  - Process automation systems

Acceptance testing must be performed

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Presentation Summary

Presentation Summary

1. Dust deflagrations and explosions continue to occur in the US and worldwide
   - Hazard awareness is still growing
2. The retroactive requirement to complete a DHA is intended to address the hazard awareness gap
   - NFPA standards have aligned around fundamental DHA requirements
   - The 2018 IFC explicitly mandates a DHA for new and existing facilities / processes
3. DHAs must evaluate material hazards, building hazards, and equipment hazards
   - Hazard management can be achieved by prescriptive compliance, performance-based design, and risk analysis
4. Hazard management is a wholistic approach consisting of engineering controls and administrative controls
   - Proactive (design-phase) DHAs provide the best chance to eliminate / manage hazards
5. Preventative and mitigating measures must be engineered and appropriate for the application

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Questions and Discussion

Thank You

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