Industrial Explosion Protection

September 21, 2023
Michael Carlin, IEP Technologies

What is an Explosion?

- Sudden and rapid pressure rise releasing energy
- Most common is of course combustion event
  - Flame propagates through fuel : air mix
  - Temperature increase from ~20°C to 1800°C
  - The expansion of gas generates the pressure

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Characteristic of an Explosion

- Commonly begins with the ignition of a fuel that burns very rapidly.
- Produces a large and sudden release of gas.
- An explosion need not involve a fire.
- When a container bursts from increased internal pressure, sudden release also called an explosion.

Significant Combustible Dust Explosions Leading Up to OSHA Directive CPL 03-00-008 since 1995

- 12-11-95 Malden Mills, Methuen, MA — 37 injured
  - Nylon Fiber
- 02-26-99 Jahn Foundry, Springfield, MA — 3 dead/9 injured
  - Phenolic Resin Dust
- 02-01-99 Ford River Rouge, Dearborn, MI — 6 dead/36 injured
  - Secondary Coal Dust Explosion
- 05-16-02 Rouse Polymerics, Vicksburg, MS — 5 dead/7 injured
  - Rubber Dust
- 01-29-03 West Pharmaceutical Services, Kinston, NC — 6 dead/dozens of injuries
  - Polyethylene Dust
- 02-20-03 CTA Acoustics, Corbin, KY — 7 dead
  - Resin Dust
- 10-29-03 Hayes Lemmerz Manufacturing Plant — 1 dead/1 severely burned
  - Aluminum Dust
- 02-07-08 Sugar Manufacturer, Port Wentworth, GA — 14 dead/over 40 injured
  - Sugar Dust

OSHA Directive CPL 03-00-008

National Emphasis Program on Combustible Dusts

“Purpose. This instruction contains policies and procedures for inspecting workplaces that handle combustible dusts that are likely to cause dust deflagrations, other fires, or explosions. These dusts include, but are not limited to:

– metal dust, such as aluminum, magnesium, and some forms of iron dusts;
– wood dust;
– coal and other carbon dusts, including carbon black;
– plastic dust, phenolic resins, toner, and additives;
– rubber dust;
– biosolids;
– other organic dust, such as sugar, flour, paper, soap, and dried blood; and
– certain textile materials.”

OSHA Directive CPL 03-00-008

National Emphasis Program on Combustible Dusts

- General Duty Clause requiring safe and healthful workplace
- Issued 10-18-2007, updated March 2008 & January 2023
- Testing samples for combustibility
- **Explosion mitigation requirements per NFPA 654 / 652**
- **Deflagration isolation required per NFPA 654 / 652**
- Reviewing housekeeping (1/32”)
- **Citations and Fines**

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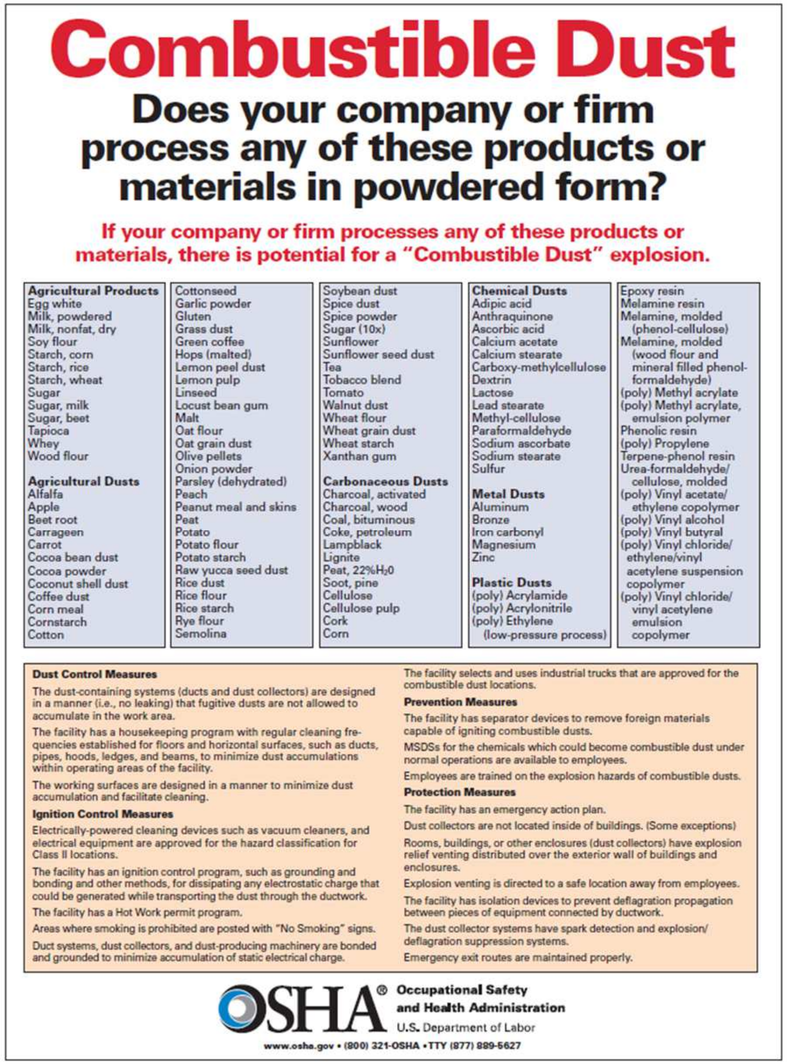
OSHA and Agricultural Facilities

National Emphasis Program on Combustible Dusts

- Does not pertain to grain facilities, which must comply with 29 CFR 1910.272 (Inspection of Grain Handling Facilities)
- If processing of agricultural products occurs, OSHA CSHOs have been enforcing to NFPA 654
- When there is disconnect between NFPA 654 and other NFPA documents (NFPA 61), majority of enforcement has been based on NFPA 654
- Consolidation of NFPA documents being performed (NFPA 660, Correlating Committee)

OSHA Directive CPL 03-00-008



Combustible Dust

Does your company or firm process any of these products or materials in powdered form?

If your company or firm processes any of these products or materials, there is potential for a "Combustible Dust" explosion.

Agricultural Products
Egg white
Milk, powdered
Milk, nonfat, dry
Soy flour
Starch, corn
Starch, rice
Starch, wheat
Sugar
Sugar, milk
Sugar, beet
Tapioca
Whey
Wood flour

Agricultural Dusts
Alfalfa
Apple
Beet root
Carrageen
Carrot
Cocoa bean dust
Cocoa powder
Coconut shell dust
Coffee dust
Corn meal
Cornstarch
Cotton
Cottonseed
Garlic powder
Gluten
Grass dust
Green coffee
Hops (malted)
Lemon peel dust
Lemon pulp
Linseed
Locust bean gum
Malt
Oat flour
Oat grain dust
Olive pellets
Onion powder
Parsley (dehydrated)
Peach
Peanut meal and skins
Peat
Potato
Potato flour
Potato starch
Raw yucca seed dust
Rice dust
Rice flour
Rice starch
Rye flour
Semolina
Soybean dust
Spice dust
Spice powder
Sugar (10x)
Sunflower
Sunflower seed dust
Tea
Tobacco blend
Tomato
Walnut dust
Wheat flour
Wheat grain dust
Wheat starch
Xanthan gum

Carbonaceous Dusts
Charcoal, activated
Charcoal, wood
Coal, bituminous
Coke, petroleum
Lampblack
Lignite
Peat, 22%H_2O
Soot, pine
Cellulose
Cellulose pulp
Cork
Corn

Chemical Dusts
Adipic acid
Anthraquinone
Ascorbic acid
Calcium acetate
Calcium stearate
Carboxy-methylcellulose
Dextrin
Lactose
Lead stearate
Methyl-cellulose
Paraformaldehyde
Sodium ascorbate
Sodium stearate
Sulfur

Metal Dusts
Aluminum
Bronze
Iron carbonyl
Magnesium
Zinc

Plastic Dusts
(poly) Acrylamide
(poly) Acrylonitrile
(poly) Ethylene (low-pressure process)
Epoxy resin
Melamine resin
Melamine, molded (phenol-cellulose)
Melamine, molded (wood flour and mineral filled phenol-formaldehyde)
(poly) Methyl acrylate
(poly) Methyl acrylate, emulsion polymer
Phenolic resin
(poly) Propylene
Terpene-phenol resin
Urea-formaldehyde/cellulose, molded
(poly) Vinyl acetate/ethylene copolymer
(poly) Vinyl alcohol
(poly) Vinyl butyral
(poly) Vinyl chloride/ethylene/vinyl acetylene suspension copolymer
(poly) Vinyl chloride/vinyl acetylene emulsion copolymer

Dust Control Measures

The dust-containing systems (ducts and dust collectors) are designed in a manner (i.e., no leaking) that fugitive dusts are not allowed to accumulate in the work area.

The facility has a housekeeping program with regular cleaning frequencies established for floors and horizontal surfaces, such as ducts, pipes, hoods, ledges, and beams, to minimize dust accumulations within operating areas of the facility.

The working surfaces are designed in a manner to minimize dust accumulation and facilitate cleaning.

Ignition Control Measures

Electrically-powered cleaning devices such as vacuum cleaners, and electrical equipment are approved for the hazard classification for Class II locations.

The facility has an ignition control program, such as grounding and bonding and other methods, for dissipating any electrostatic charge that could be generated while transporting the dust through the ductwork.

The facility has a Hot Work permit program.

Areas where smoking is prohibited are posted with "No Smoking" signs.

Duct systems, dust collectors, and dust-producing machinery are bonded and grounded to minimize accumulation of static electrical charge.

The facility selects and uses industrial trucks that are approved for the combustible dust locations.

Prevention Measures

The facility has separator devices to remove foreign materials capable of igniting combustible dusts.

MSDSs for the chemicals which could become combustible dust under normal operations are available to employees.

Employees are trained on the explosion hazards of combustible dusts.

Protection Measures

The facility has an emergency action plan.

Dust collectors are not located inside of buildings. (Some exceptions)

Rooms, buildings, or other enclosures (dust collectors) have explosion relief venting distributed over the exterior wall of buildings and enclosures.

Explosion venting is directed to a safe location away from employees.

The facility has isolation devices to prevent deflagration propagation between pieces of equipment connected by ductwork.

The dust collector systems have spark detection and explosion/deflagration suppression systems.

Emergency exit routes are maintained properly.

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– Section E.9.e
  - 5(a)(1) citations may be issued for deflagration and explosion hazards if SLTC (OSHA's Salt Lake Technical Center) finds Kst values of the submitted dust sample to be greater than zero.

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Industries at Risk

- Chemical
- Petrochemical
- Grain
- Food
- Pharmaceutical
- Aerosol
- Steel
- Cement
- Wood

NFPA and Explosion Protection

Applicable Codes (USA)

- *NFPA 68* Venting of Deflagrations
- *NFPA 69* Explosion Prevention Systems

} Prescriptive requirements for the design of explosion protection methods

- *NFPA 654* Combustible Particulate Solids
- *NFPA 664* Wood Processing
- *NFPA 61* Agricultural and Food Products
- *NFPA 484* Metal Dusts
- NFPA 652 Fundamentals of Combustible Dust

- NFPA 660 proposed new standard consolidating fundamentals and industry-specific requirements

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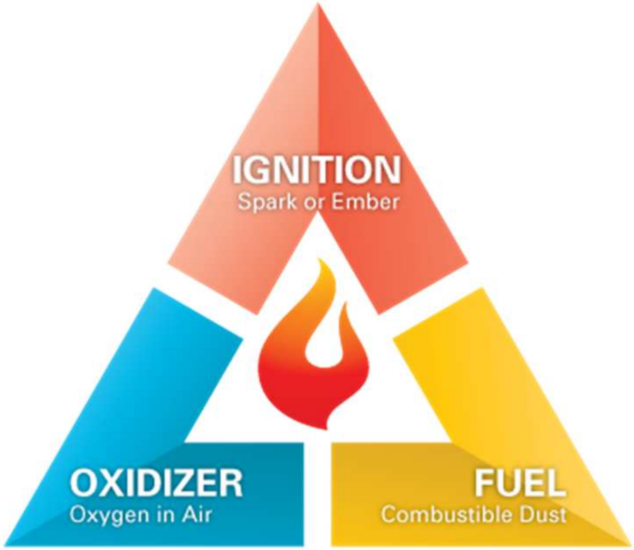
Combustion / Flash Fire



The Combustion Triangle

Dust Deflagration Criteria

The Combustion Triangle

1. Fuel - Dust is combustible
2. Oxygen - Dust is dispersed in air or another oxidant
3. Ignition source - electrostatic discharge, spark, glowing ember, hot surface, friction heat, flame
4. Dispersion - Concentration of dispersed dust is at or above the minimum explosible concentration (MEC)
5. Confinement of a vessel

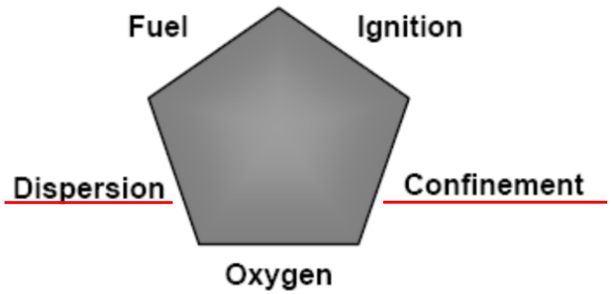


Figure 2. Dust explosion pentagon

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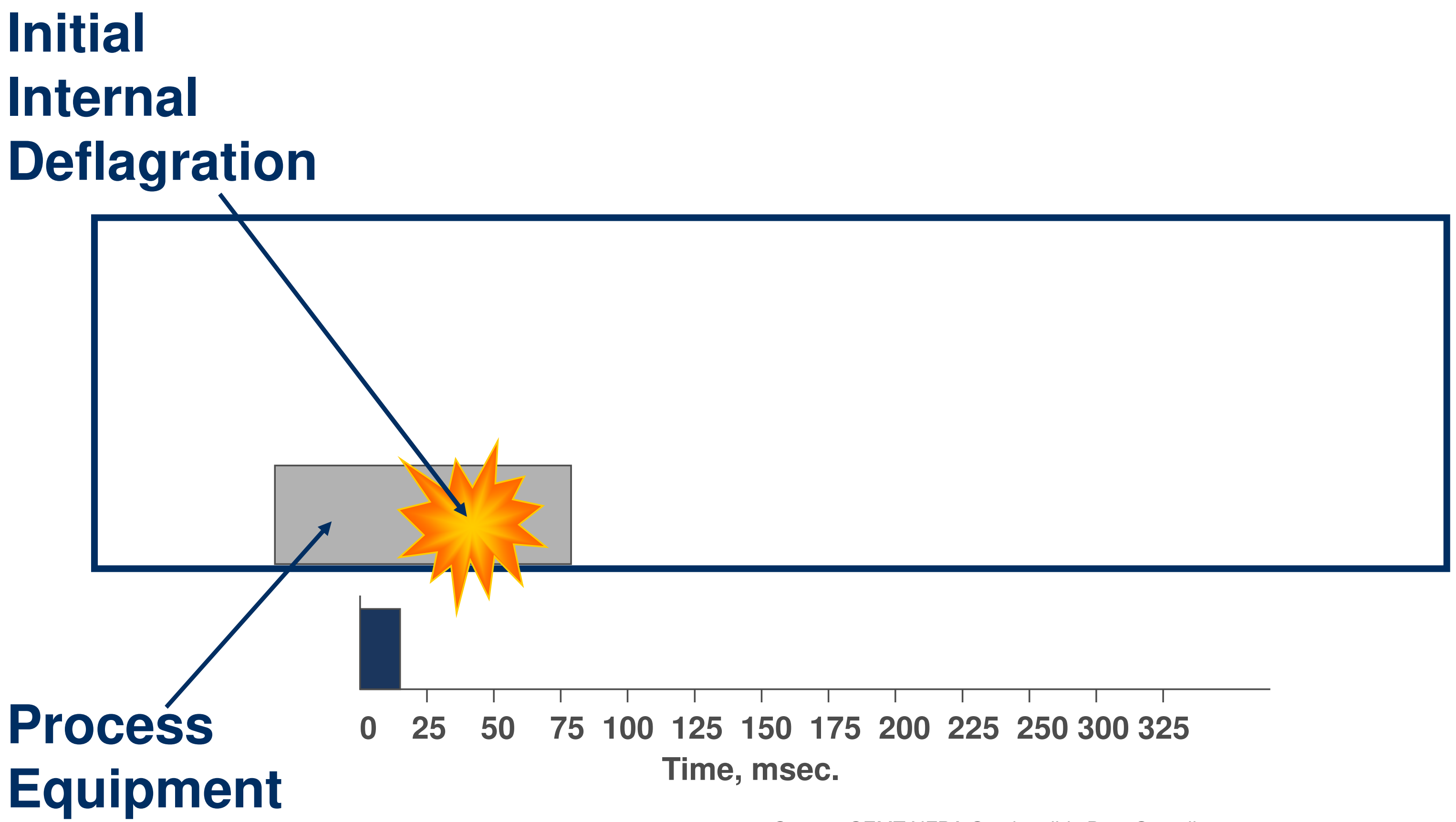
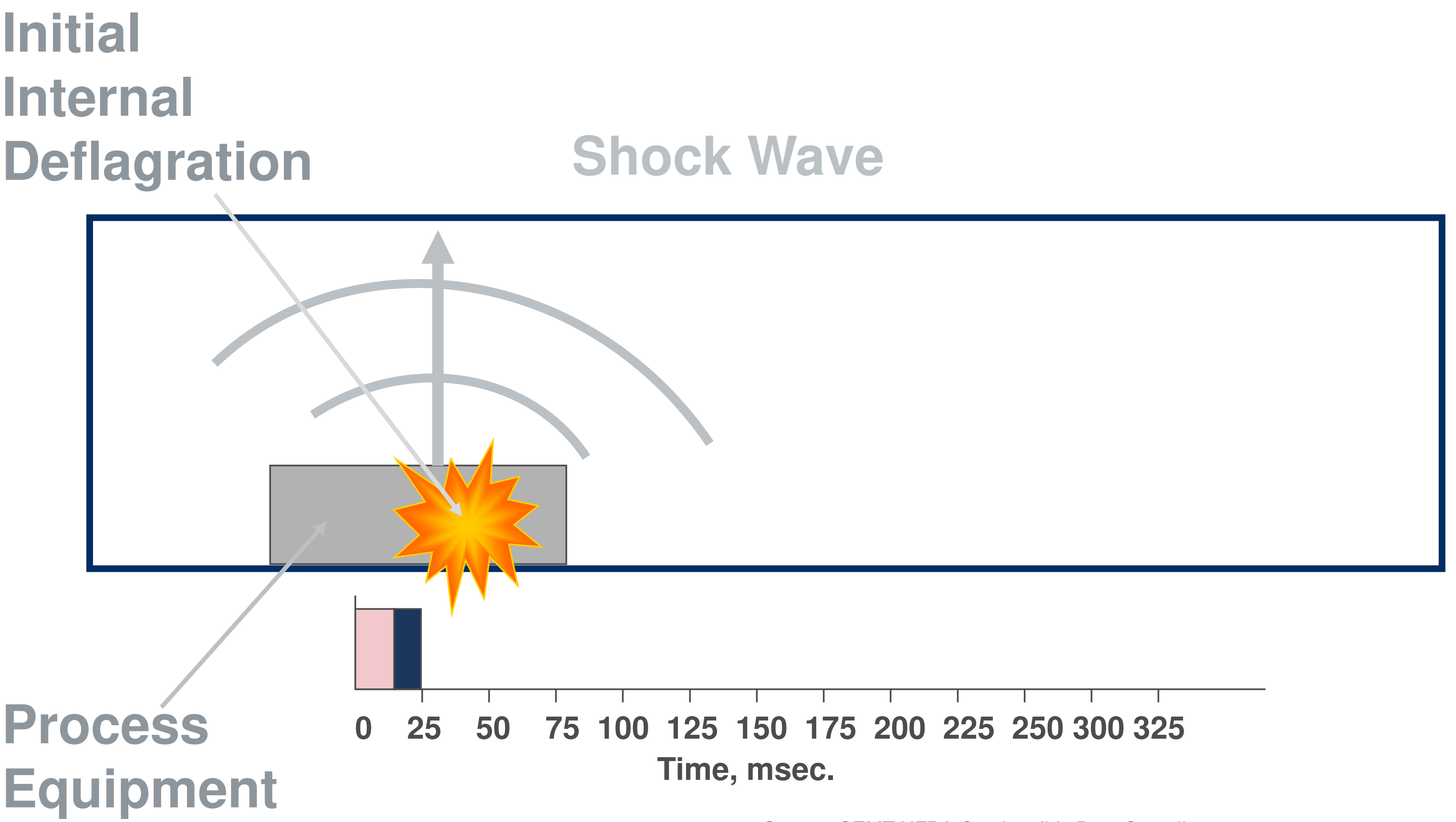
Typical Explosion Event



Source: CEMT NFPA Combustible Dust Compliance

Typical Explosion Event



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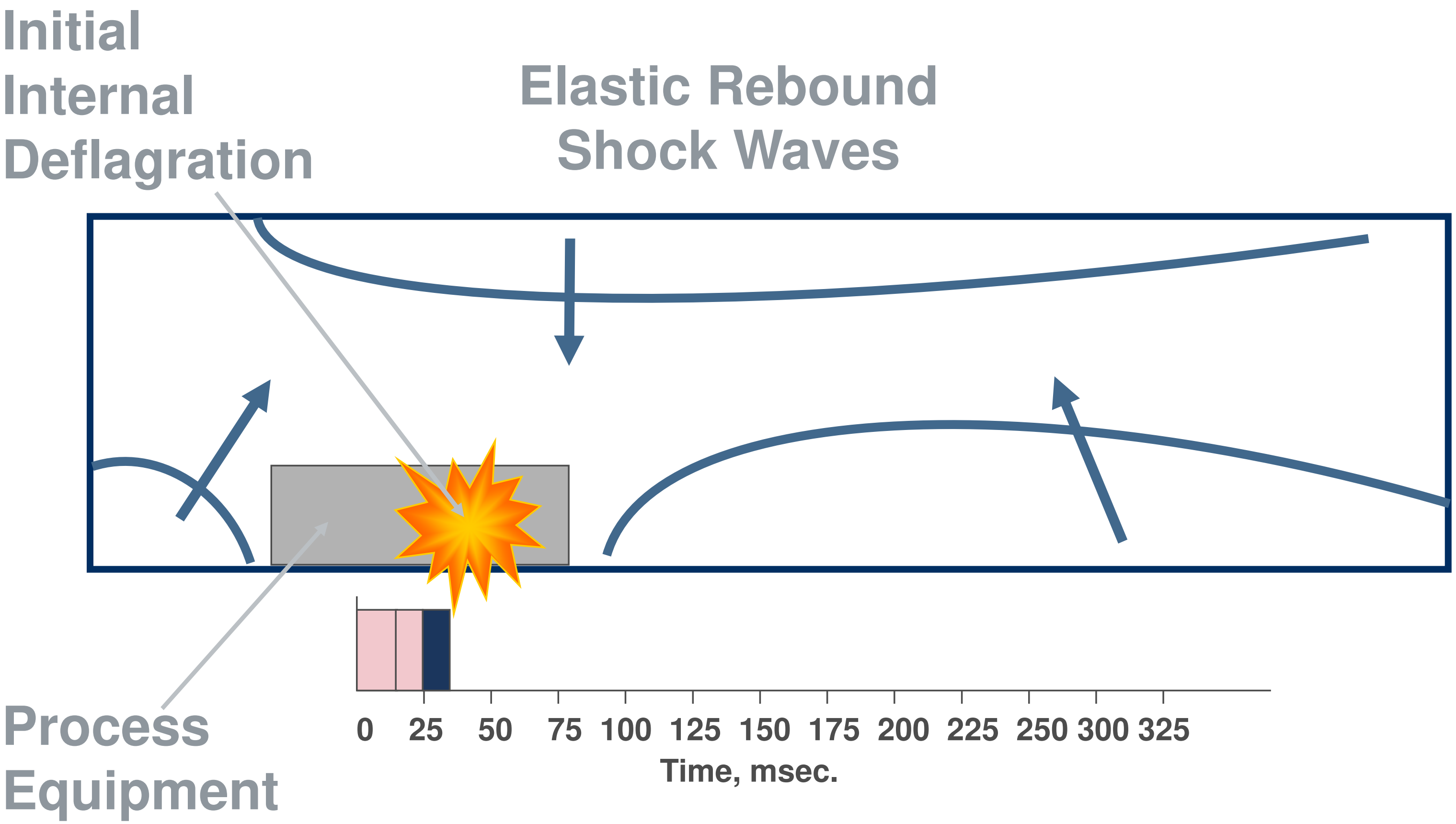

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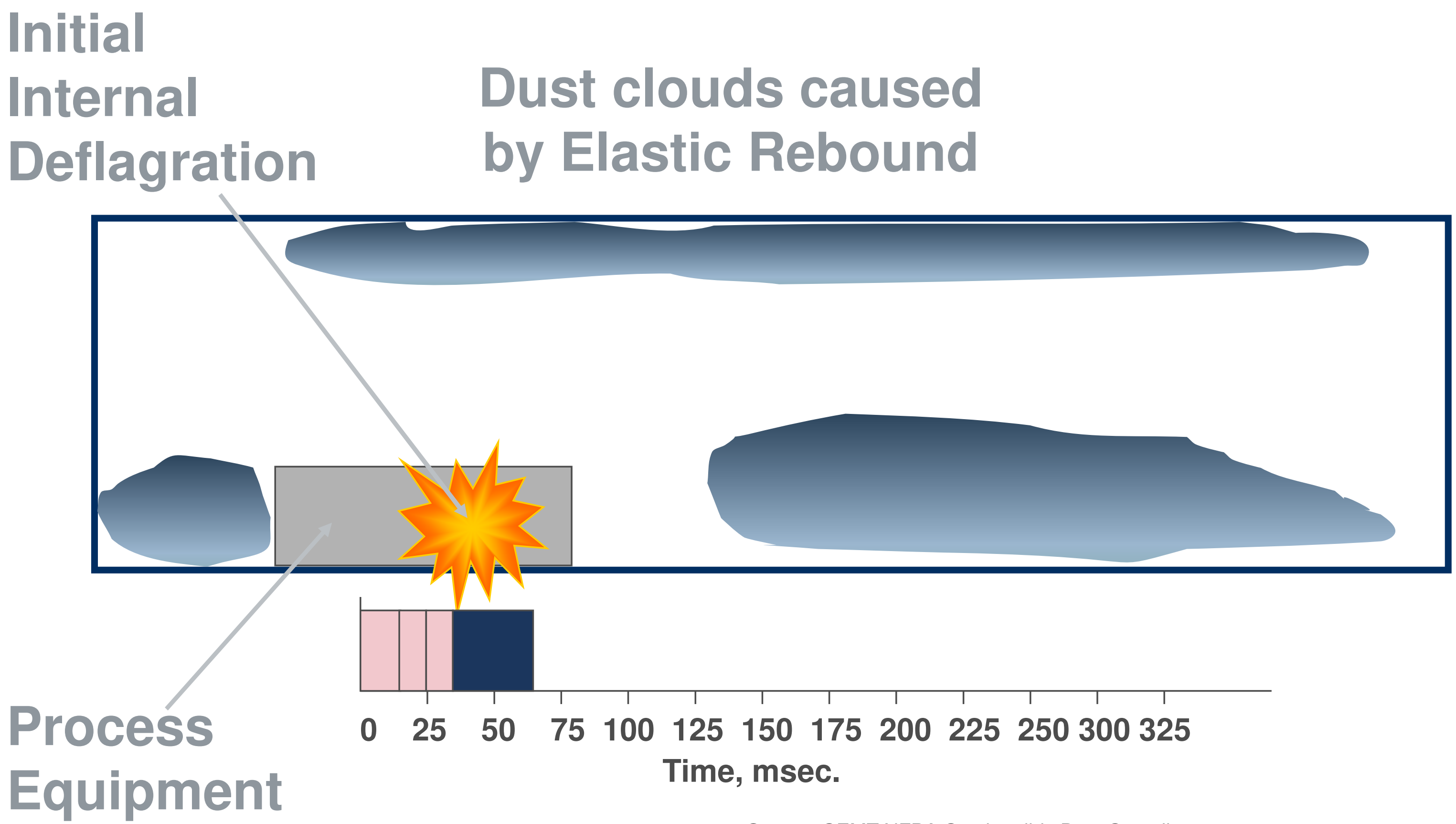
Typical Explosion Event



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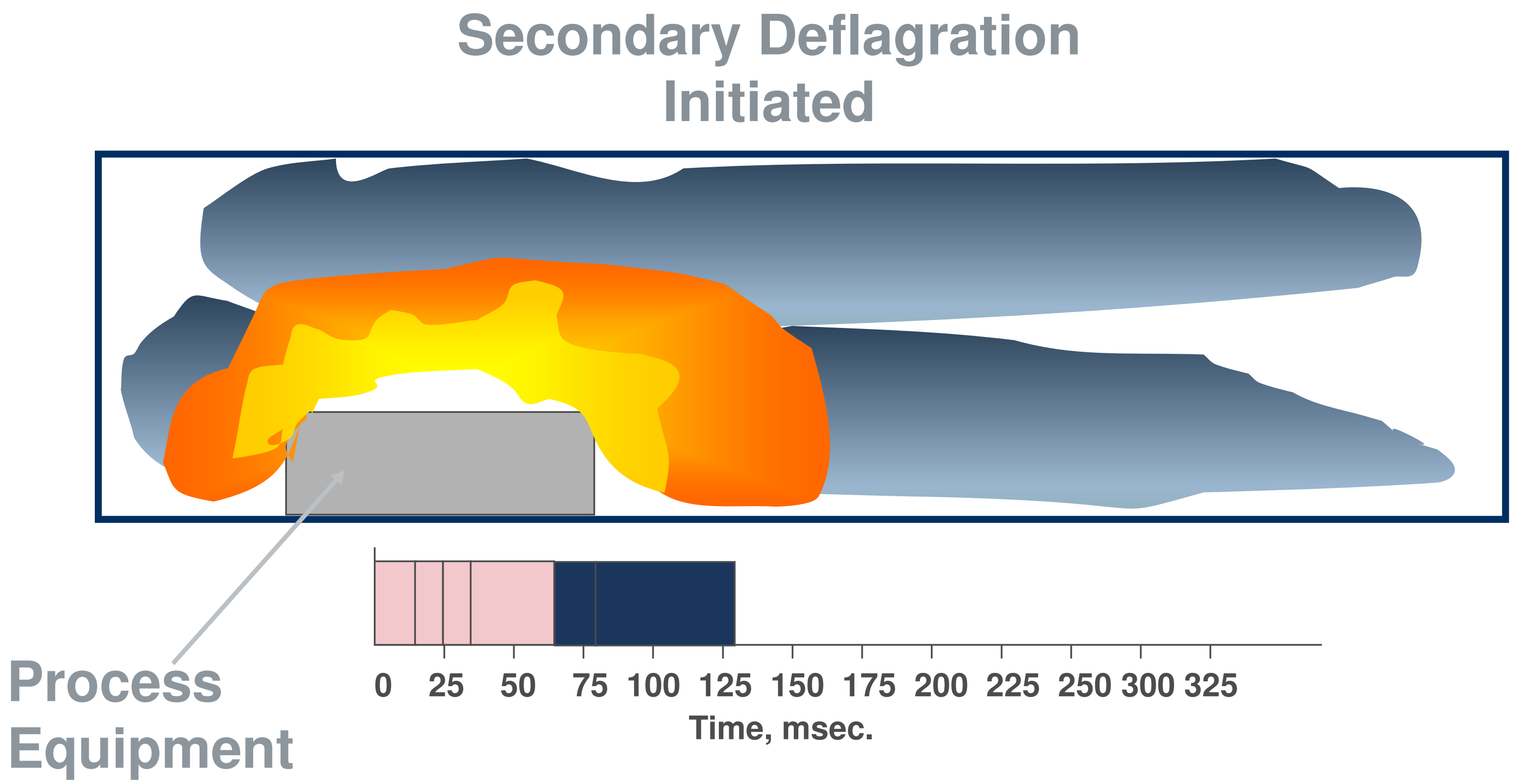

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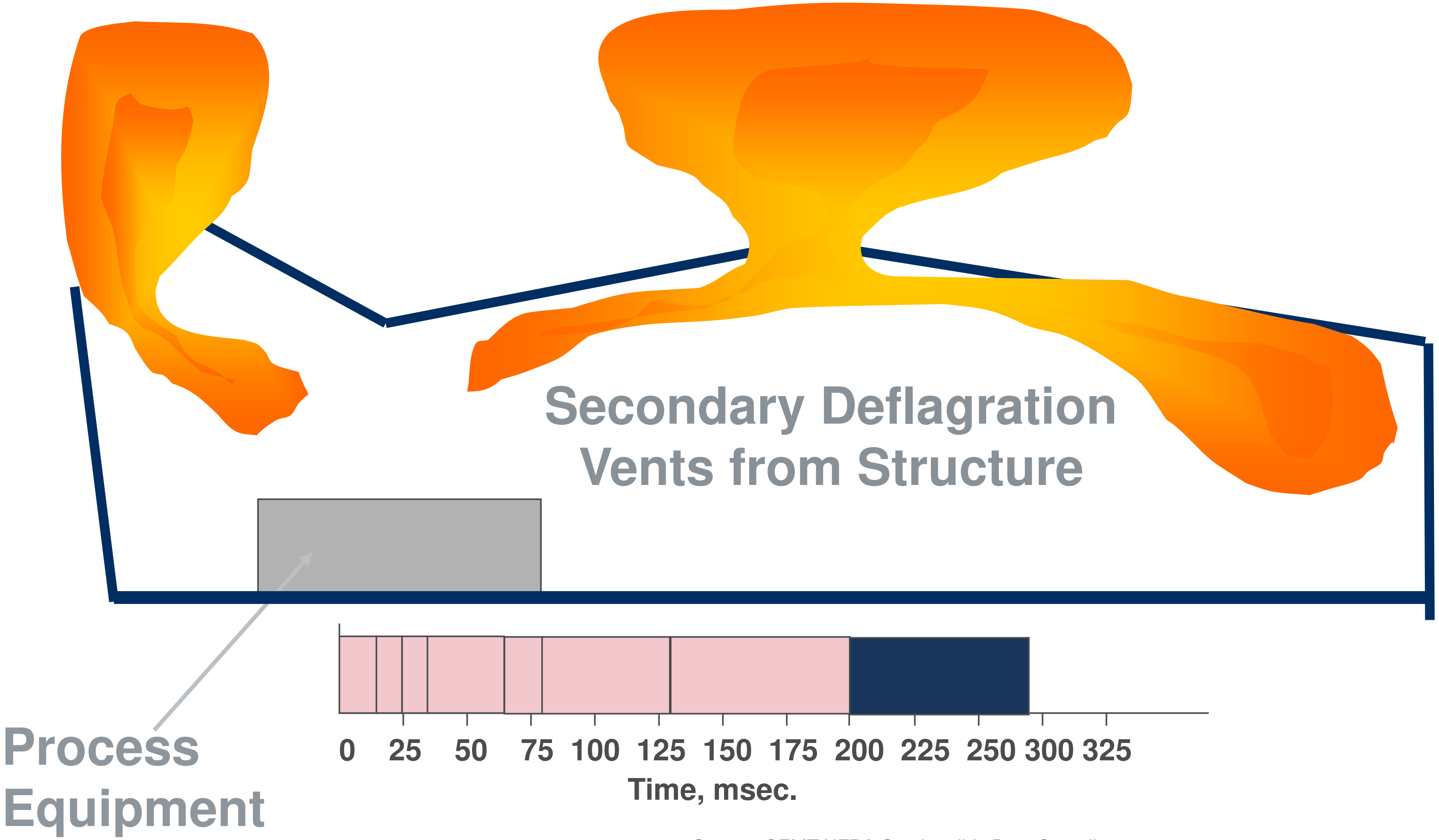
Typical Explosion Event



Source: CEMT NFPA Combustible Dust Compliance

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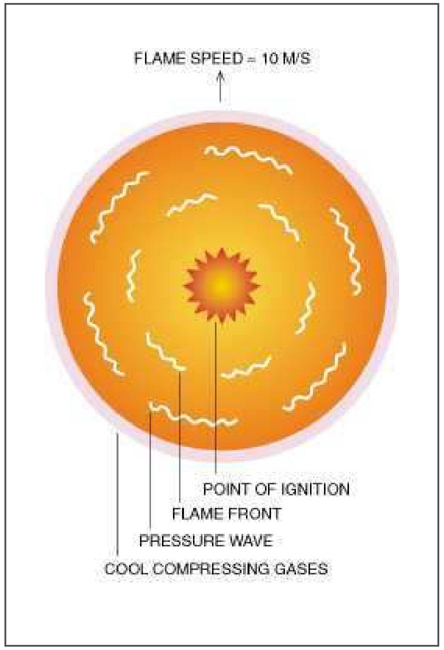
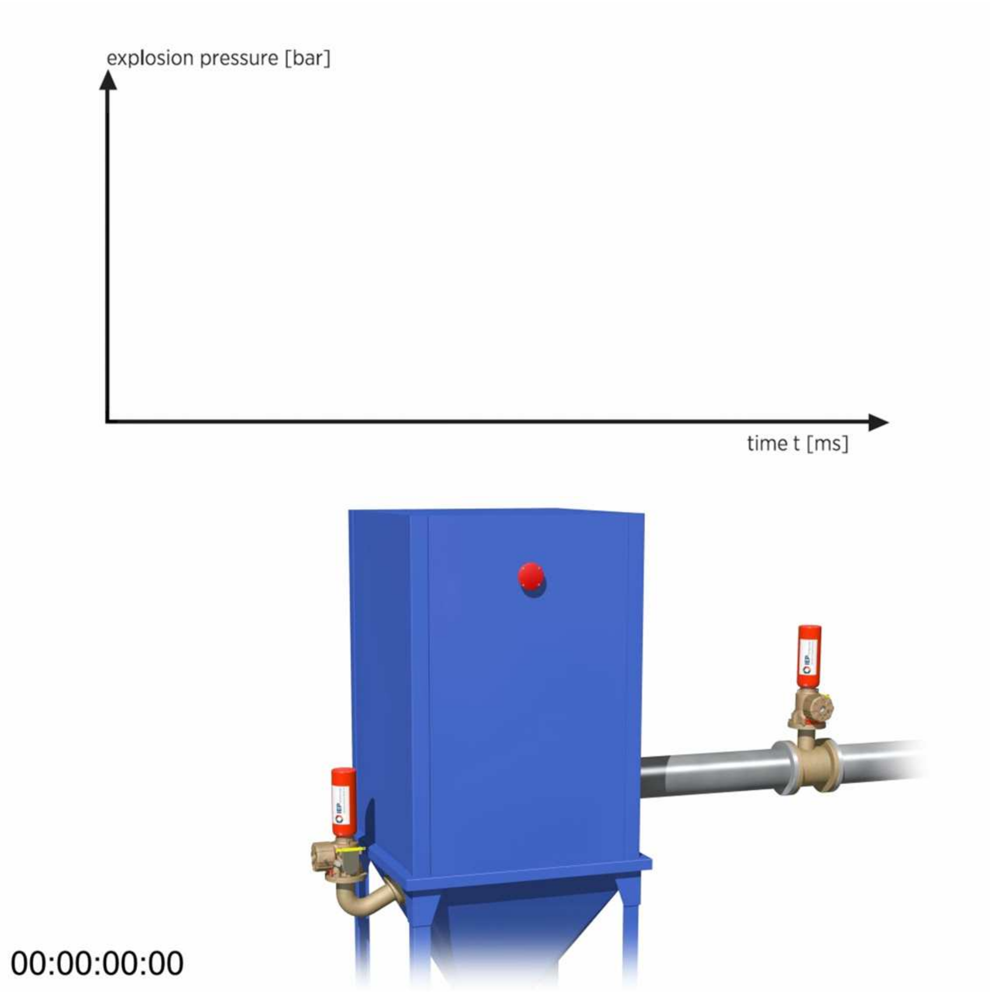
Secondary Explosions

- Secondary dust explosions, due to inadequate housekeeping and excessive dust accumulations.
- Secondary dust explosions due to propagation through interconnected ducts, chutes, conveyors, …etc.

Deflagration Principle



- Flame Speed ~30 ft/s
- Pressure Wave ~1100 ft/s



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Secondary Explosion

Hayes Lemmerz - Aluminum Alloy Wheel MNF, IN

October 29, 2003
• Aluminum Dust
• 1 worker killed
• 6 injuries

Secondary Explosion

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Explosion Risk Hazard Awareness

281 dust explosion incidents over 25 year period

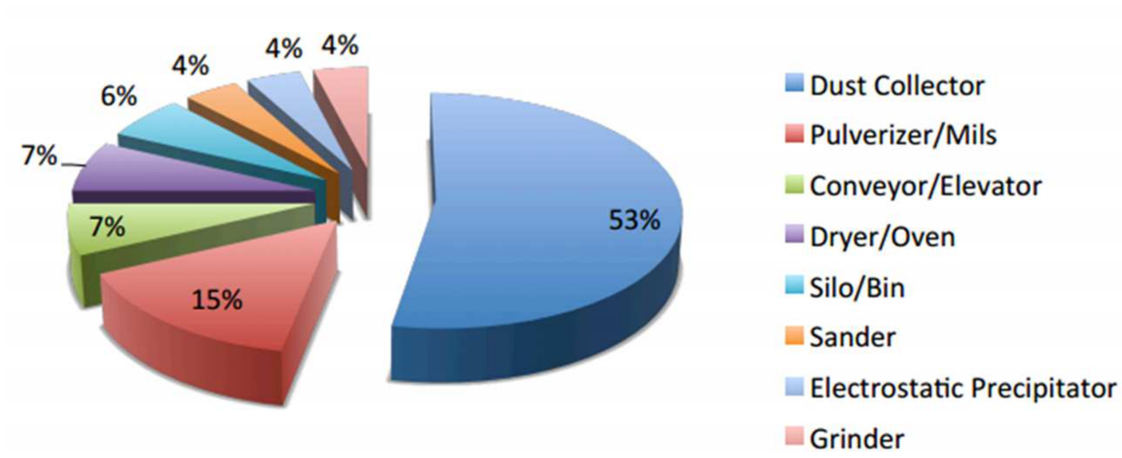
44 Different states in US

Various industries

Various combustible dusts

119 fatalities

718 injuries



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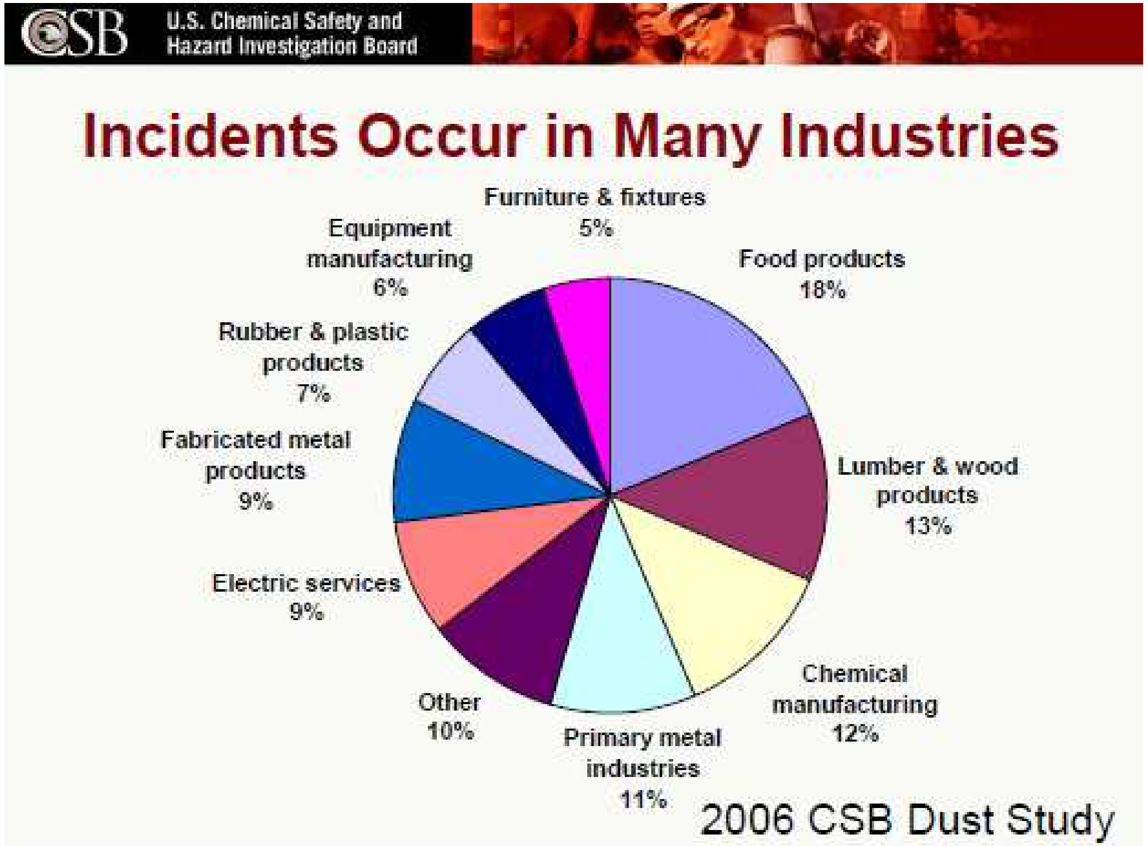
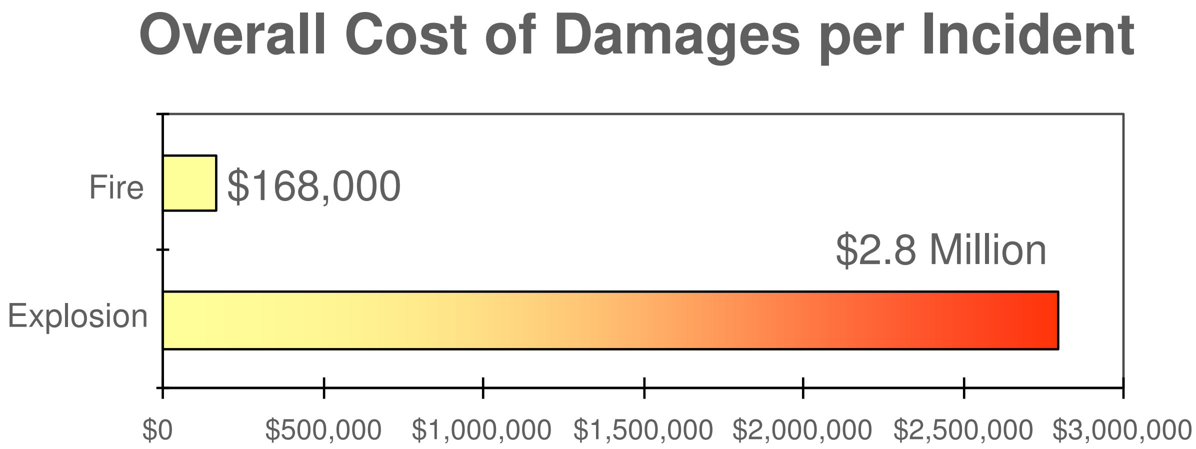
Explosion Summary, 1980 to 2005



Loss Comparison

Explosions account for 4% of incidents yet:



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U.S. CSB Investigation of Fatal Dust Explosions

- Plastics Mfg. in NC
- Polyethylene Powder
- 6 fatalities
- Hundreds of injuries
- Plant destroyed
- Was major employer

- Acoustic Board Mfg.
- Kentucky
- 7 fatalities
- 37 injured
- Use phenolic resin powder as binder for fiberglass mats

- Wheel Manufacture
- Indiana
- Aluminum Alloy Dust
- 1 worker killed
- 6 injuries

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CSB Study Findings

- 281 dust explosions over 25 year period (1980-2005)
- 119 fatalities, 718 injured
- MSDS for combustible dusts do not contain explosion hazard information
- US safety regulations do not address dust explosion mitigation requirements
- Consensus standards provide guidance, but are voluntary unless adopted by state or local AHJs
- OSHA responsible per General Duty Clause requiring safe and healthful workplace

Chemical Safety Board Findings

Common Factors in ALL of the Studied Catastrophic Events

- Workers were unaware of the dust explosion hazard
- Non-conformance to NFPA standards
- Unsafe accumulation of dust (poor housekeeping)
- Procedures/training for dust control inadequate
- Dust collection systems were not adequately protected for explosions
- Warning events were accepted as normal and not resolved
- Process changes occurred without hazard reviews
- Government enforcement officials, insurance underwriters
- EH&S professionals failed to identify dust explosion hazards

US Dust Incidents by Industry, 2006-2017

Source: US Chemical Safety and Hazard Investigation Board

Casualties included:

- 59 Deaths
- 303 Injuries

International Fire Code and NFPA

International Fire Code

- *"This code contains numerous references to standards promulgated by other organizations that are used to provide requirements for materials and methods of construction. This chapter contains a comprehensive list of all standards that are referenced in this code. These standards, in essence, are part of this code to the extent of the reference to the standard."*
- Explosion protection-related standards referenced in the IFC include:
  - NFPA 30B – Aerosol Products
  - NFPA 61 – Agricultural and Food Processing Facilities
  - NPFA 69 – Explosion Prevention Systems
  - NFPA 484 – Metal Dust
  - NFPA 652 – Fundamentals of Combustible Dust
  - NFPA 654 – Combustible Particulate Solids
  - NFPA 655 – Sulfur
  - NFPA 664 – Wood Processing and Woodworking Facilities
- IFC adopted as part of fire code in 41 of 50 US states

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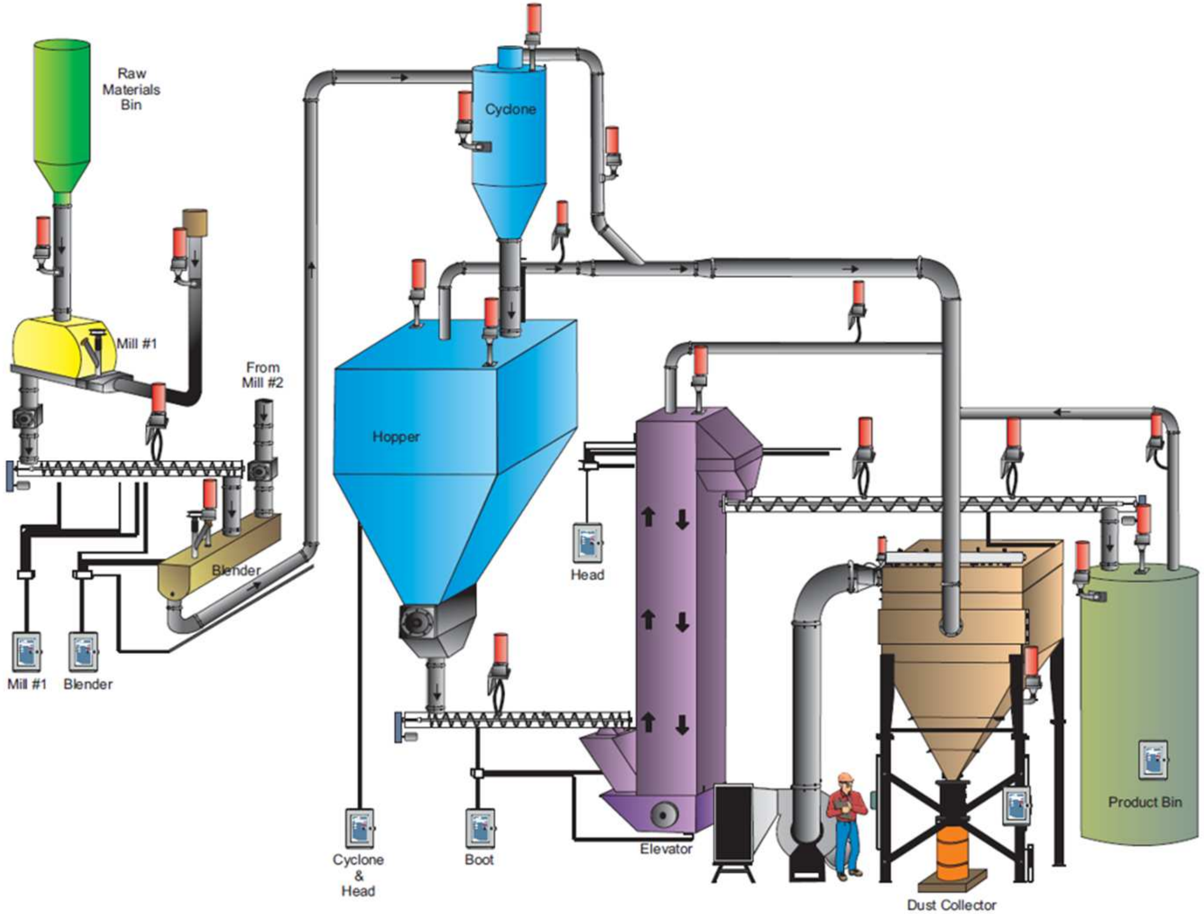
Explosion Threat - Equipment

- Dust Collectors
- Cyclones
- Dryers (Spray, Fluid Bed, Rotary)
- Mixers, Blenders
- Mills, Grinders, Pulverizers
- Reactors
- Bins, Hoppers, Silos
- Pneumatic Conveying
- Mechanical Conveying



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Where to Start

Dust Hazard Analysis – 2016 NFPA 652 Standard on the Fundamentals of Combustible Dust Compliance

- Chapter 7 of NFPA 652 requires all facilities to have a DHA performed within three years. (7.1.2.2) **2019 Edition extended to September 7th, 2020**
- Standard is retroactive, and applies to existing processes, facilities and operations. (7.1.2)
- Makes the business or corporate owner/operator of each facility responsible to have the DHA performed. (7.1.2.1)
- Allows the Industry Related Standards to prevail in conflict and is becoming the minimum standard thru subcommittees.
  - 484 – Hazard Analysis (5 Years) / Retroactivity
  - 61 - Retroactivity
- Redefines AHJ as someone responsible for enforcement.
- The facilities processes including physical and chemical properties of hazardous materials.
- The design of fire and explosion safety provisions for the building and processes.

Where to Start

NFPA 652-2019 Edition

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.
5.1.1 Where dusts are determined to be combustible or explosible, the hazards associated with the dusts shall be assessed in accordance with Chapter 7.
5.1.2 Where dusts are determined to be combustible or explosible, controls to address the hazards associated with the dusts shall be identified and implemented in accordance with 4.2.4.

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
5.2.2* Test results, historical data, and published data shall be documented and, when requested, provided to the authority having jurisdiction (AHJ).
5.2.3 The absence of previous incidents shall not be used as the basis for deeming a particulate to not be combustible or explosible.
5.2.4 Where dusts are determined to not be combustible or explosible, the owner/operator shall maintain documentation to demonstrate that the dusts are not combustible or explosible.

ST Classification and Kst

ST Classification	K_{st} Value
ST – 1	1 – 200
ST – 2	201 – 300
ST – 3	301 and above

Example Pittsburgh seam coal has a Kst of 129 bar-m/sec, making it an ST-1 dust

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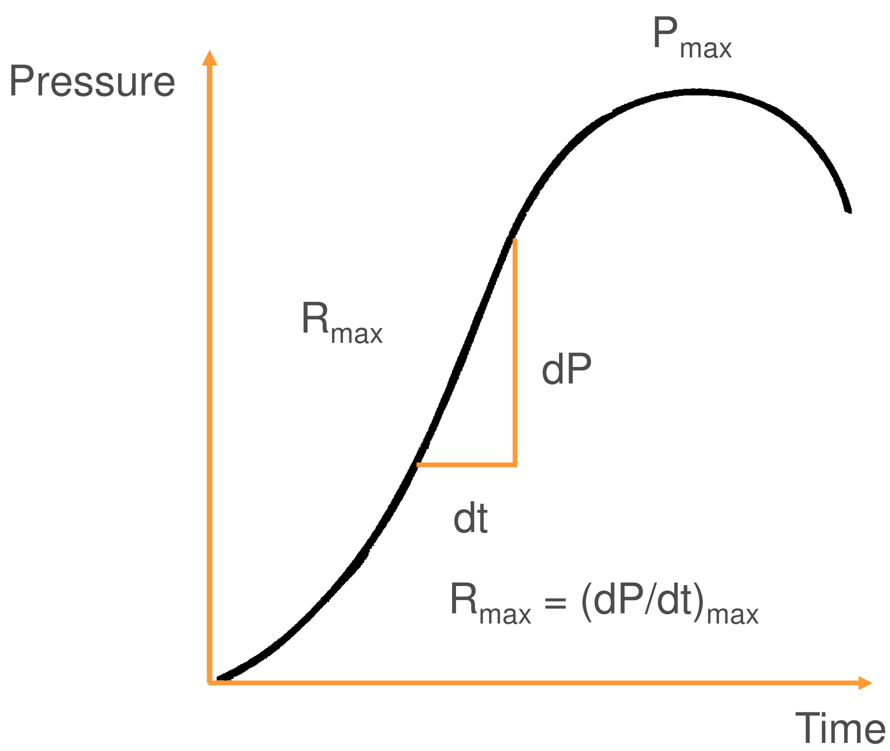
Explosibility Calculation



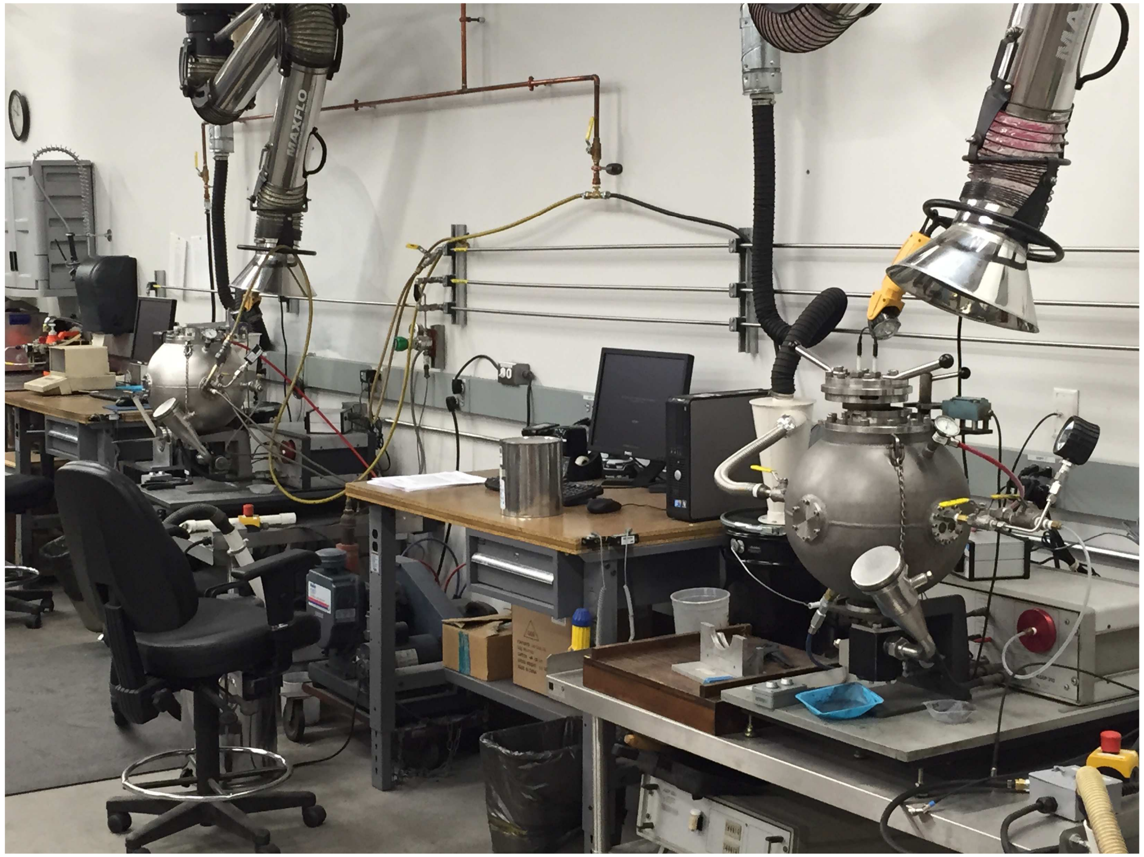
$K_{st} = R_{max} \times V^{1/3}$ [bar-m/s]

Where

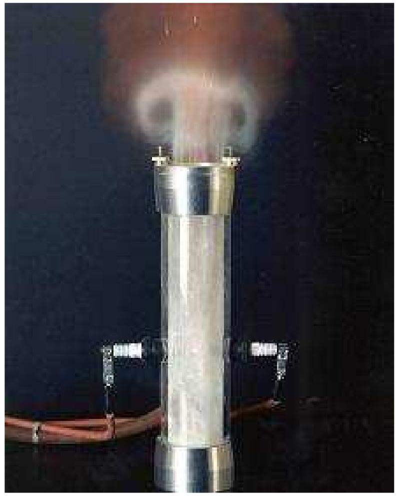
R_{max} = The maximum rate of pressure rise [bar/s]

V = The volume of the test vessel [m^3]

Combustible Material Testing



20-Liter Test Vessel for
Kst, Pmax Determination



Go-No Go
Test

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Explosion Hazard Evaluation

A thorough review of the plant, processes, equipment and materials

CONSIDER:

- Normal, Abnormal and Upset Conditions
- Ignition Sources
- Geometry and Strength
- Housekeeping
- Process Temperature and Pressure Limits
- Existing Explosion Prevention and Protection Measures
- Material Hazards

Explosion Prevention Measures

- Process Hazard Evaluation
- Ignition Control
  - Bonding/Grounding
  - Electrical Equipment/Classification
  - Control of Friction, Impact Spark Potential
  - Hot Work Procedures
- Housekeeping
- Hazard Training and Awareness
- Management of Change

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Ignition Sources

13 Ignition Sources acc. to DIN EN 1127-1

1. Hot surfaces
2. Flames and hot gases
3. Mechanically generated sparks
4. Power supplies (electrical apparatus)
5. Stray electrical currents, cathodic corrosion protection
6. Static electricity
7. Lightning
8. Electromagnetic waves, radio frequency
9. Electromagnetic waves
10. Ionizing radiation
11. Ultrasound
12. Adiabatic compression and shock waves
13. Exothermic reactions

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NFPA 654 2020 Edition
Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids

- Chapter 9 Hazard Management: Mitigation and Prevention
- 9.7.1 Explosion Prevention and Protection.
- 9.7.1.1 Explosion Protection for Equipment.
- 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
- 9.7.1.2 If the method in 9.7.1.1(5) is used, test data for specific dust and diluent combinations shall be provided and shall be acceptable to the authority having jurisdiction.

NFPA 652 2019 Edition
Fundamentals of Combustible Dust

- 9.7 Explosion Prevention/Protection.
- 9.7.1 General. Where a dust explosion hazard exists within an enclosure, measures shall be taken as specified in Section 9.7 to protect personnel from the consequences of a deflagration in that enclosure.
- 9.7.2 Risk Assessment. A documented risk assessment acceptable to the AHJ shall be permitted to be conducted to determine the level of protection to be provided, including, but not limited to, the measures addressed in Section 8.9.
- 9.7.3 Equipment Protection.
- 9.7.3.1* General. Where an explosion hazard exists within any operating equipment greater than 8 ft3 (0.23 m) of containing volume, the equipment shall be protected from the effects of a deflagration.
- 9.7.3.2 Explosion protection systems shall incorporate one or more of the following methods of protection:
- (1) Oxidant concentration reduction in accordance with NFPA 69
- (2) Deflagration venting in accordance with NFPA 68
- (3) Deflagration venting through listed flame-arresting devices in accordance with NFPA 68
- (4) Deflagration pressure containment in accordance with NFPA 69
- (5) Deflagration suppression system in accordance with NFPA 69
- (6) Dilution with a noncombustible dust to render the mixture noncombustible
- 9.7.3.3 Enclosures and all interconnections protected in accordance with 9.7.3.2 shall be designed to withstand the resultant pressures produced during the deflagration event.

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Explosion Protection Methods

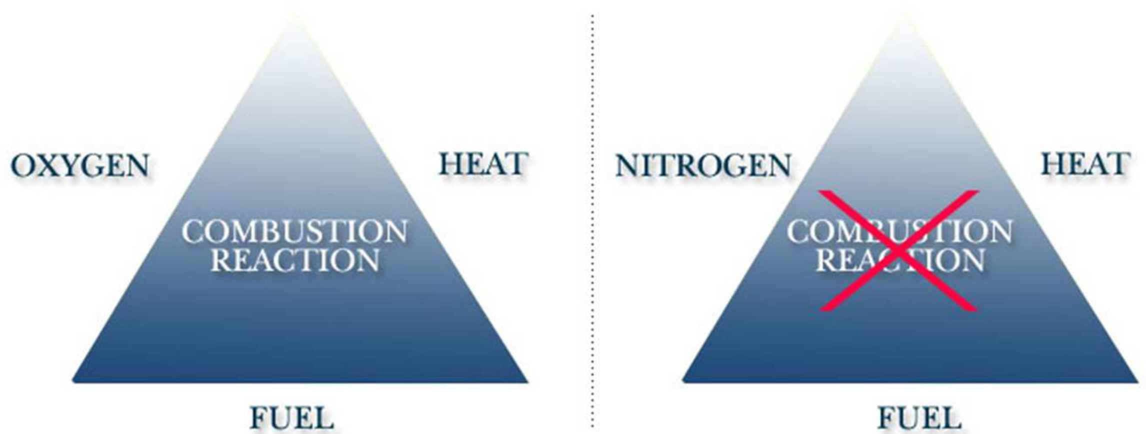
- Containment – not typical
- Inerting – not typical
- **Deflagration Suppression**
- **Deflagration Relief Venting**
- **Deflagration Isolation**

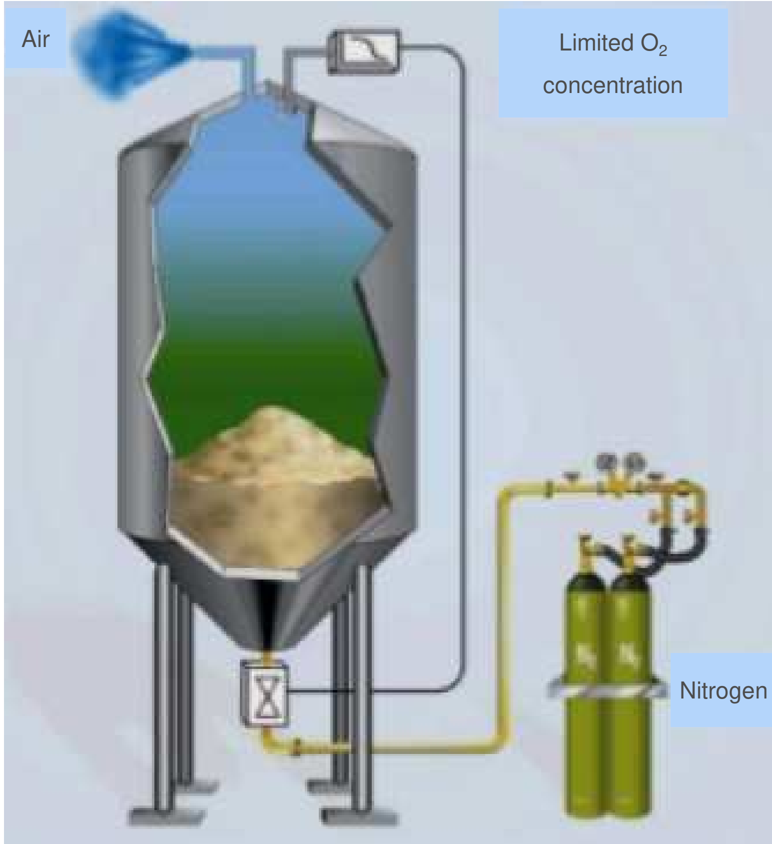
Containment

- Withstand Maximum Deflagration Pressure
- ASME Pressure Vessel Code
- Initial Pressure 30 psig max
- NFPA 69

Inerting

- Lowering Oxygen Concentration
- Inert Gases: Nitrogen, Carbon dioxide, Argon
- NFPA 69





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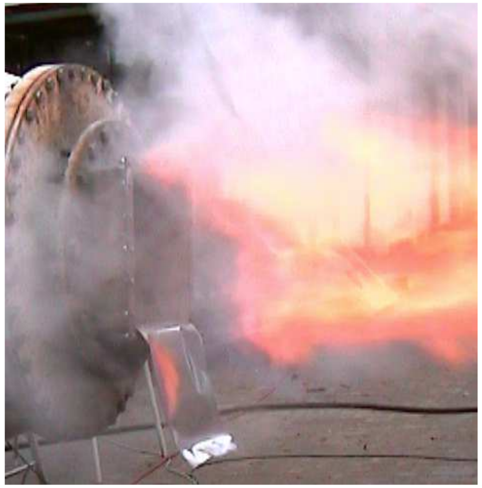
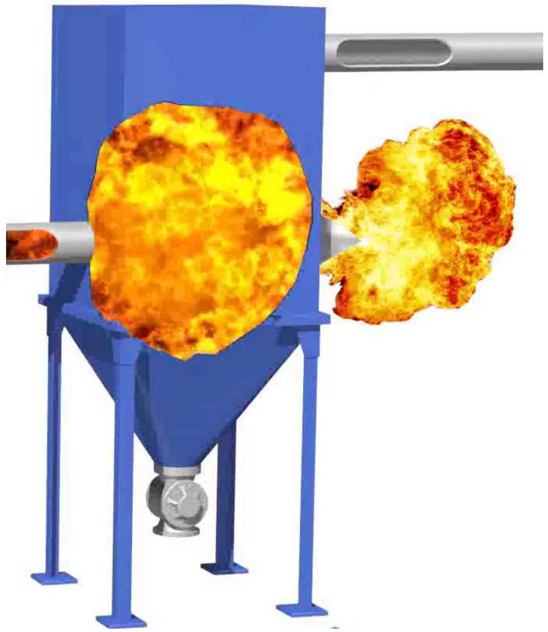
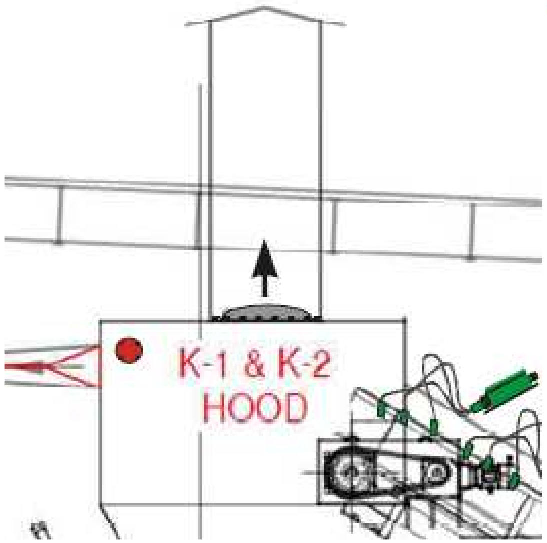
Deflagration Relief Vents

– Rupture-style
– Flat / domed / curved
– Square / rectangular / round
– Optional burst sensors
– Optional Insulated Models







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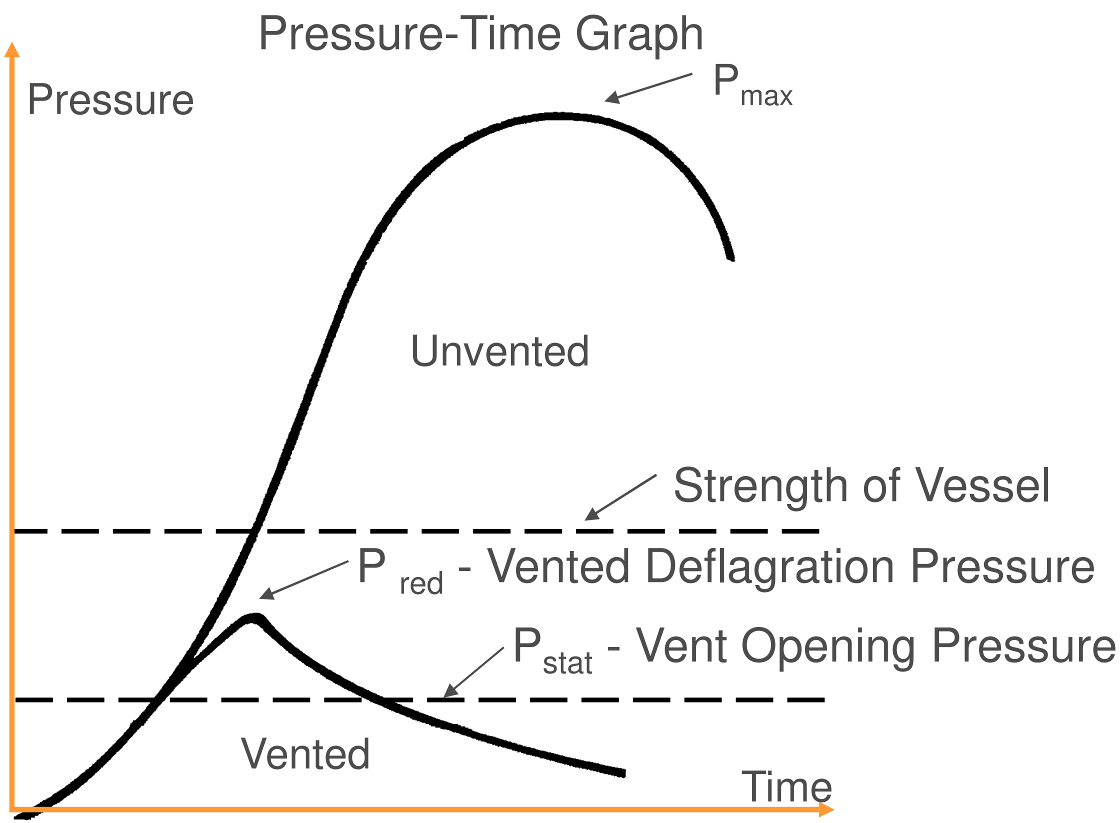
Vented Dust Explosion

- Fireball 7x volume of vessel
- Flame ejection >50’
- Must vent to safe area
- NFPA 68 to address thermal heat in next release

Vented Dust Explosion

Vented Explosion



Fireball Dimensions

NFPA 68-2018 Edition

8.9.2.2 The maximum width and height of the projected flame shall be taken as D and shall be assumed to be equally distributed around the centerline of the vent discharge *(see Figure 8.9.2.2).*

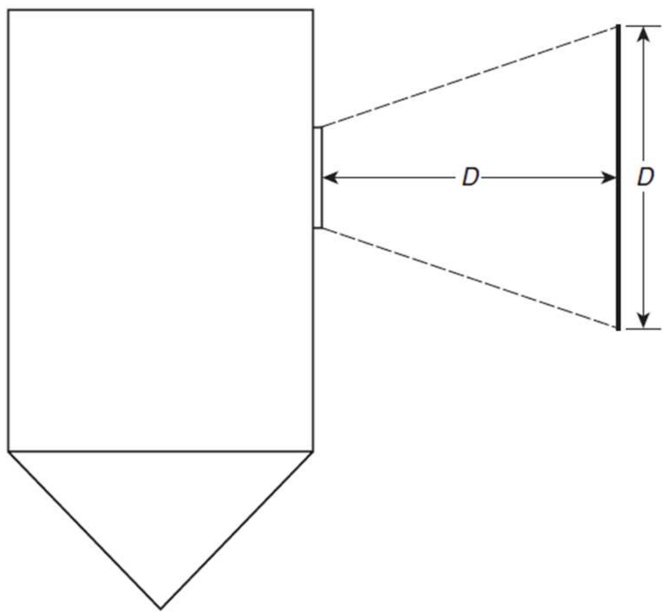


FIGURE 8.9.2.2 Fireball Dimensions.

8.9.2* In the case of dust deflagration venting, the distance, D, shall be expressed by Equation 8.9.2:

$$D = K \cdot \left(\frac{V}{n}\right)^{1/3} \qquad \textbf{(8.9.2)}$$

where:

D = axial distance (front) from the vent (m)
K = flame length factor: 10 for metal dusts, 8 for chemical and agricultural dusts
V = volume of vented enclosure (m^3)
n = number of evenly distributed vents

8.9.5 Equation 8.9.2, Equation 8.9.3, and Equation 8.9.4 shall be valid for the following conditions:

(1) Enclosure volume: $0.3\ m^3 \le V \le 10{,}000\ m^3$
(2) Reduced pressure: $P_{red} \le 1$ bar-g
(3) Static activation pressure: $P_{stat} \le 0.1$ bar-g
(4) Deflagration index: $K_{St} \le 300$ bar-m/s for Equation 8.9.2, $K_{St} \le 200$ bar-m/s for Equation 8.9.3 and Equation 8.9.4
(5) $P_{max} \le 9$ bar-g

Deflagration Relief Sizing

- NFPA 68 for Sizing
- INSIDE VESSELS: Vent ducts require additional vent area
- Vessel overpressure strength needed
- Will not stop flame propagation through inlet or exhaust

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Explosion Relief Sizing

- NFPA 68 for Vent Sizing
- INDOOR VESSELS: Vent ducts require additional vent area than outdoor vessels
  - Exception: one hydraulic diameter of vent or less of vent duct $D_h = (4*A)/P$
- Flame ejection more intense and vent opening time longer, increasing pressure
- Will not stop flame propagation through inlet or exhaust

Explosion Vent Sizing

- NFPA 68 for Sizing
- INSIDE VESSELS: Vent ducts require additional vent area
- Vessel overpressure strength needed
- Will not stop flame propagation through inlet or exhaust

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Vent Duct Length

NFPA 68-2018 Edition

6.8.6 Vent ducts and nozzles with total lengths of less than one hydraulic diameter, relative to the calculated installed vent area, irrespective of the duct area, shall not require a correction to the vent area.

The formula for the hydraulic diameter of a vent is 4A/P, with
A=area of the duct and
P=perimeter of the duct

So for a 36'x36' vent, the duct cannot be longer than (4*(36x36))/(36+36+36+36), which equals 36".

You would want to take into consideration the thickness of the wall as well when determining the overall duct length.

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Is Venting Correct Protection Solution?

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Is Venting Correct Protection Solution?

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Explosion Venting

Flameless Explosion Vents

– Passive protection means
– Decreases the energy emitted from a vented deflagration
– Allows inside venting to be performed without vent ducts
– Temperatures cooled to approx. 90^0 C
– Burst sensor for signaling activation

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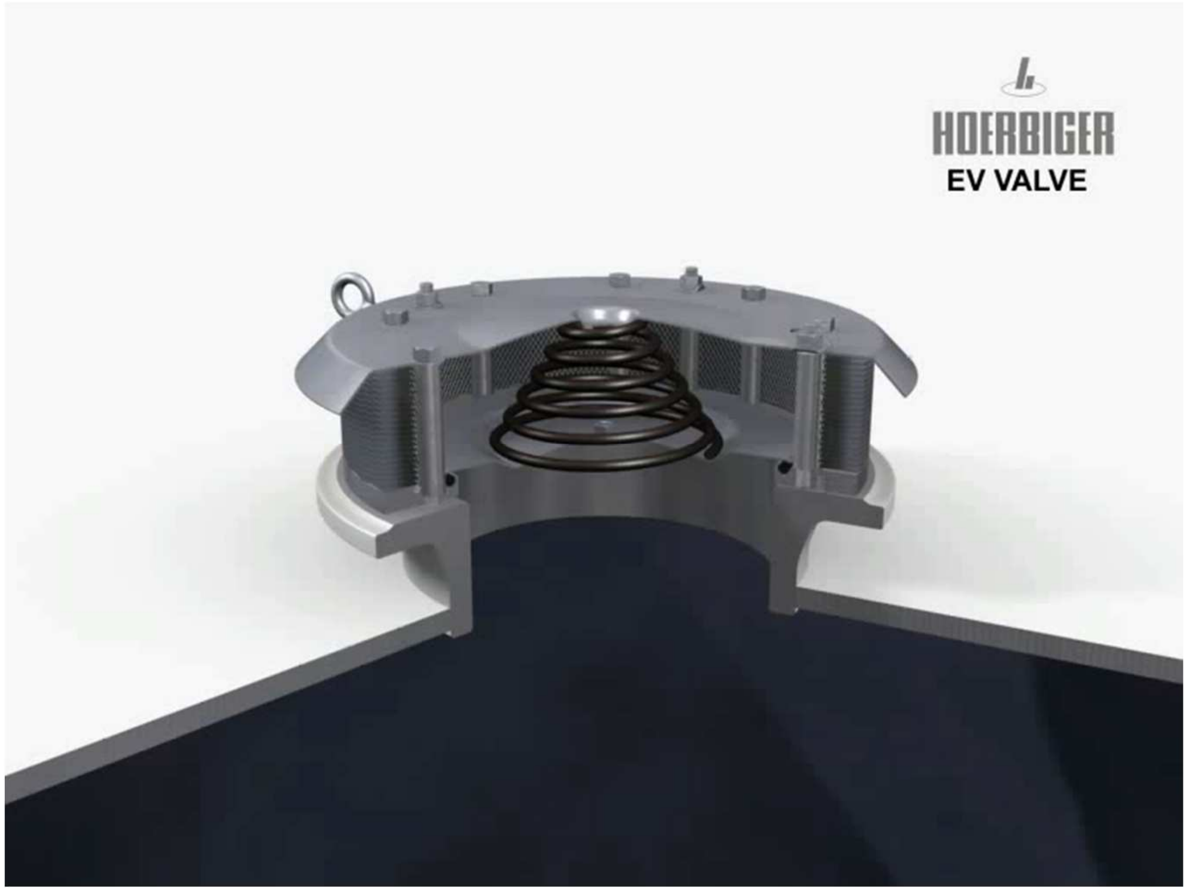
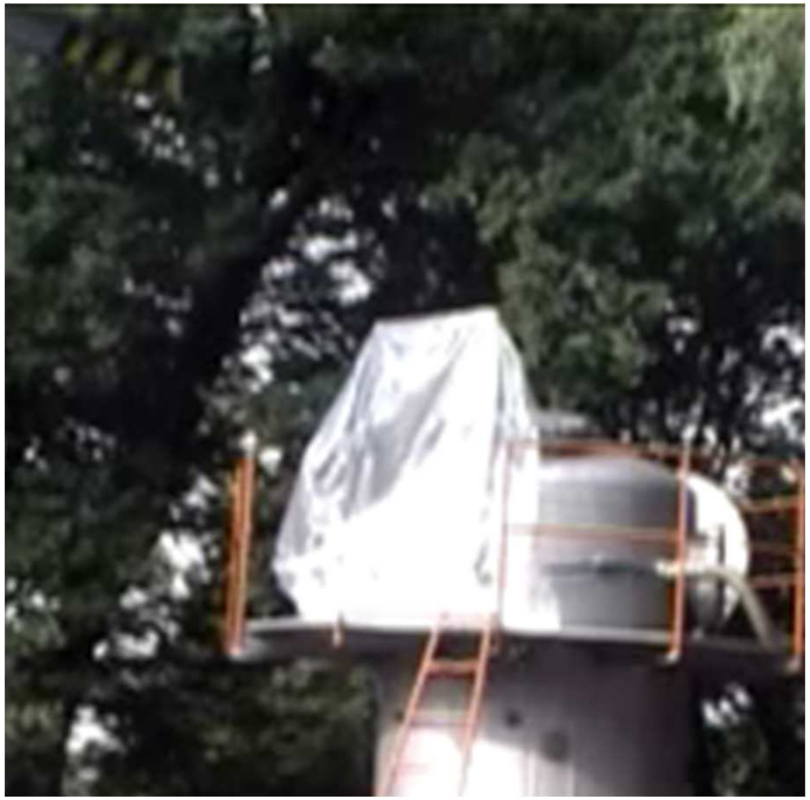
Spring Style Flameless Vents

Spring Style Flameless Vents



Flameless Explosion Vents

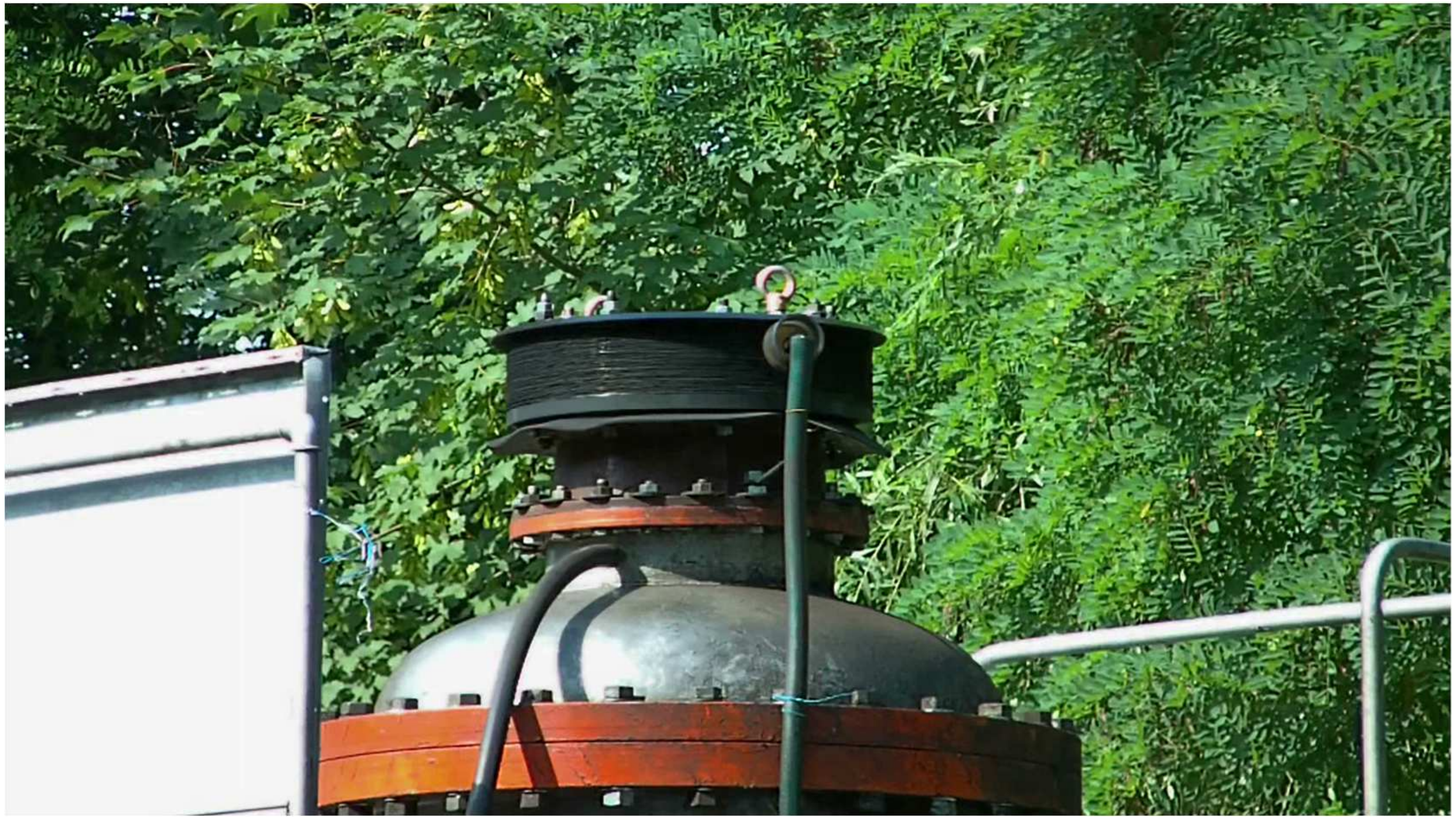
Spring Style – <u>without</u> flame arrestor



Spring Style – <u>with</u> flame arrestor

Spring Style Flameless Vents

Spring Style Flameless Vents



Flameless Explosion Vents - Considerations

- Does not suppress deflagration, fire could remain in vessel. Fire protection must be considered
- Flame propagation issue still exists. Deflagration isolation must be considered
- Safe zone needed around unit (hot gases, toxicity)

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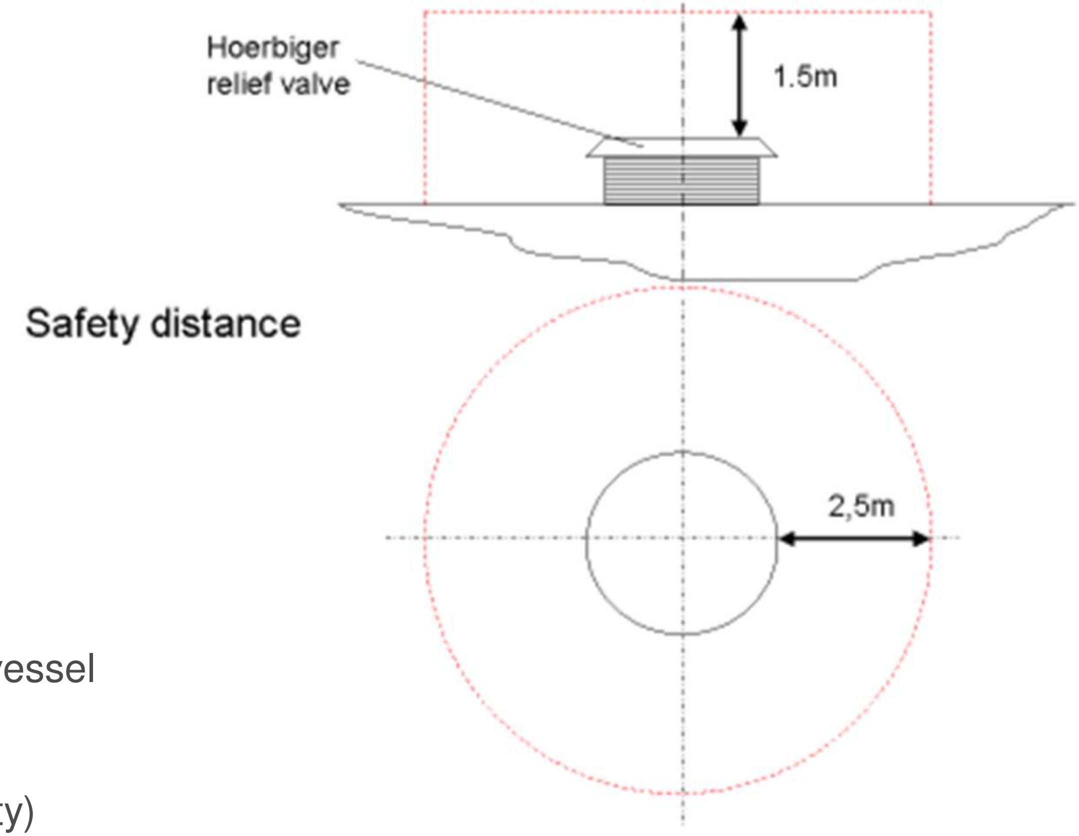
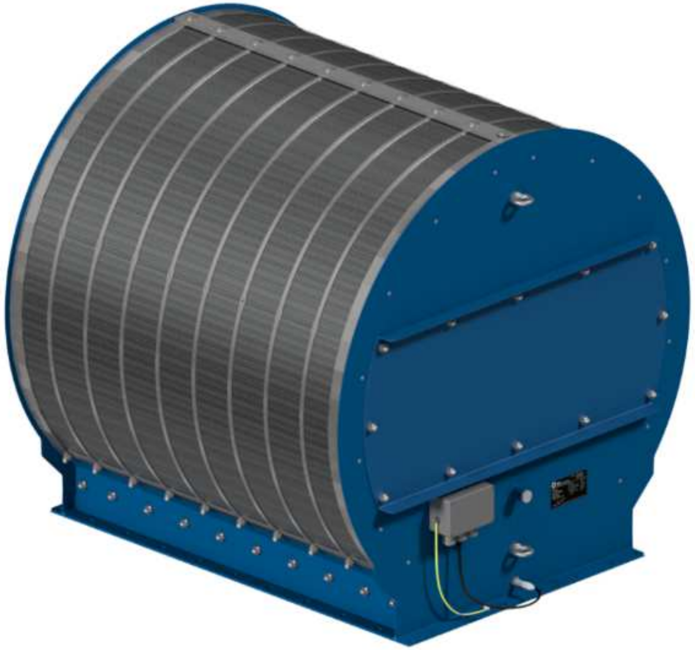
Spring Style Flameless Vents



- Efficiency of Vent must be considered
- Does not suppress deflagration, fire remains in vessel
- Flame propagation issue still exists
- Safe zone needed around unit (hot gases, toxicity)

Flameless Explosion Vent



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Flameless Explosion Venting

- Please take a moment to think about this concept
- ~70m^3 of fluid cooled from ~1800°C to ~500°C in ~400ms

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Flameless Explosion Venting

- Combination of a pressure relief device with flame arrestor
- Explosion pressure relief without external flame escape
- Two key topics
  - Venting efficiency
  - Flame arrestor blockage

- Dependencies on:
  - K_{st}
  - Protected vessel aspect ratio and device location
  - Dust concentration
  - Dust particle size
  - Ignition location
  - $p_{red,max}$

Application – Recommended Safety Area

Vented "gas", while flameless, still contain hot and hazardous products of combustion.

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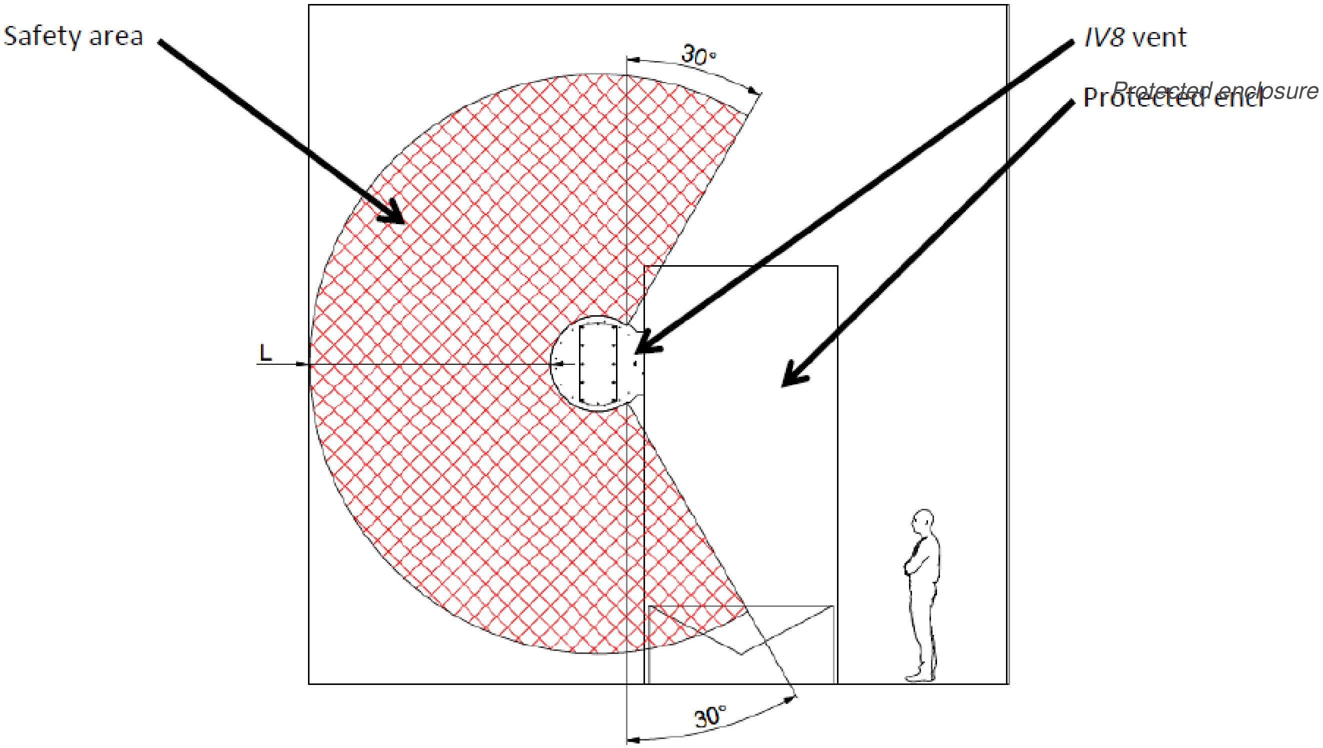
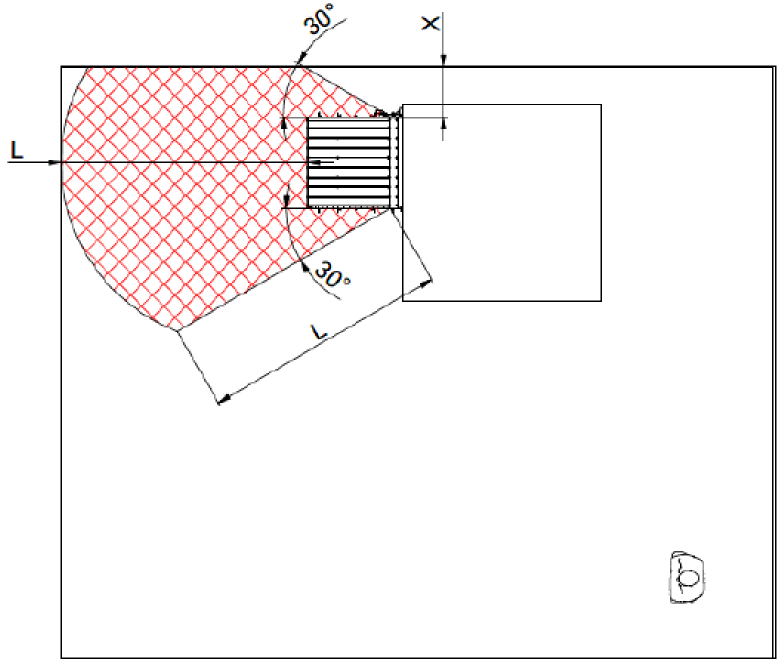
Application – Recommended Safety Area

Type	Protected volume per device [m³]	L [m]	X [m]
586 x 920	12.3	2.5	0.5





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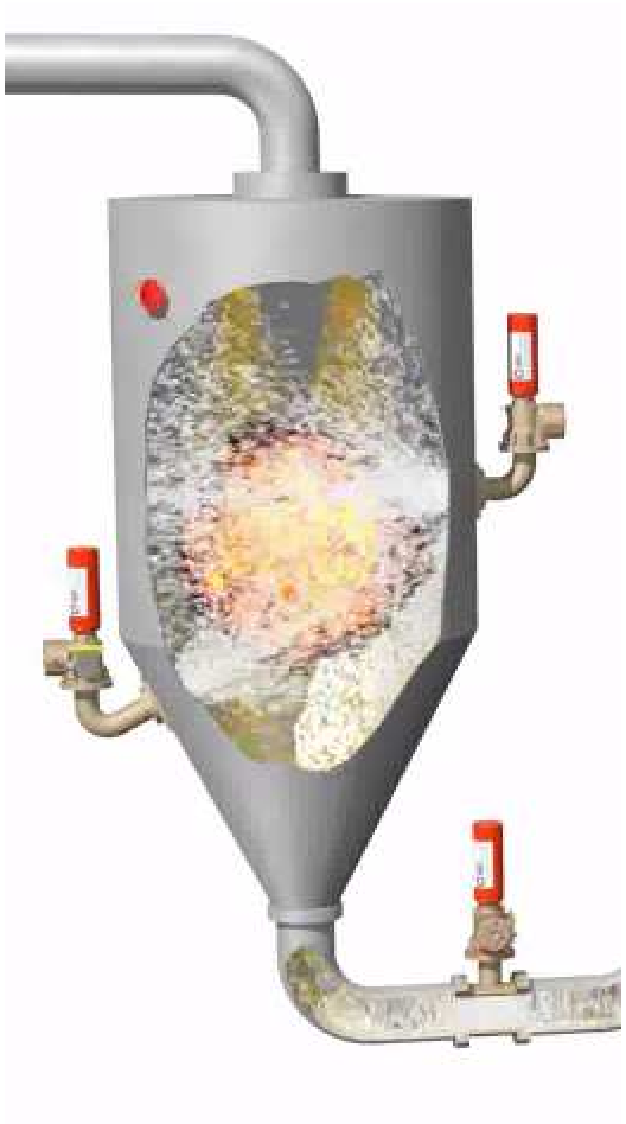
Explosion Suppression



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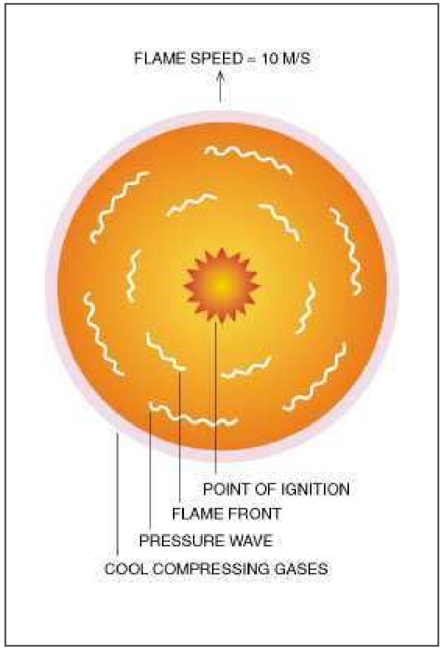
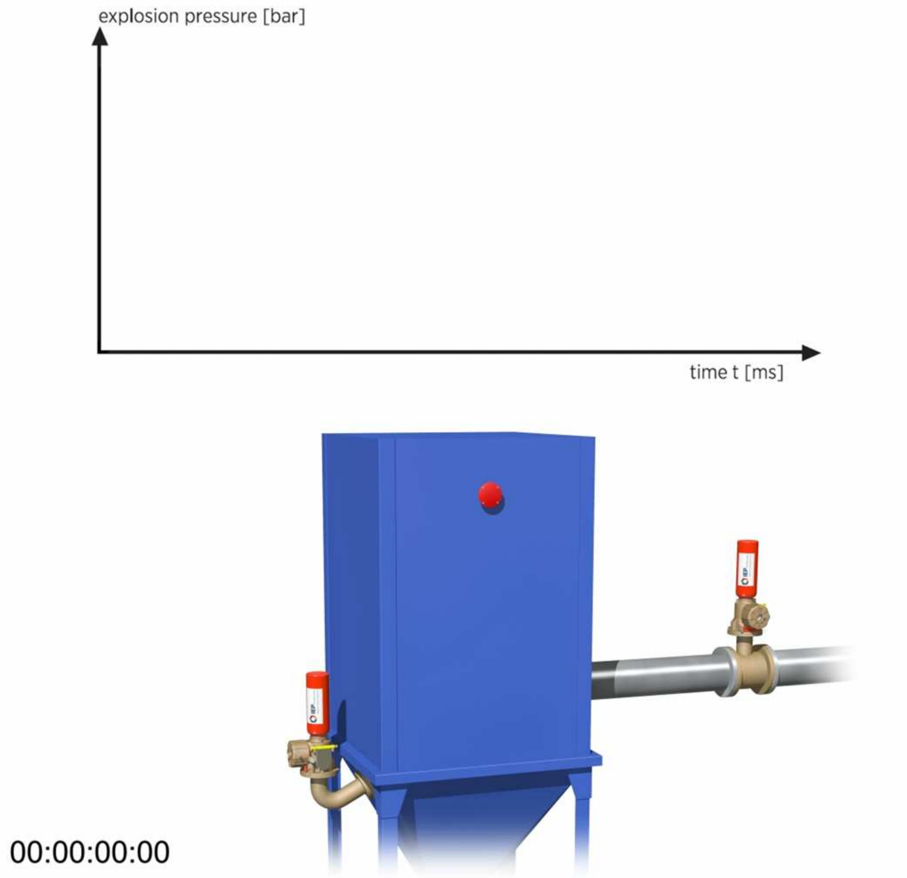
Deflagration Principle



– Flame Speed ~30 ft/s
– Pressure Wave ~1100 ft/s



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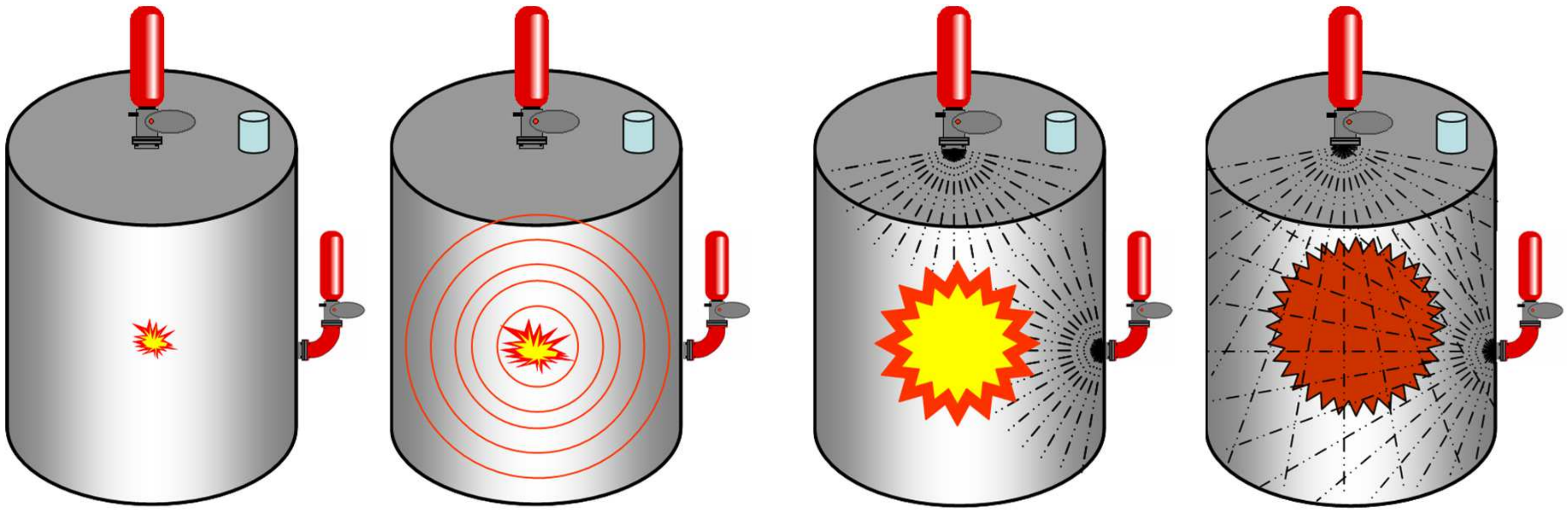
Explosion Suppression

Pressure wave ~300 m/s
Flame front ~10 m/s



Ignition:
Time = 0 ms
Pressure = 0 bar(g)

Detection:
Time = 20 ms
Pressure = 0.05 bar(g)

Suppressors Actuate:
Time = 35 ms
Pressure = 0.08 bar(g)

Suppression Complete:
Time = 80 ms
Pressure = 0.20 bar(g)

Explosion Suppression Components

Pressure Detection

Control Unit

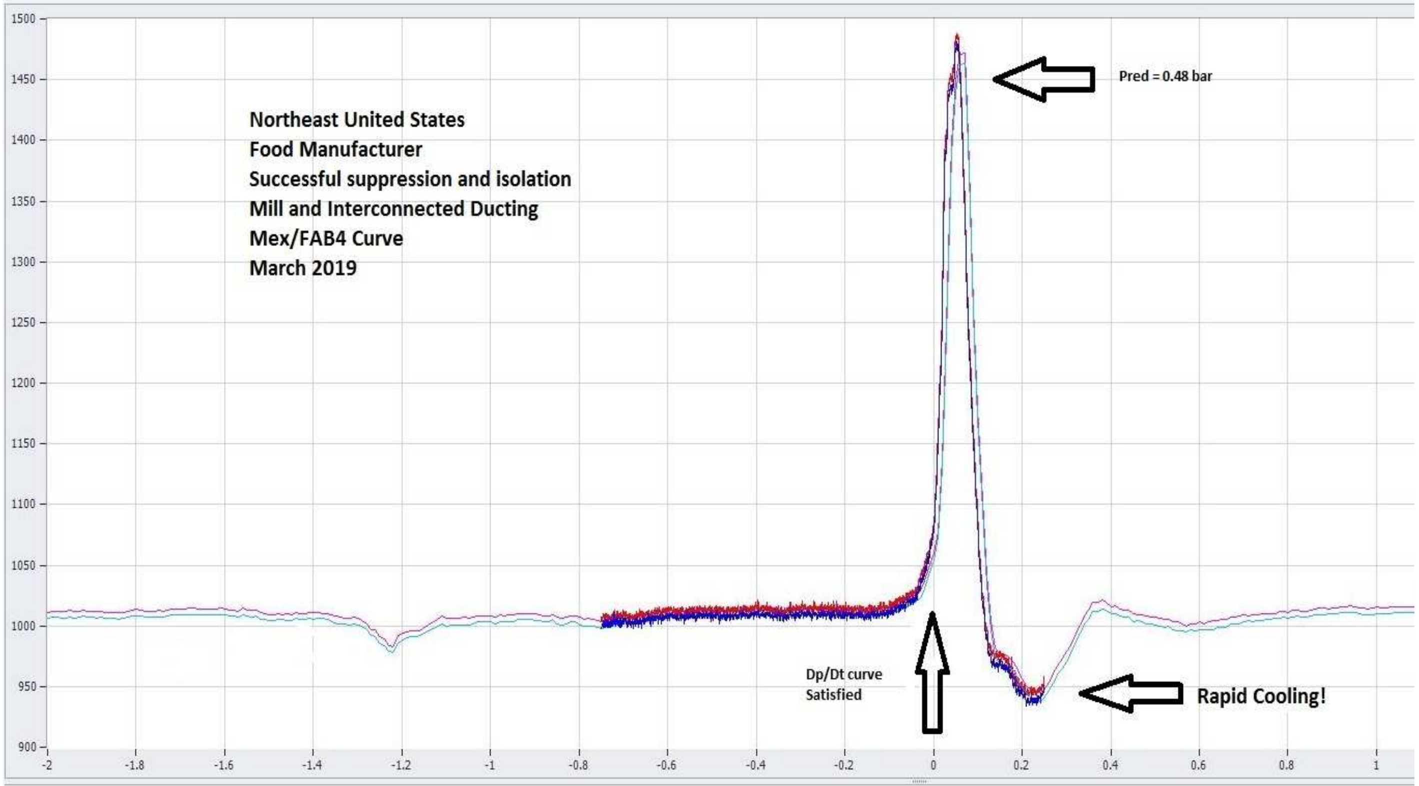
Explosion Suppression
Extinguisher

Successful Suppression

Northeast United States Food Manufacturer

Application: Powder mill and interconnected ducting

- Mill blade broke off caught in screen creating sparks
- Ignited powder
- Mex on mill discharge detected pressure increase due to deflagration
- Pred = 0.48 bar



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Shut Down Conditions

NFPA 69, 3.3.42 Trouble Signal. A signal that results from the detection of a trouble condition.

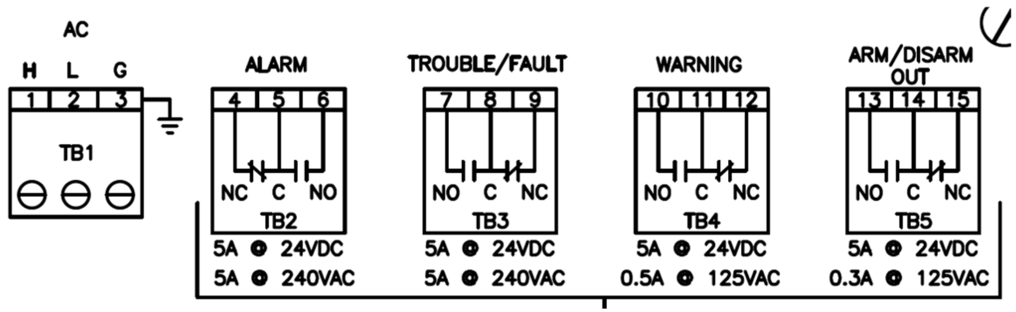
3.3.42.1 *Trouble Condition*. An abnormal condition in a system due to a fault.

Alarm Signal. Detectors initiated an extinguisher release.

10.4.6 Process Shutdown. Upon activation, the suppression system shall initiate an immediate, automatic shutdown of the protected process.

10.4.6.1 Upon receipt of a trouble signal from the suppression system, which indicates the protection system could be compromised, the protected process shall initiate an immediate, automatic, and orderly shutdown.

10.4.6.2 Upon receipt of a supervisory signal from the suppression system, which indicates that a problem exists but that the protection system is not compromised, qualified personnel shall investigate and repair the problem at the next shutdown period.



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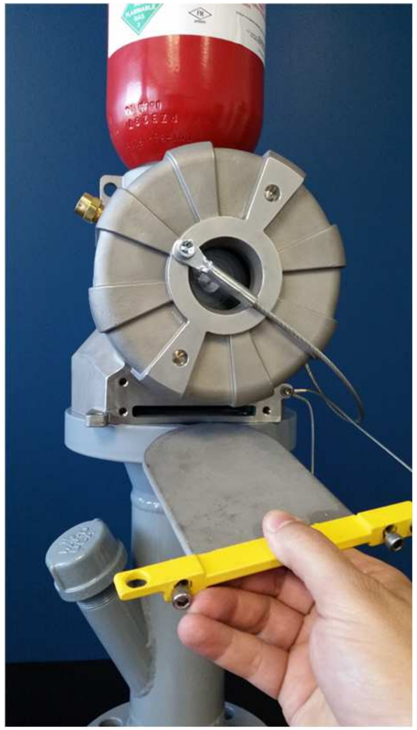
PistonFireII - Lockout Plate

– Process Maintenance

- OSHA lockout plate allows safer access into vessel as compared to disarming alone (mechanical barrier in addition to electrical lockout).
- Lockout plate is secured in place with bolts and lockout cable
- Suppressor cannot be armed when OSHA plate is installed.



Explosion Suppressor Discharge

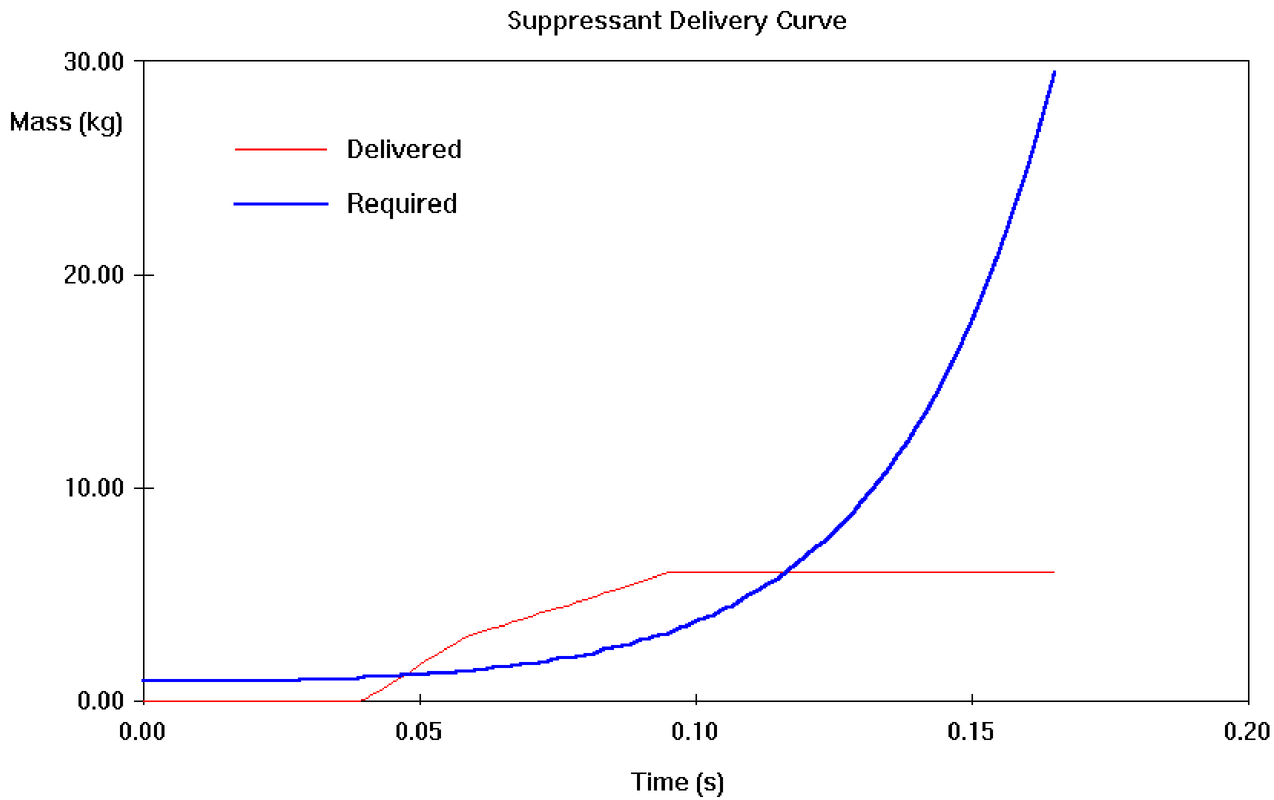
Suppression Discharge Nozzles

- Disperses suppressant
- End sealed with silicone cap, to prevent plugging in discharge pipe
- Spreader cap blows off during discharge
- Means for inspection a must per NFPA 69

Pipe cap for inspection
of discharge nozzle

Computer Model

- Vessel Volume
- Length/Diameter Ratio
- Explosivity Characteristics
  - K_{ST}, P_{MAX}, AIT
- Detection Setpoint
- Extinguisher Orientation
- Style of HRD
- Type of Suppressant
- Volume of Suppressant
- Agent Throw



Explosion Isolation

- NFPA 69
  - Chapters 11 & 12
- NFPA 654
  - 7.1.6.1 - in accordance with NFPA 69
- NFPA 652
  - 9.7.4.1 – in accordance with NFPA 69
- NFPA 664
  - 8.2.4.5 – in accordance with NFPA 69

Why Isolate?

– SECONDARY EXPLOSIONS
  - Secondary explosions due to inadequate housekeeping and excessive dust accumulations.
  - Secondary explosions due to flame propagation through interconnected ducts can lead to enhanced explosions
  - Secondary explosions are the main threat to personnel and property

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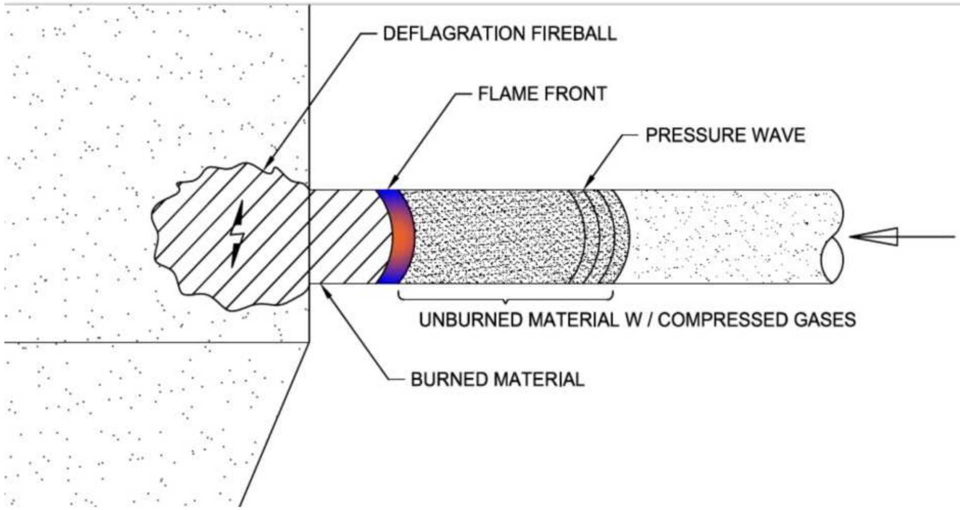
Why Isolate? – the Technical Reason

– Flame Velocity and Enhanced Explosion

- Spherical fireball growth from ignition point
- Pressure generation causes flow field near to duct
- Flame is stretched at this boundary (increase in burning rate)
- Flame accelerates in duct due to pressure piling effects
- Flame front can transition to detonation as flame speed approaches speed of sound



Deflagration Protection – Why Isolate?

- Pressure Piling and Enhanced Explosions
- NFPA 69, A11.1.1
  - Increase violence of the explosion
  - Accelerated rates of pressure rise from flame-jet ignition
  - Pressure Piling can increase Pmax
  - Potential for stronger ignition source at higher pressures
    - *Enhanced explosion can make existing protection inadequate*!
  - Protection is designed for ignition originating in the protected vessel

Active Isolation Techniques

NFPA 69 2019 Edition

11.2* Isolation Techniques. Isolation methods shall be permitted to be used to interrupt or mitigate flame propagation, deflagration pressure, pressure piling, and flame-jet ignition between items of equipment. Active isolation systems shall be permitted to be based on various techniques that include, but are not limited to, the use of the following components:

(1) Chemical barrier
(2) Fast-acting mechanical valve
(3) Externally actuated float valve
(4) Actuated pinch valve

Passive Isolation Techniques

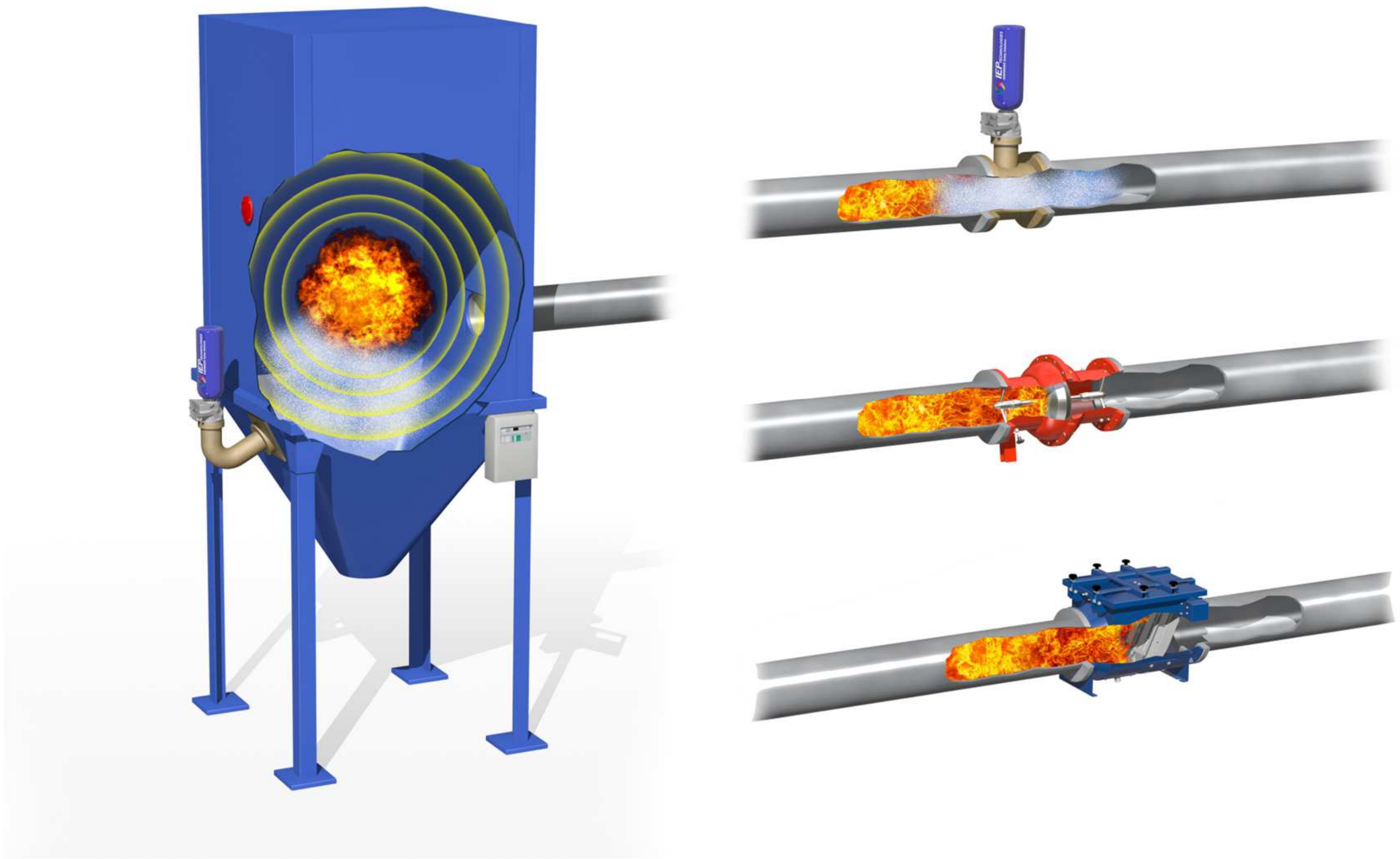
NFPA 69 2019 Edition

12.2 Passive Isolation Techniques. Passive isolation system design shall be permitted to be based on various techniques that include, but are not limited to, the use of the following equipment:

(1) Flame front diverters
(2) Passive float valves
(3) Passive flap valves
(4) Material chokes (rotary valves)
(5) Static dry flame arresters
(6) Hydraulic (liquid seal)–type flame arresters
(7) Liquid product flame arresters

Dust Collector Inlet Propagation

Explosion Isolation



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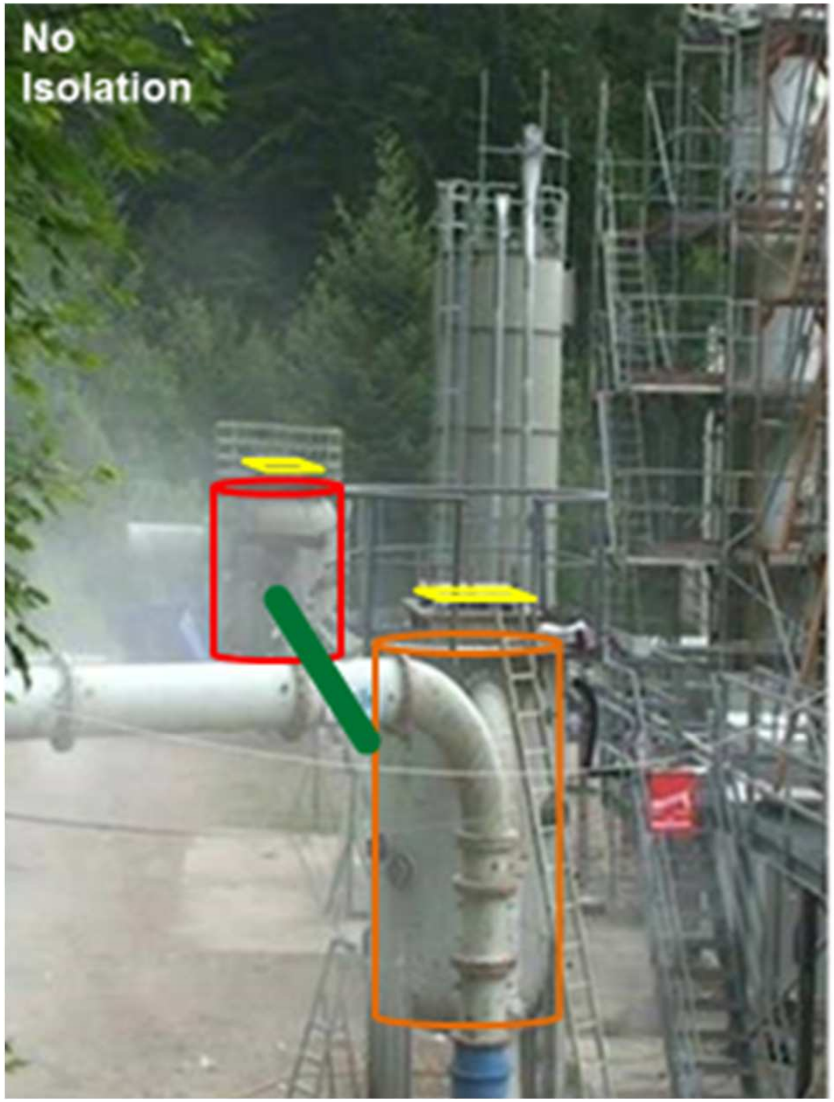
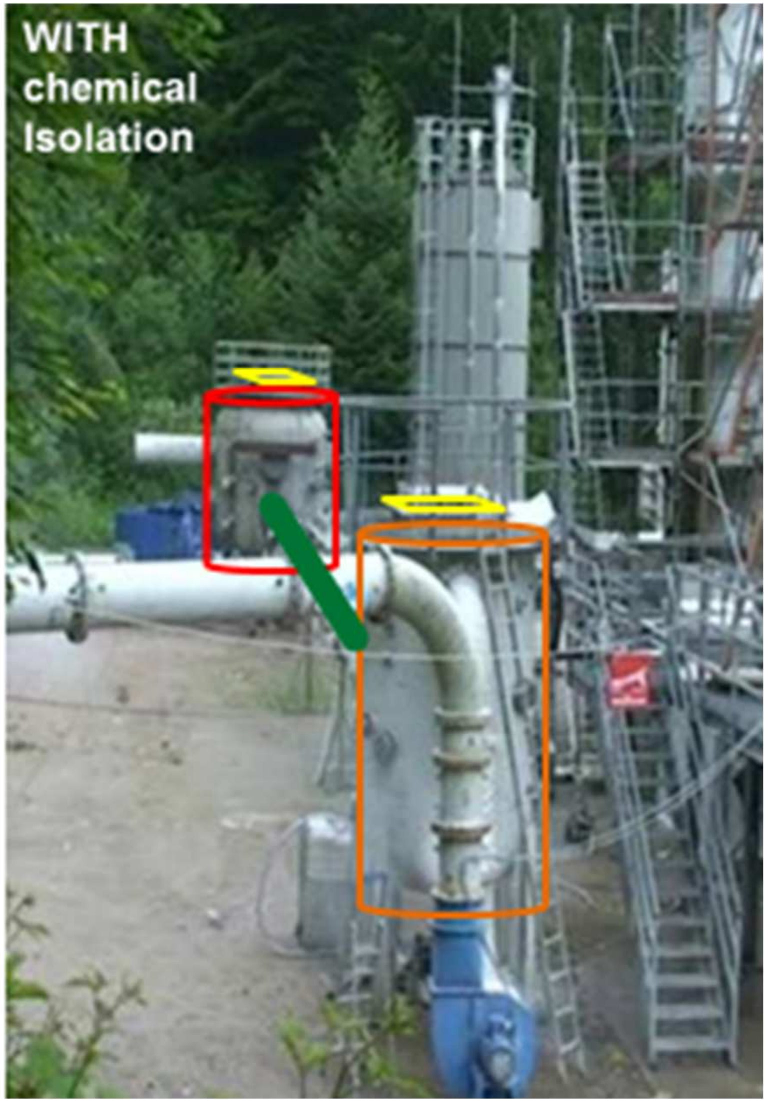
•Slow motion with “NO” Isolation

•Slow Motion with Isolation


No
Isolation


WITH
chemical
Isolation

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No
Isolation


Isolation
1x2kg HRD

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No Isolation


Isolation 1x2kg HRD

Explosion Isolation

- **Explosion Isolation is more complicated than suppression**
  - Deflagration Severity impacts isolation location requirement
  - Strong explosions have different pressure time curves than weak explosions

- *Strong explosions can be detected faster*
- *Weaker explosions more challenging to isolate*

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Why Isolate?

REGULARTORY REQUIREMENTS

NFPA 652

9.7.4* Equipment Isolation.

9.7.4.1 Where a dust explosion hazard exists, isolation devices shall be provided in accordance with NFPA 69 to prevent deflagration propagation between connected equipment

NFPA 654

7.1.6* Isolation of Equipment and Work Areas.

7.1.6.1* Where an explosion hazard exists, isolation devices shall be provided to prevent deflagration propagation between connected equipment and/or work areas in accordance with NFPA 69.

OSHA Citations – "lacked deflagration (flame front) propagation protection (isolation)

UNITED STATES DEPARTMENT OF LABOR

Occupational Safety and Health Administration

CONTACT US FAQ A TO Z INDEX ENGLISH ESPAÑOL

OSHA STANDARDS TOPICS HELP AND RESOURCES

Citation

Inspection	Reporting ID	Open Date	SIC	Establishment Name

Citation	Issuance Date	Hazard Category

OSH ACT of 1970 Section (5)(a)(1): The employer did not furnish employment and a place of employment which were free from recognized hazards that was causing or were likely to cause death or serious physical harm to employees in that employees were exposed to combustible dust explosion, deflagration, or other fire hazards presented by cartridge-media dust collectors handling combustible paper dust that were installed and operated in a manner to expose employees to the byproducts of internal deflagrations and fire. On or about November 01, 2016 employees were exposed to the following conditions: a) An indoor cartridge media dust collector was used to collect combustible paper dust from the upstream paper sheeters and bailing process. (i) The dust collector lacked deflagration (flame front) propagation protection (isolation) for the following connections: The upstream process (dirty air inlet), the return air exhaust (clean air outlet), and the unit's material discharge hopper (material outlet). This exposed employees to flame front hazards. (ii) The dust collector exhausted filtered air directly indoors and lacked recognized means to protect building occupants from the hazardous byproducts of a developing fire (i.e. smoke, embers, toxic gases). This exposed employees to fire hazards. b) An outdoor cartridge media dust collector was used to collect combustible paper dust from the upstream paper shredding, sheeters and bailing process. (i) The dust collector lacked deflagration (flame front) propagation protection (isolation) for the following connections: The upstream process (dirty air inlet), the return air exhaust (clean air outlet), and the unit material discharge hopper (material outlet). This exposed employees to flame front hazards. (ii) The dust collector exhausted filtered air directly indoors and lacked recognized means to protect building occupants from the hazardous byproducts of a developing fire (i.e. smoke,

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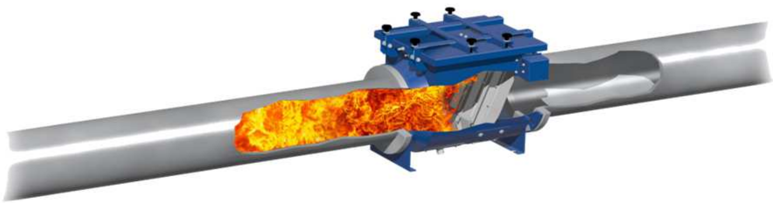
How to Isolate?

Passive Isolation
NFPA 69 Chapter 12

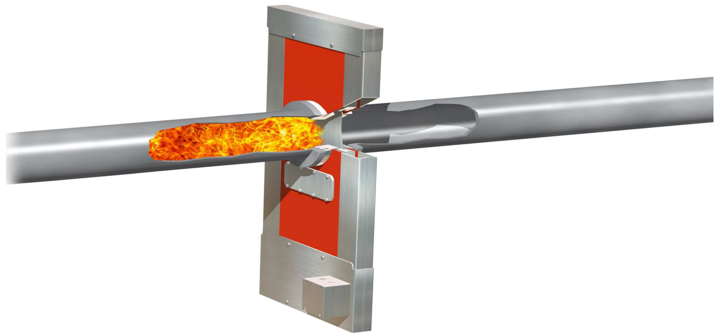
- Explosion pressure actuates mechanical device



Active Isolation
NFPA Chapter 11

- Chemical – Suppressant barriers

- Mechanical – Metal barrier



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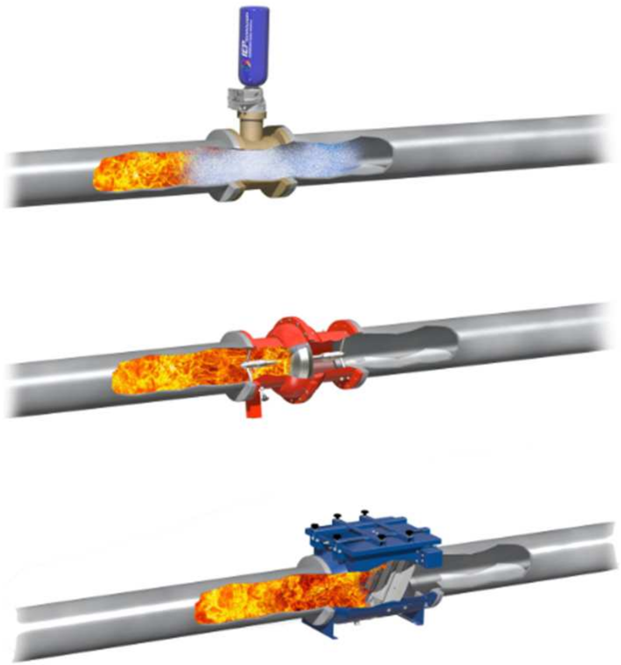
Explosion Isolation

Active and Passive



The application will drive selection

- Duct size
- Kst, Pmax
- Horizontal/Vertical
- Duct geometry
- Dust loading
- Organic/Metal dust
- Food grade
- Is the dust hygroscopic
- Certification/3rd Party Approval

Passive Explosion Isolation

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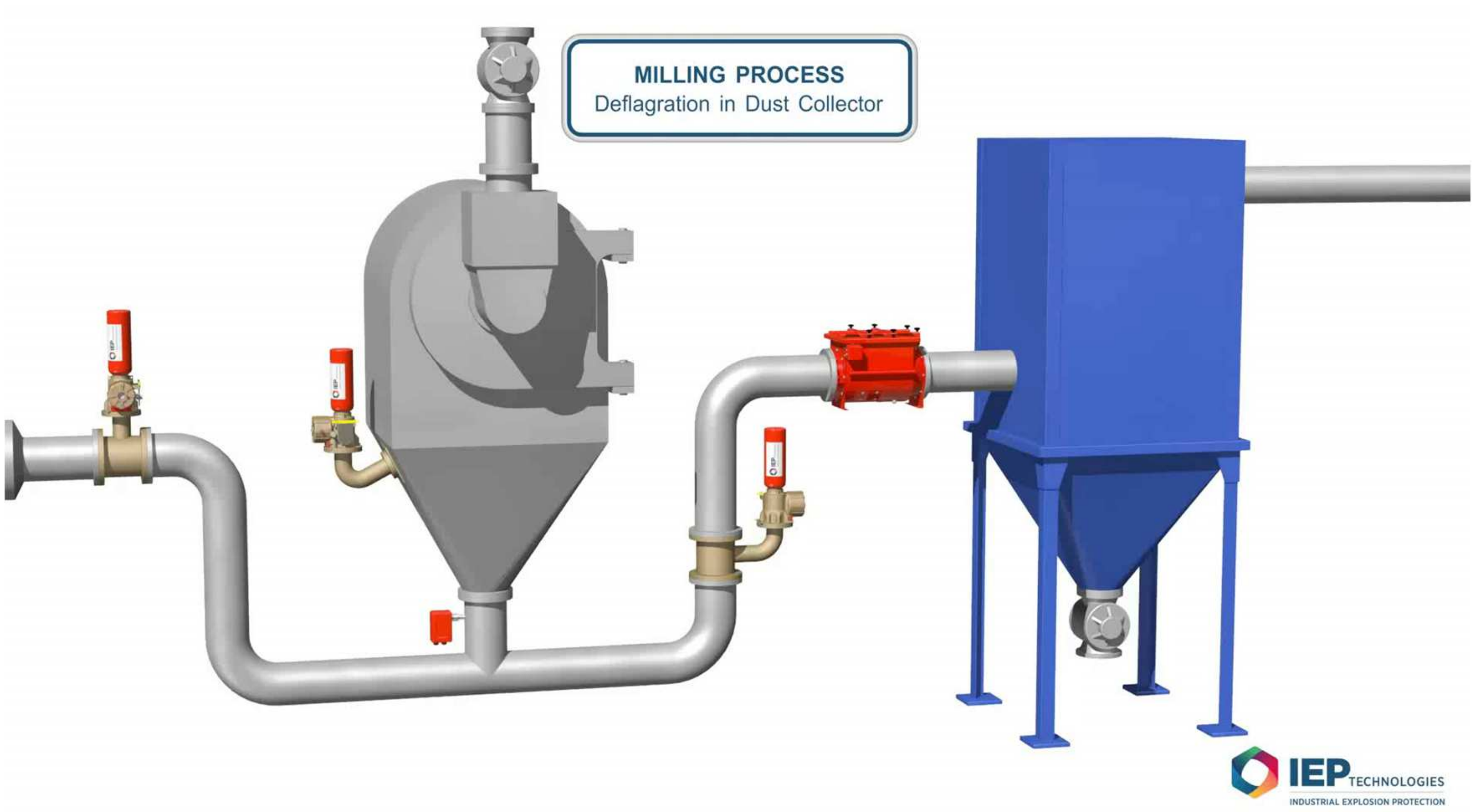
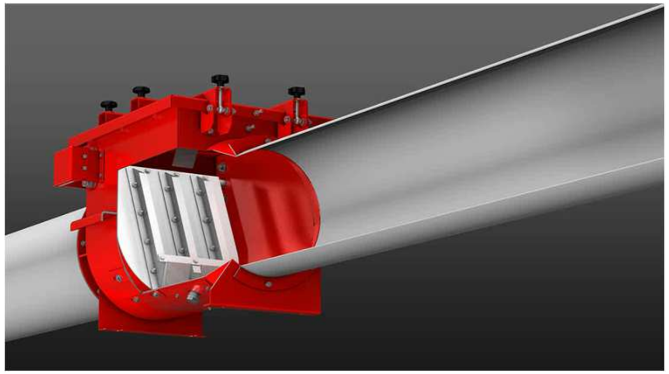
Passive Explosion Isolation

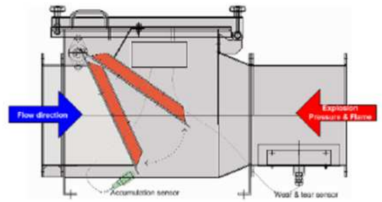


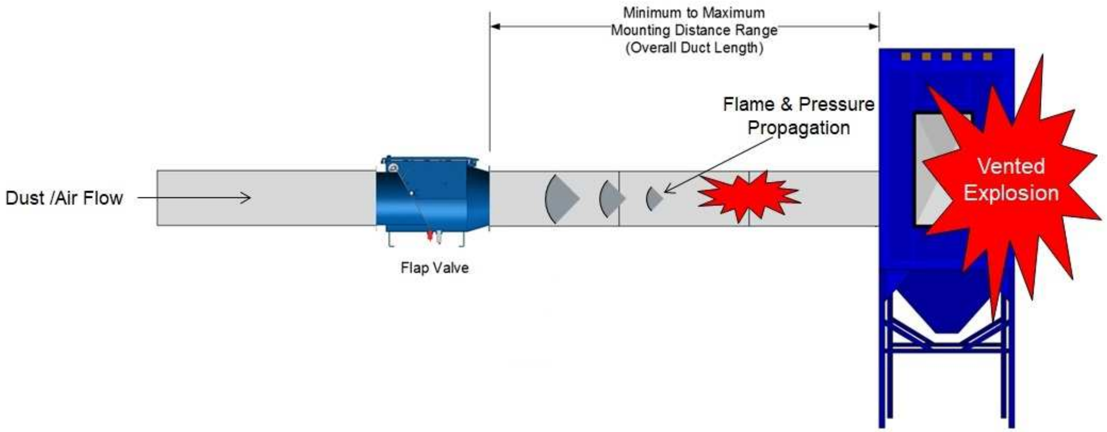
Explosion Isolation – Passive Flap Valve

Inlet isolation to a vented dust collector

- Horizontal mounting
- Low dust loading
- Specific Kst range (high and LOW)
- Some pressure drop
- Locking mechanism
- Strict ducting requirements (before/after)
- Certifications







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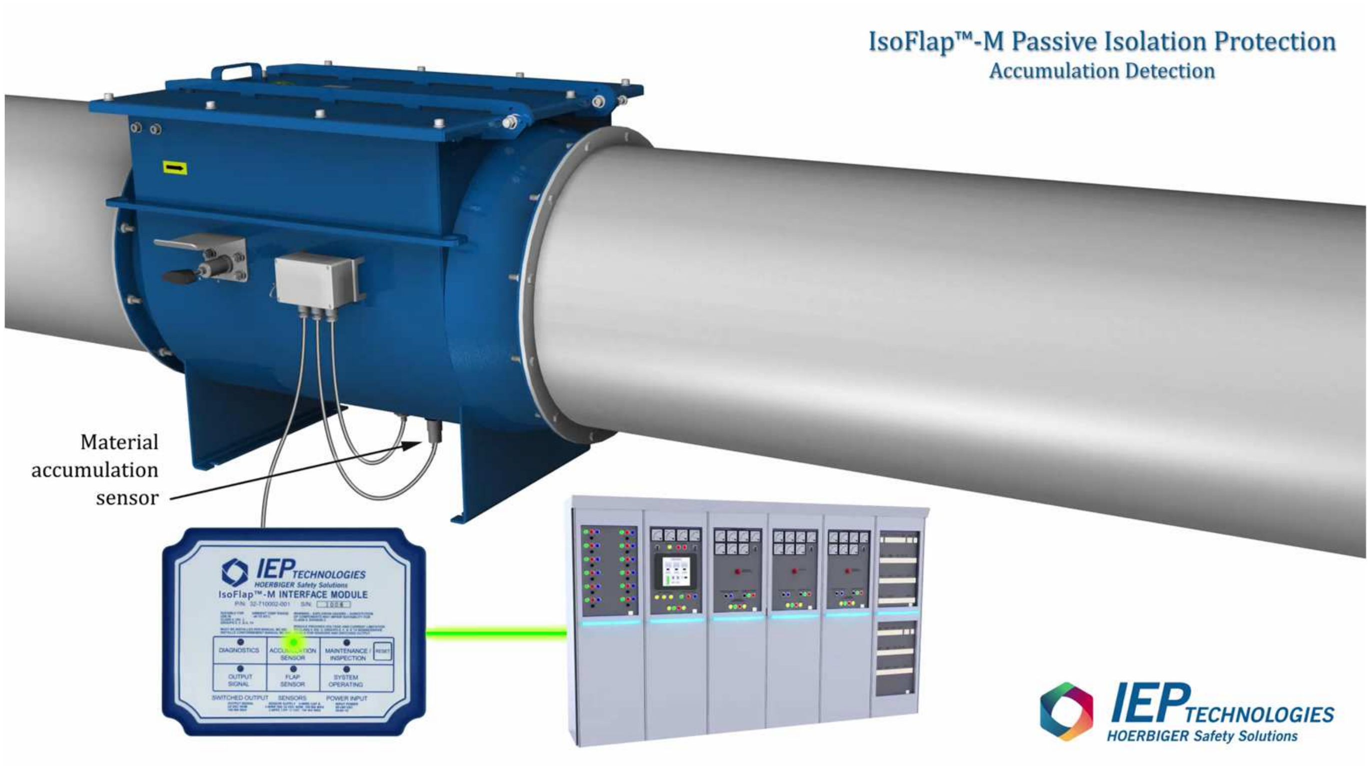
Isolation Flap Valve



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Technical Data Flap Valve

<table>
<tr><th>Nominal Diameter mm (in)</th><th>K_{ST} max. bar m/sec</th><th>Minimum Vessel Volume m^3 (ft^3)</th><th>P_{RED} max. bar (psi)</th><th>Minimum Mounting Distance with 0 or 1 Elbow m (ft)</th><th>Minimum Mounting Distance with 2 Elbows m (ft)</th><th>Maximum Mounting Distance m (ft)</th><th>Pressure Drop @ 20 m/s or 3950 ft/min Pa (in-H_20)</th></tr>
<tr><td>100 (4)</td><td rowspan="3">300
(ST1 & ST2)</td><td rowspan="3">0.46 (16.2)</td><td>1.0 (14.5)</td><td>1.5 (5.0)</td><td>2.6 (8.5)</td><td rowspan="6">7 (23.0)</td><td>200 (0.804)</td></tr>
<tr><td>150 (6)</td><td rowspan="2">1.0 (14.5 for ST1
0.5 (7.25) for ST2</td><td rowspan="2">2.0 (6.6)</td><td rowspan="2">Elbows not allowed for ST2</td><td>190 (0.764)</td></tr>
<tr><td>200 (8)</td><td>220 (0.884)</td></tr>
<tr><td>250 (10)</td><td rowspan="9">200
(ST1)</td><td rowspan="3">1.7 (60.0)</td><td rowspan="6">0.5 (7.25)</td><td rowspan="3">3.5 (11.5)</td><td rowspan="3">4.7 (15.4)</td><td>260 (1.045)</td></tr>
<tr><td>315 (12)</td><td>280 (1.125)</td></tr>
<tr><td>355 (14)</td><td>300 (1.206)</td></tr>
<tr><td>400 (16)</td><td rowspan="3">1.6 (56.5)</td><td rowspan="6">5 (16.4)</td><td rowspan="3">6.4 (21.0)</td><td rowspan="6">8.0 (26.2)</td><td>240 (0.964)</td></tr>
<tr><td>450 (18)</td><td>260 (1.045)</td></tr>
<tr><td>500 (20)</td><td>280 (1.125)</td></tr>
<tr><td>560 (22)</td><td rowspan="3">6 (212.0)</td><td rowspan="3">0.45 (6.5)</td><td rowspan="3">6.1 (20.0)</td><td>310 (1.246)</td></tr>
<tr><td>630 (25)</td><td>330 (1.326)</td></tr>
<tr><td>710 (28)</td><td>350 (1.407)</td></tr>
</table>

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Explosion Test

DN 355mm (14 inch) Flap valve
St1 2 elbows, 1,6m3 Test vessel

Explosion Test

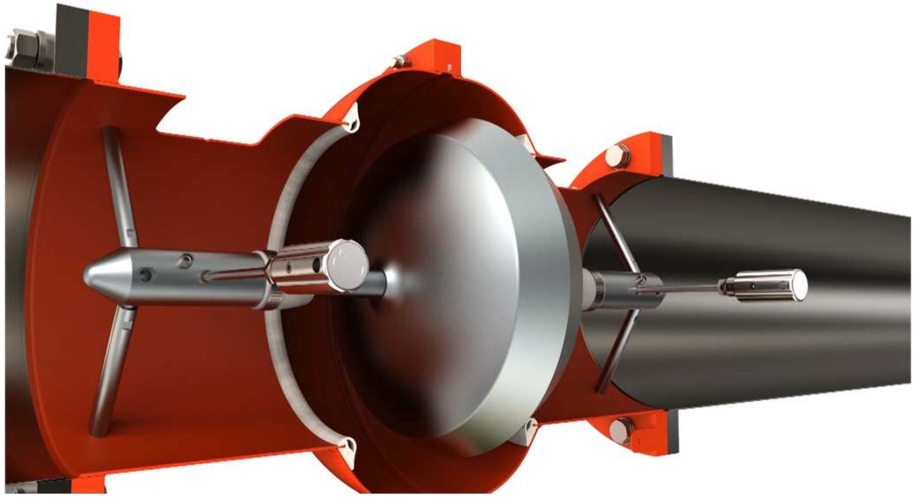
DN 500mm (20 inch) Flap valve
St1 2 elbows, 1,6m3 Test vessel

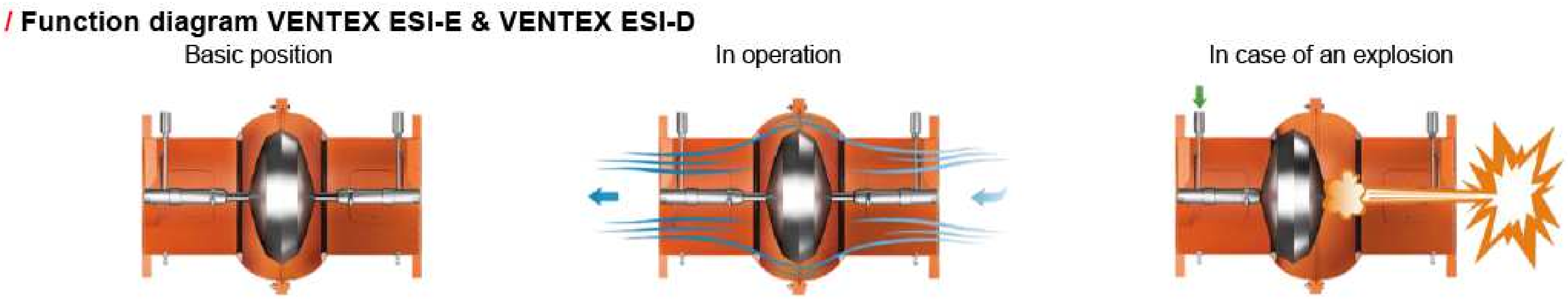
Flap Valve Isolation

NFPA 69-2019 Edition
12.2.3.4 Flow-Actuated Flap Valve Design Criteria. Flap valve design criteria shall comply with 12.2.3.4.1 to 12.2.3.4.6.
12.2.3.4.1 The anticipated differential pressure across the valve during deflagration, as determined by the valve manufacturer, shall be greater than the flap valve closing pressure.
12.2.3.4.2 Upon actuation from a deflagration pressure wave, the flap plate shall close and remain sealed via a locking mechanism to prevent flame and burning material propagation.
12.2.3.4.3 The flap valve shall have an inspection door to allow periodic inspection of the flap plate and seal.
12.2.3.4.4 Upon activation, the flap valve shall initiate an immediate, automatic shutdown of the protected process.
12.2.3.4.5 A continuous signal shall be provided to ensure that valve operation is not compromised by the accumulation of a dust layer on the bottom interior of the valve.
12.2.3.4.5.1 Upon receipt of a signal indicating that the flap valve could be compromised, the protected process shall initiate an immediate, automatic, and orderly shutdown.
12.2.3.4.5.2 A documented risk assessment and an appropriate inspection protocol and frequency shall be permitted in lieu of the continuous signal in 12.2.3.4.5, where acceptable to the authority having jurisdiction.
12.2.3.4.6* The conveying ductwork between the protected vessel and the flap valve shall be of sufficient strength to withstand the expected peak pressure.
12.2.3.5 System Certification. The flow-actuated flap valve deflagration isolation system design methodology and application range shall be supported by appropriate testing and certified by a recognized testing organization acceptable to the authority having jurisdiction. (*See A.10.4.2.1.)*
12.2.3.5.1 A performance demonstration shall determine the following:
(1) Minimum and maximum location placement distances from the expected ignition source
(2) Minimum and maximum Kst
(3) Maximum number of flow direction changes
(4) Maximum dust loading
(5) Maximum air velocity
(6) Range of allowable Pred within the protected enclosure where the ignition might occur
12.2.3.5.2 Upon request, the system manufacturer shall provide to the owner or operator documentation supporting that the design is in compliance with the manufacturer's independent third-party approval, including application limitations, and is suitable for the hazard to be protected.

Explosion Isolation - Passive Float Valve

Clean air exhaust, Air infeed
- Very low dust loading (50 g/m3)
- Horizontal or Vertical mounting
- Wide Kst range
- Some pressure drop
- Locking mechanism
- Can be active if faster needed





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Float Isolation Valve

NFPA 69 2014 Edition

12.2.2.2 Float Valve Design Criteria. Float valve design criteria shall comply with 12.2.2.2.1 through 12.2.2.2.4.

12.2.2.2.1 The anticipated differential pressure across the valve during deflagration, as determined by the valve manufacturer, shall be greater than the float valve closing pressure.

12.2.2.2.2 The normal process flow velocity at the valve shall be less than the specified limit for the float valve closure.

12.2.2.2.3 The valve shall include a means to latch it in the closed position upon actuation.

12.2.2.2.4 A signal shall be provided that indicates the valve is in the closed position.

12.2.2.3 System Certification. The float valve deflagration isolation system design methodology and application range shall be supported by appropriate testing and certified by a recognized testing organization acceptable to the authority having jurisdiction. *(See A.10.4.2.1.)*

12.2.2.3.1 A performance demonstration shall include the required minimum and maximum location placement distances from the expected ignition source and the range of allowable Pred for the enclosure where the ignition might occur.

12.2.2.3.2 Upon request, the system manufacturer shall provide to the owner or operator documentation supporting that the design is in compliance with the manufacturer's independent third-party approval, including application limitations, and is suitable for the hazard to be protected

12.2.2.4* Float Valve Application Limits. Float valves shall not be permitted to be used under the following circumstances:

(1) With slow propagating explosions, below the limits of the test data (Bartknecht, 1989)

(2) In a stream containing significant quantities of accumulating dust, as specified by the manufacturer

Example – Passive Isolation on Collector Inlet and Return

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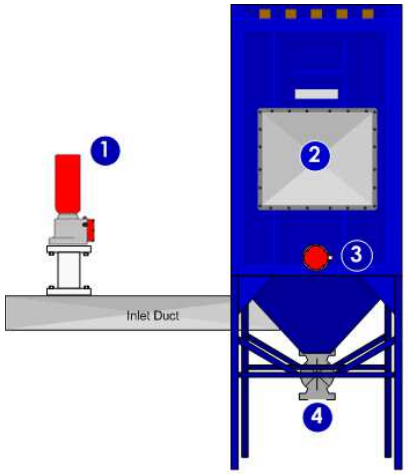
Explosion Isolation - Rotary Valve



Deflagration isolation by flame quenching (close-clearance valves)

- Must have a certified Pred
- Minimum 6 vanes
- Metal body and vanes
- Interlocked
- .008 inch clearance

Note: Rotary valves are capable of prevent flame front propagation but may not prevent the passage of burning embers

Rotary Valves NFPA 69-2019 Edition

12.2.4* Material Chokes (Rotary Valves). Material chokes shall be permitted to be used as isolation devices for processes handling dusts.
12.2.4.1* Rotary Valve System Design Considerations. Rotary valve system design considerations shall include the following:
(1) Deflagration characteristics of the combustible material
(2) Volume, configuration, and operating characteristics of the equipment to be protected and the conveying system
(3) Type of deflagration protection used on the vessel
(4) Maximum deflagration pressure that the rotary valve will experience
12.2.4.2 Rotary Valve Design Criteria. Rotary valves intended for deflagration isolation systems shall be designed according to one of the following isolation concepts:
(1) Deflagration isolation by flame quenching (close-clearance valves)
(2) Deflagration isolation by material blocking (product layer above the valve)
12.2.4.3* The design criteria in 12.2.4.3.1 through 12.2.4.3.9 shall be applicable to either concept defined in 12.2.4.2.
12.2.4.3.1 The valve body and rotor shall have sufficient strength to withstand the maximum anticipated explosion pressure, Pred.
12.2.4.3.2 The design basis shall include the specific explosion characteristics (KSt and Pmax) of the powder being handled.
12.2.4.3.3 The valve pressure resistance shall be certified or tested by a knowledgeable test authority.
12.2.4.3.4 There shall be at least six vanes on the rotor, diametrically opposed.
12.2.4.3.5 At least two vanes on each side of the valve housing shall be in a position of minimum clearance at all times.
12.2.4.3.6 The valve shall have metal body and vanes unless it is shown by test data that nonmetallic or composite materials prevent flame passage.
12.2.4.3.7 Rotary valve bearings shall be mounted externally.
12.2.4.3.8 An independent explosion detection device or interlock from another installed explosion prevention or control system on the same protected enclosure shall be interlocked to automatically stop the rotary valve upon a deflagration event.
12.2.4.3.9 The need for performance testing of the valve design shall be determined by the authority having jurisdiction.
12.2.4.4* Rotary Valve with Material Blocking.
12.2.4.4.1 A material block shall be maintained above rotary valves with a design clearance between vane and valve body greater than 0.2 mm (0.008 in.).
12.2.4.4.2 A level control switch shall be provided and interlocked to the rotary valve to maintain a minimum material layer above the valve inlet flange.
12.2.4.4.3 The minimum maintained material level above the inlet flange shall be at least equal to the larger of the valve inlet equivalent diameter or 0.3 m (1 ft).
12.2.4.5* Close-Clearance Rotary Valves.
12.2.4.5.1 Close-clearance rotary valves shall be designed with a clearance between vane and valve body of = 0.2 mm (0.008 in.).
12.2.4.5.2 The clearance between vane and valve body shall be small enough to prevent the passage of flame between the rotor and valve housing.
12.2.4.5.3 Actual clearance of such rotary valves shall be measured before installation and monitored using a predictive maintenance program such that the design clearance is not exceeded due to wear.
12.2.4.6 Rotary Valve Application Limits. Rotary valves shall not be permitted to be used as an isolation device for systems handling hybrid mixtures or gases.

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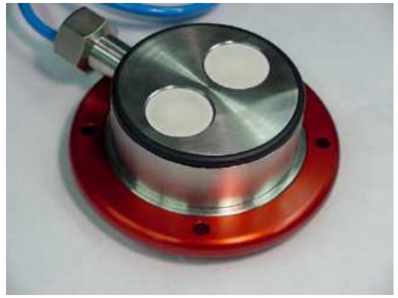
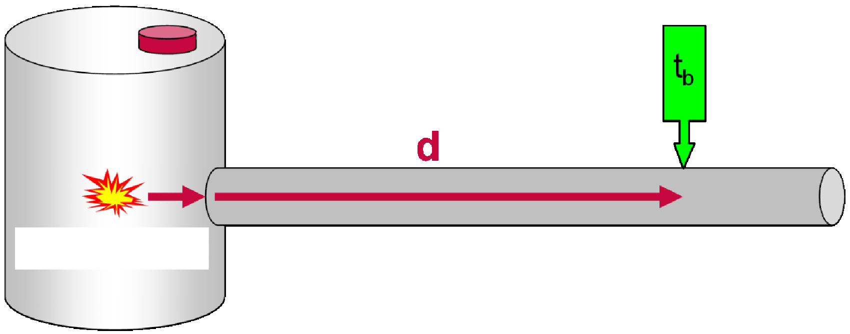
Explosion Isolation – Active Isolation System

- **System comprises three components**
  - Detection: pressure or optical
  - Control
  - Isolation device
    - → Suppressor
    - → Fast acting mechanical valve





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Chemical Explosion Isolation

Wide range of applications

- Large Duct sizes
- Up to Kst 500
- Horizontal / Vertical
- Suits any duct geometry
- Dust loading can be high / low
- Food grade

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Active Explosion Isolation Barrier - Mechanical

- Provides a barrier for flame and pressure
- Typically must be used on pipe or heavy-gauge duct
- Large reaction loads
- Usually most expensive option
- Most common use – pharmaceutical applications due to high cost of material contamination if chemical isolation is used

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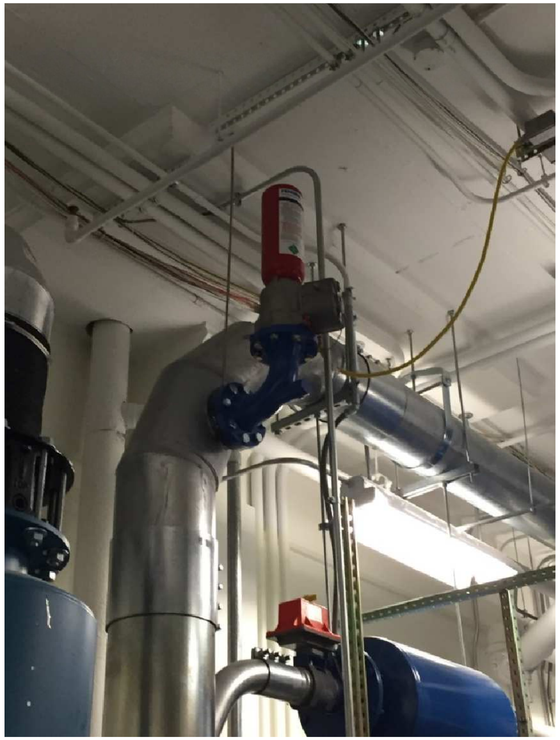
Fast-Acting Mechanical Valves

NFPA 69-2019 Edition
11.2.2* Fast-Acting Mechanical Valves.
11.2.2.1 Fast-acting mechanical valves shall prevent propagation of flame and combustion-generated pressure beyond the fast-acting valves by providing a positive mechanical seal. The mechanical valve shall be capable of withstanding the maximum expected deflagration pressures, including pressure piling.
11.2.2.2* The mechanical isolation system shall consist of one or more detectors, a control panel, and a fast-acting valve assembly.
11.2.2.2.1 Actuation shall be based on detection of pressure or radiant energy with a control panel, to provide the initiating signal to the mechanical valve.
11.2.2.2.2 The mechanical valve assembly shall include a means of rapidly moving the valve trim.
11.2.2.3 The isolation design shall include all information required to install and operate the system, including the following information:
(1) Detection specification of activation pressure or rate for pressure detection
(2) Detector location requirements and limits for pressure or optical detection
(3) Minimum placement location for mechanical valve relative to the protected volume or detector location
(4) Maximum placement location for mechanical valve relative to the protected volume or detector location
(5) Maximum process and ambient temperature
(6) Minimum actuation pressure
11.2.2.4 Limitations. The specific application limitations created by equipment performance specifications and process conditions shall not be exceeded. These limitations include the following:
(1) Minimum and maximum distance of a valve from the duct entrance
(2) Process flow rates
(3) Direction of flow
(4) Orientation of the valve
(5) Flow resistance
(6) Pdetection less than Pstat when the enclosure is vented
(7) Process temperature
11.2.2.5* Mechanical isolation system components exposed to the process environment shall be capable of withstanding the maximum expected deflagration pressure, including pressure piling.

Mechanical Isolation Barrier

Chemical Explosion Isolation

Chemical Explosion Isolation



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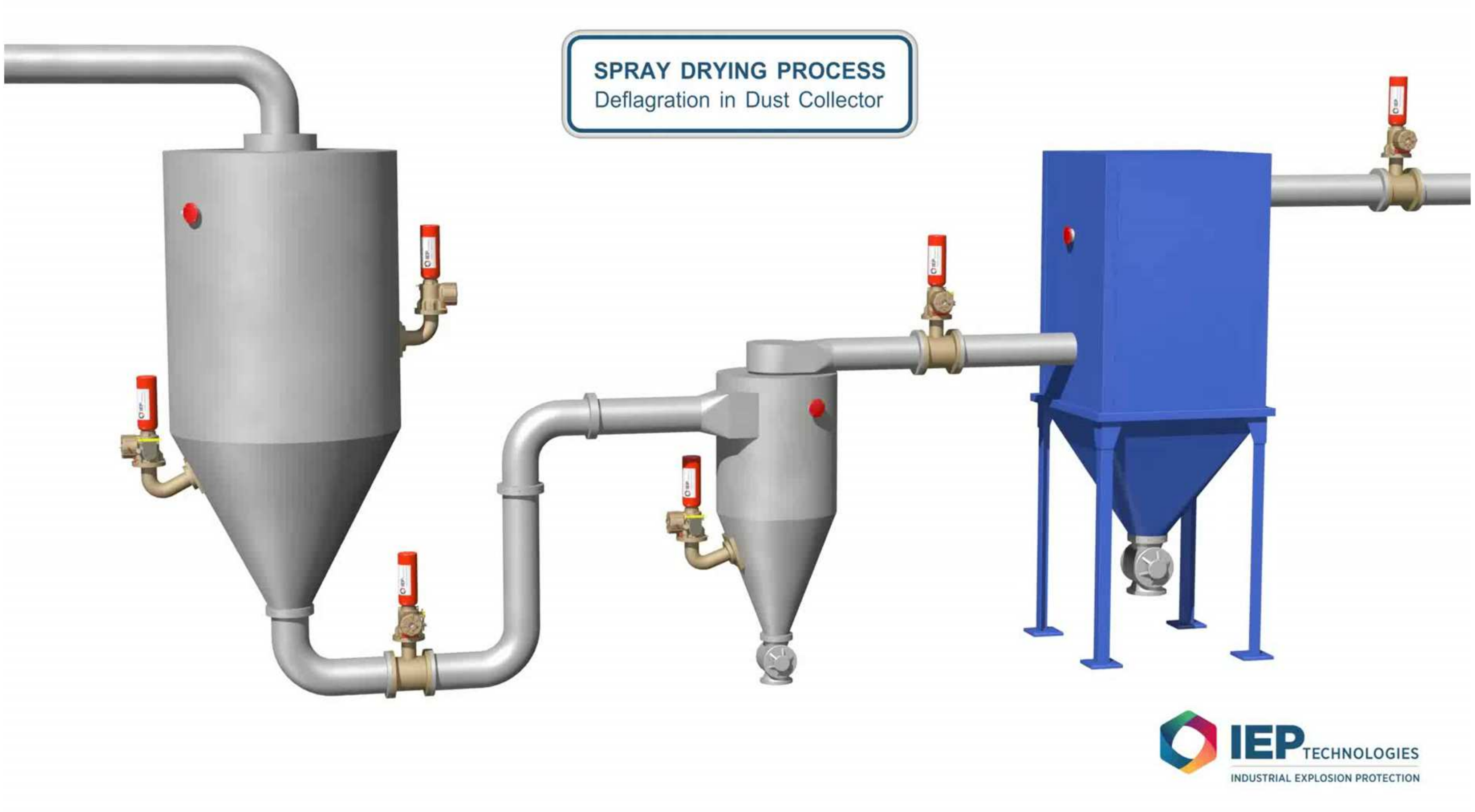
Chemical Explosion Isolation



Why do I need deflagration isolation?
Corn Starch – Propagation (Kst ~ 200 bar-m/s)

How does metal dust compare?
Aluminum Powder – Propagation (Kst ~ 400 bar-m/s)

IEP TECHNOLOGIES
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NFPA 654 Combustible Particulate Solids
2013 Edition

- 7.1.6* Isolation of Equipment.
- 7.1.6.1 Where an explosion hazard exists, isolation devices shall be provided to prevent deflagration propagation between connected equipment in accordance with NFPA 69, *Standard on Explosion Prevention Systems*.
- 7.1.6.2 The requirement of 7.1.6.1 shall not apply where all of the following conditions are met:
- (1) The material being conveyed is not a metal dust or hybrid mixture.
- (2) The connecting ductwork is smaller than 4 in. (100 mm) nominal diameter.
- (3) The maximum concentration of dust conveyed through the duct is less than 25 percent of the minimum explosive concentration (MEC) of the material.
- (4) The conveying velocity is sufficient to prevent accumulation of combustible dust in the duct.
- (5) All connected equipment is properly designed for explosion protection by means other than deflagration pressure containment.
- 7.1.6.3 Isolation devices shall not be required where oxidant concentration has been reduced or where the dust has been rendered noncombustible in accordance with 7.1.4.1(1) or 7.1.4.1(5).
- 7.1.7* Isolation of Upstream Work Areas. Where an explosion hazard exists, isolation devices shall be provided to prevent deflagration propagation from equipment through upstream ductwork to the work areas in accordance with NFPA 69, *Standard on Explosion Prevention Systems*.
- 7.1.8* Systems for the pre-deflagration detection and control of ignition sources, installed in accordance with NFPA 69, *Standard on Explosion Prevention Systems*, shall be permitted to be used to reduce the probability of occurrence of a deflagration in the following:
- (1) In ductwork supplying air-material separators
- (2) In recycled air from air-material separators to a building
- (3) In ductwork between process equipment
- 7.1.9 Fire Protection for Facility. Where a fire propagation hazard exists, the requirements of Chapter 10 shall apply.

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NFPA 654 Combustible Particulate Solids
2020 Edition

- 9.7.2* Isolation of Equipment and Work Areas.

- N 9.7.2.1* Where an explosion hazard exists, isolation devices shall be provided to prevent deflagration propagation between connected equipment and/or work areas in accordance with NFPA 69.

- N 9.7.2.2 Isolation devices shall not be required where oxidant concentration has been reduced or where the dust has been rendered noncombustible in accordance with 9.7.1.1(1) or 9.7.1.1(5).

NFPA 652 Fundamentals of Combustible Dust
2016 Edition

- 8.9.4 Equipment Isolation.
- 8.9.4.1* Where a dust explosion hazard exists, isolation devices shall be provided to prevent deflagration propagation between connected equipment in accordance with NFPA 69.
- 8.9.4.2 The requirement of 8.9.4.1 shall not apply where all the following conditions are met:
- (1) The material being conveyed is not a metal dust or hybrid mixture.
- (2) The connecting ductwork is smaller than 4 in. (100 mm) nominal diameter.
- (3) The maximum concentration of dust conveyed through the duct is less than 25 percent of the MEC of the material.
- (4) The conveying velocity is sufficient to prevent accumulation of combustible dust in the duct.
- (5) All connected equipment is properly designed for explosion protection by means other than deflagration pressure containment.
- 8.9.4.3 Isolation devices shall not be required where oxidant concentration has been reduced or where the dust has been rendered noncombustible in accordance with 8.9.3.2(1) or 8.9.3.2(6).
- 8.9.4.4 Isolation of Upstream Work Areas. Where a dust explosion hazard exists, isolation devices shall be provided to prevent deflagration propagation from equipment through upstream ductwork to the work areas in accordance with NFPA 69.

NFPA 652 Fundamentals of Combustible Dust
2019 Edition

- 9.7.4* Equipment Isolation.

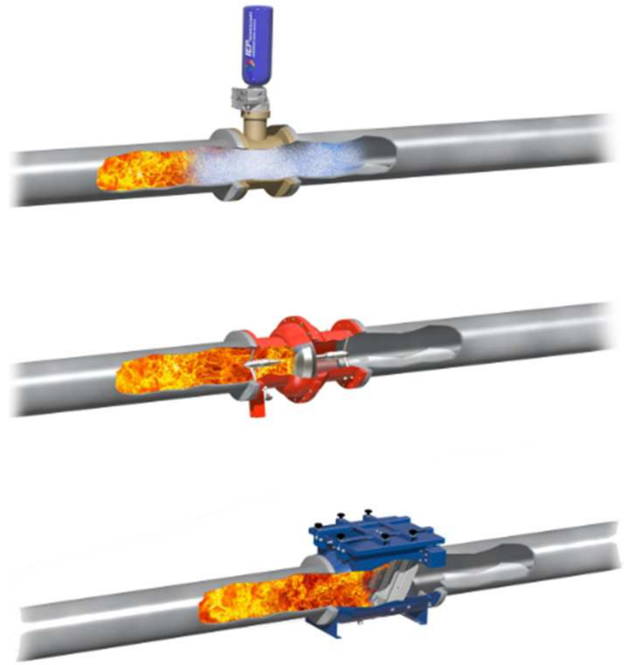
- 9.7.4.1 Where a dust explosion hazard exists, isolation devices shall be provided in accordance with NFPA 69 to prevent deflagration propagation between connected equipment.

- 9.7.4.2 Isolation devices shall not be required where oxidant concentration has been reduced in accordance with 9.7.3.2(1) or where the dust has been rendered noncombustible in accordance with 9.7.3.2(6).

- 9.7.4.3 Where a dust explosion hazard exists, isolation devices shall be provided in accordance with NFPA 69 to prevent deflagration propagation from equipment through ductwork to the work areas.

Isolation Conclusion

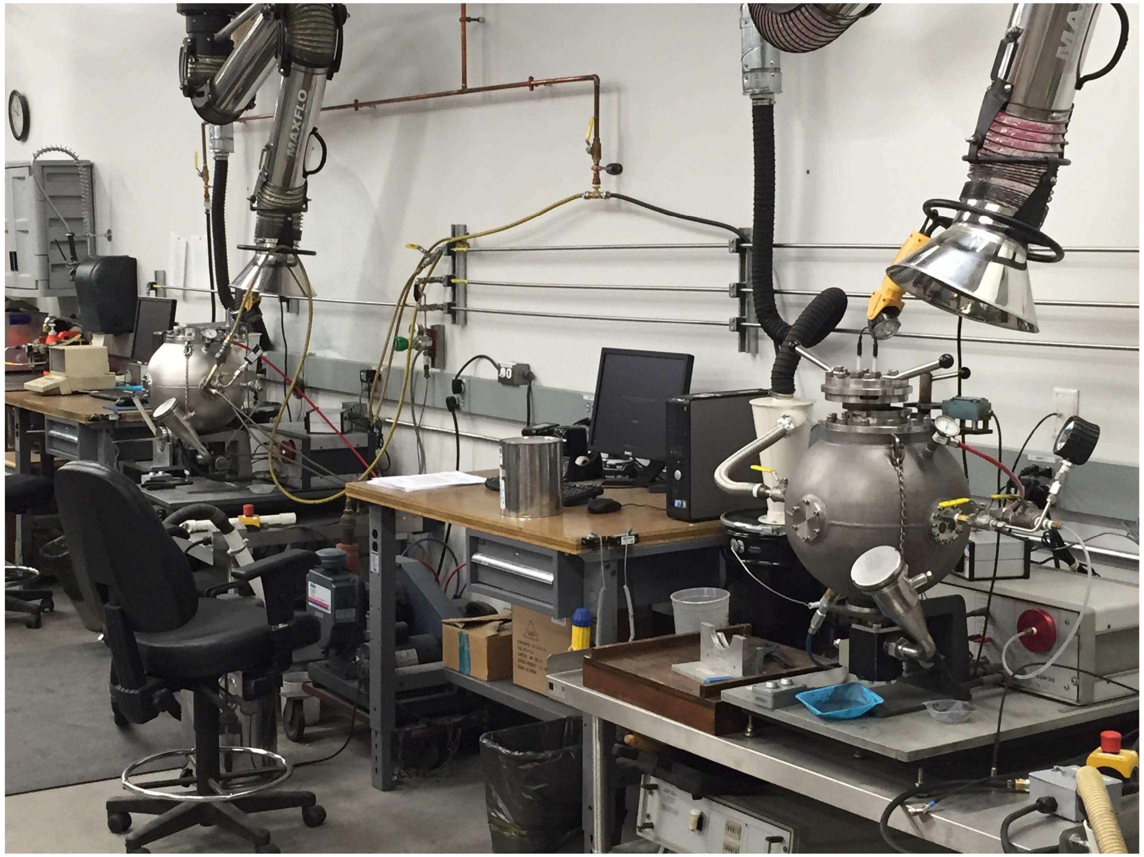
- The need for deflagration isolation is accepted
- Isolation is more challenging than Suppression
- There are a wide range of solutions available
- But the solution must meet the requirements and be certified for the application



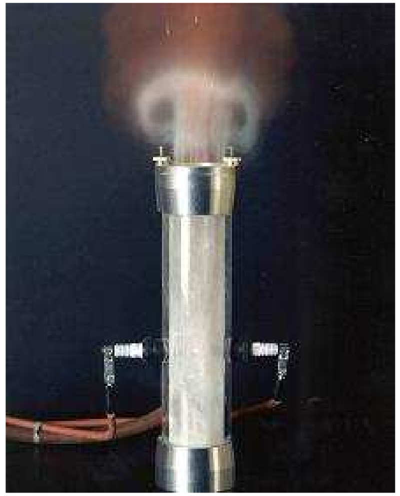
Selecting a Protection Method

- Location of vessel
- Can vessel be safely vented
- Inlet duct configuration
- Exhaust duct – to atmosphere or plant
- Operating pressure
- In-line fan
- Explosivity characteristics of material being handled

Combustible Material Testing



20-Liter Test Vessel for
Kst, Pmax Determination



Go-No Go
Test

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Combustible Material Testing

- Explosibility Parameters
  - Dust cloud reactivity (Pmax and Kst)
  - Minimum explosible dust concentration
- Ignition Characteristics
  - Dust cloud minimum ignition temperature
  - Dust cloud minimum ignition energy
  - Dust layer minimum ignition temperature
- Minimum safe oxygen concentration

Explosion Risks – Process Areas

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Selecting a Protection Method

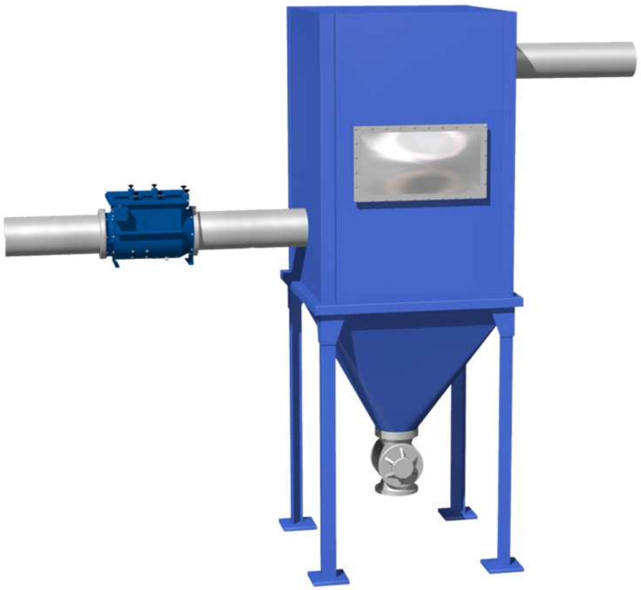
- Location of vessel
  - Indoors vs Outdoors (Question 1)
- Can vessel be safely vented
- Inlet duct configuration
  - Size and quantity (Question 2)
- Exhaust duct
  - Returns back into plant vs outside atmosphere (Question 3)
- Operating pressure
- In-line fan
  - Push vs pull system
- Explosivity characteristics of material being handled
  - Kst / Pmax (Question 4)

Dust Collectors

- Air-Material Separators
- Common in most mfg. facilities
- Major Explosion Threat in Mfg Plant
  - Finest Dust in facility
    - Easiest to Ignite
    - Highest Explosive Properties
  - Serves multiple vessels – propagation likely

Collectors - Protection Option 1

Deflagration Venting with Passive Inlet Isolation

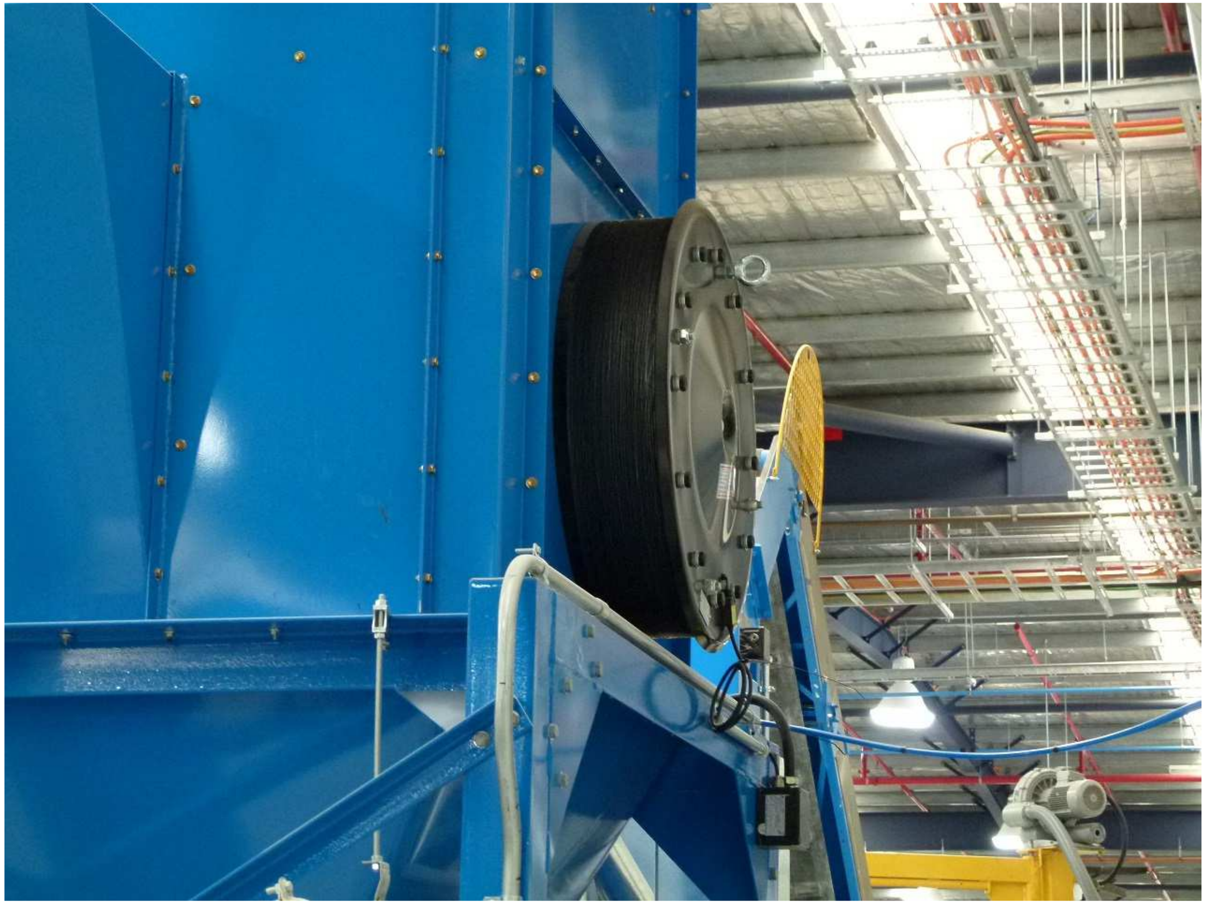


Flameless Explosion Venting is also suitable

- Allowable when venting can safely be used, exhaust directed outside
- Lowest initial cost
- Service completed at plant level

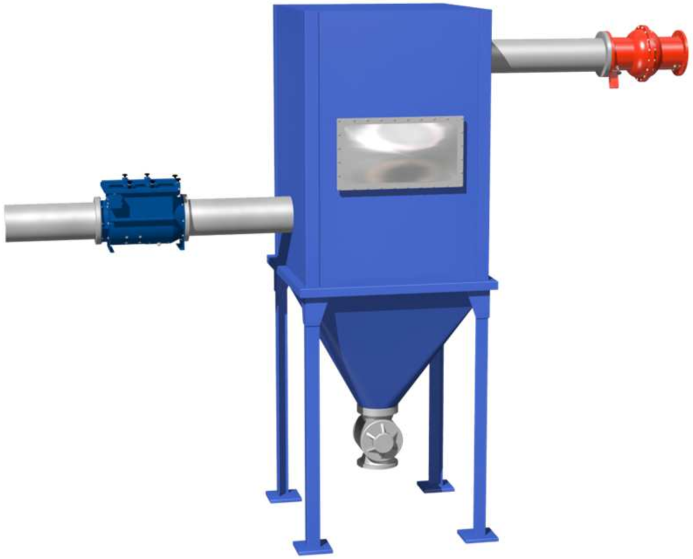
Filter – Venting with Passive Isolation

Collector – Flameless Venting



Collectors - Protection Option 2

Venting with Passive Inlet and Exhaust Isolation



Flameless Explosion Venting is also suitable

- Passive System
- Moderate initial cost
- Safe area to relieve hot gases
- Exhaust recirculated into plant
- Service completed at plant level

Receiver – Flameless Venting with Passive Isolation

Collectors - Protection Option 3

Deflagration Venting with Chemical Inlet Isolation

Flameless Explosion Venting is also suitable

- Active System
- Moderate cost
- Can't use flap valve
  - Kst too high
  - Diameter
  - Spacing
  - Duct Orientation
- Exhaust directed outside
- Service at plant level or outsourced to manufacturer

Filter – Venting with Chemical Isolation

Collectors - Protection Option 4

Deflagration Suppression with Chemical Inlet Isolation

- Active system
- Indoors or outdoors
- Venting not a viable option
- Service at plant level or outsourced to manufacturer

Collector – Suppression with Inlet Isolation

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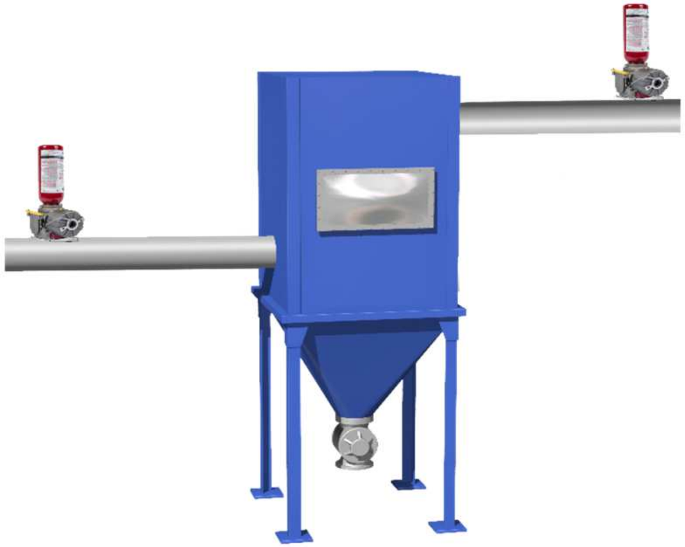
Collectors - Protection Option 5

Deflagration Venting with Chemical Inlet + Exhaust Isolation



Flameless Explosion Venting is also suitable

- Active system
- Outdoors, or indoors if vent can be ducted outside
- Exhaust recirculated into plant
- Service at plant level or outsourced to manufacturer

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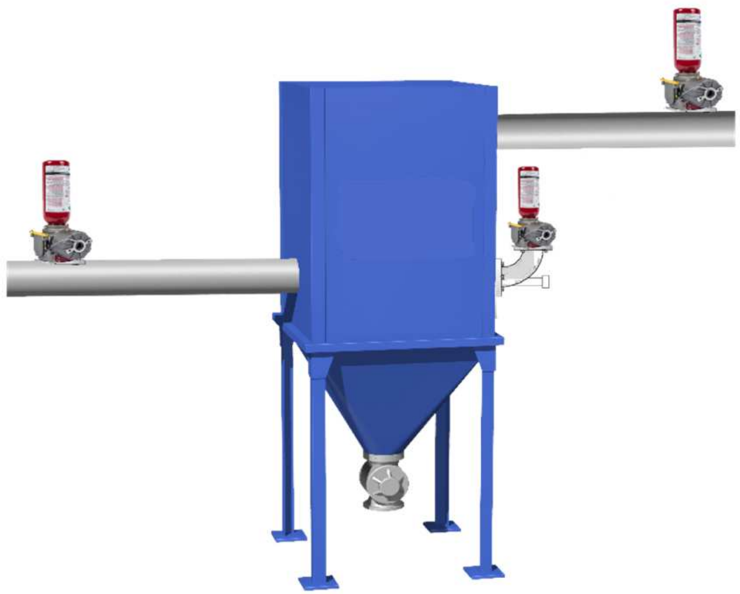
Collectors - Protection Option 6

Deflagration Suppression with Chemical Inlet + Exhaust Isolation



- Active system
- Outdoors or indoors
- Exhaust recirculated into plant
- Service at plant level or outsourced to manufacturer

Filter – Suppression with Inlet & Exhaust Isolation

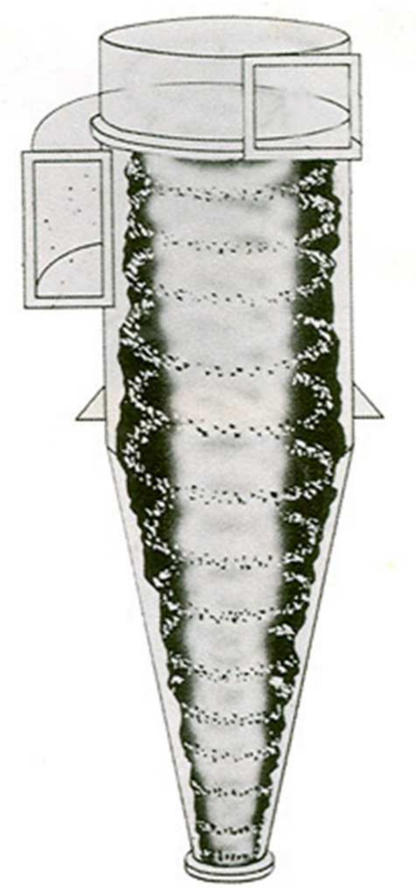
Selecting a Protection Method

- Location of vessel
  - Indoors vs Outdoors
- Can vessel be safely vented
- Inlet duct configuration
  - Size and quantity
- Exhaust duct
  - Returns back into plant vs outside atmosphere
- Operating pressure
- In-line fan
  - Push vs pull system
- Explosivity characteristics of material being handled
  - Kst / Pmax

Air Separation Vessels & Fire Protection

- Required when a fire hazard is present (NFPA 654, Chapter 7 and Chapter 9)
- Piped sprinkler system most common method
- Special fire protection systems allowed as alternatives
  - Must follow appropriate NFPA code
  - Must minimize generation of dust cloud during discharge (NFPA 654 9.8.3.7.2) – could lead to an explosion!
- Due to high airflow, delay in thermal detection should be considered.

Air Separation Vessels - Cyclones



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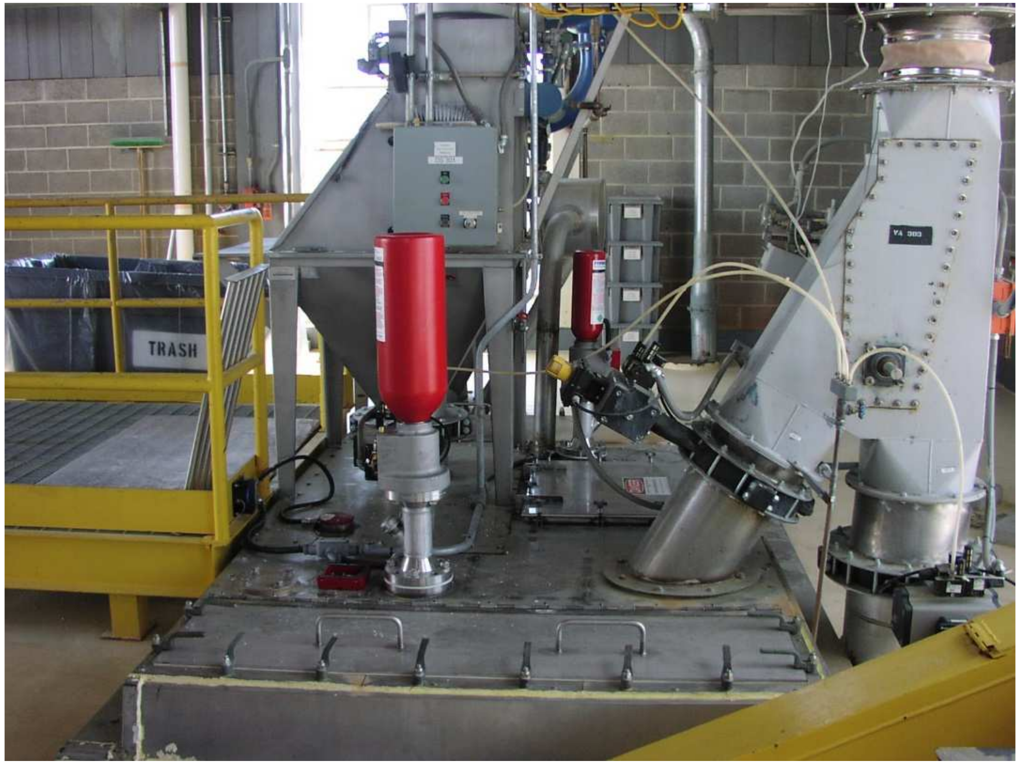
Blenders



Mills / Pulverizers

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Product Conveying

Pneumatic Conveying

Mechanical Conveying

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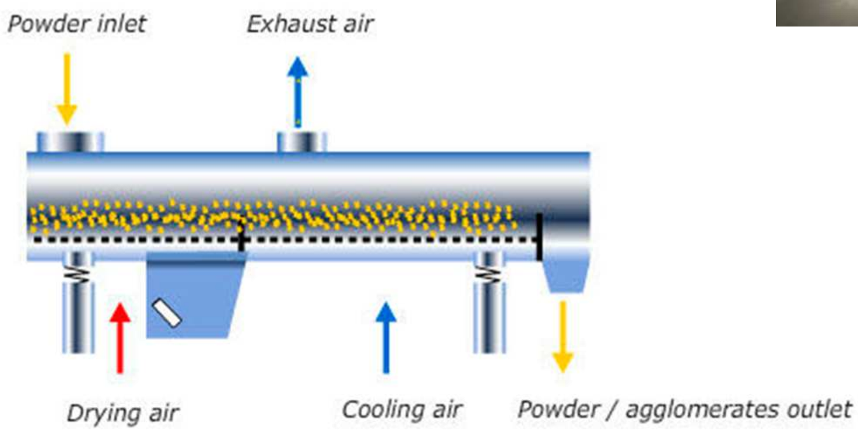
Spray Dryers

Fluid Bed Dryers



Silos / Hoppers

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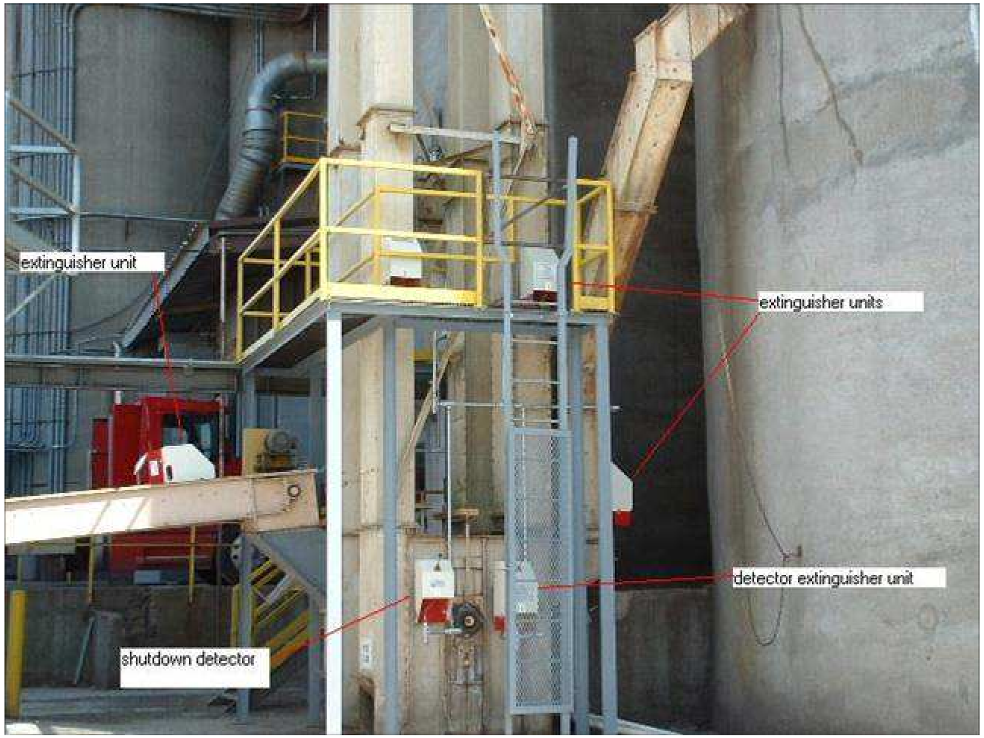
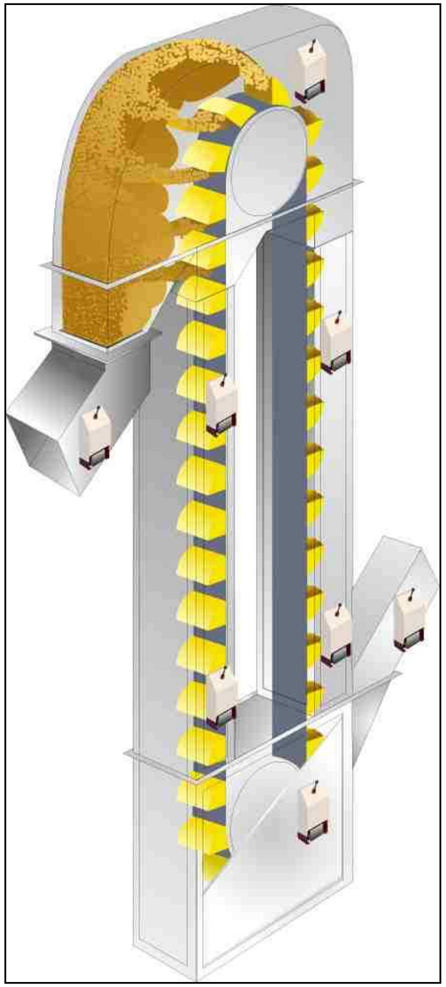
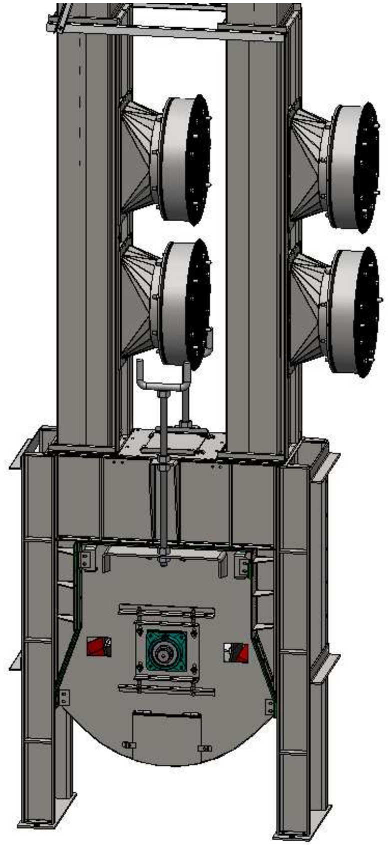
Bucket Elevators







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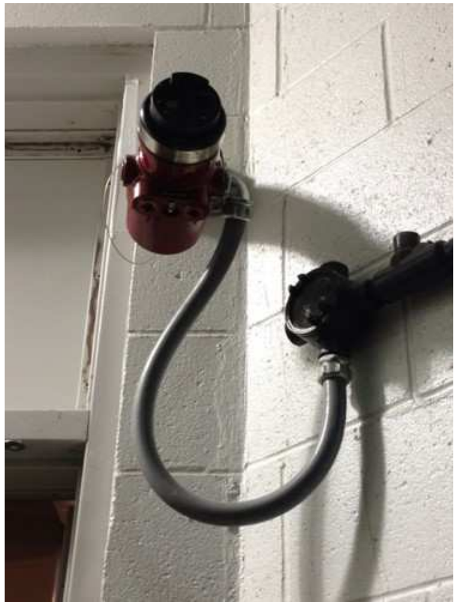
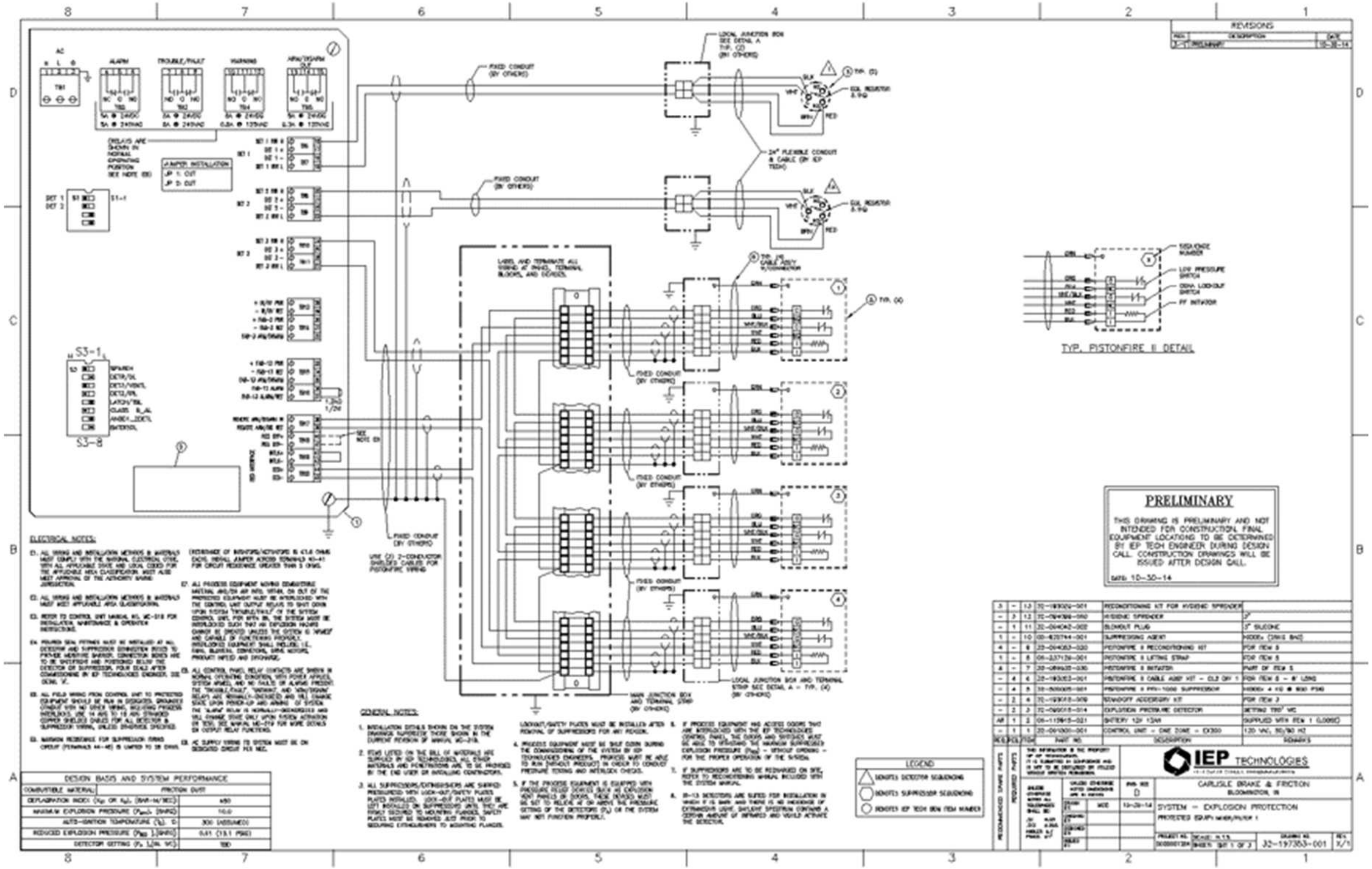
Combustible Vapor - Manned

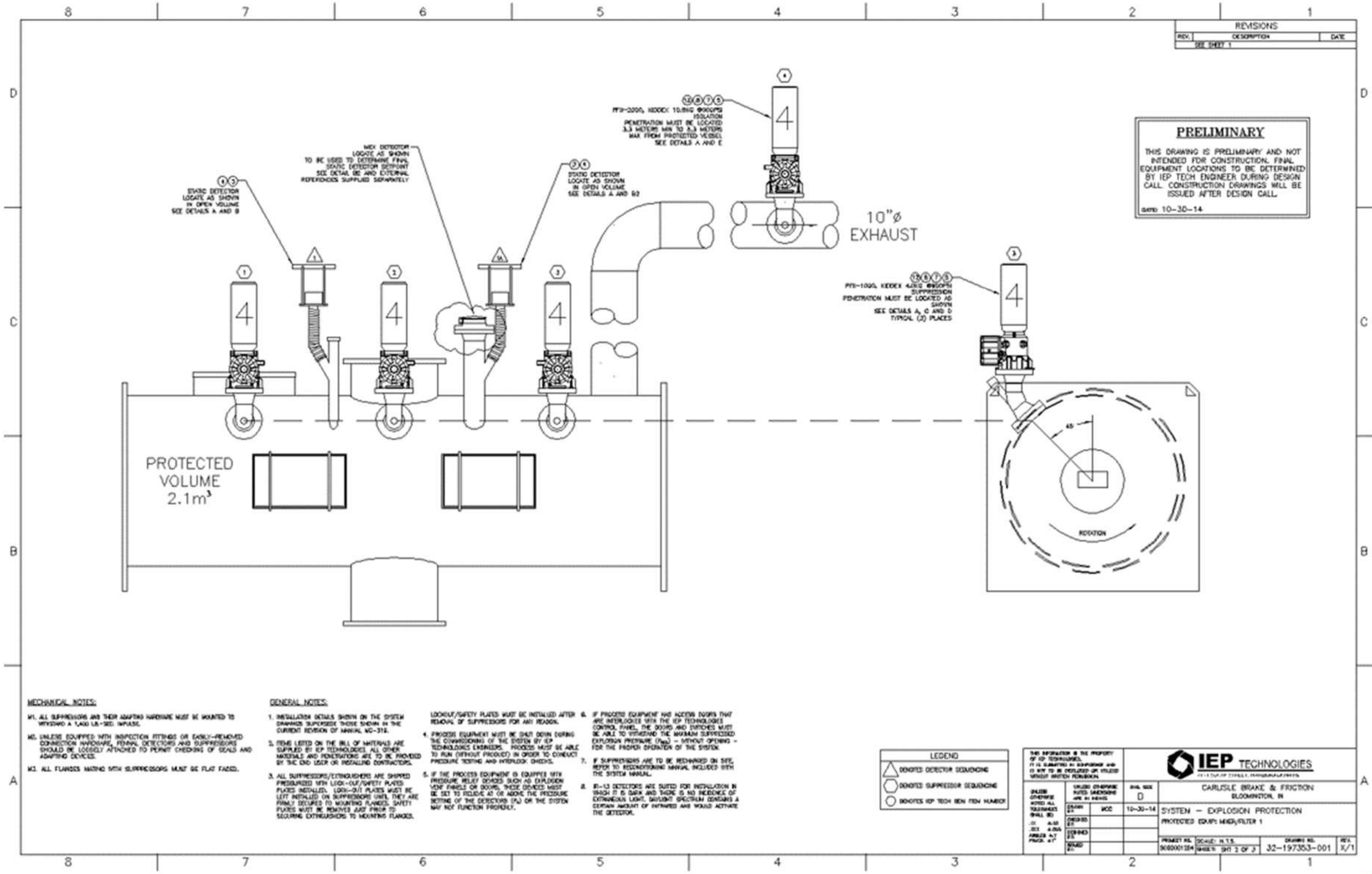
- Chemical Storage Rooms
- Chemical Mixing Rooms
- Aerosol Fill Rooms/Gashouses
- Hydrocarbon Gas Filling
- Hydrocarbon Reclaim Areas



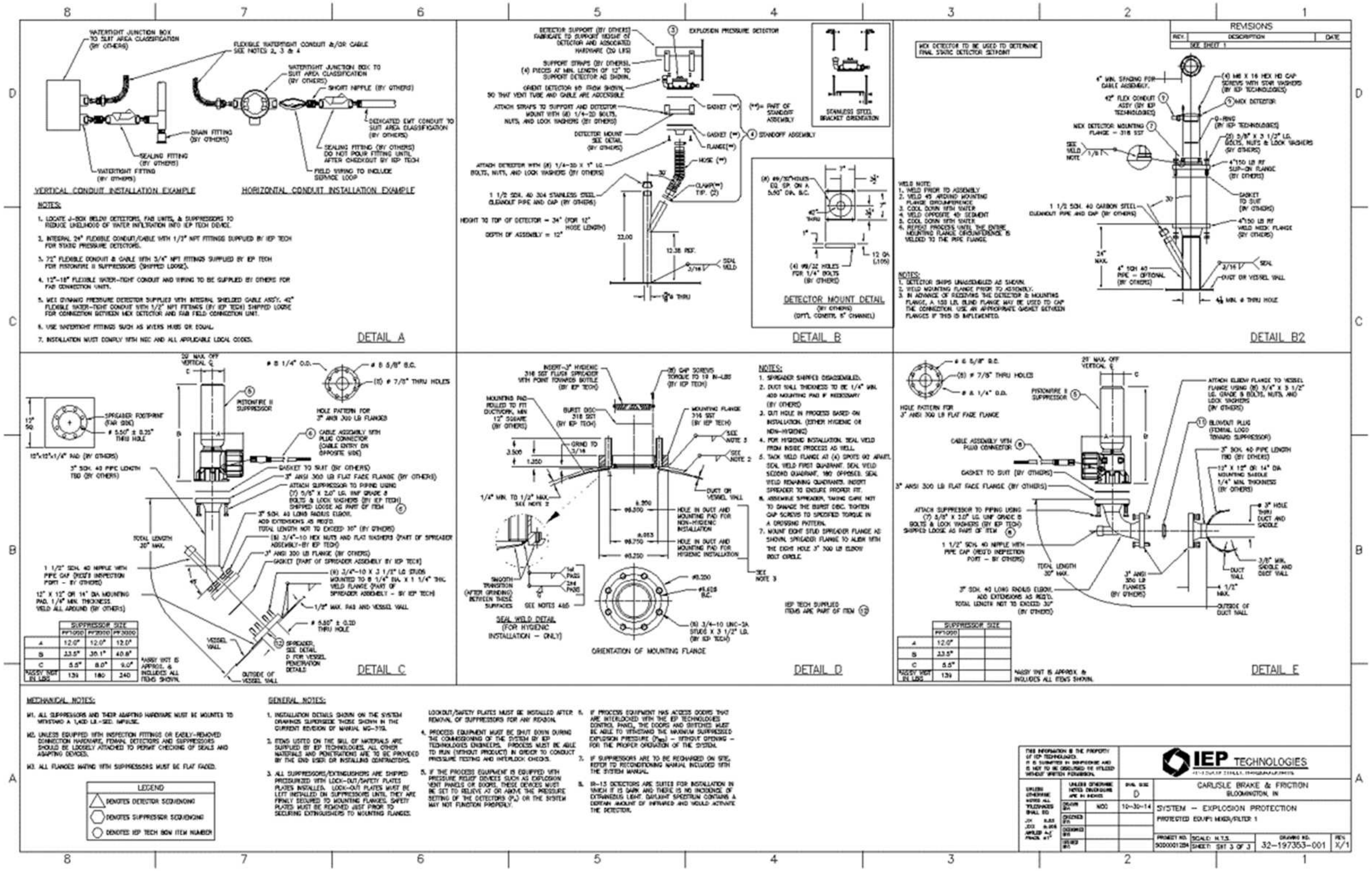
Drawings - Electrical



Drawings – Component Locations



Drawings – Installation Details



Installation Check Out – NFPA 69 Section 15.7

1. Conduct a walkthrough and general visual inspection of correct location, size, type, and mounting of all system components.
2. Physically inspect system components, including mechanical and electrical component integrity.
3. Conduct control unit functional testing.
4. Make point-to-point wiring checks of all circuits.
5. Ensure continuity and condition of all field wiring.
6. Inspect sensing pathway and calibrate initiating devices.
7. Verify correct installation of system components including sensing devices, fast-acting valves, suppressant storage containers, nozzles, spreader hoses, protective blow-off caps, plugs, and stoppers.
8. Conduct automatic fast-acting valve stroke test.
9. Conduct prevalidation testing, verify system interlocks, and shutdown circuits.
10. Identify and fix discrepancies before arming and handing off to user or operator.
11. Recalibrate detection sensing devices to final set points.
12. Complete record of system commissioning inspection, including hardware serial numbers, detector pressure calibrations, and suppressor and valve actuator charging pressure (psig), as appropriate.
13. Conduct end user training as required in Section 15.10.
14. Conduct final validation testing for authority having jurisdiction.
15. Arm the explosion prevention system.

System Inspections

- Inspection Frequency: Once every 3 months – OSHA/NFPA 69 Requirement
- Only Individuals specifically trained by EP manufacturer may perform system inspections.
- Process must be shut down to perform system inspections. Process equipment moving material or air through AMS must shut down when EP system is disarmed.
- Any changes to process or material being handled must be identified and reviewed to determine if system design is affected.

    Example: Combustible material other than that listed on drawings may have different explosivity characteristics and affect system's ability to suppress explosion.

Correct any discrepancies!

NFPA 484 – Standard for Combustible Metals Changes

NFPA 484 - 2012 Edition

Dust Collector Protection Summary for metal dusts.

- Dust collector must be located outside
- Dust collector must be vented per NFPA 68
- Clean air exhaust must be outside
- Inlet duct must have inlet isolation per NFPA 69 or inlet duct must be vented to outside
- Design to prevent ESD

NFPA 484 - 2015 Edition

Section 18.7 Machining, Fabrication, Finishing, and Media Blasting

18.7.4 Dust Collection

Dust collection shall be in accordance with Chapter 9

Chapter 9 Dust Collection

9.4.13.13 Explosion Protection.

9.4.13.13.1 Collectors shall be protected by a minimum of one of the following explosion protection methods:

(1)*Deflagration venting in accordance with NFPA 68, Standard on Explosion Protection by Deflagration Venting, which includes the following:

(a) Where deflagration venting is used on indoor dust collectors, the vents shall be ducted to the outside and the flow resistance shall be included in the vent design in accordance with NFPA 68.

(b)*Vent ducts shall be designed to prevent accumulation of moisture.

(2) Oxidant concentration reduction in accordance with NFPA 69, Standard on Explosion Prevention Systems, which includes the following:

(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.

(3) Deflagration pressure containment in accordance with NFPA 69

(4)*Deflagration suppression in accordance with NFPA 69, where the suppressant has been shown to be chemically compatible and effective with the material collected

(5)*Dilution with a compatible, noncombustible material to render the mixture noncombustible

(6)*Deflagration venting through a listed dust retention and flame-arresting device that has been shown effective with the metal being collected.

NFPA 484 - 2015 Edition

Chapter 9 Dust Collection

9.2.3.4* Fans or blowers shall be located outside of all manufacturing buildings and shall be located to minimize entrance of dust into the building from the fan exhaust.

9.4.13.2* Dry-type dust collectors shall be located outside of buildings unless permitted by **9.4.13.15**

9.4.13.15 Indoor Dry-Type Dust Collectors

9.4.13.15.4 Dry-type dust collectors shall be permitted to be located indoors where the requirements of **9.4.13.15.4.1** and **9.4.13.15.4.2** are met.

9.4.13.15.4.1 A hazards analysis shall be conducted in accordance with Section 5.2 to ensure that the risk to personnel and operations is minimized for both new and existing systems.

9.4.13.15.4.2* The material being collected shall meet all of the following criteria:

(1) The Pmax is less than 8 bar-g as measured using the ASTM E1226 test method.

(2) The Kst is less than 150 bar-m/s as measured using the ASTM E1226 test method.

(3) The minimum ignition energy (MIE) is greater than 100 mJ as measured using the ASTM E2019.

(4) The material is not a UN Class 4.2 solid as tested using UN 4.2 self-heating test methods.

9.4.13.15.7.5 Recirculation of exhaust air from a dry-type dust collector into the building shall be prohibited.

9.4.13.15.7.9 The collector exhaust duct located inside the building shall use one of the following deflagration protection methods:

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

(2)*Deflagration isolation in accordance with NFPA 69

NFPA 484 - 2019 Edition

- *N* 11.2.4.4* Dry-Type Air-Material Separator (AMS) Requirements.
- *N* 11.2.4.4.1* Dry-type filter media AMS shall not be used for metal dusts being collected in air with a Kst greater than 150 bar-m/s or for niobium, tantalum, titanium, zirconium, and hafnium unless their use is supported by a dust hazard analysis (DHA) that is acceptable to the AHJ.
- *N* 11.2.4.4.2 Media dust collectors shall be provided with all of the following ignition prevention measures:
- (1) Where the minimum ignition energy of the dust is less than 1000 mJ, the filter media shall be static-dissipative and shall be effectively bonded to the conductive filter frame.
- (2) Accumulations on filter media shall be limited to levels below the thresholds for any oxidative self-heating ignition and any possible ignition due to exothermic reaction with humid air. These thresholds shall be determined as part of the dust collection dust hazard analysis (DHA) conducted in accordance with Chapter 7.
- (3) Accumulation levels during the operation shall be monitored across the media by pressure drop or an equivalent sensor; if the accumulation exceeds the predetermined limits, a controlled shutdown of the collector and dust generation equipment shall be implemented.
- (4) Periodic inspections and replacement of media shall be based on intervals determined by the pressure drop across the filter media or by indication of self-heating detection equipment based on moisture reactivity.
- *N* 11.2.4.4.3* The ingress, accumulation, or condensation of water in a dry-type AMS shall be prevented.

NFPA 484 - 2019 Edition

- *N* 11.2.4.4.4 Dry-Type AMS Limitations.
- *N* 11.2.4.4.4.1* Electrostatic collectors shall be prohibited.
- *N* 11.2.4.4.4.2 Enclosureless dry-type AMS shall be prohibited.
- *N* 11.2.4.4.4.3* Self-contained, dry-type AMS, down-draft benches, and environmental control booths (e.g., buffing, grinding, and finishing booths) with integral filter media in the wall shall be prohibited.
- *N* (A) Self-contained, dry-type AMS, down-draft benches, and environmental control booths (e.g., buffing, grinding, and finishing booths) with integral filter media in the wall shall be permitted where a DHA has been performed and less than 0.22 kg (0.5 lb) of dust less than 500 microns is collected and emptied each day.
- *N* (B) Self-contained, dry-type AMS devices, down-draft benches, and environmental control booths (e.g., buffing, grinding, and finishing booths) with integral filter media in the wall shall be permitted where a DHA has been performed and less than 0.22 kg (0.5 lb) of dust less than 500 microns is collected and emptied each day.
- *N* 11.2.4.4.5* The accumulation of material inside any area of the dry-type AMS other than the discharge containers designed for that purpose and for normal operation of the AMS shall not be permitted.

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NFPA 484 - 2019 Edition

- *N* 11.2.4.4.11 Explosion Protection.
- *N* 11.2.4.4.11.1 Where provided, explosion protection shall be directed to a safe location away from areas where personnel are normally present.
- *N* 11.2.4.4.11.2 Collectors shall be protected by a minimum of one of the following explosion protection methods:
- (1)* Deflagration venting in accordance with NFPA 68, which includes the following requirements:
- (a) Where deflagration venting is used on indoor dust collectors, the vents shall be ducted to the outside and the flow resistance shall be included in the vent design.
- (b)* Vent ducts shall be designed to prevent accumulation of moisture.
- (2) Oxidant concentration reduction in accordance with NFPA 69, which includes the following requirements:
- (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.
- (3) Deflagration pressure containment in accordance with NFPA 69
- (4)* Deflagration suppression in accordance with NFPA 69, where the suppressant has been shown to be chemically compatible and effective with the material collected
- (5)* Dilution with a compatible, noncombustible material to render the mixture noncombustible
- (6)* Deflagration venting through a listed dust retention and flame-arresting device that has been shown to be effective with the metal being collected through independent third-party testing

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- *N* 11.2.4.4.11.3 If the method in 11.2.4.4.11.2(5) is used, test data for specific dust and diluent combinations shall be provided and shall be acceptable to the authority having jurisdiction.
- *N* 11.2.4.4.11.4 Where an explosion hazard exists and is not protected by 11.2.4.4.11.2(2) or 11.2.4.4.11.2(5), isolation devices that have been shown to be compatible and effective with the material collected shall be provided to prevent deflagration propagation between connected equipment in accordance with NFPA 69.
- *N* (A)* Explosion isolation shall be provided in accordance with NFPA 69 between the dust collector and upstream process.
- *N* (B) Where explosion isolation is not provided, a documented risk assessment acceptable to the authority having jurisdiction shall be permitted to be conducted to determine alternate protection methods.
- *N* 11.2.4.4.11.5 The selection of the type and location of vents or weak sections of the collector shall be designed to minimize injury to personnel and to minimize blast and fire damage to nearby equipment or structures.
- *N* 11.2.4.4.11.6 Where collectors are provided with deflagration vents, the area within the deflagration vent's discharge area shall be marked.
- *N* 11.2.4.4.11.7 Signage shall be posted near the dust collector that reads, at a minimum, the following,
  - CAUTION:THIS DUST COLLECTOR CAN CONTAIN EXPLOSIBLE DUST.
  - KEEP OUTSIDE THE MARKED AREA WHILE EQUIPMENT IS OPERATING.
- *N* 11.2.4.4.11.8 Where collectors are provided with deflagration vents, vent closures shall be clearly marked with, at a minimum, the following text:
  - WARNING:EXPLOSION RELIEF DEVICE

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- *N* 11.2.4.4.12 Collected Material.
- *N* 11.2.4.4.12.1 Discharge containers for collectors shall be emptied before or when 100 percent of the storage capacity of the container is attained.
- *N* 11.2.4.4.12.2 Dust shall be removed from collectors at least once each day and at more frequent intervals if conditions warrant.
- *N* 11.2.4.4.12.3 Material removed from the collector shall be permitted to be recycled into a process or mixed with an inert material in a volume ratio of five parts inert material to one part metal dust and, once mixed, shall be recycled or disposed of in accordance with local, state, and federal regulations.
- *N* 11.2.4.4.12.4 Precautions shall be taken to avoid creating dust clouds when removing dust from the collectors.
- *N* 11.2.4.4.12.5 The dust removed shall be recycled or disposed of in accordance with local, state, and federal regulations.
- *N* 11.2.4.4.12.6 The dust shall be discharged into metal containers that shall be promptly and tightly covered to avoid the creation of airborne fugitive dust.

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- *N* 11.2.4.4.13* Requirements for the Clean Air Exhaust.
- *N* 11.2.4.4.13.1 Recycling of exhaust air from fixed dry-type dust collectors into buildings shall not be permitted unless all of the following requirements are met:
- (1)* The material being collected has a calculated adiabatic flame temperature below 2300°C (4172°F).
- (2) Water has been shown to be an effective extinguishing agent for the material being collected.
- (3) Combustible or flammable gases or vapors are not present either in the intake or in the recycled air in concentrations above applicable industrial hygiene exposure limits or 1 percent of the LFL, whichever is lower.
- (4)* Combustible particulate solids are not present in the recycled air in concentrations above applicable industrial hygiene exposure limits or 15 mg/m3, whichever is lower.
- (5)* The oxygen concentration of the recycled air stream is between 19.5 percent and 23.5 percent by volume.
- (6) Provisions are incorporated to prevent transmission of flame and pressure effects from a deflagration in an AMS back to the facility unless a DHA indicates that those effects do not pose a threat to the facility or the occupants.
- (7) Provisions are incorporated to prevent transmission of smoke and flame from a fire in an AMS back to the facility unless a DHA indicates that those effects do not pose a threat to the facility or the occupants.
- (8) The system includes a method for detecting AMS malfunctions that would reduce collection efficiency and allow increases in the amount of combustible particulate solids returned to the building.
- (9) The building or room to which the recycled air is returned meets the housekeeping requirements of Chapter 9.
- (10) Recycled-air ducts are inspected and cleaned at least annually.

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- *N* 11.2.4.4.13.2 For materials not meeting items 11.2.4.4.13.1(1) and 11.2.4.4.13.1(2), they shall meet the following requirements prior to allowing the recirculation:
- (1) The maximum amount of metal in a combustible form accumulating in the discharge container will not exceed 4.5 kg (10 lb) of material with a maximum of 0.45 kg (1 lb) of material less than 500 microns for an aggregate of 4.95 kg (11 lb) total.
- (2) The collector annually collects a maximum of 300 lb of metal in a combustible form that is less than 500 microns.

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- *N* 11.2.4.4.14 Dry-type dust collectors shall be located outside of buildings unless permitted by 11.2.4.4.15.
- *N* 11.2.4.4.15* Indoor Dry-Type Air-Material Separator (AMS).
- All portions of 11.2.4.4 on dry-type AMS requirements shall apply to indoor dry-type AMS in addition to this section.
- *N* 11.2.4.4.15.1 A hazards analysis shall be conducted in accordance with Section 5.2 and Chapter 7 to ensure that the risk to personnel and operations is minimized for both new and existing systems.
- *N* 11.2.4.4.15.2 The collector shall be designed to comply with all applicable requirements in this chapter.
- *N* 11.2.4.4.15.3 The requirements for fire protection for indoor dry-type dust collection systems shall apply retroactively.
- *N* (A) An automatic fixed fire suppression system shall be provided with a fire extinguishing agent that has been shown to be effective with the material collected for indoor collectors.
- *N* (B) An automatic fixed fire suppression system shall not be required where the amount of material collected is less than 0.45 kg (1 lb) combustible metal and the dust collector is emptied after each day of operation.
- *N* (C) Collected material shall not be stored in the collector, but shall be continually emptied from the collector into a sealed metal container through an isolation device in accordance with NFPA 69.
- *N* (D) The collection of materials other than iron or steel dust shall be prohibited in collectors with a dirty volume greater than 0.57 m3 (20 ft3) or an airflow greater than 2549 m3/hr (1500 ft3/min).
- *N* (E)* Media collectors shall contain a filter break (i.e., broken bag) detection system that automatically shuts down the collector and connected equipment if a filter break is detected.

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- *N* 11.2.4.4.15.4* The exhaust duct from the fan discharge shall exit the building using as straight and short a path as is practical.
- *N* 11.2.4.4.15.5* The collector inlet duct, exhaust duct, and blower shall be inspected at least every 6 months to ensure that material is not accumulating.
- *N* 11.2.4.4.15.6 The collector exhaust duct located inside the building shall use one of the following deflagration protection methods:
- (1) Deflagration pressure containment in accordance with NFPA 69
- (2)* Deflagration isolation in accordance with NFPA 69

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- *N* 11.2.4.4.15.7* If the material meets either of the following criteria, the additional requirements in 11.2.4.4.15.7(A), 11.2.4.4.15.7(B), and 11.2.4.4.15.7(C) apply:
- (1) The material is a UN Class 4.3 solid as tested using UN 4.3 water reactivity test methods.
- (2)* Water has not been shown to be an effective extinguishing agent (*see Table A.8.3.3*).
- *N* (A)* Media collectors shall include automatic cleaning of filters, and the pressure drop across the filter shall be continuously monitored and alarms activated if the pressure is outside of established operating ranges.
- *N* (B) The collector shall contain a warning sign stating the following:
- THIS COLLECTOR CONTAINS COMBUSTIBLE METAL DUST.DO NOT EXTINGUISH WITH WATER.
- *N* (C) The emergency response plan required in Section 8.5 shall include the following information to emergency responders:
- (1) Location of indoor dry-type dust collectors
- (2) Direction that the collector is not to be opened to extinguish a fire
- (3)* Direction that a fire in the collector is not to be extinguished with water
- (4) A description of the automatic fire extinguishing system on the collector
- (5) A list of effective extinguishing agents for the material being collected in the collector

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- *N* 11.2.4.4.15.8 Indoor dry-type dust collectors shall be permitted for metals covered by Chapter 16 – Other Metals, meeting the following requirements:
  - (1) The Pmax is less than 8 bar-g as measured using the test method in ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*.
  - (2) The Kst is less than 150 bar-m/s as measured using the test method in ASTM E1226.
  - (3) The minimum ignition energy (MIE) is greater than 100 mJ as measured using the test method in ASTM E2019, *Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air*.
  - (4) The material is not a UN Class 4.2 solid as tested using UN 4.2 self-heating test methods.
  - (5) The collection of materials other than iron or steel dust is prohibited in collectors with a dirty volume greater than 0.57 m3 (20 ft3) or an airflow greater than 2549 m3/hr (1500 ft3/min).

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- *N* 11.2.4.4.15.9 Indoor dry-type dust collectors shall be permitted for metals other than those covered by Chapter 16, provided that one of following provisions are met:
- (1) The maximum amount of metal in a combustible form accumulating in the collector receptacle shall not exceed a maximum accumulation of 4.5 kg (10 lb) of material greater than 500 microns with a maximum of 0.45 kg (1 lb) of material less than 500 microns for an aggregate of 5 kg (11 lb) total.
- (2) The collector annually collects a maximum of 136 kg (300 lb) of metal in a combustible form that is less than 500 microns.
- (3) The AMS has a dirty volume less than 0.2 m3 (8 ft3) or an airflow less than 850 m3/hr (500 ft3/min) and is emptied daily.

Metal Dust

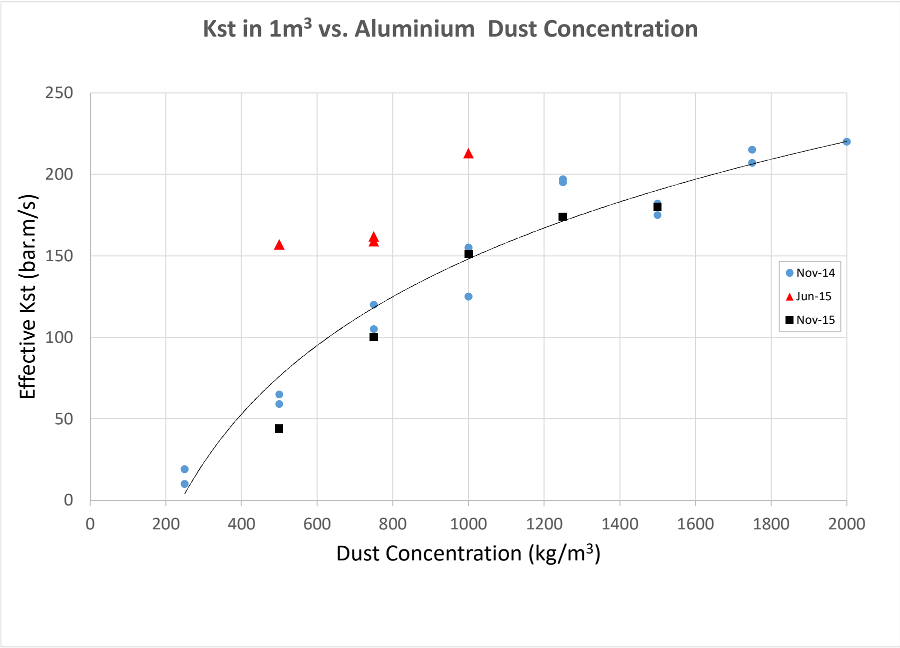
- Very different to organic deflagrations
- Flame temperatures are very high (2X carbon)
- Metal can melt and vaporize
- Oxygen not the only “oxidant” (aluminum nitride)
- K_{st} range up to 1000 bar.m/s
- K_{st} changes with time as oxide layer develops
- Metal Dusts = Solid Rocket Fuel

Metal Dust

- Aluminum does NOT follow the cubic law (Volume $^{1/3}$)

- K_{st} is volume dependent!
- Single Al dust:
- 20L – K_{st} = 200 bar.m/s
- 1m^3 – K_{st} = 400 bar.m/s

- K_{st} is concentration dependent!



- ASTM E1226 tests are not sufficient

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Metal Dust

– Organic Deflagration – Carbon based material

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Metal Dust

– Metal Dust deflagration

NFPA 664 – Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities

Wood Working Applications

NFPA 664

9.3.3.2 Pneumatic Conveying and Dust Collection Systems.

9.3.3.2.1 General Requirements.

9.3.3.2.1.1 Pneumatic conveying systems shall be designed in accordance with NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, except as modified by this standard.

Wood Working Applications

NFPA 664

- **9.7 Explosion Prevention / Protection.**
- **9.7.1 Equipment Protection.**
- **9.7.1.2* Dust Collectors with Deflagration Hazards.** Dust collectors with a deflagration hazard having a dirty side volume greater than 0.23 m3 (8 ft3) shall be designed and constructed in accordance with one of the following options:
- (1)*Dust collectors constructed of welded steel or other noncombustible material of sufficient strength to withstand the maximum unvented deflagration pressure of the material being collected
- (2)*Dust collectors protected by a listed deflagration suppression system in accordance with NFPA 69, *Standard on Explosion Prevention Systems*, with a design strength exceeding the maximum reduced deflagration pressure of the material being collected
- (3)*Dust collectors equipped with deflagration relief vents in accordance with NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, with a design strength exceeding the maximum reduced deflagration pressure of the material being collected
- (4) Dust collectors located outdoors and representing minimal exposure to personnel and the public at large with weaker construction, subject to a risk analysis acceptable to the authority having jurisdiction
- (5) Enclosureless dust collectors of any strength suitable for the use intended shall be permitted without any additional explosion protection requirements

Wood Working Applications

NFPA 664

- **9.3.5 Recycling of Air-Material Separator Exhaust.** Recycling of air-material separator exhaust to buildings shall be permitted if the provisions of 9.3.5.1 through 9.3.5.4 are met.
- **9.3.5.1*** The system shall be designed to prevent return of dust with a minimum efficiency of 99.9 percent at 10 µm.
- **9.3.5.2** Recycling of air-material separator exhaust to the building shall not be permitted under any circumstances where combustible gases, vapors, or hybrid mixtures are involved.
- **9.3.5.3** Recycling of air-material separator exhaust to the building shall not be permitted when the recycled stream reduces the concentration of oxygen below 19.5 percent by volume in the work area.
- **9.3.5.4*** Air from air-material separators or dust collectors deemed to have a fire hazard shall meet the provisions of 9.3.5.4.1, 9.3.5.4.2, 9.3.5.4.3, or 9.3.5.4.4.

Wood Working Applications

NFPA 664

- **9.3.5.4.1*** For dust collection systems of capacity less than or equal to 2.36 m3/sec (5000 cfm), one of the following shall apply:
- (1) The system shall be equipped with listed spark detection, designed and installed in conformance with the relevant sections of *NFPA 72*, *National Fire Alarm and Signaling Code*, located on the duct upstream from the dust collector and downstream from the last material entry point, connected directly to a listed spark extinguishing system, designed and installed in conformance with NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*, or
- (2) The system shall be protected in accordance with 9.3.5.4.2.

Wood Working Applications

NFPA 664

- **9.3.5.4.2*** For dust collection systems of capacity greater than 2.36 m3/sec (5000 cfm), the following shall apply:
- (1) The system shall be equipped with a listed spark detection system, designed and installed in conformance with the relevant sections of *NFPA 72*, *National Fire Alarm and Signaling Code*, located on the duct upstream from the dust collector and downstream from the last material entry point, or on the exhaust side of the dust collector, to detect fire entering or occurring within the dust collector, respectively, and
- (2) The exhaust air duct conveying the recycled air back to the building shall be equipped with a high-speed abort gate activated by the spark detector in 9.3.5.4.2(1), and the abort gate shall be sufficiently fast to intercept and divert any burning material to atmosphere before it can enter the plant.
- (3)*The abort gate is provided with a manual reset so that, after it has aborted, it can be reset to the normal position only by manual interaction at the damper; automatic or remote reset shall not be allowed. A powered reset is acceptable if it can be activated only by manual interaction at the damper location.

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Wood Working Applications

NFPA 664

- **9.3.5.4.3** Air from enclosureless dust collectors meeting the requirements of 9.3.4(7) shall be permitted to be exhausted into the building.

- **9.3.5.4.4** Air from cyclone pre-cleaners, located outside the building and having a capacity of 2.36 m3/sec (5000 cfm) or less shall be permitted to be ducted directly to enclosureless dust collectors located within the building without provisions.

9.3.4 ***AMS Locations***

*(7)*Indoors for enclosureless dust collectors meeting all of the following criteria:*

(a) The collector is used only for dust pickup from wood processing machinery (i.e., no metal grinders and so forth).

(b) The collector is not used on sanders, molders, or abrasive planers having mechanical material feeds through the machine.

(c) Each collector has a maximum air-handling capacity of 2.36 m3/sec (5000 cfm).

(d) The fan motor is of a totally enclosed, fan-cooled design.

(e) The collected dust is removed daily or more frequently if necessary to ensure efficient operation.

(f) The collector is located at least 6.1 m (20 ft) from any means of egress or area routinely occupied by personnel.

(g) Multiple collectors in the same room are separated from each other by at least 6.1 m (20 ft).

Wood Working Applications

NFPA 664

9.3.3.2 Pneumatic Conveying and Dust Collection Systems.

9.3.3.2.1 General Requirements.

9.3.3.2.1.1 Pneumatic conveying systems shall be designed in accordance with NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, except as modified by this standard.

Wood – Enclosureless Collectors
Current NFPA 664 Provisions

9.3.4 AMS Locations. Dust collectors shall be located in accordance with one of the following:

(7)* Indoors for enclosureless dust collectors meeting all of the following criteria:

(a) The collector is used only for dust pickup from wood processing machinery (i.e., no metal grinders and so forth).

(b) The collector is not used on sanders, molders, or abrasive planers having mechanical material feeds through the machine.

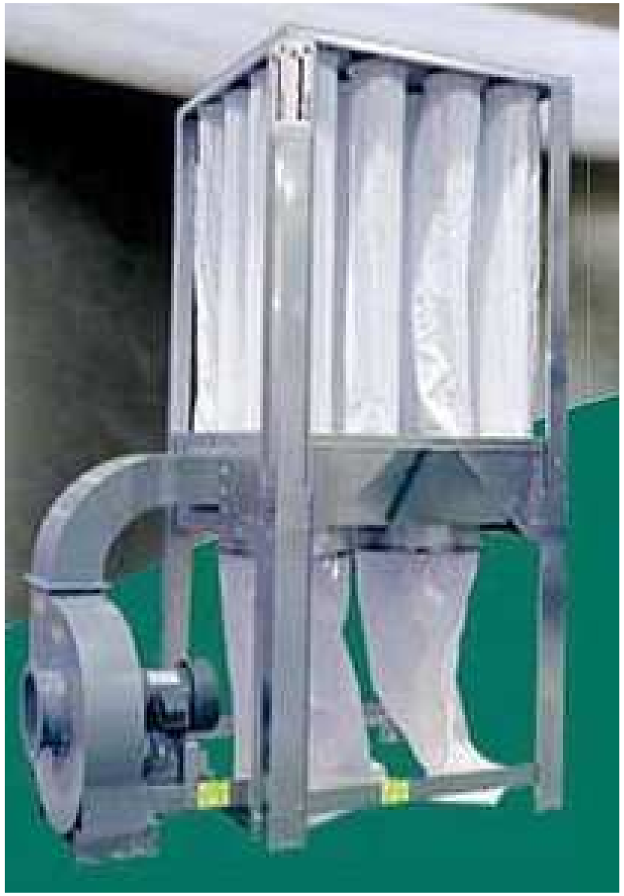
(c) Each collector has a maximum air-handling capacity of 2.36 m3/sec (5000 cfm).

(d) The fan motor is of a totally enclosed, fan-cooled design.

(e) The collected dust is removed daily or more frequently if necessary to ensure efficient operation.

(f) The collector is located at least 6.1 m (20 ft) from any means of egress or area routinely occupied by personnel.

(g) Multiple collectors in the same room are separated from each other by at least 6.1 m (20 ft).



Conclusion / Takeaways

What material are you handling?

Where is your DHA?

Is the explosion protection fit for the application?

- Flap valves are most popular but don’t fit all applications – Kst limitations, within installation requirements
- Venting to a safe area?

Inspections – all explosion protection equipment – passive or active requires documented inspections – ask to provide to ensure discrepancies are resolved.

Is the explosion protection equipment interlocked so the process shuts down when it is supposed to?

Thank You!

Questions?

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