Date: March 2nd – 5th, 2020
Place: Universty of Novi Sad, Serbia

SPECIAL MOBILITY STRAND

Explosions of Flammable Industrial Dusts

Faculty of Security Engineering
Department of Fire Engineering
University of Žilina
Slovak Republic

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Explosions of Flammable Industrial Dusts

Learning Objectives

- *Theory of Flammable Industrial Dust Explosions*
- *Flammability, Reactivity and Dust Explosion Hazards*
- *Characteristics, Fire and Explosive Properties of Flammable Dust*
- *Health Properties of Flammable Industry Dust*
- *Process Safety Incidents in Particular Types of Industry*
- *Risk Prevention and Controls*

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Explosions of Flammable Industrial Dusts

- *An explosion of dust - a rapid combustion of fine particles suspended in the air, particularly in an enclosed location*
- *Flammable dust - a set of pulverized particles of the solid substance which exist in the gassy environment. These dust particles have the dimensions lower than 0,5 mm.*
- *Aerosol*
- *Aerogel*

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Explosions of Flammable Industrial Dusts

Difference between fires and explosions

- *Rate of energy release*
- *Fires release energy slowly, explosions release energy rapidly*
- *Fires can result from explosions, explosions can result from fires*

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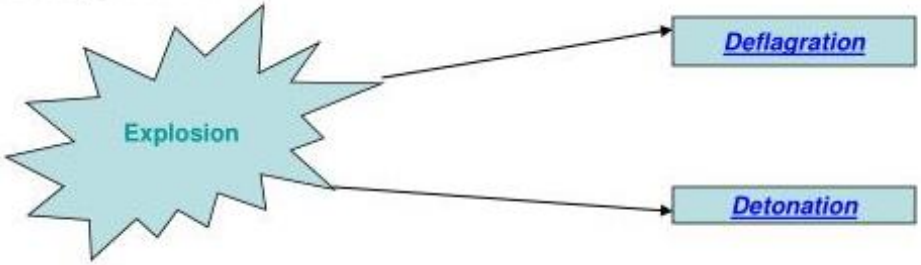
Deflagration. **Propagation of a combustion zone at a speed that is less than the speed of sound in the unreacted medium.**

Detonation. **Propagation of a combustion zone at a velocity that is greater than the speed of sound in the unreacted medium.**

Explosion. **The bursting or rupture of an enclosure or a container due to the development of internal pressure from deflagration.**



Source: https://www.slideserve.com/perrin/combustible-dust-national-emphasis-program

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Deflagration to Detonation Transition

In some situations, a subsonic flame may accelerate into a supersonic flame. This deflagration to detonation is difficult to predict but occurs most often when eddy currents or other turbulence are present in the flames.
This can happen if the fire is partially confined or obstructed. Such events have occurred in industrial sites where extremely combustible gasses have escaped, and when ordinary deflagration fires encounter explosive materials.

Source: https://www.slideserve.com/perrin/combustible-dust-national-emphasis-program

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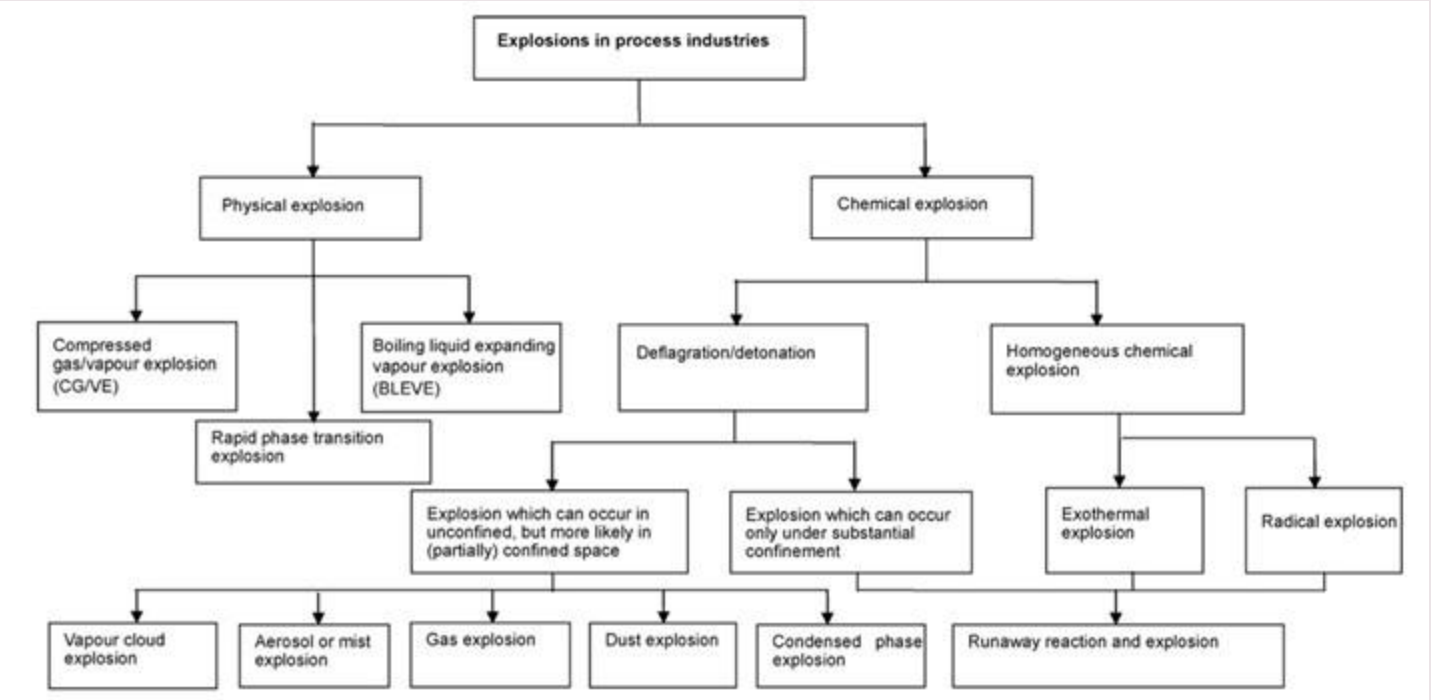

Source: https://slideplayer.com/slide/3828363/

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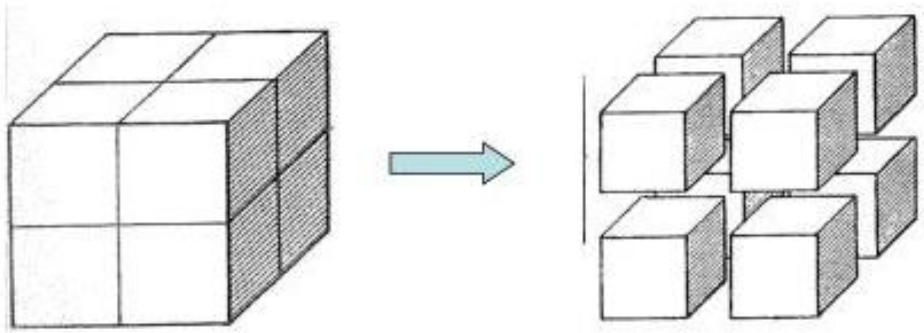
Surface Area of Industrial Flammable Dust

Surface Area Increases with increasing subdivision



Figures Source: Dust Explosions in the Process Industries, Second Edition, Rolf K Eckhoff

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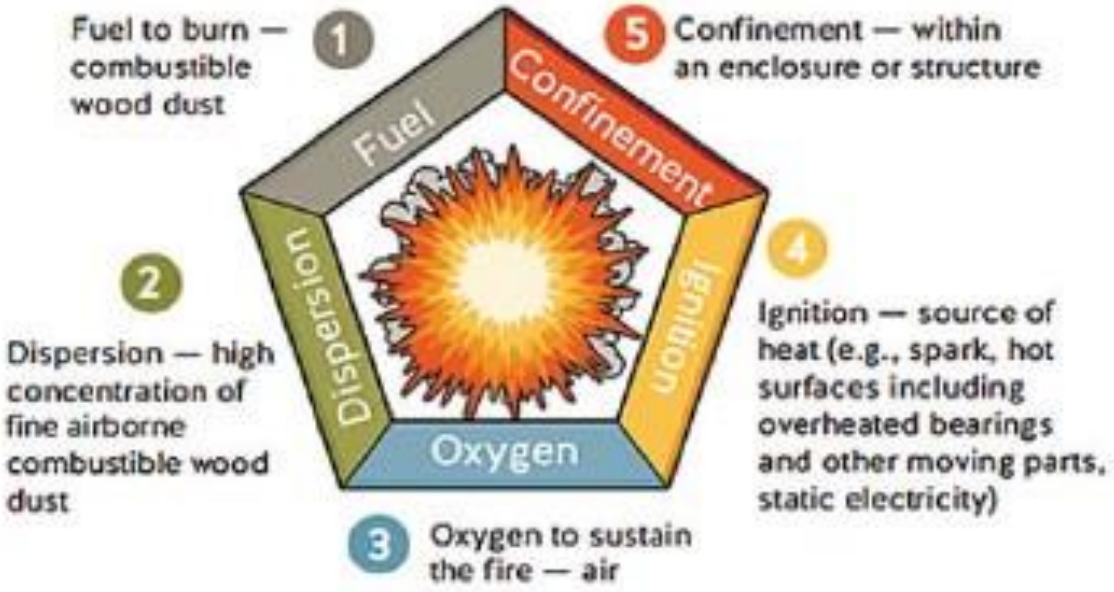
Explosions of Flammable Industrial Dusts

Dust Explosion Pentagon



Source: http://www.turkchem.net/combustible-dusts-and-dust-explosions.html

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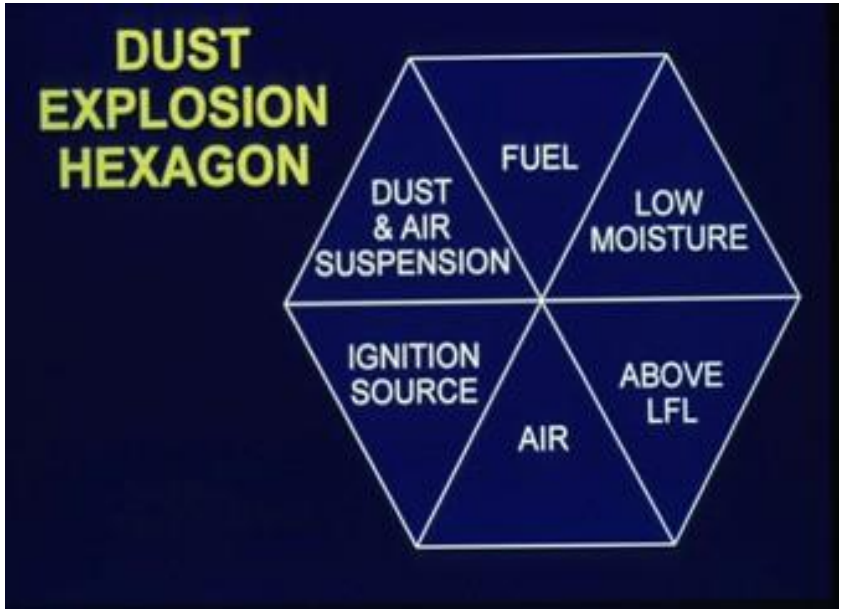
Dust Explosion Hexagon



Moisture

When fuel contains a higher moisture content, then the dust burning process is extinguished

Source: https://slideplayer.com/slide/4616500/

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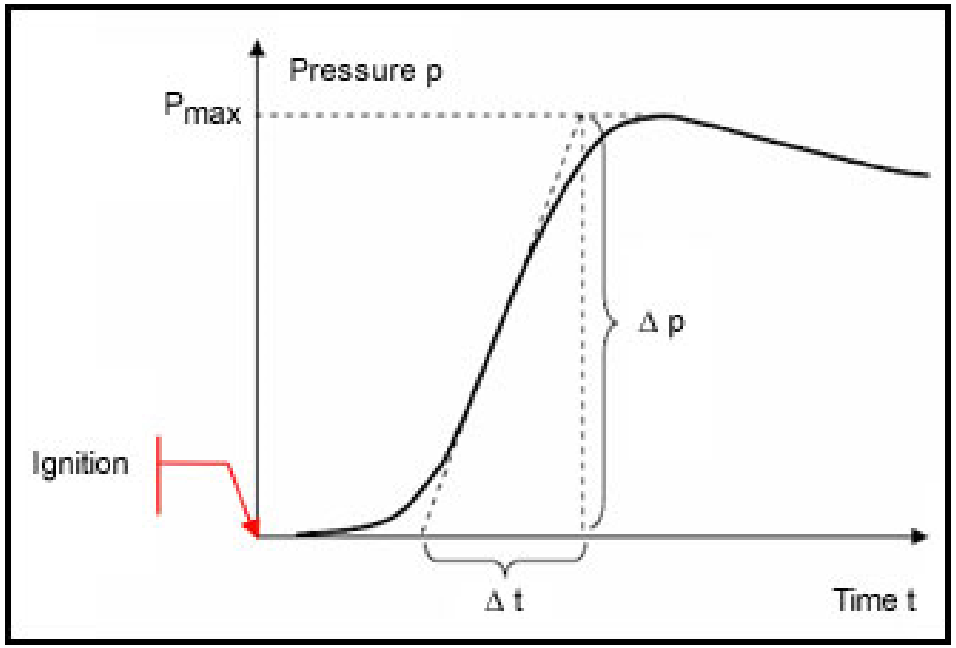
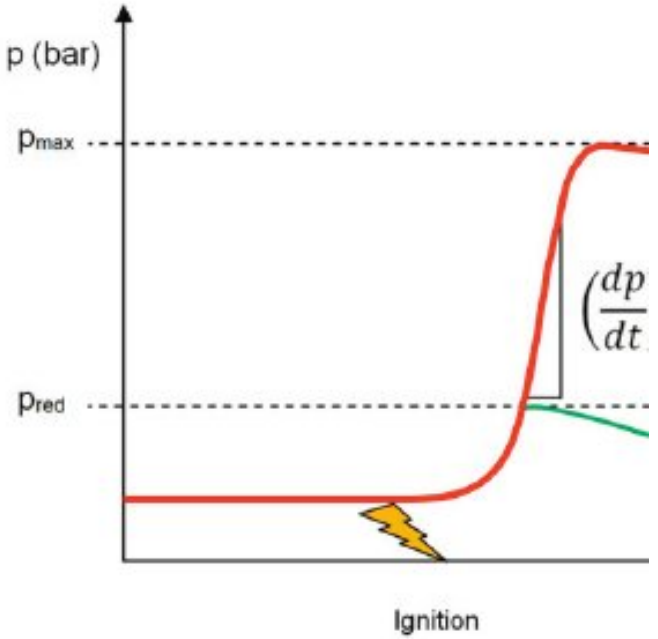
Explosions of Flammable Industrial Dusts

Dust Explosion Curve





Source: https://www.exschutz.net/en/basic-information-on-explosions.html
https://www.researchgate.net/figure/Relationship-between-dust-concentration-and-explosion-pressure_fig4_257725849

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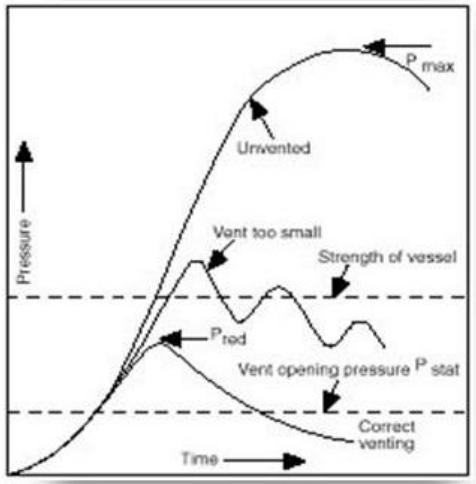
Explosions of Flammable Industrial Dusts

Explosion Severity of Dust Cloud, K_{st} (ASTM E 1226)

- An indication of the severity of dust cloud explosion
- Data produced:
  - *Maximum developed pressure,* P_{max}
  - *Maximum rate of pressure rise,* $(dP/dt)_{max}$
- Deflagration index (explosion severity) K_{st}

$$K_{st} = (dP/dt_{max}) \cdot V^{1/3} \quad \text{[bar.m/s]}$$

Where V is the volume of the test vessel (m^3)



- Used for the design of deflagration protection (venting, suppression, Containment)

Source: https://www.slideserve.com/william-doyle/dust-explosion-hazard-assessment-and-control-an-overview

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Characteristics of Flammable Dust

- *lower explosive limit,*
- *maximum explosion pressure,*
- *maximum rate of pressure increasing,*
- *deflagration index K_{St},*
- *maximum explosive pressure,*
- *minimum ignition energy,*
- *ignition temperature of the settled dust,*
- *ignition temperature of the whirled dust,*
- *limiting oxygen content,*
- *minimum explosible concentration,*
- *etc.*

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Explosions of Flammable Industrial Dusts

Characteristics of Flammable Dust

Minimum Explosible Concentration (MEC)

The minimum concentration of combustible dust suspended in air, measured in mass per unit volume that will support a deflagration.

Lower Flammable Limit (LFL)

The lower flammable limit is the lowest concentration of a combustible substance in an oxidizing medium

Upper Flammable Limit (UFL)

The upper flammable limits is the highest concentration of a combustible substance in an oxidizing medium that will propagate a flame.

Source: https://www.slideserve.com/xaviera-bowers/combustible-dust-national-emphasis-program

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Explosions of Flammable Industrial Dusts

Characteristics of Flammable Dust

- **Minimum Ignition Temperature (MIT). The lowest temperature at which ignition occurs.**
  - Lower the particle size – Lower the MIT
  - Lower the moisture content - Lower the MIT
- **Minimum Ignition Energy (MIE).** The lowest electrostatic spark energy that is capable of igniting a dust cloud.
  - Energy Units (millijoules)
  - Decrease in particle size and moisture content – decreases MIE
  - An increase in temperature in dust cloud atmosphere - decreases MIE
- **Deflagration Index, Kst** – Maximum dp/dt normalized to 1.0 m^3 volume.
- **Pmax** – The maximum pressure reached during the course of a deflagration.

Source: https://www.slideserve.com/xaviera-bowers/combustible-dust-national-emphasis-program

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Explosions of Flammable Industrial Dusts

Characteristics of Flammable Dust

Typical Dust Parameters	
Cloud ignition energy	5 mJ and higher
Minimum explosive concentration	0.02 oz/ft^3 and higher
Maximum pressure developed	30 … 150 psi
Rate of pressure rise	less than 15,000 psi/sec
Ignition temperature—cloud	200 °C and higher
Ignition temperature—layer	150 °C and higher

Source: Ernest C. Magison, Electrical Instruments in Hazardous Locations, 3rd ed. (Pittsburgh: Instrument Society of America, ca. 1978), 317

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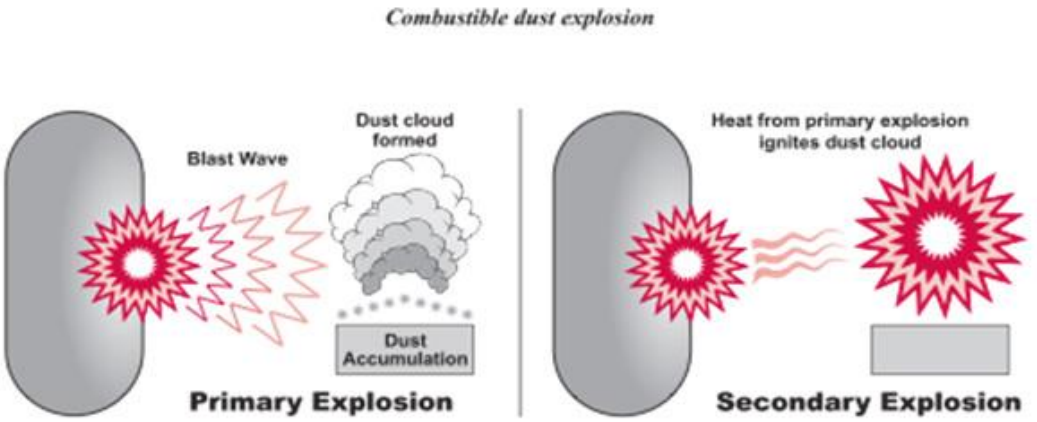
Flammable Industrial Dust Explosion Spreading



Source: https://prestivac.com/blog/the-elements-of-a-dust-explosion

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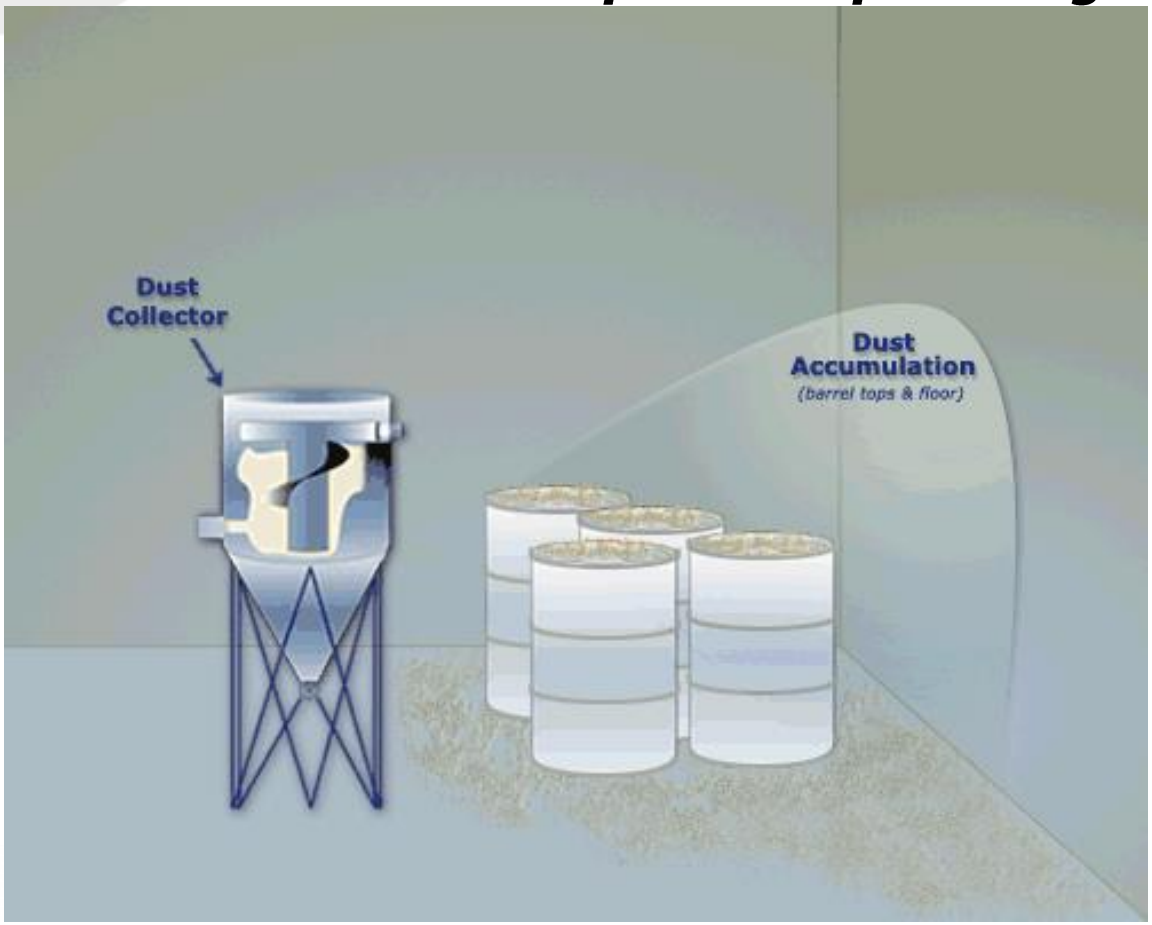
Flammable Industrial Dust Explosion Spreading



Source: https://slideplayer.com/slide/6428415/

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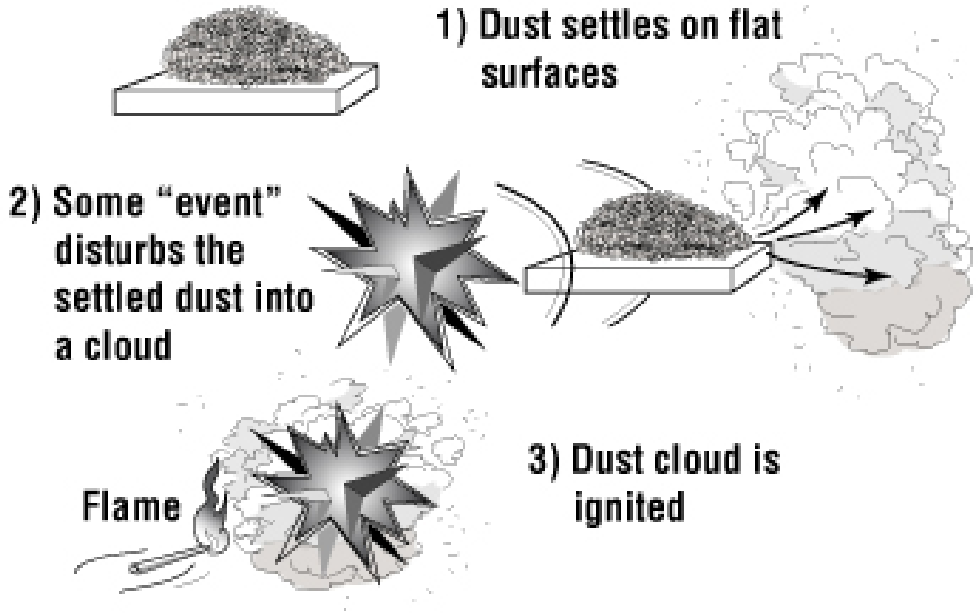
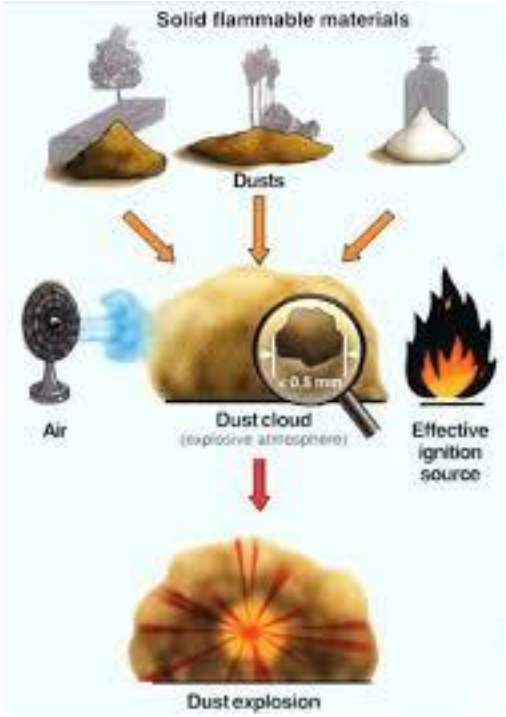
Explosions of Flammable Industrial Dusts

Ignition of Settled Dust





Source: https://www.ccohs.ca/oshanswers/chemicals/combustible_dust.html?=undefined&wbdisable=true
Source: https://www.materialstoday.com/hardmetals-and-ceramics/features/recognising-static-hazard-is-key-to-countering/

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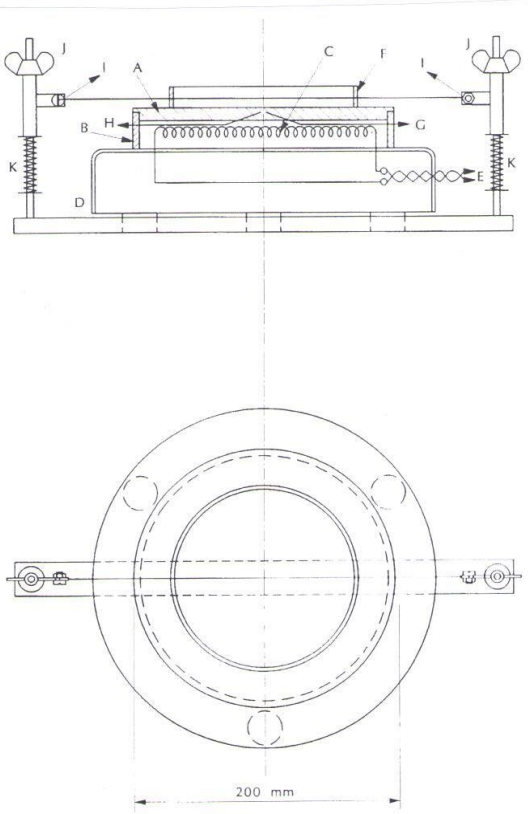
Minimum Ignition Temperature Testing – Dust Layer

Experimental measurements are carried out on an apparatus for determining the minimum ignition temperature in the settled state according to the procedure in Slovak technical standard STN EN 50281-2-1.



Scheme of equipment for measuring ignition temperature of settled dust, A - heated board, B - hem (boarder), C - heating, D – base of heating, E - outlet for connection of heating to the power supply and control, F – ring for the dust layer, G - thermocouple in the control board, H - thermocouple in the temperature recorder, I – thermocouple for temperature recording in the dust layer, J - thermocouple height adjustment, K - spring

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Minimum Ignition Temperature - Dust Layer, (ASTM E 2021)

- MIT of dust layer is the lowest temperature of a heated free-standing surface capable of igniting a dust layer (12.7mm thick)
- With thicker layers, smoldering / glowing may start at a lower temperature
- Test applicable only for materials which will not melt or evaporate before reaching the ignition temperature

Source: https://www.slideserve.com/william-doyle/dust-explosion-hazard-assessment-and-control-an-overview

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Explosions of Flammable Industrial Dusts

Minimum Ignition Temperature

- Minimum Ignition Temperature tests provide information on:
  - Sensitivity to ignition by:
    - hot environments and surfaces of some processing equipment and plant
    - hot surfaces caused by overheating of bearings and other mechanical parts due to mechanical failure
    - frictional sparks
  - Maximum exposure temperature (Temperature Rating) for electrical equipment

Source: https://www.slideserve.com/william-doyle/dust-explosion-hazard-assessment-and-control-an-overview

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Explosions of Flammable Industrial Dusts

Minimum Ignition Temperature Testing – Whirled Dust

https://www.youtube.com/watch?v=cSVYiEwQhLs

Source: https://www.sigma-hse.com/process-safety-testing/dust-and-powder/minimum-ignition-temperature-mit

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Explosions of Flammable Industrial Dusts

Types of Flammable Industrial Dusts Present in Incidents

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_20
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

Source: https://www.mcrsafety.com/blog/combustible-dust-an-overview

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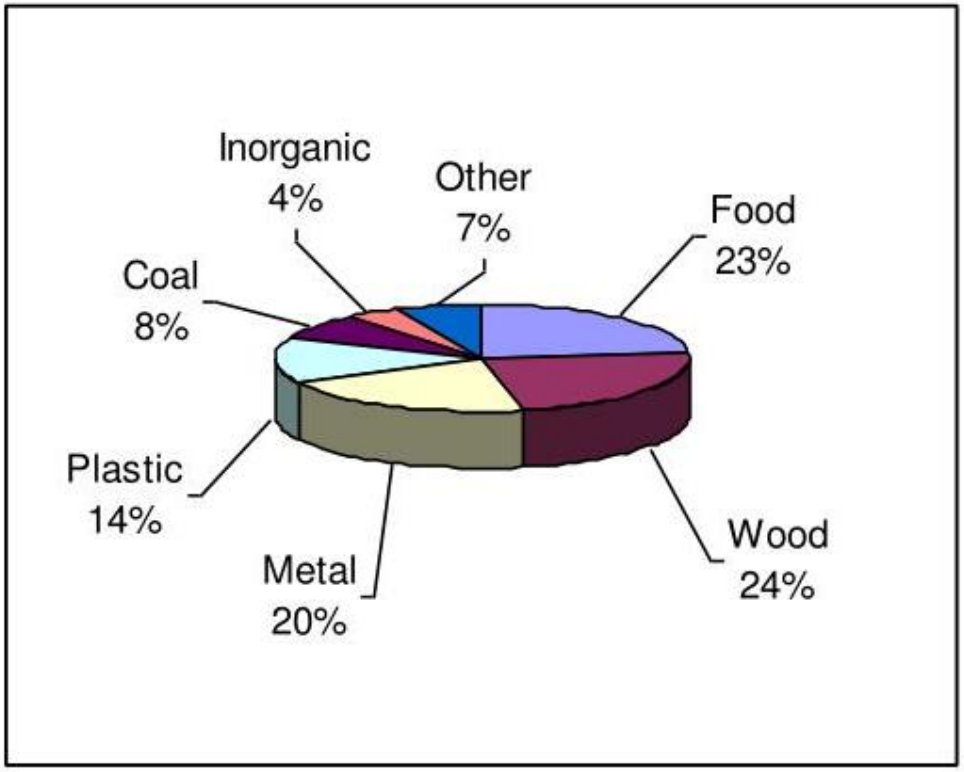
Explosions of Flammable Industrial Dusts

Types of Flammable Industrial Dusts Present in Incidents



Source: https://www.slideserve.com/perrin/combustible-dust-national-emphasis-program

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Explosions of Flammable Industrial Dusts

Relationship between ATEX Zones and required equipment

Ex MACHINERY

ATEX Zone			Equipment			
Zone: a place in which an explosive atmosphere is...	ATEX Zone		Level of protection is assured in...	Category	Marking	
	Gases	Dusts			Gases	Dusts
continually present	0	20	the event of two faults occurring indepen-dently of each other	1	Ex II 1G	Ex II 1D
likely to occur in normal operation occasionally	1	21	the event of one equipment fault	2	Ex II 2G	Ex II 2D
not likely to occur in normal operation and only for very short durations	2	22	normal operation	3	Ex II 3G	Ex II 3D

Source: https://trends.directindustry.com/ex-machinery/project-187967-169114.html

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Industrial Risks of Flammable Dust

Source: https://www.aiche.org/academy/videos/csb-sugar-dust-explosion
https://www.ccpengineering.com/combustible-dusts.html

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Polyethylene Dust Explosion – Pharmaceutical Industry

Source: https://www.csb.gov/preliminary-findings-confirm-blast-at-west-pharmaceutical-services-in-kinston-nc-was-a-dust-explosion-fueled-by-plastic-powder-used-in-manufacturing/

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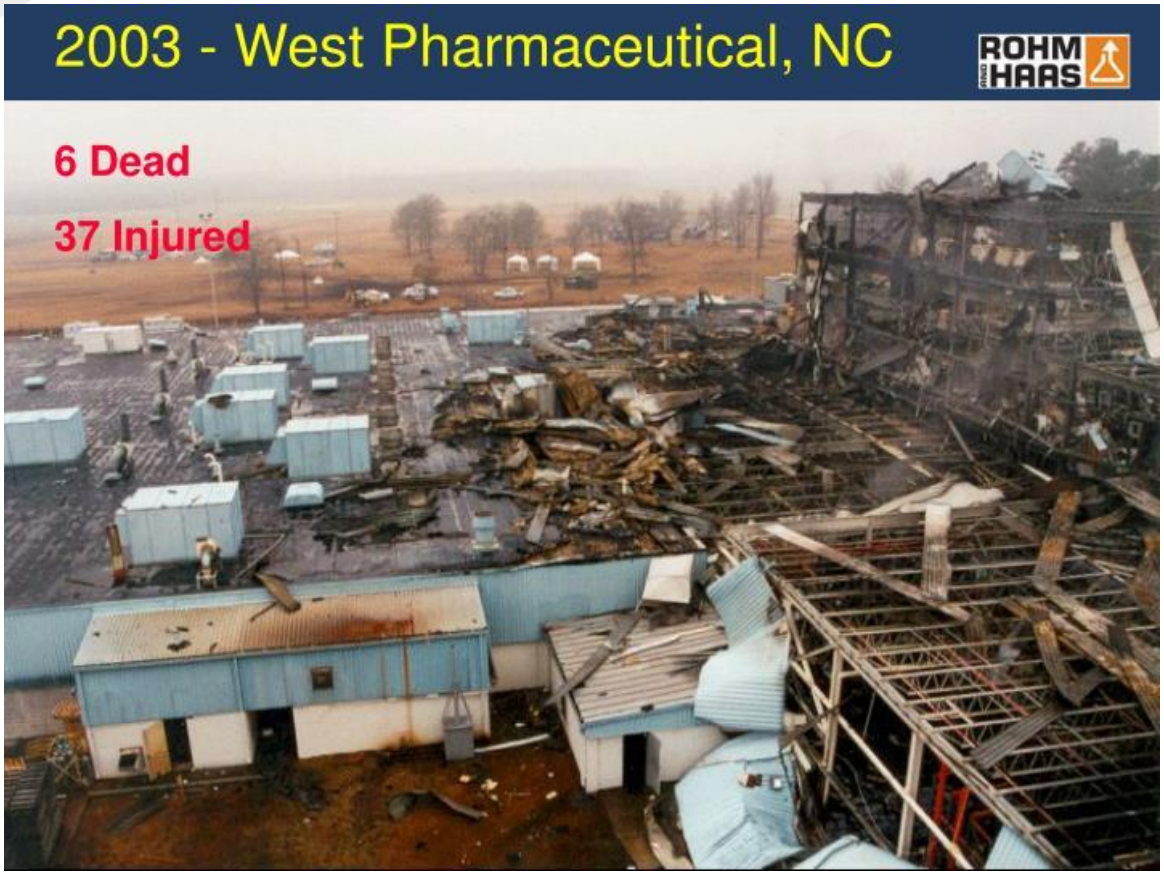
Explosions of Flammable Industrial Dusts

Polyethylene Dust Explosion – Pharmaceutical Industry



Source: https://www.slideserve.com/gari/conditions-for-dust-explosions

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Metal Dust Explosion in China

Source: https://www.ruwac.com/news/deadly-metal-dust-explosion-in-china-serves-as-a-warning-to-american-manufacturers-too/

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Flammable Wood Dust Explosion

https://www.youtube.com/watch?v=70fZqHsEdMo&t=81s

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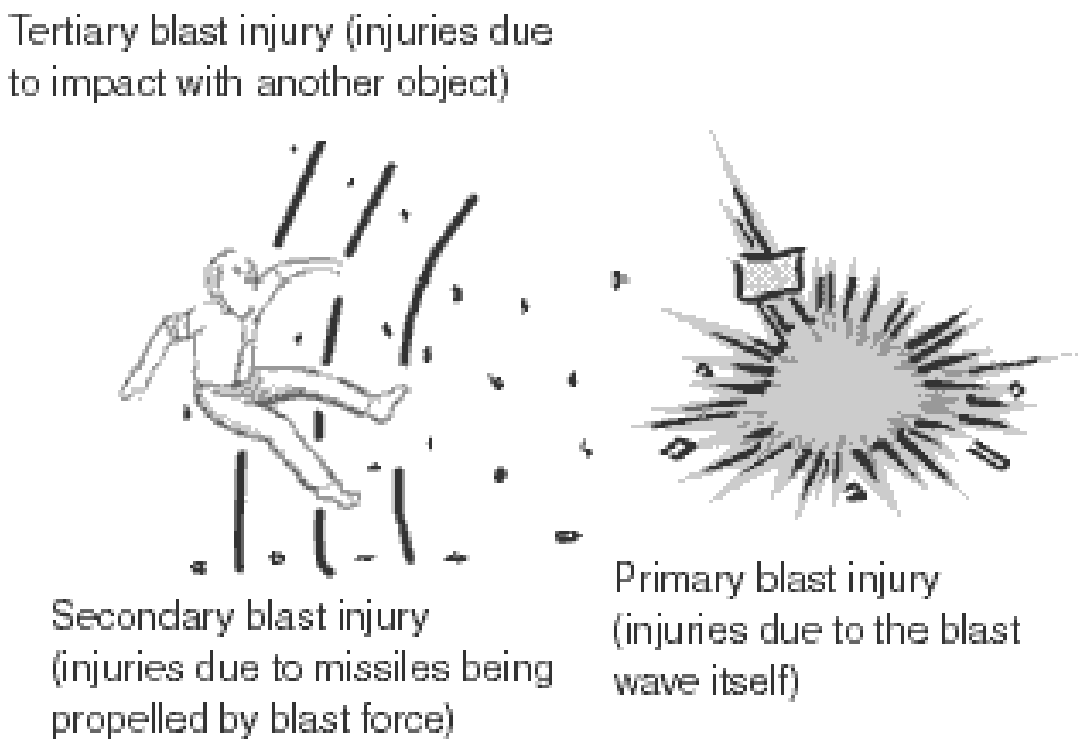
Health Risks of Industrial Flammable Dusts



Source: https://www.reliasmedia.com/articles/4602-evaluation-and-management-of-patients-with-blast-injuries-in-the-ed

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Health Risks of Industrial Flammable Dusts

Source: https://www.reliasmedia.com/articles/4602-evaluation-and-management-of-patients-with-blast-injuries-in-the-ed

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ATEX directive

ATEX is an abbreviation for "ATmosphere EXplosible". At the same time, ATEX is the abbreviated name of the European Directive 2014/34/EC concerning the placing on the market of explosion-proof electrical and mechanical equipment, components and protective systems. It came into force on 1 July 2003, and all new equipment and protective systems have been subject to it since that date.

Source: https://www.simona.de/en/service/atex/definitions/what-is-atex/

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ATEX directive

There are two ATEX directives (one for the manufacturer and one for the user of the equipment):

•the ATEX 95 equipment directive 94/9/EC, Equipment and protective systems intended for use in potentially explosive atmospheres (This directive is superseded by the new one, as indicated afterwards. The information in this article is not yet updated and some information refers to the old one.)

•the ATEX 137 workplace directive 99/92/EC, Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres.

Source: https://www.simona.de/en/service/atex/definitions/what-is-atex/

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ATEX directive

Connection between ATEX 137 and ATEX 95 (1)
Directive 2014/34/EC (ATEX 95) defines specifications for the provision and use of electrical and non-electrical equipment in an explosive atmosphere. The essential safety and health protection requirements for equipment are defined in a classification system. The requirements defined by the two Directives for manufacturers and plant operators are shown in the table below.

Source: https://www.simona.de/en/service/atex/definitions/what-is-atex/

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ATEX directive

Essential requirements for manufacturers "ATEX 95" - 2014/34/EC	Essential requirements for users "ATEX 137"
Definition of the area for use of equipment, specifications of Equipment Group II / Category	Definition of zones in an installation selection of appropriate equipment
Category 1:	Zone 0/20
Category 2:	Zone 1/21
Category 3:	Zone 2/22
The equipment must conform to the essential safety and health requirements or the relevant standard	Compliance with the relevant requirements concerning installation, putting into service and maintenance
Performance of a risk/ignition source analysis for the equipment in question	Performance of a hazard analysis for the operating area need for coordination
Issue of an Attestation of Conformity	Issue of an Explosion Protection Document
Appropriate quality assurance	Regular updating

Source: https://www.simona.de/en/service/atex/definitions/what-is-atex/

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Explosions of Flammable Industrial Dusts

Prevention fo Dust Explosion

- ***Eliminate fuel if possible***
- ***Prevent dust suspensions***
- ***Add moisture***
- ***Keep fuel below LEL***
- ***Reduce oxygen below MOC***
- ***Eliminate ignition sources***

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Explosions of Flammable Industrial Dusts

Active protection
Passive protection
Primary protection *– measures to prevent or to minimize the formation of an explosive mixture, it is to eliminate at least one of the factors necessarily present in the explosion of flammable dust.*
Secondary protection *- measures to prevent ignition of the explosive mixture.*
To eliminate an explosive dust-oxygen mixture it is possible to use industrial vacuum cleaners or adding inert substances (e.g. nitrogen, carbon dioxide, water vapor, limestone) to areas with an explosive atmosphere to keep the oxygen concentration below the limit (eg in mills, dryers, etc.).
Secondary protection is the elimination of initiating resources, which may be, for example, hot surfaces, flame, hot gases, mechanical sparks, electrical operating equipment.

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Explosions of Flammable Industrial Dusts

Conclusion:

Safety with the appearance of flammable metal dust is linked to the observance of principles, including a detailed analysis of the relevant technological process and consideration of the possibility of emergencies.

The practical application of all legislation applicable to the relevant technological operation can greatly prevent the occurrence of extraordinary events associated with the explosion of flammable metal dust, thereby saving the human lives, protecting the health of workers as well as specific technological facilities and operations.

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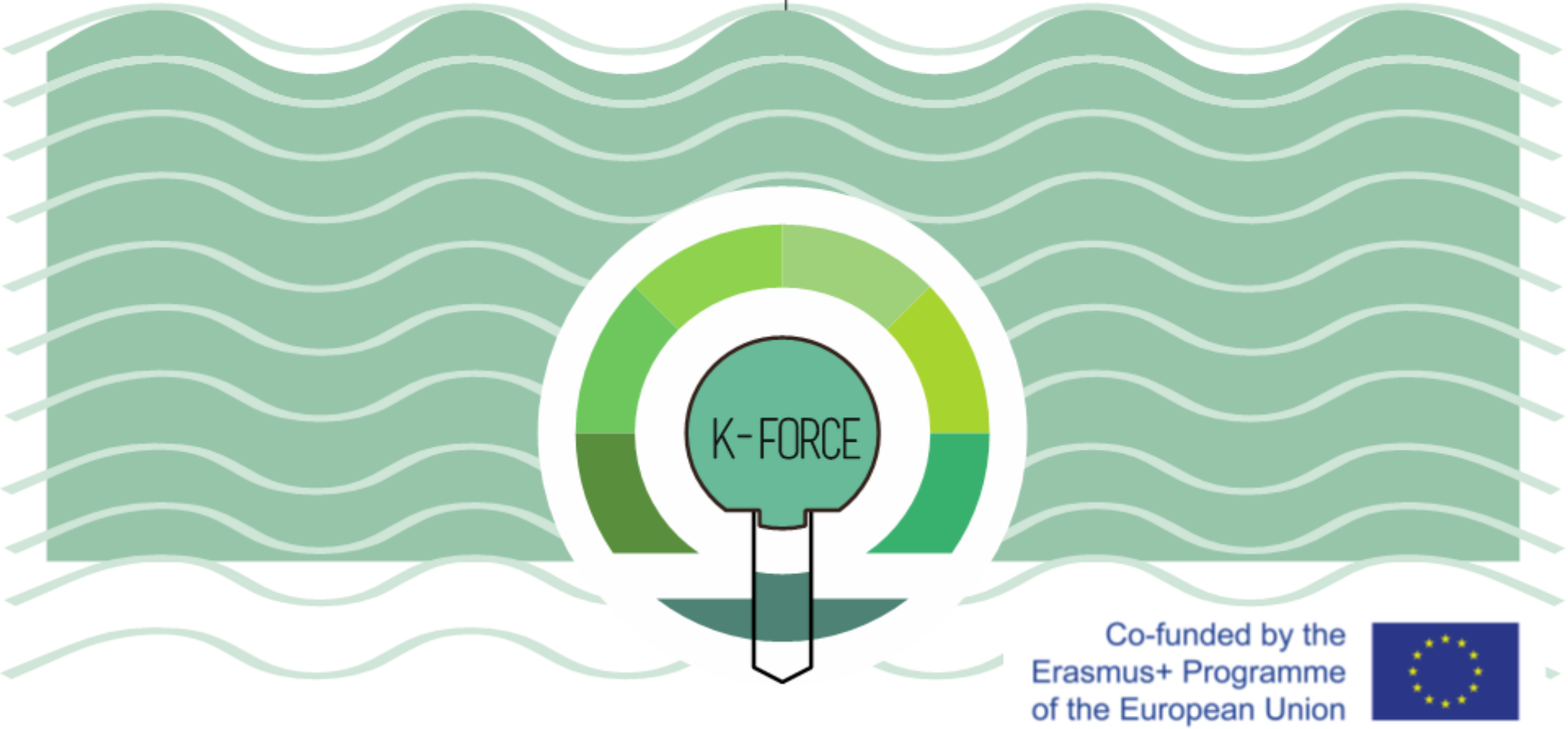

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Thank you
for your attention

Ing. Miroslava Vandlíčková, Ph.D.
miroslava.vandlickova@fbi.uniza.sk

Knowledge **FO**r **R**esilient so**C**i**E**ty