

SS 667:2020: Handling, Storage & Processing of Combustible Dust




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Biography

- Bachelor of Chemical Engineering
- IChemE Professional Process Safety Engineer
- Professional Engineer (Chemical)
- MOM Workplace Safety and Health Officer

- Convener SS532 workgroup
- Member Cybersecurity RA for Process Safety workgroup

- Safety Manager at  Aster



Overview

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| SS667 Background & Introduction | 3 |
| Hazard identification and DHA | 10 |
| Combustible Dust Explosion Testing | 15 |
| Hazard Management – Prevention & Mitigation | 19 |
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SS667: Code of practice for handling, storage and processing of combustible dust

Background & Introduction



Scope of SS 667

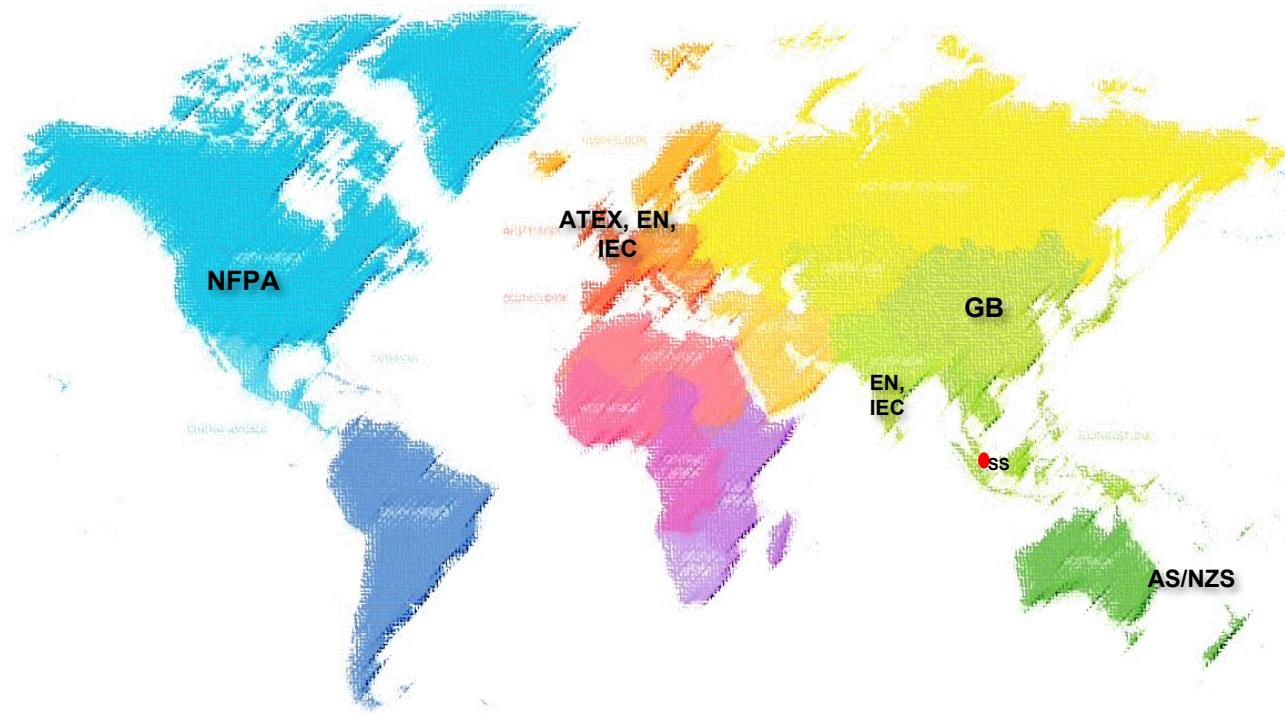
Applicable to industries (e.g. food processing, woodworking factories, pharmaceutical, petrochemical, specialty chemicals, additive manufacturing, and logistics industry), **research institutions** and **institutes of higher learning (IHL)** that **manufacture, process, blend, convey, repackage, generate or handle combustible dusts or combustible particulate solids**.

Not applicable to **warehousing of sealed containers** of such materials when not associated with an operation that handles or generates combustible dust.

Guidance in the areas of dust hazard identification, characterisation and analysis, hazard management via mitigation and prevention, process equipment safety specifications, storage requirements, facility and system design including performance-based design options as well as safety management system implementation



Overview - International Combustible Dust Codes



- Influenced by the jurisdiction's legal framework i.e. European, Great Britain, USA, China
- It is a “mixed bag” of regulations, directives, standards, guidelines, industry association codes.



NFPA Combustible Dust Standard Framework

NFPA 652

Fundamentals of Combustible Dust Hazard Management and Dust Hazard Analysis

**NFPA
61**

Agricultural &
Food

**NFPA
482**

Metal dusts

**NFPA
664**

Wood
Processing

**NFPA
654**

Manufacturing,
Processing
Handling

**NFPA
655**

Sulfur

Industry Related Standards

ASTM
Testing
Methods

NFPA 68, 69, 70, 77, etc.

Engineering Controls: Deflagration Venting, Explosion Prevention Systems, Electrical Code, Static Electricity



Singapore Combustible Dust Standard Framework

TR87

SS 667

Fundamentals of Combustible Dust Hazard Management and
Dust Hazard Analysis

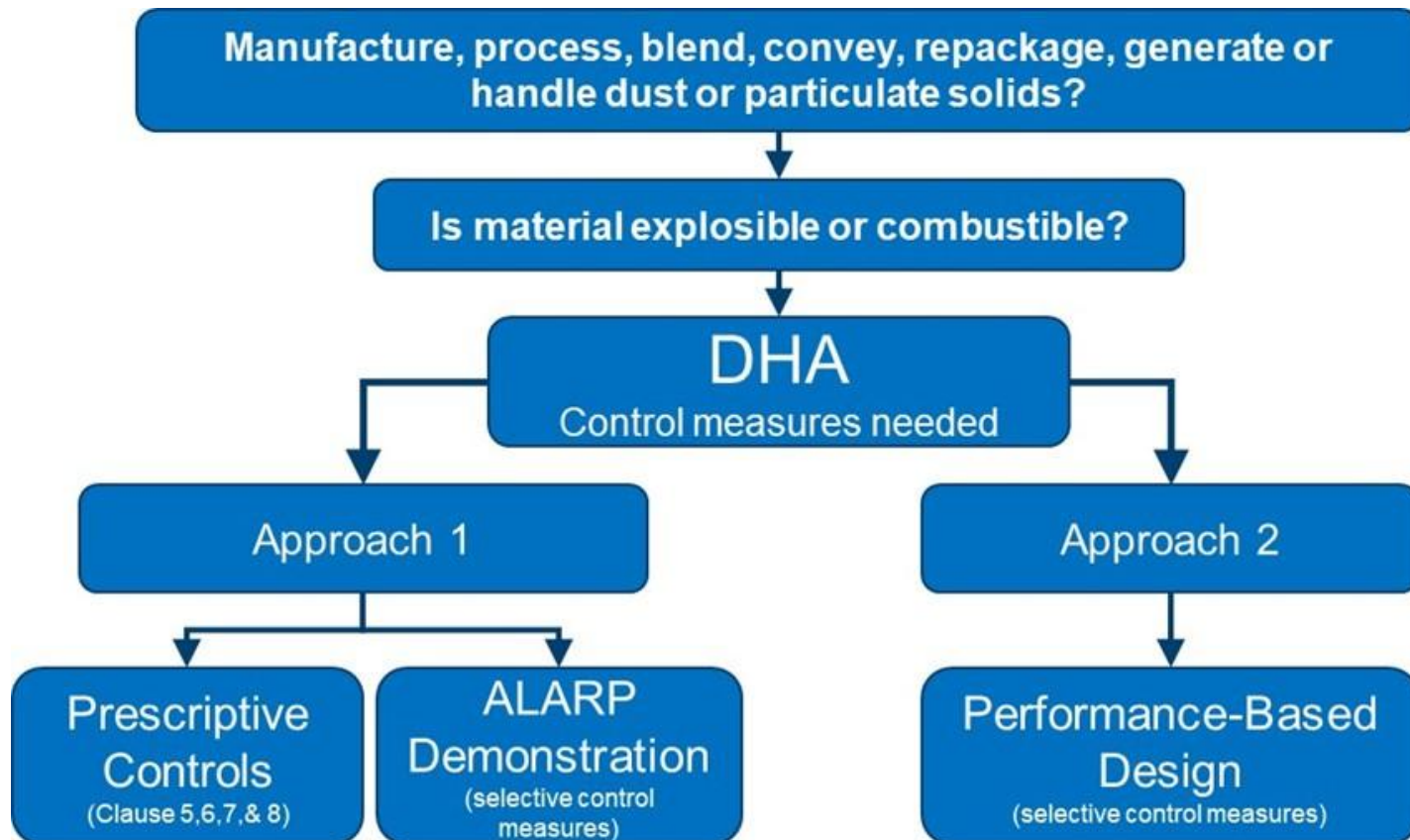
SS 555, 645, 52, EN, IEC, NFPA 68, 69, 70.

Engineering Controls: Deflagration Venting, Explosion Prevention
Systems, Electrical Code, Static Electricity, Fire alarms/ sprinklers

ASTM
&
ISO/IEC
Testing
Methods



SS667 – Overall Methodology



Contents of SS 667

4. Hazard identification and dust hazard analysis

- Material hazard identification
- Dust hazard analysis (DHA)

5. Hazard management: prevention and mitigation

- Ignition source control
- Explosion prevention/protection
- Fugitive dust emission control
- Housekeeping
- Fire protection

6. Process Equipment

- E.g. Material transfer, ducts, conveyors, air moving device, air material separators, mixers, dryers

7. Storage requirements

- Combustible metals
- Bulk storage
- FIBC/RIBC/IBC
- Fine particulate waste metal

8. Facility and system design

9. Performance-based design options

10. Safety Management System (SMS)



Hazard identification and dust hazard analysis



Hazard Identification

- Material hazard identification is to **determine** whether a solid material is **combustible or explosible**
 - **Representative** historical facility data or published data
 - **Laboratory tests** on representative samples
- **Absence of previous incidents** must not be used to discount the potential
- If a material is determined to be combustible or explosible, a **Dust Hazard Analysis (DHA)** is required

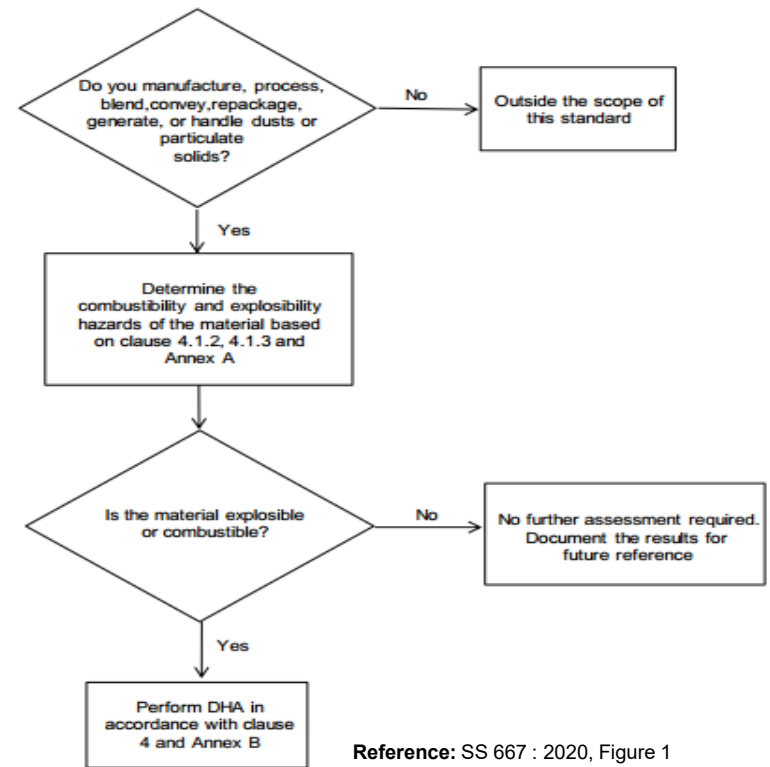


Figure 1 – Material hazard identification flow chart



Combustibility tests

| Material combustibility category | Applicability of this code | NFPA | GHS | BZ number | | Hazard grade classification | |
|-----------------------------------|---|--|---|---|----------------------|--|--------------|
| | | Source: UN Recommendations on the Transport of Dangerous Goods, Manual of Test and Criteria Part III, Sub-section 33.2.1 | | Source: VDI 2263 Part 1, Burning Behaviour | | Source: SCDF Fire Code | |
| Non-combustible solids | Does not fall under the requirements of this code. | No reaction | Preliminary screening test = Negative NOTE – Further observation would be required to evaluate if it is to be classified as non-combustible solid or limited combustible solids (refer to NFPA or BZ descriptors). | 1 – No ignition | No spreading of fire | Not applicable | |
| Limited-combustible solids | Full compliance with the requirements of this code. | Glowing but no propagation along the powder train | | 2 – Brief ignition and rapid extinction 3 – Localised combustion or glowing with practically no spreading | | 4 – Glowing without sparks (smouldering) or slow decomposition without flame | Fire spreads |
| | | Propagation, but too slow to include the test material in Division 4.1 | | 5 – Burning with flame or spark generation 6 – Very rapid combustion with flame propagation or rapid decomposition without flame | 1 | | |
| Readily/Highly combustible solids | Full compliance with the requirements of this code. | Propagation sufficiently fast to qualify for inclusion in Division 4.1, Category 1 or 2 | Division 4.1, Category 2 Non-metal powders: a) Wetted zone stops fire for at least 4 min; and b) Burning time < 45 s or burning rate > 2.2 mm/s Metal powders: 5 min < burning time ≤ 10 min | | | | |
| | | | Division 4.1, Category 1 Non-metal powders: a) Wetted zone does not stop fire; and b) Burning time < 45 s or burning rate > 2.2 mm/s Metal powders: burning time ≤ 5 min | | | | |

NOTE – If the material is known to be explosible, it may be assumed as combustible without performing a combustibility test.

Reference: SS 667 : 2020, Table 1



Dust hazard analysis (DHA)

DHA is a **systematic** review to **identify and evaluate** fire and explosion hazards, and **identify control measures** for risk reduction

The DHA

- Identifies hazardous **scenarios**
- Provides a **link** between hazards and specific control measures

Dust properties such as MIE, MIT are required for conducting the DHA

- Annex A, Table A.1 contains the details

The DHA must be led by a **competent person**

The DHA **methodology** must be appropriate to the facility considering its **complexities**

The DHA **results** must be documented, maintained throughout the **lifecycle**

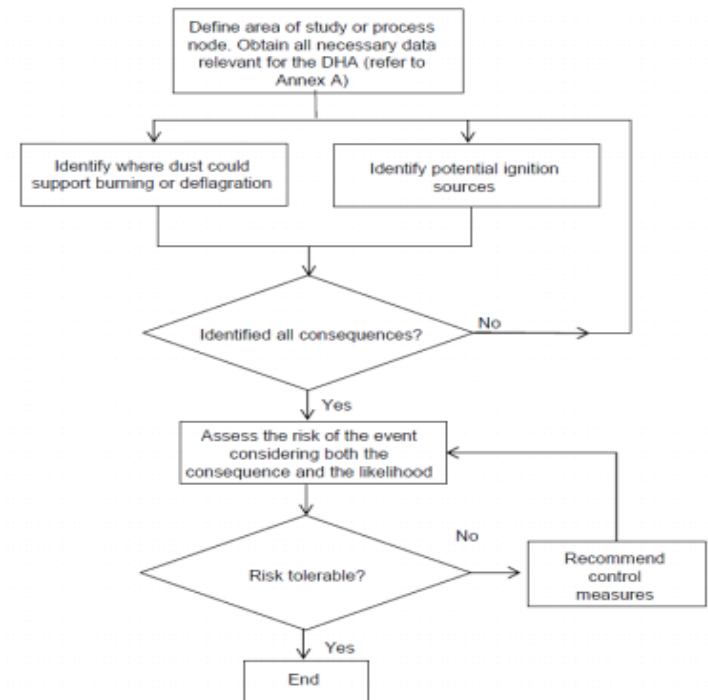


Figure 2 – Dust hazard analysis (DHA)



Dust properties and test methods

Table A.1 – Standard test methods to determine explosibility properties

| Property | Test methods | |
|--|---|---|
| | ISO/IEC standards | Other equivalent standards |
| Minimum ignition energy (MIE) of dust cloud in air | ISO/IEC 80079-20-2, Material characteristics – combustible dusts test methods | ASTM E2019, Standard test method for minimum ignition energy of a dust cloud in air ISO/IEC 80079-20-2 Explosive atmospheres. Material characteristics. Combustible dusts test methods |
| Minimum ignition temperature (T_c) of dust clouds (MIT/MAIT) | ISO/IEC 80079-20-2, Material characteristics – combustible dusts test methods | ASTM E1491, Standard test method for minimum autoignition temperature of dust clouds BS EN 50281-2-1:1999 Electrical apparatus for use in the presence of combustible dust. Test methods. Methods of determining minimum ignition temperatures |
| Maximum explosion pressure (P_{max}), rate and maximum rate of pressure rise (dP/dt), and explosion severity (K_{st}) Table A.2 should be referred to for examples of K_{st} values of dust | ISO/IEC 80079-20-2, Material characteristics – combustible dusts test methods | ASTM E1226, Standard test method for explosibility of dust clouds BS EN 14034-1:2004+A1:2011 Determination of explosion characteristics of dust clouds. Determination of the maximum explosion pressure P_{max} of dust clouds BS EN 14034-2:2006+A1:2011 Determination of explosion characteristics of dust clouds. Determination of the maximum |

| | | |
|---|--|--|
| | | rate of explosion pressure rise (dP/dt) _{max} of dust clouds |
| Minimum explosible concentration (MEC) | ISO 8130-4:1992 Coating powders — Part 4: Calculation of lower explosion limit | ASTM E1515, Test method for minimum explosible concentration of combustible dusts BS EN 14034-3:2006+A1:2011 Determination of explosion characteristics of dust clouds. Determination of the lower explosion limit LEL of dust clouds |
| Minimum ignition Temperature (T_c) of dust Layers (LIT) | ISO/IEC 80079-20-2, Material characteristics – combustible dusts test methods | ASTM E2021, Standard test method for hot-surface ignition temperature of dust layers |
| Limiting oxygen concentration (LOC) | | ASTM E2931 - 13, Test method for limiting oxygen (oxidant) concentration of combustible dust clouds BS EN 14034-4:2004+A1:2011 Determination of explosion characteristics of dust clouds. Determination of the limiting oxygen concentration LOC of dust clouds |

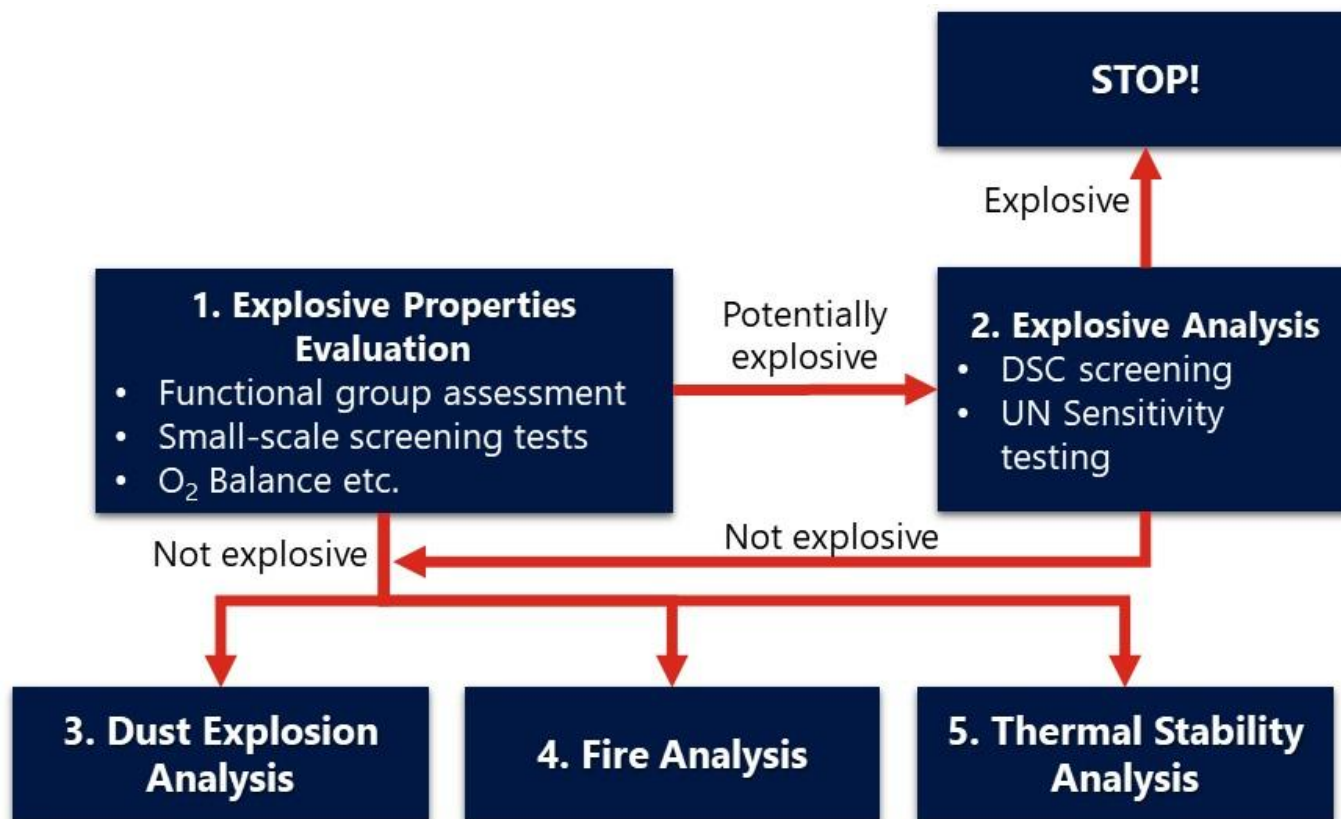
Reference: SS 667 : 2020, Annex A, Table A.1



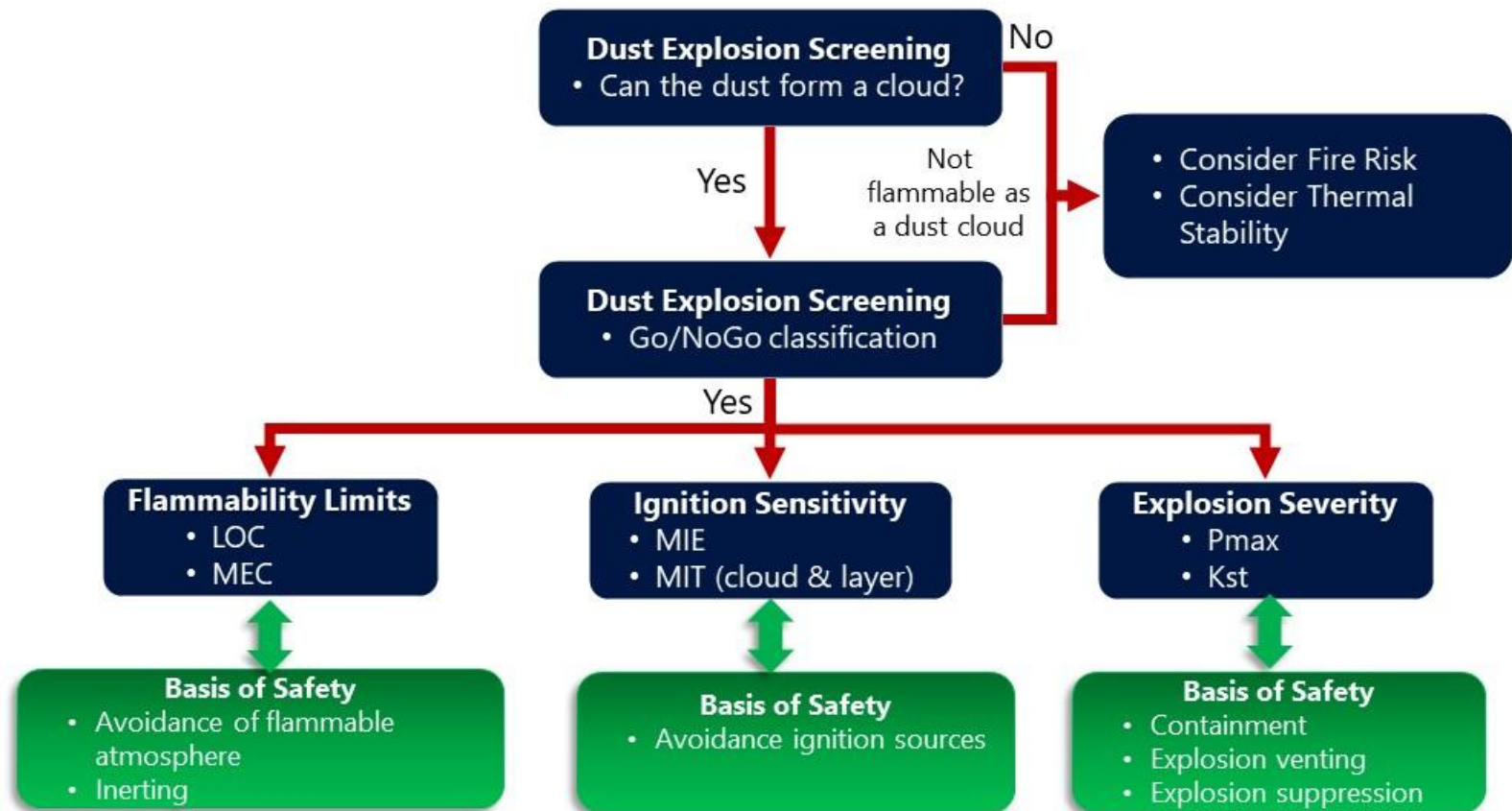
Combustible Dust Explosion Testing



Explosive Properties Evaluation



Strategy for Dust Explosion Testing



Dust Explosion Screening (“Go/No-Go”)



[Modified Hartmann Test](#)



20L Sphere Test

Ignition Sensitivity (MIE, MIT)



[Minimum Ignition Energy \(MIE\)](#)



[Minimum \(cloud\) Ignition Temperature \(MIT\)](#)



[Minimum \(Layer\) Ignition Temperature \(LIT\)](#)

Potential ignition sources can include electrostatic discharges, mechanical (grinding / frictional) sparks or hot surfaces.

Flammability Limits (LOC, MEC)

- Working under an oxygen depleted atmosphere is the most conventional way of avoiding the presence or formation of flammable atmospheres.
- Requires the determination of:
 - The lower flammable limit of the powder or Minimum Explosible Concentration (MEC)
 - Limiting Oxygen Concentration (LOC) below which a dust cloud becomes nonflammable.
- These data are usually generated using the [20L Sphere apparatus](#)



Explosion Severity (Pmax, Kst)

- [The 20 Litre Sphere test](#) provides the necessary explosion severity data including:
 - maximum explosion pressure (Pmax)
 - rate of pressure rise (dP/dt) data expressed as a dust explosion constant (Kst).
- The maximum explosion pressure is used for containment design and the dust explosion constant is used for the specification of pressure relief venting or suppression system design.



Hazard management: prevention and mitigation



Hazard management

- The hazard management clauses **supplement DHA and its decisions**
- The clauses outline the **considerations** in the provision of **control measures**
- If a DHA identifies the need for control measures listed under Clause 5, 6, 7 or 8, **one of the following approaches** can be adopted:



Approach 1 (Prescriptive and selective ALARP demonstration):

- Provide the prescribed control measures in accordance with Clause 5, 6, 7 and 8
- In case of not providing the prescribed control measures (possibly a few), As Low As Reasonably Practicable (ALARP) demonstration is required to demonstrate the risks are at ALARP without the prescribed control measures

Approach 2 (Performance-based):

- Implement the performance-based design in accordance with Clause 9



Basis of safety

The set of control measures required for a safe operation is commonly referred as **basis of safety**

| Category | Basis of safety examples |
|-------------------------------|--|
| Prevention | <ul style="list-style-type: none">• Operating below Minimum Explosible Concentration (MEC)• Operating below Limiting Oxygen Concentration (LOC) |
| Avoidance of ignition sources | <ul style="list-style-type: none">• Preventing and/or minimising ignition sources |
| Mitigation | <ul style="list-style-type: none">• Providing explosion relief panels• Providing explosion suppression systems |



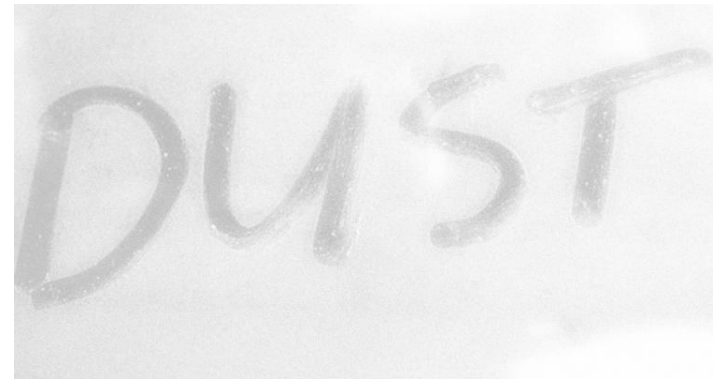
Control measures

| Control measures | Description | Category |
|--|--|-------------------------------|
| Housekeeping | <ul style="list-style-type: none"> Housekeeping through a written procedure Personnel training on housekeeping | Prevention and/or mitigation |
| Ignition source control | <ul style="list-style-type: none"> Process ignition sources (e.g., mechanical, electrostatic, electrical) External ignition sources (e.g., hot work) | Avoidance of ignition sources |
| Fugitive dust control | <ul style="list-style-type: none"> Measures for managing fugitive emissions (e.g., local exhaust ventilation) | Prevention |
| Explosion prevention and protection | <ul style="list-style-type: none"> Oxidant concentration reduction Dilution with a non-combustible dust to render the mixture non-combustible | Prevention |
| | <ul style="list-style-type: none"> Explosion venting Explosion pressure containment Explosion suppression | Mitigation |
| Flash fire protection | <ul style="list-style-type: none"> Flash fire protection for personnel (e.g., personal protective equipment) | Mitigation |
| Fire protection | <ul style="list-style-type: none"> Fire protection for buildings and structures Fire detection, suppression and extinguishing systems | Mitigation |



Housekeeping – a critical control measure

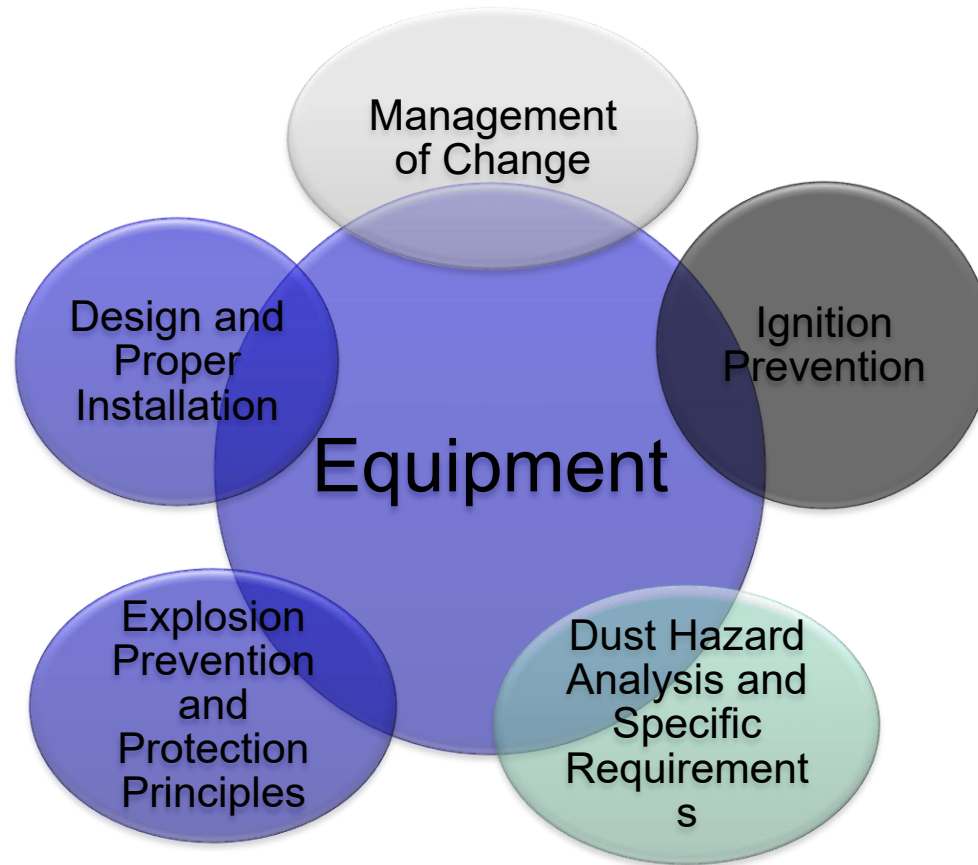
- **Catastrophic** consequences were historically caused by secondary explosions
- Housekeeping is a critical control measure for preventing and/or mitigating **secondary explosions**
- **Key points to note**
 - Develop and implement a housekeeping regime through a **written procedure**
 - Provide **appropriate equipment and tools** for handling combustible dusts
 - **Train personnel** on proper cleaning methods and proper use of housekeeping equipment and tools



Equipment controls



Process Equipment



Process Equipment: Type of Equipment

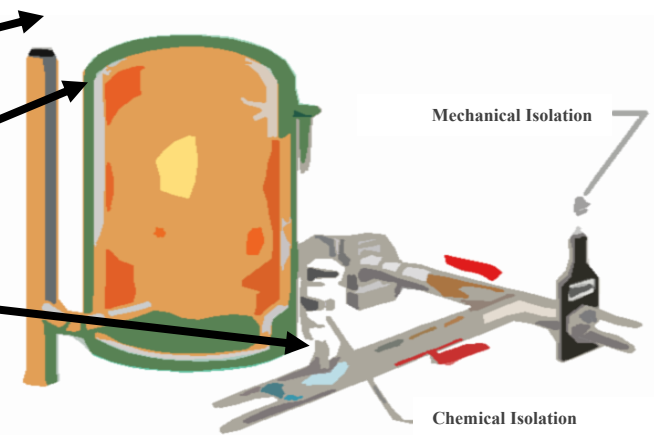
| | | | |
|--------------------------|---|--------------------------|-------------------------------------|
| Material transfer system | Systems conveying hybrid mixtures | Piping and valves | Duct systems |
| Sight glasses | Pressure protection system | Material feeding devices | Bucket elevators |
| Enclosed conveyors | Conveyors, spouts and throws of materials | Air moving devices | Air material separator |
| Particle size separators | Mixers, blenders and size reduction equipment | Dryers | Transportation and receiving trucks |



Process Equipment: Type of Equipment

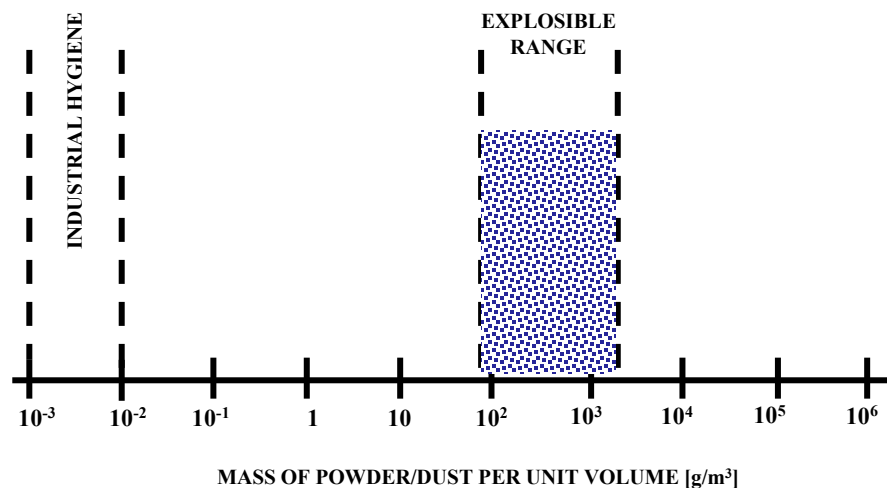
Application of requirements from clause 5:

- equipment with dust explosion hazard and a containing **volume >0.2 m³** requires utilisation of one or more of the following methods of protection:
 1. Oxidant concentration reduction
 2. Deflagration venting
 3. Deflagration pressure containment
 4. Deflagration suppression systems
 5. Dilution with a noncombustible dust to render the mixture noncombustible



Process Equipment

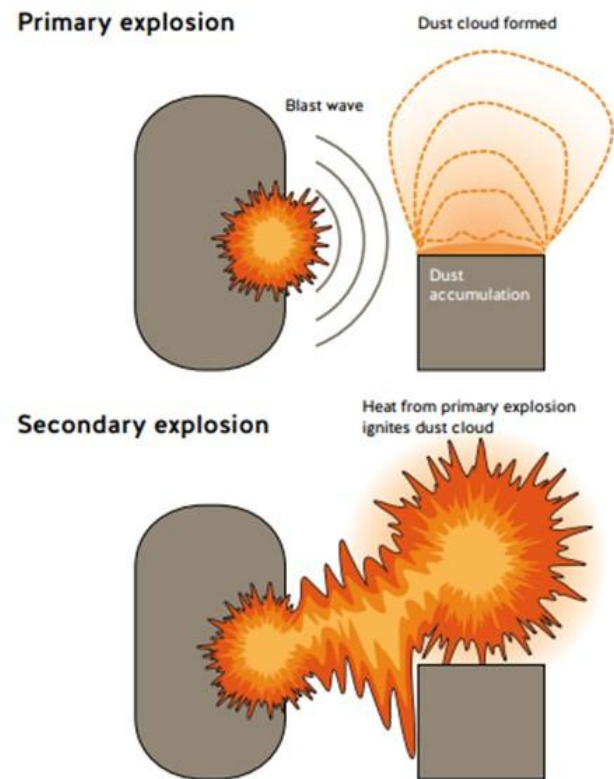
- Equipment specific requirement covers:
 - Minimising presence of combustible materials and accumulation of materials within process.
 - E.g. Requirements during design, operation, start-up and shut-down stages and access for cleaning.
 - Operating out of explosion limits.
 - Specific ignition prevention requirements.
 - E.g. charge accumulation, electrostatic resistivity, overload/overheating requirements, tramp material and spark detection/removal.



Process Equipment

(Cont'd.)

- Equipment modifications.
 - E.g. additions of duct works, qualifying access doors as explosion venting panels
- Prevention of domino effects.
 - E.g. Locating equipment outside of occupied areas, prevention of secondary explosion risk, dust escapement and disturbances, improper explosion venting.
- Allows ALARP demonstration or performance-based approach should certain clauses cannot be fulfilled.



Source: https://www.ccohs.ca/oshanswers/chemicals/combustible_dust.html



Storage requirements

General Requirements

Maximum Allowable Quantities (MAQ)

Storage of Combustible Metal Powders

Flexible and Rigid Intermediate Bulk Containers

Storage of Waste Combustible Metals



Storage Requirements - Maximum Allowable Quantities (MAQ) of Powders

Working Storage - Storage of flammable, pyrophoric and water reactive powders is intended to cater for the normal need of working stock.

Table 3 – Maximum allowable quantity in a working area

| Hazard description | Classification | | MAQ | | | |
|-------------------------------|----------------|-----------|---------------------------------------|------------------------------------|--|---|
| | | | Dedicated metal cabinet | | Fire safety cabinet | |
| | GHS | UNRTDG | Without fire suppression system kg | With fire suppression system kg | Without fire suppression system ^b kg | With fire suppression system ^c kg |
| Flammable | | Class 4.1 | 56.7 | 113.4 | 113.4 | 226.8 |
| Pyrophoric^a | | Class 4.2 | Not allowed | 1.8 | Not allowed | 3.6 |
| Water reactive | Cat 1 | Class 4.3 | 2.3 | 4.6 | 4.6 | 9.2 |
| | Cat 2 | | 22.7 | 45.4 | 45.4 | 90.8 |
| | Cat 3 | | 56.7 | 113.4 | 113.4 | 226.8 |

^a Permitted only in buildings equipped throughout with an automatic sprinkler system.

^b Fire safety cabinet with a minimum fire rating of 30 min.

^c Fire safety cabinet with a minimum fire rating of 10 min.



Storage Requirements - Maximum Allowable Quantities (MAQ) of Powders

Requirements for Additional Fire Safety Cabinet in a Working Area

Any storage of powders in quantities exceeding the MAQ stipulated in Table 1 shall comply with the requirements stipulated in Table 4.

Table 4- Additional fire safety cabinets in a working area

| | Maximum number of fire safety cabinets | Minimum fire rating of fire safety cabinet (Mins) |
|--|--|---|
| Without fire suppression system | 2 | 60 |
| With fire suppression system | 2 | 30 |

NOTE – Quantity stored in each fire safety cabinet cannot exceed the MAQ stipulated in Table 3.

Storage requirements for dedicated storage area

Dedicated storage of flammable, pyrophoric and water reactive powders shall be in a fire compartment with a minimum of 2-hours fire rating and shall comply with the requirements stipulated in Table 3

Table 3- Dedicated storage area

| | Maximum number of fire safety cabinets | Minimum fire rating of fire safety cabinet (Mins) |
|--|--|---|
| Without fire suppression system | 2 | 30 |
| With fire suppression system | 4 | 10 |



Storage Requirements - Maximum Allowable Quantities (MAQ) of Powders

Illustrations Showing Working and Dedicated Area's

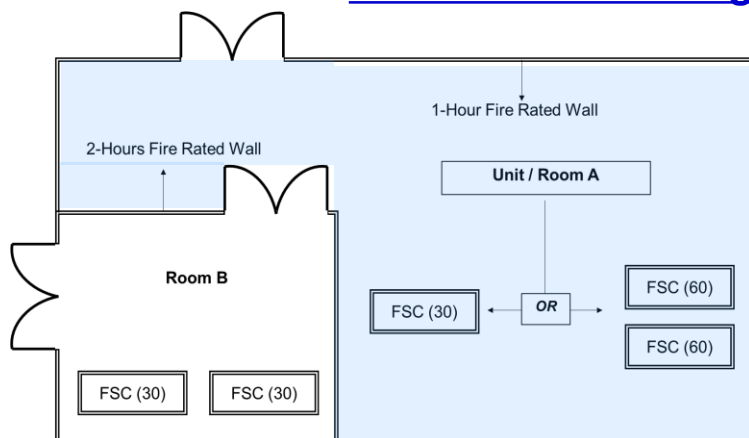


Figure 1 – Storage **without fire suppression system**

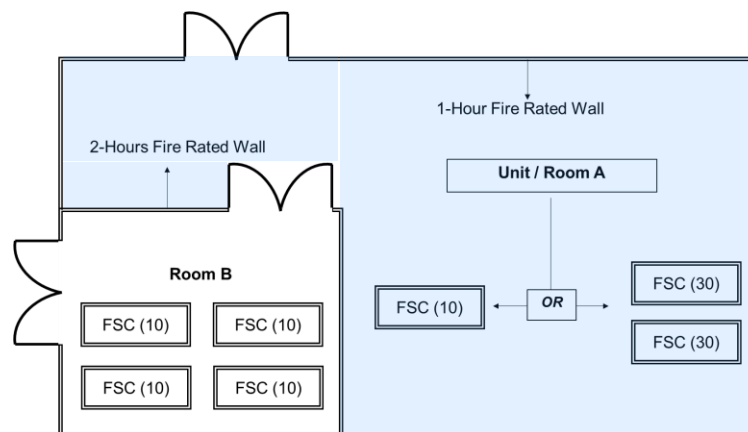


Figure 2 – Storage **with fire suppression system**

Fire safety cabinet each with maximum capacity not exceeding MAQ stipulated in Table 1 (**XX** refers to fire rating in minutes)

Room B is a dedicated fire compartment with a **minimum of 2-hours fire rating**, only used for powder storage in fire safety cabinets



Storage Requirements – Bulk Storage

1. Any storage of powders exceeding quantities defined for the “Working Storage Area” shall be classified as “Bulk Storage” and stored in a dedicated fire compartment with a minimum of 2-hours fire rating. The storage of metal powders shall be designed in consultation with the relevant local authority. It is presupposed that additional fire safety provisions are provided, as required, in accordance with applicable statutory and regulatory requirements.
2. Bulk storage of powders in any individual fire compartment shall not exceed the MAQ stipulated in Table 6.

Table 6 – Maximum allowable quantity (MAQ) for bulk storage

| | Classification | | Maximum Allowable Quantity (kg/m ²) |
|-----------------------|----------------|-----------|---|
| | GHS | UNRTDG | |
| Flammable | | Class 4.1 | 1200 |
| Pyrophoric | | Class 4.2 | 38.1 |
| Water reactive | Cat 1 | Class 4.3 | 48.5 |
| | Cat 2 | | 480 |
| | Cat 3 | | 1200 |

NOTE 1 – The MAQ for bulk storage of powders is intended to specify the maximum load permitted per m² of the floor area of the fire compartment.

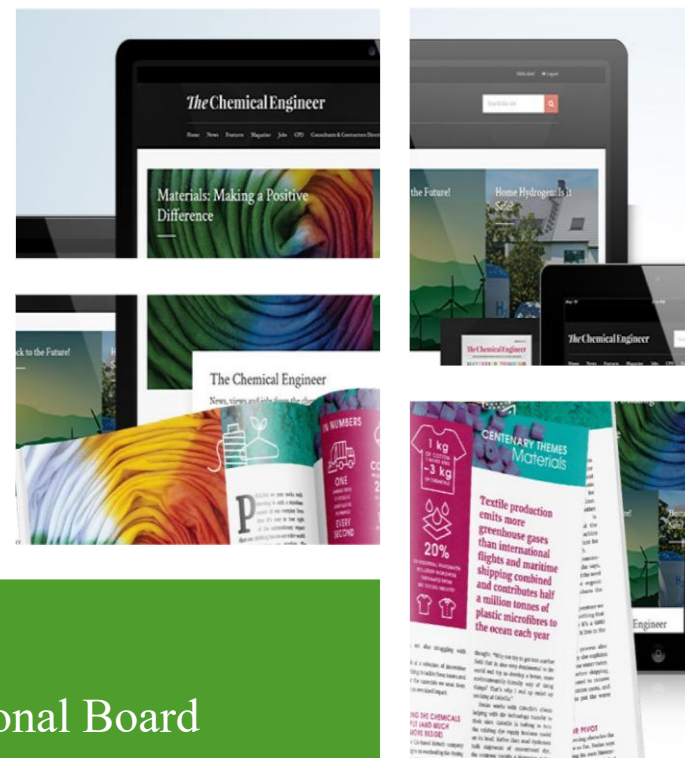


Storage of Combustible Metal Powders

- Where the combustible metal powder is reactive with water, metal-powder storage areas shall be kept dry and an automatic fire suppression system appropriate for the type of metal powders shall be used.
- Combustible metal powder shall be stored in a manner where it does not inadvertently come into contact with incompatible materials. For example, this can be achieved by the use of fire safety cabinets and separate storage rooms.
- Combustible metal powder shall be stored in closed steel drums or other closed noncombustible materials.
- Metal powder-handling areas or metal powder-processing areas shall not be used for primary storage of powders



Thanks for listening



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