Institute of Sustainability for Chemicals, Energy and Environment
A*STAR ISCE²

SS667:2020: Handling, Storage & Processing of Combustible Dust

WSH Forum on Strengthening Combustible Dust Safety in Workplaces -- “Launch of WSH Guidelines on Combustible Dust”

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ARES (Public)

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Overview

SS667: Code of practice for handling, storage and processing of combustible dust

Background & Introduction

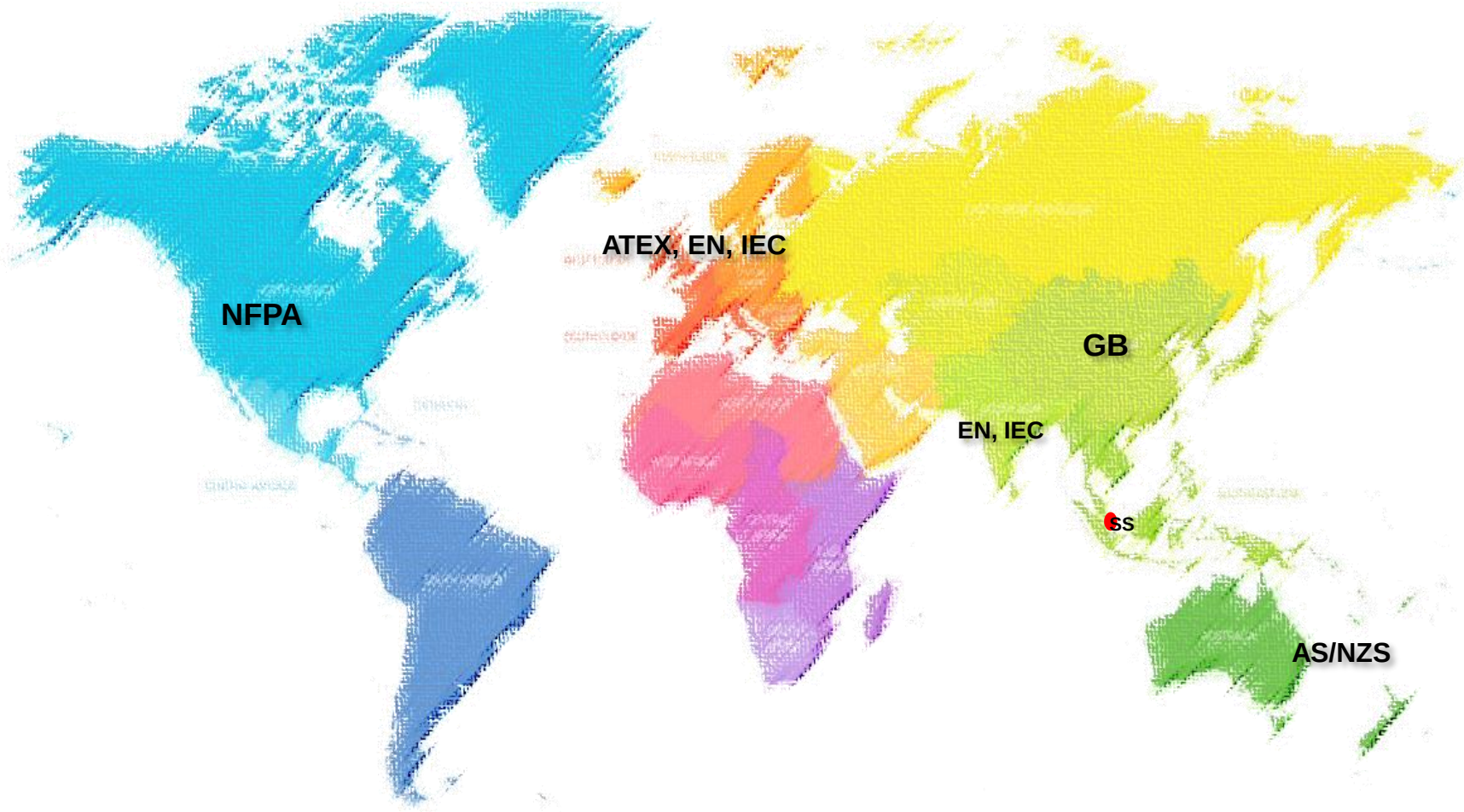
Scope of SS 667

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

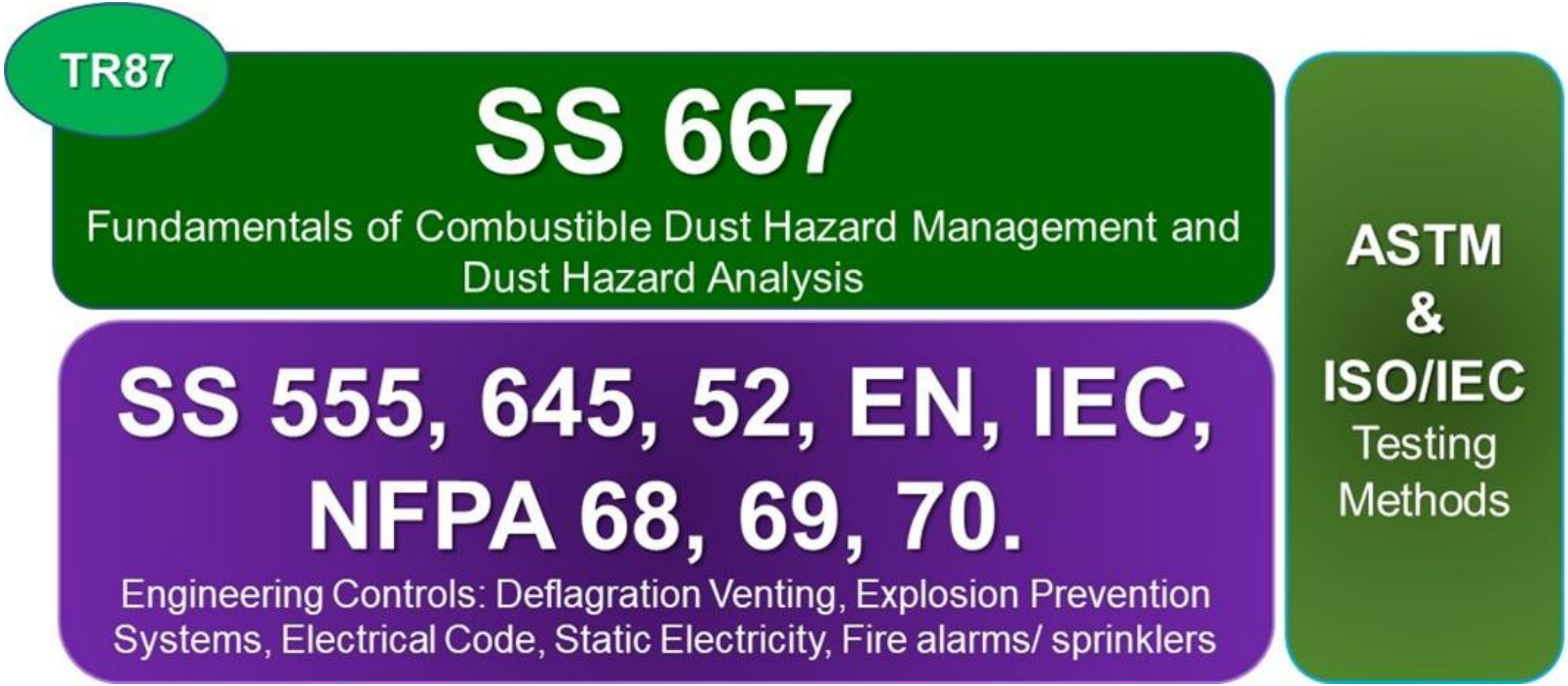
Overview - International Combustible Dust Codes



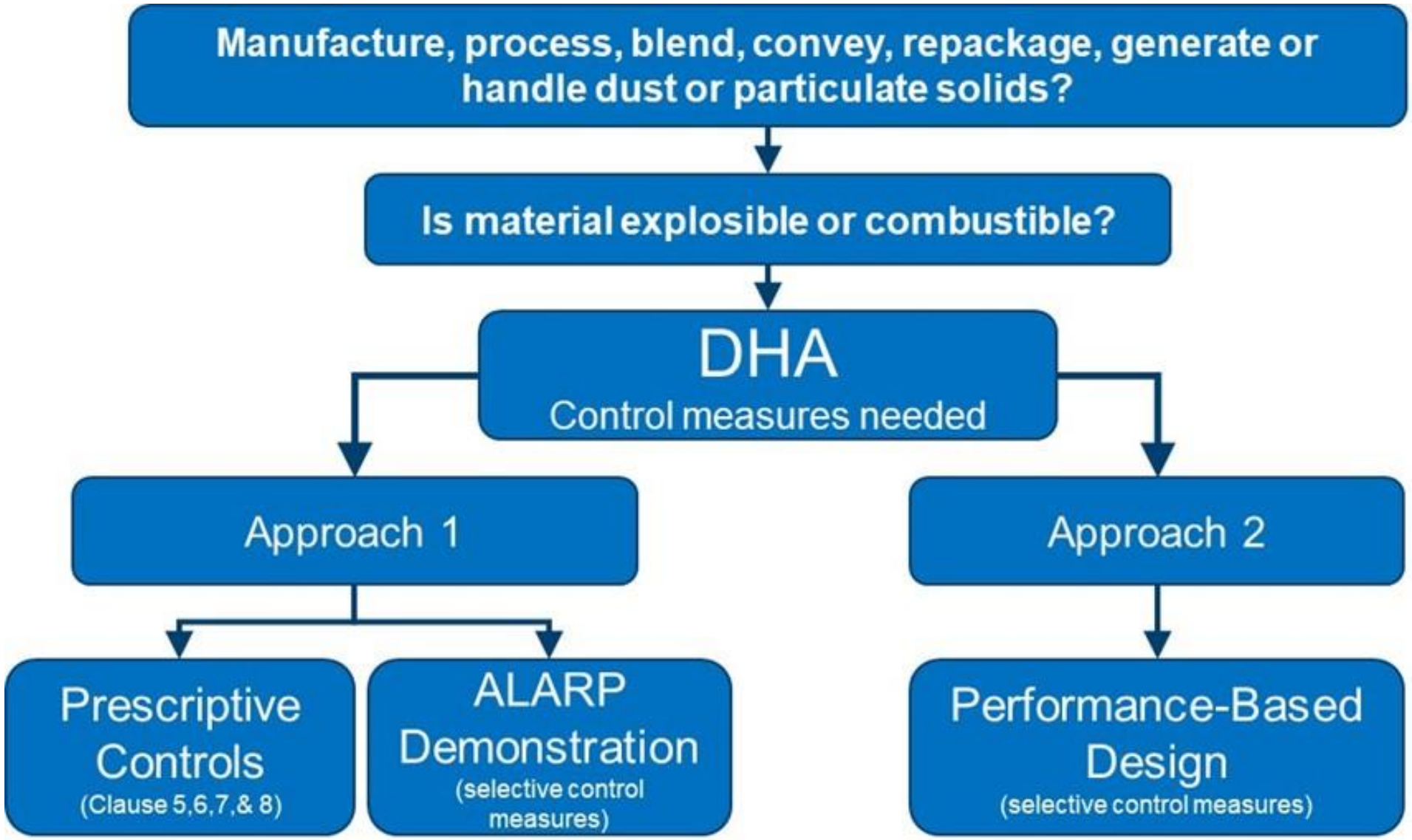
- Influenced by the jurisdiction's legal framework i.e. European, Great Britain, USA, China
- It is a “mixed bag” of regulations, directives, standards, guidelines, industry association codes.

NFPA Combustible Dust Standard Framework

Singapore Combustible Dust Standard Framework



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

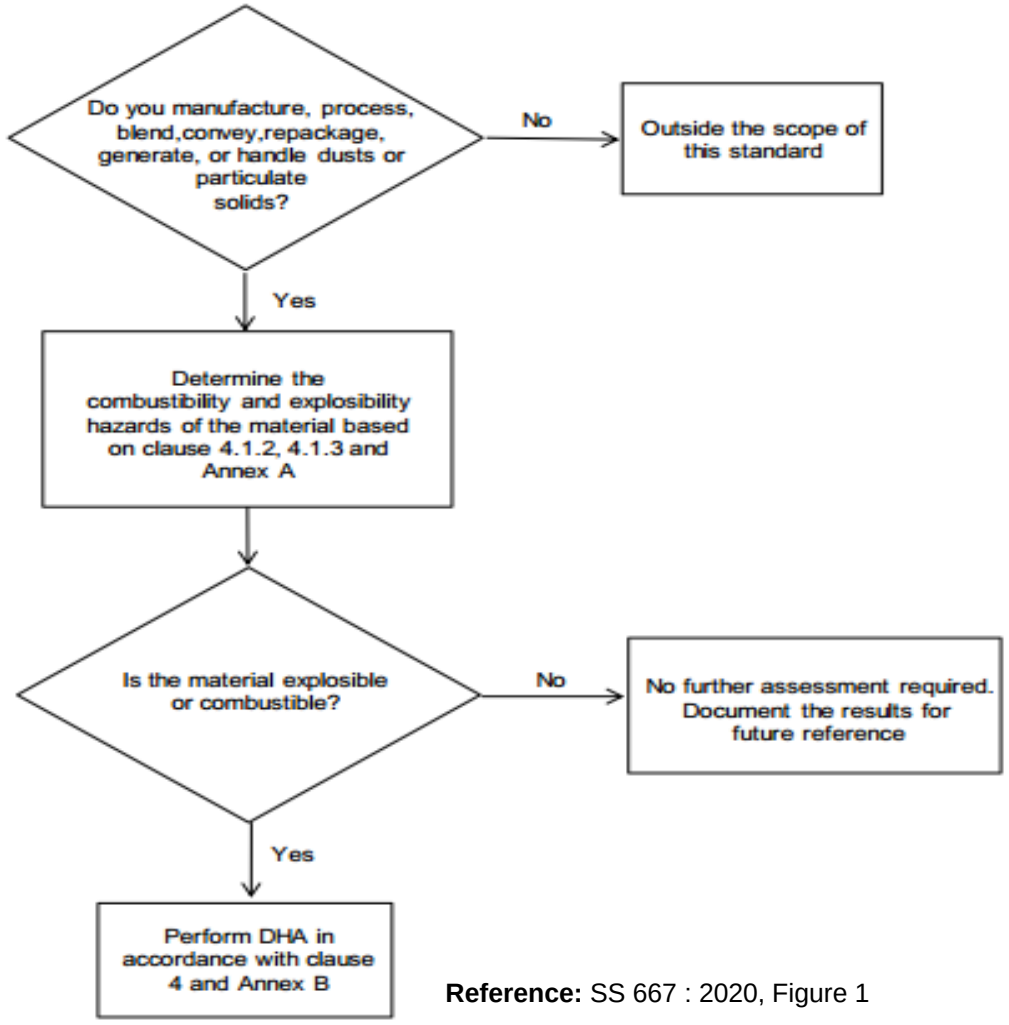
9.Performance-based design options

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



Reference: SS 667 : 2020, Figure 1

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		0
		Propagation, but too slow to include the test material in Division 4.1		4 – Glowing without sparks (smouldering) or slow decomposition without flame	Fire spreads	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	5 – Burning with flame or spark generation 6 – Very rapid combustion with flame propagation or rapid decomposition without flame		2 – 4
			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**

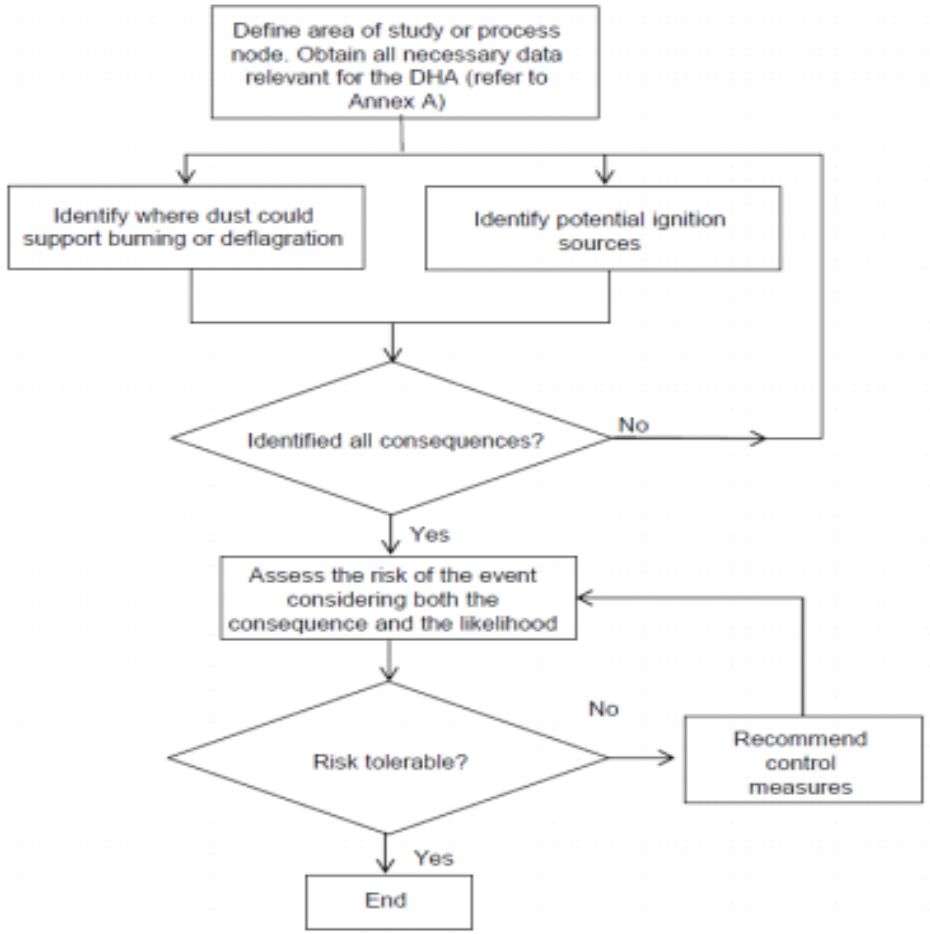


Figure 2 – Dust hazard analysis (DHA)

Dust properties and test methods

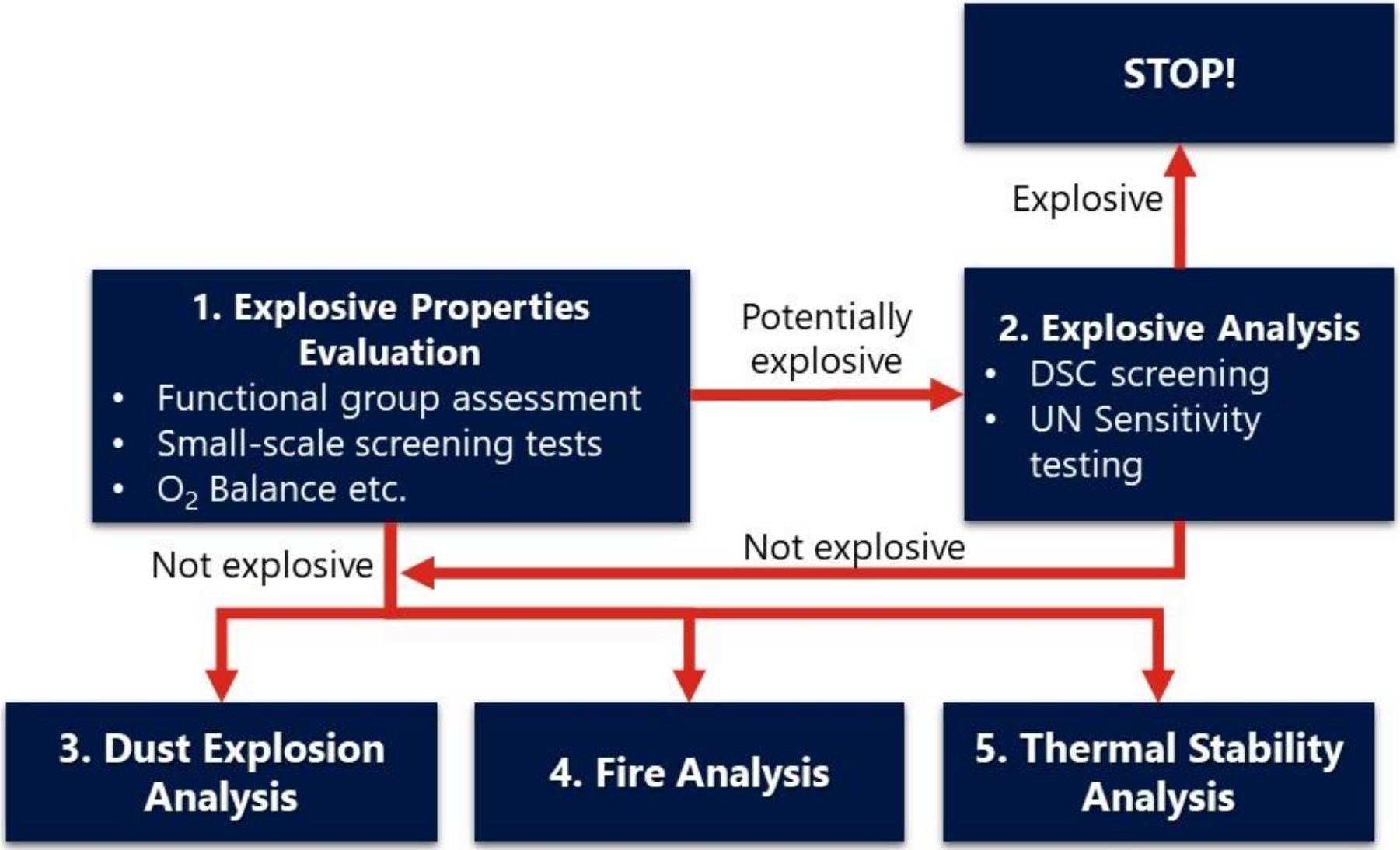
Table A.1 – Standard test methods to determine explosibility properties

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

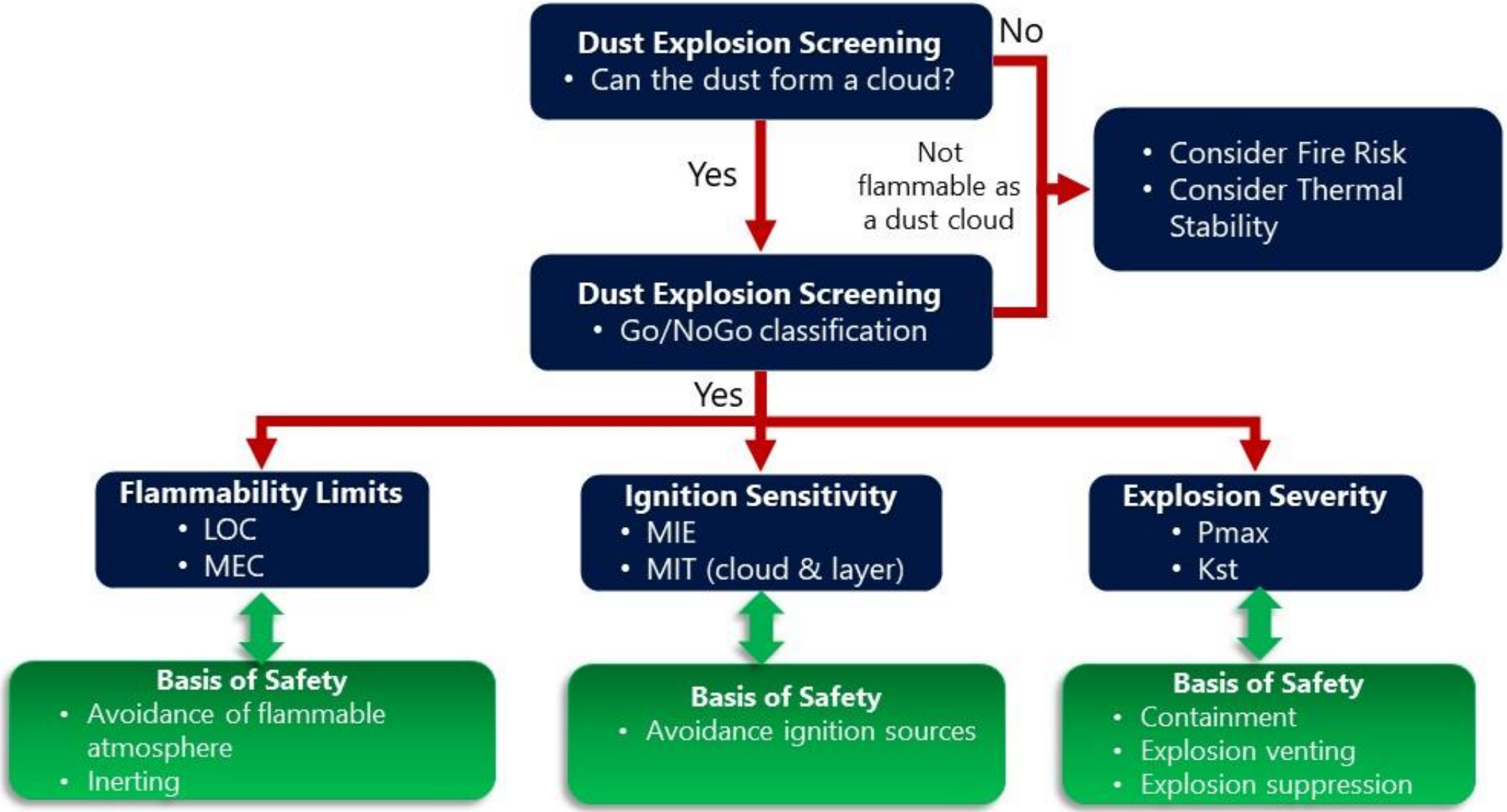
Reference: SS 667 : 2020, Annex A, Table A.1

Combustible Dust Explosion Testing

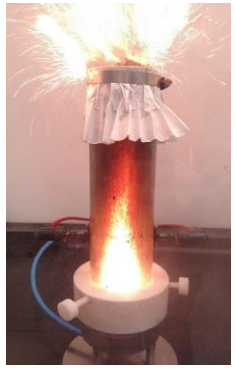
Explosive Properties Evaluation



Strategy for Dust Explosion Testing



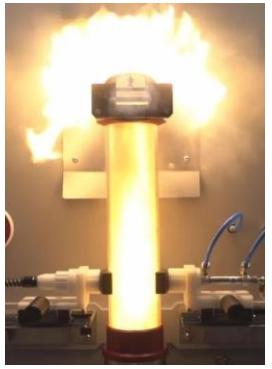
Dust Explosion Screening ("Go/No-Go")



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	• Operating below Minimum Explosible Concentration (MEC) • Operating below Limiting Oxygen Concentration (LOC)
Avoidance of ignition sources	• Preventing and/or minimising ignition sources
Mitigation	• Providing explosion relief panels • Providing explosion suppression systems

Control measures

Control measures	Description	Category
Housekeeping	• Housekeeping through a written procedure • Personnel training on housekeeping	Prevention and/or mitigation
Ignition source control	• Process ignition sources (e.g., mechanical, electrostatic, electrical) • External ignition sources (e.g., hot work)	Avoidance of ignition sources
Fugitive dust control	• Measures for managing fugitive emissions (e.g., local exhaust ventilation)	Prevention
Explosion prevention and protection	• Oxidant concentration reduction • Dilution with a non-combustible dust to render the mixture non-combustible	Prevention
	• Explosion venting • Explosion pressure containment • Explosion suppression	Mitigation
Flash fire protection	• Flash fire protection for personnel (e.g., personal protective equipment)	Mitigation
Fire protection	• Fire protection for buildings and structures • Fire detection, suppression and extinguishing systems	Mitigation

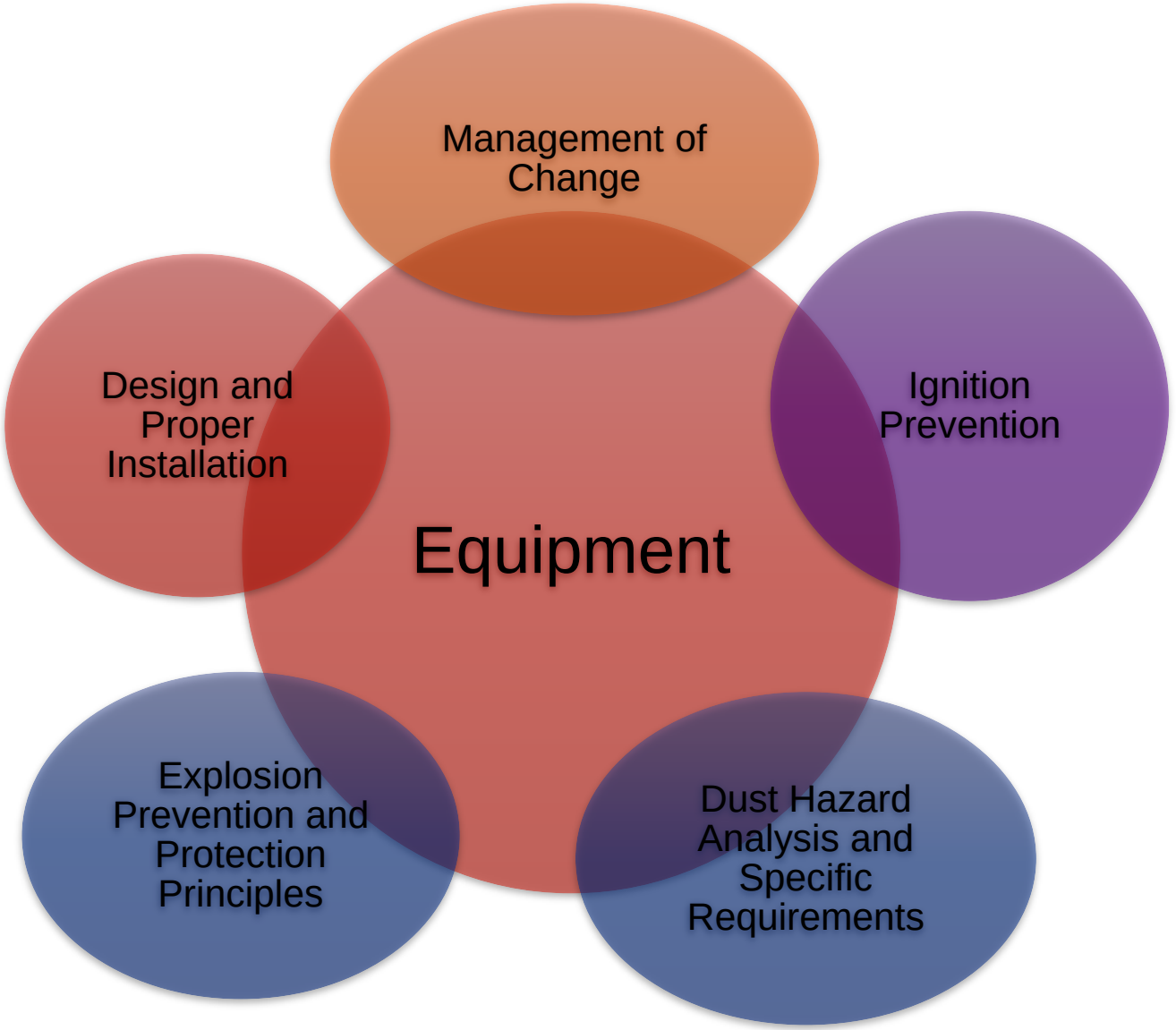
Housekeeping – a critical control measure

- **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

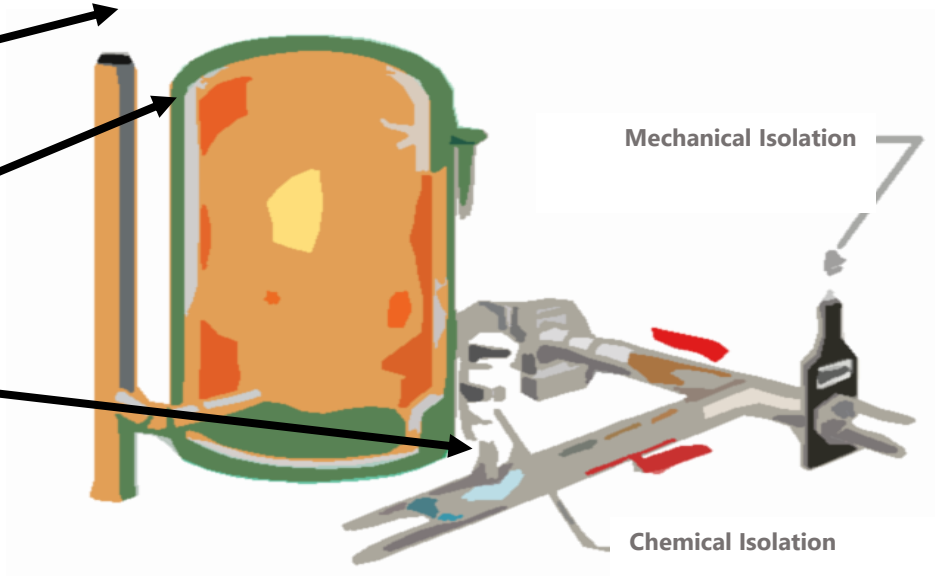
Material transfer system	Systems conveying hybrid mixtures	Piping and valves	Duct systems
Sight glasses	Pressure protection system	Material feeding devices	Bucket elevators
Enclosed conveyors	Conveyors, spouts and throws of materials	Air moving devices	Air material separator
Particle size separators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

Process Equipment: Type of Equipment

Application of requirements from clause 5:

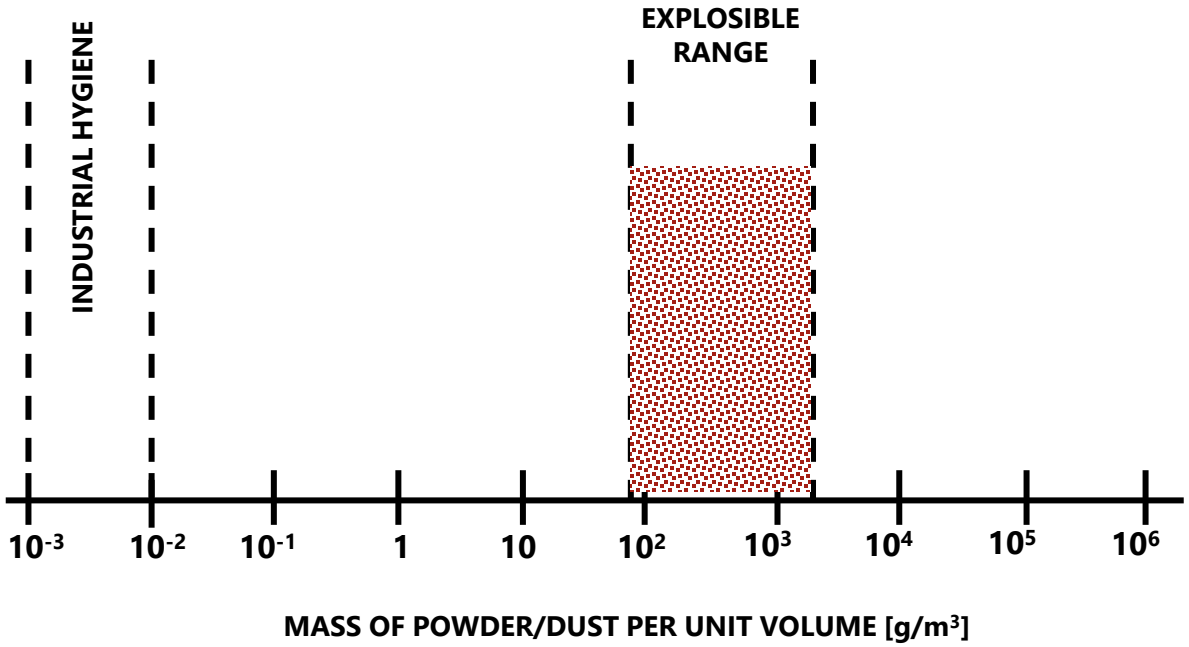
- equipment with dust explosion hazard and a containing **volume >0.2 m^3** requires utilisation of one or more of the following methods of protection:

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

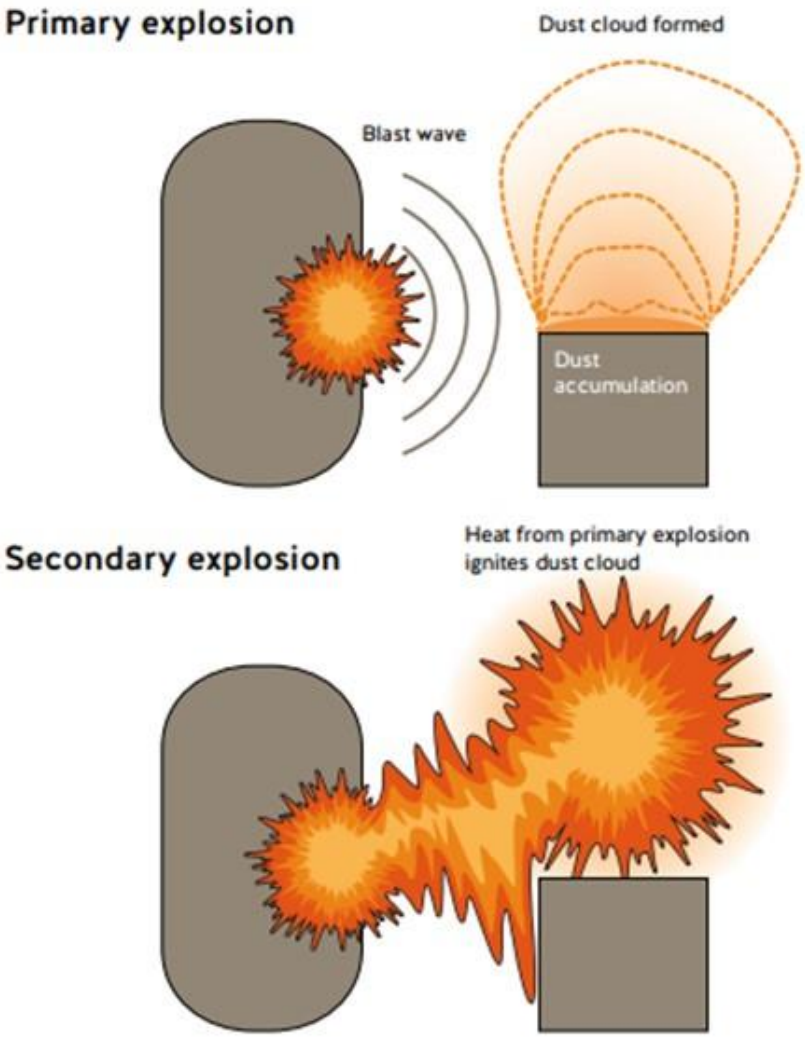
- Equipment specific requirement covers:
  - Minimising presence of combustible materials and accumulation of materials within process.
    - E.g. Requirements during design, operation, start-up and shut-down stages and access for cleaning.
  - Operating out of explosion limits.
  - Specific ignition 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

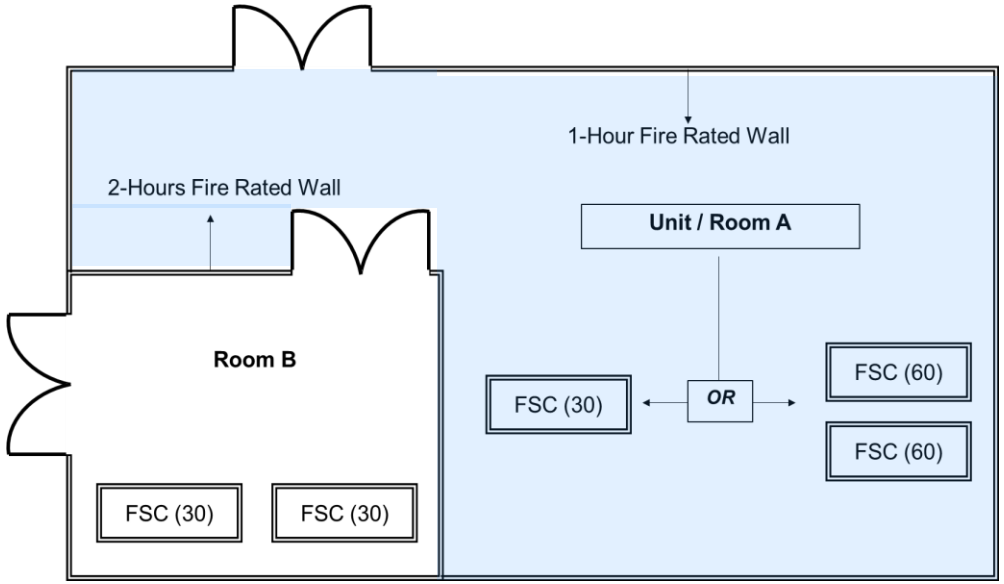


Figure 1 – Storage **without fire suppression system**

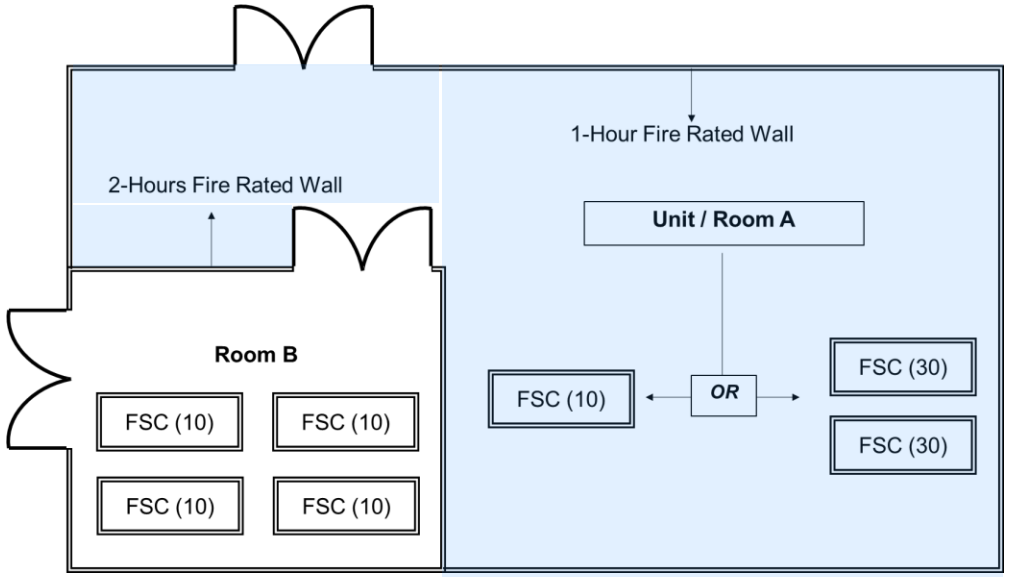


Figure 2 – Storage **with fire suppression system**

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 m^2 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

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