

Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals

**Sub-Committee of Experts on the Globally Harmonized
System of Classification and Labelling of Chemicals**

23 November 2016

Thirty-second session

Geneva, 7-9 December 2016

Item 2 (c) of the provisional agenda

Classification criteria and hazard communication:

Dust explosion hazards

Dust explosion hazards: Status report, December 2016 meeting agenda, and proposed continuance of work

**Transmitted by the expert from the United States of America on behalf
of the informal correspondence group on dust explosion hazards**

Introduction

1. This informal paper provides an update of the work performed by the correspondence group since the 31st session of the Sub-Committee.

Background

2. The Sub-Committee agreed to keep the work being done on dust explosion hazards on its programme of work for the 2015-2016 biennium (see ST/SG/AC.10/C.4/56).

3. Since the last meeting of the Sub-Committee, the correspondence group met in late-July, in mid-October, and in early November 2016.

Status report

4. Since the July 2016 meeting, the correspondence group has met and continued its work on developing a draft annex on dust explosion hazards. The work has progressed quickly, with the group completing its initial review of the annex.

5. The group has agreed that the work is now ready for initial review by the Sub-Committee. The Sub-Committee is invited to review and comment on the draft annex, provided in Annex I of this paper. The draft annex contains several comment bubbles identifying work that has been developed based on feedback from the group, but not reviewed. The correspondence group intends to review the annex in its entirety and updating as its next step.

6. Based on feedback from the Sub-Committee and additional comments provided by the correspondence group, a working paper is planned for the July 2017 meeting of the Sub-Committee.

December 8, 2016 meeting agenda

7. At the December 8th meeting, the correspondence group will continue discussions on the draft annex on dust explosion hazards. The group will also review and discuss any outstanding actions. As always, Sub-Committee members are invited to participate in the meeting, which will be held in Room S4 (Moroccan room), on the 3rd floor of the Palais from 17:30 – 19:30.

Proposal to continue the work of the informal correspondence group

8. The correspondence group discussed continuing the work on dust explosion hazards at the November 2016 meeting and propose to continue work on Workstream #3 on a step-by-step basis. Using the agreements established in the 27th session of the Sub-Committee (See ST/SG/AC.10/C.4/54 and INF.17 (27th session)) and the November 2016 meeting, the correspondence group will continue discussions in the next biennium to complete the work on developing an annex to address dust explosion hazards.

Annex I

Draft Annex X

“Guidance for other hazards which do not result in classification”

AX.1 Introduction

This guidance is meant to help identify other hazards, which do not result in classification but may pose a risk in supply and use, under certain circumstances.

AX.2 Dust explosions

AX.2.1 Scope and applicability

Any solid substance or mixture, which is somehow combustible, may pose a dust explosion risk in the form of fine particles in an oxidizing atmosphere such as air. The need for a risk assessment includes more than substances or mixtures classified as flammable solids according to Chapter 2.7. In addition, it should be considered that dusts may be formed (intentionally or unintentionally) during transfer or movement, or in a facility during handling or mechanical processing (e.g., milling, grinding) of substances/mixtures/articles (e.g., agricultural commodities, wood products, pharmaceuticals, dyes, coal, metals, plastics). Thus, the possibility of the formation of small particles and their potential accumulation should be assessed. In case a possible dust explosion risk is identified, effective countermeasures should be implemented as required by national legislation, regulations, or standards.

This guidance aims at giving an orientation as to when combustible dusts may be present and thus, when the risk of a dust explosion has to be considered. The guidance

- specifies the factors contributing to a dust explosion,
- gives a flowchart which helps to identify possible dust explosion risks on the background of these factors,
- explains the decisive steps in the flowchart,
- includes principles of risk mitigation and countermeasures, and
- makes clear in which cases support by expert knowledge is required.

AX.2.2 Definitions

Combustible dust: means finely divided solid particles of a substance or mixture that are liable to catch fire or explode upon ignition when dispersed in air or other oxidizing media.

Combustion: Energy releasing (exothermic) oxidation reaction (of and with) combustibles.

Dispersion: Distribution of fine dust particles in the form of a cloud.

Explosion: Abrupt oxidation or decomposition reaction producing an increase in temperature, pressure, or both simultaneously.¹

Explosible dust atmosphere: A dispersion of a combustible dust in air which after ignition results in a self-sustaining flame propagation.

Particle size: Smallest sieve aperture through which a particle will pass if presented in the most favourable orientation.²

Minimum Explosible Concentration (MEC)/Lower Explosible Limit (LEL): The minimum concentration of a combustible dust dispersed in air measured in mass unit per volume that will support an explosion.

Maximum explosion pressure: Highest pressure value registered in a closed vessel for a dust explosion at optimum concentration.

Minimum ignition energy: lowest electrical energy stored in a capacitor, which upon discharge is sufficient to effect ignition of the most sensitive dust/air mixture under specific test conditions.

Minimum ignition temperature of a dust cloud: lowest temperature of a hot surface on which the most ignitable mixture of a dust with air is ignited under specified test conditions.

Deflagration index (K_{st}): the dust deflagration index is a safety characteristic related to the severity of a dust explosion. The larger the value for K_{st} , the more severe the explosion. Dust specific, volume independent characteristic which is calculated using the cubic law equation:

$$(d_p/d_t)_{max} \cdot V^{1/3} = const. = K_{st}$$

where:

$(d_p/d_t)_{max}$ = maximum rate of pressure rise

$V^{1/3}$ = volume of testing chamber

Dusts are classified into dust explosion classes according to their K_{st} - value:

St 1: $0 < K_{st} \leq 200 \text{ bar m s}^{-1}$

St 2: $200 < K_{st} \leq 300 \text{ bar m s}^{-1}$

St 3: $K_{st} > 300 \text{ bar m s}^{-1}$

The maximum rate of pressure rise resp. the volume independent K_{st} - value and maximum explosion pressure are used to design safety measures (e.g. pressure venting).

¹ Some further information: Explosions are divided into deflagration and detonation depending on whether they propagate with subsonic velocity (deflagration) or supersonic velocity (detonation). The reaction of a combustible dust which is dispersed in air and ignited normally propagates with subsonic speed, i.e. as a deflagration. Whereas explosive substances ("Explosives"; see Chapter 2.1) carry the potential for highly energetic decomposition in themselves and react in the condensed phase, combustible dusts need dispersion in the presence of an oxidizing atmosphere (in most cases: oxygen) to create an explosive dust atmosphere.

² For explanations on the particle size see also the information to Rhomb 5 in the flow-chart.

Limiting oxygen concentration (LOC): maximum oxygen concentration in a mixture of a combustible dust and air and an inert gas, in which an explosion will not occur, determined under specific test conditions.

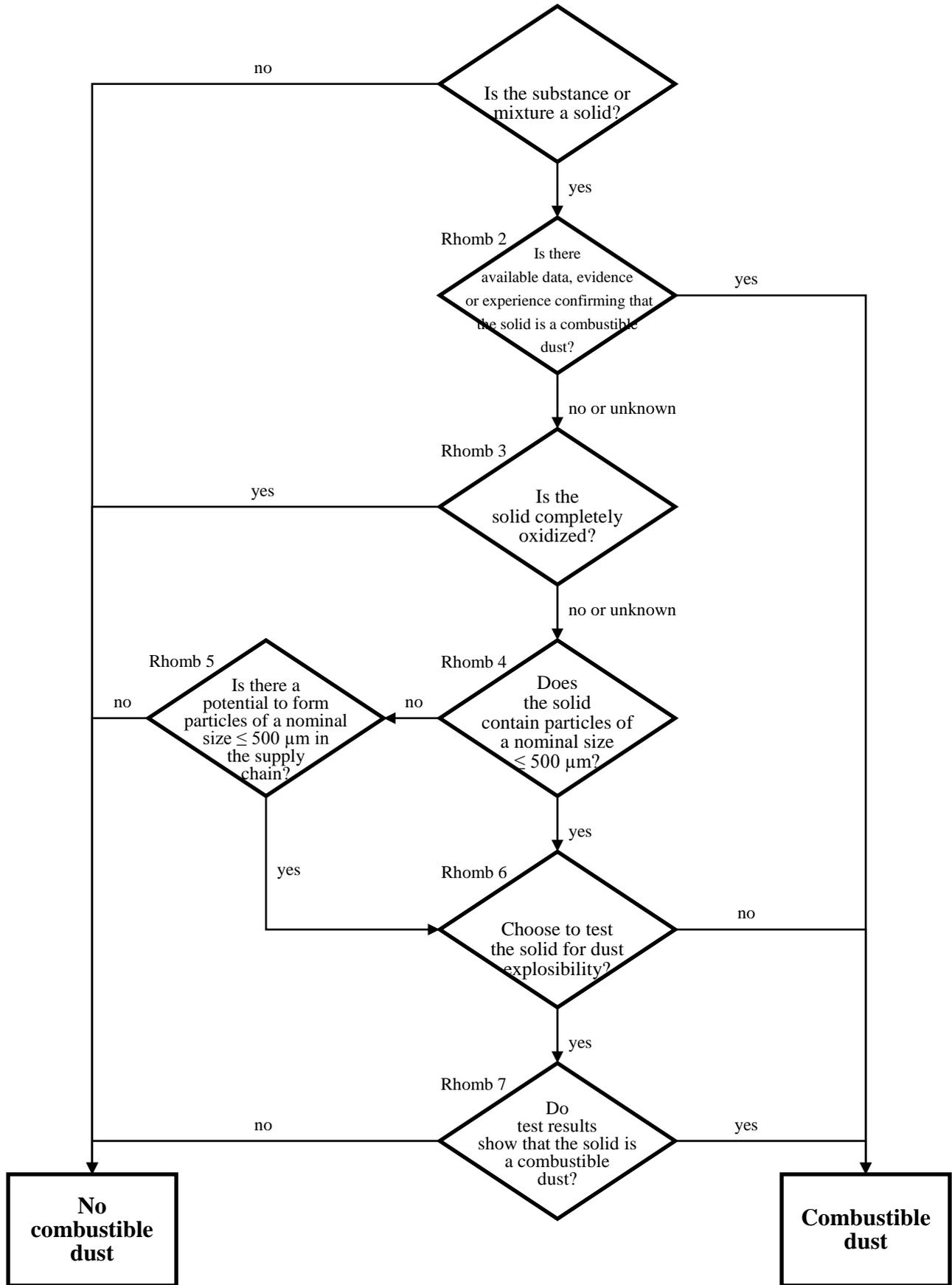
AX.2.3 Factors contributing to a dust explosion

A dust explosion may occur when there is a combustible dust, air or another oxidizing atmosphere, an ignition source, and the concentration of the combustible dust dispersed in air or another oxidizing atmosphere is above the minimum explosible concentration. The relationship between these factors is complicated and is explained in the following sections. In many cases, expert advice may be needed.

AX.2.3.1 Combustible dust

Figure AX.2.3.1 presents a flow-chart that helps to identify whether a substance or mixture is a combustible dust and hence whether the risk of a dust explosion has to be assessed. Section AX.2.3.1.1. contains a detailed discussion and explanation of each rhomb used in the flow-chart.

Figure AX.2.3.1: Flow-chart for combustible dust risk decisions



AX.2.3.1.1 Explanations to Figure AX.2.3.1: Flow-chart for combustible dust risk decisions

Use of available data:

Care has to be taken when using available data, because the behavior of combustible dusts is very sensitive to conditions such as particle size, moisture content etc. If the conditions under which available data were generated are not known or are not equal to the substance or mixture under investigation, the data might not be applicable and a conservative approach is recommended (when going through the flow-chart).

Rhomb 2:

Clear evidence for a possible dust explosion hazard may be obtained from publicly available incident reports with relevance for the considered substance or mixture. Similarly, if experience has shown that the substance or mixture is combustible in a powdery form a dust explosion risk can be assumed.

The following available data indicate a possible dust explosion risk:

- Classification of the substance or one of the components of the mixture as pyrophoric or flammable solid.
- Specification of relevant information such as MIE, K_{st} values, flammability limits, ignition temperatures.
- Results from screening tests (such as Burning index acc. to VDI 2263, Hartmann tube acc. to ISO IEC 80079-20-2; see also rhombs 4 and 6).

NOTE 1: If a substance or mixture is not classified as flammable, this does not preclude a potential dust explosibility.

NOTE 2: A possible dust explosion risk should be assumed for any organic or metallic material which is handled in a powdery form or from which a powder may be formed in processing unless explicit evidence to the contrary is available.

NOTE 3: It is common practice, in the absence of data, to assume the presence of a combustible dust and to apply appropriate risk management measures (see section AX.2.5.1).

Rhomb 3:

When a solid substance or mixture is completely oxidized, further combustion will not occur. Consequently, the solid substance or mixture will not ignite, even if it is exposed to a source of ignition. However, if a solid substance or mixture is not entirely oxidized, combustion of the solid substance or mixture is possible if it is exposed to a source of ignition.

Rhomb 4:

When assessing the particle size with regard to the risk of dust explosions, only the fine particles with a size $\leq 500 \mu\text{m}$ are relevant³, regardless of the median of the whole sample being actually higher than $500 \mu\text{m}$. Hence, only the dust fraction itself and not the mixture of coarse and fine particles have to be considered to evaluate the risk of forming explosible dust atmospheres. A lower concentration limit for the content of dust particles in a solid (e.g., by weight percent) that will lead to such a risk cannot be defined. Reasons are:

- Already small amounts of dust are able to form dust-air mixtures, which are able to react in a dust explosion. A (combustible) dust cloud of a volume of 10 litres or larger has to be considered as hazardous even when unconfined. Assuming the lower explosion limit of a combustible dust is 30 g/m^3 , an amount of 0.3 g dispersed in 10 litres of air would be sufficient to form a hazardous explosive dust atmosphere.
- Dust may not be equally distributed in substance or mixture and may accumulate and/or separate.

The $500 \mu\text{m}$ size criterion is based the fact that particles of greater size generally have a surface-to-volume ratio that is too small to pose a deflagration hazard. However, this criterion should be used with care. Flat platelet-shaped particles, flakes, or fibers with lengths that are large compared to their diameter usually do not pass through a $500 \mu\text{m}$ sieve, yet could still pose a deflagration hazard. In addition, many particles accumulate electrostatic charge in handling, causing them to attract each other, forming agglomerates. Often agglomerates behave as if they were larger particles, yet when they are dispersed they present a significant hazard. In such cases, a conservative approach is recommended and the material should be treated as presenting a dust explosion hazard.

Rhomb 5:

At this stage in the flow chart it is clear that the solid does not contain particles smaller than $500 \mu\text{m}$ – as presented. In that form it is not a combustible dust. However, it is not completely oxidized and fine particles could form during transport, handling, or processing. Therefore, such conditions should be critically reviewed in detail, especially with respect to long-term effects which may lead to the formation of fine particles, e.g., by mechanical stress such as abrasion during transport or processing or the malfunction of equipment.

If such effects cannot be excluded, an expert opinion should be sought.

If it is chosen to test the solid, it has to be kept in mind that the solid as presented does not contain particles $\leq 500 \mu\text{m}$, so that it has to be ground for the purposes of testing.

Rhomb 7:

Properties such as particulate size, chemistry, moisture content, shape, and surface modification (e.g. oxidation, coating, activation, passivation) can influence the explosion behavior. Standard tests determine whether a dust is actually able to form explosible mixtures with air.

If testing of the dust explosibility is carried out, it should be done in accordance with recognized and validated testing standards, such as those listed in Annex AX.2.7.1.

³ The \leq sign is used in order to correspond to the respective information in NFPA 652, Standard on the Fundamentals of Combustible Dust. It should be understood, though, that this code implies a precision which this parameter does not have.

AX.2.3.2 Concentration of combustible dust

A dust explosion may occur if the concentration of combustible dust dispersed in the air reaches a minimum value, the minimum explosible concentration/lower explosible limit (MEC/LEL), and does not exceed a maximum, an upper explosible limit (UEL). Both values are specific for each substance/material.

The MEC/LEL of many materials have been measured, varying from 10 to about 500 grams per cubic meter. For most practical purposes it may be assumed that 30 grams per cubic meter is the minimum explosible concentration (MEC/LEL) for most combustible dusts (it has to be taken into account that 30 grams dispersed in one cubic meter of air, resemble a very dense fog). The UEL are not well defined and have poor repeatability under laboratory test conditions. Since the UEL is of little practical importance, data for this parameter is rarely available.

AX.2.3.3 Air or other oxidizing atmospheres

Generally air is the oxidizing agent in dust explosions, however, if combustible dusts are handled in other oxidizing gases or gas mixtures dust explosions might occur as well.

AX.2.3.4 Ignition sources

Dust explosions will occur when an effective ignition source is present in an explosible dust-air mixture (explosible atmosphere). The effectiveness of a potential source of ignition means the ability to ignite an explosible atmosphere. It depends not only on the energy of the ignition source, but also on its interaction with the explosible atmosphere.

The assessment of ignition sources is performed in a two-step procedure: First, possible ignition sources are identified. In the second step, each possible ignition source is assessed with respect to its ability to ignite the explosive atmosphere. The ignition sources identified as effective in this procedure then require special countermeasures within the explosion protection concept.

The following is a list of potential sources of ignition:

- Hot surfaces
- Flames and hot gases
- Mechanically generated sparks
- Electric apparatus
- Stray electric currents and cathodic corrosion protection
- Lightning
- Static electricity
- Radio frequency electromagnetic waves (10^4 Hz - $3 \cdot 10^{12}$ Hz)
- Electromagnetic waves ($3 \cdot 10^{11}$ Hz - $3 \cdot 10^{15}$ Hz)
- Ionizing radiation
- Ultrasonics
- Adiabatic compression and shock waves
- Exothermic reactions, including self-ignition of dusts

AX.2.4 Factors impacting the severity of a dust explosion

Give the four factors explained above in Annex AX.2.3, other conditions also influence how severe a dust explosion can be. The more significant of these are environmental factors and confinement, which are explained below. Since the list of factors presented in this section is not complete, expert advice should be sought when assessing the hazards in a given situation.

AX.2.4.1 Influence of temperature, pressure, oxygen availability, and humidity

Safety relevant data are frequently given under the tacit assumption of atmospheric conditions and are usually valid in the following range (“standard atmospheric conditions”):

- temperature $-20\text{ }^{\circ}\text{C}$ to $+60\text{ }^{\circ}\text{C}$
- pressure 80 kPa (0.8 bar) to 110 kPa (1.1 bar)
- air with standard oxygen content (21 % v/v)

An increase in temperature may have multiple effects such as a decrease in Minimum Explosible Concentration (MEC) and Minimum Ignition Energy (MIE), thus increasing the likelihood of a dust explosion.

An increase in pressure tends to lower the Minimum Ignition Energy (MIE) and the Minimum Ignition Temperature of a dust cloud while the Maximum Explosion Pressure will rise. The effect is increased sensitivity, thus the likelihood of a dust explosion and a more severe impact.

Higher oxygen contents can severely increase the sensitivity of an explosive atmosphere and the impact in case of an explosion due to higher explosion pressures.

Low or high humidity (of air, gas phase) may influence the occurrence of electrostatic discharges.

Therefore, the risk and severity of dust explosions under non-standard atmospheric conditions should be evaluated by experts in consideration of the actual process conditions.

AX.2.4.2 Confinement

Confinement means the dust is in an enclosed or limited space. A combustible dust (as defined above) can react without confinement or when confined. When confined the effects of such a reaction can be more serious and characteristics as the maximum explosion pressure might be higher than under unconfined conditions. The confinement allows pressure to build up, increasing the severity of an explosion. ~~Therefore, the release of a combustible dust outside of a confined area means that it has escaped confinement and which significantly minimizes the potential explosion severity.~~

AX.2.5 Hazard prevention, and risk assessment and mitigation

AX.2.5.1 General explosion protection concept for dusts

Table AX.2.5.1: General concept for prevention & mitigation measures concerning dust explosion, shows the principles of explosion protection. The chart presents both preventive and mitigative measures, and identifies which safety characteristics are most relevant with regard to the individual measures proposed. Refer to Annex 4, Table A4.3.9.2: Data

relevant with regard to physical hazard classes (supplemental), for additional guidance on relevant safety characteristics.

1. The first priority should involve the application of preventive measures in order to avoid the formation of an explosible dust atmosphere. Good work practices, such as housekeeping, can assist in limiting dust accumulations. A written housekeeping plan with periodic inspection of the facility for excessive dust levels, with emphasis on priority areas, is suggested to address accumulation. Housekeeping should be conducted concurrent with operations. Good housekeeping practices can prevent the pressure wave from a primary, initial explosion, usually from inside of equipment or enclosures, from disturbing dust accumulations putting them into suspension. If the dust concentration exceeds the lower explosive limit in the space, a secondary explosion can occur. Additional examples of such measures are shown in the column titled, "Avoidance or reduction of explosible dust atmospheres".
2. If one cannot take measures to avoid or reduce explosible dust atmospheres, then, ignition sources should be assessed and avoided if relevant. Ignition sources can include fires and heat caused by the frictional energy of mechanical equipment. Heat or arcing caused by the failure of or the use of improper electrical equipment, such as lighting, motors, and wiring, has also been identified as an ignition source. Improper use of welding and cutting equipment can be a factor. Periodic inspections, lubrication, and adjustment of equipment can be a major tool to prevent ignitions which can lead to explosions. Additional examples of what to consider when evaluating ignition sources is shown in the column titled "Avoidance of ignition sources".
3. If ignition of an explosible dust atmosphere cannot be excluded, the effects should be mitigated by appropriate measures. [Equipment and buildings with known explosible dust hazards should be equipped with devices or systems designed to prevent an explosion, minimize its propagation, or limit the damage it causes. Explosion relief venting is one of the most common approaches taken to reduce the maximum explosion pressure.](#) Examples of [other](#) mitigating measures are shown in the column titled "Minimizing effects of a dust explosion".

[The NFPA has developed guidance and standards discussing explosion prevention systems and the use of deflagration venting. Section AX.2.7.2 includes a list of regulations and guidance documents on prevention and mitigation of dust explosion hazards.](#)

[Containment, others?](#)

In all cases, every facility should have a safety program and an established emergency action plan that outlines what is to be done in the event of a fire or explosion. A method is needed to notify everyone at the facility that there is an emergency when they might be at risk. Generally, a central alarm system, page system or horn can be used to signal the need for evacuation. All workers at a facility should be trained in the hazards of dust explosion and proper action.

Table AX.2.5.1: General concept for prevention and mitigation measures concerning dust explosions

Prevention		Mitigation
Avoidance or reduction of explosible dust atmospheres	Avoidance of ignition sources	Minimizing effects of a dust explosion
<u>Relevant safety characteristics</u> <ul style="list-style-type: none"> Dust explosibility Avoidance of combustible dusts by [examples below] <ul style="list-style-type: none"> Substitution Passivation Application of dust-free processes ... 	Identification of relevant ignition sources <ul style="list-style-type: none"> Identification of relevant areas and activities (zoning) Identification of potential ignition sources Determination of relevant safety characteristics (see below) 	<u>Relevant safety characteristics</u> <ul style="list-style-type: none"> Maximum explosion pressure Deflagration index (K_{st}) Explosion pressure proof design by [examples below] <ul style="list-style-type: none"> Venting (reduction of explosion pressure) Explosion resistance ...
<u>Relevant safety characteristics</u> <ul style="list-style-type: none"> Lower explosion limit (LEL) Avoidance of reaching the explosion range by [examples below] <ul style="list-style-type: none"> Good house keeping Exhaust ventilation Dust reduced procedures ... 	<u>Relevant safety characteristics</u> <ul style="list-style-type: none"> Minimum ignition energy Minimum ignition temperatures (dust clouds and dust layers) Self-ignition behaviour Prevention of effective ignition sources by [examples below] <ul style="list-style-type: none"> Avoidance of open fire or flames No smoking Limitation of surface temperatures Use of approved electrical and mechanical equipment (according to respective zone) Prevention of electrostatic discharges (e.g., grounding, dissipative materials) Prevention of mechanical heating or sparks (e.g., temperature monitoring, misalignment monitoring of moving parts, ...) Spark detection and extinguishing ... 	Explosion suppression by [examples below] <ul style="list-style-type: none"> Explosion detection and dispersion of extinguishing media (powder, water, ...) ...
<u>Relevant safety characteristics</u> <ul style="list-style-type: none"> Limiting oxygen concentration (LOC) Oxygen reduction by [examples below] <ul style="list-style-type: none"> Inerting (N_2, CO_2, argon, flue gas, water vapour, ...) 		Explosion isolation by [examples below] <ul style="list-style-type: none"> Ignition and flame resistant components (rotary valves, double acting valves, quick acting gate valves, ...) Extinguishing barriers ...

AX.2.5.2 Considerations for dust explosion protection during operations

Table AX.2.5.* provides potential considerations during production processes. Production processes include such activities as drying, filling, mixing, milling, and grinding. The table provides guidance as to what should be considered in various operations associated with ignition sources, as presented in Table AX2.5.1 above. The table provides an example of the detailed analysis of ignition sources, but no such analysis is provided for the other two columns. To consider other prevention measures, the type of detailed information evaluated and presented in this ignition source table should be considered. Expert advice may be needed to develop detailed analysis of appropriate preventive and mitigative measures.

AX.2.6 Supplemental information for hazard communication

As explained in Chapter 1.4.6.3, there are many communication elements which have not been standardized in the harmonized system. Some of these clearly need to be communicated to the downstream user. Competent authorities may require additional information, or suppliers may choose to add supplementary information on their own initiative. Each party producing or distributing a product that is determined to be hazardous, including if it becomes hazardous during downstream processing, should create and provide their downstream user appropriate hazard information, in the form of a Safety Data Sheet or another format as appropriate, to alert the user to the hazards.

For substances or mixtures, at a minimum, Sections 2, 5, 7, and 9 of the Safety Data Sheet should provide information on combustible dusts. Annex 4 in the GHS provides further guidance on each section of the SDS. For example, Section 2 (A4.3.2) addresses hazards that do not result in classification; Section 5 (A4.3.5) covers requirements for fighting a fire; Section 7 (A4.3.7) provides guidance on safe handling practices and Section 9(A4.3.9) describes the physical and chemical properties of a substance or mixture.

To communicate the hazards of dust explosions in a standardized manner, competent authorities or suppliers may use the phrases “Warning” and “May form explosible dust-air mixture if dispersed” on labels and/or safety data sheets of substances or mixtures that can be identified as combustible dusts under the approach described in this annex.

AX.2.7 References

AX.2.7.1 Test Methods

Recognized and scientifically validated testing methods and standards, such as those listed below, should be used when conducting analysis on dust explosibility.

International Standards

- ISO/IEC 80079-20-2, "Explosive atmospheres - Part 20-2: Material characteristics – Combustible dusts test methods"

National Consensus Standards

- ASTM E1226, “Standard Test Method for Explosibility of Dust Clouds”

- VDI* 2263-1, "Dust Fires and Dust Explosions; Hazards – Assessment – Protective Measures; Test Methods for the Determination of the Safety Characteristics of Dusts"

AX.2.7.2 Regulations and guidance on prevention and mitigation

There are a number of documents available providing guidance on preventive and mitigation measures to minimize or eliminate dust explosions. A partial list is provided below. Users of this annex are encouraged to use country-specific documents (e.g. those addressing specific hazards associated with such items as wood, coal, sulfur, and combustible metals, and for agricultural and food processing facilities), where available.

- Directive 1999/92/EC of the European Parliament and of the Council [ATEX], Annex 1
- U.S. OSHA's Combustible Dust Directive [Combustible Dust National Emphasis Program]
- National Fire Protection Association (NFPA)
 - NFPA 652: Standard on the Fundamentals of Combustible Dust
 - [NFPA 654: Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids](#)
 - [NFPA 68: Standard on Explosion Protection by Deflagration Venting](#)
 - [NFPA 69: Standard on Explosion Prevention Systems](#)

*VDI stands for "Verein Deutscher Ingenieure"