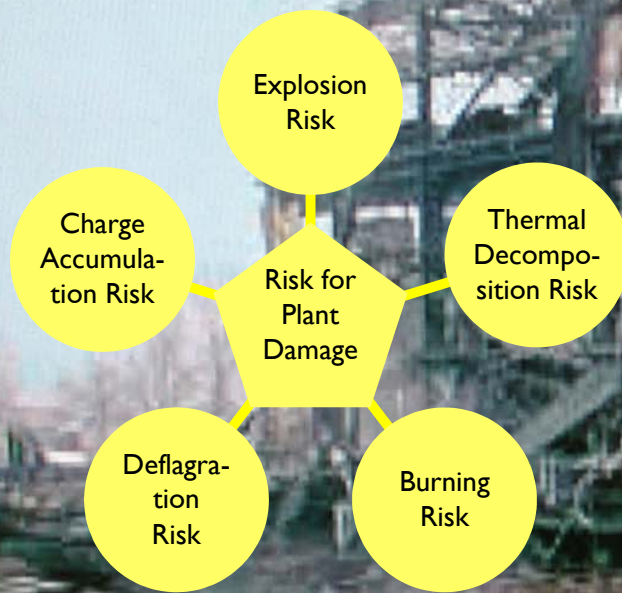


# Powder as a Risk Factor in Multi-product facilities



## Topic 4: Powder handling in Multi-product facilities

Running physical processes with powders in Multi-product facilities asks for a systematic approach to assess their risks. State of the art is

- to be aware of the hazard potentials inherent in the physical processes with powders
- to decide whether the given Multi-product facilities are able to handle the hazard potentials of the powder in question
- to implement the proper technical and organisational measures and the proper personnel selections for a safe operation of the chemical plant derived from the knowledge of the hazard potentials



The **picture on the front page** shows the West Pharmaceutical Services facility destroyed by polyethylene dust explosion rephotographed from a photo by the CSB Investigation Report Combustible Dust Hazard Study; U.S. Chemical Safety and Hazard Investigation Board, Report No. 2006-H-1, November 2006.

The **description of the accident** is an excerpt from the above mentioned report. We have chosen this accident of all the discussed dust explosions, because this explosion happened in a facility in which no powder was processed.

On January 29, 2003, a massive dust explosion at the West Pharmaceutical Services facility in Kinston, North Carolina, killed six workers and destroyed the facility. The explosion involved a part of the building used to compound rubber.

West produced rubber syringe plungers and other pharmaceutical devices at the facility. In the rubber compounding process, freshly manufactured rubber strips were dipped into a slurry of polyethylene, water, and surfactant to cool the rubber and provide an anti-tack coating. As the rubber dried, fine polyethylene powder drifted on air currents to the space above a suspended ceiling.

Polyethylene powder accumulated on surfaces above the suspended ceiling, providing fuel for a devastating secondary explosion. While the visible production areas were kept extremely clean, few employees were aware of the dust accumulation hidden above the suspended ceiling, and the material safety data sheets for the polyethylene slurry included no dust explosion warning. Even those employees who were aware of the dust accumulation had not been trained about the hazards of combustible dust. West did use a safety review process when the compounding system was designed and modified, but the dust explosion hazard was not addressed during the reviews. OSHA, the local fire department, an insurance underwriter, and an industrial hygienist had inspected the facility, but none had identified the potential for a dust explosion. In addition, the electrical equipment above the suspended ceiling in the rubber compounding section was not rated for use around combustible dust, as the National Electric Code (NEC) requires (for areas where combustible dust can accumulate). The CSB determined that if West had adhered to NFPA standards for combustible dust, the explosion could have been prevented or minimised.

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Second Edition, February 2013

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# Powder Handling in Multi-Product Facilities

## Introduction

*The core business of Multi-Product Chemistry is to manufacture products by the control of reactive chemicals. The reactivity of chemicals that makes them useful also makes them hazardous.*

*Multi-product chemistry possibly is the branch of industry that have the broadest spectrum of dangers. Liquid, solid and gaseous chemicals are processed partly under high pressure and at high temperatures. They might be toxic, combustible, decomposable and explosible.*

*Multi-product chemistry produces, stores and transport's chemicals with technical methods that might be faulty and susceptible to faults. And all that in plants that are not designed and built for a production in question, organised divisionally of labour and controlled by personnel that make mistakes occasionally.*

*The profile of demand of a chemical production process as a rule does not suit the profile of capabilities of a Multi-product facility. Shortcomings will be removed by appropriate completion. Those shortcomings that can not be removed economically by technical measures will be bridged by organisational measures.*

*Hence the safe operation of a Multi-product facility will be ensured by three different tools*

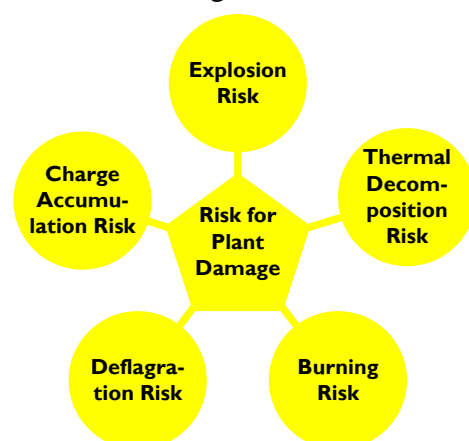
- *process engineering and apparatus measures*
- *PLT measures*
- *organisational measures*

*In order to design the appropriate measures it is necessary to understand the nature of the reactive chemicals that are processed. Reactive hazards should be evaluated using reviews on all new processes and on all existing processes on a periodic basis. There is no substitute for experience, good judgement, and good data in evaluating potential hazards.*

*The following few pages show the reader a meaningful approach when assessing whether a given powder can be processed safely in a multi-product facility. Besides to the applied knowledge in our safety laboratories (formerly central safety laboratories of Clariant that we have bought in 2005) the following references were used.*

- *Test Methods for the Determination of the Safety Characteristic of Dusts VDI 2263 and Dust Fires and Dust Explosion VDI 2263*
- *Reactive Chemicals by Tatao Yoshida; Elsevier, Amsterdam, Science Publishers B.V. 1987.*
- *Electrostatic Hazards in Powder handling by Martin Glor; Research Studies Press Ltd. 1988*

Powder handling and its inherent risks

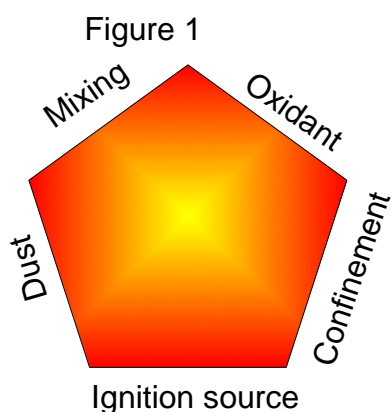


# 1 Powder as a Risk Factor in Multi-product facilities

## 1.1 General properties of powder processing

The processing of powders forms dust due to abrasion of coarse solids. Dust consists of finely divided solids with various shapes and different weights and particle size of less than approximately 500 µm. When it reacts with oxygen accompanied by heat liberation it is called combustible dusts.

Combustible powders are particularly hazardous, because they have a very high surface area-to-volume ratio. When finely divided as powders or dusts, solids burn quite differently from the original material in the bulk. Dust and fiber deposits can spread fire across a room or along an edge or on a roof beam very quickly. On the other hand, accumulations of dust can smoulder for a long time span, giving little indication that combustion has started until the fire suddenly flares up, possibly when no one suspects a problem. Many of the combustible powders produced by industrial processes are explosible when they are suspended as a dust cloud in air. A spark may be sufficient to ignite them. After ignition, flame spreads rapidly through the dust cloud as successive layers are heated to ignition temperature. The hot gases expand and produce pressure waves, which travels ahead of the flames. Any dusts lying on surfaces in the path of the pressure waves will be thrown into the air and could cause a secondary explosion more violent and extensive than the first. Even seemingly small amounts of accumulated dust can cause catastrophic damage.

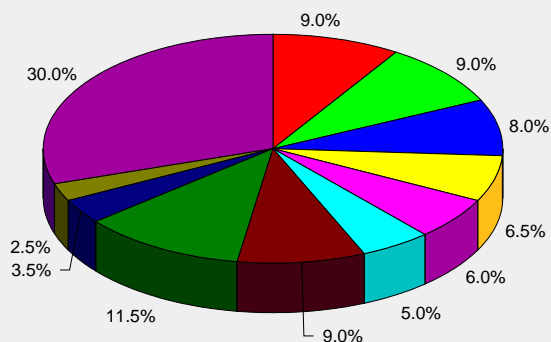
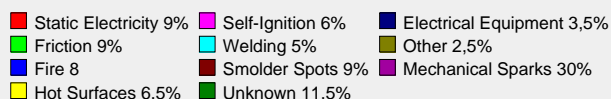


Hence fire and explosion hazards are inherent with physical processes of powders. Certain conditions must be fulfilled to trigger an explosion from combustible dusts and the flammable dust air mixtures resulting from them. It needs an ignition source, a combustible powder and a large enough surface area in contact with the oxygen that is present in the air (figure 1).

Dust explosion differs from gas explosion and in some cases they are much more devastating. If a gas air mixture is ignited, the force of the resulting explosion causes a rapid dissipating gas cloud. As a result the gas air mixture dilutes to a concentration that is lower than necessary for further combustion. Hence, if no additional gas is added, the explosion is over after several milliseconds. This is not so with combustible dusts. If a draught of air swirls up a layer of dust in a small area the dust forms a combustible dust air mixture. In the case that this mixture is ignited by an ignition source, an explosion is triggered. The force of the resulting explosion swirls up more dust, which is also ignited, and –under some conditions– destroy entire buildings or facilities.

Various ignition sources for dusts are known. Figure 2 shows the results of statistical studies, which examined

Figure 2: Ignition Sources of Dust Explosions



the ignition sources of dust explosions. It shows that mechanically produced sparks were responsible in almost one third of the cases and 13% of the explosions are caused by open fire and welding. So it becomes obvious that many responsible people are not aware of the hazard of dust explosions. The studies have shown that different industries are concerned by dust explosions, including branches of the food and wood processing industries, paper and synthetic production, pharmaceutical production and others.

The course of a solid gas reaction depends primarily upon the reactive surface of the solid particle and its chemical properties. The reactive surface is dependent upon the fineness and the concentration of the solid. The kind of combustion of solid substances may vary over a wide range. It may appear like a slowly glowing fire or a rapid explosion depending on whether a dust is dispersed or settled.

**Dispersed and settled dust interacts with each other. Dispersed dust may settle. Dust layers may become airborne due to external influences such as the pressure wave of a propagating explosion.**

**Dust layers** are formed by settling, dumping or packaging. Once ignited, they show different kind of behaviour:

- They may show a slow reaction such as burning, glowing or smouldering.
- Those that do not set free flammable gases after ignition may generate glowing fires.
- If flammable gases are set free, open fires may start. Open fires are favoured by fresh air. Lack of air may result in smouldering fires.
- Inside dust deposits the available oxygen from the air may only be sufficient for a local limited glowing, or smouldering fire. The needed amount of oxygen for the combustion has to reach the reaction zone through convection or diffusion.
- Fires in dust accumulations may also start by auto-ignition due to elevated ambient temperatures, high product temperatures or micro biological heating. Large powder accumulations favour auto-ignition.
- Exothermic reactions with oxygen or thermal decomposition may lead to self heating of powders, even at room temperature. Such a slow self heating may gradually accelerate and result in an auto-ignition or rapid decomposition with pressure generation. Large dust accumulations may be endangered to such behaviour because of poor heat transfer.
- A continuous conversion –a deflagration– of a high energy contenting powder may start by locally initiated decomposition. Contrary to a fire it cannot be stopped with oxygen deficiency. Normally large amounts of hot gases are set free which possibly may also be flammable.

### **Decomposition reactions**

Exothermic decomposition of powders, accompanied by the generation of much heat and gas, is a common cause of accidents in the chemical industry. Decomposition reactions can follow three different physicochemical mechanisms. The literature distinguishes between deflagration, detonation and thermal explosion.

**Deflagration** is a decomposition reaction that can be initiated locally and is propagated through the entire material in a self-sustaining exothermic reaction. The initiation of deflagration depends on the material properties; it can be triggered by friction, impact or a sufficiently powerful heat source (e.g. by contact with hot apparatus).

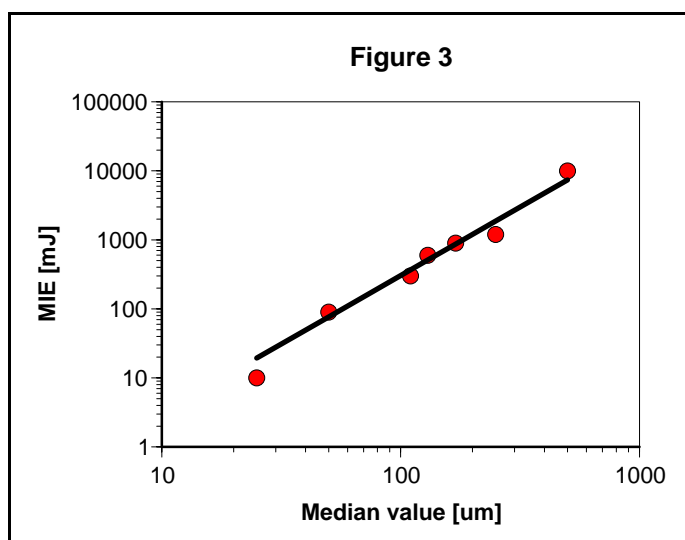
**Detonation** is also a decomposition reaction that can be initiated locally and is propagated through the material in the form of a reaction front not by heat transfer, but by means of a shock wave sustained by the energy set free by the decomposition reaction.

A **thermal explosion** is not initiated locally and spreads throughout the entire volume of material more or less homogeneously and not as a moving front. If a powder capable of thermal decomposition finds itself in a situation where more heat is produced than can be dissipated to the surroundings, spontaneous overheating occurs resulting in a thermal explosion. This explosion is typified by a progressive increase in heat output and a massive rise in temperature and pressure.

- If overheatings occur during drying processes of organic powders, then part of them may evaporate or decompose pyrolytically and form flammable gases or aerosols. Mixed with air, they may form an explosive atmosphere. So, dusty substances may create an explosion hazard without the presence of dispersed dusts.

**Dispersed dust**, dust clouds, dust air mixtures, within certain limits of concentration, may burn like an explosion in the cause of ignition. The dispersion of dust in air is limited in time and space, hence a homogeneous dust-air mixture does not exist. Therefore, the explosible limits of dusts do not have the same significance for safety considerations as the ones for gas-air mixtures, especially the upper explosible limits. Dust explosions may be feared for dust concentrations in air of more than  $20 \text{ g/m}^3$ .

For Multi-product facilities it is not possible to calculate the concentration of uniformly distributed dust. The concentrations in the different partial volumes of an installation can be completely different. Therefore, the hazard of an explosion may exist for parts of a building or sections of vessels or equipment even if the overall concentration based on the total volume is outside the explosible range.



#### Some characteristics of the behaviour of dust/air mixtures

Gas air mixtures react most violently in the range of the stoichiometric content of oxygen. Dust explosions need a higher oxygen content than the stoichiometric one.

The finer the dust the longer the dust air mixture will remain suspended and larger maximum explosion pressure and rate of pressure rise result. Dusts with smaller particle size have lower minimum ignition energies (Figure 3). Particles having a diameter larger than approximately  $500 \mu\text{m}$  will generally not react like an explosion. However, if such a grit contains fines within the explosible range, then part of the grit will also participate in an explosion. It has to be aware that coarse particles generate fines through abrasion. A lower limit for the content of fines in the coarse product that will not require measures for explosion protection cannot be given. The determining factor is always the amount of dust present or available for dispersion.

Higher **oxygen concentrations** result in more violent explosions and lower oxygen concentrations in less violent explosions. When inert gas is added to a dust-air mixture so that the oxygen content in the gaseous medium is lowered to the limiting oxygen concentration, dust explosions will not occur. The limiting oxygen concentration is characteristic for each dust type. For dust explosion the limiting oxygen concentration is markedly higher than that for dust fires.

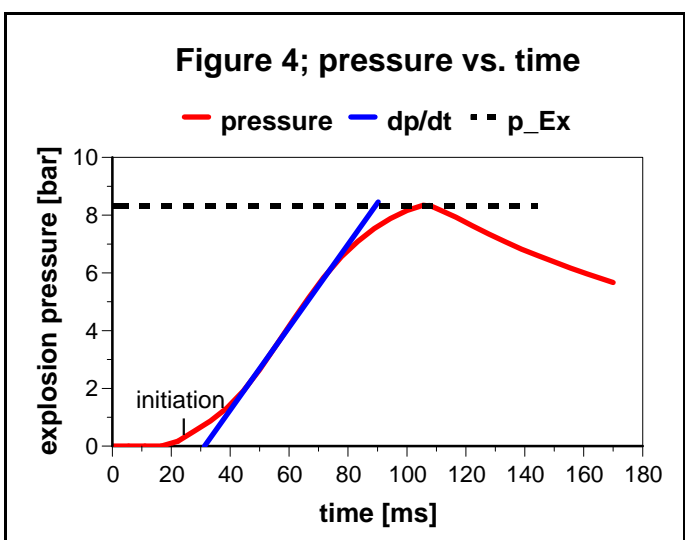




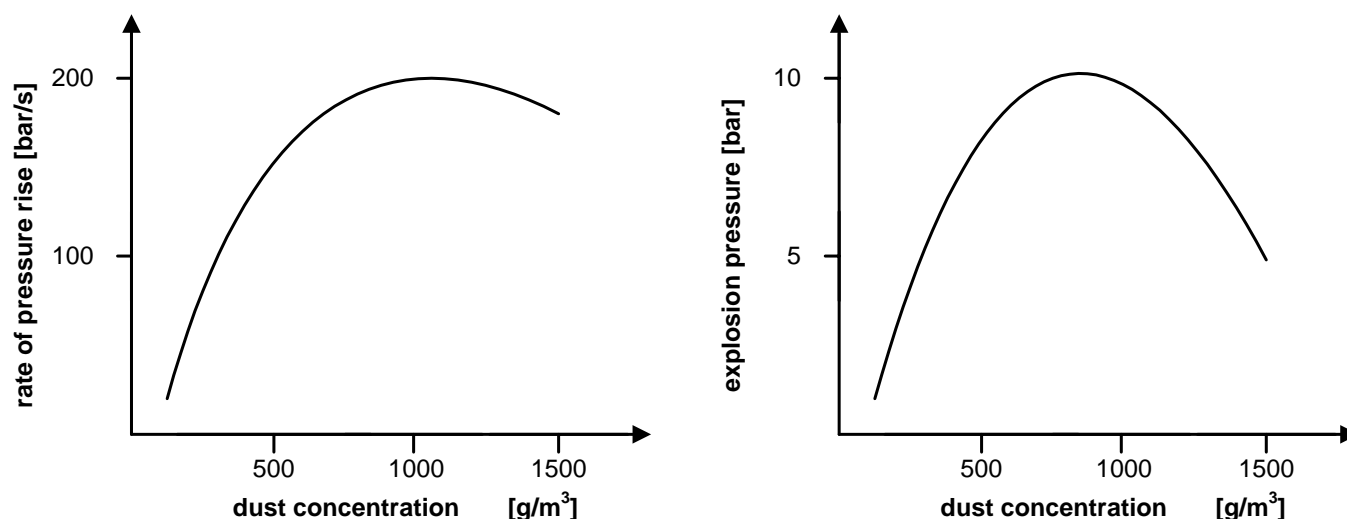
Figure 4 shows the **pressure vs. time curve** of a dispersed combustible powder. The parameters that characterise the curve are the explosion pressure  $p_{ex}$  and the highest rate of pressure rise  $dp/dt$ . If the parameters  $p_{ex}$  and  $dp/dt$  are plotted in relation to the dust concentration, the maximum explosion pressure, the maximum rate of pressure rise and the limits of the explosible range can be seen for a given powder (figure 5).

In a closed spherical vessel with volumes bigger than 20 litres with the ignition source that is placed in the centre, the maximal explosion pressure is nearly independent of the volume. On the contrary the maximum rate of pressure rise depends systematically on the volume of the vessel. For any given volume of a spherical vessel the maximum rate of pressure rise can be calculated by the so called cubic law

$$\frac{dp}{dt} \Big|_{\max} * V^{1/3} = K_{st}$$

where the  $K_{st}$ -value is a characteristic constant of a given powder. It is equal to the maximum rate of pressure rise in a closed vessel of 1 m<sup>3</sup>.

**Figure 5**



To give a rough idea of the order of magnitude of the explosion data the typical values of organic powders are

- 5 to 10 bar for the maximum explosion pressure
- 100 to 300 bar\*m/s for  $K_{st}$ -value

The explosion data –maximum explosion pressure and  $K_{st}$ -value– describes the course of an explosion of a powder in a closed system. These parameters are important for the design of protective measures such as explosion containment, explosion relief venting and explosion suppression.

However, these parameters do not tell us anything about the ignition hazard that is inherent in a given powder. The characteristic that defines the ignition hazard of a dust cloud with respect to a possible ignition by an ignition source is the **Minimum Ignition Energy (MIE)**.

Most powders show a natural charge separation mechanism, and when this manifests itself, it can very often lead to potentially hazardous and explosive situations.

Independent of the powder formulation and the conductivity of the equipment, most powders become charged during transport, handling and processing. This occurs when the powder resistivity lies above about  $10^8 \Omega \cdot m$ , a value which is surpassed by most organic powders.

Physical operations with powders, such as transport, filling, emptying, blending, milling etc, involve separation processes between the particles themselves, and the particles and the walls of the installations. As a result, contact charging is the main cause for the charge build-up on powders during industrial handling and processing.

The hazard of a charged powder is that its discharge may ignite an explosible atmosphere. Therefore, knowledge of the occurrence and incendivity of discharges during physical operations with powders is essential for safety assessments. Handling of powders has been proved to be prone to ignition and explosion.

An **elevated initial pressure** causes an increased explosion pressure and increased rate of pressure rise. This is to be expected whenever an explosion propagates from one vessel into another interconnected unit.

A **lowering of the initial pressure** reduces the explosion pressure.

A **temperature increase** at ambient pressure result in a decrease of the explosion pressure. Due to present experience, there will be only a minor influence upon the rate of pressure rise. The minimum ignition energy, the limiting oxygen concentrations and the lower explosible limit will be reduced.

The influence of **water content and content of inert solids** is smaller than generally assumed. A marked decrease of the violence of the explosion occurs only at relatively high contents of water or inert solids. However, many products with a water content of more than 10 % are hard to disperse. Therefore, the risk for the formation of an explosible dust air mixture from settled dust is reduced. The capability for dispersion may also be reduced by admixing other materials. In the case of metallic dusts the presence of moisture may generate hydrogen that will form an explosive mixture in air.

Dust air mixture with **higher turbulence** shows increased explosion violence.

**Elongated vessels or pipelines** may cause detonations that show much higher pressures and flame velocities than explosions.

- Explosions result in pressures of 10 bar and in flame velocities up to 500 m/s.
- Detonation leads to pressures up to 30 bar and flame velocities of up to 2000 m/s.

The coexistence of flammable gas or vapour and combustible dust in air is called **Hybrid Mixture**. Hybrid mixture occurs for example while using flammable solvents, while generating gas from overheated dusty products or by generating hydrogen from moist metallic dusts. Hybrid mixture causes larger explosion characteristics and shows smaller minimum ignition energies than plain dust/air mixtures. They may be explosible at concentrations that are below the lower explosible limits for the gases, vapours or dusts alone.

## 1.2 Risk analysis with powder processing in Multi-product plants

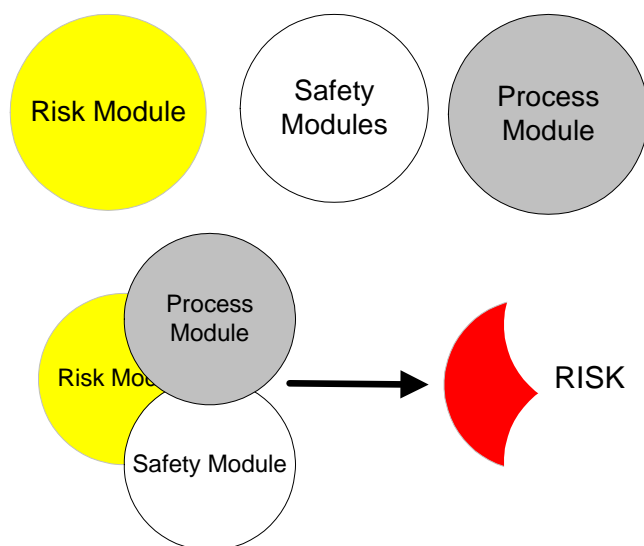
Very different chemical and physical processes are carried out in the same Multi-product installation. Control of the process is then to a large extent determined by the particular characteristics of the process in question and of the plant. There is a need to understand in what extent the process is handled by the plant and what role the operator plays.

Hence running physical processes with powders in Multi-product facilities ask for a systematic approach to assess their risks. State of the art is

- to be aware of the hazard potentials inherent in the physical processes with powders.
- to decide whether the given Multi-product facilities are able to handle the hazard potentials of the powder in question.
- to implement the proper technical and organisational measures and the proper personnel selections for a safe operation of the process steps derived from the knowledge of the hazard potentials.

The systematic approach consists in four tasks:

- **First**, visualising the inherent hazards of the process step on the base of testing results. The powder in question has to be classified into «Risk Modules».
- **Second**, visualising the capabilities of the plant. The plant that processes the powder has to be classified into «Process Modules».
- **Third**, visualising the safety that is needed to handle the process step in a specific plant. The available «Safety Modules» have to be visualised.
- **Fourth**, the Risk Modules, the Process Module and the Safety Modules have to be overlapped in order to visualise the potential risk.



### 1.3 Visualising the inherent hazards of the process step

It is difficult to approximate the hazard of a powder by examining case histories and carrying out computations. Also, there is no easy task to judge whether the operation will be safe when the powder is handled in a given plant. Experimental work is necessary to visualise the hazard that is associated with the handling of a powder in a process step.

The most reliable method of estimating the hazard potential of a powder regarding to ignition, fire, explosion and thermal decomposition is to carry out a combination of standard tests.

Knowledge of the danger of a powder involves understanding of the **tendency** to react hazardously and the danger of **violence** of decomposition, deflagration or explosion.

The **tendency with which a hazardous reaction occurs** varies with the external stimuli. Different types of hazard potentials are recognised.

**The tendency** with which a powder

- is ignited by external source of flame
- decomposes or ignites upon heating
- decomposes exothermically at elevated temperature
- releases spontaneously heat that triggers a homogenous thermal explosion

U.S. Chemical Safety and Hazard Investigation Board (CSB) reveals Material Safety Data Sheet (MSDS) Weaknesses in Addressing the Explosion Potential of Combustible Dusts.

MSDS are the primary document for communicating the hazards of a chemical compound, and convey these hazards from the manufacturer to the purchaser (employer), and from the employer to employees.

MSDS give information about the chemical compound, including its name(s) or components, emergency contact information, physical and health hazards, means of protecting workers from exposure, physical data, emergency and fire-fighting measures, and environmental information for the proper use and disposal of the material.

The investigations of CSB of the explosions that occurred in the US since 2000 have shown that the MSDS for the materials that exploded have inadequately communicated the combustible dust hazards. As a result the CSB reviewed the MSDS of 140 powders known to be combustible dusts to statistically determine if the problem of inadequate dust hazard communication is widespread.

Due to statistical studies approx. 59% of the MSDS random sample includes some remarks concerning the explosive hazard of the dust.

However, only 5% of the MSDS reference the appropriate NFPA standard for managing dust hazards.

None of the MSDS list physical properties of combustible dusts or explain why dusty conditions should be avoided (for example to minimise secondary explosion potential).

- decomposes, ignites or explodes due to ignition sources or by mechanical stimuli such as friction or impact
- decomposes according to a mechanism of deflagration or detonation.

Or **the tendency** with which

- a mechanically initiated decomposition triggers a deflagration or an explosion
- a hot spot triggers a decomposition reaction that leads to deflagration or detonation
- a shock wave initiates decomposition reaction
- a detonation propagates in the powder.

The **violence of decomposition**, which is closely related to the amount of actual damage, must be estimated while keeping in view with the manner with which the powder is handled. Characteristics for determining the violence of decomposition reactions are the rate of decomposition or explosion, the temperature and the rate of pressure attained, the amount of gas produced and the heat of reaction. These characteristics are affected not only by the type of powder, but also by the presence of additives, of its quantity, the method of storing, the size of packing unit, and the type of container.

#### **1.4 Nothing left to chance – SCHNYDER'S way to look at powder processes**

All the safety data that are needed to visualise the inherent fire, explosion and thermal stability hazards of the processed powder are evaluated with standardised test methods of our «**Powder Pack**» and «**Special Tests**».

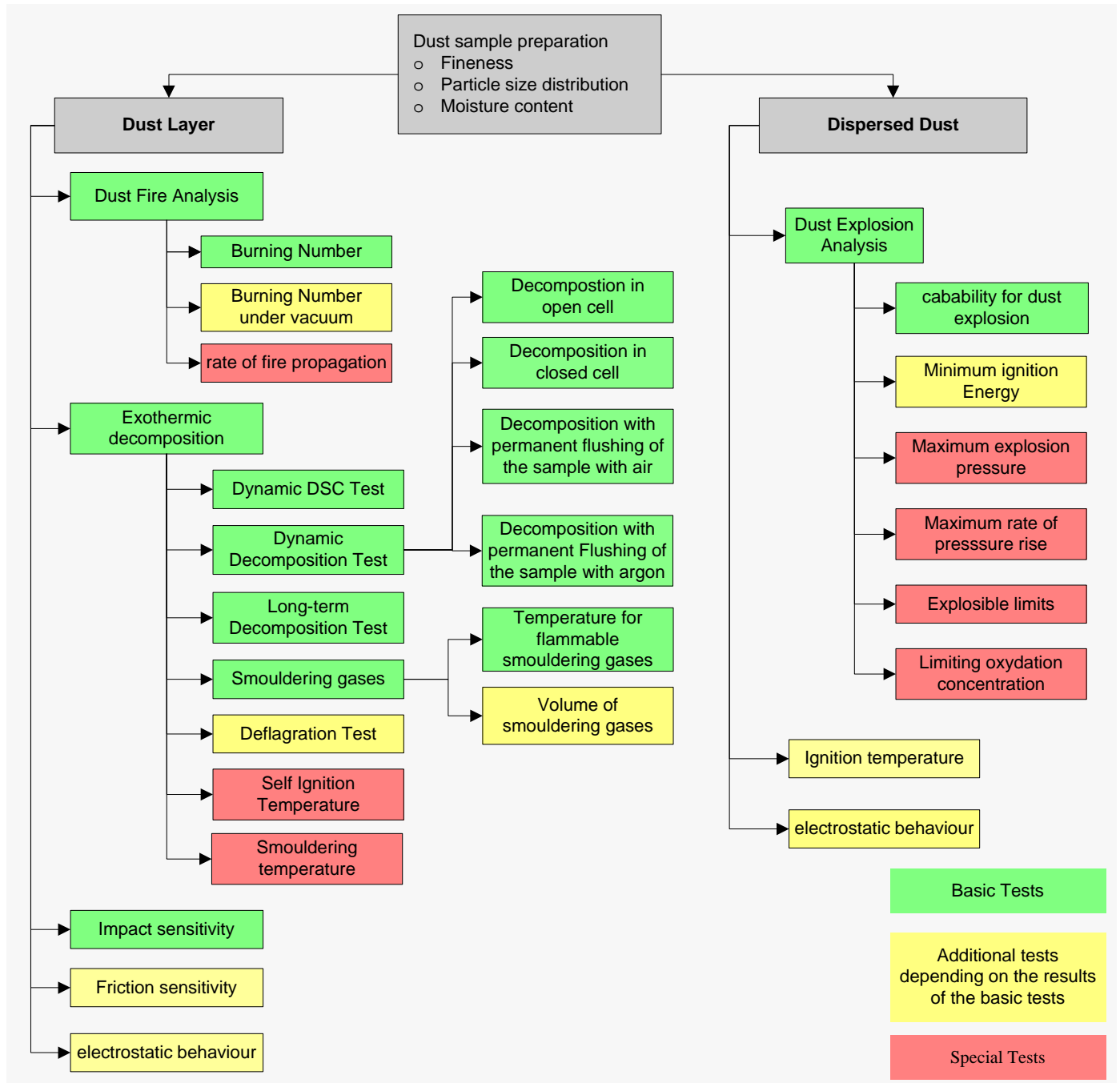
Tests are run for dust layer and for dispersed dust. The Powder Pack is divided in two parts:

- The «Basic Tests».
- The extent of «Additional Tests» depends on the results of the Basic Tests.

The testing results allow to visualise the inherent hazards of a powder by risk modules (see the following chapter). These form the basis for deciding whether the powder can be processed safely in the given plant with its existing safety measures.

This systematic approach to visualise the inherent hazard by processing powders is the result of long experience in this matter and is proven on our experience of working together with small to big-sized chemical industries. It allows our clients to decide whether the processing of a new product is well within the plant design criteria for a range of flammability and thermal stability properties. The Powder Pack allows our clients to do their safety assessment of the powder handling on an efficient manner.

The figure below shows our approach.



Result of Basic Test	Additional Test
Powder shows a spontaneous decomposition	Test for Volume of Decomposition Gas (VDI 2263)
Powder is suspected to deflagrate	<ul style="list-style-type: none"> <li>Deflagration Test (VDI 2263)</li> <li>Friction sensitivity</li> </ul>
Powder shows a positive Dust Explosion Test	<ul style="list-style-type: none"> <li>Minimum Ignition Energy for raised dust (EN 13821; VDI 2263)</li> <li>Minimum Ignition Temperature for raised dust (BAM)</li> <li>Powder resistivity (EC 93, EN 61241)</li> </ul>

**Special Tests for the assessment of special risks** comprise the tests to answer special questions to handle the very hazardous powders.

- Ignition Test in 400 ml Wire Basket (SIT400), VDI 2263
- Storage Test in 200 ml Dewar (VDI 2263)
- Smouldering Temperature according to EN 50281, where the maximum surface temperature derived from LTT is too conservative.
- Maximum Explosion Pressure and  $K_{St}$ -Value
- Explosible Limits
- Limiting Oxygen Concentration

### 1.5 Classification of the Risk Modules of the processed powder

On the base of the testing results the inherent hazards of a powder are visualised by risk modules.

We define the following Risk Modules:

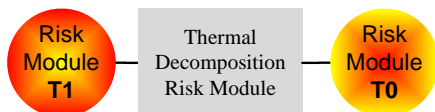
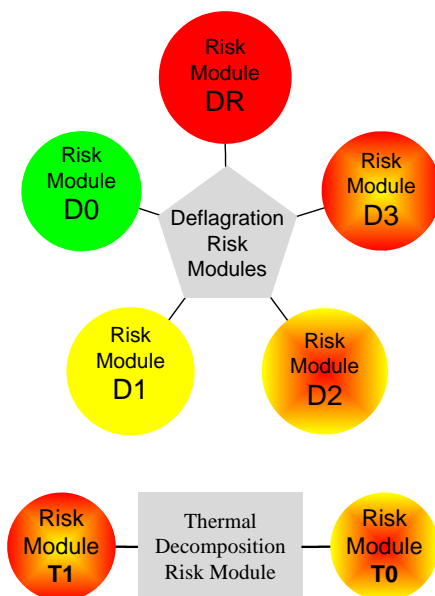
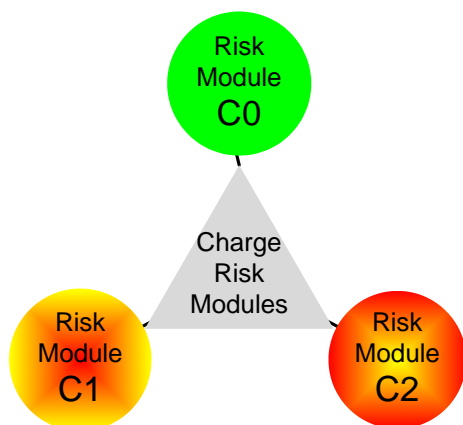
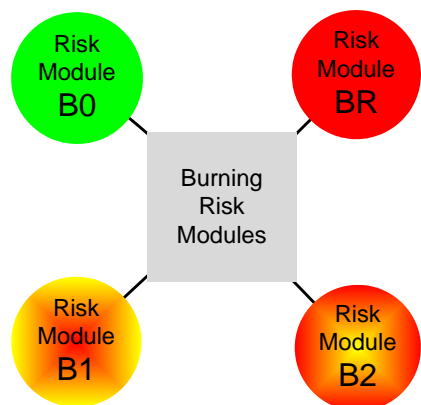
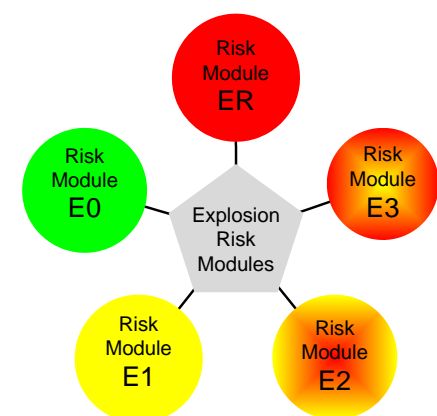
- Explosion Risk Module
- Burning Risk Module
- Thermal Decomposition Risk Module
- Deflagration Risk Module
- Charge Accumulation Risk Module

Due to the specific hazards of the powder the risk modules are subdivided into risk module-sections. Every risk module-section allows to analyse the process module that processes the powder and to define whether the safety modules are proper suited.

What the criteria are for the classification of the specific hazards and how the testing results are formed into risk modules is explained in chapter four.

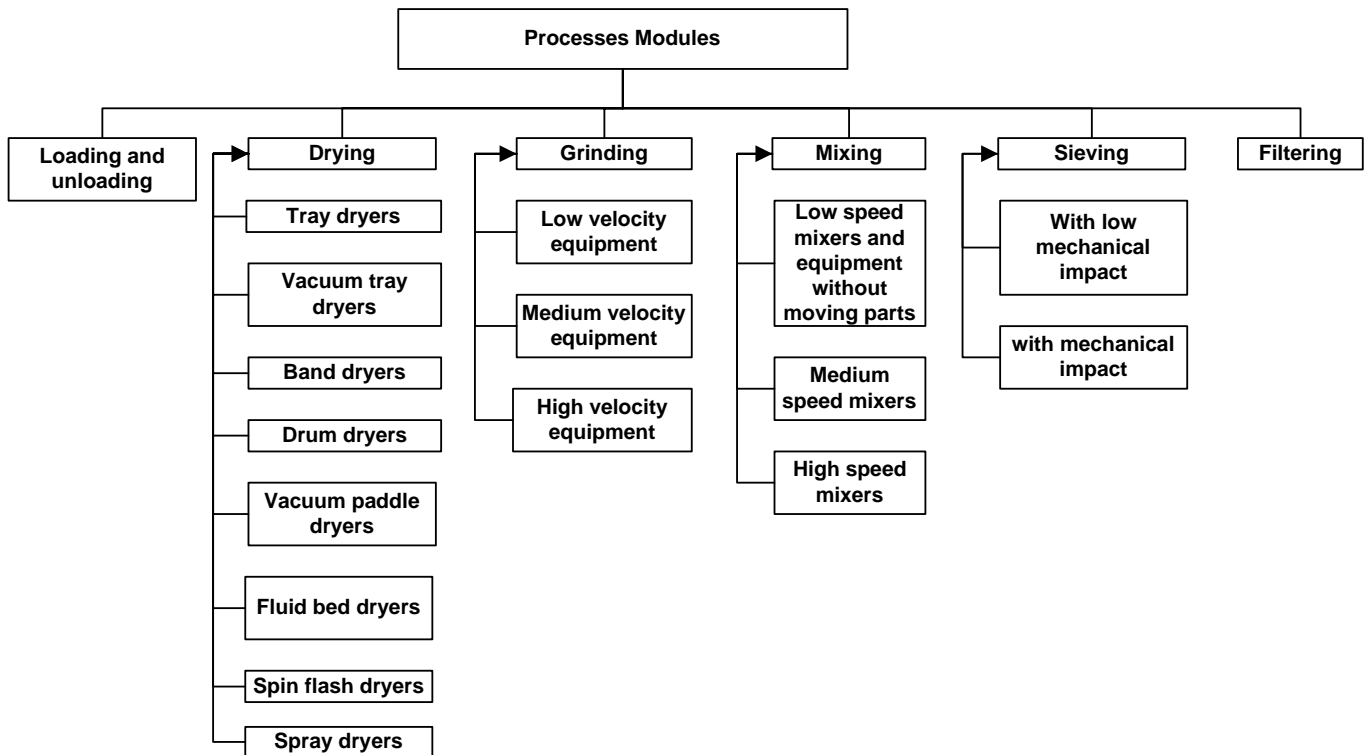
The classification to a risk module may change during the process.

- A solid may contain flammable solvents before drying but not after the drying process.
- A flammable solvent that is well bound in a solid may be released after a grinding process.
- Some granulation processes start with dry powder that is treated during the process with flammable solvents.



## 1.6 Classification of the Processes Modules

### 1.6.1 The Process Modules



### 1.6.2 Process Modules drying powders

Dryer	Principle	Mode	Moving of Powder	Atmosphere
Tray dryers	The solid is dried in ovens operating at normal pressure without mechanically treating	batch	Static powder layer	air/nitrogen
Vacuum tray dryers	Drying of the solid in ovens operating under a vacuum without mechanically treating.	batch	Static powder layer	vacuum
Band dryers	The solid is dried on a band that moves the solid through a heating chamber at normal pressure	continuous	Static powder layer	air/nitrogen
Drum dryers (Twin Cone Dryers)	The solid is dried under a vacuum in a container that rotates	batch	by rotating <sup>1)</sup>	vacuum
Vacuum paddle dryers	The solid is dried under a vacuum with permanent stirring	batch	by stirring	vacuum
Fluid bed dryers	The solid is dried in a fluid bed with or without vibrating	batch or continuous	by air/nitrogen	air/nitrogen
Spin flash dryers	Drying of mechanically divided paste in a rotating air flow «spin», with very short residence time «flash»	continuous	by stirrer and by air/nitrogen	air/nitrogen
Spray dryers without or with wall sensors <sup>2)</sup>	Co-current disk or nozzle spray dryer	continuous	by air/nitrogen	air/nitrogen

<sup>1)</sup> The mechanically treating of the powder is low.

<sup>2)</sup> The thermal exposure of the wall deposits is monitored by at least two temperature sensors, which are installed in the spray dryer at the same height in opposite positions at the distance of about 5 to 10 cm from the wall at the hottest spot where wall deposits are expected to be formed. Temperature limits can be set for all sensors. When one of the sensors detects that a temperature limit is attained or when the parity check indicates an irregular temperature difference the heating of the inlet air, but not the fans, is switched off and if possible feeding is immediately switched from product feed to water feed. At the same time the attainment of the temperature limit must be indicated by an easily detectable alarm signal.

In general, the maximum drying time is limited to 72 hours. For drying time that last longer than 72 hours special assessments are necessary.

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### 1.6.3 Process Modules Mixing, Sieving, Grinding

**Process Conditions:** The powder is treated with or without mechanical impact on the solids. There is no thermal heating of the solid. The maximum bulk temperature of the solid is 90 °C. The following apparatus are considered:

- **Mixers:** High speed mixers, turbo mixers, gravity mixers, drum or barrel mixers double cone mixers, tumbling mixers, screw-belt mixers, conical screw mixers, trough mixers
- **Sieves:** shaking, oscillating, brushing and vibrating sieves, attrition or granulating sieves
- **Mills:** Primary crushers, Swing-hammer crushers, Swing-hammer and beater mills, Impact crushers, Turbo mills, Fitzmills, Inclined Bar Turbo mills, Pin-Disc mills, Cross Beater mills, Pin mills, Vibrator mills, Vibration Grinding mills, Ball mills.
- **Screw conveyors**

The safety relevant characteristics of the apparatus can be differentiated as follows:

- **High velocity equipment:** Moving parts of the equipment with a relative velocity  $>10$  m/s are in contact either with the bulk material or with explosive mixtures of combustible powders or flammable vapours and air.
- **Medium velocity equipment:** Moving parts of the equipment with a relative velocity 1 to 10 m/s are in contact either with the bulk material or with explosive mixtures of combustible powders or flammable vapours and air.
- **Low velocity equipment and equipment without moving parts:** The equipment does not contain any moving parts or the moving parts in contact either with the bulk material or with explosive mixtures of combustible powders or flammable vapours and air have a relative velocity  $<1$  m/s.

### 1.6.4 Process Modules Filtering

**Process Conditions:** Separation of solid particles from process gas or dust extraction streams. Collecting the solids below filters. An explosive atmosphere prevails at least for short times during operation or when cleaning off the filter elements.

**Filter Apparatus:** Cloth-, Bag-, Candle- or Cassette-Filters. The apparatus can be classified as follows:

- **Process Off-Gas or Dust Extraction Filters:** Volume (entire case) up to 1000 m<sup>3</sup>, gas flow 1 to 1000 m<sup>3</sup>/min.
- **Small mobile Filters (for example in Vacuum Cleaners):** Volume (entire case) up to 0.01 m, gas flow  $< 3$  m<sup>3</sup>/min.



## 1.7 Safety Modules

### 1.7.1 Safety Module 1, General Measures

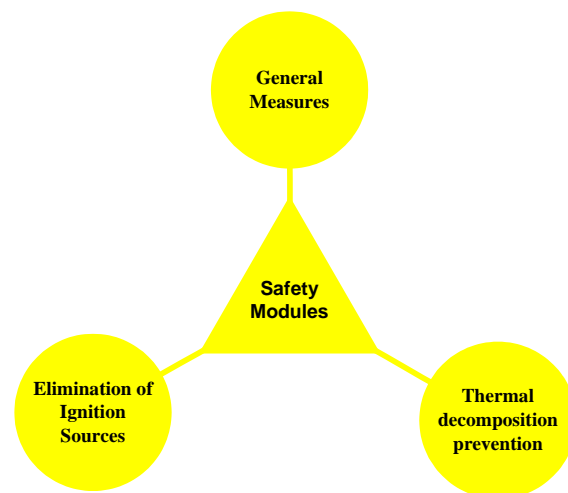
**Personal Protection:** Appropriate **Personal Protection Equipment** shall be used for open handling of powders.

Where inert gas blanketing is applied, measures are necessary to avoid exposure of personnel to oxygen deficient atmospheres. Examples are: The application of proper procedures for start-up, shutdown and process interruptions (to avoid release of inert gas into the production room) or the application of oxygen detectors.

Measures are necessary to avoid unprotected contact of personnel with hot surfaces of process equipment or hot process gas.

Protective devices should be in place to avoid mechanical injury such as squeezing and cutting due to moving parts from stirrers, choppers and rotating drums.

**Ex-Zones:** The likelihood of the presence of flammable mixtures of dust and or flammable vapours in all parts of the plant is described in agreement with international standards according to the following scheme:



explosive flammable gas or vapours	Zone <sup>1)</sup>	Class / Division <sup>2)</sup>	explosive dust clouds	Zone	Class / Division <sup>2)</sup>
A	0	I/1	A	20	II/1
B	1	I/1	B	21	II/1
C	2	I/2	C	22	II/2
D			D		

<sup>1)</sup> according to European Standard EN-1127, EU-Directive 94/6/EC

<sup>2)</sup> Fire Code of the National Fire Protection Association NFPA Code 69, NFPA Code 654 (USA)

A	occurs continuously or for long periods or frequently
B	is likely to occur in normal operation
C	is not likely during normal operation. If it occurs it will exist only for a short period.
D	does not occur

Normal operation includes all procedures associated with the function for which the system is intentionally used. It includes also the start-up, shut down, loading and unloading processes.

**Maintenance:** Safety installations, such as inerting and temperature limit monitoring system, have to be incorporated into the established maintenance program. Visual checks for damage of moving parts must be carried out on a regular basis. More comprehensive tests, for example check of unbalance, searches for hair cracks are required according to the manufacturer's recommendation.

A «permit to work system» shall be implemented and used to ensure that hot work is not carried out in areas with a high fire bad or in Ex-Zones without special precautions.

## 1.7.2 Safety Module 2, Elimination of Ignition Sources

In areas and during process phases where explosive atmospheres prevail, ignition sources for gas and dust explosions must be eliminated as described below.

The following ignition sources are considered:

Ignition source	incentive for		
	flammable gases and vapours	combustible dusts	deposits and layers of combustible powders
open flames	always	always	always
hot surfaces	If the temperature is above the MIT of the gas/vapour <sup>1)</sup> usually >500 °C	If the temperature is above the MIT of the dust <sup>2)</sup>	If the temperature is above the SIT <sup>3)</sup> for the respective layer thickness
impact and friction	see mechanical sparks	see mechanical sparks	In case of impact or friction sensitive powders. When handling deflagrating powders.
mechanical sparks	always	If the relative velocity of the moving parts is >1 m/s <sup>4)</sup> and the dust explosion test is positive or has a MIT <600°C <sup>5)</sup> .	Whenever the combustibility index is >3.
electrical sparks	always	If the equivalent energy of the discharge is larger than the MIE of the dust.	Whenever the combustibility index is >3.
static electricity	always	If the equivalent energy of the discharge is larger than the MIT of the dust. Propagating brush discharges, sparks and cone discharges are to be considered <sup>6)</sup> .	usually no hazard
chemical reactions, self ignition of dusts	always	Glowing nests with a surface 25 cm <sup>2</sup> such nests are to be expected only if the combustibility index is >3.	

<sup>1)</sup> Safety margin (80% of the MIT in °C obtained under standard conditions)

<sup>2)</sup> Safety margin (66% of the MIT in °C obtained under standard conditions)

<sup>3)</sup> Safety margin 75 °C

<sup>4)</sup> For relative velocities between 1 m/s and 10 m/s a special assessment is necessary

<sup>5)</sup> A more detailed analysis requires knowledge of the materials involved in friction, the MIE and the MIT of the dust

<sup>6)</sup> See Technical Glossary

MIT means Minimum Ignition Temperature

SIT means Self Ignition Temperature

MIE means Minimum Ignition Energy

The occurrence of ignition sources is assessed using the following scale.

For the assessment only those ignition sources are considered which could ignite the respective atmosphere or layer. The minimum requirements with respect to elimination of incentive ignition sources are based on the assessment.

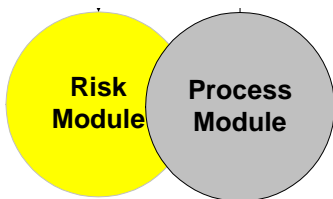
		explosive atmosphere			
		1: occurs continuously or for long periods or frequently			
		2: is likely to occur in normal operation			
		3: is not likely in normal operation; if it occurs it will exist only for a short period			
		4: does not occur			
		1	2	3	4
ignition source	A				
	B				
	C				
	D				
A: occurs during normal operation					
B: does not occur during normal operation but only as a result of rare malfunctions					
C: does not occur during normal operation but only as a result of very rare malfunctions					
D: does not occur					

	acceptable
	A protection concept is required which reduces the occurrence of an explosive atmosphere and/or the occurrence of incentive ignition sources so that an acceptable situation is achieved. A single measure/system is usually sufficient.
	A protection concept is required which reduces the occurrence of an explosive atmosphere and/or the occurrence of incentive ignition sources so that an acceptable situation is achieved. Usually this requires a fail-safe protective measure system, or two independent measures systems, with the result that in case of failure of one of them, the situation is still acceptable.

### 1.7.3 Safety Module 3, Thermal decomposition prevention

Due to the instability of the material to be dried, the drying temperature has to be controlled. The correct placements of temperature sensors for a given dryer are determined according to the following table.

Dryer Type	Heating medium	Inlet Air Temperature	Outlet Air Temperature	Wall Temperature
Tray dryers	yes			
Vacuum tray dryers	yes			
Band dryers		yes	yes <sup>2)</sup>	
Drum dryers (Twin Cone Dryers)	yes			
Vacuum paddle dryers	yes			
Fluid bed dryers		yes	yes <sup>2)</sup>	
Spin flash dryers		yes	yes <sup>2)</sup>	
Spray dryers without wall sensors		yes <sup>1)</sup>	yes	
Spray dryers with wall sensors			yes	yes
<sup>1)</sup> Inlet temperature determined by the plant manager, if wall deposits can be excluded.				
<sup>2)</sup> may be used as a redundant temperature control where required				



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## 2 Overlap Risk Modules and Process Modules

### 2.1 Overlap Risk Module and Process Module drying solids

The needed protection concepts depend on the **Explosion Risk Module** and the **Equipment Type**.

#### 2.1.1 Drying powders with Risk Module ER, BR, or DR

A special risk assessment is required when processing powders that show risk modules ER, BR, or DR.

#### 2.1.2 Drying powders with Risk Module E3

**Used Dryer:** Tray dryers, Band dryers, Fluid bed dryers, Spray dryers without and with wall sensors.

- Areas inside the equipment, where an explosive atmosphere may be formed are preferably inert in order to avoid a gas or dust explosion.
- If inerting of the system is not possible, adequate protective measures<sup>1)</sup> have to be taken against the effects of a possible explosion.
- Ignition sources are eliminated according to Safety Module 2.

**Used Dryer:** Vacuum tray dryers, Drum dryers (Twin Cone Dryers) and Vacuum paddle dryers:

- During loading the dryer measures are taken to avoid the formation of explosive vapour-air mixtures or hybrid mixtures, for example by ventilation or inert gas blanketing.
- During the process, the explosion risk is reduced by applying vacuum. Heating may only be started after the pressure is reduced to <100 mbar or to the vapour pressure of the solvent to be removed. Non-return valves should prevent back flow of air into the dryer in case of a failure of the vacuum pump. In case of failure of the vacuum the formation of an explosive vapour atmosphere should be avoided, for example by automatic inerting or adequate ventilation. The dryer is equipped with a pressure relief device for the case of plugging of the vapour filter (for example release of lid after evacuation, special port where the lid is held by vacuum only).
- Ignition sources are eliminated according to Safety Module 2.

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<sup>1</sup> For example explosion venting, explosion pressure resistant design or explosion suppression in combination with measures to disengage the explosion. Design of protective measures must be made on the basis of safety data (K-values) by specialists following acknowledged codes (e.g. VDI or NFPA standards). As a standard, design should be made for K-values up to 299 bar\*m/s. Lower specifications are allowed, as long as it is shown that only products with K-values up to the design value are handled. The design documentation must be available. The effect of residual solvent on the K-value is to be considered. For small equipment simplified protection concepts (shields, hazard zones, safety cabins) may be applied.

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### 2.1.3 Drying Powder with Risk Module E1 and E2

**Used Dryer:** Fluid bed dryers, Spin flash dryers, Spray dryers without wall sensors and Spray dryers with wall sensors.

- Either Inert gas blanketing is applied in areas inside the equipment, where an explosive atmosphere may be formed.
- Or Adequate protective measures<sup>2)</sup> are taken against the effects of a possible explosion.

Ignition sources are eliminated according to Safety Module 2.

**Used Dryer:** Tray dryers and Band dryers

- Neither Inert gas blanketing for areas inside the equipment, where an explosive atmosphere may be formed.
- Nor Protective measures<sup>2)</sup> are required.

Ignition sources are eliminated according to Safety Module 2.

**Used Dryer:** Vacuum tray dryers, Drum dryers (Twin Cone Dryers) and Vacuum paddle dryers

- During the process, the explosion risk is reduced by applying vacuum. Non-return valves should prevent back flow of air into the dryer in case of a failure of the vacuum pump. In case of failure of the vacuum, an easily detectable alarm is triggered.
- The dryer is equipped with a pressure relief device for the case of plugging of the vapour filter (for example release of lid after evacuation, special port where the lid is held by vacuum only).

Ignition sources are eliminated according to Safety Module 2.

## 2.2 Overlap Risk Modules and the Modules Mixing, Sieving, Grinding

### 2.2.1 Special Risk Assessment

A special Risk Assessment is required when processing all solids with Risk Modules ER, BR or DR.

### 2.2.2 Selection of the protection concept

The needed protection concepts depend on the Explosion Risk Module and the equipment type:

- **Required for powders with risk module E3:** For High velocity equipment and Medium velocity equipment, the areas inside the equipment, where an explosive atmosphere may be formed are preferably inert in order to avoid a gas or dust explosion. If inerting of the system is not possible adequate protective measures<sup>3)</sup> have to be taken against the effects of a possible explosion.

Ignition sources are eliminated according to Safety Module 2.

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<sup>2)</sup> See footnote 1

<sup>3)</sup> See footnote 1

- 
- **Required for Powders with risk modules E1, E2 and E3:** For High velocity equipment, Medium velocity equipment and Low velocity equipment and equipment without moving parts.

Either Inert gas blanketing is applied for areas inside the equipment, where an explosive atmosphere may be formed

Or Adequate protective measures<sup>4)</sup> against the effects of a possible explosion are taken.

Ignition sources are eliminated according to Safety Module 2.

- **Required for Powders with risk modules E1, E2:** For Medium velocity equipment and Low velocity equipment and equipment without moving parts.
- If ignition sources can not be eliminated reliably according to Safety Module 2 inert gas blanketing is applied for areas inside the equipment where an explosive atmosphere may be formed or adequate protective measures<sup>5)</sup> are taken against the effects of a possible explosion.

## 2.3 Overlap Risk Modules and Filtering Modules

### 2.3.1 Special Risk Assessment

A special Risk Assessment is required when processing powders with Risk Modules ER, BR or DR.

### 2.3.2 Selection of the Protection Concept

The needed protection concept depends on the Explosion Risk Module and the equipment type:

### 2.3.3 Process Off-Gas or Dust Extraction Filters

- **Required for risk module E3:**

Either areas inside the equipment, where an explosive atmosphere may be formed are inert.

Or appropriate protective measures against the effects of a possible explosion<sup>6)</sup> are in place.

- **Required for risk modules E1, E2:**

Either areas inside the equipment, where an explosive atmosphere may be formed are inert.

Or appropriate protective measures against the effects of a possible explosion<sup>7)</sup> are in place.

Or Ignition sources are eliminated reliably according to Module 2. The ventilator and its drive<sup>8)</sup> are installed on

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<sup>4)</sup> See footnote 1

<sup>5)</sup> See footnote 1

<sup>6)</sup> See Technical Glossary

<sup>7)</sup> See Technical Glossary

<sup>8)</sup> This applies also to other mechanical parts with relative speeds of >1 m/s

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the clean air side or upstream of the dust source and an accidental breakthrough of the filter is detected and the respective alarm stops the process.

- Possible solutions are:
  - ❖ Detection of the pressure drop across the filter
  - ❖ Detection of particles on the clean-air side of the filter
  - ❖ The installation of a «police-filter» (small filter down stream of the main filter, before the ventilator) which is periodically controlled.

#### 2.3.4 Small mobile Filters (for example in Vacuum Cleaners)

- **Required for risk module E3:**

Either areas inside the equipment, where an explosive atmosphere may be formed are inert.

Or appropriate protective measures against the effects of a possible explosion<sup>9)</sup> are in place.

Or Ignition sources are eliminated reliably according to Module 2. The ventilator and its drive<sup>10)</sup> are installed on the clean air side or upstream of the dust source and an accidental breakthrough of the filter is detected and the respective alarm stops the process.

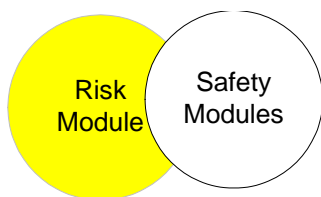
- Possible solutions are:
  - ❖ Detection of the pressure drop across the filter
  - ❖ Detection of particles on the clean-air side of the filter
  - ❖ The installation of a «police-filter» (small filter down stream of the main filter, before the ventilator) which is periodically controlled.
- **Required for risk module E1, E2:**

Ignition sources are eliminated reliably according to Module 2. The ventilator and its drive are installed on the clean air side or upstream of the dust source.

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<sup>9</sup> See Technical Glossary

<sup>10</sup> This applies also to other mechanical parts with relative speeds of >1 m/s



### 3 Taking the Safety Modules into consideration

#### 3.1 Considering Safety Module 1, the General Measures

##### 3.1.1 Electrical and mechanical Equipment

The installation of the equipment must fulfil the regulations on explosion protection. For new or modified equipment only certified equipment should be installed:

- Required for risk modules E1 and E2:

Zone	20	21	22
Category (EU)	DG1	DG1,2	DG1,2,3
Category (US)	CL II, Div 1	CL II, Div 1	CL II, Div 2
Groups (US)	E, F, G		

- Required for risk module E3:

Zone	0	1	2
Category (EU)	DG1	G1,2	G1,2,3
Groups (EU)	IIA, IIB, IIC <sup>1)</sup>		
Category (US)	CL I, Div 1	CL I, Div 1	CL I, Div 2
Groups (US)	A B C; D OR IIA, IIB, IIC		

<sup>1)</sup> IIC applied only to Risk Module R

##### 3.1.2 Ex Zones

- **Required for risk module E3:** Ex-Zones (Zones 0, 1 and 2 for flammable vapours and hybrid mixtures) must be defined and ignition sources must be excluded according to the respective zones.
- **Required for risk modules E1 and E2:** Ex-Zones (Zones 20, 21 and 22 for combustible dusts) must be defined and ignition sources must be excluded according to the respective zones.

##### 3.1.3 Fire Protection and Emergency Measures

- **Generally required for all risk modules:** A non-smoking policy must be implemented to ensure that open flames are avoided in areas with a high fire load or in Ex-Zones without special precautions.
- **Required for risk modules B1, B2, E1, E2 and E3:** For non inert areas of the equipment rapid fire suppression must be ensured. The extinction capacity must be adequate for the fire load and the extinguishing medium must be suitable for the product.
- **Required for risk modules D1, D2 and D3:** Rapid fire suppression must be ensured, even in inert equipment. The extinction capacity must be adequate for the fire load and the extinguishing medium must be suitable for the product.
- **Required for risk modules B2, D1, D2 and D3:** For equipment, which is not inert, fast switching off (from a remote place or automatically) in case of a fire must be ensured unless there is a permanent supervision during the process by operating personnel.



- **Required for risk modules D1, D2 and D3:** Fast shut down of the process in case of a fire or an explosion must be ensured even in inert equipment unless there is a permanent supervision during the process by operating personnel.
- **Required for risk modules D1, D2 and D3:** If the preceding operation includes heating of or mechanical stress on the product mobile containers, barrels or packages into which the solid is transferred must be kept for at least 24 h in a controlled area provided with rapidly available fire fighting equipment before shipping or storage in a warehouse (guarantee).
- **Required for risk modules D2 and D3:** Fire detectors must be mounted in the room or in the equipment. Where permanent presence of operators is ensured fire alarm push buttons are a possible alternative.

## 3.2 Considering Safety Module 2, Elimination of Ignition Sources

### 3.2.1 Glowing particles

- **Required for all risk modules:** In equipment, which is directly heated by gas flames appropriate retaining devices must be provided to avoid the transfer of glowing particles into areas where explosive mixtures may occur or where combustible materials are present.
- **Required for risk modules E1, E2, E3 combined with B2:** If solid is directly fed from dryers (continuous mode) or equipment exerting high mechanical stress on the product (e.g. mechanical mills) into containers, which are

Neither Inert

Nor Protected <sup>11)</sup> against the effects of an explosion

Measure It must be ensured that the process is stopped if glowing particles are identified. A possible measure is IR detection and separation in the transfer channel.

### 3.2.2 Mechanical Ignition sources

Applied only for equipment types: Vacuum Paddle Dryers, Spin Flash Dryers, Spray Dryers (with and without wall sensors), High velocity equipment and Medium velocity equipment.

- **Required for risk module E3:** It is difficult to eliminate mechanical sparks reliably, because ignition can not be ruled out even at relative velocities  $v_{rel} < 1$  m/s. Therefore measures according to chapter 1.7.1 must be taken, see protection concept.
- **Required for risk module E2:** Deviations from normal operation which result in friction between moving parts of the equipment in locations where explosive mixtures may occur must be avoided, for example by

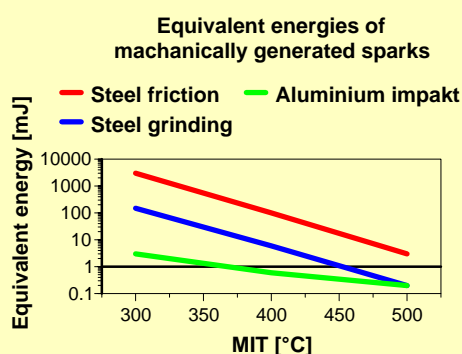
**Mechanically generated sparks** are the most common cause of explosion. Mechanical sparks arise when hard foreign objects get into an apparatus with moving parts. Mechanical sparks are glowing particles that emerge due to mechanical treatment of a metal surface and not the hot surface resulting during the separation process. Three types of spark can be distinguished.

- **Grinding sparks** arise when materials are pressed for a short time (20 to 50 ms) against a ceramic-bonded grinding wheel.
- **Impact sparks** caused by violent impact of different material combinations against each other.

<sup>11</sup> See footnote 1

- **Friction sparks** -particularly steel friction sparks- arise when different metals at high relative velocity and for times of about 0.5 to 2 seconds are rubbed together.

The ignition behaviour of mechanically generated sparks of dust air mixtures depends on the minimum ignition energy (MIE) and the minimum ignition temperature (MIT) on the processed powder. The effectiveness of these sparks decreases from steel friction sparks to steel grinding sparks to aluminium impact sparks. The figure below shows that the type of sparks producing material, together with the MIT and the MIE of the processed powder, determines whether an ignition of a dust air mixture has to be anticipated from grinding, friction or impact sparks. The different sparks can be assigned different «equivalent ignition energies» towards dust air mixtures with an MIT of less than or equal to 500 °C. For example, if the MIT of a powder is 300 °C, steel friction sparks can ignite the resulting dust air mixture only with an MIE (equivalent energy) up to 3000 mJ. The equivalent ignition energy is the amount of energy which, when transformed into an electrical spark discharge, has the same incentive as the sparks shown in the figure below.



**Practical Relevance:** For assessing whether or not a powder can be processed in a given facility, the MIE and the MIT of the processed powder must be known. Powders with values that are below the corresponding curve can be ignited.

- ❖ monitoring and limiting the power consumption of the drive
- ❖ limiting the momentum of the drive
- ❖ protection against foreign bodies (e.g. with a sieve, safety pre crushers, metal separators)
- ❖ detecting possible unbalance of spinning disks in spray dryers.

There is no risk from mechanical sparks at relative velocities  $v_{rel} < 1$  m/s.

- **Required for risk module E1:** Deviations from normal operation which result in friction between moving parts of the equipment in locations where explosive mixtures may occur must be avoided, for example by

- ❖ monitoring and limiting the power consumption of the drive
- ❖ limiting the momentum of the drive
- ❖ protection against foreign bodies (e.g. with a sieve, safety pre crushers, metal separators)
- ❖ detecting possible unbalance of spinning disks in spray dryers

There is no risk from mechanical sparks if

$$v_{rel} < 1 \text{ m/s or}$$

$v_{rel} 1\text{-}10 \text{ m/s}$  **and**  $MIT_{Dust}$  is lower than the following values depending on the Minimum Ignition Energy (MIE)<sup>12)</sup>

MIE [mJ]	3-10	10-30	30-100	100-300	300-1000	>1000
MIT [°C]	<500	<465	<430	<395	<360	<325

### 3.2.3 Static Electricity

- **Required for risk modules E1, E2 and E3:** In Ex-Zones all parts of the equipment made of electrostatically conductive material must be grounded. This includes any filter elements and conductive mobile items such as containers, trolleys or flaps.
- **Required for risk modules E1, E2 and E3:** The selection of containers shall comply the state of art on «Admittance of Packages for Flammable Products Regarding the Ignition Hazards due to Static Electricity».
- **Required for risk modules E2 and E3:** In order to avoid static sparks from the operators the following measures must be taken for loading and unloading.

In **Zones 0, 1, 20 and 21** the floor must be conductive (leakage resistance  $< 10^8$  Ohm) and all operating personnel must wear conductive footwear (leakage resistance  $< 10^8$  Ohm).

- **Required for risk modules E1, E2 and E3:** Non-conductive liners (thickness  $< 9$  mm) and non-conductive ducts (wall thickness  $< 9$  mm)

<sup>12)</sup> determined with inductance

where intense charge separations occur (e.g. due to pneumatic transfer, transfer by gravity via loading chutes longer than 3 m, stirring, fluidising), must have a breakdown voltage <4 kV.

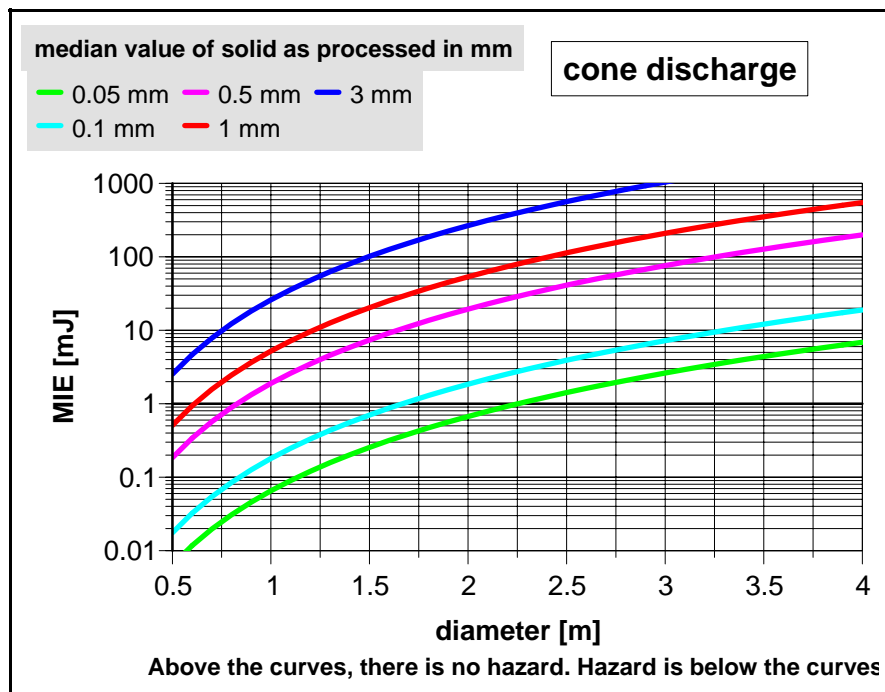
- **Required for risk modules E3:** The size of non-conductive parts such as windows and pipes must be limited as follows <sup>13</sup>:

Zone	0	1
Maximum area of non-conductive surfaces [cm <sup>2</sup> ]	25	100
Maximum area of non-conductive surfaces surrounded by a grounded conductive frame [cm <sup>2</sup> ]	25	400
Maximum diameter of non-conductive elongated structures (pipes, cables) [mm]	3	30

- **Required for risk modules E1, E2 and E3:** If the bulk resistivity >10<sup>10</sup> Ωm (risk module C2), filling powders into containers or equipment having a diameter which is larger than the value given in the graph for the respective MIE (**M**inimum **I**gnition **E**nergy [mJ]) and M (median value of solid as processed in mm) bears the risk of hazardous cone discharges.

- **Required for risk modules E1 and E2:** Appropriate countermeasures are

- ❖ Using a smaller container.
- ❖ Inserting earthed elements (wires, rods) into the silo/container to reduce the distance to the next earthed point.
- ❖ Carrying out such operations under inert conditions.
- ❖ Filling solids by gravity in small portions (e.g. bags of 25 kg) in intervals of one minute and observing a relaxation time of 15 minutes after 20 portions (this measure is not sufficient for highly insulating polymer powders and granules). Limiting the total amount of solid that is loaded by gravity (loading chute <3m) to 500 kg.



- **Required for risk module E3:** Remember that MIE for hybrid mixtures can be considerably lower than for the respective powder without flammable vapour. MIE decreases with increasing temperature. Such operations involves the risk of brush discharges and should be carried out under inert conditions.

### 3.2.4 Hot Surfaces

- **Required for risk module E3:** The maximum surface temperature in Ex-Zones must not exceed

<sup>13</sup> See TRBS 2153 (Technische Regeln für Betriebssicherheit), for bent non-conductive surfaces, e.g. collars. Formerly regulated under BGR 132.

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$$T_{\text{surface,max}} \leq 66\% \text{ of MIT}_{\text{dust}} [^{\circ}\text{C}] \text{ and}$$

$$T_{\text{surface,max}} \leq T_{\text{smouldering,5 mm}} - 75 \text{ } ^{\circ}\text{C} \text{ and}$$

$$T_{\text{surface,max}} \leq \text{AIT}_{\text{vapour}}^{14)}$$

With respect to heating powders in dryers should be noted that the desired result is achieved by applying the measures listed in Safety Module 3. However, hot spots like heat bridges<sup>15)</sup> or window lamps require special assessments.

- **Required for risk modules E1 and E2:** The maximum surface temperature in Ex-Zones must not exceed

$$T_{\text{surface,max}} \leq 66\% \text{ of MIT}_{\text{dust}} [^{\circ}\text{C}] \text{ and}$$

$$T_{\text{surface,max}} \leq T_{\text{smouldering,5 mm}} - 75 \text{ } ^{\circ}\text{C}$$

whichever is lowest. With respect to heating powders in dryers should be noted that the desired result is achieved by applying the measures listed in Safety Module 3. However, hot spots like heat bridges<sup>16)</sup> or window lamps require special assessments.

### 3.3 Considering Safety Module 3, Thermal Decomposition

#### 3.3.1 Temperature Limits

- **Required for risk module T0:** The temperature limit(s) determined above must not be higher than the following values, based on LTT, or that based on SIT400, whichever is selected<sup>17)</sup>:

$$T_{\text{limit}} \leq \text{LTT} - 20 \text{ } ^{\circ}\text{C} \text{ or } \text{SIT400} - 20 \text{ } ^{\circ}\text{C}$$

- **Required for risk module T1:** For batch processes the temperature limit(s) determined above depend on the drying time  $t_{\text{dry}}$ <sup>18)</sup>. They must not be higher than the following values, based on LTT, or the value based on SIT400, whichever is selected:

$$t_{\text{dry}} \leq 24\text{h} \quad T_{\text{limit}} \leq \text{LTT} - 30 \text{ } ^{\circ}\text{C} \text{ or } \text{SIT400} - 20 \text{ } ^{\circ}\text{C}$$

$$t_{\text{dry}} \text{ lasts } 24 \text{ to } 48\text{h} \quad T_{\text{limit}} \leq \text{LTT} - 40 \text{ } ^{\circ}\text{C} \text{ or } \text{SIT400} - 20 \text{ } ^{\circ}\text{C}$$

$$t_{\text{dry}} \text{ lasts } 48 \text{ to } 72\text{h} \quad T_{\text{limit}} \leq \text{LTT} - 50 \text{ } ^{\circ}\text{C} \text{ or } \text{SIT400} - 30 \text{ } ^{\circ}\text{C}$$

For continuous processes and batch processes with thermal exposure >72h, the temperature limits must be based on SIT400:

$$T_{\text{limit}} \leq \text{SIT400} - 30 \text{ } ^{\circ}\text{C}$$

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<sup>14</sup> Auto-Ignition-Temperature; Definition see «Technical Glossary»

<sup>15</sup> Definition see «Technical Glossary»

<sup>16</sup> Definition see «Technical Glossary»

<sup>17</sup> Drying under inert conditions or under vacuum, higher drying temperatures might be possible based on safety studies under inert conditions (e.g. Dewar tests, see 4.8).

<sup>18</sup> The interval is defined as the time between two unloadings with visual check for residues in the dryer at the same time. Residues must be removed before the following drying campaign because of the possibility of a delayed decomposition which could lead to an ignition.

- **Required for risk modules D2 and D3:** The temperature limit(s) determined above (risk modules T0 and T1) shall be further reduced by 10 °C.
- **Required for risk modules T0, T1, D2 and D3:** If (one of) the temperature limit(s) is reached, the heating must switch off automatically and at the same time an easily detectable alarm must be triggered. Air supply (Dryer Types: Tray dryers, Band dryers, Fluid bed dryers, Spin flash dryers, and Spray dryers without and with wall sensors, stirring (types Vacuum paddle dryers and Spin flash dryers) and rotation (type Drum dryers) shall not be interrupted automatically.
- **Required for risk modules D2 and D3:** The temperature of the heating medium must be inherently limited that the temperature limits determined above (risk modules T0, T1, D2 and D3) can not be exceeded physically

**or**

the dryer must be equipped with a redundant temperature control system, which is also linked to the emergency stop.

- **Required for risk modules T0, T1, D2 and D3:** In order to avoid heat accumulation in large bulk volumes, the following deviations shall trigger an easily detectable alarm:
  - ❖ failure of the fans (Dryer Types: Fluid bed dryers, Spin flash dryers, Spray dryers without and with wall sensors),
  - ❖ stirring failure (Dryer Types: Vacuum paddle dryers and Spin flash dryers)
  - ❖ rotation failure (Dryer Type: Drum dryers)
  - ❖ Within 4h the process must be restarted or effective cooling of the solid must be ensured.

### 3.3.2 Heat Accumulation in large Volume

- **Required for all risk modules:** If a solid that is known to be stable<sup>19)</sup> at ambient temperatures is packed/intermediately stored at temperatures below 45 °C, no further safety precautions with respect to the temperature control are required. In all other cases, safety measures 2 and 3 have to be observed.
- **Required for all risk modules:** If the solid shall be packed or intermediately stored in a container or in process equipment for an unlimited time it must be cooled to at least the maximum permissible packing/intermediate storage temperature  $T_{Pmax}$ .

$T_{Pmax}$  depends on the dimension of the package (R). Depending on the shape of the package or vessel R represents:

- ❖ for cylindrical vessels (e.g. barrels): R = radius

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<sup>19)</sup> Due to thermal analytical investigation.

- ❖ for conical vessels:  $R = 2/3$  of the radius of the cone at maximum filling height (e.g. receivers of mills, NAUTA mixers)
- ❖ for cubical packages (e.g. Pallets):  $R = 1/2$  of the length

Dimension	$T_{Pmax}$ based on	
	LTT	SIT400
$R \leq 15$ cm	LTT - 50 °C	SIT400 - 50 °C
$15$ cm $< R \leq 25$ cm	LTT - 60 °C	SIT400 - 70 °C
$25$ cm $< R \leq 50$ cm	LTT - 80 °C	SIT400 - 90 °C
$50$ cm $< R \leq 100$ cm	LTT - 100 °C	SIT400 - 110 °C

If the product shall be packed/intermediately stored into a container for a limited intermediate storage time  $\tau$  it must be cooled to at least the maximum permissible packing/intermediate storage temperature  $T_{Pmax}$ . Compared with packing/intermediate storage without limitation in time  $T_{Pmax}$  is allowed to be higher:

$$\text{For } \tau \leq 48\text{h} \quad T_{Pmax} = \text{LTT} - 40 \text{ °C}$$

In any case the packing/intermediate storage temperature must not exceed 90 °C.

- ❖ If the expected packing/intermediate storage temperature is higher than  $T_{Pmax}$  given in safety measure 2, further investigations are necessary. Experts must be consulted.

### 3.3.3 Deflagration Risk Modules

Dangerous for the Equipment: Vacuum paddle dryers, Spin flash dryers, high and medium velocity equipment.

- **Required for risk modules D1 and D2:** Deviations from normal operation which result in excessive friction of parts in contact with bulked powder must be avoided, e.g. by
  - ❖ monitoring and limiting the power consumption of the drive
  - ❖ protection against foreign bodies (e.g. with a sieve, metal separators)
  - ❖ limiting the momentum of the drive
- **Required for risk modules D1 and D2:** Blockage of material flow must be detected (e.g. level meters, flow meters, overload protection of stirrers and screw conveyors) and the process must be stopped if blockage occurs. The action to be taken in case of blockage must be described in an operation procedure. Manual corrective action may only be carried out according to this procedure and with the designated tools.
- **Required for risk modules D1 and D2:** Bearings, which are in contact with the product must

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Either Be protected against heating by friction (e.g. by dust-tight construction, by flushing with nitrogen or air, controlled cooling, lubrication).

Or Be equipped with a temperature control and alarm.

The temperature limit should be set to

$T_{\text{limit}} \leq \text{LTT} - 20 \text{ }^\circ\text{C}$  or  $\text{SIT400} - 30 \text{ }^\circ\text{C}$  whichever is selected.

In any case the temperature must not exceed  $90 \text{ }^\circ\text{C}$  or the melting point of the solid, whichever is lower.

- **Required for risk module D2:** In order to avoid hazardous self accelerating of the deflagration, venting of closed equipment at low pressures must be foreseen.
- **Required for risk module D2:** In order to limit damage in case of a deflagration, the amount of powder in the equipment or the downstream receiver must not exceed 400 kg unless it can be flooded with water with a fixed flooding installation.
- **Required for risk module D3:** Processing this solid in equipment of types Vacuum paddle dryers, Spin flash dryers, High and Medium velocity equipment bears the risk of a violent deflagration. Safety measures must be taken based on a specific risk assessment.

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## 4 Safety Tests

### 4.1 Sample Preparation

The sample preparation is standardised as follows:

- If not known, the melting temperature from the sample is measured.
- If it is possible due to the melting temperature of the sample, it is dried at 60 °C under a vacuum.
- The sample is ground and sieved to the particle size < 63 µ for dust explosion tests and < 250 µ for all the other tests.
- The particle size distribution is measured.

#### Annotations:

- Samples that consist in more than one chemical compound are ground and sieved, because sieving may separate the sample not only regarding the particle size but also regarding to the different chemical compounds.
- The particle size has an influence on the result of the following tests: Dust Explosion Test, Minimum Ignition Energy, Minimum Ignition Temperature. Even if the particle size complies with the standard < 63 µ there may be differences in the results of the explosion tests between fractions with different medium values. To control this effects we provide you with particle size histograms for the original sample and the tested sample.

### 4.2 Fire Analysis

Assessment of the ability of a powder layer to propagate a flame or smoulder throughout its mass especially where ignition could spread from a localised source of ignition. With the powder pack the fire properties of a powder are assessed under laboratory conditions using the **Burning Behaviour Test (VDI 2263)**.

This test is performed at ambient temperature (20 °C) and at elevated temperature (100 °C) as well. It provides an indication –using a combustibility index number, 1 to 6– of the extent to which a localised hot spot will propagate throughout a given sample of powder.

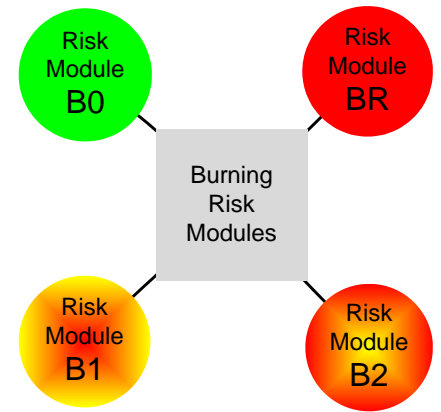
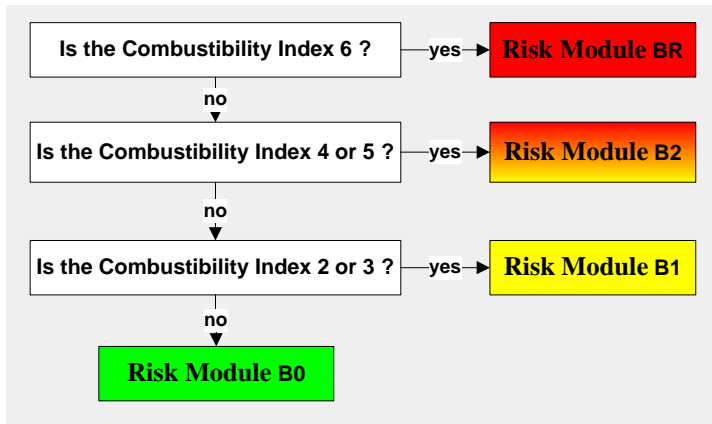
Combustibility Index Number according to Burning Behaviour Test (VDI 2263)	
1	no ignition
2	ignition and rapid extinction
3	local smouldering or burning
4	propagation and smouldering
5	propagation of open fire
6	flash fire

If the combustibility index of a given sample of powder is 4, 5 or 6 the sample material is also tested under vacuum. The powder is considered to be potentially deflagrating if its combustibility index number measured under a vacuum is > 1.



**Remarks:** If the powder has a low melting point the true combustibility is not reflected by this test. In this case, the test is performed after the addition of 20% of a non-melting, inert material (silica gel) to the sample.

**Classification into Burning Risk Modules:** The powder is classified into Burning Risk Modules. For the classification the Combustibility Index at 100 °C is relevant.



### 4.3 Impact Sensitivity Analysis

The impact sensitivity of a dry powder is assessed by the drop hammer test according to Lütolf or BAM (VDI 2263). This test determines whether a blow is capable to initiate a decomposition or an explosion in a powder sample.

- A detonation is detected when the noise level registered by the microphone is 5 dB above the base value, obtained without sample.
- The material is considered to be impact sensitive if a detonation is detected within a series of ten tests.
- If the test shows no decomposition, then the sample is classified as not impact sensitive.

**Remarks:** Impact sensitive materials are subject by law to severe restrictions for warehousing and transport in many countries.

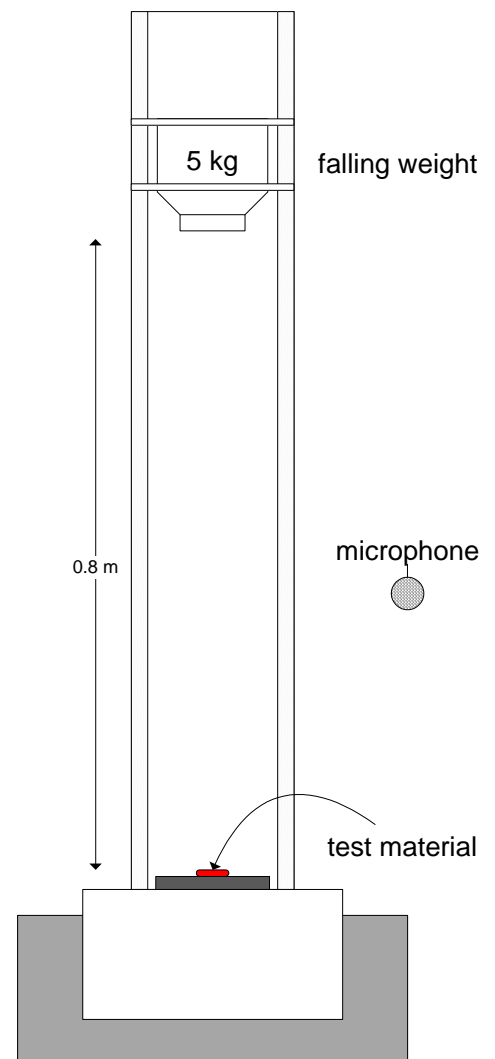
### 4.4 Dust Explosion Analysis

#### 4.4.1 Dust Explosion Test (VDI 2263)

The dust explosion hazard of a powder and its violence in air qualitatively is assessed in the **modified Hartmann Tube**.

**The test is carried out** with the following amounts of sample: 36, 120, 240, 600 and 1200 mg - corresponding to dust concentrations of 30, 100, 200, 500 and 1000 g/m<sup>3</sup>.

**The assessment** of the entire test is positive if within the tests with different dust concentrations any single test has shown a positive result according to the table.



Result	Indication	Rating	Assessment
No dust explosion no dust fire	0	0	negative
Dust fire combustion. The flame spreads through at least the upper half of the tube. The lid is not necessarily lifted.	0	1	positive
Weak dust explosion	1	1	
Violent dust explosion	2	2	

#### Remarks:

- The particle size has an influence on the result of this test.
- The international dust explosion classes St-classes, according to VDI 2263 are not identical to the classes resulting from this test. Dusts classified as 0 according to this test may be St 1 and often have a minimum ignition energy >10 J. Dusts classified as 1 according to this test are usually St 1 with a minimum ignition energy <10 J. If only dust combustion is observed or if dust explosion is observed only with the incandescent coil the corresponding dust has in most cases minimum ignition energies of >1 J. For more quantitative evaluations, tests in a 20 L-Sphere are necessary (see Special Tests).

#### 4.4.2 Minimum Ignition Energy (MIE)

**Objective:** To determine the minimum energy of an electrostatic or mechanical spark capable of igniting a dispersed dust under ambient conditions according to EN 13821; VDI 2263.

**Apparatus:** The Minimum Ignition Energy is measured using the Hartmann tube with a movable electrode together with a MIKE-3 Test equipment (Kühner) for automatic control and evaluation.

**Procedure:** MIE measurement involves repeatedly dispersing varied concentrations of dust through sparks of known energy. The powder concentrations for these tests are above the Minimum Explosion Concentrations (MEC). If an ignition is observed then the spark energy is reduced until no further dust ignitions occur for all reasonable combinations of dust concentration and ignition delay. The sparks are either purely capacitive in nature or that created by an inductor.

**Assessment:** The Minimum Ignition Energy is recorded as the lowest energy capable of igniting a dispersed dust - at its most sensitive concentration. The minimum ignition energy is between the value for which **no** ignition occurred and the next higher ignition energy for which ignition was observed.

#### Remarks:

- With the «Powder Pack», we investigate the Minimum Ignition Energy with inductance. We chose the inductance (L) of the discharge circuit as 1 mH.

$$H \text{ means Henry } [H = \frac{V \cdot s}{A} = \Omega \cdot s]$$



- MIE measured with inductance in the spark circuit results in more conservative values (a factor 3-10 lower). We recommend to use the more conservative value in a first approach and to consider the value measured without inductivity only in more detailed risk assessments. Basically MIE measured without inductivity must be considered for static electricity considerations and the value with inductivity is to be used when considering mechanical sparks.
- The particle size has an influence on the result of this test.
- The Minimum Ignition Energy is temperature dependent. MIE at elevated temperatures can be calculated from MIE measures at  $RT_{(T=25\text{ }^{\circ}\text{C})}$  by the equation:

$$\log(MIE_T[J]) = -4.056 + \{1.873 - 0.624 * \log(T[{}^{\circ}\text{C}])\} * \{4.056 + \log[MIE_{25}[J]]\}$$

#### 4.4.3 Minimum Ignition Temperature for Dust Cloud (MIT)

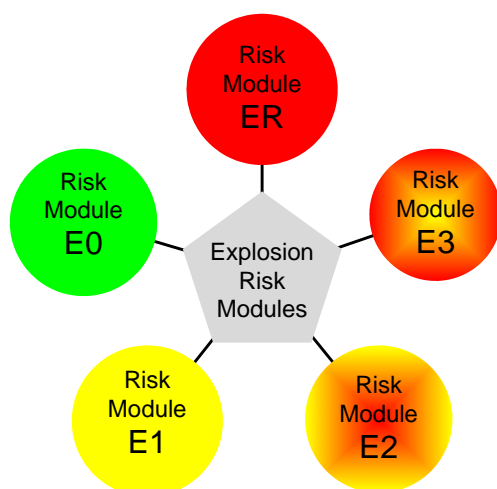
**Objective:** Evaluation of the minimum temperature of a hot surface capable of causing ignition of a dust cloud according to VDI 2263.

**Apparatus:** For this test the equipment designed by BAM VDI 2263 is used.

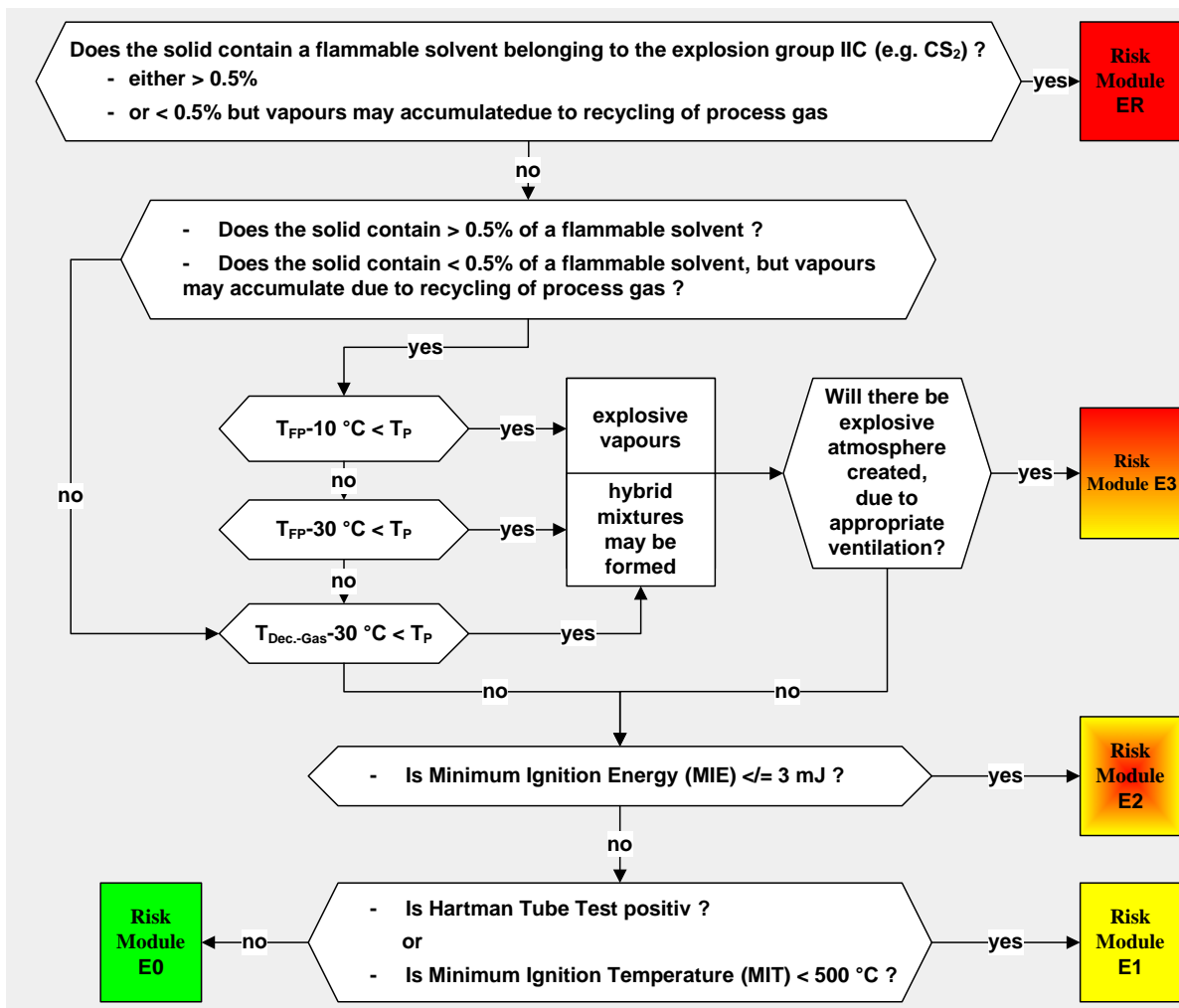
**Procedure:** The temperature in the oven is stabilised at the test temperature. A defined amount of powder with the particle size  $< 63\text{ }\mu\text{m}$  is blown into the oven. It is visually observed whether an explosion occurred or not. The test is repeated until the temperature  $T'$  is found at which for the powder quantities between 100 mg and 1500 mg at least one ignition is observed and at the temperature of  $T' - 10\text{ K}$  no ignition is observed in the mentioned concentration range. Three trials for each dust concentration are run.

**Assessment:** The minimum ignition temperature of a dust cloud is recorded as the lowest temperature of a furnace at which ignition takes place.

**Remarks:** The particle size has an influence on the result of this test.



## 4.4.4 Classification into Explosion Risk Modules



$T_P$  = process temperature;  $T_{FP}$  = Flash Temperature; MIE = Minimum Ignition Energy;  
MIT = Minimum Ignition Temperature

## 4.5 Exothermic Decomposition Reaction Analysis

### 4.5.1 Dynamic Differential Scanning Calorimetry (DSC)

The first information on thermal stability of a powder is assessed by conventional Differential Scanning Calorimetry (DSC). The method uses a very small amount of test material (approx. 5 mg). These tests were run in closed crucible under inert gas atmosphere in the temperature range of 30 °C to 400 °C using the heating rate of 5 K/min.

**From the experiments the following data are assessed:**

- The onset temperature of the first exothermy corresponds to the first deviation of the DSC-signal from the baseline in positive direction.
- The specific decomposition energy in a closed inert crucible is obtained by integrating all positive parts of the power signal dividing by the sample mass.

- A sample is considered to be **potentially deflagrating** if the decomposition energy is higher than 500 J/g and the (estimated) apparent activation energy is  $> 200$  kJ/mol.

#### 4.5.2 Dynamic Decomposition Test

With the **Dynamic Decomposition Test** the thermal stability and the thermal decomposition characteristic of a powder are assessed.

In a series of **RADEX** systems quantitative dynamic **Differential Thermal Analysis** experiments were run in the temperature range of 25 °C to 360 °C with samples of approx. 2 g with the following experimental conditions:

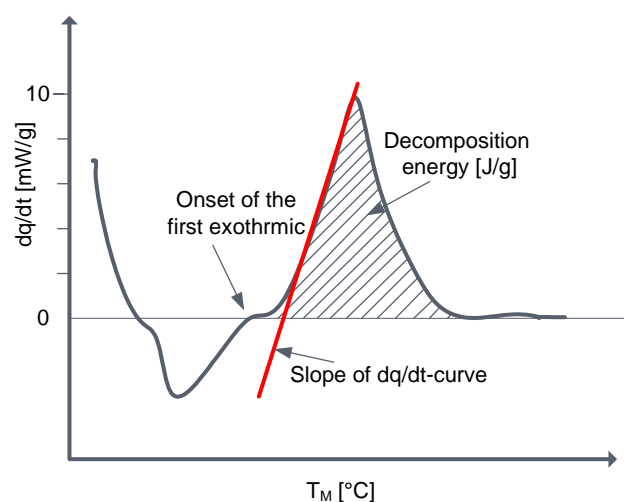
- **Air open:** A tube that is open against normal atmosphere.
- **In air stream:** Permanent flushing of the sample with air (5 L/h) preheated to the oven temperature.
- **In inert gas stream:** Permanent flushing of the sample with inert gas (5 L/h) preheated to the oven temperature.
- **Air closed:** autoclave filled with air.
- The experiments are run with the **heating rate** of 45 K/h.

**From the experiments the following data are assessed:**

- The onset temperatures of the first exothermy are evaluated for all test conditions. It corresponds to the first deviation of the dq/dt signal from the baseline in positive direction.
- The onset temperature of the first endothermy is evaluated for the open tube. It corresponds to the first deviation of the dq/dt signal from the baseline in negative direction.
- The specific decomposition energy in the closed tube is obtained by integrating all positive parts of the power signal on the plot. The decomposition energies  $\Delta H$  are classified:

low		$\Delta H$	$< 100$ J/g
medium	100 J/g	$< \Delta H$	$< 300$ J/g
high	300 J/g	$< \Delta H$	

- The decomposition is said to be **spontaneous** if the corresponding maximum dq/dt is larger than 100 mW/g and the slope of the dq/dT curve in the plot according is larger than 8 [mW/g/K].
- A sample is considered to be **potentially deflagrating** if
  - Either Its decomposition energy in the closed tube is  $> 700$  J/g.
  - Or Its decomposition energy in the closed tube is  $> 500$  J/g and its decomposition in the open tube is spontaneous.



- A sample is considered to be **self-reactive** if its specific decomposition energy in the closed tube is  $> 300$  J/g.
- If in the autoclave an exothermy is observed which in the open tubes is hidden by evaporation of residual solvent more detailed investigations are necessary.
- A sample is considered to be **Air-Dependent Decomposition** if the decomposition reaction is significantly slower in the absence or under reduced supply of oxygen. The assessment is based on comparison of dynamic decomposition tests under different atmospheres.

#### 4.5.3 Long-term Decomposition Test

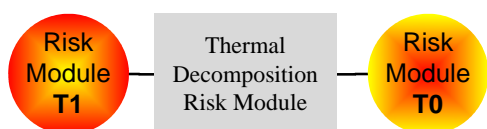
The **Long-Term Temperature (LTT)** is the maximum temperature (rounded to the nearest multiple of  $10$  °C) at which in an isoperibolic test with a detection limit better than  $1$  W/kg no exothermic signal is detected for 16 h.

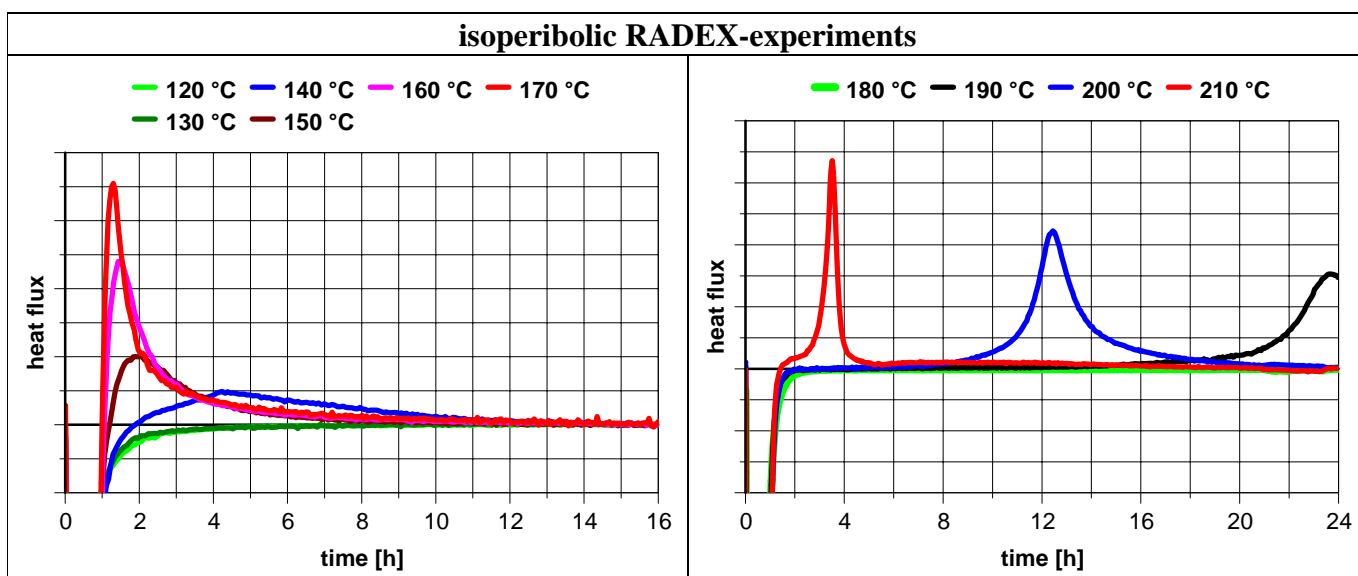
In a series of **RADEX** systems quantitative isoperibolic **Differential Thermal Analysis** experiments were run in the temperature range of  $50$  °C to  $360$  °C with samples of approx.  $2$  g with the following experimental conditions:

- The experiments are run in closed systems (mini autoclaves, closed under air).
- The test temperature is chosen at least  $50$  °C below the onset of the first exothermy observed in the dynamic decomposition test. An isoperibolic test is run with a thermal exposure time of 16 hours. The power of heat is measured.
- If an exothermy is observed, the experiments are repeated each time decreasing the test temperature by  $10$  °C until no exothermy is observed during at least 16 h and the assessment is possible.
- If no exothermy is observed, the experiments are repeated each time increasing the test temperature by  $10$  °C until an exothermy is observed within 16 h and the assessment is possible.

#### From the experiments the following data are assessed

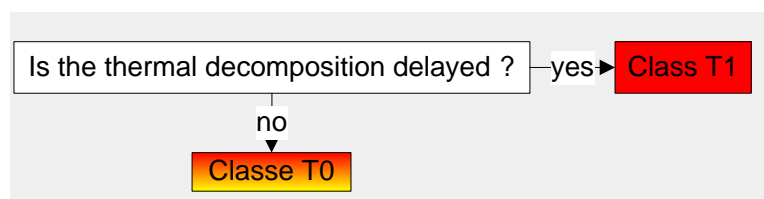
- An exothermic decomposition is observed if during the thermal exposure time the specific heat production rate exceeds one mW/g.
- The **LTT** is the highest temperature (rounded to  $10$  °C) at which in an isoperibolic test during 16 h no exothermy is detected. This implies that LTT plus  $10$  °C is the lowest temperature at which an exothermy is detected.
- A decomposition is said to be delayed by more than 8 h at LTT if based on the tests done above LTT an exothermic signal  $>1$  mW/g is to be expected after more than 8 h at LTT.
- The decomposition is said to be spontaneous if the slope of the  $dQ/dt$  at  $LTT + 20$  °C is larger than  $10$  mW/g.





The example in figure left hand shows that in this case the 16 hours LTT is 120 °C. The example in figure right hand shows that in this case the 16 hours LTT is 180 °C but a delayed decomposition is detected.

Due to the result of the Long-term Decomposition Test the powder is classified into **Thermal Decomposition Risk Modules**.



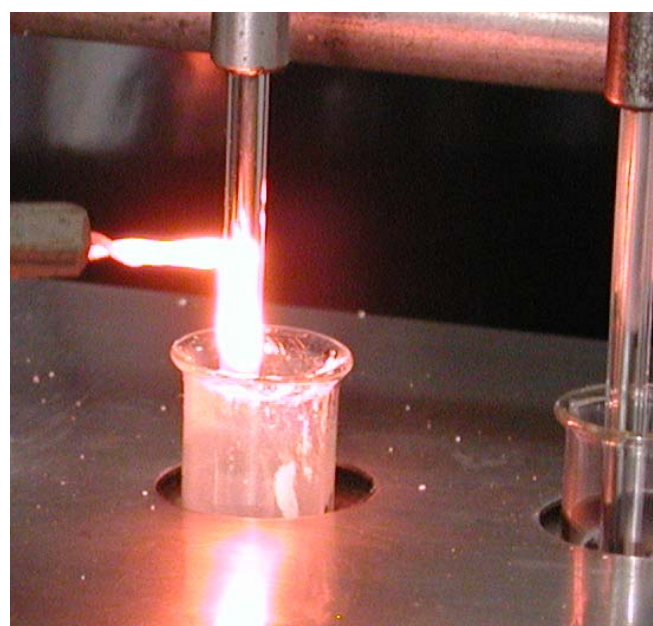
**Remarks:** Sometimes the term auto catalytic have been used for delayed decompositions. However, as the definition of delayed decompositions includes the condition at which the expected signal at LTT is greater than the detection limit, not all decompositions formerly categorised as auto catalytic, fall in the category of delayed decompositions.

#### 4.5.4 Test for Flammable Decomposition Gas (VDI 2263)

**Objective:** With this test it is visualised whether the powder develops flammable smouldering gas and when, at which temperature this will happen.

**Procedure:** An isoperibolic differential thermal experiment is run in the temperature range of room temperature to 550 °C with the heating rate of 2.5 K/min. The sample size is approximately 4.5 ml. Every time interval of four minutes the hot platinum wire with the temperature of 1000 °C is held over the sample tube. Each time interval corresponds to an increase in temperature of 10 °C.

**Assessment:** The temperature is evaluated at which flammable decomposition gases are detected.



#### 4.5.5 Test for Volume of Decomposition Gas

**Objective:** With this test it is visualised what amount of flammable smouldering gas the powder evolves upon heating.

**Procedure:** The weighted amount (approx. 2 g) of the sample is filled into the test tube. The tube is connected to the flow measurement system. The equipment is heated to 350 °C and stabilised. The test tube is inserted into the equipment. The gas evolved is collected during 5 minutes. The gas volume is read from the gas flow measurement system.

**Assessment:** The volume of decomposition gas is given in L/kg.

#### 4.5.6 Deflagration Test

**Objective:** Investigation whether a powder deflagrates after local ignition.

**Instrument:** A glass tube (length 180 mm, inner diameter 43 mm) that is open at the top and closed at the bottom. At the bottom is a glow plug connected to a power supply that allows to heat the glow plug. Three thermocouples are mounted at distances of 50, 80 and 110 mm from the top of the glow plug. In addition, a thermocouple is inserted into the bottom of the test tube to monitor the proper operation of the glow plug.

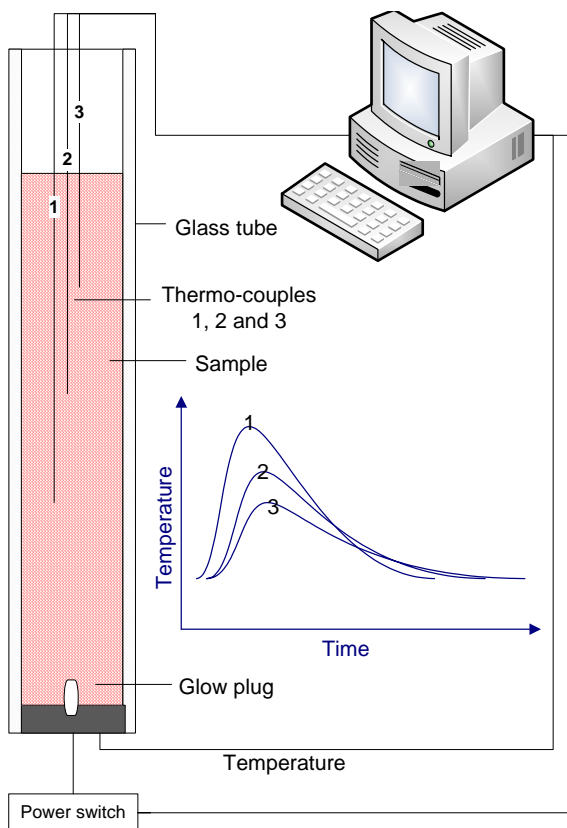
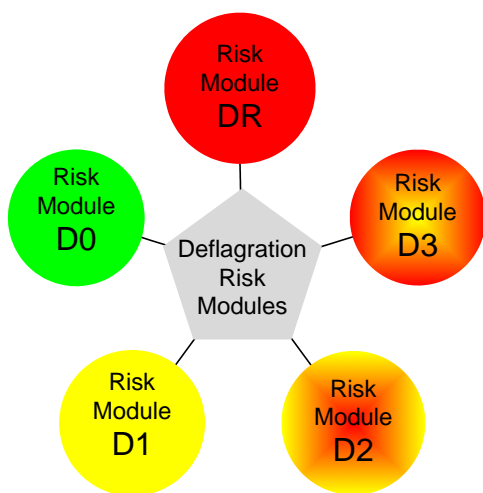
**Preliminary work:** To exclude the risk of an explosion DSC tests combined with Yoshida Method are carried out before starting the deflagration test.

**Procedure:** Approximately 200 ml of the sample material is filled into the test tube and preheated to the temperature of 70 - 100 °C. The thermocouples are inserted into the sample and fixed at the determined position. The glow plug is switched on for 4 minutes. The temperatures of the thermocouples are recorded for one hour.

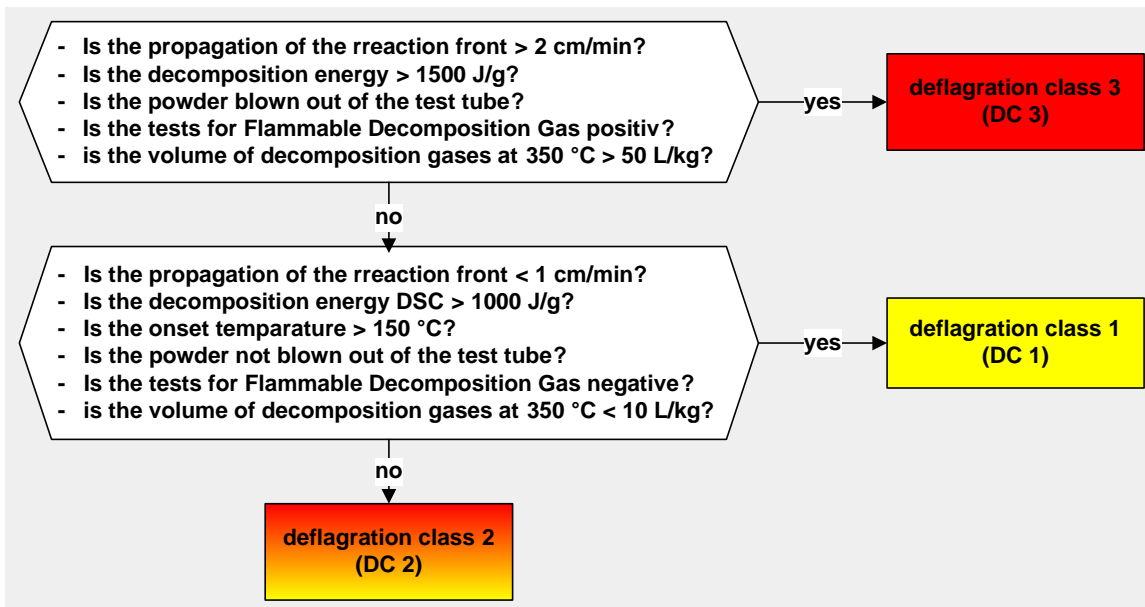
**Assessment:** It is evaluated whether the local ignition causes a local or an overall decomposition of the sample. From the temperature curves of the thermocouples it is evaluated whether all parts of the sample reached the decomposition temperature (for example obtained from a decomposition test). The evaluation is made according to the table.

Decomposition temperature is reached	Spread of decomposition	
	locally	overall
locally	negative	positive
overall	positive	positive

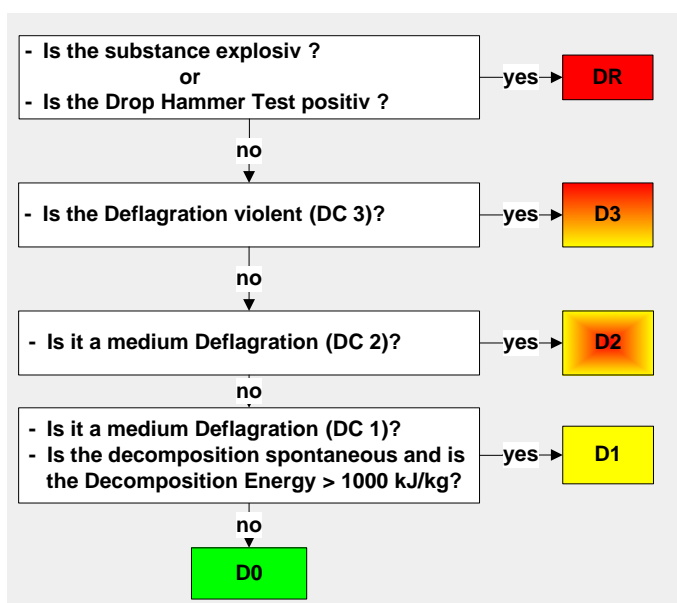
If the assessment is «positive» the deflagration class is determined according to the following scheme.







As a base for risk analysis the powder is classified into **Deflagration Risk Modules** using the results of the Deflagration Test, the Thermal Decomposition Test and the Drop Hammer Test.

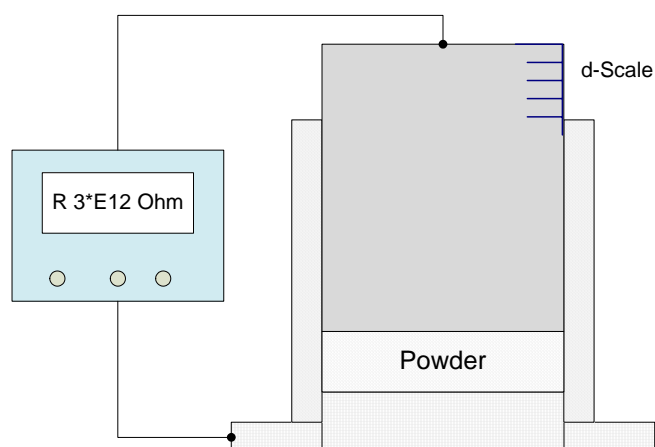


#### 4.6 Electrical Resistivity

**Objective:** Evaluation of the specific electrical resistivity of a powder, in order to understand the hazard of electrostatic charge accumulation.

**Instrument:** A cell with known cross section - A - is used in combination with a Tera-Ohm-Meter.

**Procedure:** The powder is filled into the cell. The upper electrode is slowly inserted into the Teflon jacket and the powder is slightly compressed to form a slab of even thickness. The spacing - d - of the electrodes is registered.

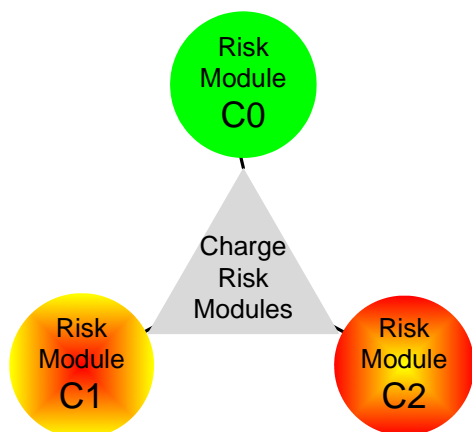


Voltage and meter range are adjusted until a stable digital value is displayed. The experiment is repeated 5 times.

**Assessment:**

- The specific resistance is calculated according the equation  $\rho[\Omega m] = R[\Omega] * \frac{A[m^2]}{d[m]}$ .
- The average and standard deviation of  $\rho$  are calculated. If  $avg(\rho) > 2 * dev(\rho)$  then the result is given as  $avg(\rho) \pm dev(\rho)$  and  $avg(\rho)$  is used for classification, otherwise the result is given as  $\rho = \rho_{min}$  to  $\rho_{max}$  and  $\rho_{max}$  is used for the classification.
- Powders with  $\rho > 10^{10} \Omega m$  are critical with respect to the formation of cone discharges.
- Powders with  $\rho > 10^8 \Omega m$  are critical with respect to charge accumulation.

As a base for risk analysis the powder is classified into **Charge Accumulation Risk Modules.**

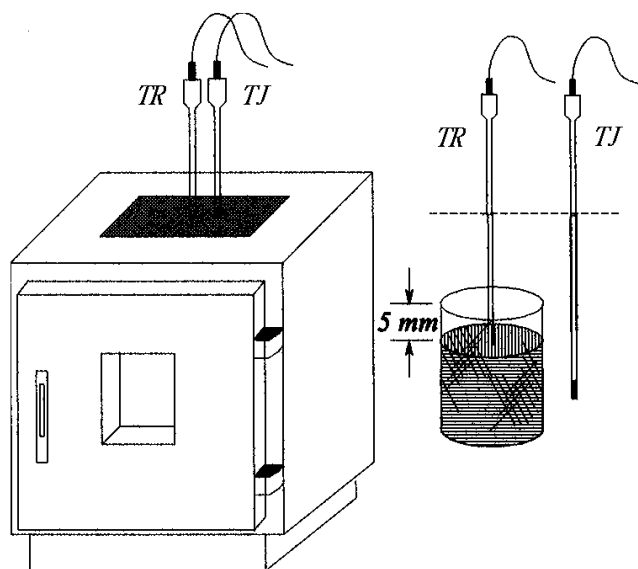


Specific resistance	Charge Accumulation Risk Module
$\rho > 10^{10} \Omega m$	C2
$\rho > 10^8 \Omega m$	C1
$\rho < 10^8 \Omega m$	C0

**4.7 Self Ignition Test in a 400 ml Wire Basket (SIT400)**

**Objective:** Evaluation of the Self Ignition Temperature (SIT) of a powder in a 400 ml wire basket.

**Instrument:** SEDEX-Oven with hot air circulation, with an air inflow that ensures permanent oxygen supply of 2 L/min. Cylindrical wire basket (height 80 mm, diameter 80 mm). The construction of the basket is so that the sample is also in contact with air at the bottom. Temperature sensors for the oven and for the sample temperature.



**Procedure:** The sample is filled into the wire basket up to 5 mm from the top. The basket is mounted in the oven so that the centre of the wire basket has the distance of 8 cm from the wall of the oven. The sample temperature is measured in the centre of the sample.

The test temperature is chosen as the onset temperature of the first exothermy with high energy as observed in the dynamic decomposition test. An isoperibolic test is run with an thermal exposure time of at least 72 hours (or until self-ignition is observed). If self ignition is observed, the steps 1 to 6 are repeated decreasing the test temperature by 10 K each time, until no self-ignition is observed. If no self ignition is observed, the steps 1 to 6 are repeated, increasing the test temperature by 10 K each time until self-ignition is observed.

### Assessment:

- Self ignition is observed if the temperature difference between the sample and the oven exceeds 20 K.
- The Self Ignition Temperature (SIT) in the 400 ml wire basket is the lowest temperature (rounded to 10 °C) at which in an isoperibolic test during at least 72 h self ignition is observed. This implies that at SIT<sub>400</sub> minus 10 °C no self ignition according to step one is observed.

### 4.8 Warm Storage Test in a Dewar

**Objective:** Evaluation of the onset temperature of an exothermic decomposition on near-adiabatic conditions.

**Instrument:** SEDEX Apparatus with hot air circulation.  
Sampleholder: 200 ml Dewar vessel with a cover. Temperature sensors for the oven and the sample temperature. The test arrangements adjust the oven temperature in line with the sample temperature.

**Procedure:** The starting temperature is chosen approximately 50 °C below the onset of the first exothermy observed in a dynamic decomposition test.

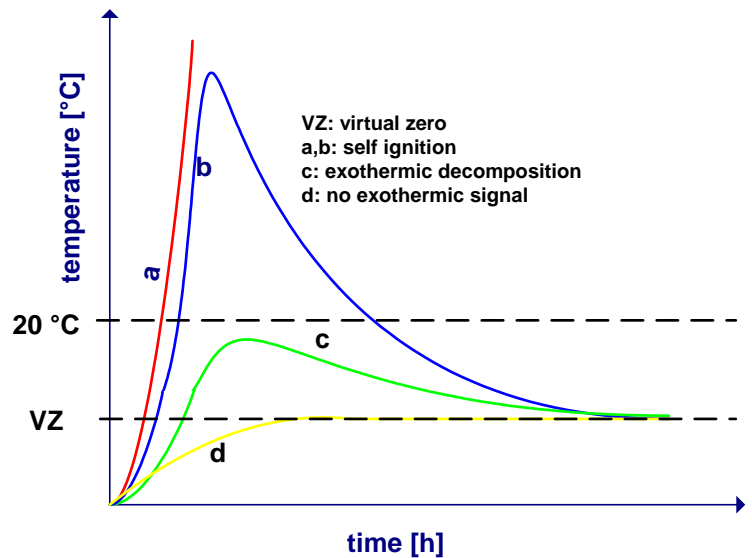
The sample is heated to the test temperature and then filled into the Dewar vessel. The Dewar vessel is mounted in the oven. The temperature sensor is installed. The test is run with an thermal exposure time of at least 72 h (or until an exothermy is observed). If an exothermy is observed, the experiment is repeated each time decreasing the test temperature by 10 °C until no exothermy is observed. If no exothermy is observed, the experiment is repeated each time increasing the test temperature by 10 °C until an exothermy is observed.

**Assessment:** The onset of the first exothermy in a Dewar is the highest temperature (rounded to 10 °C) at which during at least 72 h no exothermy is observed.

**Annotation:** The result from the experiments gives a temperature-time curve of self heating, which in turn yields an induction time as the characteristic parameter. This is defined as the time between reaching the storage time and attaining the maximum rate of temperature rise. Multiple tests at graded storage temperatures are generally necessary in order to determine the temperature dependence of the induction time.

### 4.9 Smouldering Temperature

**Objective:** Evaluation of the smouldering temperature of a dust layer of 5 mm thickness according to EN 50281



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**Apparatus:** A hot plate with an adjustable temperature control. A metallic ring that allows to prepare a layer of 5 mm thickness on the surface of the hot plate. A temperature sensor placed in the centre of the ring slightly above the hot plate.

**Procedure:** A layer of 5 mm thickness is formed. The temperature of the heating plate is adjusted to the test temperature and the thermal equilibrium is established. It is visually observed if an ignition or smouldering occurs within 2h. The following observations are equivalent to an ignition:

- formation of flames, embers or glowing nests,
- temperature in the dust layer exceeds 450 °C,
- temperature in the dust layers at least 250 °C higher than temperature of the heating plate.

The test is repeated until the temperature is found at which at least one ignition is observed within four trials and at T minus 10 °C no ignition or smouldering is observed in four trials.

**Assessment:** The smouldering temperature is defined as the lowest temperature –rounded to the lower multiple of 10 °C– at which a smouldering appearance or ignition is observed.

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## Technical Glossary

<b>Air-Dependent Decomposition</b>	Decomposition that is significantly slower in the absence or under reduced supply of oxygen. Assessment is based on comparison of dynamic decomposition tests under different atmospheres.
<b>Auto Ignition Temperature</b>	Lowest temperature of a surface that can ignite a mixture of vapour or gas and air in contact with it.
<b>Auto catalytic</b>	A decomposition is called auto catalytic if its product(s) accelerate the decomposition working as a catalyst. Auto catalytic decomposition is the most hazardous delayed decomposition. For the analysis of an auto catalytic decomposition the duration of thermal exposure is essential. (See also «delayed decomposition».)
<b>AIT</b>	See Auto Ignition Temperature.
<b>AZT<sub>24</sub></b>	Temperature at which the induction time under adiabatic conditions (time to explosion, time to maximum rate) for a decomposition reaction is 24h.
<b>Brush discharges</b>	Discharge between a conductor and a charged conductive or non-conductive surface. Incentive for gases, vapours and hybrid mixtures.
<b>Certified equipment</b>	According to EN 1127, equipment is classified into three categories: <b>Category 1:</b> <ul style="list-style-type: none"><li>• For Zones 0,1 and 2 if designed for mixtures of gas, vapour mist with air.</li><li>• For Zones 20, 21 and 22 if designed for mixtures of dust with air</li></ul> <b>Category 2:</b> <ul style="list-style-type: none"><li>• for Zones 1 and 2 if designed for mixtures of gas, vapour or mist with air</li><li>• for Zones 21 and 22 if designed for mixtures of dust with air</li></ul> <b>Category 3:</b> <ul style="list-style-type: none"><li>• for Zone 2 if designed for mixtures of gas, vapour or mist with air</li><li>• for Zone 22 if designed for mixtures of dust with air</li></ul> The equipment should be labelled with the appropriate EX-Symbol or CE-Sign.
<b>Class I, Locations (NFPA, USA)</b>	An area in which a hazardous explosive mixture of flammable vapour or gas in air is or may be present.
<b>Class I, Division 1 (NFPA, USA)</b>	An area in which a hazardous explosive mixture of flammable vapour or gas in air is present <ul style="list-style-type: none"><li>• continuously or intermittently or periodically under normal operating conditions</li></ul> or <ul style="list-style-type: none"><li>• frequently because of maintenance or repair work</li></ul> or <ul style="list-style-type: none"><li>• where a failure would lead simultaneously to a flammable mixture and provide an incentive ignition source</li></ul>

**Class I Division 2 (NFPA, USA)**

An area in which a hazardous explosive mixture of flammable vapour or gas in air is present

- only in case of an accidental rupture or breakdown of a normally closed System (container, pipe)
- or
- in case of failure of the ventilation which normally prevents the formation of the explosive atmosphere
- or
- adjacent to a Division 1 location where explosive vapours or gases may occasionally be communicated

**Class II Locations (NFPA, USA)**

An area that is hazardous because of the presence of combustible dust.

**Class II, Division 1 (NFPA, USA)**

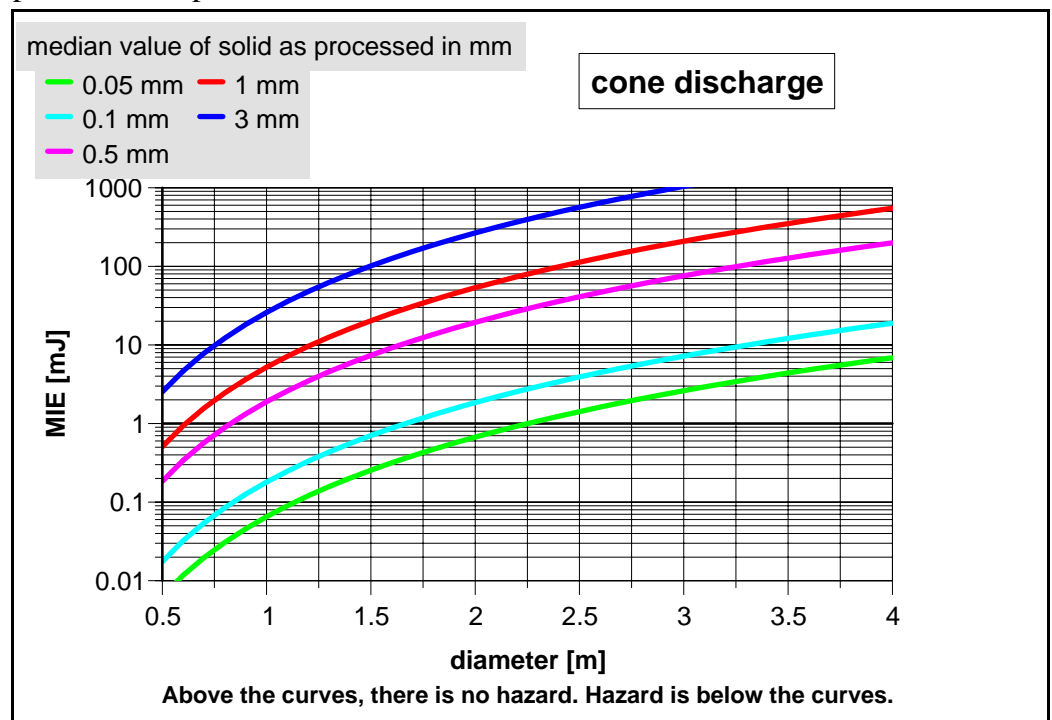
An area in which a hazardous explosive atmosphere by dust suspended in air is present

- continuously or intermittently or periodically under normal operating conditions
- or
- where a failure would lead simultaneously to an ignitable mixture and provide an incentive ignition source

**Class II, Division 2 (NFPA, USA)**

An area in which deposits and accumulations of combustible dust may be ignited by arcs, sparks, burning material or contact to electrical equipment, but where the dust will not normally be in suspension in the air or will not be likely to be thrown into suspension by the normal Operation in quantities sufficient to produce an explosive mixture.

**Cone discharges**



Discharge between a pile of non-conductive powder or granules and the grounded wall of the container. Dust bears the risk to be ignited if the bulk resistivity is  $>10^{10}$  Ohm\*m and the Minimum Ignition Energy (MIE) is smaller than:

$$MIE[mJ] < 5.22 * d[m]^{3.36} * M[mm]^{1.462}$$

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<b>Deflagration</b>	<p>A decomposition reaction, which after local ignition propagates until the entire sample is decomposed even without a supply of air/oxygen. The speed of the reaction front is less than the velocity of sound in the material.</p> <p>In recent European Standards this hazardous behaviour is also called «Spontaneous Decomposition» (See «Spontaneous Decomposition».) In US and English literature the term Deflagration is also used for an explosion propagating at subsonic velocity. Deflagrating materials (in the sense of this brochure) in general show a spontaneous decomposition with high decomposition energy.</p>
<b>Delayed Decomposition</b>	<p>Some materials show exothermic decomposition after a certain induction period. Within the induction period they seem to be stable. The duration of this induction period depends on the temperature. In these cases, safety margins depend on the duration of the operation. Formerly all delayed decomposition reactions have been termed «auto catalytic». However, auto catalytic decomposition reactions are just a special type of delayed decomposition reaction. (See auto catalytic.)</p>
<b>DSC</b>	<b>Differential Scanning Calorimetry</b>
<b>DTA</b>	<b>Dynamic Differential Thermal analysis:</b> Test method to evaluate the thermal stability of materials. The test samples are placed in an oven, which then is heated, according to a defined temperature program, while the temperature difference between the sample and an inert reference point in the oven is recorded. In dynamic DTA the temperature is increased linearly with time, whereas in isoperibolic (and isothermal) DTA the sample is exposed for a specified period of time to a constant temperature.
<b>Dynamic decomposition</b>	<p>In a dynamic decomposition test the test material is heated in an oven with a constant heating rate. While gradually increasing the temperature, the temperature difference between the sample and the oven or a reference material is recorded. A positive difference signal is indicative of an exothermic reaction of the test material.</p>
<b>Effective ignition source</b>	Ignition source with an equivalent ignition energy that is higher than the minimum ignition energy of the considered explosive mixture.
<b>Ex-Zones 22 (Europe, EN-1127)</b>	<p>An area in which either</p> <ul style="list-style-type: none"> <li>• a hazardous explosive atmosphere, formed by a dust cloud in air is not likely to occur in normal operation, and if it does occur, it will exist for a short period only</li> <li>• accumulations or layers of combustible dust are present</li> </ul>
<b>Ex-Zone 0 (Europe, EN-1127)</b>	<p>An area in which a hazardous explosive gas atmosphere is present</p> <ul style="list-style-type: none"> <li>• continuously</li> </ul> <p>or</p> <ul style="list-style-type: none"> <li>• for long periods</li> </ul> <p>or</p> <ul style="list-style-type: none"> <li>• frequently</li> </ul>
<b>Ex-Zone 1 (Europe, EN-1127)</b>	An area in which a hazardous explosive gas atmosphere is likely to occur in normal operation.
<b>Ex-Zone 2 (Europe, EN-1127)</b>	An area in which a hazardous explosive gas atmosphere is not likely to occur in normal operation, and if it does occur, it will exist for a short period only.

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<b>Ex-Zone 20</b> <b>(Europe, EN-1127)</b>	<p>An area in which a hazardous explosive atmosphere formed by a dust cloud in air is present</p> <ul style="list-style-type: none"> <li>• continuously</li> </ul> <p>or</p> <ul style="list-style-type: none"> <li>• for long periods</li> </ul> <p>or</p> <ul style="list-style-type: none"> <li>• frequently</li> </ul> <p>Dust layers of unknown or excessive thickness may be formed. Dust layers on their own do not constitute a zone 20.</p>
<b>Ex-Zone 21</b> <b>(Europe, EN- 1127)</b>	<p>An area in which a hazardous explosive atmosphere formed by a dust cloud in air is likely to occur in normal operation. Layers of combustible dust will in general be present.</p>
<b>Explosion decoupling</b>	See «Measures to disengage an explosion»
<b>Explosion Pressure Resistant</b>	<p>An explosion pressure resistant apparatus is designed in accordance with a pressure vessel code. Such an apparatus will sustain an internal explosion without permanent deformation and without damage due to material fatigue of components. Design and reliability of the technical safety installation must be certified by the supplier or confirmed by acknowledged expert(s), for example within a risk assessment.</p>
<b>Explosion Pressure Shock-Resistant</b>	<p>An explosion pressure shock-resistant apparatus is designed to sustain the pressure of an internal explosion without rupture; however small localised deformations may appear which are permanent. A special test is required after an explosion to determine whether the apparatus can be reused without repair. Design and reliability of the technical safety installation must be certified by the supplier or confirmed by acknowledged expert(s), for example within a risk assessment.</p>
<b>Explosion Suppression</b>	<p>Installation allowing the extremely fast injection of an extinguishing medium when a beginning explosion is detected, thereby preventing a pressure build-up that could damage the equipment. Design and reliability of the technical safety installation must be certified by the supplier or confirmed by acknowledged expert(s), for example within a risk assessment.</p>
<b>Fire Load</b>	<p>The fire load depends on the amount of product processed in the apparatus and thus varies according to the size of the apparatus. Assuming that a dust fire propagates on the surface of the product, the necessary extinguishing water supply <b>W</b> can be determined according to the following equation:</p> $W = w * A \text{ [L/min]}$ <p>w: means specific water supply [L/min * m<sup>2</sup>];  typical value = 10 [L/min * m<sup>2</sup>] (<i>Source: Documentation for specialist meetings «Storing of Hazardous Substances» (vds 2273);  Verband der Sachversicherer e.V.; D-5000 Köln 1 (290, p 14)</i>)</p> <p>A: means active product surface [m<sup>2</sup>]</p> <p><b>Example:</b> For a NAUTA mixer with an upper housing diameter of 3 m an active product surface in case of a dust fire is calculated to be about 7 m<sup>2</sup>. According to the above equation, the extinguishing water required is calculated to be 70 L/min.</p>

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<b>Flash Point</b>	Minimum temperature at which, under specified test conditions, a liquid gives off sufficient combustible gas or vapour to ignite momentarily on application of an effective ignition source.
<b>Heat Bridges</b>	Equipment parts which due to their high heat conductivity transfer heat from a hot area, for example an inlet air channel, to some other part of the equipment and lead there to a local hot-spot. Such hot-spots are particularly dangerous if they are in contact with the material to be processed.
<b>Hybrid mixture</b>	Mixture of air, which contains combustibles of different physical states, for example dispersed powder and flammable vapours, aerosols and flammable vapours.
<b>Inerting</b>	Reduction of oxygen in a closed system to a concentration at which ignition of an explosive atmosphere (with explosive vapours or dusts) can be excluded. The reduced oxygen concentration must be ensured during the entire operation, if necessary by additional supply of inerting gas. Usually nitrogen is used for inerting. The application of carbon dioxide is also possible but the suffocation risks must be considered. Design and reliability of the technical safety installation must be inspected by an authorised expert.
<b>Inherent hazard</b>	Property of a powder that has the potential of causing undesirable effects or consequences.
<b>isoperibolic</b>	In an isoperibolic decomposition test the test material is exposed to a constant temperature over a certain period of time. The temperature difference between the sample and the oven or a reference material is recorded. A positive difference signal is indicative of an exothermic reaction of the test material. The thermal exposure time in the standard isoperibolic test of at least 16h.
<b>K<sub>G</sub>, K<sub>St</sub></b>	Normalised pressure increase rate: $K = V^{1/3} * (dp/dt)_{max}$
<b>Limiting Oxygen Concentration (LOC)</b>	Maximum oxygen concentration in a mixture of a combustible and air and an inert gas, in which an explosion will not occur, determined under specified test conditions. If the ignition energy is limited to values typical for brush discharges (<5mJ) a much higher LOC results than with the standard ignition energy. In practice it may be of interest to know this value, called Oxygen Concentration Limit avoiding ignition by Brush discharges (OLB).
<b>LTT</b>	The 8h-Long-Term Temperature is the maximum temperature (rounded to the nearest multiple of 10 °C) at which in an isoperibolic DTA with a detection limit better than 1 W/kg no exothermic signal is detected for 8h.
<b>Measures to disengage an explosion</b>	Installations that prevent the propagation of an explosion from an apparatus into an adjacent one, for example star wheel locks or rapid-closing valves. Design and reliability of the technical safety installation must be certified by the supplier or confirmed by acknowledged expert(s), for example within a risk assessment.
<b>Minimum explosible concentration (MEC)</b>	Minimum amount of dust, dispersed in air, that is required to spread an explosion.
<b>Median value</b>	In a powder consisting of particles with different diameter, 50% by weight consists of particles with a diameter below or equal to the median value, i.e. the median value is the 50% point in the integrated particle size distribution with respect to weight contribution.

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<b>Minimum Ignition Energy (MIE)</b>	Lowest electrical energy stored in a capacitor which upon discharge is sufficient to effect ignition of the most ignitable atmosphere of the considered material under specified test conditions.
<b>Minimum Ignition Temperature (MIT)</b>	Lowest temperature of a surface that is capable to ignite the explosive mixture of dust and or vapour with air under defined experimental conditions.
<b>Parity-Check</b>	Monitoring of a physical or chemical property such as temperature, pressure, pH, etc. with two independent sensors and on-line comparison of the two values. Should the difference between the values attain a pre-set limit, an alarm and/or an automatic shutdown is triggered.
<b>Physical process</b>	A series of operations for the physical treatment or transformation of a material using a defined procedure and equipment.
<b>Physical unit Operation</b>	A physical treatment or transformation of materials carried out by a specific type of equipment.
<b>Pressure Relief Device</b>	Installation that prevents the pressure build-up by venting the equipment in case of an explosion through specially designed openings such as rupture disks, explosion flaps, panels etc., design and reliability of the technical safety installation must be certified by the supplier or confirmed by acknowledged expert(s), for example within a risk assessment.
<b>Process deviation</b>	Change within a process that is unintentional.
<b>Process modification</b>	Deliberate change within a process.
<b>Propagating brush discharges</b>	Discharge between a conductor and a very highly charged non-conductive surface (usually an insulating layer on a conductive support). Incentive for gases, vapours, hybrid mixtures and dusts.
<b>Protection grade</b>	Status of a piece of equipment indicating the Risk Modules for which the existing permanent safety measures (construction, standard procedures) are sufficient.
<b>Rapid fire suppression</b>	Rapid fire suppression means that fire protection measures are taken to ensure that a fire in a particular piece of equipment or a part of the plant can be controlled such that damage is limited the area of origin of the fire.
<b>Representative sample</b>	Sample having the same composition and being produced according to the same procedure as the solid that is actually processed. Samples that are to be tested <i>as submitted</i> , should also reflect the particle size distribution and the content of residual solvent of the processed material.
<b>Risk assessment</b>	Procedure for appraisal of risks with the aim of implementing specific safety measures, if they are necessary.
<b>Risk Module</b>	Categorisation of solids based on their safety data, which allows to identify the necessary safety measures in the Safety Concepts as described by this brochure.
<b>Risk Modules ER, BR and DR</b>	Solids classified into Risk Modules ER, BR and DR have hazardous properties that are not covered by the safety measures described in this brochure. The safety measures are taken based on a specific risk assessment and the expert should be contacted.

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<b>Safety data</b>	Safety data results that are obtained by standard test methods, providing information on the hazardous properties of the solid.
<b>Safety measures</b>	Safety measures actions or installations to reduce the risk of a process.
<b>Safety Quarantine</b>	Fire compartment for intermediate storage of hazardous products coming directly from a production step for observation. In case of a self-ignition or a deflagration, the fire must not spread to other areas. Usually goods are stored in quarantine for 24 h. Drums must not be closed during quarantine and before, leaving quarantine, they should be checked for hot-spots, if necessary with a thermometer. A rapidly available fire suppression must be ensured.
<b>Self-Ignition Temperature (SIT)</b>	Temperature, at which the heat produced by the decomposition is sufficient to cause self-heating resulting in ignition. SIT is not a fixed material property, but depends also on extensive parameters like the volume. For the specific definition of SIT400.
<b>SIT</b>	See Self-Ignition Temperature.
<b>Smouldering Temperature</b>	The lowest surface temperature (rounded to multiples of 10 °C) at which a circular powder layer with a diameter of 80 mm and a thickness of 5 mm ignited or starts smouldering.
<b>Spark discharges</b>	Discharge between two conductive parts in a sudden burst, attendant by a luminous phenomenon between the conductors. Incentive for gases, vapours, hybrid mixtures and dusts.
<b>Spontaneous Decomposition</b>	The dynamic decomposition test shows a rapid thermal decomposition, see chapter 4.5.2.
<b>Standard quality material</b>	Materials being manufactured or bought in, based on defined quality specifications.
<b>Standard Test Conditions</b>	As a standard, samples are dried (60 °C), ground and sieved (63 µm for dust explosion tests, 250 µm for all other tests) by the test laboratory. Upon request, tests of the sample <i>as submitted</i> is possible. When using safety data from <i>as submitted</i> samples, this deviation from the standard must be considered.
<b>Static electricity</b>	See «non-conductive materials», «Brush discharges», «Propagating brush discharges», «Spark discharges», «Cone discharges».
<b>Temperature limit</b>	A temperature that is set on a control device. In case the actual temperature attains the temperature limit, appropriate safety measures will be initiated, for example triggering of an alarm signal, switching off the heater etc.
<b>T<sub>onset,dyn</sub></b>	Begin of an exothermic reaction derived from dynamic differential thermal analysis (DTA). T <sub>onset,dyn</sub> is the temperature at which the DTA curve deviates from the baseline in exothermic direction.
<b>Wall Deposits</b>	Dust layers on the walls of the equipment. In spray dryers, wall deposits occur if the processed product adheres to the walls. By definition, wall deposits are considered to be relevant, if the wall is not visible, i.e. when light reflection from the metallic wall is not observable due to deposited dust. If the dust layer is so thin that the wall is shining through the dust, this is not considered as safety relevant.

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**Zone**

See «Ex-Zone» and «Division».

<b>explosive flammable gas or vapours</b>	<b>Zone <sup>1)</sup></b>	<b>Class / Division <sup>2)</sup></b>	<b>explosive dust clouds</b>	<b>Zone</b>	<b>Class / Division <sup>2)</sup></b>
A	0	I/1	A	20	II/1
B	1	I/1	B	21	II/1
C	2	I/2	C	22	II/2
D			D		

<sup>1)</sup> according to European Standard EN-1127, EU-Directive 94/6/EC

<sup>2)</sup> Fire Code of the National Fire Protection Association NFPA Code 69, NFPA Code 654 (USA)

A	occurs continuously or for long periods or frequently
B	is likely to occur in normal operation
C	is not likely during normal operation. If it occurs it will exist only for a short period.
D	does not occur

Normal Operation includes all procedures associated with the function for which the system is intentionally used. It includes also the start-up, shut down, loading and unloading processes.

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## Closing Remarks

Thank you for reading this booklet to end. We hope that the described approach can help you to understand how to proceed when assessing whether a powder can be processed safely in a Multi-product facility.

Please let us know if you think that this approach would enable you to standardize the safety assessment of the powder processes in your Multi-product facility.

Please do not hesitate to contact us if you wish to have information on how we support our clients in this matter and what the costs are.

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# 20 Years Anniversary SCHNYDER Safety in Chemistry Ltd.

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- investigate existing processes with regard to inherent hazards, generate «runaway scenarios» relevant to the operation in question and use risk analyses as a basis to develop bases for decisions important for the management to facilitate selection of the best procedure
- develop safety integrated more economical processes –based on the knowledge of the thermal hazard potentials– as basic conditions.

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- all chemical processes can be run and investigated for safety, quality and efficiency.
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