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ISSA AISS IVSS

International Section for the Chemical Industry

Dust Explosions

Protection against explosions due to flammable dusts

ISSA AISS IVSS

suva

Swiss National Accident Insurance Fund
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THE INTERNATIONAL SOCIAL SECURITY ASSOCIATION (ISSA)

has more than 300 members (government authorities and public institutions) in more than 120 countries, half of whom are concerned with occupational safety. The headquarters of the ISSA is at the International Labour Organization in Geneva. Its main objective is the promotion and improvement of SOCIAL SECURITY in all parts of the world.

To intensify work safety in plants in the chemical industry, including the plastics, explosives, mineral oil, and rubber industries, the

INTERNATIONAL SECTION OF THE ISSA ON THE PREVENTION OF OCCUPATIONAL RISKS AND DISEASES IN THE CHEMICAL INDUSTRY

was set up in 1970. It has its chair and secretariat at the Berufsgenossenschaft der chemischen Industrie, D-69115 Heidelberg, Germany.

To improve work safety and health protection in industrial plants, the

INTERNATIONAL SECTION "MACHINE SAFETY" OF THE ISSA

was established in 1975. It handles matters relating the safety of machinery, plant, and systems. It has its chair and secretariat at the Berufsgenossenschaft Nahrungsmittel und Gaststätten, D-68165 Mannheim, Germany.

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Dust Explosions

Protection against explosions due to flammable dusts

Compendium for industrial practice

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Publisher

International Section on the Prevention of Occupational Risks and Diseases in the Chemical Industry of the International Social Security Association (ISSA)
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Preface

The **I**nternational **S**ocial **S**ecurity **A**ssociation **(ISSA)** has set itself the task of using professionally orientated sections to publicize by means of information exchange, publications, and colloquia the risks such as industrial accidents and occupational diseases recognized in the field of social security, and to offer suggestions for their reduction.

The committee of the "Section Chemistry" of the ISSA has set up an "Explosion Protection" working party to promote the international exchange of experience among experts, and to work jointly to develop solutions for specific problems. By this means, the working party aims to contribute to a high, and, among industrial countries, comparable standard of technology in the field of explosion protection. It is ready and willing to pass on its knowledge to countries less well developed industrially. The present booklet was compiled in close collaboration with the "Section Machine Safety" of the ISSA.

The purpose of this compendium is to provide those plant managers, safety officers, and persons with similar responsibilities without any specialized knowledge of the field of explosion protection with the means to assess whether or not explosion hazards due to dust may exist in their own plant. It is not the aim of the compendium to provide an answer to the question concerning the necessity and feasibility of explosion protection measures; for that, the specialized knowledge of the expert is indispensable.

Questions concerning health protection are not treated in this booklet.

Dr E. Radek

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of the
"Chemistry Section" Committee

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Contents

Prerequisites for the occurrence of dust explosions

What is an explosion?

An explosion is a chemical reaction involving a flammable substance which takes place very rapidly and during which large amounts of energy are released.

What is a detonation?

A detonation is an explosion in which the rate at which the chemical reaction or flames spread through the reacting mixture accelerates to a speed greater than the velocity of sound. An explosion in a long pipeline, for example, can develop into a detonation.

When can an explosion hazard due to dust exist in my plant? [1)]

Such a hazard can exist when flammable dust (powder, flour) is manufactured or otherwise handled in the plant, or if flammable solid material is processed in such a way as to create dust.

What are solid flammable materials?

These are materials which can react (combust) with oxygen (e.g. in atmospheric concentrations) with the evolution of heat. This definition includes not only many natural products and other materials in everyday use, e.g. wood, coal, grain, plastics, etc., but also many metals if they are in the finely divided state, e.g. steel wool.

[1)] For explosion hazards due to flammable gases, vapors, or mists, refer to the ISSA brochure "Gas Explosions: Protection against explosions due to mixtures of flammable gases, vapors, or mists with air".

What is dust?

The term "dust" refers to particles of solids with a diameter less than 0.5 mm. If such materials are prepared by design, they are known as powder or flour. Dust can also arise, however, from the abrasion of coarse-grained material (e.g. grain) during transportation, or in the treatment and processing of solids (e.g. sawdust, swarf). Small amounts of dust in the coarse material must also be taken into consideration.

What is the difference between a dust fire and a dust explosion?

When a dust layer is ignited, a fire breaks out. A dust fire can develop into a dust explosion. Ignition of a dust cloud, on the other hand, can lead to an explosion which, in contrast to a fire, is associated with (generally very rapid) pressure changes and sudden heat development. This exceptionally violent reaction is responsible for the particular hazards associated with a dust explosion.

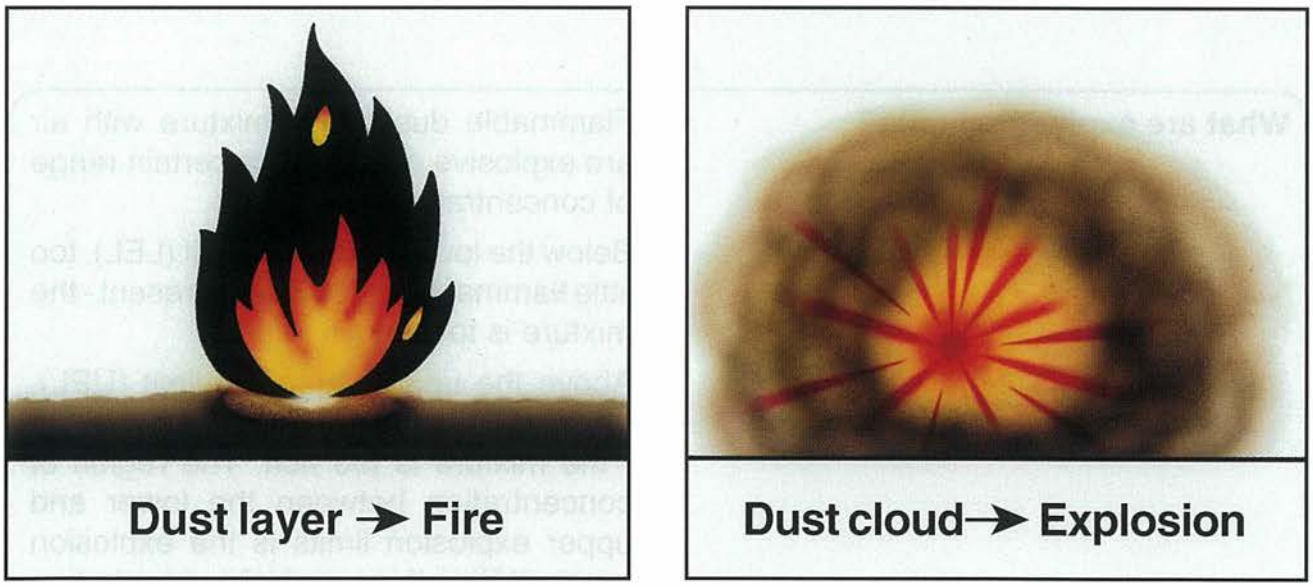

Fig. 1: Difference between a fire and an explosion

If flammable dust occurs in the plant, an explosion hazard can exist!

What is an explosive dust atmosphere?

An explosive dust atmosphere is present when flammable dust is present in air in such quantities (within the explosion limits) that a reaction can propagate self-sustainingly after ignition.

When does a dust explosion occur?

An explosion due to dust can occur when all the following conditions are fulfilled simultaneously at one location (see Fig. 2):

- fine, flammable solid matter in the form of a dust cloud mixed with air within the explosion limits, i.e.
  - •• sufficient dust and
  - •• sufficient oxygen

  as well as
- an effective ignition source.

What are explosion limits?

Flammable dusts in admixture with air are explosive only within a certain range of concentration.

Below the lower explosion limit (LEL), too little flammable substance is present - the mixture is too lean.

Above the upper explosion limit (UEL), too much flammable substance is present - the mixture is too rich. The region of concentration between the lower and upper explosion limits is the explosion range. Within this range of concentration a mixture is explosive, i.e. an explosion hazard exists. The explosion limits are expressed in g/m^3. Values of the explosion limits depend on the particular substance. If they are unknown, they can be determined experimentally.

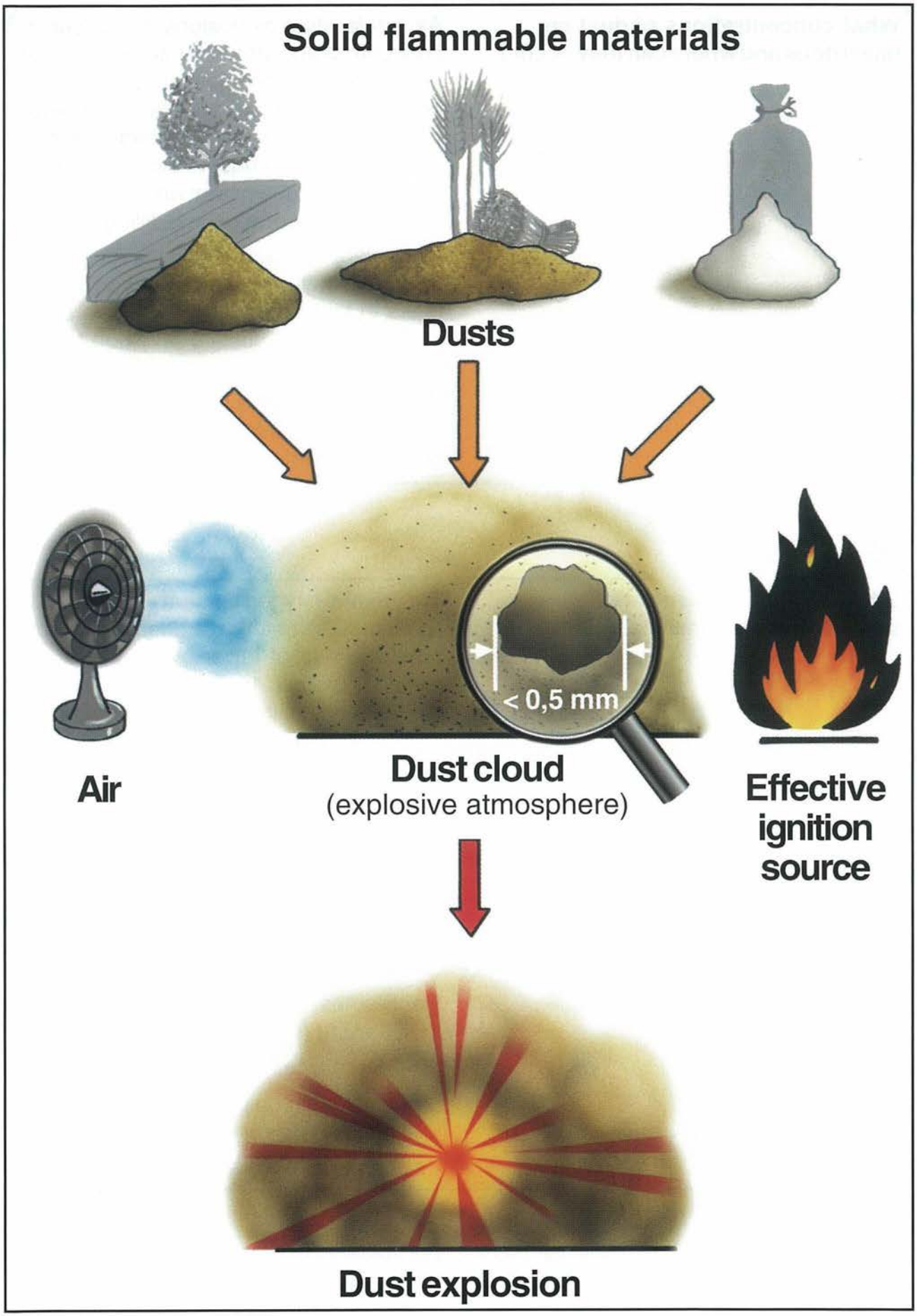

Fig. 2: Prerequisites for the occurrence of dust explosions

What concentrations of dust are hazardous and where can they occur?

As a rule, dust explosions can occur at concentrations greater than 20 g/m^3 of air. Such dust concentrations occur frequently inside equipment (e.g. grinders, mixers, filters, elevators). Sometimes they can occur due to dust emission close to dust-handling equipment which has openings when in operation (e.g. filling points).

If there are dust deposits in the room (e.g. in the vicinity of filling points, or due to leaks in the equipment) explosive dust/air mixtures can occur briefly due to turbulence.

Dust explosions are still possible even at concentrations of more than one thousand grams per cubic meter of air.

What oxygen concentrations are sufficient for a dust explosion?

The normal oxygen content of atmospheric air is sufficient. Some dusts, however, are explosive at lower oxygen concentrations (below 10 vol.%). When the oxygen content is greater than that of air, more violent explosions occur.

What are ignition sources?

Of the many possibilities in industrial practice, the following ignition sources[1)] are of greatest significance:

- Hot surfaces
- Flames, glowing (smoldering) material
- Mechanically-generated sparks
- Electrical equipment (electrically-generated sparks)
- Electrostatic discharge sparks

[1)] See ISSA brochure "Ignition Sources".

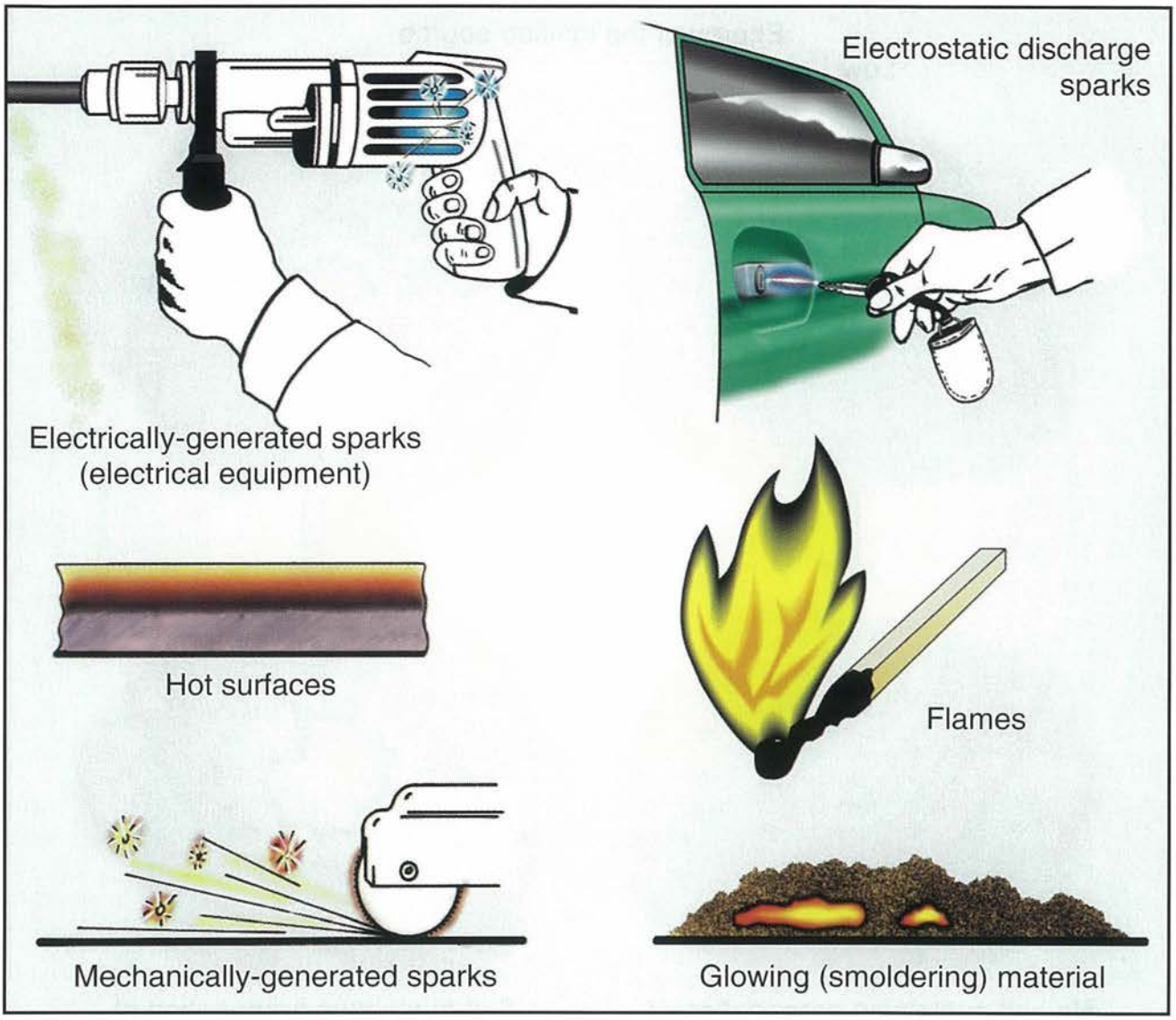

Fig. 3: Possible ignition sources

What is an effective ignition source?

Not every ignition source has sufficient energy to ignite all types of explosive mixture, i.e. not every ignition source is also an effective ignition source in a given situation.

An ignition source is effective when it can supply enough energy to the explosive atmosphere to cause initiation of a self-sustaining propagation of the combustion.

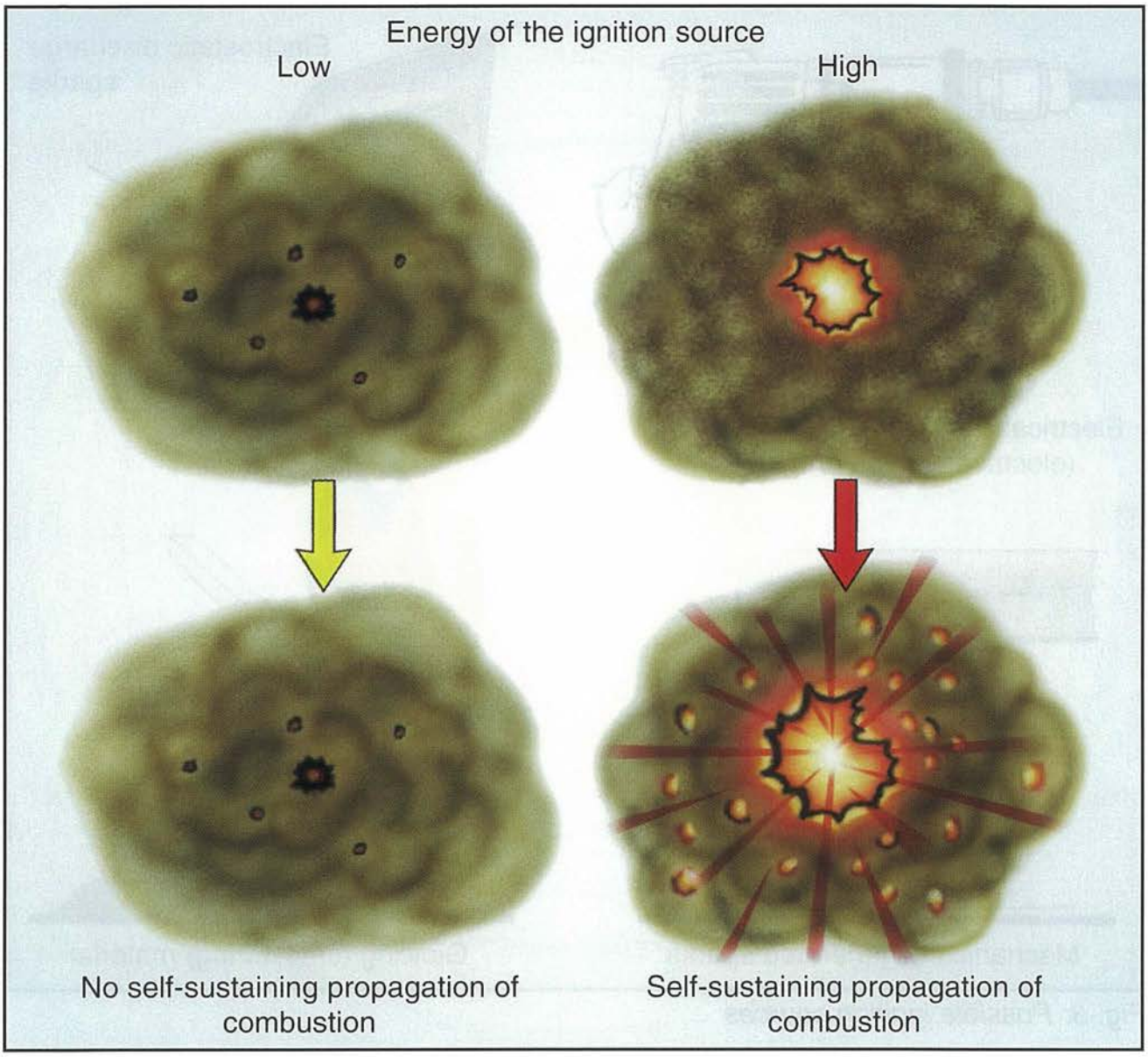

Fig. 4: Effectiveness of ignition sources

Reliable avoidance of one of the three prerequisites - dust cloud, air (oxygen), or ignition source - can prevent dust explosions.

How frequently do dust explosions occur and what are their possible consequences?

Dust explosions occur more frequently than is generally supposed. In Europe, there is an average of at least one dust explosion per day. Dust explosions often cause major damage costing millions of euros, and may also result in injury and even death.

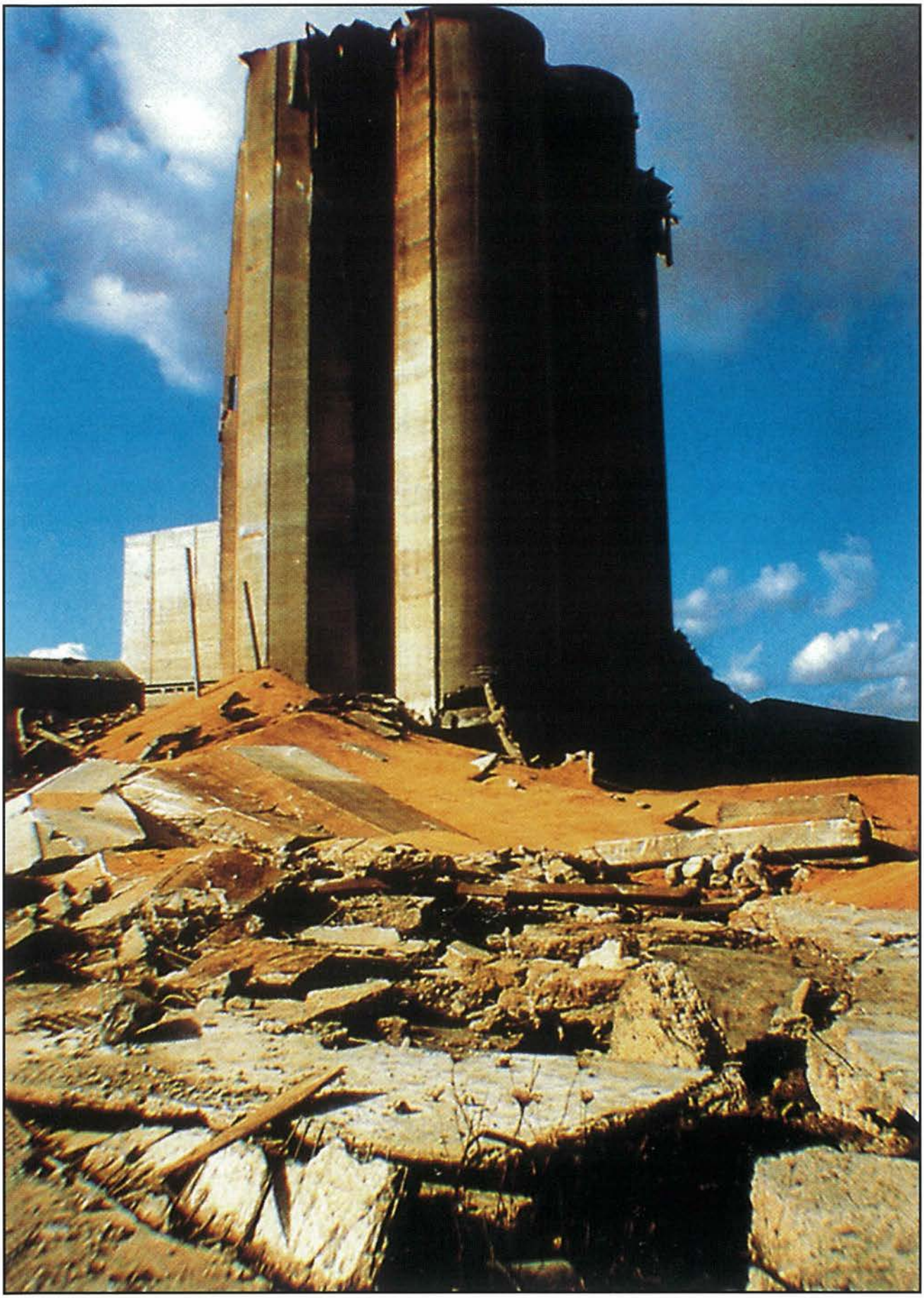

Fig. 5: Effects of a dust explosion in a malthouse: after the explosion only a few of the 16 silo cells remained standing

Protective measures

If, after consideration (e.g. in relation to safety), a dust explosion hazard is thought to exist, measures must be taken. The following possibilities exist:

- Prevention of an explosion
  ("preventive explosion protection")
  - •• Avoidance or restriction of the formation of explosive atmospheres
  - •• Avoidance of effective ignition sources
- Avoidance of the hazardous consequences of an explosion
  ("constructional explosion protection")

Combinations of these possibilities can be appropriate or even necessary. Preventive and constructional measures should always be accompanied by organizational and, where appropriate, design measures.

Prevention of dust explosions

How can dust explosions be prevented?

Dust explosions can be prevented if

- the flammable dust can be replaced by a non-flammable dust;
- the dust concentration can be kept so low that an explosive dust/air mixture is never actually formed;
- the oxygen concentration necessary for explosive combustion of the dust is not present; or
- effective ignition sources can be excluded with certainty.

Replacement of flammable by non-flammable substances

This measure has only limited applicability and is restricted to replacing flammable filling materials by non-flammable materials. The admixture of inert dust is generally only effective if the inert dust makes up more than half of the mixture.

Limiting the dust concentration

In contrast to gases and vapors, use of this measure for dusts is limited. This is because dust concentrations can change very quickly:

- decrease due to settlement (sedimentation)
- increase due to blowing

Spraying with liquids, or use of larger-grained material, can prevent the formation of high dust concentrations.

Limitation of the oxygen concentration (inerting)

The oxygen is displaced by non-flammable gases such as nitrogen or carbon dioxide to such an extent that an explosion can no longer take place. This measure is extremely reliable, but mostly applicable only in closed plant units. It calls for high equipment expenditure, must be monitored by measurement and, under certain circumstances, entails high subsequent costs, depending on the size and gastightness of the system (inert gas consumption).

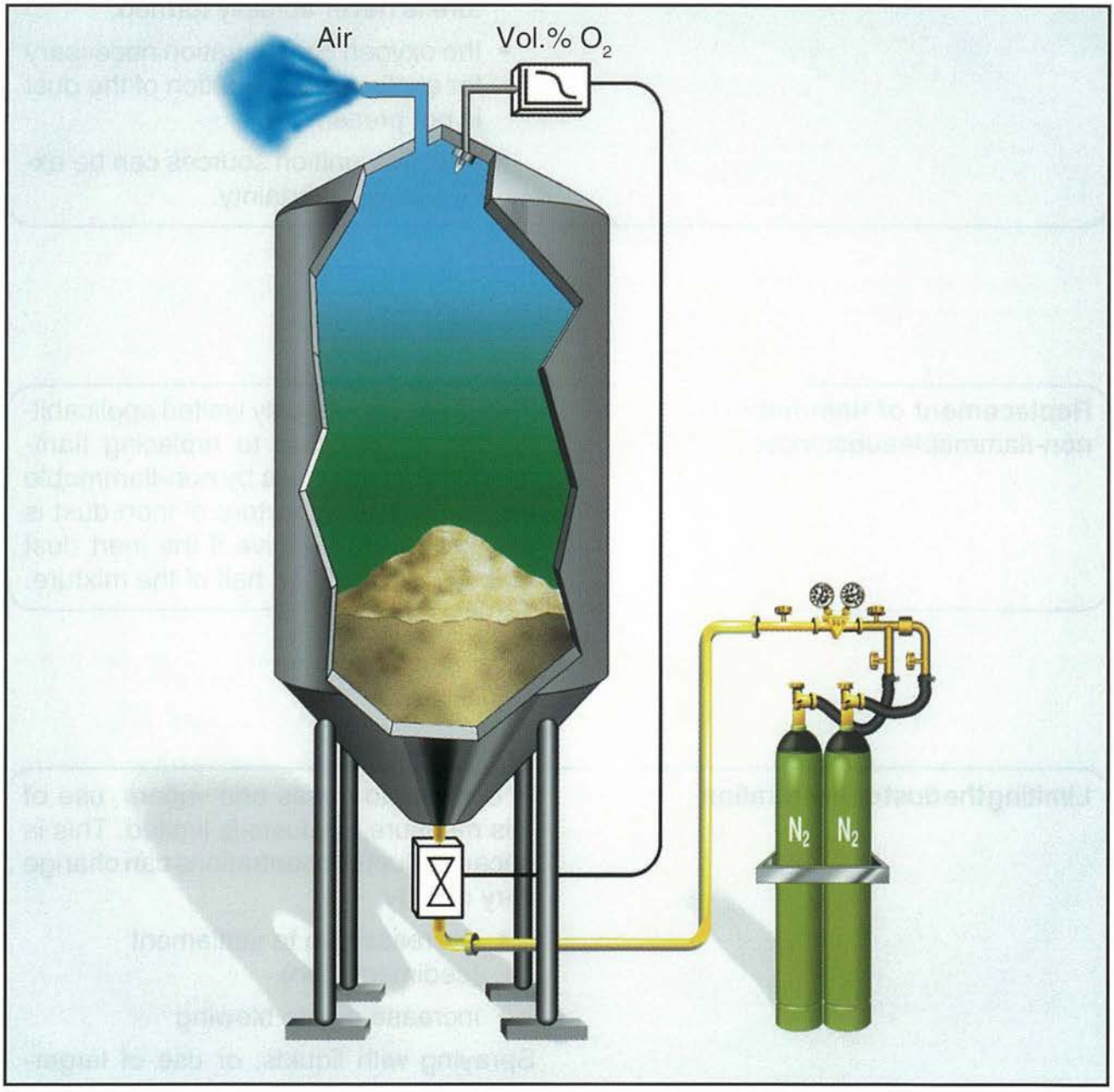

Fig. 6: Inerting with nitrogen and measuring/monitoring the oxygen concentration

Avoidance of effective ignition sources

This measure should always be employed even when the constructional measures described later are applied. However, in practice, when used alone it is frequently not reliable enough.

What are zones?

Areas in which there is an explosion hazard are divided into zones[1)] depending on how frequently and for how long an explosive atmosphere occurs or is present.

The purpose of zones is to determine the extent of the measures required for avoiding effective ignition sources.

Fig. 7: Avoidance of effective ignition sources

[1)] See ISSA brochure "Ignition Sources".

Fig. 8: Vacuum cleaning to avoid blowing dust

Avoidance of an explosive atmosphere or ignition sources prevents explosions!

Avoidance of effective ignition sources as the only protective measure requires a corresponding risk analysis.

Avoidance of hazardous effects of dust explosions

If a dust explosion cannot be excluded with certainty, measures must be taken to ensure that no hazardous effects due to the dust explosion arise. These measures are also called "constructional measures", since vessels and plant components must be constructed or equipped to ensure that the explosion causes no injury to personnel, and minimal damage to buildings and equipment.

When can constructional measures be implemented?

These must always be considered for every new plant unit. Retrofitting to provide greater safety with old systems is usually also possible, but here, however, special considerations are necessary.

What constructional measures are available for explosion protection?

The effects of a dust explosion can be limited by:

- explosion-resistant construction
- explosion venting
- explosion suppression
- explosion isolation

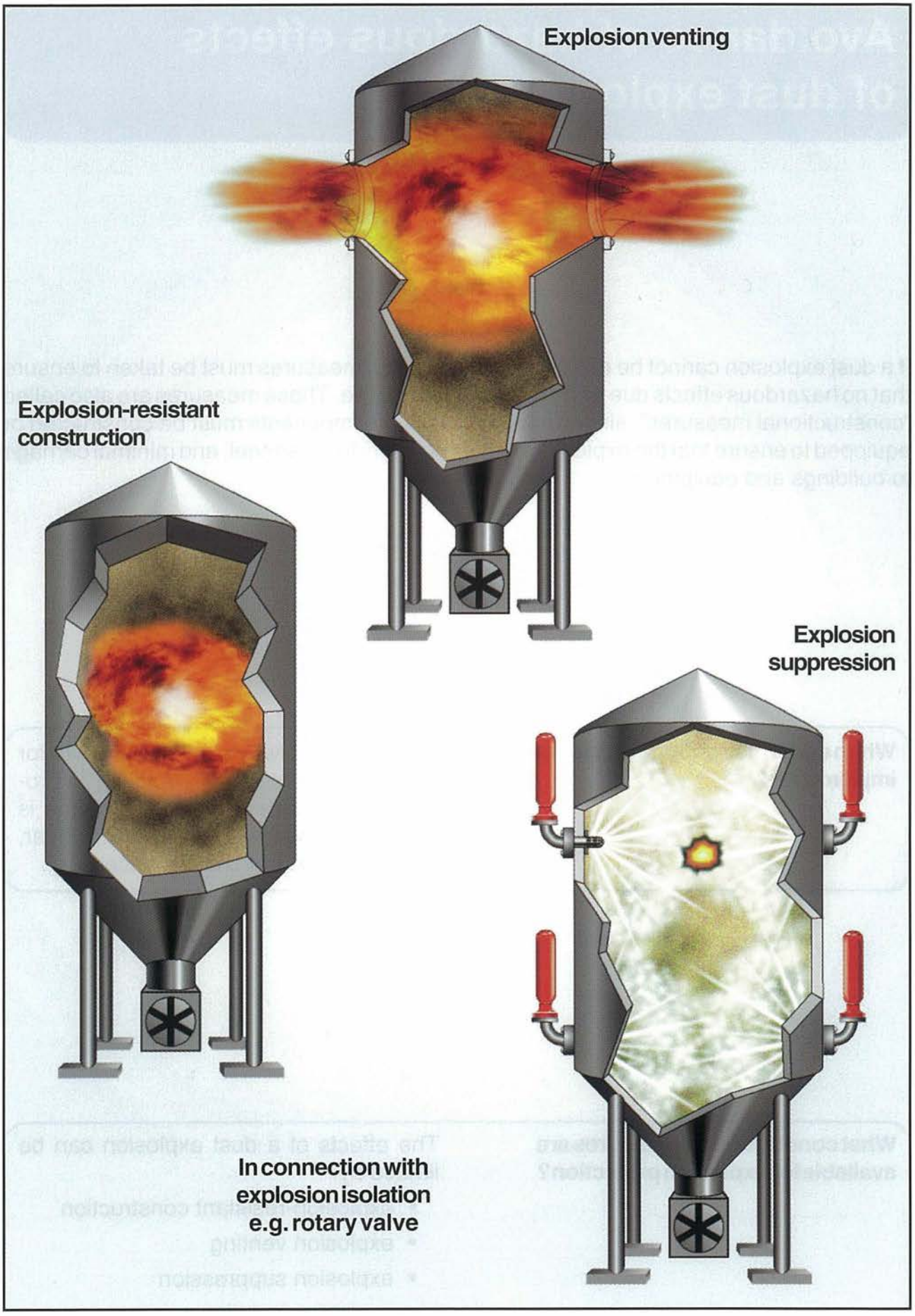

Fig. 9: Examples of constructional measures

Explosion-resistant construction

Explosion-resistant vessels and units, including connecting pipelines, shut-off devices, etc. must withstand the expected explosion overpressure without rupturing.

In this connection note the difference between

- explosion pressure resistant construction, in which the equipment is designed like a pressure vessel, so that the pressure stress of an explosion does not result in permanent deformation; and
- explosion pressure shock resistant construction, in which permanent deformation is permitted, and the equipment must be repaired or replaced as necessary following the explosion.

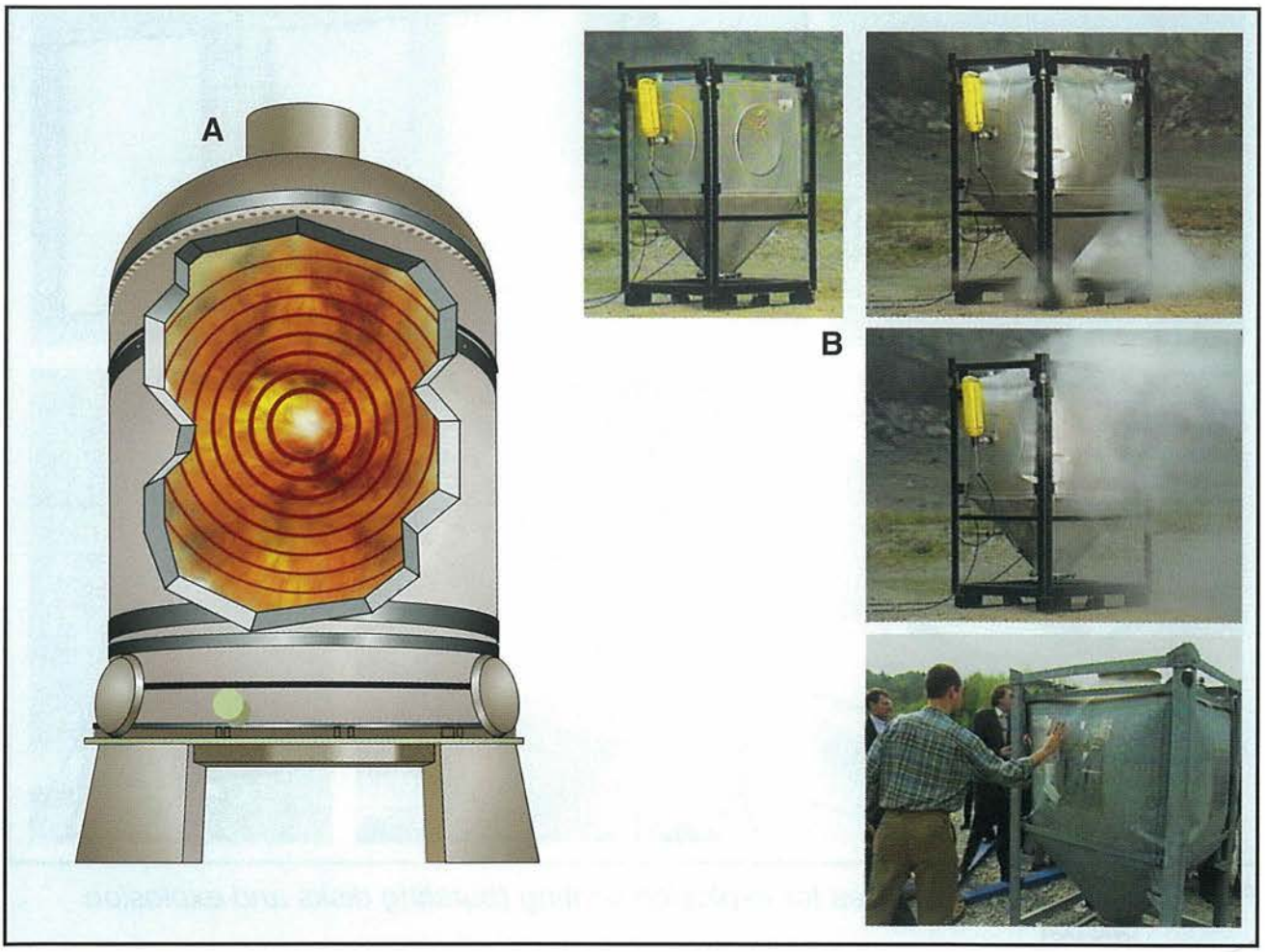

Fig. 10: Examples of explosion pressure resistant vessels.
A: explosion pressure resistant construction, B: explosion pressure shock resistant construction, before and after the explosion

Explosion venting

For the purpose of explosion venting, a vessel which is to be protected is provided with a venting device which opens at a specified pressure which must be considerably below the vessel strength. Such devices include, for example, bursting disks and explosion doors.

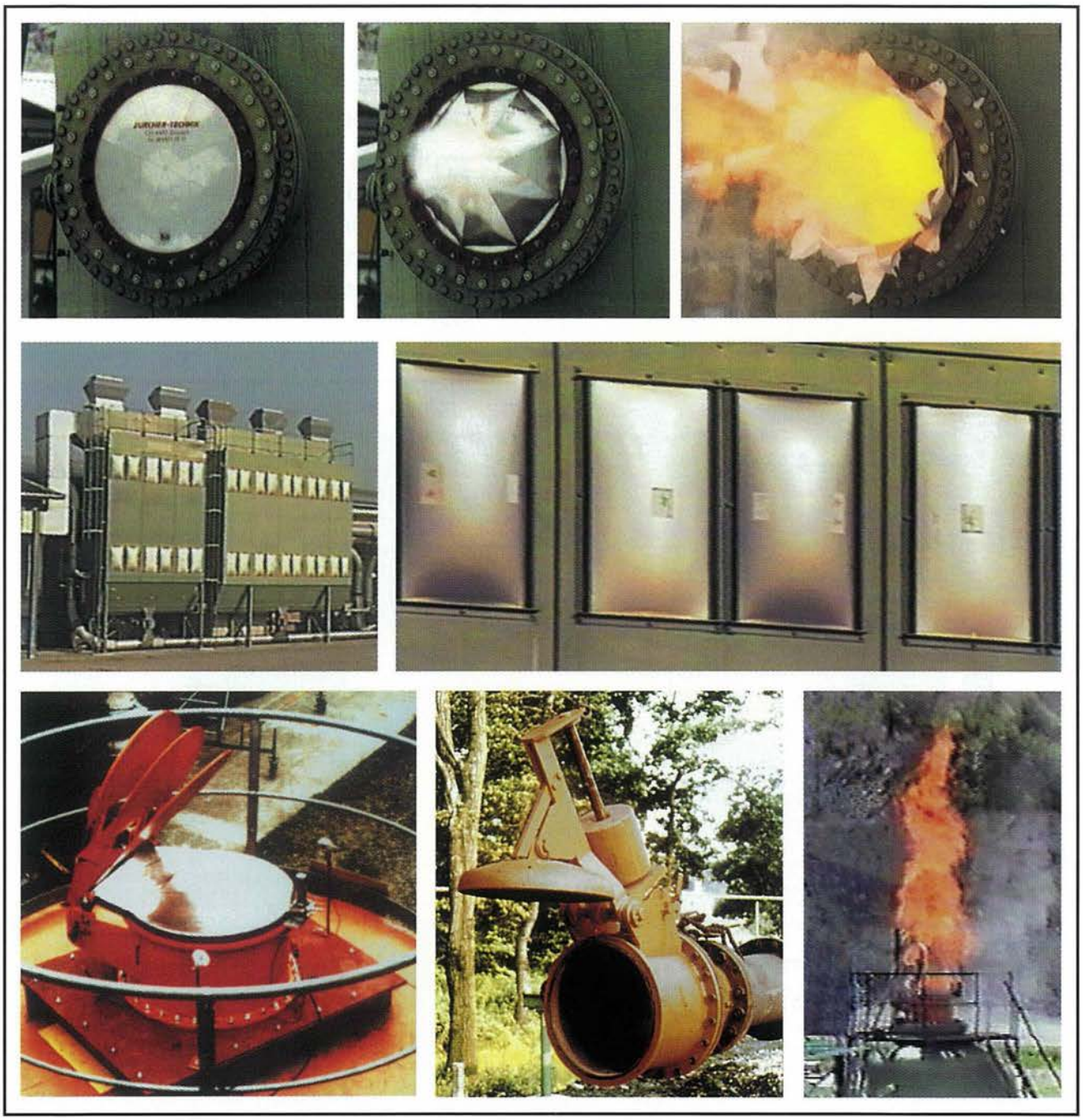

Fig. 11: Examples of devices for explosion venting (bursting disks and explosion doors)

Always vent explosions in a "non-hazardous" direction, never into the work area!

Explosion suppression

An explosion suppression unit recognizes an incipient explosion by means of flame or pressure detectors, and suppresses the explosion in the initial phase by rapid injection of extinguishing agents.

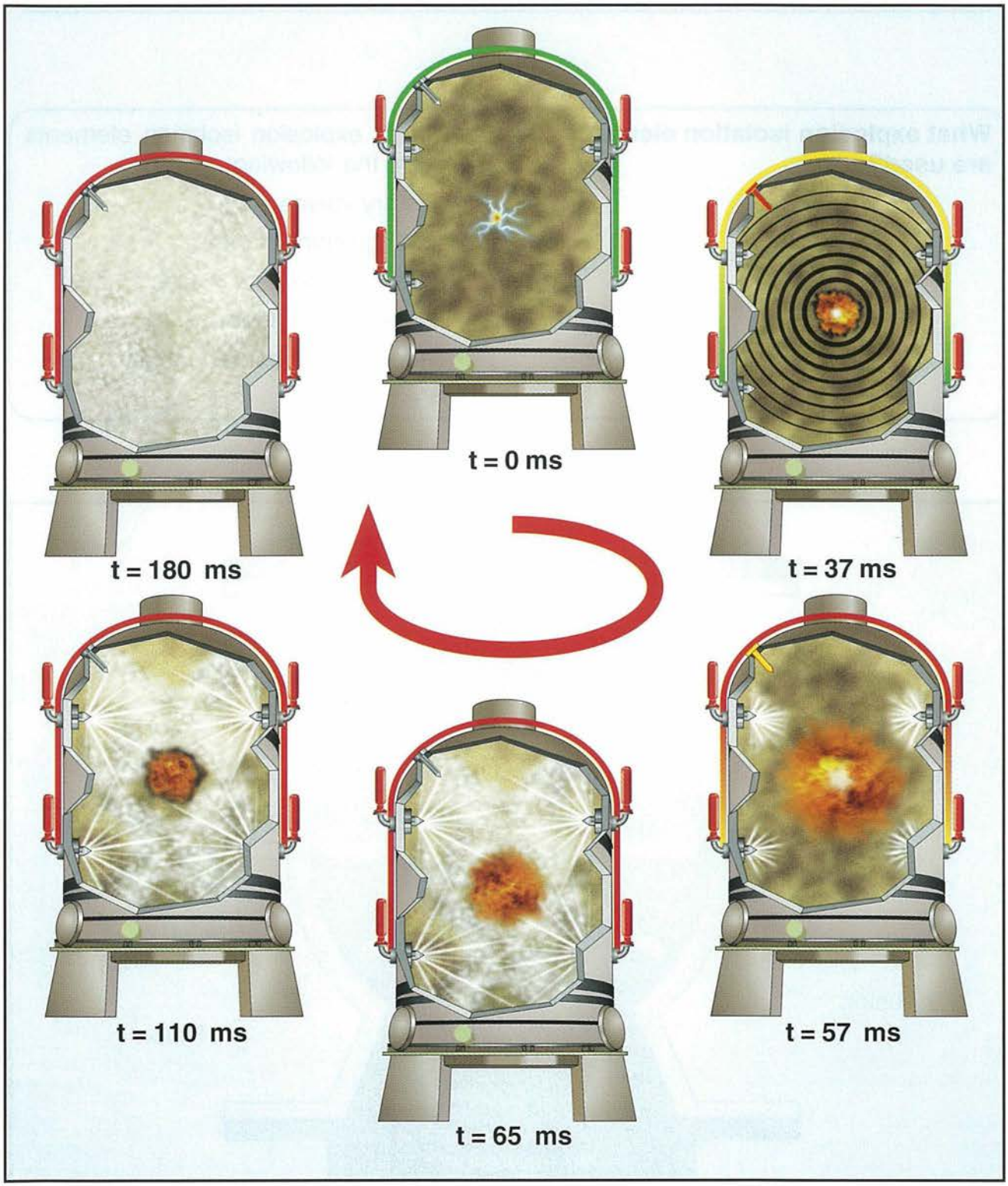

Fig. 12: Principle of explosion suppression (time sequence in a 5 m³ container)

Explosion isolation	To prevent an explosion in parts of the plant which are protected by constructional measures from spreading into other parts of the plant or workrooms (whether protected or not), explosion isolation measures are usually necessary. Such measures can further confine the area affected by an explosion.

What explosion isolation elements are used?	The main explosion isolation elements used are the following: • Rotary valves • Extinguishing barriers • Rapid-action gate valves • Rapid-action flaps • Rapid-action barrier valves • Vent ducts

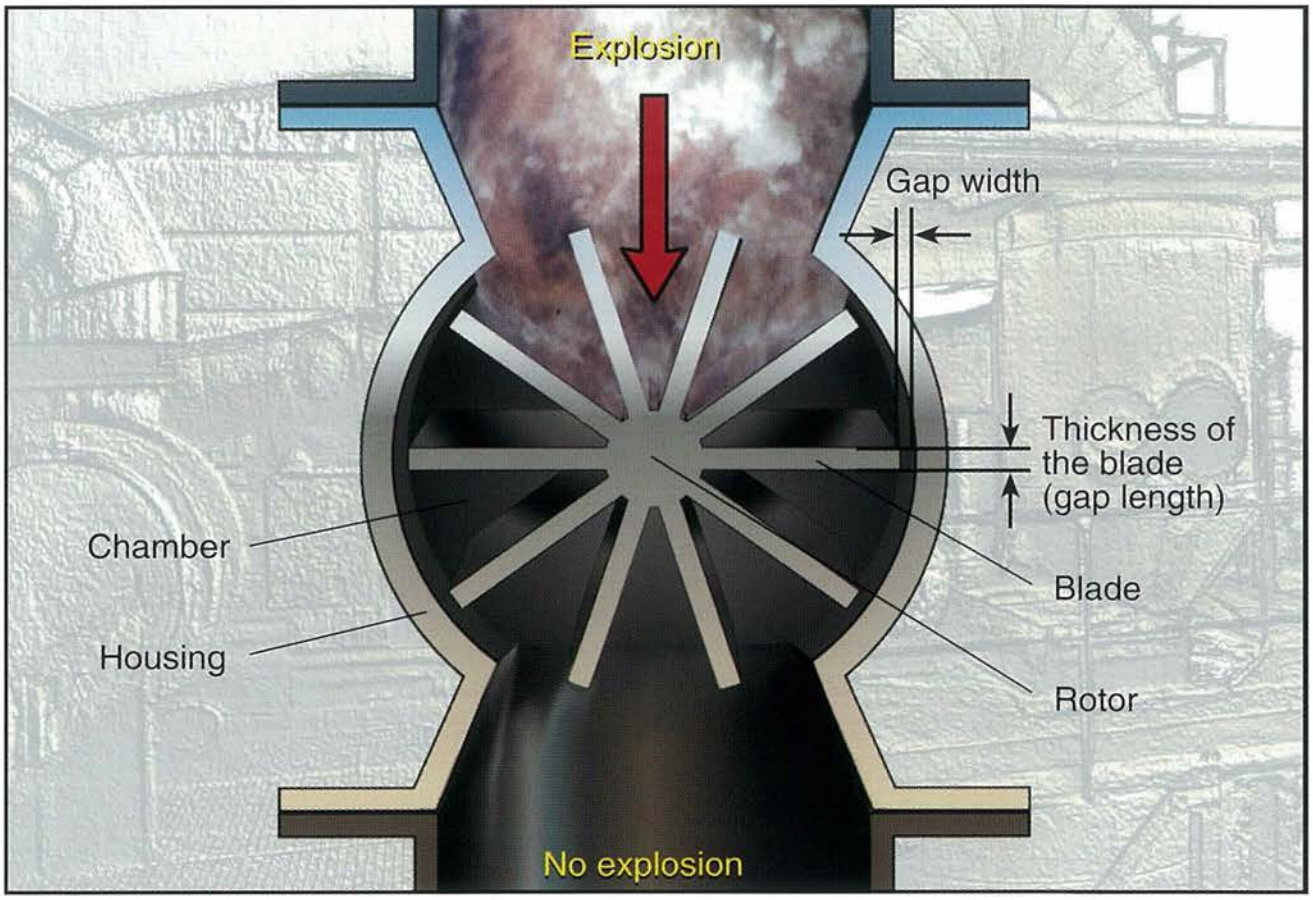

Fig. 13: Explosion isolation by rotary valve

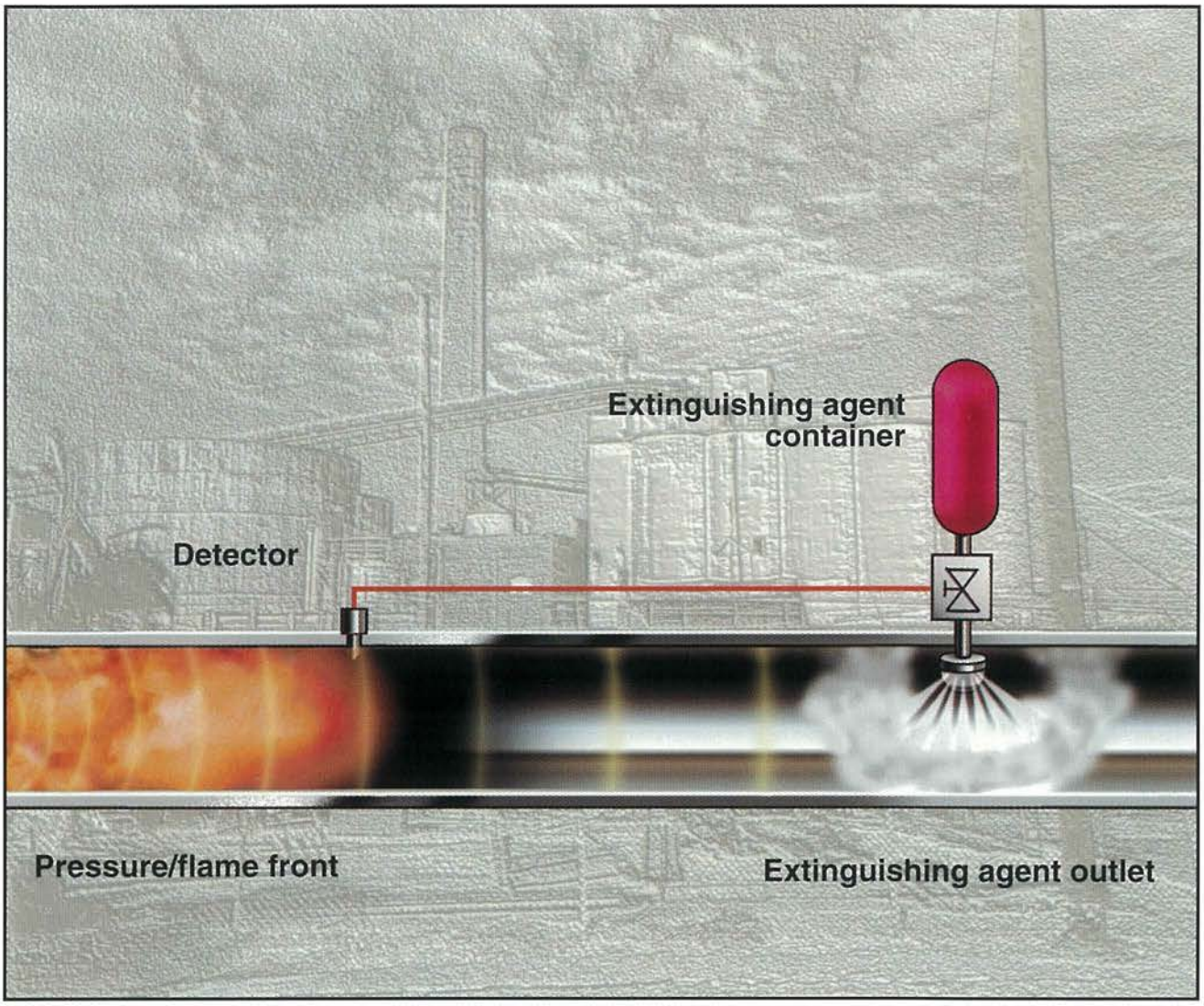

Fig. 14: Explosion isolation by extinguishing barrier

When taking decisions concerning the choice of constructional explosion protection measures, a number of influencing parameters must be taken into consideration.

Assigning dimensions to them generally requires expert knowledge.

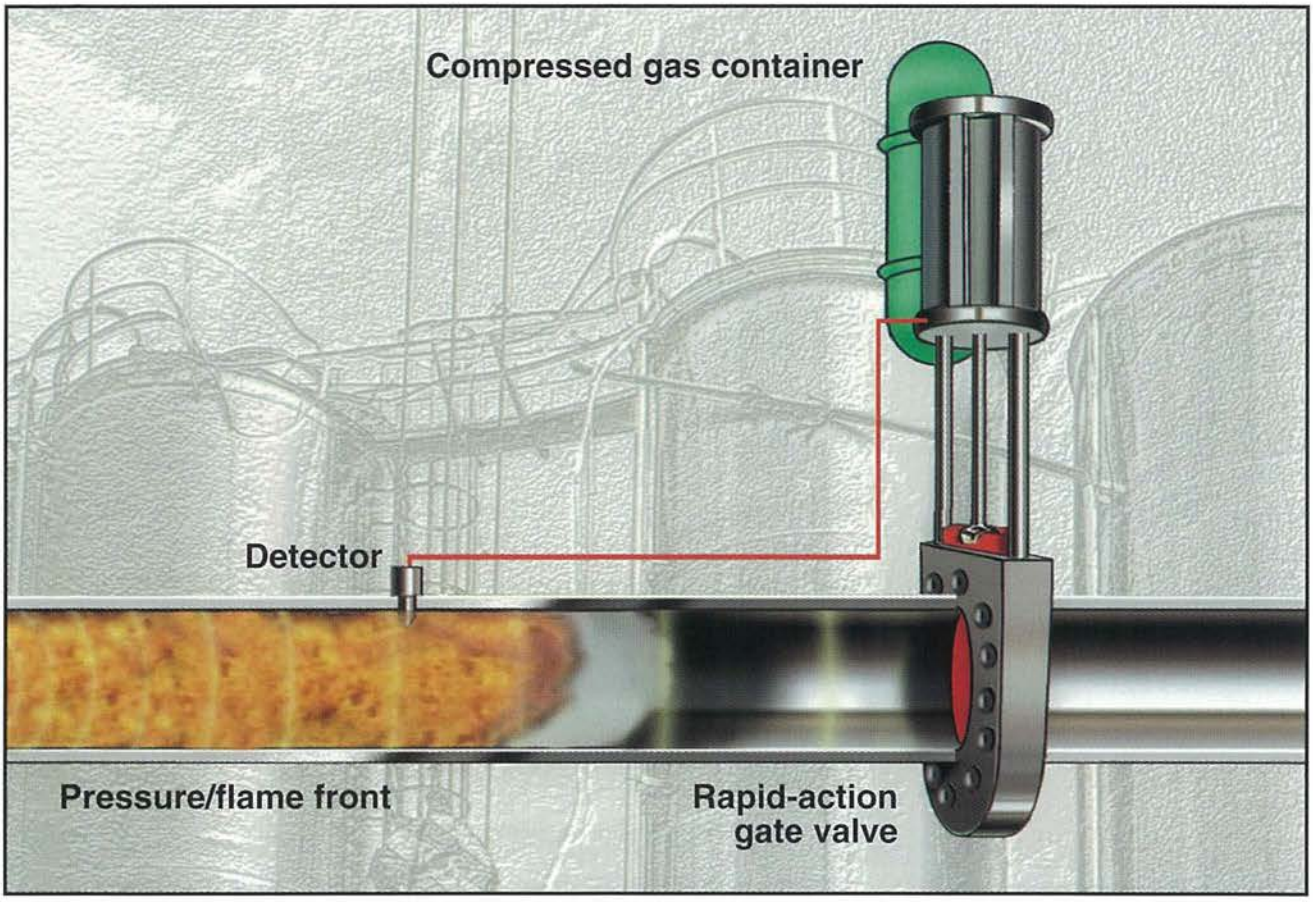

Fig. 15: Explosion isolation by rapid-action gate valve

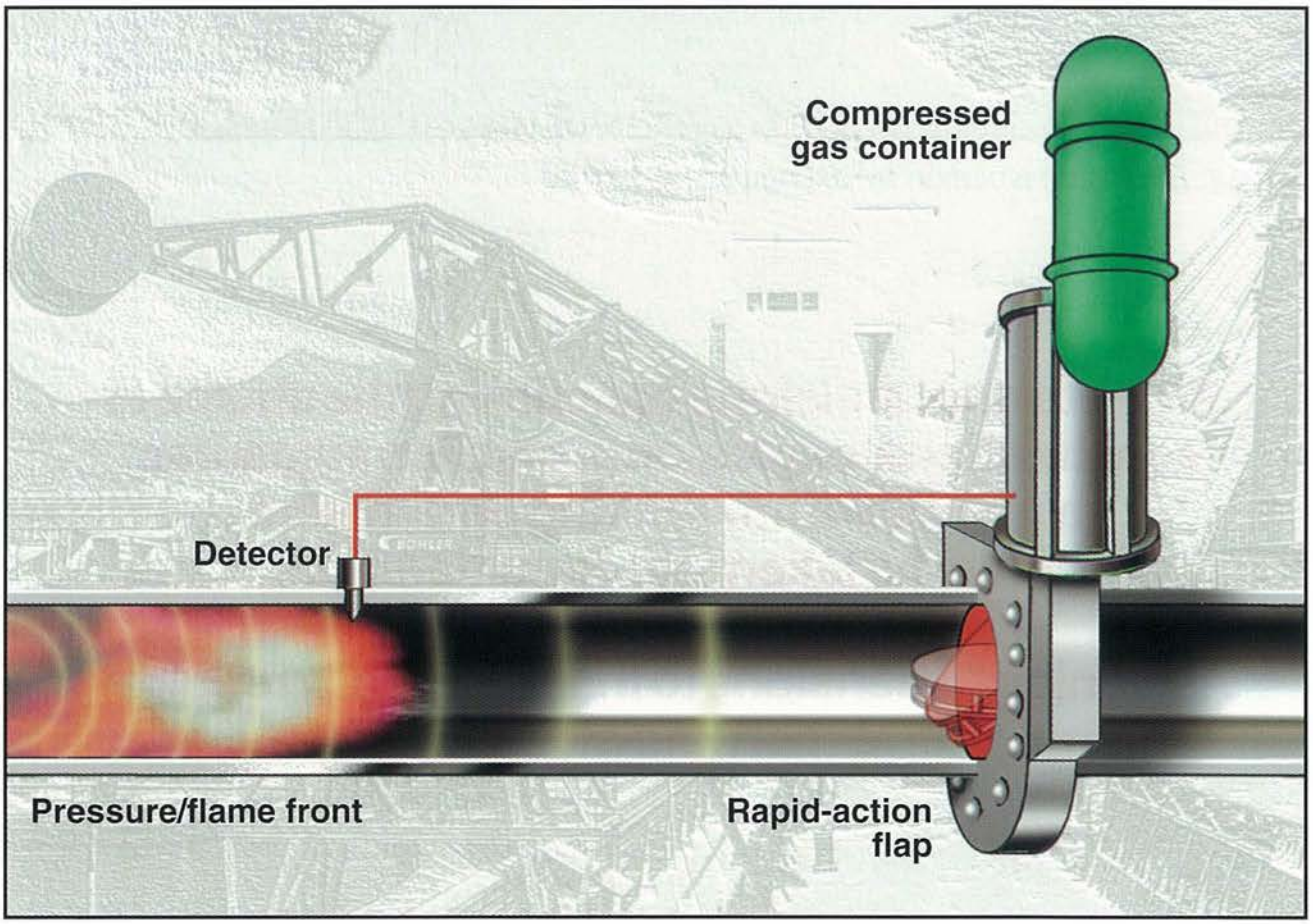

Fig. 16: Explosion isolation by rapid-action flap

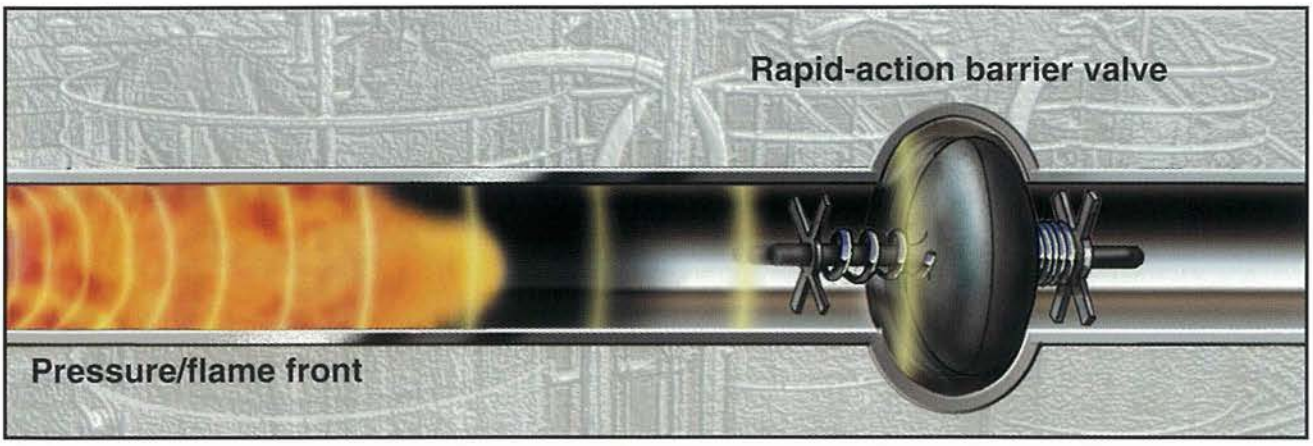

Fig. 17: Explosion isolation by rapid-action barrier valve

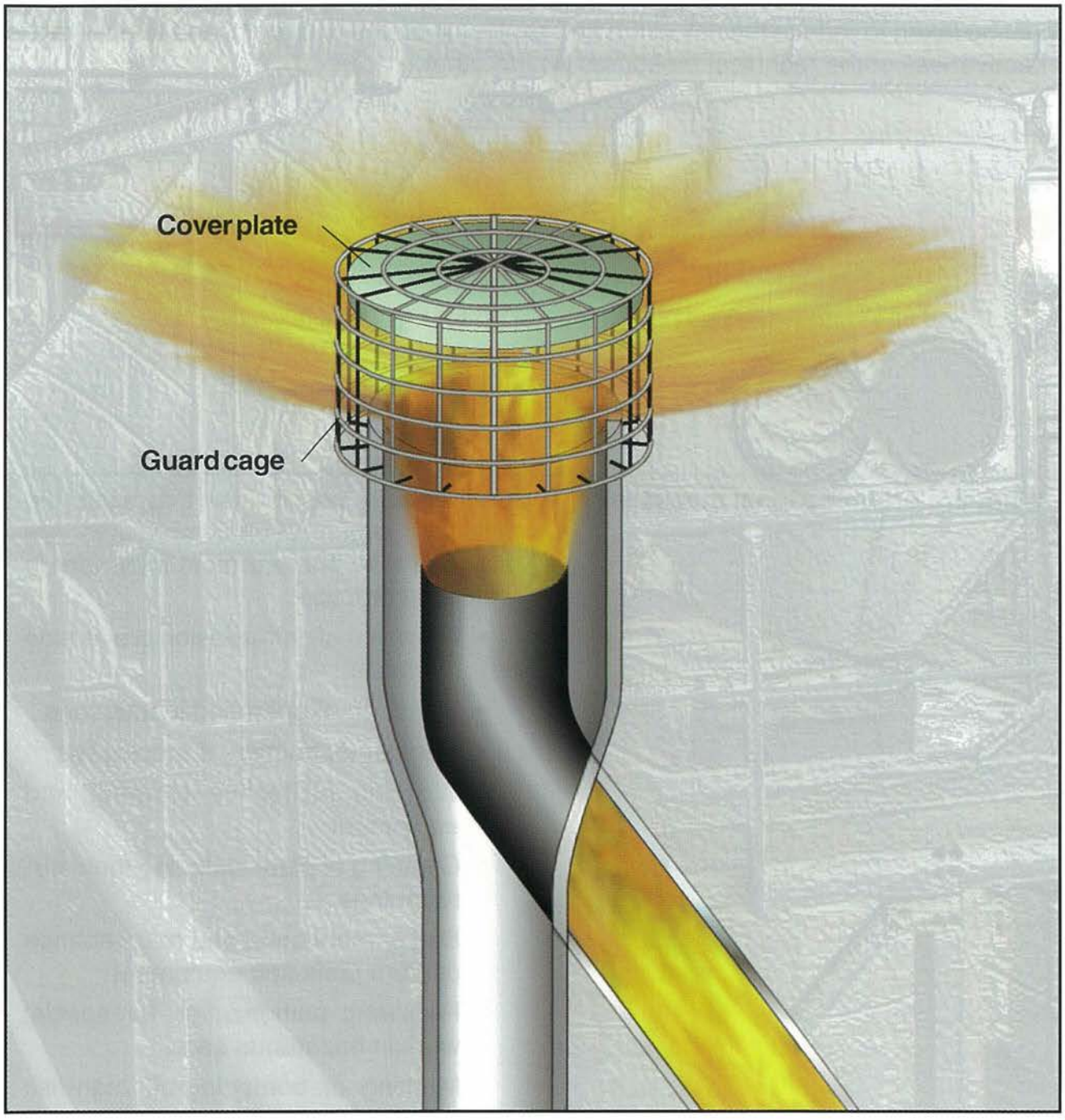

Fig. 18: Explosion isolation by vent duct

Organizational measures

Complementary to preventive and constructional measures, organizational measures must be taken to reduce the risk of fire and explosion on the one hand, and to ensure the effectiveness of the technical measures on the other.

Organizational measures are generally defined and implemented within the framework of a safety management system.

What are organizational measures?

Of the many possibilities that exist, the following organizational measures are among those that are most important in industrial practice:

- Provision of an explosion prevention manual
- Provision of operating instructions
- Regular instruction of employees
- Wearing protective clothing and equipment
- Cleaning of plant units and their surroundings
- Safety monitoring and maintenance of plant units and equipment
- Requiring authorization for special work in hazardous areas
- Marking or cordoning-off high-risk zones

Provision of an explosion protection manual

The explosion protection document contains information such as:

- A description of the plant area, process, activities, and substance quantities
- Substance data (safety parameters)
- Risk assessment
- Separation into zones
- Technical and organizational protection measures
- Emergency measures, plant instructions, and work authorization

Provision of operating instructions

The operating instructions must govern the behavior of the employees during normal operation and in the case of a malfunction. The responsibilities for the implementation of the measures must be clearly specified.

Regular instruction of employees

The employees must be informed of possible hazards at regular intervals, and their attention drawn to the proper code of behavior.

Wearing protective clothing and equipment

The necessary protective clothing and equipment, e.g. conductive shoes, must be provided, used, and kept in serviceable condition.

Cleaning plant units and their surroundings

Great importance must be attached to the cleaning of units, and particularly their surroundings, to remove dust deposits. This is because even a one-millimeter layer of dust is sufficient to form an explosive dust/air mixture if dispersed into the air by, for example, the pressure wave of a primary explosion. Cleaning must therefore be carried out not only at regular intervals but also particularly during or after work which produces any dust deposits.

Safety monitoring and maintenance of the plant and equipment	Particular attention should be paid to regular checking and maintenance of the units, particularly the safety devices such as explosion doors, sensors, rapid-action slide valves and any equipment/plant items which can act as ignition sources, e.g. bearings, elevator belts. The introduction of a "safety maintenance check program" (checklist) has proved its worth in practice.

Authorization required for special work in areas with explosion hazard	Carrying out special work such as welding, grinding, or maintenance of electrical equipment in areas with an explosion hazard must be subject to written authorization (fire, welding, and entry permits).

Signposting or closure of high-risk zones	Areas (zones) which are endangered by explosion, such as the areas around charge and discharge openings, filling units, and slide valves, must be signposted. Areas where there is a hazard due to explosion venting (effects of pressure and flames) or due to the use of inert gases (danger of suffocation) must be signposted and cordoned off.

Organizational measures increase and augment the effectiveness of the preventive and constructional explosion protection measures.

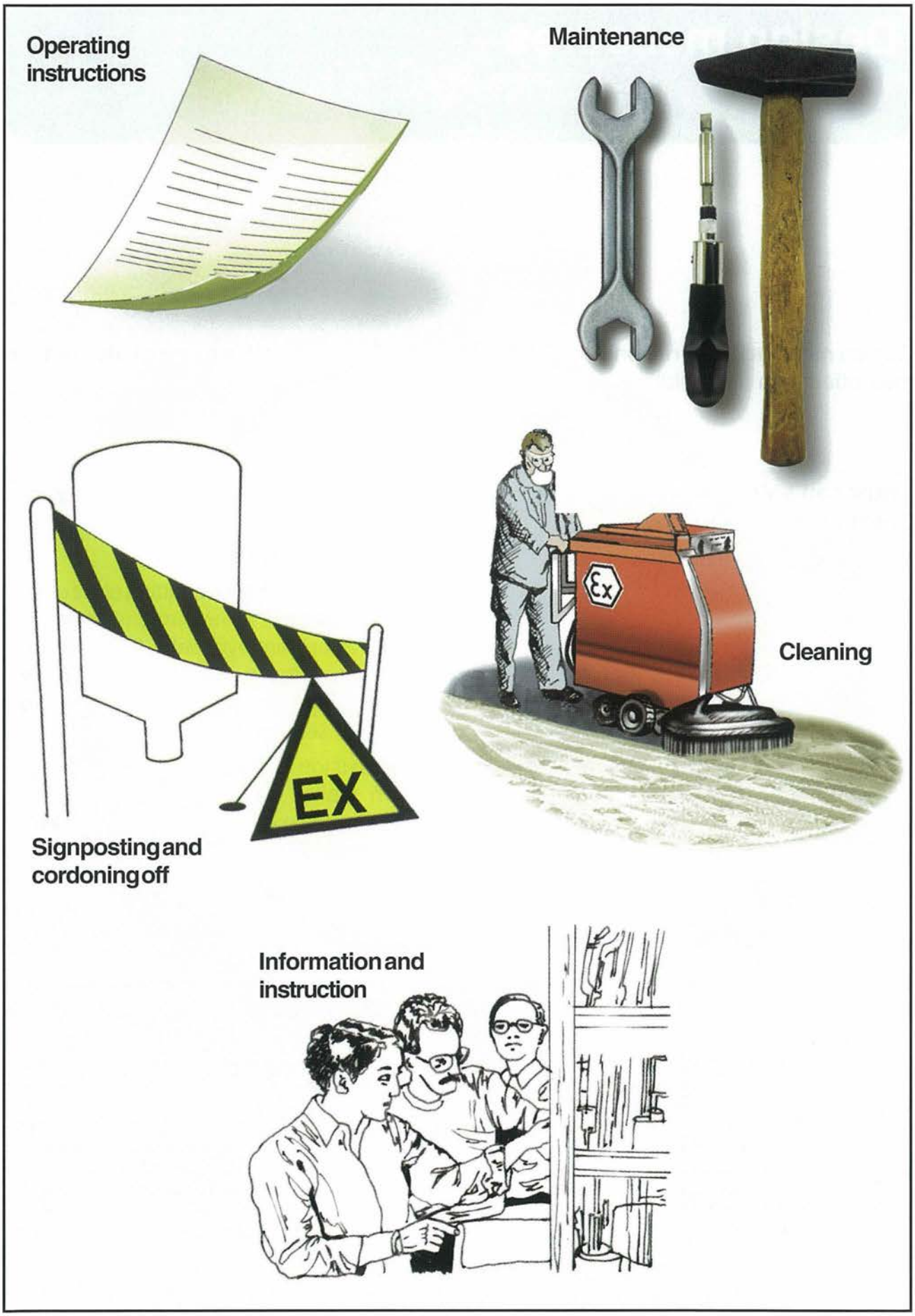

Fig. 19: Organizational measures

Design measures

Design measures can not only limit the hazards due to dust explosions, but also reduce their effects on the building.

How can safety be increased by design measures?

Design measures to improve safety include, for example

- Fire compartments;
- Separation of dust-emitting plant units such as sack filling stations, transfer points on conveyor belts, from closed, and therefore non-dust-emitting plant units by, for example, separating walls, sealing of openings;
- Provision of smooth surfaces (e.g. on walls), and addition of sloping surfaces (e.g. on beams, windowsills) to reduce dust deposits.

Design measures can produce a significant improvement in safety.

Safety parameters

Application of the safety measures mentioned requires knowledge of the combustion and explosion parameters[1)] of the dust in question. These parameters are not physical constants, but depend on the condition of the dust and the method of investigation. For the design of individual protective measures, the parameters listed on page 38 must be known in each case. The illustration below shows schematically an example of a test apparatus with 1 m^3 vessel for determining the explosion parameters of dusts.

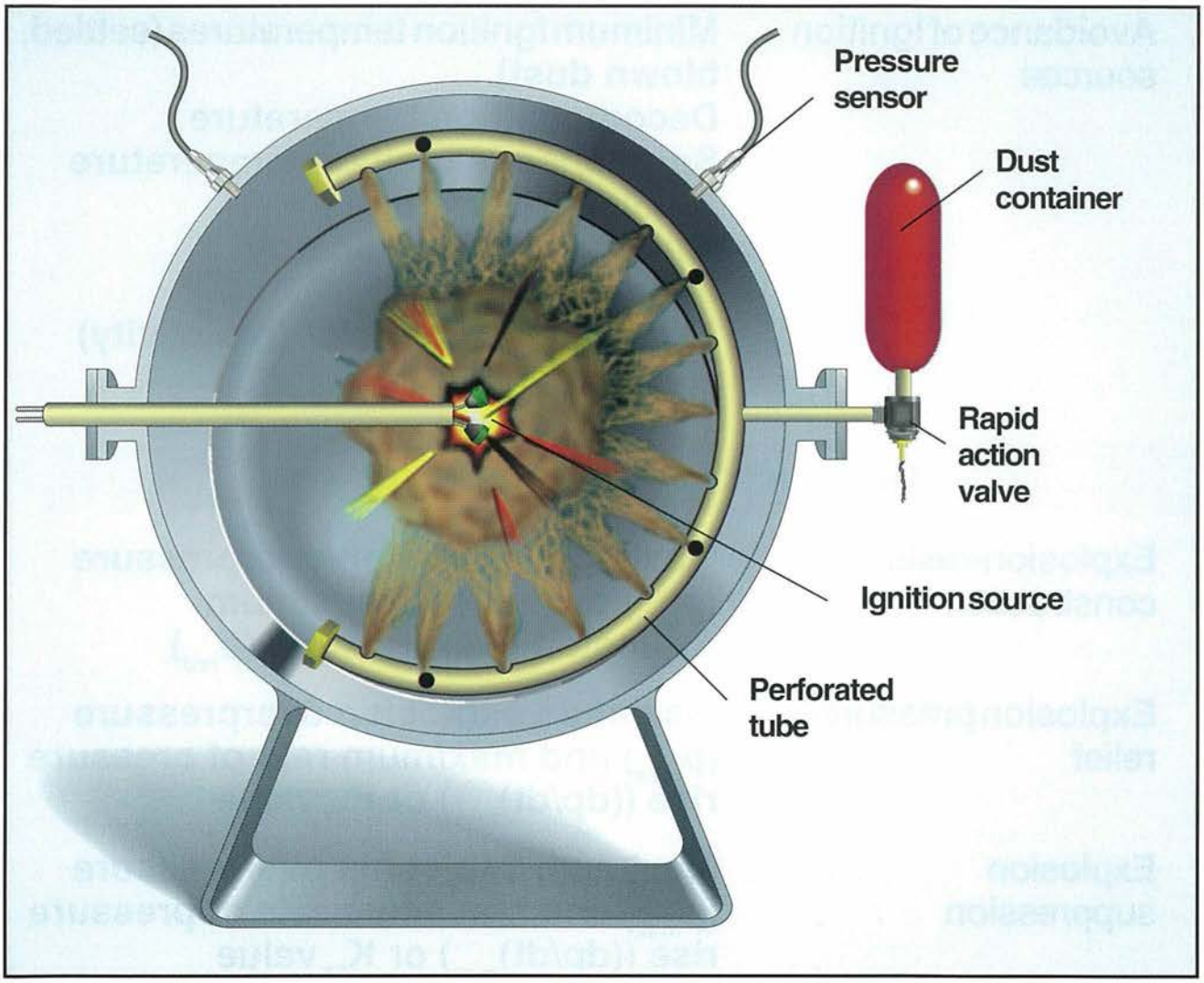

Fig. 20: Test apparatus for determining dust explosion parameters (1 m^3 vessel)

The interpretation of safety parameters must be left to the expert.

[1)] See ISSA brochure "Determination of the Combustion and Explosion Characteristics of Dusts"

Protective measures	Parameters needed for the design of protective measures
Preventive Explosion Protection	
Replacement of flammable materials	Flammability, explosibility
Concentration limitation	Explosion limits
Inerting	Limiting oxygen concentration
Avoidance of ignition sources	Minimum ignition temperatures (settled, blown dust) Decomposition temperature Spontaneous ignition temperature Smolder temperature Minimum ignition energy Impact sensitivity Electrostatic behavior (resistivity)
Constructional Explosion Protection	
Explosion-resistant construction	Maximum explosion overpressure (p_{max}) or reduced maximum explosion overpressure (p_{red})
Explosion pressure relief	Maximum explosion overpressure (p_{max}) and maximum rate of pressure rise $((dp/dt)_{max})$ or K_{St} value
Explosion suppression	Maximum explosion overpressure (p_{max}) and maximum rate of pressure rise $((dp/dt)_{max})$ or K_{St} value
Explosion isolation	Gap width limits Minimum ignition temperature of the dust cloud Minimum ignition energy

Notes

References

[1] Commission of the European Community, Directive 94/9/EC of the European Parliament and the Council dated March 23, 1994, for the harmonization of the legal regulations of member states for devices and protective systems designated for use in areas subject to explosion hazards, published in the Official Journal of the EC, L 100, dated August 19, 1994, pages 1-29 (ATEX 100a, new ATEX 95).

[2] Commission of the European Community, Directive 99/92/EC of the European Parliament and the Council dated December 16, 1999, on minimum requirements for improving the safety and health of workers potentially at risk from explosive atmospheres (15th individual directive within the meaning of Article 16(1) of Directive 89/391/EEC), Official Journal of the EC, L 023, dated January 28, 2000, pages 57-64 (ATEX 118a, new ATEX 137).

[3] EN (European Standard), *Explosive Atmosphere - Explosion Protection - Part 1: Basics and Methodology*, EN 1127-1, August 1997.

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ISSA publications on explosion protection

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Section for the Chemical Industry
"Explosion Protection" Working Party

Dust Explosions (G/E/It)
(2003)

Gas Explosions (G/E/It)
(2001)

Safety of Liquid Gas Installations - Propane and Butane (G/E/F/It/Sp)
(1992)

Static Electricity - Ignition hazards and protection measures (G/E/F/It)
(1996)

Ignition Sources (in preparation)

Address for orders: ISSA Chemistry Section
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IVSS

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"Dust Explosions" Working Party

Dust explosion protection of machines and apparatus

- Basic Principles (G/E)
  (2003)
- Collection of Examples (G/E/F)
  (1990)

Explosion Suppression (G/E/F)
(1990)

Determination of the Combustion and Explosion Characteristics of Dusts (G/E)
(1997)

Explosion Isolation (G/E)
(in preparation)

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