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ISSA AISS IVSS

International Section for the Chemical Industry

Gas Explosions

Protection against explosions due to mixtures of flammable gases, vapors, or mists with air

ISSA AISS IVSS

suva

Swiss Accident Insurance Fund
PO Box 4358
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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 in Geneva, at the International Labour Organization. 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 plants the

INTERNATIONAL SECTION "MACHINE SAFETY" OF THE ISSA

was established in 1975. It handles matters relating to 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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Protection against explosions due to mixtures of flammable gases, vapors, or mists with air

Compendium for industrial practice

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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 International Social Security Association (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 prevention.
The committee of the "Section Chemistry" of the ISSA has set up a working party "Explosion Protection" to promote the international exchange of information among experts and to develop jointly 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 Protection" 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 flammable gases, vapors, or mists in admixture with air can 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; here, the specialized knowledge and experience of the expert is indispensable.

Questions concerning health protection are not treated in this booklet.

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Prerequisites for the occurrence of 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 flammable gases, vapors, or mists exist in my plant? [1)]	Such a hazard can exist when the production and storage, or other handling, of flammable liquids or flammable gases in the plant leads to the formation of gases, vapors, or mists.
What is meant by flammable liquids?	These are liquids whose vapors or mists can form an explosive atmosphere with air. Flammable vapors arise from liquids at a temperature above the flash point. Mists can be formed in the spraying of liquids.

[1)] Explosion hazards due to combustible dusts, ISSA booklet "Dust Explosions", p. 37.

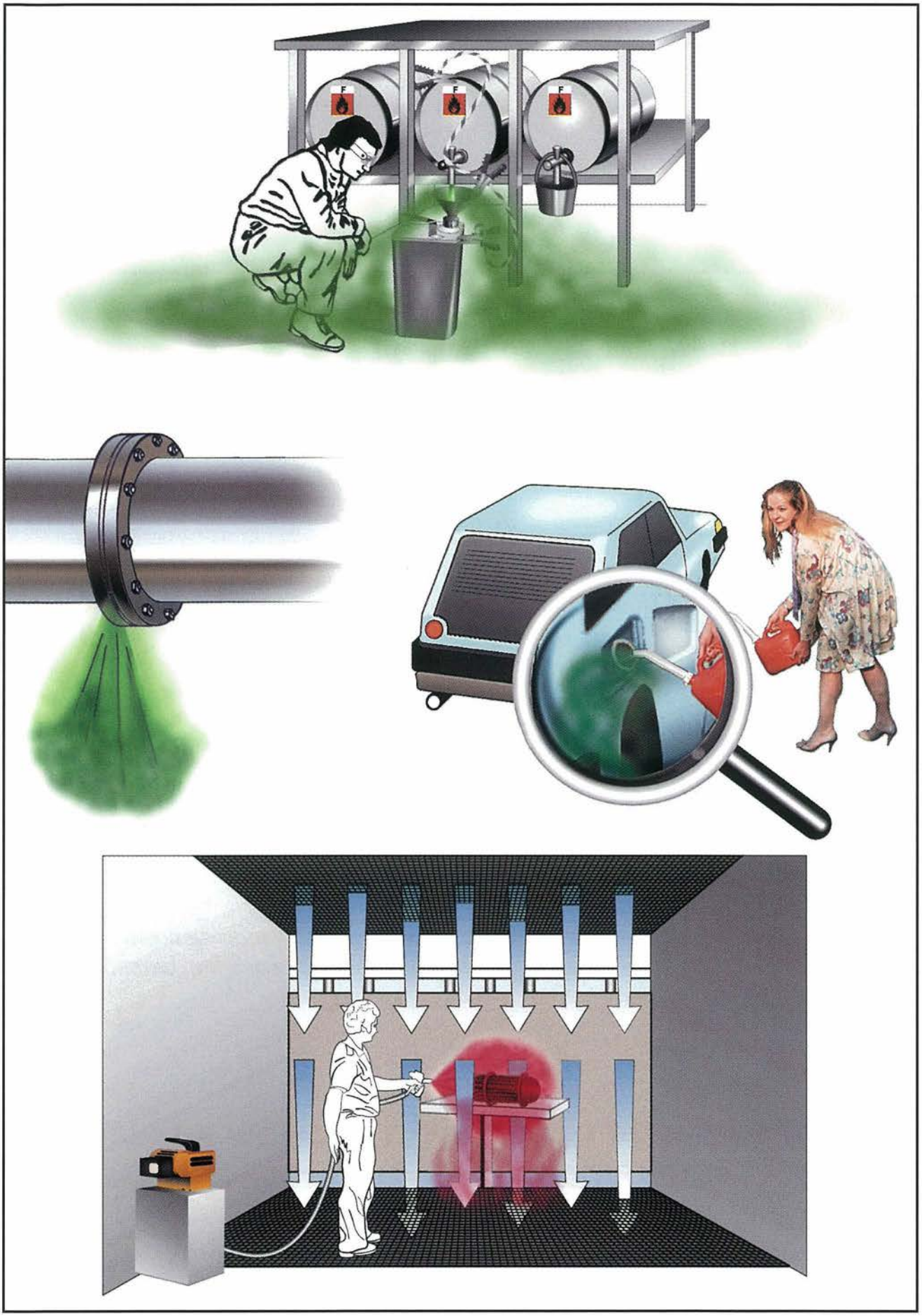

Fig. 1: Examples of the formation of vapors and mists from flammable liquids

What is the flash point of a liquid?

The flash point of a flammable liquid is the lowest temperature at which, under prescribed conditions, vapor is evolved from the liquid in sufficient quantity that this immediately ignites on contact with an effective ignition source.

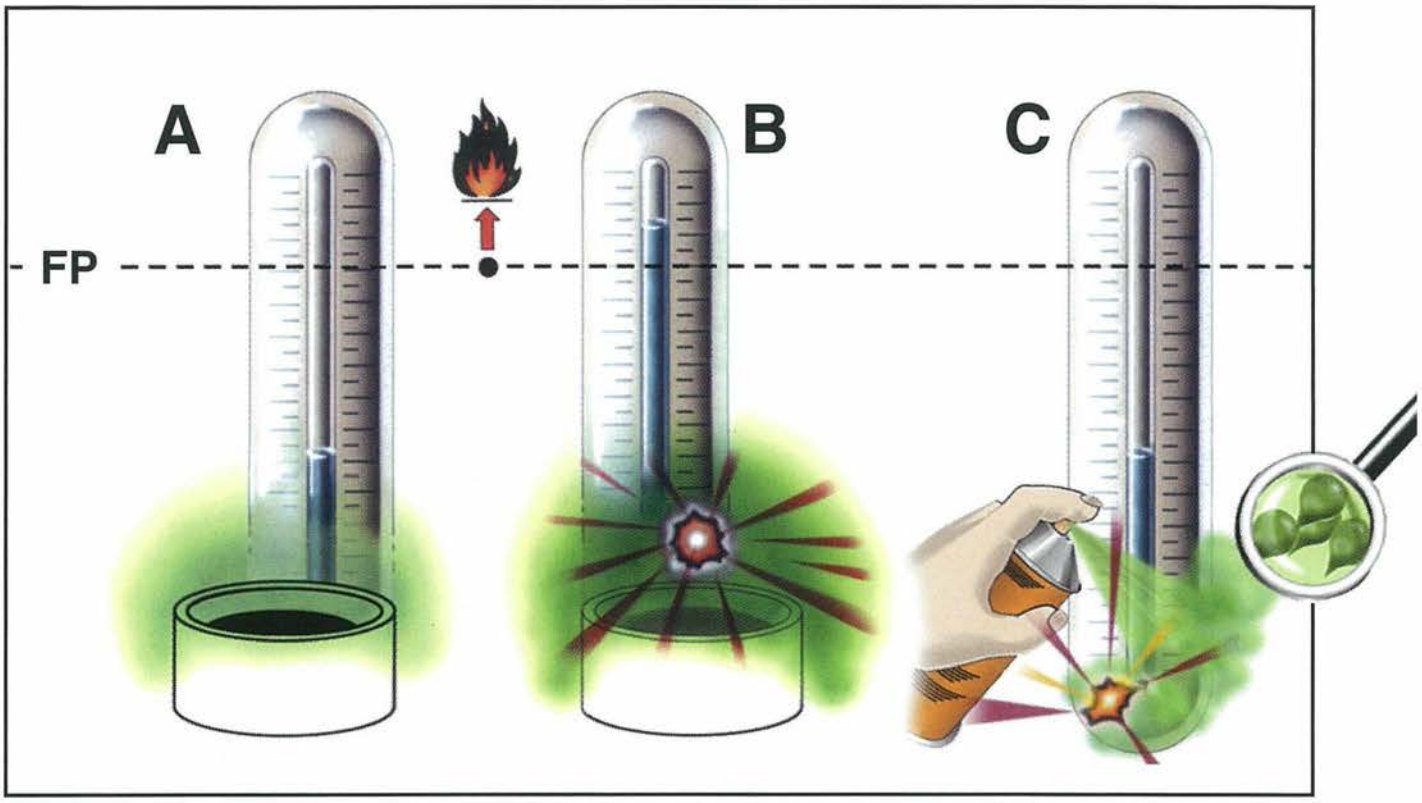

Fig. 2: Illustration of the flash point (FP)

A: Flash point above working temperature: not enough vapor, no explosion hazard

B: Flash point below working temperature: enough vapor, explosion hazard

C: Flash point above working temperature, but with spraying: aerosol (mist), explosion hazard

If the flash point of the liquid is below ambient or processing temperature an explosion hazard exists!

Mists of flammable liquids can create a fire and explosion hazard even below the flash point!

What is an explosive atmosphere?

An explosive mixture is a mixture of flammable gas, vapor, or mist in air in such quantities (within the explosion limits) that an explosion occurs after ignition.

When does an explosion occur?

An explosion due to flammable gases, vapors, or mists can occur when the following conditions are fulfilled at the same time and at one and the same place (see Fig. 3):

- flammable gases, vapors, or mists mixed with air within the explosion limits, i.e.
  - •• sufficient fuel content and
  - •• sufficient oxygen content

  as well as
- an effective ignition source.

Guaranteed avoidance of <u>one</u> of these requirements can prevent an explosion!

What are explosion limits?

Flammable gases, vapors, or mists in admixture with air are explosive only within a certain range of concentration (see Fig. 4).
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 explosive range. Within this range of concentration a mixture is explosive, i.e. an explosion hazard exists. The explosion limits are expressed as vol % or in g/m^3. Values of the explosion limits depend on the particular substance. If they are unknown, they can be determined experimentally.

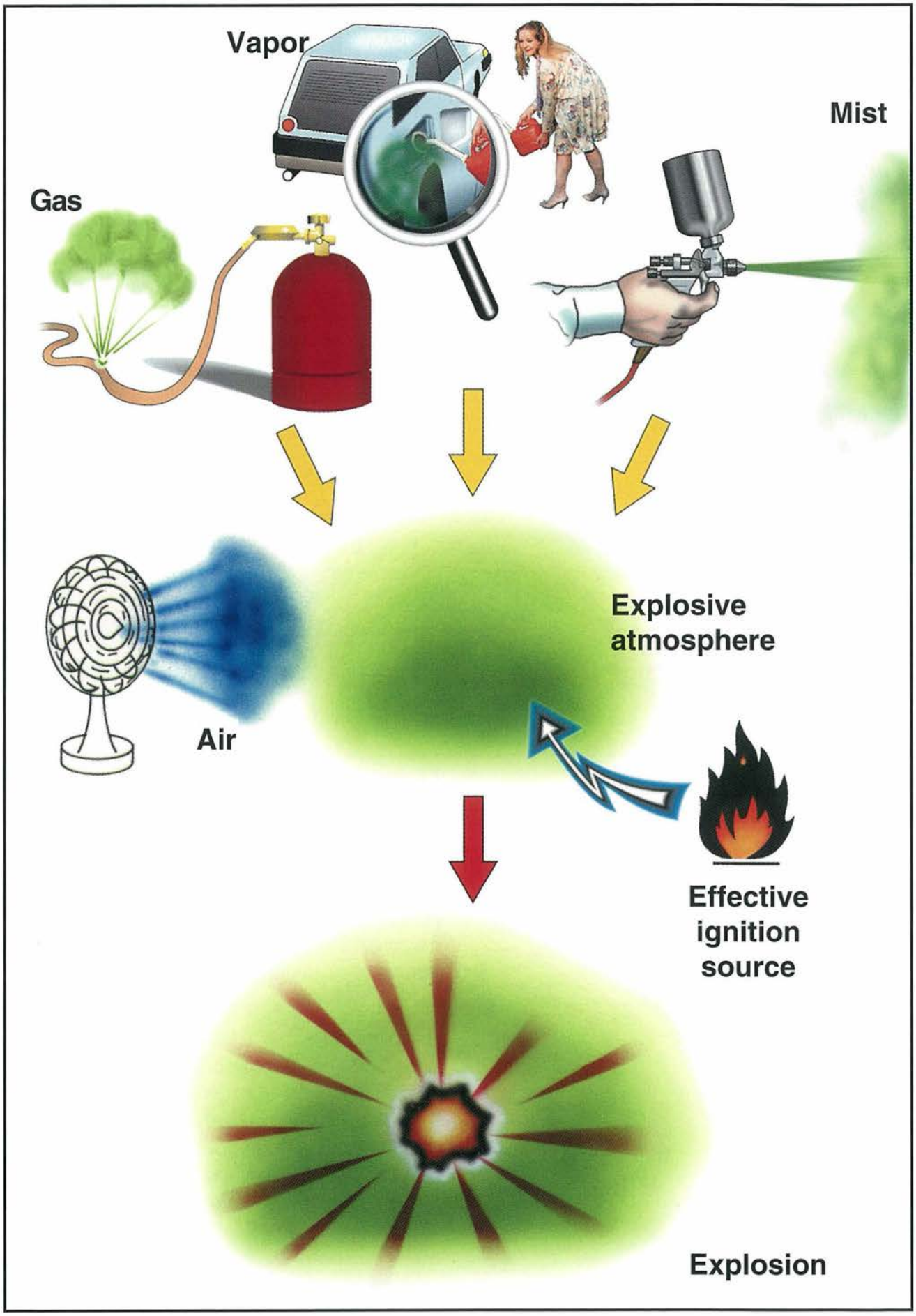

Fig. 3: Prerequisites for the occurrence of explosions

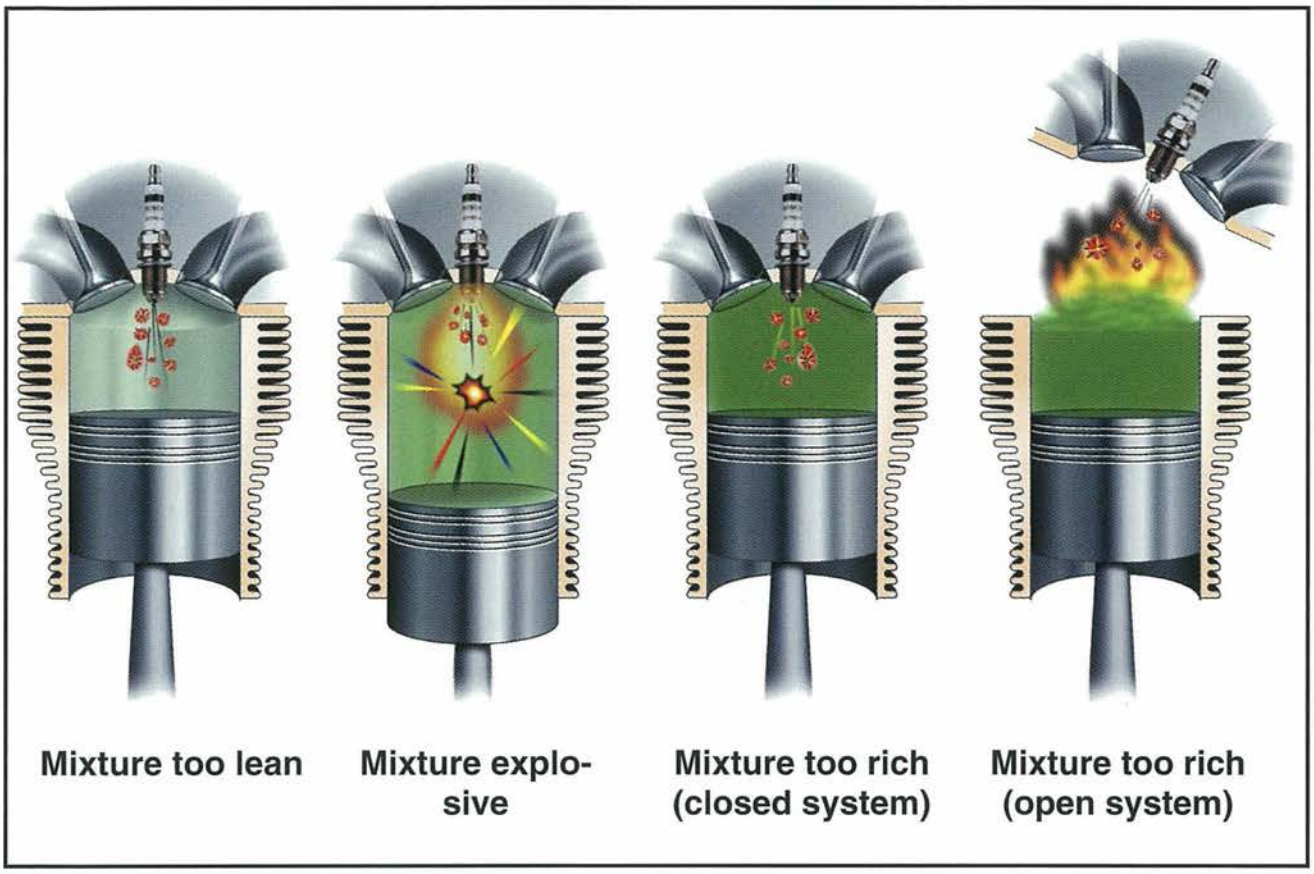

Fig. 4: Explosion limits

What oxygen concentration is needed for an explosion?

The normal oxygen content in air is sufficient. Flammable gases, vapors, or mists are, however, also explosive at lower oxygen contents. The highest oxygen content at which an explosion is no longer possible is the limiting oxygen concentration. 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 prime importance (see Fig. 5):

- hot surfaces
- fire, naked flames, glowing material
- mechanically generated sparks
- electrically generated sparks
- electrostatic discharge sparks

[1)] ISSA booklet "Ignition Sources", p. 37.

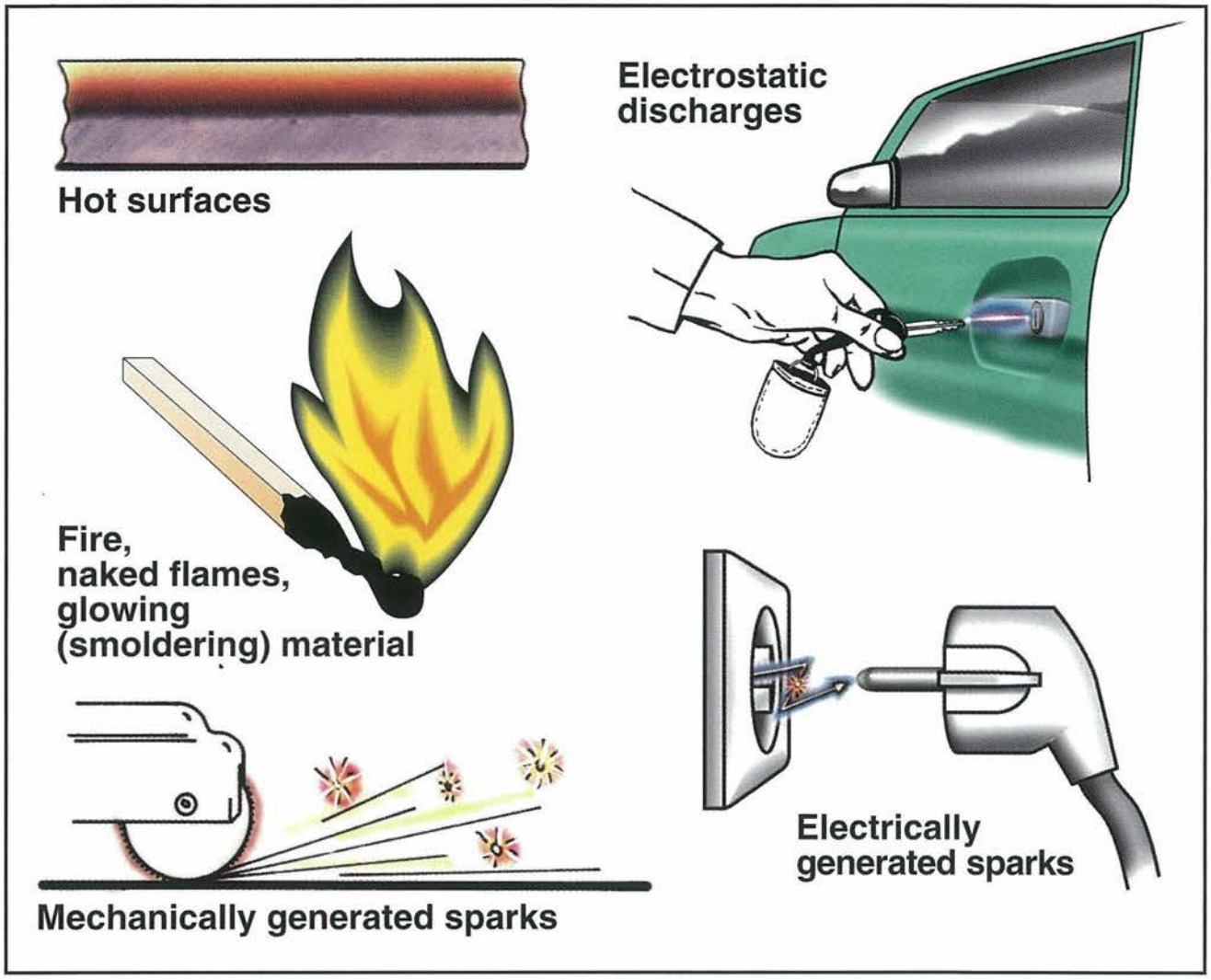

Fig. 5: Possible ignition sources

What is an effective ignition source[1)]?

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 reaction.

An explosion hazard can exist if flammable gases or liquids are handled in the plant.

[1)] ISSA booklets "Static Electricity" and "Ignition Sources", p. 37.

Protective measures

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

- Prevention of the occurrence of an explosion ("explosion prevention")
  - avoidance or restriction of the formation of explosive atmospheres
  - avoidance of effective ignition sources
- Avoidance of the hazardous consequences of an explosion ("explosion protection")

Combinations of these possibilities can be appropriate or even necessary. Technical measures should always be accompanied by organizational measures.

In the case of flammable gases, vapors, and mists, avoiding explosive atmospheres has higher priority than avoiding ignition sources, or explosion protection measures, which means, for example

- replacing flammable substances by inflammable ones
- implementing ventilation measures
- inerting plant.

An important explosion protection measure in relation to flammable gases, vapors, and mists is the explosion isolation of parts of the plant, e.g. pipelines and vessels.

Prevention of the occurrence of an explosion

What measures are available to prevent explosions?

Explosions can be prevented when

- the flammable substance can be replaced by a non-flammable substance;

or

- the concentration of the flammable substance can be kept so low that the fuel/air mixture is too lean for an explosion;

or

- the oxygen required for explosive combustion of the mixture can be excluded or kept below the limiting oxygen concentration;

or

- effective ignition sources can be reliably eliminated.

Replacement of flammable by non-flammable substances

For example, in some cases the following replacements can be made:

- flammable solvents and cleaning agents by water or non-flammable solvents
- flammable hydraulic fluids by non-flammable liquids
- hydrocarbons with low flash point by hydrocarbons with a flash point which exceeds the room and processing temperature by a sufficient margin

Limiting the explosive atmosphere

Limiting the quantity, or distribution, of the explosive atmosphere can, for example, be achieved by:

- closed systems (sealed construction)
- automatic shut-off devices
- ventilation measures
- gas alarm units in combination with ventilation measures
- reliably maintaining the working temperature at a value below the flash point

Ventilation

In ventilation, a distinction is made between natural ventilation, which is generally sufficient only in the open air, and forced ventilation. In contrast to natural ventilation, forced ventilation allows the circulation of greater quantities of air, and control over the air flow (e.g. avoidance of unventilated spaces). In addition, the concentrations present can be calculated beforehand with considerably greater reliability.

Gas alarm units (see Fig. 7)

Gas alarm units have the task of monitoring, under specified operating conditions, regions where an explosive atmosphere can occur. The use of gas alarm units can, for example, enable protective measures to be automatically triggered, or plants shut down, in an emergency. Gas alarm systems must be suitable for the planned application. According to many existing national regulations, these units must be tested to ensure perfect working order.

Relative density of the gases or vapors: influence on ventilation

(see Fig. 6)

In forced ventilation, the relative density of the flammable gases or vapors must be taken into account. The relative density of the vapors of flammable liquids is always greater than that of air. The same applies to gases except acetylene, ammonia, cyanide, ethylene, carbon monoxide, methane, and hydrogen.

In the case of gases and vapors which are heavier than air, the exhaust gas outlets should be positioned near the floor, and for gases lighter than air, near the ceiling.

Fig. 6: The spreading behavior of liquified gas (taken as example)

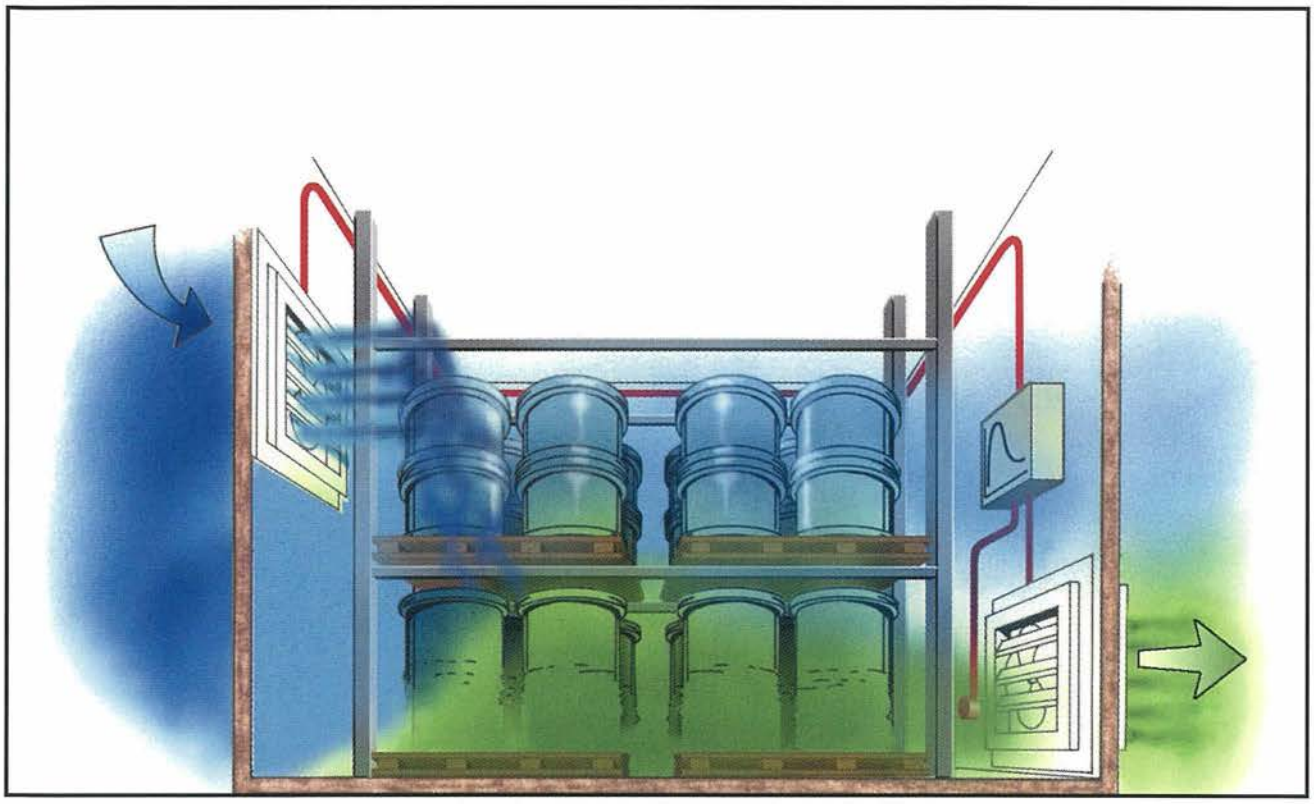

Fig. 7: Use of a gas alarm unit in combination with forced ventilation measures in a solvent store

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 the oxygen concentration falls below the limiting oxygen concentration and 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 quality, must be monitored by measurement, and depending on the size and tightness of the system can entail high operating costs (inert gas consumption).

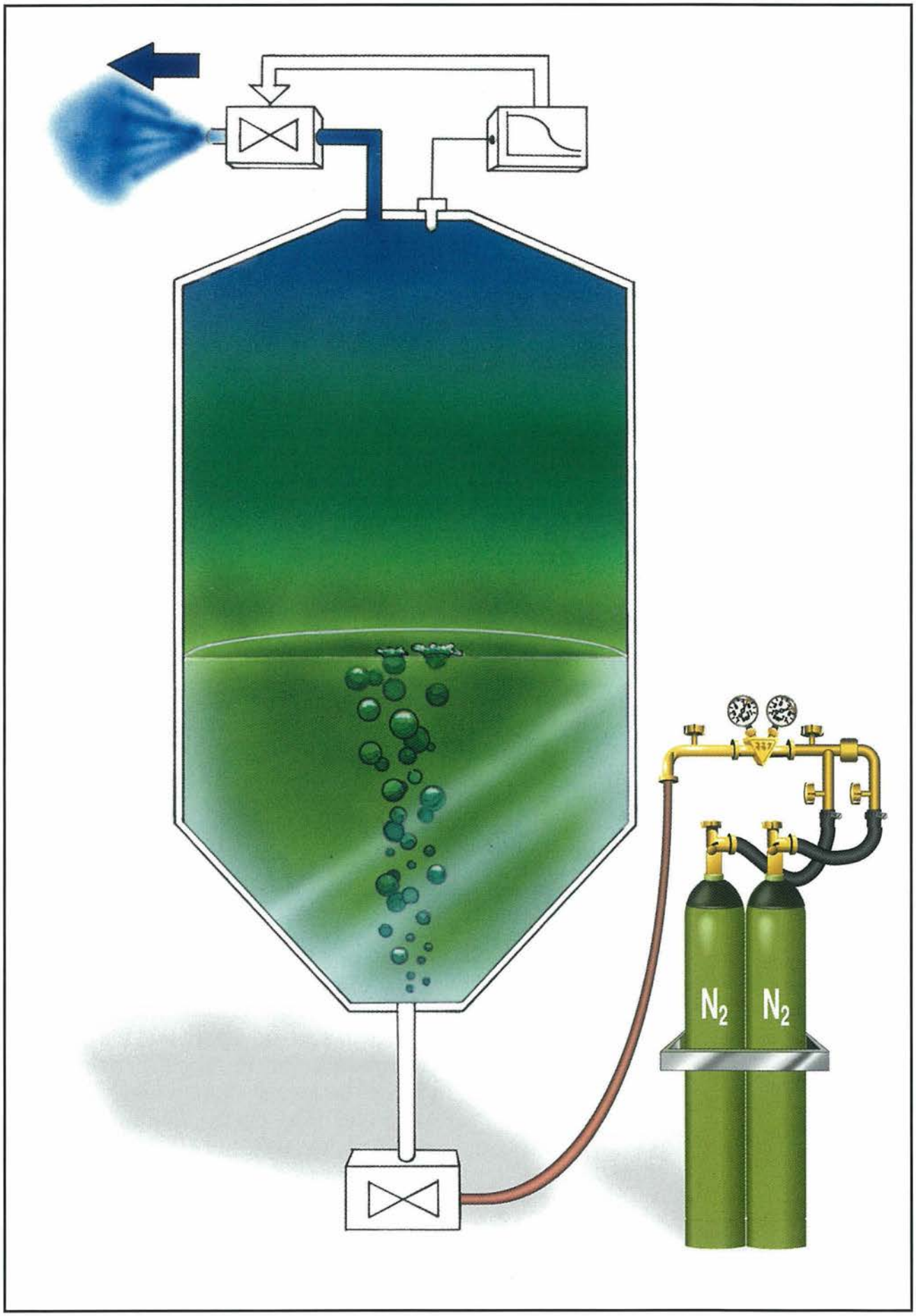

Fig. 8: Inerting

Avoidance of effective ignition sources

This measure - avoidance of effective ignition sources - should always be employed, even when constructional measures are applied, unless the explosive atmosphere is avoided with certainty. On its own, however, it is generally not reliable enough in practice.

Effective ignition sources[1)] must be avoided in places where an explosive atmosphere is present or can occur, i.e. in areas where there is an explosion hazard, these are divided into zones.

Fig. 9: Avoidance of effective ignition sources

[1)] ISSA booklets "Static Electricity" and "Ignition Sources", p. 37.

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.

Avoiding an explosive atmosphere or eliminating ignition sources prevent an explosion!

In practice, it is generally not possible to avoid effective ignition sources with sufficient reliability; other protective measures are thus often necessary.

[1)] ISSA booklet "Ignition Sources", p. 37.

Avoidance of the hazardous effects of an explosion

Measures which avoid the hazardous effects of an explosion are also referred to as constructional explosion protection measures. These measures involve constructing or equipping vessels and plant components in such a manner as to ensure that the explosion causes no injury to personnel and minimal damage to buildings and equipment.

What constructional explosion protection measures are available?

The effects of an explosion can be limited by:

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

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 if necessary following the explosion (see Fig. 11).

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 or 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

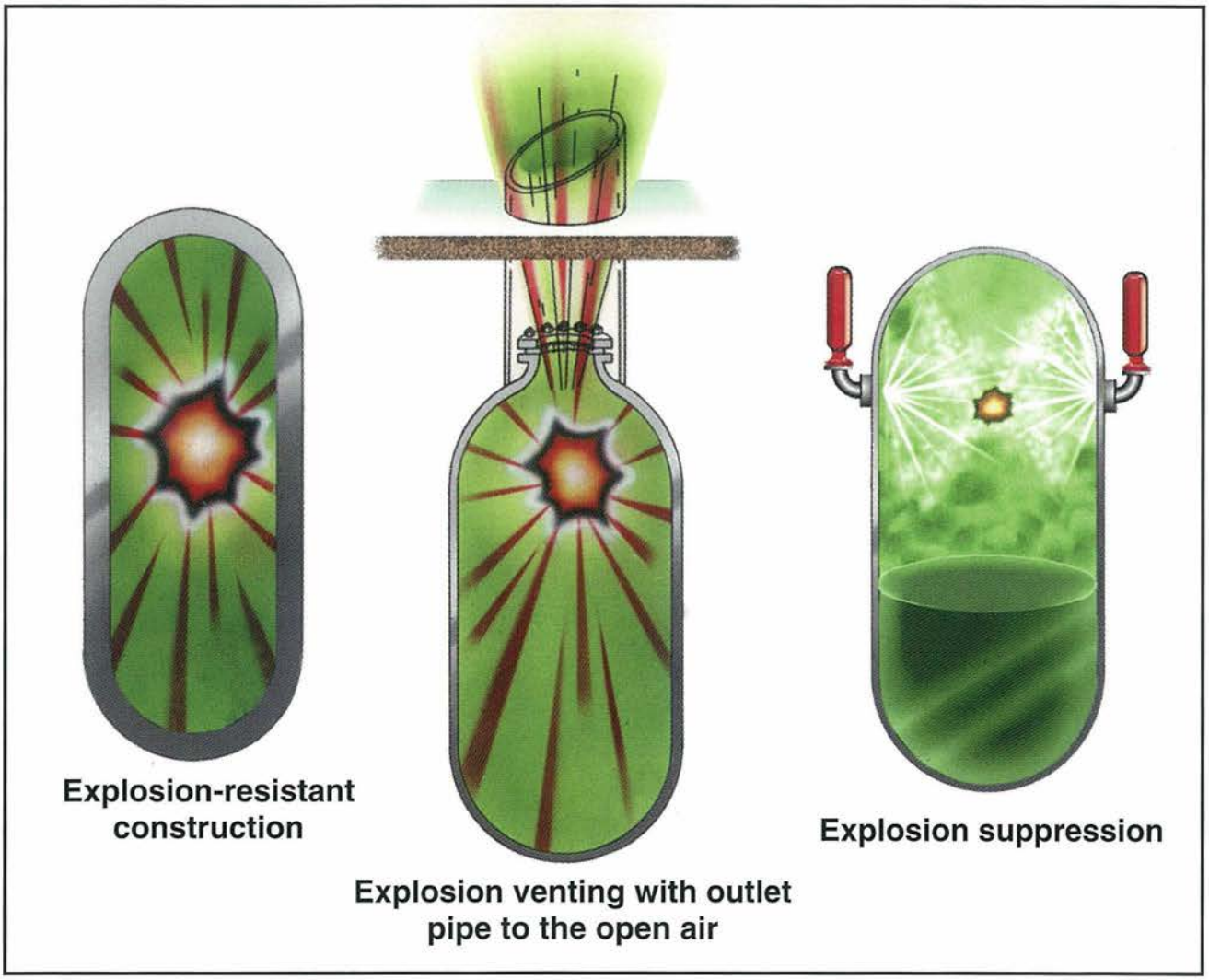

Fig. 10: Examples of constructional explosion protection measures

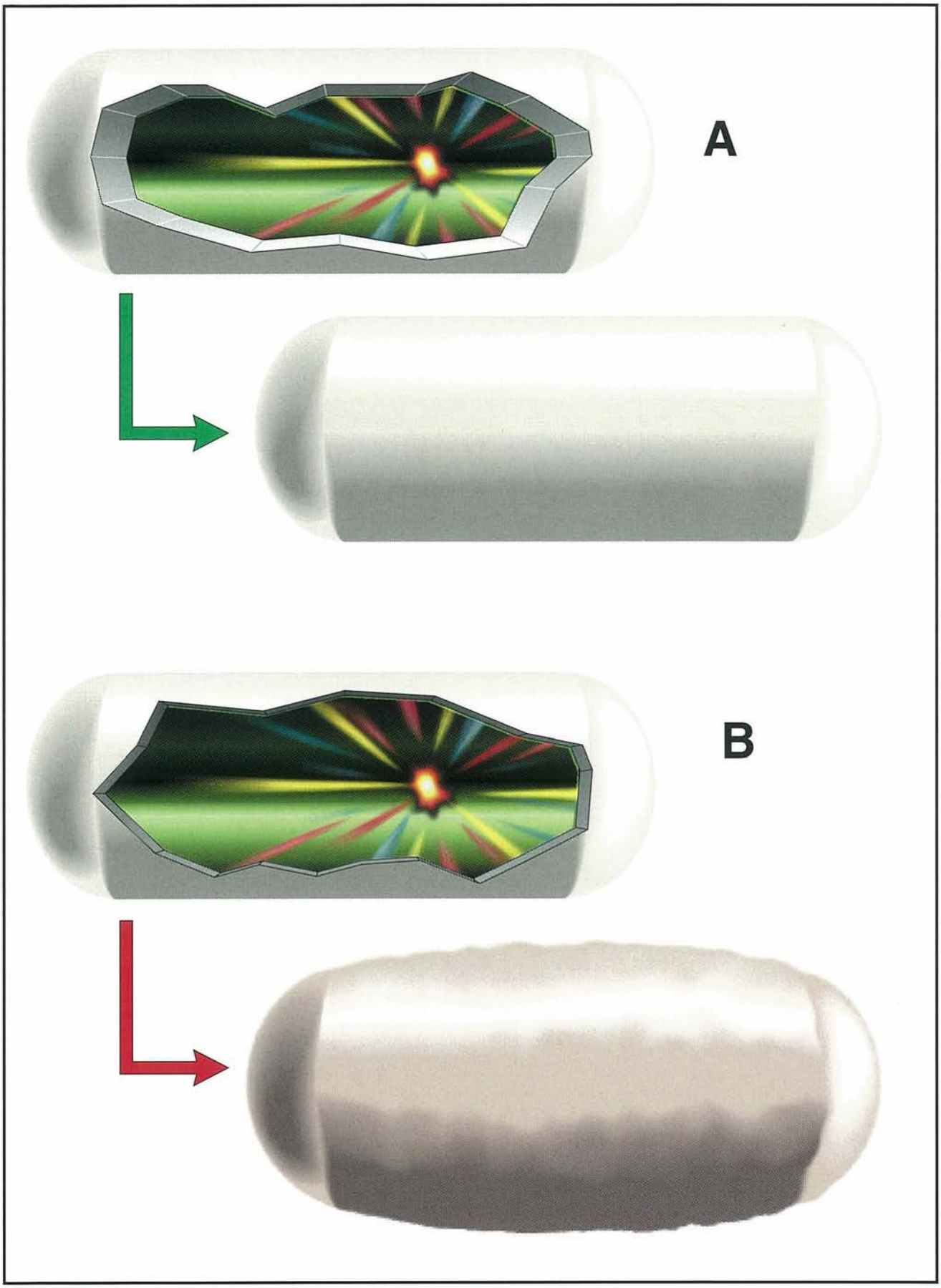

Fig. 11: Examples of explosion-resistant tanks before and after occurrence of an explosion - A: explosion-pressure-resistant construction
B: explosion-pressure-shock resistant construction

Explosion isolation

If plant units (e.g. vessels) in which an explosion can occur are connected together, these must be isolated by suitable devices so that the explosion in one vessel does not transmit to the second vessel. This can limit the area affected by an explosion.

What items of equipment are used for explosion isolation?

For gases and vapors the main items used are

- explosion arresters
- flame arresters
- detonation arresters

in pipelines or on vessels (see Fig. 12).

When taking decisions concerning the choice of constructional explosion protection measures, a number of influencing parameters must be taken into consideration. Designing them generally requires expert knowledge.

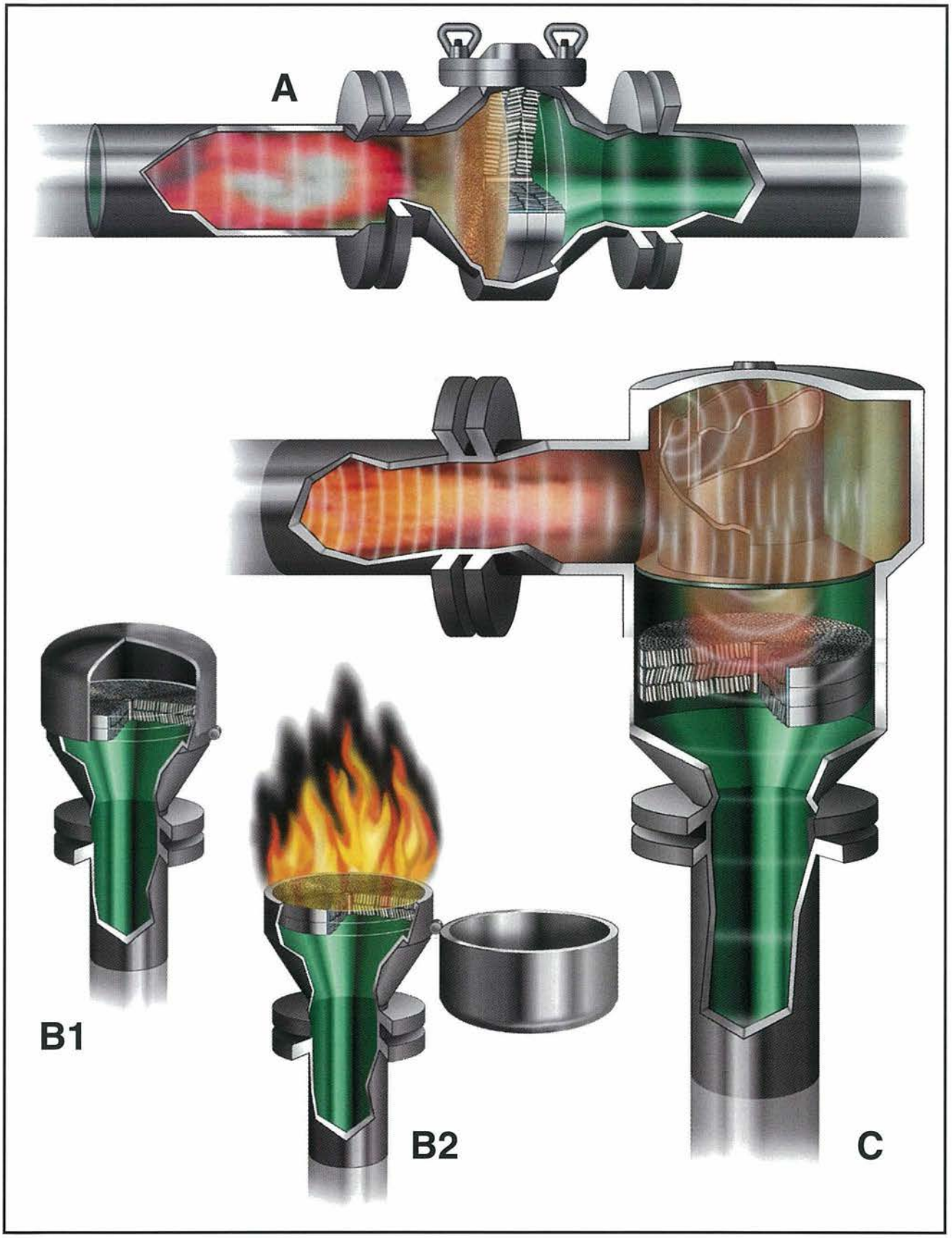

Fig. 12: Explosion isolation by
A: in-line explosion arrester
B1: end-of-line flame arrester
B2: end-of-line flame arrester endurance burning
C: detonation arrester

Organizational measures

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

What are organizational measures?

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

- provision of user instructions
- instruction of employees
- monitoring and maintenance of plant units and equipment
- wearing protective clothing and equipment
- only carrying out work in areas with an explosion hazard after appropriate authorization
- marking or cordoning-off high-risk zones

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

Provision of operating instructions

The operating instructions must govern the behavior of the employees during normal operation as well as when malfunctions occur. The responsibilities for the implementation of the measures must be specified clearly.

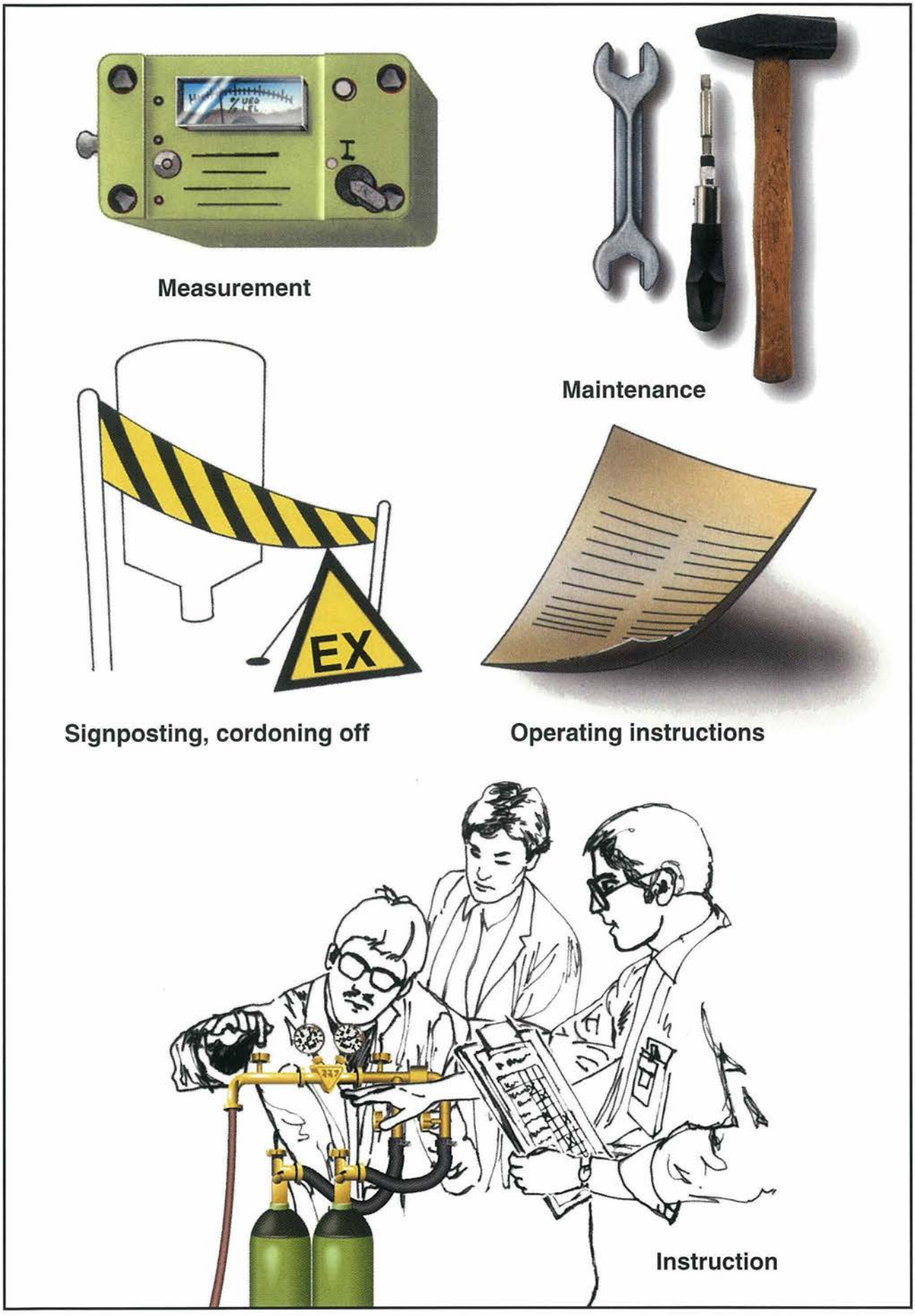

Fig. 13: Examples of organizational measures

Instruction of employees	The employees must be informed of possible hazards at regular intervals and their attention drawn to the proper behavior.
Monitoring and maintenance	Particular attention should be paid to regular checking and maintenance of the plant, particularly the safety devices such as flame traps, sensors, and any equipment/plant units which could act as ignition sources. The introduction of a "safety maintenance check program" (checklist) has proved its worth in actual practice.
Wearing protective clothing and equipment	The necessary protective clothing and equipment, e.g. conductive shoes, must be provided, used, and kept in serviceable condition.
Carrying out special work in areas endangered by explosions	Carrying out special work such as welding, grinding, or maintenance of electrical equipment in areas with an explosion hazard must be subject to the issue of written authorization (fire, welding, and entry permits).
Signposting or cordoning-off of high-risk zones	Areas (zones) which are endangered by explosion, such as the areas around charge and discharge openings, filling units, pumps, and slide valves must be signposted and cordoned off if necessary. This also applies to 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).

Design measures

Design measures can limit not only hazards due to explosions caused by flammable gases, vapors, or mists, but also their effects on the building.

How can safety be improved by design measures?

Design measures to improve safety include, for example:

- fire compartments
- sealing of openings where cables, pipes, vessels, etc. emerge from areas with an explosion hazard in such a way as to prevent the spread of gases and flammable liquids or their vapors
- installing siphons on ducting (e.g. for floor drainage) in areas with an explosion hazard
- separation of endangered plant units, e.g. filling stations for flammable liquids, pump rooms for flammable liquids, or compressor stations, from less endangered units
- explosion isolation of areas to prevent explosion propagation

A significant improvement in safety can be achieved by design measures.

Safety parameters

Application of the safety measures mentioned requires a knowledge of the explosion parameters of the flammable gases or liquids used.

In the case of a mixture of flammable liquids, the flammability and explosion characteristics of the individual components cannot be used as a basis for the assessment of the explosion hazard. In such cases, the low-boiling mixtures which, for example, lower the flash point and the lower explosion limit are of particular significance.

For the design of individual protective measures, the parameters on the opposite page must be known for each case.

Interpretation and application of safety parameters must be left to the expert.

Protective measure	Parameter
Explosion prevention	
Replacement	Combustion behavior
	Flash point
Concentration limitation	Flash point
	Lower explosion limit
	Upper explosion limit
	Density with respect to air
Inerting	Limiting oxygen concentration
Avoidance of ignition sources	Minimum ignition temperature
	Minimum ignition energy
	Conductivity (electrostatic behavior)
Explosion protection	
Explosion-resistant construction	Maximum explosion overpressure
Explosion suppression	Maximum rate of pressure rise and maximum explosion overpressure
Explosion venting	Maximum rate of pressure rise and maximum explosion overpressure
Explosion isolation	Minimum experimental safe gap

References

[1] EN (European Standard), *Explosive Atmospheres - Explosion Prevention and Protection - Part 1: Basic Concepts and Methodology*, EN 1127-1, 1997.

[2] Bartknecht W., *Explosion Protection - Fundamentals and Applications*, Springer Verlag, Berlin, 1993.

[3] ESCIS (Expert Commission for Safety in the Swiss Chemical Industry), *Safety Tests for Chemicals*, Suva, Chemistry Section, Lucerne, 1997 (in German).

[4] VDI (Verein Deutscher Ingenieure)[1)], *Dust Fires and Dust Explosions - Hazards, Assessment, Protective Measures; Inerting,* VDI 2263-2, VDI Verlag, Düsseldorf 1992

[5] ESCIS, *Inerting - Methods and Measures for the Avoidance of Ignitable Substance - Air Mixtures in Chemical Production Equipment and Plants*, Suva, Chemistry Section, Lucerne, 1994.

[6] ESCIS, *Static Electricity - Rules for Plant Safety*, Suva, Chemistry Section, Lucerne, 1988.

[7] VDI, *Dust Fires and Dust Explosions - Hazards, Assessment, Protective Measures; Pressure-Shock-Resistant Vessels and Apparatus; Calculation, Construction and Tests,* VDI 2263-3, VDI Verlag, Düsseldorf, 1990.

[1)] Association of German Engineers

ISSA publications on explosion protection

ISSA

Section for the Chemical Industry
"Explosion Protection" Working Party

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

Gas Explosions (G/E/It)
(2000)

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 explosion protection of machines and apparatus

- Basic Principles (G/E)
  (2000)
- Collection of Examples (G/E/F)
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Explosion Suppression (G/E/F)
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Determination of the Combustion and Explosion Characteristics of Dust (G/E)
(1997)

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Notes

THE ISSA AND THE PREVENTION OF OCCUPATIONAL RISKS AND DISEASES

The ISSA Standing Committee on the Prevention of Occupational Risks and Diseases brings together occupational safety specialists from all over the world. It promotes international cooperation in this field, and undertakes special studies on topics such as the role of the press, radio, and television in occupational safety, and integral strategies for the workplace, road traffic, and domestic household. It also coordinates the activities of the seven international sections for the prevention of occupational risks and diseases, which are active in various industries and in agriculture, and which have their secretariats in various different countries. Two further sections are concerned with information technology in the field of occupational safety, and with relevant research.

The activities of the international sections of the ISSA comprise:

- the international exchange of information between bodies concerned with the prevention of occupational risks
- the organization of conferences of committees and working parties, round-table discussions, and colloquia at the international level
- the performance of surveys and investigations
- the promotion of research
- the publication of corresponding information

Further information relating to these activities and the general work of the ISSA in the field of occupational safety can be found in the leaflet "Safety Worldwide". It is available in English, German, French, and Spanish from the secretariat of the Section.

MEMBERSHIP OF THE INTERNATIONAL SECTIONS

Each international section of the ISSA has three categories of member:

● Full Member	Full members and associate members of the ISSA, Geneva, and other nonprofit organizations can apply for membership as a Full Member
● Associate Member	Other organizations and companies can become Associate Members of a section if they have knowledge of the area for which the section is responsible.
● Correspondent	Individual experts can become Corresponding Members of a section.

Further information and application forms are available directly from the secretariats of the individual sections.

AT LEAST ONE OF THESE ISSA SECTIONS ON THE PREVENTION OF OCCUPATIONAL RISKS CORRESPONDS TO YOUR OWN FIELD OF INTEREST: DO NOT HESITATE TO CONTACT ITS SECRETARIAT

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