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cloud areas three zone categories 20E, 21E, and 22E are defined in accordance with the definitions in 7.1.4.2.

In addition, a zone category SE is defined as follows: an area in which very small quantities of explosives may be present, where its ignition could not cause the subsequent initiation of other hazardous materials, significant damage to equipment, or injury to personnel.

7.2 Basic Design Concepts for Electrical Apparatus

7.2.1 Gases and Vapors

A series of standardized basic design concepts for electrical apparatuses intended for use in explosive gas atmospheres have been available for a long time. The details are described in a corresponding series of international standards (IEC, CENELC etc.). The following summary is mainly based on BBC (1983). The figures are from Eckhoff (1996).

7.2.1.1 Intrinsic Safety (Ex 'i')

This design concept can be used for apparatuses to be used in all three Zones (0, 1 and 2). An intrinsically safe circuit is a circuit in which no spark or any other thermal effect can be generated, which is capable of causing ignition of a given explosive atmosphere. The basic principles of intrinsically safe design are given in Figure 7–9.

In order to prevent hot-surface ignition of an explosive gas/vapor atmosphere by electrical apparatuses, the apparatuses must be designed so as to ensure that the temperatures of all surfaces that can make contact with the explosive atmosphere are below the minimum ignition temperature of the explosive atmosphere (see Section 2.2.4.4). For practical reasons it has been agreed internationally to standardize on a limited number of temperature classes for electrical appartatuses, and these are given in Table 7–4. Table 2–2 in Chapter 2 gives the minimum ignition temperatures and the corresponding temperature classes for a range of combustible gases and vapors in air.

The intrinsic safety concept originated in UK nearly 100 years ago through the pioneering work by Wheeler and others. British Standard

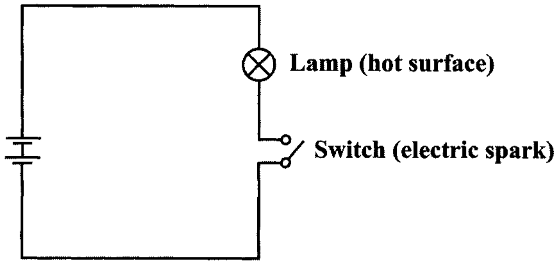

Figure 7-9 Illustration of two types of ignition sources that are to be prevented by intrinsically safe (Ex 'i') systems: Incendiary electric spark/arcs generated by closing or breaking electrical circuits (switch in figure), or incendiary hot surfaces (lamp in figure).

Table 7-4 Temperature Class Symbols Indicating Internationally Standardized Maximum Permissible Sufrace Temperatures of Electrical Apparatus

T1	450°C
T2	300°C
T3	200°C
T4	135°C
T5	100°C
T6	85°C

1259 from 1945 contains detailed specifications for intrinsically safe electrical circuits for mining underground. British Standard 1538 from 1949, dealing with *Intrinsically Safe Transformers Primarily for Bell Signalling Circuits* covered electrical devices for mining underground. These systems had to satisfy the following conditions:

- the secondary voltage of the supply transformer of these circuits was limited to 15 V
- the current was limited (by a resistor) to a maximum of 1.5 A
- the signal was to be given by a bell
- the local cables in the mine were two bare wires laid in parallel

An intrinsically safe apparatus is an electrical apparatus in which all the circuits are intrinsically safe. Intrinsically safe electrical apparatuses are produced to different standards depending on the ignition sensitivity of the explosive atmosphere in which the apparatuses are to be used (gas groups I for coal mines and groups IIA, IIB and IIC for other activities. See Table 2–2 and Section 2.2.7.2 in Chapter 2). The reference gases are methane for group I, and propane, ethylene and hydrogen for groups IIA, IIB and IIC respectively.

In addition intrinsically safe electrical apparatuses are divided into the categories Ex 'ia' and Ex 'ib'. Ex 'ia' comprises electrical apparatus that shall not be capable of causing ignition neither in normal operation, nor with one fault and with any combination of two faults. Category Ex 'ib' comprises electrical apparatus incapable of causing ignition in normal operation and with one single fault. The traditional approach was that only Ex 'ia' apparatus could be used in Zone 0, but more recently allowance has also been granted for some other concepts (see Section 7.2.1.8).

In intrinsically safe circuits a distinction is made between intrinsically safe electrical apparatus and *associated* electrical apparatus. An electrical apparatus is intrinsically safe when all its circuits are intrinsically safe. In an associated electrical apparatus not all circuits are intrinsically safe but contains circuits that can affect the intrinsic safety. Typical examples of intrinsically safe electrical apparatus are passive two- or four-terminal networks, limit switches, and measuring instruments containing a coil. Associated electrical apparatus is, for example, power supply units for intrinsically safe circuits with intrinsically safe output. Associated electrical apparatus must either be mounted outside the hazardous area or be fitted with an additional type of protection.

Safety barriers are isolating elements generally accommodated outside hazardous areas to isolate intrinsically safe circuits from non-intrinsically safe circuits so reliably that any chance of mutual influence is excluded. Safety barriers with galvanic isolation are used, i.e. transformers, d.c. transformers and relays, and also those without galvanic isolation, i.e. safety barriers containing diodes or Zener diodes.

In principle the intrinsic safety of e.g. simple inductive or capacitive circuits can be assessed theoretically by means of the appropriate curves in Figure 2–30 and Figure 2–31 in Section 2.2.6, based on the minimum ignition energy (MIE) of the explosive gas atmosphere in which the apparatus is to be located. However, often direct testing of the electrical apparatus of concern, using the standard spark test apparatus shown in Figure 2–29 in Section 2.2.6 is required. This apparatus is designed to produce both closing and breaking contacts in the actual explosive gas mixture. The standard test gas mixtures are:

- Gas group I: (8,3 ± 0.3) % methane in air
- Gas group IIA: (5,25 ± 0.25) % propane in air
- Gas group IIB: (7.8 ± 0.5) % ethylene in air
- Gas group IIC: (21 ± 2) % hydrogen in air

7.2.1.2 Flame Proof Enclosures (Ex 'd')

This design concept can be used for apparatuses to be used in Zones 1 and 2. Flame proof design implies that electric parts which can ignite an explosive atmosphere are placed in an enclosure which can withstand the pressure developed during an internal explosion of an explosive mixture and which prevents the transmission of the explosion to any explosive atmosphere surrounding the enclosure. The principle of flame-proofing is illustrated in Figure 7–10.

The following aspects are central in the design of flame proof enclosures:

- For enclosures in which the contained electrical/electronic circuits are essentially activated, the volume to be considered is the free volume. For luminaries, the volume is determined without the lamps fitted.
- The flame proof joint is the place where corresponding surfaces of two parts of an enclosure come together and prevent the transmission of an internal explosion to the explosive atmosphere surrounding the enclosure.
- The width of flame proof joint is the shortest path through the joint, from the inside to the outside of an enclosure.
- The gap of flame proof joint is the distance between the corresponding surfaces of a flame proof joint when the electrical apparatus has been assembled. For cylindrical surfaces, the gap is the difference between the diameters of the bore and the cylindrical component inserted into the bore.

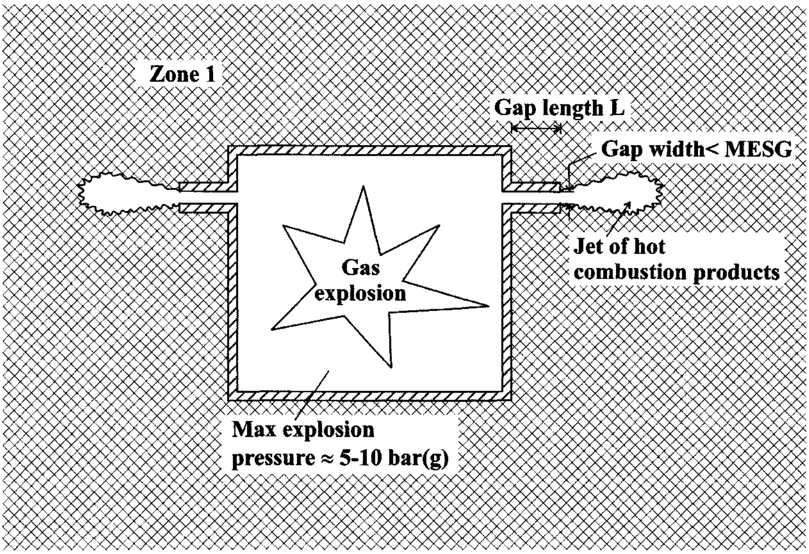

Figure 7–10 Illustration of a flame proof enclosure (Ex 'd'). The enclosure must satisfy three main requirements: Gap widths < MESG at actual conditions; enclosure to withstand the maximum internal overpressure that an internal gas explosion can produce at actual conditions; and temperature of external enclosure surface < min. ign. temp. at actual conditions.

- The maximum experimental safe gap for an explosive mixture is the maximum gap of a joint of 25 mm width which prevents any transmission of an explosion in ten tests made under standard test conditions, using the apparatus illustrated in Figure 2–44 in Section 2.2.7.
- Pressure piling is the increase in the explosion pressure above the normally expected pressure, e.g. as a result of subdivision of the flameproof enclosure. (See Figure 2–60 in Section 2.4.5.2).
- A quick acting door or cover is a door or cover provided with a device which permits opening or closing by a simple operation, such as the movement of a lever or the rotation of a wheel.
- A door or cover fixed by screws is a door or cover the opening or closing of which requires the manipulation of several screws or nuts.

The design of flameproof joints is specified in detail in international standards. The flameproof joints can be flanged, cylindrical, spigot and threaded joints. The design of non threaded gaps shall withstand the mechanical stresses arising. The surfaces of joints shall be machined so that their average roughness does not exceed certain limits. The joint surfaces should be protected against corrosion, by grease, electroplating, chemical treatment etc. Painting is not acceptable. The width of a joint shall be at least the minimum values specified in the standards, and interconnecting compartments shall be precluded as far as possible.

As for intrinsically safe apparatus, the design of flameproof enclosures also depends on the ignition properties of the explosive gas atmosphere in which the enclosure is to be used. If the standard MESG (see Table 2–2 and Section 2.2.7.2 in Chapter 2) of this gas atmosphere is known, the gas group to which the actual gas belongs is also known. International standards then specify the design requirements to be satisfied. Nevertheless, flameproof enclosures shall also be tested for their ability both to withstand the pressure of an explosion inside the enclosure, and to prevent transmission of an internal explosion to an explosive gas cloud on the outside.

The tests of the ability of the enclosure to withstand the pressure of an internal explosion are made in two stages. First the maximum explosion pressure, or reference pressure, is measured by igniting an explosive gas mixture inside the enclosure to be tested. The number of tests to be made and the explosive mixture to be used in the tests depend on which gas group the enclosure is to be exposed to. When the reference pressure has been determined a proper pressure test is carried out, either as a static or a dynamic test. In a static test, a test pressure exceeding the reference pressure by a factor of typically 1.5 shall be maintained inside the enclosure for a specified time. In a dynamic test, the enclosure is also subjected to 1.5 times the reference pressure, and the rate of rise of pressure shall be similar to that obtained during the determination of the reference pressure by the explosion tests. The tests are considered satisfactory if the enclosure has not suffered any damage or permanent deformation liable to weaken any of its parts.

For the test for non transmission of an internal explosion the enclosure is placed in a test chamber and the same explosive mixture is introduced both inside the enclosure and in the test chamber in which the enclosure is placed. The initial pressure before igniting the inside mixture is normally atmospheric both inside and outside the enclosure.

7.2.1.3 Increased Safety (Ex 'e')

This design concept can be used for apparatuses to be used in Zones 1 and 2. Increased safety is a type of protection by which measures are taken so as to prevent the possibility of excessive temperatures and of the occurrence of arcs and sparks inside the enclosure and on the external parts of it, in normal service. The principles of the concept of increased safety are illustrated in Figure 7–11.

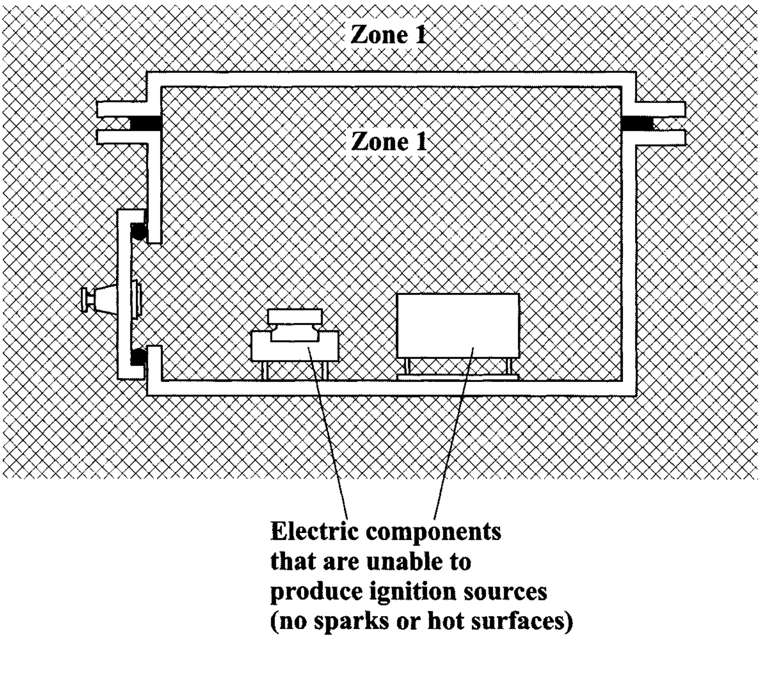

Figure 7–11 Illustration of increased safety enclosure (Ex 'e'). The enclosure must satisfy the following main requirements: No ignition sources permitted inside enclosure; satisfactory sealing (IP-protection) against ingress of water and dust; enclosure body made of earthed anti static material; and temperature of external enclosure surface < min. ign. temp. at actual conditions.

The following aspects are central in the design of increased-safety enclosures:

- The limiting temperature is the highest permissible temperature of an electrical apparatus or a part of an electrical apparatus. This depends on the minimum ignition temperature of the substances with which the hot surfaces may make contact.

- The minimum clearances between conducting parts at different potential shall satisfy specific requirements stated in international standards.
- The creeping distances between conducting parts at different potential shall meet specific requirements stated in international standards. The creeping distance is the shortest distance between two conducting parts along the surface of the insulating parts.

The insulating parts are often provided with ribs or notches, to increase the creeping distances. Notches in the surface of insulating parts may be taken into consideration for calculating the creeping distance only if the notches are at least 3 mm deep and 3 mm broad; ribs only if they are at least 3 mm high and their width is appropriate to the mechanical strength of the material, the minimum being 1 mm.

For the increased safety type of protection special attention is paid to the design of terminals for external connections and the internal connections. As these parts can be ignition sources, it is required that each connection shall be made such that the contact does not deteriorate due to heating in service, alteration of the insulating material or vibration, i.e. its contact resistance remains constant even during a protracted period in service. Terminals for external connections shall be generously dimensioned to permit the effective connection of conductors of a cross-section at least corresponding to the rated current of the electrical apparatus. The terminals shall be

- fixed in their mountings without possibility of self-loosening
- constructed in such a way that the conductors cannot slip out from their intended location
- designed to assure proper contact without deterioration of the conductors
- designed/machined without sharp edges
- designed so that they cannot be twisted or permanently deformed during normal tightening
- designed to assure that the contact that they are providing are not appreciably impaired by temperature changes in normal service

The size of the terminal compartment should enable perfect connections to be made using common tools. In the interior of electrical apparatus, connections shall not be subject to undue mechanical stress. Solid insulating materials shall have mechanical characteristics which are suitable at temperatures at least 20 K above the temperature attained in continuous rated service.

Normally enclosures containing live bare parts shall as a minimum provide a degree of protection of IP 54, whereas enclosures containing insulated parts only shall as a minimum provide a degree of protection of IP 44.

7.2.1.4 Pressurized Apparatus (Exp)

This design concept can be used for apparatuses to be used in Zones 1 and 2. Pressurized apparatus Exp is a type of protection by which the entry of a surrounding atmosphere into the enclosure of the electrical apparatus is prevented by maintaining, inside the enclosure, a protective gas at a higher pressure than that of the surrounding atmosphere. The principle is illustrated in Figure 7–12.

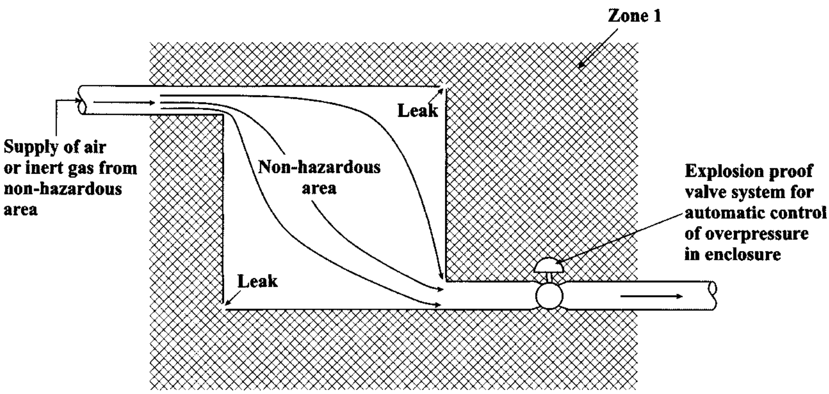

Figure 7–12 Illustration of pressurized enclosure (Ex 'p').

The overpressure is maintained either with or without a continuous flow of the protective gas. It is then assumed that no flammable gas or vapor is introduced into the enclosure and that it contains no internal source of flammable gas or vapor. The protective gas can be can be air, inert gas or another suitable gas.

Purging is the process of passing a quantity of protective gas through the enclosure and ducts, before the application of voltage to the electrical apparatus inside the enclosure, so that any explosive atmosphere possibly present in the enclosure is expelled and any such explosive atmosphere in the pressurized enclosure is reduced to a concentration significantly below the lower explosive limit. The quantity of protective gas required for purging shall be at least 5 times the volume of the free space in the enclosure and its associated ducts. The overpressure is maintained within the pressurized enclosure by continuous circulation of the protective gas through the enclosure after purging. This type of pressurized enclosure, besides providing protection against explosion, also aids dissipation of any heat from electrical apparatus inside the purged enclosure.

Pressurization with leakage compensation provides this type of protection as long as the supply of protective gas is sufficient to compensate for any inevitable leakages from the pressurized enclosure and its ducts.

The measures specified for this type of protection include specific requirements for the construction of the enclosure and its associated components, including the inlet and exhaust ducts and for the auxiliary controlled apparatus necessary to ensure that the overpressure is established and maintained safely. The protection devices and the ducting for the protective gas shall prevent sparks or incandescent particles from being ejected from the enclosure. The enclosure, ducts and their connecting parts shall be able to withstand an overpressure equal to 1.5 times the maximum overpressure specified in normal service. The materials used for the enclosure and the ducts shall not be affected either by the specified protective gas or by the flammable gases or vapors in which they are to be used. Doors and covers that can be opened without using a tool shall be interlocked so that the electrical supply is disconnected automatically when they are opened and cannot be restored until they are closed.

An automatic device shall be provided by the operator at his own responsibility to operate automatically when the overpressure fails below the minimum prescribed value. A minimum overpressure of 0.5 mbar (50 Pa) shall be maintained relative to the external pressure at any point within the enclosure.

7.2.1.5 Oil-Filled Enclosures (Ex 'o')

This design concept can be used for apparatuses to be used in Zones 1 and 2. Oil immersion is a type of protection in which the electrical apparatus or parts of it are immersed in a specified quality mineral oil in such a way that an explosive atmosphere which may be above the oil or outside the enclosure cannot be ignited by the electrical components. The principle is illustrated in Figure 7–13.

Current standards assume that the electrical apparatus immersed in the oil is fixed in its operating position in accordance with specific installation instructions. All parts capable of producing arcs or sparks in normal service shall be immersed in the oil at a minimum depth. Devices shall be provided so that the oil level can be easily checked when the electrical apparatus is in service. The highest and lowest oil levels permissible in normal service should be clearly marked. To ensure that electrical apparatuses satisfy the requirements for this type of protection certain tests shall be carried out with the highest and the lowest oil level corresponding to a fault in the level gauge, and with an explosive mixture of air and hydrogen above the oil.

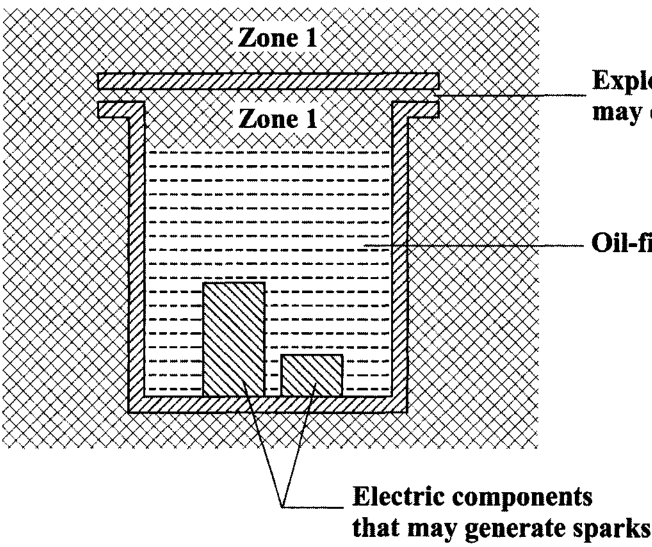

Figure 7–13 Illustration of oil filled enclosure (Ex 'o').

7.2.1.6 Sand-Filled Enclosures (Ex 'q')

This design concept, illustrated in Figure 7–14, can be used for apparatuses to be used in Zones 1 and 2. The following is based on BBC (1983). Sand filling is a type of protection in which the enclosure of electrical apparatus is filled with a non-combustible solid material in a finely granulated state so that, in the intended conditions of service, any electric spark occurring within the enclosure of an electrical apparatus will not ignite a surrounding explosive atmosphere.

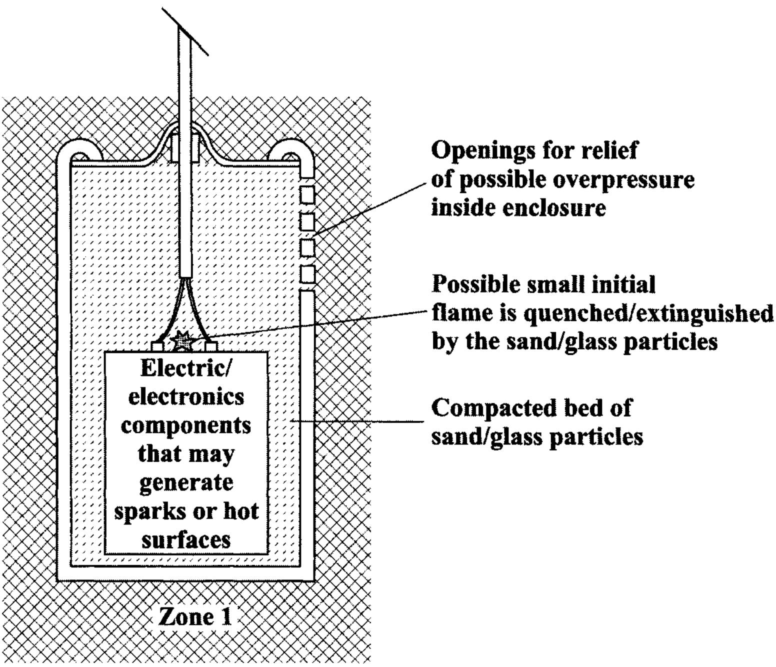

Figure 7–14 Illustration of sand filled enclosure (Ex 'q').

Short circuit time or arcing time is the time during which the arcing current flows through the electrical apparatus, counted from its initiation to its final extinction.

The screen is a perforated metal sheet fixed inside the enclosure, within the mass of the filling material, in such a way as to cover all the live parts of the electrical apparatus inside the enclosure. The minimum safe height is the shortest vertical distance between the free surface of the filling material, after it is suitably shaken down, and the nearest live part, which prevents transmission of ignition by an electric arc of such current and duration as has been specified for the construction of the electrical apparatus. When the electrical apparatus is provided with a screen, the minimum safe height is the sum of the protection height and the height of the reserve layer. The protection height is the distance between the screen and the nearest live part of the electrical apparatus inside the enclosure. The height of the reserve layer is the thickness of the filling material above the screen, designed to fill up any accidentally formed voids in the safety layer.

The enclosure of powder filled electrical apparatus shall generally be of metal. Some other materials may be permitted, provided their mechanical and thermal properties are satisfactory. The enclosure in its normal service condition, with all openings closed as in normal use, shall comply with the degree of protection IP 54 (see Section 7.2.3.2.1), and adequate mechanical strength shall be confirmed in a hydraulic test.

The quartz sand used as filling material or a filling material of similar quality shall not contain more than 0.1% by weight of water at the time of filling and shall be suitably shaken down in order to prevent the formation of voids. No part made of any organic material shall be used above the live parts, or between them and the walls of the enclosure.

Bare live parts shall be suitably spaced from each other and from the walls of the enclosure. For electrical apparatus with nominal voltage less than or equal to 500 V and factory-enclosed so as to prevent dismantling without destruction, a distance of 4 mm between live parts, and a distance of 5 mm between live parts and the enclosure are sufficient.

Irrespective of its volume, the enclosure shall be subjected to a hydraulic type test with a pressure of 0.5 bar (g) without the occurrence of permanent deformation exceeding 0.5 mm in any of its dimensions. The pressure shall be applied for at least 1 minute.

7.2.1.7 Encapsulation (Ex 'm')

This design concept can be used for apparatuses to be used in Zones 1 and 2. The basic principle is illustrated in Figure 7–15.

Encapsulation (Ex 'm') is a type of protection in which the parts that could ignite an explosive gas atmosphere are enclosed by a polymer compound seal in such a way that the explosive atmosphere cannot come in contact with any sparking or heating which may occur within the encapsulation. The polymer compound can be thermo-setting, thermo-plastic

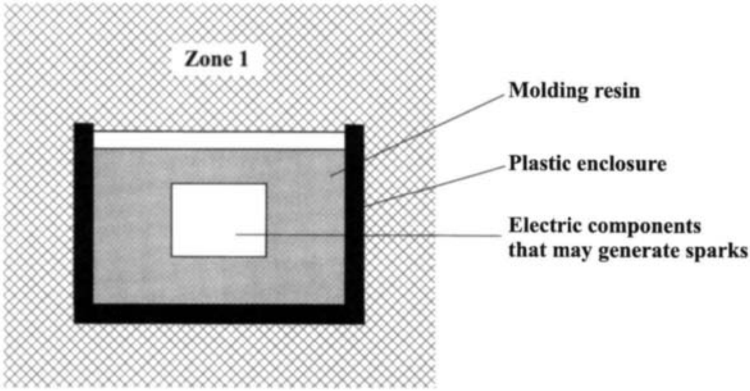

Figure 7–15 Illustration of encapsulated/molded enclosure (Ex 'm').

and elastomer materials with and without fillers and/or other additives. The temperature range of the polymer is the temperature range within which its characteristics satisfy the standard requirements both in service and during storage. The continuous service temperature of the polymer is the maximum temperature to which it can be continuously exposed. The choice of polymer for a particular application depends on the duty that the polymer has to perform in the apparatus to be encapsulated.

The suitability of the polymer and the encapsulation in which it is used are verified by tests of e.g.

- dielectric strength of the polymer
- water absorption of the polymer
- thermal endurance of the polymer and other parts of the component
- maximum surface temperature of the component

7.2.1.8 Design Concepts for Zone 0 Other than Ex 'ia'

During the last decade it has been agreed internationally (International Electrotechnical Commission) that there is a need for additional design concepts than just Ex 'ia' (see Section 7.2.1.1) for electrical apparatuses to be used in Zone 0. The new Zone 0 concepts are typically combinations of at least two independent applications of design concepts for Zone 1 apparatuses.

7.2.1.9 Special Design for Use in Zone 2 Only (Ex 'n')

In the course of the last twenty years special concepts for design of special apparatuses for use in Zone 2 only have been developed. These concepts are essentially just more liberal versions of the design concepts adopted for Zone 1 (and 0) apparatuses. Up to now all the Zone 2 design requirements have been collected in a single independent Ex 'n' standard. In the future specific minimum Zone 2 requirements may be integrated in the various separate standards describing the design concepts outlined in Section 7.2.1.1 to Section 7.2.1.7 above.

7.2.2 Clouds of Liquid Droplets

No specific standards or guidelines for designing electrical apparatuses enclosures to prevent ingress of explosive clouds of liquid droplets seems to exist. However, in the case of sprays of liquids of low boiling points, where one can assume immediate complete evaporation as soon as the drops have been generated, the protection methods for gases described in Section 7.2.1 apply.

7.2.3 Dust Clouds

7.2.3.1 Introduction

The paragraph from NFPA (1997) quoted in Section 7.1.4.1 also indeed applies to design of electrical apparatuses. In this context, the paragraph may be slightly re-phrased by replacing the initial word "walls" by "simple enclosures." Hence:

> Simple enclosures are much more important in separating hazardous and non-hazardous zones in the case of combustible dusts than in the case of combustible gases. Only completely non-perforated solid walls make satisfactory barriers in the case of gases, whereas closed doors, light-weight partitions, and even partial partitions could make satisfactory barriers between hazardous and non-hazardous zones in the case of dusts.

7.2.3.2 Preventing Ignition of Combustible Dusts by Keeping Potential Ignition Sources inside Enclosures that Prevent Hazardous Ingress of Dust

7.2.3.2.1 The "IP" Code for Prevention of Dust Ingress

The use of suitable enclosures to keep dust away from delicate electrical and mechanical components has long traditions. Irrespective of specific hazardous effects, the presence of dusts is generally incompatible with delicate equipment and components, just from the point of view of cleanliness and tidiness. The various reasons for applying this concept include:

- Combustible dust can form an explosive cloud inside the enclosure and cause a dust explosion there.
- Combustible dust can form dust layers inside the closure and cause dust fire there.
- Electrically conductive dust can cause short-circuiting inside the enclosure.
- Abrasive and/or corrosive dusts can damage delicate mechanical components inside the enclosure.

In the context of preventing ignition of combustible dusts, only the first and second reasons are relevant. Furthermore, when considering that formation of explosive dust clouds inside enclosures of a reasonable standard, by ingress of dust from the outside, is highly unlikely, the possibility of dust fire is in fact the only hazard that has some relevance in the present context.

IEC (2001) has produced a standard, named the "IP" code, which defines various "degrees of protection" against ingress of solid objects, including ingress of dust particles, and ingress of water. The initials "IP" just means "International Protection." According to IEC (2001), the "degrees of protection" offered by a given enclosure are to be specified by two digits, the first referring to ingress of solid objects, the second to ingress of water. For solid objects 6 levels of protection are defined, ranging from objects larger than 50 mm (digit 1) to dusts (digits 5 and 6). For water, the corresponding range is from protection from gentle dripping (digit 1) to protection from continuous complete immersion (digit 8). The code also specifies specific test methods by which enclosures can be tested for compliance with the requirements of the various degrees of protection.

It is important to note that the IEC "IP" code, IEC (2001), does not cover protection against ingress of explosive gases. Satisfactory protection against ingress of gas is very difficult to achieve using simple enclosure technology, e.g. flanges with gaskets, because gas molecules will migrate though even very tiny openings, in particular if there is a pressure drop across the opening. For this reason it was necessary to introduce all the additional technologies to either prevent ingress of explosive gases into enclosures (oil-filled, pressurized and molded enclosures) described in Section 7.2.1, or to prevent ignition of explosive gas that has entered the enclosure (enclosures filled with glass beads or sand, elimination of potential ignition sources inside enclosure), or to prevent transmission of an explosion inside the enclosure to a possible external explosive atmosphere (flame proof enclosures), also described in Section 7.2.1.

However, in the case of dusts none of these additional measures are required to prevent formation of explosive dust clouds inside enclosures. Common enclosure technology, e.g. flanges with gaskets, provides the protection required. The IEC IP code specifies two levels of prevention of ingress of dust into enclosures, viz. "dust protected" (digit 5) and "dust-tight" (digit 6), which are defined as follows:

- Dust protected

  A limited quantity of dust is allowed to penetrate into the enclosure under certain conditions (IP 5X).

- Dust tight

  No dust is allowed to penetrate into the enclosure (IP 6X).

IEC (2001) also specifies the tests to which enclosures of categories IP 5X and IP 6X have to be subjected. The enclosure to be tested is placed inside a test chamber where a very dense cloud of fine talcum powder is maintained continuously during the test period either by a powder circulation pump, as illustrated in Figure 7–16, or by some other means. Depending on the practical circumstances in industry in which the enclosure to be tested is to operate, tests can be conducted either with a slight negative pressure inside the enclosure to be tested, as also illustrated in Figure 7–16, or with no pressure difference across the enclosure wall.

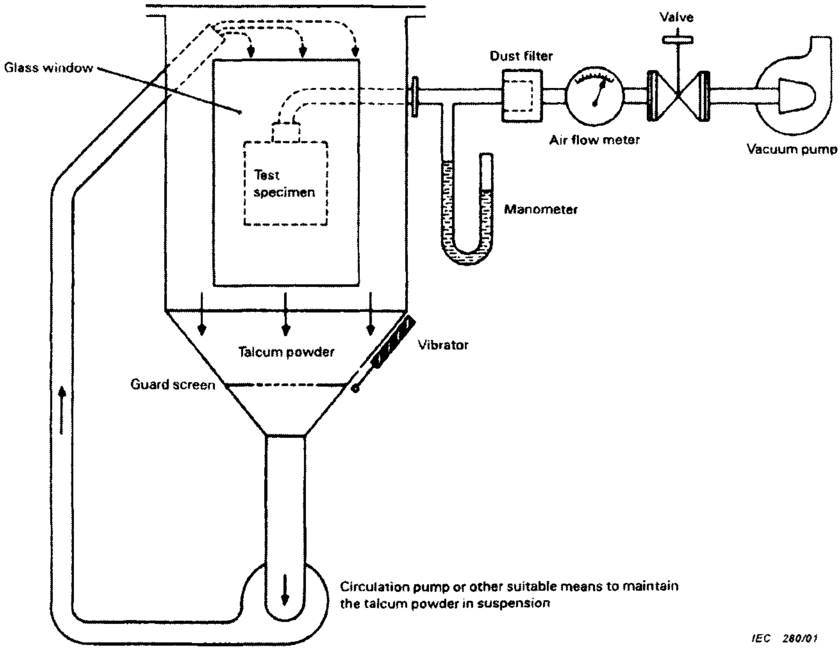

Figure 7–16 Illustration of method used for testing enclosures for their ability to prevent ingress of dust. From IEC (2001).

Figure 7–17 shows an actual test cabinet according to IEC (2001) during dust ingress testing of a three-phased geared electric motor. The circulation of talcum powder had been stopped before the photograph was taken.

CENELEC (1998) specifies the IP requirements for combustible dusts as follows:

- Zone 20 and Zone 21: IP 6X
- Zone 22: IP 6X for electrically conductive dusts IP 5X for electrically non-conductive dusts

CENELEC (1998) also specifies marking codes to be used to identify the degree of protection offered by a given enclosure.

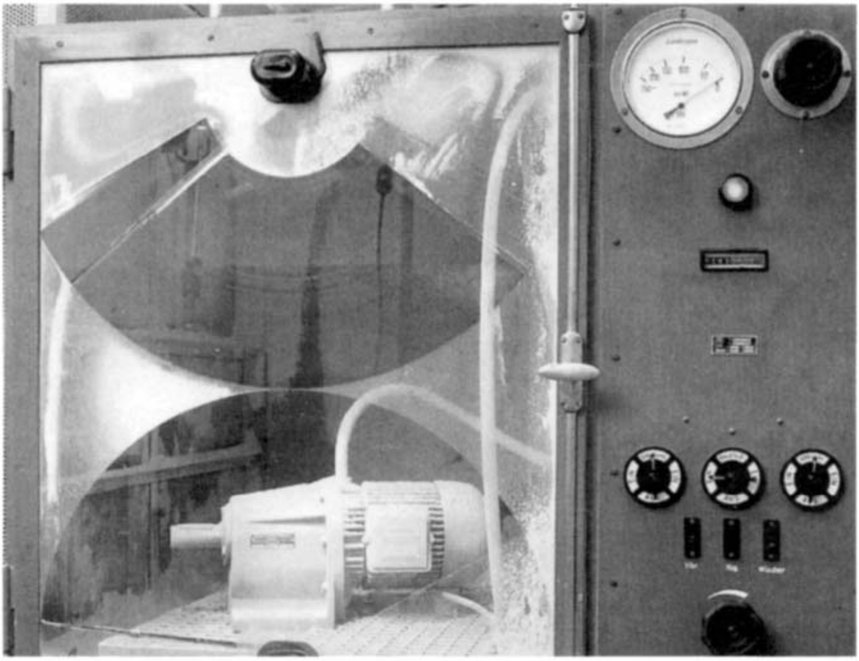

Figure 7–17 Photograph of an actual test cabinet according to IEC (2001) during dust ingress testing of a three-phased geared electric motor. From Greiner (2001).

7.2.3.2.2 Prevent Ion of Ignition of Dust Clouds and Dust Layers by Hot External Enclosure Surfaces

Ignition of dust clouds and dust layers by hot surfaces is discussed in Chapter 5. Although it is known that the minimum ignition temperature of a given dust cloud is not a true inherent constant of the cloud, results from the laboratory scale tests illustrated in Figure 5–25 are regarded as representative of the dust tested. It is customary to require that the maximum temperature of the dust free enclosure surface does not exceed 2/3 of the minimum ignition temperature for dust clouds, in °C, as measured in this standard test.

In the case of ignition of dust layers by hot surfaces, the test method illustrated in Figure 4–4 in Chapter 4 is used. Tests with a given dust, varying the thickness of the dust layer, shows that the minimum ignition temperature decreases systematically with increasing layer thickness. It is customary to require that the maximum temperature of the enclosure surface be at least 75°C lower than the minimum ignition temperature determined in the test. Figure 7–18 indicates how the maximum permissible enclosure surface temperature decreases systematically with increasing dust layer thickness, for three different dusts having minimum hot surface ignition temperatures of 250°C, 320°C, and 400°C respectively for 5 mm layer thickness. However, if a large part of the hot surface is covered by a comparatively thick dust layer, the surface temperature of the enclosure may increase to a value significantly higher than that attained in the absence of dust. In that case Figure 7–18 does not apply, and special assessment will be required. This may imply both special tests and mathematical model simulations.

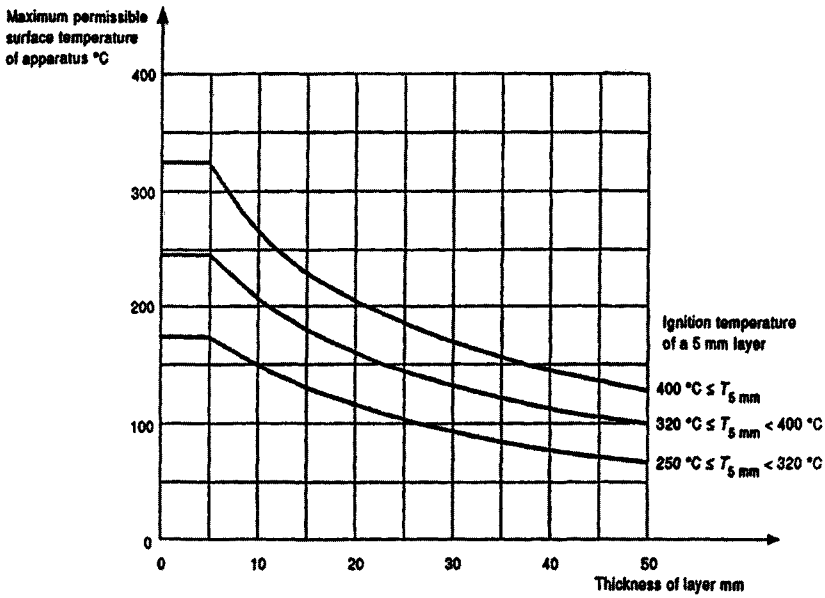

Figure 7–18 Graphs for maximum permissible temperatures of enclosure surfaces as functions of the thickness of a layer of combustible dust on the surface. It is assumed that the dust layer on enclosure surface does not significantly increase the temperature of the surface as compared to that attained without a dust layer. From CENELEC (1998).

7.2.3.2.3 Other Requirements to IP Enclosures

- Enclosures made of plastic materials must be able to withstand certain specified thermal load tests, both in the range of low and high temperatures. This also applies to any plastic materials used for cementing.

- Enclosures must be able to withstand relevant tests for mechanical strength.
- All metal parts, which by becoming electrostatically charged can give rise to electrostatic discharges that can ignite clouds or layers of the dust in question, must be properly earthed and bonded.
- In order to avoid propagating brush discharges (see Chapter 2 and Chapter 5) enclosures made of plastic materials must satisfy certain requirements to the maximum permissible insulation resistance to earth, the maximum permissible breakdown voltage across the thickness of the plastic wall, or the minimum permissible thickness of external plastic insulation on metal.
- Exposed parts of enclosures must not contain metals that are able to generate impact sparks that can ignite clouds or layers of the actual dust.

7.2.3.3 Other Proposed Methods for Design of Enclosures for Electrical Apparatus to be Used in Areas Containing Combustible Dusts

7.2.3.3.1 Background

For a long time design of equipment for areas containing combustible dusts in order to prevent ignition of the dust has essentially been based on the two basic principles discussed so far. The first is isolation of potential ignition sources by means of enclosures that keep the dust out to the required extent (IP 5X or 6X), the second is prevention of ignition of the actual dust (layer or cloud) by the enclosure surface. This philosophy was up to recently governing both the standardization work in IEC and in Europe. There does not seem to be any valid reason for departing from this simple, sound philosophy as the basis in international standardisation work also in the future. Nevertheless, a new series of dust standards for electrical apparatus has been produced in an attempt to "align" standards for dusts with those for gases.

7.2.3.3.2 Pressurized Enclosures

The basic idea of the Exp standard for gases has been outlined in Section 7.2.1. The controversy presented by this standard when adapted to combustible dusts is discussed by Eckhoff (2003). The dust standard is both superfluous and inherently self-contradictory.

If the interior of electrical apparatus enclosures has to be kept entirely free of dust particles (dusts of abrasive or corrosive materials may damage delicate moving components, or accumulation of layers of electrically conductive dusts may short circuit electric/electronic circuitry), it generally does not represent any substantial difficulties to design dust tight enclosures satisfying the requirements of the enclosure standard IP 6X. In the case of comparatively large apparatus enclosures, e.g. instrument cabinets, with doors and windows fitted with rubber gaskets and locking arrangements, it may be difficult to completely prevent ingress of dust. However, transmission of explosive dust clouds from the outside of the enclosure to its interior, through possible narrow gaps and holes can be entirely excluded. Hence, a pressurization standard for combustible dusts to prevent dust explosions inside enclosures, is superfluous.

The self-contradiction of the standard lies in the following erratic assumption: If particles in a dust cloud embracing an enclosure should enter it though narrow holes and gaps, the particles will stay suspended in the atmosphere inside the enclosure, and eventually form an explosive dust cloud inside the enclosure, as if the dust particles were gas molecules. This assumption is basically wrong, If significant quantities of dust particles do, over some time, enter an enclosure at all, they will not accumulate as cloud, but as a layer. For a more extensive discussion, see Eckhoff (2003).

7.2.3.3.3 Encapsulation by Molding

As part of the effort to align dust standards with gas standards a new standard for encapsulation of electrical equipment for combustible dust atmospheres by molding has been produced. This is a type of protection by which electrical parts that can ignite an explosive atmosphere are molded into a compound material in such a way that the atmosphere cannot make contact with these parts. The compounds can be thermosetting, thermoplastic, epoxy resins, elastomers etc., with or without fillers. It is difficult to see that this comprehensive standard for dusts, which is to a large extent an edited copy of the corresponding gas standard, is very helpful.

As discussed in Section 7.2.1, the basic issue of the molding concept, i.e. to prevent the formation of an explosive atmosphere inside enclosures, is not relevant for dusts. A relevant specific issue with dusts would rather be to make sure that molded components, if embedded in dust deposits, do not give rise to self-heating/self-ignition of the dust deposits.

7.2.3.3.4 Intrinsically Safe Electrical Apparatus

In practice electrical circuits, switches, etc., to be used in areas containing combustible and/or electrically conductive dusts, should always be kept inside enclosures. This will prevent significant quantities of dust from making contact with electrical components in general, including components that may generate electric sparks and/or hot surfaces. Hence, direct adoption of the entire concept of "intrinsically safe design" from the gas/vapor domain into the domain of combustible dusts does not seem to be an optimal approach.

However, there are some highly special applications where there is a genuine need for intrinsically safe apparatus in environments containing combustible powders/dusts. One example is capacitive level indicators for solid bulk materials stored in silos and bins. In this case a live capacitor "plate," in the form of a bare metal rod/rope, carrying a voltage with respect to earth, is directly exposed to the combustible powder/dust inside the silo or bin. An ignition risk could arise from electrical sparks generated by direct contact between the energised bare metal rope and any grounded metal part of the silo.

Figure 7–19 illustrates the application of this type of level indicator. The basic principle of measurement is as follows: A short electric pulse (ns wave package) is emitted from the sensor head at the top of the silo and travels down the vertical metal rod/rope. At the point where the rod/rope becomes immersed in the powder, its impedance changes abruptly, which causes a partial reflection of the electrical pulse from this point and backwards to the sensor head at the top. The distance d from the sensor head at the silo top to the powder surface is then d = 1/2 ct. Here c is the speed of the electromagnetic wave pulse passing along the metal rod/rope, and t is the time from pulse emission at the sensor head till the return of the reflected pulse from the point along the rod/rope where the surrounding medium changes from gas to bulk powder.

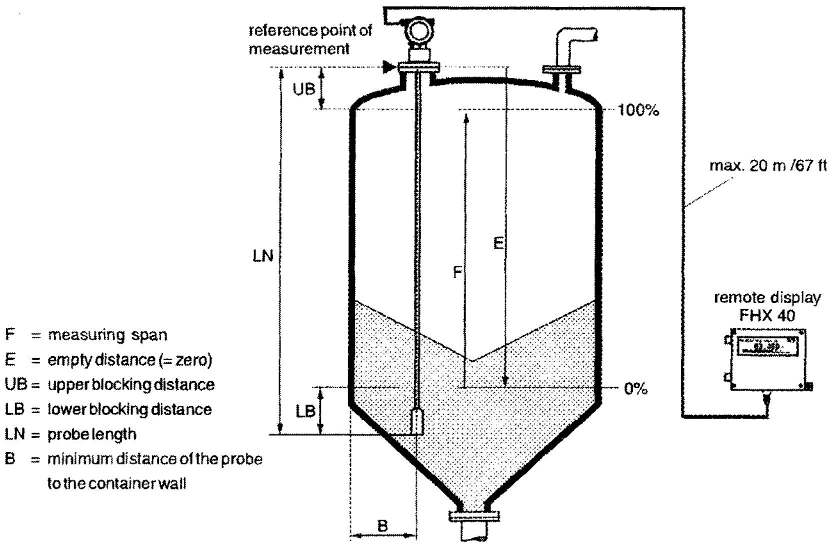

Figure 7–19 Illustration of the use of a capacitive level indicator for powders in silos. Courtesy of G. Klotz-Engmann, Endress + Hauser, Germany.

7.2.4 Explosives/Pyrotechnics

7.2.4.1 CENELEC (1997)

CENELEC (1997) does not specify any specific standards for design of electrical equipment to be used in areas where explosives, propellants or pyrotechnics are produced and/or handled. Instead the standard specifies conditions under which electrical apparatus standards for gases and vapors (Section 7.2.1) or for dusts (Section 7.2.2) apply. The following general guidelines are given:

- In areas endangered by explosive substances only the electrical apparatus which are absolutely necessary for the operation of the electrical installations shall be used. Where this is not practicable, apparatus should be installed in the area with the lowest risk.
- Electrical apparatus shall be selected on the basis of its design or protected by additional structural measures and installed in such a way that in prescribed use the protection against the penetration of

dust and water and against electrical, chemical, thermal or mechanical influences required for operational safety is maintained.

- Cable glands should be either made from a suitable non-corrodible material or be electroplated with e.g. chromium or nickel.
- The design of enclosures for electrical apparatuses should such as to minimize the possibilities of accumulation of dust layers, and facilitate cleaning operations.
- In cases where electrical apparatus in an area E1 is subjected only to accumulation of explosive substances as layers, at the same time as the apparatus is provided with additional devices for preventing accumulation of such substances on and inside the electrical apparatus (e.g. dust covers or additional enclosures), the requirements for area E2 apply.
- Electrical apparatus, with the exception of cables and cords, may be used in general at ambient temperatures up to 40°C. The influence of adjacent heat sources shall be taken into account.
- In cases where ambient temperatures exceed 40°C electrical apparatus that has been specially designed for these conditions shall be used.
- Where explosion-proof electrical apparatus are used, it shall be ensured that the explosion protection as in prescribed use is retained.

7.2.4.2 Australian Interim Standard

The Australian interim standard (2004) specifies the following requirements of electrical equipment to be installed and used in the various zones as defined in Section 7.1.5.6:

- Zone 0E: Exia and other special solutions permitted in zone 0 (see Section 7.2.1)
- Zone 1E: Exia and other special solutions permitted in zone 0, Exib, Exe, Exp, Exo, Exq, Exm (Section 7.2.1)
- Zone 2E: Same as for zone 1E
- Zone 20E: Dust tight enclosures (IP 6X see Section 7.2.3.2.1), Exia, Exm
- Zone 21E: Dust tight enclosures, Exia and Exib, Exp, Exm

- Zone 22E: Dust tight enclosures, Exia and Exib, Exp, Exm
- Zone SE: Normal electrical equipment can be used

The standard also specifies the following maximum permissible surface temperatures of electrical equipment:

- Zone 0E: T5 (see Table 7–4)
- Zone 1E: T5
- Zone 2E: T4
- Zone 20E: T5 or cloud ign. temp. of dust minus 75°C, whichever is the lower
- Zone 21E: T5 or cloud ign. temp. of dust minus 75°C, whichever is the lower
- Zone 22E: T4 or cloud ign. temp. of dust minus 75°C, whichever is the lower
- Zone SE: Normal electrical equipment can be used