INTRINSIC SAFETY
BASIC PRINCIPLES

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IGNITION TRIANGLE

In many industrial processes, the presence of flammable materials (gases, vapours, liquids, dusts, fibres and flyings) requires the adoption of safety practices to protect both, plant and personnel, from the risk of fires and explosions.

An explosion or fire can occur when, in certain areas at certain times, an explosive or flammable mixture and a means of ignition, thermal or electrical, are present.
Flammable materials are grouped according to the ignition energy (Gas Groups) and classified for their minimum ignition temperature (Temperature Class), while Area classification (“Zone” in Europe, “Division” in the USA) takes into account the probability of the presence of an explosive mixture.

Electrical equipment, in Hazardous Areas (“Locations” in the USA), constitute potential sources of danger because they may generate arcs or sparks or hot surfaces which could ignite the explosive atmosphere.

Ignition Triangle

From a chemical point of view, oxidation, combustion and explosion are all exothermic reactions with different reaction speeds. For such reactions to take place, it is essential that the following three components be present simultaneously in due proportions:

- **Fuel:** flammable vapors, liquids or gases, or combustible dusts or fibers;
- **Oxidizer:** generally, air or oxygen;
- **Ignition Energy:** electrical or thermal.

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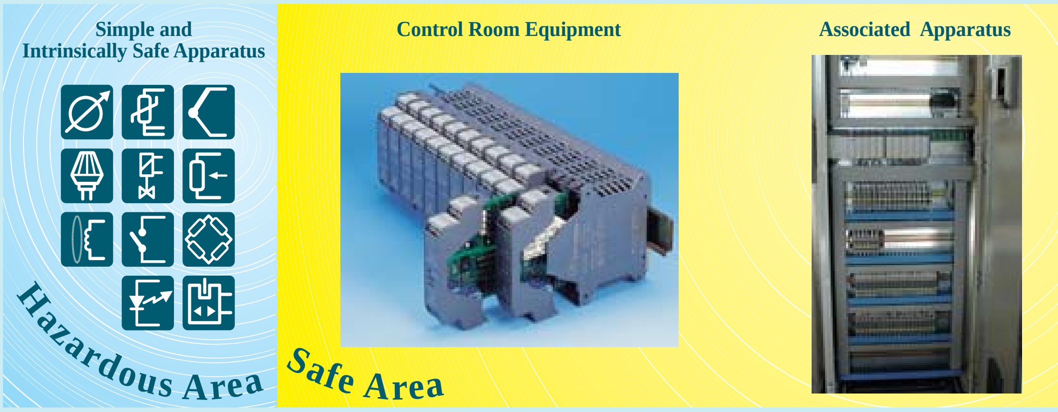
Protection methods

Basic safety concept is to avoid the simultaneous existence of a dangerous atmosphere and a source of ignition by:
Containing the explosion within a well-defined space where it will not cause any harm.

Physically segregating the sources of energy from the explosive mixtures.
Preventing the release of sufficient energy to ignite any explosive mixture.



According to the safety concept and the way to apply it, there are different explosion protection methods suitable to enable electrical equipment to be used in Hazardous Area.

All these techniques are ruled by national and international standards, as well as codes of practice, that define how to design and install the equipment, while recognized authorities issue the conformity certificate of the apparatus or systems. Among the protection methods, the simplest and most effective, applied to electrical and electronic instrumentation, is Intrinsic Safety.

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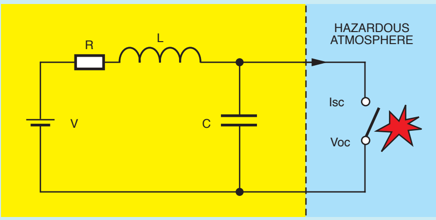
The basic principle of intrinsic safety is to limit, under normal and foreseeable fault conditions, the amount of electrical energy in Hazardous Area circuits such that any sparks or arcs or high surface temperatures will not ignite the explosive atmosphere.

Electrical equipment, in Hazardous Area, as well as the interconnected instrumentation in Safe Area, must be designed to reduce the open circuit voltage (Voc) and short circuit current (Isc) to values that cannot cause ignition by opening, closing or earthing the circuit or by heating of any parts belonging to the circuit.



Intrinsic Safety works on the principle of preventing the possibility of explosion by limiting the electrical energy and the surface temperature.

Resistive Circuits

A circuit is considered as resistive when the reactive part, inductance and capacitance, is zero or negligible (figure A)

The energy released by this type of circuit depends essentially on the power supply source V and the current limitation due to the presence of resistor R.

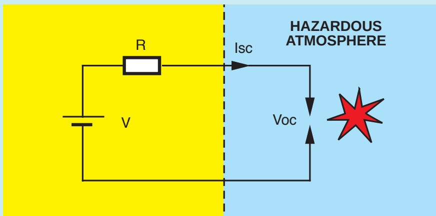


figure A

Schematic of a resistive circuit.

In this case, it is difficult to correlate the minimum ignition energy (MIE) with a circuital situation that generates the spark.

The experimental tests on this type of circuit have demonstrated that the capacity for igniting a dangerous mixture depends on the open- circuit voltage (Voc = V) and the short-circuit current (Isc = V/R).

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The ignition curve for resistive circuits is shown in Figure B.

This graph shows the ignition curve relative to the group of gases that are considered by the standards.

The trend curve shows that the lower the open-circuit voltage, the greater the amount of power that can be used safely.

This characteristic allows process instrumentation that works with voltages on the order of 20-30 V to be used efficiently in intrinsic safety applications.

For a more detailed ignition curve, refer to Appendix 5.

The inherent low power involved, even in unfavourable circumstances, gives some advantages that can not be obtained with other techniques:

- Intrinsic safety is the only method accepted for the most Hazardous Areas (Zone 0; DIV. 1).
- Maintenance and calibration of field equipment can be carried out while the plant is in operation and the circuit “live”.
  Low voltages are also safe for personnel.
- No special mechanical protection of field wiring is required but ordinary instrument cabling is acceptable.

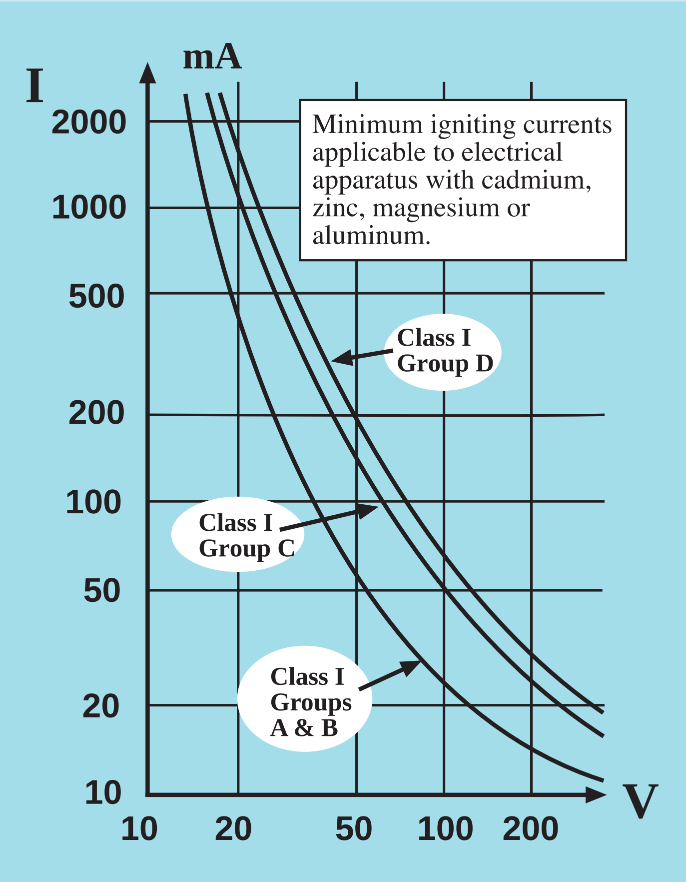

figure B

In Intrinsic Safety applications three basic parts have to be considered:

- Hazardous Area devices (Simple Apparatus), or equipment (Intrinsically Safe Apparatus).
- Safety interfaces (Associated Apparatus).
- Interconnecting cables.

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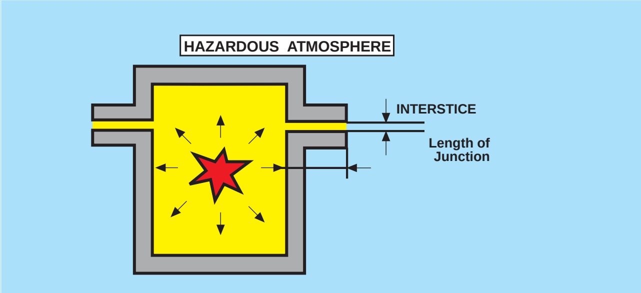
Simple Apparatus

Passive components (switches, resistive sensors, potentiometers), simple semiconductor (LEDs, photo-transistors) and simple generating devices (thermocouples, photocells) are regarded as Simple Apparatus if they do not generate or store more than: 1.5 V, 100 mA, 25 mW (see IEC 60079-11 and EN 50020 standards).
Simple Apparatus can be used in Hazardous Area without certification; they have to be assessed for the temperature classification on the basis of the matched output power of the interface device.



Other techniques work on the principles of keeping the hazardous material away from the circuit, containment of the explosion, or preventing arcs, sparks or hot surfaces.

Intrinsically Safe Apparatus

Transmitters, I/P converters, solenoid valves and any other "energy-storing" device must be certified as Intrinsically Safe Apparatus suitable for use in Hazardous Area, according to the zone, or division, classification and gas characteristics (group and temperature class).
For more details refer to Appendix 6.

Associated Apparatus

Interfaces between field and control room equipment, usually called "Barriers or Isolators", protect the Hazardous Area circuits by limiting the voltage and current in normal and in fault conditions. Two types of intrinsically safe interfaces exist: "Zener Barriers" and "Galvanic Isolator Barriers"; they basically differ for the way the potentially dangerous energy, from control room equipment, is diverted to prevent it from passing through to the Hazardous Area circuits.
Barriers must be designed and certified as Associated Apparatus suitable for connection to intrinsically safe or simple apparatus in Hazardous Area. Associated apparatus are the key to any intrinsically safe system because they define maximum allowable safety parameters of the circuits connected to the Hazardous Area terminals of the barriers.

Interconnecting Cables

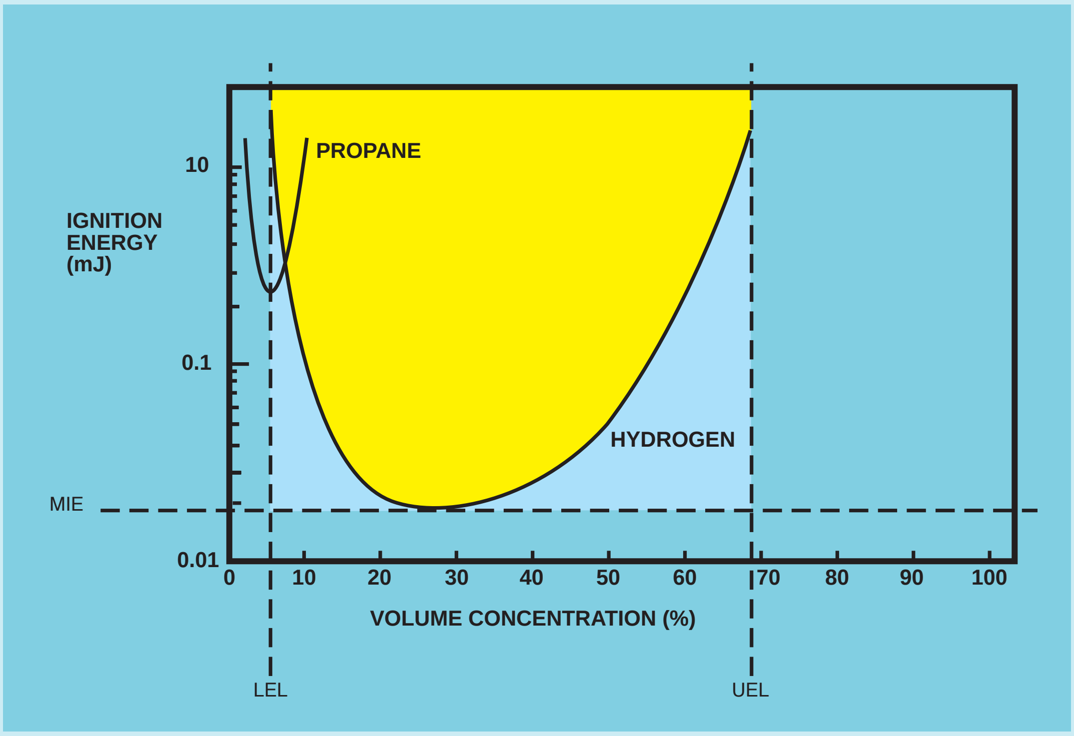
Low voltage and current, in intrinsically safe circuits, allow the use of ordinary instrumentation cables provided that capacitance and inductance are taken into account in assessing the safety of the system; cable parameters seldom are a problem and long distances can be easily achieved.

EXPLOSIVE MIXTURE CHARACTERISTICS

The risk of an ignition of an air/gas mixture depends on the probability of the simultaneous presence of the following two conditions:

- Formation of flammable or explosive vapors, liquids or gases, or combustible dusts or fibers with atmosphere or accumulation of explosive or flammable material;
- Presence of an energy source "electrical spark, arc or surface temperature" that is capable of igniting the dangerous mixture present.

It is possible to draw an ignition characteristic for each type of fuel. The characteristic curves of hydrogen and propane are illustrated in this page.



Ignition energy in relation to hydrogen and propane air/gas concentration

EXPLOSIVE MIXTURE CHARACTERISTICS

A minimum ignition energy (MIE) exists for every fuel that represents the ideal ratio of fuel to air. At this ratio, the mixture is most easily ignited. Below the MIE, ignition is impossible for any concentration.
For a concentration lower than the one corresponding to the MIE, the quantity of energy required to ignite the mixture increases until a concentration value is reached below which the mixture cannot be ignited due to the low quantity of fuel. This value is called the lower explosive limit (LEL).

In the same way, when increasing the concentration the energy requirement increases, and a concentration value is identified above which ignition cannot occur due to the low quantity of an oxidizer. This value is called the upper explosive limit (UEL).

THE CHOICE BETWEEN "ZENER BARRIERS" AND "GALVANICALLY ISOLATED BARRIERS"

Safety barriers are protection devices placed between, Hazardous and non Hazardous Area interconnected apparatus with the purpose of limiting the energy, in the Hazardous Area, to a level lower than the minimum required to ignite the explosive atmosphere.
The intrusion of excessive electrical energy into Hazardous Area circuits, due to fault conditions in the Safe Area, can be prevented by:

- diverting the fault energy to earth ("ground" in the USA).
- Or by blocking the fault energy with isolating elements.

During fault conditions, voltage and current levels, which can appear in Hazardous Area, are limited to safe values.

Zener barriers

Since their introduction, long ago, "Zener Barriers" have been widely used as safety interfaces to meet the majority of applications in Hazardous Areas.
Based on energy-diversion concept, this type of barrier is a very simple network of components arranged as shown in Figure 1.
In normal operating conditions, the barrier passes electrical signals, in both directions, without shunting them.
When a fault voltage (250 Vrms max.) appears at the non Safe Area terminals of the barrier, the resulting high current flows to ground through the fuse and zener diodes. The fuse is rated to blow very quickly in order to prevent the failure of zener diodes and to isolate, when blown, Hazardous from Safe Area circuits.
Standards require that the fuse must not be accessible for substitution to avoid errors that could impair safety; thus once the fuse is blown it is necessary to replace the whole barrier.

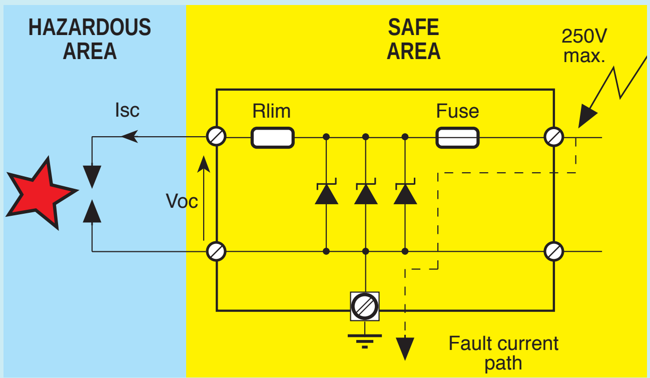


Fig. 1

During fault transient, the open circuit voltage (Voc) at the Hazardous Area terminals of the barrier is clamped to zener voltage, while the short circuit current (Isc), in Hazardous Area, is limited by the output resistor (Rlim).
These values, Voc and Isc, are relevant to assess maximum allowable capacitance and inductance, at the Hazardous Area terminals, for the gas groups that cannot be ignited by those values.

The efficiency of a barrier depends on a good ground connection which must provide a return path for the fault current, back to the Safe Area, preventing any substantial increase in the voltage and current at the Hazardous Area terminals.

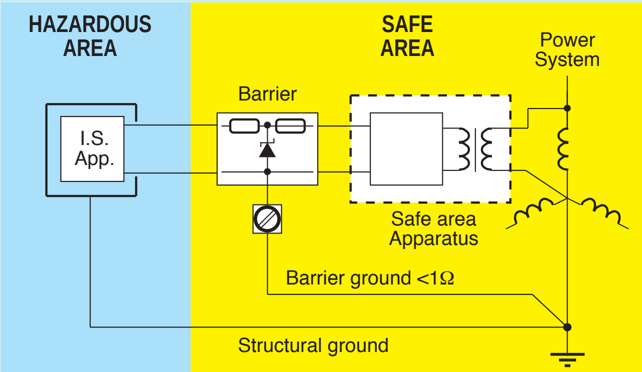


Fig. 2

This is accomplished by using a dedicated conductor which must be run, separately from any other structural ground, to the reference ground point (see Figure 2).

The resistance from the furthest barrier to the ground point must be maintained at less than 1Ω and standard requirements are for a minimum size of 4 mm^2 (12 AWG in the USA).

“Zener Barriers” are simple, reliable and low cost devices, however they present some drawbacks that must be considered when choosing them for intrinsic safety applications.

Main disadvantages are:

- A good ground connection must be provided and maintained.
- Field devices must be isolated from ground (and maintained as such).
- Voltage drop across the barriers can make some applications difficult.
- Improper connection or voltage surges could blow the fuse.
- Very poor common mode rejection (Common mode regection is the immunity of a device to interfering voltages applied at both input terminals with respect to ground).

Galvanically Isolated Barriers

Problems that arise with “Zener Barriers” can be overcome by using safety interfaces based on the concept of isolation rather than energy diversion.

The basic difference consists in providing isolation, between Hazardous and Safe Area circuits, by using components, such as transformers, relays, and optocouplers, that must comply with requirements of safety standards to guarantee safety (see Figure 3).

When properly designed, “Galvanic Isolator Barriers” do not permit the fault voltage (250 Vrms Max) to reach the energy limitation circuit that must be able to withstand only the maximum voltage at the secondary side.

Galvanic isolation allows the energy limitation circuit to be floating from ground; thus a ground connection, as well as a protective fuse, for this circuit are not needed.

Safety parameters, Voc and Isc, are determined in a similar way to that used for “Zener Barriers”.

The main features of “Galvanic Isolator Barriers” are:

- A dedicated ground connection is not required and field devices can be connected to ground.
- Full voltage is available to field devices.
- Signal conditioning and circuit protection are combined in a single unit.
- Simple installation and commissioning with elimination of ground loops.
- High common mode voltage can be tolerated.

Intrinsic Safety Interfaces

All I.S. interfaces use zener diode techniques to limit the flow of power into the hazardous area.

In simple form, they can employ shunt diode circuits in which excess current is routed to ground through a direct earth connection.

These products are commonly known as Zener Barriers.

Alternatively, the instrument signal can be passed through transformers and associated modulation and demodulation circuits to simplify earth grounding and installation, by galvanically isolating the hazardous circuit from the safe area circuit and power source.

These products are commonly known as Galvanic Isolators.

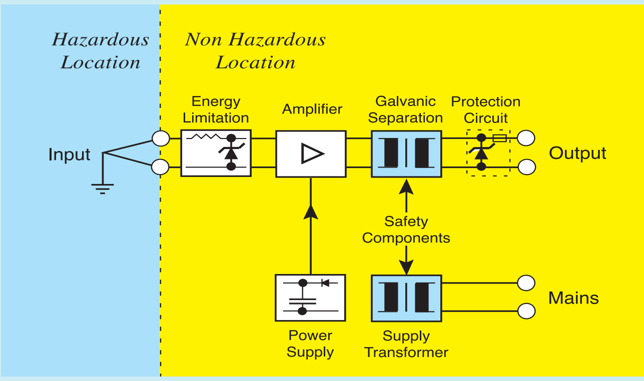


Fig. 3

INSTALLATION OF **INTRINSICALLY SAFE** AND ASSOCIATED APPARATUS

North American cable Installation

Electrical apparatus in hazardous (classified) locations may be installed using one of the following three basic installation systems:

- **Conduit Systems:** The electrical wiring is installed inside closed, threaded metal pipes (rigid steel or intermediate metal conduit) approved for the purpose.
  The pipes are screwed into entrances in the enclosures which contain electrical equipment. The entire conduit system is required to be explosion-proof and frequently requires a seal between the connected enclosure and the pipe. In Class I, Division 2 locations, the conduit system need to be explosion-proof only between any explosion-proof enclosure and the required sealing fittings. In Class I, Division 1 locations in Canada, one difference is that threaded steel intermediate conduit is not acceptable.
- **Cable Systems with Direct Entry:** In the U.S. the NEC will not allow cables (except for mineral-insulated [MI] cable and cables used in intrinsically safe systems) to be installed in Class I, Division 1 locations. In Class I, Division 2 locations certain cable constructions are allowed (refer to API RP14F).
  In Canada for Class I, Division 1 locations, armored and metal-sheathed cables with matching cable glands, tested to the requirements of CSA standard C22.2, No. 174, are permitted for direct entry to explosion-proof equipment.
- **Cable Systems with Indirect Entry:** Indirect entry cable systems offer a decided advantage in that it can be connected without opening the explosion-proof equipment. The connection is to terminals made in an "increased safety" terminal chamber.

European Practice EN50.039

Below are the European requirements for cable installation in intrinsically safe systems according to the EN 50.039 standard, Intrinsically Safe System "i."

1.0 Connecting

Conductors of an Intrincally Safe electrical system.

1.1 General

The electrical parameters and all characteristics of specific connecting conductors of an intrinsically safe electrical system must be specified in the system's descriptive document because **Intrinsic Safety** relies on them.

1.2 The multi-conductor

cables can contain one or more intrinsically safe circuits; however, they can not contain any non-intrinsically safe circuits, apart from particular applications as specified in the European standard EN 50.020.

2.0 Multi-Conductor

Cables Containing Different Intrinsically Safe Circuits.

2.1 Conductors

The radial thickness of the isolation material must be appropriate for the diameter of the conductor and the nature of the isolation material.

For the normally used isolation material, for example polyethylene, the minimum must be such to tolerate an applied test voltage with an alternate voltage with intrinsically safe circuit with a minimum of 500 V.

2.2 Conductor Shields

When conductor shields guarantee the individual protection of intrinsically safe circuits in a way that avoid the circuits to come in contact with each other, the rate of isolation of those shields must be at least equal to 60% in surface.

2.3 Cables

The multi-conductor cables must be able to tolerate an applied test voltage with an alternate voltage with an rms value equal to:

- 500 V applied between any shield and/or armor connected together and all of the conductors of the cables connected together.
- 1000 V, applied between a bundle of half the cable conductors connected together and a bundle including the other half of the cable conductors connected together.

2.4 Tests

All the tests required to prove the conformity with points 2.1, 2.2, and 2.3 must be performed by the cable manufacturer.

All the applied voltage tests must be performed conforming to a method specified in an appropriate cable standard.

If such a method does not exist, the tests must be performed as follows:

- The voltage must be alternate and with sinusoidal wave form, and a frequency within 48 and 62 Hz.
- A voltage must be obtained from a power transformer with an output at least equal to 500 VA.
- The voltage must be gradually increased up to the specified value in a time frame of at least 10 seconds and maintained at such value for at least 60 seconds.

3.0 Types of Multi-Conductor Cables

The different points to be considered for multi-conductor cables used in intrinsically safe electrical systems depend on the type of cable used.

3.1 Type A Cables

Cables conforming to the requirements per points 1.1, 1.2, 2.1, 2.2, and 2.3. Do not consider any fault between the circuits if each circuit has an individual conductive shield.

Note: For any shield connection, for example grounding, refer to the installation rules.

3.2 Type B Cables

Fixed cables efficiently protected against damages and conforming to the requirements per points 1.1, 1.2, and 2.3.
Do not consider any fault between the circuits if a peak voltage greater than 60 V is not present in any of the cable circuits.

3.3 Type C Cables

Cables conforming to the requirements per points 1.1, 1.2, 2.1, and 2.3.
It is necessary to consider up to two connections between conductors and simultaneously up to four interruptions of the conductors.

3.4 Type D Cables

Cables conforming to the requirements per points 1.1 and 1.2.
There is no limit to the number of connections between conductors and simultaneously the number of interruptions of the conductors that must be considered.

European Cable Installation

In Europe the installation, or laying, of the cable can be performed in the following ways:

- **Pipe laying:**
  The cable must be furnished with isolation of an anti-abrasive function, if the laying condition does not exclude damaging during insertion.

- **Direct-ground laying:**
  The cable must be specified for this particular type of installation.

- **Suspended pipe laying:**
  The cable must be incapable of propagating fire and must be protected against mechanical and chemical damage with continuous isolation, incorporated or external.

When installing, or laying, cable in specific environments, the cable must be suitable for that environment unless adequate protective measures, such as pipes, special installation methods, thermal isolation, etc, are used.
Intrinsically safe circuit conductors must not be contained in a tray or pipe that includes conductors of non intrinsically safe electrical circuits unless certain precautions are taken, such as the containment of the intrinsically safe conductor or the non intrinsically safe conductor within a grounded shield.
When designing and installing intrinsically safe systems, keep in mind that capacitance and inductance parameters of the connecting cables are important factors, even if they are not always determining factors.
The capacitance and inductance values of the cable (generally, given in pF/m and μH/m) should be easily available from the cable manufacturer.
However, if there are difficulties in obtaining this data, the following values can be hypothesized (but only in an extreme situation).

Capacitance: 200 pF/m

Inductance: I μH/m

As an alternative to the inductance, another characteristic of the cable, the inductance/resistance ratio (L/R), can be used and is normally given in μH/Ω.
This parameter permits more flexibility in the cable installation process.