Understanding Hazardous Area Sensing

Intrinsic Safety

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Note: This handbook is intended for the understanding of Intrinsically Safe Technology. The examples used in this handbook are intended to enhance the understanding of the technology and should not be viewed as an engineering specification.

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Electricity In Hazardous Areas

Using electricity in potentially explosive areas has been a concern since the beginning of the twentieth century. These hazardous areas can vary greatly in size, explosive fuel, or use of equipment. The explosive atmosphere may contain fumes, dust or fibers. Because of this variety, equipment designed to operate safely in an atmosphere containing flammable dust, for instance, may not be safe in an atmosphere containing the vapors or fumes from gasoline. Users of electrical equipment in these varied atmospheres are faced with a universal problem. Should they use a traditional technology that provides a traditional solution for most situations, or multiple technologies - a precise one for each situation?

There are many traditional solutions to protect common industrial equipment. Enclosures for protecting equipment such as motors and lighting equipment are proven and mature. The enclosures and wiring methods for electrical distribution equipment such as circuit breakers and conduits are also well proven. Enclosures for primary controls such as contactors and motor starters are safe and functional.

On the other hand, requirements for pilot duty (secondary) control are increasing and constantly changing. Most industries wrestle with the age-old problem of making their products faster, better, and in more variety. To accomplish the first two, faster and better, the production/processing loop needs to be closed. Instead of having a human looking for a variable, say pressure, and then making a decision based on the actual vs. desired, the information is transmitted to an industrial computer for real-time processing and corrections.

This is not a revelation to anyone in the industry, but what is significant is that a faster and better process can often be achieved by adding more monitoring points and programming new control logic.

You have all heard the old saying attributed to the Model T FORD: “The customer can have any color he wants as long as it’s black”. There are so many options, variations, and modifications available today that some form of computer intelligence is used in most production and/or scheduling. To create this type of flexibility, sensors are being placed in every imaginable location. Some sensors may not even have a function most of the time, but there may be a critical time or an unusual project that requires crucial information from that sensor.

Satisfactory, but traditional, sensing solutions (pre-1980’s) are a rarity today. Speed in many processes cannot live with the limitations of 50-60 Hz AC control systems and certainly, a computer would not know what to do with this voltage.

A system that puts the eyes and ears of industrial computers in the hazardous area is the optimum solution.

Low-Voltage and Low-Current Circuits

Monitoring and reporting today in hazardous areas utilize microelectronics. Most of this equipment does not require voltages greater than 24 VDC or amperages greater than 100 milliamps. Nothing can be gained from a high power source: it simply cannot be utilized.

Often this type of safety equipment uses current and voltage-limiting components, such as fast-acting fuses, thermistors, chokes, diodes, and resistors. These protective components may be needed in some harsh environments even if the atmosphere is not explosive.

What constitutes a low voltage and low current circuit in a hazardous area? Let's look at a question-answer rhetorical statement: "If 1,000 Volts and 1,000 Amps can cause an explosion, and 0 Volts and 0 Amps can't, we can identify at least three ranges between the extremes that can be called SAFE, QUESTIONABLE, and DANGEROUS".

The SAFE practice of using low voltage and low current in a hazardous area is called **INTRINSIC SAFETY**.

Intrinsic Safety - A Proven Technology

Intrinsic Safety was developed and is now a proven technology in Europe. European manufacturers had needs that, until recently, were not significant in North America. The cost of land in Europe is very high and has resulted in very compact processing plants. In these dense plants, hazardous areas are often in close proximity to one another. In North America, where land is cheaper, several feet, yards and even miles are incorporated between hazardous areas. Today, in North America we now have some of the same needs but for different reasons. Land is still relatively cheap here, but to buy land and build a plant that either produces or uses anything that sounds like a "hazardous chemical", takes the wisdom of Solomon and the patience of Job. We will see more utilization of existing locations. Intrinsic Safety is a safe and proven technology that is ready to feed the data-hungry PLCs and industrial computers, ready to provide the flexibility needed today, and ready to aid in retrofit and compact plant designs.

CHAPTER 1
Introduction

1.1 Past and Present

Before we start the evolution, the milestones and red-letter dates of the past 80 years of Intrinsic Safety (which all good text of this kind is supposed to do), we will cheat a little and look at a recent definition from the 1999 National Electrical Code.

Article 504-2 :

> **INTRINSICALLY SAFE CIRCUIT:** A circuit in which any spark or thermal effect is incapable of causing ignition of a mixture of flammable or combustible material in air, under prescribed test conditions.
>
> **INTRINSICALLY SAFE SYSTEM:** An assembly of interconnected intrinsically safe apparatus, associated apparatus, and interconnecting cables, in which those parts of the system which may be used in hazardous (classified) locations are intrinsically safe circuits.

The main points to focus on are:

> "...any spark or thermal effect is incapable of causing ignition"
> "...may be used in hazardous (classified) locations"

With today in mind we will look at the past.

Intrinsic safety began on October 14, 1913, in Glamorganshire, South Wales. A coal mine explosion killed 439 workers. The investigation of the cause of the explosion was not conclusive. The experts at that time believed the explosion was caused by an electrical spark or possible falling rocks. The mines in this part of the British Isles are noted for firedamp. Firedamp gas is found in mines, especially in coal mines. This gas is mostly Methane.

When a miner filled a coal cart on steel rails, he would connect the cart to a towline. Then the miner would short two bare wires mounted on the wall with his shovel. This would complete a circuit, including a battery and an electromagnet clapper type bell. The bell was located above ground near a steam-powered winch. The winch operator would then pull the coal cart out of the mine.

At first glance, the above systems are not that much different than some simple systems of nearly 80 years later that the National Electrical Code calls "Intrinsically Safe". But there is a difference.

1.2 Investigation And Understanding

Technically, there is one major flaw in the system that probably caused the disaster in South Wales. The inductive coil of the bell cyclically stores and releases energy. The bell constantly makes and breaks its own circuit as it rings. At some point, just before the clapper hits the gong and before it breaks its own circuit, the coil has stored its maximum energy. If the miner pulled away his shovel at the precise instant the energy in the coil would have been at a maximum, and if the firedamp fuel and air were properly mixed, then an explosion would have been probable. As the investigation proceeded with testing and understanding, intrinsic safety was born.

The development in the early years was slow. Until the mid 1950's, intrinsic safety was used most often when there were no other solutions. This is the case in some mining applications (there is no valve to shut off mother nature's supply of firedamp gas during maintenance). The late 1950's saw intrinsically safe methods being used in many non-mining applications. The results were good and there were no explosions, but each application was extremely engineering intensive. The steps taken by the British and Germans during the 1920's and 1930's look small and slow by today's standards, but each step was tedious and significant.

The 1960's were the "Tower of Babel" for intrinsic safety. Most countries, and often several industries within a country, had developed their own unique standards. In the U.S., the Instrument Society of America (ISA) had seen the value of intrinsic safety as early as 1949. But it was not until 1965 that the ISA published RP 12.2: "Intrinsically Safe and Non-Incendive Electrical Instruments".

The 1970's were the decade of standardization. To list all of the standards, their respective organizations, and their important points would be impossible. The most important in the U.S. was the 1975 revision of the National Fire Protection Association's older NFPA 493-1967. This new revision created a U.S. standard that was similar in content, function, requirements, and format to CENELEC (a multi-country European electrical committee) and IEC (International Electrotechnical Committee). OSHA, third party approval agencies (ETL, FM, and UL), local inspectors, NFPA and the National Electrical Code were now able to assume their typical role and place. Intrinsic safety was now able to fit into every-day businesses.

The 1980's were the decade in which European manufacturers introduced a variety of intrinsically safe equipment in North America.

The petro-chemical industry, a truly international industry, implemented more intrinsically safe equipment for control and instrumentation. The 1990's have seen intrinsic safety used in many other industries as well.

1.3 Glossary

Most of the words used in intrinsic safety are based upon common words. We will present the words here that have a slightly different meaning or added meaning rather than in an appendix in the back of this book. We will not include or try to redefine yet another meaning for "resistor". "Resistor" and most other electrical words take on no unique meaning when used with intrinsic safety.

AMPLIFIER
An input to output device where neither the input circuit nor the output circuits have any wires in common.

ANALOG DEVICE
Any device that is able to produce a continuous signal proportional to a measurable condition. In an intrinsically safe circuit, the analog device, say a 4-20 mA signal, may be in either the hazardous or non-hazardous area.

ASSOCIATED APPARATUS
Apparatus in which the circuits are not necessarily intrinsically safe themselves, but that affect the energy in the intrinsically safe circuits and are relied upon to maintain intrinsic safety. Associated apparatus may be either #1 or #2:

1. Electrical apparatus that has an alternate type of protection for use in the appropriate hazardous (classified) location, or

2. Electrical apparatus not so protected that shall not be used within a hazardous (classified) location.

BARRIER
(see SHUNT DIODE BARRIER)

CAPACITANCE
The ability of any electrical component (including wire) to store an electrical charge.

CONDUCTANCE
The measurement of the ability to transmit electrical current. (The high conductance of the system ground is especially important when shunt diode barriers are used).

COUPLER (also **INDUCTIVE COUPLER**)
This is a unique amplifier in that the input and output circuits share a single power source. Some of the usual functions of an amplifier are also available with couplers, that is changing voltages and currents.

DIGITAL DEVICE
(see DISCRETE DEVICE)

DISCRETE DEVICE
Any device that is able to produce an "OFF/ON', "LOW/HIGH", "NO/YES", or "0/1" data signal. The reason to include it here is to point out that "DISCRETE DEVICE" often connotes "DIGITAL DEVICE". The term "DIGITAL DEVICE" has taken on a broader meaning today because devices such as modems use a string of discrete data.

ENTITY CONCEPT/ENTITY APPROVAL
This is a method to combine individually approved apparatus to form an intrinsically safe circuit. One manufacturer's input device can be wired to another manufacturer's interface device without the two apparatus ever being tested in combination. Comparing parameters assigned to each device assesses the intrinsic safety of the combination.

FAULT
A defect or electrical breakdown of any component, spacing, or insulation that may adversely affect the electrical or thermal characteristics of a circuit.

GROUND

1. The Earth or some other large conducting but isolated body, i.e., the frame of an aircraft in flight.
2. The conducting system connecting an individual part to Earth.

GROUNDING
(in reference to bonding). Article 250-96 of the 1999 National Electrical Code requires bonding of metal raceways, cable trays, cable armor, cable sheath, enclosures, frames, fittings, and other metal non-current-carrying parts that are to serve as grounding conductors, even if a separate grounding conductor is used. The methods and equipment used must be able to maintain a high-integrity, low

impedance ground when used with a circuit using shunt Zener Diode barriers as an interface between the hazardous and non-hazardous area. Other National Electrical Code articles to review include 504-50, 504-60, 250-92, and 250-100.

INDUCTANCE
The ability of any electrical component (including wire) to oppose the current flow and therefore store electrical energy. The practical difference between “CAPACITANCE” and “INDUCTANCE” in an intrinsically safe circuit is minimal. Both store energy, but an INDUCTOR will release energy when a circuit is broken and a CAPACITOR will release energy when the circuit is made.

INDUCTIVE COUPLER (see COUPLER)

INSULATOR
A material that conducts electrons slowly. The importance to intrinsic safety is that air (a spatial distance) is often an insulator.

INTERFACE DEVICE
This term has so many meanings that they are almost meaningless. In intrinsic safety, this apparatus is the device that divides and electrically protects the circuit in the hazardous area from the circuit in the non-hazardous area.

INTRINSICALLY SAFE APPARATUS
Apparatus in which all the circuits are intrinsically safe.

INTRINSICALLY SAFE CIRCUIT
A circuit in which any spark or thermal effect is incapable of causing ignition of a mixture of flammable or combustible material in air under prescribed test conditions. A footnote to this definition is that, in the U.S., the National Electrical Code Articles 500-1 to 500-7 defines the flammable or combustible material. Material that can ignite and burn at near room temperatures is not included or classified.

LOOP CONCEPT/LOOP APPROVAL
(see SYSTEM CONCEPT/ SYSTEM APPROVAL)

NONINCENDIVE CIRCUIT
A circuit in which any spark or thermal effect is incapable of causing ignition of a mixture of flammable or combustible material in air under normal operating conditions. Nonincendive circuits differ from intrinsically safe circuits primarily in that equipment faults are not considered in the analysis of nonincendive circuits.

Two faults are considered in intrinsically safe circuit analysis. Nonincendive circuits may be used in Division 2 or Zone 2 hazardous areas using wiring suitable for similar non-hazardous areas.

NONINCENDIVE EQUIPMENT
Equipment that, under normal operating conditions, has no arcing or sparking contacts or exposed surfaces that operate hotter than the autoignition temperature of a surrounding hazardous atmosphere. The electrical energy used in nonincendive equipment may be sufficient to ignite the hazardous atmosphere, but unless there is a fault, there is no ignition mechanism. Nonincendive equipment is suitable for use in Division 2 or Zone 2 hazardous locations, although the wiring must be protected against damage.

RTD
A device that is used to measure temperature. The resistance changes in relation to a temperature change. It is considered a simple apparatus because it doesn't generate or store significant electrical energy — therefore it is considered safe for the hazardous area without requiring approval.

SIMPLE APPARATUS
A device that can neither generate nor store more than any of the following values:

20 µJoules
1.2 Volts
0.1 Amps
25 mWatts

SHUNT DIODE BARRIER
(also BARRIER) A type of interface device that may use fuses to clear faults, resistors to limit current, Zener diodes to limit excessive voltage or standard diodes for proper polarity. This type of device requires a high-integrity ground connection.

SHORT CIRCUIT PROTECTION
In reference to switching amplifiers: the ability of the solid state output to withstand a direct short without damage to itself.

SWITCHING AMPLIFIER
(also **ISOLATION SWITCHING AMPLIFIER** and **TRANSFORMER ISOLATED BARRIER**, switching type). These are many words used to describe an isolated interface device that is used for discrete signals. These interfaces actually use many of the same components that are used in shunt diode barriers. However, they include an isolating transformer and often an optical amplifier to achieve

isolation between the hazardous-area circuit, the non-hazardous-area circuit, and the power source. A high-integrity ground is not required.

SYSTEM CONCEPT/ SYSTEM APPROVAL
A method of assessing the intrinsic safety of a circuit in which all of the interconnected devices are examined together as a complete system.

THERMOCOUPLE
A voltage-producing device that produces a very small voltage and current proportional to temperature. This device is safe for the hazardous area and is considered a simple apparatus.

THERMISTOR
A special type of RTD that has a relatively large resistance change at a particular temperature.

TRANSFORMER ISOLATED BARRIER
(see SWITCHING AMPLIFIER)

ZENER DIODE
A solid state device that blocks a current flow in reverse bias until a critical voltage is reached and then is able to conduct current in this reverse bias mode without damage to itself.

Notes:

CHAPTER 2
The Hazardous (Classified) Location

2.1 Location

Articles 500 through 505 of the National Electrical Code cover the requirements for electrical equipment and wiring for all voltages in locations where fire or explosion hazards may exist due to flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers or flyings. Explosives such as gun powder or dynamite, or pyrophoric materials are not covered. An example of a pyrophoric is pure sodium. When this metal is exposed to moist air at near room temperature, it will burn violently. The properties of the flammable or explosive material in an area do not change whether the area is in France or Texas, or whether the electrical wiring is protected by purged and pressurized enclosures, explosionproof enclosures, or is intrinsically safe. Physical and chemical properties such as ignition temperature are not the jurisdiction of man.

2.2 What Constitutes A Hazardous (Classified) Location?

Here is how Article 500 of the National Electrical Code classifies hazardous location:

Table 2.2a: *Class*

Class	Type of Fuel
Class I	Gases & Vapor
Class II	Combustible Dust
Class III	Fibers

Table 2.2b: *Division*

Division	Possibility of fuel being present
Division 1	Present or likely to be present in normal operation
Division 2	Not present in normal operation, could be present in abnormal operation

Table 2.2c: *Group*

Group	Specific Type of Fuel
Group A	Acetylene
Group B	Hydrogen
Group C	Acetaldehyde, Ethylene, Methyl Ether
Group D	Acetone, Gasoline, Methanol, Propane
Group E	Metal Dust
Group F	Carbon Dust
Group G	Grain Dust

Table 2.2d: Temperature Identification Codes (max.surface operation temperature of apparatus at marked ambient)

T1	=	450 °C	T3A	=	180 °C
T2	=	300 °C	T3B	=	165 °C
T2A	=	280 °C	T3C	=	160 °C
T2B	=	260 °C	T4	=	135 °C
T2C	=	230 °C	T4A	=	120 °C
T2D	=	215 °C	T5	=	100 °C
T3	=	200 °C	T6	=	85 °C

2.3 Class

In the United States, we use the term CLASS to divide the types of fuel into families. Unfortunately, the terms Class I, II and III have taken on a street meaning that they should not. An explosion that might occur in a Class I area should not be thought of as being more dangerous, more damaging, or more probable than an explosion in a Class II area. The mangled and melted steel after a gas explosion isn't much different from the fractured and pulverized reinforced concrete after a grain dust explosion.

The original concept of **CLASS** was more meaningful than it is today.

Class I: Gas was defined as a molecule or a compound (multiple different molecules) or a fuel mixed with oxygen molecules.

Class II: Dust was defined as a mixture of compounds and oxygen molecules.

Class III: Fibers and lint were defined as particles bigger than dust.

Class I, Class II and Class III are handled in a similar manner by today's technology: intrinsically safe, purged and pressurized, and immersion methods. All these methods are designed to prevent even the smallest explosion. Chapter 3: METHODS AND EQUIPMENT FOR SAFE INSTALLATIONS will talk more about the differences.

2.4 Division

Here in the United States, we often physically divide a hazardous area into two parts. The line that divides these two parts is based upon the probability that a dangerous fuel-to-air mixture will occur. Here's an example:

Division 1: The inside of a gasoline storage tank.

Division 2: A storage room for oil based paints (a few times a year maybe a can is opened to verify the color, then covered and sealed again).

For the examples, we picked two opposite and obvious extremes. The National Electrical Code gives the following definitions:

Class I, Division 1 locations are areas:

1. in which ignitable concentrations of flammable gases or vapors can exist under normal operating conditions;
2. in which ignitable concentrations of such gases or vapors may exist frequently because of repair or maintenance operations or because of leakage;
3. in which breakdown or faulty operation of equipment or processes might release ignitable concentrations of flammable gases or vapors, and might also cause simultaneous failure of electric equipment in such a way as to directly cause the electrical equipment to become a source of ignition.

Class I, Division 2 locations are areas:

1. in which volatile flammable liquids or flammable gases are handled, processed, or used, but in which the liquids, vapors or gases will normally be confined within closed containers or closed systems from which they can escape only in case of accidental rupture or breakdown of such containers or systems, or in case of abnormal operation of equipment;
2. in which ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and which might become hazardous through failure or abnormal operation of the ventilating equipment;
3. that are adjacent to a Class I, Division 1 location, and to which ignitable concentrations of gases or vapors might occasionally be communicated unless such communication is prevented by positive-pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided.

Points 2 and 3 of Class I, Division 2 above both deal with positive ventilation. The difference is the last part of point 3, “effective safe-guards against ventilation failures are provided”. If effective safeguards are incorporated, then the area is not classified. It is non-hazardous. If there is positive ventilation, but without an effective safeguard against ventilation failure, then the location is a Division 2 area.

Class II, Division 1 locations are areas:

1. in which combustible dust is in the air under normal operating conditions in quantities sufficient to produce explosive or ignitable mixtures;

2. where mechanical failure or abnormal operation of machinery or equipment might cause such explosive or ignitable mixtures to be produced, and might also provide a source of ignition through simultaneous failure of electric equipment, operation of protection devices, or from other causes;

3. in which combustible dusts of an electrically conductive nature may be present in hazardous quantities.

Class II, Division 2 locations are areas:
where combustible dust is not normally in the air in quantities sufficient to produce explosive or ignitable mixtures, and dust accumulations are normally insufficient to interfere with the safe dissipation of heat from electrical equipment, or may be ignitable by abnormal operation or failure of electrical equipment.

Class III, Division 1 locations are areas:
in which easily ignitable fibers or materials producing combustible flyings are handled, manufactured, or used.

Class III, Division 2 locations are areas:
in which easily ignitable fibers are stored or handled other than in the process of manufacture.

The Class/Division text is taken from the National Electrical Code. This was done because it is the most subjective topic concerning hazardous areas. The determination of the Division requires understanding, common sense, and experience. If in doubt, Division 1 equipment can be used in Division 2 areas, **IF** the Class and Group ratings are the same. This is per the 1999 National Electrical Code, Article 500-5(a),paragraph 3.

2.5 Group

The GROUP may be the most meaningful nomenclature of the hazardous area terms. A group identifies materials with similar explosion properties. For Class I materials, the determination of the group is based heavily upon the requirements of explosionproof enclosure technology, i.e. maximum explosion pressure, maximum safe clearance between parts of a clamped joint in an enclosure, and ignition energy.

For Class II materials, the determination is based upon the tightness of the joints of assembly and shaft openings (to prevent entrance of dust in the dust-ignitionproof enclosure), the blanketing effect of layers of dust on the equipment that may cause overheating, electrical conductivity of the dust, and the ignition temperature of the dust.

Class III materials, lint shavings and fibers, are not broken down into groups. Tables 2.5a and 2.5b list the materials that are considered representative of the Groups and Classes.

Table 2.5a: *Class I Materials.*

Group	Representative Material	Autoignition Temperature	Ignition Energy Milliwatt/ Seconds
Group A	Acetylene	305 °C	0.017
Group B	Hydrogen	520 °C	0.017
Group C	Ethylene	450 °C	0.08
Group D	Methane	630 °C	0.3

Table 2.5b: Class II Materials

Group	Representative Material	Minimum Cloud or Layer Ignition Temp.	Ignition Energy Milliwatt/ Seconds
Group E	Aluminum Dust	550 °C	15.0
Group F	Hard Coal Kentucky Bituminous	180 °C	60.0
Group G	Wheat	220 °C	240.0

2.6 Temperature Identification

Unfortunately, materials refuse to neatly arrange themselves by explosion pressure, maximum safe gap, ignition energy and ignition temperature. There are many materials with a high ignition temperature and a low ignition energy or vice versa. As materials are grouped largely by ignition energy, ignition temperature must be considered independently.

Prior to the 1971 National Electrical Code, the minimum ignition temperature of a Class I Group was considered the limit for all materials in the group (see Table 2.6).

However, this was overly restrictive and new gases continually caused a need for revision of the limits. A new system was needed. In 1971, temperature identification numbers were introduced (see Table 2.2d, page 14). Today, unless the maximum operating temperature of the equipment at its maximum marked ambient temperature is less than the most critical temperature rating T6 85°C, the equipment must be marked with the appropriate temperature identification code. This enables the user to ensure that specific equipment will not ignite a specific material due to hot surfaces as well as to sparks. Class II Group temperatures did not change like the Class I Group temperatures.

Table 2.6a: Class I Group Temperature prior to 1971

Group	°C
Group A	280 °C
Group B	280 °C
Group C	180 °C
Group D	280 °C

(For individual Class I material ratings, see Table 2.2d., page 14)

Table 2.6b: Class II Group Temperature Ratings

Equipment that is NOT Subject to Overloading		Equipment (such as Motors or Power Transformers) that MAY be Overloaded	
Group	Temperature	Normal Operation Temperature	Abnormal Operation Temperature
Group E	200 °C	200 °C	200 °C
Group F	200 °C	150 °C	200 °C
Group G	165 °C	120 °C	165 °C

2.7 Alternative Approach

A problem with the classification system described in Article 500 of the National Electrical Code is that most of the rest of the world outside of North America uses a different system. Article 505, adopted in the 1996 Code cycle, offers an alternative method of area classification that is more in line with international standards.

This method, at present, covers only Class I gas or vapor atmospheres. Class II (dust) and Class III (fibers or flyings) atmospheres are not covered.

1. Zones:

Areas classified per Article 505 are divided into three Zones based on the probability of an ignitable concentration being present, rather than into two Divisions as per Article 500. Areas that would be classified Division 1 are further divided into Zone 0 and Zone 1. A Zone 0 area is more likely to contain an ignitable atmosphere than Zone 1 area. Division 2 and Zone 2 areas are essentially equivalent.

Table 2.7a: *Zones (probability of hazardous atmosphere)*

Zone 0	Ignitible concentrations are present continuously or for long periods.
Zone 1	Ignitible concentrations are likely to exist for short periods under normal conditions, as a result of repair or maintenance operations, or due to leakage.
Zone 2	Ignitible concentrations are not likely to exist under normal conditions, but could be present as a result of an accident or unusual operating conditions.

2. Gas Groups:

The specific flammable materials are divided into groups in similar fashion to Article 500 classification. However, the group names are different and actually backwards from the familiar system, something that seems to happen when concepts cross the Atlantic.

Table 2.7b: *Gas Groups (specific type of atmosphere)*

Group IIC	Acetylene and Hydrogen (Equivalent to Class I, Groups A and B)
Group IIB	Acetaldehyde, Ethylene (Equivalent to Class I, Group C)
Group IIA	Acetone, Ammonia, Ethyl Alcohol, Gasoline, Methane, Propane (Equivalent to Class I, Group D)

3. Temperature Codes:

The usage of temperature codes is nearly identical to that in Article 500 except that only the basic 2-digit codes are used. The finer 3-digit codes, i.e. T2A, T2B, etc., are not included in Article 505.

Table 2.7c: Temperature Codes (maximum surface temperature of the apparatus).

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

2.8 Effective Differences

Zone classification, in addition to simply providing a greater degree of international harmonization, also provides some significant real advantages. For example, intrinsically safe equipment that is intended for use only in Zone 1 can be examined considering only one equipment fault rather than the two faults that are considered in Zone 0 and Division 1 equipment examinations. This can result in less expensive, more functional equipment. Also, a number of protection techniques that are not traditionally considered appropriate for Zone 0 or the most hazardous Division 1 applications are now enabled for Zone 1 applications. These include:

- Increased safety
- Encapsulation
- Hermetic sealing
- Powder filling
- Oil immersion

Standards for Zone 1 applications of these techniques are in preparation at this writing in response to the adoption of Article 505. Each of these protection methods, particularly increased safety, will be a significant new tool for installations of electrical equipment in hazardous locations.

3.1 Overview of Hazardous Location Protection Techniques

In this chapter, we will explain how the four primary hazardous-area safety technologies can be combined to give the best solution.

1. **Explosionproof Enclosures**
   This method is designed to meet safety requirements by containing, controlling, cooling and then venting any possible explosion. This type of equipment is used in Class I hazardous areas. Usage includes lighting fixtures, motors, disconnects, and line voltage controls. Typically, this equipment either uses or distributes full power. In Class II and III hazardous areas, dust-ignitionproof enclosures are used to keep the hazardous material from the ignition source. The dust-ignitionproof enclosures are often made of the same material as the explosionproof enclosures. Some of the enclosures carry multiple Class ratings, i.e. Class I, II, III, Division 1, Groups C, D, E, F, and G.

2. **Purged And Pressurized Enclosures**
   This method can create one or more of the following:

   - **Z-type purge:** A non-hazardous enclosure interior within a Division 2 area.
   - **Y-type purge:** A Division 2 enclosure interior within a Division 1 area.
   - **X-type purge:** A non-hazardous enclosure interior within a Division 1 area.

A protective gas, usually air, is supplied to the room or enclosure. In Class I applications, it is intended to reduce the concentration of flammable gases to acceptable levels. In Class II applications, the positive pressure prevents entry of dusts. This method is often used in control rooms with computer equipment or special motors and drives. Also, nitrogen is sometimes used as a source of clean protective gas for instrument work.

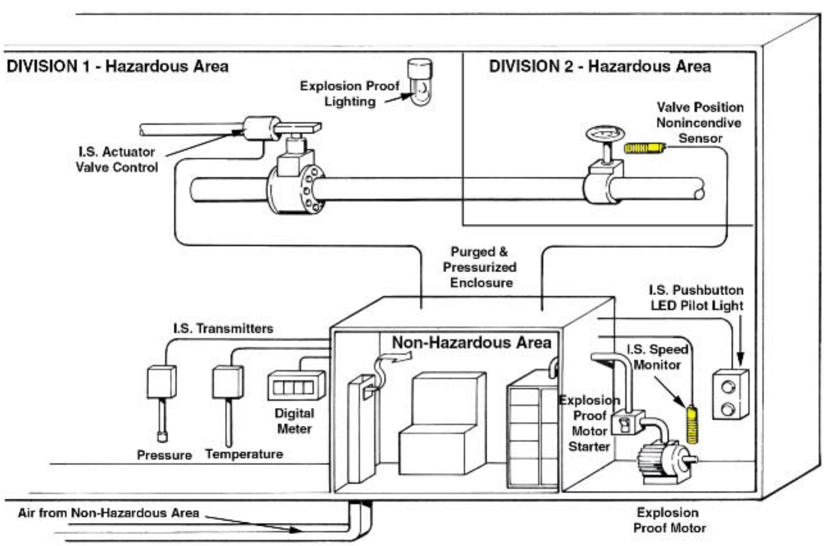
3. **Intrinsically Safe Systems**
   This method limits the thermal and electrical energy to the hazardous area to prevent ignition. Typical uses include instrumentation, sensors, position and speed monitoring, and pilot duty controls. These systems use standard enclosures and eliminate most of the cable sealing.

4. **Nonincendive Equipment and Circuits**
   Nonincendive methods provide a means to use standard equipment in less hazardous Division 2 locations. Heavy enclosures, a protective gas supply, or intrinsic safety barriers are not required. Nonincendive equipment must not have normally arcing contacts or produce excessive heat. The energy is not limited, so wiring method restrictions apply.

   In nonincendive circuits, the energy is limited as in intrinsic safety, but only normal operating conditions are considered. Wiring methods are not restricted.

By integrating all four of these methods, the featured capabilities of each can be combined to utilize what each one does best. The drawing in Figure 3.1 below shows how each method can be integrated.

Figure 3.1: *The Hazardous Location Protection Technique*



3.2 Explosionproof Enclosures

This method is used in Class I, Division 1 areas for all equipment and Class I, Division 2 areas that contain equipment that is arcing, i.e. motor starter. Made of a rigid, non-combustible material, this enclosure is not designed to keep out vapors. In fact, it would be impossible to do so.

To give you an idea of the size of a molecule of vapor, we have created a relative size comparison. This comparison relates the size of a molecule to the permitted air gap of flange-to-flange explosionproof enclosures.

- .0015 inches is the maximum flange-to-flange air gap permitted on an explosionproof enclosure.
- .000,000,34 inches is the X, Y, Z dimension of the average molecule of methane as a gas at 20 degrees C and at 1 atmosphere (sea level).
- .000,000,008,1 inches is the X, Y, Z dimension of a methane molecule itself.

If the methane molecule were equated to a 70 foot diameter hot air balloon then:

- The .0015 inch flange-to-flange air gap would be proportional to 2,454 miles. This is almost equal to the Canadian and United States Western seaboard.
- That 70-ft. balloon obviously could get into the 2,454-mile coastline every once in a while. The methane molecules will also get into the enclosure.

This method does not prevent an internal explosion but controls the explosion. If an explosion occurs within the enclosure, the pressure can deform the flange-to-flange joint. But the gases from the explosion are cooled as they pass through the flange. By the time hot gases reach the outside, they are cooled to the point where they will not ignite any potentially explosive fuel-to-air mixture.

An alternate method is to use a threaded joint. The concept is the same; the hot gases from an interior explosion must travel a specific distance before they are cool enough to be safe.

Several manufacturers in the United States have produced functional explosionproof enclosures that do the job they were designed for with a healthy safety margin. This method does require a certain degree of attention to detail during installation and repair. The cover of the explosionproof enclosure must be bolted to the box per the manufacturer's specifications. Many manufacturers recommend that the flange be given a light coating of oil to prevent corrosion of the critical machined flange-to-flange joint. Care also must be taken not to cross

Figure 3.2a: *Explosionproof Enclosure-Threaded Joint*

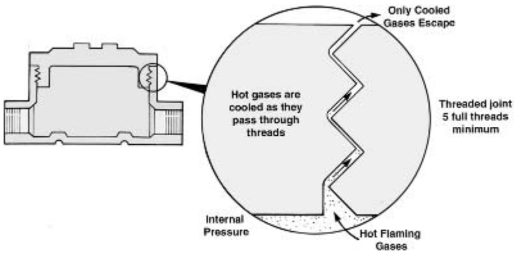


Figure 3.2b: *Explosionproof Enclosure - Machined Flange Joint*

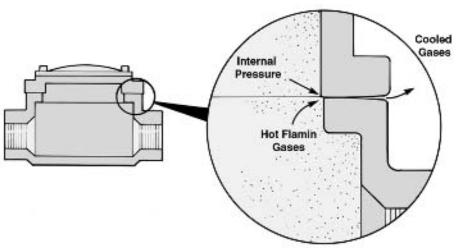


Figure 3.2c: *Normal Flange Joint*

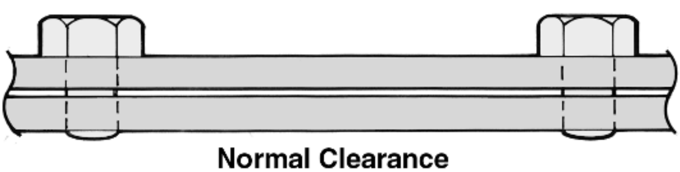
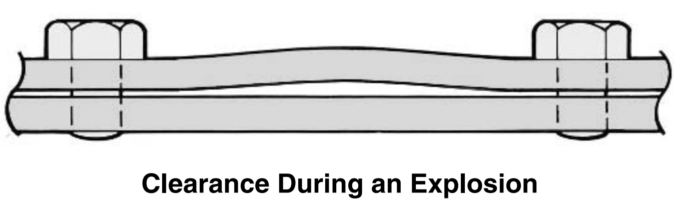


Figure 3.2d: *Flange Joint Deformed During an Explosion.*



thread the threaded-type joint. Older and some larger enclosures today require that a specific cover be married to a specific box for life. These older and larger enclosures were measured for the maximum permitted .0015 inch air gap mentioned above as the cover and box were created together.

There is no feasible alternate to explosionproof enclosures when a motor, disconnect, motor starter, circuit breaker, or lighting must be located in a Class I area. With good installation and maintenance, this method to distribute, control, or use power is quite safe.

3.3 Dust-Ignitionproof Enclosures

Many types of dust will explode at relatively low temperatures. The design of this type of equipment must be able to dissipate heat if the equipment is energy using. It must also keep out dust particles. The resultant enclosure for Class II, Division 1 is very similar to Class I, Division 1, but for different reasons: one is designed to control an explosion, the other is designed to prevent an explosion.

Installation and maintenance are important to the system's total safety capabilities just as it was with Class I explosionproof enclosures. Good housekeeping is also important. The manufacturers of this equipment know that some dust will accumulate on the equipment, and when too much accumulates, it will fall off and onto the floor. But if the floor is not cleaned, the motor or other equipment will eventually become buried in dust, which acts like an insulating blanket. It does not take a degree in thermodynamics to know that if the temperature keeps rising, eventually there will be a fire.

For motors, lighting and disconnects, this is the best method for safety and the only feasible method.

3.4 Purged And Pressurized Systems

The National Electrical Code does not go into much detail on purged and pressurized systems, because the Code is concerned with electrical wiring methods and practices. Another NFPA document, NFPA 496, covers these systems. In grain elevators, a room sometimes will be made with the same reinforced concrete that is used to make the tall silos. These rooms may actually be the bottom 10 feet of a silo with a reinforced concrete ceiling and 100 feet of stored grain above it. The construction of these rooms is a structural problem.

The ventilation is a mechanical problem. The electrical problem is to detect quickly the loss of ventilation and then kill all power to the room.

If the above happens, then this is considered a type X purged and pressurized system. It is a non-hazardous area within a hazardous area. This is an excellent way to take advantage of the power of today's industrial computers, the features of the modern motor-control centers, and the convenience of having lighting and power panel boards in the same room in a NEMA 1 construction.

Another type of purged and pressurized system is the Z type. It would typically have an alarm system to warn of a ventilation loss, but would not automatically shut down the power to the room. Therefore, the interior of the room would be considered a Division 2 location.

Each of the types of purged and pressurized systems can apply to smaller enclosures as well as a room. A purged and pressurized system sometimes is the only feasible way to handle certain equipment such as large DC drive motors or computer monitors. Another advantage is that the clean air can be conditioned (cooled and dehumidified) to extend the life of the equipment.

3.5 Intrinsic Safety

Chapters 4 and 5 will provide details on this method. In intrinsically safe systems, the thermal and electrical energy is limited to the point that ignition is not possible. You cannot power motors or provide even minimal lighting with the allowed energy. But, the inputs from dry contacts, photoelectric, inductive and capacitive sensors, RTDs, thermocouples, and most measurements that can be defined by an electrical signal such as 4-20 mA or 0-10 VDC can use the benefits of intrinsic safety. The outputs are more limited, but LED pilot lights and certain small actuators are common.

Sometimes, troubleshooting control circuits connected to a PLC is nearly impossible to do cold. Intrinsically safe circuits can be worked on hot. The maintenance person can open a NEMA 1, NEMA 4, or NEMA 12 enclosure in the hazardous area that contains intrinsically safe equipment. Typically, the voltage is less than 24 VDC and may be tested live. If a loose hot wire goes to ground, nothing happens. If the probe on the VOM slips and causes a short, nothing happens. If the VOM is set to ohms rather than volts, at least there is a chance to change the fuse.

3.6 Nonincendive Methods

Chapter 6 will provide details of nonincendive methods. These methods are useful in similar applications to intrinsic safety. Power switching equipment and heavy current users are not good candidates for this method, although some applications that cannot be intrinsically safe can be nonincendive. Examples are line-powered instruments and sensors. These often can fit the nonincendive equipment concept with only a little attention to detail in their design.

The real usefulness of nonincendive methods depends on realistic area classification. The reality of most processing facilities is large Division 2 areas surrounding smaller Division 1 areas. However, Division 1 methods are often used throughout for flexibility. It is extremely difficult to change a rigid metal conduit system with poured seals if the Division boundaries change. It's largely a tear-it-out-start-over proposition. However, low-power solid-state technology has enabled many more measurement and control functions to be intrinsically safe or nonincendive in recent years. These systems don't require rigid metal conduit, and do away with most sealing even if conduit is used for mechanical protection. There are now very good reasons to use the flexible and inexpensive Division 2 methods in Division 2 areas.

3.7 No Single Solution

All four methods function together to provide a safe and functional solution. Each method has its place and can do certain things better than the other methods. Used appropriately, a system can be constructed to serve virtually any need that is cost effective, and above all else, safe.

Notes:

4.1 An Application

Instead of describing a generic application that is trivial by its universal depiction of reality, we will be specific from the start (Figure 4.1, page 31). This atmosphere will have hexane fumes, as well as corrosive fumes.

A) An electric motor and pump are located in a hazardous area. The pump transfers a hexane base liquid from a storage tank to a blending tank.

B) A pneumatic valve, also in the hazardous area between the storage tank and the pump, remains closed except during the transfer.

C) The pump is started from a batch sequencer program in the PLC.

D) The pump starts with the valve closed.

E) After the auxiliary contacts on the pump motor contactor pull in, the electric solenoid valve opens, allowing the compressed air from the plant's air system to drive the valve to an open position.

F) The valve must open completely in 5 seconds after the pump starts, or an alarm is sounded.

We will not go into the stopping of the pump, closing of the valve or an emergency shut down, since this discussion is on intrinsic safety, not ladder logic programming.

4.2 A Typical Installation

A typical installation would have the PLC in a NEMA 1 or 12 enclosure, shown in Figure 4.2 (page 33). Below the PLC would be the protective devices (fuses etc.) and wire terminal blocks for non-intrinsically safe circuits. At the bottom would be the intrinsically safe interface devices - amplifier or barrier types. The intrinsically safe circuits would exit at the bottom of the enclosure. No other wiring except intrinsically safe circuits would be allowed in this area.

Although 30 Volt and less intrinsically safe circuits can be installed without the typical explosionproof seals and conduit, often some form of mechanical protection is used.

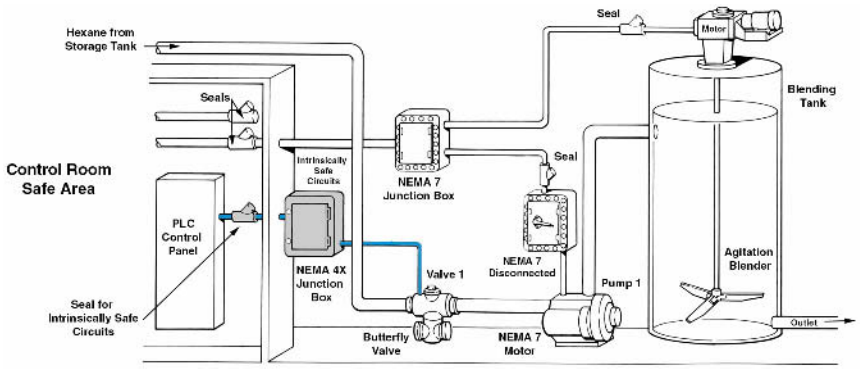
If the mechanical protection is well ventilated, such as a perforated cable tray, no seals are required when transitioning a Division boundary:

- Safe area to Division 2
- Division 2 to Division 1

If a conduit is used for protection, then at some point between the hazardous area and the PLC cabinet, the conduit must be sealed in accordance with Article 500 of the National Electrical Code. This seal keeps the hazardous material from entering the PLC cabinet that may have 120 VAC.

Once in a continuous, uniform hazardous area, no more seals, special enclosures, or conduit are required to maintain the safety of the circuit, as long as it stays separated from non-hazardous circuits. Some people will use flex, plastic conduit, or open cable tray for physical or chemical protection. Corrosion-resistant NEMA 4X conduit and enclosures are easy to use. They will last in some very corrosive and hazardous atmospheres. Intrinsically safe circuits should be identified to remind personnel that special care is required. In enclosures and junctions, the terminals of intrinsically safe circuits should be clearly identified. Conduits, cable trays and open wiring should be identified with permanent labels that are visible after installation, spaced no further than 25 feet apart. An exception to this requirement is that the color blue may be used to identify intrinsically safe wiring, cable trays, boxes, etc., if blue isn't used for other purposes.

Figure 4.1: *(Example 1)*



Example 1 (Figure 4.1) shows the following:

- The Hazardous Area Division 1, Division 2, and the safe area.
- In the safe area is the control room that houses the PLC, motor control center, lighting panel boards, and switch-gear.
- The motor and disconnect are located in the Division 1 area. Both are explosionproof and must be at least Class I, Division 1, Group D, and temperature T2D.
- Multiple seals are shown for the pump motor power circuit back to the control room and motor-control center.
- One seal is shown in the control room for the intrinsically safe conduit just before it penetrates the wall. The conduit goes through the control room wall and then terminates in a NEMA 4X junction box. The balance of the intrinsically safe circuits are in lightweight, easy-to-install plastic conduit and enclosures. The enclosure and conduit provide mechanical protection, are not easily corroded and can be washed down.

There are four intrinsically safe circuits in this drawing:

- The open position of the valve (sensor).
- The closed position of the valve (sensor).
- Open valve (solenoid).
- Closed valve (solenoid).

Figure 4.2 (page 33) shows what a typical control cabinet may look like. The intrinsically safe interface devices are located at the bottom of the cabinet. The terminals for the intrinsically safe circuits going into the hazardous location is shown at the bottom. Two inches (50 mm) must separate this wiring from any non-intrinsically safe circuits.

A generic PLC program may look something like Figure 4.3 (page 34). There is no revelation to be found. In fact, intrinsically safe circuits DO NOT REQUIRE “special engineering around a problem”. Once through the first seal, the intrinsically safe circuits may be handled the same way as a standard 24 VDC circuit. For the intrinsically safe circuits, there is no difference between this blending tank of explosive hexane or a blending tank for chicken noodle soup. Therein lies the great benefit of intrinsic safety.

Figure 4.2 *Example 1*

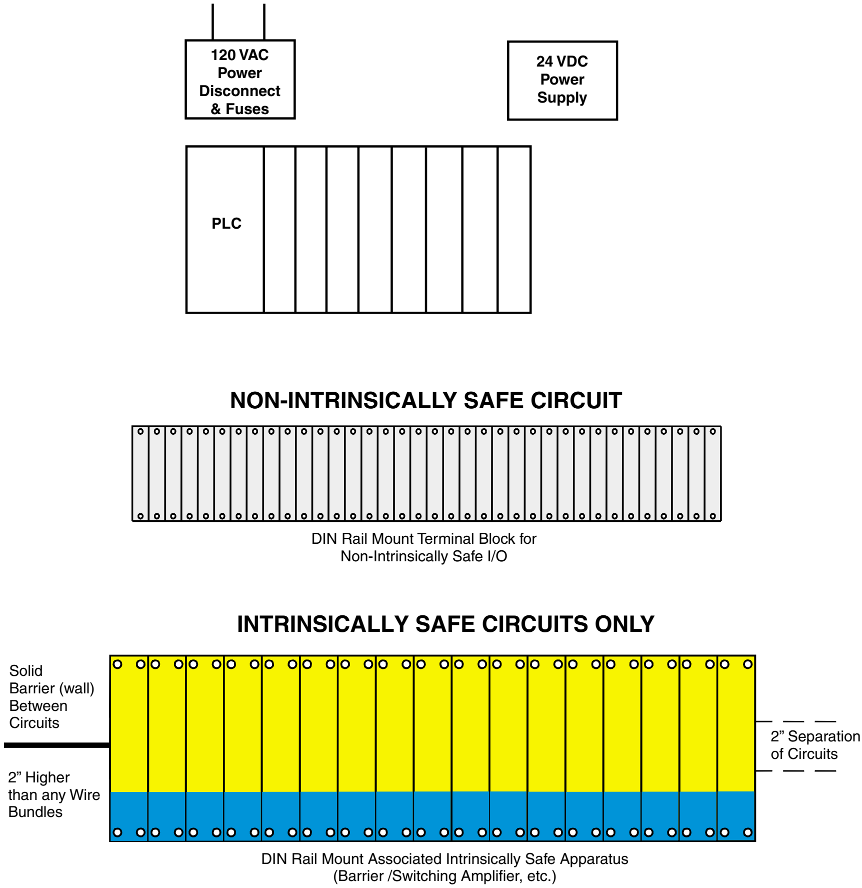


Figure 4.3 *Example 1*

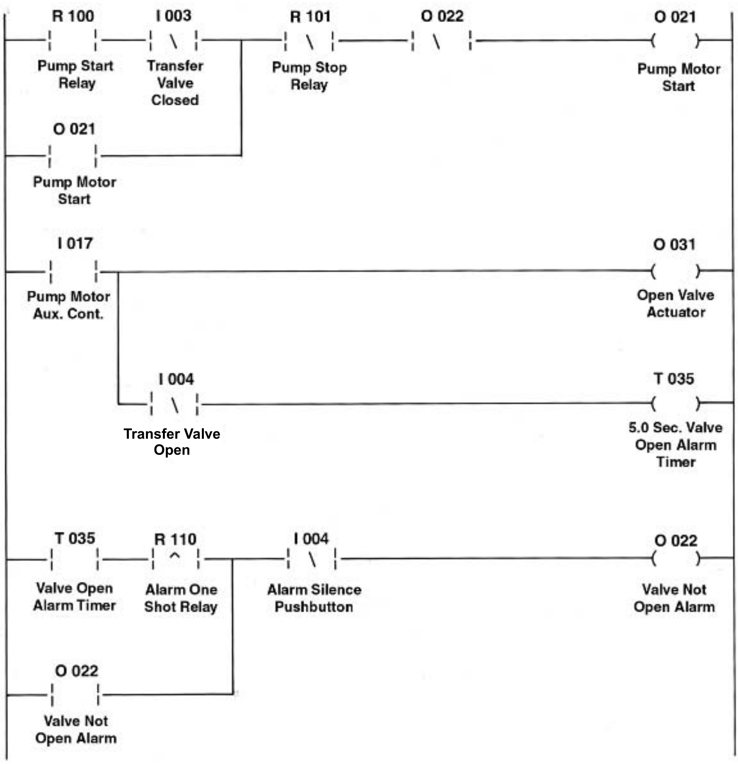
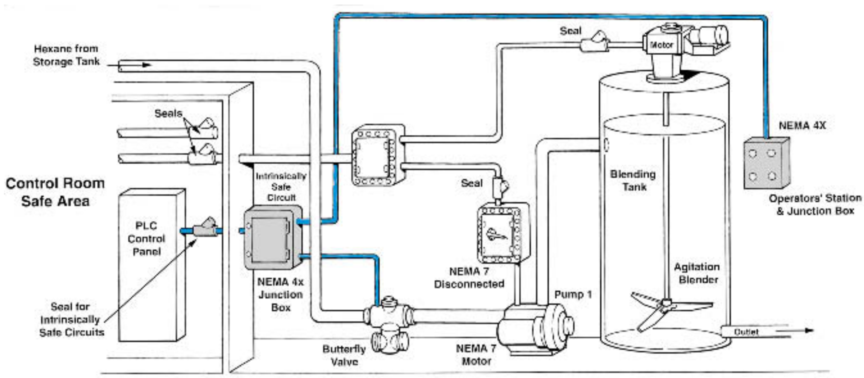


Figure 4.4 *Example 2*



Example 2 (Figure 4.4) shows the following:

- A local operator control station has been added to the hazardous area.
- The enclosure for the control station is NEMA 4X because of the corrosive atmosphere. In other atmospheres, NEMA 12, NEMA 3R, or even NEMA 1 could be used. The control station (shown in detail in Figure 4.5, page 36) would also use the NEMA 4X pushbuttons and selector switches, now available from several manufacturers. The pushbuttons and selector switches do not require a third party approval since they do not generate or store electrical energy.
- A major problem in the past with low voltage and low current has been corrosion on the contact points and, eventually, the loss of the signal. The major pushbutton control manufacturers have “Logic Level” contact blocks. These newer contact blocks are either sealed or use inert metals such as palladium.
- Most lighting circuits can take advantage of intrinsically safe circuits. A two-position maintained selector switch with one contact block can be used to send a signal from the hazardous area to turn on or turn off lighting. If isolation-type interfaces are used, relay outputs are available. The relay output may be used if the load is small or used as a pilot device to operate a lighting contactor. The power for the lighting must go back into the hazardous area to the lighting fixtures and must be wired per Article 500 of the National Electrical Code; but the ON/OFF switch, the

Figure 4.5

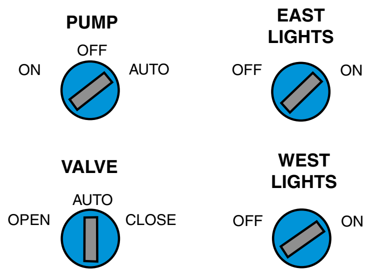


Figure 4.6 *Example 3*

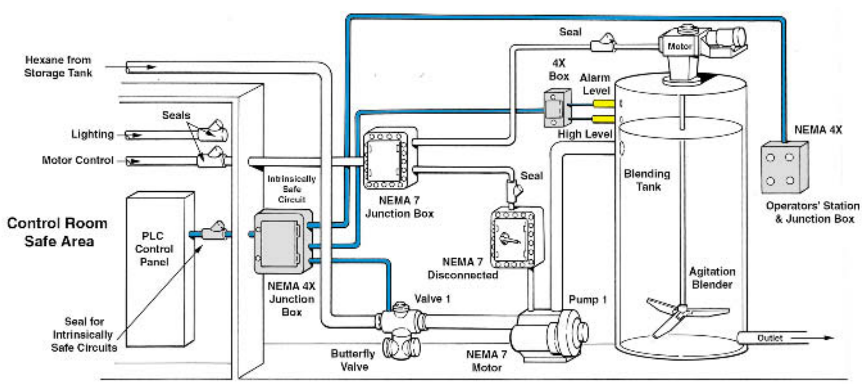
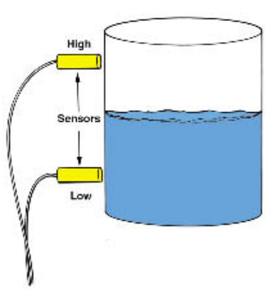


Figure 4.7



lighting contactor, and circuit breaker can be maintained in a normal fashion.

Example 3 (Figure 4.6) shows the following:

- Level control has been added to the blending tank. An alternate example of level control is shown in Figure 4.7 (page 36). A level is maintained between a low and high set point with two sensors. **TURCK's MS41-22Ex0-R** isolation amplifier and an intrinsically safe sensor can look through a low dielectric window or a low dielectric tank wall and see a high dielectric liquid.
- The **MS41-22Ex0-R** logic-switching amplifier does not require additional hardware or software. Its relays can turn on and off the pump starter coil.
- The **MS41-22Ex0-R** can also be used as a lock-out control (Figure 4.8, page 38) to prohibit pumping possible contaminating liquid into the tank without supervisory control. Details of the control wiring are shown in **TURCK's** Automation Interface and Logic Control catalog.

For Example 3 (Figure 4.6):

- A "high level" and an "alarm level" have been added. Two intrinsically safe capacitive sensors are used to see the hexane level through a low-dielectric sight glass. The potentiometers on the capacitive sensors have been adjusted to tune out the window and see the hexane. The high-level sensor is wired back to the PLC via an intrinsically safe interface module. The alarm level sensor is wired back to a switching amplifier that has a relay output. This relay is placed in series with the pump-motor starter coil circuit.
- Most switching amplifiers can be programmed with a jumper or a DIP switch to have a N.O. (normally open) output or a N.C. (normally closed) output. The newer switching amplifiers also have an input-monitoring feature to detect either a shorted or open input. In this example, the switching amplifier can be set up to open the relay under the following conditions:
  - Failed power source to the switching amplifier.
  - Open or shorted intrinsically safe input circuit.
  - The alarm level sensor sees the hexane.

Figure 4.8

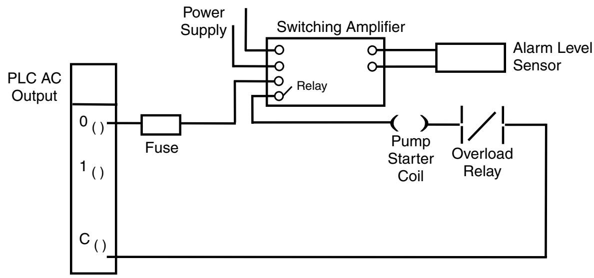


Figure 4.9 *Example 4*

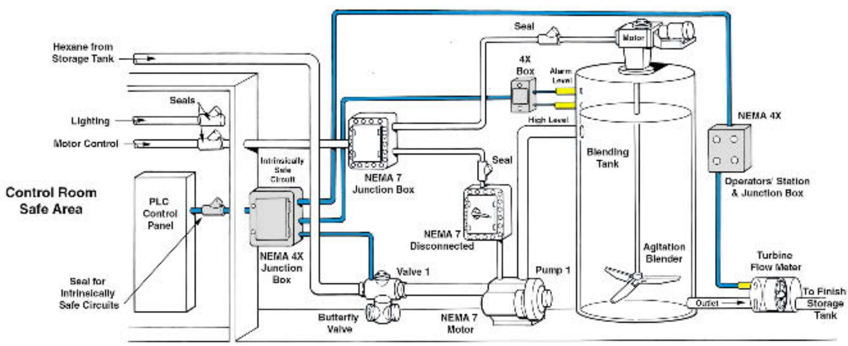
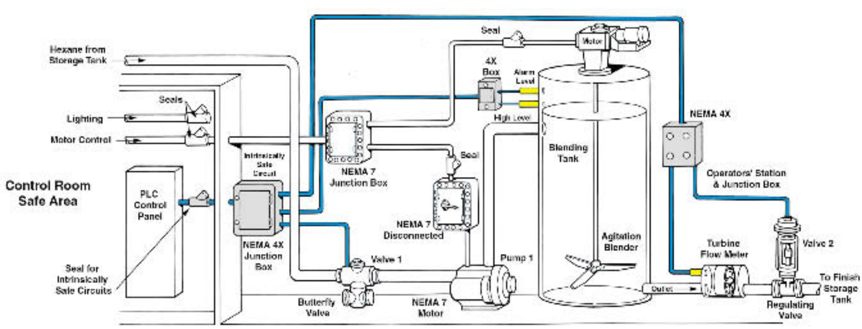


Figure 4.10 *Example 5*



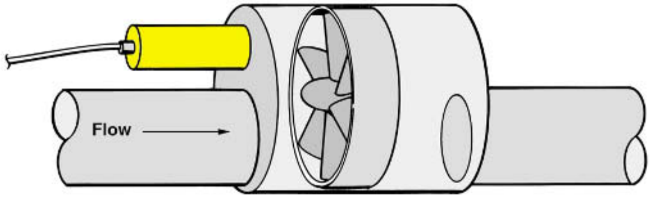
Example 4 (Figure 4.9) shows the following:

- A turbine-type flow monitor has been added to an outlet pipe. There are many ways to reliably measure and monitor flow. This type could produce a pulse output for each blade of the turbine. A sensor is seeing each blade as the fluid flows by. This output could go back to a high speed input on the PLC or to a stand-alone controller/monitor. Figure 4.11 shows how the sensor sees the blades in a turbine.

Example 5 (Figure 4.10) shows the following:

- A regulating valve has been added to the application. This valve is similar to the open/close valve in the base example except that this valve is not limited to only opened or only closed. This valve can modulate to vary the output, or maintain a constant flow rate as other variables change. This valve closes the loop started by the turbine flow meter in Figure 4.9, Example 4 (page 38). The valve, the solenoid, and the PLC hardware and software are now at premium cost compared to the open/close valve. But the intrinsically safe interface module and wiring costs are the same.

Figure 4.11



We could go on and on adding more sophistication to this application. Instruments to monitor pressure, temperature, weight, and to detect many chemicals could be added to the application. Control that was excessively expensive, difficult to install, or troublesome to maintain is now only a slight premium over non-hazardous area control using intrinsically safe equipment. The next chapter will look at methods to handle discrete and analog circuits.

CHAPTER 5
Intrinsically Safe Equipment

5.1 Ignition Curves

An associated intrinsically safe apparatus is the interface module that limits the higher control-room current and voltage to a low current and voltage that cannot cause a fire or explosion in the hazardous area. But what is a dangerous amount of electrical energy? Certainly too much voltage and current would cause a sufficient spark to ignite some combustibles. Section 2 of this tutorial described the fuel. In this section, we'll discuss the relationship of a spark and heat to the fuel. Figure 5.1 (page 41) shows the voltage-to-current relationship for Class I, Class II, Division 1, Groups A through G.

This log-log graph shows current on the vertical axis and voltage on the horizontal axis. To be safe, the voltage and the current must be to the left and below the Group curve that applies to the intended atmosphere. Since the curve represents possible ignition, a safety factor of 1.5 is applied to the allowed energy. For Groups A & B, the curve is the same.

Intrinsic safety deals with preventing an explosion, not containing an explosion, as is the case with explosionproof equipment. For prevention, the two Groups A & B are the same. Hydrogen and acetylene have the same ignition energy, differing only in their post-ignition properties. Group C is as usual and the only exception to Group D is the gas, methane. Methane is a very balanced ionic molecule that, due to its ionic nature, is relatively inert unless in the presence of more strongly charged compounds such as air. Although it takes a substantial spark to ignite methane, it is characteristic of some other Group D gases in the presence of an open flame.

The graph is for circuits containing aluminum, cadmium, magnesium, and/or zinc. These four metals produce a high-temperature incendiary spark. These curves reflect the worst case scenario. Because of the low power required by today's electronics, most manufacturers of intrinsically safe equipment find it safer (and easier) to start out by designing the equipment for the worst-case specifications.

Before leaving this graph, special mention should be made of Class III fuels. Class III requires a significant spark to cause ignition. The paramount requirement for Class III fuels is the surface temperature of the exposed apparatus. This requirement is the same as for Class II Group G fuels: less than 165°C (329°F). If the device in the hazardous area is approved for Class III Division 1 installation, then the temperature of any exposed parts is less than 165°C.

Not all circuits are resistive. Circuits with capacitors and coils can store energy that can be released when the circuit is opened or shorted.

Figure 5.1 *Resistance Circuits-Ignition Curves for all Circuit Metals*

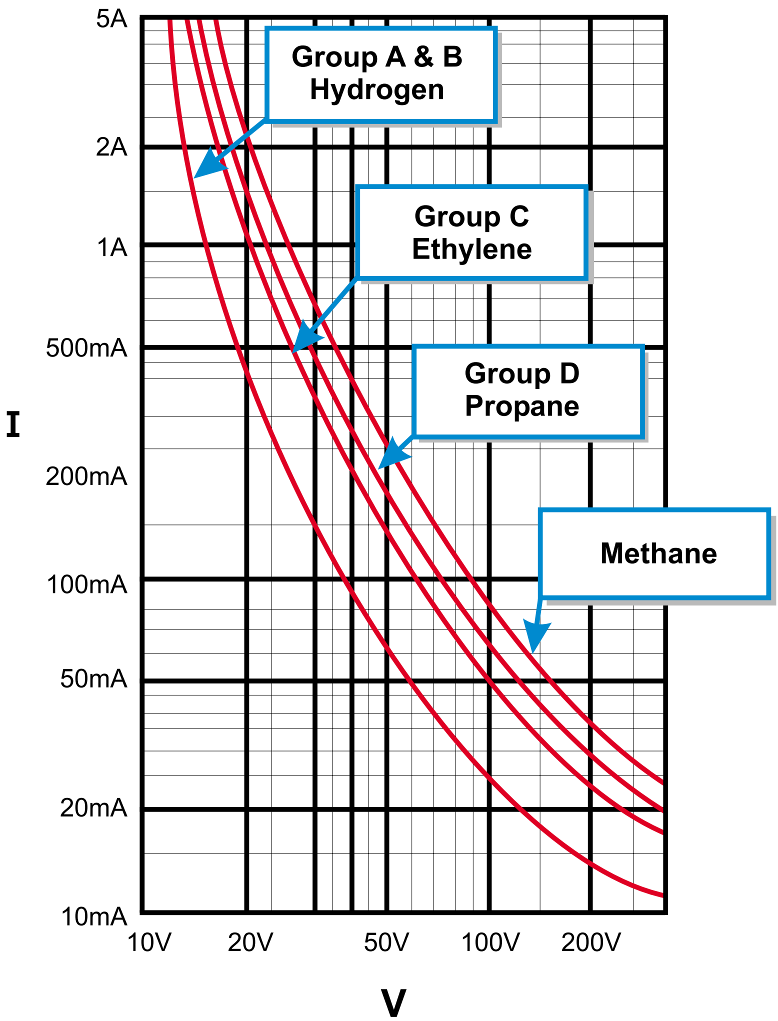


Figure 5.2 (page 44) shows the relationship between capacitance and voltage for the worst case: Group A and Group B (hydrogen). What is significant is that if a small series resistor is added to the circuit, the voltage of the spark is reduced when the capacitor is shorted. Four curves are shown with 0Ω to 40Ω series resistors. Again, to be safe, the circuit must be below and to the left of the applicable curve with a 1.5 safety factor on energy.

If a circuit has a coil or other inductive component, then opening the circuit causes a release of stored energy. Figure 5.3 (page 46) shows the relationship between inductance and current. The various groups are shown similarly to the Resistance Circuit Ignition Curves. Again, the safe area is below and to the left with a 1.5 safety factor on energy.

5.2 System Approval versus Entity Approval

As mentioned in the introduction of this tutorial, there are two types of approvals associated with intrinsically safe equipment. **SYSTEM APPROVAL** requires that the intrinsically safe apparatus in the hazardous area be matched with an associated intrinsically safe apparatus and approved together as a system. The components of an intrinsically safe circuit are shown in Figure 5.4 (page 48).

ENTITY APPROVAL requires each apparatus to stand on its own and be approved accordingly. The user or system integrator can then select the best of each component for his application.

SYSTEM APPROVAL is not as cut and dried as it would seem at first glance. Wire has a certain amount of inductance and capacitance per length. Therefore, the system approval must either specify the wire and maximum length between the approved components, or give data so that the wire can be selected in the field. This is typically accomplished by specifying the amount of capacitance (C_{cable}) and inductance (L_{cable}) that may be added to the circuit as wire or cable.

When the electrical parameters of the wire are unknown, ANSI/ISA RP12.6 states the following default values may be used:

Capacitance	60.0 pF/ft	(196.9 pF/m)
Inductance	.20 µH/ft	(.66 µH/m)

In an **ENTITY APPROVAL** each apparatus is examined separately by an NRTL and assigned a set of entity parameters. For intrinsically safe apparatus these are:

V_{max} = Maximum voltage that may safely be applied to the intrinsically safe apparatus.

I_{max} = Maximum current that may safely be applied to the intrinsically safe apparatus.

C_i = Internal unprotected capacitance of the intrinsically safe apparatus.

L_i = Internal unprotected inductance of the intrinsically safe apparatus.

Each channel of the associated apparatus is assigned:

V_{oc} = Maximum open-circuit voltage that can appear across the intrinsically safe connections of the associated apparatus under fault conditions.

I_{sc} = Maximum short-circuit current that can be drawn from the intrinsically safe connections of the associated apparatus under fault conditions.

C_a = Maximum capacitance that can safely be connected to the associated apparatus.

L_a = Maximum inductance that can safely be connected to the associated apparatus.

Some NRTLs identify two additional parameters for combinations of more than one channel of associated apparatus:

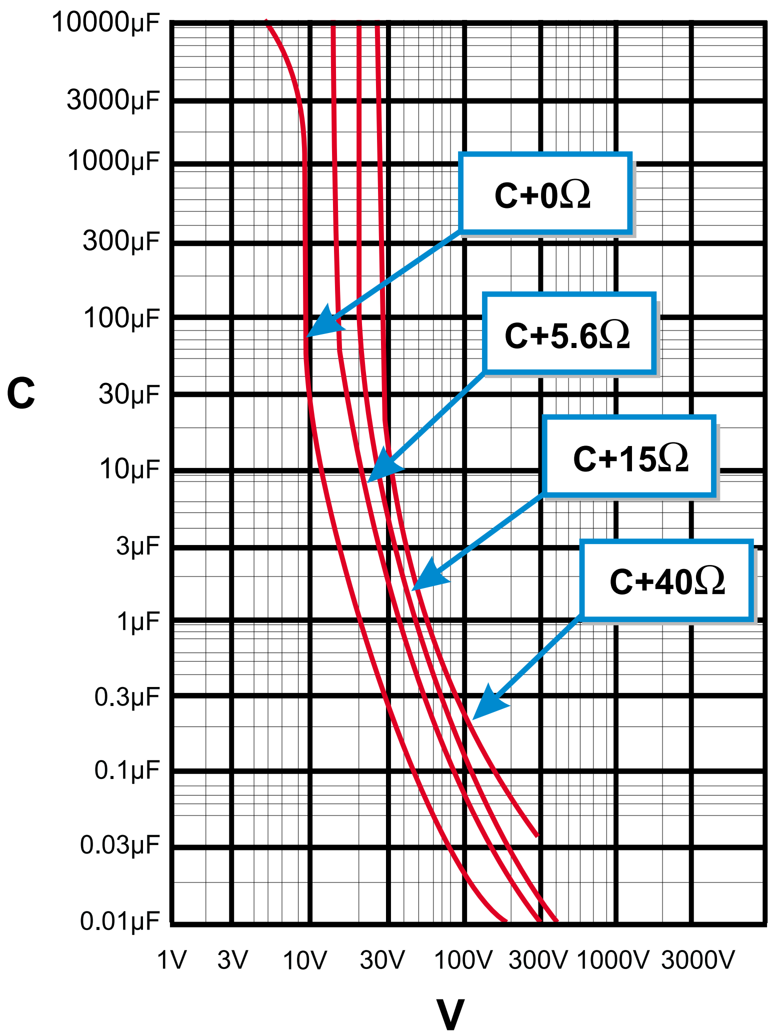
V_t = Maximum voltage between any two channels.

I_t = Sum of the currents from all channels of the given combination.

Other NRTLs simply identify the terminals to which the parameters apply in multichannel situations. The concepts are otherwise identical. However, care must be taken to ensure that the parameters apply to the exact connection under consideration.

V_{max} and I_{max} are selected by the intrinsically safe apparatus manufacturer to be used for comparison to associated apparatus parameters. Their values do not

Figure 5.2 *Capacitance Circuits-Ignition Curves for Groups A and B for all Circuit Metals*



necessarily bear any relationship to the normal operating voltage and current of the device. To be useful, values high enough to allow inter-connection with appropriate associated apparatus must be selected. The values of V_{max} and I_{max} are limited only to the maximum voltage and current that the intrinsically safe apparatus can receive and remain intrinsically safe, based on stored energy and thermal considerations.

The V_{max} and I_{max} values specified for a given intrinsically safe apparatus, taken together and compared to the ignition curves, may fall in the ignition-capable area of the curve. This is not a problem because any NRTL-approved associated apparatus to which the intrinsically safe apparatus might be connected always will have V_{oc} and I_{sc} parameters that are not ignition capable.

The associated apparatus parameters V_{oc} and I_{sc} (or V_t and I_t) are determined under worst case fault conditions. Single channel V_{oc} and I_{sc} values have a linear relationship and can be used to calculate the power that can be drawn from the associated apparatus. However, V_t and I_t are independent from each other, and likely to have been determined under different fault scenarios.

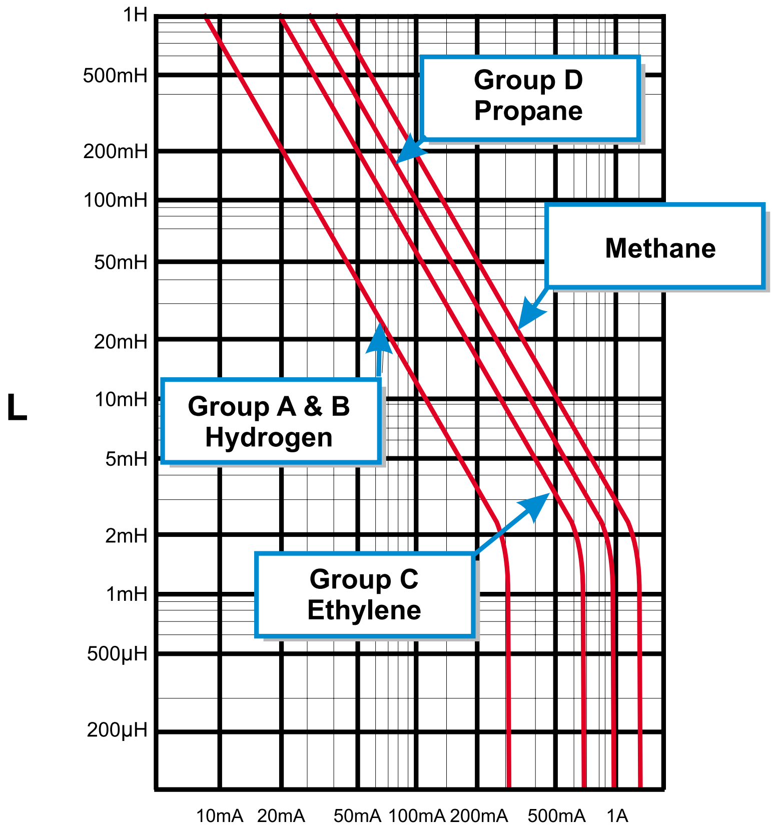
Figure 5.5 (page 49) summarizes the relationship between the intrinsically safe apparatus parameters and the associated apparatus parameters. If Figure 5.5 is satisfied and the system is installed properly, then the circuit is intrinsically safe. There is no guarantee that it will function properly, but it will not be the cause of an explosion. For additional information on the Entity concept, see ISA TR12.2, “Intrinsically Safe System Assessment Using the Entity Concept”.

5.3 Associated Intrinsically Safe Apparatus: Zener Diode Barrier

A very basic Zener diode barrier may be constructed similar to Figure 5.6 (page 50). The purpose of this barrier is to limit the current (I_{sc}) to the intrinsically safe apparatus in the hazardous area, with current limiting resistors. The resistor drops the voltage, thereby limiting the current. One size of resistor, therefore, cannot function in all cases. The Zener diodes protect the hazardous area from any possible high voltages in the controller.

If the voltage in the safe area goes higher than (V_{oc}), then the Zener diodes will no longer block the positive current from the ground. When this happens, the fuse will blow. A replaceable fuse can protect against component destruction. Figure 5.7 (page 51) shows a barrier with a replaceable fuse. When sized properly, the fuse F1 will blow before R1 or Z1 will destruct. If too large of a fuse is used, R1

Figure 5.3 *Inductance Circuits-Ignition Curves at 24 volts for all Circuit Metals*



would be destroyed if a fault occurred. The resistor acts as a fuse in this case, and then the barrier would have to be removed and the whole barrier replaced. If too small a fuse is used, then the circuit may draw more current than the fuse will permit, and the fuse will blow.

Selection of a Zener Diode Barrier is usually not a problem. There are two parts:

a) Is the circuit safe?
b) Will it function properly?

1. Review the operational voltage and current of the intrinsically safe apparatus and the associated intrinsically safe apparatus.

2. When selecting the barrier, attempt to use standard or application-dedicated barriers.

3. If one is not available, then choose a barrier with parameters that match the parameter of the intrinsically safe apparatus but do not exceed them.

4. When Figure 5.5 (page 49) has been satisfied (including C_{cable} and L_{cable}), the circuit is safe.

5. Next, the circuit must be analyzed using Ohm's law to determine if the supply requirements of the intrinsically safe apparatus and the load of the controller input in the safe area have been satisfied. Voltage loss due to wire resistance should be included.

Sourcing PLC input cards or other sourcing controllers require special considerations compared to sinking input cards. Figure 5.8 (page 51) shows typical wiring for a sinking input. Figure 5.9 (page 51) shows a sourcing input. Since the terminal point to the load on the sourcing PLC input card is not earth grounded, then current could flow from the safe to the hazardous area if blocking diodes were not in the intrinsically safe return circuit. Three (3) diodes are used in this blocking barrier for redundancy. Also, a ground fault at any point after the barrier, but before the input terminal on the PLC, will usually blow the fuse. Universal (sinking or sourcing) input cards are available from most PLC manufacturers, but care should be taken not to mix sinking and sourcing on a common group of inputs.

5.4 Grounding In The Hazardous Area

Grounding in the United States has usually meant grounding of all metal parts (bare wire, etc.) that could accidentally come in contact with live electricity. The practice and methods are designed for personnel protection. Stray currents and different ground potentials of a few volts usually cannot even be felt, much less hurt humans. But those few volts can follow a return wire of an intrinsically safe circuit or even fool a diode (reverse biased), and allow high currents from the safe area into the hazardous area. When dealing with AC power, or switching type DC power supplies, there are too many possible fault conditions to cover them all in this tutorial.

Figure 5.4 *Components of Intrinsically Safe Circuits*

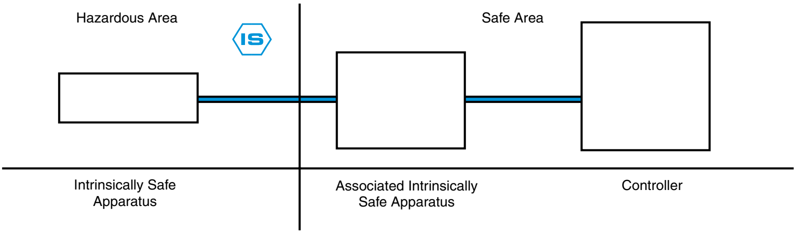


Figure 5.10 (page 52) shows a typical sinking circuit. In this example, the DC power supply is isolated form the AC line before it is rectified. The double fault shown on both sides of the barrier and a high potential ground at the barrier would be rare, but this fault would be extremely dangerous. If the two ground faults and the ground at the barrier are at uniform earth ground then there is an operational error (the PLC input locks on), but there is no hazard.

Another example of an operational error due to poor grounding of the system is shown in Figure 5.11 (page 52). If the ground fault in the hazardous area is at a higher potential than the ground at the barrier, there will be some current flow. This will result in a false instrument signal that may be hard to detect. If the ground fault and the barrier are at the same potential, the signal will go off-scale high, and a simple program in the PLC would recognize it immediately.

It may not be possible to have an absolute uniform ground between the hazardous area and the safe area. A high potential in the hazardous area does not cause a potential explosive spark but the signal may be in error. The resistance between all the ground points, the DC power supply, the controller common, and the barrier must be less than 1Ω. When barriers are used that require a high-integrity ground, a preventive maintenance should be established and followed to ensure the integrity of the ground.

5.5 Isolation Amplifiers

Isolation amplifiers are another step in the evolution of associated intrinsically safe apparatus. Isolation amplifiers have some of the same components as the Zener diode barrier. Figure 5.12 (page 52) shows a generic switching isolation amplifier to be used with NAMUR sensors and dry contacts. The input power, the signal input from the hazardous area, and the output to the controller are all isolated from

Figure 5.5

Intrinsically Safe Apparatus		Associated Intrinsically Safe Apparatus
Hazardous Area		**Safe Area**
Alias: Intrinsically safe sensor, switch, instrument		Alias: Barrier, switching amplifier, isolation amplifier
V_{max}	$\geq$	V_{oc}
I_{max}	$\geq$	I_{sc}
$L_i + L_{cable}$	$\leq$	L_a
$C_i + C_{cable}$	$\leq$	C_a

each other. The high-integrity ground is not required because the control room power is completely isolated from the intrinsically safe hazardous area circuits. The output to the controller, whether it is a transistor or a relay, is isolated and operates at the intended voltage of the controller, not a reduced voltage as is the case with barriers. Isolation switching amplifiers operate in many ways similar to the barrier. When the input is shorted, the isolation transformer that is operating at near saturation cannot deliver any more VA. This isolation transformer is similar to the current limiting resistors in the barrier. The fuse in the isolation switching amplifier is there in case of component failure. The fuse is not replaceable and the only time it would blow is if the isolation transformer would fail.

A variety of outputs is available:

- NPN, isolated and non-isolated
- PNP, isolated and non-isolated
- Relays, single and double pole
- Linear transistors for analog

Because of the external power input logic, a variety of LEDs can be added to the isolation switching amplifier. The logic can be as simple as a switch to select a N.O. (normally open) or N.C. (normally closed) output, or a user programmable high and low set-point for an analog input. A common logic function is to detect opens or shorts on the intrinsically safe input circuit. If an error is detected on the input circuits, an alarm transistor or relay changes state.

Selection of an isolation switching amplifier is quite easy. First, the entity or loop parameters (Figure 5.5) must be satisfied. The next step is matching the output of the switching amplifier to the input of the controller. But this is no different than matching any input and output. An analogy could be made to selecting an interposing ice cube relay, and in many cases this is what the selection amounts to.

An example from **TURCK's** Automation catalog for the **MK13-UPF-Ex0/24 VDC** is shown in Figures 5.13 and 5.14 (page 53 & 54). This switching amplifier is used for NAMUR sensors and dry contacts. The connection diagram shows the input and output terminal points, as well as programming features and the type of output. The function truth table describes the output and status with respect to the different inputs and programming. This amplifier can be programmed for N.O., N.C or complementary. The PNP transistor output on terminal point 6 is the alarm output. It is ON when the input circuit is within range. When there is a short or open in the input circuit, this PNP transistor is OFF. The second page also shows the device specifications.

5.6 The Future

The Zener diode barrier is mature technology. There are very few applications for which there is not a barrier. Isolation amplifiers are younger technology and there will be times when no solution is available. As the intrinsic safety market matures in North America, more products will become available.

The hazardous area process can be handled nearly the same way as the non-hazardous area process using intrinsically safe products. Equipment that is needed to efficiently monitor and control a process does not have to cost an arm and a leg to purchase and install, as was the case with explosionproof equipment. And, at a slight premium, isolation amplifiers are available that will reduce design engineering. A high-integrity ground does not have to be installed, periodically checked, and maintained using isolation amplifiers.

Figure 5.6 *Basic Zener Diode Barrier (may be constructed similar to diagram below)*

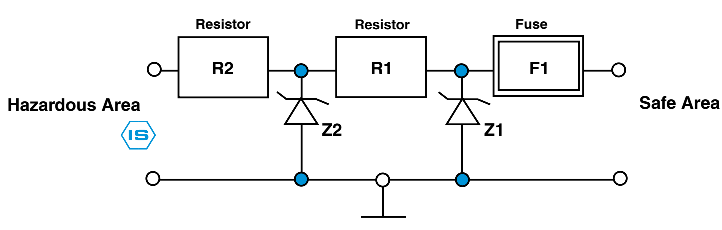


Figure 5.7 *Barrier with a Replaceable Fuse*

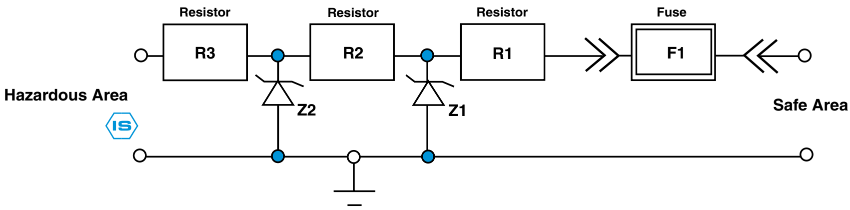


Figure 5.8: *Typical Wiring for a Sinking Input*

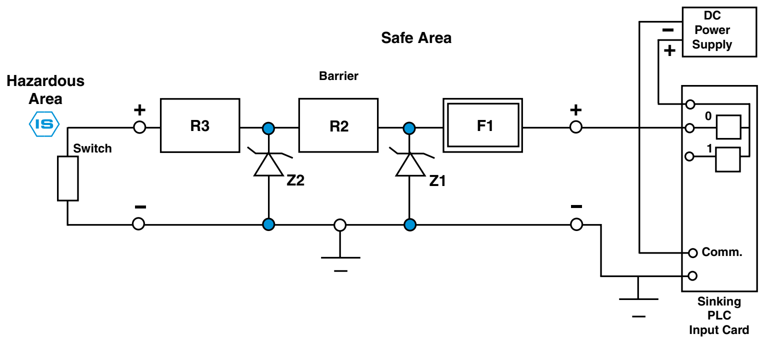


Figure 5.9 : *Sourcing Input (PLC input cards or other sourcing controllers)*

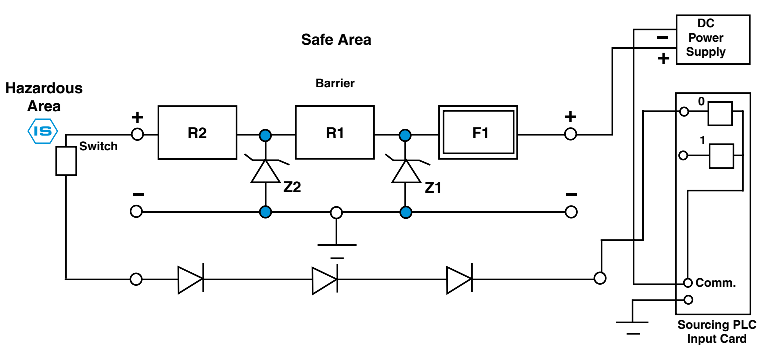


Figure 5.10: Typical Sinking Circuit

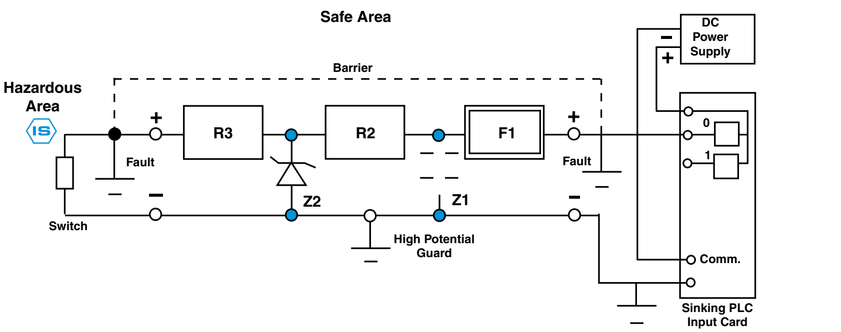


Figure 5.11 Example of Operation Error due to Poor Grounding of the System

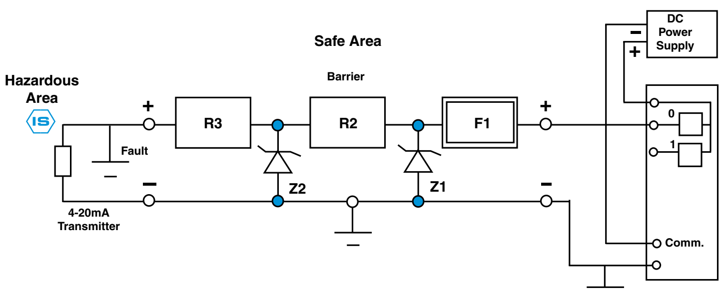


Figure 5.12 Generic Switching Isolation Amplifier to be used with NAMUR Sensors and Dry Contacts

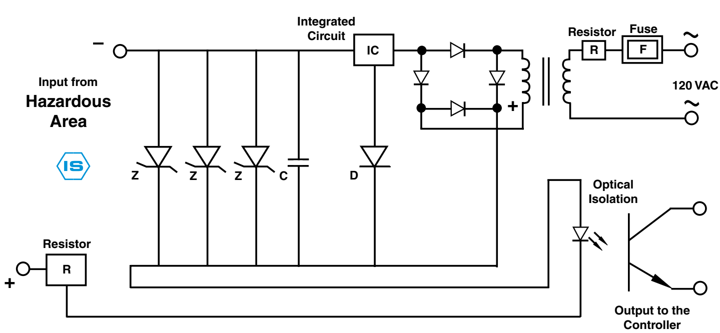
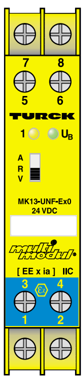


Figure 5.13 *Example **MK13-UPF** from TURCK's Automation Catalog (page B7)*

TURCK
Switching Amplifiers



MK13-UNF-Ex0/24VDC
MK13-UPF-Ex0/24VDC

The **MK13-UNF-Ex0/24VDC** and **MK13-UPF-Ex0/24VDC** are single channel switching amplifiers with intrinsically safe input circuits. They are used to isolate and transfer discrete signals from a hazardous location to a non-hazardous location. Inputs are typically NAMUR sensors or dry contacts, although devices providing a variable resistance conforming to DIN 19234 may be used - e.g. variable resistors, thermistors, etc.

PNP - MK13-UPF-Ex0/24VDC
NPN - MK13-UNF-Ex0/24VDC

Each provide two short-circuit protected transistor outputs. A three-position switch on the front cover selects the output mode. Positions "A", "R" and "V" represent direct mode (N.O.), inverse mode (N.C.) and complementary mode, respectively. The output mode is dependent on the input device. Refer to Truth Table.

In positions "A" and "R", output 1A follows the input signal, while the Alarm/1B output provides indication of faults in the input circuit. The Alarm/1B output remains energized during normal operation.

In position "V", the Alarm/1B output provides an output complementary to output 1A. No alarm indication is provided in position "V".

The input circuit is monitored for short-circuit and wire-break. If a fault in the input circuit occurs, both outputs are de-energized and the green LED is switched off.

When dry contacts are the input device, the input circuit monitoring function must be turned off by jumpering terminals 3-4, or resistors must be added to the switch as shown in Contact Configuration.

A yellow LED indicates switching status.

Connection Diagram

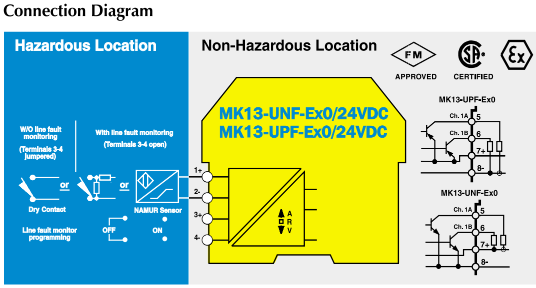
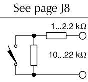
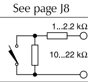


Figure 5.14 *Example **MK13-UPF** from TURCK's Automation Catalog (page B8)*

TURCK

Selectable Fault Output
Programmable Line Monitoring
MK13-UNF-Ex0/24VDC
MK13-UPF-Ex0/24VDC

Switching Amplifiers

Type	**MK13-UNF-Ex0/24VDC**	**MK13-UPF-Ex0/24VDC**
ID Number	M7505400	M7505200
Power Supply		
Supply voltage	10-30 VDC, ≤10% ripple	10-30 VDC, ≤10% ripple
Current consumption	approx. 20 mA	approx. 20 mA
Galvanic isolation	between hazardous and non-hazardous circuits, test voltage 2.5 kVrms	between hazardous and non-hazardous circuits, test voltage 2.5 kVrms
Input Circuits		
Nominal operating characteristics (per DIN 19234)		
- Voltage	8 V	8 V
- Current	8 mA	8 mA
- Switching threshold	1.55 mA	1.55 mA
Intrinsic Safety Parameters	See page J8	See page J8
Contact Configuration		
Output Circuits	two NPN transistor outputs	two PNP transistor outputs
Voltage drop	≤2.5 V	≤2.5 V
Switching current, each output	100 mA, short-circuit protected	100 mA, short-circuit protected
Switching frequency	≤3 kHz	≤3 kHz
Housing Style	Diagram A (page A17)	Diagram A (page A17)

Truth Table

Programming	**Input**			**Output** (terminals 3-4 open)				**Input**	**Output** (term. 3-4 jumpered)	
				Normal		Short or Wire-Break			Normal	
A/R Switch Position	**Dry Contacts**	**Inductive NAMUR**	**Capacitive NAMUR**	**Channel** 1A Alarm/1B	**LED** Yellow Green	**Channel** 1A Alarm/1B	**LED** Yellow Green	**Dry Contacts**	**Channel** 1A Alarm/1B	**LED** Yellow Green
A				Off	Off	Off	Off		Off	Off
				On	On	Off	Off		On	On
A				On	On	Off	Off		On	On
				On	On	Off	Off		On	On
R				On	On	Off	Off		On	On
				On	On	Off	Off		On	On
R				Off	Off	Off	Off		Off	Off
				On	On	Off	Off		On	On
V				On	On	Off	Off		On	On
				On	On	Off	Off		Off	On
V				Off	Off	Off	Off		Off	Off
				On	On	Off	Off		On	On

Notes:

CHAPTER 6

Nonincendive Methods for Division 2 Hazardous Locations

6.1 Terminology

Properly classified Division 2 locations aren't often hazardous. They are essentially 'buffer zones' around Division 1 locations in which an explosive atmosphere will never be present under normal conditions and only rarely as a result of unforeseen equipment failures. If electrical faults in equipment occur fairly rarely, the risk of these events happening simultaneously is negligible. However, acceptable protection methods for Division 2 locations seem to be less widely understood than those for Division 1 locations, despite the lesser hazard. This is partly due to the fact that the somewhat cumbersome term 'nonincendive' is used to describe two very different Class I, Division 2 protection methods:

- Nonincendive Equipment
- Nonincendive Circuits

6.2 Nonincendive Equipment

Simply put, if you supply nonincendive equipment with its rated power and use it per its instructions, it won't produce heat or sparks capable of igniting a hazardous atmosphere. It must not have normally arcing contacts and must not produce heat in excess of 80% of the ignition temperature of the hazardous atmosphere. There is no fixed restriction on the amount of power as long as the preceding statement remains true. The energy level carried by the interconnecting wiring may far exceed the ignition curves. Therefore, a Division 2 wiring method must be used. The acceptable methods may be found in NEC Article 501-4(b).

Quick disconnects are considered normally arcing if they don't require a tool for disconnection.

Benefits:

- No NRTL approved safety barrier, special enclosure or supply of protective gas required.
- Higher power AC sensors can be approved as well as low power DC sensors.

Drawbacks:

- A Division 2 wiring method must still be used.
- The sensor must be adaptable to a Division 2 wiring method.
- Quick disconnects are not allowed unless they require a tool for disconnection.

Figure 6.1 summarizes the key Nonincendive Equipment concepts.

Figure 6.1 *Nonincendive Equipment*

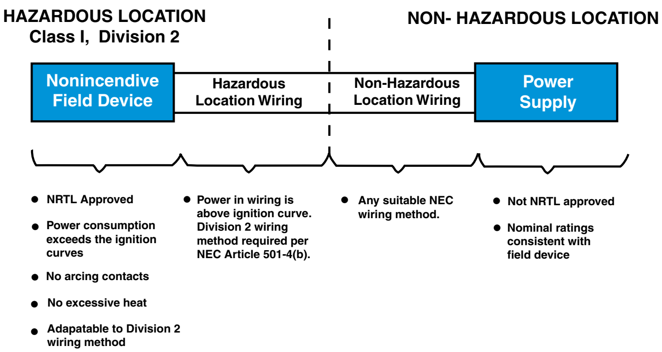
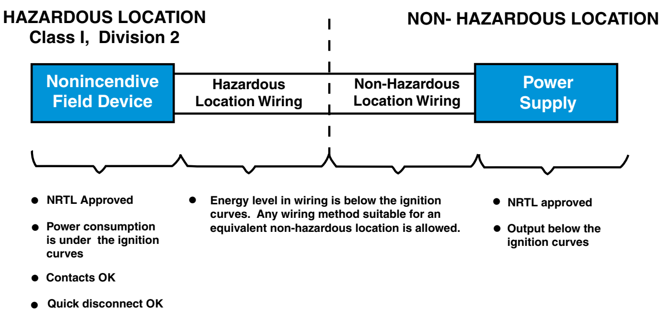


Figure 6.2 summarizes the key Nonincendive Circuit concepts.

Figure 6.2 *Nonincendive Circuit*



6.3 Nonincendive Circuits.

The electrical energy in a Nonincendive Circuit is incapable of igniting a specific hazardous atmosphere under normal conditions. The concept is very similar to intrinsic safety but with lower safety factors and no faults considered in equipment examinations.

The energy level carried by the interconnecting wiring is below the ignition curves with a 10% margin. Therefore, any wiring method suitable for an equivalent non-hazardous location is acceptable.

Quick disconnects are also permitted because their disconnection doesn't result in an ignition-capable spark.

Benefits:

- No special wiring.
- Quick disconnects allowed.
- Sensors that can't be adapted to a Division 2 wiring method can be used.

Drawbacks:

- Only relatively low power devices can be used.
- The power supply must be NRTL approved.
- The wiring must be separated from other types.

6.4 Typical Installations

Figure 6.3 (pages 60-61) includes 6 examples that illustrate key nonincendive concepts. In all cases, the wiring method must be sealed at the point of exit from the hazardous area if it can transport hazardous gases into the non-hazardous area. Examples of wiring methods that require sealing are: conduit, enclosed wireways and busways, and large loosely packed multicore cables. Poured explosionproof seals are not required in these applications. The seal is intended only to protect against the transport of un-ignited gas with low differential pressure. It is not intended to stop an explosion-induced flamefront under pressure.

Examples 1 - 4 depict sensors approved as nonincendive equipment. These sensors could conceivably be powered by up to 250 VAC.

Examples 5 and 6 depict sensors used in nonincendive circuits. The sensors used in such installations would necessarily need to operate on relatively low power.

Example 1 Installation of a threaded cylindrical sensor using conduit.

A threaded cylindrical sensor may be wired to a rigid metal conduit system using a thread adapter. The conduit must be sealed at the point it leaves Division 2. No seal is required at the sensor and no NRTL approval for the non-hazardous location device is required.

Example 2 Installation of a threaded cylindrical sensor using cable trays or wireways.

Power limited tray cable (PLTC) or instrument tray cable (ITC) in cable trays may be used for the home run from a sensor. However, the drop from the tray to the sensor must use a Division 2 wiring method as well. The tray or wireway must be sealed as it exits the Division 2 area if it is capable of transporting hazardous gases. This is not necessary when the wireway is open or well ventilated as with ladders, messenger wires, etc.

Example 3 Installation of a sensor with a terminal compartment using raceway.

The sensor may alternately have a terminal compartment with a threaded entry or an entry that will accept a conduit hub. A raceway in this context could be a flexible conduit system. PLTC or ITC cable must be used within the raceway. The raceway must be sealed at the point it leaves Division 2.

Example 4 Installation of a slot sensor in a general purpose enclosure.

A sensor that has no terminal chamber or barrel threads and thus can’t be adapted to a Division 2 wiring method may be used only if it is part of a nonincendive circuit, as in 6, or is installed within an enclosure. If the latter method is used, the enclosure need only be a general purpose enclosure meeting the requirements of ANSI/ISA S82, requiring a tool to open, and providing a method to accommodate a Division 2 wiring method, such as a conduit hub or knock-out. A common example of such an installation is sensors used for valve position indication within a dedicated enclosure.

Example 5 Installation of a sensor that has a quick disconnect.

A quick disconnect may be used if it is approved as part of a nonincendive circuit and the power supply is also approved. The two devices may be approved as a system or have compatible nonincendive field circuit parameters. No special wiring method is required other than what would be required for an equivalent non-hazardous location.

Example 6 Installation of a sensor that can't be adapted to Division 2 wiring method.

A sensor that has no terminal chamber or barrel threads and thus can't be adapted to a Division 2 wiring method, may be used if it is approved as part of a nonincendive circuit and the power supply is also approved. The two devices must be approved as a system or have compatible nonincendive field circuit parameters.

Figure 6.3 *Installation Examples of Nonincendive Equipment and Circuits*

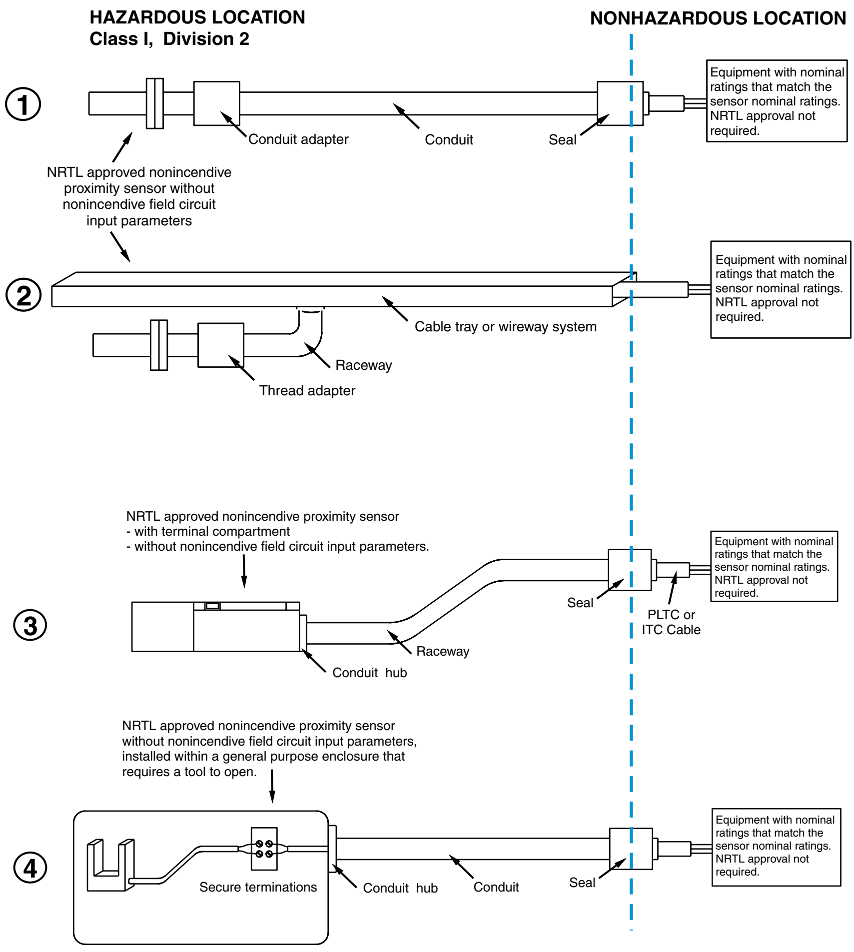
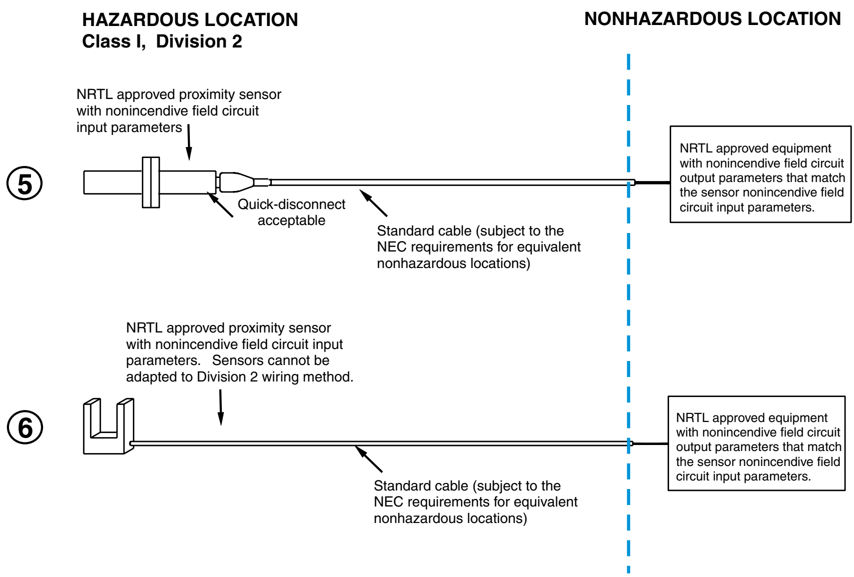


Figure 6.3 Continued... *Installation Examples of Nonincendive Equipment and Circuits*



6.5 Cost Effective and Flexible

Properly applied, these methods are the most cost effective and flexible of any of the hazardous-location protection methods. The equipment is essentially standard equipment approved for use and the ease with which the wiring can be changed is rivaled only by intrinsic safety.

Safety depends upon the proper classification of the area and the use of well maintained, quality equipment. This will ensure that the coincidence of an ignitable concentration of gas or vapor and an electrical fault will have an extremely low probability.

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