INTRINSIC SAFETY

THE ART
OF
INTRINSIC SAFETY

RONAN

Contents

We need to start our discussion on Intrinsic Safety with some background about ignition, combustion, and explosions. Since our goal is to prevent an explosion, we first need to know how an explosion can occur.

An explosion requires the proper environment in order to exist. By eliminating those conditions an explosion is **impossible!**

The three ingredients necessary for an explosion (fuel, oxidizer and ignition source) make up the Ignition Triangle (see Figure 1-1). All of the triangle's components must be present in the correct proportions for ignition to occur.

Once ignition occurs, if the conditions are right, a combustion wave can grow from the ignition. An explosion is any uncontrolled combustion wave.
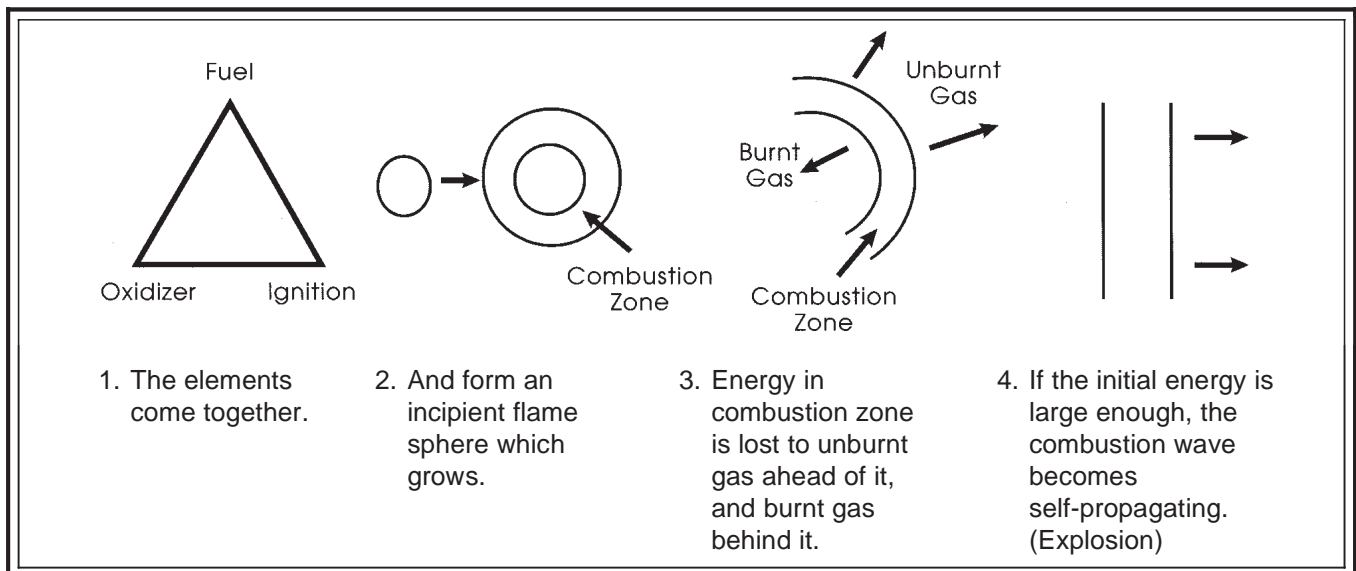
THE COMBUSTION PROCESS

An explosion starts when the fuel and oxidizer are present in the correct proportions, and an ignition source (i.e. spark) occurs. Energy then proceeds along a narrow combustion zone, and is conducted to unburnt gas ahead of the flame front as well as to burnt gas behind the flame.
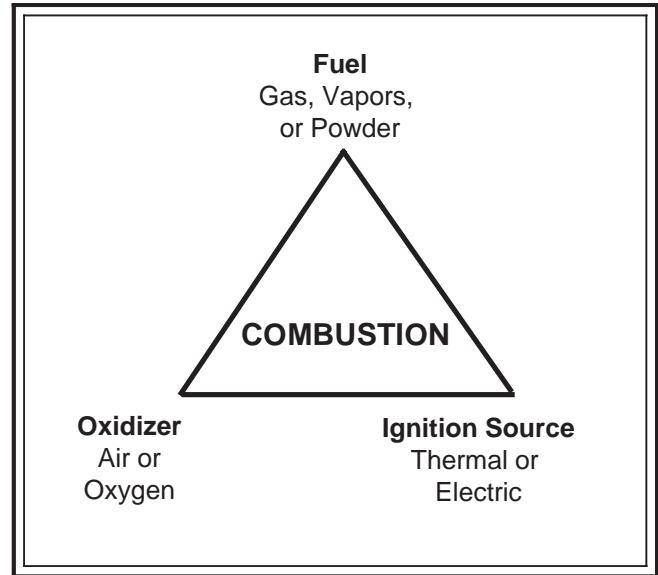
Figure 1-1: The Ignition Triangle
In order for an explosion to occur, the ignition triangle must have all the ingredients in the correct proportions.

Initially, most of the energy is supplied by the spark. If more energy is supplied by the spark (through the combustion zone) than is lost to the surrounding gas, the flame sphere will grow. As the diameter of the sphere increases, the wave begins to resemble a planar wave. Eventually, the amount of energy produced by combustion is sufficient to continually supply energy

1. The elements come together.

2. And form an incipient flame sphere which grows.

3. Energy in combustion zone is lost to unburnt gas ahead of it, and burnt gas behind it.

4. If the initial energy is large enough, the combustion wave becomes self-propagating. (Explosion)

Figure 1-2: Incipient Flame Sphere.
The Incipient Flame Sphere must reach a critical diameter if combustion is to become a self-propagating explosion.

to the unburnt gas ahead of the flame, thereby causing the wave to self propagate. Figure 1-2 shows the beginning stages of combustion. The larger the initial spark is, the easier it is for the wave to propagate.

If the initial spark is not large enough, (i.e. not enough energy), the combustion zone will not have enough energy to self propagate. It will just collapse upon itself, and fizzle out. This means a small spark can occur in a potentially explosive air/gas mixture, with no danger of an explosion. The maximum amount of energy of this "safe" spark varies with the specific air/gas mixture present.

GAS GROUPING

Figure 1-3 illustrates the effect of concentration on ignition energy. Every air/gas mixture has a certain concentration which is the most easily ignited concentration (MEIC). When trying to prevent an air/gas mixture from exploding, the safest approach is to assume the mixture is always at its MEIC. Therefore, the maximum energy you may safely allow must be less than the minimum ignition energy (MIE) of that specific air/gas mixture.

Many gases have similiar ignition characteristics. Instead of having thousands of "Concentration vs. Ignition Energy"
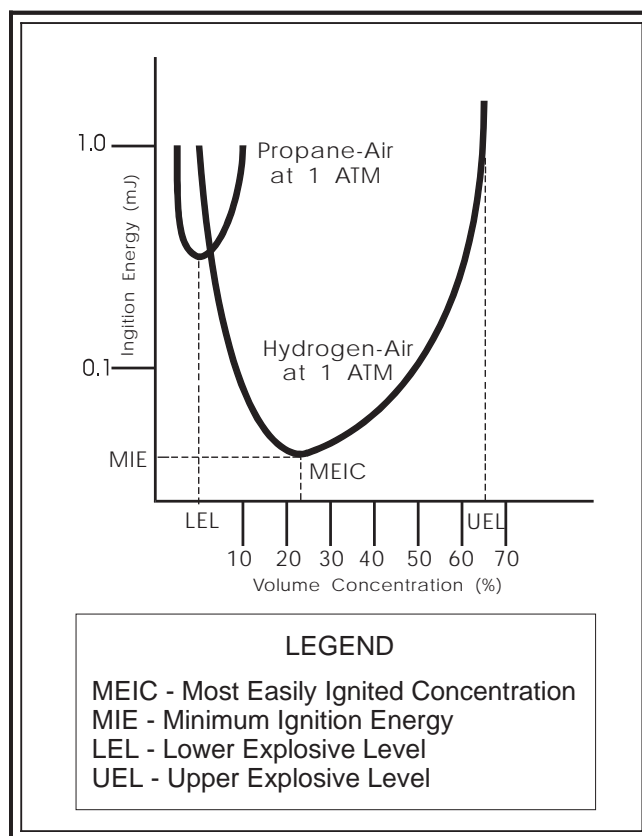
Figure 1-3:
The Effect of Concentration on Ignition Energy.

curves, gases with similar curves are grouped together. There are four different groups (or curves), two of which are shown in Figure 1-3. The actual curve shown, representing the group, is the most easily ignited gas of the group.

3

Area Classification

CLASSES

Hazardous materials (such as gas or dust) are classified by their generic type as follows:

Class I - Flammable Gases or Vapors.

Class II - Combustible Dusts.

Class III - Fibers or Flyings (particles normally suspended in air).

CLASS I: GASES AND VAPORS

Materials are grouped according to their level of explosion hazard. The following groups are listed in order of the most to the least easily ignited.

Group A - Acetylene (has a tendency to form copperacetylides which are easily ignited by friction).

Group B - Hydrogen, Hydrogen Mixtures.

Group C - Ethylene, most Ethers, some Aldehydes.

Group D - Alkanes (Butane, Ethane, Methane, Octane, Propane), Hydrocarbon Mixtures (Diesel Oil, Kerosene, Petroleum, Gasoline), Alcohols, Ketones, Esters, Amines, Alkenes, Benzenoids.

CLASS II: COMBUSTIBLE DUSTS

Group E - Metallic Dusts (Resistivity<100 kohms/cm).

Group G - Non-Conductive Dusts, which include agricultural, plastic, chemical and textile dusts. (Resistivity>100 kohms/cm).

Note: Since 1974, a dividing line of 100 kohms/cm separates groups E & G.

DIVISIONS

Locations are classified by division according to the probability that an explosive concentration of hazardous material may be present.

Division 1 - defines locations where there lies a high probability that an explosive concentration is present during normal operation. To be classified Division 1, there has to be a minimum of 100 hours/year, or 1% probability that an explosive material is present. In Europe, Division 1 is subdivided into Zone 0 and Zone 1. Zone 0 has the highest probability of an explosive concentration being present (greater than 10% probability). Zone classifications are not presently made in North America, but may be in the future.

Division 2 - defines locations where there lies a low probability that an explosive mixture is present during normal operation (10 hours/year, or 0.1% of the time).

There are three different philosophies or approaches which have been used to prevent explosions. All deal with the ignition triangle (Figure 1-1) differently.

PERMIT IGNITION

This method allows all three elements of the ignition triangle to be present, but controls the location of the flame or explosion. Examples of this include a pilot light on a gas stove, a flare stack, and an explosion-proof housing. The key safety feature here is the physical device which controls or limits the explosion location. Permitting ignition is normally costly and requires high maintenance.

CONTROL ATMOSPHERE

This method segregates the hazardous fuel/air mixture from the ignition source. If you have a hazardous mixture in one room, you can put your potential ignition sources in another room. The key safety feature here is the physical device which controls the segregation. See Figure 3-1 for one example. Another more common example is purging or pressurization. Controlling the atmosphere can be a very complex and costly procedure.

ELIMINATE THE IGNITION SOURCE

The simplest method! Since all three elements of the Ignition Triangle are necessary for an explosion, why not eliminate one or more of the elements?

By the very nature of a hazardous process, the fuel can not be removed. Notice that in a general purpose environment, the fuel is the absent element, with oxidizer and ignition source safely present.

Rarely is the oxidizer (air) removed. The halon fire extinguisher is an example of an absent oxidizer. It works by replacing oxygen with halon, thereby suffocating the fire.

The ignition source can be removed. By inserting an energy limiting barrier, any potential ignition source can be eliminated. This method is the only true combustion **prevention** method. The other possible solutions are actually combustion protection.

METHODS FOR SAFE CONTROL IN HAZARDOUS AREAS

Taking these three explosion prevention philosophies and implementing them produces a variety of techniques. These include:

Figure 3-1: One way to separate the fuel/air mixture from the ignition source.

- ◆ Pneumatic (Air)
- ◆ Fiber Optics (Light)
- ◆ Explosion-Proof Enclosures (Electric)
- ◆ Purging or Pressurization (Electric)
- ◆ Encapsulation (Electric)
- ◆ Oil Immersion or Powder Filling (Electric)
- ◆ Intrinsic Safety (Electric)

Let's review each of these in a little detail.

PNUEMATIC SYSTEM

Pnuematic systems are a safe means of combustion control because they are powered by air. This type of system is practical in operations where clean compressed air is available. A typical pneumatic field device is a control valve. Pneumatics can be used in only a limited number of operations, for limited distances and have a slow reaction time.

FIBER OPTICS OR PHOTOVOLTAICS

Photovoltaic loops provide a safe means of control because they are powered by light. A light beam goes out to the hazardous area and is either reflected back to the safe area or is interrupted. This has limited distance capabilities, is affected by dust or mist, and is limited to contact sensing applications.

Fiber-optic loops are also a safe means of control because they are powered by light. When the light reaches the instrument however, it will probably need to be converted to electricity. In these cases, the electrical safety methods discussed next must be used. Fiber optics has some potential for contact sensing but special contacts need to be used, and are not yet readily available.

EXPLOSION PROOF ENCLOSURES

The use of explosion-proof enclosures is a method which allows ignition to occur, but prevents any significant damaging results from the ignition.

The explosion-proof enclosure contains the explosion so that it does not spread to the surroundings and cause damage to the plant and the personnel. There are bolt-on enclosures (shown) and screw-on enclo-
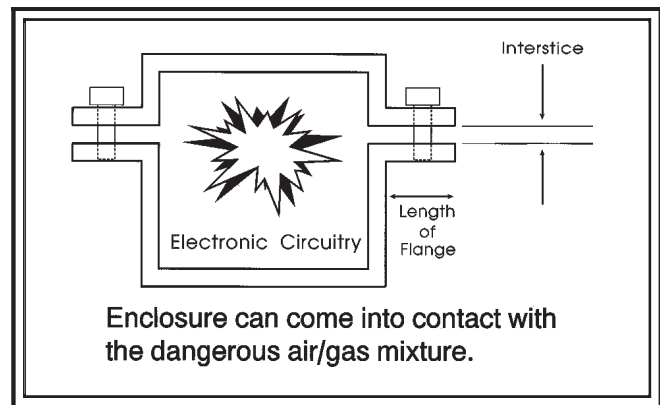

Figure 3-2: Explosion Proof Enclosure.

sures available. Both types do not allow the explosive energy to completely escape the enclosure.

Care must be taken not to mar the flanged surfaces. Also, all bolts must be torqued down correctly. One missing or loose bolt or scratched surface could provide a path for the explosion to reach the outside world. Explosion-proof enclosures are designed to resist the excess pressure created by an internal explosion. They are built with a variety of materials, including cast aluminum, cast iron, welded steel and stainless steel.

PURGING (PRESSURIZATION)

Purging prevents explosions by maintaining a protective inert gas within the enclosure at a pressure that is greater than the external atmosphere. This method prevents the dangerous air/gas mixture from entering the enclosure. Pressure may be preserved with or without a continuous flow of the inert gas. Pressure loss or opening of enclosure cause the sys-
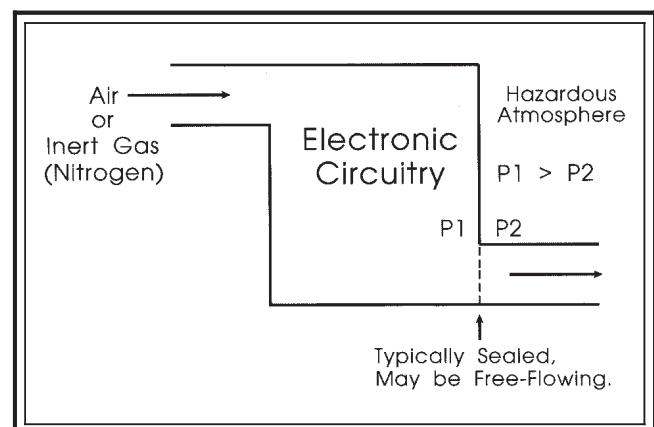
Figure 3-3: Purging.

tem to alarm or power down depending on the type of purge.

There are three types of purging methods, each of which reduce the area classification within an enclosure. Type X reduces classification from Division 1 to Non-Hazardous. Type Y reduces classification from Division 1 to Division 2. Type Z reduces classification from Division 2 to Non-Hazardous.

Certain criteria must be met in order for a purging process to get rated as Type X, Y or Z (and thereby reduce the area classification accordingly). These criteria are listed in Figure 3-4.

ENCAPSULATION

The encapsulation method encloses the hazardous operation with a resin potting material that prevents accidental shorting of electrical components. This method offers effective mechanical protection that works well as a complement to other prevention processes. If a spark does occur, it can not escape through the potting material into the hazardous environment.

MISCELLANEOUS PROTECTION METHODS

The intent of this chapter is to give the reader a background of all the various explosion prevention methods available. The most popular methods are: explosion proof housing, purging, and intrinsic safety. The rest of this book will concentrate only on intrinsic safety. Before we do that, how-
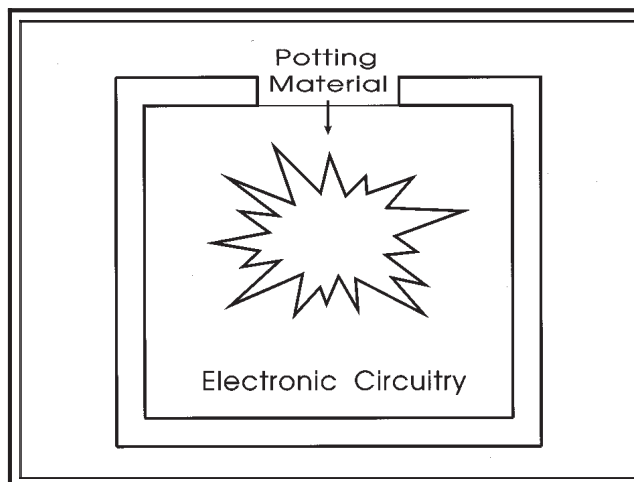

Figure 3-5: Encapsulation.

ever, let's review a few miscellaneous protection methods. These methods are not used very often, but they provide an interesting insight to explosion prevention.

Oil Immersion - A piece of equipment is immersed in oil. A spark can not pass through the oil covering to ignite the surrounding atmosphere. This method is sometimes used for large electrical apparatus such as transformers. The electrical apparatus may even have moving parts since the oil will not impede the movement.

Powder Filling - An enclosure containing electronics is filled with quartz powder. The level and granulometry of the powder is specified by an approval agency (CENELEC). A spark can not pass through the quartz powder and ignite the

TYPE Z PURGE REDUCES ENCLOSURE FROM DIVISION 2 TO NON-HAZARDOUS	TYPE Y PURGE REDUCES ENCLOSURE FROM DIVISION 1 TO DIVISION 2	TYPE X PURGE REDUCES ENCLOSURE FROM DIVISION 1 TO NON-HAZARDOUS
1. Label stating four volumes of purge gas needed before power. 2. Pressure of 0.1 inch water. 3. Enclosure temperature < 80% of ignition temperature of gas. 4. Purge failure alarm or indicator. (No automatic power-off necessary.) 5. Warning nameplate. 6. 1/4 inch tempered glass window.	1. Label stating four volumes of purge gas needed before power. 2. Pressure of 0.1 in water. 3. **Fused** based on enclosure thickness to ensure enclosure temperature < 80% of ignition temperature of gas. 4. Purge failure alarm or indicator. (No automatic power-off necessary.) 5. Warning nameplate. 6. 1/4 inch tempered glass window. 7. Equipment mounted within exclosure must meet Division 2. (Hermetically Sealed Switches, Relays, Contacts.)	1. **Timer** to allow 4 volumes of purge gas. 2. Pressure of 0.1 in water. 3. Fused based on enclosure thickness to ensure enclosure temperature < 80% of ignition temperature of gas. 4. **Power Disconnect** on purge loss. (Pressure or flow actuated.) 5. Warning namplate. 6. 1/4 inch tempered glass window. 7. Automatic power disconnect switch on door.

Figure 3-4: Purging Methods.
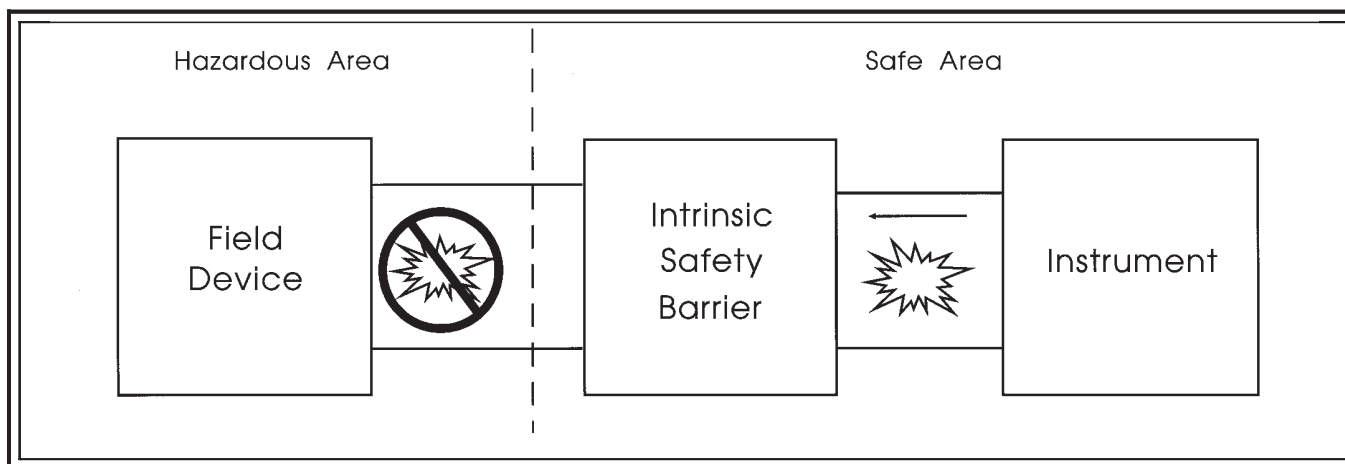
Figure 3-6: Intrinsic Safety removes the ignition source from the ignition triangle. The official definition is as follows: Intrinsically safe equipment and wiring shall not be capable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific atmospheric mixture in its most easily ignited concentration.

surrounding atmosphere. No moving parts are possible.

Non-Incendive - Also called Simplified Protection Method in Europe, it is widely used in England. This protection method does not consider fault conditions. It assures you can not ignite a hazardous air/gas mixture during normal functioning. Devices which may spark during normal operation such as relays and switches must be hermetically sealed. This safety method only applies to Division 2 areas.

Increased Safety - Developed in Germany. Recognized by CENELEC. Takes into account connections, wiring, components, distances and temperature changes.

Sealing (Limited Breathing) - Uses seals and gaskets. The enclosure is tightened so gas accumulation does not increase above lower explosive level (see figure 1-3) for a period longer than the presumed presence of the hazardous gas/dust.

INTRINSIC SAFETY

Intrinsic Safety (I.S.) removes the ignition source from the ignition triangle. The official definition is as follows: Intrinsically safe equipment and wiring shall not be capable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific atmospheric mixture in its most easily ignited concentration.

METHOD	ADVANTAGES	DISADVANTAGES
Pneumatic	1. Self-contained system 2. Non-electric (air)	1. Limited distances 2. High maintenance 3. Limited number of operations
Fiber Optic or Photovoltaics	1. Speed 2. Non-electric (light)	1. Cost 2. Special components (switches, etc.) 3. Limited distance, environment & applications
Explosion-Proof Enclosures	1. Familiarity 2. Proven applications 3. High voltage	1. High cost 2. High maintenance, no live maintenance 3. Size, weight
Purging (Pressurization)	1. Lowers the area classification 2. Can be used in applications where nothing else can be used	1. High cost & maintenance, limited access 2. Gas supply needed 3. No live maintenance
Encapsulation, Miscellaneous	1. Good complement 2. Mechanical protection	1. Not approved 2. Throw-away
Intrinsic Safety	1. Low maintenance 2. Low installation cost 3. Many applications	1. New in North America

Figure 3-7: Comparison of Safety Methods.

Ronan's Series X57 Intrinsic Safety Barriers eliminate the ignition source from the ignition triangle, thereby preventing combustion. There are two basic types of ignition sources.

THERMAL IGNITION

The first type of ignition source is thermal. A hot surface can cause ignition by spontaneous combustion. This is why every hazardous area has a temperature classification (see Table 4-1 for a full listing of all the temperature classifications).

Let's take one example of how temperature classification works. A hazardous area classified as T4 risks explosion if any surface gets hotter than 135°C (275°F). Faulty motor windings, for example, can create such a high temperature very quickly. Any piece of equipment used inside this particular hazardous area must not be capable of generating a temperature greater than 135°C. Only equipment rated at T4, T5, or T6 would be allowed in this hazardous area.

Maximum Surface Temperature		Europe	USA/ Canada
Fahrenheit	Centigrade		
842	450	T1	T1
572	300	T2	T2
536	280		T2A
500	260		T2B
446	230		T2C
420	215		T2D
392	200	T3	T3
356	180		T3A
329	165		T3B
320	160		T3C
275	135	T4	T4
248	120		T4A
212	100	T5	T5
185	85	T6	T6

Figure 4-1: Temperature Classifications.

IGNITION BY SPARK

The second type of ignition source is the spark. Matches and cigarette lighters fall into this category. Many chemical plants place containers at the entrance where people must put their matches or lighters before entering.

A spark can also be produced electronically. Any electronic device which stores or produces energy can cause a spark. Let's discuss three different electronic ignition mechanisms in more detail.

CLOSING OF CONTACTS IN CAPACITIVE CIRCUITS

A capacitor stores energy in the electrical field between its plates, and this energy can present itself as a spark in the hazardous area.

When the switch in Figure 4-2 is open in a capacitive circuit, the capacitor charges to a voltage "V", and accumulates an energy equal to one-half the capacitance (C) times the square of the voltage.

$$E = 1/2 \ CV^2$$

When the contacts close in a capacitive circuit to discharge a capacitor, a spark can form just before the contacts touch. Because the contacts are almost touching, the size of the spark is small.

The switch shown in this example can also represent field wiring which is accidently shorted.

Figure A-1, in Appendix A, compares the ignition voltage to capacitance.
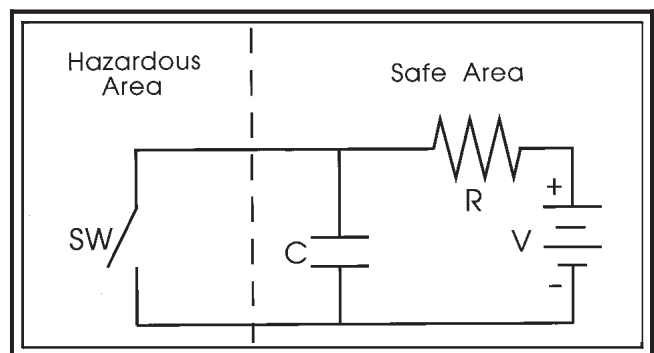
Figure 4-2: Closing of contacts in capacitive circuits.
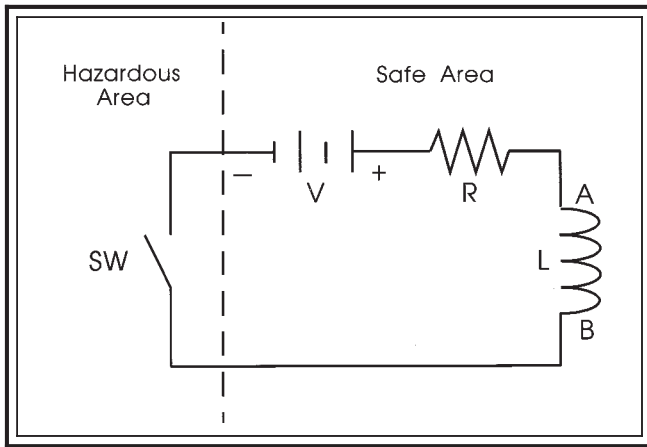
Figure 4-3: Opening contacts in inductive circuits.

OPENING CONTACTS IN INDUCTIVE CIRCUITS

The energy stored in the magnetic field of an inductor can be released in the form of a spark in the hazardous area.

With the switch in Figure 4-3 closed, the inductor L stores an energy equal to one-half the inductance times the square of the current.

$$E = 1/2 \, Li^2$$

When the switch opens, the inductor "tries" to keep current flowing from A to B as it had been before the switch was opened. The voltage which attempts to continue this current flow is determined by the equation

$$V = L(di/dt)$$

The term "di/dt" is the change in current with respect to time. This number can be very large because the current will change from its previous value to zero, the instant the switch is opened. If the inductance is large, then the voltage developed (which is equal to L * di / dt) is large, and a spark could appear between the two electrodes formed by the switch opening.

The switch shown in this example can also represent field wiring which is accidently cut.

Figure A-2, in Appendix A, compares ignition current to inductance.

OPENING AND CLOSING OF CONTACTS IN RESISTIVE CIRCUITS

In this instance, shown in Figure 4-4, the ability to ignite the hazardous atmosphere depends on the open circuit voltage ($V = V_{OC}$), and the short circuit current ($I_{SC} = V/R$). Energy from the power supply could be released in the form of a spark at the point of the circuit opening or shorting.

Figure A-3, in Appendix A, compares the ignition current to voltage for resistive circuits.
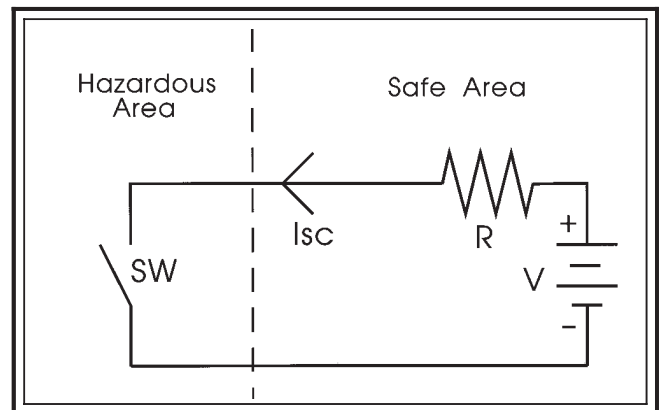
Figure 4-4: Opening and closing of contacts in resistive circuits.

Figure 5-1: The Intrinsic Safety Barrier. Notice the intrinsic safety barrier is always located in the safe area.

I.S. BARRIER INTERCONNECTION

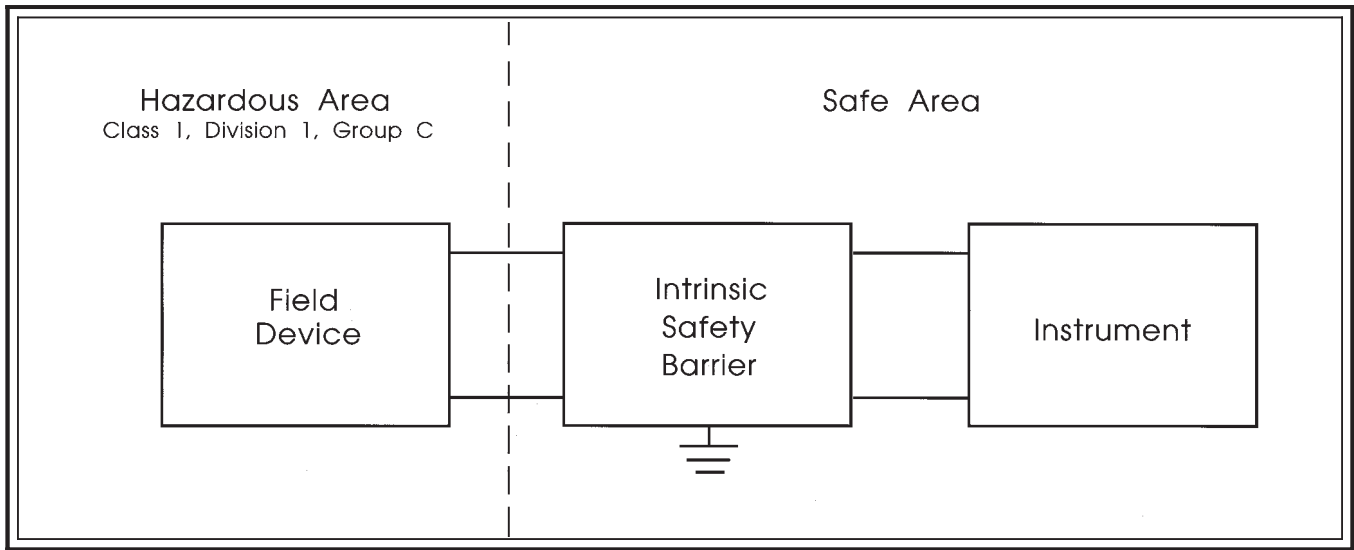As illustrated in Figure 5-1, an intrinsic safety barrier is inserted in the non-hazardous, or safe area between the instrument and the field device. The barrier blocks dangerous energy from being transmitted from the instrument to the hazardous area. This energy could be from a power supply, stored in capacitors, stored in inductors, or some combination of the three. This energy could be released due to some combination of faults (open circuits, shorts, grounds, etc.) occurring in the system.

The field devices used in any hazardous area must be one of two types:

Simple Apparatus - Barriers may be used with devices which qualify as "simple apparatus" without specific approval for the simple apparatus. A simple apparatus is a field device which meets the following requirements:

◆ Device does not store more than 1.2 Volts or 20µ Joules.

◆ Device does not draw more than 100 mAmps.

◆ Device does not dissipate more than 25 mWatts.

Some examples of simple apparatus include: thermocouples, RTD's, switches and LED's.

I.S. Certified Apparatus - Any device which does not fall into the category of simple apparatus must be I.S. Certified. This includes transmitters, current to pressure convertors, solenoid valves, et. al. Certification may come from FM, CSA, BASEEFA, or the regional qualifying agency (see chapter 8 for more details).

An intrinsic safety barrier is used to connect a non-certified piece of electrical equipment in a safe area to a certified or simple field device in a hazardous area. A barrier **cannot** be used to make an uncertified device safe in a hazardous area. If a field device is uncertified, it can have internal energy storing components. These components, in the case of a fault, may cause a spark, which in turn may start the combustion process. *The barrier only protects the non-certified device in the safe area from transmitting dangerous energy to the hazardous area.* In summary, the barrier is an energy limiting device placed on the electrical wires between the safe and hazardous areas.
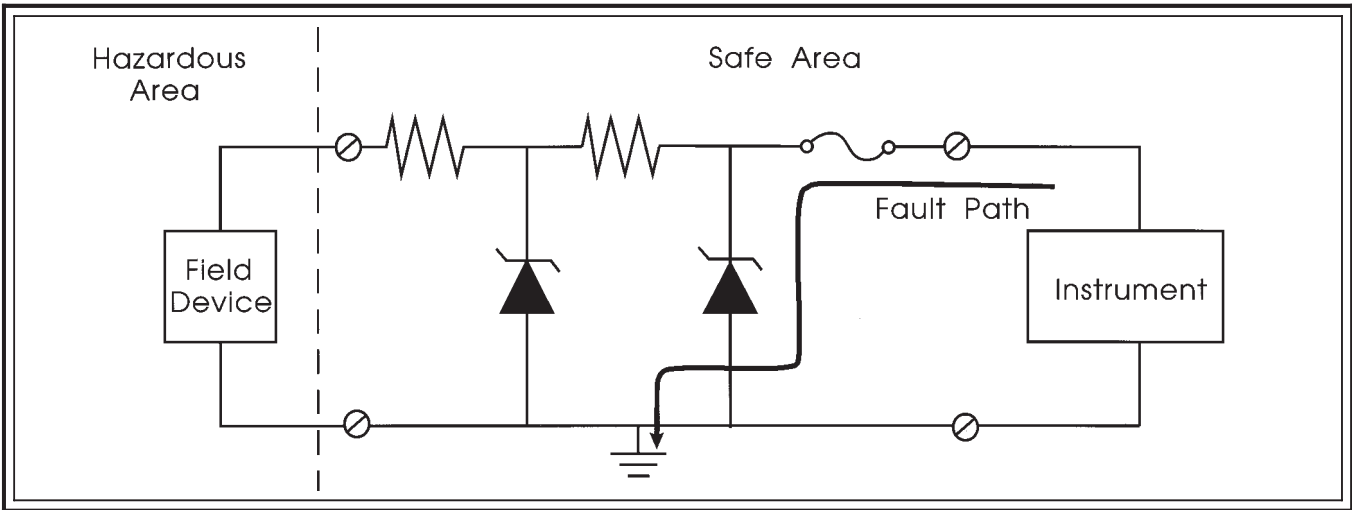
Figure 5-2: Zener Barrier Fault Path.

There are two basic varieties of intrinsic safety barriers: the zener barrier and the active barrier. Let's review each of them in a little detail.
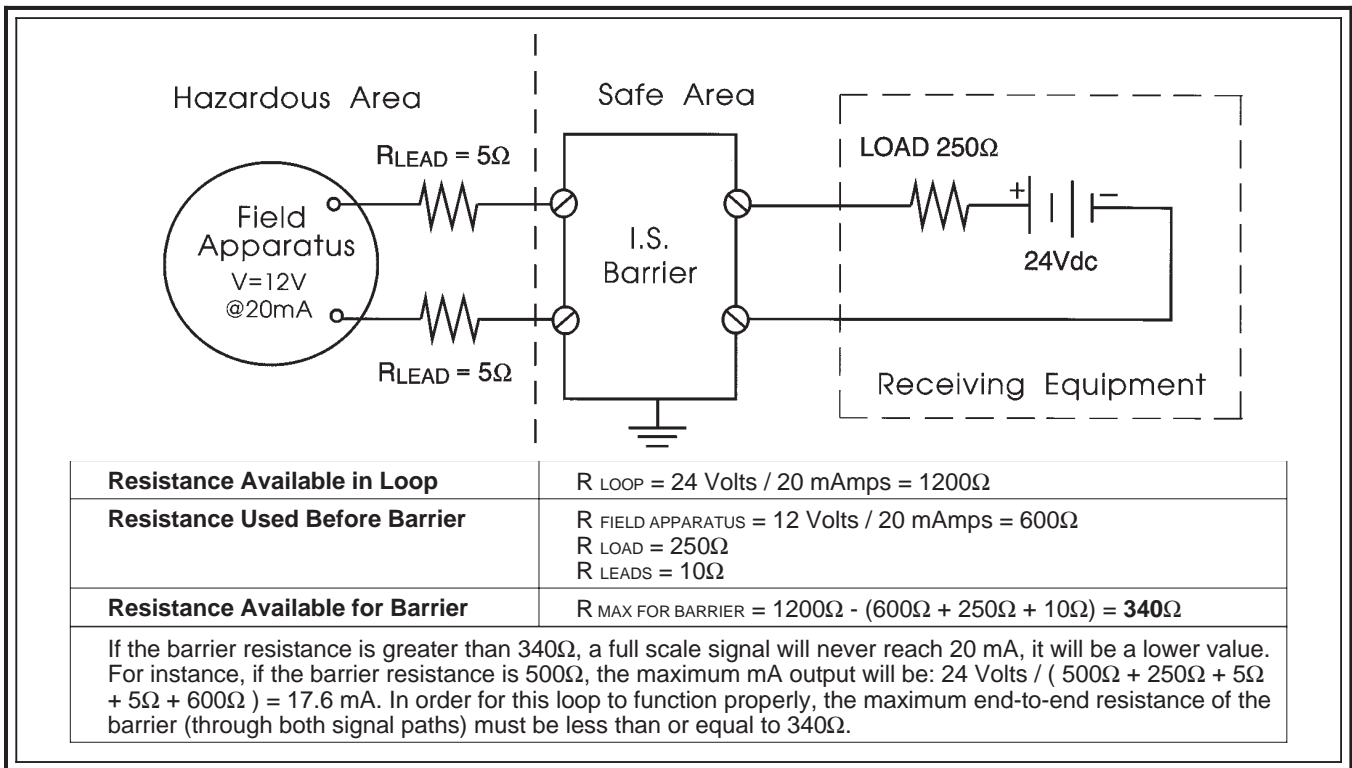
ZENER BARRIER

The zener diode barrier works by diverting potentially dangerous energy to ground before it can reach the hazardous area.

The zener diodes limit the fault voltage to the hazardous area. There are two such diodes for redundancy. The series resistor limits current to the hazardous area, and is considered an infallible component. The arrow in Figure 5-2 shows the resultant path if excess current enters the barrier as a result of excess voltage input from the instrument.

Since a zener barrier is powered by the loop and it has a current limiting resistor, it has a voltage drop across it. This barrier, in addition to protecting against

Resistance Available in Loop	R LOOP = 24 Volts / 20 mAmps = 1200Ω
Resistance Used Before Barrier	R FIELD APPARATUS = 12 Volts / 20 mAmps = 600Ω R LOAD = 250Ω R LEADS = 10Ω
Resistance Available for Barrier	R MAX FOR BARRIER = 1200Ω - (600Ω + 250Ω + 10Ω) = **340Ω**
If the barrier resistance is greater than 340Ω, a full scale signal will never reach 20 mA, it will be a lower value. For instance, if the barrier resistance is 500Ω, the maximum mA output will be: 24 Volts / (500Ω + 250Ω + 5Ω + 5Ω + 600Ω) = 17.6 mA. In order for this loop to function properly, the maximum end-to-end resistance of the barrier (through both signal paths) must be less than or equal to 340Ω.	

Figure 5-3: Will the resistance of a zener barrier adversely affect this 24 V, 4-20 mA transmitter loop? Not if it is less than 340Ω.
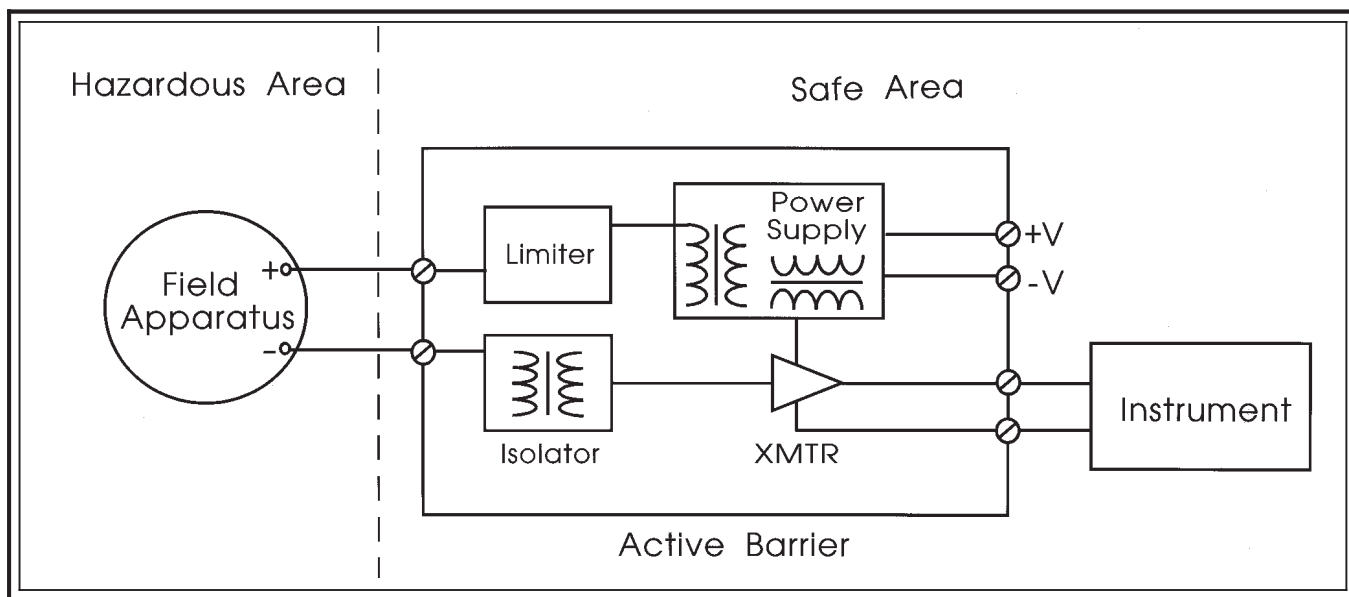
Figure 5-4: Active Barrier. An active barrier is sometimes called a galvanically isolated barrier.

dangerous energy entering the hazardous area, must allow the loop to function normally.

The example in Figure 5-3 shows a 24 V, 4-20 mA transmitter loop.

In this example, the sum of the voltage drops around the loop can be calculated and verified that they are less than 24 V. Instead, since the maximum resistance of the barrier is specified ($R_{MAX\ END\ TO\ END}$), Ohm's law is used (V = IR) to calculate the total resistance available in the loop. Either method (loop voltage or loop resistance) works identically. What we are trying to decide is whether or not the resistance of the barrier will adversely affect the loop.

ACTIVE BARRIER

An active barrier uses transformers, opto-isolators or relays to provide isolation between the hazardous area and the non-hazardous area. It does not require an intrinsically safe ground connection. Either or both the hazardous area or the non-hazardous area signals may be grounded.

This may be the most logical barrier choice if a high quality I.S. grounding point is not available.

Figure 5-4 shows a diagram of an active barrier. The barrier requires a 24 Vdc power supply, and can typically drive larger loads than a loop powered zener barrier.

◇6◇ Installation

REQUIREMENTS FOR INTRINSIC SAFETY

Intrinsically safe systems should satisfy these requirements:

◆ Ensure that there is a positive separation of intrinsically safe and non-intrinsically safe circuits. This prevents the ignition capable energy from intruding into the intrinsically safe circuit.

◆ Separate conduit, panduit, cable trays, etc. should be used for I.S. wiring to keep it separate from the non-I.S. wiring. If conduit is used, it must be sealed per the applicable code. This is to prevent the conduit from becoming a means of conducting flammable material from the hazardous to the non-hazardous location. I.S. wiring must always be identified. This can be performed by tagging the wires, labelling the junction boxes, and/or color-coding the I.S. wires light blue.

◆ Ensure that the entity parameters, upon which approval of the system is based, match up correctly.

ENTITY CONCEPT

The entity concept has been approved by Factory Mutual since 1978. The approval agency specifies the maximum energy a barrier can ever deliver, as well as the maximum energy a field device can ever receive and still be safe. The entity concept allows interconnection of I.S. barriers to I.S. field devices not specifically tested in such combinations. It also allows mixing of equipment from different manufacturers without additional approvals.

Certification of barriers and field devices is based on the following conditions. Barrier entity parameters (from FM) must state the maximum voltage and current delivered under fault conditions. A field device entity parameter must state the maximum current and voltage which

the hazardous area device can safely receive.

An I.S. barrier can safely be used with a field device if it has a maximum voltage and current less than or equal to that which the field device can safely receive. All these parameters are defined by the approval agency.

Entity Equations for Current and Voltage

$$I_{TOTAL} \text{ (Barrier)} \leq I_{MAX} \text{ (Field Device)}$$

$$V_{TOTAL} \text{ (Barrier)} \leq I_{MAX} \text{ (Field Device)}$$

In addition to voltage and current, the entity parameters also include two more terms to ensure that the energy storing devices in the field do not store up a dangerous amount of energy. These terms deal with the total capacitance and total inductance of the system.

A barrier has parameters which state the maximum capacitance and maximum inductance which can be safely connected to it. A field device has parameters which state the equivalent capacitance and inductance of the field device. Since wiring has capacitance and inductance, this also needs to be considered. The capacitance of the field wiring must be added to the capacitance of the field device to determine whether the total capacitance for the

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**Entity Equations
for Capacitance and Inductance**

Capacitance + Capacitance ≤ Capacitance
(Field Device) (Field Wiring) (I.S. Barrier Max)

Inductance + Inductance ≤ Inductance
(Field Device) (Field Wiring) (I.S. Barrier Max)

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field exceeds the maximum allowed for connecting to the I.S. barrier. The same principle applies to the inductance.

GROUNDING

When using zener barriers, the dangerous energy is diverted to ground. Therefore, it is important to ensure a high quality intrinsic safety ground. In fact, because this grounding is so critical, two separate ground connections from each barrier are recommended, each with a resistance of less than 1 ohm.

The following rules should be adhered to for I.S. grounding:

◆ Since zener diode barriers work by diverting fault currents, they must have a good quality ground.

◆ The impedance of the conductor from the barrier ground bus to the ground connection should be less than 1 ohm.

◆ Follow local codes.

◆ Ground cables should be insulated.

◆ Ground cables should be protected mechanically if there is a risk of damage.

◆ Ground cable should be an uninterupted run to the nearest high integrity earth point.

◆ Redundant cables are advisable.

Intrinsically safe products and systems are certified or approved as safe by various agencies. These same agencies also approve explosion-proof devices, enclosures and accessories.

Why doesn't a customer just buy safety products from a vendor, connect them up, and pronounce the system safe? Why does he need an approval agency?

The approval agency does all the safety analysis for the end user. The user now does not have the responsibility for determining whether or not the system is safe. Most users do not have the extensive ignition testing facilities found at the approval agencies. For a user to evaluate all the equipment he uses would require an enormous investment.

Another important reason for going through an approval agency is that the user reduces his liability by specifying only approved devices (including simple devices) for use in hazardous areas. Most insurance companies require approved devices in the hazardous areas. Large companies that are self-insured typically require all approved devices as well.

The certification agencies in the U.S.A. are Underwriters Laboratory (UL) and Factory Mutual Research Corporation (FM or FMRC). Typically, FM does most of the intrinsically safe approvals. UL has steered more towards handling approvals for systems rated at 115 Vac and higher, which have no application in intrinsic safety.

FM has been around for well over 100 years. FM started when a group of insurance companies formed a lab to test products used in the properties they insured. This agency approves a wide variety of equipment, materials, and services for property conservation. A few of these products are fire extinguishers, automatic sprinkler systems, building materials, shut-off valves, and electrical equipment used in hazardous areas. Such

electrical equipment would include explosion-proof, non-incendive, and intrinsically safe devices.

Equipment rated as intrinsically safe is recognized by article 500 of the National Electrical Code as safe for use in hazardous locations without special enclosures or physical protection that would otherwise be required.

The Factory Mutual approval standard for intrinsic safety is number 3610, dated October, 1988. Any intrinsically safe product, whether it is located in the hazardous area or it connects to a device in the hazardous area, must meet this approval standard. After January 1, 1992, any device which was not examined or not re-examined under this new standard can not be sold as an I.S. device. This new standard attempts to get rid of all the various I.S. products on the market approved to old standards. In the past, companies would get a "grandfather clause" and sell new devices approved to old standards.

The sharp customer will want to verify that any I.S. product he purchases (i.e. I.S. field device, I.S. barrier, or product with integral I.S. barrier) is approved to the new standard. He will also want to know what applications the approval is for: e.g., can you use the product with two barriers connected in parallel, or one barrier connected to two field devices? Additionally, he will want to know the entity parameters for the product. The customer can ask the vendor for a copy of the approval as well as for the appropriate installation drawings.

The design standard, which both FM and UL design their approval processes to meet, is ANSI/UL 913 (formerly NFPA 493). The installation standard is ANSI/ISA RP12.6, "Installation of Intrinsically Safe Instrumentation Systems in Class I Hazardous Locations." This documentation should be used for guidance on I.S. installations. The National

Electrical Code, section 504, also discusses I.S. installation.

In Canada, I.S. product approvals are obtained through the Canadian Standard Association (CSA). This group develops the standard and also certifies devices to the standard.

When obtaining FM and CSA approvals for intrinsic safety, the equipment must also meet the requirements for general purpose use. For FM, this means you must also meet the requirements of the Factory Mutual Standard for Electrical Utilization Equipment. This ensures a piece of equipment is not a shock or fire hazard.

When someone specifies FM approval, they should specify which type of FM approval they require. If it is general purpose (G.P.) approval, a device which is approved for I.S. or G.P. can be used. If the approval is for I.S., only I.S. approved devices may be used.

8 Definition of Barrier Terms

VOLTAGE

Open Circuit Voltage (V_{OC}) - The maximum voltage a barrier can deliver to the hazardous area in the case of a fault. This value is assigned by Factory Mutual based on the configuration of the barrier application. This entity parameter is tested and assigned by Factory Mutual.

Basic Safety Specification (V) - Approximate maximum voltage a barrier can deliver to the hazardous area. The design engineer will want to use V_{OC} instead of this term.

Working Voltage (V_{WK}) - The maximum dc voltage (or peak ac voltage) that can be connected between the safe area terminals and ground, with the hazardous area terminals open circuited. This is the maximum voltage the barrier can safely pass with no (or very little) leakage current through the zener diodes to ground.

Maximum Voltage (V_{MAX}) - The maximum peak voltage which can be sustained without opening the fuse. The hazardous area terminals are open circuited for this measurement. If they are not, then this current will reduce V_{MAX}. This is a measure of zener diode breakdown tolerance, and fuse characteristics. This I.S. barrier term should not be confused with the V_{MAX} entity parameter of a field device.

RESISTANCE

Basic Safety Specifications (Ohms) - The value of the terminating resistor. This resistor performs the current-limiting function, and is a wire wound (infallible) resistor.

Maximum End-to-End Resistance (Ohms) - The total resistance of the barrier between the safe and the hazardous area connection terminals, including all resistors and fuses.

CURRENT

Short Circuit Current (I_{SC}) - The maximum current a barrier can deliver to the hazardous area in a fault situation. It is based on the configuration of the barrier application. This entity parameter is tested and assigned by Factory Mutual.

Basic Safety Specification (mA) - The approximate maximum short circuit current available in the hazardous area under fault conditions. This value is calculated from the basic safety specifications for voltage and resistance (V/R).

Intrinsically safe barriers are designed to be application oriented. If you want a barrier for any application, an RTD, for example, you can select one of the few barriers a company has designed for RTD's. You may have a choice of a zener barrier to work with a two wire RTD, another zener barrier to work with a three wire RTD, and yet another zener barrier to work with a four wire RTD. You may also have a choice of an isolating active barrier and even a barrier which takes a three wire RTD input, performs signal conditioning, and gives an isolated, linearized, 4-20 mA output.

In general, once you know the application, you can choose from a small subset of a manufacturers' large variety of barriers. There are certain steps that you need to go through to select the proper barrier.

We are now ready to go through the process of selecting an I.S. barrier for an application. We will go through all the steps required so you can become familiar with them. Two examples follow, both with the same application.

The first example is basic barrier selection. It takes into account voltage and current. The second example is advanced barrier selection and is shown in Chapter 10. In this example, we take the basic barrier selection and expand it to include capacitance and inductance. These four parameters: voltage, current, capacitance, and inductance help form the entity concept which allows users to safely "mix and match" barriers and field devices from different manufacturers.

These examples show two considerations the user needs to look at when selecting a barrier. The first is that the barrier allows the loop to function during normal operating conditions. The second is that the loop is safe during fault conditions. In order to impress certain points, these examples do not review the voltage drop that will occur across the barrier when
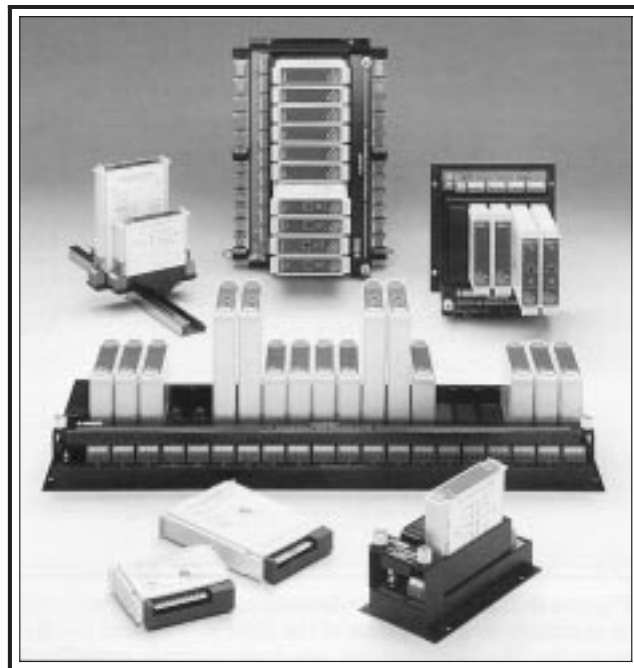

current passes through the barrier resistance. This must be considered, because during normal operating conditions, we do not want the voltage drop across the barrier to adversely affect the circuit. This will not affect the safety of the loop, it will just not allow the loop to function properly. These examples do not attempt to choose between an active or a zener barrier. The benefits of each were discussed earlier. The examples work equally well for both active and zener barriers.

Lastly, these examples do not consider multiple channel barriers, connecting multiple field devices to one barrier, or connecting multiple barriers to one field device. This gets a little more complicated. Any barrier must have an approved installation drawing showing that it is approved for the particular connection you are considering.

BASIC BARRIER SELECTION

When selecting a barrier, you must ask the following questions:

◆ What is the hazardous area classification?
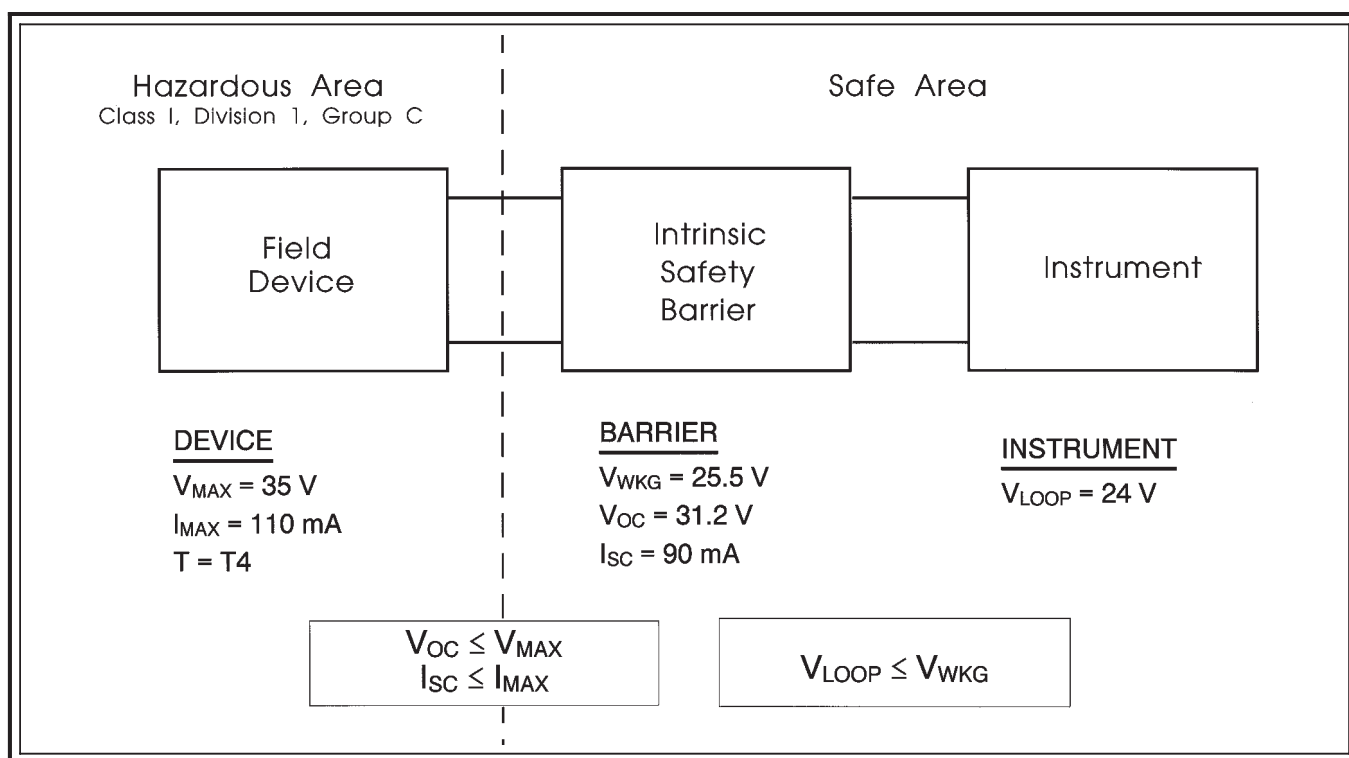
Figure 9-1: Basic Barrier Selection. In order to simplify the understanding of barrier selection, we will not consider the capacitance or inductance of the field wiring and the field device in the basic example. We will add this to the advanced example. The basic barrier selection example satisfies the three equations, therefore it is an approved loop. In addition to the three equations, the field device must be approved for use in that particular hazardous area (CL1, DIV1, GPC, T4). The barrier must also be approved for connection to that hazardous area (CL1, DIV1, GPC). All the critical safety approval parameters can be found in the installation drawings done by the manufacturer of the barrier and the field device.

◆ What is the input voltage to the barrier with respect to ground (AC, +DC, or -DC)? This is called V_{LOOP}.

◆What is the maximum voltage and current which can be applied to the field device (V_{MAX} and I_{MAX})? These are the entity parameters of the field device assigned by FM.

You will want to follow these guidelines when selecting a barrier:

◆ Select a barrier that is approved for use in the hazardous area where it will be installed.

◆ V_{LOOP} ® V_{WKG} (barrier)

◆ V_{OC} (barrier) $\leq V_{OC}$

◆ I_{SC} (barrier) $\leq I_{MAX}$

V_{WKG} = working voltage
V_{OC} = max voltage delivered to the hazardous area
I_{SC} = max current delivered to the hazardous area
V_{MAX} = max voltage which can safely be applied to the field device
I_{MAX}= max current the field device can safely draw

Figure 9-1 shows a barrier connected between an instrument in the safe area and an I.S. approved field device. The barrier can be safely used here and has full approval. During normal operating conditions, this instrument loop operates at +24 Vdc. The zener diodes in the barrier do not start to conduct any voltage to ground until that voltage reaches +25.5 Vdc. Thus, under normal operating conditions, the barrier is transparent to the loop.

During fault conditions, the maximum voltage the barrier can ever deliver to the hazardous area is 31.2 V. The field device is approved safe for that hazardous area if it never receives more than 35 V. The barrier ensures this. The barrier can never deliver more than 90 mA to the hazardous area during fault conditions. The field device is safe as long as it never receives more than 110 mA. The barrier ensures this as well. Therefore, because the voltage and current entity parameters match

20

up correctly, this loop is approved intrinsically safe.

This was a little bit simplified, and did not consider the capacitance and inductance entity parameters. In reality, all the entity parameters (voltage, current, capacitance and inductance) must match up correctly in order for the loop to be approved intrisically safe. The entity parameters are all given by the approval agency and obtained through the manufacturer. These are shown in an installation drawing. There is one installation drawing from the barrier manufacturer and one from the I.S. field device manufacturer. Both of these should be obtained by the user to ensure correct design. And keep in mind, just because the loop is safe does not mean that it works!

The normal operating conditions are given by the manufacturer and are not subject to approvals.

Let's take the next step and discuss capacitance and inductance.

CABLE CAPACITANCE AND INDUCTANCE

A cable (or wire) is an energy storing device. A cable stores capacitive energy and inductive energy. From an intrinsic safety standpoint, this cabling needs to be analyzed to ensure safety at the system level. What good does it do to limit the amount of energy which can be passed through the barrier if potentially dangerous energy can be stored in the cable?

Figure 9-2 diagrams the relationship of capacitive energy to cable length and of inductive energy to cable length. Capacitive energy stored in cabling increases as cable length increases.
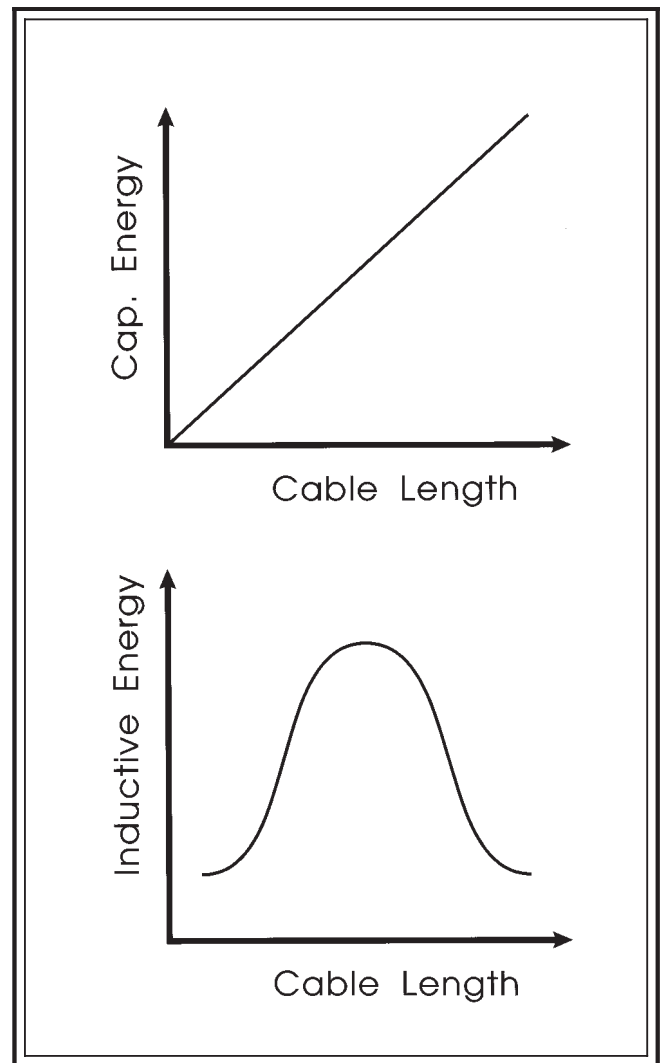
Figure 9-2: Cable Capacitance and Inductance.

The maximum inductive energy which is stored in the cable is related to the ratio L/R, and is independent of the cable length.

The L/R parameter is the unit inductance of the cable divided by the unit resistance of the cable. This parameter is used in the example in Chapter 10.
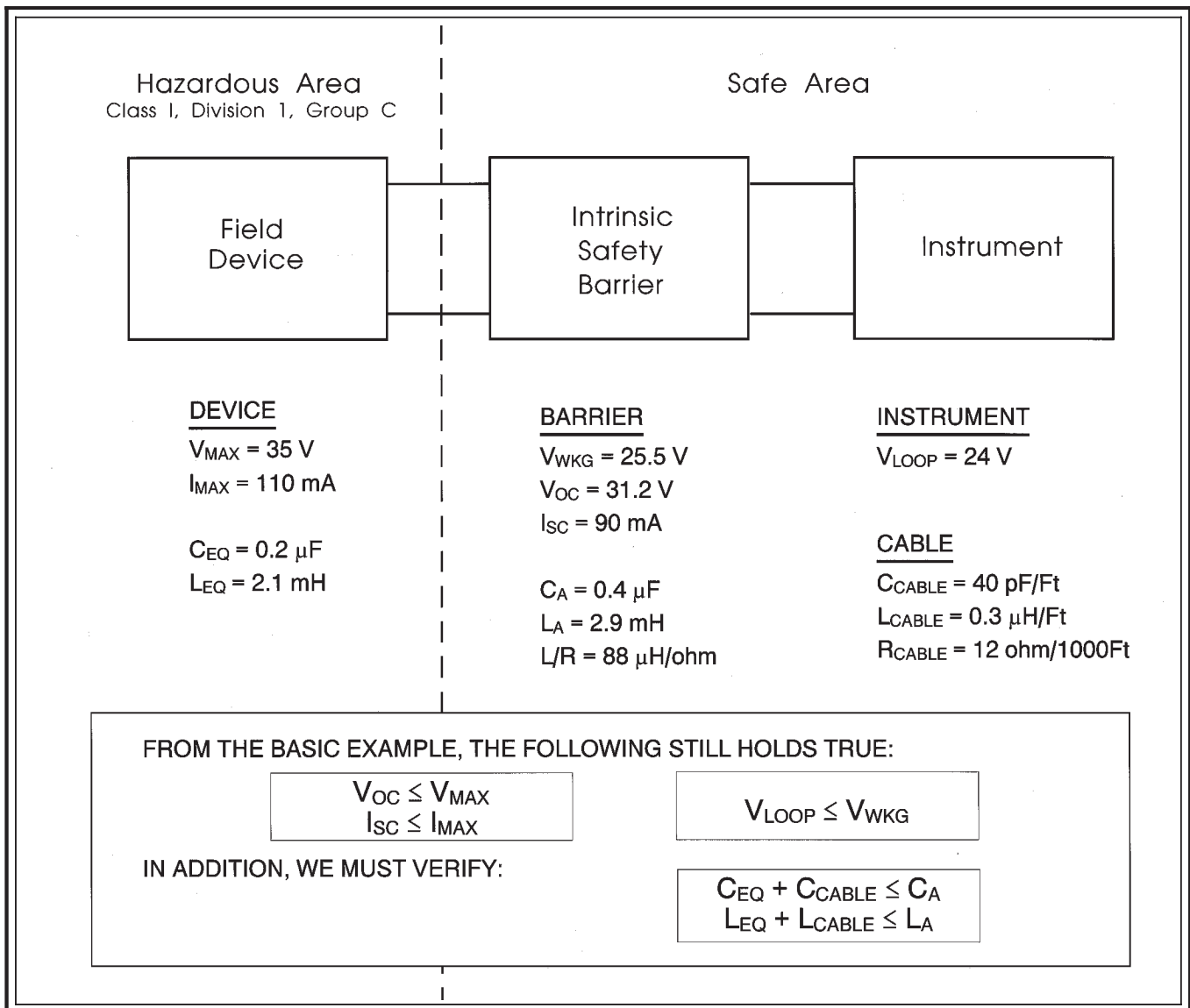
10 Advanced Barrier Selection
(Includes Cabling)

Let's go through our first example a second time, taking into consideration capacitance and inductance. In addition to the questions asked in the basic selection, we need to ask the following:

◆ For the field device: What is the value of the capacitance and inductance appearing at its terminals? (This is called C_{EQ} and L_{EQ} and is specified by FM.)

◆ For the cables: What is the capacitance and inductance of the cable used [C_{CABLE} (in pF/ft.), and L_{CABLE} (in µH/ft.)]? The L/R ratio of the cable can be used instead of the inductance/ft., simplifying the calculations.

◆ For the barrier: What is the amount of capacitance and inductance which may be safely connected to it? This is called C_A and L_A and is specified by FM.)

Hazardous Area
Class I, Division 1, Group C

Safe Area

Field Device

Intrinsic Safety Barrier

Instrument

DEVICE

$V_{MAX} = 35$ V
$I_{MAX} = 110$ mA

$C_{EQ} = 0.2$ µF
$L_{EQ} = 2.1$ mH

BARRIER

$V_{WKG} = 25.5$ V
$V_{OC} = 31.2$ V
$I_{SC} = 90$ mA

$C_A = 0.4$ µF
$L_A = 2.9$ mH
$L/R = 88$ µH/ohm

INSTRUMENT

$V_{LOOP} = 24$ V

CABLE

$C_{CABLE} = 40$ pF/Ft
$L_{CABLE} = 0.3$ µH/Ft
$R_{CABLE} = 12$ ohm/1000Ft

FROM THE BASIC EXAMPLE, THE FOLLOWING STILL HOLDS TRUE:

$$V_{OC} \leq V_{MAX}$$
$$I_{SC} \leq I_{MAX}$$

$$V_{LOOP} \leq V_{WKG}$$

IN ADDITION, WE MUST VERIFY:

$$C_{EQ} + C_{CABLE} \leq C_A$$
$$L_{EQ} + L_{CABLE} \leq L_A$$

Figure 10-1: Advance Barrier Selection. In this example, we take the basic example and also consider the capacitance and inductance of the field wiring and the field device.

The following simple equations need to be satisfied:

$$C_{EQ} + C_{CABLE} \leq \underline{C_A}$$
$$L_{EQ} + L_{CABLE} \leq \underline{L_A}$$

Figure 10-1 illustrates the previous example with capacitance and inductance taken into consideration. The maximum allowable cable capacitance, and therefore maximum allowable cable length is calculated as follows:

$$\underline{C_{EQ} + C_{CABLE} \leq C_A}$$

$$
\begin{aligned}
C_{CABLE} &= C_A - C_{EQ} \\
&= 0.4\ \mu F - 0.2\ \mu F \\
&= 0.2\ \mu F\ max \\
Length &= 0.2\ \mu F\ /\ 40\ pF\ /\ ft \\
&= 5000\ ft\ max
\end{aligned}
$$

Due to Capacitive Energy

$$\underline{L_{EQ} + L_{CABLE} \leq L_A}$$

$$
\begin{aligned}
L_{CABLE} &= L_A - L_{EQ} \\
&= 2.9\ mH - 2.1\ mH \\
&= 0.8\ mH\ max \\
Length &= 0.8\ mH\ /\ 0.3\ \mu H\ /\ ft \\
&= 2667\ ft\ max
\end{aligned}
$$

Due to Inductive Energy

Since capacitive energy increases per unit length, 5000 ft. is the max. cable length permitted due to capacitive energy. However, inductive energy calculations result in a maximum length of 2667 ft.

The ideal intrinsic safety system designer takes the capacitance and inductance into account at the beginning of the design, not as an afterthought to verify safety.
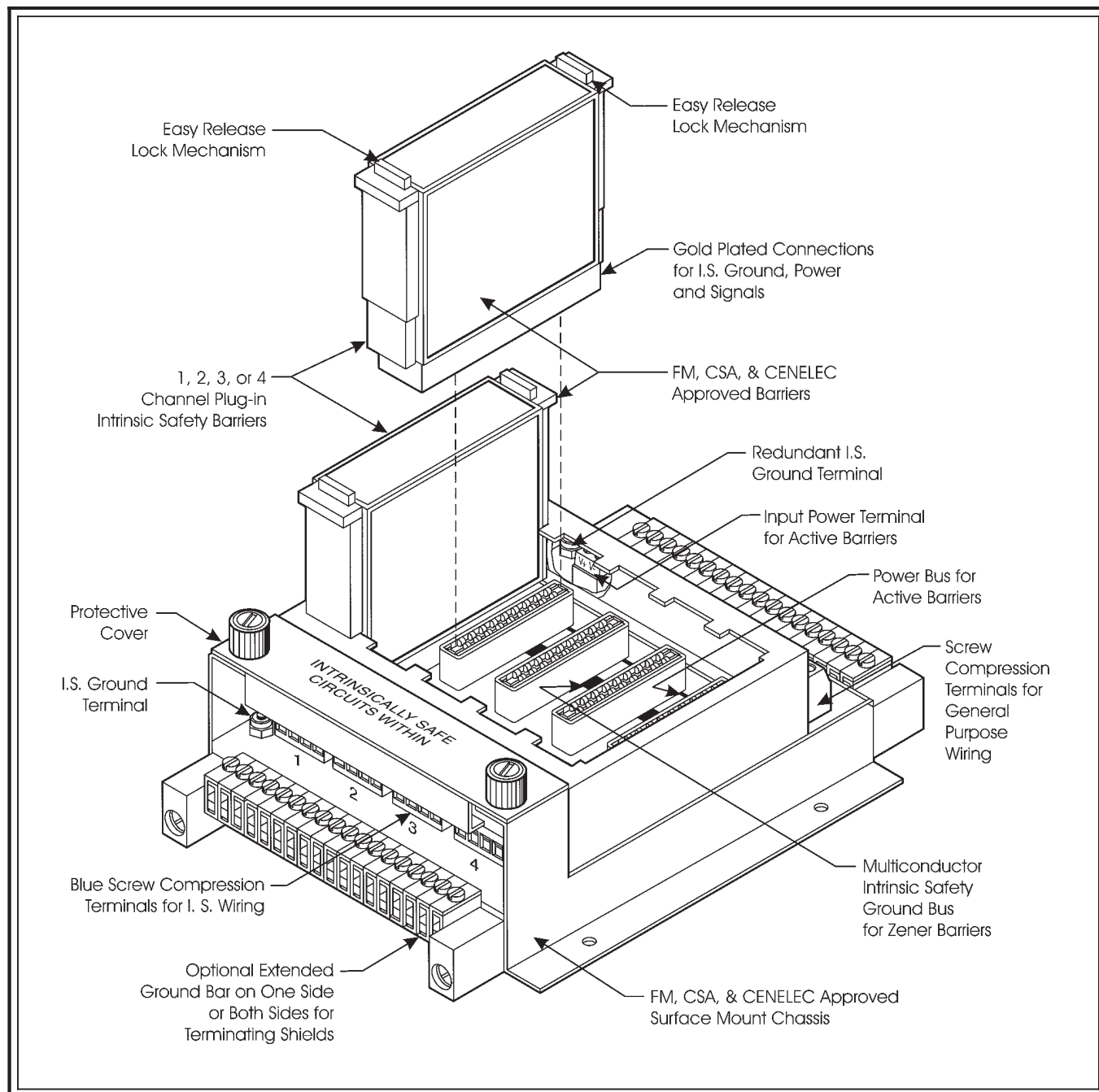
The designer can calculate that capacitance and inductance allowed in the cable. Next, knowing his longest cable length, he can calculate some cable requirements. The values used in the above example (40 pF/ft. and 0.3 μH/ft.) are typical parameters and are usually not exceeded in instrumentation cable. By defining maximum cable parameters, the designer is leaving nothing to chance.

Ronan's Philosophy on the Intrinsic Safety Barrier

Before designing the X57 Series, Ronan investigated many different factors that should go into the design of an intrinsic safety barrier.

Several factors involved meeting the requirements of the various approval agencies. In the development of the I.S. approval standards, these agencies took

Easy Release Lock Mechanism

Easy Release Lock Mechanism

Gold Plated Connections for I.S. Ground, Power and Signals

1, 2, 3, or 4 Channel Plug-in Intrinsic Safety Barriers

FM, CSA, & CENELEC Approved Barriers

Redundant I.S. Ground Terminal

Input Power Terminal for Active Barriers

Power Bus for Active Barriers

Protective Cover

I.S. Ground Terminal

INTRINSICALLY SAFE CIRCUITS WITHIN

Screw Compression Terminals for General Purpose Wiring

Blue Screw Compression Terminals for I. S. Wiring

Multiconductor Intrinsic Safety Ground Bus for Zener Barriers

Optional Extended Ground Bar on One Side or Both Sides for Terminating Shields

FM, CSA, & CENELEC Approved Surface Mount Chassis

Figure 11-1: Intrinsic Safety Barriers with Surface Mount Chassis.

extra safety precautions with each step. Some of these measures include: assuming any mixture present is at its most easily ignited concentration, 1.5 safety factor on the maximum current allowed, two ground wires for redundancy, and two zener diodes required per channel.

When these safety standards were released, an alarming fact was discovered. Although no explosions have occurred with intrinsic safety barriers properly installed, explosions have resulted from faulty installations.

Further research and customer feedback illustrated a major need for easy installation, low maintenance and safety assurance. Observation of I.S. loops in the field showed additional areas where improvement was needed.

Taking all of these factors into account, Ronan developed a chassis-based design with modular (plug-in) barriers. All wiring connects directly to the chassis, not to the individual barriers. Also, a metal cover plate is provided to insulate the blue hazardous area terminal blocks. This gives additional protection for the intrinsically safe wiring. These design features have many advantages:

◆ The chassis has FM, CSA, and BASEEFA (CENELEC) approvals.

◆ Users wire up their system and can verify wiring accuracy before inserting any barriers in the loop. This minimizes the risk of losing any barriers during start up.

◆If a barrier needs to be removed or replaced, wire removal is not necessary. The old barrier snaps out easily and the new one snaps in.

This eliminates a major cause of intrinsic safety problems: maintenance. Most manufacturers of barriers do not provide additional safety in their mounting package to reduce installation and maintenance errors. Here's a direct quote from another manufacturer of barriers concerning replacement of intrinsic safety barriers.

"Should a safety barrier require removal from the intrinsically safe circuit please follow these guidelines.

Disconnect the wiring from the safety barrier's nonhazardous terminals prior to disconnecting wires from the intrinsically safe terminals.

Cover bare wire ends with tape or other insulating material, especially those conductors that are towards the hazardous (classified) location.

Disconnect the safety barrier from ground. In most cases this step will also remove the safety barrier from the mounting hardware.

Reverse this procedure to mount the new barrier."

Obviously these guidelines leave much to be desired.

◆ The chassis is easily installed and ready to use, unlike the flimsy "do-it-yourself" mounting arrangements available elsewhere.

◆ The zener barriers, which require ground, all connect to an FM approved internal I.S. ground bus. This bus connects to two external mounting studs which the user connects to I.S. ground. In a typical 20 position chassis, this reduces the number of crucial ground connections by 95%.

◆ The active barriers, which require 24 Vdc to operate, all connect to an internal power bus. This reduces the number of power connections by up to 95%.

◆ Any barrier can connect to any position in any chassis.

Keying of barrier and chassis positions is available in order to prevent putting a barrier in the wrong position.

In short, Ronan took an acceptable standard and went the extra mile to make it better, developing a design strategy that does not rely on ideal situations. Ronan I.S. Barriers provide safety along with ease of installation and maintenance in the real world.

Appendix: Ignition Graphs

The following are some of the many graphs which an intrinsic safety approval agency uses when certifying a field device for use in a particular hazardous area. These are the actual ignition graphs for the various gases. They represent the amount of electrical energy required to cause the combustion of an air/gas mixture at its most easily ignited concentration. The area under the curves represents an energy which is too small to cause an explosion.

Figure A-1 applies to resistance-capacitance circuits only. This graph compares the ignition voltage to capacitance for a Group B gas at its most easily ignited concentration. Various current limiting resistors are added in series to the discharge path of the capacitance. This is shown to lower the effective capacitance.
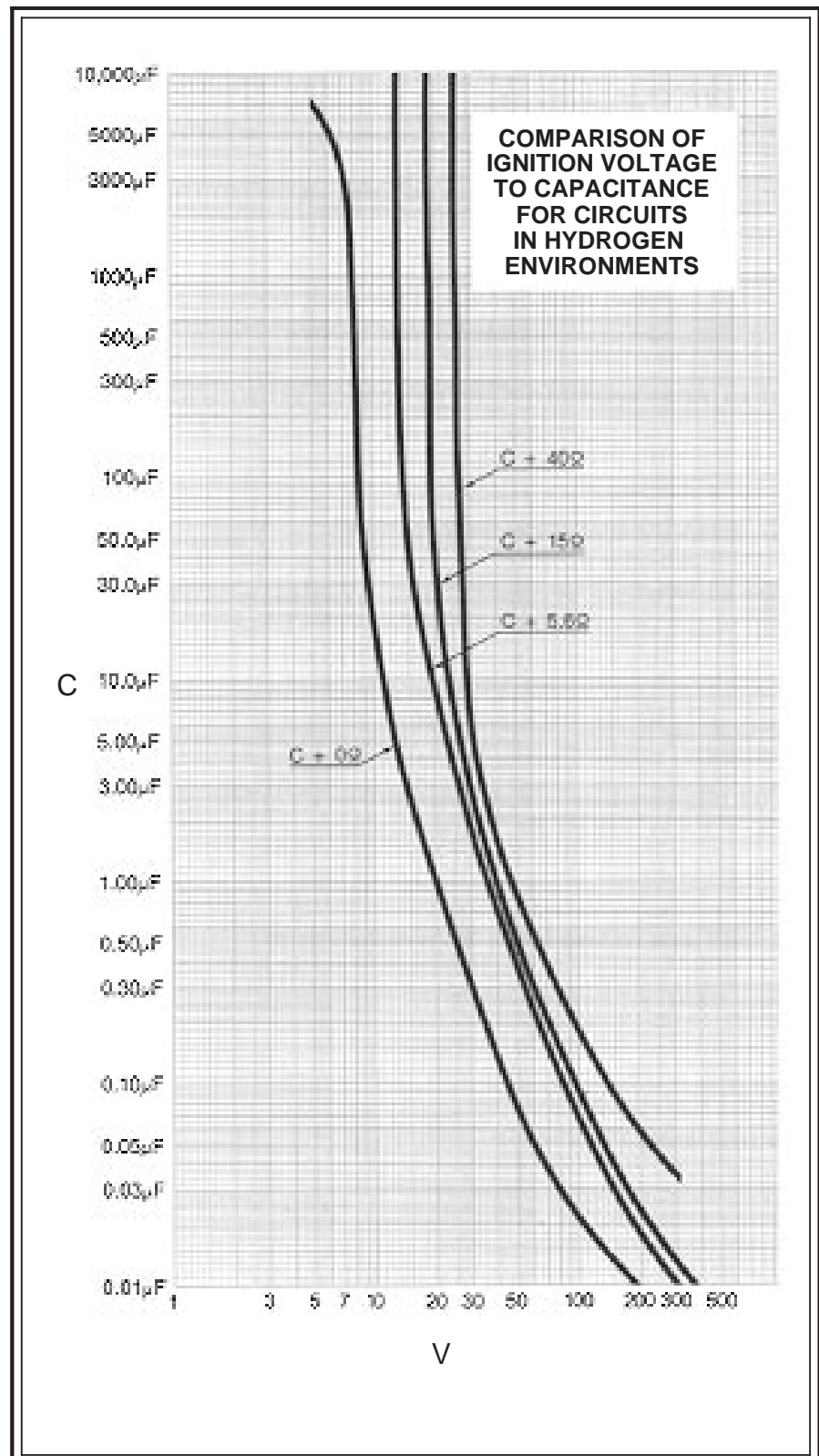

Figure A-1: Capacitance Circuits

Figure A-2 applies to resistance-inductance circuits only. This graph compares the ignition current to voltage for specific values of inductance. The curves represent the inductive energy required to cause the combustion of a Group B gas at its most easily ignited concentration.

Figure A-3 applies to resistive circuits only and shows the combinations of voltage and current which will ignite air/gas mixtures for groups A, B, C and D. When designing intrinsically safe products, a safety factor of 1.5 is applied to the ignition current allowed.
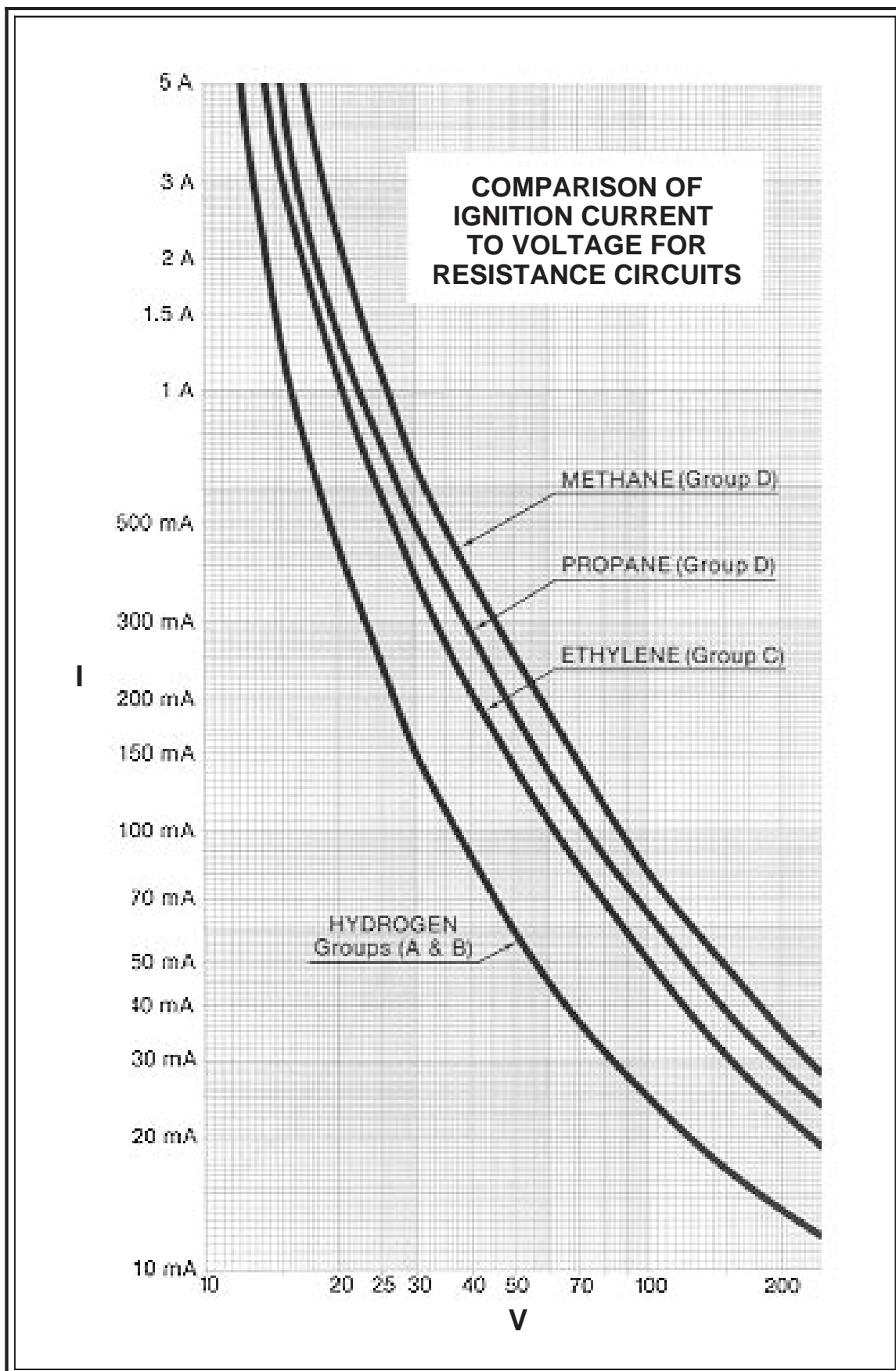
The approval agencies apply safety factors when using these graphs. You are not allowed to have a circuit which operates just below the ignition energy required for a particular gas. This would be too close to a potentially dangerous situation.

The selection of which intrinsic safety barrier to use for a particular application does not entail the use of these graphs
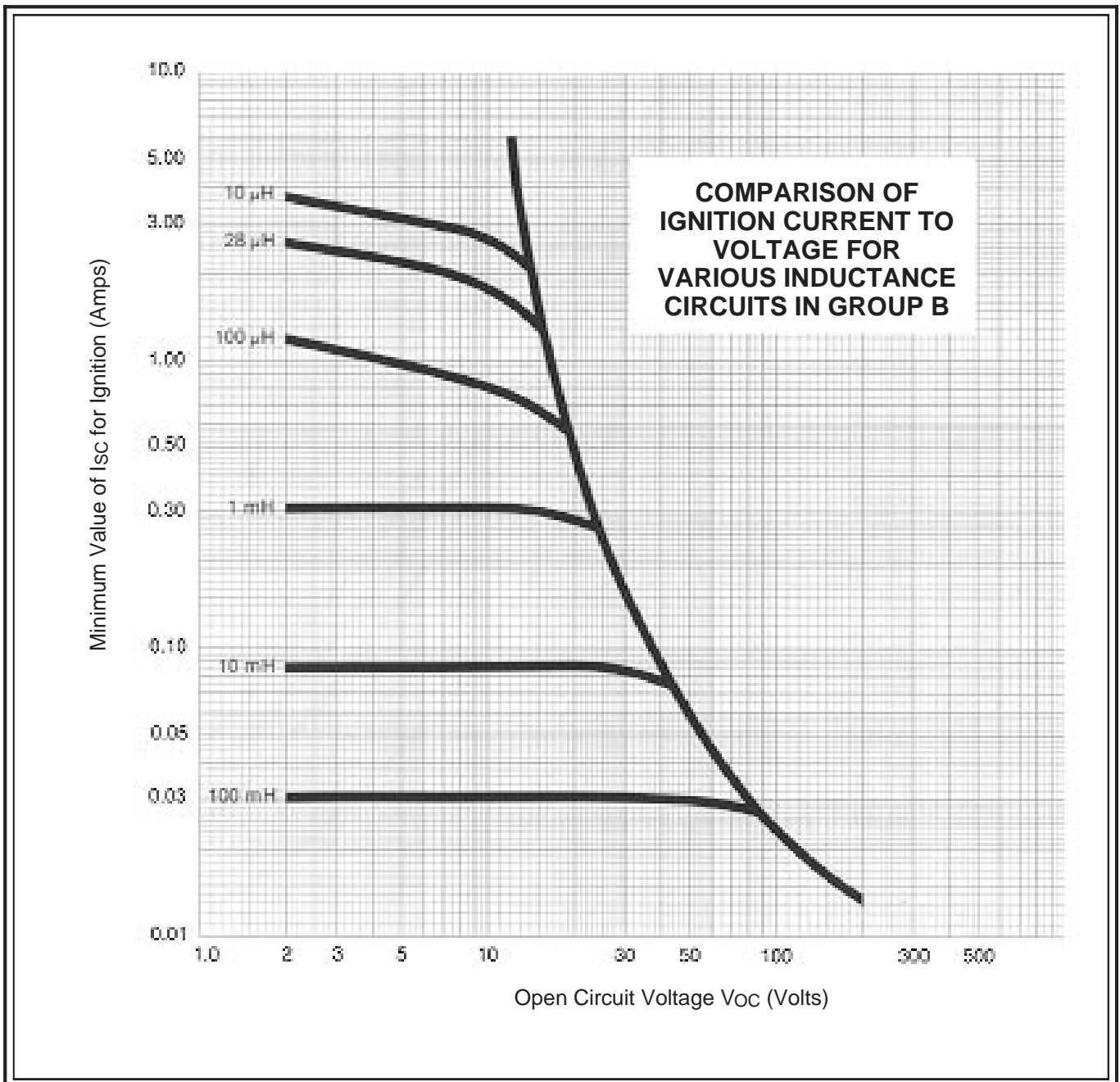
Figure A-2: Inductance Circuits

Figure A-3: Resistance Circuits