CRITERIA FOR THE EVALUATION AND TEST OF INTRINSICALLY SAFE APPARATUS AND ASSOCIATED APPARATUS (ACRI2001)

U.S. Department of Labor
Mine Safety and Health Administration
Approval and Certification Center
Electrical Safety Division
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1.0 PURPOSE

This document is the criteria MSHA uses to evaluate electrical apparatus, or parts of such apparatus, whose circuits are intended to be intrinsically safe as required by Title 30 of the Code of Federal Regulations (30 CFR).

2.0 SCOPE

The requirements of these criteria apply to:

2.1. Intrinsically safe instruments, devices, and associated apparatus intended for use in gassy underground mines or tunnels where permissible equipment is required.

2.2. Intrinsically safe circuits that are connected to or designed to be installed on MSHA-approved mining equipment.

2.3. Associated apparatus located outside the gassy location of underground mines and tunnels, if the intrinsic safety of the electrical circuits or apparatus in the gassy location may be influenced by the design and construction of the associated apparatus.

Conformance with these criteria indicates compliance with the intrinsic safety requirements of 30 CFR, but all other applicable requirements of 30 CFR must be met before an MSHA approval, intrinsic safety evaluation, or certification will be issued.

The authority for this document is from 30 CFR, Sections 18.20(b), 18.68(a)(1), 19.1(b), 20.1(c)(2), 22.6, 23.6, and 27.20(a).

3.0 REFERENCES

3.1. ACRI2010 “Encapsulation Criteria”

3.2. ACRI2011 “Intrinsically Safe Active Voltage/Current Power Source Criteria”

4.0 DEFINITIONS

4.1. **Associated Apparatus** - Apparatus in which the circuits are not themselves intrinsically safe, but which connect to intrinsically safe circuits. An example of an associated apparatus is a power supply, located within a certified explosion-proof enclosure on a mining machine that powers an intrinsically safe control circuit.

4.2. **Clearance Distance** - The shortest distance between two conductive parts measured through air.

4.3. **Constant Temperature** – The equilibrium temperature of the device with the prescribed test parameters. This occurs when the final temperature is within 3% of the minimum and maximum temperature readings recorded over the previous 15 minute time period.

4.4. **Creepage Distance** - The shortest distance between two conductive parts measured along the surface of the insulating material between them.

4.5. **Elementary Circuit** – The circuits shown on Figures 11.1, 11.2, 11.3, and 11.4.

4.6. **Fault** - A defect or an electrical breakdown of any component, spacing, or insulation that alone or in combination with other faults may adversely affect the electrical or thermal characteristics of an intrinsically safe circuit. The primary fault and all resulting defects and breakdowns are considered to be a single fault.

4.7. **Field Wiring** – All wiring that does not meet the definition of internal wiring. Field wiring is subject to the possibility of becoming disconnected or damaged.

4.8. **Internal Wiring** - Wiring and electrical connections that are made within a suitable enclosure by the manufacturer.

4.9. **Intrinsically Safe Apparatus** - Apparatus in which all circuits are intrinsically safe.

4.10. **Intrinsically Safe Circuit** - A circuit in which any spark or thermal effect produced either normally or under specified fault conditions is incapable, under the test conditions prescribed in these criteria, of causing an ignition of a methane-air atmosphere or a coal dust layer.

4.11. **Maximum Safe-Area Voltage** - The maximum voltage available to the associated apparatus. The maximum safe-area voltage may be a voltage higher than the nominal input voltage. For example, the high voltage backlight circuit of a computer display may be considered the maximum safe-area voltage of a line powered computer system.

4.12. **Protective Component or Assembly** - A component or assembly that is so unlikely to fail in a manner that will lower the intrinsic safety of the circuit that it may be considered not subject to fault when analysis or tests for intrinsic safety are made.

4.13. **Shunt Diode Barrier Assembly** - A network, which is manufactured as an individual apparatus rather than as part of a larger apparatus, of fuse and/or resistor protected shunt diodes and series current limiting resistors that limit current and voltage to specified levels. This network can contain no other type of components for limiting the current and voltage to intrinsically safe levels.

4.14. **Special Fastener** – A fastener that can not be unfastened by hand or with a commonly carried object such as a coin, key, knife, etc. Acceptable examples of special fasteners include: hexagonal head and torx head; and examples that are not acceptable include flat head and Phillips head.

4.15. **Suitable Enclosure** – An enclosure that prevents both the ingress of dust and physical damage.

5.0 CRITERIA

5.1. <u>Fundamental Requirements</u>

5.1.1. Intrinsically safe circuits shall be incapable of releasing enough electrical or thermal energy in normal operation and with up to two independent fault conditions to cause ignition of a flammable mixture of methane and air of the most easily ignitable composition.

5.1.2. The surface temperature of enclosures and components of intrinsically safe circuits that could be exposed to coal dust in normal operation and under fault conditions shall not cause thermal ignition of a coal dust layer.

5.1.3. Associated apparatus shall maintain the intrinsic safety of all intrinsically safe circuits connected to it, under normal conditions and with up to two independent faults in the associated apparatus.

5.1.4. Systems consisting of associated apparatus and intrinsically safe circuits shall be subjected to the two fault criteria on a system basis.

5.1.5. All intrinsically safe and associated apparatus shall meet the construction requirements of Section 7.0.

5.2. Normal Operation - For the purpose of an intrinsic safety evaluation, normal operation shall include all of the following:

5.2.1. The supply voltage will be the worst-case condition up to:

5.2.1.1. The maximum voltage for battery powered circuits as indicated in Section 9.3.6, or

5.2.1.2. 1.2 times the nominal input voltage for line powered circuits.

5.2.2. Tolerances and adjustments of all components in a combination that represents the most unfavorable condition.

5.2.3. Opening, shorting, reversing polarity, and/or grounding of the field wiring, including terminals, within a cable of the intrinsically safe circuit. Conductors that are individually shielded to a common ground will not be subject to short-circuit fault to other current-carrying conductors within the cable. Each shield shall be grounded to the associated apparatus at only one point. If the shield must be terminated within a hazardous location, it shall be bonded to the associated apparatus ground.

5.2.4. Environmental conditions of a maximum ambient temperature of 40°C, a maximum oxygen concentration of 21 percent in air, and a nominal pressure of one atmosphere.

5.3. Fault Conditions - All electrical conductors, components, and spacings are considered subject to fault in the fault analysis except for the following:

5.3.1. Protective components identified in Section 8.0 that have been evaluated and found to be unlikely to fail in a manner that would decrease circuit safety.

5.3.2. Positive physical separation between electrical conductors will not be subject to short-circuit fault if the spacing complies with Section 7.1.

5.4. Safety Factor - In the determination of intrinsic safety, a safety factor of 1.5 on energy will be used for normal operation and one fault analysis. No safety factor will be used for a two fault analysis. Determination of maximum surface temperature shall be done with no safety factor on current or voltage.

6.0 CIRCUIT EVALUATION METHOD

6.1. General Evaluation Approach - Circuits shall be evaluated for intrinsic safety in the following manner:

6.1.1. Circuits shall be analyzed to determine the worst-case circuit parameters in normal operation and under the fault conditions specified in Section 5.0. Each possible ignition source where a circuit interruption, short circuit, overheated component, or ground fault may occur in the hazardous location shall be considered. The circuit shall be in normal operation per Section 5.2 before faults are applied.

6.1.2. Ignition sources such as the following shall be considered:

6.1.2.1. Sources of Spark Ignition

6.1.2.1.1. Discharge of a capacitive circuit

6.1.2.1.2. Interruption of an inductive circuit

6.1.2.1.3. Intermittent making and breaking of a resistive circuit

6.1.2.1.4. Hot wire fusing

6.1.2.2. Sources of Thermal Ignition

6.1.2.2.1. Heating of a wire strand

6.1.2.2.2. Glowing of a filament

6.1.2.2.3. High surface temperature of components

6.1.3. Construction details shall be reviewed for compliance with Section 7.0.

6.1.4. Circuits shall be tested according to MSHA's standard test procedures (http://www.msha.gov/Techsupp/ACC/StandardTestProcs/StandardTestProcs.asp). Section 10.0 contains summaries of these standard test procedures.

6.2. Circuit Compliance Verification - Compliance with the fundamental requirements of Section 5.1 will be demonstrated by the following procedures:

6.2.1. Testing the circuit according to the test requirements of Section 10.1 or comparing the calculated or measured value, whichever is worse, of current, voltage, and associated inductances and capacitances to the appropriate figures in Section 11.0 to determine if the current and voltage levels are less than the values specified in Sections 6.2.1.1 through 6.2.1.3. The circuit conditions are to include all normal and fault conditions described in this document.

6.2.1.1. For normal or one fault conditions, the current and voltage shall not exceed 90 percent of the respective values determined from Figures 11.1 and 11.2 after a $\sqrt{1.5}$ safety factor is applied to both current and voltage. The current shall not exceed 90 percent of the value determined from Figure 11.3 after a $\sqrt{1.5}$ safety factor is applied. The voltage shall not exceed 90 percent of the value determined from Figure 11.4 after a $\sqrt{1.5}$ safety factor is applied.

6.2.1.2. For two fault conditions, the current and voltage shall not exceed 90 percent of the respective values determined from Figures 11.1 and 11.2. The current shall not exceed 90 percent of the value determined from Figure 11.3. The voltage shall not exceed 90 percent of the value determined from Figure 11.4.

6.2.1.3. As an alternative to verifying compliance with Figures 11.2, 11.3, or 11.4, elementary circuits with energy levels below 0.3mJ (minimum ignition energy of methane-air atmospheres as specified in "Electrical Instruments in Hazardous Locations", 4th Edition by Ernest Magison) are acceptable. The maximum electrical energy of the circuit shall be calculated from the formulas $E = \frac{1}{2}LI^2$ (Figures 11.2 and 11.3) and $E = \frac{1}{2}CV^2$ (Figure 11.4), where L is the inductance, I is the current through the inductor, C is the capacitance, and V is the voltage across the capacitor.

Note 1: Circuits that can be readily assessed in terms of elementary circuits represented by the ignition curves shown in Figures 11.1 through 11.4 shall be tested according to the spark ignition test of Section 10.0 when their parameters are between 90 and 100% of the respective ignition curve. These types of circuits whose parameters are equal to or above 100% of the ignition curve are considered failures and shall not be tested.

Note 2: Circuits that cannot be readily assessed in terms of elementary circuits represented by the ignition curves shown in Figures 11.1 through 11.4, such as circuits that employ active current or voltage limiting devices (ref. ACRI2011), circuits that include inductive components whose value cannot be verified by measurement, circuits in which the current or voltage exceed those indicated on the curves (e.g. resistive circuit greater than 5 amperes), circuits that have energy from a power source in parallel with the capacitive discharge energy, circuits that consist of both capacitance and inductance, and circuits that do not comply with Sections 6.2.1.1 and 6.2.1.2 are to be evaluated by the test procedures in Section 10.1.

Note 3: The curves in Figure 11.4 represent the discharge of the energy stored in the capacitor and do not include the energy from the power source.

6.2.2. Verifying that the device meets the physical construction requirements of Section 7.0 where necessary to assure intrinsic safety.

6.2.3. Testing protective components and assemblies to determine compliance with the test requirements of Section 10.0.

6.3. <u>Spark Ignition Evaluation</u> – This section details the application of faults, particularly the insertion of the spark test apparatus.

6.3.1. The use of the spark test apparatus to produce short circuits, open circuits, and ground faults shall be considered normal operation and is a non-countable fault for the following situations:

6.3.1.1. At terminals not meeting Section 7.4.4, or

6.3.1.2. Between conductors of any non-shielded field wiring, or

6.3.1.3. For field wiring, between conductors within a properly grounded shield and between the enclosed conductors and the shield, or

6.3.1.4. Between internal connections or across internal creepage distances, clearances, distances through casting compound and distances through solid insulation that are less than 1/3 of that specified in Table 7.1, or

6.3.1.5. Between uninsulated live parts not protected from the ingress of dust by a dust-tight enclosure, by encapsulation, by adherent insulating coating or equivalent, or

6.3.1.6. Between external terminals of an apparatus (ref. Section 7.3.4), excluding charging terminals, or

6.3.1.7. Between charge terminals not complying with Sections 9.3.11.2, 9.3.11.3, or 9.3.11.4.

6.3.2. The use of the spark test apparatus to produce short circuits, open circuits, and ground faults shall be considered a countable fault for the following situations:

6.3.2.1. To simulate the intermittent failure of a component, provided the component has external spacings that comply with Table 7.1, and that failure is not subsequent to a primary fault, or

6.3.2.2. To simulate faults between conductors separated by distances greater than 1/3, but less than, the values specified in Table 7.1, provided the circuit meets the requirements of Section 7.1, or

6.3.2.3. Between charge terminals complying with Sections 9.3.11.2 (one fault), or 9.3.11.3 (two faults), or 9.3.11.4 (one fault).

6.3.3. The use of the spark test apparatus shall not be considered:

6.3.3.1. Across separately properly-grounded shielded conductors, or

6.3.3.2. Between shunt protective components and inductive components complying with Section 8.6, or

6.3.3.3. Across creepage distances, clearances, distances through casting compound and distances through solid insulation that meet the requirements of Table 7.1, provided the circuit meets the requirements of Section 7.1, or

6.3.3.4. Within associated apparatus other than at the intrinsically safe circuit terminals, or

6.3.3.5. Between terminals of separate circuits that comply with the requirements of Section 7.4.4, or

6.3.3.6. After two countable faults have already been utilized in the circuit evaluation, except when the fault is non-countable (ref. Section 6.3.1).

7.0 CONSTRUCTION REQUIREMENTS

TABLE 7.1
CLEARANCES, CREEPAGE DISTANCES, AND
DISTANCES THROUGH CASTING COMPOUND AND INSULATIONS[a,b]

1. Nominal Voltage[c]	10	30	60	90	190	375	550	750	1000	1300	1575	3.3 Kv	4.7 Kv	9.5 Kv	15.6 Kv
2. Creepage Distance (mm)	1.5	2	3	4	8	10	15	18	25	36	40	67	90	160	240
3. Creepage Distance Under Coating (mm)	0.5	0.7	1	1.3	2.6	3.3	5	6	8.3	12	13.3	23	30	53	80
4. Minimum Comparative Tracking Index[d]	–	--	--	–	175	175	175	175	175	175	300	--	--	--	--
5. Clearance (mm)	1.5	2	3	4	5	6	7	8	10	14	16	27	36	60	100
6. Distance Through Casting Compound[e] (mm)	0.5	0.7	1	1.3	1.7	2	2.4	2.7	3.3	4.6	5.3	9	12	20	33
7. Distance Through Solid Insulation (mm)	0.5	0.5	0.5	0.7	0.8	1	1.2	1.4	1.7	2.3	2.7	4.5	6	10	16.5

[a]Creepage distance is to be assessed on the basis of the maximum continuing nominal rms voltage. Clearance is to be assessed on the basis of the maximum normal peak voltage.

[b]For circuits 1500V or greater and with high power capability the danger due to power arcing in the circuit is to be taken into account.

[c]The value of the voltage is the nominal rms voltage for assessing creepage distance and nominal peak voltage for assessing clearance distance, tolerance not considered. The voltages are to be the sum of the normal operating voltages of the circuits being considered. For sinusoidal voltages, the peak voltage shall be considered to be $\sqrt{2}$ times the nominal rms voltage.

[d]Use Standard Test Method for Comparative Tracking Index of Electrical Insulating Materials, ASTM D3638-85.

[e]Separation distance requirements for the inner layers of multi-layer PC boards shall be assessed using the Distance Through Solid Insulation Values.

[f]Solid insulation is insulation which is prefabricated (e.g. extruded or molded but not poured). Examples of solid insulation would be sheet or sleeving or elastomeric insulation on wiring. An insulator that is fabricated from two or more pieces of electrical insulating material which are solidly bonded together would also be considered solid insulation. Varnish and other similar coatings are not considered to be solid insulation.

NOTES: To convert millimeters to inches, multiply by .03937. Different nominal voltages may not be extrapolated from the data shown (e.g. 20 volts with a creepage and clearance distance of 1.75mm, for example).

7.1. Creepage and Clearance Distances - Creepage and clearance distances between uninsulated live parts that are protected by a suitable enclosure shall be considered not subject to short-circuit fault if, taking into consideration likely movement of components, they are equal to or greater than the values given in Table 7.1, except as noted in Sections 7.1.1 through 7.1.4. Where uninsulated live parts are not protected from the ingress of dust by a dust-tight enclosure, by encapsulation, by adherent insulating coating or equivalent, it shall be assumed that all spacings do not meet the creepage and clearance distances of Table 7.1. All connections between live or grounded parts and conductors are considered in the most unfavorable condition. The number of such connections is unlimited.

7.1.1. The requirements in Section 7.1 apply to:

7.1.1.1. Conductors within an intrinsically safe circuit,

7.1.1.2. Conductors of a non-intrinsically safe circuit and intrinsically safe circuit, and

7.1.1.3. Conductors of different intrinsically safe circuits.

7.1.2. Clearances, creepage distances, and distances through casting compound and insulations that are less than the value specified in Table 7.1 but at least 1/3 of this value are to be considered connected if connection impairs intrinsic safety. Each such connection is to be counted as a fault subject to the requirements in Section 6.0.

7.1.3. If the separation between two conductors is less than 1/3 of the value specified in Table 7.1, the conductors are to be considered normally connected if connection impairs intrinsic safety. This is not to be considered a fault in the analysis.

7.1.4. If more than two conductors are involved and the spacing between adjacent conductors is less than 1/3 the applicable value in Table 7.1, the individual spacings are to be added until the total spacing equals or exceeds 1/3 the applicable value. Only that number of conductors is to be considered connected. A single fault is to be counted. Within a total dimension equal to the applicable table value, only one such group of conductors is to be considered connected.

7.1.5. The creepage distances specified in Table 7.1 apply to printed circuit boards and other circuits that are protected by a suitable enclosure. The creepage distances under coating apply to printed circuit boards that are covered by an adherent insulating coating that is:

7.1.5.1. At least two layers thick of materials (such as two coats of varnish) that have a minimum dielectric voltage rating of 200 volts per 0.025 mm of thickness; or

7.1.5.2. A single layer not less than 0.7 mm thick.

7.1.6. The requirements in Section 7.1 do not apply where grounded metal (e.g., printed wiring or a partition) separates an intrinsically safe circuit from other circuits and other parts of the same circuit, provided breakdown to ground does not adversely affect intrinsic safety and the grounded conductor can carry the maximum current that would flow considering normal and fault conditions. A grounded metal partition shall have strength and rigidity so that it is unlikely to be damaged, be of sufficient thickness, and have current-carrying capacity to prevent burn-through or loss of ground under fault conditions. A partition at least 0.25 mm thick attached to a rigid, grounded metal portion of the apparatus and meeting the test requirements in Section 10.8 complies with the requirements of this subsection. The 0.25 mm minimum thickness complies from the standpoint of current-carrying capacity.

7.1.7. Composite separations (e.g. through a combination of air and insulation) shall be calculated on the basis of referring all separations to one line of Table 7.1. For example at 60 volts:

clearance (line 5) = 6 x separation through solid insulation (line 7);

clearance (line 5) = 3 x separation through casting compound (line 6);

equivalent clearance = actual clearance + (3 x any additional separation through casting compound) + (6 x any additional separation through solid insulation).

To be not subject to short-circuit fault, the above calculated equivalent composite clearance or separation shall not be less than the clearance value specified in Table 7.1. Any calculated equivalent composite clearance or separation which is below 1/3 of the relevant value specified in Table 7.1 shall be considered a non-countable fault. Any calculated equivalent composite clearance or separation which is above 1/3 but less than the value specified in Table 7.1 is considered a countable fault.

7.2. Encapsulation

7.2.1. Where encapsulation is used to separate conductors and components of an intrinsically safe circuit from (1) non-intrinsically safe circuits, (2) other intrinsically safe circuits, (3) other parts of the same circuit, or (4) grounded metal, the distance between electrical conductors shall comply with the distance through casting compound values in Table 7.1 and the encapsulant shall:

7.2.1.1. Be adherent to any emerging conductors or components, including printed circuit board substrates;

7.2.1.2. Have sufficient rigidity to comply with the test requirements specified in Section 10.14.1; and

7.2.1.3. Have a rating at least equal to the maximum temperature of any encapsulated component or conductor that results under normal and fault conditions after encapsulation. Alternatively, temperatures higher than the continuous operating temperature may be accepted provided that they do not cause any damage to the encapsulant that would adversely affect the type of protection. The encapsulant needs to pass the force, impact, and any other mechanical tests required of the encapsulant after a thermal event that causes it to exceed its temperature rating, if applicable. For example, if the thermal event causes the encapsulant to exceed its rating, but it is only a one time event, then these tests would not be necessary if the entire circuit relying on the encapsulant is disabled.

Note: Where encapsulation is used as an alternate form of protection to intrinsic safety, it shall be evaluated according to ACRI2010.

7.2.2. Where encapsulation is used to reduce the risk of ignition of a potentially flammable atmosphere by the following types of components (1) piezo-electric devices and their connection to any suppression devices, (2) energy storage devices and their protective components, and (3) fuses that would be a source of ignition if broken, the encapsulant shall:

7.2.2.1. Have a minimum thickness between such components and the free surface of at least 1/2 of the distance through casting compound values of Table 7.1, but no less than 1 mm; and

Note: If the surface of the encapsulant is in contact with an enclosure of electrical insulating material, the thickness of the enclosure shall be included when determining compliance with this section.

7.2.2.2. Have sufficient rigidity to comply with the test requirements specified in Section 10.14.1.

7.2.3. Where encapsulation is used to reduce surface temperatures, the encapsulant shall:

7.2.3.1. Have sufficient volume and minimum thickness over the hot component or conductor necessary to reduce the encapsulant surface temperature to the acceptable level as measured with the encapsulant in place;

7.2.3.2. Have a continuous operating temperature greater than the temperature on the hottest surface that it contacts under normal and fault conditions with the encapsulant in place; and

7.2.3.3. Have sufficient rigidity to comply with the test requirements specified in Section 10.14.1.

7.2.4. If the encapsulant is not protected from shock by another enclosure or partition it shall also comply with Section 10.14.2.

7.3. <u>Field Wiring Connections</u> - Terminals for intrinsically safe circuits shall be adequately separated from terminals for non-intrinsically safe circuits and from other intrinsically safe circuits by one or more of the methods in Sections 7.3.1 through 7.3.3.

7.3.1. Separation may be accomplished by distance. The distance between adjacent terminals separating intrinsically safe and non-intrinsically safe circuits shall be at least 50 mm. The distance between adjacent terminals of different intrinsically safe circuits shall be at least 6 mm. The layout of the terminals and the wiring method used shall prevent any wire that becomes disconnected from one terminal from contacting other terminals.

Note: Additional precautions such as wiring tie downs or special wiring methods may be necessary to provide adequate separation. This is especially true when terminals are arranged one above the other. In such cases, spacing alone will not usually provide adequate separation.

7.3.2. Separation may be accomplished by locating intrinsically safe and non-intrinsically safe terminals in separate enclosures or by the use of either an insulating partition or a grounded metal partition between terminals.

7.3.2.1. Separate enclosures or partitions within common enclosures shall be designed to prevent wiring of an intrinsically safe circuit from contacting the wiring of a non-intrinsically safe circuit, taking into consideration stowage of excess wire in each compartment.

7.3.2.2. Partitions used to separate terminals shall extend to within 1.5 mm of enclosure walls to provide adequate separation. Alternately, a partition shall provide a minimum path of 50 mm between the terminals when measured in any direction around the partition.

7.3.2.3. Metal partitions shall be grounded and shall possess sufficient strength and rigidity that they are not likely to be damaged when making field wiring connections (see Section 7.1.6).

7.3.2.4. Nonmetallic insulating partitions shall possess sufficient thickness and shall be so supported that they cannot be readily deformed and can meet the test requirement of Section 10.8.

7.3.3. Plugs and receptacles used to connect intrinsically safe circuits shall not be interchangeable with other plugs and receptacles within the same apparatus, except where interchange does not affect intrinsic safety. Each plug and receptacle shall be clearly identifiable as to proper installation.

7.3.4. Contacts external to the apparatus, excluding charging contacts (ref. Section 9.3.11, shall be considered normally connected.

7.3.5. Terminals and connections shall be adequately marked for connection where miswiring would affect intrinsic safety.

7.4. Internal Wiring Conductors - Internal wiring conductors which are not rigidly supported so as to maintain the minimum spacings specified in Table 7.1 shall be insulated according to Sections 7.4.1 and 7.4.2 and separated according to Sections 7.4.3 and 7.4.4.

7.4.1. Where breakdown may adversely affect the intrinsic safety of the same or separate intrinsically safe circuits, each circuit shall be wired with insulated conductors having a grade of insulation capable of withstanding an ac test voltage of 500 volts rms or twice the normal working voltage of the intrinsically safe circuit, whichever is greater. Alternatively, a dc voltage may be used as described in Section 10.7.1.1.

7.4.2. Non-intrinsically safe circuits in the same enclosure with intrinsically safe circuits shall be wired with insulated conductors having a grade of insulation capable of withstanding an ac test voltage of 2U + 1000 volts, with a minimum of 1500 volts rms, where U is the sum of the rms values of the voltages of the intrinsically safe circuit and the non-intrinsically safe circuit. Alternatively, a dc voltage may be used. See Section 10.7 for dielectric test procedure.

7.4.3. Segregation of the intrinsically safe and non-intrinsically safe wiring may be accomplished by enclosing either type of wiring in a grounded shield capable of carrying the fault current that would flow if the non-intrinsically safe circuit were to become connected to the shield.

7.4.4. The clearance between two terminals of different intrinsically safe circuits shall be at least 6 mm unless no ignition hazard results from connection.

7.5. Dust-Tight Enclosures

7.5.1. An enclosure is considered dust-tight if it has no openings and all joints are either gasket-sealed; threaded (minimum 3 full-thread engagement); or, sealed by continuous welding, brazing, soldering, or fusion of glass.

7.5.2. An MSHA-certified explosion-proof enclosure is considered dust-tight.

7.5.3. Any enclosure meeting the requirements of an appropriate dust exclusion test such as the Outdoor Dust Test described in NEMA Publication 250, "Enclosures for Electrical Equipment (1000 Volts maximum)," or that is rated at least IP5X per IEC 60529 "Degrees of Protection Provided by Enclosures (IP Code)", is acceptable.

7.5.4. A circuit assembly encapsulated to a depth of at least 1 mm that either complies with the test requirements specified in Section 10.14.2, or is mounted within a rugged enclosure (that may or may not be dust-tight).

7.5.5. The enclosure of a portable apparatus shall continue to be dust-tight after the drop test described in Section 10.10.

7.5.6. Each component of an intrinsically-safe circuit not enclosed in a dust-tight enclosure whose surface temperature would exceed 150°C under normal and fault conditions shall meet the requirements of the coal dust thermal ignition test described in Section 10.11.

8.0 PROTECTIVE COMPONENTS

8.1. General - In evaluating intrinsically safe apparatus and associated apparatus, components complying with the following sections shall be considered not subject to fault, if they also meet the requirements of Section 9.1.1.

8.2. Transformers - Transformers used as protective components for supplying intrinsically safe circuits shall meet the following construction requirements and the test requirements of Section 10.1.

8.2.1. The winding supplying the intrinsically safe circuit shall be electrically separated from all other windings by one of the following types of construction:

8.2.1.1. Type 1(a): The windings are side by side on one leg of the core and separated by an insulating partition of not less than 0.71 mm thickness.

8.2.1.2. Type 1(b): The windings are on different legs of the core.

8.2.1.3. Type 2(a): The windings are wound one over another, with high temperature insulation between the windings, crossover leads and splices supplying the intrinsically safe circuit and all other windings, crossover leads, and splices.

Note: An imbedded one time thermal fuse may be used to prevent Type 1(a), 1(b), and 2(a) transformers from bursting into flames.

8.2.1.4. Type 2(b): The windings are wound one over another with a grounded shield of copper foil or an equivalent wire winding between the input winding, and all other windings, crossover leads, and splices (see Section 8.2.2).

8.2.1.5. Type 3: The transformer construction is the same as either a Type 1(a), Type 1(b), or of a Type 2(b) with at least one shield ground lead. In addition, the power dissipation in the windings is inherently limited such that no primary fuse or other protection is required.

8.2.2. For Type 2(b) construction, the following shall apply:

8.2.2.1. The thickness of the copper foil shield or the diameter of the wire shield shall be such that, in the event of a short circuit between any winding and the shield, the latter will be able to withstand without breakdown the current that flows until the fuse or circuit breaker operates. The shield is considered to be adequate if it is made of copper foil at least 0.13 mm thick.

8.2.2.2. The shield shall be provided with two independently connected leads to the ground connection, each of which is capable of withstanding without damage the current that flows before the fuse or circuit breaker operates. The shield grounding leads are considered to be adequate if each lead is at least equal in size to the primary leads of the transformer but not less than No. 24 AWG.

8.2.2.3. A wire wound shield shall consist of at least two layers of windings.

8.2.3. The input circuit to power supply transformers of Type 1(a), Type 1(b), and Type 2(b) construction shall include a fuse or circuit breaker in each ungrounded input line. The manufacturer, part number, and rated current shall be marked on the apparatus in a position adjacent to the fuse or on the fuse holder.

8.2.4. The core of a power supply transformer shall be provided with a ground connection, except where grounding is not practicable, as with insulated toroidal core transformers used in dc to dc converters.

8.2.5. All transformers shall be impregnated or encapsulated in order to consolidate the windings. Tape-wrapping alone shall not be considered adequate to consolidate the windings.

8.3. Damping Windings - Damping windings shall be considered not subject to fault if they are of reliable mechanical construction, such as seamless metal tubes, windings of bare wire continuously short circuited by soldering, or the equivalent.

8.4. Current-Limiting Resistors - Current-limiting resistors are not subject to short-circuit fault if:

8.4.1. They are operated at no more than 2/3 of their power ratings at the maximum fault voltage or they meet the test requirements of Section 10.3; and

8.4.2. They are of the metal, metal oxide film, thick film, or of the single layer wire wound type with mechanical protection to prevent unwinding of the wire in the event of breakage, or any similar construction whose failure mode increases resistance.

Note: The peak open-circuit voltage (refer to Table 9.3.6) shall be used to determine maximum fault voltage for circuits with a battery as a power source.

8.5. Blocking Capacitors

8.5.1. A blocking capacitor assembly connected between an intrinsically safe circuit and a non-intrinsically safe circuit shall be considered not subject to simultaneous short-circuit fault if two capacitors are connected in series and each capacitor is rated or able to withstand an ac test voltage of twice the voltage across the capacitors plus 1000 volts rms. They shall be high reliability types such as hermetically sealed or ceramic capacitors. Electrolytic or tantalum capacitors shall not be used for this purpose. Failure of a single capacitor is a countable fault.

8.5.2. If the capacitors are connected in an intrinsically safe circuit, they need not withstand the test voltage determined in Section 8.5.1 if they are each rated for three times the fault voltage across the assembly.

8.6. Shunt Protective Components Fitted to Inductive Components - Shunt protective components, such as diodes and zener diodes fitted to inductive components, shall be considered not subject to simultaneous open-circuit fault if:

8.6.1. The shunt protective component is redundant (2 components), so that there is no unacceptable increase in energy in the intrinsically safe circuit if one of the components becomes defective as determined by the spark ignition test requirements of Section 10.1.

8.6.2. The shunt protective component is mechanically secured to the inductive component by soldering, brazing, or welding.

8.6.3. The shunt protective components and the connection to the inductive component meet the requirements of Section 7.2.2.

8.6.4. The shunt protective components are protected by a suitable enclosure, protected by a rugged enclosure and are mounted to printed circuit boards that are covered with an adherent insulating coating, or encapsulated with a compound that complies with the test requirements specified in Section 10.14.2.

8.6.5. The shunt protective component is connected close to the inductive component such that both cannot become disconnected due to a single fault, unless the disconnection of either of the shunt components results in disconnection of the inductive component.

8.6.6. Semiconductor components used as shunt protective components shall be each continuously rated to carry the current that would flow if they failed in the short-circuit mode. For example, a zener diode with a forward and reverse current rating greater than this current satisfies this requirement.

8.7. Shunt Diode Barrier Assemblies - Shunt diode barrier assemblies shall be considered protective assemblies if they meet the requirements of Sections 8.7.1 through 8.7.7 or Section 8.7.8.

Note: Certain requirements of Section 8.7 may not apply to shunt diode barrier circuits integrated into other circuits.

8.7.1. Barrier component failures shall not increase the energy in the intrinsically safe circuit to an unacceptable level upon application of the maximum voltage to the assembly. The maximum voltage of the non-intrinsically safe circuit is assumed to be 250 volts rms unless a higher value is specified. This is the maximum safe-area voltage; application of this voltage is normally considered a fault condition.

8.7.2. Construction of the shunt diode barrier assembly shall comply with the following:

8.7.2.1. Barrier current-limiting resistors shall meet the requirements of Section 10.3;

8.7.2.2. Resistor-protected diodes shall meet the requirements of Section 10.4.2;

8.7.2.3. The fuse of a fuse-protected barrier shall operate at least 10 times faster than the open circuit time of the shunt diode, as detailed in Section 10.4.4; and

8.7.2.4. Barrier shunt diodes shall be duplicated so that the assembly remains effective if one of the diodes open-circuits.

8.7.3. The design of shunt diode barriers shall be such that the assembly can readily be seen to be mounted correctly.

8.7.4. At least one terminal or connection shall be provided on each barrier or barrier assembly for connecting the barrier circuit to ground. The grounding terminal or connection shall be sized to accommodate a No. 12 AWG minimum grounding conductor. The following constructions or their equivalents are considered suitable:

8.7.4.1. A No. 8 wire binding screw that engages the terminal plate by at least two full threads. The terminal plate shall be no less than 1.25 mm thick, and shall be provided with upturned lugs or the equivalent to hold the conductor in place.

8.7.4.2. A pressure-type wire connector that complies with the requirements for such connectors. (Soldering lugs, push-in conductors, quick-connects, or similar friction fit connectors are unacceptable.)

8.7.4.3. Bolting the barrier to a grounding bus.

8.7.5. The ungrounded terminals of the intrinsically safe circuit shall be separated from the ungrounded terminals of the non-intrinsically safe circuit by no less than 50 mm. They shall be protected to prevent accidental contact with leads connected to other terminals.

8.7.6. Fuse-protected shunt diode barriers shall be either encapsulated or constructed so that the fuse is not accessible for replacement.

8.7.7. Where components are not encapsulated, the housing shall be constructed so as to prevent access to the components and to provide protection equivalent to encapsulation.

8.7.8. A shunt diode barrier assembly tested and listed by a nationally recognized testing laboratory may be considered suitable for use as a protective device in equipment if the test report and the manufacturer's specifications indicate the barrier meets the requirements of Sections 8.7.1 through 8.7.7.

8.8. Optical Isolators - Optical isolators shall be considered not subject to a short-circuit fault between the input and output circuits if they comply with the construction requirements of Section 7.1 and the test requirements of Section 10.13.

8.8.1. Exception #1: Optical isolators that are operated at not more than 2/3 of their ratings under normal and fault conditions shall not be subjected to the test requirements of Section 10.13 if they meet the construction requirements of Section 7.1.

8.8.2. Exception #2: Optical isolators shall not be subjected to the construction requirements of Section 7.1 if each device that is used in MSHA-evaluated equipment is tested according to Section 10.13.1.

8.9. Fuses

8.9.1. Fuses used to protect components from overheating shall be considered not subject to short-circuit fault if they meet the requirements of Sections 8.9.3 and 8.9.4.

8.9.2. The cold resistance of fuses may be considered not subject to short-circuit fault provided the fuse passes the protective current-limiting resistor test of Section 10.3 and it meets the requirements of Sections 8.9.3 and 8.9.4. In the absence of available information, the value of the cold resistance may be taken as the minimum resistance when measured at 20°C.

Note: Fuse time-current characteristics exclude consideration of fuses as effective to prevent a spark ignition hazard.

8.9.3. The component(s) protected by fuses shall be evaluated at the fuse manufacturer’s specified current with a specified opening time of two minutes or less. Note: Average time current curves shall not be used for this purpose. Example: A component protected by a fuse that is specified to operate at (a) 110% of its rating in 4 hours and (b) 300% of its rating in 10 seconds would be evaluated at 3 times the fuse rating.

8.9.4. Fuses used as protective components shall be soldered, welded, brazed, or encapsulated. They should not operate, when considering up to two faults, at more than 2/3 of their maximum interrupt current and voltage rating as specified by the manufacturer of the device.

8.10. Relays - Where intrinsically safe and non-intrinsically safe circuits are connected to the same relay, the relay shall withstand a dielectric strength test (see Section 10.7) of $4U_n$ or 2500 V, whichever is greater, where U_n is the highest nominal operating voltage of the device. The internal and external creepage and clearance distances shall comply with Section 7.1. The current and voltage switched by the contacts in the non-intrinsically safe circuits shall not exceed 5 amps and 250 volts, dc or rms, and in addition the product of the current and voltage shall not exceed 100 VA.

For higher values, the circuits shall be connected to the same relay only if the circuits are additionally separated by a grounded metal partition or an insulating partition. A grounded metal partition shall not be used where breakdown to ground would adversely affect intrinsic safety. A metal partition at least 0.25 mm thick, attached to a grounded metal part of the device, or an insulating partition at least 0.7 mm thick complies with this requirement. A partition thinner than 0.7 mm must meet the test requirements of Sections 10.7 and 10.8. A thicker insulating partition may be required to take into account ionization due to operation of the relay.

8.11. Wires, Connections, and Traces – Wires, connections, and printed circuit board traces which form part of the apparatus, shall be considered not subject to open-circuit fault in the following cases, provided a single, complete assembly of wire, connection, and/or trace is capable of meeting the test of Section 10.16, are protected from damage by a rugged enclosure, and the wires, connections, and traces are protected from environmental contamination by one of the following methods: contained within an enclosure with at least an IP55 rating per IEC 60529 “Degrees of Protection Provided by Enclosures (IP Code)”, encapsulated, protected with an adherent insulating coating, or equivalent.

8.11.1. Wires

8.11.1.1. Where two wires are in parallel, or

8.11.1.2. Where a single wire has a diameter of at least 0.5 mm and has an unsupported length of less than 50 mm or is mechanically secured adjacent to its point of connection, or

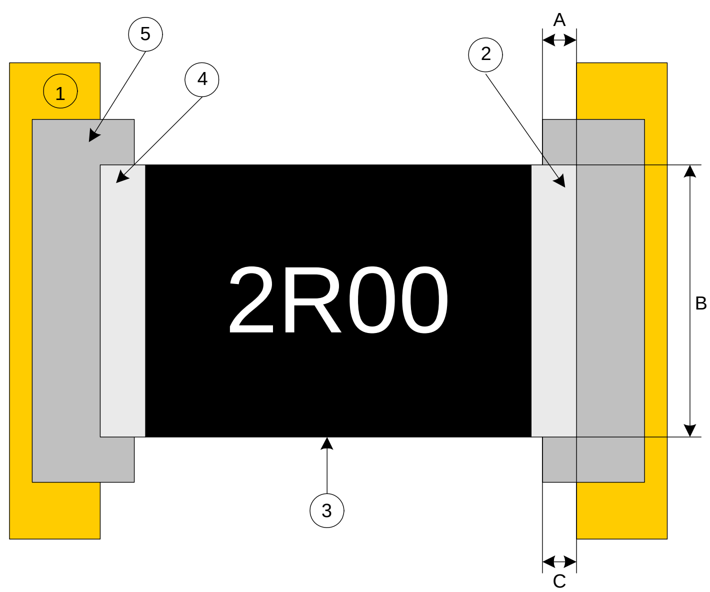
8.11.1.3. Where a single wire is of stranded or flexible ribbon type construction has a cross-sectional area of at least 0.125 mm^2 (0.4 mm diameter), is not flexed in service and is either less than 50 mm long or is secured adjacent to its point of connection;

8.11.2. Connections (excluding external plugs, sockets and terminals):

8.11.2.1. Where there are two connections in parallel; or

8.11.2.2. Where there is a single soldered joint in which the wire passes through the board (including through-plated holes) and is either bent over before soldering or, if not bent over, machine soldered or has a crimped connection or is brazed or welded; or

8.11.2.3. Where there is a soldered joint of a surface mount component of at least 2 mm in length as shown below; or



Key:
1 PCB circuit track
2 Solder interface between board pad and component pad (A+B+C must be greater than or equal to 2 mm)
3 Properly connected component
4 Component solder pad
5 PCB solder pad dimensioned per component manufacturer's specification

8.11.2.4. Where there is a single connection which is screwed or bolted and conforms to the following requirements:

8.11.2.4.1. It is fixed to its mountings without possibility of self-loosening,

8.11.2.4.2. It is constructed in such a way that the conductor(s) cannot slip out from their intended location during tightening,

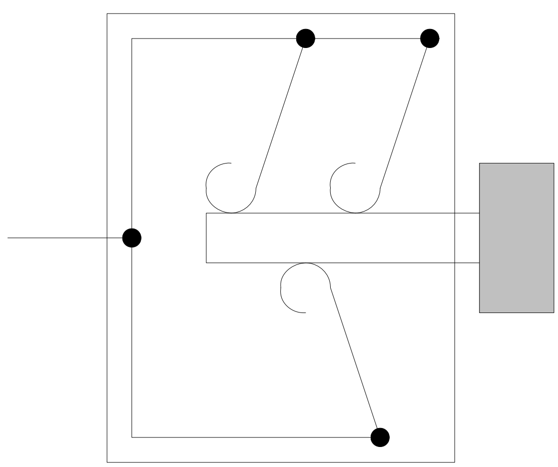
8.11.2.4.3. It is assembled such that proper contact is assured without damage to the conductors,

8.11.2.4.4. It is installed in an area where there are no sharp edges which would damage the conductor,

8.11.2.4.5. It shall not be able to be turned, twisted, or permanently deformed during normal tightening, and

8.11.2.4.6. It shall not be constructed of aluminum.

8.11.2.5. Where there is an internal connector within the enclosure, and the connection is comprised of at least three independent connecting elements, with these elements connected in parallel as shown below. Where the connector may be removed at an angle, one connection element shall be present at, or near to, each end of the connector.



Note: When the connector is completely disconnected, the circuits should remain intrinsically safe.

8.11.3. Printed circuit board traces

8.11.3.1. Where two traces of at least 1 mm width are in parallel, or

8.11.3.2. Where a single track is at least 2 mm wide or has a width of 1% of its length, whichever is greater.

Note: Printed circuit board traces of material other than copper are permitted but will require special consideration.

8.11.3.3. Where traces on different layers are connected by either a single via of at least 2 mm circumference, or two parallel vias of at least 1 mm circumference, and these vias are joined to each other in accordance with Sections 8.11.3.1 or 8.11.3.2.

9.0 OTHER COMPONENT REQUIREMENTS

9.1. Derating of Discrete Components

9.1.1. All components affecting intrinsic safety shall be operated, in normal operation, at not more than 2/3 of their rated current, voltage, or power, as appropriate.

Exceptions: Transformers, nominal current rating of fuses, hold/trip ratings of thermal trips (PTCs), and relay coils need not comply with this requirement.

9.1.2. Components other than protective components operated at or below their rated current, voltage, or power, as appropriate under fault conditions are only subject to countable faults.

9.1.3. Components operated above their rated current, voltage, or power, as appropriate shall be tested to determine whether they would be considered a fault not subsequent to a primary fault.

9.2. Plug-In Boards and Components - Plug-in boards and components shall not be interchangeable with nonidentical boards or components in the same equipment if intrinsic safety is affected by such interchange.

9.3. Cells and Batteries - These requirements shall apply to battery operated apparatus in which the entire assembly, including batteries, is intended to be used in a hazardous location and is not provided with other means of protection, such as an explosion-proof enclosure. These requirements shall apply to both primary (nonrechargeable) and secondary (rechargeable) cells and batteries.

9.3.1. Battery cells shall be of a type from which there can be no spilling of electrolyte or shall be enclosed to prevent attack of circuits that affect intrinsic safety by the electrolyte. Compartments containing batteries which emit flammable gas shall be ventilated to prevent accumulations of ignitable concentrations.

9.3.2. All cells in a battery shall be of the same electrochemical system, cell design, and rated capacity and shall be made by the same manufacturer.

9.3.3. Batteries shall not contain a mixture of primary and secondary cells.

9.3.4. Primary and secondary cells or batteries shall not be used inside the same apparatus enclosure if they are readily interchangeable.

9.3.5. Primary batteries shall not be recharged. Where another voltage source exists inside apparatus containing primary batteries and there is a possibility of interconnection, precautions shall be taken to prevent charging current passing through them.

9.3.6. For the purpose of spark ignition evaluation and test, the battery voltage shall be considered to be the maximum open-circuit voltage of a fresh or fully charged battery based on measurement, the manufacturer’s specifications, or voltages listed below, whichever is greatest. For the purpose of surface temperature assessment, the battery voltage shall be considered to be the manufacturer’s specified nominal voltage, or voltages listed below, whichever is greatest.

Primary Cell Table 9.3.6

Positive electrode	Electrolyte	Negative electrode	Peak open-circuit voltage for spark ignition hazard	Nominal voltage for component surface temperature assessment
Manganese dioxide	Ammonium chloride, zinc chloride	Zinc	1.73	1.5
Oxygen	Ammonium chloride, zinc chloride	Zinc	1.55	1.4
Carbon monofluoride	Organic electrolyte	Lithium	3.7	3
Manganese dioxide	Organic electrolyte	Lithium	3.7	3
Thionyl chloride ($SOCl_2$)	Non-aqueous inorganic	Lithium	3.9	3.6
Iron disulfide (FeS_2)	Organic electrolyte	Lithium	1.83	1.5
Copper (II) oxide (CuO)	Organic electrolyte	Lithium	2.3	1.5
Manganese dioxide	Alkali metal hydroxide	Zinc	1.65	1.5
Oxygen	Alkali metal hydroxide	Zinc	1.68	1.4
Silver oxide (Ag_2O)	Alkali metal hydroxide	Zinc	1.63	1.55
Silver oxide (AgO, Ag_2O)	Alkali metal hydroxide	Zinc	1.87	1.55
Sulphur dioxide	Non-aqueous organic salt	Lithium	3.0	3.0

Secondary Cell Table 9.3.6

Cell Type	Electrolyte	Peak open-circuit voltage for spark ignition hazard	Nominal voltage for component surface temperature assessment
Lead-acid (wet)	Sulphuric acid (SG 1.25)	2.67	2.2
Lead-acid (dry)	Sulphuric acid (SG 1.25)	2.35	2.2
Nickel-cadmium	Potassium hydroxide (SG 1.3)	1.55	1.2
Nickel-iron	Potassium hydroxide (SG 1.3)	1.6	-
Nickel metal hydride	Potassium hydroxide	1.5	1.2
Lithium	Non-aqueous organic salt	4.2	3.6

9.3.7. For the purpose of evaluation and test, the battery short-circuit current shall be the maximum current under short-circuit conditions as determined by the flash current test of Section 10.9.

9.3.8. When conducting tests that require applying a test factor of 1.5, one of the following methods, or their equivalents, shall be used:

9.3.8.1. Additional individual cells identical to the cells used in a multi-cell battery pack may be added in series or parallel, as appropriate, to yield a simulated battery with at least 1.5 times the capacity of the battery used in the apparatus;

9.3.8.2. The battery voltage or current, as appropriate, may be simulated with a suitable power supply or high capacity battery and the voltage or current increased so that the energy level is increased by a factor equal to 1.5; or

9.3.8.3. The intended batteries may be used either two in series for double voltage and/or two in parallel for double current, as appropriate, yielding a test factor greater than 1.5.

Note: Section 9.3.8.3 may be a more stringent test than Sections 9.3.8.1 and 9.3.8.2 but may be used if it simplifies testing. Failure to pass this test does not imply the circuit is unsafe. Intrinsic safety may be determined by use of Section 9.3.8.1 or 9.3.8.2.

9.3.9. When batteries are used for a spark ignition test, four tests with fresh or fully-charged batteries, two for each polarity, shall be conducted.

9.3.10. Battery-operated apparatus in which the battery requires energy-limiting components for intrinsic safety shall have the energy-limiting components as an integral part of the battery assembly or use replaceable batteries with the energy-limiting components contained separately within the equipment.

9.3.10.1. When an energy-limiting component is necessary and is provided as an integral part of the battery assembly, it shall form a complete replaceable unit with the battery assembly. The construction of the battery assembly shall prevent the energy-limiting component from being bypassed. The battery assembly, if replaceable in a hazardous location, shall remain intrinsically safe after being subjected to the drop test in Section 10.10.

9.3.10.2. When the energy-limiting components are contained separately within the apparatus, they shall be located as close to the battery terminals as practical, and the apparatus shall be constructed as follows:

9.3.10.2.1. The battery housing or attachment shall be arranged so that each individual intrinsically safe battery cell can be installed and replaced without short circuiting the battery output and without applying the battery output to the load side of the energy-limiting components.

9.3.10.2.2. The battery housing shall be secured with the use of special fasteners, or equivalent.

9.3.10.2.3. For hand-held portable apparatus, such as gas detectors and radios, the construction shall prevent the ejection or separation of the batteries from the apparatus even under rough-use conditions, as represented by the drop test described in Section 10.10.

9.3.10.2.4. The equipment shall be marked to warn against replacement of the batteries in a hazardous location (see Section 12.5).

9.3.11. Apparatus or battery packs that are provided with external contacts for recharging the batteries shall be provided with means to prevent the batteries from delivering ignition-capable energy to the contacts when any pair of the contacts is accidentally short-circuited. This may be accomplished by one or more of the following:

9.3.11.1. Providing blocking diodes or series resistors in the charging circuit. These are subject to fault, unless they are Protective Current-Limiting Resistors per Section 8.4.

9.3.11.2. Recessing at least one contact of a pair of contacts so that a circular disc probe 1.2 mm thick and 18 mm in diameter will not touch the contact. In this case, short-circuiting of the pair of charging contacts shall be counted as one fault.

9.3.11.3. Separately recessing each contact of a pair of contacts so that a circular disc probe as defined in Section 9.3.11.2 cannot touch either contact. In this case, short-circuiting of the pair of charging contacts shall be counted as two faults.

9.3.11.4. Separately recessing each contact of a pair of contacts at least 0.5 mm below the plane of the surrounding surface and separating the two contacts such that two circular disc probes as defined in Section 9.3.11.2 may touch the contacts but cannot be arranged in any way to simultaneously touch and complete a short circuit between the two contacts. In this case, short-circuiting of the pair of charging contacts shall be counted as one fault.

9.3.12. If the charging contacts are not arranged in accordance with Section 9.3.11.2, 9.3.11.3, or 9.3.11.4, short-circuiting of the charging contacts shall be considered a condition of normal operation.

9.3.13. If the charging contacts are not separated in accordance with the minimum distances required in Section 7.1, short circuiting of the charging contacts shall be considered a condition of normal operation.

9.3.14. Lithium batteries shall meet the preceding requirements applicable to batteries used in intrinsically safe circuits and the following:

9.3.14.1. Lithium batteries shall not explode or cause a fire when tested per the Underwriters Laboratory Inc.: "Standard for Lithium Batteries – UL 1642," in their intended application for technician-replaceable batteries. If not accepted for use in their intended application (e.g. parallel cells), then the batteries must comply with Section 9.3.14.4.

Note: Underwriters Laboratory (UL) recognition of a lithium battery does not necessarily indicate whether any samples of the battery exploded or caused a fire during the tests. The results of the tests for "technician-replaceable" cells included in the UL test report for the battery must be reviewed by MSHA to determine compliance with Section 9.3.14.

9.3.14.2. The intended use of the lithium battery shall meet all applicable engineering considerations and conditions of use included in the UL 1642 report.

9.3.14.3. Lithium cells shall not be replaceable by the user. They are to be replaced by a qualified technician only. Encapsulating the cell(s) in a solidified insulating material, soldered to a printed circuit board, or protected from user access by special fasteners are examples of methods to comply with this requirement. Alternate methods may be acceptable to comply with this requirement. A warning label shall be placed on or near the cell(s) to indicate the cell(s) is/are not to be replaced by the user. Location of this label shall be acceptable to MSHA.

9.3.14.4. A lithium battery used in a circuit with another power source (which may include other lithium batteries) shall not explode or cause a fire when up to 1.5 times the maximum fault voltage and current is applied to the battery. The maximum voltage and current that could be applied to the lithium battery shall be determined using a worst-case, two-fault analysis of the circuit. Both battery-aiding and battery-opposing currents shall be considered in the analysis and shall not exceed the maximum allowable values in the UL 1642 report.

9.4. Piezo-Electric Components – A piezo-electric component mounted as it would be in its intended application shall not generate an electrical output that exceeds 1500 microjoules when tested according to Section 10.15.

9.5. Component Thermal Considerations

9.5.1. Each component operated above its ratings, or identified as a potential source of thermal ignition shall be tested to determine its maximum surface temperature under worst-case conditions or subjected to the tests of Section 10.6 or 10.12.

9.5.2. Components that exceed a maximum surface temperature of 150°C under normal or fault conditions shall meet the test requirements of Section 10.11.

9.5.3. Components that exceed a maximum surface temperature of 530°C under normal or fault conditions shall meet the test requirements of Section 10.6.

9.6. Lamps – The heated filament of an incandescent lamp or the arc of a gaseous-discharge lamp shall not ignite an explosive mixture of methane-in-air when the glass envelope is broken. Testing shall be conducted in accordance with Section 10.12.

10.0 TEST PROCEDURES

10.1. Spark Ignition Test

10.1.1. General Requirements

10.1.1.1. Each circuit requiring spark ignition testing shall be tested to ensure that it is incapable of causing ignition under the conditions specified in Sections 5.0 and 6.0.

10.1.1.2. Normal and fault conditions shall be simulated during the test using suitably rated components. Factors shall be added as described in Section 10.1.2. The test apparatus described in Section 10.1.3 shall be used. The test apparatus contacts shall be operated in a chamber filled with the gas mixture and verified in accordance with Section 10.1.4.

10.1.2. Test Factors - The safety factor of 1.5 required by Section 5.0 at the point of test is to be achieved by the methods given in Section 10.1.2.1, 10.1.2.2, or 10.1.2.3 below. The use of a more easily ignitable test gas, such as propane or oxygen-enriched methane-in-air mixtures, shall not be used to obtain the safety factor.

10.1.2.1. Resistive circuits ($L \leq 5\ \mu H$). The energy shall be increased at the point of test by a factor of 1.5 using one of the following methods in order of preference as follows:

10.1.2.1.1. Increasing the test voltage $\sqrt{1.5}$ times.

10.1.2.1.2. Decreasing the value of limiting resistance to obtain 1.5 times the test current.

10.1.2.1.3. Increasing both the voltage and current to obtain the 1.5 safety factor on energy.

10.1.2.2. Inductive circuits (L > 5 μH). The energy at the point of test shall be increased by a factor of 1.5 using one of the following methods in order of preference as follows:

10.1.2.2.1. Increasing the supply voltage $\sqrt{1.5}$ times to obtain $\sqrt{1.5}$ times the test current.

10.1.2.2.2. Decreasing the value of limiting resistance to obtain $\sqrt{1.5}$ times the test current.

10.1.2.3. Capacitive circuits. The energy shall be increased at the point of test by a factor of 1.5 by increasing the test voltage $\sqrt{1.5}$ times.

10.1.3. Spark Test Apparatus

10.1.3.1. The spark test apparatus to be used for conducting the spark ignition tests required by these criteria shall be as specified in IEC Publication 60079-11, Annex B: "Spark-test Apparatus for Intrinsically Safe Circuits."

10.1.3.2. The parameters of the spark test apparatus may be varied to adequately test the circuit under evaluation. This would include:

10.1.3.2.1. Removing two or more of the wire electrodes, starting and stopping the spark test apparatus, or reducing the speed to allow adequate charging time for capacitive circuits (in order of preference).

10.1.3.2.2. Changing the wire electrode diameter or material to prevent hot wire ignitions when currents greater than 5 amperes are tested. 10 mil tungsten electrodes are to be used for currents from 5 to 10 amperes. No. 24 AWG copper electrodes are to be used for currents exceeding 10 amperes.

10.1.4. Calibration of Spark Test Apparatus

10.1.4.1. The sensitivity of the spark test apparatus shall be checked before and after each test conducted in accordance with Section 10.1.5. When a circuit being tested has an inductance of less than or equal to 5 μH, a resistive calibration in accordance with Section 10.1.4.2 shall be used.

For circuits with an inductance of 5 μH or more, an inductive calibration in accordance with Section 10.1.4.3 shall be used.

10.1.4.2. For resistive calibration in methane, the spark apparatus shall be connected to a 24 volt D.C. supply or battery that is limited to a 1.45 ± 0.05 amperes short-circuit current by a non-inductive resistor.

10.1.4.3. For inductive calibration in methane, the spark apparatus shall be connected to either a 24 volt D.C. power supply or to a 24 volt battery, in series with an air core inductance of 100 ± 10 millihenries (with the actual value known within 2 percent) and non-inductive resistance added to the circuit to reduce the current to 106 ± 1 milliamperes.

10.1.4.4. The spark test apparatus shall be run for 400 revolutions of the tungsten wire holder with the holder at positive polarity. Ignition of the test gas during this period validates calibration.

10.1.5. Spark Test Procedure

10.1.5.1. The spark test apparatus shall be inserted in the circuit under test at each point where it is considered that an interruption, short circuit, or ground fault may occur in the hazardous area (see Section 6.3).

10.1.5.2. The test gas used shall be an 8.3 ± 0.2 percent methane-in-air mixture.

10.1.5.3. Each circuit shall be tested for 1000 revolutions of the tungsten wire holder in the spark test apparatus. The polarity of the spark apparatus electrodes shall be reversed after 500 of the revolutions. An ignition of the test gas indicates failure of the circuit under test.

10.1.5.4. If ignition does not occur during the test, calibration of the spark test apparatus shall be repeated. If the calibration does not comply with the requirements of Section 10.1.4, the spark test of the circuit under test shall be considered invalid.

10.1.6. Spark Testing of High Frequency/High Voltage Circuits - When evaluating the intrinsic safety of ac electrical circuits operating with both voltage level and frequency exceeding 24V peak and 60Hz, respectively, or ac circuits exceeding either 24V peak or 60Hz and not readily assessable from the published ignition curves, the circuits shall only be accepted on the basis of spark ignition testing with the tests conducted under the following conditions:

10.1.6.1. The test conditions at the point of test shall be modified by electrical means to achieve the required safety factor. The test gas used shall be an 8.3 ± 0.2 percent methane-in-air mixture. The use of a more easily ignitable test gas, such as propane or oxygen-enriched methane-in-air mixtures, shall not be used to obtain the safety factor.

10.1.6.2. Spark ignition testing shall be conducted on the spark test apparatus for 1000 revolutions of the electrode holder. The connecting leads to the spark test apparatus shall be reversed after 500 revolutions.

10.1.6.3. Two spark ignition tests shall be conducted. One test shall be conducted with tungsten electrodes and cadmium disc in the spark test apparatus. The second test shall be conducted with No. 24 AWG copper electrodes and copper disc in the apparatus. The circuit under test is considered to pass if no ignitions are obtained during both tests.

10.1.6.4. The sensitivity of the spark test apparatus shall be checked before and after each test with a 24 vdc inductive or resistive circuit, whichever is more appropriate to the circuit being tested.

10.1.6.4.1. For inductive circuits with No. 24 AWG copper electrodes and copper disc in the apparatus, current levels shall be limited to 160 ± 2 milliamperes by using an air core inductance of 100 ± 10 millihenries (with the actual value known within 2%) in series with the power supply.

10.1.6.4.2. For resistive circuits with No. 24 AWG copper electrodes and copper disc in the apparatus, current levels shall be limited to 3.6 ± 0.1 amperes short-circuit current by a non-inductive resistor.

10.1.6.4.3. The spark test apparatus shall be run for 400 revolutions of the electrode holder with the holder at positive polarity. Ignition of the test gas during this period validates calibration.

10.1.7. Other Considerations

10.1.7.1. Electric motors used in intrinsically safe circuits shall be tested for spark ignition in the "locked rotor" condition if this represents the "worst-case" condition.

10.1.7.2. Oscillators, especially those used in dc-to-dc converters, shall be tested considering the "worst-case" tolerance values and faults of associated components.

10.1.7.3. The spark ignition testing of circuits powered by constant voltage transformers shall be conducted using the maximum voltage/current from the transformer considering the tolerance value and faults of capacitors used across transformer windings.

10.2. Tests For Protective Transformers

10.2.1. Transformer Dielectric Test

10.2.1.1. Transformers for direct connection to a supply voltage shall be evaluated for dielectric strength by being capable of withstanding the tests of Section 10.7 using the following test voltages, where U_n is the highest rated voltage of any winding under test:

Test Voltages (rms)	Where Applied
$4U_n$ or 2500V, whichever is greater	Between input and output windings
$2U_n$ or 1000 V, whichever is greater	Between all output windings and the core and screen
$2U_n$ + 1000 V or 1500 V, whichever is greater	Between each winding supplying an intrinsically safe circuit and every other output winding

10.2.1.2. For transformers not intended for direct connection to a supply voltage, the test voltage between input and output windings shall be $2U_n$ + 1000 volts rms or 1500 volts, whichever is greater.

10.2.2. Type Tests

The transformer shall be evaluated for dielectric strength by being subjected to the appropriate type test described below, followed by a voltage test of $2U_n$ + 1000 volts rms or 1500 volts, whichever is greater, between any winding used to supply the intrinsically safe system and all other windings (see Section 10.7). No type test is normally required for Type 2(b) construction.

10.2.2.1. Type 1(a) and Type 1(b) Transformers

10.2.2.1.1. The transformer's secondary winding or windings shall be short-circuited or loaded in such a way as to give the highest input current not exceeding 1.5 times the fuse or circuit breaker rating. The protective fuse or circuit breaker in the primary circuit shall be bypassed.

10.2.2.1.2. The temperature rise of the transformer shall not exceed the permissible value for the class of insulation used when in continuous operation for at least 6 hours or up to the moment when the imbedded one-time thermal fuse, if any, functions.

10.2.2.1.3. If an output winding is fitted with a current-limiting resistor so arranged that a short circuit cannot occur directly across the winding, the test shall be carried out with the resistor in the circuit.

10.2.2.2. Type 2(a) Transformer

10.2.2.2.1. The test shall be carried out by loading the secondary winding(s) to draw maximum primary current with the input winding subjected to its rated input voltage. The input current shall not be limited.

10.2.2.2.2. The transformer shall be tested for 6 hours or until failure, whichever occurs first. Either the input winding or the output winding(s) may short circuit to the core during this test, provided shorting of the output winding(s) to the core does not result in non-intrinsically safe energy levels in the hazardous location.

10.2.2.2.3. The transformer shall not burst into flames during the test.

Note: An imbedded one-time thermal fuse may be used to prevent Type 1(a), 1(b), and 2(a) transformers from bursting into flames.

10.2.2.3. Type 3 Transformer - The transformer shall be operated with any or all secondary windings short-circuited, depending on which represents the more severe condition of heating and with rated voltage applied to the input winding until thermal equilibrium is established. Any thermal fuse or other current- or temperature-sensitive protective devices shall be short-circuited during this test. The temperature rise of the transformer shall at no point exceed the permissible value for the class of insulation employed.

10.3. Current-Limiting Resistor Test

10.3.1. Current-limiting resistors shall be tested up to 1.5 times the maximum fault voltage across the resistor to determine if the resistor would decrease in resistance by more than 10 percent. The voltage and current shall be monitored during the following tests to calculate the change in resistance value:

10.3.1.1. The resistor shall be tested at 1.5 times the maximum fault voltage across the resistor, unless protected by a fuse complying with Sections 8.9.3 and 8.9.4.

10.3.1.2. If the resistor is protected by a fuse complying with Sections 8.9.3 and 8.9.4, the resistor shall be subjected to the following two tests: (1) at a voltage of 1.5 times the maximum fault voltage with the fuse connected in series with the resistor, and (2) at the appropriate multiple of the fuse rating without the fuse in the circuit (ref. Section 8.9.3).

10.3.1.3. If the resistor or fuse open circuits during the tests described in Section 10.3.1.1 or 10.3.1.2 above, the resistor shall be tested by increasing the voltage or current (whichever is limiting) to 1.5 times the maximum voltage across the resistor in steps to determine its maximum decrease in resistance value.

10.3.2. The above tests shall continue until the resistor reaches a constant temperature or there is no further change in resistance.

10.3.3. During each test, the resistor shall not: (1) decrease in resistance by more than 10 percent of its pre-test value; (2) flame; or (3) deform such that an adjacent conductor could short-circuit the resistor.

10.4. Shunt Diode Protective Barrier Assembly Tests

10.4.1. Barrier current-limiting resistors that affect intrinsic safety shall satisfy the test requirements for current-limiting resistors in Section 10.3.

10.4.2. Resistor-protected barrier diodes shall withstand continuously (i.e., reaches constant temperature or until it is obvious that no further deterioration will occur) or fail without rendering the barrier ineffective when subjected to 1.5 times the maximum current which will flow continuously through the resistor when up to the maximum safe-area voltage is applied to the barrier. Any other result based on testing would constitute a failure.

10.4.3. Zener diode maximum voltage shall be determined by one of the following or equivalent methods:

10.4.3.1. The summation of the nominal zener voltage, maximum tolerance of the zener, and the zener voltage change with current and temperature shall be considered under fault current flow through the zener. The fault current for a fuse protected zener shall be equal to the appropriate multiple of the fuse rating (ref. Section 8.9.3).

The formula to calculate Vmax, the zener diode maximum voltage, is as follows:

$$V_{max} = V + V_{tol} + \Delta V_{temp}$$

Where V_{max} = Zener Diode Maximum Voltage

V = Zener Diode Nominal Voltage

V_{tol} = “+” voltage tolerance of Zener Diode

ΔV_{temp} = Change in Zener Voltage due to change in Temperature

10.4.3.2. Operation of the zener diode at a current level sufficient to initiate thermal breakdown, thus determining the voltage across the zener just prior to breakdown. The zener diode maximum voltage shall be the highest voltage measured during tests.

10.4.4. The adequacy of the fuse in preventing open circuiting of the zener diode shall be determined by one of the following methods:

10.4.4.1. The barrier assembly fuse shall be substituted by a similar type fuse having an amperage rating 10 times greater than the appropriate multiple of the fuse rating (ref. Section 8.9.3). The substituted fuse shall open prior to diode open-circuit failure, upon application of up to the maximum safe-area voltage.

10.4.4.2. A current flow of the appropriate multiple of the fuse rating (ref. Section 8.9.3) shall be applied to the barrier assembly, without the fuse, for 10 times longer than the operating time of the fuse without open circuit diode failure that would render the barrier ineffective. The operating time of the fuse shall be determined by test or taken from the manufacturer's operating time versus current curve at the appropriate multiple of its current rating.

10.5. Temperature Tests

10.5.1. Except as otherwise noted, temperatures shall be measured either by thermocouples consisting of wires not larger than No. 24 AWG or by equivalent means.

10.5.2. A thermocouple shall be used for determining the temperature of a coil or winding of a protective transformer if it can be mounted without removal of encapsulating compound or similar material: (1) on the integrally applied insulation of a coil without a wrap, or (2) on the outer surface of a wrap that is not more than 0.8 mm thick and consists of cotton, paper, rayon, or similar material (but not of asbestos or similar thermal insulation). The change-of-resistance method of Section 10.5.5 shall be used if the thermocouple measurement cannot be conducted in accordance with the foregoing considerations.

10.5.3. Tests shall be conducted until constant temperatures are attained.

10.5.4. A thermocouple junction shall be securely held in thermal contact with the surface of the material whose temperature is being measured.

10.5.5. The formula for obtaining the temperature rise of a protective transformer winding by the resistance method is as follows (windings are to be at ambient temperature at the start of the test):

$$\Delta t = R/r(k+t_1) - (k+t_2)$$

Where Δt = the temperature rise, °C

R = the resistance of the coil at the end of the test, ohms

r = the resistance of the coil at the beginning of the test, ohms

t_1 = the room temperature, °C, at the beginning of the test

t_2 = the room temperature, °C, at the end of the test

k = 234.5 for copper, 225.0 for aluminum electrical conductor (EC grade).

10.5.6. If the temperature of the wires of a circuit under evaluation exceeds 530°C, during normal operation or under fault conditions, the wire shall meet the test requirements of Section 10.6.

10.6. Small Component Thermal Ignition Test - Small components and small gage wire with a surface temperature greater than 530°C, under normal or fault conditions, shall not cause ignition of a methane-in-air mixture when tested according to Sections 10.6.1 through 10.6.5. The components shall be tested according to the procedures of the Temperature Test in Section 10.5. Components which are located in an MSHA-certified explosion-proof enclosure are exempt from this test.

10.6.1. The flammable test gas mixture used shall be 7.7 percent ± 0.2 percent methane-in-air. The test gas mixture shall be ignited by other means prior to testing to verify presence of a flammable mixture.

10.6.2. If practical, the component shall be mounted in the equipment as intended. The flammable mixture shall be introduced into the equipment enclosure so as to assure contact between the mixture and the surface of the component being tested. If this is impractical, such a condition shall be simulated so as to assure representative test results, taking into consideration other parts of the equipment in the vicinity of the component being tested that could affect the temperature of the mixture and the flow of the mixture around the component due to ventilation and thermal effects.

10.6.3. The test shall be conducted under the normal or fault conditions specified in Section 5.0 (with no safety factor applied), whichever produces the maximum surface temperatures on the component.

10.6.4. The test shall also be conducted under the normal or fault conditions that produce the maximum release of thermal energy whenever this is different than the conditions of Section 10.6.3 and the temperature exceeds 530°C.

10.6.5. The tests specified in Sections 10.6.3 and 10.6.4 shall continue until constant temperature of the component under test and surrounding parts is attained or until the temperature of the component under test drops to a value equal to or less than 530°C as a result of failure of the component, whichever occurs first. If failure of the component terminates the test, four additional samples shall be tested to assure that ignition will not occur up to the maximum fault current. If no ignition occurs, the mixture is to be ignited by other means to verify presence of a flammable mixture.

10.7. Dielectric Test

10.7.1. The following test method shall be used:

10.7.1.1. The test shall be made with an ac voltage of a substantially sinusoidal waveform at a frequency between 48 Hz and 62 Hz or alternately with a dc voltage having no more than a 3 percent peak to peak ripple at a level of $\sqrt{2}$ times the specified ac voltage.

10.7.1.2. The power supply shall have sufficient volt-ampere capacity to maintain the test voltage, taking into account any leakage current which may occur.

10.7.1.3. The voltage shall be increased steadily to the specified value in a period not less than 10 seconds and then maintained for at least 60 seconds.

10.7.2. There shall be no breakdown of the insulation or dielectric between the test points during testing.

10.8. Mechanical Test - Partitions shall withstand a force of 30 Newtons. The force shall be applied using a rigid test rod having a 6 mm diameter ball at the point of contact. The force shall be applied to the weakest point on the partition, or, if the weakest point can not be determined, at the approximate center of the partition for 10 seconds. There shall be no deformation of the partition that would defeat its purpose.

10.9. Flash Current Test - Batteries shall be tested and the highest measured short-circuit current will be used for analysis and test. Transients during the first 20 microseconds of the test will be disregarded.

10.10. Drop Test

10.10.1. Portable apparatus and user-replaceable battery packs that contain energy-limiting components to achieve intrinsic safety shall be subjected to the following drop test:

10.10.1.1. The apparatus shall be dropped six times with not more than one impact at the same point from a height of 0.9 m onto an oak platform.

10.10.1.2. If appropriate, a nonrestrictive guide may be used to assure a free-fall drop on the surface to be tested.

10.10.1.3. There shall be no separation or ejection of the battery or batteries from the apparatus, nor other fault that could affect intrinsic safety.

10.11. Coal Dust Thermal Ignition Test - Components that may be covered by coal dust and exhibit a surface temperature greater than 150°C, under normal, single fault, or two fault conditions shall not ignite a coal dust layer when tested according to Sections 10.11.1 through 10.11.4. Components that are located in a dust-tight enclosure or an MSHA-certified explosion-proof enclosure are exempt from this test.

10.11.1. The device shall be mounted in its normal position and shall be covered with coal dust to a depth of 12 mm, but no more than 18mm. The dust used shall be Pittsburgh Seam Coal Dust fine enough to pass through a 200 mesh screen.

10.11.2. The device shall be operated under fault conditions appropriate to the device until constant temperature is attained.

10.11.3. The test may be performed using a laboratory power source and with the component placed in a fixture provided that the test simulation is no less severe than if the device itself was tested.

10.11.4. The component fails the test if there is evidence of smoldering or ignition of the coal dust.

10.12. Lamp Breakage Test - The heated filament of an incandescent lamp or the arc of a gaseous-discharge lamp shall not ignite an explosive mixture of 7.7 ± 0.2 percent methane-in-air when the glass envelope is broken while the bulb is energized.

10.12.1. A series of 30 tests shall be conducted with a safety factor of $\sqrt{1.5}$ on the maximum fault voltage applied to the lamp. A lower voltage may be applied if premature burnout of the bulb occurs. The envelope is to be broken quickly and completely and the filament is not to be broken by the breakage of the envelope.

10.12.2. If the lampholder assembly contains a special ejection device or a filament-quenching device, the glass envelope shall be broken within the test chamber without intentionally affecting the operation of the circuit breaking device.

10.13. Optical Isolator Test

10.13.1. Each optically-coupled isolator shall withstand a minimum dielectric voltage of either 2500 volts (rms) or four times the maximum fault voltage (whichever is greater) between its input and output. The test voltage shall be applied between its input and output pins. The voltage is to be increased from zero to the minimum dielectric voltage in 10 seconds and then maintained at that voltage for 60 seconds.

10.13.2. Apply the maximum test voltage to the input side of the isolator for 1 minute. Determine if the isolator continues to withstand the minimum dielectric voltage as tested per Section 10.13.1.

10.13.3. Ramp the voltage connected to the input side of the isolator from zero to the maximum test voltage in a 10 minute period. Determine if the isolator continues to withstand the minimum dielectric voltage as tested per Section 10.13.1.

10.13.4. Ramp the voltage connected to the output side of the isolator from zero to the maximum test voltage in a 10 minute period. Determine if the isolator continues to withstand the minimum dielectric voltage as tested per Section 10.13.1.

10.13.5. For acceptable performance each sample of the isolator must withstand the specified dielectric voltage.

10.14. Encapsulation Test

10.14.1. An encapsulant shall withstand a force of 30 Newtons applied using the flat end of a 6 mm diameter solid test rod. The force is to be applied for at least 10 seconds in a direction perpendicular to the surface of the encapsulant. The encapsulant may transiently move during the test but shall not permanently deform or be damaged in a way that impairs the protection provided.

10.14.2. An encapsulant that is not protected from shock by another enclosure or partition is also to be subjected to an impact test of 2 joules. A test mass having a hardened steel impact head 25 mm in diameter shall be allowed to fall vertically. The direction of the impact is to be normal either to the flat surface being tested, or to a tangent to the surface if the surface is not flat. The encapsulant may transiently move during the test but shall not permanently deform or be damaged in a way that impairs the protection provided.

10.15. Piezo-Electric Component Test

10.15.1. A test mass having a hardened steel impact head 25 mm in diameter shall be allowed to fall vertically such that the apparatus containing the piezo-electric component is impacted with an energy of 20 joules. The direction of the impact is to be normal either to the flat surface being tested or to a tangent to the surface if the surface is not flat.

10.15.2. The test shall be conducted twice on those surfaces which are accessible when the apparatus is mounted as it would be in its intended application.

10.15.3. For acceptable performance, the maximum output energy generated by the piezo-electric component during the test shall not exceed 1500 microjoules. The maximum electrical energy generated by the piezo-electric component shall be calculated from the formula $E = \frac{1}{2}CV^2$, where C is the measured capacitance of the device and V is the maximum output voltage generated.

10.16. Wire, Connection, and Trace Test - The current carrying capacity of a single wire, connection, and/or trace (including vias if applicable) is to be tested for 1 hour with a current of 1.5 times the maximum continuous current which can flow at that point under normal and fault condition. The application of this test current shall not cause the tested wire, connection, and/or trace to fail to open circuit or to be separated from its substrate at any point.

11.0 IGNITION CURVES

The ignition curves shown in Figures 11.1 through 11.4 shall be used to determine if a circuit under evaluation can be accepted without testing. These curves have been digitized and can be found at: http://www.msha.gov/TECHSUPP/ACC/application/application.htm.

The hardcopy curves or data extrapolated from the hardcopy curves remain the official version.

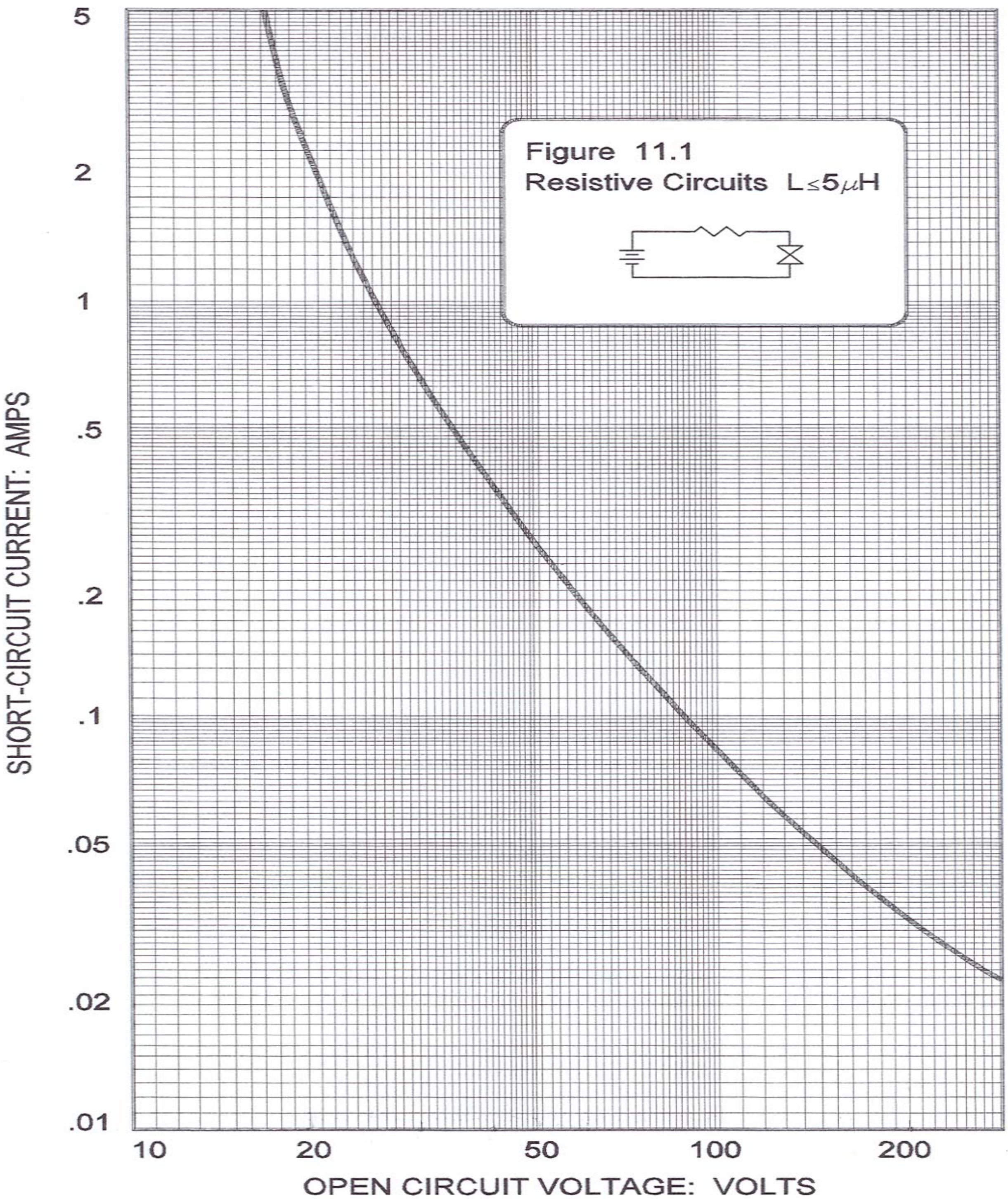


Figure 11.1
Resistive Circuits L≤5μH
SHORT-CIRCUIT CURRENT: AMPS
5
2
1
.5
.2
.1
.05
.02
.01
10
20
50
100
200
OPEN CIRCUIT VOLTAGE: VOLTS

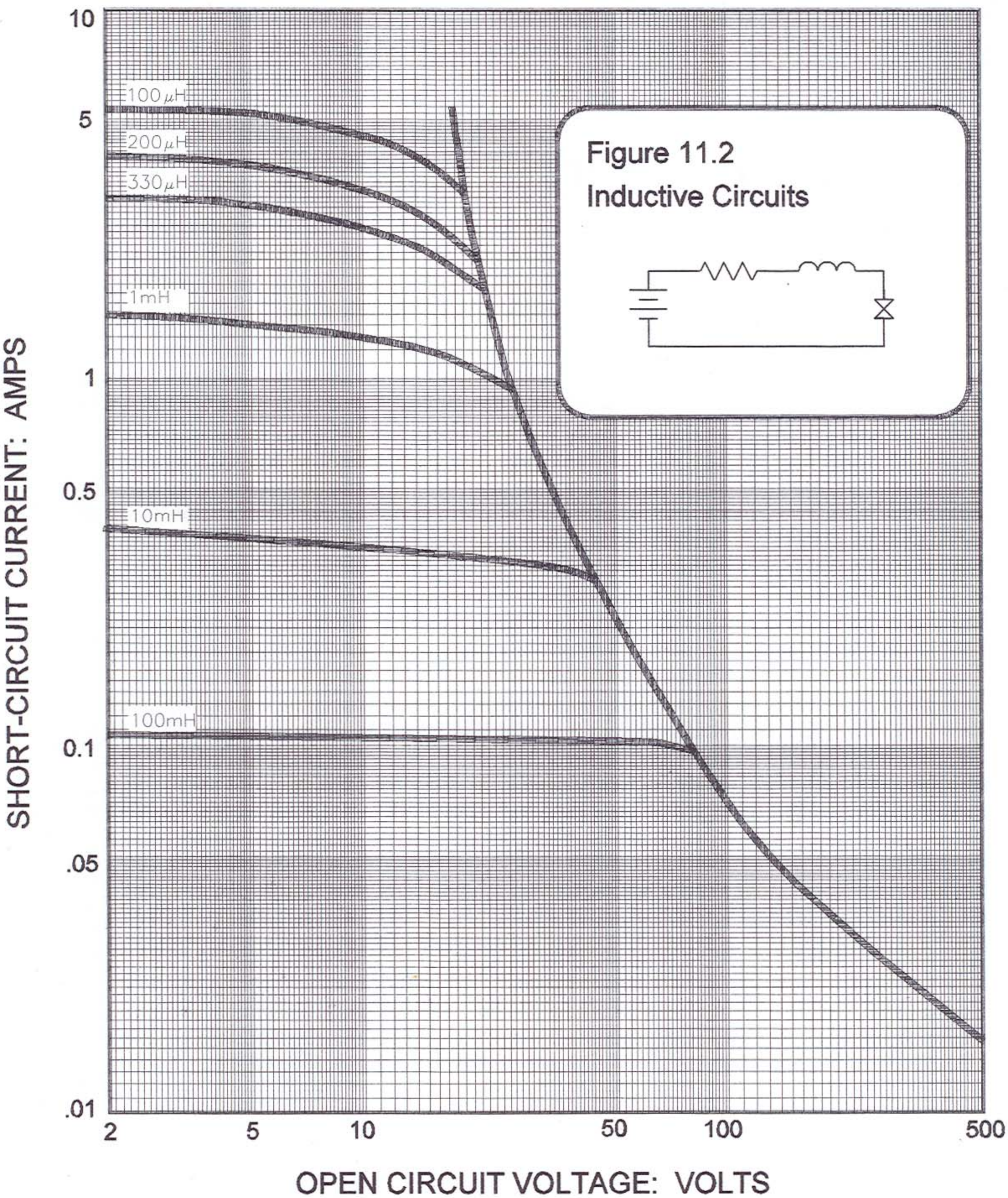


Figure 11.2
Inductive Circuits
100µH
200µH
330µH
1mH
10mH
100mH
SHORT-CIRCUIT CURRENT: AMPS
10
5
1
0.5
0.1
.05
.01
2
5
10
50
100
500
OPEN CIRCUIT VOLTAGE: VOLTS

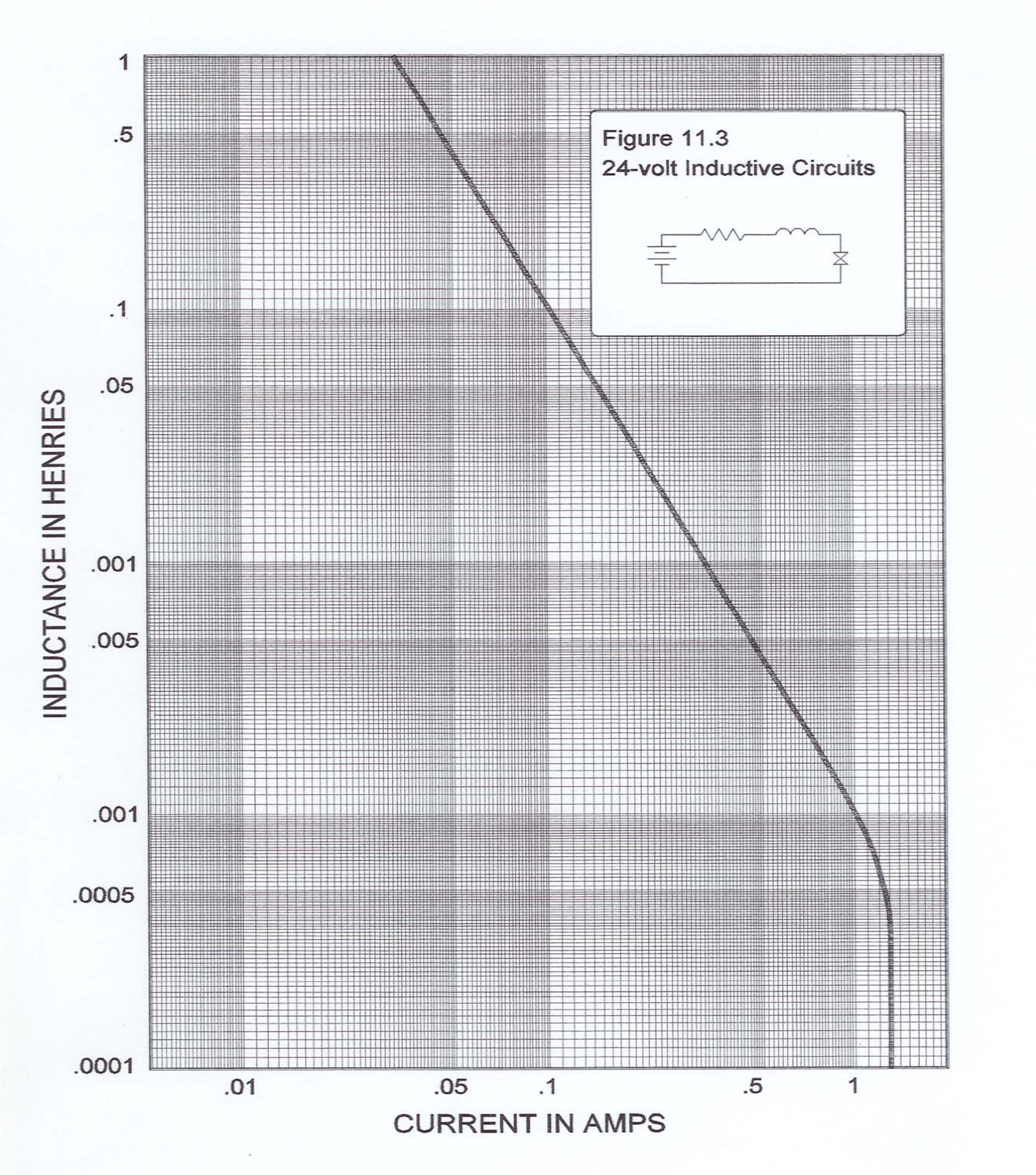


Figure 11.3
24-volt Inductive Circuits
INDUCTANCE IN HENRIES
1
.5
.1
.05
.001
.005
.001
.0005
.0001
.01
.05
.1
.5
1
CURRENT IN AMPS

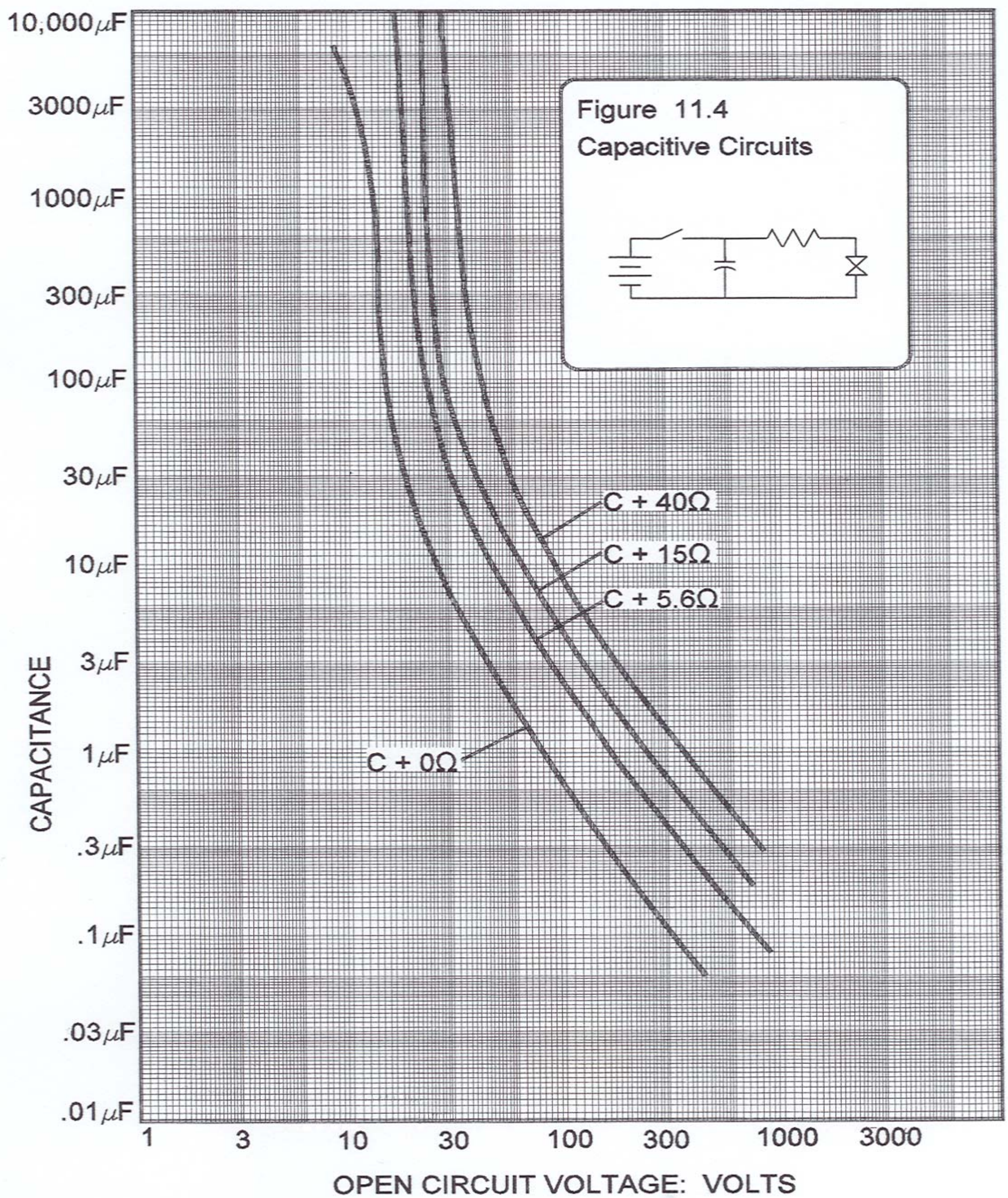


Figure 11.4
Capacitive Circuits
10,000µF
3000µF
1000µF
300µF
100µF
30µF
10µF
3µF
1µF
.3µF
.1µF
.03µF
.01µF
CAPACITANCE
C + 40Ω
C + 15Ω
C + 5.6Ω
C + 0Ω
1
3
10
30
100
300
1000
3000
OPEN CIRCUIT VOLTAGE: VOLTS

12.0 MARKING

All information necessary for external connections affecting safety shall be provided with the equipment (e.g., maximum voltage, minimum resistance, maximum inductance, or in special cases a specific type of apparatus to be connected). As much information as possible shall be provided on the apparatus label. If it is impractical to mark some small pieces of apparatus with all the required information on the apparatus label, it shall be provided on the wiring diagram and in an installation or operation manual.

12.1. Minimum Marking/Approval Plate - The minimum marking on an approval plate shall include the following:

12.1.1. The manufacturer's name, the MSHA logo, the approval number, serial number (if not identified elsewhere), model or part number, and the word "Permissible" followed by the generic name of the approved equipment.

12.1.2. The statement, "Tested for Intrinsic Safety in Methane Air Mixtures Only."

12.1.3. A list of the applicable conditions of use or a reference to the document that lists the conditions of use.

12.1.4. MSHA approval plate information may be combined with other approval agency information, as long as all of the information required by MSHA appears.

12.2. Minimum Marking/Intrinsic Safety Evaluation Label - The minimum marking on an intrinsic safety evaluation label shall include the following:

12.2.1. The manufacturer's name, the intrinsic safety evaluation number, the model or part number, and the generic name of the assembly.

12.2.2. A list of the applicable conditions of use or a reference to the document that lists the conditions of use.

12.3. Additional Marking/Intrinsically Safe Apparatus - Where practicable, the apparatus shall be marked with the following information:

12.3.1. An indication that the apparatus is intrinsically safe.

12.3.2. Where repair is possible, a label worded, "WARNING: Any substitution of components or modification to the circuit may defeat intrinsic safety."

12.3.3. A reference to accompanying literature if it provides special installation, maintenance, or operating instructions.

12.3.4. The MSHA evaluation number, when appropriate.

12.4. Additional Marking/Associated Apparatus - Associated apparatus shall have the following markings:

12.4.1. Where repair is possible, a label worded, "WARNING: Any substitution of components or modification to the circuit may defeat intrinsic safety."

12.4.2. A reference to accompanying literature if it provides special installation, maintenance, or operating instructions.

12.4.3. Any other necessary information, in particular, an indication of any other type of protection required and its characteristics such as a warning statement indicating that the apparatus must be located in fresh air or housed in a MSHA-certified explosion-proof enclosure.

12.4.4. The MSHA evaluation number, when appropriate.

12.5. Battery-Powered Apparatus Marking - Battery-powered apparatus shall be marked with a warning statement to indicate the size and voltage of the batteries used. Alternatively, a warning statement indicating a specific battery (e.g., by manufacturer and model number) shall be used. Apparatus with replaceable cells also need a warning statement to indicate that all cells must be replaced with fresh cells at the same time and that cells from different manufacturers must not be mixed. If the batteries are not intrinsically safe the apparatus shall be marked, "Warning: Batteries must only be changed in a fresh air location."

12.6. Terminal Marking - Terminals, terminal boxes, and plugs and receptacles of intrinsically safe circuits shall be clearly marked, as with a label "Intrinsically Safe" and shall be clearly distinguishable. Where a color is used for this purpose it shall be bright blue.

12.7. Permanence of Markings

12.7.1. All permanent markings shall be legible and prominent and located so they are visible after installation of the equipment except as follows:

12.7.1.1. The permanent marking required for associated apparatus need not be located on the outside of the enclosure of apparatus that is intended for the use in a customer supplied MSHA-certified explosion-proof enclosure provided it is readily visible by removing a cover after installation.

12.7.1.2. The permanent marking concerning battery replacement that is required to be on apparatus need not be located on the outside of the enclosure of small portable battery-operated apparatus if the marking is located so that it is readily visible when replacing batteries.

12.7.2. The marking shall be molded, die-stamped, paint-stenciled, stamped or etched metal that is permanently secured.