

1.0 PURPOSE

This document contains specific requirements for the construction and testing of electrical assemblies or parts thereof intended to be used in equipment submitted for approval under Title 30, Code of Federal Regulations, Parts 18, 19, 20, 22, 23 and 27, when protection is provided by encapsulation. The encapsulation is intended to prevent an explosion of a methane-air atmosphere by sparking or hot parts. Potted components complying with 30 CFR 18.31(b) are not subject to this criteria; they are evaluated to the criteria in ACRI2012.

2.0 SCOPE

These requirements apply to all components that use encapsulation to provide safety by separating potential ignition sources from potentially explosive atmospheres. It is divided into two sections, one of which deals with encapsulated circuitry that is non-incendive in normal operation, and another that covers encapsulated circuits and devices that are incendive in normal operation.

3.0 REFERENCES

- 3.1. 30 CFR Parts 18, 19, 20, 22, 23, and 27
- 3.2. ACRI2001 "Criteria for the Evaluation and Test of Intrinsically Safe Apparatus and Associated Apparatus"
- 3.3. ASTP2219 "Impact Test of Encapsulated Electrical Assemblies"
- 3.4. ASTP2224, "Encapsulated Assembly Force Test"
- 3.5. ASTP2240, "Encapsulation Absorption Test"
- 3.6. ASTP2241, "Encapsulation Adhesion Test"
- 3.7. ASTP2242, "Encapsulation Dielectric Test"
- 3.8. ASTP2243, "Drop Test Of Encapsulated Assemblies"
- 3.9. ASTP2245 "Encapsulation Thermal Endurance Test"

4.0 DEFINITIONS

- 4.1. Adhesion - Moisture, gas and dust tight permanent agglutination of a compound to a surface.
- 4.2. Casting - An object at or near finished shape obtained by solidification of a compound in a mold.
- 4.3. Compound - Thermosetting, thermoplastic and elastomeric materials, with or without fillers and/or additives, are considered, after solidification, to be compounds.
- 4.4. Continuous operating temperature - Temperature range within which, according to the details given by the manufacturer, the properties of the compound, during operation, satisfy the requirements of this standard on a permanent basis during the foreseen lifetime of the equipment.
- 4.5. Encapsulation - The process of applying the compound to enclose an electrical device(s) by suitable means.
- 4.6. Free space - Intentionally created space surrounding components or space inside components
- 4.7. Free surface - Compound surface exposed to the explosive atmospheres and/or dust layers.
- 4.8. Incendive - Able to release enough electrical or thermal energy to ignite a flammable mixture of the most easily ignitable composition of methane and air.
- 4.9. Normal Operation - Operation of apparatus conforming electrically and mechanically within its design specification and used within the limits specified by the manufacturer and MSHA-defined conditions of use, application of the worst-case non-countable faults and normal operating conditions as stated in ACRI2001.
- 4.10. Potting - An encapsulation process in which the mold remains attached to the electrical device.
- 4.11. Protective Device - Devices intended to eliminate or reduce the consequences of equipment failure.
- 4.12. Solid Insulation - Insulation material which is extruded or molded, but not poured. Note - Insulators fabricated from two or more pieces of electrical

insulating material which are solidly bonded together may be considered as solid. Varnish and similar coatings are not considered to be solid insulation.

4.13. Temperature range - The range of temperature within which the properties of the compound, in operation or storage, permit compliance with this document.

4.14. Void - Unintentional space created as a consequence of the encapsulation process.

5.0 CRITERIA

5.1. General. The documentation shall specify the compound(s) used and the processing method(s). As a minimum, those properties of the compound(s) on which the protection depends shall be provided. Due consideration shall be given in the selection of compounds to allow for the expansion of components during operation and in the event of allowable faults. Encapsulated circuits that are non-incendive in normal operation (with no countable faults applied) are subject to the construction criteria in Section 5.4 below. Encapsulated circuits that are incendive in normal operation - (with no countable faults applied) are subject to the construction criteria in Section 5.5. The applicant shall provide the lifetime of those properties on which the protection depends shall be provided.

NOTE: The choice of the compound(s) to be used for a specific application is dependent on the task each compound has to perform. In general, testing a compound once is not sufficient for universal use.

5.2. Description of the compound. Documentation submitted by the applicant shall describe precisely the compound used and the production method during encapsulation. This compound description shall include the following:

5.2.1. The name and address of the manufacturer of the compound.

5.2.2. The exact and complete reference of the compound, and, if relevant percentage of fillers and any other additives, the mixture ratios and the type designation.

5.2.3. If applicable, any treatment of the surface of the compound(s), for example varnishing.

- 5.2.4. If applicable, to obtain correct adhesion of the compound to a component any requirement for pre-treating of the component; for example: cleaning, or etching.
- 5.2.5. Temperature range of the compound.
- 5.2.6. Maximum continuous operating temperature of the compound.
- 5.2.7. The color of the compound used for the test samples where the compound specification will be influenced by changing the color.
- 5.2.8. Resistance to chemicals.
- 5.2.9. Dielectric strength.
- 5.2.10. Volume resistivity.
- 5.2.11. Surface resistivity.
- 5.2.12. Arc resistance.
- 5.2.13. Permeability.
- 5.2.14. CTI Value (or Performance Level Category (PLC))
- 5.3. Requirements for compound. Selection of the encapsulation compound should be made based on the following specific requirements:
 - 5.3.1. Encapsulation compound shall cure in a solid, irreversible state so as to make a non-serviceable assembly. A solid, non-serviceable, cured material will be determined using published specifications provided by the manufacturer of the encapsulation compound. The force test in ASTP2224 will be conducted to determine compliance.
 - 5.3.2. Encapsulation material, when cured, shall have a minimum dielectric strength of 200 volts per 0.025 mm (0.001 inch) of thickness. Testing to verify the dielectric strength of the encapsulation compound will be conducted in accordance with the dielectric strength test specified in ASTP2242.
 - 5.3.3. Encapsulation compound shall adhere to any object protruding from the encapsulated assembly and shall ensure against the possible entry of

moisture or hazardous gases through this seal. The seal shall be verified in accordance with the adhesion test in ASTP2241.

- 5.3.4. Encapsulation compound shall be non-permeable. Permeability shall be determined in accordance with ASTP2240.
- 5.3.5. Encapsulation compound shall not decompose by electrical means at the maximum voltage available from within the encapsulated assembly. Maximum voltage is to be determined per ACRI2001. Decomposition shall be determined by review of the results obtained during the dielectric strength test specified in ASTP2242 as conducted per 5.3.2 above.
- 5.3.6. Encapsulation compound shall be resistant to chemicals. Chemical resistance shall be determined using specifications published by the manufacturer of the encapsulation compound. If determined necessary, specialized chemical resistance tests may be devised and implemented.
- 5.3.7. Encapsulation compound shall be resistant to changes in temperature. Resistance to changes in temperature shall be determined in accordance with ASTP2245.
- 5.3.8. Encapsulation compound shall provide protection for the electrical assembly against impact. Testing to determine resistance of the free surface of encapsulated assemblies to damage from impact shall be conducted in accordance with ASTP2219.
- 5.3.9. Encapsulation compound shall provide protection against damage to the electrical assembly caused by a drop. Drop testing portable encapsulated assemblies shall be conducted in accordance with ASTP2243.
- 5.4. Construction requirements for non-incendive encapsulated circuits. This section applies to circuits that are non-incendive under normal operation.
 - 5.4.1. The minimum separation distance between encapsulated conductive parts and components, and the free surface of the casting compound shall be at least half the values shown in row 6 of Table 7.1 in ACRI2001, with a minimum of 1 mm. When the casting compound is in direct contact with and adheres to an enclosure of insulating material conforming to row 7 of Table 7.1 in ACRI2001, no other separation is required (see Figure 1 in the Appendix).

All circuits connected to the encapsulated conductive parts and/or components and/or bare parts protruding from the casting compound shall be intrinsically safe. Fault conditions within the casting compound shall be assessed but the possibility of spark ignition inside the encapsulation shall not be considered.

For associated apparatus, fault conditions within the casting compound shall be assessed.

The casting compound shall be free of voids, except that encapsulation of components containing free space (transistors, relays, fuses, etc.) is allowed. This shall be verified by dissecting a sample of the assembly in its marketable form for inspection and photographing.

NOTE: Further guidance is given in the Appendix.

In addition, where a casting compound is used to reduce the ignition capability of hot components, for example diodes and resistors, the volume and thickness of the casting compound shall reduce the maximum surface temperature of the casting compound to the desired value.

5.4.2. Where a casting compound is used, it shall conform to the following:

- 5.4.2.1. Have a temperature rating, specified by the manufacturer of the casting compound or apparatus, which is at least equal to the maximum temperature achieved by any component under encapsulated conditions, under normal operation and with up to the two worst-case faults to the encapsulated circuitry. Alternatively higher temperatures than the rated casting compound temperature shall be accepted provided that they do not cause any damage to the casting compound, as determined by test, that would adversely affect the type of protection;
- 5.4.2.2. Have, at its free surface, a CTI value of at least that specified in Table 7.1 of ACRI2001 if any bare conductive parts protrude from the casting compound;
- 5.4.2.3. Only materials passing the impact test in ASTP2219 shall have its free surface exposed and unprotected, thus forming part of the enclosure;

5.4.2.4. Be adherent to all conductive parts, components and substrates (and wall surfaces, if applicable) except when they are totally enclosed by the casting compound.

5.5. Construction requirements for incendive circuits. This applies to circuits that are incendive when applying no countable faults, as defined in ACRI2001.

5.5.1. General. Where the encapsulation forms part of the external enclosure it shall comply with the applicable enclosure requirements of ACRI2001 (e.g., those for surface temperature and ruggedness). Appropriate action shall be taken to accommodate the expansion of components during normal operation and in the event of faults according to 5.5.2. In 5.5.2 to 5.5.9, the requirements differ according to whether the compound adheres to the enclosure. Where adhesion is specified, the aim is to prevent the ingress of explosive atmospheres and moisture at the boundary surfaces (for example enclosure-compound, compound-parts that are not completely embedded in the compound, such as printed wiring boards, connection terminals, etc.). If additional treatment for the boundary surfaces is required in order to ensure adhesion, this shall be included in the manufacturer's documentation.

Where adhesion is required to maintain the type of protection, it shall be maintained after completion of all the prescribed tests.

All external circuits connected to the encapsulated conductive parts shall meet the requirements of 30 CFR Part 18 and/or ACRI2001.

5.5.2. Determination of faults

5.5.2.1. Fault examination. The encapsulation protection shall be maintained even in the case of an unfavorable input condition and unfavorable output load and with application of up to the two worst-case internal electrical faults, as defined by ACRI2001. Protective components and adequate separation distances shall not be subject to fault.

The failure of some components may result in an unstable condition, for example, alternating between high and low resistance. In those cases, the condition that results in maximum power condition shall be considered. If a fault leads to one or more subsequent faults, for example, due to the

overload of a component, the primary and subsequent fault(s) shall be considered to be a single fault.

5.5.2.2. Protective components. The following components shall be considered to be infallible if they are encapsulated according to the requirements of this standard, if they are suitable for the temperature range at the site of installation and if they are not operated at more than 2/3 of their rated voltage, rated current and rated power specified by the manufacturer of the respective component:

- resistors, that comply with Section 8.4 of ACRI2001,
- semiconductors, if they are used in accordance with 8.6 and 8.7 of ACRI2001.

Where semiconductor devices are used to limit current, two devices shall be used.

Transformers, optocouplers, and relays acceptable for the segregation of different circuits under ACRI2001 shall be considered not subject to short-circuit fault.

5.5.2.3. Separation distances. It is not necessary to consider the possibility of a fault occurring as described in 5.5.2.1 in respect of voltage breakdown, if the distances between bare current-carrying parts

- of the same circuit, or
- of a circuit and grounded metal parts, or
- of two separate circuits (sum of the working voltages shall be taken as the voltage for Table 1; where one of the working voltages is less than 20 % of the other, it shall be ignored)

comply with the requirements of 5.5.2.3.1 and if applicable 5.5.2.3.2.

5.5.2.3.1. Distances through the compound. Distances through compound shall be considered to be infallible if they comply with the values in Table 1, provided that they were fixed mechanically before encapsulation.

Table 1 – Distances through the compound

Voltage V r.m.s. or d.c. (see note) V	Minimum distance mm
≤63	0.5
≤400	1
≤500	1.5
≤630	2
≤1 000	2.5
≤1 600	4
≤3 200	7
≤6 300	12
≤10 000	20
NOTE For all voltages, the actual voltage may exceed the value given in the table by up to 10 %.	

5.5.2.3.2. Distances through solid insulation. Distances through solid insulation shall be considered to be not subject to fault if the minimum thickness of solid insulation is 0.1 mm and meets the dielectric strength test of ASTP2242.

5.5.3. Free space in the encapsulation. The compound shall be free of voids. The sum of the free spaces shall not exceed 10 cm³. Additional requirements for the thickness of compound are given in Table 2.

Table 2 – Minimum thickness of compound from free space

Minimum thickness of compound from free space to:	Free space ≤ 1 cm ³	Free space > 1 cm ³ ≤ 10 cm ³	Free space > 10 cm ³ ≤ 100 cm ³
Free space or free surface	3 mm	3 mm (pressure test in accordance with 5.5.7.6)	Not permitted
Non-metallic or metal enclosure with adhesion (see note)	3 mm (enclosure* + compound)	3 mm (enclosure* + compound) (pressure test in accordance with 5.5.7.6)	Not permitted

Minimum thickness of compound from free space to:	Free space $\leq 1 \text{ cm}^3$	Free space $> 1 \text{ cm}^3 \leq 10 \text{ cm}^3$	Free space $> 10 \text{ cm}^3 \leq 100 \text{ cm}^3$
Non-metallic or metal enclosure without adhesion	3 mm	3 mm (pressure test in accordance with 5.5.7.6)	Not permitted

* Enclosure must be greater than or equal to 1 mm to be considered

5.5.4. Thickness of the compound

5.5.4.1. General. If the surface of the compound is totally or partly surrounded by an enclosure and the enclosure is part of the protection, the enclosure or parts of the enclosure shall comply with the applicable enclosure requirements of ACRI2001 (e.g., those for surface temperature and ruggedness). The minimum thickness of the compound with or without a surrounding enclosure shall comply with the requirements of 5.5.4.2 to 5.5.4.4 as applicable. In all cases the encapsulant is additionally subjected to the dielectric strength test of ASTP2242.

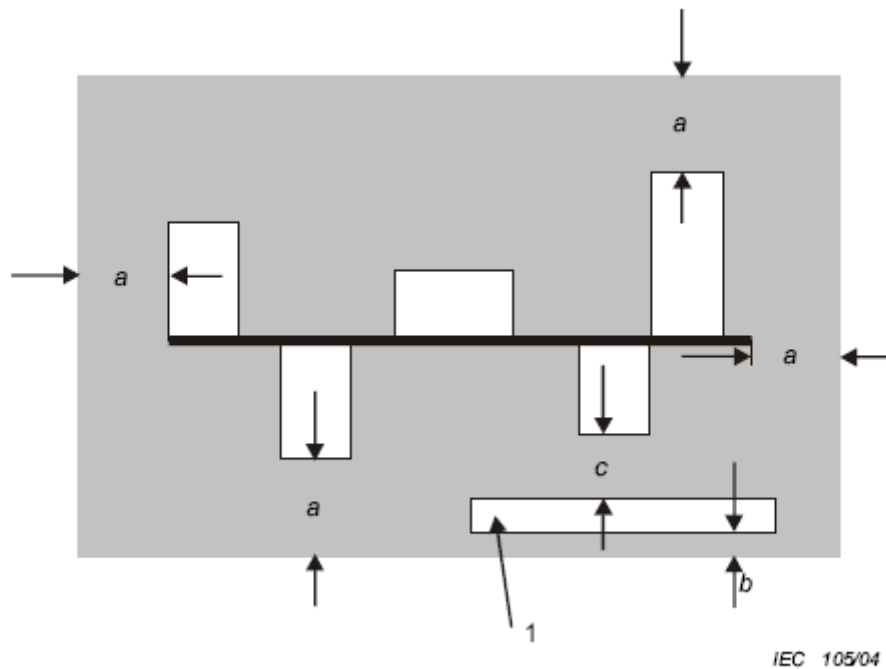
5.5.4.2. Encapsulated apparatus with free surface. The thickness of the compound between its free surface and the components or conductors in the encapsulation, as shown in Figure 1, shall comply with the following: dimension $a \geq 3 \text{ mm}$; dimension $c \geq$ distance according to Table 1; and dimension $b \geq 3 \text{ mm}$.

where:

a is the distance between the component and the free surface,

b is the distance between a non current carrying part and the free surface,

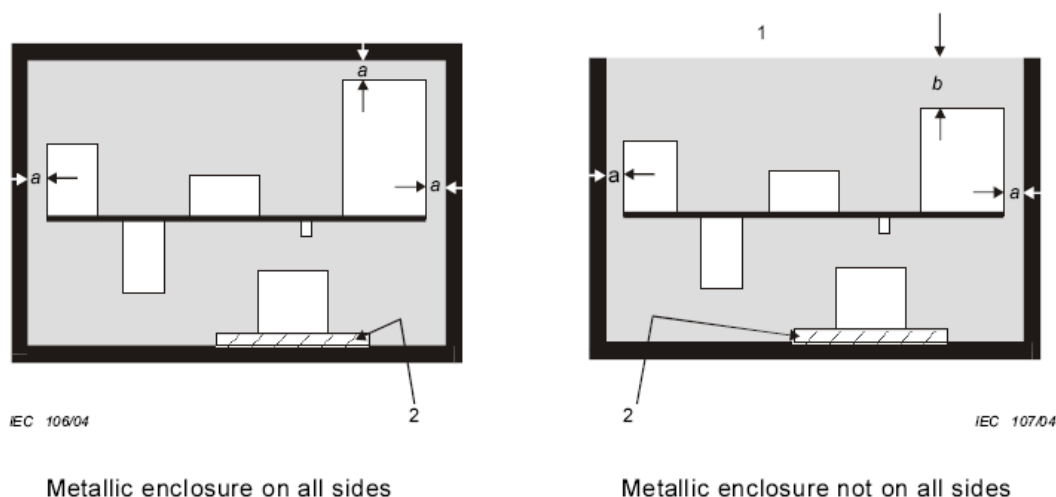
c is the distance between the component and non current carrying parts inside the encapsulation.



Key:
1 Non current carrying part

Figure 1 – Distances between free surface of compound and components or conductors

- 5.5.4.3. Encapsulated apparatus with metal enclosure. The thickness of the compound between the wall or the free surface of the compound and the components or conductors in the encapsulation, as shown in Figure 2, shall comply with the following: dimension $a \geq 3 \text{ mm}$; dimension $b \geq 3 \text{ mm}$, where: a is the distance between the component and the inside wall of the enclosure; and b is the distance between the component and the free surface.



Key

1 Free surface

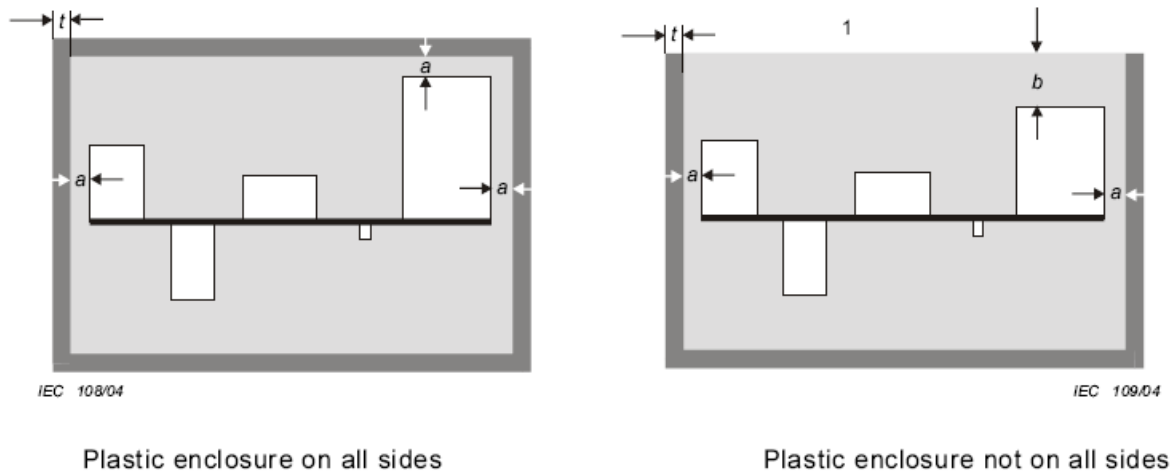
2 Solid insulation material, see 5.5.2.3.2

Figure 2 – Distances between the wall or the free surface of the compound and the components or conductors.

5.5.4.4. Encapsulated apparatus with plastic enclosure. The thickness of the compound between the wall or the free surface of the compound and the components or conductors in the encapsulation as shown in Figure 3 shall comply with Table 3.

Table 3 – Thickness of the compound between the wall or the free surface of the compound and the components or conductors

Enclosure with adhesion to the compound		Enclosure without adhesion to the compound	
$t < 1 \text{ mm}$	$t \geq 1 \text{ mm}$	$t < 1 \text{ mm}$	$t \geq 1 \text{ mm}$
$a \geq 3 \text{ mm}$	$(a + t) \geq 3 \text{ mm}$	$a \geq 3 \text{ mm}$	$a \geq 3 \text{ mm}$
$b \geq \text{distance in accordance with Table 1, but not less than } 3 \text{ mm}$			
where a is the distance between the component and the enclosure, b is the distance between the component and the free surface, t is the wall thickness			

**Key**

1 Free surface

Figure 3 – Distances between the wall or the free surface of the compound and the components or conductors

5.5.4.5. Rigid, multi-layer printed wiring boards with through connections.

5.5.4.5.1. General. Multi-layer printed wiring boards complying with the minimum distances in 5.5.4.5.2 and operated at voltages less than or equal to 500 V, shall be considered to be encapsulated providing they meet 5.5.4.5.2.

5.5.4.5.2. Minimum distances. The insulation of the copper-clad laminates (cores) and the adhesive films shall comply with the requirements of 5.5.2.3.2. The minimum distance between the printed circuit conductors and the edge of the multi-layer printed wiring board or any hole in it shall be at least 3 mm. If the edges or holes are protected with metal or insulating material extending at least 1 mm along the surface of the board from the edges or holes, the distance of the printed wiring conductors may be reduced to 1 mm. Insulating material shall comply with the requirements for conformal coating in accordance with ACRI2001. Metal coating shall have a minimum thickness of 35 μm , see also Figure 4 and Table 4.

5.5.4.5.3. Table 4 – Minimum distances for multi-layer printed wiring boards

Distance	Required distance
a	3 mm
b	3 mm
c	3 mm
d	0,1 mm, see 5.5.2.3.2
e	in accordance with Table 1

where

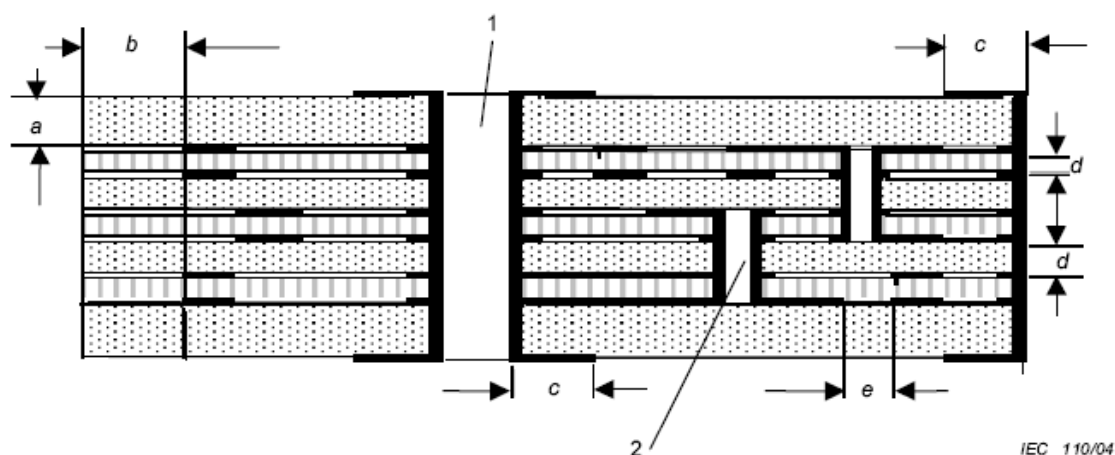
a is the distance between the current carrying part and the outside surface through the cover layer;

b is the distance between the current carrying part and the outside surface along the cover layer;

c is the length of metal or insulation extending along the surface of the board from the edge or the hole;

d is the thickness of the adhesive film or the core;

e is the distance between two circuits inside the multilayer

**Key**

Core and cover layer

Adhesive film

Copper

1 Through contact for termination

2 Through contact to connect the printed conductors to the layers

Figure 4 – Minimum distances for multi-layer printed wiring boards

5.5.5. Switching contacts. Switching contacts are not permitted.

5.5.6. External connections. The entry of all electric conductors, including cables, into the compound shall be designed in such a way that the ingress of an explosive atmosphere into the encapsulated apparatus under normal operating or specified fault conditions is prevented. This may be achieved

by a bare conductor path in the compound that is at least 5 mm long. When compounds are used to secure the connection cable, the cable shall be suitably protected against damage from flexing. If the entry takes the form of a cable that is permanently connected to the encapsulated apparatus, the pull test shall be carried out according to ASTP2241.

5.5.7. Protection of bare live parts. Bare live parts that pass through the surface of the compound shall intrinsically safe per ACRI2001.

5.5.8. Protective devices

5.5.8.1. General. Where the encapsulated apparatus is not able to withstand two faults without exceeding the continuous operating temperature (COT) of the encapsulant, or the temperature class, then a protective device shall be provided either external to the apparatus or directly integrated into the apparatus.

The protective device shall be capable of interrupting the maximum fault current of the circuit in which it is installed. The rated voltage of the protective device shall at least correspond to the working voltage. Where the encapsulation contains a cell or battery and a safety device is provided to prevent excessive overheating (see 5.6.6), the safety device can also be considered as a protective device, providing it also protects all other components inside the same encapsulation from exceeding the COT or temperature class.

5.5.8.2. Electrical protective devices

5.5.8.2.1. General. Fuses shall have a voltage rating not less than that of the circuit and shall have a breaking capacity not less than the fault current of the circuit. Unless otherwise specified, a fuse shall be assumed to be capable of passing 2 x rated current continuously. The time-current characteristic of the fuse shall ensure that the COT of the encapsulant or the temperature class are not exceeded. The time-current characteristics of the fuses shall be stated by the manufacturer of the fuses.

NOTE: In the case of electrical supply networks where the rated voltage does not exceed 250 V, the prospective short-circuit fault current is usually 1500 A.

- 5.5.8.2.2. Protective devices that are connected to the encapsulated apparatus. Where an external protective device or protective circuit is used to control the correct application of voltage, current and power to apparatus, the performance of the external protective device or protective circuit shall be equivalent to that for a limiting device or circuit in accordance with ACRI2001. The permitted levels of voltage, current and power shall be determined by the thermal characteristics of the encapsulated apparatus and not by the requirements for the intrinsic safety.
- 5.5.8.3. Thermal protective devices. Where required, two thermal protective devices shall be used to protect the encapsulation from damage caused by local heating, for example, by faulty components or from exceeding the maximum surface temperature (temperature class). The thermal coupling of the device to the component being monitored shall be sufficient.

Only non-resettable thermal protective devices shall be used. These devices have no provision for being reset and open a circuit permanently after being exposed to a temperature higher than their operating temperature for a given maximum period. Adequate thermal connection shall be achieved between the monitored component and the thermal protective device. The switching capability of the device shall be defined and shall be not less than the maximum possible load of the circuit.

NOTE Resettable devices may be used for functional reasons. If these devices are used, they should operate at temperatures lower than the operating temperature of the thermal protective device.

- 5.5.8.4. Built-in protective devices. Protective devices integral with the encapsulated apparatus shall be of the enclosed type such that no compound can enter during the encapsulation process. The suitability

of the protective device for the intended purpose shall be confirmed either by a) a declaration by the manufacturer; or b) testing of samples.

NOTE: Devices in glass, plastic, ceramic or otherwise sealed are regarded as enclosed types.

5.5.8.5. Temperature.

5.5.8.5.1. General. The maximum surface temperature and the maximum value of the continuous operating temperature of the compound shall not be exceeded during normal operation. The encapsulated apparatus shall be protected in such a way that the encapsulation is not affected under specified fault conditions.

5.5.8.5.2. Temperature of encapsulated components. The hottest component(s) shall be determined. The maximum temperature in the compound, adjacent to the hottest component(s), shall be determined for normal operation. NOTE The determination of the hottest component may be done by calculation or manufacturer's specification or by a practical test prior to encapsulating the components.

5.5.8.6. Pressure test

5.5.8.6.1. Test procedure. Any individual free spaces between 1 cm³ and 10 cm³ and, a test sample with a pressure connection shall be prepared. Where there is more than one free space of a size requiring testing, the pressure shall be carried out simultaneously in all those free spaces. The pressure test shall be carried out on a sample that has already been submitted to the thermal endurance tests. The test shall be carried out at least 1,000 kPa for at least 10 s.

5.5.8.6.2. Acceptance criteria. During the test, the sample shall withstand the pressure without venting or releasing pressure for at least 10 seconds. After testing, the sample shall be subjected to a visual inspection and no damage to the compound that could impair the type of protection shall be observed, for example, cracks in the compound, exposure of the encapsulated components or failure of adhesion.

5.6. Cells and batteries

- 5.6.1. General. When evaluating battery control arrangements with respect to the potential release of gas, the full range of operating temperatures, internal resistance and voltage capability shall be considered. It shall be assumed that batteries can become unbalanced, but cells with negligible resistance or voltage capability need not be taken into account. Only batteries complying with ACRI2001 are permitted.
- 5.6.2. Prevention of gassing. Electrochemical systems that can release gas during normal operation are not permitted. If the release of gas in the event of a fault cannot be precluded, the gassing shall be minimized by a safety device in accordance with 5.6.9. With secondary cells the safety device shall be effective not only during charging, but also during discharging. This also applies for charging outside the hazardous area.
- In particular,
- a) vented cells shall not be used,
 - b) sealed cells with "regulating valves" shall not be used,
 - c) gas-tight cells that, within the range of the ambient temperature of the electric apparatus, do not release gas under any operating or fault conditions may be used without a safety device in accordance with 5.6.9,
 - d) gas-tight cells that do not fulfill the requirements of 5.6.2 c) shall have a safety device in accordance with 5.6.9.
- 5.6.3. Permissible electro-chemical systems. Only systems shall be used where sufficient experience has shown that they do not release gas during operation. In general, only the batteries listed in Tables 5 and 6 are known to meet these requirements. Note: Voltages are listed for identification purposes only.

Table 5 - Allowable primary cells

Positive electrode	Electrolyte	Negative electrode	Rated voltage V	Maximum no-load voltage V
Manganese dioxide	Ammonium chloride	Zinc	1.50	1.73
Oxygen	Ammonium	Zinc	1.40	1.55

Positive electrode	Electrolyte	Negative electrode	Rated voltage V	Maximum no-load voltage V
	chloride			
Carbon fluoride	Organic	Lithium	3.00	3.70
Manganese dioxide	Organic	Lithium	3.00	3.70
Manganese dioxide	Alkali metal hydroxide	Zinc	1.50	1.65
Oxygen	Alkali metal hydroxide	Zinc	1.40	1.68
Silver oxide	Alkali metal hydroxide	Zinc	1.55	1.63
Silver oxide	Alkali metal hydroxide	Zinc	1.55	1.87

Table 6 – Allowable secondary cells

Type	Electrolyte	Rated voltage V	Maximum no-load voltage V
Nickel-cadmium	Potassium/Sodium solution	1.20	1.55
Nickel-metal-hydride	Potassium solution	1.20	1.50
Lithium	Organic salts	3.60	4.20

5.6.4. Protection against inadmissible temperatures and damage to the cells

Batteries under worst case load shall comply with either a) or b):

a) in normal service the surface temperature of the cells shall not exceed either the temperature specified by the manufacturer of the cells or batteries or 80°C at the maximum ambient temperature of the apparatus, and the maximum charging and discharging current shall not exceed the safe value specified by the manufacturer, or

b) batteries shall be provided with one or more safety devices as described in 5.6.5 to 5.6.9, to prevent unacceptable overheating or gassing inside the encapsulation.

- 5.6.5. Reverse current. Where there is another voltage source in the same enclosure, the encapsulated battery and its associated circuits shall be protected against charging by other than the circuit specifically designed for charging. For example, by separating the battery and its associated circuits from all other voltage source(s) inside the enclosure, using the clearance distances specified in Table 1 for the highest voltage capable of causing the reverse current.
- 5.6.6. Current limitation. The maximum surface temperature shall be determined using the highest fault current per the requirements of ACRI2001.
- 5.6.7. Protection against the polarity reversal and deep discharge of the cells. When more than 3 cells are used in series, the cell voltage shall be monitored. During discharging, if the voltage falls below the limit value for the cell voltage specified by the manufacturer of the cells or battery, the safety device shall disconnect the cells.

NOTE 1. If several cells are connected in series, cells can change polarity during discharge due to the various capacities of the cells in a battery. These "reversed pole" cells can enter an inadmissible gassing range. Where a deep discharge protection circuit is installed to prevent reverse polarity charging of cells during discharge, the minimum cut-off voltage shall be that specified by the cell or battery manufacturer. After disconnecting the load, the current shall be no more than the discharge capacity at the 1000 h rate.

NOTE 2. If too many cells are connected in series, there may be no safe protection due to the tolerances of the individual cell voltages and the deep discharge protection circuit. Generally no more than six cells (in series) should be protected by one deep discharge protection circuit.

- 5.6.8. Charging of batteries. The charging circuits shall be fully specified as part of the apparatus. The charging system shall be such that either

a) with one fault condition of the charging system, the charging voltage and current shall not exceed the limits specified by the manufacturer; or

b) if, during charging, it is possible for the limit values specified by the manufacturer of the cells or battery for the cell voltage or the charging current to be exceeded, a separate safety device in accordance with 5.7 shall be provided to avoid a release of gas and exceeding the manufacturer's maximum rated cell temperature.

- 5.6.9. Requirements for safety devices for cells and batteries. Where required, the safety devices shall form safety related parts of a control system. It shall be the responsibility of the manufacturer to provide the information necessary to maintain the safety integrity of the control system.

APPENDIX

NOTE Figure 1 illustrates some applications of encapsulation by casting compound. Figure 2 shows some further application of encapsulation where no enclosure is used.

1. Adherence

NOTE A seal should be maintained where any part of the circuit emerges from the encapsulation and the casting compound must adhere at these interfaces.

The exclusion of components encapsulated with casting compound from the creepage distance requirements is based upon the removal of the likelihood of contamination. The measurement of CTI is, in effect, a measurement of the degree of contamination needed to cause breakdown in a separation between conductive parts. The following assumptions emerge from this basic consideration:

- if all electrical parts and substrates are totally enclosed, that is if nothing emerges from the encapsulation, then there is no risk of contamination and hence breakdown from contamination cannot occur;
- if any part of the circuit, for example a bare or insulated conductor or component or the substrate of a printed circuit board, emerges from the encapsulation, then, unless the casting compound adheres at the interface, contamination can enter at that interface and cause breakdown.

2. Temperature

The casting compound should have a temperature rating conforming to 5.4.

NOTE All casting compounds have a maximum temperature above which they may lose or change their specified properties. Such changes may cause cracking or decomposition which could result in surfaces hotter than the outside surface of the casting compound being exposed to an explosive gas atmosphere.

It should be noted that components which are encapsulated may be hotter or colder than they would be in free air, depending on the thermal conductivity of the casting compound.

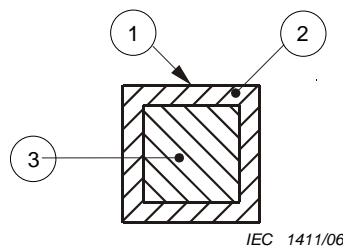
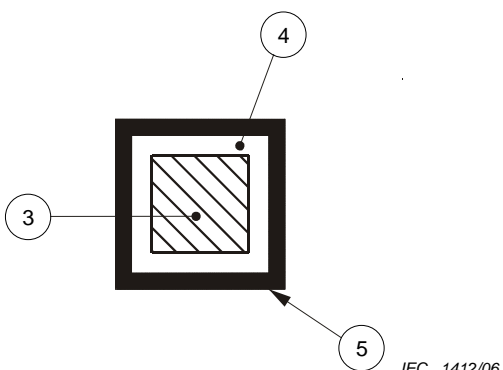
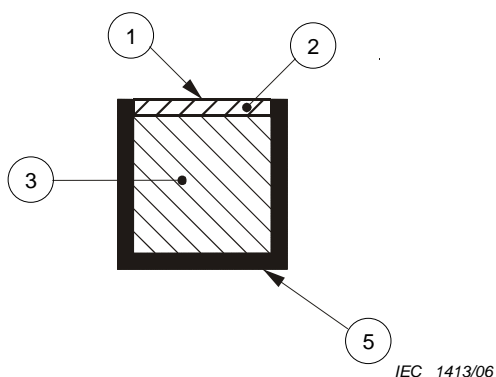
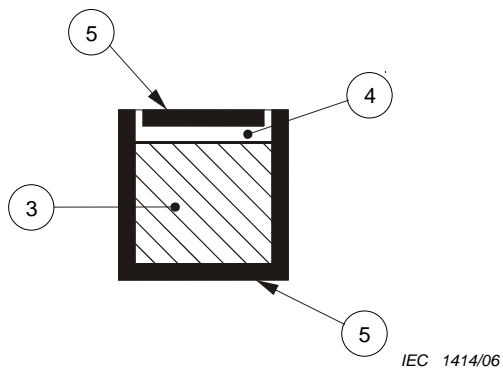
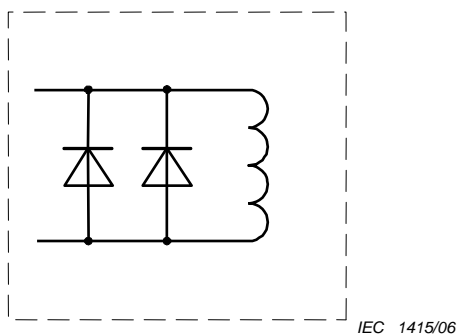


Figure 1a – No enclosure

**Figure 1b – Complete enclosure****Figure 1c – Open enclosure****Figure 1d – Enclosure with cover****Key**

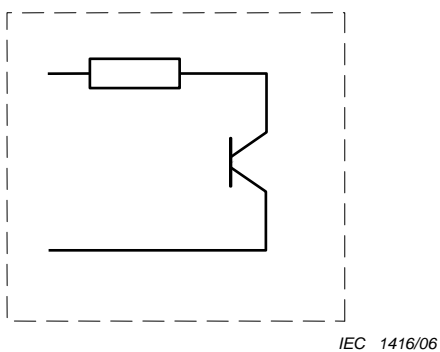
- 1 Free surface
- 2 Encapsulant – $\frac{1}{2}$ of row 6 of Table 7.1 of ACRI2001 with a minimum of 1,00 mm
- 3 Component – encapsulant need not penetrate
- 4 Encapsulant – no specified thickness
- 5 Metal or insulating enclosure
 - no specified thickness for metallic enclosure
 - Insulation thickness shall conform to row 7 of Table 7.1 of ACRI2001

Figure 1 – Examples of encapsulated assemblies conforming to 5.4



1 mm minimum thickness to free surface.

Figure 2a – Mechanical



Thickness determined by external surface temperature.

Figure 2b – Temperature

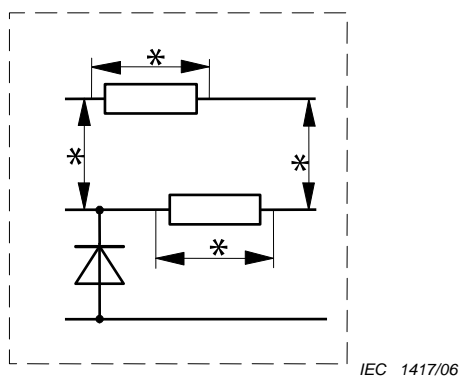
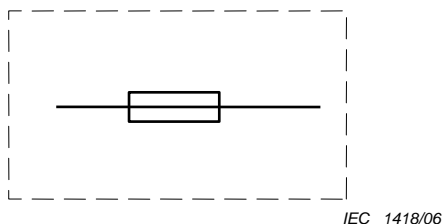


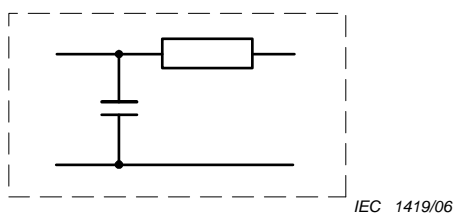
Table 7.1 of ACRI2001 applies. Row 6 applies to marked separation. 1 mm minimum thickness to free surface.

Figure 2c – Separation of circuits



1 mm minimum thickness to free surface.

Figure 2d – Protection of fuses in an intrinsically safe circuit



1 mm minimum thickness to free surface.

Figure 2e – Exclusion of gas

Figure 2 – Applications of encapsulation without enclosure