UL 840

STANDARD FOR SAFETY

Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment

UL Standard for Safety for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840

Third Edition, Dated January 6, 2005

Summary of Topics

This revision to ANSI/UL 840 dated April 19, 2022 is being issued to update the title page to reflect the most recent designation as a Reaffirmed American National Standard (ANS). No technical changes have been made.

Text that has been changed in any manner or impacted by UL's electronic publishing system is marked with a vertical line in the margin.

The requirements are substantially in accordance with Proposal(s) on this subject dated February 4, 2022.

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UL 840

Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment

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Third Edition

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This ANSI/UL Standard for Safety consists of the Third Edition including revisions through April 19, 2022.

The most recent designation of ANSI/UL 840 as a Reaffirmed American National Standard (ANS) occurred on April 19, 2022. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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INTRODUCTION

1 Scope

1.1 These requirements cover an alternate approach to specifying through air and over surface spacings for electrical equipment through the use of the principles of insulation coordination.

1.2 The complete principles of insulation coordination involve the consideration of the combination of clearances, creepage distances, and the properties of solid insulation used to constitute the insulation system. The empirical data gathered thus far has been used to develop the requirements for clearances and creepage distances as presented in this standard. The data needed to develop the evaluation procedure for solid insulation is still being gathered. When available, this evaluation procedure will be added to this standard and is not expected to affect the requirements for clearances and creepage distances.

1.3 These requirements may be used as an alternate to required spacing levels specified in end-product standards. The end product standard spacing requirements may be based on use and systems where overvoltages are not controlled, or if controlled, the level of control is unknown.

1.4 These alternate requirements are intended to be applied to a particular product category if the standard covering the product category specifically references UL 840 or any of the requirements therein.

1.5 Users of these requirements may need to specify the overvoltage levels and the methods of control which will be utilized, and establish the pollution degree to which the product insulation system will be expected to be subjected.

1.6 It is not intended that the test values in this standard be employed for production line testing. However, users of these requirements will need to establish a means to ensure that production controls applied to permit the spacing reduction remain in effect during the manufacture of the product. This could include sample testing or physical measurements or another equivalent means.

1.7 Users of these requirements will additionally need to ensure that influencing factors not addressed in this standard, such as mechanical movement, field placement of conductive material, and product damage, will not affect the system for insulation coordination. Examples are the deformation of the enclosure, movement of the fittings for conduit or armored cable, or the improper installation of field wiring. Clearances and creepage distances at those locations must be verified for compliance by physical measurement in accordance with Section 10, Measurement of Clearance and Creepage Distances.

2 Glossary

2.1 For the purpose of this standard, the following definitions apply.

2.2 CLEARANCES – Through air spacing.

2.2A COMBINATION WAVEFORM – A surge delivered by a generator which has the inherent capability of applying a 1.2/50 μs voltage wave across an open circuit, and delivering an 8/20 μs current wave into a short circuit. Also called a combination surge.

2.3 CREEPAGE DISTANCES (CREEPAGES) – Over surface spacings.

2.4 FUNCTIONAL OVERVOLTAGE – Deliberately imposed transient overvoltages necessary for the function of a device.

2.5 GENERAL ENVIRONMENT – The overall area or space in which the equipment is located. Commonly referred to as ambient conditions.

2.6 IMPULSE WITHSTAND VOLTAGE – The highest peak value of impulse voltages, of prescribed form and polarity, that does not cause breakdown under specified conditions of test.

2.7 INSULATION COORDINATION – The correlation of insulating characteristics of electrical equipment:

a) With expected overvoltages and characteristics of overvoltage protective devices (a key consideration for clearances); and

b) With the expected micro-environment and pollution protective means (key considerations for creepage distances).

2.8 LEAKAGE CURRENT – The current that can be measured as flowing between test points during a dielectric voltage-withstand test.

2.9 LIGHTNING OVERVOLTAGE – The transient overvoltage at a given location on a system due to a specific lightning discharge.

2.10 MICRO-ENVIRONMENT – The conditions that immediately surround the clearance or creepage distance under consideration. The micro-environment of the creepage distance or clearance and not the general environment of the equipment determines the effect on the insulation. The micro-environment might be less severe or more severe than the general environment that the equipment is in. It includes all factors influencing the insulation, such as climatic, electromagnetic, and generation of pollution.

2.10A NOMINAL DISCHARGE CURRENT (In) – Peak value of the current, selected by the manufacturer, through the SPD having a current waveshape of 8/20 where the SPD remains functional after 15 surges.

2.11 OPERATING VOLTAGE – The voltage across two points occurring due to normal operation of the product when controls are set in any position.

2.12 OVERVOLTAGE CATEGORY – Grouping of products based on typical installed location with respect to overvoltage protection and available energy. See note c of Table 8.1.

2.13 POLLUTION – Any addition of contaminants, solid, liquid or gaseous (ionized gases), and moisture that may produce a reduction of dielectric strength or surface resistivity.

2.14 POLLUTION DEGREE – The level of pollution present at the location on or in a product where the clearance and creepage distance measurement is made, and can be controlled by design of the product. For example, enclosures can be used to achieve pollution degree 3, heaters within enclosures can help achieve pollution degree 2, and encapsulation can be used to achieve pollution degree 1. See 9.3.

2.15 RATED VOLTAGE – The voltage employed for test purposes by the end-product standard.

2.16 RECURRING PEAK VOLTAGE – Deliberately or naturally imposed transient overvoltage that exceeds the steady state voltage, and is caused by operating a control or adjustable component. The voltage level will be consistent for the same operation under the same conditions. Insulating materials can be degraded by ozone generated by partial discharges due to recurring peak voltages.

2.16A SURGE PROTECTIVE DEVICE (SPD) TYPE DESIGNATIONS – SPD Type designations are as follows:

TYPE 1 – Permanently connected SPDs intended for installation between the secondary of the service transformer and the line side of the service equipment overcurrent device, as well as the load side, including watt-hour meter socket enclosures and intended to be installed without an external overcurrent protective device.

TYPE 2 – Permanently connected SPDs intended for installation on the load side of the service equipment overcurrent device - including SPDs located at the branch panel.

TYPE 3 – Point of utilization SPDs, installed at a minimum conductor length of 10 meters (30 feet) from the electrical service panel to the point of utilization, for example cord connected, direct plug-in, receptacle type and SPDs installed at the utilization equipment being protected. The distance of 10 meters (30 feet) is exclusive of conductors provided with or used to attach SPDs.

TYPE 4 COMPONENT ASSEMBLIES – Component assembly consisting of one or more Type 5 components together with a disconnect (integral or external) or a means of complying with the limited current tests.

TYPE 1, 2, 3 COMPONENT ASSEMBLIES – Consists of a Type 4 component assembly with internal or external short circuit protection.

TYPE 5 – Discrete component surge suppressors, such as MOVs that may be mounted on a PWB, connected by its leads or provided within an enclosure with mounting means and wiring terminations.

2.17 SWITCHING OVERVOLTAGE – The transient overvoltage at a given location on a system due to a specific switching operation or fault.

2.18 SYSTEM VOLTAGE – The rated supply or line voltage to which the product will be connected.

2.19 TRANSIENT OVERVOLTAGE – Nonperiodic voltages that may be caused by switching, lightning, or function of a device.

3 Units of Measurement

3.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

4 Undated References

4.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

5 Components

5.1 Except as indicated in 5.2, a component of a product covered by this standard shall comply with the requirements for that component.

5.2 A component is not required to comply with a specific requirement that:

a) Involves a feature or characteristic not required in the application of the component in the product covered by this standard, or

b) Is superseded by a requirement in this standard.

5.3 A component shall be used in accordance with its rating established for the intended conditions of use.

5.4 Specific components are incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions.

6 Insulation Coordination

6.1 This standard uses the principles of insulation coordination to provide requirements for clearances and creepage distances for electrical equipment. A design consideration is to prevent undesirable breakdowns in some areas due to their disruptive nature and potential for risk of fire and electric shock. Insulation coordination also requires the awareness of the insulating material properties so that design of the product can utilize the reduced spacing concept.

6.2 Insulation coordination, as evaluated and implemented through the use of this standard, can be achieved in a multiconcept process.

a) The first concept detailed in Section 7, Clearance A (Equivalency), of this standard is an alternative approach to measuring spacings currently defined in various product standards. This approach uses a dielectric voltage-withstand test impulse to evaluate equivalence of designed spacings to the predefined dimension. An actual reduction in spacings can be permitted through a refinement in manufacturing techniques while maintaining equivalent breakdown levels.

b) The second concept detailed in Section 8, Clearance B (Controlled Overvoltage), of this standard, a step in the insulation coordination process, is the selection of clearances based on the level of overvoltage protection and pollution degree.

c) The third concept detailed in Section 9, Creepage Distances, of this standard is the selection of an appropriate set of creepage distances based on operating voltage, pollution degree and material tracking characteristics.

d) The last concept, currently anticipated though not described in detail in this standard, is the choice of solid insulation to coordinate with the clearances and creepage distances chosen. The solid insulation must have suitable tracking properties for creepage considerations and it must have a breakdown level exceeding that of the controlled overvoltage level provided.

6.3 The database upon which these requirements are based is contained in the International Electrotechnical Commission (IEC) Publications for Insulation Coordination Within Low Voltage Systems Including Clearances and Creepage Distances for Equipment, 664, and the Supplement, IEC Publication 664A.

6.4 The data contained in these IEC documents relate the ability of clearances to withstand overvoltages based on the characteristics of the electrical field. For a specified overvoltage, an inhomogeneous field condition of two electrodes, which is represented by a point and a plane, requires the largest clearance. As the condition of the electric field is improved by control of electrode shape, the clearance required to withstand the overvoltage decreases. The limit for this decrease in clearance is that of the homogenous field which is represented by two parallel planes. Using this data it is possible to evaluate clearances by their ability to withstand overvoltages. It should be recognized that the use of this technique requires the regular rechecking of the ability of the clearance to withstand the prescribed overvoltage because of possible variations in the production process, the wearing of tools, or other factors that might influence the clearance or electrical field condition. The database may also be used to specify, for a given overvoltage, the inhomogeneous field clearance, and the continued provision of this clearance may be made by measurements of the clearance.

6.5 The data contained in these documents relating to the selection of creepage distances is based on an evaluation of empirical data coming from experience, and the results of extensive testing of certain combinations of materials in differing pollution degrees. The major variables for the selection of creepage distances are the arc tracking characteristics of the material used and the conditions of pollution. The four pollution degrees are based on the levels of moisture and contaminants at the creepage distance and therefore, the pollution degree which may exist.

6.6 The values for creepage distances presented in this standard are for equipment being subjected to long term stress. Many products, and circuits within those products, are only subjected to short term or intermittent stress. End-product standards can permit a reduction in minimum creepage distance based on this use factor. A single row reduction (in Table 9.1) while maintaining the same pollution degree and material group, would be typical.

6.7 These requirements are based on the electrical characteristics of the clearances and creepage distances, and the assumption that the spacings will be maintained over the life of the equipment. In those locations where the spacings may be influenced by other conditions, the end-product standard users will need to separately consider whether use of this standard is appropriate. Examples might be the spacings between terminals that may be reduced by protruding wires or strands, or the spacings to enclosures where possible indentations may reduce the spacings. Spacings at arcing parts may need to be additionally evaluated for conductive deposits or loss of material during arcing tests.

6.8 Within this standard, clearance and creepage distance requirements are separate and may be individually referenced. While creepage distances cannot be less than the associated clearances, each spacing parameter is influenced by different conditions. The clearances may be measured or tested, and can be further reduced by controlling overvoltages and pollution degree. Creepage distances may be measured, and may be reduced by controlling the materials and pollution degree present in the equipment.

6.9 Other considerations which must be employed when pursuing insulation coordination include the following:

a) Insulation systems consist of a set of series and parallel insulators (of air and solid and liquid insulation for example) and control over the system and internal spacings and voltages;

b) Air is considered a renewable insulation material;

c) Transient overvoltages may occur due to both internal (circuit generated) and external (lightning) events; and

d) Solid (nonrenewable material) insulating material should have a dielectric strength greater than the associated creepages and clearances.

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7 Clearance A (Equivalency)

7.1 Other than as noted in 1.6, the requirements of this section may be used to evaluate clearances less than those specified for the end product while maintaining the same overvoltage withstand capability for the equipment.

7.2 A clearance, less than the specified minimum through air spacing, in the product standard, may be suitable if acceptable results are obtained when tested in accordance with Section 14, Dielectric Voltage-Withstand Tests, using a voltage with a value in accordance with Table 7.1. For specified minimum clearances between the values in Table 7.1, interpolation may be used to determine the test voltage.

Table 7.1
Test voltages for verifying through air spacings (clearances)

End-product Standard specified minimum through air spacing,		Test voltages, kilovolts									
		AC impulse, AC peak, or DC					AC rms				
		Altitude[a], m or (air pressure, kPa)[b]					Altitude[a], m or (air pressure, kPa)[b]				
Inches	(mm)	0 (101.3)	200 (98.8)	500 (95.0)	1000 (90.0)	2000 (80.0)	0 (101.3)	200 (98.8)	500 (95.0)	1000 (90.0)	2000 (80.0)
1/64	(0.4)	1.7	1.7	1.7	1.6	1.5	1.2	1.2	1.2	1.2	1.1
1/32	(0.8)	2.2	2.1	2.1	2.0	1.9	1.5	1.5	1.5	1.4	1.3
3/64	(1.2)	2.75	2.7	2.65	2.5	2.3	1.95	1.9	1.9	1.75	1.6
1/16	(1.6)	3.3	3.3	3.2	3.0	2.7	2.4	2.3	2.3	2.1	1.9
3/32	(2.4)	4.4	4.3	4.1	3.9	3.5	3.1	3.0	2.9	2.8	2.5
1/8	(3.2)	5.3	5.2	5.0	4.8	4.3	3.7	3.7	3.6	3.4	3.0
3/16	(4.8)	6.9	6.8	6.6	6.2	5.6	4.9	4.8	4.7	4.4	4.0
1/4	(6.4)	8.3	8.2	7.9	7.5	6.8	5.9	5.9	5.6	5.3	4.8
3/8	(9.5)	10.9	10.7	10.3	9.8	8.8	7.7	7.7	7.3	7.0	6.3
1/2	(12.7)	14.0	13.7	13.2	12.5	11.2	9.9	9.7	9.3	8.9	7.9
1	(25.4)	25.5	24.6	24.0	22.7	20.2	18.2	17.6	17.1	16.2	14.4

[a] Next lower specified altitude to be used for intermediate altitudes.

[b] Values of air pressure in kilopascals are provided to permit testing at pressures simulating elevations different from the elevation of the test facility.

7.3 The withstand capability of a clearance is related to air pressure, therefore, the selection of test voltage is to be based on the altitude of the test location.

8 Clearance B (Controlled Overvoltage)

8.1 The requirements of this section may be used to evaluate clearances where the levels of overvoltage are controlled.

8.2 Control of overvoltages may be achieved by either:

a) Providing overvoltage devices or systems as an integral part of the product; or

b) Marking the product with the rating of overvoltage control to which the product is to be connected, and the energy handling capability of the overvoltage device, if appropriate.

8.3 With reference to the marking in 8.2, the users of this standard must determine the appropriate method to state that the overvoltage control device or system should comply with the requirements in 8.4.1. One of the alternatives to marking the product would be to provide the information in published documentation.

8.4 *Deleted*

8.4.1 Devices or systems used for overvoltage control shall comply with the following items a through d:

a) The requirements in the Standard for Surge Protective Devices, UL 1449.

b) Type 1, Type 2, and Type 3 surge protective devices shall have a maximum continuous operating voltage not less than the operational voltage rating of the power system configuration to which the surge protective devices is connected.

c) Type 4 and 5 surge protective devices shall have a maximum continuous operating voltage at least equivalent to the line-to-line voltage of the input system of the assembly.

Exception: Type 4 surge protective devices that have been subjected to limited current, intermediate current and short circuit current tests need only be rated for the maximum continuous operating voltage of the power system.

d) Be evaluated for use for one of the following:

1. Type 1 applications when used on the line side of service equipment,

2. Type 1 or Type 2 applications when used on the load side of service equipment feeder circuit applications or branch circuit applications,

3. Type 3 applications when used in branch circuit or control circuit applications or,

4. Type 5 discrete component surge suppressors or Type 4 component assemblies when used in branch circuit or control circuit applications and rated with a nominal discharge current (In) where the In value is as specified in Table 8.2 based on the system operating voltage and the Over-Voltage category,

5. Type 4 component surge suppressors when used in branch circuit or control circuit applications and provided with "other" rating where the Operating Duty Cycle is based on a kV/kA combination waveform test equal to the values given in Table 8.2 based on the system input voltage and Over-Voltage Category of the equipment.

8.4.2 Surge protective devices may be employed in order to improve the transient impulse over-voltage control within an assembly and decrease required clearance distances. This reduction in required clearance distance is based on the voltage protection rating (VPR) of the surge protective device and the resulting clearance distance as shown in Table 8.1. The surge protective device shall comply with 8.4.1 and items a) and b) below:

a) The Measured Limiting Voltage (MLV) of the surge protective device shall not exceed the impulse voltage withstand value provided in Table 8.1 for the measured clearance, and

b) Be provided with one of the following:

1. A Nominal Current Discharge Rating (In) or Operating Duty Cycle based on a kV/kA combination test waveform equal to the values given in Table 8.2 . The impulse voltage withstand value chosen shall be at least that equal to the impulse voltage withstand value in Table 8.1 based on the system input voltage and Over-Voltage Category of the equipment under test,

2. A Nominal Current Discharge Rating (In) or Operating Duty Cycle based on a kV/kA combination test waveform equal to the impulse voltage value given in Table 8.2 and current value equal to rated impulse voltage divided by the circuit impedance on the input side of the surge protective device plus 2 ohms. The impulse voltage withstand value chosen shall be at least equal to the impulse voltage withstand value in Table 8.1 based the system input voltage and Over-Voltage Category of the equipment under test, or.

3. The entire assembly complies with the Operating Duty Cycle testing as outlined in the Standard for Surge Protective Devices, UL 1449, using a combination waveform as defined in item 1 above.

Table 8.1
Minimum clearances for equipment[a]

Phase-to-ground[b] rated system voltage (rms and dc)				Rated impulse withstand voltage peak, kV[d]	Clearance, mm[e]			
Overvoltage category[c]					Pollution degree[f]			
I	II	III	IV		1	2	3	4
50	–	–	–	0.33	0.01	0.2	0.8	1.6
100	50	–	–	0.50	0.04	0.2	0.8	1.6
150	100	50	–	0.80	0.10	0.2	0.8	1.6
300	150	100	50	1.5	0.5	0.5	0.8	1.6
600	300	150	100	2.5	1.5	1.5	1.5	1.6
1000	600	300	150	4.0	3.0	3.0	3.0	3.0
1500	1000	600	300	6.0	5.5	5.5	5.5	5.5
–	1500	1000	600	8.0	8.0	8.0	8.0	8.0
–	–	1500	1000	12.0	14.0	14.0	14.0	14.0
–	–	–	1500	16.0	19.4	19.4	19.4	19.4

[a] The minimum values for pollution degrees 2, 3, and 4 are premised on the concept that pollution which may be present in these micro-environments may bridge small clearances.

[b] For ungrounded systems or systems with one phase grounded, the phase-to-ground voltage is considered to be the same as the phase-to-phase voltage for the purposes of using this table.

[c] Typical examples of categories for products are given below. Users of this standard will need to establish that rated impulse voltage values are appropriate for the expected applications of the products covered.

Category IV – Primary Supply Level. Overhead lines and cable systems including distribution and its associated overcurrent protective equipment (equipment installed at the service entrance).

Category III – Distribution Level. Fixed wiring and associated equipment (not electrical loads) connected to the primary supply level, Category IV.

Category II – Load Level. Appliances and portable equipment and the like connected to the distribution level, Category III.

Category I – Signal Level. Special equipment or parts of equipment such as low-voltage electronic logic systems, remote controls, signaling and power limited (per NEC Article 725) circuits connected to the load level, Category II.

[d] Value to use based on the rating of the overvoltage protection means.

[e] Linear interpolation of the values is permitted.

[f] See 9.3.

Table 8.2
Correlation Between Equipment Overvoltage Category and Surge Protective Device Combination Waveform Test Values

Phase-to-ground[a] rated system voltage (rms and dc)				Rated impulse withstand voltage peak, kV	Combination Waveform Test Current or Nominal Discharge Current, I_n[b]
Overvoltage category					
I	II	III	IV		
50	–	–	–	0.33	165 A
100	50	–	–	0.50	250 A
150	100	50	–	0.80	400 A
300	150	100	50	1.5	750 A
600	300	150	100	2.5	1250 A
1000	600	300	150	4.0	2,000 A
1500	1000	600	300	6.0	3,000 A

[a] For ungrounded systems or systems with one phase grounded, the phase-to-ground voltage is considered to be the same as the phase-to-phase voltage for the purposes of using this table.

[b] Based on Rated impulse withstand voltage peak / 2 ohm upstream impedance.

8.5 If a clearance is used to perform the function of controlling overvoltages, then consideration must be given to the ability of the clearance to handle the energy which may be available, to the overvoltage breakdown level of other clearances, and to the changes which may occur in and to an electric field when arc-over occurs.

8.6 The end product standards that reference this standard will need to specify if a mechanism to indicate the failure of a component of the system or device employed for overvoltage protection is required. For example, the mechanism could indicate that a transient voltage surge suppressor is no longer functional due to the absorption of an excessive amount of energy.

8.7 Line connected devices and circuits shall be assigned both a phase-to-ground rated system voltage and an overvoltage category as specified in Table 8.1. Circuits, line connected or secondary, employing the clearances of Table 8.1, shall be protected for the rated impulse withstand voltage peak identified in Table 8.1. The switching test detailed in Section 12, Switching Test, should be conducted unless circuit analysis reveals that the appropriate protection is provided wherever Table 8.1 clearances are used.

8.8 Except as noted in 1.7, clearances may be:

a) Evaluated by the dielectric voltage-withstand test in 14.2.1; or

b) Selected and measured in accordance with the dimensions in Table 8.1.

8.9 Clearances selected and measured in accordance with the dimensions in Table 8.1 do not require testing.

9 Creepage Distances

9.1 The requirements of this section may be used to evaluate creepage distances. Creepage distances shall be at least the value in Table 9.1 or Table 9.2, based on the operating voltage across the distance, the comparative tracking index (CTI) of the insulating material, and the level of pollution expected or controlled at the creepage distance. For printed wiring boards using Table 9.2, the existence of recurring voltages is to be evaluated in accordance with 9.6.

Table 9.1
Minimum acceptable creepage distances[w]

Operating voltage, volts ac rms or dc[z]	Creepage distances for equipment subject to long-term stress, mm											
	Pollution degree 1	Pollution degree 2			Pollution degree 3				Pollution degree 4		
	All material groups	Material group[x]			Material group[x]				Material group[x]		
		I	II	IIIa,b	I	II	IIIa	IIIb	I	II	IIIa
10	0.08	0.4	0.4	0.4	1.0	1.0	1.0	1.0	1.6	1.6	1.6
12.5	0.09	0.42	0.42	0.42	1.05	1.05	1.05	1.05	1.6	1.6	1.6
16	0.1	0.45	0.45	0.45	1.1	1.1	1.1	1.1	1.6	1.6	1.6
20	0.11	0.48	0.48	0.48	1.2	1.2	1.2	1.2	1.6	1.6	1.6
25	0.125	0.5	0.5	0.5	1.25	1.25	1.25	1.25	1.7	1.7	1.7
32	0.14	0.53	0.53	0.53	1.3	1.3	1.3	1.3	1.8	1.8	1.8
40	0.16	0.56	0.8	1.1	1.4	1.6	1.8	1.8	1.9	2.4	3.0
50	0.18	0.6	0.85	1.2	1.5	1.7	1.9	1.9	2.0	2.5	3.2
63	0.2	0.63	0.9	1.25	1.6	1.8	2.0	2.0	2.1	2.6	3.4

Table 9.1 Continued on Next Page

Table 9.1 Continued

Operating voltage, volts ac rms or dc[z]	Creepage distances for equipment subject to long-term stress, mm										
	Pollution degree 1	Pollution degree 2			Pollution degree 3				Pollution degree 4		
	All material groups	Material group[x]			Material group[x]				Material group[x]		
		I	II	IIIa,b	I	II	IIIa	IIIb	I	II	IIIa
80	0.22	0.67	0.95	1.3	1.7	1.9	2.1	2.1	2.2	2.8	3.6
100	0.25	0.71	1.0	1.4	1.8	2.0	2.2	2.2	2.4	3.0	3.8
125	0.28	0.75	1.05	1.5	1.9	2.1	2.4	2.4	2.5	3.2	4.0
160	0.32	0.8	1.1	1.6	2.0	2.2	2.5	2.5	3.2	4.0	5.0
200	0.42	1.0	1.4	2.0	2.5	2.8	3.2	3.2	4.0	5.0	6.3
250	0.56	1.25	1.8	2.5	3.2	3.6	4.0	4.0	5.0	6.3	8.0
320	0.75	1.6	2.2	3.2	4.0	4.5	5.0	5.0	6.3	8.0	10.0
400	1.0	2.0	2.8	4.0	5.0	5.6	6.3	6.3	8.0	10.0	12.5
500	1.3	2.5	3.6	5.0	6.3	7.1	8.0	8.0	10.0	12.5	16.0
630	1.8	3.2	4.5	6.3	8.0	9.0	10.0	10.0	12.5	16.0	20.0
800	2.4	4.0	5.6	8.0	10.0	11.0	12.5	y	16.0	20.0	25.0
1000	3.2	5.0	7.1	10.0	12.5	14.0	16.0	y	20.0	25.0	32.0
1250	4.2	6.3	9.0	12.5	16.0	18.0	20.0	y	25.0	32.0	40.0
1600	5.6	8.0	11.0	16.0	20.0	22.0	25.0	y	32.0	40.0	50.0
2000	7.5	10.0	14.0	20.0	25.0	28.0	32.0	y	40.0	50.0	63.0
2500	10.0	12.5	18.0	25.0	32.0	36.0	40.0	y	50.0	63.0	80.0
3200	12.5	16.0	22.0	32.0	40.0	45.0	30.0	y	63.0	80.0	100.0
4000	16.0	20.0	28.0	40.0	50.0	56.0	63.0	y	80.0	100.0	125.0
5000	20.0	25.0	36.0	50.0	63.0	71.0	80.0	y	100.0	125.0	160.0
6300	25.0	32.0	45.0	63.0	80.0	90.0	100.0	y	125.0	160.0	200.0
8000	32.0	40.0	56.0	80.0	100.0	110.0	125.0	y	160.0	200.0	250.0
10000	40.0	50.0	71.0	100.0	125.0	140.0	160.0	y	200.0	250.0	320.0

[w] Linear interpolation of the values is permitted.

[x] See 9.2.

[y] Material group IIIb shall not be used for application in pollution degree 3 above 630 volts.

[z] It is appreciated that tracking or erosion will not occur on insulation subjected to a working voltage of 32 volts and below. However, the possibility of electrolytic corrosion has to be considered, and for this reason, minimum creepages have been specified.

Table 9.2
Minimum acceptable creepage distances on printed wiring boards[a,d]

Operating voltage, volts ac rms or dc	Minimum creepage, mm	
	Pollution degree	
	1[b]	2[c]
10 – 50	0.025	0.04
63	0.04	0.063
80	0.063	0.1
100	0.1	0.16
125	0.16	0.25

Table 9.2 Continued on Next Page

Table 9.2 Continued

Operating voltage, volts ac rms or dc	Minimum creepage, mm	
	Pollution degree	
	1[b]	2[c]
160	0.25	0.4
200	0.4	0.63
250	0.56	1.0
320	0.75	1.6
400	1.0	2.0
500	1.3	2.5
630	1.8	3.2
800	2.4	4.0
1000	3.2	5.0

[a] Use Table 9.1 for pollution degrees 3 and 4.

[b] Material Groups I, II, IIIa, IIIb.

[c] Material Groups I, II, IIIa. For Material Group IIIb use Table 9.1.

[d] Linear interpolation of the values is permitted.

9.2 The material groups of Table 9.1 and Table 9.2 are related to the CTI performance level category values of insulating materials that are specified in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, to be included in the group, as follows:

Material Group:

I – CTI ≥ 600 (PLC = 0)

II– 400 ≤ CTI < 600 (PLC = 1)

IIIa – 175 ≤ CTI < 400 (PLC = 2 or 3)

IIIb – 100 ≤ CTI < 175 (PLC = 4)

Note: PLC stands for Performance Level Category, and CTI stands for Comparative Tracking Index.

9.3 Pollution degrees based on the presence of contaminants and possibility of condensation or moisture at the creepage distance are as follows:

a) Pollution Degree 1 – No pollution or only dry, nonconductive pollution. The pollution has no influence.

b) Pollution Degree 2 – Normally, only nonconductive pollution. However, a temporary conductivity caused by condensation may be expected.

c) Pollution Degree 3 – Conductive pollution, or dry, nonconductive pollution that becomes conductive due to condensation that is expected.

d) Pollution Degree 4 – Pollution that generates persistent conductivity through conductive dust or rain and snow.

9.4 Steps can be taken to control the pollution degree at the creepage distance by design features or the consideration of the operating characteristics of the product. See following examples:

a) Pollution degree 1 can be achieved by the encapsulation or hermetic sealing of the product. For printed circuit boards, coatings may be used that comply with the performance criteria of Section 15.

b) Pollution degree 2 can be achieved by reducing possibilities of condensation or high humidity at the creepage distance, through the provision of ventilation or the continuous application of heat, through the use of heaters or continuous energizing of the equipment when it is in use. Continuous energizing is considered to exist when the equipment is operated without interruption every day and 24 hours per day or when the equipment is operated with interruptions of a duration which do not permit cooling to the point of condensation to occur.

c) Pollution degree 3 can be achieved by the use of appropriate enclosures which act to exclude or reduce environmental influences, particularly moisture in the form of water droplets.

9.5 It is also necessary to consider some conditions where equipment may make the pollution degree at creepage distances more severe than the general environment. Examples of this concern would be operation which generates contaminates such as carbon brush particles or the arcing of switch parts.

9.6 The value of recurring peak voltages appearing across creepage distances based on Table 9.2 on printed wiring boards shall be limited to a value not greater than the maximum allowable recurring peak voltage given in Table 9.3. The measurement of recurring peak voltages is to be in accordance with Section 13, Recurring Peak Voltage Determination.

Exception No. 1: Measurement in accordance with Section 13 need not be done if circuit analysis can be employed to determine the maximum recurring peak voltage due to regular operating characteristics, and due to adjustment of device controls.

Exception No. 2: The value of the recurring peak voltage need not be limited to the value in Table 9.3 if no air or gases are in contact with the related creepage point. Coating or encapsulation does not necessarily ensure that no air or gases are present.

Table 9.3
Maximum recurring peak voltage related to creepage distance on printed wiring boards[a]

Creepage distance mm	Maximum allowable recurring peak voltage
0.025	330
0.04	336
0.063	345
0.1	360
0.16	384
0.2	400
0.25	450
0.4	600
0.5	640
0.56	678
0.63	723
0.75	800
1.0	913
1.3	1049

Table 9.3 Continued on Next Page

Table 9.3 Continued

Creepage distance mm	Maximum allowable recurring peak voltage
1.5	1140
1.6	1150
1.8	1250
2.0	1314
2.4	1443
2.5	1475
3.2	1700
4.0	1922
5.0	2200

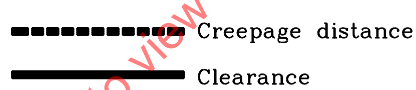
[a] Voltage and creepage values may be interpolated linearly.

10 Measurement of Clearance and Creepage Distances

10.1 Clearance and creepage distances are to be measured as illustrated in the examples contained in Figure 10.1. In Figure 10.1, X is the width of the groove. The "X" value can be determined from Table 10.1.

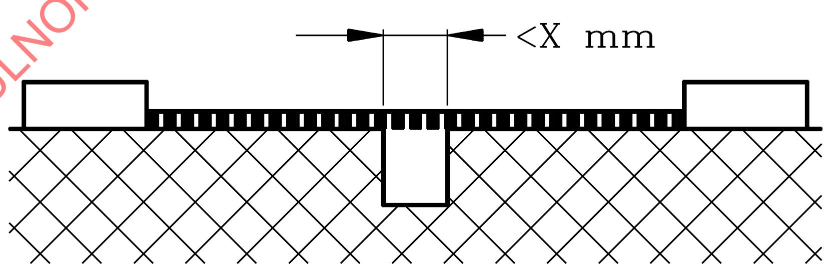
Figure 10.1

Examples of clearance and creepage distance measurement



S3433

EXAMPLE 1

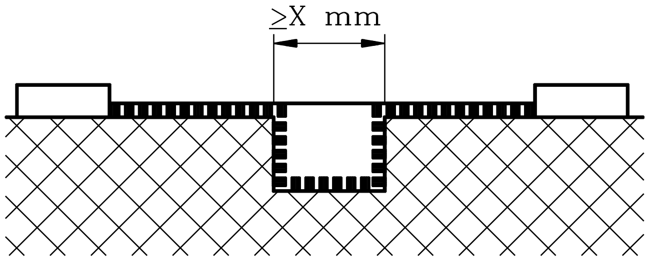


S3409A

Condition: Path under consideration includes a parallel, diverging or converging-sided groove of any depth with a width less than X mm.

Rule: Creepage distance and clearance are measured directly across the groove as shown.

EXAMPLE 2

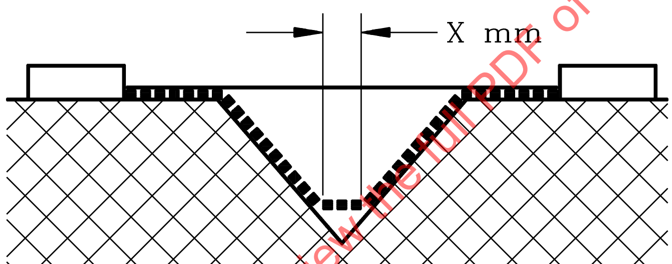


S3410A

Condition: Path under consideration includes a parallel or diverging-sided groove of any depth with a width equal to or more than X mm.

Rule: Clearance is the "line of sight" distance. Creepage path follows the contour of the groove.

EXAMPLE 3

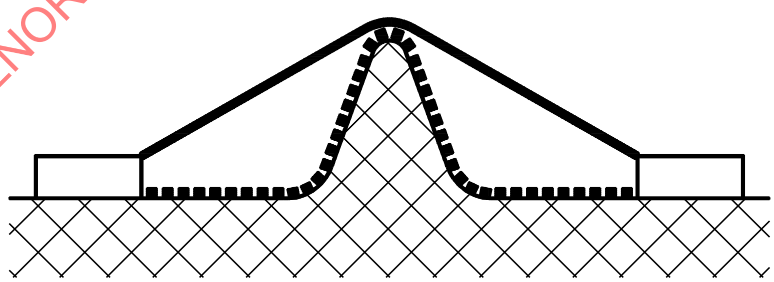


S3411A

Condition: Path under consideration includes a V-shaped groove with a width greater than X mm.

Rule: Clearance is the "line of sight" distance. Creepage path follows the contour of the groove but "short-circuits" the bottom of the groove by X mm link.

EXAMPLE 4

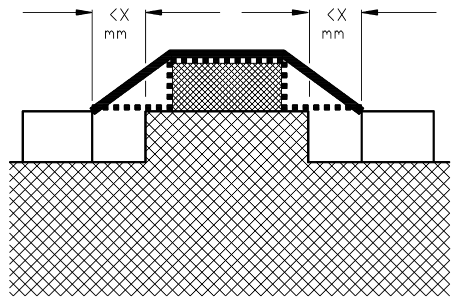


S3412

Condition: Path under consideration includes a rib.

Rule: Clearance is the shortest air path over the top of the rib. Creepage path follows the contour of the rib.

EXAMPLE 5

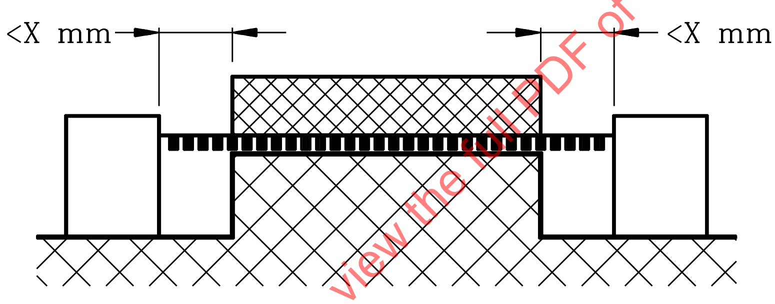


S3502

Condition: Path under consideration includes a cemented joint with grooves less than X mm wide on each side.

Rule: Clearance is the shortest air path over the top of the joint. Creepage distance is measured directly across the grooves and follows the contour of the joint.

EXAMPLE 6

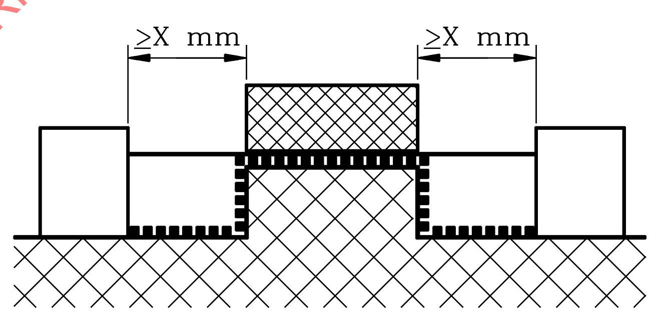


S3413A

Condition: Path under consideration includes an uncemented joint with grooves less than X mm wide on each side.

Rule: Creepage and clearance path is the "line of sight" distance shown.

EXAMPLE 7

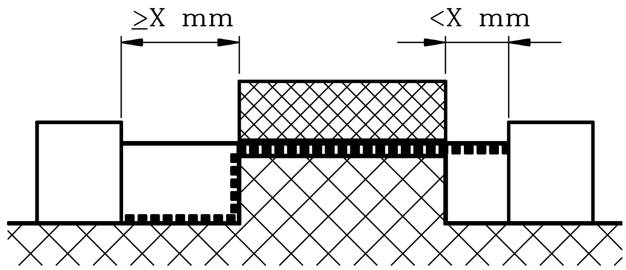


S3414A

Condition: Path under consideration includes an uncemented joint with grooves equal to or more than X mm wide on each side.

Rule: Clearance is the "line of sight" distance. Creepage path follows the contour of the grooves.

EXAMPLE 8

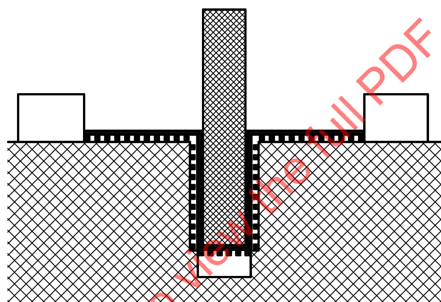


S3415A

Condition: Path under consideration includes an uncemented joint with a groove on one side less than X mm wide and the groove on the other side equal to or more than X mm wide.

Rule: Clearance and creepage paths are as shown.

EXAMPLE 9

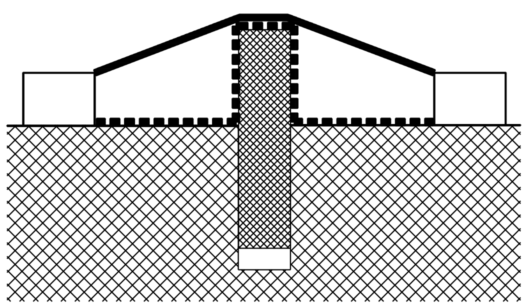


S3503

Condition: Path under consideration includes an uncemented barrier when path under the barrier is less than the path over the barrier.

Rule: Clearance and creepage paths follow the contour under the barrier.

EXAMPLE 10

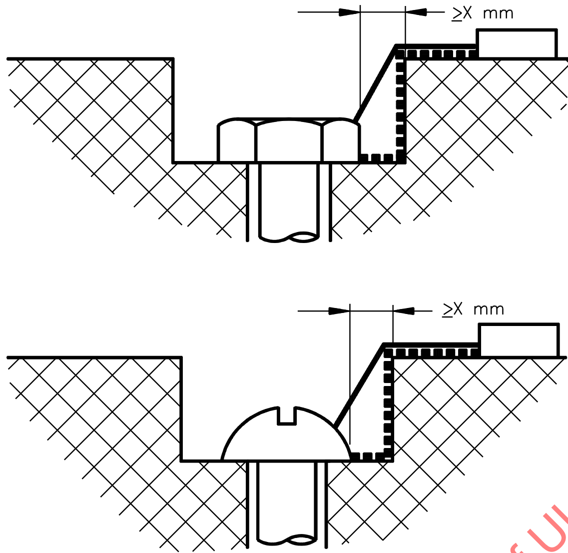


S3504

Conditions: Path under consideration includes an uncemented barrier when path over the barrier is less than the path under the barrier.

Rule: Clearance is the shortest air path over the top of the barrier. Creepage path follows the contour of the barrier.

EXAMPLE 11

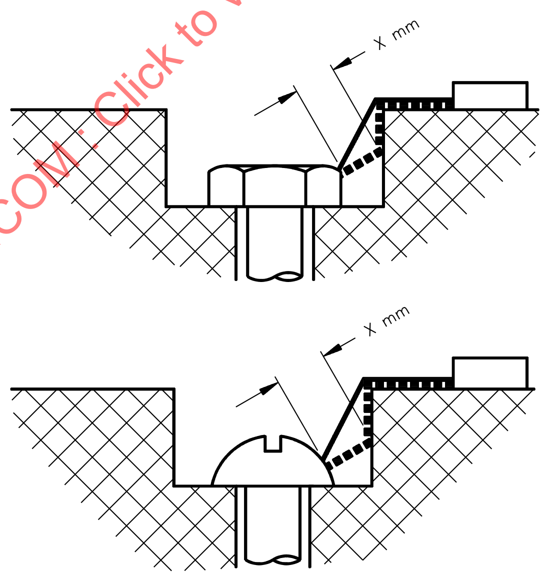


S3419A

Condition: Path under consideration includes a gap between head of screw and wall of recess that is equal to or more than X mm wide.

Rule: Clearance is the shortest air path through the gap and over the top surface. Creepage path follows the contour of the surfaces.

EXAMPLE 12

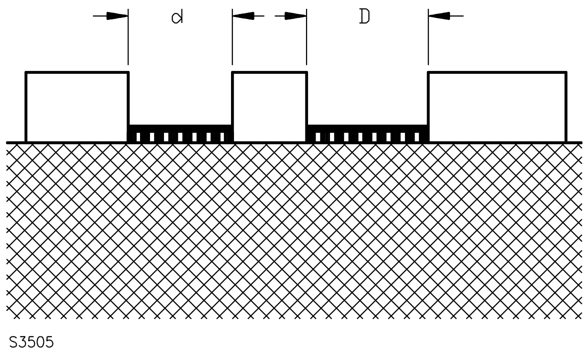


S3418A

Condition: Path under consideration includes a gap between head of screw and wall of recess that is less than X mm wide.

Rule: Clearance is the shortest air path through the gap and over the top surface. Creepage path follows the contour of the surfaces but "short-circuits" the bottom of the recess by X mm link.

EXAMPLE 13



Condition: Path under consideration includes an isolated part of conductive material.

Rule: Clearance and creepage paths are the sum of d plus D. Where d or D is smaller than X, it shall be considered as zero.

10.2 The "X" values are a function of pollution degree and shall be as specified in Table 10.1.

Exception: If the associated permitted clearance is less than 3 millimeters, the X value is one-third of the clearance.

Table 10.1
Width of grooves by pollution degree

Pollution degree	X value millimeters
1	0.25
2	1.0
3	1.5
4	2.5

11 Use of Coatings to Achieve Insulation Coordination

11.1 A coating intended to be used on a printed wiring board as an alternate to providing required creepage distances under the coating shall comply with Section 15, Printed Wiring Board Coating Performance Test.

11.2 A coating intended to be used on a printed wiring board to provide a Pollution Degree 1 environment shall comply with 15.1 – 15.5.

PERFORMANCE

12 Switching Test

12.1 Where required by Section 8, Clearance B (Controlled Overvoltage), line and load terminals of a device are to be monitored for generated voltages during normal operation, including adjusting switches and controls, at rated operational voltage under load and no-load conditions. Generated voltages shall not be greater than the rated impulse withstand voltage peak specified in Table 8.1 for the device. This monitoring is to be done using an oscillographic study during a suitable test such as an overload test.

13 Recurring Peak Voltage Determination

13.1 To determine the maximum recurring peak voltage, as required in 9.6, a device having a coated or uncoated printed wiring board(s) is to be tested in accordance with 13.2.

13.2 Devices having a coated wiring board are tested in the uncoated condition. The device is to be operated under conditions for which it is intended. Controls and adjustments are to be manipulated for 100 cycles. The voltage at the point of reduced creepage distance shall be monitored by an oscilloscope having a frequency response of at least 1 megahertz.

Exception: Those controls and adjustments which have been shown to have no effect on the measured voltage for 5 cycles between maximum and minimum, need not be cycled 100 times.

14 Dielectric Voltage-Withstand Tests

14.1 Testing in lieu of measuring clearances

14.1.1 If one or more components would cause the indication of a breakdown because they complete the path between the points being tested, those components may have one termination disconnected, so long as the points in question are subjected to the same test voltage.

14.1.2 Clearance values may be verified by conducting the impulse withstand voltage test described in 14.1.4. The equipment shall withstand the voltage impulse without breakdown or disruptive discharge. Breakdown is considered to have occurred when the leakage current exceeds 4 milliamperes or when the test voltage is interrupted prior to completion. Operation of an overvoltage protective device is not considered a breakdown.

14.1.3 If a disruptive discharge occurs through an overvoltage protective device or system, that device or system is to be removed from the circuit and the test voltage is to be reduced to the impulse withstand voltage of that device or system. The test voltage is then to be applied across the load side at the point where the overvoltage protection was connected.

14.1.4 With reference to 7.2 and 8.7, a previously untested product is to be used. The voltage is to be full lightning 1.2/50 microsecond impulses in accordance with Techniques for High-Voltage Testing, ANSI/IEEE 4-1995 (2001). Three positive and three negative impulses are to be applied. The minimum interval between pulses is to be 1 second. Other equivalent methods, as shown in Table 7.1 or Table 8.1, as appropriate, may be used. The test voltage is to be applied at the supply input to the product under considerations. See Table 14.1

Table 14.1
Test methods to be used to test spacings

Type of test	Impulse	AC rms	AC peak or DC	AC peak 1/2 sine wave	AC peak ramp
Rate of rise	1.2/50	–	–	–	6000 V/sec.
Hertz	–	50 – 60	50 – 60	50 – 60	50 – 60
Duration of test	3 Pos. & 3 Neg.[a] cycles	3 Pos. & 3 Neg.[a] cycles	3 Pos. & 3 Neg.[a] cycles DC, min. 10 ms	3 Pos.& 3 Neg.[a]	4 – 5 mA leakage current detection[b]

[a] The available current is to be limited to 4 – 5 milliamperes. The test equipment can be power limited or designed to shut off by the detection of 4 – 5 milliampere leakage current.

[b] The measured voltage must exceed the values in Table 7.1 or Table 8.1 as appropriate when the leakage current of 4 – 5 milliamperes is measured.

14.2 Testing for controlled overvoltage

14.2.1 With regard to 8.8, the dielectric voltage-withstand test for verifying clearances in equipment with overvoltage control is to be conducted in accordance with 14.2.2, and 14.1.1 – 14.1.4.

14.2.2 Three samples of the equipment that have not been previously tested are to be connected to a source of supply operating at rated voltage. Consideration must be given to connecting a filter at the equipment input to prevent the surge from reaching the supply source.

15 Printed Wiring Board Coating Performance Test

15.1 General

15.1.1 A coating intended to be used on a printed wiring board that has creepages in accordance with Table 9.2, pollution degree 1, shall comply with the requirements in 15.1 – 15.5.

15.1.2 A coating intended to be used on a printed wiring board as an alternate to providing required creepage distances shall comply with 15.1 – 15.11.

15.1.3 A printed-wiring board that is used with a coating is to be evaluated in accordance with the Standard for Printed-Wiring Boards, UL 796, and is to be acceptable for the temperature, solder conditions, conductor size, and adhesive to the base material under the conditions encountered in the end-use application. Tests are to be conducted on a fully processed printed-wiring board representative of production, containing such items as inks and solder resists, if applicable.

15.1.4 Test samples are to be provided with the minimum creepage, as applicable, and the minimum coating thickness using the pattern shown in Figure 15.1. The samples are to be prepared by normal production means employing the primer or cleaner employed by the end-product manufacturer. Lead wires that are considered acceptable for the voltage stress and temperatures involved are to be attached.

Exception: A representative printed wiring board with components removed may be used for this test.