

ANSI/ISA-S12.10-1988

Approved January 29, 1988

American National Standard

Area Classification in Hazardous (Classified) Dust Locations



ANSI/ISA-S12.10 — Area Classification in Hazardous (Classified) Dust Locations

ISBN 1-55617-095-5

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Preface

This preface is included for informational purposes and is not part of ISA-S12.10.

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1 Purpose

This standard recommends procedures for classifying locations made hazardous by the presence of a cloud or blanket of combustible dust. It conforms with the U.S. *National Electrical Code*® (*NEC*®)* and the *Canadian Electrical Code (CEC)*, and is intended to expand and clarify both.

2 Scope

This standard refers only to combustible mixtures created by dusts — such as agricultural, carbonaceous, plastic, chemical, and metal dusts. Such materials are classified in *NEC*® Article 500 as Class II, Groups E, F, and G.

This standard classifies a location based on its dust cloud concentration, its accumulated combustible dust layer thickness, and its dust bulk resistivity; it also contains references to, and data on, the explosivity of common dusts, as well as references to laboratory equipment and test procedures for evaluating the explosivity of dusts.

This standard is intended for use by persons trained in the design and installation of instrument systems and by inspection authorities in the approval of such installations.

NOTE: This standard is not intended to address hazards created by the emission of Class I combustible gases from combustible dusts, e.g., the emission of methane from freshly crushed coal.

3 Definitions

Combustible dusts: Dusts which (when mixed with air in certain proportions) can be ignited and will propagate flame.

Combustible dust layer: Any surface accumulation of combustible dust that is large enough to propagate flame or will degrade and ignite.

Dust: Any finely divided solid material 420 μ m or smaller in diameter (material passing a U.S. No. 40 Standard Sieve).

NOTE: *Larger-sized particles can also cause explosions — see [References 4 and 15](#).*

Minimum cloud ignition temperature: The minimum temperature at which a combustible dust atmosphere will autoignite and propagate an explosion.

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Minimum dust layer ignition temperature: The minimum temperature of a surface that will ignite dust lying on it after a long time (theoretically, until infinity) (see Reference 4). In most dusts, free moisture has been vaporized before ignition.

Minimum explosion concentration: The minimum concentration of a dust cloud that, when ignited, will propagate flame away from the source of ignition.

NOTE 1: The measurable combustible properties of dusts depend not only on the chemical structure of the dust, but on test conditions, dust particle size, weight, density, and other particle characteristics.

NOTE 2: See Appendix A.1 for NEC® definitions.

4 Dust explosion parameters and variables

4.1 The nature of a dust explosion. A dust explosion is the rapid burning of a cloud of dispersed dust accompanied by the release of thermal energy in a pressure wave. The flame can travel rapidly through the dust cloud, igniting other adjacent combustibles.

An initial explosion often dislodges settled dust from building structures and machinery. This dislodged settled dust may be ignited by glowing residue from the initial explosion, and a secondary explosion may follow. The quantity of dust thus redispersed may cause more extensive injury and property damage than the initial dust cloud. Good housekeeping in an area made hazardous (classified) by dust is vitally important, and will keep accumulations on structures and machinery to a minimum.

Even a puff of air in the presence of an ignition source or a small flame can initiate a dust explosion. While dust accumulated as a layer will not explode ordinarily, it may melt, char, or burn. This burning can generate heat and air turbulence that may disperse further amounts of dust, which may then explode.

4.2 Dust dispersion mechanics and control. Dust often disperses horizontally from its source. The extent of dispersion depends on the initial horizontal air velocity, the release height, and the particle settling time. For spherical particles the settling time can be estimated from Stokes's Law, as given in Equation 1:

$$V_s = \frac{h}{t} = \frac{g\rho D^2 10^{-8}}{18\mu} \quad (\text{Eq. 1})$$

where

V_s = still air settling velocity, in centimeters per second

h = release height, in centimeters

t = settling time, in seconds

g = gravitational constant, 980 cm/s²

ρ = particle density, in grams per cubic centimeter (1.44 g/cm³ for dry flour)

D = particle size (diameter), in micrometers

μ = air viscosity, in poises (180 X 10⁻⁶ P [X 10¹ = Pa·s] at normal temperature and pressure)

Equation 1 is applicable for particles from 1 to 100 μm in diameter (in free fall), with approximately a 10-percent error at low concentrations. The larger particles will fall nearby; the smaller particles will fall some distance from the release point.

Well-designed process equipment and buildings have surfaces which are smooth and easily cleaned, and lack ledges or inaccessible pockets where dust could accumulate. Process dust should be mechanically sealed in process piping, vessels, and ducts when practical. Where dusty materials must be handled in the open, dust should be collected. Frequent cleanup of settled dust will substantially reduce the likelihood of combustible dust accumulations in a location and substantially reduce the likelihood of a *major secondary dust explosion*.

4.3 Dust cloud ignition. The factors usually considered in dust cloud ignition are the following:

- 1) Minimum explosion concentration
- 2) Minimum cloud ignition temperature
- 3) Minimum ignition energy
- 4) Maximum explosion pressure
- 5) Maximum rate of explosion pressure rise
- 6) Minimum oxygen concentration

These terms are defined and discussed in References 3,4, 6–9, 11, and 12.

The preceding factors are influenced by

- 1) Composition
- 2) Particle size
- 3) Moisture content
- 4) Particle shape
- 5) Particle surface area
- 6) Oxygen concentration

[Table 1](#) compares the relative ignition properties of Class I and Class II materials. Laboratory explosion pressures are approximately the same for both classes, but detonation and pressure piling can cause that pressure to increase significantly. Whether this will happen or not depends on the shape of the enclosure. The lower explosive limit (LEL) is a measure of Class I explosive concentration. The values of explosion pressure, time to peak pressure, and explosion pressure rate of rise depend on the volume and geometry of the test apparatus. The minimum explosion concentration is a similar measure for Class II materials. Unlike Class I materials, the surface ignition temperature for Class II materials (dusts) must be expressed both for layer and cloud form. The two usually are not equal.

4.4 Dust layer ignition. The two factors to be considered in combustible dust layer ignition are the layer ignition temperature and the combustible dust layer thickness.

The layer ignition temperature of most materials is lower than their cloud ignition temperature. (A few comparisons are made in [Table 1](#).) A prolonged elevated temperature will decrease the minimum layer ignition temperature. For cornstarch, the layer ignition temperature changes from 500°C for 0.3 hours (h) to 150°C for 70 h.

The combustible dust layer thickness is the minimum thickness that will allow a fire or glow to propagate in a settled dust. A method for determining the minimum combustible dust layer thickness is given in Appendix A.5.

5 Procedures for the classification of various areas of existing plants

(Measurement procedures and examples are given in Appendix A.)

5.1 Division 1 Locations. Locations should be classified as Division 1 if any of the following conditions exist:

- 1) The dust cloud exists under normal conditions at concentrations above the minimum explosion concentration.

NOTE: Combustible dust clouds may be seen. An explosive dust cloud concentration (see A.3) must usually reach the point where visibility is limited to a few feet. Division 1 locations usually exist inside and around process equipment, e.g., at filling and dispensing points, and inside and around leak points where accumulations of dust exist.

- 2) "Large" dust accumulations (refer to Appendix A.5 and Figure 1) may exist for extended periods of time (usually due to inadequate housekeeping or dust removal systems).

NOTE: Good housekeeping and/or the installation of dust collection systems can substantially reduce the accumulation of dust.

Table 1 — Comparison of relative ignition properties of Class I and Class II materials

Ignition Property	Class I: Gases & Vapors				Class II: Dust Clouds			
	Methane	Propane	Hydrogen	Acetylene	Wheat Starch	Rice	Safflower Meal	Sugar
Minimum ignition energy, mJ	0.30	0.25	0.019	0.017	20	40	20	30
Maximum explosion pressure, kg/cm ² (1 kg/cm ² = 1 kPa)	7.17	8.58	7.39	10.3	7.38	6.54	5.90	6.40
Time to peak pressure, s	70	46	7	14	—	—	—	—
Explosion pressure rate of rise, kg/cm ² /s	—	—	—	—	597.6	253.1	203.9	351.5
Lower explosive limit, % volume	5.0	2.1	4.0	2.5	—	—	—	—
Minimum explosion concentration, mg/L	—	—	—	—	25	45	55	35
Autoignition temperature, °C	435	198	470	272	—	—	—	—
Layer surface ignition temperature, °C	—	—	—	—	—	220	210	400
Cloud/surface ignition temperature, °C	—	—	—	—	420	440	460	370

*Recent work indicates that minimum ignition energies are considerably lower than these values when long spark discharge times are used. [See Reference 5.](#)

NOTE: The values indicated above are based on the techniques described in References 3,4, 6–9, 11, and 12.

- 3) Conditions exist which could meet Division 2 requirements, but the dust is conductive.

NOTE: *An electrically conductive dust will produce heating and possibly ignition of the dust if allowed to bridge energized electrical terminals. Therefore, a Division 1 classification is required.*

- 4) Where mechanical failure or abnormal operation might simultaneously result in ignitable mixtures and an ignition source through failure of electrical equipment.

5.2 Division 2 locations. Locations should be classified as Division 2 if any of the following conditions exist:

- 1) The frequency of occurrence of a combustible dust cloud is very low.
- 2) Dust accumulations (see Appendix A.5.1 and Figure 1) exceed the combustible dust layer thickness but are not sufficient to justify a Division 1 classification.

NOTE: An effective housekeeping program and a properly designed and installed dust removal system can substantially reduce dust accumulation.

- 3) The location is adjacent to a Division 1 location, unless the dust is conductive (see Section 5.1).

NOTE: Where conductive dusts are involved, there is only a Division 1 classification.

- 4) Dust is processed in an enclosed system but an occasional leak occurs at flexible connections, rotary feeders, or other such sources,

NOTE: The Division 2 classification extends wherever the dust layer thickness exceeds the combustible dust layer thickness.

- 5) Locations where combustible dust is processed in an enclosed system where release through venting relief panels, seal failures, or accidental rupture may result in abrupt release of combustible concentrations.

5.3 Unclassified locations. Locations should be noted as "unclassified" under the following conditions:

- 1) Where the dust cloud concentration does not exceed the minimum explosion concentration; and
- 2) Where the combustible dust layer exists infrequently.

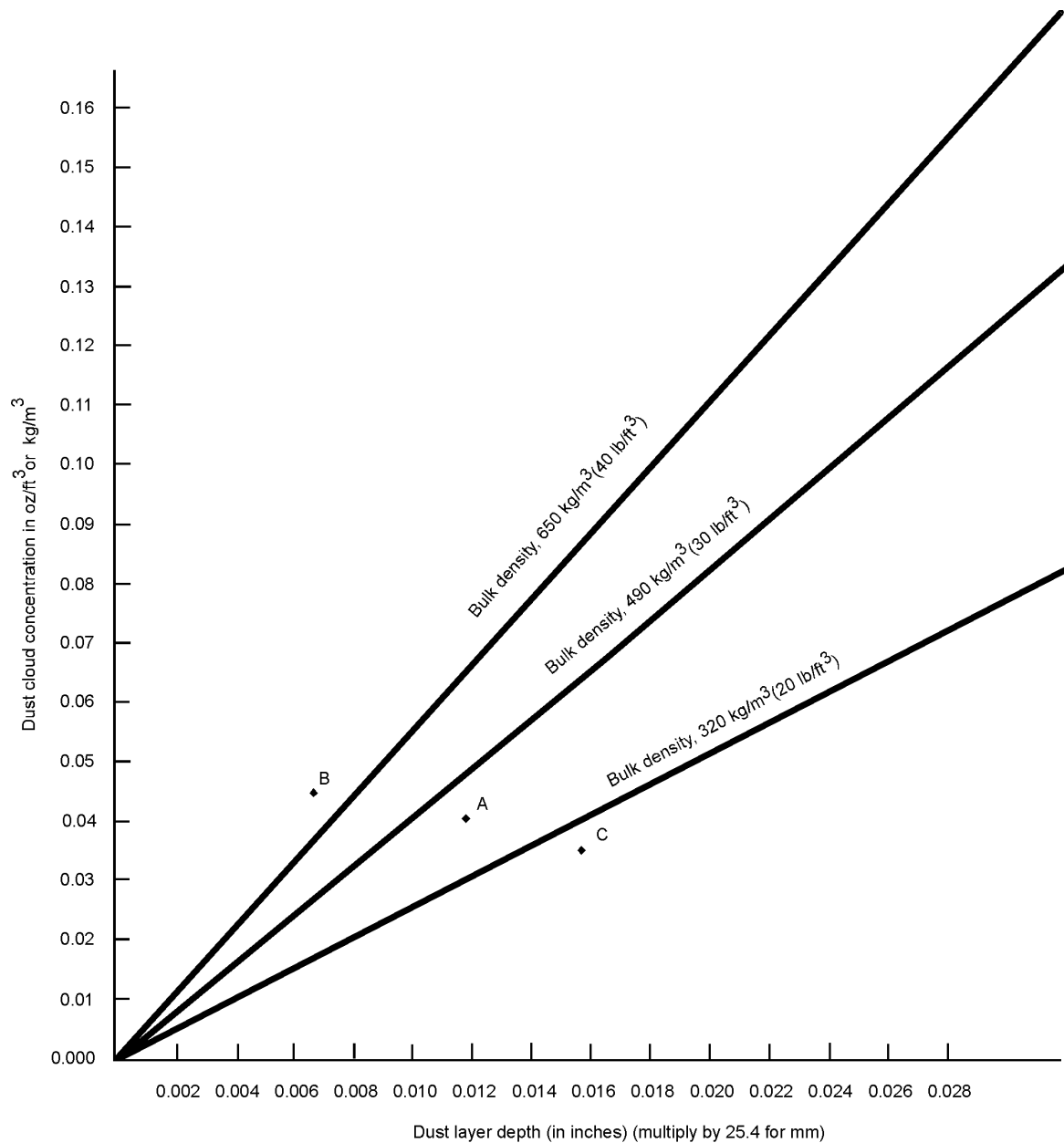
Examples are:

- a) Where excellent housekeeping is provided to areas adjacent to a Division 2 location.
- b) Where the dust layer has diminished to less than the combustible dust layer thickness.

The means of defining the extent of the areas to be classified as "nonhazardous" (unclassified) are

- 1) Measurement — refer to the appendixes.
- 2) Appraisal — use judgment based on experience with the measurement of dusty areas.

Probability definitions of Divisions 1 and 2 have been mentioned in international standards and are discussed in [Reference 2](#); they are included in [Appendix A](#) as reference material.



A is cornstarch — minimum explosive concentration is 0.04 kg/m³ (0.04 oz/ft³) (minimum depth of dust to produce this density is 0.012).

B is sugar — minimum explosive concentration is 0.045 kg/m³ (0.045 oz/ft³) (minimum depth of dust to produce this density is 0.0068).

C is wood flour — minimum explosive concentration is 0.035 kg/m³ (0.035 oz/ft³) (minimum depth of dust to produce this density is 0.016).

Figure 1 — Dust cloud concentration vs. dust layer depth for height of 3 m (10 ft) — assuming uniform dust distribution

6 Procedures for the classification of various portions of new process areas during the design stage

Set classification goals for each location in the design stage of new process areas by a team comprised of persons responsible for

- 1) Process and electrical design
- 2) Corporate insurance
- 3) Concurrence with fire and electrical regulations

This team should prepare confirming documents delineating the agreed limits of Division 1, Division 2, and the nonhazardous areas.

6.1 This team should establish the classification of each location on the basis of

- 1) Experience and data from similar installations
- 2) The types of material being processed and their physical properties
- 3) Layout of the facilities
- 4) Ventilation of the location and local exhaust at emission points
- 5) Housekeeping standards

NOTE: After the classifications have been assigned, criteria are specified to ensure construction of a facility meeting the requirements for the classified areas.

6.2 The minimum layer and dust cloud ignition temperature of the materials to be handled or processed should be determined. If the temperature is lower than that designated in Article 500 of the NEC®, the classification documentation should include temperature requirements for the specific application.

Knowledgeable and responsible individuals should maintain proper housekeeping practices to ensure that the established classifications are not violated.

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Appendix A

This appendix is intended to clarify ISA Standard S12.10 and to explain the philosophy on which it is based. It is not part of the standard.

A.1 NEC® References

The following are extracted from the *National Electrical Code*® (NEC®) (ANSI/NFPA 70-1987).*

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500-6. Class II Locations. Class II locations are those that are hazardous because of the presence of combustible dust. Class II locations shall include those specified in (a) and (b) below.

a) **Class II, Division 1.** A Class II, Division 1 location is a location: (1) in which combustible dust is in the air under normal operating conditions in quantities sufficient to produce explosive or ignitable mixtures; or (2) where mechanical failure or abnormal operation of machinery or equipment cause such explosive or ignitable mixtures to be produced, and might also provide a source of ignition through simultaneous failure of electric equipment, operation of protection devices, or from other causes; or (3) in which combustible dusts of an electrically conductive nature may be present in hazardous quantities.

(FPN):** Combustible dusts which are electrically nonconductive include dusts produced in the handling and processing of grain and grain products, pulverized sugar and cocoa, dried egg and milk powders, pulverized spices, starch and pastes, potato and woodflour, oil meal from beans and seed, dried hay, and other organic materials which may produce combustible dusts when processed or handled. Electrically conductive dust are dusts with a resistivity less than 10^5 ohm-centimeter. Dusts containing magnesium or aluminum are particularly hazardous and the use of extreme precaution will be necessary to avoid ignition and explosion.

b) **Class II, Division 2.** A Class II Division 2 location is a location where combustible dust is not normally in the air in quantities sufficient to produce explosive or ignitable mixtures, and dust accumulations are normally insufficient to interfere with the normal operation of electrical equipment or other apparatus, but combustible dust may be in suspension in the air as a result of infrequent malfunctioning of handling or processing equipment and where combustible dust accumulations on, in, or in the vicinity of the electrical equipment may be sufficient to interfere with the safe dissipation of heat from electrical equipment or may be ignitable by abnormal operation or failure of electrical equipment.

(FPN): The quantity of combustible dust that may be present and the adequacy of dust removal systems are factors that merit consideration in determining the classification and may result in an unclassified area.

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**FPN = fine-print note.

(FPN): Where products such as seed are handled in a manner which produces low quantities of dust, the amount of dust deposited may not warrant classification.

* * *

The following excerpt is from Article 500-3:

(FPN No. 1): It is important that inspection authorities and users exercise more than ordinary care with regard to installation and maintenance.

(FPN No. 2): ... for Class II locations, Groups E, F, and G, the classification involves the tightness of the joints of assembly and shaft openings, to prevent entrance of dust in the dust-

ignition-proof enclosure, the blanketing effect of layers of dust on the equipment that may cause overheating, electrical conductivity of the dust, and the ignition temperature of the dust. It is necessary, therefore, that equipment be approved not only for the class, but also for the specific group of the gas, vapor, or dust that will be present.

(FPN No. 13): Group E: Atmospheres containing combustible metal dusts regardless of resistivity, or other combustible dusts of similarly hazardous characteristics having resistivity of less than 10^5 ohm-centimeter.

(FPN No. 14): Group F: Atmospheres containing carbon black, charcoal, coal or coke dusts which have more than 8 percent total volatile material (carbon black per ASTM D1620; charcoal, coal and coke dusts per ASTM D271) or atmospheres containing these dusts sensitized by other materials so that they present an explosion hazard, and having resistivity greater than 10^2 ohm-centimeter but equal to or less than 10^8 ohm-centimeter.

(FPN No. 15): Group G: Atmospheres containing combustible dusts having resistivity of 10^5 ohm-centimeter or greater.

(FPN No. 16): Certain chemical atmospheres may have characteristics that require safeguards beyond those required for any of the above groups. Carbon disulfide is one of these chemicals because of its low ignition temperature, 100°C (212°F), and the small joint clearance to arrest its flame.

(FPN No. 17): Certain metal dusts may have characteristics that require safeguards beyond those required for atmospheres containing the dusts of aluminum, magnesium, and their commercial alloys. For example, zirconium, thorium and uranium dusts have extremely low ignition temperatures (as low as 20°C [68°F]), and minimum ignition energies lower than any material classified in any of the Class I or Class II Groups.

(FPN No. 18): Certain dusts may require additional precautions due to chemical phenomena that can result in the generation of ignitable gases. See National Electrical Safety Code (ANSI C2-1984), Section 127A-Coal Handling Areas....

* * *

d) Class II Temperature. The surface temperature marking specified in ... [NEC® marking requirements] shall be less than the ignition temperature of the specific dust and in no case shall it be greater than the temperature given below for Groups E, F, and G. (See Classification of Gases, Vapors, and Dusts for Electrical Equipment in Hazardous (Classified) Locations, NFPA 497M-1986 for minimum ignition temperatures of specific dusts.)

Exception: Equipment subject to overloads shall not exceed 150°C (302°F) in normal operation and shall not exceed the ignition temperature of the specific dust or 200°C (392°F), whichever is lower, when installed in locations which are classified due to carbonaceous dusts.

The maximum surface temperature for which equipment was approved prior to this requirement shall be assumed to be as follows:

Class II Group	Equipment that is Not Subject to Overloading		Equipment (such as Motors or Power Transformers) that May Be Overloaded			
			Normal Operation		Abnormal Operation	
	Degrees C	Degrees F	Degrees C	Degrees F	Degrees C	Degrees F
E	200	392	200	392	200	392
F	200	392	150	302	200	392
G	165	329	120	248	165	329

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The following excerpt is taken from Article 502-1:

502-1. General. The general rules of this Code shall apply to the electric wiring and equipment in locations classified as Class II locations in Section 500-6.

Exception: As modified by this article.

"Dust-ignitionproof," as used in this article, shall mean enclosed in a manner that will exclude ignitable amounts of dusts or amounts that might affect performance or rating and that, where installed and protected in accordance with this Code, will not permit arcs, sparks, or heat otherwise generated or liberated inside of the enclosure to cause ignition of exterior accumulations or atmospheric suspensions of a specified dust on or in the vicinity of the enclosure.

Equipment installed in Class II locations shall be able to function at full rating, without developing surface temperatures high enough to cause excessive dehydration or gradual carbonization of any organic dust deposits that may occur.

(FPN): Dust that is carbonized or excessively dry is highly susceptible to spontaneous ignition.

Equipment and wiring of the type defined in Article 100 as explosionproof shall not be required and shall not be acceptable in Class II locations unless approved for such locations.

Where Class II, Groups E and F dusts having a resistivity less than 10^5 ohm-centimeter are present in hazardous quantities, there are only Division 1 locations.

* * *

The following excerpt is taken from Section 500-2:

... Intrinsically safe equipment and wiring shall not be capable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific flammable or combustible atmospheric mixture in its most easily ignitable concentration.

* * *

The following definition is taken from Article 100:

Dusttight: So constructed that dust will not enter the enclosing case under specified test conditions.

(FPN): For test conditions other than for rotating equipment, see ANSI/NEMA 250-1979, Enclosures for Electrical Equipment, Paragraph 250.5.05.

A.2 Probability definitions of area classification

A location should be considered Division 1 if a combustible dust cloud is above the minimum explosion concentration over 0.1 percent (8.8 h/yr) of the time.

A location should be considered Division 2 if a combustible dust cloud is above the minimum explosion concentration over 0.01 percent (0.88 h/yr) of the time, but less than or equal to 0.1 percent (8.8 h/ yr) of the time.

Locations may be considered unclassified when the likelihood of a combustible dust cloud is equal to or less than 0.01 percent (0.88 h/yr) of the time.

A.3 Procedure for determining dust cloud concentration

The following test procedures supplement the procedures described in Sections 5 and 6.

A.3.1 Disk sampling apparatus. The following apparatus are used for disk sampling:

- 1) A vacuum pump with a free air capacity of 45 L/min for 20 min, rotary-vane-type with an oilless-type motor
- 2) A rotameter with a capacity of 0 to 35 L/ min
- 3) A rubber hose with a 0.95-cm (3/8-in.) outside diameter and 63.5 cm (25 in.) long
- 4) Two filter disk holders, 5.08 cm (2 in.) in diameter
- 5) A laboratory balance
- 6) Filter disks, 5.08 cm (2 in.) in diameter, glass fiber, submicrometer pore size, low pressure drop at flow of 35 L/min
- 7) Business envelopes
- 8) A stop watch

A.3.2 Tape sampling apparatus. The following apparatus are used for tape sampling:

- 1) A tape sampler, consisting of a carbon-vane vacuum pump, an adjustable timer, and a mechanism for indexing the tape from the "sample reading" timer position. A photodensitometer is also needed for "reading" the tape as it is darkened by dust.
- 2) A recording milliammeter for recording photodensitometer output.

In addition to the apparatus listed above, the following items are also required:

- 1) Extension cords
- 2) Face masks

A.3.3 Procedure. "Long-time" samples are taken with the vacuum pump for approximately 5-min periods, using a filter disk as the sample collector. Filter holders are connected to the vacuum pump unit through the 0.95-cm (3/8-in.) tubing. The tubing connection permits free movement so that the observer can select the dustiest location to sample by sight. Tubing also permits downward flow into the filter for the most conservative orientation of the collector. Once the flow is collected, the loaded collector is carefully covered with the paired filter disk. The pair is carefully placed in a small business envelope to preserve the sample as a whole.

Net weight gain is determined by using an analytical balance to determine the difference in the weights of the two filters before and after sampling. Air quantity is determined by reading the rotameter on the vacuum pump and the stop watch. The disk sampler concentration is then calculated.

"Short-time" samples are taken by using the tape spot-sampler with the photodensitometer. The sampler automatically collects timed samples through an inlet tube for an adjustable sampling period of 1 to 120 seconds (s). Specks of dust on the tape are analyzed in the photodensitometer for the percentage of light transmission. The tape sampler is used to learn the maximum short-time concentrations, rather than 5-min averages (which are found with the disk sampler). Sampling periods from 7 to 60 s are used.

The optimum sampling period is found between a period which is too short (when insufficient staining occurs), and a period which is too long (when a dust load thick enough to choke the sampling slot accumulates). When such a choke occurs, the tape will tear. The best sampling period is found by trial and error.

The samplers are correlated by taking concurrent samples from the same area. Densitometer readings are converted to coefficient-of-haze (COH) numbers by means of Equation A-1:

$$\text{COH/1000 linear feet} = \frac{\text{Area} \times 10^5}{\text{Volume}} \log_{10} \frac{100}{(\% \text{ Transmittance})} \quad (\text{Eq. A-1})$$

COH can be determined by Equation A-1. [See also Figure A-1](#). COH values for each test are averaged and a maximum-to-average ratio is calculated. This ratio, multiplied by the calculated disk sampler concentration, is defined as the average "short-time concentration" (STC). Area and volume constants are used as a ratio and therefore cancel out.

Short-time concentration (STC) values are then compared to Publication NMAB 353-3's minimum explosive concentration values for the product involved. A safety factor is then applied to the measured data to account for momentary peaks of concentrations higher than those of the measured data (note the paragraph immediately following). By making this comparison (with the safety factor applied to the STC) and by using an estimate of the frequency of the sampled condition, the location classification can be determined.

Bureau of Mines investigations (see References 3,4, 6–9, 11, and 12) indicate that a dust explosion can begin within 10 to 20 ms of ignition. The peak pressure occurs within 50 to 100 ms of ignition. The minimum tape sampling period per sampling point is 1 to 20 s. Since a peak concentration lasting only a portion of this period could result in an explosion, an additional safety factor is applied to the measurements. These times depend on the volume of their test enclosure.

Since instruments are usually mounted within 1.52 m (5 ft) of the floor, samples should also be taken within 1.52 m (5 ft) of the floor. Settled dust is agitated to ensure that maximum dust concentration is present during sampling. This agitation adds settled material to any dust cloud normally present during operations. Of all the possible locations in an area for sampling, the operator should choose by sight that location having the densest dust cloud after the agitated dust has settled. This method probably normally places more dust into the air than most abnormal operating conditions, thus building in an additional safety factor.

A.3.4 Safety factor considerations. Safety factors are added for the following reasons:

- 1) To adjust for the probability that the concentration for 10 ms at the test location may exceed the average during a 5-s measuring period, and
- 2) To adjust for possible errors of apparatus and techniques.

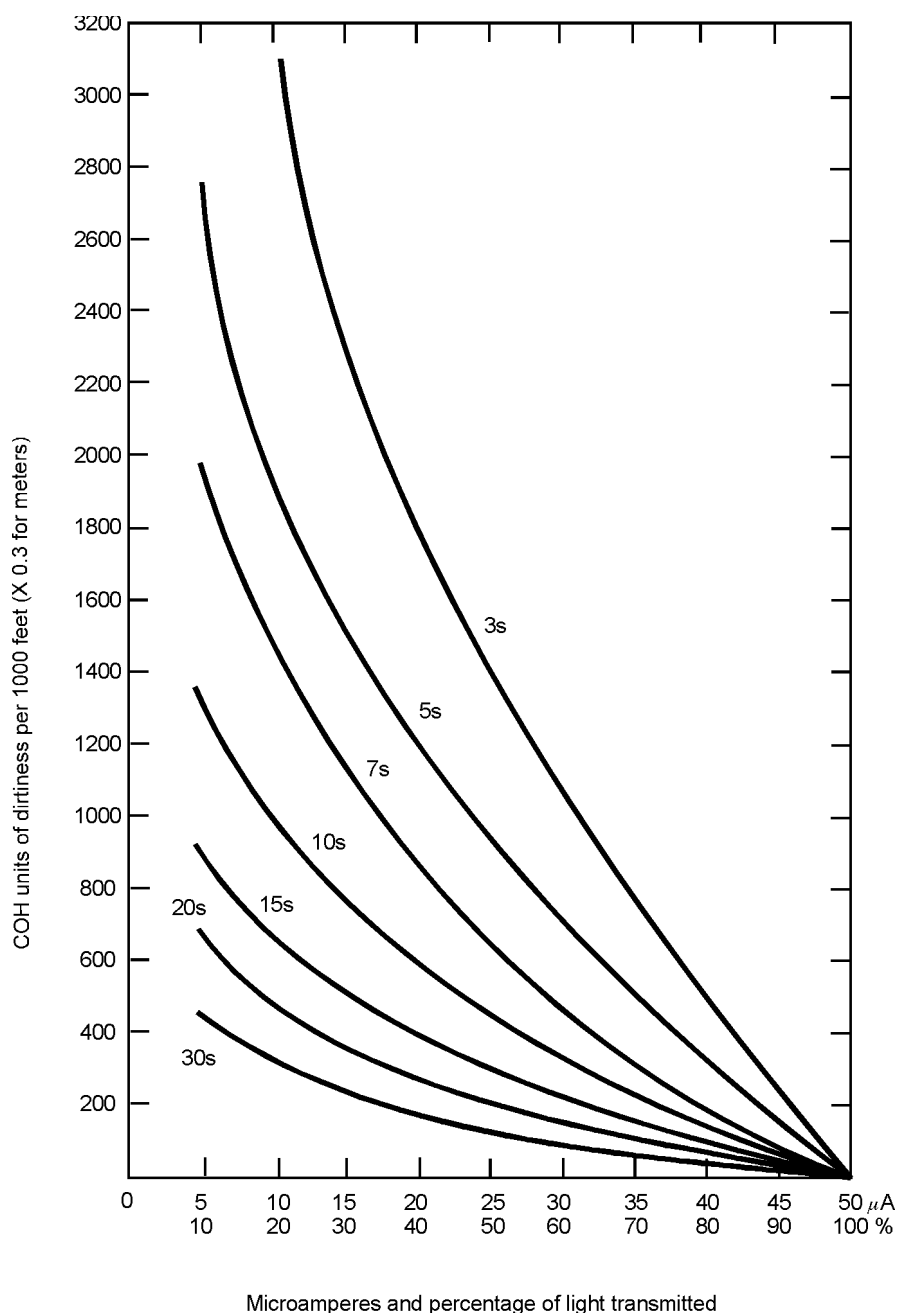


Figure A.1 — Coefficient-of-haze (COH) units of dirtiness vs. microamperes and percentage of transmittance (for use with photodensitometer)

Since momentary concentrations exceed the measured concentrations, they require an additional safety factor. The tape sampler is limited to 5- and 10-s minimum sampling periods, and dust explosions can begin within 20 ms after dust is supplied with ignition energy. Until instruments with sufficient response capabilities are introduced and proven, an additional safety factor of 2 is recommended to allow for possible high-consistency processing.

Errors of apparatus and technique stem largely from two sources — errors in reading time durations (using the stop watch) and the rotameter. (Errors in reading the balance are usually negligible when weighing over 1 g with a ± 0.1 -mg accuracy balance.)

A.4 Procedure for determining dust layer thickness

The thickness of a uniform layer is best measured by sweeping a small area (measuring approximately 0.2 m² [2 ft²]) and recording the volume swept. The thickness is calculated from the volume and the area measured. Care should be taken to allow time for the swept material to settle in the measuring device before reading the volume. The area chosen for sweeping should be near the electrical instrument in question (or on the surface of that instrument).

Dust ignition explosivity factors are related to changes in dust physical properties, i.e., particle diameter, moisture content, etc. (Reference Figures A-2 through A-10.) Increasing either moisture content or particle size of dusts increases their ignition energy, ignition temperature, and minimum explosive concentration and decreases the explosion pressure and the rate of pressure rise.

A.4.1 Example of determination of dust layer thickness to propagate a flame

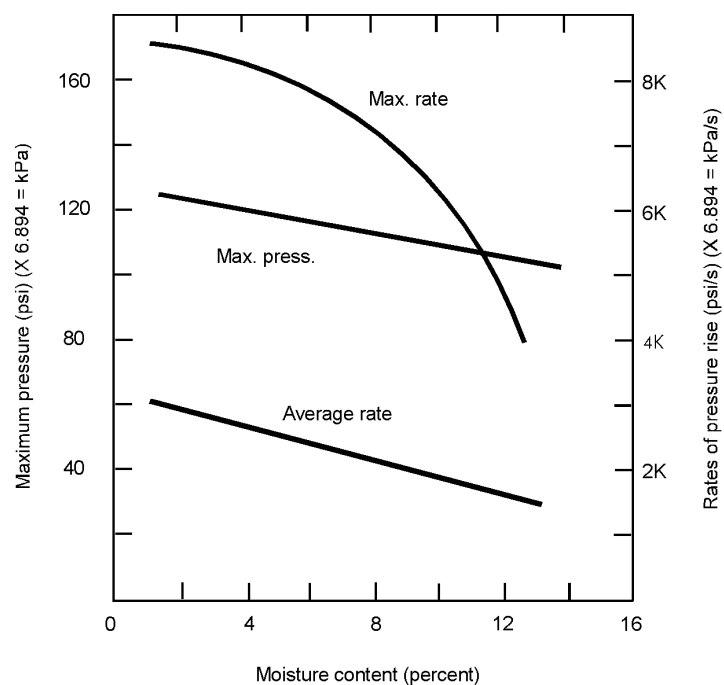
Example: Dust is poured into the settling chamber and then dispersed to produce a layer. The required volume of dust can be approximated from the following:

Volume	Area	Typical Layer
0.5 L (1 pt)	0.84 m ² (9 ft ²)	0.6 mm (0.022 in.)
0.75 L (2 pt)	0.84 m ² (9 ft ²)	1.1 mm (0.044 in.)
1.4 L (3 pt)	0.84 m ² (9 ft ²)	1.7 mm (0.066 in.)

The heating wire or electric charcoal-fire starter, heated to a dull red color, is carefully placed into the layer. For thin layers, charring of only the dust in contact with the heater is observed; no propagation takes place. As the layer thickness is increased, a point is reached when the dust continues to burn and flame propagates away from the heat source. This thickness is defined as the combustible dust layer thickness. Additions smaller than 0.5 L (1 pt) will improve the estimate of the combustible dust layer thickness.

The following figures illustrate the properties of a dust.

NOTE: Figures A-2 through A-10 were taken from the U.S. Bureau of Mines' Publication RI 4725, *Explosibility of Cornstarch*.



Dust concentration: 500 mg/L
Dust fineness: through 325 mesh (0.043 mm)
 $k = 1000$

Figure A.2 — Pressure and rate of rise (cornstarch explosion) vs. percent of moisture

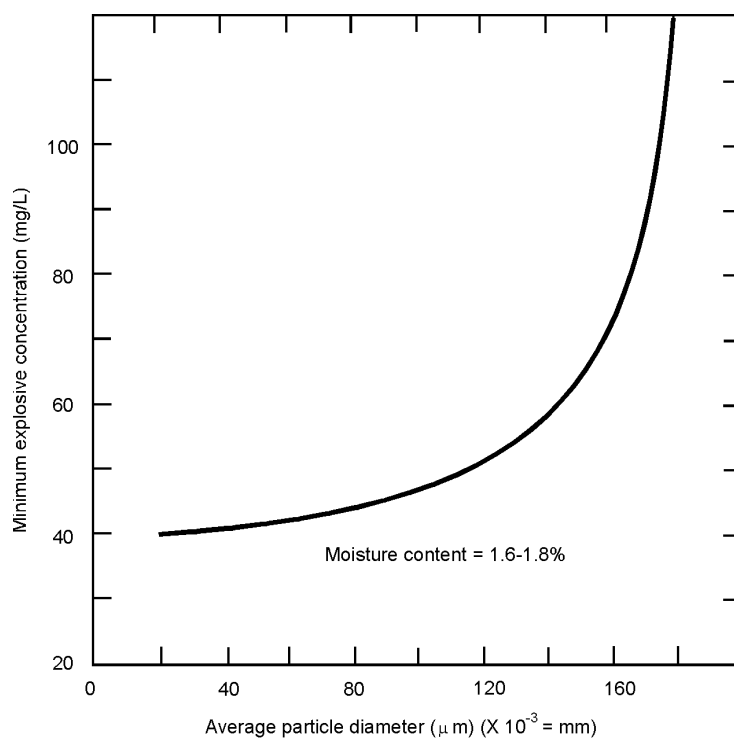


Figure A.3 — Minimum explosion concentration (cornstarch explosion) vs. particle diameter

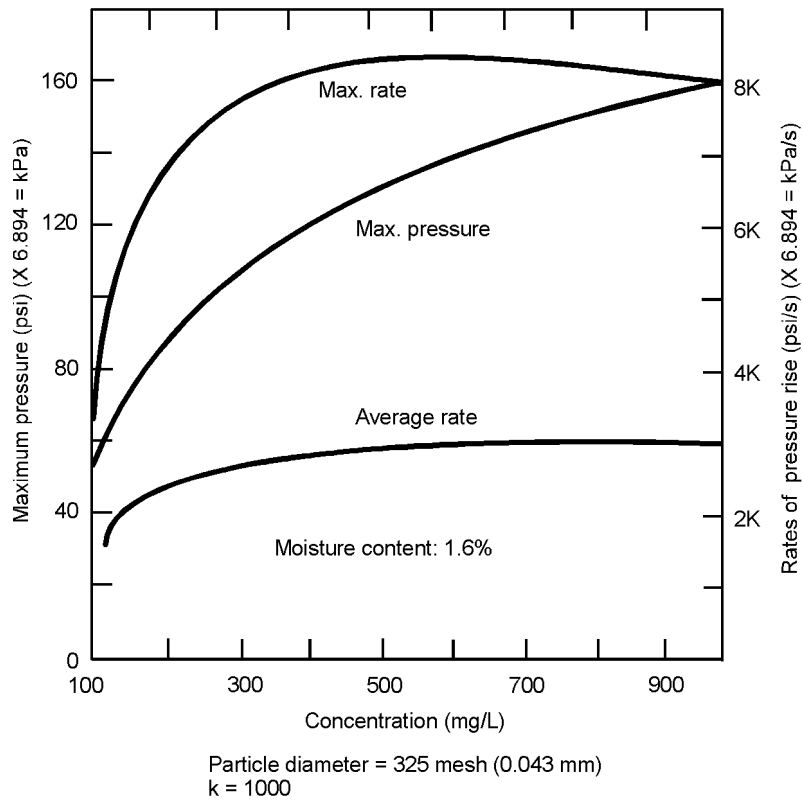


Figure A.4 — Pressure and rate of rise (cornstarch explosion) vs. concentration

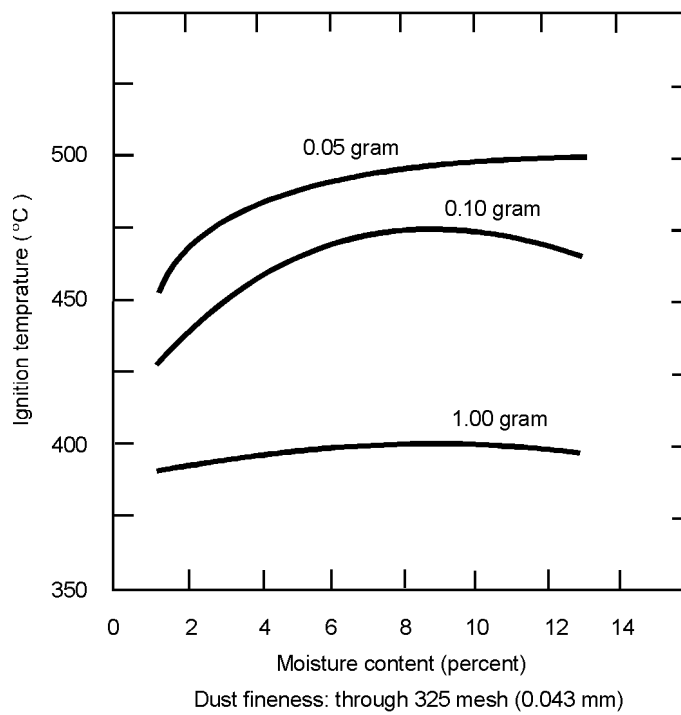


Figure A.5 — Ignition temperature vs. percent of moisture (cornstarch)

A.5 Procedure for classifying areas based on dust layer accumulations

NOTE: Dust accumulations should be avoided by providing adequate housekeeping procedures and/or dust removal systems.

A combustible dust layer can be the source of a cloud. A cloud may be created by moving equipment, drafts, ventilation, or an air pressure wave generated by an explosion.

Figure 1 gives the minimum dust depth necessary to develop a uniform 3-m-high (10-ft-high) cloud that is at the minimum explosion concentration. This curve assumes 100-percent uniform dispersion of the combustible dust layer and therefore represents a highly theoretical, worst-case situation for most industrial facilities. If the combustible dust layer thickness exceeds this value, the area should be classified Division 2. This dust layer thickness is very small (e.g., 0.304 mm [0.012 in.] for cornstarch) and is a layer just thick enough to cover a floor or surface so that its color is not visible. *Therefore, dusty areas where the layer is just thick enough to obscure the floor or surface color should be classified "Division 2."* As the combustible dust layer thickness increases, a thickness is reached where dust-tight equipment is no longer acceptable and dust-ignitionproof equipment should be used. This thickness depends on the dust layer ignition temperature, the susceptibility to dust accumulation of dust-tight (Division 2) equipment, the degree of dust dispersion, etc. This layer thickness is impossible to determine for any specific situation, but as a general guide, 3 mm (1/8 in.) is considered an acceptable thickness as a dividing line between Divisions 1 and 2. *Therefore, where the combustible dust layer thickness exceeds 3 mm (1/8 in.), a Division 1 classification should be used.*

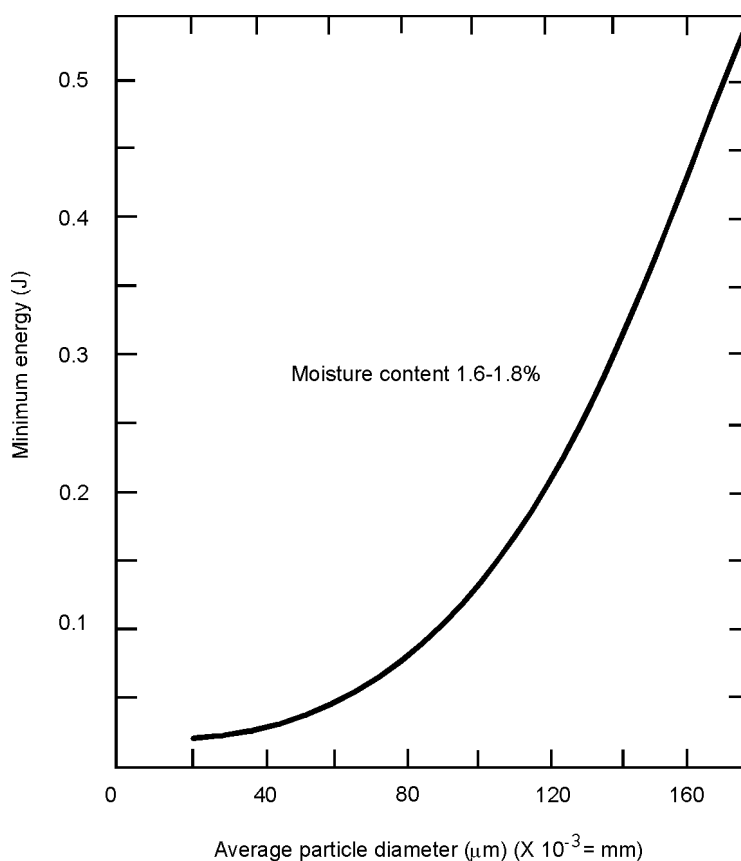


Figure A.6 — Minimum (ignition) energy (cornstarch explosion) vs. particle diameter

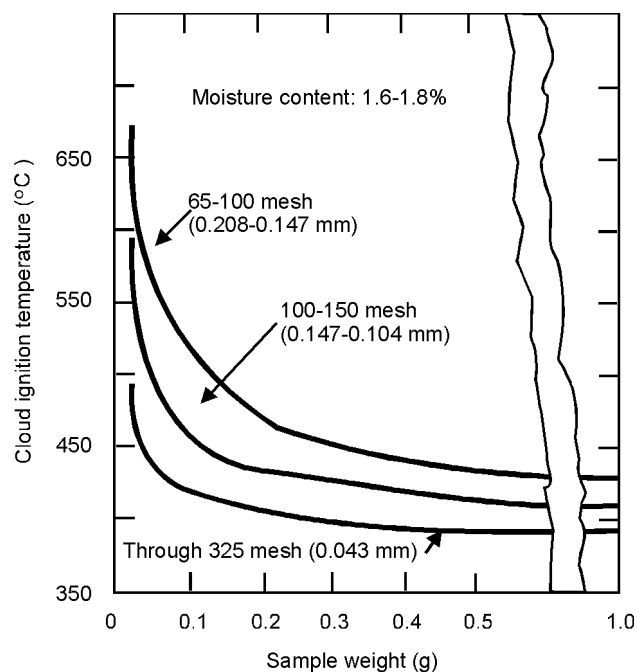


Figure A.7 — Ignition temperature (cornstarch cloud explosion) vs. sample weight

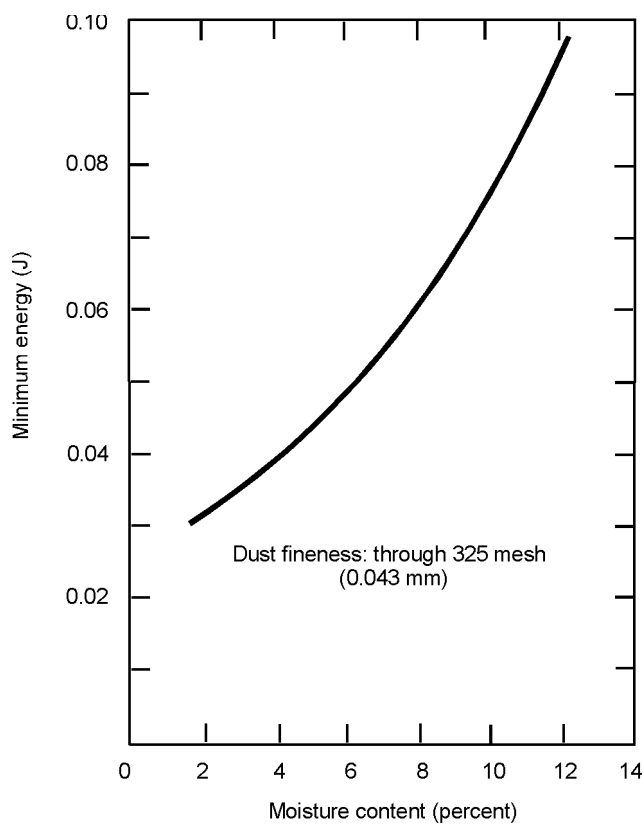


Figure A.8 — Minimum ignition energy vs. percent of moisture (cornstarch)

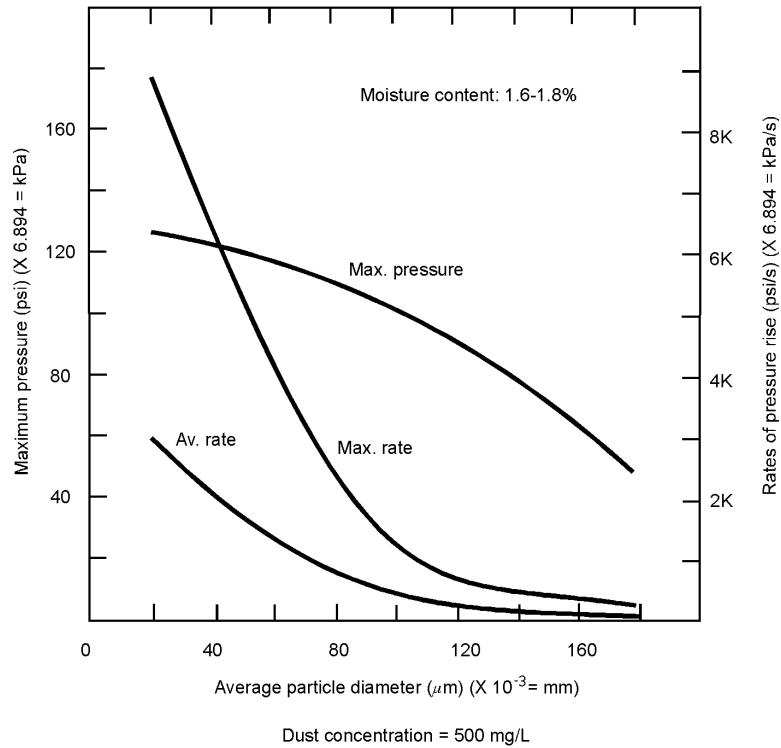


Figure A.9 — Maximum (explosion) pressure vs. particle diameter (cornstarch)

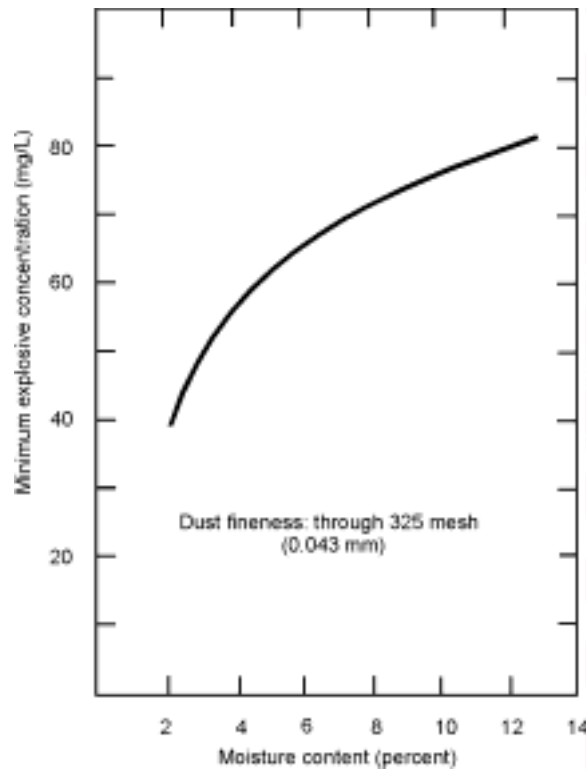


Figure A.10 — Minimum explosion concentration vs. percentage of moisture (cornstarch)

A.6 Resistivity measurements

The objective of these tests is to measure the resistivity of a dust in order to facilitate the classification of dusts as having high, medium, or low resistivity relative to breakdown and possible ignition. The test provides for the following:

- 1) Values of resistivity
- 2) Evidence of the passing or failing of a voltage-withstand test
- 3) A cell and the measuring means (see Figure A-11) by which a dust sample can be tested and the various factors (as listed below) that influence classification can be evaluated. Such influences, when present in the area to be classified, include the following:
 - a) Ambient temperature, including heating by electrical apparatus
 - b) Wetting by liquids
 - c) Packing (not pressurized)
 - d) Vibrating
 - e) Washing by nonflammable gases or vapors
 - f) Aging, with voltage applied

The test voltage for passage of the withstand test should exceed by a significant safety factor the allowable voltage per distance of the class of equipment in use.

A.6.1 Theory. Resistivity, conductivity, and resistance are all related. Conductivity is the inverse of resistivity; accordingly, conductivity = 1/resistivity. The relationship between resistance and resistivity is shown in Equation A-2:

$$R_s = \frac{\rho L}{a} = \frac{\rho L}{hw} \quad (\text{Eq. A-2})$$

where

R_s = sample resistance, in ohms (see Figure A-11)

L = resistance path length, in centimeters (1.26 cm used)

h = height

w = width

a = area of the resistance path, $h \times w$, where h and w are in centimeters, and

ρ = resistivity of the path, in ohm-centimeters (empty cell air capacitive reactance is calculated to be 3000 M Ω at 60 Hz, so can be neglected)

The sample cell is shown in Figure A-11. Empty cell resistance influenced the sample resistance determination. The sample serves to provide the following:

- 1) It conforms the bulk material to simple dimensions that will fit Equation A-2.
- 2) It provides electrodes between which the bulk material resistance is measured. The empty cell resistance is assumed to form a parallel resistance path with the cell samples.

If

R_a = empty cell resistance,

R_c = filled cell resistance, and

R_s = sample resistance in the cell,

then,

$$\frac{1}{R_c} = \frac{1}{R_a} + \frac{1}{R_s} \quad (\text{Eq. A-3})$$

Solving for R_s ,

$$R_s = \frac{R_c R_a}{R_a - R_c} \quad (\text{Eq. A-4})$$

A.6.2 Apparatus and measuring equations. A circuit, shown in Figure A-11, is provided for measuring the voltage and current of the sample and for protecting the instruments in case of sudden sample cell failure. Resistor R_1 is sized to protect the transformer in case of cell flashover. The shunt switch is opened to take a reading at Voltmeter Eight (V_8). By measuring the voltage drop across shunt resistor R_2 , the cell current can be calculated from Ohm's Law. A voltmeter with an input resistance of over 1 M Ω should be used. Depending on the loaded cell resistance, the shunt resistor is assigned values of 10 000 to 160 000 Ω . The empty cell resistance is approximately 1000 M Ω . The cell voltage is equal to one of the terms, IR_c , in Kirchhoff's Law, written for voltage drops around the transformer's secondary circuit (Equation A-5). Refer to Figure A-11 when considering Equation A-5.

$$V_2 = IR_1 + IR_c + IR_2 \quad (\text{Eq. A-5})$$

Values for the various terms in Equation A-5 and their accuracy are considered. When current through Voltmeter 8 is neglected, the cell current is given by Equation A-6. When shunt resistance is less than 10 percent of the Voltmeter 8 input resistance and when a 10-percent error is acceptable in the sample resistance calculation, the current through the voltmeter is negligible. With a 100-to-1 ratio (neon sign) transformer, the secondary voltage, V_2 , is 100 times the primary voltage, V_1 , read on Voltmeter 10.

$$I = \frac{V_8}{R_2} \quad (\text{Eq. A-6})$$

Substitutions from Equation A-6 for I and $100 \times V_1$ are made into Equation A-5. Equation A-5 is then solved for R_c , and R_c is then substituted into Equation A-4. The result is Equation A-7.

$$R_s = \frac{R_a \left[\left(100 \frac{V_1}{V_8} - 1 \right) R_2 - R_1 \right]}{R_a - \left(100 \frac{V_1}{V_8} - 1 \right) R_2 + R_1} \quad (\text{Eq. A-7})$$

Sample resistance in the cell is calculated from a relationship of circuit constants and measured quantities.

Equation A-2 is solved for resistivity ρ ; sample resistance R_a is substituted. The result is resistivity, given in Equation A-8.

$$\rho = \frac{hw}{L} \times \frac{R_a \left[\left(100 \frac{V_1}{V_8} - 1 \right) R_2 - R_1 \right]}{\left[R_a - \left(100 \frac{V_1}{V_8} - 1 \right) R_2 + R_1 \right]} = \frac{hw}{L} R_s \quad (\text{Eq. A-8})$$

In Equation A-8, resistivity is expressed entirely in terms of circuit constants, cell dimensions, and measured electrical quantities.

A.6.3 Sample calculations. A sample calculation for activated carbon follows:

$$V_1 = 60 \text{ V}$$

$$V_8 = 75.3 \text{ V}$$

$$R_1 = 1 \cdot 10^5 \Omega$$

$$R_2 = 6 \cdot 10^3 \Omega$$

$$R_a = 2.4 \cdot 10^9 \Omega$$

$$R_s = \frac{2.4 \cdot 10^9 \left\{ \left(\frac{100 \cdot 60}{75.3} - 1 \right) [(6 \cdot 10^3) - (1 \cdot 10^5)] \right\}}{\left[(2.4 \cdot 10^9) + (1 \cdot 10^5) - \left(\frac{100 \cdot 60}{75.3} - 1 \right) \right] (6 \cdot 10^3)} \quad (\text{Eq. A-9})$$

$$= 1(80 - 1)(6 \cdot 10^3) - (1 \cdot 10^5) = 3.72 \times 10^5 \Omega$$

Cell dimensions are:

$$h = 1.42 \text{ cm}$$

$$w = 9.92 \text{ cm}$$

$$L = 1.26 \text{ cm}$$

Using Equation A-8 and the sample:

$$\rho = \frac{(1.42 \cdot 9.92)}{1.26} \times 3.72 \cdot 10^5 \Omega\text{-cm} = 4.2 \text{ M}\Omega\text{-cm} \quad (\text{Eq. A-10})$$

Cell voltage = V_2 less the voltage across R_1 and R_2 ; $V_2 = 100 \times V_1 = 6000 \text{ V}$ across R_2 ; $V_8 = 75.3 \text{ V}$ across R_1 ; and voltage = IR_1 by Equation A-6.

$$IR_1 = \frac{75.3}{6000} (100\,000) = 1255 \text{ V} \quad (\text{Eq. A-11})$$

Cell voltage is $6000 - 75.3 - 1255 = 4669 \text{ V}$. Electrode spacing is 1.26 cm. Voltage stress across the bulk sample is

$$: \frac{4669}{1.26} = 3706 \text{ V/cm}$$

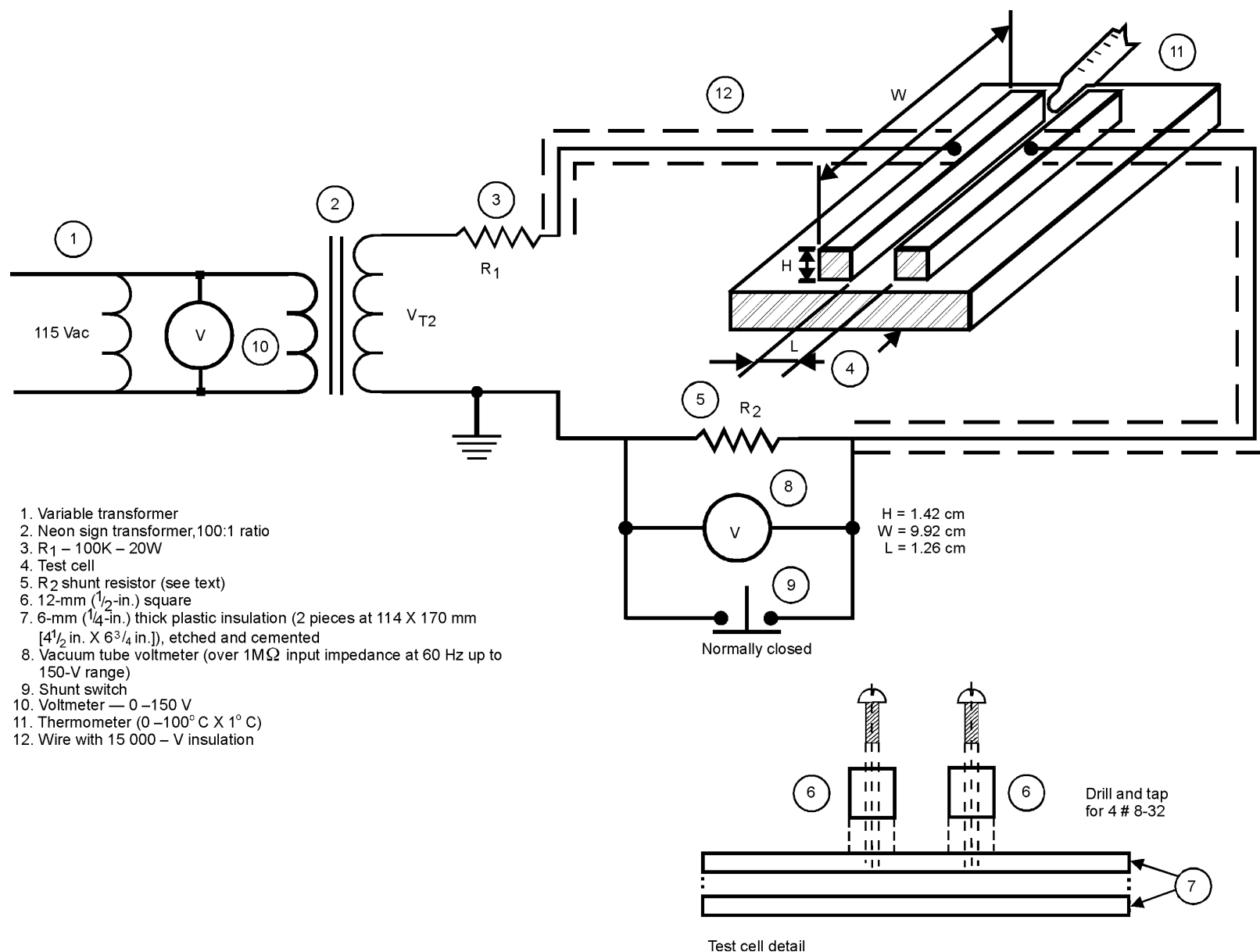


Figure A.11 — Nonpressurized resistivity test apparatus

A.6.4 Procedure. The steps in the test procedure are as follows:

- 1) Prepare circuit and sample cell shown in Figure A-11.
- 2) Clean cell, metal, and plastic insulation, by using cleaning solvent for electrical equipment.
- 3) Read meters with the applied voltage increased in five steps, to apply up to 60 V at V_1 , (6000 V at V_{T2}).
- 4) Using Equations A-4, A-5, and A-6, calculate empty cell resistance, R_a (assume R_s is infinite); then determine $(R_a - R_c)$.
- 5) Return applied voltage to zero. Load sample cell chamber, removing bulk material until it is even with the top and ends of the chamber.
- 6) Subject bulk material to the necessary modifying environmental influences for the test.

A.6.5 Wet test. Conduct the wet test as follows:

- 1) With a face tissue (as a filter) lining a paper cup, fill the cup with bulk powder and add liquid encountered in the plant.
- 2) Lift tissue and bulk material carefully from the cup, wrap, and squeeze out the excess liquid.
- 3) Carefully open the tissue and spoon the material into the sample cell, tapping down the material until air voids are eliminated. Remove all material from the top and ends of the chamber.
- 4) Read all meters with the applied voltage increased in five steps, applying voltages to 60 V at V_{10} (6000 V at V_{T2}).
- 5) Calculate the sample resistance and resistivity using Equations A-7 and A-8.

A.6.6 Vibration test. Conduct the vibration test as follows:

- 1) Using a dry or wet sample, fill the sample cell with material, tapping it down to fill air voids. Remove any excess.
- 2) Clamp the cell to a vibrating device.
- 3) Repeat Steps (4) and (5) from A6.5 (wet test) and Step 1 from above (vibration test).

A.6.7 Aging test. Conduct the aging test as follows:

- 1) Repeat the preceding steps as desired for wet, vibrated, or dry sample; record the meter readings.
- 2) Insert a precision thermometer into sample cavity (reference Figure A-11). Read and record the temperature after steady state is reached.
- 3) Read and record other significant environmental data (e.g., wet and dry bulb temperatures).
- 4) Leave cell under high applied voltage for the desired period and check periodically for changes in shunt voltage drop (V_θ) and sample temperature. Read and record values from all meters and thermometers.
- 5) Apply five different applied voltage levels at end of the aging period and calculate R_s , and ρ using Equations A-7 and A-8.

A.6.8 Dry test. Repeat Steps 3, 4, and 5 of A6.5 (wet test), but without wetting the sample.

A.6.9 Collecting and aging samples. Samples should be collected where material is likely to leak into equipment enclosures or where dust might cause tracking or insulation flashover. Maintain sample conditions (wet, dry, hot, greasy, etc.) and test as soon as possible. Otherwise, measure temperature and other variables. Reproduce conditions on test.

A.6.10 Personnel. Tests and calculations should be performed under the direction of a technically qualified person. He/ she should be qualified in the usual laboratory skills of observation and deduction, as well as mathematics (algebra).

A.6.11 Breakdown. When conducting the above tests, if the resistance decreases as the applied voltage increases, one should be alerted to watch for avalanche breakdown, as evidenced by a sudden rise in the voltmeter reading.

A.6.12 Selected materials were tested by these methods, and the results are given in Figures A-12 through A-19.

All materials were placed into the cell, completely filling the cell without packing it. Materials in the semiconductor range, the high resistivity range, and wetted carbons (Figure A-15) were placed in an electrical field of 4 to 6 kV/ cm for a sufficient period of time to detect resistivity change.

For most tests, the temperature of the materials, the ambient temperature, and the relative humidity were measured. The ambient temperature was between 24°C (75°F) and 25.5°C (78°F), and the relative humidity was from 25 to 35 percent.

The tests produced nonlinear curves of resistivity as a function of volts per centimeter over a range of voltages (reference Figures A-14 through A-17). [Tables A-1 and A-2](#) give mean and minimum resistivity values for insulating and semiconductor dusts. Activated carbon, coal, petroleum coke, and photocopier toner ([Table A-2](#)) should not be grouped with other semiconductor dusts, but rather with the insulators listed in [Table A-1](#).

For a consideration of protection ratings and their relationship to area classification, see [Table A-3](#).

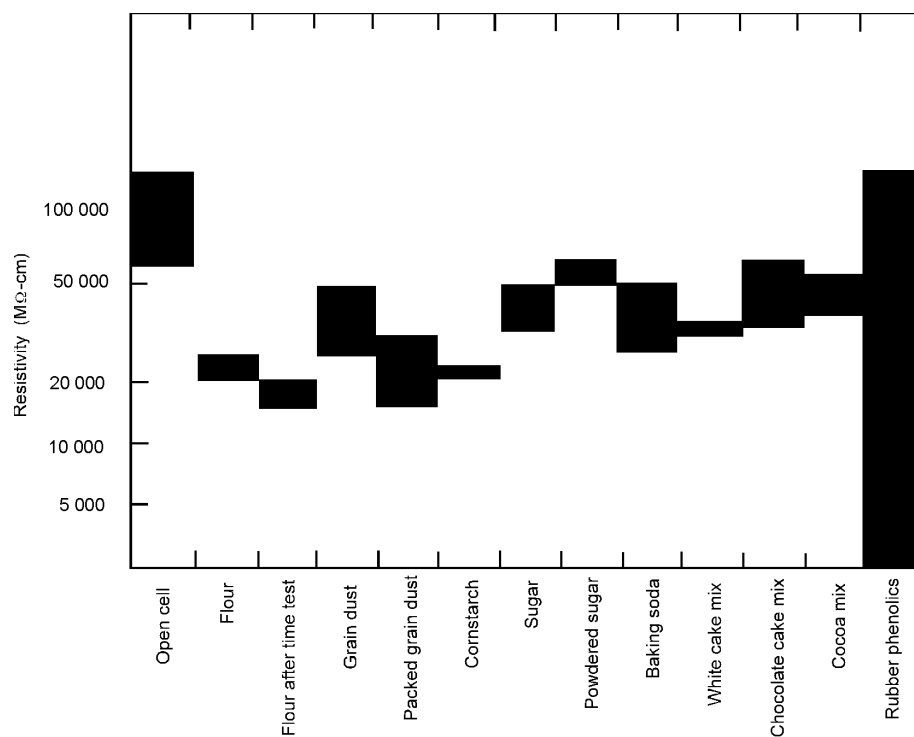
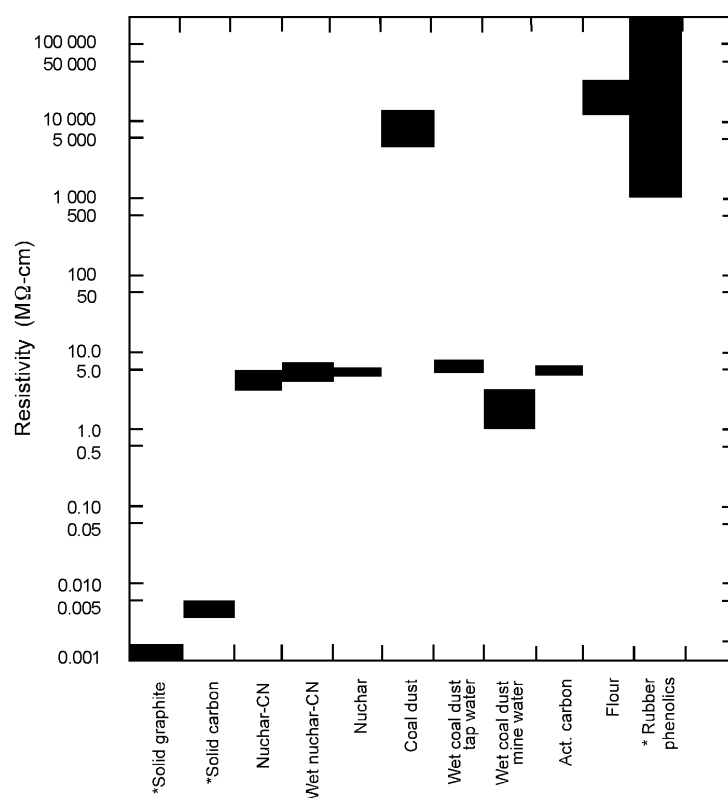


Figure A.12 — Resistivity range of food powders



*From tables

Figure A.13 — Resistivity range of carbon powders

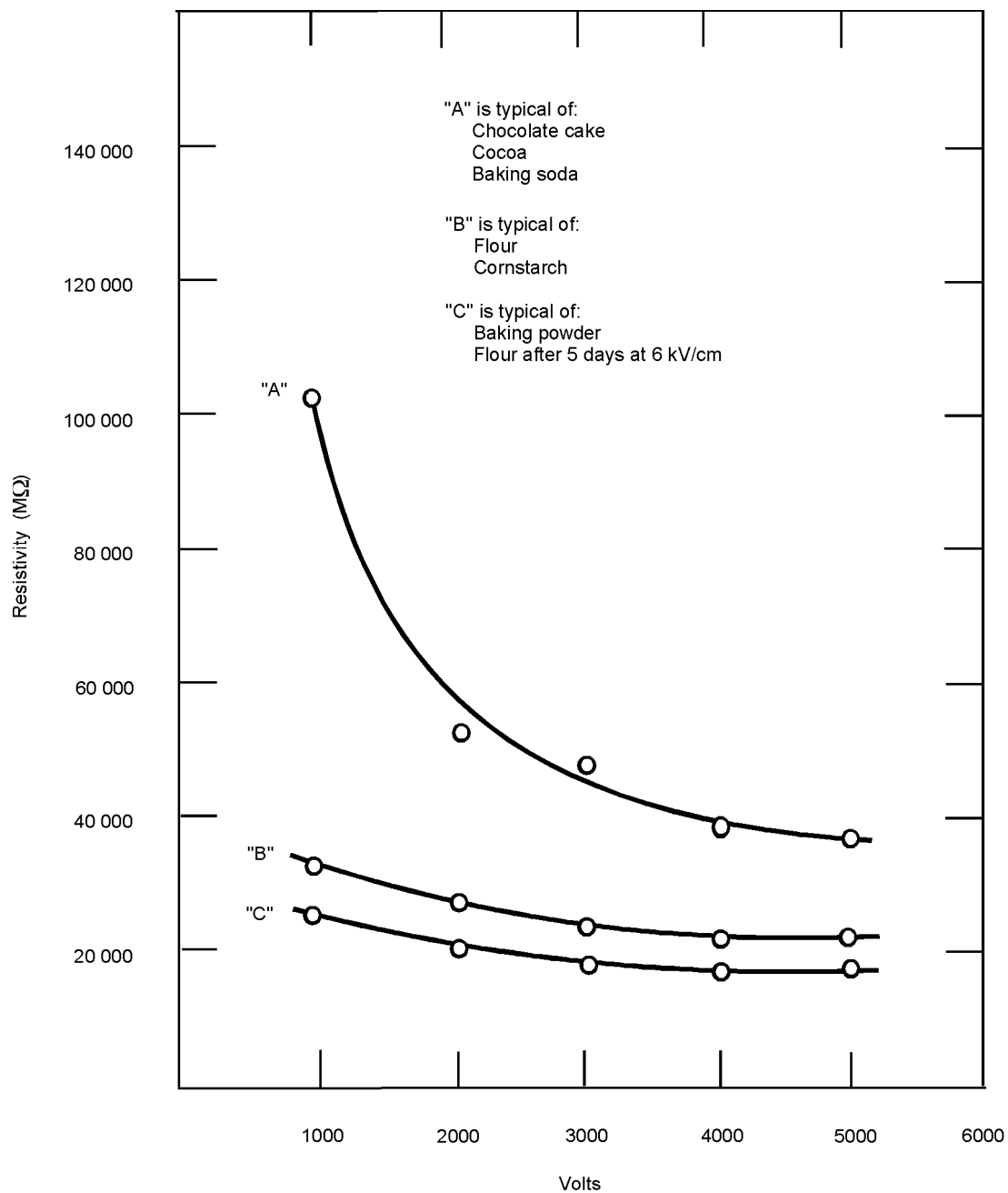


Figure A.14 — Resistivity range of insulator powders to 5000 V/cm

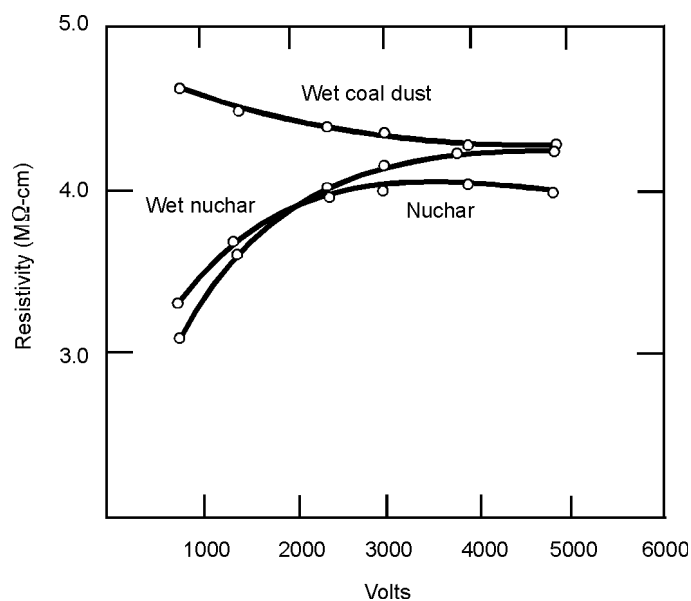


Figure A.15 — Resistivity range of wet and dry carbon powders to 5 000 V/cm

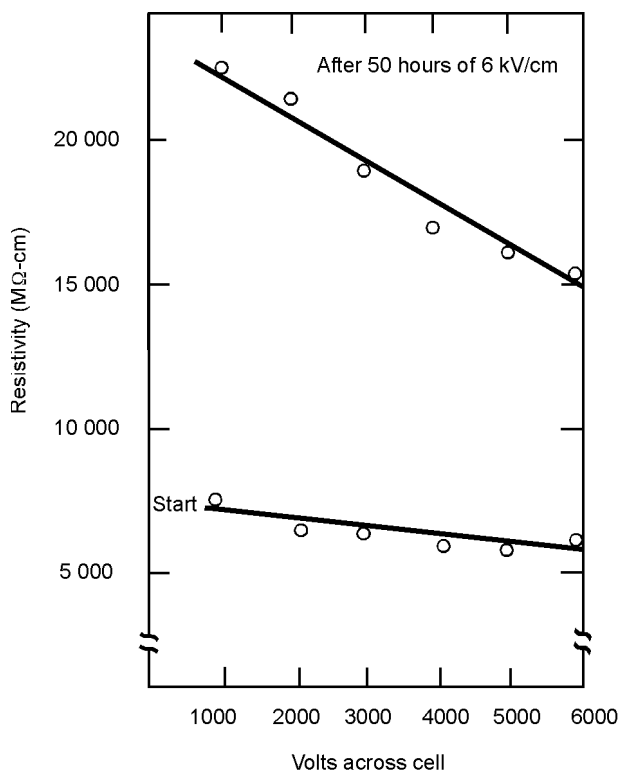


Figure A.16 — Resistivity range of coal (aged and starting) to 5 000 V/cm

Figures A.12 and A.13 show the maximum and minimum values measured. Figure A-18 lists resistivities of all dusts sampled and groups them by resistivity range into insulators, semiconductors, and conductors according to high, medium, or low resistivity of the sample.

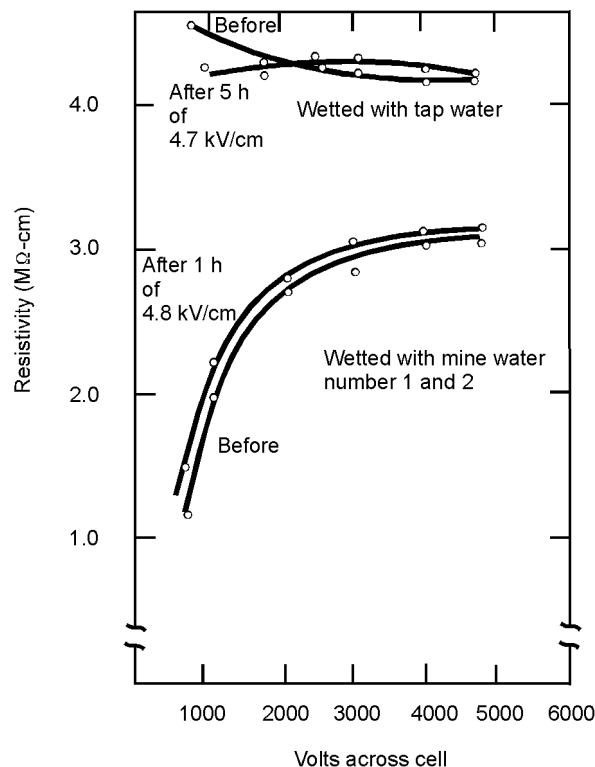


Figure A.17 — Resistivity range of wet coal (tap- and-mine-water-wetted)

Figure A.12 illustrates that food powder and grain dust resistivities were in the range of the poorer insulators, 10^4 to 10^6 MΩ-cm.

Figure A.13 illustrates that dry carbon dust resistivities were three to six orders of magnitude greater than those of solid carbon.

Figures A.13 and A.17 illustrate that the resistivity of mine-water-wetted coal dust was half that of tap-water-wetted coal dust.

Figure A.13 illustrates that tap water decreased coal dust resistivity by three orders of magnitude.

In Figure A.14, the resistivities of chocolate cake, cocoa, and baking soda dropped to less than 40 percent of the first reading as the voltage per centimeter (stress) increased to 5 kV/cm.

Comparing Figures A.15 and A.17, the resistivities of nuchar, wet nuchar, and mine-water-wetted coal dusts increased as the voltage per centimeter increased.

In Figure A.15, water wetting did not significantly change the resistivity of nuchar.

Figures A.15, A.16, and A.17 illustrate that the resistivity of wet coal dust decreased as voltage stress increased.

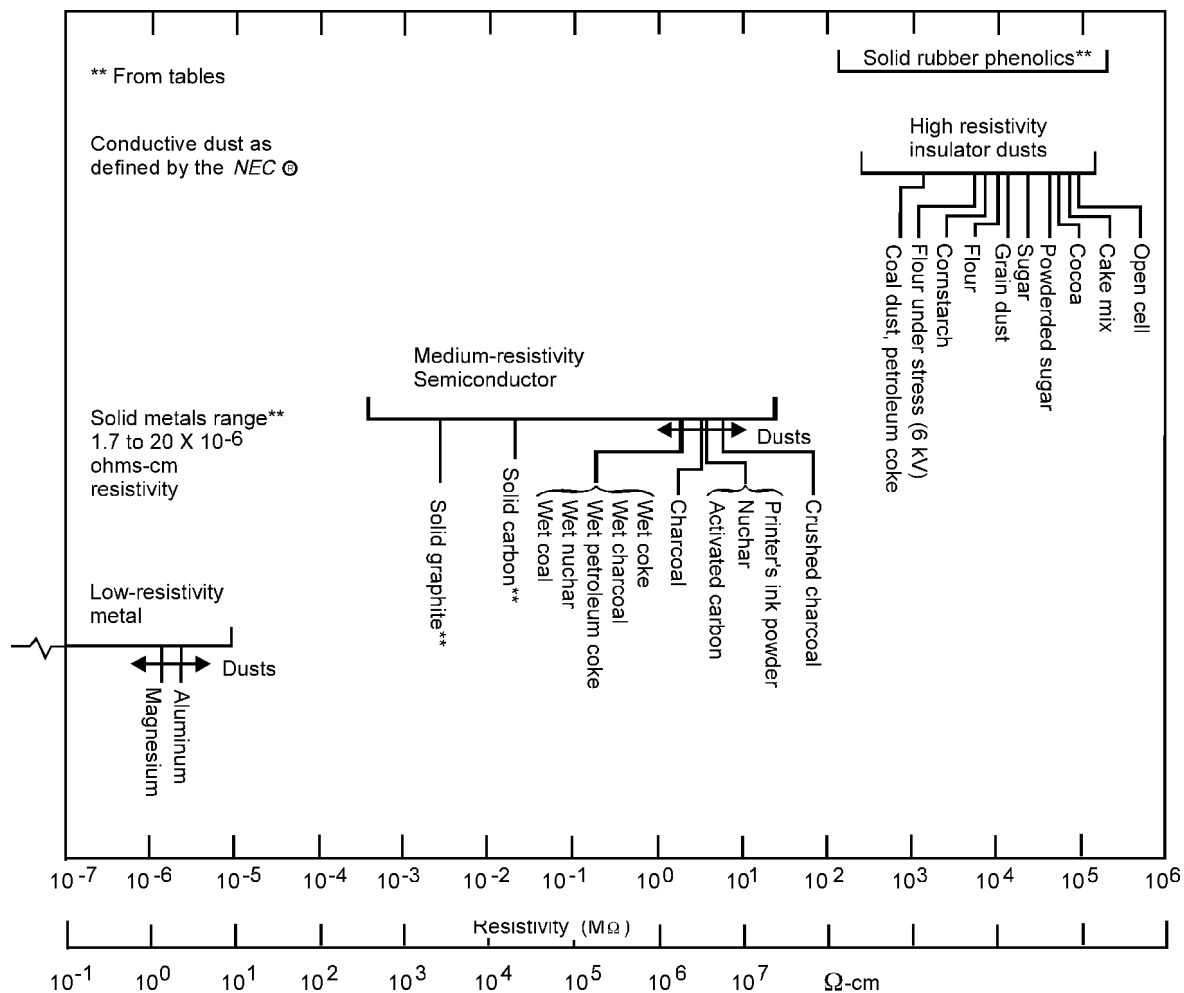


Figure A.18 — Ranges of resistivities

In Figure A.17, mine-water-wetted coal dust resistivity increased by three times as voltage stress increased.

In Figure A.17, both initial and aged tap-water-wetted samples maintained nearly the same resistivities as the voltage stress was increased.

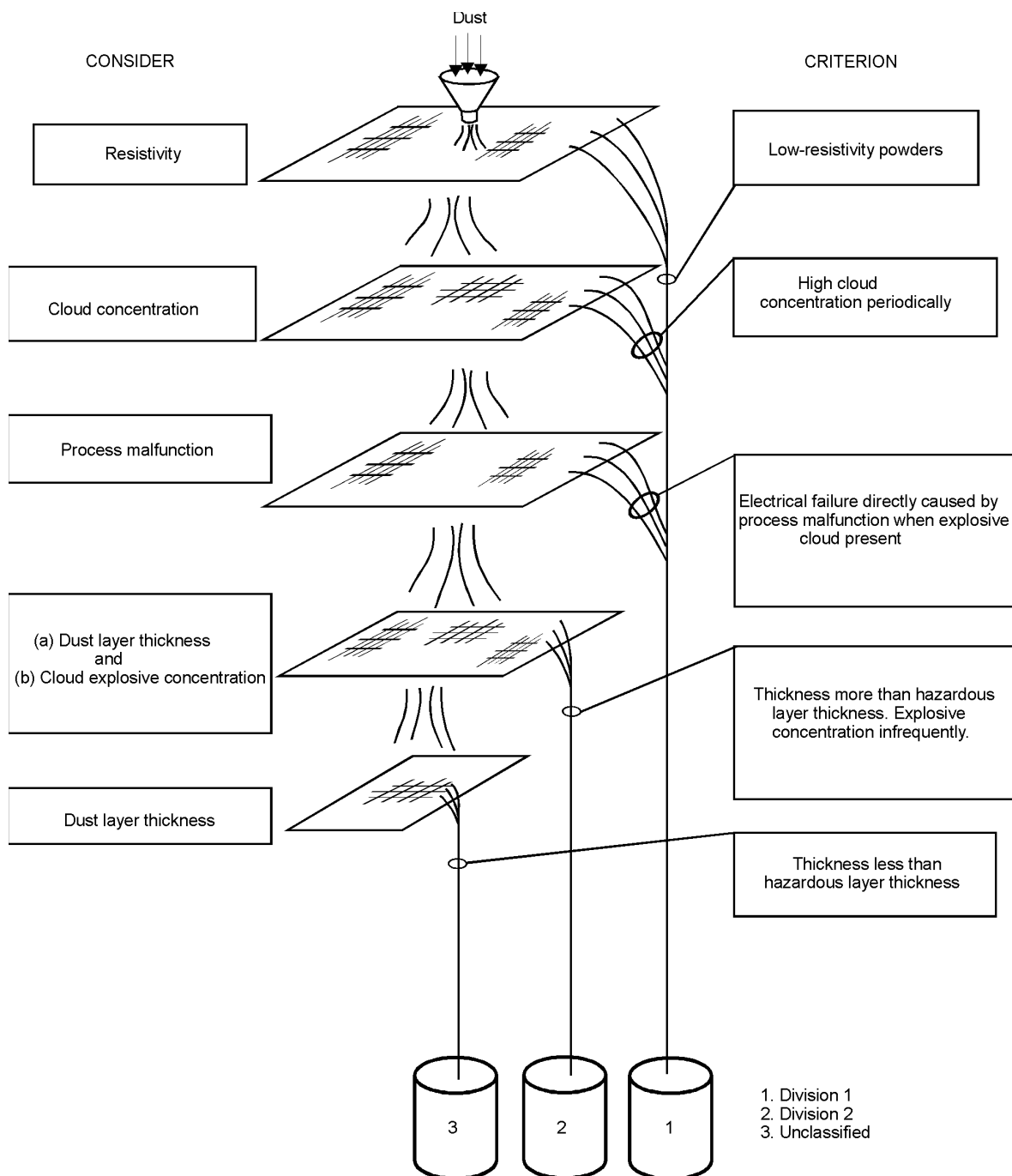
A.6.13 Conclusions. When a sample has withstood 1000 V/cm without breakdown and has not shown a temperature of over 10 percent (in $^{\circ}\text{C}$) during a prolonged test at high voltage, it is deemed to have passed the breakdown test. Breakdown is defined as resistivity decreasing to under $100 \Omega\text{-cm}$ as applied cell voltage is increased and/ or as other environmental tests are applied. Passing the breakdown test qualifies the dust to be considered nonconducting.

Passing the breakdown test *does not* mean, however, that the dust will not interfere with sensitive instruments if significant quantities of dust seep into the instrument enclosure.

When the sample is a metal powder, it likely will produce a dead short at low applied voltages (as it did in the committee's test), easily detected with a simple ohmmeter. Such samples should be considered to be conductors.

Table A.1 — Resistivity of dusts, insulators

Material	Resistivity (M Ω -cm)	
	Average	Minimum
Sugar	55 000	35 300
Powdered sugar	76 700	54 200
Chocolate cake mix	70 000	35 300
Cocoa mix	54 700	37 700
Baking soda	51 600	28 000
Cornstarch	23 700	21 000
Flour (before test)	23 200	20 000
Flour (after 5 days of 6 kV/cm)	19 100	17 500
Sulfur	56 200	27 700
Grain dust	41 600	22 000
Grain dust (packed)	26 100	17 200
White cake mix	35 000	32 700
Baking powder	19 300	15 600
Photocopier toner	63 500	22 300
Coal	5 430	5 040
Crushed petroleum coke	5 160	3 590



NOTE: Dust layer considerations discussed in A-2 and A-5 are not included in this figure, as they are optional.

Figure A.19 — Classification sieves

Table A.2 — Resistivity of dusts, semiconductors (nonmetallic conductors)

Material	Resistivity (MΩ-cm)				Increase from Ambient Temperature, °C (°F)
	Length of Test	Average	End	Minimum	
Flour	5 days	23 300	19 100	17 500	1.1 (2)
Coal dust	4 days	5 430	15 600	5 040	1.5 (3)
Crushed petroleum coke	—	5 160	—	3 590	—
Photocopier toner	—	63 500	—	22 300	—
Activated carbon	15 hours	4.08	4.15	3.98	5.0 (9)
Nuchar	3 days	4.37	Same	4.31	6.1 (11)
Nuchar-CN	3 days	3.89	3.90	3.09	9.4 (17)
Wet nuchar-CN	2 days	3.79	Same	3.29	2.2 (4)
Wet coal dust					
Tap water	5 hours	4.34	4.36	4.19	5.0 (9)
Mine water No. 1	1 hour	2.58	2.60	1.30	—
Mine water No. 2	1 hour	2.59	2.59	1.21	—
Printer's ink powder	—	4.12	—	4.02	—
Crushed coal coke	—	4.09	—	3.99	—
Crushed charcoal	—	6.86	—	4.50	—
(after vibrating)	—	5.56	—	4.50	—
Wet charcoal, coal coke, and petroleum coke	—	4.07	—	3.99	—

Table A.3 — Protection related to area classification (formerly in ISA Standard S12.11)

Rating Circuit	+ Rating Device	+ Rating Enclosure	= Rating Sum ^a	(Safe for)	NEMA Type ^b
0—Ignition-capable	0—Open	0—General-purpose ^c	0—Nonhazardous		1
0—Ignition-capable	0—Open	1—Dust-tight	1—Division 2 ^d		13
0—Ignition-capable	0—Open	2—Dust-ignition-proof	2—Division 1		9
0—Ignition-capable	1—Potted, sealed, oil-immersed	0—General-purpose ^{c,e}	1—Division 2		1
0—Ignition-capable	1—Potted, sealed, oil-immersed	1—Dust-ignition-proof ^e	2—Division 1		9
0—Ignition-capable	0—Open	1—Pressurized ^f for Div. 2 ^c	1—Division 2 ^d		1
0—Ignition-capable	0—Open	2—Pressurized ^f for Div. 1	2—Division 1		13
1—Not ignition-capable ^g	0—Open	0—General-purpose ^{c,e}	1—Division 2 ^d		1
1—Not ignition-capable	0—Open	1—Dust-ignition-proof ^e	2—Division 1		9
1—Not ignition-capable	0—Open	0—Pressurized ^f for Div. 2 ^c	1—Division 2		1
1—Not ignition-capable	1—Potted, sealed, oil-immersed	0—General-purpose ^c	2—Division 1		1
2—Intrinsically safe ^h	0—Open	0—General-purpose ^c	2—Division 1		1

^a When the sum of the special protection ratings equals 0, the combination may safely be located in a nonhazardous location. When the sum equals 1, a Division 2 location is acceptable. When the sum equals 2, a Division 1 location is acceptable. This means that in a Division 1 location, two improbable failures must occur to make a combination (established above) unsafe. In Division 2 locations, one highly probable failure must occur to make the installation unsafe. A lower value is reasonable for Division 2 because the hazardous atmosphere itself is improbable of occurring.

^b NEMA - National Electrical Manufacturers Association, Standard No. 250-1985, "Enclosures for Electrical Equipment (1000 Volts Maximum)."

^c General-purpose enclosures should have six full sides and all unused openings closed.

^d No Division 2 allowed for Group E dusts.

^e Temperature limits of Footnote f must be met.

^f The following requirements apply to enclosures with a volume of 0.283 m³ (10 ft³) or less. The enclosure shall be pressurized with an alarm or indication of pressurizing system failure. The device may be mechanical, pneumatic, or electrical, and the signal may be audible or visual. Pressure should be set at 0.3 Pa (0.1 in. w.g.) minimum and 13 Pa (0.5 in. H₂O minimum for dust of specific particle density of 130 or less and greater than 2100 kg/m³) (130 lb/ft³), respectively. In Division 1 locations, the power supply shall be interlocked with the door switch. There shall be an appropriate caution sign for cases where the door switch cannot be used, warning against opening the enclosure in the presence of a hazardous atmosphere. The enclosure temperature under a combustible dust layer shall not exceed 80% of the layer ignition temperature of the combustible dusts. These and other requirements for pressurized enclosures are in ANSI/ NFPA 496-1986.

^g Circuit is not capable of causing ignition of the dust under normal operating conditions.

^h Intrinsically safe systems shall be approved for the specific group (dust).

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ISBN: 1-55617-095-5