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THE EXPLOSION HAZARD CLASSIFICATION OF GASES AND DUSTS RELATIVE TO USE OF ELECTRICAL EQUIPMENT

Report of the Committee on
Studies on Hazardous Substances

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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ABSTRACT

The present empirical system for classifying gases and dusts as to their potential explosion hazard in workplaces where electrical equipment is located functions reasonably well. It would be desirable to generate a scheme for classification that is based on scientific first principles, but achievement of that goal is far off. Nevertheless, because of the continued rapid introduction of new chemicals into the market and their increased use in international trade, there is a need for improved testing and classification procedures--in particular, procedures uniformly acceptable to the international community concerned with protection of the workplace environment. In this report the testing methods and classification schemes used in the United States are reviewed, and their drawbacks are discussed. Information derived from an international symposium at which scientists from other countries gave their views provided additional input. A set of conclusions and recommendations was developed, and these constitute the main thrust of this report.

PREFACE

The National Materials Advisory Board (NMAB) of the National Research Council has a long history of study of the hazards associated with the use of electrical equipment in areas containing combustible materials. These studies have been sponsored by different branches of the government, and the results and recommendations from them have been published in a number of NMAB reports. The present study was sponsored by the Occupational Safety and Health Administration (OSHA), and the National Institute of Occupational Safety and Health (NIOSH) provided funds for an international symposium. This final report in the series summarizes the meetings, studies, and symposium.

Efforts by this and earlier committees to achieve correlations among various flammability properties and classifications have shown that, even though trends and correlations exist in a general sense, they are not precise enough. However, they show that nature is not capricious, and the right questions must be posed about combustibility of both gases (vapors) and dusts so that one can achieve a better understanding of the underlying scientific principles on which to base classification--and try to get away from the empiricism used today. This is particularly true when trying to classify the ever-increasing numbers of new products and families of products showing up in commerce.

At best, one has only very weak predictive capabilities. For the present, one must continue to use what is at hand, while seeking improvements. Also, in view of the increasing commerce among nations, it is important to strive for internationalization of classification, including methods of measurement. Orderly dividing lines between groups based on natural (scientific) reasons would be much more universally acceptable.

The chairman is deeply grateful to the many persons who have contributed to this work, invariably with high enthusiasm, penetrating thoughtfulness, once in a while volubly in heated discussions but certainly not without sincerity, but all for the good of the common weal and for the benefit of our fellows in the workplace. Particular thanks go to the members of the committee, liaison representatives and sponsors, to Dr. Stanley M. Barkin, Mrs. Marlene Crowell, and other members of the NMAB staff, who have all been unstinting in their cooperation and contributions to the success of this work. The chairman also wishes to thank his own staff at the Naval Research Laboratory, particularly Ms. Evelyn Childs, who over many years contributed markedly and cheerfully to many detailed studies leading up to this final report.

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EXECUTIVE SUMMARY

There are many ways of classifying fire and explosion hazards in the use of chemicals in commerce: ease of ignition (from pyrophoric to nonignitable), violence (from detonation to cool flames), volatility (from low to high flash points), etc. This study is restricted to the problem of protecting the workplace when combustible gases (or vapors) and dusts may exist in the presence of electrical equipment, including malfunctions or failures of such equipment. Since gases (or vapors) vary widely in their combustibility properties, they have been classified into groups in the National Electrical Code (NEC) in the United States depending on their ability to propagate a flame through a restricted gap. This is called the maximum experimental safe gap (MESG). In the United States, the MESG has been measured mostly using the Westerberg apparatus at Underwriters Laboratories, but worldwide it is measured using devices that have different gap lengths and depths and different time constants. Classification of individual substances into groups is based on arbitrary dividing lines in the MESGs. Liquids, per se, are classified only by the measured MESGs for their vapors. In the NEC, combustible dusts are classified only on the basis of their electrical conductivity. At present, the United States does not utilize any of the international schemes for either classification or measurement.

The present classification schemes should be improved because the schemes for gases (and vapors) are empirical, the dividing lines between groups are arbitrary, and the method of measurement in the United States is not satisfactory. For dusts, differences in combustibility are not included in the classification. Yet, just to show perspective, for grain dusts there are some 3000 to 4000 fires per year in some 12,000 to 14,000 grain elevators in the United States, and some 15 to 20 explosions, with considerable loss of property (and, occasionally, life). Although many of these were not initiated by electrical sources, nonetheless, combustibility of dusts, about which there is limited basic understanding, should be included in electrical classifications.

It is recognized by the committee that, to a large extent, the current system of classification works reasonably well and has given reasonable protection. It is also recognized that the present classification systems are mostly empirical, and it would be desirable to generate classification schemes based on scientific first principles. However, that goal is far in the future. With the continuing proliferation of chemicals and materials in commerce along with the increase in international trade, problems have arisen in their classification, in existing classification schemes, and particularly in methods used for testing for classification purposes. The main objective of the committee was to develop a set of conclusions and recommendations addressing these problems.

In summary, a system for classifying gases in the presence of electrical equipment is needed to promote safety. Today, MESG is the best practical parameter for this classification. A better, but somewhat imperfect, methodology for determining MESG than the Westerberg is the 20-ml apparatus used for classification in Europe. In the present schemes used worldwide, the dividing lines for classifying different chemicals into groups are arbitrary and differ from one scheme to another. Despite this, they are still useful, and support should be given toward internationalizing testing and standardizing the dividing lines between groups.

Similarly, systems for classifying dusts are needed to promote safety. A classification scheme should be developed that takes into account combustibility of clouds and layers, including those having high electrical conductivity. Internationalization of testing and classification is desirable. Dusts should be classified exclusively into Groups E and G using the recommended resistivity method. All coal dusts should be classified as Group G. Efforts to develop a more acceptable procedure and test vessel than the Hartmann bomb should be supported.

CHAPTER 1

BACKGROUND OF CLASSIFICATION PROBLEMS

CLASSIFICATION OF GASES

In the United States, the National Fire Protection Association's Code 70 (commonly known as the National Electrical Code [NEC]*) is the accepted standard for industrial, commercial, and residential electrical installations. Until 1984, the Code contained a list of flammable gases and vapors divided into Groups A, B, C, and D. Groups A and B together are equivalent to International Electrochemical Commission (IEC) Group IIC. Groups C and D are similar to but not identical to IEC Groups IIB and IIA, respectively.

Early classification of materials was based on tests of proprietary explosion-proof (flameproof) enclosures. There were no published criteria. Also, equipment was approved relative to the lowest ignition temperature of any material in the group--180°C for Group C, 280°C for Groups A, B, and D. Dusts were not listed but were categorized into Groups E, F, and G. The history of combustible dust classification is discussed later.

In the 1962 National Electrical Code, the following materials were listed:

- Group A--acetylene

- Group B--hydrogen or gases or vapors of equivalent hazard, such as manufactured gas

- Group C--ethyl ether vapors, ethylene, or cyclopropane

- Group D--gasoline, hexane, naphtha, benzene, butane, propane, alcohol, acetone, benzol, lacquer solvent vapors, or natural gas

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*National Electrical Code and NEC are registered trademarks of the National Fire Protection Association that designate ANSI/NFPA 70.

A list such as that in the 1962 NEC contains only a few of the thousands of flammable materials used in commerce. Therefore, about 1965 the U.S. Coast Guard asked the National Academy of Sciences to form a panel to classify 200 materials of commerce likely to be carried in vessels under Coast Guard jurisdiction. The Electrical Hazards Panel of the Committee on Hazardous Materials was formed, and its early objectives were twofold:

- Classify the listed materials in accordance with NEC groupings
- Define a scheme for classifying new materials based on physical, chemical, and flammability properties of the material

The panel studied many ways to estimate the hazard classification of a material. Some of the relationships considered were the ratio of the upper flammability limit to the lower flammability limit; the heat of combustion times the lower flammability limit; and the ratio of the lower flammability limit to the stoichiometric concentration in air. Most were fairly good guides for classification, but none would classify all of the materials that had already been classified in the same groups in which they were listed in the NEC.

The panel reported to the U.S. Coast Guard in 1970 that no clear-cut scheme could be defined. It then assigned tentative classifications to the 200 substances of interest to the Coast Guard. Classification considered homology, similarity of chemical structure, flammability characteristics such as the maximum experimental safe gap (MESG), the minimum igniting current (MIC), or the minimum igniting energy (MIE), and the hazard level assigned by other authorities such as Underwriters Laboratories and NFPA. Primary emphasis was on classification relative to explosion-proof (flameproof) apparatus.

In North America, as in most of the rest of the world, the principal types of protection for electrical apparatus in hazardous locations are explosion-proofing, which assumes an explosion within the enclosure that must be contained; pressurization of the enclosure to prevent the entry of flammable material from without; and intrinsic safety, which is based on the fact that the apparatus cannot under normal or fault conditions release sufficient energy to cause ignition. Flammability properties are not of concern with the pressurization technique because no explosion occurs. The correlation between grouping relative to MESG and grouping relative to ignition currents has been well-enough established that a grouping based primarily on MESG considerations is acceptable in practice for intrinsic safety applications as well. When the panel delivered its recommended classifications, it suggested the testing of 21 compounds in the Westerberg explosion test vessel at Underwriters Laboratories, Inc., to provide reference MESG data.

In 1973, when these data became available, the panel reconsidered its classification of the 200 materials. It recommended testing an additional 11 compounds. In 1975, the panel issued its final report (*1*) to the U.S. Coast Guard.

Despite the panel's inability to find a simple formula for classifying materials based on fundamental material properties, one major change in U.S. practice grew from the panel's work. It became obvious early in the work that spontaneous ignition temperature is not correlated with other ignition and combustion properties of flammable gases and vapors and therefore should not be included in any classification scheme. In 1971, through the efforts of panel members, the association of spontaneous ignition temperature with the grouping of materials was discontinued, and the hazard due to ignition by hot surfaces of electrical equipment was dealt with in the NEC by assigning a temperature code to the apparatus. In this respect U.S. practice was harmonized with international practice.

After publication of the report to the U.S. Coast Guard, the Occupational Safety and Health Administration (OSHA) requested the classification of additional materials. Approximately 520 gases and vapors were classified in a report (*2*) that included another review of the classification of materials previously classified for the U.S. Coast Guard.

Further work, also sponsored by OSHA, resulted in approximately 1500 gases and vapors and 350 dusts being classified in reports issued in 1982 (*3*, *4*). Throughout these classification projects, the methodology and constraints remained essentially the same: For gases and vapors, (a) existing classifications in the NEC were maintained--i.e., the dividing lines between groups, however arbitrary or ill-defined, were not changed; (b) if MESG data were available they were used as the basis for classification; (c) if MESG data were not known, the judgment was made based on homology, chemical similarity, classification assigned by other authorities, or MIC or MIE. If there were differences of opinion among committee members, a classification into the next most hazardous group was usually assigned, so the classification of many materials was conservative.

Also, since the use of conduits is a common installation practice in the United States, concern was expressed about "pressure-piling" for some substances. By use of a "conduit" attached to the Westerberg apparatus, this effect could be measured by rate of pressure rise and total pressure. This led to a double classification scheme for some materials such that, if conduits were to be used, the substance would be classified in a more stringent group than if conduits were not used. For example, butadiene was classified as B/D, where D would be its normal classification based on MESG, but, because of its high propensity to pressure-pile, it would be classified in Group B if conduits were used. (See also Conclusion 6 in Chapter 3 of this report.)

All of these constraints led to mixed feelings about the work. Nevertheless, the classification of many new materials was a service to industry and government. This work, as it was published, was included in the NEC until 1984, when the lengthy list was removed from the NEC and published as NFPA 497M, which is referenced in the NEC.

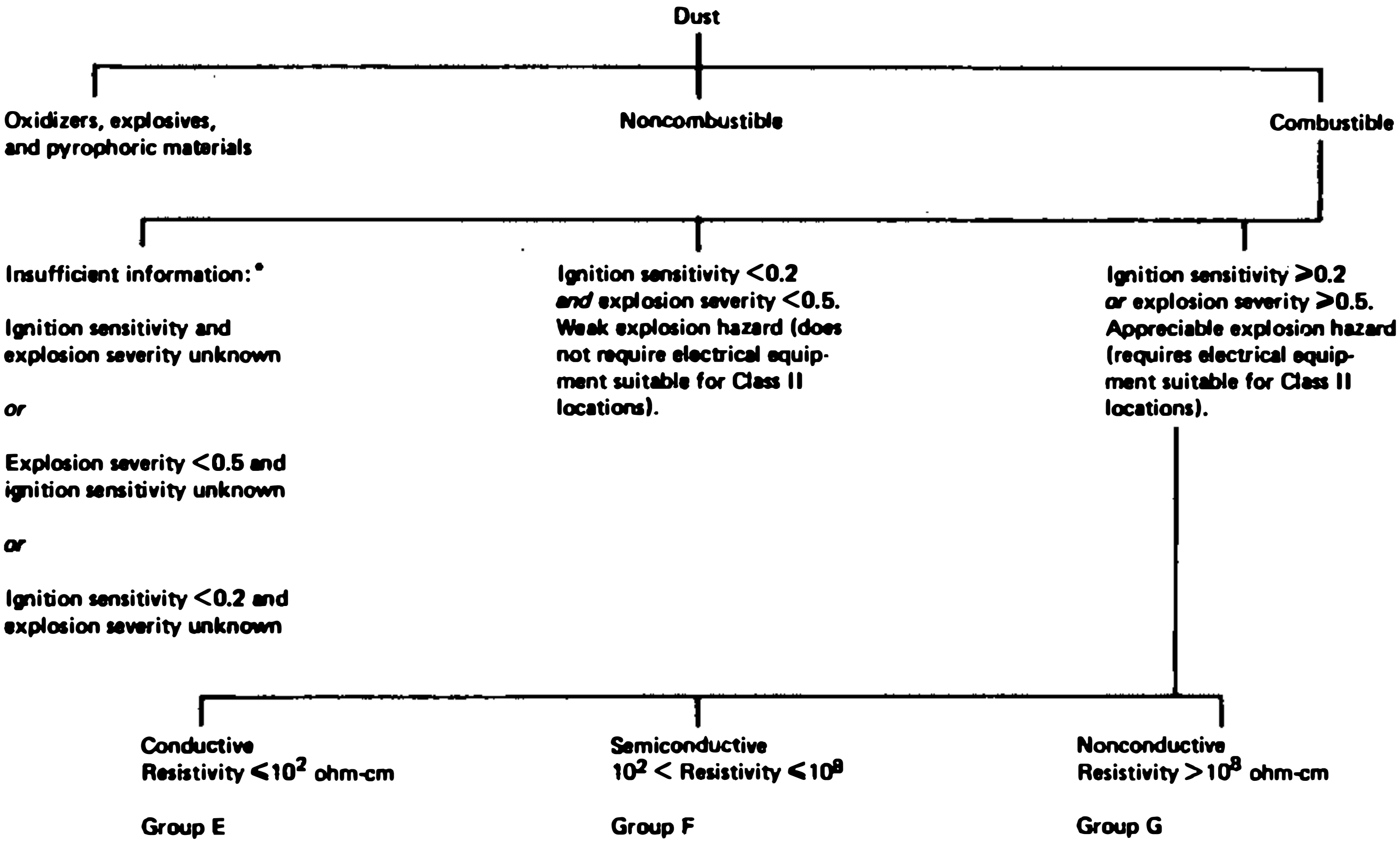
CLASSIFICATION OF DUSTS

In the 1971 NEC, dusts were classified as follows:

- Group E--metal dusts, including aluminum, magnesium, and their commercial alloys and other metals of similar hazardous characteristics
- Group F--carbon black, coal, or coke dust
- Group G--flour, starch, or grain dust

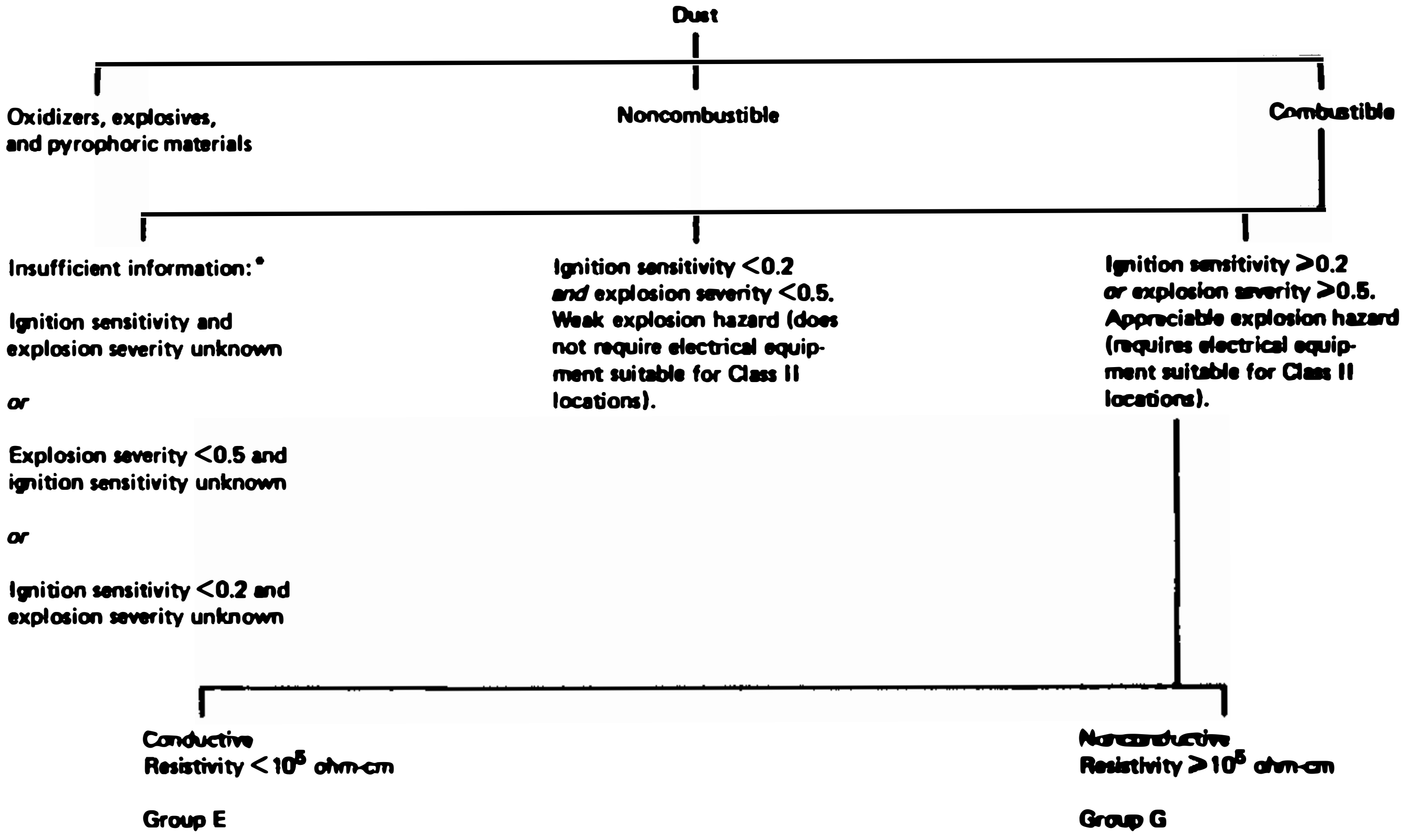
During the late 1960s and early 1970s, the Instrument Society of America (ISA) Committee SP12 was preparing standards S12.01 and S12.11 for area classifications in dusty locations and selection of equipment for use in such locations. These documents, published in 1973, were based on NEC definitions but were intended to provide more specific guidance to people working in industries exposed to dust hazards. The documents recognized that Groups E, F, and G dusts are essentially conducting, semi-conducting, and insulating dusts, respectively (where a conductive dust might provide an arc-initiating mechanism). When the National Research Council's Committee on Evaluation of Industrial Hazards began to classify dusts for OSHA, it considered the ISA proposals. It classified dusts into Groups E, F, and G as defined in the NEC (Figure 1), but it also recommended changes to the NEC classification scheme.

Based on a review of the ISA work and some experimentation by committee members, the committee next recommended that a conductive dust be defined as one having a resistivity less than 10^5 ohm-cm. Some carbonaceous dusts, such as carbon black and activated charcoal, have resistivities on the order of 10^3 ohm-cm. Coals and cokes have resistivities well above 10^5 cm. Eventually, the 10^5 ohm-cm dividing line became recognized and resistivity definitions were accepted, so that in 1984 Group F was dropped in the NEC, and all dusts were to be classified as conducting or nonconducting (Figure 2). This change in definition led to an easy rationale for classifying dusts because it eliminated the ambiguity of having both conductive and nonconductive dusts in Group F. (The 1987 Code restored Group F for reasons related primarily to certification of motors for use in the presence of coal dusts. The rationale is unclear.)



*Treat as if ignition sensitivity were ≥ 0.2 *or* explosion severity were ≥ 0.5 and base group classification on resistivity or on best judgment.

FIGURE 1 Classification of dusts (using the 1981 NEC resistivity guidelines).



*Treat as if ignition sensitivity were ≥ 0.2 *or* explosion severity were ≥ 0.5 and base group classification on resistivity or on best judgment.

FIGURE 2 Classification of dusts into Groups E and G.

Reduced to its simplest form, the classification rationale for dusts can be expressed in two questions:

- Is it combustible?

- Is its resistivity above or below 10^5 ohm-cm?

This classification scheme does not consider flammability properties. In North America, protection against dust explosions has been based on designing electrical apparatus so that dust does not come into contact with potential ignition sources. In those areas where the hazard is high--i.e., where a conductive dust might provide both an arc-initiating mechanism and the fuel for an explosion, or where clouds of nonconducting dusts are normally present--the enclosure is not only made tight to exclude dust but is also of robust construction so that electrical faults to the enclosure will not cause hot spots that might ignite a dust layer.

Where nonconductive dust clouds are present only under abnormal conditions, the enclosure need only be of gasketed or telescoping construction designed to exclude entry of dust.

Because the type of protection assumes that the ignition source and the dust do not come in contact, the enclosure need not contain an explosion. The flammability and explosion properties of dust therefore do not need to be considered when classifying them.

There is, however, a need to define the criterion for deciding when a dust is an explosion hazard and needs to be classified for the purposes of electrical equipment utilization. If it is only a fire hazard, special apparatus is unnecessary.

THE TASK OF THE COMMITTEE

At the conclusion of its work in 1982, the Committee on Evaluation of Industrial Hazards issued a report (*5*) that reviewed the history of hazardous material classification at the National Academy of Sciences and summarized the concerns of the committee about the weaknesses of the classification process used. These concerns were

- The unpredictable effects of precompression in the Westerberg apparatus because the secondary chamber volume does not greatly exceed that of the ignition chamber.

- The lack of correlation of MESG values from the Westerberg apparatus with values from the International Electrotechnical Commission (IEC) standard 20-ml apparatus and other apparatus used in European laboratories.

- The ill-defined use of data on pressure and rate of pressure rise in addition to MESG data for purposes of classification.

- The lack of a clear rationale for using pressure-rise data as a part of the classification scheme.

- The traditional use of gasoline, an ill-defined material, for determining the boundary between Groups C and D. The boundaries should be determined by pure compounds.

- The use of explosion severity and ignition sensitivity relations at the U.S. Bureau of Mines formed by arbitrarily referencing a particular Pittsburgh coal and requiring data that are not now being routinely gathered.

In 1984, at the request of OSHA, the present committee was formed. This committee was charged with reviewing the history and practice of hazardous material classification and making recommendations regarding the issues raised in the 1982 report (5). The committee was impelled not only by a desire to recommend a method that would eliminate the vagaries associated with past classifications, but also by the recognition that, as the electrical apparatus market becomes more international, there must be compatibility between U.S. and other classification methods.

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CHAPTER 2

COMMITTEE ACTIVITIES

It is generally recognized that atmospheres containing flammable gases, vapors, or combustible dusts can cause workplaces to be unsafe because explosions can result from ignition sources such as electrical equipment. In addition, current methods used in the United States for classifying such atmospheres can yield data that compromise safety by affecting the choice of proper workplace equipment.

OSHA requested the National Research Council to investigate various explosion parameters relative to the ignition of combustible gases and dusts by sources normally found in the workplace so that corrective actions to ameliorate such conditions could be developed on a more scientific basis. The Committee on Studies on Hazardous Substances was appointed to conduct the investigation. The initial OSHA charge to the committee was directed toward improving methodologies for properly categorizing atmospheres made hazardous by the presence of combustible gases, vapors, and dusts. It was hoped that these improvements would address problems associated with existing classification anomalies.

OSHA has a continuing interest in knowing if characteristic explosion parameters exist that can, from a practical standpoint, serve as a basis for a common classification system that reasonably permits categorization, and hence prediction, of explosion hazards of industrial atmospheres containing combustible gases, vapors, or dusts. The ultimate purpose intended by OSHA, therefore, is to have the results of the study lead to more scientifically based recommendations for improved safety procedures reflecting real-world environments.

The approach to the problem taken by the committee was to review applicable data derived from previous studies involving similar classification investigations and to use this material as starting points for the current effort. Since domestic and international practices involving the methodology for determining explosive parameters for both gases and dusts were to be studied, one principal means for gathering information consisted of an international symposium to which scientists having related expertise were to be invited to discuss their work and provide a desirable interchange of ideas.

The committee was also directed to perform work in which technical conclusions and recommendations would be drawn from the committee's past efforts. The basis for these efforts involved test and measurement investigations for flammable gases and ignitable dusts that might ultimately lead to an appropriate system of classification for the purpose of achieving workplaces that are safe. As part of the concluding effort by the committee, recommendations were directed toward obtaining a common classification system that would reasonably categorize and predict explosion hazards of industrial gases and dusts.

To achieve the objectives of the study, a number of tasks were carried out by the committee. One required the committee to study the methodology for determining the explosion parameters of both gases and dusts for classification purposes. The review covered both domestic and international practices.

Another task involved conducting an international symposium to which scientists would be invited to present their views and discuss developments in their countries relative to classification systems, measurement techniques, and special studies involving flammable gases and ignitable dusts. Discussions would be focused on comparisons of the test equipment and techniques used to establish the data bases for classification; also included would be comparisons between U.S. and international classification systems for categorizing flammable gases and combustible dusts. The symposium was held on July 15-18, 1986, in Washington, D.C. Proceedings of the symposium were published (*1*). Preceding this, another symposium on industrial dust explosions was held on June 10-13, 1986, in Pittsburgh, sponsored by ASTM Committee E-27, the Bureau of Mines, and NFPA (*2*).

As a follow-up activity to these symposia, the committee reviewed all the data presented by the participants. Comments and discussions by the scientists on developments in their countries relative to classification systems, measurement techniques, and special investigations involving flammable gases and ignitable dusts were studied. Comparisons were made with classification data bases obtained from U.S. methods, and the committee then drew technical conclusions from its analysis for submittal to OSHA.

The final task involved recommendations to be made to OSHA. Specifically, the committee was requested to develop recommendations for action based on previous studies of the methodology, both domestic and international, used for the determination of explosion parameters of gases and dusts. The recommendations made to OSHA for purposes of classification were to be both general and specific.

The results of these tasks are presented in this report.

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CHAPTER 3

CLASSIFICATION OF GASES

In the United States, ANSI/NFPA 70, the National Electrical Code, is the accepted standard for all kinds of electrical installations in industrial, commercial, and residential occupancies. Although it is a voluntary, nongovernmental consensus standard, it derives its authority from the fact that the federal, state, and local governments and government agencies, including the Occupational Safety and Health Administration, adopt the NEC requirements into their laws, ordinances, and regulations (*1*, p. 1).

Class I hazardous locations were first classified into groups in the 1937 edition of the NEC. It was recognized that the degree of hazard varied for different materials and that equipment suitable for use where gasoline or methane was handled was not necessarily suitable for use where hydrogen or acetylene was handled. It was not logical to require in gasoline filling stations the explosion-proof equipment suitable for use in hydrogen atmospheres.

Classification of flammable gases and vapors into groups is necessary to permit the manufacturers to design and the testing laboratories to evaluate explosion-proof and other types of equipment intended for use in hazardous locations using gases representative of the appropriate groups. Without classification into groups, either (a) equipment would have to be tested individually for each and every gas-air mixture in which it was intended to be used, or (b) the equipment would have to be tested with the worst known gas-air mixture.

The first alternative not only would be extremely time-consuming and expensive but also would preclude the use of the equipment in an atmosphere containing a gas not identified or for one that had not been tested, even though the explosion characteristics of that gas were less severe than some of the gases for which the equipment had been tested.

The second alternative would require much more expensive equipment than necessary for most installations. It would require that equipment in gasoline filling stations, natural gas pumping stations, paint spray booths, and similar Group D locations be suitable for hydrogen and acetylene atmospheres, even though such atmospheres do not exist in these locations. There are currently no commercially available explosion-proof motors suitable for Group A or B locations.

CLASSIFICATION METHOD

The need for a system of classification has been recognized in all developed countries, and such a system is mandated by the requirements of the IEC (*1*, pp. 11-15, 87, and 144-145).

The vast majority of electrical equipment designed for use in flammable gas atmospheres is of the explosion-proof (flameproof) design. Intrinsic safety, another protection technique, is limited to low-energy systems, such as signal equipment. It is not suitable for equipment such as electric lighting fixtures, circuit breakers, motors, and motor controllers. The other major protection system, purged and pressurized enclosures, is a custom-design technique that does not lend itself, as does explosion-proof apparatus, to off-the-shelf equipment made on a production line.

Explosion-proof apparatus is defined in the NEC as follows:

> Apparatus enclosed in a case that is capable of withstanding an explosion of a specified gas or vapor which may occur within it and of preventing the ignition of a specified gas or vapor surrounding the enclosure by sparks, flashes, or explosions of the gas or vapor within, and which operates at such an external temperature that a surrounding flammable atmosphere will not be ignited thereby.

The MESG is the maximum gap between plain parallel flanged surfaces of a given width that in experimental tests will not, upon combustion of the mixture within the apparatus, result in ignition of the same mixture outside the apparatus. Electrical enclosures require parts that can be separated to permit wiring and maintenance or to permit operating or mechanical shafts to extend outside the enclosure. Therefore, joints and gaps between parts of an explosion-proof enclosure, however small, are necessary.

The principal problem in designing an explosion-proof enclosure is in manufacturing the gap between joined parts so that it is small enough to prevent propagation of the explosion from within the enclosure to the surrounding flammable atmosphere--i.e., making the gap less than the MESG. It is because the MESGs for hydrogen and acetylene are so small that explosion-proof motors and generators for use in hydrogen and acetylene atmospheres are not available commercially. Maintaining these tight clearances where the motor or generator shaft leaves the enclosure is extremely difficult on a production-line basis.

Other methods of classification, such as flammability limits, combustion times, and flame temperatures, are not directly related to explosion-proof equipment. Although there seems to be a relationship between such parameters, or combinations of them, and MESG, the relationship is not sufficiently consistent or reliable to be used as a classification parameter (*1*, pp. 2 and 26).

Although MIC has a relationship to MESG (*1*, pp. 2, 3, and 87), this relationship is not at present sufficiently well understood to permit its use as a method of classifying gases and vapors in which explosion-proof apparatus is to be used.

The MESG is the parameter used in most other developed countries of the world for classification of flammable gases and vapors, and it is the method recommended by the IEC (*1*, pp. 14, 27, 84, 94, 130, 146, 220, 245, and 254).

The method currently used in the United States employs the Westerberg Explosion Test Vessel. This apparatus was developed by Underwriters Laboratories (UL) in the 1960s to compare the explosion characteristics (MESG and explosion pressure) of known materials to unclassified or new materials of commerce (*2*). In the late 1960s and early 1970s this apparatus was used by industry to investigate a number of previously unclassified materials for classification in the NEC. Later the predecessor committees to the present Committee on Studies on Hazardous Substances recommended that additional unclassified materials be investigated for the U.S. Coast Guard, OSHA, and NIOSH (*1*, pp. 2-3).

Although the Westerberg Explosion Test Vessel provides results consistent with those in other test apparatus for most materials, the results do not agree with IEC test results for other materials. A prime example is ethyl ether, which also happens to be the material whose MESG is used as the dividing line in the United States between Group B and Group C materials.

The primary reason for this difference in measured MESG between the Westerberg Explosion Test Vessel and other test methods appears to be that the primary explosion chamber is larger than the secondary or receptor chamber. This results in prepressurization of the unburned mixture in the secondary chamber before the hot gases from the explosion in the primary chamber pass through the gap between the chambers. This condition does not represent the actual use of explosion-proof equipment, where the volume of the unburned mixture (the flammable atmosphere surrounding the enclosure) is essentially infinite in comparison to the volume of the exploding mixture in the enclosure.

Another problem with this particular apparatus is the shape of the gap between the two chambers, which differs from the sharp-edged flange normally encountered in explosion-proof enclosures.

The differences and reasons for the anomaly in the MESG test results using various test equipment have been explored in detail (*1*, pp. 6, 88-92, 97, and 151; *3*).

In addition to technical problems with the construction of the Westerberg Explosion Test Vessel, the apparatus is unique. The only known operating equipment available is at UL in Northbrook, Illinois. The equipment is very large (some 4.5 m in length), and because of the volume of the test chambers (over 47 l), considerable flammable material is needed to conduct a series of tests. The extended time necessary for conducting tests can result in costs of many thousands of dollars per material tested.

There are two other test vessels that have been used extensively for conducting MESG experiments. One is the 8-l test vessel developed in the United Kingdom and the other is the 20-ml test vessel developed in West Germany (*1*, pp. 35-37 and 103-107). Both are spherical test vessels with an equatorial adjustable flanged gap. In both vessels the volume of the secondary or receptor chamber is essentially infinite with respect to the volume of the primary explosion chamber. The shape of the gap in both vessels is consistent with the commonly encountered shape of the flanged joint surfaces of explosion-proof apparatus.

Test results obtained from use of the 20-ml vessel are consistent with those from use of the 8-l vessel, and the 20-ml vessel is the test apparatus recognized as the IEC test method (*1*, pp. 85 and 151). Only a small amount of material is necessary for conducting tests, the equipment is relatively compact, and it is available in a number of locations.

The 8-l and 20-ml equipment have, however, limitations that do not exist in the Westerberg test apparatus. One limitation relates to the maximum pressure that might be realized within the test apparatus. The Westerberg apparatus has a very large ratio of the primary chamber volume to the open gap area (L*). Thus, the pressure in the primary chamber can increase considerably and, in fact, approach constant volume combustion pressure. Under these conditions, sonic flow, supersonic flow, and shock waves can occur and thereby affect the explosion process in the secondary chamber. Relatively speaking, the L* for the 20-ml equipment is very small, and hence much lower pressures are realized. The 8-l vessel is intermediate between the 20-ml equipment and the Westerberg apparatus. Neither the 20-ml nor 8-l equipment is fitted with pressure transducers, and so the actual pressures obtained are undetermined. The L* of most explosion-proof apparatus is probably somewhere between that of the 8-l equipment and the Westerberg test apparatus. Thus, explosion testing of explosion-proof apparatus by testing and approval laboratories could result in high pressures and, hence, greater probability of ignition.

A second limitation of the spherical test vessels is that they provide no mechanism for testing turbulent mixtures, which the Westerberg apparatus does. If the MESG of a new material is reduced as a result of turbulence so that a new material would be classified into a more hazardous group, use of the 20-ml test vessel would result in misclassification of the material. However, the change in MESG as a result of turbulence is not great, based on present test data. In tests of the actual explosion-proof apparatus, any rotating elements can be activated for the test, thereby producing turbulence in the mixture and possibly lowering the MESG of the mixture.

A third limitation is that, unlike the Westerberg apparatus, the 20-ml and 8-l spherical test vessels do not permit testing for the likelihood of pressure-piling (see Conclusion 6 and Recommendation 6).

The 20-ml apparatus is recognized by the IEC as the standard test method for measuring MESG, and such equipment exists in a number of locations. A considerable volume of test data is already available using this test method. The equipment is relatively inexpensive to build and use compared to the Westerberg equipment.

CONCLUSION 1. A system for classifying gases in the presence of electrical equipment is needed to promote safety. Today, the maximum experimental safe gap (MESG) is the best practical parameter for this classification. The method of measuring MESG in the United States using the Westerberg test apparatus leaves much to be desired. A better, but somewhat imperfect, methodology for determining MESG is the 20-ml apparatus that has been evaluated and is in use for classification in Europe.

RECOMMENDATION 1. At present, use the 20-ml apparatus for measuring MESG.

INTERNATIONAL STANDARD

Almost all major corporations are now international in operation. For example, the international trade in automobiles is enormous. Similarly, major construction companies bid on contracts for projects worldwide. In these kinds of operations it is clearly advantageous to have international standards. On the other hand, the majority of existing plants were constructed to local or regional standards, and changing standards and equipment for these plants would be prohibitively expensive. However, since international marketing is the wave of the future, the role and importance of international standards will increase.

Individual gases are classified according to their MESG value. Ideally, one could take a number of gases that have MESGs reasonably close together but well separated from others and classify them in a certain group (e.g., A, B, C, or D in the United States). The particular group would then dictate the requirements for electrical equipment. Of course, with hundreds of gases to classify, and nature being what it is, the MESGs determined result in a relatively continuous listing. That is, there are no obvious MESG demarcation values, and hence the dividing lines between different groups become somewhat arbitrary.

However, logic and practicality should still apply. For one thing, the gas or liquid chosen for determining a dividing line should be a pure substance. Otherwise, variations in composition from one sample to another would yield different MESGs and these could possibly correspond to different groups. An example is the selection of the MESG of gasoline as the dividing line between Groups C and D in the U.S. system. There are other examples where the dividing lines selected may be poor choices. According to Magison and Phillips (*1*, p. 279), the IEC classification of IIA is for those gases with an MESG over 0.9 mm. This is weak from the standpoint that there are a number of gases with MESGs grouped around 0.9 mm but few gases around 0.8 mm. Accordingly, the latter figure would seem to make more sense.

There are differences between standards in different countries in the arbitrary dividing lines between different classes of compounds. The dividing line between the IEC's Groups A and B of 0.035 in. (0.89 mm) differs from the dividing line between the U.S. Groups C and D of 0.029 in. (0.74 mm). Phillips (*1*, p. 87) suggests that 0.8 mm (0.031 in.) might be a better demarcation point for IEC. Magison (*1*, p. 279) suggests "the consequences of an error in drawing the line between IIA and IIB (IEC) or between D and C (USA) are not very severe in practice, so we are not necessarily constrained...by deciding in advance that we can't change it." Compromise on this dividing point seems possible.

Magison (*1*, p. 279) states, "The line between IIB and IIC or between Group C and Group B is fairly easy to draw because there are relatively few materials in Group IIC and IIB at present." Again, compromise for the dividing line between IIC and IIB and B and C seems possible.

Classification I (IEC) is to be used in an atmosphere that might contain methane: This group is reserved specifically for coal mine applications. This is a use, not a material classification, and therefore should not be of concern for the present discussion.

The remaining difference is the two classifications used in the United States (Groups A and B) versus the one classification IIC used in IEC. Of the several compounds listed in the 1982 NMAB publication (4), only three are given Group A; approximately 22 are given an unqualified Group B; and approximately 11 more are given a qualified Group B (C) or B (D) rating. In other words, approximately 1 percent of the classified materials use two of the four classes. Given the small number of compounds and the arbitrariness of classification, international agreement should be possible.

CONCLUSION 2. In the present schemes used worldwide, the dividing lines for classifying different chemicals into groups are arbitrary and differ from one scheme to another. Despite this, they are still useful, but it is highly desirable to internationalize testing and classification into a single scheme.

RECOMMENDATION 2. Support internationalizing testing and standardize the dividing lines between groups. Do this through the IEC and the ISO.

FUNDAMENTAL UNDERSTANDING

It appears that the MESG is the best method now available for classifying flammable gases and vapors. Thus, it would be convenient if a predictive method for determining MESG could be established, especially if the predictions could be firmly based on the fundamental transport, kinetic, chemical, and thermodynamic properties of the fuel-air mixture and the mechanical system of interest. However, as Lee (*1*) pointed out, only the semi-theoretical approach of Phillips (*1*) is available, and it is of limited use because it incorporates empirical constants. Phillips lists the following deficiencies in his theory:

- Internal ignition position affects the results, and the effect is not always clear.
- Extrapolation of the dimensional analysis is unwise.
- The burning velocity is needed but is not always available.
- Only laminar heat transfer effects are included.
- Oxygen-enriched mixtures display unexplained variation in predicted MESGs.

At present, Phillips' semi-theoretical treatment correlates MESG data quite well for the situations studied. However, for a new compound for which data are limited or not available, the theory requires further development.

In general, the only technique now available for classifying untested compounds is based on analogy and homology. An earlier committee classified about 1500 chemicals by such methodology, including some "seat-of-the-pants" decisions based on the experience of the committee members (4). The published classifications have been widely used. The classifications were based on results from the Westerberg apparatus. The MESG measurements on the Westerberg apparatus can differ substantially from measurements made using the 20-ml and 8-l apparatus, which are commonly used in Europe. The approach of classification based on analogy and homology has been shown to be workable but is unproved at present. Additional work on the theory and modeling of the process of propagation of ignition (or its quenching) is needed. A closely related need is to obtain additional experimental data to guide and confirm the theoretical analysis. Without additional theoretical and experimental work, the seat-of-the-pants analysis will have to be continued (*5*). As Phillips (*1*) noted, the MESG is known for more chemicals than the other parameters in his theory, so it is simpler to use experimental MESGs at present. In addition, the constants in his theory are based on data from the 20-ml and 8-l apparatus. The MESG values predicted using the Phillips theory may not correlate well with those used for classification in the 1982 report (4), which are based on measurements using the Westerberg apparatus. Thus, at least some of the effort should go to measuring MESGs directly. If anomalies are found, they can point the way to better fundamental understanding.

CONCLUSION 3. A predictive method for classifying a new compound based on scientific principles does not exist. The approach using homology and analogy is the best available at present.

RECOMMENDATION 3. Support research to obtain a better understanding of the scientific principles involved in the combustibility of gases as related to classification.

GAS MIXTURES

Classification of combustible gas mixtures is even more difficult than that for single gases because of the problems of predicting the properties of the mixtures. Transport and thermodynamic properties of mixtures can be estimated with good accuracy (if the concentrations of the gases and their individual properties are known). Chemical kinetic parameters usually cannot be estimated for mixtures because the reaction mechanisms and rates are not known and cannot be estimated reliably. Although Phillips' theory can be used for some mixtures, it is successful primarily for measuring temperature effects and the effects of moisture, not effects caused by interactions in mixtures of combustible gases. It is also apparatus-dependent because of the empirical correlations it contains. Thus, additional theoretical and experimental work will be required if better predictions, or even correlations, are to be made for mixtures.

CONCLUSION 4. It is not known how to predict the classification of mixtures.

RECOMMENDATION 4. Undertake experimental work on mixtures to establish a data base for classification purposes.

CORRELATIONS BETWEEN METHODS

IEC Report 79-12 (*6*) provides criteria for classifying materials in IEC groups IIA, IIB, and IIC that correspond, in general, to the NEC's Groups D, C, and A plus B, respectively. The classification scheme is based on the ratio of the MIC of the material to be classified to that of methane, or the MESG of the material.

The intent of the IEC report is that the MESG and the MIC ratio be based on measurements in the Standard IEC 20-ml apparatus described in IEC Publication 79-1A (*7*) and the spark test apparatus described in IEC Publication 79-3 (*8*). However, it is recognized that MIC data from other apparatus, especially the break-spark apparatus used in the United Kingdom for many years and MESG data taken with an 8-1 sphere, can be used, if necessary.

The limits for the three groups are as follows:

	MESG	MIC Ratio
IIA	$\geqq 0.9$ mm	> 0.8
IIB	> 0.5 to < 0.9 mm	0.45 to 0.8
IIC	$\leqq 0.5$ mm	< 0.45

One determination is adequate when

For IIA: MESG > 0.9 mm	*or*	MIC ratio > 0.9
For IIB: MESG between 0.55 and 0.9 mm	*or*	MIC ratio between 0.5 and 0.8
For IIC: MESG < 0.5 mm	*or*	MIC ratio < 0.45

Determination of both the MESG and the MIC ratio is required when

Only the MIC ratio has been determined and it is between 0.8 and 0.9

Only the MIC ratio has been determined and it is between 0.45 and 0.5

Only the MESG has been determined and it is between 0.5 and 0.55 mm

The technical basis for the IEC work lies primarily in three documents. Slack and Woodhead (*9*) correlated MESG data obtained in an 8-1 sphere with MIC data obtained with the break-spark apparatus No. 2 used at the Safety in Mines Research Establishment in the United Kingdom. Helwig and Nabert (*10*) correlated data taken in the 20-ml MESG apparatus, MIC data taken in the standard IEC apparatus (*8*), quenching distance measured in a 0.3-cm^3 chamber, and MIE data from Lewis and von Elbe (*11*) at the U.S. Bureau of Mines. The Lunn and Phillips report (*12*) summarized data on MESG taken by several laboratories using different-sized chambers. The agreement between MESGs obtained in an 8-1 sphere with those obtained in the standard 20-ml apparatus is good.

CONCLUSION 5. There appears to be a correlation between MESG and MIC that could lead to a rapid, inexpensive screening method.

RECOMMENDATION 5. Make a study of the correlation between MESG and MIC and of other correlations for use as screening technologies.

PRESSURE-PILING

Pressure-piling can be defined as prepressurization of the unburned flammable mixture ahead of the moving flame front caused by turbulence generation ahead of this front because of motion induced by the presence of the flame. It is most common in tunnels or pipes, but it can occur within explosion-proof apparatus that is compartmentalized, such as between end bells of a motor.

In the United States, threaded rigid conduit is generally the most common wiring system used in Class I, Division 1, hazardous locations. Wiring systems in Class I, Division 1, hazardous locations in the United States differ from wiring systems in similar locations in other countries, where cable is the primary wiring method used (*1*, p. 15). Pressure-piling can and does occur through the conduits used in the United States unless prevented by seals in the conduit system.

This pressure-piling condition is the reason for the dual rating of some flammable materials in the present NEC. For example, butadiene would be classified Group D based on measurement of its MESG in the 20-ml test vessel. It would be and has been so classified using the Westerberg equipment. However, tests in the Westerberg apparatus have already demonstrated that butadiene produces explosion pressures in the Group B range when a simulated rigid conduit wiring system is used. This is the reason the NEC permits use of Group D equipment in a butadiene atmosphere only when all conduits are sealed. Explosion tests using propane or pentane for Group D equipment, as typically done, would not represent by a considerable margin the performance of explosion-proof equipment used in a butadiene atmosphere if all conduits were not sealed. Similar problems exist for other materials that have already been tested (ethylene oxide, propylene oxide, and acrolein) and may exist for materials not yet tested.

However, it was the position of the committee that, because of the very high dependence of the extent of pressure-piling on the geometry of the system (e.g., bends, wiring, constrictions, etc., in the pipe), pressure-piling dangers should be handled by approaches other than a dual classification scheme.

CONCLUSION 6. Pressure-piling is of concern in the United States because of installation practices (use of conduit).

RECOMMENDATION 6. Recognize the hazards associated with pressure-piling but do not use it for the classification of materials.

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CHAPTER 4

CLASSIFICATION OF DUSTS

PARAMETERS FOR CLASSIFICATION

Although key parameters for classification are combustibility and electrical conductivity for situations involving electrical equipment, many other parameters must be recognized. The measurement of conductivity is now well established and accepted; that for combustibility is not totally satisfactory. In the industrial situation where dust might be present in association with electrical equipment, the statement from Chapter 1 is apropos. Reduced to its simplest form, the classification rationale for dusts can be expressed in two questions:

- Is it combustible?
- Is its resistivity above or below 10^5 ohm-cm?

Where a combustible dust may be present, protection against ignition is provided by designing electrical equipment so that dust does not come in contact with possible igniting sources. In those areas where the hazard is high, i.e., where a conductive dust might provide both an arc-igniting mechanism and fuel for the explosion, or where clouds of nonconducting dust are normally present, the electrical enclosure not only is tight to exclude dust, but also is of robust construction so that electrical faults to the enclosure will not cause hot spots that might ignite a dust layer.

Thus, for the electrical system, the basic characteristics of a dust needing definition essentially are the electrical conductivity, the MIE, the minimum temperature for ignition of a cloud and of a layer, and the minimum explosible concentration. While knowledge of these parameters may be sufficient to minimize potential ignition by electrical systems, more basic information about dusts is needed to promote overall safety where combustible dusts are present. In general, information is needed on a dust's

- Ignitability
- Dispersibility
- Spontaneous ignition tendency

- Ignition susceptibility by frictional sparks
- Static generation tendencies
- Reactivity with moisture (humidity) and oxidizers other than oxygen
- Thermal stability
- Explosion development in closed or partially closed systems

A straightforward method for determining the electrical conductivity of a dust was given in an earlier NMAB report (*1*). That same publication presented a proposed standard method for determining the ignition temperature of a dust layer. Although considerable research data are available on measurement of the other parameters, intensive and extensive studies are needed to provide the basic information still required. This will then provide industry, government, and the public with the tools to promote safe working and living environments. It is of basic importance that the findings from research receive universal acceptance and application so that international exchange of equipment and results can be promoted.

CONCLUSION 1. Systems for classifying dusts are needed to promote safety. Key parameters for classification should incorporate combustibility for all dusts, including those of an electrically conductive nature, which in the United States, are recognized as a special hazardous category. The technique for measuring conductivity is satisfactory; that for combustibility is not totally satisfactory.

RECOMMENDATION 1. Develop a classification scheme that takes into account combustibility of clouds and layers, including those having high electrical conductivity.

FUNDAMENTAL UNDERSTANDING

The combustion characteristics of dusts involve significant additional physical and chemical phenomena than those for gases and vapors. For example, in the combustion of gases the important phenomena are the thermodynamic and transport properties, equivalence ratios, and chemical kinetics. In the case of dusts, there are the additional influences of particle size, particle shape, porosity, particle size distribution, moisture content, agglomeration, devolatilization, concentration and distribution of concentration, thermal radiation, and heterogeneous burning. In a number of cases, many of the important phenomena may be interrelated, thus adding greatly to the complexity. A further deterrent to gaining a sound understanding of the combustion of dusts may be attributed to the difficulty of conducting tests where all of the major variables are controlled. A case in point involves the combustion of a dust cloud. The formation of this cloud by dispersing the dust is often nonreproducible and difficult to characterize. This complicates the assessment of the data, in that "dense" versus "dilute" clouds give different results.

CONCLUSION 2. The scientific understanding of the combustibility behavior of dusts is further behind that for gases (vapors) because the processes that are involved are more complex.

RECOMMENDATION 2. Continue research to obtain a better understanding of the scientific principles involved in the combustibility of dusts as related to classification.

INTERNATIONAL STANDARDIZATION

As was indicated previously in the section on gases, international standards should be established as soon as possible. Because the combustion process for dusts is more complex than for gases and vapors and scientific understanding of it is very incomplete, the classification system for dusts is in a relatively primitive state. Consequently, there is an opportunity for international cooperation to develop test procedures and classifications. In fact, the standardization of testing equipment and classification of the flammable and/or explosion hazard of dusts are currently being considered. The various working groups of the IEC's Subcommittee 31H are considering the design of laboratory equipment and tests for measuring ignition temperatures of clouds and layers, as well as electrical resistivity of dust layers. The United States has representation on many of the working groups. Work is also proceeding on the measurement of minimum explosible concentration and MIE. Some consideration has been given to the possibility of devising a comprehensive classification scheme for explosible dusts (*2*, pp. 109-123).

Evaluation of the ignitibility of dusts in almost every country is conducted using procedures similar to those used in the past in the United States (ignition temperature of dust clouds in a small tubular furnace similar or equal to the Godbert-Greenwald furnace, layer ignition temperatures by the hot-plate method, minimum explosible concentration and MIE in a vertical tube apparatus essentially similar to the Hartmann apparatus). These methods are used in England, the Netherlands, Germany, and France.

The procedures involved in classifying dusts according to their potential explosion severity are also fairly similar. Most countries use spherical bombs ranging from 20 l to 1 m^3 or larger. The primary arguments concern the best methods of dispersing the dust and the best level and type of igniting source.

Within 10 years, the results from the various working groups of the IEC should be available for consideration by the member countries, and then a standard classification scheme for dusts might be implemented.

CONCLUSION 3. Internationalization of testing and classification is desirable. There is no uniformity in test equipment, in test procedures, and in reporting results for classification purposes.

RECOMMENDATION 3. Develop acceptable international test methods for measuring and reporting the combustibility of dusts. The United States should continue to participate actively in and influence the development of these international standards with the objective of developing a universally accepted hazard index.

SCREENING FOR COMBUSTIBILITY

The general procedure for testing for combustibility consists of dispersing a quantity of fine dust into or across a burner flame. The apparatus used in Norway consists of a steel tube containing an oxyacetylene welding torch flame with no excess oxygen. A quantity of dust is then dispersed into the flame and ignition is denoted by propagation of flame out of the tube.

Another cheap and quick method for determining whether a dust is combustible consists of dispersing fine dust across a laboratory burner or the flame from a portable propane torch. Ignition is denoted by flame propagating through the dust cloud. If ignition is not readily apparent, more extensive testing may be needed before a final classification of "nonflammable" or "nonignitable" is assigned.

The choice of method is not very critical because this is a screening test.

CONCLUSION 4. A quick, inexpensive method is needed to screen dusts for combustibility.

RECOMMENDATION 4. Devise a test based on the dispersal of dust into a standardized flame to determine whether the dust is combustible.

ELIMINATION OF GROUP F

In its report, "Classification of Combustible Dusts in Accordance With the National Electrical Code" (*3*), the NMAB Committee on Evaluation of Industrial Hazards recommended that Group F be eliminated and dusts be classified into Groups E and G on the basis of electrical resistivity, ignition sensitivity, and explosion severity. The NFPA's Technical Committee on Electrical Equipment in Chemical Atmospheres agreed with this recommendation and submitted a series of proposals for revision of the 1981 edition of the NEC to eliminate Group F locations from the Code. The NEC Committee also agreed with these recommendations, and Group F was deleted from the 1984 edition of the NEC. During the processing of the 1987 edition of the NEC, the NEC Committee reinstated Group F.

The substantiation for the reinsertion of Group F did not introduce any information that the Committee on Evaluation of Industrial Hazards did not have or consider when it made its original recommendation to delete Group F. In addition, the NFPA technical committee that originally submitted the proposal to the NEC Committee was not consulted when the change in the Code was decided upon.

It is recognized that some segments of industry may have had problems with the changes introduced in the 1984 edition of the Code, but it is the committee's belief that these problems could have been resolved without reintroducing Group F.

The committee recognizes that there may be a few coal dusts (Group F) that have resistivities slightly less than 10^5 ohm-cm and therefore would be classified as Group E under the provisions of the 1984 NEC. The committee believes this problem could be solved very simply by indicating that all coal dusts are classified Group G, even though they may have resistivities somewhat below 10^5 ohm-cm. This would overcome the problem that the motor industry and motor users have reported. Motor users were required to install Group E equipment because they did not know ahead of time the source of the coal or what the resistivity would be. It was not the intent of the Committee on Evaluation of Industrial Hazards that coal dust having a resistivity slightly below 10^5 ohm-cm be classified Group E or that electrical resistivity be the sole method of classifying dusts as Group E or G materials.

CONCLUSION 5. Classification of dusts in Group F in the present NEC, NFPA 70, is unnecessary.

RECOMMENDATION 5. Classify dusts exclusively into Groups E and G using the recommended resistivity method. All coal dusts should be classified as Group G.

LIMITATIONS OF TEST CHAMBERS

The Hartmann bomb was probably the earliest apparatus used for generating data on the combustion characteristics of dusts. This technique has the advantage of convenient size (and thus relatively small amounts of dust per test). It is also easy to use. However, there are limitations that, in some cases, lead to appreciable errors. For one thing, the bomb is cylindrical, and the flame propagating in the radial direction is influenced by the wall earlier than the flame propagating in the axial direction. Furthermore, the air blast used to disseminate the dust generates appreciable turbulence, which then decays fairly rapidly. The dust concentration is not uniform throughout the cloud, and the magnitude at the ignition location is not known; neither is the particle size distribution and velocities at that point. All of these factors affect the ignition and flame propagation characteristics.

In classifying dusts relative to the NEC, the main concern is to preclude ignition, because even a weak explosion is capable of seriously burning personnel. It is understood that the electrical apparatus is sealed against entry of the dust. Thus the important quantities are cloud ignition temperature, layer ignition temperature, minimum cloud ignition energy, minimum explosion concentration, and electrical resistivity. The severity of the explosion also enters in classifying according to hazard. Accordingly, the maximum pressure and the maximum rate of pressure rise are also important.

Concern over the reliability of the Hartmann bomb data along with the problems in large-scale devices and venting requirements led to a number of alternative techniques. Bartknecht (*4, 5*) developed a 1-m^3 sphere apparatus with an improved dust dispersion technique and performed extensive testing. Comparisons with Hartmann-generated data revealed reasonable agreement in many cases but appreciable differences in a substantial number of other cases. Later efforts by Siwek (*6*) and Cashdollar and Hertzberg (*7*) have utilized a 20-l sphere. A recent technique by Kauffman et al. (*2, p. 43*) is interesting in that the dust concentration is relatively uniformly distributed in a spherical jet-stirred reactor (larger than 1 m^3). However, to date this facility has not been used for routine testing.

Although advances have been made in determining the fundamental combustion properties of dusts, much remains to be done. In addition, many large-scale tests have been conducted. However, it is impossible to test for all of the configurations and conditions that can exist in practice. Accordingly, it is imperative that a good foundation be made through the collection of trustworthy fundamental data. Analysis and experience can carry this information over to the multitude of situations encountered in practice.

Throughout the world, researchers in the field of dust explosions have concurred that the 1.2-l Hartmann apparatus should not be used to evaluate the pressures and rates of pressure rise developed by explosions of dust. Again, these researchers are in agreement that the pressures and rates should be measured in the 20-l to 1-m^3 chambers.

A large amount of data has been collected on dusts using larger chambers. These data should be collected, collated, compared, and evaluated in the same manner as the data from the Hartmann apparatus.

CONCLUSION 6. The Hartmann bomb is useful for testing but has limitations. Concepts and methods of measurement need to be more clearly defined.

RECOMMENDATION 6. Efforts to develop a more acceptable test vessel and procedure should be abetted.

There is a decided need for a dedicated central laboratory in the United States for evaluating the flammability and explosion hazards of dusts from chemicals encountered or proposed for use in industrial workplaces.

OSHA has constructed a new laboratory capable of conducting evaluations of dust explosion hazards in its Salt Lake City facility. However, it is not yet operational.

A laboratory of the type needed would conduct ignition tests and classification evaluations on an estimated several hundred samples submitted or collected each year. The data generated would include parameters such as dust resistivity or conductivity, ignition temperatures of clouds and layers, minimum explosible concentration, MIE, maximum pressures and rates of pressure rise, and the chemical and physical characteristics of the dust samples. This compilation of data would also assist in the development of standards.

The United Kingdom under the present Health and Safety Executives Factories Act requires the manufacturers or producers of dusts, either as a product or a byproduct, to evaluate the fire and/or explosion hazard of the dust. This can be done in-house, or the task can be contracted out, but the responsibility for providing the information lies with the producer.

CONCLUSION 7. There is no laboratory in the United States doing systematic testing for classification by a generally accepted method.

RECOMMENDATION 7. Establish a laboratory in the United States dedicated to the measurement of dust combustibility and electrical conductivity and the development of standards.

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APPENDIX A

GLOSSARY OF ACRONYMS AND TERMS

Acronyms

ANSI	American National Standards Institute
IEC	International Electrotechnical Commission
ISA	Instrument Society of America
ISO	International Standards Organization
MESG	Maximum experimental safe gap
MIC	Minimum igniting current
MIE	Minimum igniting energy
NAS	National Academy of Sciences
NEC	National Electrical Code
NFPA	National Fire Protection Association
NIOSH	National Institute of Occupational Safety and Health
NMAB	National Materials Advisory Board
OSHA	Occupational Safety and Health Administration
UL	Underwriters Laboratories, Inc.

Definitions of Terms

Class I Locations: Those locations in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitible mixtures. Division 1 locations within Class I are those where the gases or vapors exist continuously, intermittently, or periodically. In Division 2 locations the gases or vapors are normally confined or ventilated.

Cloud Ignition Temperature (Tc): The minimum furnace temperature at which flame is observed in one or more of a prescribed number of ignition trials on dusts.

Explosion Severity: Equal to $(\dot{P}\cdot P)_2/(\dot{P}\cdot P)_1$ where subscripts 1 and 2 refer to Pittsburgh coal dust and the test dust, respectively.

Ignition Sensitivity: Equal to $(Tc\cdot E\cdot C)_1/(Tc\cdot E\cdot C)_2$ where subscripts 1 and 2 refer to Pittsburgh coal dust and the test dust, respectively.

Layer Ignition Temperature: The lowest temperature of a hot surface at which ignition occurs in a dust layer of a given thickness following a prescribed testing procedure.

Maximum Rate of Pressure Rise ($\dot{P}$): The steepest slope of the pressure-time curve for the explosion of a dust in the test apparatus.

Maximum Pressure (P): The maximum explosion pressure (corrected for the initial pressure) developed during the explosion of a dust in the test apparatus.

Minimum Cloud Ignition Energy (E): The energy of a spark that is the least required to ignite a dust cloud and produce a flame propagation of a prescribed length in a tube.

Minimum Explosion Concentration (C): The lower explosive limit or the least concentration of a dust that will sustain an explosion under the test conditions.

Maximum Experimental Safe Gap: The maximum gap between plain parallel flanged surfaces of a given width that in experimental tests will not, upon combustion of the mixture within the apparatus, result in ignition of the same mixture outside the apparatus.

Minimum Igniting Current: The minimum current necessary to produce a flame in a gas (vapor) under the test conditions.

Minimum Igniting Energy: The energy of the ignition source that is the least measured to produce a flame in a gas (vapor) under the test conditions.

Pressure Piling: Prepressurization of the unburned flammable mixture ahead of the moving flame front caused by turbulence generation ahead of this front because of motion induced by the presence of the flame. It is most common in tunnels or pipes, but it can occur within explosion-proof apparatus that is compartmentalized, such as between end bells of a motor.

APPENDIX B

BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS

HOMER W. CARHART received B.S., M.A., and Ph.D. degrees in chemistry at Dakota Wesleyan University, University of South Dakota, and the University of Maryland, respectively. After teaching chemistry at Gallaudet College, he joined the Naval Research Laboratory, where he is at present head of the Navy Technology Center for Safety and Survivability. His research interests include hydrocarbon fuels, propellants, spontaneous ignition, flammability, chemical and biological warfare defense, combustion, fire protection, damage control, and submarine atmospheres.

MURRAY JACOBSON has a B.A. in chemistry from Gettysburg College. His employment at the Mine Safety and Health Administration, Department of Labor, has consisted of about 40 years in dust and gas explosion research, respirable dust problems in mines, and industrial hygiene in the mining and mineral processing industries. He has served on NFPA panels and was the chairman of the Correlating Committee of the Dust Explosions Hazard Committees.

JOHN H. S. LEE received B.Sc. and Ph.D. degrees in mechanical engineering from McGill University and a M.Sc. from the Massachusetts Institute of Technology. After obtaining his doctorate he joined the faculty of McGill University, where he is currently a professor of mechanical engineering and director of the Shock Wave Physics Research Laboratory. His research interests are in the fields of combustion, explosion, and shock wave phenomena.

ERNEST G. MAGISON received a B.S. in electrical engineering at Tufts University. He has been active in standards-writing activities of the Instrument Society of America, National Fire Protection Association, and International Electrotechnical Commission, particularly those relevant to preventing ignition by electrical equipment. Mr. Magison is a senior engineering fellow and manager, Regulatory Affairs, Honeywell Process Control Division, and an adjunct professor at Drexel University.

PHILLIP S. MYERS received a B.S. degree from McPherson College, a B.S. degree from Kansas State College, and a Ph.D. degree in mechanical engineering from the University of Wisconsin. After graduation he joined the faculty of the University of Wisconsin, where he is at present a professor of mechanical engineering. He is a member of the National Academy of Engineering and past national president of SAE. His research interests include combustion in internal combustion engines, thermodynamics, heat power, pyrolysis of propane, fuel sprays and vaporization, and welding heat transfer.

JOHN NAGY received B.S. and M.S. degrees in physics from Carnegie-Mellon University. After graduation he was employed by the U.S. Bureau of Mines and the Mine Safety and Health Administration until his retirement. He is at present serving as a consultant on mining and on industrial dust explosions.

J. ARTHUR NICHOLLS graduated from Wayne State University with a B.S. and from the University of Michigan with an M.S. and Ph.D. in aeronautical engineering. He is a professor of aerospace engineering at the University of Michigan, with research activities in gas dynamics, heterogeneous and homogeneous combustion, and engine-generated pollutants.

PETER J. SCHRAM has a B.S. in electrical engineering from the University of Wisconsin. He has served on National Fire Protection Association and Instrument Society of America panels. His industrial employment comprises more than 20 years of experience at Underwriters Laboratories, Inc., and his present position as chief electrical engineer at the National Fire Protection Association.

J. REED WELKER received B.S. and M.S. degrees from the University of Idaho and a Ph.D. in chemical engineering from the University of Oklahoma. After obtaining his doctorate he worked at the Research Institute, University of Oklahoma. Subsequently he was employed at University Engineers, Inc., and Applied Technology Corporation before assuming his present position as professor of chemical engineering at the University of Arkansas. His research interests include fire research and safety, atmospheric dispersion, liquified natural gas plant safety, and fire extinguishment and control.

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The present empirical system for classifying gases and dusts as to their potential explosion hazard in workplaces where electrical equipment is located functions reasonably well. It would be desirable to generate a scheme for classification that is based on scientific first principles, but achievement of that goal is far off. Nevertheless, because of the continued rapid introduction of new chemicals into the market and their increased use in international trade, there is a need for improved testing and classification procedures--in particular, processes uniformly acceptable to the international community concerned with protection of the workplace environment. In this report the testing methods and classification schemes used in the United States are reviewed, and their drawbacks are discussed. Information derived from an international symposium at which scientists from other countries gave their views provided additional input. A set of conclusions and recommendations was developed, and these constitute the main thrust of this report.

17. Key Words and Document Analysis. 17a. Descriptors

Combustible gases and dusts
Testing and classification
National Electrical Code (NEC)
Maximum experimental safe gap (MESG)
Hartmann bomb
Westerberg apparatus

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