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FIRE HAZARD CLASSIFICATION OF CHEMICAL VAPORS RELATIVE TO EXPLOSION-PROOF ELECTRICAL EQUIPMENT

BY

ELECTRICAL HAZARDS PANEL
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The contents of this report reflect the views of the Electrical Hazards Panel of the Committee on Hazardous Materials, National Academy of Sciences which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Coast Guard. This report does not constitute a standard, specification or regulation.

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FIRE HAZARD CLASSIFICATION OF CHEMICAL VAPORS RELATIVE TO EXPLOSION-PROOF ELECTRICAL EQUIPMENT

A Progress Report prepared by the
Electrical Hazards Panel
of the
Committee on Hazardous Materials
Division of Chemistry & Chemical Technology
National Research Council
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H. Carhart
Panel Chairman

D. L. Katz
Committee Chairman

Washington, D.C.
February 10, 1970

ABSTRACT

At the request of the U.S. Coast Guard, a detailed study has been made by the Electrical Hazards Panel of the Committee on Hazardous Materials to determine the feasibility of classifying some 200 chemicals of commerce according to the classifications given in the National Electric Code, NEC 500, by using a scheme based entirely on available physical and flammability properties only. If successful, the system would eliminate the present laborious process of actually testing the piece of electrical equipment in the vapors of the particular chemical of concern.

Because of the paucity of approved compounds classified in the present NEC 500, the classification base-lines used in the present study were extended to include those of the British Standards, B.S. 229, Explosion-proof, and B.S. 1259, Intrinsically-safe, equipment, plus a new list of 15 chemicals recently included as tentative in the present NEC 500 classification based on extensive testing at the Underwriters' Laboratories.

The physical-chemical and flammability properties studied either alone or in combination in trying to establish correlations with the base-lines above were: the limits of flammability, especially the ratio of these limits (upper/lower), flash points, vapor pressures, quenching distances, spontaneous ignition temperatures, maximum safe gaps, minimum ignition currents, minimum ignition energies, pressure rises, and heats of combustion.

Although in the attempted correlations many trends were found in a qualitative sense indicating that relationships and dependencies do exist in a general way among properties studied, none were found that were unequivocal or even sufficiently reliable to merit recommendation at the present. In every instance, there were maverick compounds that just would not fall in line.

Therefore, it is concluded that the time has not yet arrived when we can classify chemicals in a rigid mathematical way according to the NEC-500-type

classification using available physical-chemical and flammability properties only.

However, the Panel does feel that tentative classifications could be made for many of the compounds of interest to the U.S. Coast Guard. The assignments would have to be made by a group of knowledgeable individuals using available physical-chemical and flammability properties plus the concepts of homology and analogy, and even intuition acquired by long experience when insufficient data was available. It is a recommendation resulting from this study that such tentative classifications be made, and the Panel will address itself to this subject. The criteria for present classification such as by NEC 500 also need critical examination and this also will be considered. Intrinsic safety will be the next main topic for Panel study.

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FOREWORD

A request has been made by the U.S. Coast Guard to the National Research Council Committee on Hazardous Materials to consider the classification, based on the NFPA National Electric Code (NEC 500),[1] of over 200 chemicals which are being, or are proposed to be, transported by water. It was further requested that serious consideration be given to possible classification based on known, or easily obtained, physical, chemical or flammability properties of the chemicals rather than on the traditional, very cumbersome and costly requirement of actually testing exhaustively a new piece of electrical gear in the vapors of the given chemical or substance to determine whether such gear would be safe in such an environment or not.

In partial compliance with the Coast Guard request, Professor Donald L. Katz, Chairman of the NRC Committee, appointed a Panel on Electrical Hazards to study the matter. This report describes the studies made by the Panel to date and as such constitutes a progress report to the parent Committee.

The Panel on Electrical Hazards consists of:

H. W. Carhart, Chairman	Naval Research Laboratory
G. H. Damon	Bureau of Mines
H. C. Hoy	Oak Ridge National Laboratories
J. T. Leonard	Naval Research Laboratory
E. C. Magison	Professional Engineer, Abington, Pennsylvania
A. H. McKinney	E. I. duPont de Nemours & Co., Inc.
F. A. Van Atta	Department of Labor
W. C. Westerberg	Underwriters' Laboratories (Ret.)
H. H. Fawcett	Technical Secretary, NRC Committee on Hazardous Materials

INTRODUCTION

There are three common ways of enhancing protection from fire or explosion in the use of electrical equipment in areas where the concentration of vapors of combustible materials may exceed the lower flammability limit. These are: (a) use of explosion-proof equipment; (b) use of intrinsincally safe equipment, and (c) pressurizing or purging.

The concept of protection by explosion-proof equipment is based on the assumption that the vapors can penetrate the housing of the equipment and be ignited therein, but, the design and construction of the equipment must be such that any ensuing fire or explosion will be contained within the housing and not propagate out into the area surrounding the piece of equipment. Devices that use a considerable amount of power, such as motors, pumps, lights, switches, conduits, etc., usually use this means of protection. Because of the magnitude of power used, such equipment might easily release sufficient energy internally in the form of a spark, arc, or heat, under either operating or failure conditions, to ignite any flammable vapors that might have penetrated the housing of the equipment.

Intrinsically safe equipment, consisting of such items as meters, gauges, controllers, instruments, etc., usually have much lower power requirements. The concept of protection here is to design the equipment such that even under failure conditions of very low probability any possible release of energy (e.g., spark or arc) will be so small that under no conditions will it ignite the combustible vapor present (i.e., the energy released is less than the minimum ignition energy for the particular combustible). Hence, no fire can ensue.

The concept of protection by pressurizing or purging is to place the piece of electrical equipment inside a container which is either pressurized or purged continously with clean air or inert gas so that there is no possibi-

lity of flammable vapors from the surrounding area ever reaching a potential source of ignition within the electrical equipment iself.

The studies made by the Panel to date have purposely been restricted to consideration of explosion-proof equipment only.

CLASSIFICATION SYSTEMS

Chemicals vary markedly in their physical, chemical and flammability characteristics. Some are much more hazardous than others and a given piece of electrical explosion-proof equipment may be safe in one environment, but not in another. Differences in ease of ignition, heat and pressure release, diffusivity, quenching distances, flame velocities, reactivity, etc., account for the differences. In recognition of this, chemical vapors are classified into four Groups in NEC 500, as shown in Table 1, with Group A having the most severe requirements for explosion-proof equipment.

If the NEC 500 classification is to be used as the standard, then the ideal rationale for classifying additional materials would be to find a set of values of known or readily measurable properties that would so distinguish each Group of substances listed in Table 1 that by an assessment of the comparable set of values for each new chemical, its classification would almost be automatic. However, a cursory examination of readily available flammability and other properties of the substances listed in Table 1 (which is the complete list at present--an additional 15 compounds are classified tentatively as shown in Table 2) immediately leads to the conclusion that the list is much too restrictive to be used as a highly definitive guide for establishing classifications with a high degree of confidence--based on such properties. Therefore, in order to broaden the base, the British classification for explosion-proof equipment based on British Standards 229,[2] and the German classification based on VDE 0165/8.60[3] were also considered. In the British system, 39 substances have been classified into four main categories, based to a large extent on maximum safe gap values (i.e., the largest gap of a flanged slit through which a flame just barely will not propagate), but also considering pressures generated by an internal explosion, and other factors. The numerical values for slit widths on which classification is based are given in Table 3.

In the German system, compounds are classified in two ways: 65 compounds by the maximum slit width values, and several hundred compounds by their spontaneous ignition temperatures (SIT). The numerical values for classification are given in Table 3, which also gives the values set by the International Electrical Commission (IEC), the USA criteria and the relevant regulations. Since the dividing lines for slit widths for the various categories are so similar for the IEC, Germans and British, the values taken from B.S. 229 will be used primarily in the present report.

Although there is general agreement on classification of most compounds common to VDE 0165, B.S. 229 and/or NEC 500, not all of them fall in comparable categories, as can be seen in Table 4. This complicates considerably any attempt to establish correlations of flammability properties with classification systems.

In addition to B.S. 229, British Standards 1259[5] categorizes close to 100 substances for purposes of classifying intrinsically-safe apparatus and circuits. This system is based on values for the minimum currents needed to just ignite vapors of a compound by an arc. Slack and Woodhead[6] have established a correlation between maximum experimental safe gaps (m.e.s.g.) and minimum igniting currents (m.i.c.), based on the compounds common to both B.S. 229 and B.S. 1259. Except for a few minor deviations, this also leads to a correlation of the classification categories given in B.S. 229 and B.S. 1259. This is shown in Figure 1. If, for a given compound, only the m.i.c. value is known, the m.e.s.g. value can be obtained from the graph given in Figure 1. If the correlation is accepted, this gives a much greater number of compounds that could serve as a base for finding a common denominator that might be used to make correlations with other flammability properties.

It must be mentioned here that attempts to establish correlations of measured flammability properties with classification are still being considered

by others, in this country (e.g., NFPA) and abroad (e.g., the PTB, the German counterpart of the U.S. Bureau of Standards). The IEC is also presently studying the possibility of establishing rules for classification based on minimum ignition currents, minimum ignition energy and safe gaps.[4]

FLAMMABILITY AND OTHER PROPERTIES

The real questions that arise now are: What relevant physical, chemical, and/or flammability properties are readily available that could be used to establish correlations for the chemicals that are of interest to the Coast Guard? What data are now available in the literature (or could be determined easily), how reliable are they, and can they be used? Obviously, vapor pressures, or related values such as boiling points, are important and are available. Heats of combustion, spontaneous ignition temperatures, flash points, and flammability limits are also available for a large number of the compounds of interest.[7,8,9] However, intuitively one would also like to have reliable values for quenching distance (safe gap concept), minimum ignition energies (spark or arc), flame velocities, rate and amount of energy release (rate and total pressure rise), and others, for which data are less available, and in some cases cumbersome to obtain.

Spontaneous ignition temperatures (SIT) are important mainly in that it is necessary to establish a limit for the maximum permissible temperature (with a suitable safety factor thrown in) of the outer face of the casing enclosing an electrical device. Interestingly enough, the literature values for SIT for a given substance quite often vary, sometimes quite markedly. This is because of the great influence of the container geometry (size, shape, etc.) on the experimentally determined value. Also, for many organic materials there are two apparently distinct mechanisms by which spontaneous ignition can occur, and the value obtained depends on which one is controlling, which

again is influenced by environmental conditions. SIT is very dependent on chemical structure and very little related to other flammability charateristics.

Ideally, flash points should essentially be the temperature values for the intersections of the lower flammability and vapor pressure curves (when plotted against temperature). Thus, flash points are highly dependent on volatility and this in itself is useful as an index of safety. However, measured flash points are dependent on the particular apparatus and procedure used for measurement. Since there are a number of these, measured flash points are not absolute values and sometimes can even be quite misleading. Thus, they must be interpreted and used intelligently, particularly when dealing with mixtures or impure materials.

Quenching distances, flame velocities, and pressure rises should be highly relevant to classification, but, as mentioned before, data are limited and harder to obtain. As will be shown later for quenching distances (or minimum gaps), literature data are not always consistent nor in agreement. Minimum ignition energies are of particular interest to intrinsic safety, but are somewhat correlatable to safe gaps,[6] and, hence, might be useful in that sense. Again, however, experimental conditions are so important that the literature values for minimum ignition energies do not always agree, as can be seen, for example, by comparison of the data of Calcote, et al,[10] and that of Metzler.[11] Metzler also presents a correlation between minimum ignition energies and quenching distances. Although this correlation is really quite good, nonetheless, there is still just enough scatter of data to make one apprehensive of using this approach as a tool for classification.

One of the few things left, then, are the two flammability limits, lower and upper. It has been suggested by A. H. McKinney (a member of the Panel),

that the ratio of upper to lower limits (UFL/LFL) gives a fairly good index of flammability properties, particularly as related to hazard. If this ratio is large the given compound is more dangerous (assuming sufficient volatility, etc.). The behavior of many compounds shows that this generalization is true in a qualitative sense, and even semi-quantitative. The question remains, however, is it rigid enough to serve as a reliable tool for classification? Fortunately a considerable body of data on UFL and LFL for many chemicals exists.[7,8]

ATTEMPTED CORRELATIONS

Since, as pointed out earlier, there are not enough compounds in the NEC 500 list, an attempt was made to correlate UFL/LFL with the B.S. 229 classification and with the m.e.s.g. (B.S. 229) as shown in Figures 2 and 3 (using selected compounds chosen to illustrate the point). It is seen that there is enough scatter and overlap to conclude that the correlation is not good enough, and it is advisable to look elsewhere.

Recent papers by LeVine,[12] and Dufour and Westerberg,[13] give the background and results obtained in a study performed at the Underwriters' Laboratories by W. C. Westerberg (a Panel member) and coworkers. In this work, 15 selected chemicals were subjected to flammability tests in a highly instrumented system consisting of two cylinders connected by a variable gap, and, when desired, to a long piece of pipe. Selected vapor mixtures were ignited in one of the vessels or at the far end of the pipe. The device also has the capability of running tests under turbulent gas conditions if desired (e.g., simulation to a running electric motor). Thus, safe gaps (i.e., no penetration of flame into second vessel) and total pressure rises could be measured under quiet or turbulent conditions, as well as maximum pressure rises due to "pressure-piling" effects in the pipe (e.g., simulation to electrical conduits). Based on the excellent and duplicable results obtained, and by comparison

with corresponding data obtained on chosen compounds from the NEC 500 list, the 15 compounds have been classified according to the NEC 500 groupings. These proposed classifications were issued on 14 February 1968, by the Correlating Committee of the NFPA as a Tentative Interim Amendment to the 1968 Edition of the NEC.[13] If fully accepted, a much broader basis thus becomes available for making comparisons using the NEC 500 classification (in keeping with the original Coast Guard request).

Data obtained in the above study[13] for maximum safe gap and maximum pressure under conditions of turbulence and pressure-piling (the most severe conditions) are given in Table 2. The data (including 7 compounds originally in the NEC 500 list for comparison) are arranged by decreasing gap size. The rationale for classification (last column, Table 2) is based on gap size, pressure rise, and SIT (SIT values taken from NFPA-325M) since these properties are indeed important to the design and operation of explosion-proof electrical equipment located in a hazardous environment.

Although experimentation of the type done at the Underwriters' Laboratories is more straight-forward and controllable than the testing of actual electrical equipment in a hazardous environment, nonetheless, it still involves a fair amount of tedium and time to accumulate all the data needed. Therefore, if a rigid correlation of the data in Table 2 with the data presently available in the literature could be established, the classification of other chemicals would be greatly simplified. Accordingly, a comparison of UFL/LFL versus gaps and classifications, as given in Table 2, was made. These are shown in Figures 4 and 5 respectively. Again, it can be seen that the correlation is not completely rigid.

In the proposal for acceptance of the classifications given in Table 2 to the NFPA,[13] it was also recommended that butadiene be placed in Group D,

and ethylene and propylene oxides in Group C, if connecting conduits are sealed off from the electric equipment (i.e., to prevent possible pressure-piling effects which were found to be high for these compounds). But even with these changes, correlations with UFL/LFL are still not rigid.

Heats of combustion (ΔH) of many chemicals are also readily available in the literature. For most hydrocarbons the product of ΔH and LFL is reasonably constant,[14,15] but for more hazardous materials, such as H_2, this product is much lower. Thus, it was of interest to compare $\Delta H.LFL$ with classification schemes. This is illustrated in Figure 6 which shows a plot of $\Delta H.LFL$ versus classification using the assignments from Table 2. Again, since an overlap is seen, the correlation is not rigid.

In addition to the schemes already discussed, several other combinations of readily available physical, chemical and/or flammability properties have also been examined, at least cursorily, to see if they showed promise. Unfortunately, to date, no combination has been found that could be considered really acceptable for classification purposes even though it is obvious that there certainly are parallelisms. Flammability, especially when connected with hazard, is a very complex business, and does not lend itself to simple quantification, particularly when additional complications are introduced by electrical and mechanical gear. The fact that there are many parallelisms among flammability properties implies that nature is not really capricious, and is trying to tell us that she does indeed have order in her system. As a result, there is still the uneasy intuitive feeling that correlations might indeed exist but we have not yet found them. Perhaps it is just that we have not yet learned how to ask nature the right questions.

Part of our troubles arise from the fact that when we try to measure a property, we must use specific techniques and devices for the purpose which we

try to design in the best fashion we can. That we have not reached the ultimate, particularly in the field of flammability hazard, is evidenced by the fact that different experimenters do not always get the same answers when trying to measure the same property. For example, Figure 7 shows a comparison of data for experimental safe gaps taken from B.S. 229 and from Table 2. Both sets of data have been obtained in well designed equipment and by careful procedure. Yet, they do not agree (even the coincidence line does not extrapolate to the origin). It is recognized, of course, that flammability properties are not simple and in most cases both the procedure and the equipment can have a marked influence on results obtained. The current controversies over which flash points to use (e.g., open versus closed cup), the disagreements over the true values, significance and application of SIT values, and the wide discrepancies in literature values for these and other flammability parameters, are all cases in point. It is difficult to believe that nature should be that capricious. It is more likely that, in our courting her, she is being demure in resisting our probing into her secrets too fast and too far.

DISCUSSION

In assessing our present position, we must conclude that we are not yet ready to classify chemicals (in the vapors of which we plan to use explosion-proof electrical equipment) based on readily available data or easily determined flammability properties. However, other helpful generalizations might be suggested. For example, it might be considered that using flash point as a criterion (and interpreting and using it intelligently) the following argument might be made. If a substance has a flash point well above any temperature that substance will encounter, then the problem is not one of hazard due to vapors in a given space because in such space the concentration of vapor would be below the lower flammability limit. However, mist or foam formation and

liquid wetting might still pose problems which cannot be ignored in the overall design. Possibly, then, dividing lines, based on whether flash points are above or below them, might be useful in particular applications. Another example would be to use homology. Thus, it would be quite reasonable to expect that if a substance such as, say, n-hexane were classified in a given Group, its next higher homolog, n-heptane would also fall into the same Group. But reliance on such a system could be carried only just so far, and such judgments would have to be made by individuals who have had considerable experience in the field and who have developed intuition in addition to knowledge of experimental facts.

In trying to reach a conclusion, on which at least a tentative recommendation might be made regarding classification, it appears that the best solution at present would be to perform tests on chemicals of concern by a scheme such as that used at the Underwriters' Laboratories, and couple such tests with other information available. It would be desirable that the tests include the effects of turbulence and pressure-piling. Such a procedure, even though it is time-consuming and does require special apparatus, is nevertheless much simpler than the present requirement of testing actual electrical gear in vapor-air mixtures of the chemical compound of interest to determine whether it is explosion-proof or not. Furthermore, it has the added advantage of giving consistent results (which include quantitative values for pressures, gaps, etc.) so that new knowledge about flammability behavior of additional chemicals is engendered and, thus, comparisons among chemicals would become much more significant.

If one attempts to subdivide safety from fire in the use of explosion-proof electrical equipment, three important components emerge. As mentioned earlier, these were recognized in the Underwriters' Laboratories work, and

were used as a basis for the proposed classification.[13] These three items (cf. Table 2) deal with the (1) maximum safe gap, (2) the pressure rise, and (3) the spontaneous ignition temperature, all of which are related to the design and structure of electrical equipment. The first two items assume that a fire or explosion can take place inside the housing of the equipment.

It is impractical to try to make electrical systems completely hermetically sealed. Thus, flanges, joints, seals (especially around moving parts such as shafts on motors and pumps), etc., will have a small clearance which may enlarge in time due to corrosion, wear, use and/or abuse. From a safety standpoint, then, it is imperative that such a clearance (slit or hole) never exceed the maximum safe gap for the particular chemical vapor in which the electrical system is to be used. The rationale here is that if a fire gets started inside the housing, it would be quenched before it could propagate out through the clearance into the main vapor space surrounding the equipment--a vapor space which might contain an explosive mixture, which if ignited could cause a disaster. Thus, reliable data on maximum safe gaps are important.

The second item, pressure rise, has to do with the strength of the housing of the electrical gear, thus affecting its design and structure. The concept here is that as a result of a fire or explosion inside the housing, the increased pressure generated by the fire or explosion might buckle, bulge or distort the housing sufficiently to open up any existing clearances (or create new ones) in the equipment to a size greater than the maximum safe gap. This would allow the still active fire to propagate through the clearance into the main vapor space surrounding the equipment. Under turbulent conditions in a confined space (e.g., a running motor), pressure build-up is often greater than under quiescent conditions. Hence, the need for obtaining reliable pressure-rise data under conditions of both turbulence and quiescence.

Also, the phenomenon of pressu -piling in long tubes (e.g., electrical conduits) varies with the flammable material, and maximum pressures reached may be much higher than those generated in other geometric shapes. Hence, the desirability for data on pressure-piling in addition to other pressure-rise values.

The third item, spontaneous ignition temperature, does not assume that a fire is started inside the housing. It is concerned with external (or skin) temperatures reached anywhere on a given electrical system--temperatures resulting from heat generated by work, friction and/or ohmic resistance. Since the outside skin of a piece of explosion-proof equipment might be in direct contact with a potentially explosive mixture, knowledge of spontaneous ignition temperatures becomes important. Values for spontaneous ignition temperatures for most chemicals of interest are already available (e.g., NFPA-325M), but it must be cautioned again that in the determination of SIT values, the results obtained are very dependent on the procedure and equipment used. Literature SIT values for a given substance may vary considerably, in some instances by as much as several hundred degrees.

As can be seen from Table 2, the three flammability criteria discussed above are not interdependent. Indeed, for safety purposes in the classification of chemicals, they should be considered as being mutually exclusive and each one should be used separately as a criterion for classification.* That no single one of them can be used alone is illustrated in Figure 8, in which the UL data for safe gaps only are plotted against the proposed classification (cf. Table 2). It can be seen that there are decided overlaps. This is because a given compound (e.g., butadiene) may have a comparatively large safe

*See footnote, p. 16

gap, (0.031 in., and thus would appear to be safe), but also generate a comparatively large pressure rise, (260 psi, thus making it more hazardous). Therefore, such a compound would have to be placed in a more restrictive Group in NEC 500 (cf. in Table 2, butadiene being proposed for Group B, with gasoline, 0.029 in. gap., 160 psi pressure, already assigned to Group D). By the same token a compound may have a low value for SIT and, regardless of its other values, this would require that it be placed in a higher Group (cf. in Table 2, isoprene, SIT of 220°C, being proposed for Group C, with gasoline, SIT of 280°C, already assigned to Group D). It is evident, then, that each one of the three criteria should act as independent cut-offs for classification, and for a given compound to be classified in any one Group, it must meet all three requirements that would be set for that Group, not just one or two of them.

The question next arises as to what the cut-off values should be for each of the three criteria for each Grouping. In the UL work[13] these were based on values determined for the compounds already included in NEC 500 (marked with an asterisk in Table 2) using the same technique as that used for the rest of the chemicals. But as has already been pointed out, the paucity of compounds listed in the original NEC 500, especially in the more stringent categories, forces the use of a rather small base on which to make judgments. Indeed, because of this, an apparent anomaly results from the values that are available for use as cut-offs for spontaneous ignition, e.g., ethyl ether, SIT of 180°C, (Group C) has a SIT much lower than hydrogen, SIT of 585°C, (Group B) and also lower than acetylene, SIT of 300°C, (Group A). But, as new knowledge and experience are gained, a broader base will become available on which to make judgments, and values for cut-offs will eventually be established with more confidence.

On an optimistic note, it would seem that in time, then, if reliable

values were obtained for the three flammability criteria discussed above for any new chemical, these might be used as a means for its classification. This would certainly be a great improvement over the present cumbersome method.

FUTURE PLANS

Since it has been shown that a reliable NEC 500-type classification system cannot be made at the present time based on literature values for physical, chemical and/or flammability properties of chemicals, and since it has been implied earlier in the DISCUSSION that tentative classifications might be arrived at (for many compounds at least) by a panel of people knowledgeable in the area, the Panel is proceeding along the following lines. Relevant physical and flammability data on each chemical of interest to the Coast Guard are being sorted and compiled and a master list is being prepared. The data will first be tabulated and the flammability limits and vapor pressures (or boiling points) will be categorized by computer by Mr. McKinney (DuPont). These categorizations and other available data will be furnished to the Panel members for individual judgments on tentative classifications, from which, then, collective judgments will be made. Outside counsel will obviously be solicited in this process. Compounds for which data are lacking or are questionable, or on which agreement cannot be reached, will be left open. Compounds from such a group would be excellent candidates for further laboratory study, particularly by the Underwriters' Laboratories technique. The cost of such studies would be about $1000 per compound, depending on the properties of the individual gas or vapor.

There is a decided feeling among Panel members that the present method of classification by the NEC 500 is somewhat arbitrary, being based, as it is, too much on the history of its development, and that a more clean-cut rationale, based on laboratory data, for the values delineating the divisions between

classes, or for defining classes, is sorely needed. However, since the Panel was enjoined not to depart from the current NEC 500 classification, the subject has not been pursued. However, the Panel does feel that this concept should be studied further, and it is our intention at least to consider it seriously at a later date.*

Looking farther into the future, the subject of Intrinsic Safety will be the next main topic for study by the Panel.

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*In this regard, the Panel Chairman applauds as another step in the right direction the very recent proposal being made by the Sectional Committee on Electrical Equipment in Chemical Atmospheres (Richard Y. LeVine, Chairman) of the NFPA Committee on Chemicals and Explosives to amend Section 500-2 of the NEC, which has just been brought to his attention (12/10/69). This proposal is based on the recognition that explosion characteristics and ignition temperatures are two critical but <u>independent</u> properties of a chemical. It recommends that in addition to Group classification based on explosion characteristics that Section 500-2 of the NEC include spontaneous ignition temperatures for all the chemicals listed and that it be required that maximum surface temperatures be marked on approved equipment. This will permit selection of equipment for use with a given chemical on the basis of explosion characteristics (Group) <u>and</u> ignition temperature.

The pressure and need to modify the criteria used for classification is shown further by other proposals that will be made (to Panel 14 of the NFPA Electrical Code Committee) to modify the NEC 500 to use minimum safe gaps as a primary basis for classification rather than the present method, so that new compounds may be added to the classification system more readily (Private communication from Ernest Magison, a panel member, to the panel chairman, dated 11/26/69).

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LIST OF FIGURES

Table 1

NEC - 500 CLASSIFICATION

Group *	Substances
A	Acetylene
B	Hydrogen, manufactured gas
C	Ethyl ether, ethylene, cyclopropane
D	Gasoline, hexane, naphtha, benzine, butane, propane, alcohol, acetone, benzol, lacquer solvent, natural gas

* Solids, which are classified into Groups E-G, will not be considered here

Table 2

UNDERWRITER'S LABORATORIES FLAMMABILITY DATA
ON GAS AND VAPOR-AIR MIXTURES (13)

Chemical Atmosphere	Expt'l. Max. Safe Gap (in.)	Maximum Explosion Press. (psi)	Min. Ign. Temp. (°C)	Tentative Group Classif. (NEC 500)
p-Xylene	0.048	128	529	D
Vinyl Acetate	0.041	128	427	D
*Butane	0.039	145	405	D
Ethylene Dichloride	0.039	109	413	D
Ammonia	0.039	56	651	D
*Propane	0.037	148	466	D
Styrene	0.037	133	490	D
Propylene	0.036	150	497	D
Isoprene	0.034	153	220	C
Acrylonitrile	0.032	160	481	D
Butadiene	0.031	260	429	B
*Gasoline	0.029	160	280	D
Vinyl Chloride	0.029	148	451	D
*Ethylene	0.027	180	450	C
Propylene Oxide	0.021	280	449	B
UDMH	0.018	109	249	C
Acetaldehyde	0.017	164	174	C
Ethylene Oxide	0.013	>1000	429	B
*Diethyl Ether	0.012	200	180	C
*Hydrogen	0.003	845	585	B
*Acetylene	0.003	1140	300	A
Carbon Disulfide	0.002	205	100	None **

* Presently classified in NEC 500

** Requires safeguards beyond those required for NEC 500 groups.

Table 3

BASES FOR COMPOUND CLASSIFICATION (ELECTRICAL EQUIPMENT) (3)

International Electrical Commission

Slit Width

Group 1 - >1mm
2 - 0.6-1.0mm
3 - 0.38-0.6mm
4 - <0.38mm

Regulations

IEC-Publ. 79-1
IEC-Publ. 79-2

German

Slit Width

Fire damp - >1mm
Class 1 - >0.6mm
2 - 0.4-0.6mm
3 - <0.4mm

Ignition Temp.

Group G1 - >450°C
G2 - 300-450°C
G3 - 200-300°C
G4 - 135-200°C
G5 - 100-135°C

Regulations

VDE 0051/X,43
VDE 0165
VDE 0170/71

British

Slit Width

Group 1 - >0.86mm (only methane)
2 - >0.64mm
3 - 0.38-0.64mm
4 - <0.38mm

Regulations

B. S. Code of Practice CP1003
B. S. 229

USA

Tentative NEC classification based on slit width, max. press., and min. ign. temp. by comparison with NEC 500 compounds (See Tables 1 and 2)

Regulations

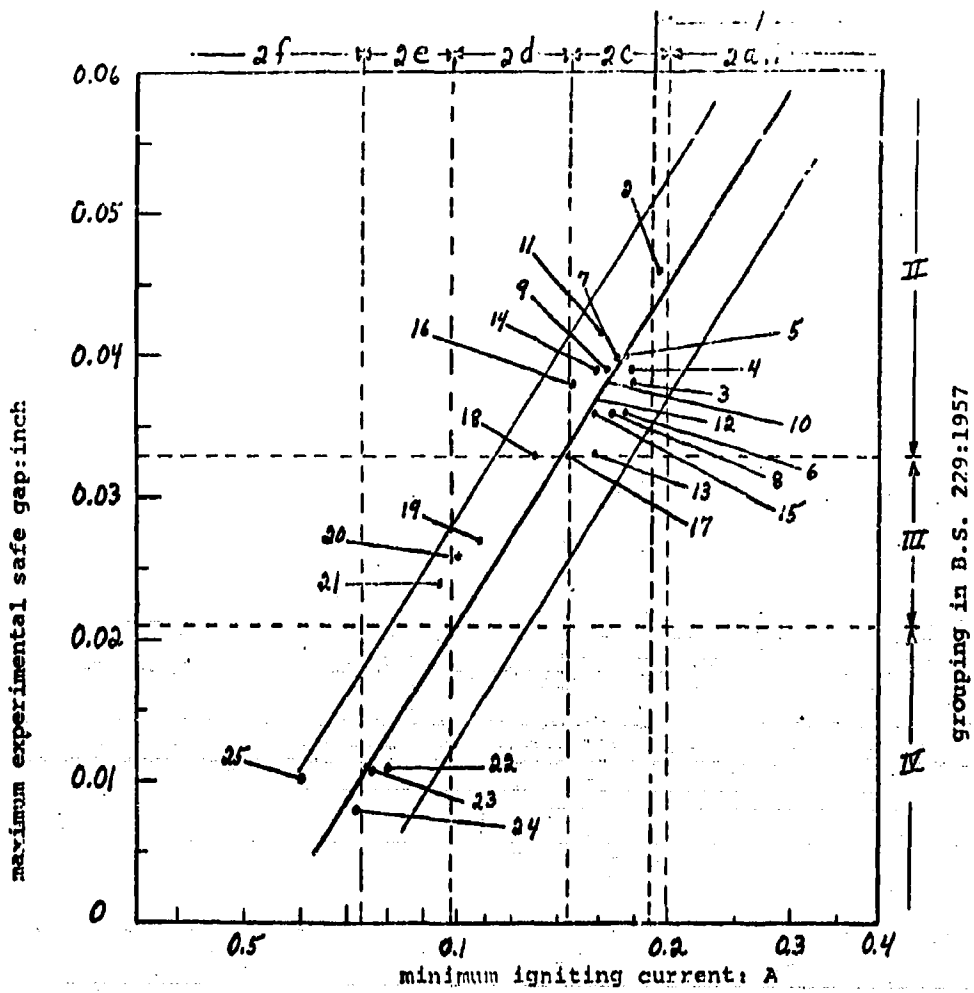
NEC 500

Table 4

COMPARISON OF U.S., BRITISH AND GERMAN CLASSIFICATIONS

Compound	Tentative NEC500 (US)	B.S 229 (BRIT.)	VDE 0165 (GER.)
Carbon Disulfide	None*	4	3b
Acetylene	A	4	3c
Hydrogen	B	4	3a
Butadiene	B	2	2
Ethylene Oxide	B	3	2
Propylene Oxide	B	-	2
Acetaldehyde	C	-	1
Diethyl Ether	C	3	-
Ethylene	C	3	2
Isoprene	C	-	2
Ammonia	D	2	1
Butane	D	2	1
Gasoline	D	-	1
Propane	D	2	1
Propylene	D	-	1
Styrene	D	-	1
Vinyl Chloride	D	2	1
p-Xylene	D	2	1

* Requires safeguards beyond those required for NEC 500 Groups.



2.	Methane	10.	N-Hexane	18.	Buta-1:3-diene
3.	Chloroethylene	11.	Butane	19.	Ethylene
4.	Methyl acetate	12.	Cyclohexane	20.	Ethylene oxide
5.	N-Butyl acetate	13.	Methylethyl ketone	21.	Town gas
6.	N-Heptane	14.	Benzene	22.	Water gas
7.	Acetone	15.	Carbon monoxide	23.	Hydrogen
8.	Methyl alcohol	16.	Propane	24.	Carbon disulphide
9.	Pentane	17.	Diethyl ether	25.	Acetylene

FIGURE 1

Redrawn from Slack, C. and Woodhead, D. W., Proc. I.E.E. 113 297 (1966)

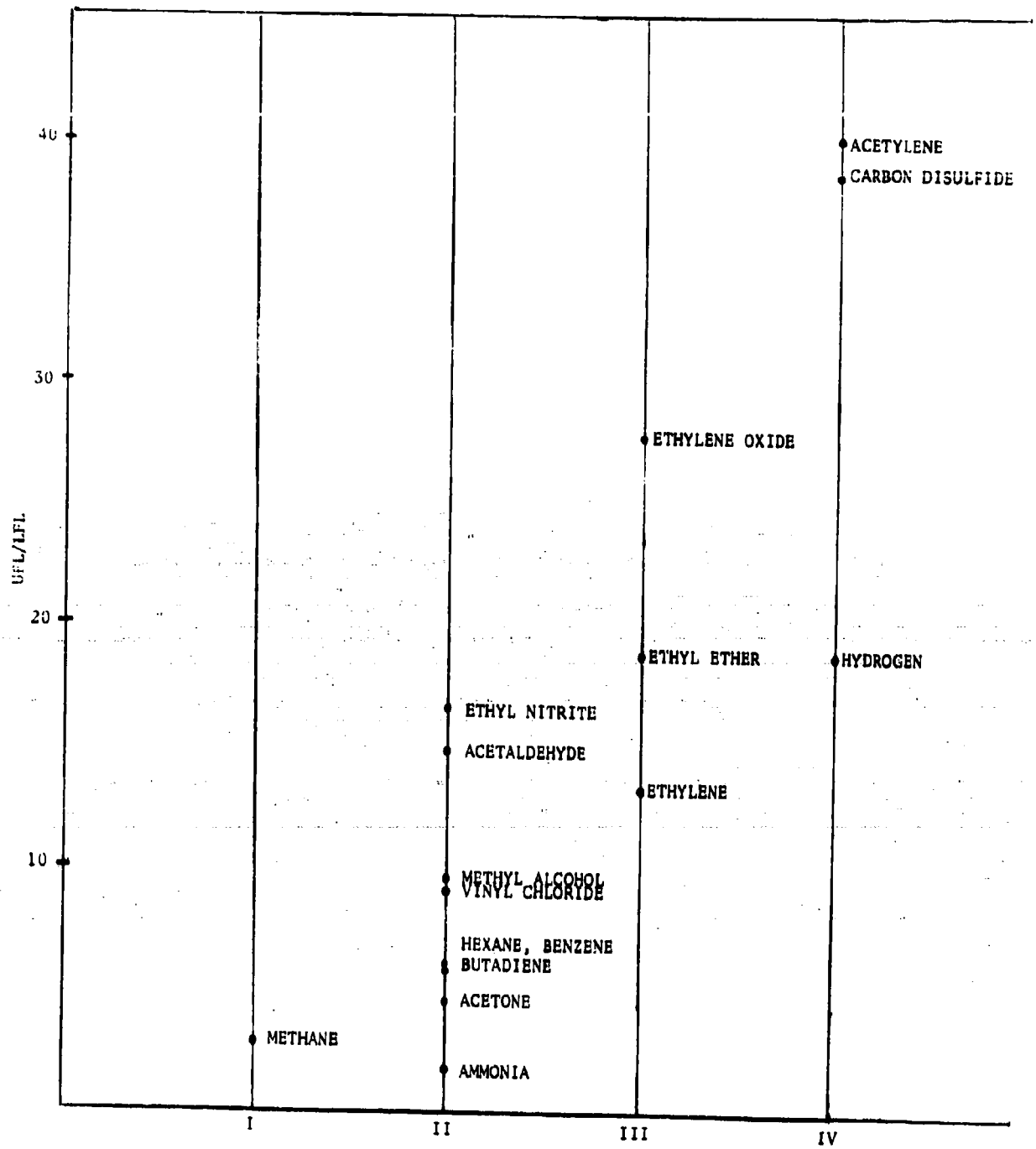


FIGURE 2: B.S. 229 GROUP

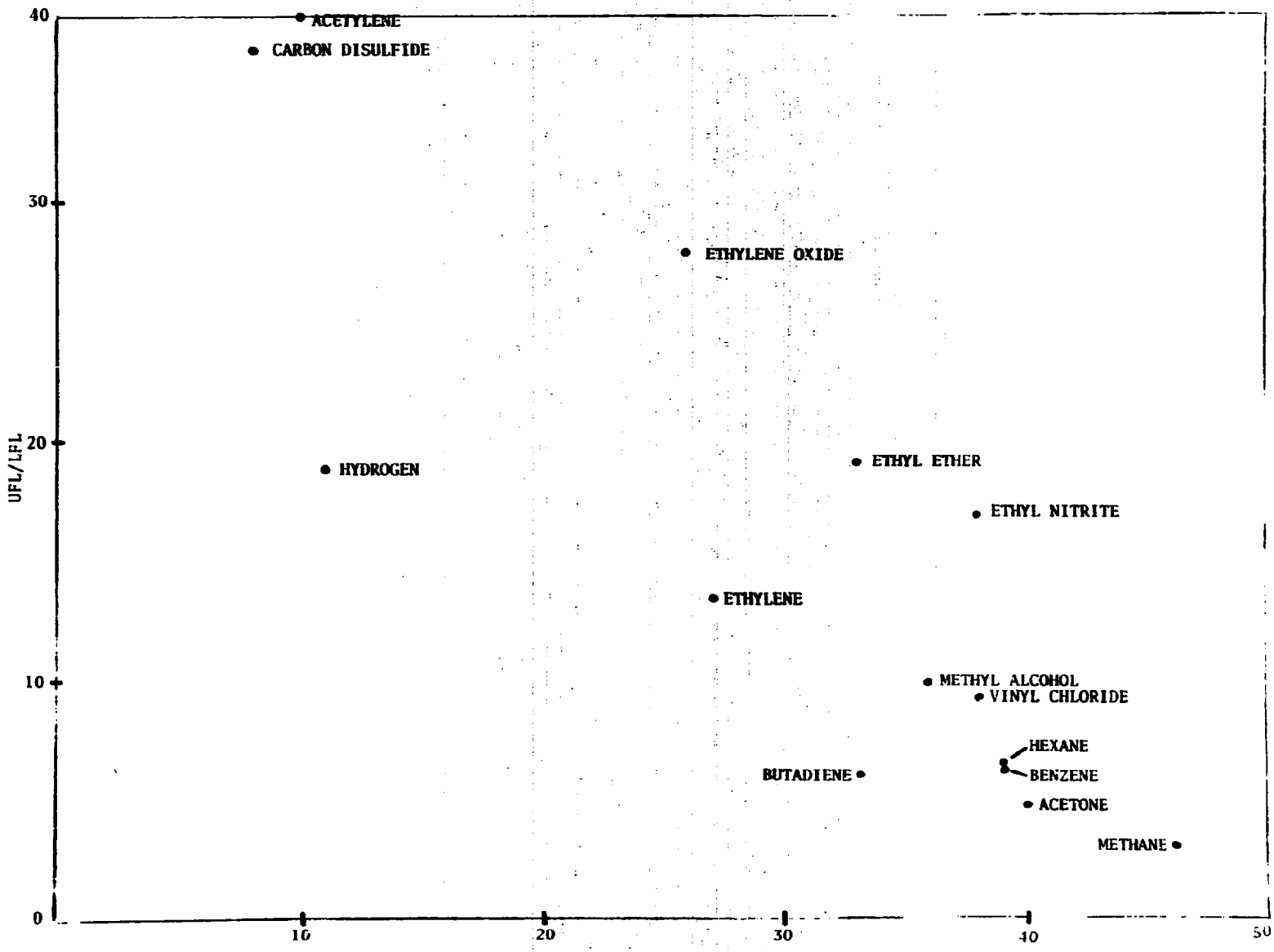


FIGURE 3: B.S. 229 MAXIMUM EXPERIMENTAL SAFE GAP, MILS

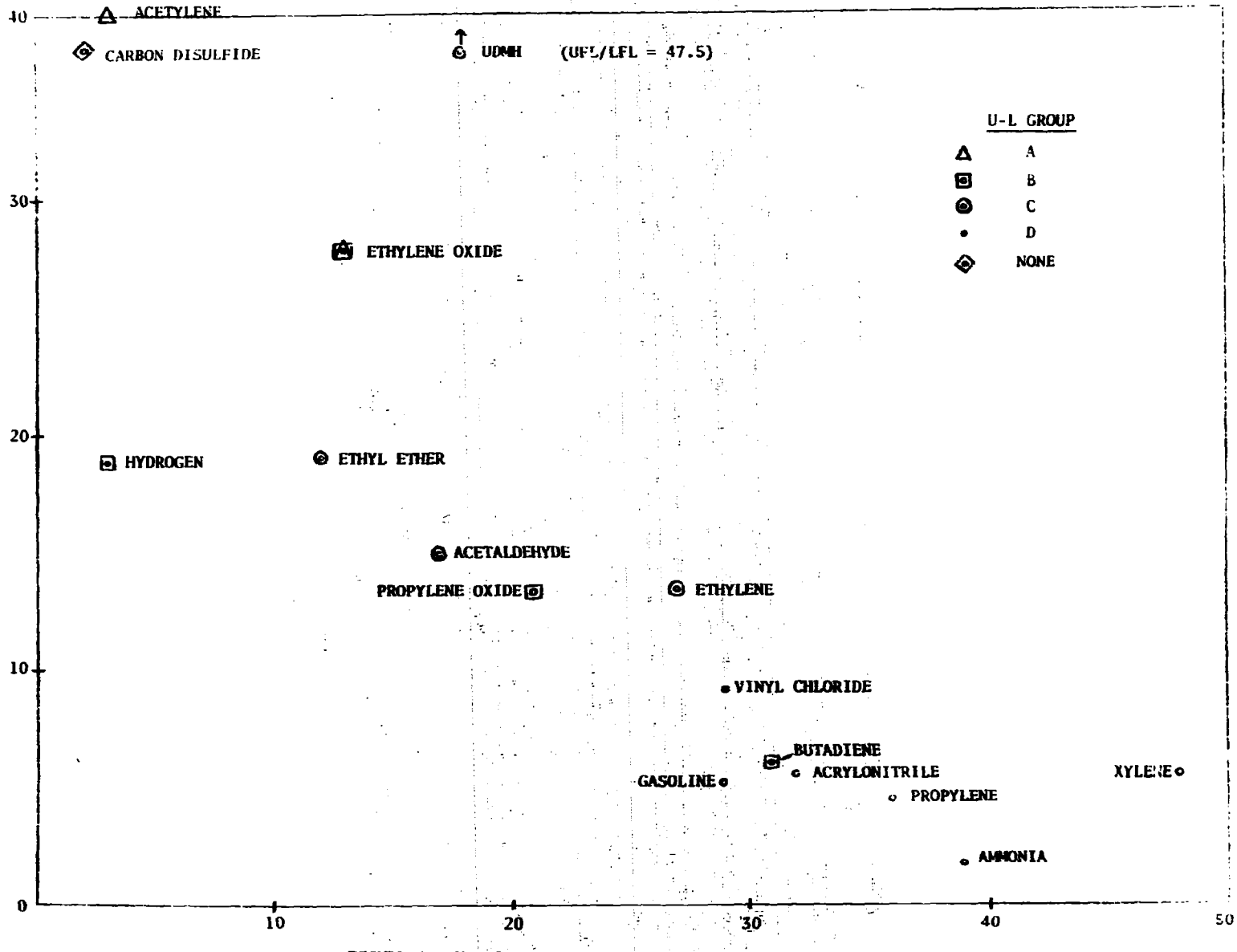


FIGURE 4: U-L EXPERIMENTAL MAXIMUM SAFE GAP, MILS

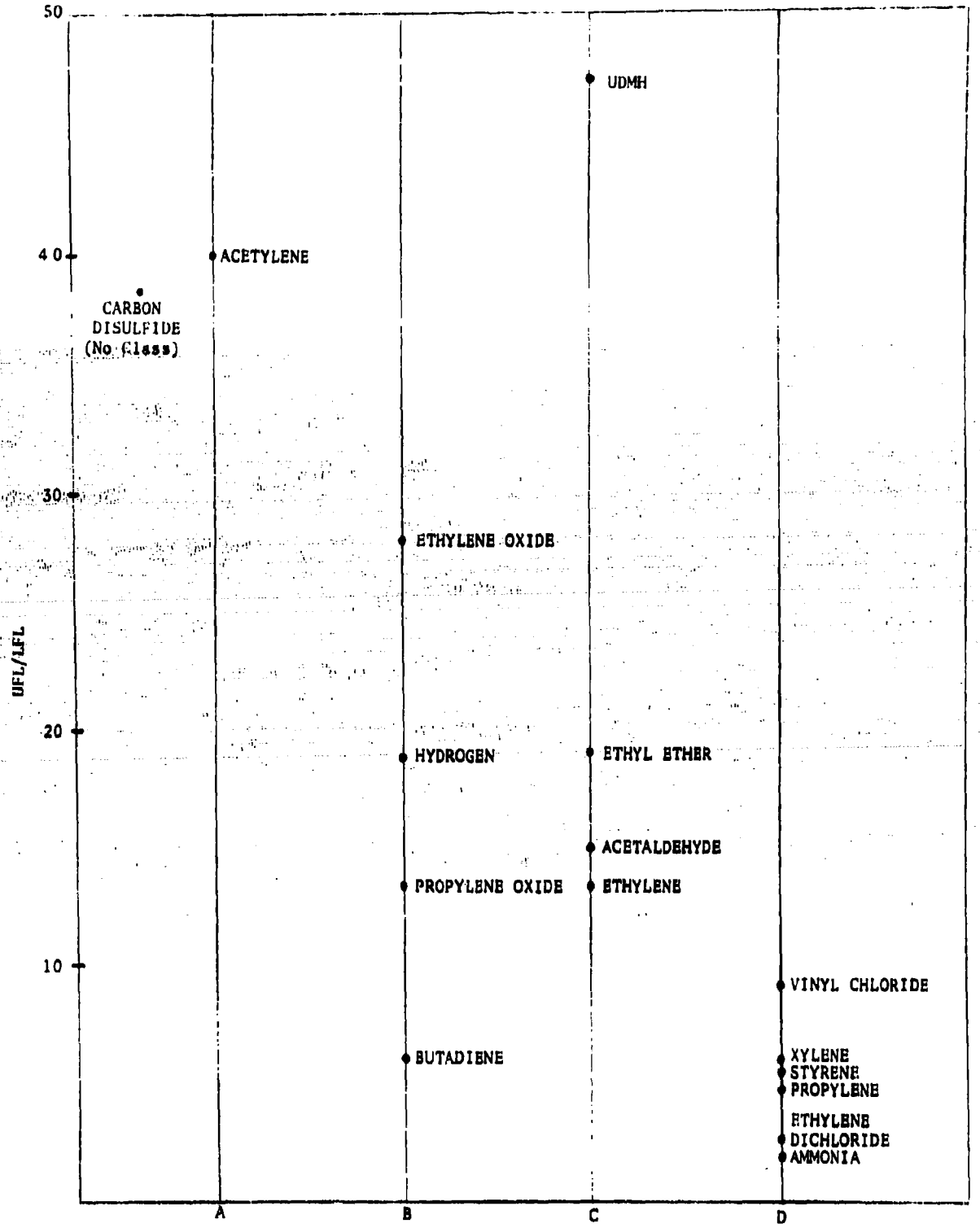


FIGURE 5: TENTATIVE GROUP CLASSIFICATION (NEC 500)

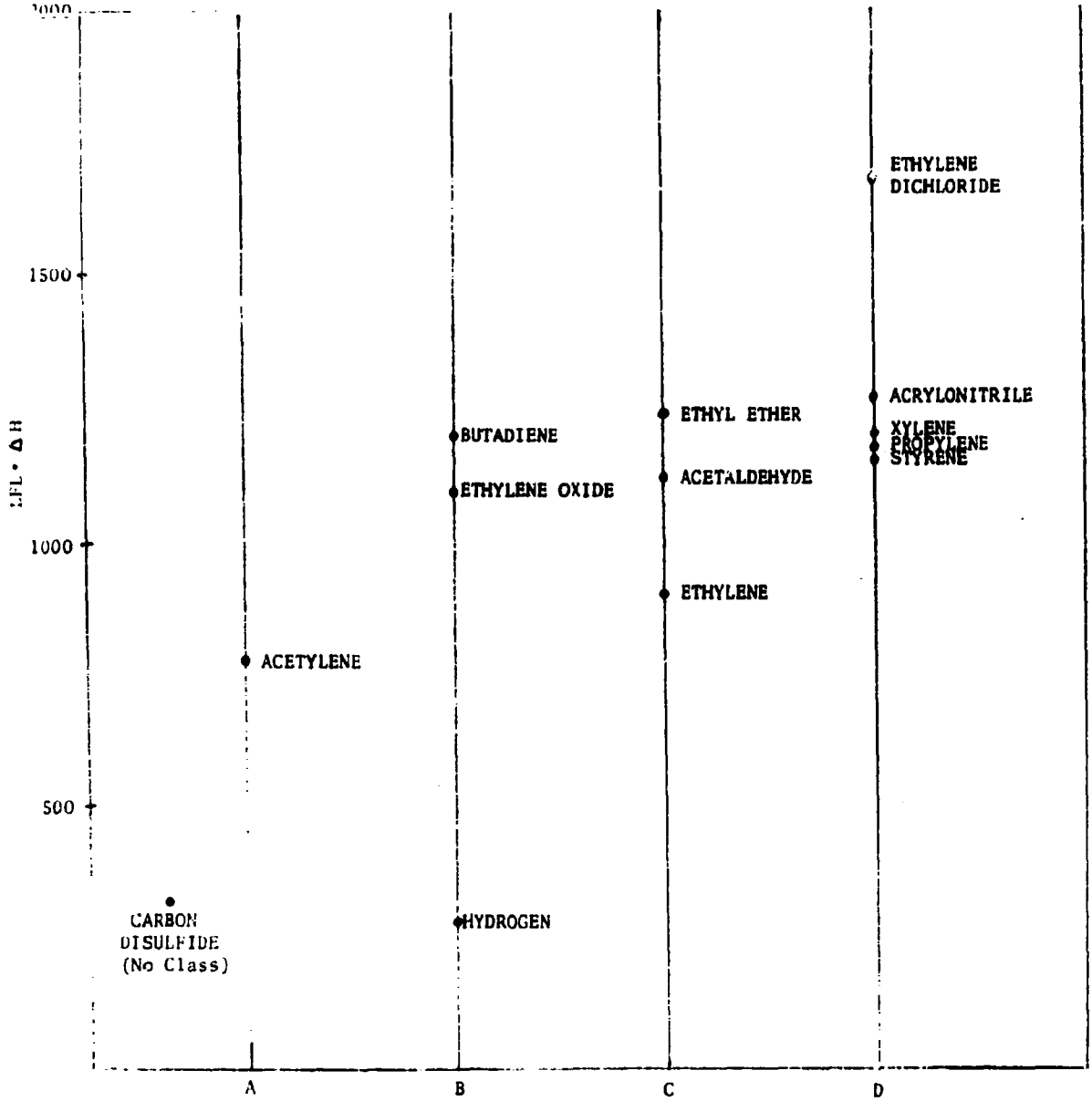


FIGURE 6: TENTATIVE GROUP CLASSIFICATION (NEC 500)

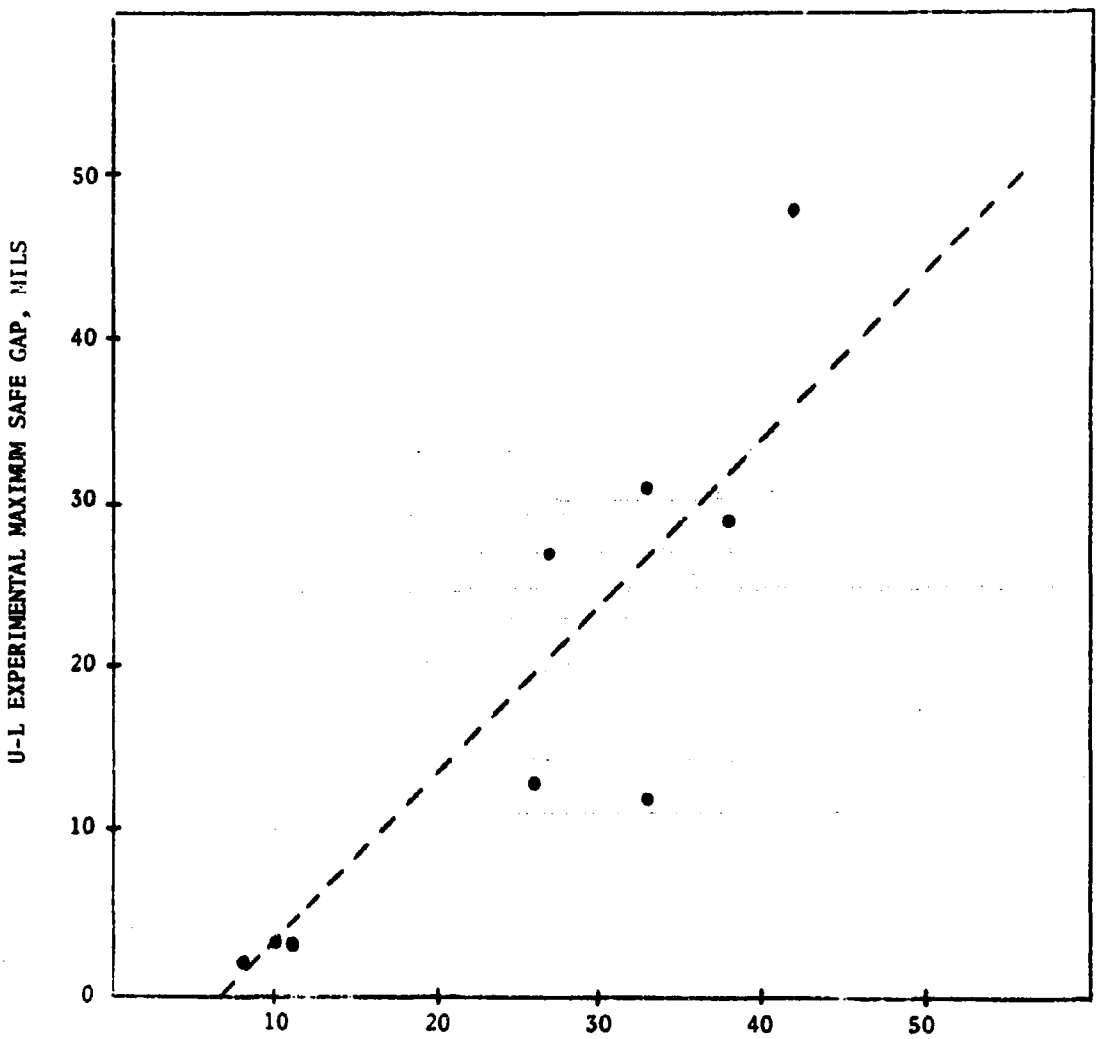


FIGURE 7: B.S. 229 MAXIMUM EXPERIMENTAL SAFE GAP, MILS

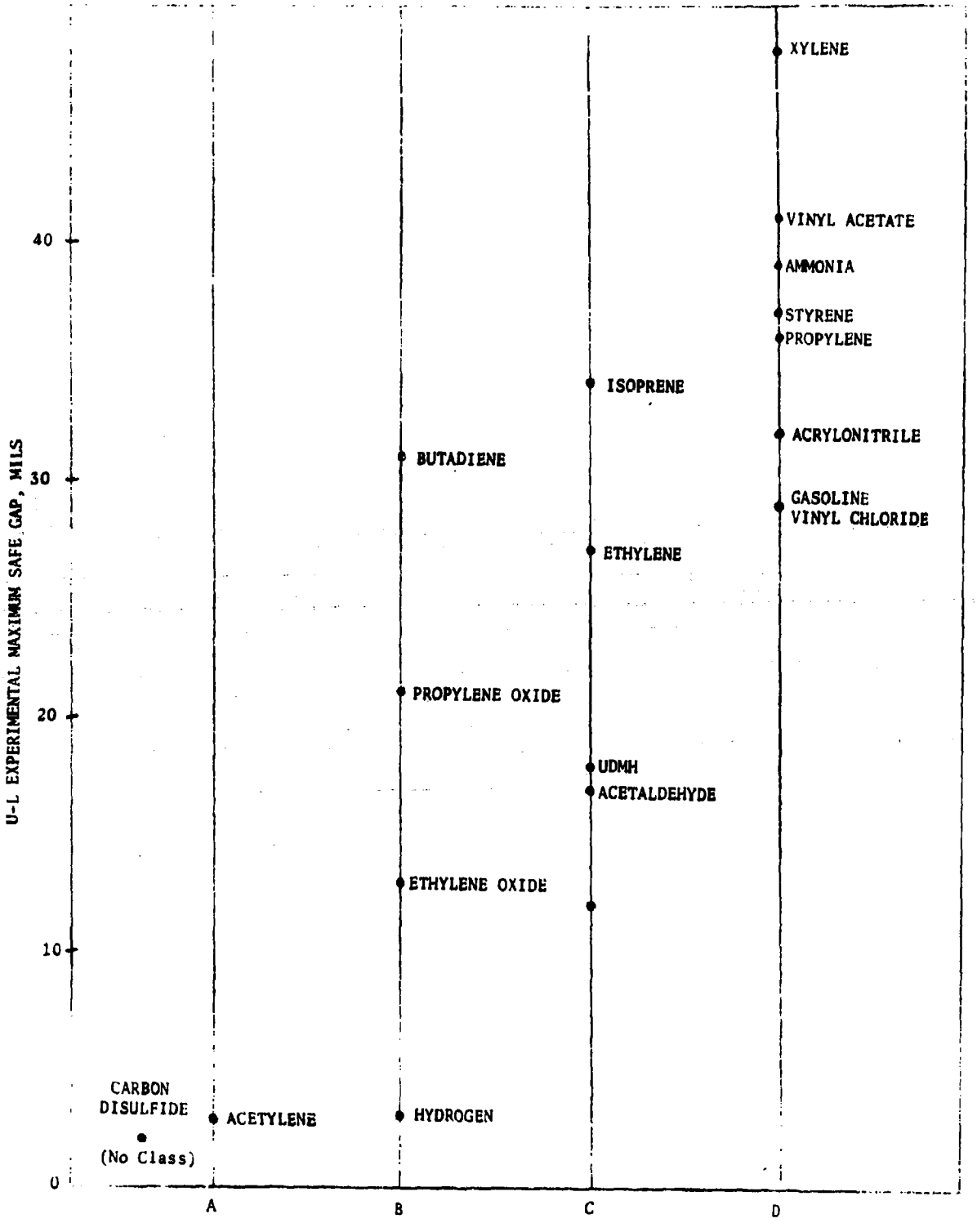


FIGURE 8: TENTATIVE GROUP CLASSIFICATION (NEC 500)

~~UNCLAS~~ Security Classification

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13. ABSTRACT

At the request of the U.S. Coast Guard, a detailed study has been made by the Electrical Hazards Panel of the Committee on Hazardous Materials to determine the feasibility of classifying some 200 chemicals of commerce according to the classifications given in the National Electric Code, NEC 500, by using a scheme based entirely on available physical and flammability properties only. If successful, the system would eliminate the present laborious process of actually testing the piece of electrical equipment in the vapors of the particular chemical of concern.

Because of the paucity of approved compounds classified in the present NEC 500, the classification base-lines used in the present study were extended to include those of the British Standards, B.S 229, Explosion-proof, and B.S. 1259, Intrinsically-safe, equipment, plus a new list of 15 chemicals recently included as tentative in the present NEC 500 classification based on extensive testing at the Underwriters' Laboratories.

The physical-chemical and flammability properties studied either alone or in combination in trying to establish correlations with the base-lines above were: the limits of flammability, especially the ratio of these limits (upper/lower), flash points, vapor pressures, quenching distances, spontaneous ignition temperatures, maximum safe gaps, minimum ignition currents, minimum ignition energies, pressure rises, and heats of combustion.

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ABSTRACT (continued)

Although in the attempted correlations many trends were found in a qualitative sense indicating that relationships and dependencies do exist in a general way among properties studied, none were found that were unequivocal or even sufficiently reliable to merit recommendation at the present. In every instance, there were maverick compounds that just would not fall in line.

Therefore, it is concluded that the time has not yet arrived when we can classify chemicals in a rigid mathematical way according to the NEC-500-type classification using available physical-chemical and flammability properties only.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electrical Equipment						
Fire Hazard						
Explosion-proof						
Hazard Classification						
Chemicals						
Flammability						
Flash Point						
Ignition Currents						
Spontaneous Ignition						
Ignition Energy						
Heat of Combustion						
Vapor Pressure						