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CONTENTS

General Concepts and Scope	
1-1 Purpose and Scope.....	5
1-2 General Concepts	5
1-3 Basic Considerations in the Preparation of Standards.....	6
Temperature Classification of Insulating Materials	
1-4 Material Test Procedures.....	7
1-5 Classes of Insulating Materials.....	7
1-6 Factors Affecting the Thermal Evaluation of Insulating Materials.....	8
1-7 Definitions of Insulating Materials.....	8
Temperature Classification of Insulation Systems	
1-8 Insulation Systems—General	9
1-9 Definition of Insulation System Classes.....	9
1-10 Thermal Evaluation Test Procedures for Insulation Systems.....	9
1-11 Limiting Temperatures for Insulation Systems.....	10
Temperature and Its Measurement for Equipment Rating Purposes	
1-12 Definition of Terms.....	10
1-13 Derivation of Temperature Rise.....	10
1-14 Limiting Insulation Temperature.....	11
1-15 Ambient Temperature	11
1-16 Hottest-Spot Temperature Allowance.....	11
1-17 Limiting Observable Temperature Rise.....	11
1-18 Methods of Temperature Determination.....	12
1-19 Selection of Methods of Temperature Determination.....	12
1-20 Effects of Altitude.....	13

APPENDIX I

Temperature Characteristics of the United States and Canada.....	14
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APPENDIX II

Bibliography	19
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GENERAL PRINCIPLES UPON WHICH TEMPERATURE LIMITS ARE BASED IN THE RATING OF ELECTRIC EQUIPMENT

GENERAL CONCEPTS AND SCOPE

1-1. Purpose and Scope

These principles are intended to serve as a guide in the preparation of AIEE and other Standards which deal with the selection of temperature limits and the measurement of temperature for specific types of electric equipment. They include an outline of the fundamental considerations which determine the selection of temperature limits, appropriate methods of temperature measurement, and a discussion of the factors to be considered in applying the principles to specific cases. Guiding principles are also included for the development of Test Procedures for the thermal evaluation and classification of electrical insulating materials and of insulation systems for use in electric equipment.

Insulating materials, as referred to herein, include processed compositions of raw materials and simple combinations thereof before they are fabricated into coils or other structures identified with specific parts of electric equipment.

Insulation systems, as referred to herein, include fabricated and processed combinations of insulating materials with the associated parts of electric equipment. Such equipment may contain more than one insulation system.

The recommendations are not mandatory nor is it expected that they will be followed precisely. It is recognized that variations will be necessary to suit the widely different types of equipment and service conditions that are considered in equipment Standards. The temperature limits and other provisions given herein are not intended to be used for rating or testing equipment for which specific AIEE, American, or other recognized Standards are available. The companion AIEE publications* Nos. 1A, 1B, 1D, 1E and 1F complement and extend the concepts outlined in the present document.

1-2. General Concepts

Temperature rise limits established for rating pur-

- * AIEE No. 1A—"Report on General Principles for Rating Electrical Apparatus for Short-Time, Intermittent or Varying Duty"
- AIEE No. 1B—"Report on Guiding Principles for the Specification of Service Conditions in Electrical Standards"
- AIEE No. 1D—"Guide for the Preparation of Test Procedures for the Thermal Evaluation of Electrical Insulating Materials"
- AIEE No. 1E—"Guide for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electrical Equipment"
- AIEE No. 1F—"Report on Guide for Statistical Analysis of Test Data"

poses are most useful if they correspond to the performance of electric equipment operating under usual service conditions.

The temperature limits for electric equipment should be so chosen that they will result in a satisfactory life under normal operating conditions. In addition, permissible emergency temperature limits and corresponding ratings may be established including the durations and frequencies of emergency operation to which these limits apply. Temperature is not the only design criterion since the suitability of an insulation system for a specific application is influenced by other requirements such as endurance under electrical and mechanical stress, vibration, exposure to moisture, chemicals, etc., and by the atmosphere or enclosure in which the equipment operates.

In choosing temperature rise limits suitable for particular conditions, the following general concepts may be helpful:

1. Marked changes in the electrical and mechanical properties of insulating materials may occur progressively as a result of prolonged exposure to high temperature. The materials may soften, lose weight, or become brittle, and their chemical composition and structure may change. The effects of high temperature may differ widely depending upon the particular environmental conditions. Insulation does not usually fail by immediate breakdown at some critical temperature, but rather as a result of gradual deterioration with time.
2. The limiting temperature at which an insulation system may be operated depends upon the degree and intermittency of the loading, the degree of reliability required, and the length of life desired, as well as upon the insulation used. A given material may be satisfactory for use at different limiting temperatures, depending upon the type and size of equipment in which it is used, and the kind of service to which the equipment is subjected.
3. The electrical properties of insulation cannot be directly correlated with mechanical strength. Generally, because of chemical changes and the removal of moisture, the dielectric strength of new insulation increases initially with age. Subsequently, the dielectric strength begins to decrease, but it may not fall below its initial value until the insulation has lost practically all of its mechanical strength. This physical disintegration finally results in electrical breakdown.

Thus, how long insulation may be serviceable will depend not only upon the materials used

but also upon the effectiveness of the physical support for the insulation and the severity of the forces tending to disrupt it. Even though portions of insulation structures have become oxidized or embrittled under the influence of high temperature, successful operation of the equipment may continue for years, if the insulation is not disturbed.

Because of the effects of mechanical stress, the forces of thermal expansion and contraction may impose temperature rise limitations on large equipment, even though higher temperature rise limits have proven satisfactory in small equipment using similar insulating materials.

4. The life of equipment is dependent to a considerable extent upon the degree of exclusion of oxygen, moisture, dirt, and chemicals from the interior of its insulation structure. At a given temperature, therefore, the life of equipment may be longer if the windings are suitably enclosed than if they are freely exposed to industrial atmospheres. Favorable results are obtained by the use of chemically inert gases or liquids as cooling or protective media.
5. The life of equipment also depends upon the care it receives during manufacture and installation, and upon maintenance during operation. Successful operation cannot be expected of insulation which has been damaged or displaced.
6. The rate of physical deterioration of insulation, under the influence of temperature and time, increases rapidly with an increase in temperature. A fairly precise method of determining insulation life at elevated temperature is provided by the modern concept that the logarithm of the insulation life is a function (usually linear) of the reciprocal of the absolute temperature. When the logarithms of the hours of life found by thermal evaluation tests at three or more different temperatures are plotted against the reciprocals of the absolute temperatures they will usually, but not always, form a straight line. The life at any other temperature can then be estimated by judicious extrapolation. Individual time-temperature life curves for different insulating materials and insulation systems should be determined by thermal evaluation tests.
7. The ambient temperature directly affects the temperature attained by equipment in operation. Data recorded at various Weather Bureau stations in the United States are given in Appendix I.

1-3. Basic Considerations in the Preparation of Standards

The desired life of electric equipment depends upon the initial investment, reasonable maintenance, needed reliability, obsolescence, the importance of size and weight, and other factors. In considering such factors,

predominant conditions rather than extreme requirements should be used as a basis for Standards. For some types of equipment and service, a life of thirty years or more may be expected with a high degree of reliability. For other types of equipment a life of only a few years or a few hours may be satisfactory.

The great variety of physical factors and economic considerations entering into the problem of standardization makes it essential to give much weight to experience records. Standard values that are entirely safe for extreme conditions, or which allow for very improbable combinations of unfavorable factors, will result in products too costly for the majority of applications and consequently will not be respected. No laboratory or factory tests can fully simulate the many combinations of temperatures, loads, mechanical stresses, voltage surges, and atmospheric conditions met with in service. To what extent extreme conditions may be discounted without incurring unreasonable maintenance on standard equipment can only be determined by practical experience over a considerable period of time.

The temperature rise values generally used for electric equipment are the results of long experience and have proved to be reasonably satisfactory. The general principles outlined herein suggest that major changes in existing Standards should be made only when they are indicated to be desirable in the light of new test data, additional operating experience, new measurement techniques, or changes in service requirements.

Important recent trends to which consideration has been given in preparing these revised principles include:

1. The growing tendency to rely on accelerated life tests, as provided in AIEE Test Procedures, to determine appropriate limiting temperatures and fields of usefulness for complete insulation systems, and for individual insulating materials.
2. The availability of many new insulating materials whose characteristics and appropriate fields of use cannot be determined from their chemical composition alone and, therefore, must be determined by test.
3. The great expansion of new fields of application such as equipment for nuclear energy production, for aviation and military duty, for mobile use, and for air conditioning, which uses are increasing the varieties of special purpose equipment to be supplied by the electrical industry, and the ranges of temperature which must be considered in their operation.
4. The continuing and greater use of enclosed types of equipment often operating in controlled gases or liquids.
5. A trend toward operating some electric equipment at or close to limiting insulation temperature.

6. A trend toward operating some electric equipment in short-time duty periods at higher than normal temperature in such a way as to make the average rate of thermal deterioration over the total elapsed time consistent with a desired life expectancy.

Standards for different types of electric equipment should be correlated with each other to ensure that the thermal performance and life expectancies of associated elements in a complete electric system will be consistent under short-time overload and emergency conditions, as well as in normal service. However, it is important to allow freedom to use different temperature rise limits for individual types of equipment and for specific applications in accord with their individual economic requirements.

A principal purpose of the development and use of Test Procedures for life testing insulation systems and insulating materials is to enable more accurate estimates to be made of the life expectancy of equipment under particular service conditions. In the course of time it will be desirable to correlate further the various Standards to make the life expectancies of associated equipment more consistent with each other and better suited to give the desired degree of reliability.

TEMPERATURE CLASSIFICATION OF INSULATING MATERIALS

1-4. Material Test Procedures

Test procedures for the thermal evaluation of insulating materials should be developed by the appropriate Technical Committees. The many factors outlined below to be considered and the philosophy underlying the development of material Test Procedures are described in detail in AIEE No. 1D, "Guide for the Preparation of Test Procedures for the Thermal Evaluation of Electrical Insulating Materials." This Guide should be followed when preparing Test Procedures.

Material Test Procedures cannot take into account all of the many different influences that affect the life of insulation in different equipment and applications. The useful life of a material in a particular electric equipment may be quite different from the life determined by testing the material alone. It is also recognized that the life of a material used in one type of electric equipment may be different from the life of the same material applied in another type of equipment. The suitability of insulating materials in electric equipment and in combination with other materials is determined by experience or preferably by insulation system tests.

Conditions encountered in the use of insulation such as irradiation, voltage stress, and corona may degrade and limit the life of some insulating materials irrespective of thermal degradation. These effects as well as the physical and chemical properties of insulating

materials must be evaluated separately to assure their fitness for a particular application. The evaluation of degrading influences such as these is considered to be outside of the scope of these Principles.

The material Test Procedures will, however, provide thermal life data that can be used to compare the relative thermal life of insulating materials. Using a Test Procedure, the test life of an accepted material as a function of temperature can be determined. Since the nominal temperature of a material that has been accepted for a long time will have been established by experience, its life-temperature characteristic determined by test provides a basis for comparison with the thermal endurance of a new material. By assigning a minimum thermal endurance value for each Test Procedure, based on the test life of accepted materials, the nominal temperature of new materials thus may be established. The appropriate Technical Committee will determine the minimum thermal endurance values based on test conditions for use in establishing the nominal temperature of new insulating materials.

The purpose of assigning each material to a definite nominal temperature, therefore, is to facilitate comparisons between materials and to provide a single designation for each class for purposes of standardization. The severity of the tests and their duration are arbitrarily chosen for convenience, accuracy, and economy in testing. Therefore, the life expectancy under the test conditions may be shorter than, and has no uniform relation to, the life expectancy of the material in actual service. Materials of a given nominal temperature may be used as components of complete insulation systems that are assigned widely different limiting temperatures, depending upon the results of thermal evaluation tests of the insulation system.

1-5. Classes of Insulating Materials

The classes of insulating materials are relative classes and the temperatures in the definitions are not intended as limiting temperatures in equipment rating. Essentially the same life in service is expected for the various temperature classes of materials at their respective nominal temperature ratings. The nominal temperature ratings do not restrict the use of materials at other temperatures when referred to in equipment standards. These classes are defined in Table 1-7. Numerical temperature classes are based on experience with existing materials in each class. Other materials may be included in these classes where they have equivalent life at the nominal temperature for the class when evaluated by material Test Procedures.

Temperature classes of insulating materials have traditionally been established by definitions based on the composition of the materials. Methods of temperature classification based on the results of thermal evaluation tests are coming into use.

Classes of insulating materials are given in Table 1-5.

TABLE 1-5

Temperature Classification of Insulating Materials

Materials Class

Class 90

" 105

" 130

" 155

" 180

" 220

Over 220 Class

1-6. Factors Affecting the Thermal Evaluation of Insulating Materials

The major factor affecting the life of insulating materials is thermal degradation. Moisture, chemical contamination, and mechanical stress may contribute to failure, especially after the material has been weakened by thermal deterioration. The rate of thermal degradation of materials is influenced by environmental and other factors. The thermal characteristics of a material may be radically altered by exposure to nuclear radiation and by various processing techniques.

Because of these many factors, realistic temperature classifications for insulating materials should be based on information obtained from field experience and from thermal aging tests. They cannot be based on composition alone.

1-7. Definitions of Insulating Materials

Table 1-7 gives the definitions for insulating materials of the several classes listed in Table 1-5. Each of the definitions is stated in two ways. First, the compositions are given of typical materials associated with the particular class on the basis of long experience. Second, the requirements are given for materials which may be included in the class on the basis of experience or accepted tests.

As experience is gained with the Test Procedures now under development, it is expected that more reliance will be placed on the classification by test.

TABLE 1-7

Definitions of Insulating Materials

Class	Definition
Class 90	Materials or combinations of materials such as cotton, silk, and paper without impregnation. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have comparable thermal life at 90 C*.
Class 105	Materials or combinations of materials such as cotton, silk, and paper when suitably impregnated or coated or when immersed in a dielectric liquid. Other materials or combinations may be in-

cluded in this class if by experience or accepted tests they can be shown to have comparable thermal life at 105 C*.

Class 130 Materials or combinations of materials such as mica, glass fiber, asbestos, etc., with suitable bonding substances. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have comparable thermal life at 130 C*.

Class 155 Materials or combinations of materials such as mica, glass fiber, asbestos, etc., with suitable bonding substances. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have comparable thermal life at 155 C*.

Class 180 Materials or combinations of materials such as silicone elastomer, mica, glass fiber, asbestos, etc., with suitable bonding substances such as appropriate silicone resins. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have comparable thermal life at 180 C*.

Class 220 Materials or combinations of materials which by experience or accepted tests can be shown to have the required thermal life at 220 C*.

* These temperatures are, and have been in most cases over a long period of time, benchmarks descriptive of the various classes of insulating materials, and various accepted test procedures have been or are being developed for use in their identification. They should not be confused with the actual temperatures at which these same classes of insulating materials may be used in the various specific types of equipment, nor with the temperatures on which specified temperature rise in equipment standards are based. (See paragraphs 1-1, 1-2, 1-3, 1-9, 1-13 and 1-14)

1. In the above definitions the words "accepted tests" are intended to refer to recognized Test Procedures established for the thermal evaluation of materials by themselves or in simple combinations. Experience or test data, used in classifying insulating materials, are distinct from the experience or test data derived for the use of materials in complete insulation systems. The thermal endurance of complete systems may be determined by Test Procedures specified by the responsible Technical Committees. A material that is classified as suitable for a given temperature may be found suitable for a different temperature, either higher or lower, by an insulation system Test Procedure. For example, it has been found that some materials suitable for operation at one temperature in air may be suitable for a higher temperature when used in a system operated in an inert gas atmosphere. Likewise some insulating materials when operated in dielectric liquids will have lower or higher thermal endurance than in air.
2. It is important to recognize that other characteristics, in addition to thermal endurance, such as mechanical strength, moisture resistance, and corona endurance, are required in varying degrees in different applications for the successful use of insulating materials.

Over 220 Class Materials consisting entirely of mica, porcelain, glass, quartz, and similar inorganic materials. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have the required thermal life at temperatures over 220 C*.

TEMPERATURE CLASSIFICATION OF INSULATION SYSTEMS

1-8. Insulating Systems—General

Experience has shown that the thermal life characteristics of composite insulation systems cannot be reliably inferred solely from information concerning component materials. To assure satisfactory service life, insulation specifications need to be supported by service experience or life tests. Accelerated life tests are being used increasingly to evaluate systems using the many new synthetic insulating materials that are available thus shortening the period of service experience required before they can be used with confidence. Tests on complete insulation systems, representative of each type of equipment, are necessary to confirm the performance of materials for their specific functions in the equipment.

The electrical insulation of equipment is made up of many different components selected to withstand the widely different electric, mechanical, and thermal stresses occurring in different parts of the structure. How long an insulation system will be serviceable depends on the effectiveness of the physical support for the insulation, and the severity of the forces acting on it as well as on the materials themselves and the service environment. Therefore, the length of useful life of the insulation system will depend on the way that its individual components are arranged, their interactions upon each other, and the contribution of each component to the electrical and mechanical integrity of the system.

1-9. Definition of Insulation System Classes

An insulation system is an assembly of insulation materials in a particular type, and sometimes size, of equipment. In general, a specific piece of equipment has one insulation system but, for some types of equipment having two or more distinct subassemblies, it may be desirable to consider that there are a corresponding number of insulation systems.

Most equipment Standards now classify the insulation in one or more insulating material classes and include appropriate limiting temperature rise standards for equipment using each of these classes. Although this classification has nominally been by material classes, the wide divergence in both observable temperature and hottest-spot temperature between different types of equipment of the same material class indicates that the real classification was by insulation systems.

Insulation systems classes may be designated by letters, numbers or other symbols and may be defined as assemblies of insulating materials in association with equipment parts. These systems may be assigned a system temperature rating based on service experience or by an accepted test procedure which can demonstrate an equivalent life expectancy. Existing insulation systems have generally been service proven. New or modified systems may be evaluated by accepted test procedures, and when so evaluated must have equal or longer thermal endurance than a service proven system of the same class at the test conditions. A new insulation system may also be classified in a higher class by test if it has equal or greater thermal endurance at appropriately higher test temperatures when compared to a service proven insulation system under the same test conditions. It is hoped that eventually insulation system classes may be defined by test specifications rather than solely by comparison.

1-10. Thermal Evaluation Test Procedures for Insulation Systems

It is the responsibility of each Technical Committee to develop Test Procedures suitable for the temperature-life evaluation of the insulation systems used in the equipment. These Test Procedures should be in general accord with the principles outlined herein but they may differ for the various types of equipment in whatever ways are appropriate to allow for differences in their insulation systems and for the many conditions to which the equipments are exposed in service. A principal objective of these Test Procedures is to enable the performance of new and old insulation systems to be compared directly in a practical way and in a reasonable time thus providing a sound basis for introducing new insulation systems into service.

The tests for the evaluation of insulation systems should be chosen so that each component of the system will perform under the test conditions in a manner similar to its operation in service. However, the severity of the tests should be enough greater than the conditions encountered in service to enable the performance of the system to be determined in a reasonable time. Prolonged exposure to high temperature is the principal aging factor employed in these tests. Other tests such as exposure to moisture and voltage, are chosen in such a way as to develop and disclose promptly any significant weakness or deterioration of the insulation system. So far as practicable, the atmospheric and other environmental conditions should be similar to those usually encountered in service. When such conditions are made more severe, at the discretion of the responsible Technical Committee, the effect on acceleration of the test should be considered.

The chief criterion of life expectancy is the elapsed time-at-temperature whether the temperature is the result of continuous or cyclic loading, overloads, or operation at other than normal ambient temperature.