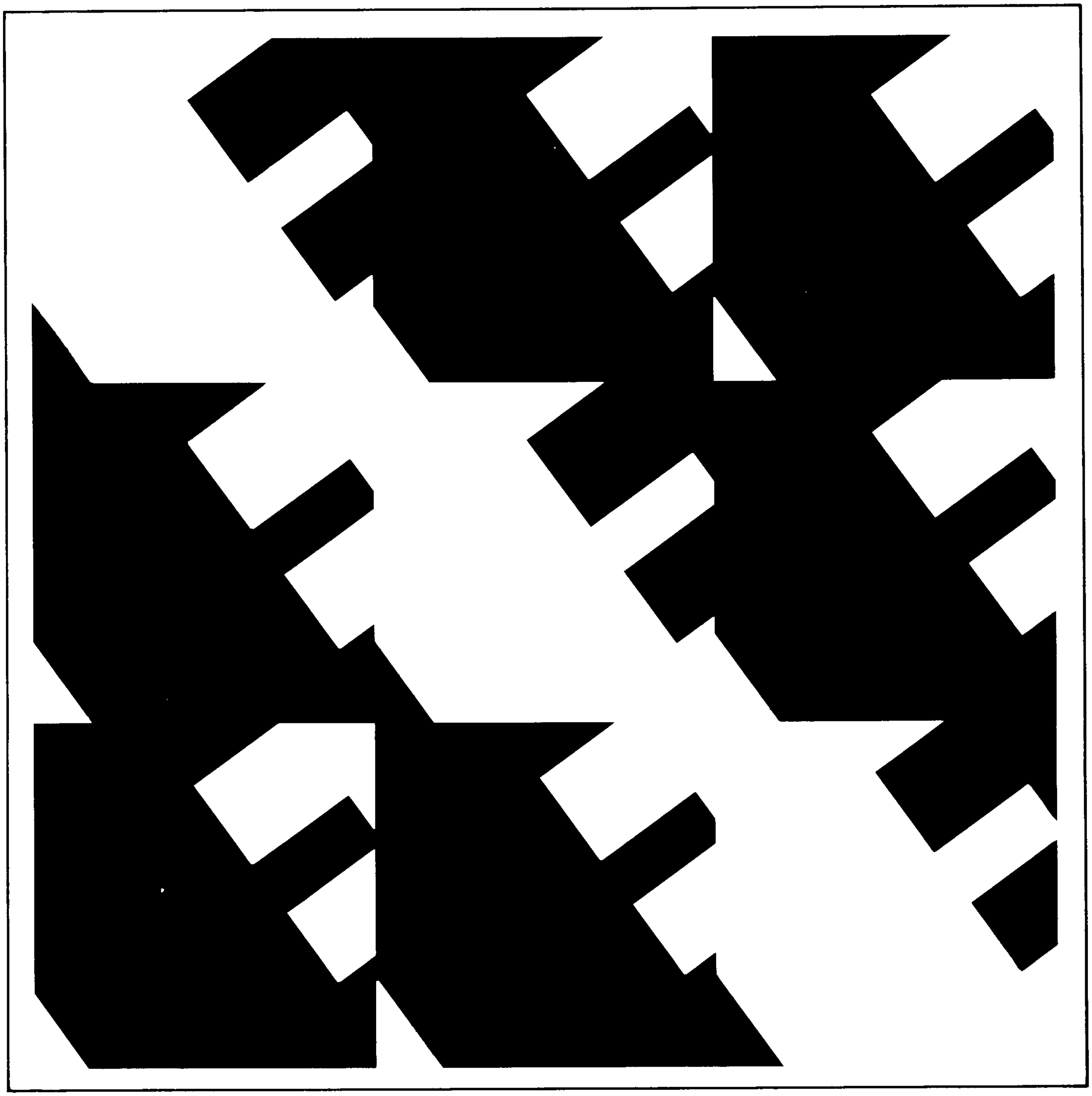
IEEE Std 259-1974
(Reaffirmed 1980)

# IEEE Standard Test Procedure for Evaluation of Systems of Insulation for Specialty Transformers



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# IEEE Standard Test Procedure for Evaluation of Systems of Insulation for Specialty Transformers

Sponsor

**Transformer Committee of the IEEE Power Engineering Society**

Approved June 22, 1972
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**IEEE Standards Board**

Approved June 22, 1972

## IEEE Standards Committee

## Foreword

(This foreword is not a part of IEEE Std 259-1974, Test Procedure for Evaluation of Systems of Insulation for Specialty Transformers.)

Specialty transformers include types of transformers covered by American National Standard C89.1-1961 (R1969), Requirements and Terminology for Specialty Transformers. Generally, these transformers have their primary windings connected to secondary distribution circuits of 600 V or less, and they supply power to lighting systems, machine tools, and other power loads.

The IEEE charged its technical committees with the responsibility for developing test procedures for the thermal evaluation and classification of insulation systems used in electric equipment. These are to be in general accord with IEEE Std 1-1969, General Principles for Temperature Limits in the Rating of Electric Equipment. The principal objective is to enable the performance of new and old insulation systems to be compared directly in a practical way and in a reasonable time, and to provide a sound basis for introducing new insulation systems into service.

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 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 Institute wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge, and have conducted experimental work on which many of the IEEE publications are based.

This test procedure was prepared by the Working Group on Insulation Requirements for Specialty Transformers for the Subcommittee on Insulation Life of the Transformer Committee.

The Working Group, which developed this test procedure, had the following members at the time of approval:



The Insulation Life Subcommittee who approved this standard had the following membership at the time of approval.

## Contents

# IEEE Standard Test Procedure for Evaluation of Systems of Insulation for Specialty Transformers

## 1. Scope and Introduction

The intent of this standard is to establish a uniform method by which the life of specialty transformer insulation systems can be compared. Thermal degradation is generally one of the major factors affecting the life of most insulating materials. It was chosen to be the major environmental factor in this standard. Other environmental factors, such as vibration, thermal shock, and moisture, have been included to simulate operating conditions. These factors have been chosen in such a way as to develop and disclose promptly any significant weaknesses during the temperature aging of an insulation system.

This standard is offered as a guide for preparing samples, conducting tests, and analyzing results. This information is presented in the following three principal sections:

*Insulation Test Specimens.* Describes the types of insulation specimens suitable for use in the evaluation tests.

*Test Cycle.* Recommends the test cycle for use in the insulation evaluation tests. The cycle consists of a series of exposures to heat, vibration, thermal shock, moisture, and voltages to which the test specimen may be subjected to represent the cumulative effects of long service, under accelerated conditions. Information is included for selecting varying test conditions for several different transformer applications.

*Interpretation of Data.* Gives information on establishing the criteria of failure, methods for analyzing test results, and a guide for interpreting test results.

It is recognized that some transformers may have special requirements other than those included in this standard. In these cases, special tests should be added to the test cycle. It is all-important that when insulation systems are compared, the test samples must be subjected to precisely the same test cycle.

This standard provides a statistical method for establishing a life-temperature relationship of an insulation system. This life-temperature relationship is relative. To have any significance, it must be backed up with adequate field service data or be compared to similar life test data of insulation system with known service reliability.

This standard is intended to be an evaluation test and not a production inspection or acceptance test.

## 2. Insulation Test Specimens

Whenever possible, actual transformers should be used for the thermal evaluation of insulation systems. In the case of small transformers, they are the simplest, most direct, and least expensive test specimens. Some guides that can be used in selecting these specimens are given in Section 4.4.

In those cases where the actual transformer is too large to use it as a test specimen, a representative-size specimen may be used. The lack of experience with large transformers prevents the establishing of a standard test model. In the use of reduced-size specimens, adequate consideration should be given to all the conditions and environments affecting the life of the simulated transformer. Each situation may involve a number of different arrangements to cover adequately the various combinations of conditions affecting the performance of the insulation system. It shall be the responsibility of each testing laboratory to select and use suitable models. Full and complete design information on the model shall be published at the time of presenting test data.

Whether the test specimens are actual transformers or models, consideration should be given to the following items when designing and building the specimens.

**Table 1**
Test Schedule

| *Purpose* | *Part* | *Test* | *Remarks* |
|---|---|---|---|
| Initial Test | I | Dielectric Proof Test | Beginning of first cycle only |
| Basic Test Cycle | II | Temperature Aging | Four 20-hour periods |
| | III | Mechanical Stress | See Table 2 |
| | IV | Thermal Shock (when specified) | See Table 2 |
| | V | Moisture Exposure (or special atmosphere) | See Table 2 |
| | VI | Electrical Proof Test | See Section 3.6 |
| Continual Testing | | Repeat the basic test cycle until failure occurs (Parts II, III, IV, V, and VI) | |

**Table 2**
**Test Conditions Imposed on Transformers for Different Applications**

| *Test* | *Application* | | | |
|---|---|---|---|---|
| | *Indoor* | *Outdoor* | *Contamination Atmosphere* | *Military* |
| III. Mechanical Stress Section 3.3 | 1.5 g Min for 10 000 cycles | 1.5 g Min for 10 000 cycles | 1.5 g Min for 10 000 cycles | 15 g Min for 20 000 cycles |
| IV. Additional Thermal Shock Section 3.4 | None | −20°C for 2 hours | None | −55°C for 2 hours |
| V. Moisture Section 3.5 | 48 hours in 90 to 95% RH at 5 to 10 degrees Celsius above normal room temperature.<br>After removal from humidity, the test specimens shall be held at normal room temperature and humidity for at least 20 minutes and not more than 30 minutes before applying electrical proof test. | 48 hours in 100% RH plus condensation at 5 to 10 degrees Celsius above normal room temperature.<br>After removal from humidity, the test specimens shall be held at normal room temperature and humidity for at least 20 minutes and not more than 30 minutes before applying electrical proof test. | Duration and atmosphere as required for the specific application. Examples of contaminating atmospheres are salt or other spray, dust fog, immersion in salt or tap water, corrosive gas, or irradiation. Details should be noted carefully to permit duplication. | 48 hours exposure to two temperature-humidity cycles as shown in Fig 1 |
| VI. Electrical Proof Test Section 3.6 | | See Section 3.6 | | |

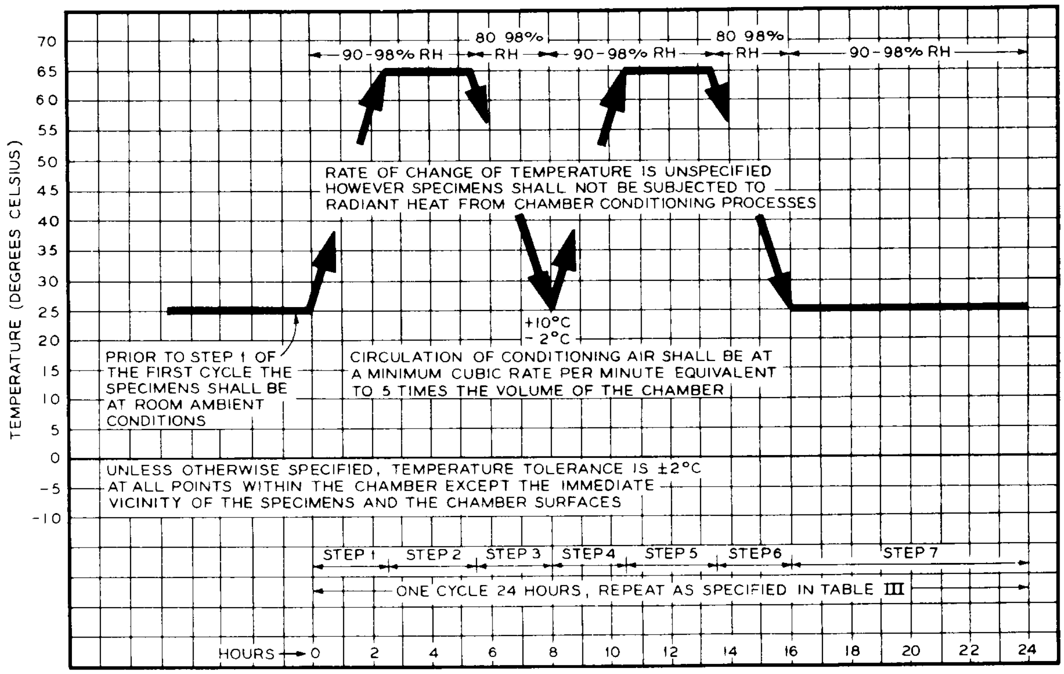


Fig 1
Graphical Representation of Moisture-Resistance Test

(1) The materials used for the various components of the specimen should be identical with those used for the actual transformers. It is suggested that only insulating materials on which life data are available be used in system evaluations. Everything possible should be done to assure that the individual components are uniform and representative of the materials used in actual service.

(2) Insulation thickness and creepage distances should be appropriate for the voltage class and industry or equipment standards or practices. The presence of corona in an insulation system will have some effect on the system's life, and its presence in the test sample may prejudice the temperature aging results.

(3) The arrangement of the different components, such as conductors, insulations, supporting members, spacers, shields, and ground, should duplicate electrically, thermally, and mechanically the conditions existing in the actual transformer.

(4) The design and construction of the specimens should be representative of the prevailing engineering practices and manufacturing procedures and processes.

(5) Provisions should be made for making electrical tests on the various insulation components.

(6) If self-heating is used, provisions should be made for exciting and loading the specimen.

## 3. Test Cycle

The test specimens shall be subjected to a repeated test cycle, consisting of the parts as given in order in Table 1. Where indicated, specific values for some of the test conditions will be found in Table 2, which provides varying degrees of severity for different applications.

It is recognized that for some equipment there may be special requirements, other than those represented in this standard, such as ability to withstand surge tests, direct-current polarizing voltages during moisture exposure, etc. For these cases, special tests should be formulated and added to the test cycle recommended herein.

It is also recognized that, depending on the test facilities available, the type of specimen employed, and other factors, slight variations in the methods of exposing the specimen may be necessary. It is all-important that, when any two different materials or insulation systems are compared, the test specimens of each shall be subjected to precisely the same exposures and other conditions of test. Unless otherwise specified, tests shall be carried out at normal room temperature and humidity (25°C ± 15°C, 50 percent relative humidity ± 30 percent relative humidity).

**3.1 Dielectric Proof Test.** Prior to the exposure to an elevated temperature on the first test cycle a dielectric proof test shall be made on all test specimens.

The dielectric proof test shall consist of applied-potential and induced-potential tests under the conditions of and at the voltages recommended by applicable standards for the type of specialty transformers involved.

Equipment for which no acceptable standard test is available may be tested according to the following recommended procedure at approximately room temperature and in normal humidity.

3.1.1 *Applied-Potential Test.*

(1) The applied-potential test shall be made by applying between each winding separately, and all other windings and ground, a 60 Hz voltage from an external source. The winding under test shall be shorted on itself during the test. All other circuits and metal parts shall be grounded during the test.

(2) The duration of the applied-potential test shall be for 1 min at the value specified in procedure (3) below.

(3) The rms test voltage shall be the $\sqrt{2}$ times normal working voltage[1] plus 1000 V. The rms test voltage shall be applied at a rate not to exceed 1000 V/s.

3.1.2 *Induced-Potential Test.*

(1) The induced-potential test shall be made by applying across the terminals of any suitable winding a voltage that will stress the turn and layer insulation at a peak value twice their normal working voltage[1] but will not stress interwinding, winding-to-core, or other insulation to voltages higher than that specified in Section 3.1.1 (3) above. A frequency twice normal is usually required to avoid core saturation.

(2) The induced-potential test shall be applied for 7200 cycles. The duration shall not exceed 60 s. Example of equivalent tests are as follows:

| Frequency (Hz) | Duration of Test (s) |
|---|---|
| 120 or less | 60 |
| 180 | 40 |
| 240 | 30 |
| 360 | 20 |
| 400 | 18 |
| 900 | 8 |

**3.2 Temperature Aging.** The temperature aging portion of the cycle shall include 80 h of "on" time in accordance with the following recommended procedure.

**3.2.1** *Recommended Procedure.*

(1) Temperature aging shall be done by exciting the transformers or test models at rated voltage and causing current to pass through the conductors until the desired test temperature is attained. When conservation of power and simplification of the test setup is important, the transformers may be loaded in a buck-boost or opposition arrangement.

(2) The test temperature is that of the hottest spot in the windings. The relationship of the hottest spot temperature to the winding temperature, determined by change of resistance, or to the temperature of an embedded detector, shall be determined for the specimen under test. (It is recommended that a formula be derived relating hottest spot temperature rise above average winding temperature to unit size, etc.)

(3) During thermal aging, the movement of air at the surface of the specimen shall be substantially only the convection caused by the specimen itself and shall not constitute forced or restricted cooling. The ambient temper-

[1] The working voltage is defined as the maximum peak voltage stress that may occur under normal rated operation across the insulation being considered. This insulation may be between windings or between winding and case or core.

ature shall be between 20°C and 40°C.[2] After the test temperature defined in procedure (2) above has been reached and made stable by the adjustment of current described in procedure (1) above, further control of the test temperature may be obtained (a) by controlling the current in the conductors to maintain the temperature of the hottest winding within ±3°C as indicated by the change of resistance method,[3] (b) by controlling the current in the conductors to maintain the temperature of a high-temperature location in or on the specimen within ±3°C, as indicated by a suitable temperature-sensing means, or (c) by controlling the ambient temperature within ±2°C and the applied voltages within ±1 percent, while the loading means is fixed. Regardless of the method of temperature control used, the temperature of the hottest winding shall be determined by the change of resistance method[3] or by the embedded detector at the conclusion of the 80 h thermal aging portion of the test cycle described in procedure (4).

(4) The transformers or test models shall be switched "on" for 20 h and "off" for 4 h in a 24 h period. While "off," the test temperature of the specimens shall be reduced to within 5°C of room ambient temperature, even if forced cooling is required. This test shall be repeated four times to constitute the 80 h temperature aging portion of the test cycle.

(5) The temperature aging shall be done at three different temperatures. From a statistical approach, it is suggested that a minimum of six specimens of the same type be tested at each temperature. The temperature values should be selected to give an estimated maximum life of about 3000 h of "on" time for the lowest temperature, of 1000 h for the middle temperature, and 350 h for the highest temperature.

3.2.2 *Alternate Procedure for Oven-Aged Energized Samples.*

(1) Temperature aging shall be done by placing the samples in an accurately controlled oven with forced circulation at the desired temperature with one winding energized at rated voltage and the other windings open-circuited. The average winding temperature of the energized units should be measured by resistance. If this temperature is more than 2°C higher than the mean oven temperature, this average winding temperature (measured by resistance) shall be considered to be the aging temperature. The temperature throughout the oven shall be within ±2 percent of the specified exposure temperature.

(2) The oven and the samples shall be turned "on" 40 h and "off" 8 h. This procedure shall be repeated two times to constitute the 80 h temperature aging of the test cycle.

(3) The temperature aging should be done at three different temperatures. From a statistical approach, it is suggested that a minimum of 6 specimens of the same type be tested at each temperature. The temperature values should be selected to give an estimated life of 3000 h of "on" time for the lowest temperature, of 1000 h for the middle temperature, and 350 h for the highest temperature.

3.2.3 *Alternate Procedure for Oven-Aged Nonenergized Samples.*

(1) Temperature aging shall be done by placing the samples in an accurately controlled oven with forced circulation at the desired temperature. The temperature throughout the oven shall be within ±2 percent of the specified exposure temperature.

(2) The oven shall be turned "on" 40 h and "off" 8 h. This procedure shall be repeated two times to constitute the 80 h temperature aging of the test cycle.

(3) The temperature aging shall be done at three different temperatures. From a statistical approach, it is suggested that a minimum of six specimens of the same type be tested at each temperature. The temperature values should be selected to give an estimated life of 3000 h of "on" time for the lowest temperature, of 1000 h for the middle temperature, and 350 h for the highest temperature.

Table 3 will serve as a guide to selection of test temperatures.

**3.3 Mechanical Stress.** After temperature aging as described in Section 3.2, each transformer or test model shall be vibrated in simple harmonic motion to give the peak ac-

[2]It is felt that transformers, to operate in ambient temperatures above 40°C, should be tested in their normal operating ambients for a more accurate determination of life. More data is needed to verify this point.

[3]Permanent changes in wire resistance may be caused by aging at temperatures (above about 250°C for copper); any such effect should be compensated for when using the change of resistance method of temperature measurement.

Table 3*

Typical Test Temperatures and Corresponding Estimated Life

| *Estimated Life, hours* | *Hottest Spot Temperature (°C) or Equivalent for Systems Expected to Operate At* | | | | | |
|---|---|---|---|---|---|---|
| | 105 °C | 130 °C | 155 °C | 180 °C | 220 °C | 250 °C |
| 3000 | 135 | 165 | 195 | 225 | 275 | 310 |
| 1000 | 150 | 180 | 215 | 245 | 300 | 340 |
| 350 | 165 | 200 | 235 | 270 | 325 | 375 |

*The temperature and times were derived from data presented in Ref [1], Section 6. The various temperatures and times do not describe any actual insulation system. They are intended only as a guide in selecting aging temperatures. The temperature cannot be expected to give the same endpoints for all insulation systems. The life curve and endpoint of a specific insulation system are relative and they must be compared to similar data on a system of known reliability and service life to be significant.

celeration and the number of cycles duration shown in Table 2.

The transformers or test models shall be so mounted that the motion occurs parallel to the axis of the coils. This vibration test should be made at room temperature with normal humidity and without any applied voltage. The vibration frequency shall not exceed 60 Hz, and resonant frequencies of the specimen should be avoided.

**3.4 Thermal Shock.** After temperature aging and mechanical stress as described in Sections 3.2 and 3.3, each transformer or test model shall be placed in a low-temperature chamber maintained within ±5°C of the value and for the duration shown in Table 2. No voltage should be supplied during this period.

**3.5 Moisture Exposure.** After temperature aging, mechanical stress, and thermal shock as described in Sections 3.2-3.4, each transformer or test model shall be exposed for the duration and to the atmosphere specified in Table 2. No voltage should be applied to the test specimens during this exposure.

NOTE: An atmosphere of 100 percent relative humidity and condensation is readily obtained by covering the floor of the test chamber with a shallow layer of water and using an immersion heater to heat the water to a temperature of from 5 to 10°C above room temperature. It is preferable to adjust the voltage across the heater to maintain this temperature, rather than to attempt thermostatic control. The exterior walls of the moisture chamber should be thermally insulated. The roof of the chamber should not be insulated and should be sloped so as to drain the condensed water to the back or sides of the cabinet and prevent drip on the samples. The interior of the cabinet should be constructed of corrosion-resistant materials, and junctions of dissimilar metals should be avoided. Doors or removable covers should be constructed with overhanging lips so that moisture collecting around them will drain into the interior of the chamber. An atmosphere of approximately 93 percent relative humidity may be obtained by covering the bottom of the test chamber with a flat tray containing a saturated solution of ammonium dihydrogen phosphate ($NH_4H_2PO_4$) or sodium sulfate, with undissolved excess of the salt present, and by providing a fan for internal air circulation.

**3.6 Suggested Electrical Proof Tests During Basic Test Cycle.**

(1) For self-heated or oven-aged energized samples, the energizing of the samples at rated voltage during each temperature cycle is generally an adequate proof test.

(2) An applied- or induced-potential test between turns, windings, and cores shall be used for oven-aged nonenergized samples. An adequate proof test would be to induce at 65 percent of the voltage used in the initial test described in Section 3.1.2(1), and high pot at 1½ times the normal working voltage. The duration of the applied and induced tests shall be as prescribed in Section 3.1.1(3) and 3.1.2(2), respectively. They should be applied immediately after moisture exposure.

## 4. Interpretation of Data

**4.1 Criteria of Failure.** The criteria by which a test specimen is considered to have failed should be fully defined prior to the start of the test. An adequate test shall be included in the test cycle to detect when a failure occurs. For example, fuse blowing can be used if current is selected as the failure criterion. The use of more than one criterion of failure will tend to make the interpretation of the test results more difficult. It is recommended that only one criterion be used.

The cause of all test-specimen failures should be determined. If it can be established that a failure was not within the insulation system under test, the data should not be included in the analysis. If a failure is not within the insulation system and it can be repaired without disturbing the insulation system, the specimen should be put back on test. For example, an electric connection may open during the test. Since electric connections are usually not a part of the insulation system, the joint should be repaired and the specimen put back on test.

**4.2 Method for Determining the Average Life.** When all the test specimens have failed, the average life at each exposure point should be calculated. It is recommended that the average life in hours be a geometric mean. The standard deviation of this life and the 95 percent confidence limits of this life shall be calculated using the logarithm of the number of hours of life and by statistical methods. From these values, an indication of the accuracy of the average life values at each exposure temperature can be determined.

Methods for processing thermal aging data are given in IEEE Std 101-1972, Guide for Statistical Analysis of Thermal Life Test Data.

**4.3 Extrapolation of Data.** The calculated regression line and the 95 percent confidence band can be used to determine the life and corresponding temperature for other than the test points. The extent to which data may reasonably be extrapolated is limited by the following requirements.

(1) The calculated regression line must plot as a straight line on the coordinates specified in Section 4.5(4).

(2) The life to be expected at a lower temperature, which may be extrapolated from data taken at higher temperatures, must be considered to be anywhere between the upper and lower confidence limits existing at the desired temperature.

**4.4 Application of Results.** As stated in the introduction of this standard, the results of the tests obtained by this procedure are for comparison purposes only. The results of a new system or system with modified materials are compared to the results of a well-known and field-service-proven system. Thus, the validity of the acceptance of a new or modified system is by obtaining an equal or higher temperature index than the known system when the regression plot is extrapolated back to a reference hour.

It is recognized that it would be impractical to evaluate every transformer model and rating built by a manufacturer. For this reason specialty transformers will have to be evaluated as classes and lines. The following points are offered here as guides for applying specific life test data to other transformer models and ratings. Life test data could be applied to other transformer models and ratings which are:

(1) Constructed with the same materials and processes

(2) Similar in configuration and construction type

(3) Of the same ambient temperature class and have the same ultimate temperature

**4.5 Report of Results.** Similar insulation systems may be used in different equipment and under varying exposure conditions. It is recommended for the sake of clarity that the test results be identified with the conditions of test and failure criteria, as well as the temperature classification and life expectancy.

A report of the results of the tests shall contain the following information:

(1) Complete description of test sample (including insulation system)

(2) Description of test cycle including dielectric tests, temperature aging, mechanical stress, thermal shock, and moisture exposure

(3) Calculated regression equation with 95 percent confidence limits

(4) A plot of regression equation and confidence limits on coordinate paper, with a logarithmic scale to represent life (hours) along the ordinate, and the reciprocal absolute temperature scale to represent temperature in degrees Celsius along the abscissa.

## 5. Standards References

The following IEEE and American National Standards publications were used as references in preparing this standard and are useful in the interpretation of its meaning.[4]

ANSI C89.1-1961 (R1969); Requirements and Terminology for Specialty Transformers

IEEE Std 1-1969, General Principles for Temperature Limits in the Rating of Electric Equipment[5]

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[4] American National Standards Institute
1430 Broadway
New York, N.Y. 10018

[5] Institute of Electrical and Electronics Engineers
345 East 47 Street
New York, N.Y. 10017

IEEE Std 101-1972, Guide for Statistical Analysis of Thermal Life Test Data [5]

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