

Guide for

Determining the effects of ionizing radiation on insulating materials —

Part 2: Procedures for irradiation and
test

Committees responsible for this British Standard

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- AEA Technology
- Adhesive Tape Manufacturers' Association
- Association of Manufacturers of Domestic Electrical Appliances
- British Cable Makers' Confederation
- British Plastics Federation
- ERA Technology Ltd.
- University of Manchester

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National foreword

This Part of BS 7811 has been prepared by Subcommittee GEL/15/2. It is identical with IEC 544-2:1991, *Guide for determining the effects of ionizing radiation on insulating materials — Part 2: Procedures for irradiation and test*, published by the International Electrotechnical Commission (IEC).

Cross-references

Publication referred to	Corresponding British Standard
IEC 212	BS 2844:1972 <i>Memorandum on conditioning of solid electrical insulating materials prior to and during testing</i>
IEC 243-1:1988	BS 2918 <i>Methods of test for electric strength of solid insulating materials</i> Part 1:1994 <i>Test at power frequencies</i>
IEC 544-1:1994	BS EN 60544-1:1995 <i>Electrical insulating materials — Determination of the effects of ionizing radiation</i> Part 1 <i>Radiation interaction and dosimetry</i> BS 2782 <i>Methods of testing plastics</i> Part 3 <i>Mechanical properties</i>
ISO 178:1993	Method 335A:1993 <i>Determination of flexural properties</i>
ISO 179:1993	Method 359:1993 <i>Determination of Charpy impact strength</i>
ISO 815:1991	BS 903 <i>Physical testing of rubber</i> Part A6:1992 <i>Method for determination of compression set at ambient, elevated or low temperatures</i>

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 14, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Introduction

When selecting insulating materials for applications in radiation environments, the component designers must have available reliable test data to compare candidate materials. To be meaningful, the performance data must be obtained on each material by standardized procedures, and the procedures should be designed to demonstrate the influence that variations of the service conditions have on the significant properties. This point is of particular concern where in normal service conditions low dose rates exist and where the insulation materials have been selected from radiation endurance data obtained from tests conducted at high dose rates.

Environmental conditions shall be well-controlled and documented during the measurement of radiation effects. Important environmental parameters include temperature, reactive medium, and mechanical and electrical stresses present during the irradiation. If air is present, radiation-induced species can enter into reactions with oxygen that would not occur in its absence. This is responsible for an observed influence of the absorbed dose rate for certain types of polymers if irradiated in air. As a result, the resistance may be as much as orders of magnitude lower than when the sample is irradiated under vacuum or in the presence of inert gas. This is generally called the “dose-rate effect”, which is described and reviewed in references [1] to [14] of Appendix B.

NOTE For the user of this standard who wants to go into more detail, the cited references are listed in Appendix B. In cases where these are not publications in internationally available journals, addresses where the cited scientific reports can be obtained are given at the end of the references.

The irradiation time can become relevant because of time-dependent complications caused by:

- a) physical effects such as diffusion-limited oxidation [8], [10] and,
- b) chemical phenomena such as rate-determining hydroperoxide breakdown reactions [10], [14].

The typical diffusion-limited effects are commonly observed in radiation studies of polymers in air. Their importance depends upon the interrelationship of the geometry of the polymer with the oxygen permeation and consumption rates, both of which depend upon temperature [10]. This means that the irradiation of thick samples in air may result in oxydation only near the air-exposed surfaces of the sample, resulting in material property changes similar to those obtained by irradiation in an oxygen-free environment. Therefore, when the material is to be used in air for a long period of time at a low dose rate, depositing the same total dose at a high dose rate in a short exposure period may not determine its durability. Previous experiments or considerations of sample thickness combined with estimates of oxygen permeation and consumption rates [8], [10] may eliminate such concerns. A technique that may be useful for eliminating oxygen diffusion effects by increasing the surrounding oxygen pressure is under investigation [8].

Radiation-induced reactions will be influenced by temperature. An increase in reaction rate with temperature can result in a synergistic effect of radiation and heat. In the case of the more commonly used thermal ageing prediction the Arrhenius method is employed; this makes use of an equation based on fundamental chemical kinetics. Despite considerable ongoing investigations of radiation ageing methodologies, this field is much less developed [9]. General equations involving dose, time, Arrhenius activation energy, dose rate and temperature are being tested for modelling of ageing experiments [10–12]. It should be noted that sequential application of radiation and heat, as it is frequently practised, can give very different results depending on the order in which they are performed, and that synergistic effects may not be properly simulated [13], [14].

The electrical and mechanical properties required of insulating materials and the acceptable amount of radiation-induced changes are so varied that it is not possible to establish acceptable properties within the framework of a recommendation. The same holds for the irradiation conditions. Therefore, this standard recommends only a few properties and irradiation conditions which previous experience has shown to be appropriate. The properties recommended are those that are especially sensitive to radiation. For a specific application other properties may have to be selected.

Part 1 of the standard (IEC 544-1) constitutes an introduction dealing very broadly with the problems involved in evaluating radiation effects. It also provides a guide to dosimetry terminology, several methods of determining the exposure and absorbed dose, and methods of calculating the absorbed dose in any specific material from the dosimetry method applied. The present part describes procedures for irradiation and test. Part 4 (IEC 544-4) defines a classification system to categorize the radiation endurance of insulating materials. It provides a set of parameters characterizing the suitability for radiation service. It is a guide for the selection, indexing and specification of insulating materials. The earlier part 3 (IEC 544-3) has been incorporated in the present part 2.

2 Scope and object

An important object of this part of the standard is to specify the controls which shall be maintained over the exposure conditions during and after the irradiation of insulating materials with ionizing radiation prior to the determination of radiation-induced changes in physical or chemical properties. A number of potentially significant irradiation conditions are discussed and various parameters which can influence the radiation-induced reactions under these conditions are specified. The objective is to emphasize the importance of selecting suitable specimens, exposure conditions and test methods for determining the effect of radiation on appropriately chosen properties. Since many materials are used either in air or in inert environments, standard exposure conditions are recommended for both of these situations. Example test reports for a number of materials are also included in Appendix A of this standard.

It should be noted that the scope of this standard does not consider measurements which are performed during the irradiation.

3 Irradiation

3.1 Type of radiation and dosimetry

The following types of radiation are covered by the standard:

- X- and γ -rays,
- electrons,
- protons,
- neutrons,
- combined γ -rays and neutrons (“reactor” radiation).

In general the radiation effects may be different for different types of radiation. However, in many practical applications, it has been found that with analogous experimental conditions, equal absorbed dose and equal linear energy transfer, the changes in properties will be only slightly dependent on the type of radiation [15–17]. Thus, the preferred type of radiation should be one for which the absorbed dose measurement is simple and precise, for example ^{60}Co γ -rays or fast electrons. For a comparison of the effect of reactor radiation with γ -rays or fast electrons, specimens with the same chemical composition can be irradiated with these various types of radiation and the radiation-induced changes can be compared.

Radiation-induced changes are related to the absorbed radiation energy, expressed by the absorbed dose. Recommended methods of dosimetry are listed in IEC 544-1. The definitions of absorbed dose, absorbed dose rate and the units are also given in IEC 544-1 and repeated here for convenience.

The absorbed dose, D , is the quotient of $d\bar{\epsilon}$ by dm , where $d\bar{\epsilon}$ is the mean energy imparted by ionizing radiation to the matter in a volume element and dm is the mass of the matter in that volume element.

$$D = \frac{d\bar{\epsilon}}{dm}$$

The absorbed dose rate, $\dot{D}$, is the increment of the absorbed dose dD in the time interval dt .

$$\dot{D} = \frac{dD}{dt}$$

Units

The SI unit of absorbed dose is the gray (Gy);

1 Gy = 1 J/kg (= 10^2 rad).

Usual multiples for higher doses are the kilogray (kGy) or megagray (MGy).

The SI unit of absorbed dose rate is the gray per second;

1 Gy/s = 1 W/kg (= 10^2 rad/s = 0,36 Mrad/h).

3.2 Irradiation conditions

The irradiation conditions which must be established are:

- type and energy of the radiation;
- absorbed dose;
- absorbed dose rate;
- surrounding medium;
- temperature;
- mechanical, electrical and other stresses;
- sample thickness.