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Guidance for dosimetry for radiation research

Lignes directrices de la dosimétrie pour la recherche dans le domaine de l'irradiation

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by ASTM Committee E61, *Radiation processing* (as ASTM E1900-97), and drafted in accordance with its editorial rules. It was assigned to Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies and radiation protection*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

ISO/ASTM 51900:2023(E)

Standard Guidance for Dosimetry for Radiation Research[1]

This standard is issued under the fixed designation ISO/ASTM 51900; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision.

1. Scope

1.1 This document covers essential recommendations for dosimetry needed to conduct research on the effects of ionizing radiation on materials, products and biological samples. Such research includes establishment of the quantitative relationship between absorbed dose and the relevant effects. This document also describes the overall need for dosimetry in such research, and for reporting of the results. Dosimetry should be considered an integral part of the experiment, and the researcher is responsible for ensuring the accuracy and applicability of the dosimetry system used.

NOTE 1—For research involving food products, note that the Codex Alimentarius Commission has developed an international General Standard and a Code of Practice that address the application of ionizing radiation to the treatment of foods and which strongly emphasizes the role of dosimetry for ensuring that irradiation will be properly performed (**1**).[2]

NOTE 2—This document includes tutorial information in the form of Notes. Researchers should also refer to the references provided at the end of the standard, and other applicable scientific literature, to assist in the experimental methodology as applied to dosimetry (**2-5**).

1.2 This document covers research conducted using the following types of ionizing radiation: gamma radiation (typically from Cobalt-60 or Cesium-137 sources), X-radiation (bremsstrahlung, typically with energies between 50 keV and 7.5 MeV), and electrons (typically with energies ranging from 80 keV to more than 10 MeV). See ISO/ASTM 51608, 51649, 51818 and 51702.

1.3 This document describes dosimetry recommendations for establishing the experimental method. It does not include dosimetry recommendations for installation qualification or operational qualification of the irradiation facility. These subjects are treated in ISO/ASTM 51608, 51649, 51818 and 51702.

1.4 This document is not intended to limit the flexibility of the researcher in the determination of the experimental methodology. The purpose of the document is to ensure that the radiation source and experimental methodology are chosen such that the results of the experiment will be useful and understandable to other scientists and regulatory agencies. The total uncertainty in the absorbed-dose measurement results and the absorbed-dose variation within the irradiated sample should be taken into account in the interpretation of the research results (see ISO/ASTM Guide 51707).

1.5 This document is one of a set of standards that provides recommendations for properly implementing dosimetry in radiation processing, and describes a means of achieving compliance with the requirements of ISO/ASTM 52628. This document is thus intended to be read in conjunction with ISO/ASTM 52628.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced documents

2.1 *ASTM Standards:*[3]

E2232 Guide for Selection and Use of Mathematical Methods for Calculating Absorbed Dose in Radiation Processing Applications

E3083 Terminology Relating to Radiation Processing: Dosimetry and Applications

2.2 *ISO/ASTM Standards:*[3]

51205 Practice for Use of a Ceric-Cerous Sulfate Dosimetry System

51026 Practice for Using the Fricke Dosimetry System

51261 Practice for Calibration of Routine Dosimetry Systems for Radiation Processing

51275 Practice for Use of a Radiochromic Film Dosimetry System

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[1] This document is under the jurisdiction of ASTM Committee E61 on Radiation Processing and is the direct responsibility of Subcommittee E61.04 on Specialty Application, and is also under the jurisdiction of ISO/TC 85/WG 3.

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[2] The boldface numbers in parentheses refer to the bibliography at the end of this document.

[3] For referenced ASTM and ISO/ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

51276 Practice for Use of a Polymethylmethacrylate Dosimetry System

51310 Practice for Use of a Radiochromic Optical Waveguide Dosimetry System

51538 Practice for Use of the Ethanol-Chlorobenzene Dosimetry System

51607 Practice for Use of the Alanine-EPR Dosimetry System

51608 Practice for Dosimetry in an X-ray (Bremsstrahlung) Facility for Radiation Processing

51649 Practice for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies between 300 keV and 25 MeV

51650 Practice for Use of Cellulose Triacetate Dosimetry System

51702 Practice for Dosimetry in a Gamma Facility for Radiation Processing

51707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing

51818 Guide for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies Between 80 and 300 keV

51956 Practice for Use of Thermoluminescence Dosimetry (TLD) Systems for Radiation Processing

52116 Practice for Dosimetry for a Self-Contained Dry-Storage Gamma Irradiator

52303 Practice for Absorbed-Dose Mapping in Radiation Processing Facilities

52628 Practice for Dosimetry in Radiation Processing

52701 Guide for Performance Charcterization of Dosimeters and Dosimetry Systems for Use in Radiation Processing

2.3 *International Commission on Radiation Units and Measurements (ICRU) Reports:*[4]

ICRU 80 Dosimetry Systems for Use in Radiation Processing

ICRU 85a Fundamental Quantities and Units for Ionizing Radiation

2.4 *ISO Standard:*[5]

12749-4 Nuclear energy, nuclear technologies, and radiological protection – Vocabulary – Part 4: Dosimetry for radiation processing

2.5 *Joint Committee for Guides in Metrology (JCGM) Reports:*

JCGM 100: 2008, GUM 1995, with minor corrections, Evaluation of measurement data – Guide to the expression of uncertainty in measurement[6]

JCGM 200: 2012, VIM International vocabulary of metrology – Basic and general concepts and associated terms[7]

2.6 *NPL Report:*[8]

CIRM 29 : Guidelines for the Calibration of Routine Dosimeters for use in Radiation Processing, Sharpe, P., and Miller, A., September, 2009.

3. Terminology

3.1 *Definitions:*

3.1.1 *absorbed dose (D)*—quotient of $d\bar{\varepsilon}$ by dm, where $d\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter of incremental mass dm (ICRU 85a), thus

$$D = d\bar{\varepsilon}/dm \tag{1}$$

3.1.1.1 *Discussion*—The SI unit of absorbed dose is the gray (Gy), where 1 gray is equivalent to the absorption of 1 joule per kilogram of the specified material (1 Gy = 1 J/kg).

3.1.1.2 *Discussion*—For the purposes of this standard, the term dose is used to mean "absorbed dose".

3.1.2 *absorbed-dose mapping*—measurement of absorbed dose within an irradiated product to produce a one-, two- or three-dimensional distribution of absorbed dose, thus rendering a map of absorbed-dose values.

3.1.3 *absorbed-dose rate* $\dot{D}$—quotient of dD by dt, where dD is the increment of absorbed dose in the time interval dt (ICRU 85a), thus

$$\dot{D} = dD/dt \tag{2}$$

3.1.3.1 *Discussion*—

(1) The SI unit is $Gy \cdot s^{-1}$. However, the absorbed-dose rate is often specified in terms of its average value over longer time intervals, for example, in units of $Gy \cdot min^{-1}$ or $Gy \cdot h^{-1}$.

(2) In gamma industrial irradiators, dose rate may be significantly different at different locations where product is irradiated.

(3) In electron-beam irradiators with pulsed or scanned beam, there are two types of dose rate: average value over several pulses (scans) and instantaneous value within a pulse (scan). These values can be significantly different.

3.1.4 *bremsstrahlung*—broad-spectrum electromagnetic radiation emitted when an energetic charged particle is influenced by a strong electric or magnetic field, such as that in the vicinity of an atomic nucleus.

3.1.5 *dose uniformity ratio*—ratio of the maximum to the minimum absorbed dose within the irradiated product.

3.1.5.1 *Discussion*—The concept is also referred to as the max/min dose ratio.

3.1.6 *dosimeter*—device that, when irradiated, exhibits a quantifiable change that can be related to absorbed dose in a given material using appropriate measurement instruments and procedures.

3.1.7 *dosimeter response*—reproducible, quantifiable change produced in the dosimeter by ionizing radiation.

3.1.7.1 *Discussion*—

(1) The dosimeter response value, obtained from one or more measurements, is used in the estimation of the absorbed dose.

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[4] Available from the International Commission on Radiation Units and Measurements, 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814 USA.

[5] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[6] Document produced by Working Group 1 of the Joint Committee for Guides in Metrology (JCGM WWG1). Available free of charge at the BIPM website (http://www.bipm.org).

[7] Document produced by Working Group 2 of the Joint Committee for Guides in Metrology (JCGM WG2), Available free of charge at the BIPM website (http://www.bipm.org).

[8] Available from National Physical Laboratory, Online, Available: http://www.chemdos.npl.co.uk/docs/NPLReportCIRM29.pdf. 8 May 2019.

(2) The response value might be obtained from such measurements as optical absorbance, peak-to-peak distance in EPR spectra, or electropotential between solutions.

3.1.8 *dosimetry system*—interrelated elements used for measuring absorbed dose, consisting of dosimeters, measurement instruments and their associated reference standards, and procedures for the system's use.

3.1.9 *measurement uncertainty*—non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used (VIM).

3.1.10 *metrological traceability*—property of a measurement whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty (VIM).

3.1.10.1 *Discussion—*

(1) The unbroken chain of calibrations is referred to as "traceability chain".

(2) It is also sometimes referred to as "measurement traceability".

3.1.11 *repeatability (of results of measurements)*—closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement (GUM).

3.1.11.1 *Discussion—*

(1) These conditions are called "repeatability conditions".

(2) Repeatability conditions include: the same measurement procedure, the same observer, the same measuring instrument used under the same conditions, the same location, repetition over a short period of time.

(3) Repeatability might be expressed quantitatively in terms of the dispersion characteristics of the results, such as standard deviation.

3.1.12 *reproducibility (of results of measurements)*—closeness of agreement between the results of measurements of the same measurand carried out under changed conditions of measurements (GUM).

3.1.13 *routine dosimetry system*—dosimetry system calibrated against a reference standard dosimetry system and used for routine absorbed dose measurements, including dose mapping and process monitoring.

3.1.14 *simulated product*—material with radiation absorption and scattering properties similar to those of the product, material or substance to be irradiated.

3.1.15 *transfer standard dosimetry system*—dosimetry system used as an intermediary to calibrate other dosimetry systems.

3.1.16 *transit dose*—absorbed dose delivered to a product (or a dosimeter) while it travels between the non-irradiation position and the irradiation position, or in the case of a movable source while the source moves into and out of its irradiation position.

3.1.17 *uncertainty budget*—statement of a measurement uncertainty, of the components of that measurement uncertainty, and of their calculation and combination (VIM).

3.1.17.1 *Discussion*—An uncertainty budget should include the measurement model, estimates, and measurement uncertainties associated with the quantities in the measurement model, covariances, type of applied probability density functions, degrees of freedom, type of evaluation of measurement uncertainty, and any coverage factor.

3.1.18 *X-radiation*—ionizing electromagnetic radiation, which includes both bremsstrahlung and the characteristic radiation emitted when atomic electrons make transitions to more tightly bound states.

3.1.18.1 *Discussion*—In radiation processing applications, the principal X-radiation is bremsstrahlung.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *nominal dose*——absorbed dose intended for the volume of interest within the irradiated sample.

Note 3—Definitions of other terms used in this standard that pertain to radiation measurement and dosimetry may be found in ISO/ASTM 52628, ASTM Terminology E3083, and ISO 12749-4. Definitions in these documents are compatible with ICRU Report 85a, and therefore, may be used as alternative references. Where appropriate, definitions used in this standard have been derived from, and are consistent with, general metrological definitions given in the VIM.

4. Significance and use

4.1 Reliable dosimetry is indispensable for research on the effects of ionizing radiation on materials and products. Without reliable dosimetry valid conclusions cannot be reached, or the wrong conclusions might be reached.

4.2 This document is intended to provide direction on how to conduct dosimetry for research and experiments on the effects of ionizing radiation on materials and products, and on the reporting of dosimetry results. Requirements on dosimetry and on dose ranges might differ between the various types of experiments to be carried out.

4.3 Proper reporting of the manner in which the irradiation was carried out is important since the degree of radiation effect might be a function of various factors, other than absorbed dose, such as the radiation source, the absorbed-dose rate, energy of the incident radiation, ambient environmental conditions during irradiation, and the type of incident radiation. This document attempts to highlight the information, including the methodology and results of the absorbed-dose measurements, necessary for an experiment to be repeatable by other researchers.

4.4 In most cases an experiment should be designed to irradiate the sample as uniformly as possible. In practice, a certain variation in absorbed dose will exist throughout the sample. Absorbed-dose mapping is used to determine the magnitude, location, and reproducibility of the maximum (D_{max}) and minimum absorbed dose (D_{min}) for a given set of experimental parameters. Dosimeters used for dose mapping must be capable of operation over the expected range of doses and must have sufficient spatial resolution to determine likely dose gradients (see ISO/ASTM 52303).

4.5 Computer simulations might provide useful information about absorbed-dose distribution in the irradiated sample, especially near material interfaces (see ASTM E2232), but are not a substitute for dosimetry.

5. Irradiation facilities and modes of operation

NOTE 4—This section is considered relevant for the user who has little prior knowledge in the field.

NOTE 5—Sections 5 and 6 give a brief overview of types of irradiation facilities and radiation source characteristics. Radiation source characteristics, the type of radiation produced, the energy of the photons or electrons, and the size and density of the samples to be irradiated will all be factors in determining how the incident radiation is absorbed in the irradiated samples. Researchers unfamiliar with radiation source characteristics are strongly encouraged to review appropriate reference materials before beginning experimentation (**2-5**).

5.1 *Types of Facilities*—This document covers the use of gamma radiation, X-radiation (bremsstrahlung), and accelerated-electron irradiators for studying the effects of ionizing radiation on materials and products.

5.2 *Self-Contained Dry Storage Gamma Irradiators*—Much of the research currently being conducted on food and other products is accomplished by using gamma radiation from either ^{137}Cs or ^{60}Co self-contained irradiators. These devices are self-shielded using lead (or other appropriate high atomic number material), and usually have a mechanism to move the sample container from the loading position to the irradiation position. See ISO/ASTM 52116.

NOTE 6—Typically, self-contained dry storage gamma irradiators have a limited irradiation volume.

5.2.1 In self-contained gamma irradiators, it is common that radiation sources are placed in an annular array around an irradiation container, such that the absorbed dose is relatively uniform in the irradiated samples.

5.2.2 Another method is to rotate the irradiation container on an irradiator turntable within the radiation field to achieve a relatively uniform dose within the sample.

5.3 *Self-Contained Wet Storage Gamma Irradiators*—Irradiation of samples may also be carried out in a wet-storage gamma irradiator used for large scale processing. The samples to be irradiated are kept dry in a specially designed container and lowered into the water next to the radiation source for irradiation of the samples.

5.4 *Self-Contained Low-energy X-ray Irradiators*—These irradiators generally consist of an electron source, an electrostatic field to accelerate these electrons, and a converter to generate X-radiation. (See for example Ref (**6**)).

5.4.1 One type of X-ray system operates a batch process where several containers with material for test are placed around and parallel to an isotropic X-ray source, and revolve around this source during irradiation while maintaining their orientation (much like chairs on a Ferris wheel), achieving acceptable dose uniformity (**6, 7**).

5.4.2 Alternately, a batch process may be operated where one or more containers are placed on a turntable which rotates the material for test next to a directional X-ray source.

5.4.3 Another method is to continuously pass trays or flat boxes between two X-ray sources, providing irradiation from two sides.

5.5 *Large-scale Gamma Irradiation Facilities*—Gamma irradiation of research samples is also carried out in large-scale irradiators, either pool-type or dry-storage. In these facilities the source typically consists of a series of rods that contain ^{60}Co and can be raised or lowered into a large irradiation room. When retracted from the irradiation room, the source is shielded by water (pool-type), or an appropriate material of high atomic number (dry-storage), or both.

5.5.1 *Automatic Operation*—A common method of irradiation is sample containers to be automatically conveyed into the irradiation room and then circulated through multiple positions around a central source in order to obtain a uniform absorbed dose. Samples are automatically conveyed out of the irradiation room, allowing the source to remain exposed for continuous operation. The source is retracted from the irradiation room when the irradiator is not in use.

5.5.2 *Batch Operation*—An alternative approach is to place one or more sample containers in the irradiation room while the source is shielded, and move the source into the irradiation position for the time required to achieve the desired absorbed dose. Depending on the design of the batch irradiator, the samples may circulate through multiple positions around the source, or may rotate in a fixed position relative to the source, or may be irradiated statically and repositioned one or more times during the exposure period. The source is retracted from the irradiator room in order to remove the samples.

5.5.3 Large-scale gamma irradiation facilities might be equipped with so-called "research loops" that allow irradiation of samples for test and research purposes.

5.6 *Large-Scale Electron and X-ray (Bremsstrahlung) Facilities:*

5.6.1 *Electron Facility*—Radiation sources for electrons (with energies greater than 300 keV) are either direct action (potential-drop) or indirect-action (microwave-powered) accelerators. The radiation fields depend on the characteristics and the design of the accelerators. Included among these characteristics are the electron beam parameters (such as, the electron energy spectrum, average electron beam current and beam current distribution on the product surface) that could affect dosimetry.

5.6.1.1 Typically, accelerators produce a narrow beam of electrons that is scanned to cover the width of the conveyor, which is where samples are irradiated. As an alternative to scanning, the beam might be diffused using a defocusing lens or scattering foils.

5.6.1.2 Electron facilities with energies less than 300 keV are typically direct action (potential-drop) accelerators. These accelerators often use extended cathodes to produce extended beams.

5.6.2 *X-ray (Bremsstrahlung) Facility*—An X-ray (bremsstrahlung) generator emits short-wavelength electromagnetic radiation, which is analogous to gamma radiation from radioactive isotopic sources. Although their effects on irradiated materials might be similar, they differ in their energy spectra, angular distribution, and dose rates.

5.6.2.1 Electrons are accelerated towards a metal target or "converter" of high atomic number (typically tungsten or tantalum). The collision of the electrons with the target generates X-radiation with a broad continuous energy spectrum.

5.6.3 *Sample Transport*—Samples are typically carried on a conveyor through the radiation field. Because of the narrow angular distribution of the radiation, use of conveyors to transport samples through the irradiation field enhances the dose uniformity in the sample.

5.6.4 Refer to ISO/ASTM 51608, 51818 and 51649 for more detailed information on electron and X-ray (bremsstrahlung) facilities and modes of operation.

6. Radiation source characteristics

6.1 *Gamma Irradiators:*

6.1.1 The radiation source used in the gamma facilities considered in this document consists of sealed elements of ^{60}Co or ^{137}Cs that are typically linear rods arranged in one or more planar or cylindrical arrays.

6.1.2 Cobalt-60 emits photons with discrete energies of approximately 1.17 and 1.33 MeV in nearly equal proportions. Cesium-137 emits photons with energy of approximately 0.662 MeV.

6.1.3 The radioactive decay half-lives for ^{60}Co and ^{137}Cs are regularly reviewed and updated. Ref (**8**) gives values of 1925.20 ± 0.25 days (5.271 years) for ^{60}Co and 11018.3 ± 9.5 days (30.1 years) for ^{137}Cs.

6.1.4 For gamma-ray sources, the only variation in the source output is the known reduction in the activity caused by radioactive decay. This reduction in the source activity, which necessitates an increase in the irradiation time to deliver the same dose, can be calculated or obtained from tables provided by the irradiator manufacturer.

NOTE 7—Errors in the decay calculation might be introduced by the existence of radioimpurities in the radiation source (for example, a small amount of ^{134}Cs present as an impurity in ^{137}Cs).

6.2 *Self-Contained Low-Energy X-ray Irradiators*—The electrons that generate X-radiation (bremsstrahlung) are accelerated to energies in the range from a few hundred keV (**6, 7**) to near 1 MeV.

6.2.1 Some currently available low-energy X-ray irradiators use tubes that generate X-radiation with a maximum energy of 150 keV. The continuous energy spectrum of the X-radiation extends from approximately 35 keV up to the energy of the electrons (**6, 7**).

NOTE 8—Because of the low photon energy, some dosimetry systems that are commonly used with gamma irradiators and accelerators are not applicable to low-energy X-ray irradiators. Farmer-type ionization chambers are appropriate as reference standard dosimetry systems for low-energy X-ray irradiators, when they are calibrated for appropriate photon energies (**6, 7**).

6.2.2 Energy of the X-radiation influences the size and shape of the sample container needed to achieve the desired level of dose uniformity. The power output influences the absorbed-dose rate and thus, time of irradiation.

6.3 *Large-Scale Electron Accelerator (Electron and X-ray (Bremsstrahlung) Modes):*

6.3.1 For an electron accelerator, the principal beam characteristics are the electron energy spectrum, the beam current, and where applicable, the instantaneous (per pulse) current together with pulse length and pulse repetition frequency (see ISO/ASTM 51649 and 51818).

6.3.1.1 Direct-action electron accelerators employ direct current (dc) or pulsed high-voltage generators and typically produce electron energies up to 5 MeV.

6.3.1.2 Indirect-action electron accelerators use microwave or very high frequency to produce electron energies typically from 1 MeV to 20 MeV

6.3.2 For an X-ray (bremsstrahlung) facility, along with beam characteristics noted in 6.3.1, X-ray target design is a critical parameter. Although the X-radiation (bremsstrahlung) is similar to gamma radiation from the radionuclides ^{60}Co or ^{137}Cs and thus their effects on materials might be similar, these kinds of radiation differ in their energy spectra, angular distributions, and absorbed-dose rates. The continuous energy spectrum of the X-ray (bremsstrahlung) extends up to the maximum energy of the electrons incident on the X-ray target (see ISO/ASTM 51608). In some cases, spectrum filtration is used to reduce the low energy component of the radiation, so as to improve dose uniformity in the sample container.

7. Dosimetry systems

7.1 Dosimetry systems are used to measure absorbed dose, usually in terms of absorbed dose to water. They consist of dosimeters, measurement instruments and their associated reference standards, and procedures for the system's use.

7.2 ISO/ASTM 52628 provides information about the selection of dosimetry systems for different applications. Most research will be conducted using routine dosimeters and transfer-standard dosimetry systems.

7.2.1 *Transfer-Standard Dosimetry Systems*—Transfer-standard dosimetry systems are specifically selected dosimeters used for transferring absorbed-dose information from an approved laboratory to an irradiation facility in order to establish measurement traceability for that facility. The transfer standard dosimeters should be carefully used under conditions that are specified by the issuing laboratory.

7.2.2 *Routine Dosimetry Systems*—Routine dosimetry systems are used for monitoring the irradiation process and for dose mapping. Proper dosimetric techniques, including calibration, should be employed to ensure that measurements are reliable and accurate. Examples of routine dosimetry systems, along with their useful dose ranges, are listed in Table 1.

7.3 A routine dosimetry system should be selected that is suitable for the research, taking into consideration those parameters associated with the radiation source and experimental set-up that might influence dosimeter response (for example, absorbed-dose range, dose rate, radiation energy, and environmental conditions, such as temperature, humidity and UV light; also see ISO/ASTM 52701) and the measurement uncertainty associated with the system. More detailed selection criteria are listed in ISO/ASTM 52628. For electron accelerator applications, it might also be essential to consider the influences of absorbed-dose rate (average and peak dose rate for pulsed accelerators), and pulse frequency when selecting a dosimeter.

7.3.1 For use, handling, storage, special precautions, calibration, etc., for a specific routine dosimetry system,

TABLE 1 Examples of routine dosimeters (see ISO/ASTM 52628)

Dosimeter	Measurement Instrument	Useful Absorbed Dose Range Units: Gy	References
Alanine	EPR spectrometer	1 to 10^5	ISO/ASTM 51607
Polymethylmethacrylate	UV/Visible spectrophotometer	10^2 to 10^5	ISO/ASTM 51276
Cellulose triacetate	Spectrophotometer	5×10^3 to 3×10^5	ISO/ASTM 51650
Thermoluminescence (TLD)	Thermoluminescence reader	1 to 10^5	ISO/ASTM 51956
Radiochromic dye films, optical wave guide	Visible spectrophotometer	1 to 10^5	ISO/ASTM 51275 ISO/ASTM 51310
Ceric cerous sulfate solution	Potentiometer or UV	5×10^2 to 5×10^4	ISO/ASTM 51205
Fricke solution	UV spectrophotometer	20 to 4×10^2	ISO/ASTM 51026
Ethanol chlorobenzene solution	Spectrophotometer, color titration, high frequency conductivity	10^1 to 2×10^6	ISO/ASTM 51538
MOSFET	Electronic Reader	1 to 2×10^2	**(9)**

recommendations given in the relevant ISO/ASTM standard and by the manufacturer should be used.

7.4 Prior to use, a dosimetry system should be calibrated. General calibration guidelines are given in ISO/ASTM 52628 and more detailed calibration guidelines are given in ISO/ASTM 51261.

7.4.1 The researcher should inquire with the operator of the irradiation facility about calibration data for the dosimetry systems used in the researcher's experiments. Such data should be referenced when reporting results of the experiments.

7.4.1.1 The calibration curve supplied by the dosimeter supplier should be considered as general information only and should not be used without further verification of its applicability.

8. Irradiator characterization

8.1 Before performing useful experiments, the researcher should ensure that the irradiation facility is characterized with respect to the key parameters that are essential for delivering accurate and reproducible doses. Documentation for this characterization should include descriptions and calibration of instrumentation and equipment necessary for the precise repetition of the experiment. Such data should be referenced when reporting results of the experiments.

8.2 The objective of the irradiator characterization is to ensure that all the equipment is working as required and properly calibrated.

9. Sample or product dose mapping

9.1 The purpose of dose mapping is to establish the most suitable irradiation geometry for samples and products including selection of all key irradiation parameters, and to provide evidence of reproducibility of dose and dose distribution.

9.1.1 This objective is accomplished through mapping the absorbed-dose distribution throughout the sample, whether this comprises a single item or group of items such as a box containing products. See ISO/ASTM 52303.

9.1.2 The absorbed dose received by any portion of a sample or product depends on the irradiator and experimental parameters, such as the source type and geometry, irradiation geometry, product composition and density, and product distribution.

9.1.3 Within the sample to be irradiated, a volume of interest should be specified. The dose and dose distribution in this volume should be established.

9.2 The irradiation experiment is often designed to irradiate the samples or products uniformly. In practice, a certain variation in absorbed dose through the sample or product will exist. Absorbed-dose mapping is used to determine the magnitude and locations of maximum and minimum dose within the sample (D_{max} and D_{min}) for a given set of parameters, including a specific irradiation geometry that should then be used throughout the experiment.

NOTE 9— Some irradiation tests, e.g. testing using irradiation from low energy electron accelerators, might require samples to be irradiated only at the surface.

9.2.1 Dose mapping involves placing dosimeters throughout the sample, both on the surface and within the sample. Placement patterns that can identify the locations of D_{max} and D_{min} should be carefully selected (see ISO/ASTM 52303). Some dosimeters exist in the form of strips or sheets, enabling the researcher to easily obtain detailed one or two dimensional dose distribution.

NOTE 10—Prior to performing dose mapping, the researcher should review the ISO/ASTM standards and scientific literature that are relevant for the experiment. Dosimetry data from previously performed experiments or theoretical calculations might provide useful information for determining the number and location of dosimeters needed.

9.2.2 Dosimeters might be placed throughout the sample in a three-dimensional grid pattern in order to obtain a map of the absorbed dose (dose map) within the sample, but more complex dosimeter placement arrangement might be needed. The level of reproducibility of the dose distribution can be determined by replication of the dose mapping procedure in several nominally identical samples using the same irradiation conditions.

9.2.3 Locations and values of D_{max} and D_{min} in the irradiated sample can be determined from the dose mapping data. If the difference between D_{max} and D_{min} in the sample is not acceptable for the intended experiment, attempts should be made to minimize the difference (see 9.3).

9.2.4 Changes in the irradiation geometry or in the radiation source characteristics might affect the absorbed-dose distribution and thus require repeating the dose mapping experiment.

9.3 *Dose Non-Uniformity:*

9.3.1 If the incident radiation is attenuated or scattered substantially in the irradiated sample, large absorbed-dose gradients may exist in the sample. The dose uniformity in the sample may be improved by irradiating the sample on a rotating turntable, or by irradiating it from two or four sides.