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Guide for dosimetry in radiation research on food and agricultural products

Guide de la dosimétrie pour la recherche dans le domaine de l'irradiation des produits alimentaires et agricoles

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75% of the member bodies casting a vote.

ASTM International is one of the world's largest voluntary standards development organizations with global participation from affected stakeholders. ASTM technical committees follow rigorous due process balloting procedures.

A project between ISO and ASTM International has been formed to develop and maintain a group of ISO/ASTM radiation processing dosimetry standards. Under this project, ASTM Subcommittee E10.01, Radiation Processing: Dosimetry and Applications, is responsible for the development and maintenance of these dosimetry standards with unrestricted participation and input from appropriate ISO member bodies.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. Neither ISO nor ASTM International shall be held responsible for identifying any or all such patent rights.

International Standard ISO/ASTM 51900 was developed by ASTM Committee E10, Nuclear Technology and Applications, through Subcommittee E10.01, and by Technical Committee ISO/TC 85, Nuclear energy.

This second edition cancels and replaces the first edition (ISO/ASTM 51900:2002), which has been technically revised.

Standard Guide for Dosimetry in Radiation Research on Food and Agricultural Products[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 guide covers the minimum requirements for dosimetry needed to conduct research on the effect of radiation on food and agricultural products. Such research includes establishment of the quantitative relationship between absorbed dose and the relevant effects in these products. This guide also describes the overall need for dosimetry in such research, and in reporting of the results. Dosimetry must be considered as an integral part of the experiment.

NOTE 1—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 that strongly emphasize the role of dosimetry for ensuring that irradiation will be properly performed (**1**).[2]

NOTE 2—This guide 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 (**2-10**).

1.2 This guide covers research conducted using the following types of ionizing radiation: gamma radiation, X-ray (bremsstrahlung), and electron beams.

1.3 This guide describes dosimetry requirements for establishing the experimental method and for routine experiments. It does not include dosimetry requirements for installation qualification or operational qualification of the irradiation facility. These subjects are treated in ISO/ASTM Practices 51204, 51431, 51608, 51649, and 51702.

1.4 This guide is not intended to limit the flexibility of the experimenter in the determination of the experimental methodology. The purpose of the guide 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.

1.5 The overall uncertainty in the absorbed-dose measurement and the inherent absorbed-dose variation within the irradiated sample should be taken into account (see ISO/ASTM Guide 51707).

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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced documents

2.1 *ASTM Standards:*[3]

E 170 Terminology Relating to Radiation Measurements and Dosimetry

E 925 Practice for Monitoring the Calibration of Ultraviolet-Visible Spectrophotometers whose Spectral Slit Width does not Exceed 2 nm

E 1026 Practice for Using the Fricke Reference-Standard Dosimetry System

E 2232 Guide for Selection and Use of Mathematical Methods for Calculating Absorbed Dose in Radiation Processing Applications

E 2303 Guide for Absorbed-Dose Mapping in Radiation Processing Facilities

E 2304 Practice for Use of a LiF Photo-Fluorescent Film Dosimetry System

E 2381 Guide for Dosimetry In Radiation Processing of Fluidized Beds and Fluid Streams

F 1355 Guide for Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment

F 1356 Practice for Irradiation of Fresh and Frozen Red Meat and Poultry to Control Pathogens and Other Microorganisms

F 1640 Guide for Selection and Use of Packaging Materials for Foods to Be Irradiated

F 1736 Guide for Irradiation of Finfish and Aquatic Invertebrates Used as Food to Control Pathogens and Spoilage Microorganisms

F 1885 Guide for Irradiation of Dried Spices, Herbs, and Vegetable Seasonings to Control Pathogens and Other Microorganisms

2.2 *ISO/ASTM Standards:*[3]

51204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing

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

[1] This guide is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.01 on Radiation Processing: Dosimetry and Applications, 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 guide.

[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.

51261 Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing
51275 Practice for Use of a Radiochromic Film Dosimetry System
51276 Practice for Use of a Polymethylmethacrylate Dosimetry System
51310 Practice for Use of a Radiochromic Optical Waveguide Dosimetry System
51431 Practice for Dosimetry in Electron Beam and X-ray (Bremsstrahlung) Irradiation Facilities for Food Processing
51538 Practice for Use of the Ethanol-Chlorobenzene Dosimetry System
51540 Practice for Use of a Radiochromic Liquid 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 Electron Beam Facility for Radiation Processing at Energies between 300 keV and 25 MeV
51650 Practice for Use of Cellulose Triacetate Dosimetry Systems
51702 Practice for Dosimetry in a Gamma Irradiation 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

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

ICRU 60 Fundamental Quantities and Units for Ionizing Radiation

2.4 *NPL Report:*

CIRM 29 : Guidelines for Calibration of Dosimeters for Use in Radiation Processing, Sharpe, P., and Miller, A., August, 1999

3. Terminology

3.1 *Definitions:*

3.1.1 *absorbed dose (D)*—quantity of ionizing radiation energy imparted per unit mass of a specified material. 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). The mathematical relationship is the quotient of $d\bar{\varepsilon}$ by dm, where $d\bar{\varepsilon}$ is the mean incremental energy imparted by ionizing radiation to matter of incremental mass dm.

$$D = d\bar{\varepsilon}/dm \quad (1)$$

3.1.1.1 *Discussion*—The discontinued unit for absorbed dose is the rad (1 rad = 100 erg/g = 0.01 Gy). Absorbed dose is sometimes referred to simply as 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* $\dot{D}$ —absorbed dose in a material per incremental time interval, that is, the quotient of dD by dt (see ICRU 60).

$$\dot{D} = dD/dt \quad (2)$$

Unit: Gy · s^{-1}

3.1.4 *accredited dosimetry calibration laboratory*—dosimetry laboratory with formal recognition by an accrediting organization that the dosimetry laboratory is competent to carry out specific activities which lead to the calibration or calibration verification of dosimetry systems in accordance with documented requirements of the accrediting organization.

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

3.1.6 *charged-particle equilibrium*—condition in which the kinetic energy of charged particles, excluding rest mass, entering an infinitesimal volume of the irradiated material equals the kinetic energy of charged particles emerging from it.

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

3.1.8 *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.

3.1.9 *dosimeter response*—reproducible, quantifiable radiation effect produced in the dosimeter by a given absorbed dose.

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

3.1.11 *electron equilibrium*—charged-particle equilibrium when the charged particles are electrons set in motion by photons irradiating the material. See charged-particle equilibrium.

3.1.12 *reference-standard dosimeter*—dosimeter of high metrological quality, used as a standard to provide measurements traceable to measurements made using primary-standard dosimeters.

3.1.13 *repeatability (of results of measurements)*—closeness of the agreement between the results of successive measurements of the same measurand carried out subject to all of the following conditions; the same measurement procedure, the same observer, the same measuring instrument, used under the same conditions, the same location, and repetition over a short period of time.

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

3.1.13.1 *Discussion*—These conditions are called "repeatability conditions." Repeatability may be expressed quantitatively in terms of the dispersion characteristics of the results.

3.1.14 *reproducibility (of results of measurements)*—closeness of agreement between the results of measurements of the same measurand, where the measurements are carried out under changed conditions such as differing: principle or method of measurement, observer, measuring instrument, location, conditions of use, and time.

3.1.14.1 *Discussion*—A valid statement of reproducibility requires specification of the conditions that were changed for the measurements. Reproducibility may be expressed quantitatively in terms of the dispersion characteristics of the results. In this context, results of measurement are understood to be corrected results.

3.1.15 *routine dosimeter*—dosimeter calibrated against a primary-, reference-, or transfer-standard dosimeter and used for routine absorbed-dose measurement.

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

3.1.17 *traceability*—property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.

3.1.18 *transfer-standard dosimeter*—dosimeter, often a reference-standard dosimeter, suitable for transport between different locations, used to compare absorbed-dose measurements.

3.1.19 *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.

3.1.20 *uncertainty (of measurement)*—parameter associated with the result of a measurement, that characterizes the dispersion of the values that reasonably could be attributed to the measurand or derived quantity (see ISO/ASTM Guide 51707).

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *residual*—difference between the observed value and the value calculated by the regression model.

3.2.2 *target 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 ASTM Terminology E 170. Definitions in Terminology E 170 are compatible with ICRU 60; that document, therefore, may be used as an alternative reference.

4. Significance and use

4.1 This guide is intended to provide direction on dosimetry for experiments in food and agricultural research, and on the reporting of dosimetry results. Research concerning the effectiveness of irradiation of food and agricultural products to achieve a defined benefit involves very different absorbed-dose specifications from one study and one product to another. For example, the absorbed dose required to sterilize fruit flies is much lower than the doses required to inactivate some bacterial pathogens in meat, or to decontaminate spices.

NOTE 4—Examples of the relevant effects of irradiation include reduction of viable food-borne bacteria, viruses and parasites and phytosanitary treatment (such as disinfestation of fruits and vegetables), prevention of sprouting, delay of ripening, and changes in product chemistry and quality. Further discussion of these effects is outside the scope of this guide. Refer to ASTM Guides F 1355, F 1356, F 1736 and F 1885.

4.2 Proper reporting of the irradiation aspect is important since the degree of biological effect may be a function of various factors such as the radiation source, the absorbed-dose rate, energy of the incident radiation, environmental effects during irradiation, and the type of incident radiation. This guide 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.

NOTE 5—Factors that may influence the response of agricultural products to ionizing radiation include genus, species, variety, vigor, life stage, initial quality, state of ripeness, temperature, moisture content, pH, packaging, shipping, and storage conditions. Although these factors are not discussed in this guide, they should be considered when planning experiments (see ASTM Guides F 1355, F 1356, F 1640, F 1736 and F 1885.

4.3 Ideally, 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 responding to doses and dose gradients likely to occur within irradiated samples.

4.4 Theoretical calculations may provide useful information about absorbed-dose distribution in the irradiated sample, especially near material interfaces (see ASTM Guide E 2232).

5. Irradiation facilities and modes of operation

5.1 *Types of Facilities*—This guide covers the use of gamma radiation, X-ray (bremsstrahlung), and accelerated electrons used for studying the effects of ionizing radiation on food and agricultural products.

NOTE 6—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 sizes and densities of the samples to be irradiated, will all be factors in determining how the incident radiation is absorbed in the experimental samples. Researchers unfamiliar with radiation source characteristics are strongly recommended to review appropriate reference materials before beginning experimentation **(2-10)**.

5.2 *Self-Contained Dry Storage Gamma and X-ray (bremsstrahlung) Irradiators*—Much of the research currently being conducted on food and agricultural products is accomplished by using gamma radiation from either ^{137}Cs or ^{60}Co

self-contained irradiators or X-ray (bremsstrahlung) 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 load to the irradiation position.

NOTE 7—Typically, self-contained dry storage gamma irradiators have a limited irradiation volume. This type of irradiator is classified as ANSI Category I, Self-contained Dry Storage Gamma Irradiators **(11)**.

5.2.1 In self-contained gamma irradiators, a common approach is to distribute the source in an annular array, such that the absorbed dose is relatively uniform around the center where the sample is irradiated.

5.2.2 For gamma and X-ray units, another method is to rotate the sample container on an irradiator turntable within the radiation field to achieve a more 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. In these facilities, the source is contained in a storage pool (usually containing water), which is shielded at all times. The samples to be irradiated are enclosed in a water-tight chamber and lowered into the water next to the radiation source.

NOTE 8—This type of irradiator is classified as ANSI Category III, Self-Contained Wet Source Storage Gamma Irradiators **(12)**.

5.4 *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.

NOTE 9—These types of irradiators are classified as ANSI Category IV, Wet Source Storage Gamma Irradiators or ANSI Category II, Dry Source Storage Gamma Irradiators **(13)**.

5.4.1 *Continuous Operation*—A common method of use is for the irradiation of sample containers to be carried on a conveyor in one or more revolutions around a central source in order to obtain a more uniform absorbed dose. The source is retracted from the irradiation room when the irradiator is not in use.

5.4.2 *Batch Operation*—An alternative approach is to place the 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.

5.5 *Electron and X-ray (Bremsstrahlung) Facilities*:

5.5.1 *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, that is, the electron energy spectrum, average electron beam current and beam current distribution on the product surface.

5.5.1.1 Typically, accelerators produce a narrow beam of electrons that is diffused to cover the width of the conveyor, which is the location at which samples will be irradiated. Diffusion of the electron beam may be accomplished using a magnetic scanner (to sweep the beam back and forth rapidly), a magnetic defocusing lens, or scattering foils.

5.5.2 *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 are generally similar, these kind of radiation differ in their energy spectra, angular distribution, and dose rates.

5.5.2.1 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-ray (bremsstrahlung) with a broad continuous energy spectrum).

5.5.3 *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, in contrast to use of static irradiation systems or shuffle-dwell systems will enhance the dose uniformity.

5.5.4 Refer to ISO/ASTM Practices 51431, 51608, and 51649 for more detailed information or 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 guide 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 **(14)**.

6.1.3 The radioactive decay half-lives for ^{60}Co and ^{137}Cs are regularly reviewed and updated. A recent publication gave values of 1925.20 ± 0.25 days for ^{60}Co and 11018.3 ± 9.5 days for ^{137}Cs **(15)**.

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, may be calculated or obtained from tables provided by the irradiator manufacturer (refer to ISO/ASTM Practice 51204).

NOTE 10—Errors in the decay calculation may 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 *Electron Accelerator (Electron and X-ray (Bremsstrahlung) Modes)*:

6.2.1 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 Practices 51431, 51649 and 51818).

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

6.2.1.2 Indirect-action electron accelerators use microwave or very high frequency (VHF) alternating current (ac) to produce electron energies typically from 3 MeV to 15 MeV.

6.2.2 For an X-ray (bremsstrahlung) facility, besides beam characteristics noted in 6.2.1, X-ray target design is a critical parameter. Although the X-ray (bremsstrahlung) is similar to gamma radiation from the radionuclides ^{60}Co or ^{137}Cs and thus their effects on materials are generally 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 Practice 51608). In some cases, spectrum filtration is used to reduce the low energy component of the radiation, so as to improve dose uniformity.

NOTE 11—In some countries, regulations may limit the maximum energy for electrons or X-ray (bremsstrahlung) used to irradiate food for human consumption.

7. Dosimetry systems

7.1 Dosimetry systems are used to determine 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 Dosimeters may be divided into four basic classes according to their relative quality and areas of application: primary-standard, reference-standard, transfer-standard, and routine dosimeters. ISO/ASTM Guide 51261 provides information about the selection of dosimetry systems for different applications. Most research will be conducted using routine dosimeters and transfer-standard dosimeters.

7.2.1 *Primary-Standard Dosimeters*—Primary-standard dosimeters are established and maintained by national standards laboratories for calibration of radiation environments (fields) and other classes of dosimeters. The two most commonly used primary-standard dosimeters are ionization chambers and calorimeters.

7.2.2 *Reference-Standard Dosimeters*—Reference-standard dosimeters are used to calibrate radiation environments and routine dosimeters. Examples of reference-standard dosimeters, along with their useful dose ranges, are listed in ISO/ASTM Guide 51261.

7.2.3 *Transfer-Standard Dosimeters*—Transfer-standard dosimeters are specifically selected dosimeters used for transferring absorbed-dose information from an accredited or national standards laboratory to an irradiation facility in order to establish traceability for that facility. These dosimeters should be carefully used under conditions that are specified by the issuing laboratory. Transfer-standard dosimeters may be selected from either reference-standard dosimeters or routine dosimeters taking into consideration the criteria listed in ISO/ASTM Guide 51261.

7.2.4 *Routine Dosimeters*—Routine dosimeters may be used for process control and dose mapping. Proper dosimetric techniques, including calibration, should be employed to ensure that measurements are reliable and accurate. Examples of routine dosimeters, along with their useful dose ranges, are listed in Table 1 and ISO/ASTM Guide 51261.

7.3 Select a routine dosimetry system suitable for the research taking into consideration those parameters associated with the radiation source and experimental set-up that may influence dosimeter response (for example, absorbed-dose range, radiation source, dose rate, energy, and environmental conditions, such as temperature, humidity and light) and the uncertainty associated with it. More detailed selection criteria are listed in ISO/ASTM Guide 51261. For electron accelerator applications, it is also essential to consider the influences of absorbed-dose rate (average and peak dose rate for pulsed accelerators), pulse rate and pulse width (if applicable) when selecting a dosimeter.

7.3.1 For use, handling, storage, special precautions, calibration, etc., for a specific routine dosimetry system, an ASTM or ISO/ASTM standard and manufacturers recommendations shall be used.

7.4 Prior to use, a dosimetry system shall be calibrated. The calibration curve supplied by the dosimeter supplier should be considered as general information and should not be used without further verification of its applicability. The calibration of the existing lot of dosimeters should be checked at regular intervals as appropriate. This check could take the form of a calibration verification exercise.

7.4.1 Calibration verification can be performed by irradiating sets of dosimeters at each of three dose points (spanning the

TABLE 1 Examples of routine dosimeters (see ISO/ASTM Guide 51261)

Dosimeter	Measurement Instrument	Useful Absorbed Dose Range (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
Lithium Fluoride Film	Fluorimeter	50 to 3×10^5	ASTM E 2304
Radiochromic dye films, solutions, optical wave guide	Visible spectrophotometer	1 to 10^5	ISO/ASTM 51275 ISO/ASTM 51540 ISO/ASTM 51310
Ceric cerous sulfate solution	Potentiometer or UV spectrophotometer	5×10^2 to 5×10^4	ISO/ASTM 51205
Fricke solution	UV spectrophotometer	20 to 4×10^2	ASTM E 1026
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	**(16)**