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Practice for dosimetry for a self-contained dry-storage gamma-ray irradiator

Pratique de la dosimétrie appliquée à un irradiateur gamma renfermant une source auto-protégée entreposée à sec

Reference number
ISO/ASTM 52116:2002(E)

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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 pilot project between ISO and ASTM International has been formed to develop and maintain a group of ISO/ASTM radiation processing dosimetry standards. Under this pilot project, ASTM Subcommittee E10.01, Dosimetry for Radiation Processing, 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 52116 was developed by ASTM Committee E10, Nuclear Technology and Applications, through Subcommittee E10.01, and by Technical Committee ISO/TC 85, Nuclear Energy.

Annexes A1 and A2 of this International Standard are for information only.

Standard Practice for Dosimetry for a Self-Contained Dry-Storage Gamma-Ray Irradiator[1]

This standard is issued under the fixed designation ISO/ASTM 52116; 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 practice outlines dosimetric procedures to be followed with self-contained dry-storage gamma-ray irradiators. If followed, these procedures will help to ensure that calibration and testing will be carried out with acceptable precision and accuracy and that the samples processed with ionizing radiation from gamma rays in a self-contained dry-storage irradiator receive absorbed doses within a predetermined range.

1.2 This practice covers dosimetry in the use of dry-storage gamma-ray irradiators, namely self-contained dry-storage ^{137}Cs or ^{60}Co irradiators (shielded freestanding irradiators). It does not cover underwater pool sources, panoramic gamma-ray sources such as those raised mechanically or pneumatically to irradiate isotropically into a room or through a collimator, nor does it cover self-contained bremsstrahlung x-ray units.

1.3 The absorbed dose range for the use of the dry-storage self-contained gamma-ray irradiators covered by this practice is typically 1 to 10^5 Gy, depending on the application. The absorbed-dose rate range typically is from 10^{-2} to 10^3 Gy/min.

1.4 This practice describes general procedures applicable to all self-contained dry-storage gamma-ray irradiators. For procedures specific to dosimetry in blood irradiation, see ISO/ASTM Practice 51939. For procedures specific to dosimetry in radiation research on food and agricultural products, see ISO/ASTM Practice 51900. For procedures specific to radiation hardness testing, see ASTM Practice E 1249. For procedures specific to the dosimetry in the irradiation of insects for sterile release programs, see ISO/ASTM Guide 51940. In those cases covered by ISO/ASTM Practices 51939, 51900, 51940, or ASTM E 1249, those standards take precedence. In addition, this practice does not cover absorbed-dose rate calibrations of radiation protection instrumentation.

1.5 *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:*

E 170 Terminology Relating to Radiation Measurements and Dosimetry[2]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[3]

E 456 Terminology Relating to Quality Statistics[3]

E 1026 Practice for Using the Fricke Reference Standard Dosimetry System[2]

E 1249 Practice for Minimizing Dosimetry Errors in Radiation Hardness Testing of Silicon Electronic Devices Using Co-60 Sources[2]

2.2 *ISO/ASTM Standards:*

51204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing[2]

51205 Practice for Use of a Ceric-Cerous Sulfate Dosimetry System[2]

51261 Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing[2]

51275 Practice for Use of a Radiochromic Film Dosimetry System[2]

51276 Practice for Use of a Polymethylmethacrylate Dosimetry System[2]

51310 Practice for Use of a Radiochromic Optical Waveguide Dosimetry System[2]

51400 Practice for Characterization and Performance of a High-Dose Gamma Radiation Dosimetry Calibration Laboratory[2]

51401 Practice for Use of a Dichromate Dosimetry System[2]

51431 Practice for Dosimetry in Electron and Bremsstrahlung Irradiation Facilities for Food Processing[2]

51538 Practice for Use of the Ethanol Chlorobenzene Dosimetry System[2]

51540 Practice for Use of a Radiochromic Liquid Dosimetry System[2]

51607 Practice for the Use of the Alanine-EPR Dosimetry System[2]

51608 Practice for Dosimetry in an X-Ray (Bremsstrahlung) Facility for Radiation Processing[2]

51650 Practice for Use of the Cellulose Acetate Dosimetry System[2]

51702 Practice for Dosimetry in a Gamma Irradiation Facility for Radiation Processing[2]

[1] This practice is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.01 on Dosimetry for Radiation Processing, and is also under the jurisdiction of ISO/TC 85/WG 3.

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[2] *Annual Book of ASTM Standards*, Vol 12.02.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

51707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing[2]
51900 Guide for Dosimetry in Radiation Research on Food and Agricultural Products[2]
51939 Practice for Blood Irradiation Dosimetry[2]
51940 Guide for Irradiation of Insects for Sterile Release Programs[2]

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

ICRU 14 Radiation Dosimetry: X-Rays and Gamma Rays with Maximum Photon Energies Between 0.6 and 50 MeV
ICRU 44 Tissue Substitutes in Radiation Dosimetry and Measurement
ICRU 51 Quantities and Units in Radiation Protection Dosimetry
ICRU 60 Fundamental Quantities and Units for Ionizing Radiation Metrology

2.4 *ANSI Standards:*[5]

ANSI N323, Radiation Protection Instrumentation Test and Calibration
ANSI Report N433.1, Safe Design and Use of Self-Contained, Dry-Source Storage Gamma Irradiators (Category I)

2.5 *NCRP Publications:*[6]

NCRP Report No. 58, Handbook of Radioactivity Measurements
NCRP Report No. 69, Dosimetry of X-Ray and Gamma Ray Beams for Radiation Therapy in the Energy Range 10 keV to 50 MeV

2.6 *ISO Publications:*[7]

ISO/IEC 17025, General Requirements for the Competence of Calibration and Testing Laboratories
ISO 11137 Sterilization of Health Care Products—Requirements for Validation and Routine Control-Radiation Sterilization

2.7 *IAEA Publication:*[8]

IAEA TECDOC-619 X-Ray and Gamma-Ray Standards for Detector Calibration

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 J/kg of the specified material (1 Gy = 1 J/kg). The mathematical relationship is the quotient of $d\bar{\epsilon}$ by dm, where $d\bar{\epsilon}$ is the mean incremental energy imparted by ionizing radiation to matter of incremental mass dm (see ICRU 51).

$$D = \frac{d\bar{\epsilon}}{dm} \tag{1}$$

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. For a photon source under conditions of charged particle equilibrium, the absorbed dose, D, may be expressed as:

$$D = \Phi \cdot E \cdot \frac{\mu_{en}}{\rho} \tag{2}$$

where:

Φ = particle fluence (particles/m^2),
E = energy of the ionizing radiation (J/particle), and
μ_{en}/ρ = mass energy absorption coefficient (m^2/kg). If bremsstrahlung production within the specified material is negligible, the mass energy absorption coefficient (μ_{en}/ρ) is equal to the mass energy transfer coefficient (μ_{tr}/ρ), and absorbed dose is equal to kerma if, in addition, charged particle equilibrium exists.

3.1.2 *absorbed-dose mapping*—measurement of absorbed dose within a process load using dosimeters placed at specified locations 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* ($\dot{D}$)—the absorbed dose in a material per incremental time interval, that is, the quotient of dD by dt.

$$\dot{D} = \frac{dD}{dt} \tag{3}$$

SI unit: Gy · s^{-1}.

3.1.3.1 *Discussion*—The absorbed-dose rate often is specified in terms of total value of D as a function of longer time intervals, for example, in units of Gy·min^{-1} or Gy·h^{-1}.

3.1.4 *activity (A)*—of an amount of radioactive nuclide in a particular energy state at a given time, the quotient of dN by dt, where dN is the expectation value of the number of spontaneous nuclear transformations from that energy state in the time interval dt (ICRU 60).

$$A = \frac{dN}{dt} \quad \text{Unit: s}^{-1} \tag{4}$$

The unit of activity, A, is the becquerel (Bq).

3.1.4.1 *Discussion*—The former special unit of activity was the curie (Ci).

$$1 \text{ Ci} = 3.7 \times 10^{10}\ s^{-1} = 3.7 \times 10^{10} \text{ Bq (exactly)} \tag{5}$$

The particular energy state is the ground state of the nuclide unless otherwise specified. The activity of an amount of radioactive nuclide in a particular energy state is equal to the product of the decay constant, λ, for that state and the number of nuclei in the state (that is, $A = N\lambda$) (see decay constant).

3.1.5 *calibration*—the process whereby the response of a measuring system or measuring instrument is characterized through comparison with an appropriate standard that is traceable to a nationally or internationally recognized standard.

3.1.6 *calibration curve*—graphical representation of the

[4] International Commission on Radiation Units and Measurements (ICRU), 7910 Woodmont Ave., Suite 800, Bethesda, MD 20810, U.S.A.
[5] American National Standards Institute, 25 West 43rd St., New York, NY 10036, U.S.A.
[6] National Council on Radiation Protection (NCRP), 7910 Woodmont Ave., Suite 800, Bethesda MD 20814, U.S.A.
[7] International Organization for Standardization (ISO), 1 rue de Varembé, Case Postale 56, CH-1211 Geneva 20, Switzerland.
[8] International Atomic Energy Agency (IAEA), Wagrammerstrasse 5, P.O. Box 100, A-1400 Vienna, Austria.

dosimetry system's response function.

3.1.7 *calibration facility*—combination of an ionizing radiation source and its associated instrumentation that provides a uniform and reproducible absorbed dose, or absorbed dose rate, traceable to national or international standards at a specific location and within a specified material, and that may be used to derive the dosimetry system's response function or calibration curve.

3.1.7.1 *Discussion*—Some manufacturers calibrate instruments in units of exposure (see 3.1.15).

3.1.8 *canister*—a container, usually an aluminum or steel cylinder, used to house the sample, or simulated product, during the radiation process.

3.1.9 *charged particle equilibrium*—the condition that exists in an incremental volume within a material under irradiation if the kinetic energies and number of charged particles (of each type) entering that volume are equal to those leaving that volume.

3.1.9.1 *Discussion*—When electrons are the predominant charged particle, the term "electron equilibrium" is often used to describe charged particle equilibrium. See also the discussions attached to the definitions of kerma and absorbed dose in ASTM E 170.

3.1.10 *decay constant* (λ)—of a radioactive nuclide in a particular energy state, the quotient of *dP* by *dt*, where *dP* is the probability of a given nucleus undergoing spontaneous nuclear transition from that energy state in the time interval dt (ICRU 60).

$$\lambda = \frac{dP}{dt} \quad \text{Unit: s}^{-1} \tag{6}$$

3.1.10.1 *Discussion*—The quantity (ln 2)/λ is commonly called half life, $t_{1/2}$, of the radioactive nuclide, that is, the time taken for the activity of an amount of radioactive nuclide to become half its initial value.

3.1.11 *dose uniformity ratio*—ratio of maximum to minimum absorbed dose within the process load. The concept is also referred to as the max/min dose ratio.

3.1.12 *dosimeter*—a device that, when irradiated, exhibits a quantifiable change in some property of the device which can be related to absorbed dose in a given material using appropriate measurement instrumentation and techniques.

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

3.1.14 *electron equilibrium*—charged particle equilibrium for electrons.

3.1.15 *exposure (X)*—the quotient of *dQ* by *dm*, where the value of *dQ* is the absolute value of the total charge of the ions of one sign produced in air when all the electrons (negatrons and positrons) liberated by photons in air of mass *dm* are completely stopped in air (ICRU 60).

$$X = \frac{dQ}{dm} \tag{7}$$

Unit: C kg^{-1}

3.1.15.1 *Discussion*—Formerly, the special unit of exposure was the roentgen (R): 1 R = 2.58 × 10^{-4} C · kg^{-1} (exactly).

3.1.16 *exposure rate* ($\dot{X}$)—the quotient of *dX* by *dt*, where *dX* is the increment of exposure in the time interval, *dt*.

$$\dot{X} = \frac{dX}{dt} \tag{8}$$

Unit: C kg^{-1} s^{-1}

3.1.17 *half life* ($t_{1/2}$)—see *decay constant.*

3.1.18 *irradiator drawer*—the cylindrical chamber in which the sample to be irradiated is transported by the sample positioning system back and forth between the loading/unloading and the irradiation positions.

3.1.19 *irradiator rotor*—the sample positioning system used to load the sample or sample holder, to rotate it to the stationary shielded irradiation position and when the irradiation is completed, to move it to the unloading position.

3.1.20 *irradiator sample chamber*—the accessible enclosed volume in which a sample or sample holder may be placed in the loading/unloading position of the irradiator (typically a gamma cell) prior to irradiation, and which can be transported by the sample positioning system to the irradiation position.

3.1.21 *irradiator turntable*—device used to rotate the irradiated samples during the irradiation to improve (decrease) the dose uniformity ratio.

3.1.21.1 *Discussion*—Some irradiator geometries, for example, with an annular array of radiation sources surrounding the sample, may not need a turntable.

3.1.22 *isodose curve*—lines or surfaces of constant absorbed dose through a specified medium.

3.1.23 *measurement intercomparison*—a process by which an on-site measurement system is evaluated against a measurement of a standard reference device or material that is traceable to a nationally or internationally recognized standard.

3.1.23.1 *Discussion*—In radiation processing, reference standard or transfer standard dosimeters are irradiated at one irradiation facility, and sent to another for analysis. For example, an issuing laboratory may send dosimeters to an irradiation facility and the irradiated dosimeters are sent back to the issuing laboratory for analysis.

3.1.24 *kerma (K)*—the quotient of dE_{tr} by *dm*, where dE_{tr} is the sum of the initial kinetic energies of all the charged particles liberated by uncharged particles in a mass *dm* of material.

$$K = \frac{dE_{tr}}{dm} \quad \text{Unit: J kg}^{-1} \tag{9}$$

The special name for the unit of kerma is gray (Gy).

3.1.25 *measurement quality assurance plan*—a documented program for the measurement process that ensures on a continuing basis that the overall uncertainty meets the requirements of the specific applications. This plan requires traceability to, and consistency with, nationally or internationally recognized standards.

3.1.26 *measurement traceability*—the ability to demonstrate by means of an unbroken chain of comparisons that a measurement is in agreement within acceptable limits of uncertainty with comparable nationally or internationally recognized standards.

3.1.27 *radioactive–source decay*—spontaneous nuclear transformation of an unstable nucleus, with emission of a particle or photon or both; rate of decay usually is expressed in terms of radionuclide decay constant or half-life.

3.1.28 *reference–standard dosimeter*—a dosimeter of high metrological quality, used as a standard to provide measurements traceable to and consistent with measurements made with primary–standard dosimeters.

3.1.29 *reset timer*—an electronic timer, usually digital, that is equipped as part of the irradiator to time the period for which the sample is to be irradiated. Besides the timer, it contains reset buttons or switches for rezeroing the timer clock, and it is usually connected to the sample positioning system, irradiator drawer, or irradiator rotor.

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

3.1.31 *sample holder*—a relatively small container that fits at a fixed or repeatable position in the enclosed chamber of the irradiation device that serves to hold the sample in a reproducible way, and, in the case of dosimeters being calibrated, serves to provide standardized electronic equilibrium conditions during irradiation. The sample holder often is referred to as the product holder.

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

3.1.32.1 *Discussion*—Simulated product often is used during irradiator characterization as a substitute for the actual product, material or substance to be irradiated. When used in routine production runs, it is sometimes referred to as compensating dummy. When used for absorbed-dose mapping, simulated product is sometimes referred to as a phantom material.

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

3.1.34 *transit dose*—absorbed dose delivered to irradiated samples while the item to be irradiated in a fixed or turntable position moves into or out of that position or while the movable source moves into or out of its irradiation position.

3.1.34.1 *Discussion*—See ISO/ASTM Guide 51261 for details.

3.1.35 *validation*—establishment of documented evidence which provides a high degree of assurance that a specified process will consistently produce a product meeting its predetermined specifications and quality attributes.

3.2 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 ASTM Terminology E 170 are compatible with ICRU 60; that document, therefore, may be used as an alternative reference.

4. Significance and use

4.1 Self-contained dry-storage gamma-ray irradiators contain radioactive sources, namely ^{137}Cs or ^{60}Co, that emit ionizing electromagnetic radiation (gamma rays), under properly shielded conditions. These irradiators have an enclosed, accessible irradiator sample chamber connected with a sample positioning system, for example, irradiator drawer, rotor, or irradiator turntable, as part of the irradiation device.

4.2 Self-contained dry-storage gamma-ray irradiators can be used for many radiation processing applications, including the following: calibration of dosimeters; dosimeter studies for research; irradiations of relatively small samples for inducing desired radiation effects or for radiation process validation purposes; irradiation of materials or biological samples for process compatibility studies; batch irradiations of microbiological, botanical, or in-vitro samples; irradiation of small animals; radiation "hardness" testing of electronics components and other materials; and batch radiation processing of relatively small containers of samples, such as blood products, insect canisters, prosthetic devices, and pharmaceuticals.

NOTE 1—In the case of irradiated health care products, pharmaceuticals, foodstuffs, animals and plants, the assurance that they are properly irradiated is of crucial importance. The irradiator operator must demonstrate by means of accurate absorbed dose measurements in sample, or in simulated product, that the specified absorbed dose is achieved (see ISO/ASTM Guide 51261, ISO/ASTM Practices 51204, 51400, 51702, and ISO 11137). For most applications, the absorbed dose is expressed as absorbed dose in water (see ISO/ASTM Guide 51261). For conversion of absorbed dose in water to that in other materials, for example, silicon, solid-state devices, polymers, see Annex A1 of ISO/ASTM Guide 51261.

4.3 Self-contained dry-storage gamma-ray irradiators contain a sealed source, or an array of sealed sources completely held in a dry container constructed of solid materials. The sealed sources are shielded at all times, and human access to the chamber undergoing irradiation is not physically possible due to design configuration (see ANSI N433.1).

4.4 For each irradiator, an absorbed–dose rate at a reference position within the sample or sample holder is measured. That measurement is used to calculate the timer setting required to deliver the specified absorbed dose. The irradiator manufacturer may perform reference-standard measurements and dose-mapping measurements within the irradiation chamber.

NOTE 2—For reference–standard dosimetry, the absorbed dose and absorbed-dose rate can be expressed in water or other material which has similar radiation absorption properties to that of the samples or dosimeters being irradiated. In some cases, the reference–standard dosimetry may be performed using ionization chambers, and may be calibrated in terms of exposure (C kg^{-1}), or absorbed dose in air, water or tissue (gray). Measurements performed in terms of exposure apply to ionization in air, and care should be taken to apply that measurement to the sample being irradiated.

4.5 Dosimetry carried out with such sources may be part of a measurement quality assurance program that is applied to ensure that the radiation process, test or calibration meets predetermined specifications **(1)**.[9]

4.6 Absorbed-dose mapping for establishing the locations of minimum (D_{min}) and maximum (D_{max}) doses usually is performed using the sample or simulated product (see 9.3).

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

5. Types of facilities and modes of operation

5.1 *Self-Contained Gamma Irradiators*—Typical self-contained dry-storage gamma-ray irradiators are illustrated in Annex A1. These irradiators house the radiation source(s) in a protective lead shield (or other appropriate solid high atomic-number material), and usually have a sample positioning mechanism tied to an accurate calibrated reset timer to lower or rotate the sample holder from the load/unload position to the irradiation position. Details on the calibration of dosimeters **(2)** and dose mapping in such irradiators may be found, respectively in ISO/ASTM Guide 51261 and in this practice (7.3 and 9.3). Details on the designs of such irradiators may be found in Refs **(1)** and **(3)**. Details on safety considerations in the use of such irradiators may be found in ANSI Report N433.1. Four common modes of operation are described. This does not purport to include all modes of operation.

5.1.1 One method of use is to rotate the sample holder or canister on an irradiator turntable in front of the source such that the only points that remain a fixed distance from the source are along an axis of rotation **(1 and 3)**.

5.1.2 A second method is to move the sample holder closer to, or away from, the radiation source using a transport mechanism. In this case, a sample is moved to a predetermined distance from the source to achieve a desired dose. A turntable may be used to achieve a uniform dose **(1)**.

5.1.3 A third method is to distribute the source in an annular array, resulting in a relatively uniform absorbed-dose distribution. In this design, the irradiator turntable normally would not be necessary **(1)**.

5.1.4 A fourth method is to use opposed sources with appropriate beam flattening to obtain a uniform dose throughout the sample holder **(1)**.

6. Radiation source characteristics

6.1 The radiation sources used in the irradiation devices considered in this practice consist of sealed elements of ^{60}Co or ^{137}Cs, which are typically linear rods or pencils arranged singly or in one or more planar or cylindrical arrays.

6.2 Cobalt-60 emits photons with energies of approximately 1.17 and 1.33 MeV in nearly equal proportions; cesium-137 emits photons with energies of approximately 0.662 MeV (see NCRP 58 for the detailed radioactive decay components).

6.3 The half-lives for ^{60}Co and ^{137}Cs are approximately 5.2708 ($\pm$0.0013) years **(4)** and 30.07 ($\pm$0.03) years **(5)**, respectively. In addition, the ^{137}Cs radiation source may contain ^{134}Cs as an impurity that may affect the dose rate produced by the radiation source over time.

6.4 For gamma-ray sources, the only variation in the source output is the known reduction in the activity caused by radioactive decay. The reduction in the source strength and the required increase in the irradiation time for the same dose (see Note 8) may be calculated **(1)** or obtained from tables provided by the irradiator manufacturer.

7. Dosimetry systems

7.1 Dosimetry systems used to determine absorbed dose or dose rate shall cover the absorbed dose range of interest and shall be calibrated before use.

7.2 *Description of Dosimeter Classes*:

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

7.2.2 Dosimeters may be divided into four basic classes according to their accuracy and areas of application: primary–standard, reference–standard, transfer–standard, and routine dosimeters. ISO/ASTM Guide 51261 provides detailed information about the selection of dosimetry systems for different applications.

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

7.2.2.2 *Reference–Standard Dosimeters*—Reference–standard dosimeters are used to calibrate radiation environments and routine dosimeters. Reference–standard dosimeters also may be used as routine dosimeters. Examples of reference–standard dosimeters along with their useful dose ranges are given in a table in ISO/ASTM Guide 51261. For the application in this practice, the following reference–standard dosimeters may be suitable: alanine, ferrous sulfate solution, ceric cerous sulfate solution, potassium/silver dichromate solution, ethanol chlorobenzene solution, calorimeter, and ionization chamber.

7.2.2.3 *Transfer–Standard Dosimeters*—Transfer–standard dosimeters are specially selected dosimeters used for transferring absorbed-dose information from an accredited or national standards laboratory to an irradiation facility in order to establish measurement traceability for that facility. These dosimeters should be used under carefully controlled conditions as per the protocol of the issuing laboratory. Transfer–standard dosimeters may be selected from either reference–standard or routine dosimeters and shall have performance characteristics that meet the requirements listed in ISO/ASTM Guide 51261.

NOTE 3—In the routine operation of a self-contained dry-storage irradiator, absorbed-dose measurements made in the sample under controlled environmental and geometrical conditions of calibration, testing, or processing provide the operator and regulatory authorities with an independent quality control record for the documentation procedure **(1)**.

7.2.2.4 *Routine Dosimeters*—Routine dosimeters may be used for quality control and routine monitoring. Proper dosimetric techniques, including calibration, shall be employed to ensure that measurements are reliable and accurate. Examples of routine dosimeters along with their useful dose ranges are given in ISO/ASTM Guide 51261.

7.2.3 *Dosimetry System Selection*—It is important that the dosimetry system be evaluated for those parameters associated with self-contained dry-storage irradiators that may influence the dosimeter response, for example, differences in gamma–ray energy, absorbed-dose rate, and environmental conditions, such as temperature, relative humidity, and light. Guidance as to desirable characteristics and selection criteria can be found in