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Practice for use of the alanine-EPR dosimetry system

Pratique de l'utilisation d'un système dosimétrique à l'alanine utilisant la résonance paramagnétique électronique

Reference number
ISO/ASTM 51607:2002(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 International Standard 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 51607 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 Use of the Alanine-EPR Dosimetry System[1]

This standard is issued under the fixed designation ISO/ASTM 51607; 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 covers materials description, dosimeter preparation, instrumentation, and procedures for using the alanine-EPR dosimetry system for measuring the absorbed dose in materials irradiated with photons and electrons. The system is based on electron paramagnetic resonance (EPR) spectroscopy of free radicals derived from the amino acid alanine.[2] It is classified as a reference standard dosimetry system (see ISO/ASTM Guide 51261).

1.2 This practice covers alanine-EPR dosimetry systems for dose measurements under the following conditions:

1.2.1 The absorbed dose range is between 1 and 10^5 Gy.

1.2.2 The absorbed dose rate is up to 10^2 Gy s^{-1} for continuous radiation fields and up to 5×10^7 Gy s^{-1} for pulsed radiation fields **(1-3)**.[3]

1.2.3 The radiation energy for photons and electrons is between 0.1 and 28 MeV **(1, 2, 4)**.

1.2.4 The irradiation temperature is between −60 and + 90°C **(2, 5)**.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *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[4]

E 178 Practice for Dealing with Outlying Observations[5]

E 456 Terminology Relating to Quality and Statistics[5]

E 668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices[4]

2.2 *ISO/ASTM Standards:*

51204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing[4]

51261 Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing[4]

51400 Practice for Characterization and Performance of a High-Dose Gamma Radiation Dosimetry Calibration Laboratory[4]

51431 Practice for Dosimetry in Electron and Bremsstrahlung Irradiation Facilities for Food Processing[4]

51707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing[4]

2.3 *ICRU Reports:*[6]

ICRU Report 14 Radiation Dosimetry: X-Rays and Gamma-Rays with Maximum Photon Energies Between 0.6 and 50 MeV

ICRU Report 17 Radiation Dosimetry: X-Rays Generated at Potentials of 5 to 150 kV

ICRU Report 34 The Dosimetry of Pulsed Radiation

ICRU Report 35 Radiation Dosimetry: Electron Beams with Energies between 1 and 50 MeV

ICRU Report 37 Stopping Powers for Electrons and Positrons

ICRU Report 44 Tissue Substitutes in Radiation Dosimetry and Measurement

ICRU Report 60 Radiation Quantities and Units

2.4 *ISO Document:*

Guide for the Expression of Uncertainty in Measurements[7]

3. Terminology

3.1 *Definitions*—Appropriate terms may be found in ASTM Terminology E 170.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *alanine dosimeter*—a specified quantity and physical form of the radiation-sensitive material alanine and any added inert substance such as a binder.

3.2.2 *alanine-EPR dosimetry system*—a system used for determining absorbed dose, consisting of the alanine dosimeters, an EPR spectrometer, the calibration curve, reference standards, and procedures for the system's use.

3.2.3 *EPR spectroscopy*—the measurement of resonant absorption of electromagnetic energy resulting from the transition of unpaired electrons between different energy levels, upon

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

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[2] The term "electron spin resonance" (ESR) is used interchangeably with electron paramagnetic resonance (EPR).

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

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

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

[6] Available from International Commission on Radiation Units and Measurements, 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814, U.S.A.

[7] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036. U.S.A.

application of radiofrequencies to a paramagnetic substance in the presence of a magnetic field.

3.2.4 *EPR spectrum*—the first derivative of the electron paramagnetic absorption spectrum as measured as a function of the magnetic field.

3.2.5 *EPR signal amplitude*—the peak-to-peak amplitude of the main signal of the EPR spectrum. This signal is proportional to the alanine-derived radical concentration in the alanine dosimeter.

3.2.6 *zero dose amplitude*—the EPR signal amplitude measurement of an unirradiated alanine dosimeter with the same EPR spectrometer parameters used for the lowest measurable absorbed dose value.

3.2.7 *calibration curve*—graphical representation of the mathematical relationship between the dosimeter EPR signal amplitude and absorbed dose, for a given type and batch of alanine dosimeters.

4. Significance and Use

4.1 The alanine-EPR dosimetry system provides a reliable means for measuring the absorbed dose. It is based on the generation of specific stable radicals in crystalline alanine by ionizing radiation.

4.2 The dosimeter contains crystalline alanine and registers the absorbed dose by an increase in the alanine-derived radical concentration. Identification and determination of the concentration of the specific alanine radical are performed by EPR spectroscopy.

4.3 Measurement of the concentration of free radicals by EPR spectroscopy is nondestructive. Alanine dosimeters can be read out repeatedly and hence can be used for archival purposes.

NOTE 1—For a comprehensive discussion of various dosimetry methods and materials applicable to the radiation types and energies discussed in this practice, see ASTM Practices E 178, E 668, ISO/ASTM Practices 51204, 51400, 51431, ISO/ASTM Guide 51261, and ICRU Reports 14, 17, 60, 34, 35, 37, 44 and 60.

4.4 Alanine-EPR dosimetry systems are used in industrial radiation processing, for example, sterilization of medical devices and pharmaceuticals, preservation of foods, polymer modifications, and radiation damage studies in materials, as reference or transfer standard or routine dosimetry systems.

5. Dosimeter Material

5.1 The dosimeter is prepared using α-alanine, CH_3-$CH(NH_2)$-COOH, in the form of polycrystalline powder.

5.2 Both stereoisomers of α-alanine are suitable for dosimetry; L-alanine is used most commonly.

5.3 The purity of the alanine shall be analytical grade (99 % or better). Alanine of appropriate purity is commercially available. Dopants (a specific trace amount of an element as additive) are not required.

6. Preparation of Dosimeters

6.1 The alanine dosimeter may be used in powdered form or as a solid compressed with a binder.

NOTE 2—Additives used in the preparation of dosimeters should not add any significant intrinsic or radiation-induced EPR signal. Examples of suitable binders are cellulose, ethylene-propylene rubber, gelatin, paraffin, polyethylene, polyethylene vinyl acetate, polystyrene, polyvinylpyrrolidone, polyvinyl propylene, and stearin. Lubricants added in the dosimeter manufacturing process are optional. An example of a suitable lubricant is stearic acid.

6.2 *Powder Dosimeters*:

6.2.1 Alanine powder may be used directly as supplied by the manufacturer.

NOTE 3—Sieving to achieve a narrower range of grain sizes from several tens to several hundreds of µm is recommended to improve the reproducibility of the EPR signal.

6.2.2 The alanine powder is contained in a sachet or capsule for use. From 50 to 200 mg of powder is typically used for a dosimeter.

6.3 *Dosimeters Using Binders*:

6.3.1 Alanine dosimeters can be prepared by compressing, casting, or extruding a mixture of alanine, binder, and lubricant (optional).

6.3.2 Usual physical shapes are pellets, films, cylinders, or cables. The dimensions depend on the inner diameter of the microwave cavity of the EPR spectrometer, the dosimeter holder and, the required precision of the measurement.

6.3.3 The softening point of the binder must be compatible with the temperature during radiation exposure.

6.3.4 The alanine content can vary. Some published values of the alanine content with different binders are polyvinylpyrrolidone (95 %) **(6)**, paraffin wax (80 to 90 %) **(2, 7, 8)**, polystyrene (70 %) **(9)**, ethylene-propylene rubber (67 %) **(10)**, and low-density polyethylene (60 to 90 %) **(11, 12)**. The sensitivity of the dosimeter is proportional to the alanine content.

6.3.5 The manufacturing process involves a number of operations, for example, mortaring, sieving, binder and lubricant (optional) addition, homogenization, pressing, or extruding. The introduction of radicals from even small amounts of paramagnetic material or from mechanical force must be avoided during the manufacturing process. Several fabrication techniques are described in Refs **(12)** and **(13)**.

6.4 *Preparation Quality Assurance*:

6.4.1 Care shall be exercised in conducting dosimeter preparation. Preparation shall be performed under clean laboratory conditions and with high-quality fabrication procedures as specified in the literature **(7, 14)**. Measurement repeatability, interspecimen variation, and batch sensitivity may be affected by each process step.

6.4.2 Important factors for measurement precision are homogeneity, reproducibility of mass, density, size, and shape of the dosimeters.

6.4.3 Representative sampling of dosimeters shall be performed for each production batch and subjected to quality control tests, for example, visual tests of surface conditions, impact tests, weight tests, and dimensional and density checks.

6.4.4 Dosimetric quality control for each production batch includes the mean batch sensitivity and interspecimen scattering of the zero-dose-signal dosimeter response.

6.4.5 To achieve the accuracy described in 13.2, the interspecimen variation of the radiation-induced response should be

within ± 1 % at a 95 % confidence level.

7. Apparatus

7.1 The following equipment and instruments are necessary to determine the radiation-induced response of the alanine-EPR dosimetry system:

7.1.1 The apparatus comprises an X-band EPR spectrometer capable of determining the alanine-derived radical concentration in a dosimeter by measurement of the EPR spectrum. A spectrometer capable of attaining the uncertainty limits described in 13.2 over the dose range of 1 to 10^5 Gy should be capable of the following settings: microwave frequency 9 to 10 GHz with automatic frequency locking (AFC); corresponding magnetic field to set a g-factor of 2.0 (at 9.8 GHz, this equals 350 mT; see Note 4) with a field scan range of 20 mT about the center field; RF modulation amplitude 0.1 to 1 mT; microwave power 0.1 to 10 mW (levelled); variable sweep time, time constant, and receiver gain according to absorbed dose. The sensitivity of the spectrometer should be at least 2×10^{11} spins/mT. The cavity should have a sample access diameter of at least 1 mm greater than the diameter of the dosimeter to be analyzed.

NOTE 4—The relationship between microwave frequency (Hz) and the magnetic field (T) is given by:

$$h\nu = g\mu_B B \quad (1)$$

where:

h = Planck's constant,
ν = microwave frequency,
g = the spectroscopic splitting factor (typically 2.0),
μ_B = the Bohr magneton, and
B = magnetic field.

7.1.2 There shall be some mechanical means of positioning the dosimeter accurately and reproducibly, in terms of both height and centricity in the cavity. The dosimeter holder is usually made of fused quartz and should be of such quality and cleanliness to contribute no interfering EPR signal.

7.2 If precise assessment of alanine dosimeter mass is required and is not provided by the manufacturer, a balance with the appropriate resolution shall be used.

8. Calibration Procedures

8.1 Calibration of the instrument and dosimeter used in the measurement of absorbed dose is a four-step process consisting of the following:

(1) Irradiation of reference alanine dosimeters;
(2) Instrument setup;
(3) Routine spectrometer performance checks; and
(4) Establishment of the calibration curve.

8.2 *Irradiation of Reference Dosimeters*—Prior to the calibration and use of the dosimetry system, the effects (if any) of temperature, humidity, absorbed dose rate, incident energy spectrum, and ultraviolet radiation on the dosimeter response shall be determined (see Section 11). These shall be taken into account during calibration and use.

8.2.1 To calibrate the alanine dosimeters, use a calibration facility that has an absorbed dose rate traceable to national standards.

8.2.2 Establish the calibration absorbed doses in terms of absorbed dose in water.

8.2.3 Absorbed dose in materials other than water may be calculated by applying conversion factors in accordance with ISO/ASTM Guide 51261.

8.2.4 Select a location in the calibration field in which the absorbed dose rate within the volume occupied by the alanine dosimeter has been demonstrated to be uniform to within ±0.5 % **(1)**.

8.2.5 When using photons for calibration (gamma rays or bremsstrahlung), surround the alanine dosimeter with a thickness of alanine-equivalent material to achieve approximate electron equilibrium conditions.

NOTE 5—As an example, for ^{60}Co gamma-ray sources, approximately 3 to 5 mm of polystyrene, an equivalent polymeric material or alanine surrounding the alanine dosimeters in all directions, effectively approximates electron equilibrium conditions.

8.2.6 Monitor and control, if possible, environmental factors such as temperature and humidity during irradiation of the alanine dosimeters. If possible, these should be held approximately constant throughout irradiation.

8.2.7 Calibrate each batch of alanine dosimeters prior to use. Use sufficient alanine dosimeters for each absorbed dose value (see Section 9 of ASTM Practice E 668).

8.2.8 The number of sets of alanine dosimeters required to establish the calibration curve of the alanine-EPR dosimetry system depends on the dose range of utilization. Use at least one set per decade of absorbed dose in the linear range. More sets may be necessary in the non-linear range (see 10.1).

8.3 *Instrument Setup*—Follow manufacturer's procedures for the setup and instrument calibration of salient parameters, either by reading the appropriate calibration files or making the appropriate electromechanical adjustments.

8.4 *Routine Spectrometer Performance Checks*—Verify proper operation of the instrument by comparing the measurement of a suitable spin standard (which might be an irradiated alanine dosimeter stored under controlled conditions, a pitch sample, or Mn(II) in CaO). If there is not agreement within an acceptable range (±1 % at 95 % confidence), repeat the steps given in 8.2 and 8.3 to ascertain any obvious faults, for example, sample position error. Sensitivity changes > 1 % can be compensated for by normalizing the dosimeter response to the value of the spin standard.

8.5 *Establishment of Calibration Curve*:

8.5.1 Obtain EPR spectra for each dosimeter irradiated according to 8.1.

8.5.2 Use the procedure described in Section 9 to measure the EPR signal amplitude.

8.5.3 Calculate and document the mean EPR signal amplitude $\bar{k}$ *and the dosimeter standard deviation* (s_{n-1}) for each set of n dosimeters at each dose value.

NOTE 6—The sample standard deviation, s_{n-1}, is calculated from the set of n measurements ($n < 30$) as follows:

$$s_{n-1} = \sqrt{\frac{\Sigma(k_i - \bar{k})^2}{n-1}} \quad (2)$$

where:
k_i = individual EPR signal amplitude, and
i = 1,2, ..., n.

A coefficient of variation greater than ±1 % at any calibration dose value requires investigation and may require the data set to be repeated depending on the precision required.

8.5.4 Choose an analytical form, for example, linear, polynomial, or exponential, that provides the best fit to the measured data. Evaluate the resulting calibration curve for goodness of fit.

NOTE 7—When any mean EPR signal amplitude deviates by more than ±3 % from the determined calibration curve, the alanine dosimeter should be remeasured (see 13.2). If the mean EPR signal amplitude still deviates to that degree, alanine dosimeters from the same batch should be irradiated to the dose under consideration. If similar discrepancies still occur, a complete re-calibration of the alanine-EPR system should be performed. See ASTM Practice E 178 for guidance on dealing with outliers.

8.5.5 Repeat the calibration procedure whenever parameters of the EPR spectrometer or of the alanine dosimeters have been changed.

9. Measurement of the EPR Spectrum

9.1 The following procedures are used for obtaining and evaluating the EPR spectrum of an irradiated alanine dosimeter:

9.1.1 Place the alanine dosimeter within the holder inside the microwave cavity of the EPR spectrometer.

NOTE 8—The dosimeter should be positioned precisely in the absolute center of the microwave cavity. A check of repeated positioning of the same dosimeter should show agreement within ±0.5 %. Check the response variation due to rotation of the dosimeter either on the cylindrical axis by 90° and the response variation due to rotation of the dosimeter around the mid-diameter of 180°.

9.1.2 Measure the EPR spectrum. See Annex A2 for examples of EPR spectrometer parameters.

9.1.3 Measure the EPR signal amplitude, *h*, of the EPR spectrum (see Fig. 1). The amplitude is measured in terms of arbitrary units. The EPR measurements can be performed manually or automatically.

NOTE 9—The peak-to-peak procedure is faster and yields more precise performance than the automated double integration method **(2)**. Unknown dosimeters must be measured using the same microwave power and modulation amplitude used to establish the calibration curve.

9.1.4 The microwave power and modulation amplitude shall be held constant throughout the establishment of the calibration curve and for all unknown dosimeter measurements. Normalize *h* for the following: sweep time, receiver gain, and number of sweeps, unless this is accomplished automatically by the EPR spectrometer.

NOTE 10—Other corrections may be necessary, for example: (*1*) linearity of *h* with dosimeter mass may have to be established, and a mass correction applied, depending on the dosimeter type and desired precision of measurement; (*2*) it may be necessary to subtract the zero-dose amplitude from *h*, depending on their relative magnitude and the desired precision of measurement; and (*3*) EPR spectrometer sensitivity changes >1 % can be compensated for by normalizing the dosimeter response to the value of the spin standard (see 8.3).

10. General Practice

10.1 The number of dosimeters required for a measurement of absorbed dose on the surface or within a material is determined by the precision of the dosimetry system and the application. Appendix X3 of ASTM Practice E 668 describes a statistical method for determining this number.

10.2 Refer to 8.1.5 to achieve approximate electron equilibrium conditions.

10.3 Identify each dosimeter appropriately in terms of batch and number.

10.4 Use the irradiation and measurement procedures in accordance with Sections 8 and 9.

10.5 Monitor the irradiation temperature and correct for its influence on the dosimeter response as necessary (see 11.1).

10.6 Handle alanine dosimeters with suitable care to avoid physical damage.

10.7 Determine the EPR signal amplitude of each alanine dosimeter after irradiation, and evaluate the absorbed dose from the EPR signal amplitude and the appropriate calibration curve.

10.8 Record the absorbed dose values and all relevant data

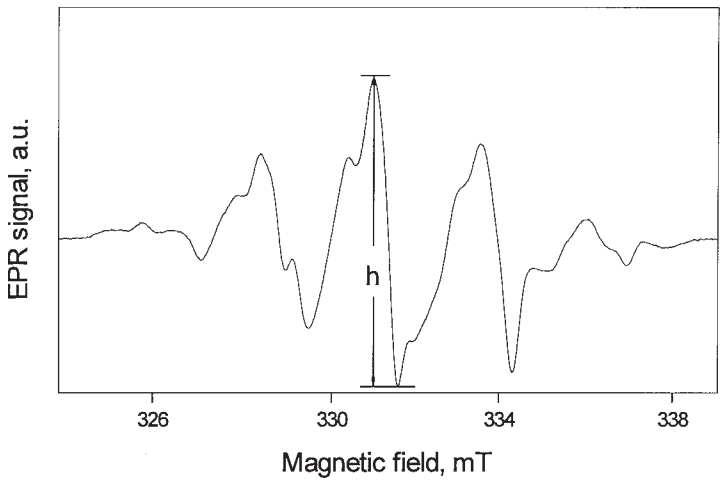

FIG. 1 EPR Spectrum of an Alanine Dosimeter Irradiated to an Absorbed Dose of 1 kGy; the Amplitude, *h*, of the Central Peak is Taken for Dose Evaluation

as outlined in Section 11.

11. Environmental Interferences

11.1 The irradiation temperature influences the response of alanine dosimeters.

NOTE 11—For alanine dosimeters that are mixed with binders, the effect of irradiation temperature on dosimeter response may be influenced by the binder type. The temperature coefficient is described by the relationship, $(\Delta h/h)/\Delta T$, where h is the EPR signal amplitude (in arbitrary units) and T is the irradiation temperature (in° C). For a paraffin binder a positive temperature coefficient of 0.18 %° C^{-1} was measured **(2, 5)**. This value is constant for absorbed doses up to 10 kGy in the temperature range between − 60 and 90°C. For absorbed doses of 50 and 100 kGy the temperature coefficient increased to 0.23 % C^{-1} and 0.31 % C^{-1}, respectively **(2, 5)**.

11.2 The humidity during pre-irradiation storage, irradiation, and post-irradiation storage can influence the response of alanine dosimeters. The effect of humidity may be reduced by sealing dosimeters in a material impervious to water.

NOTE 12—For specific alanine and paraffin dosimeters, storage conditions up to 50°C and moderate relative humidity (55 ± 5 %) do not affect the response of alanine dosimeters over a one-month period. The decrease in the EPR signal amplitude is less than 0.5 % per year under these conditions **(15)**.

11.3 Light has little influence on the radiation-induced EPR signal of the alanine dosimeters. However, prolonged exposure is not recommended **(11)**.

11.4 Ambient temperature and relative humidity conditions of the EPR laboratory shall be monitored, and controlled if possible, at all stages of analysis.

12. Minimum Documentation Requirements

12.1 *Calibration*:

12.1.1 Record the type, batch number, and manufacturer of the alanine dosimeters.

12.1.2 Record or reference the date and temperature of irradiation, dose range, radiation source, and associated instrumentation used to calibrate the alanine-EPR dosimetry system.

12.2 *Use*:

12.2.1 Record the date of irradiation and date of EPR measurement for each dosimeter.

12.2.2 Record the estimated or measured irradiation temperature, applied temperature correction, and resulting absorbed dose for each dosimeter. Reference the calibration curve used to obtain the absorbed dose values.

12.2.3 Record or reference the radiation source type characteristics.

12.2.4 Record the EPR signal amplitude and relevant EPR spectrometer settings (microwave frequency, microwave power, magnetic field strength and sweep, modulation amplitude, and gain factor settings).

12.2.5 Record or reference the precision and bias in the value of the absorbed dose (see Section 13).

12.2.6 Record or reference the measurement quality assurance plan used for the alanine-EPR dosimetry system application.

12.2.7 Record the temperature and relative humidity conditions of the EPR laboratory during all stages of analysis.

12.2.8 Store alanine dosimeters under controlled conditions, for example, in the dark at a room temperature in the range from 15 to 25°C and relative humidity in the range from 40 to 60 % **(7)**.

13. Measurement Uncertainty

13.1 To be meaningful, a measurement of absorbed dose shall be accompanied by an estimate of uncertainty. Components of uncertainty shall be identified as belonging to one of two groups:

13.1.1 Components based on the statistical analysis of a series of observations, or

13.1.2 Components based on other types of analyses.

13.1.3 Additional information is given in ISO/ASTM Guide 51707, ISO "Guide for the Expression of Uncertainty in Measurements," and Ref **(16)**, where these components are referred to as Type A and Type B, respectively. In reporting uncertainty, other classifications such as precision and bias may be useful.

NOTE 13—The identification of Type A and Type B uncertainties is based on the methodology adopted in 1993 by the International Organization for Standardization (ISO) for estimating uncertainty. This is different from the way uncertainty has been traditionally expressed in terms of "precision" and "bias", where precision is a measure of the extent to which replicate measurements made under specified conditions are in agreement, and bias is a systematic error (see ASTM Terminologies E 170 and E 456, and ASTM Practice E 177). The purpose of using the method of expressing uncertainties as Type A and Type B recommended in ISO "Guide to the Expression of Uncertainty in Measurement" is to promote an understanding of how uncertainty statements are arrived at and to provide a basis for the international comparison of measurement results.

NOTE 14—ISO/ASTM Guide 51707 defines possible sources of error in dosimetry performed in radiation processing facilities and offers procedures for estimating the resulting magnitude of the uncertainties in the measurement results. Basic concepts of measurement, estimate of the measured value of a quantity, "true" value, error and uncertainty are defined and discussed. Components of uncertainty are discussed and methods are given for evaluating and estimating their values. Their contributions to the standard uncertainty in the reported values of absorbed dose are considered and methods are given for calculating the combined standard uncertainty and an estimate of overall (expanded) uncertainty.

13.2 The combined uncertainty of an absorbed dose determined by an alanine-EPR dosimetry system should be within ±3 % at a 95 % confidence level. This combined uncertainty is based on an uncertainty of ±2 % at a 95 % confidence level in the dose rate of the calibration source. Uncertainties may be higher if corrections for pellet mass are not made or if the system is used for absorbed dose measurements below 10 Gy.

14. Keywords

14.1 absorbed dose; alanine dosimetry; dose measurements; dosimeter; dosimetry system; electron beam; electron paramagnetic resonance; electron spin resonance; EPR dosimetry; ESR dosimeter; gamma radiation; ionizing radiation; irradiation; photons; radiation; radiation processing; reference–standard dosimeter; X rays; ICS 17.240