

ISO/ASTM 51538:2017(E)



Standard Practice for Use of the Ethanol-Chlorobenzene Dosimetry System¹

This standard is issued under the fixed designation ISO/ASTM 51538; 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 the preparation, handling, testing, and procedure for using the ethanol-chlorobenzene (ECB) dosimetry system to measure absorbed dose to water when exposed to ionizing radiation. The system consists of a dosimeter and appropriate analytical instrumentation. For simplicity, the system will be referred to as the ECB system. The ECB dosimeter is classified as a type I dosimeter on the basis of the effect of influence quantities. The ECB dosimetry system may be used as a reference standard dosimetry system or as a routine dosimetry system.

1.2 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 Practice 52628 for the ECB system. It is intended to be read in conjunction with ISO/ASTM Practice 52628.

1.3 This practice describes the mercurimetric titration analysis as a standard readout procedure for the ECB dosimeter when used as a reference standard dosimetry system. Other readout methods (spectrophotometric, oscillometric) that are applicable when the ECB system is used as a routine dosimetry system are described in Annex A1 and Annex A2.

1.4 This practice applies only to gamma radiation, X-radiation/bremsstrahlung, and high energy electrons.

1.5 This practice applies provided the following conditions are satisfied:

1.5.1 The absorbed dose range is between 10 Gy and 2 MGy for gamma radiation and between 10 Gy and 200 kGy for high current electron accelerators (1, 2).² (**Warning**—the boiling

point of ethanol chlorobenzene solutions is approximately 80 °C. Ampoules may explode if the temperature during irradiation exceeds the boiling point. This boiling point may be exceeded if an absorbed dose greater than 200 kGy is given in a short period of time.)

1.5.2 The absorbed-dose rate is less than 10^6 Gy s⁻¹ (2).

1.5.3 For radionuclide gamma-ray sources, the initial photon energy is greater than 0.6 MeV. For bremsstrahlung photons, the energy of the electrons used to produce the bremsstrahlung photons is equal to or greater than 2 MeV. For electron beams, the initial electron energy is greater than 8 MeV (3).

NOTE 1—The same response relative to ⁶⁰Co gamma radiation was obtained in high-power bremsstrahlung irradiation produced by a 5 MeV electron accelerator (4).

NOTE 2—The lower energy limits are appropriate for a cylindrical dosimeter ampoule of 12-mm diameter. Corrections for dose gradients across the ampoule may be required for electron beams. The ECB system may be used at lower energies by employing thinner (in the beam direction) dosimeters (see ICRU Report 35). The ECB system may also be used at X-ray energies as low as 120 kVp (5). However, in this range of photon energies the effect caused by the ampoule wall is considerable.

NOTE 3—The effects of size and shape of the dosimeter on the response of the dosimeter can adequately be taken into account by performing the appropriate calculations using cavity theory (6).

1.5.4 The irradiation temperature of the dosimeter is within the range from -30 °C to 80 °C.

NOTE 4—The temperature dependence of dosimeter response is known only in this range (see 5.2). For use outside this range, the dosimetry system should be calibrated for the required range of irradiation temperatures.

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. Specific warnings are given in 1.5.1, 9.2 and 10.2.*

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.*

¹ This practice is under the jurisdiction of ASTM Committee E61 on Radiation Processing and is the direct responsibility of Subcommittee E61.02 on Dosimetry Systems, 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 practice.



2. Referenced documents

2.1 ASTM Standards:³

- C912** Practice for Designing a Process for Cleaning Technical Glasses
- D1193** Specification for Reagent Water
- E170** Terminology Relating to Radiation Measurements and Dosimetry
- E275** Practice for Describing and Measuring Performance of Ultraviolet and Visible Spectrophotometers
- E666** Practice for Calculating Absorbed Dose From Gamma or X Radiation
- E668** Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices
- E925** Practice for Monitoring the Calibration of Ultraviolet-Visible Spectrophotometers whose Spectral Bandwidth does not Exceed 2 nm
- E958** Practice for Estimation of the Spectral Bandwidth of Ultraviolet-Visible Spectrophotometers

2.2 ISO/ASTM Standards:³

- 51261** Practice for Calibration of Routine Dosimetry Systems for Radiation Processing
- 51707** Guide for Estimation of Measurement Uncertainty in Dosimetry for Radiation Processing
- 52628** Practice for Dosimetry in Radiation Processing
- 52701** Guide for Performance Characterization of Dosimeters and Dosimetry Systems for Use in Radiation Processing

2.3 ISO Standards:⁴

- 12749-4** Nuclear energy – Vocabulary – Part 4: Dosimetry for radiation processing

2.4 ISO/IEC Standards:⁴

- 17025** General Requirements for the Competence of Testing and Calibration Laboratories

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

- JCGM 100:2008, GUM 1995, with minor correctons** Evaluation of measurement data – Guide to the Expression of Uncertainty in Measurement⁵
- JCGM 200:2012, (JCGM 200:2008 with minor revisions) VIM, International Vocabulary of Metrology – Basis and General Concepts and Associated Terms⁶**

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.

⁴ Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, <http://www.iso.org>.

⁵ Document produced by Working Group I of the Joint Committee for Guides in Metrology (JCGM WG1). Available free of charge at the BIPM website (<http://www.bipm.org>).

⁶ 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>).

2.6 International Commission on Radiation Units and Measurements (ICRU) Reports:⁷

- ICRU Report 35** Radiation Dosimetry: Electrons with Initial Energies Between 1 and 50 MeV
- ICRU Report 80** Dosimetry Systems for Use in Radiation Processing
- ICRU Report 85a** Fundamental Quantities and Units for Ionizing Radiation

3. Terminology

3.1 Definitions:

3.1.1 *approved laboratory*—laboratory that is a recognized national metrology institute, or has been formally accredited to ISO/IEC 17025, or has a quality system consistent with the requirements of ISO/IEC 17025.

3.1.1.1 *Discussion*—A recognized national metrology institute or other calibration laboratory accredited to ISO/IEC 17025 should be used in order to ensure traceability to a national or international standard. A calibration certificate provided by a laboratory not having formal recognition or accreditation will not necessarily be proof of traceability to a national or international standard.

3.1.2 *calibration*—set of operations that establish, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realised by standards.

3.1.2.1 *Discussion*—Calibration conditions include environmental and irradiation conditions present during irradiation, storage and measurement of the dosimeters that are used for the generation of a calibration curve.

3.1.3 *calibration curve*—expression of the relation between indication and corresponding measured quantity value.

3.1.3.1 *Discussion*—In radiation processing standards, the term “dosimeter response” is generally used for “indication”.

3.1.4 *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.

3.1.5 *ethanol-chlorobenzene dosimeter*—partly deoxygenated solution of chlorobenzene (CB) in 96 volume % ethanol in an appropriate container, such as a flame-sealed glass ampoule, used to indicate absorbed dose by measurement of the amount of HCl formed under irradiation.

3.1.6 *measurement management system*—set of interrelated or interacting elements necessary to achieve metrological confirmation and continual control of measurement processes.

3.1.7 *metrological traceability*—property of a measurement whereby the result can be related to a reference through a documented unbroken chain of comparisons, each contributing to the measurement uncertainty.

3.1.8 *molar linear absorption coefficient* ϵ_m —constant relating the spectrophotometric absorbance, A_λ , of an optically

⁷ Available from the Commission on Radiation Units and Measurements, 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814, USA.

absorbing molecular species at a given wavelength, λ , per unit pathlength, d , to the molar concentration, c , of that species in solution:

$$\epsilon_m = \frac{A_\lambda}{d \times c} \quad (1)$$

(SI unit: $\text{m}^2 \text{mol}^{-1}$)

3.1.8.1 *Discussion*—It is sometimes expressed in units of $\text{L mol}^{-1} \text{cm}^{-1}$.

3.1.9 *radiation chemical yield $G(x)$* —quotient of $n(x)$ by $\bar{\epsilon}$ where $n(x)$ is the mean amount of a specified entity, x , produced, destroyed, or changed by the mean energy, $\bar{\epsilon}_m$ imparted to the matter.

$$G(x) = n(x)/\bar{\epsilon} \quad (2)$$

(SI unit: mol J^{-1})

3.1.10 *reference standard dosimetry system*—dosimetry system, generally having the highest metrological quality available at a given location, from which measurements made there are derived.

3.1.11 *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.

3.1.12 *type 1 dosimeter*—dosimeter of high metrological quality, the response of which is affected by individual influence quantities in a well-defined way that can be expressed in terms of independent correction factors.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *conductometry*—analytical method based on the measurement of conductivity of solutions.

3.2.1.1 *Discussion*—The conductivity of a solution depends on the concentration of free ions in the solution.

3.2.2 *oscillometry*—electroanalytical method of conductivity measurements, when high-frequency (1 to 600 MHz) alternating current is applied to measure or follow changes in the composition of chemical systems.

3.3 Definitions of other terms used in this standard that pertain to radiation measurement and dosimetry may be found in ISO 12749-4, ASTM Terminology E170, ICRU 85a and VIM; these definitions, therefore, may be used as an alternative references.

4. Significance and use

4.1 The ECB dosimetry system provides a reliable means of measuring absorbed dose to water. It is based on a process of radiolytic formation of hydrochloric acid (HCl) in aqueous ethanolic solutions of chlorobenzene by ionizing radiation ((7, 8), ICRU 80).

4.2 The dosimeters are partly deoxygenated solutions of chlorobenzene (CB) in 96 volume % ethanol in an appropriate container, such as a flame-sealed glass ampoule. Radiation chemical yields (G) for the formation of HCl in typical ECB solution formulations are given in Table 1.

4.3 The irradiated solutions indicate absorbed dose by the amount of HCl formed. A number of analytical methods are available for measuring the amount of HCl in ethanol (10).

TABLE 1 Radiation chemical yields (G) for the formation of HCl in typical ECB solution formulations

Concentration of CB, vol %	Density at 20 °C $\text{kg} \cdot \text{m}^{-3}$	Ratio of Coefficients ^A	Radiation Chemical Yields at 20 °C ^B ($\mu\text{mol} \cdot \text{J}^{-1}$)	
			⁶⁰ Co Gamma Radiation (9)	4 to 10 MeV Electrons (3)
4	819	0.989	0.42 ^C	
10	839	0.995	0.52	
20	869	1.006	0.59	
24	880	1.011	0.60	0.57 ^D
40	925	1.027	0.63	

^A The ratio of the photon mass energy-absorption coefficients for water and the dosimeter solution at ⁶⁰Co gamma ray energy:

$$f = \frac{(\mu_{en}/\rho)_w}{(\mu_{en}/\rho)_D}$$

^B Radiation chemical yield of HCl in the dose range from 100 Gy to 100 kGy.

^C Upper dose range 20 kGy.

^D Lower dose range 1 kGy. This formulation also contained 0.04 % acetone and 0.04 % benzene.

4.4 The concentration of chlorobenzene in the solution can be varied so as to simulate a number of materials in terms of the photon mass energy-absorption coefficients (μ_{en}/ρ) for X- and gamma radiation, and electron mass collision stopping powers (S/ρ), over a broad energy range from 10^{-2} to 100 MeV (11-14).

4.5 The ECB dosimetry system may be used with other radiation types, such as neutrons (15), and protons (16). Meaningful dosimetry of any radiation types and energies novel to the system's use requires that the respective radiation chemical responses applicable under the circumstances be established in advance.

5. Effect of Influence Quantities

5.1 Guidance on the determination of the performance characteristics of dosimeters and dosimetry systems can be found in ISO/ASTM Guide 52701. The relevant influence quantities that need to be considered when using the ECB dosimetry system are given below.

5.2 The irradiation temperature dependence of dosimeter response is a complex function of dose and temperature for each concentration of chlorobenzene (that is, for each formulation). This dependence arises directly from the temperature dependence of radiation chemical yield, G . The analysis of the published data (17) shows that the irradiation temperature dependence of G between 20 °C and 80 °C at any chlorobenzene concentration can be described by a simple exponential expression:

$$G_t = G_0 \exp[k(t - 20)] \quad (3)$$

where:

G_t = radiation chemical yield in $\mu\text{mol J}^{-1}$ at a given temperature t in °C,

G_0 = radiation chemical yield in $\mu\text{mol J}^{-1}$ at 20 °C (G_0 for different ECB solutions are given in Table 1), and

k = temperature coefficient in $^{\circ}\text{C}^{-1}$ applicable at a given dose.

5.2.1 The values of k are given in **Table 2**.

6. Interferences

6.1 The ECB dosimetric solution response is not particularly sensitive to impurities which occur in commercially available components, chlorobenzene and ethanol of the analytical reagent (AR) grade purity or equivalent (pro analysi, p.a., and puriss). For high-accuracy results, organic materials of technical grade purity (or purum) can be purified by distillation.

6.2 Care should be exercised in filling ampoules to avoid depositing solution in the ampoule neck. Subsequent heating during sealing of the ampoule may cause an undesirable chemical change in the dosimetric solution remaining inside the ampoule neck. Test tubes with ground-glass stoppers are therefore preferred to sealed ampoules for measuring doses below 100 Gy. For the same reason, care should be given to avoid heating the body of the ampoule during sealing.

6.3 The dosimetric solution is somewhat sensitive to ultraviolet light and should be kept in the dark for long-term storage. No special precautions are required during routine handling under normal laboratory lighting conditions, but strong ultraviolet (UV) sources such as sunlight should be avoided (**18**).

7. Apparatus

7.1 This practice describes mercurimetric titration of radiolytically formed Cl^- ions as a standard readout procedure for the ECB system when used as a reference-standard dosimetry system.

7.2 For the analysis of the dosimetric solution, use a precision burette capable of measuring volumes with 0.01 mL resolution. If necessary, check the original calibration of volumetric glassware and, if necessary, recalibrate to attain 0.1 % relative uncertainty. Control the temperature of all solutions during handling at 20 ± 2 °C to ensure correct measurement of volumes.

7.3 Use borosilicate glass or equivalent chemically resistant glass to store the reagents and the prepared dosimetric solution, and to perform the titration. Clean all apparatus thoroughly before use (see ASTM Practice **C912**).

7.4 Use a sealed glass ampoule or other appropriate glass container to hold the dosimetric solution during irradiation. For photons, surround the container with material of thickness sufficient to produce approximate electron equilibrium conditions during calibration irradiations. For measurement of absorbed dose in water, use materials that have radiation-absorption properties essentially equivalent to water, for example, polystyrene and polyethylene. The appropriate thick-

ness of such material depends on the energy of the photon (see ASTM Practices **E666** and **E668**).

NOTE 5—The dosimetric ampoule commonly used has a capacity of about 5 mL. Quick-break, glass ampoules or “Type 1 glass” colorbreak ampoules or equivalent containers, may be used. Commercially available pharmaceutical ampoules have been found to give reproducible results without requiring additional cleaning.

8. Reagents

8.1 Analytical reagent grade chemicals shall be used in this practice for preparing all solutions.⁸

8.2 Triply distilled water from coupled all-glass stills or water from a high-quality commercial purification unit capable of achieving Total Oxidizable Carbon (T.O.C.) content below 5 ppb should be used. Type II reagent water as specified in ASTM Specification **D1193** is also considered to be of sufficient quality for use in preparing solutions and 96 volume % ethanol.

NOTE 6—High-purity water is commercially available from some suppliers. Such water, labelled HPLC (high-pressure liquid chromatography) grade, is usually sufficiently free of impurities to be used in this practice.

9. Preparation of dosimeters

9.1 Dosimetric solutions may contain any concentration of CB. For practical reasons, only a few characteristic formulations have been thoroughly characterized. **Table 1** lists these typical formulations in terms of CB concentrations and radiation chemical yields pertaining to these concentrations.

9.2 Prepare 96 volume % aqueous ethanol first by adding absolute ethanol into a volumetric flask containing the appropriate amount of water. (**Warning**—Ethanol is flammable.) Use this aqueous ethanol for making the dosimetric solutions of the desired concentrations by adding it into volumetric flasks containing appropriate amounts of CB. Store the dosimetric solution in the dark. (**Warning**—Chlorobenzene is toxic and a skin irritant. Appropriate precaution should be taken to avoid contact with the solution during preparation and analysis of the dosimeters. Used solutions should be disposed of as hazardous waste.)

9.3 Fill the dosimeter ampoules with the dosimetric solution. Bubble the solution in the ampoule with nitrogen for about 1 min at about 1 bubble per second through a 1-mm capillary. Flame-seal immediately after bubbling. Exercise care to avoid depositing solution in the ampoule neck. Store dosimeters in the dark.

⁸ Reagent specifications are available from the American Chemical Society, 1115 16th Street, NW, Washington, DC 20036, USA.

TABLE 2 Temperature coefficients k (°C)⁻¹ for typical ECB solution formulations as derived from Ref (**17**)

Concentration of CB, vol %	2.5 kGy	5 kGy	10 kGy	15 kGy	20 kGy	25 kGy
4	-0.0002	-0.0004	-0.0007	-0.0011	-0.0015	-0.0019
10	0.0018	0.0014	0.0009	0.0002	0.0	0.0
20, 25, 40	0.0037	0.0031	0.0020	0.0013	0.0008	0.0

NOTE 1—For intermediate doses interpolation should be made.

NOTE 7—To minimize the removal of the vapor above the dosimetric solution in the ampoules, the nitrogen is saturated with the vapors of the dosimetric solution by passing it through ECB solution of the same composition before the bubbling of the dosimeter ampoules.

10. Calibration of the mercuric nitrate solution

10.1 The dosimeter measurement procedure is based on the titration of chloride ions formed by irradiation. Free chloride is precipitated with mercuric ions as insoluble HgCl_2 , whereupon the excess of Hg^{2+} ions gives a violet-red coloration with the indicator diphenylcarbazone in acid medium (19).

10.2 Prepare approximately $5 \times 10^{-4} \text{ mol dm}^{-3} \text{ Hg}(\text{NO}_3)_2$ in acidic aqueous ethanol. First dissolve an appropriate amount of $\text{Hg}(\text{NO}_3)_2$ in water acidified with sufficient HNO_3 to attain the concentration of the acid in the final solution, 0.05 mol dm^{-3} . (Warning—Mercuric (II) nitrate is highly toxic. Acute exposure of skin and mucous membranes produces violent corrosive effects. Chronic exposure causes many pathological changes. Appropriate precautions should be exercised in handling it. Used solutions should be disposed of as hazardous waste. Hazards of mercury poisoning can be avoided by using some of the alternative readout methods described in Annex A2 and Table A3.1 in Annex A3.)

10.2.1 Prepare standard solutions of NaCl in water. Make several concentrations to enable cross-checking. Suitable concentrations are 5×10^{-3} , 1.0×10^{-2} , 1.5×10^{-2} , and $2.0 \times 10^{-2} \text{ mol dm}^{-3}$. If kept properly in ground-glass stoppered bottles, these solutions are stable for years. Avoid contamination of the standard solutions by using for daily work small portions of these solutions kept in small ground-glass stoppered flasks. Replenish standard solutions in the small flasks as necessary.

10.2.2 Prepare $0.2 \text{ mol dm}^{-3} \text{ HNO}_3$ in ethanol and 1 % ethanolic solutions of diphenylcarbazone (DPC).

10.3 Distribute technical grade ethanol to beakers for titration, 10 mL into each. Pipet standard NaCl solution quantitatively to beakers with ethanol. Add 1 mL of $0.2 \text{ mol dm}^{-3} \text{ HNO}_3$ and 7 drops of 1 % DPC and shake. Titrate with $\text{Hg}(\text{NO}_3)_2$ solution from the burette. The solution in the beaker, which is initially yellow-orange, turns to reddish-violet at the end point.

10.4 Construct or calculate the best straight line through the points: (consumption of $\text{Hg}(\text{NO}_3)_2$) versus (milliequivalents of NaCl). The small positive intercept represents the blank; inverse slope gives concentration of $\text{Hg}(\text{NO}_3)_2$ solution.

NOTE 8—Volumes of the standard NaCl solutions should be such that the consumptions of the titrant solution on calibration are similar to the consumptions when analyzing irradiated dosimetric solutions. Take two different volumes of each standard solution to enable cross-checking. The concentration of mercuric nitrate solution should be calibrated daily.

11. Calibration of the dosimetry system

11.1 The dosimetry system shall be calibrated prior to use and at intervals thereafter in accordance with the user's documented procedure that specifies details of the calibration process and quality assurance requirements. Calibration requirements are given in ISO/ASTM Practice 51261.

11.2 *Calibration Irradiation of Dosimeters*—Irradiation is a critical component of the calibration of the dosimetry system. Calibration irradiations shall be performed at an approved laboratory.

11.2.1 Specify the dose in terms of absorbed dose to water.

11.2.2 When the ECB dosimeter is used as a routine dosimeter, the calibration irradiation may be performed by irradiating the dosimeters at (a) an approved laboratory using criteria specified in ISO/ASTM Practice 51261, (b) an in-house calibration facility that provides an absorbed dose (or an absorbed-dose rate) having traceability to nationally or internationally recognized standards, or (c) a production irradiator under actual production irradiation conditions, together with reference- or transfer-standard dosimeters issued and read by an approved laboratory.

NOTE 9—If the procedures outlined in Sections 5 – 10 are followed, the radiation chemical yield for the ethanol-chlorobenzene dosimetric solution is expected to be in agreement with the values shown in Table 1 or in the literature and to be approximately constant over the dose range. Quality control testing of the dosimetric solution can be performed by comparing dosimetric solution parameters such as the radiation chemical yield of HCl with accepted values. If the radiation chemical yield is significantly different from that in Table 1 or in the literature, there is an indication of possible contamination of the solution, or some other problem that needs to be resolved.

11.2.3 Calibration shall be performed for all new dosimetric solutions. If the preparation procedure has been demonstrated to give consistently the same radiation chemical yield, the number of absorbed-dose levels required for the calibration irradiations can be reduced to the minimum needed to check the response and to demonstrate its linearity with dose.

11.3 *Measurement Instrument Calibration and Performance Verification*—For the calibration of the instruments, and for the verification of instrument performance between calibrations, see ISO/ASTM Practice 51261 and/or instrument-specific operating manuals.

11.4 *Dosimeter Measurement by Mercurimetric Titration:*

11.4.1 Transfer the irradiated dosimetric solution into a beaker for titration. Rinse the dosimeter ampoule several times with a total volume of 5 mL of technical grade ethanol, so that the final volume in the beaker is 10 mL. Add 1 mL of $0.2 \text{ mol dm}^{-3} \text{ HNO}_3$ and 7 drops of DPC and titrate to the same color change as that observed during calibration of the mercuric nitrate solution.

NOTE 10—If high absorbed doses are to be measured, use appropriate portions of irradiated dosimetric solution, taking care that total volume in the beaker is 10 mL.

11.5 *Analysis:*

11.5.1 Subtract the blank (as defined in 10.4) from the amounts of $\text{Hg}(\text{NO}_3)_2$ solutions consumed and calculate $[\text{Cl}^-]$, the concentration of radiolytically formed Cl^- ions in each dosimeter:

$$(\text{equivalents of } \text{Cl}^-) = (\text{equivalents of } \text{Hg}^{2+}) \times \quad (4)$$

$$\frac{(\text{mL of titrant}) - (\text{blank})}{\text{mL of dosimetric solution}}$$

11.5.2 Correct response for the irradiation temperature by using Eq 3 (see 5.2).

11.5.3 Obtain a calibration curve for $[Cl^-]$ as a function of the absorbed dose, D . Fit the data by means of a least-squares method with an appropriate analytical form that best fits the data.

11.6 *Quality control:*

11.6.1 For quality control of the dosimetric solution calculate the radiation chemical yield as follows:

$$G(Cl^-) = \frac{[Cl^-]}{D\rho} \quad (5)$$

where:

D = known absorbed dose to the dosimetric solution, Gy
 ρ = density of the dosimetric solution, $kg\ m^{-3}$

11.6.2 Published values of $G(Cl^-)$ and ρ are found in **Table 1** or in the literature (**3, 9, 20**). The calculated radiation chemical yield should agree with the published values within the measurement uncertainty. If the calculated radiation chemical yield differs from the published value by more than the expanded uncertainty with a coverage factor $k = 2$, there is an indication of possible contamination of the solution or some other problem that needs to be resolved.

NOTE 11—Eq 5 is only to be used for the purpose of quality control of the dosimetric solution, and not for calculating an unknown dose from the dosimeter response $[Cl^-]$. The calibration curve obtained in 11.5.3 should be used for determining dose.

12. Application of dosimetry system

12.1 For use as a transfer-standard dosimeter, a minimum of two dosimeters should be used for each absorbed-dose measurement. The number of dosimeters required for the measurement of absorbed dose on or within a material is determined by the reproducibility associated with the dosimetry system and the required measurement uncertainty associated with the application. Appendix X3 of ASTM Practice E668 describes a statistical method for determining this number.

12.2 The measurement and analysis procedures should be performed in accordance with 11.4 and 11.5.

12.3 The absorbed dose to water is determined from the analysis results and the calibration curve.

NOTE 12—The absorbed dose to materials other than water irradiated under equivalent conditions may be calculated using the procedure given in ASTM Practices E666 and E668.

12.4 Requirements for recording the calculated absorbed dose values and all other relevant data are outlined in Section 13.

13. Minimum documentation requirements

13.1 *Calibration of the Dosimetry System:*

13.1.1 Record the dosimeter type and batch number (code).

13.1.2 Record or reference the date, irradiation temperature, temperature variation (if any), dose range, radiation source (including dose rate and energy), and associated instrumentation used to calibrate and analyze the dosimeters.

13.2 *Application:*

13.2.1 Record the date and temperature of irradiation, temperature variation (if any), and the date and temperature of absorbance measurement, for each dosimeter.

13.2.2 Record or reference the radiation source type and characteristics.

13.2.3 Record the consumption of the titrant, net consumption value, temperature correction (if applicable), and resulting absorbed dose for each dosimeter. Reference the calibration curve or the response function used to obtain the absorbed-dose values.

13.2.4 Record or reference the components of uncertainty in the value of the absorbed dose.

13.2.5 Record or reference the measurement quality assurance plan used for the dosimetry system application.

14. Measurement Uncertainty

14.1 All dose measurements need to be accompanied by an estimate of uncertainty. Appropriate procedures are recommended in ISO/ASTM Guide 51707 (see also GUM).

14.2 All components of uncertainty should be included in the estimate, including those arising from calibration dosimeter reproducibility, instrument reproducibility, and the effect of influence quantities. A full quantitative analysis of components of uncertainty may be referred to as an uncertainty budget, and is then often presented in the form of a table. Typically, the uncertainty budget will identify all significant components of uncertainty, together with their methods of estimation, statistical distributions and magnitudes.

14.3 If this practice is followed, the estimate of the expanded uncertainty of an absorbed dose determined by this dosimetry system should be less than 3 % for a coverage factor $k = 2$ (which corresponds approximately to a 95 % level of confidence for normally distributed data).

15. Keywords

15.1 absorbed dose; dose; dose measurement; dosimeter; dosimetry system; ECB; electron beam; ethanol-chlorobenzene dosimeter; gamma radiation; ionizing radiation; irradiation; photons; radiation; radiation processing; reference-standard dosimeter; X-radiation; ICS 17.240