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Practice for use of the ethanol-chlorobenzene dosimetry system

Pratique de l'utilisation d'un système dosimétrique à l'éthanol chlorobenzène

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This document was prepared by ASTM Committee E61 Radiation Processing and by Technical Committee ISO/TC 85, nuclear energy, nuclear technologies and radiological protection.

This third edition cancels and replaces the second edition (ISO/ASTM 51538:2009), which has been technically revised.

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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.

ISO/ASTM 51538:2017(E)

Standard Practice for Use of the Ethanol-Chlorobenzene Dosimetry System[1]

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 ^{60}Co 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.*

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[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.

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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 Measurement[5]

JCGM 200:2012, (JCGM 200:2008 with minor revisions) VIM, International Vocabulary of Metrology – Basis and General Concepts and Associated Terms[6]

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

[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).

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

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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: $m^2\ mol^{-1}$)

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

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

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

(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 kg · m^{-3}	Ratio of Coefficients[A]	Radiation Chemical Yields at 20 °C[B] (μmol · 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 ^{60}Co 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 μmol J^{-1} at a given temperature *t* in °C,
G_0 = radiation chemical yield in μmol J^{-1} at 20 °C (G_0 for different ECB solutions are given in Table 1), and
k = temperature coefficient in $°C^{-1}$ applicable at a given dose.

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