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Radiological protection — Minimum criteria for electron paramagnetic resonance (EPR) spectroscopy for retrospective dosimetry of ionizing radiation —

Part 2: Ex vivo human tooth enamel dosimetry

Radioprotection — Critères minimaux pour la spectroscopie par résonance paramagnétique électronique (RPE) pour la dosimétrie rétrospective des rayonnements ionisants —

Partie 2: Dosimétrie ex vivo à partir de l'émail dentaire humain

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

A list of all parts in the ISO 13304 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

Electron paramagnetic resonance (EPR) or electron spin resonance (ESR) is an approach for retrospective dosimetry of exposure to ionizing radiation in any situation where dosimetric information is potentially incomplete or unknown for an individual. EPR is a tool for retrospective evaluation of doses, pertinent as well for acute and protracted exposures in the past or recently. Doses estimated with EPR were used to correlate the biological effect of ionizing radiation to received dose, to validate other dosimetry techniques or methodologies, to manage casualties, or for forensic expertise for judicial authorities.

EPR dosimetry is based on the fundamental properties of ionizing radiation: the generation of unpaired electron species (e.g., radicals) proportional to absorbed dose. The technique of EPR specifically and sensitively detects the unpaired electrons that have sufficient stability to be observed after their generation. The amount of the detectable unpaired electrons is proportional to the total amount that were generated, and hence to the absorbed dose. These species can interact with microwaves generating the EPR signal, and therefore the relationship between the intensity of the EPR signal and the radiation dose should be established.

The most extensive use of EPR in retrospective dosimetry has been with calcified tissue, especially with enamel from teeth. EPR dosimetry is one of the methods of choice for retrospective evaluation of doses to the involved populations from the atomic weapon exposures in Japan, after the Chernobyl accident and radioactive releases of the Mayak facilities in the Southern Urals.

This document provides a guideline to perform the ex vivo measurements of human tooth enamel samples by X-band EPR for dose assessment using documented and validated procedures. The minimum requirements for reconstructing the absorbed dose in enamel, by defining precisely the technical aspects of preparing enamel samples, recording EPR spectra, assessment of radiation induced EPR signal, converting EPR yield to dose and performing proficiency tests, are described. Retrospective dose assessment using EPR has relevance in radiation effect research, validating radio-epidemiological dosimetry systems, medical management, and medical/legal requirements.

A part of the information in this document is contained in other international guidelines and scientific publications, primarily in the International Atomic Energy Agency's (IAEA) technical reports series on "Use of electron paramagnetic resonance dosimetry with tooth enamel for retrospective dose assessment"[1]. However, this document expands and standardizes the measurement and dose reconstruction procedures and the evaluation of performance.

This document is compliant with ISO 13304-1[2] with particular consideration given to the specific needs of X-band EPR dosimetry using human tooth enamel.

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Radiological protection — Minimum criteria for electron paramagnetic resonance (EPR) spectroscopy for retrospective dosimetry of ionizing radiation —

Part 2: Ex vivo human tooth enamel dosimetry

1 Scope

The purpose of this document is to provide minimum criteria required for quality assurance and quality control, evaluation of the performance and to facilitate the comparison of measurements related to absorbed dose estimation obtained in different laboratories applying ex vivo X-band EPR spectroscopy with human tooth enamel.

This document covers the determination of absorbed dose in tooth enamel (hydroxyapatite). It does not cover the calculation of dose to organs or to the body.

This document addresses:

a) responsibilities of the customer and laboratory;

b) confidentiality and ethical considerations;

c) laboratory safety requirements;

d) the measurement apparatus;

e) preparation of samples;

f) measurement of samples and EPR signal evaluation;

g) calibration of EPR dose response;

h) dose uncertainty and performance test;

i) quality assurance and control.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

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NOTE Definitions of terms used in this document that pertain to radiation measurement and dosimetry are compatible with ICRU 60[3].

3.1
air kerma
K_a
sum of the initial kinetic energies of all the charged particles liberated by uncharged ionizing radiation per unit mass of air

Note 1 to entry: This quantity is recommended for calibrating the reference photon radiation fields and reference instruments[4].

Note 2 to entry: The unit of the air kerma is given in gray (Gy), which is equal to 1 J/kg.

3.2
absorbed dose
D
quantity of ionizing radiation energy imparted per unit mass of a specific material

Note 1 to entry: The unit of the absorbed dose is given in gray (Gy), which is equal to 1 J/kg.

3.3
background signal
BGS
signal in the EPR spectrum not generated by ionizing radiation

Note 1 to entry: The background signal (BGS) is not equivalent to the signal component of the *radiation induced signal (RIS)* (3.25), which is generated by environmental background radiation.

3.4
bias
deviation of results or interferences from the true value and the estimator

3.5
calibration curve
mathematical description of the dose response relation derived by the in vitro irradiation (3.16) of tooth enamel samples to known doses

3.6
confidence interval
range within which the true value of a statistical quantity lies, given a value of the probability

3.7
decision threshold
critical value of a measurand quantifying absorbed dose (3.2) in a sample above which exposure can be identified

3.8
detection limit
smallest true value of a measurand quantifying absorbed dose (3.2) in a sample above which irradiation can be identified with given probability

3.9
electron paramagnetic resonance
EPR
electron spin resonance
ESR
magnetic resonance technique detecting the net spin (magnetic moment) of unpaired electrons of paramagnetic centres (3.22) in matter

Note 1 to entry: The terms EPR and ESR are equivalent and are widely used. The term electron magnetic resonance (EMR) also sometimes is used because it is analogous to nuclear magnetic resonance (NMR).

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3.10
EPR peak-to-peak line width
ΔB_{pp}
difference in the applied magnetic field values between the minimum and the maximum of the first derivative of a single EPR signal

3.11
EPR signal
first derivative of the electron paramagnetic resonant microwave absorption of a specific paramagnetic centre (3.22) measured as function of the applied magnetic field

Note 1 to entry: The area under the absorption curve is proportional to the amount of unpaired spins of the paramagnetic centre. Hence, the amount of spins is proportional to the double integral of the EPR signal (EPR signal intensity) or the product of EPR signal amplitude and the square of the EPR peak-to-peak line width.

3.12
EPR signal amplitude
A
peak-to-peak amplitude of the EPR signal (3.11)

3.13
EPR signal intensity
I
quantity proportional to the amount of paramagnetic centres that generated the EPR signal (3.11)

Note 1 to entry: The signal intensity can be evaluated by numerical double integration of the EPR signal by the extension of the signal along the magnetic field. The signal intensity of a specific paramagnetic centre can also be evaluated by comparing with a reference spectrum of the specific centre using least square method. The reference spectrum may result from measurement of a sample including the specific paramagnetic centre or by mathematical simulation of the spectrum.

3.14
EPR spectrometer
apparatus to measure the resonant absorption of electromagnetic energy (microwaves) resulting from the transition of the spin of unpaired electrons between different energy levels, upon application of microwave-frequencies to a paramagnetic substance in the presence of a magnetic field

3.15
EPR spectrum fitting
linear least squares curve fitting of an EPR spectrum using a set of reference EPR spectra of specific paramagnetic centres

3.16
in vitro irradiation/measurement
irradiation/measurement carried out on tooth enamel samples outside the human body

Note 1 to entry: The term ex vivo dosimetry refers to samples measured in vitro but were irradiated within the human body.

3.17
linear energy transfer
LET
d*E*/d*l*
quotient of d*E*/d*l*, as defined by the International Commission on Radiation Units and Measurements (ICRU), where dE is the average energy locally imparted to the medium by a charged particle of specific energy in traversing a distance of d*l*

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3.18
magnetic field
B
magnetic flux density (induction)

Note 1 to entry: SI unit Tesla (T) replaced the Gauss (G). 1 T = 10 000 G.

3.19
microwave bridge
apparatus to generate microwaves that are provided to the microwave resonator and to detect microwaves that were reflected at the resonator

3.20
microwave resonator
resonator for electromagnetic waves consisting of a metal box with appropriate dimensions that confines the electromagnetic fields in the microwave range and allows formation of standing waves

Note 1 to entry: For EPR measurement the sample is located inside of the microwave resonator. The term microwave cavity is equivalent to microwave resonator.

3.21
microwave resonator working volume
volume inside the resonator extending along the vertical resonator axis around the centre, within which the local sensitivity does not decrease more than 25 % relative to the maximal sensitivity at the centre

3.22
paramagnetic centre
species with unpaired electron(s)

Note 1 to entry: Paired electrons have the same quantum state but opposite spin orientation; unpaired electrons do not have a "partner" with the opposite spin. When the unpaired spin is on a molecule, it is termed a radical; when the unpaired electron is in a solid, it is termed electron or electron defect (hole) centre.

3.23
quality assurance
planned and systematic actions necessary to provide adequate confidence that a process, measurement, or service satisfies given requirements for quality

3.24
quality control
planned and systematic actions intended to verify that systems and components conform with predetermined requirements

3.25
radiation induced signal
RIS
EPR signal (3.11) resulting from paramagnetic centres (3.22) generated by ionizing radiation

3.26
reference spectrum
unit EPR spectrum of a specific paramagnetic centre (3.22) used to evaluate the intensity of the EPR spectrum of this centre in a sample under investigation

Note 1 to entry: The unit spectrum is reconstructed from EPR measurement of a sample containing the specific paramagnetic centre or by mathematical simulation.

3.27
retrospective dosimetry
dosimetry to assess dose coming from past exposures

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