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Radiological protection — Monitoring and dosimetry for internal exposures due to wound contamination with radionuclides

Radioprotection — Surveillance et dosimétrie en cas d'exposition interne due à la contamination d'une plaie par radionucléides

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Foreword

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

Introduction

In the course of their employment, radiation workers may be exposed to radioactive materials that could be incorporated into the body. Intakes of radionuclides need to be monitored to determine that any exposures are at expected levels. Internal doses resulting from intakes of radionuclides cannot be measured directly. Estimating the dose requires decisions to be made about the monitoring techniques and frequencies along with methodologies for dose assessment. The criteria governing the regimes of such a monitoring programme or for the selection of methods and frequencies of monitoring usually depends upon regulations, the purpose of the radiation protection programme, the probabilities of potential radionuclide intakes, and the characteristics of the materials handled.

For these reasons, ISO standards for monitoring programmes (ISO 20553[1]), laboratory requirements (ISO 28218), and dose assessment (ISO 27048[2]) have been developed and can be applied to many workplaces where internal contamination may occur. Their application for internal exposures due to wound contamination with radionuclides requires account to be taken of special aspects resulting from the type of wound and the associated specific biokinetics of radionuclides at the origin of contamination.

This document offers guidance for the design of a special monitoring programme and for dose assessment in the case of wound contamination with radionuclides. Recommendations of international expert bodies and international experience with the practical application of these recommendations in radiological protection programmes have been considered in the development of this document. Its application facilitates the exchange of information between authorities, supervisory institutions and employers.

Radiological protection — Monitoring and dosimetry for internal exposures due to wound contamination with radionuclides

1 Scope

This document specifies the requirements for personal contamination monitoring and dose assessment following wounds involving radioactive materials. It includes requirements for the direct monitoring at the wound site, monitoring of uptake of radionuclides into the body and assessment of local and systemic doses following the wound event.

It does not address:

— details of monitoring and assessment methods for specific radionuclides;

— monitoring and dose assessment for materials in contact with intact skin or pre-existing wounds, including hot particles;

— therapeutic protocols. However, the responsible entity needs to address the requirements for decontamination and decorporation treatments if appropriate.

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 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 5725-3, *Accuracy (trueness and precision) of measurement methods and results — Part 3: Intermediate measures of the precision of a standard measurement method*

ISO 28218, *Radiation protection — Performance criteria for radiobioassay*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC Guide 99, ISO 5725-1, ISO 5725-2, ISO 5725-3 and the following 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/

3.1
absorption
movement of material into blood regardless of mechanism, generally applied to the *uptake* (3.32) into blood of soluble substances and material dissociated from particles

3.2
activity
number of spontaneous nuclear disintegrations per unit time

Note 1 to entry: The activity is stated in becquerels (Bq), i.e. the number of disintegrations per second.

3.3
biokinetic model
model describing the time course of *absorption* (3.1), distribution, metabolism and excretion of a substance introduced into the body of an organism

3.4
clearance
net effect of the biological processes by which radionuclides are removed from the body or from a tissue, organ or region of the body

3.5
contamination
activity (3.2) of radionuclides present on surfaces, or within solids, liquids or gases (including the human body), where the presence of such radioactive material is unintended or undesirable

3.6
decision threshold
value of the estimator of the measurand which, when exceeded by the result of an actual measurement using a given measurement procedure of a measurand quantifying a physical effect or quantity, it is decided that the physical effect or quantity is present

Note 1 to entry: Otherwise, this effect is assumed to be absent.

3.7
decontamination
complete or partial removal of radioactive *contamination* (3.5) by a deliberate physical, chemical, or biological process

3.8
decorporation
method aiming to accelerate the elimination from the body of an incorporated radionuclide

3.9
detection limit
smallest true value of the measurand which ensures a specified probability of being detectable by the measurement procedure

Note 1 to entry: With the decision threshold, the detection limit is the smallest true value of the measurand for which the probability of wrongly deciding that the true value of the measurand is zero is equal to a specified value, β, when, in fact, the true value of the measurand is not zero. The probability of being detectable is consequently $(1 - \beta)$.

Note 2 to entry: The terms detection limit and decision threshold are used in an ambiguous way in different standards (e.g. standards related to chemical analysis or quality assurance). If these terms are referred to one has to state according to which standard they are used.

3.10
dose coefficient
committed tissue equivalent dose per unit acute intake $h_T(\tau)$ or committed effective dose per unit acute intake $e(\tau)$, where τ is the time period in years over which the dose is calculated [e.g. $e(50)$]

3.11
effective dose
sum of weighted *equivalent doses* (3.13) in all tissues and organs of the body

3.12
committed effective dose
sum of the products of the committed organ or tissue equivalent doses and the appropriate tissue weighting factors

Note 1 to entry: In the context of this document, the integration time is 50 years following any intake.

3.13
equivalent dose
product of the absorbed dose and the radiation weighting factor for the specific radiations at this point

3.14
local dose
equivalent dose (3.13) in a defined volume or area at the wound site

3.15
systemic dose
committed effective dose (3.12) excluding the local dose at the wound site

3.16
event
any unintended occurrence, including operating error, equipment failure or other mishap, the consequences or potential consequences of which are not or suspected not to be negligible from the point of view of protection or safety

3.17
internal exposure
exposure to radiation from a source inside the body

3.18
intake
<process> act or process of taking radionuclides into the body by inhalation, ingestion, *absorption* (3.1) through the skin or through wounds

3.19
monitoring
measurements made for the purpose of assessment or control of exposure to radioactive material and the interpretation of the results of such measurements

3.20
incorporation monitoring
monitoring (3.19) of radionuclides incorporated into the bodies of individual workers by measurement of the quantities of radioactive materials in the bodies of individual workers, or by measurement of radioactive material excreted by individual workers

3.21
individual monitoring
monitoring (3.19) by means of equipment worn by individual workers, by measurement of the quantities of radioactive materials in or on the bodies of individual workers, or by measurement of radioactive material excreted by individual workers

3.22
special monitoring programme
monitoring programme performed to quantify significant exposures following actual or suspected abnormal *events* (3.16)

3.23
quality assurance
planned systematic actions necessary to provide adequate confidence that a process, measurement or service satisfy given requirements for quality such as those specified in a licence

3.24
quality control
part of *quality assurance* (3.23) intended to verify that systems and components correspond to predetermined requirements

3.25
radiobioassay
procedure used to determine the nature, *activity* (3.2), location or retention of radionuclides in the body by direct (in vivo) measurement or by indirect (in vitro) analysis of material excreted or otherwise removed from the body

3.26
in vitro radiobioassay measurement
analyses that include measurements of radioactivity present in biological samples taken from an individual

3.27
in vivo radiobioassay measurement
measurement of radioactive material in the human body utilizing instrumentation that detects radiation emitted from the radioactive material in the body

Note 1 to entry: Normally, the measurement devices are whole-body or partial-body (e.g., lung, thyroid) counters.

3.28
responsible entity
person, body or service that is in charge of the *monitoring* (3.19) and dosimetry

3.29
retention function
function describing the fraction of an intake present in a biological compartment (whole body, tissue, organ or excreta) after a given time has elapsed since the intake occurred

3.30
time of measurement
<in vitro analysis> time at which the biological sample (e.g. urine, faeces) is taken from the individual concerned

3.31
time of measurement
<in vivo measurements> time at which the *in vivo* measurement begins

3.32
uptake
translocation of material from deposition site [*wound* (3.33), lung, etc.] into blood and subsequently to systemic organs and tissues

3.33
wound
injury to the body in which the skin or other tissue is broken, cut, pierced, torn, scraped, burned, etc.

4 Symbols and abbreviated terms

4.1 Symbols

A	activity (Bq)
$\langle A \rangle$	measured activities (Bq)
H	equivalent dose to skin (Sv)
$\dot{H}$	equivalent dose rate to skin ($Sv \cdot h^{-1}$)
$E(50)$	committed effective dose integrated over 50 years (Sv)
$e(50)$	dose coefficient: committed effective dose integrated over 50 years per unit intake, $E(50)/I$ ($Sv \cdot Bq^{-1}$)
$f(t)$	function describing the decay of a radionuclide, $e^{-\lambda t}$
I	intake (Bq)
$m(t)$	predicted fraction of the measured quantity at time t for unit intake (excretion or retention function at time t per unit intake)

4.2 Abbreviated terms

CIS	Colloid and Intermediate State
DTPA	Diethylenetriaminepentaacetic acid (Zn and Ca salts)
IAEA	International Atomic Energy Agency
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
NCRP	National Council on Radiation Protection and Measurements
PABS	Particles, Aggregates and Bound State
TPA	Trapped Particles and Aggregates.

5 Purpose and need for special monitoring programmes for internal exposures due to wound contamination with radionuclides

Under normal circumstances, workers should not have wounds. There is thus no requirement for routine monitoring, as defined in ISO 20553[1], for intakes of radioactive materials from wound events.

However, accidents leading to wounds are an occupational hazard in nearly all workplace situations. The risks of accidents can be much higher in situations where manual tasks such as cutting, machining and drilling or medical injection of radioisotopes are taking place. Thus there is a potential need for special monitoring following wound events.

The aims of monitoring and dose assessment are to aid in decisions regarding decontamination and treatment such as irrigating with water/saline, excision of the wound or decorporation therapy, to assess health consequences, and to ensure compliance with dose limits. For radionuclides that are highly retained by the body when absorbed through a wound but poorly absorbed through other intake

routes, significant doses can be received when compared to the inhalation or ingestion of similar amounts.

Accidents, and thus wound events, can occur at any time. As part of the internal dosimetry programme, the responsible entity shall:

a) consider the possible types of wounds (e.g., puncture wounds, lacerated skin) and contaminants (e.g., involved radionuclides, chemical species) in specific work environments;

b) design appropriate special monitoring programmes for these wound events;

c) make arrangements in the special monitoring programme for the measurement methods to be available on demand if a wound event should occur.

The special monitoring programme shall set a target to be able to detect a minimum committed effective dose following a wound event. It is recommended that target not exceed 1 mSv if technically feasible.

The responsible entity shall define the circumstances under which special monitoring is to be initiated. The sorts of circumstances which might lead to special monitoring include:

— wounds occurring or identified in designated contamination areas;

— wounds from contaminated objects.

6 General aspects of wound contamination

6.1 Introduction

Wounds act as routes by which radionuclides can enter the systemic circulation. While some of the material can be retained at the wound site, soluble material can be transferred to the blood and hence to other parts of the body. Insoluble material can be slowly translocated to regional lymphatic tissue, where it can gradually dissolve and eventually enter the blood. A variable fraction of insoluble material can be retained at the wound site or in lymphatic tissue for the life of the individual. Thus, a contaminated wound can result in an acute intake or a chronic uptake. The National Council on Radiation Protection and Measurements (NCRP) developed a compartment-based biokinetic model for wounds (NCRP Report 156[3]), in order to assess internal exposure resulting from a contaminated wound. The NCRP wound model is a compartmental model that deals with material at the wound site and transfer to blood. This wound model has to be coupled with the appropriate ICRP systemic model to assess exposure due to radionuclides entering the body through a wound. This document uses this system to assess internal exposure due to a contaminated wound.

The NCRP wound model has seven compartments: fragment; particles, aggregates and bound state (PABS); trapped particles and aggregates (TPA); colloid and intermediate state (CIS); soluble; lymph nodes; and blood (see Figure A.1). The applicable compartments depend on the category of contaminant to be considered for a particular wound case.

6.2 Category of wound contaminants

Seven retention categories of wound contaminants are defined in the NCRP wound model[3]. Four of these categories describe the retention at the wound site of radionuclides injected in soluble form. Solutions can be weakly, moderately, strongly or avidly retained, in order of increasing retention half-time. Soluble wound contaminants can translocate to the blood with a time course that depends on their dissolution rate in vivo.

Three additional categories are considered to describe the behaviour of radioactive material introduced into a wound in colloidal, particulate or fragment form. Both particles and fragments are solids. They differ in that fragments are too large to be ingested by connective tissue macrophages because their size is greater than 100 µm in any dimension. As opposed to soluble compounds, colloids and solids with low

solubility can have significant clearance from the wound site to the lymph nodes. Furthermore, due to the presence at the wound site of significant masses of materials, inflammatory reactions can occur in the wound tissue, leading to biological sequestration and capsule formation. These phenomena provide a biological barrier that entrap colloids, particles and fragments at the wound site. Default parameters for equations describing the retention at the wound site for the seven retention categories are detailed in Table A.1.

Radionuclides that are initially in a solution and are injected subcutaneously or intramuscularly can enter the blood directly from the soluble compartment. Wound contamination with a radioactive material is simulated through a direct deposition in the CIS compartment if a colloidal form is considered, through a direct injection in the PABS compartment if a particulate form is considered, and through a direct deposition in the fragment compartment if fragments are considered. Default transfer rates between compartments in the wound model for the various categories of radionuclides in wounds are detailed in Table A.2.

6.3 Types of wounds and their specific retention of radionuclides

The NCRP wound model does not differentiate between the different types of contaminated wounds, for example between puncture wounds and abrasions, because of a lack of relevant data. All contaminated wounds are assumed to be direct injection or direct deposition of radioactive material into a compartment of the wound model. Biokinetics of a given physicochemical form of radionuclide incorporated through contaminated wound depends largely on the type of wound and its physiological evolution (e.g., healing). Based on existing literature, it may be assumed that, in general, absorption of a given soluble radionuclide from wounds or skin contamination is in the order (from greatest to least): intravenous injection > puncture wound ≈ laceration ≈ abrasion > burned skin ≥ intact skin[3]. Types of wounds and their characteristic retention of radionuclides are detailed in Annex B.

7 Monitoring programmes to assess contamination via a wound

7.1 Introduction

Monitoring depends on the type of wound as well as the category of wound contaminant and the biokinetics and physical decay properties of the radionuclide. A contaminated wound can result in an acute uptake and/or in a chronic uptake decreasing or increasing with time. Thus the monitoring program may need to be adapted with time following the wound event. If medical treatment is implemented, it should be taken into account when designing the monitoring program.

In the case of a contaminated wound or a wound suspected to be contaminated, a special monitoring programme shall be implemented, as described in ISO 20553[1]. This special monitoring programme shall include measurements of local activity of the wound. In vivo and/or in vitro measurements shall be used to detect and quantify systemic contamination. In order to implement a special monitoring programme, information is required on the wound event, including identification of radionuclides present in the workplace.

7.2 Main steps for the monitoring and dosimetry for internal exposures due to wound contamination with radionuclides

Medical treatment of any serious injuries should take priority over dealing with radiological aspects of the contaminated wound. The sequence of actions in dealing with a potentially contaminated wound are to:

— collect information concerning the type of wound and the type of contaminant;

— assess the level of contamination of the wound;

— implement decontamination treatment, decorporation treatment and excision treatment as necessary.