INTERNATIONAL STANDARD

**ISO 20031**

First edition
2020-02

# 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*



Reference number
ISO 20031:2020(E)



ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

# Contents

Page

# 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).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on 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 the following URL: 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*.

# 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, $\beta$, 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 $\tau$ 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.

Figure 1 summarises the main steps for monitoring and dosimetry of internal exposures due to wound contamination with radionuclides. These steps are discussed in more detail in the next clauses of this document.

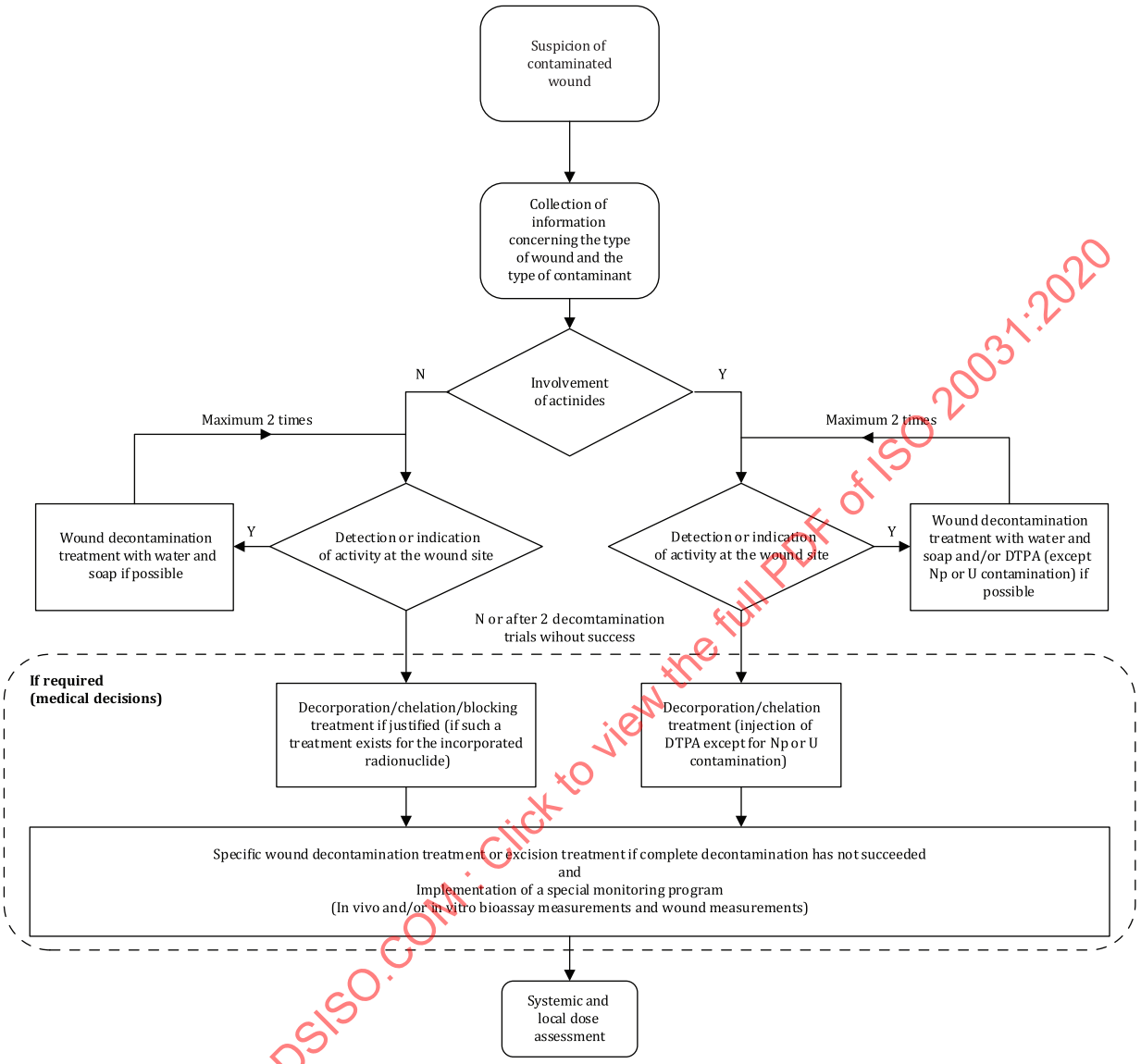



**Figure 1 — Proposed response to a contaminated wound**



## 7.3 Collection of information to characterize the contaminated wound

### 7.3.1 General

The special monitoring programme shall take into account the characteristics of the contaminated wound (type of wound, involved radionuclide(s), chemical species of radionuclide(s), radionuclide activity, surface area of the contaminated wound, depth of the contaminated wound). The collection of information should be proportionate to the potential dose consequences of the wound event.

Whatever the type of radiological contamination, medical management shall take priority over radiological assessment[4]. It may be necessary to consider protection of responders and medical personnel during the handling of contaminated items. Multiple participants may be involved during this phase of initial care of a contaminated wound, including radiation protection, medical, internal dosimetry and in some extent operational personnel. Data of interest concerning the wound case should be collected by all these participants. To facilitate data collection, a summary sheet should follow

the contaminated worker during its transfer from one department to another. An example of such a summary sheet is presented in Annex C.

### 7.3.2 Information concerning the type of wound

Information regarding the type of wound is important for monitoring and dose assessment of workers in case of a wound involving radioactive materials.

The type of wound should be described in as much detail as possible in order to categorise it into one of the categories described in 6.3.

The following information should be recorded if available:

— for puncture wounds, location, depth and diameter of the puncture;

— for lacerated skin or abraded skin, location, depth and contaminated surface area of the wound;

— for thermally-burned skin, location, grade, contaminated surface area of the burn and type of material involved in the burn (e.g., cotton, polyester, other workplace materials, etc.);

— for chemical-burned skin, the type and concentration of the chemical that induced the burn, location, grade, contaminated surface area and type of material involved in the burn (e.g., cotton, polyester, other workplace materials, etc.).

Whatever the type of wound, the presence and abundance of bleeding should be recorded. Apart from the haemorrhagic risk, bleeding has a mechanical action which tends to remove the radioactive material present at the wound site.

### 7.3.3 Information concerning the radioactive contaminant

If assessment of the dose is required, information concerning the radioactive contaminant should be described in as much detail as possible in order to determine which category of contaminant, as described in 6.2, along with associated parameters, is most appropriate.

Details of the radionuclides at the origin of the radioactive contamination should be collected. The following information should also be collected if available:

— the chemical species;

— for liquids: concentration and total activity of radionuclide(s); chemical form and concentration of the carrier;

— for solids: granulometry/size of particles/fragments and total activity of radionuclide(s);

— for vapours or gases: total activity of radionuclide(s).

If a contaminated object caused the wound, the radionuclides present on the object should be identified and their activity measured.

If the wound is surgically excised, any excised tissue and treatment wastes (e.g., compresses) shall be analysed for radioactivity. In case of a bleeding wound, treatment wastes (e.g., compresses, bandages, gauze) shall be analysed for radioactivity. Radionuclides activities in the excised tissue and treatment wastes should be included in the activity balance for the wound.

Workplace and operational conditions can also be useful in the assessment. For instance, if not enough of the contaminant is available to incur a significant dose, that can help with subsequent decision making.

## 7.4 In vivo wound measurements

In vivo monitoring is generally a rapid method (typical counting times of 5 min to 10 min) for assessing the activity of radionuclides at the wound site. The counting time may be increased depending on

the desired detection limit. Direct bioassay methods are most effective for radionuclides emitting penetrating radiation (X- or gamma-ray emitters) or radionuclides emitting energetic beta particles without accompanying photons (e.g. $^{32}$P, $^{90}$Y) if near the surface of the skin.

The choice of monitoring technique mainly depends on the radiation emitted by the radionuclide and/or its progeny. Other factors which influence the choice of monitoring technique are the decay rate of the radionuclide, the depth of the radionuclide in the wound, the retention of the radionuclide in the wound and technical feasibility of measurement.

For nuclides emitting X- and gamma radiation the selection of a detection system depends on sensitivity requirements and energies of the photons emitted. Wound monitoring generally employs NaI(Tl) scintillators and/or HPGe semiconductor detectors in an appropriate counting geometry for the detection of most fission and activation products. The main advantage of NaI(Tl) detectors is their high counting efficiency. In the case of HPGe detectors, the very high energy resolution permits accurate radionuclide identification and analysis of complex gamma spectra. For radionuclides emitting low energy photons, such as plutonium, detector types that respond well to low energy photons should be considered.

Nuclides emitting primarily alpha and beta radiations are difficult to detect and quantify if the radioactive material is embedded in the wound. In this case, if associated gamma or X rays are emitted by the radionuclide they can be used to assess the activity present.

Alpha or beta emitters without accompanying photons can be detected directly with a standard contamination survey instrument if they are located near or on the surface of the skin at the wound site. Pure beta emitters can be detected with an X-ray detector from the bremsstrahlung created by the interaction of beta radiation with tissue. In both cases, the quantification of radioactive materials at the wound site can be difficult.

The measurement laboratory shall have a method for calibrating the measurement system.

To calibrate in vivo monitoring systems for measurements of radionuclides in wound, laboratories should use source phantoms and measurement geometries corresponding as close as possible to the case or potential wound scenarios to be measured.

In order to achieve a more realistic and accurate assessment of local activity it is possible to use more complex procedures involving nuclear imaging and Monte Carlo methods[5][6][7] to simulate the wound measurement.

Activity may also be measured at the local or regional lymph nodes by in vivo techniques.

Local measurements at the wound site and, where appropriate, lymph nodes should be repeated to determine the time dependent retention of the activity of the radionuclides at these site(s).

## 7.5 Systemic activity monitoring

Radionuclides entering the bloodstream from a contaminated wound can be excreted in the urine via the kidney or in the faeces via liver and intestine. They can be retained by specific organs depending on the biokinetics of incorporated radionuclides. The retained or excreted activity provides data for biokinetic modelling and the assessment of the corresponding organ doses. Activity retained in organs can be measured (where appropriate) by in vivo methods. Excretion data can also be used to monitor the effect of chelation therapy.

Urine and/or faeces bioassay measurements should be performed as appropriate to measure activity transferred to the systemic circulation (see Annex D). The number and time periods over which the samples should be collected depends upon potential dose consequences of the wound event. Generally, sample collection should start as soon as possible after the wound event and bioassay samples should be collected after each chelation treatment. The methods applied are the same as for routine monitoring as described in ISO 20553[1]. Urine samples should be collected over 24 h periods. Methods may be applied that do not require a 24 h sample. Faecal samples should be collected over 72 h periods.

# 8 Performance criteria for radiobioassay measurements

Radiation detection at the wound site with an external detector, in vivo radiobioassay measurements, in vitro radiobioassay measurements and treatment waste measurements shall comply with the performance criteria given in ISO 28218.

# 9 Procedure for local and systemic dose assessment

## 9.1 Local (wound site) dose assessment

The purpose of local dose assessment is to determine the likelihood of deterministic effects at the wound site and to confirm compliance with dose limits to skin.

An initial conservative assessment of local equivalent dose rate should be performed both for the wound itself and the skin. Annex E provides dose coefficients for particular radionuclides that can be used for this purpose. Calculation of dose received by the skin should be treated with extreme caution especially for alpha emitters because of the difficulty of obtaining precise measurements in consideration of the depth and geometry of the contamination at the wound site.

For some applications, specialized software has been developed that provides dose to the sensitive target cells that requires location and activity of the radionuclides as input[8]. In the case of a contaminated wound, if the contaminants remain at the wound location, the equivalent dose to the skin should be calculated in order to evaluate the radiological risk. The ICRP recommendations do not clearly define the dose quantity that should be evaluated to assess this risk. Therefore the annual equivalent dose to the basal cell layer is usually assessed and compared to an annual limit of 500 mSv over 1 $cm^2$, the occupational exposure limit for dose to the skin[9]. The use of basal cells, located around 70 µm below the skin surface, as the target tissue is justified by the fact that these cells are the most radiosensitive (for more details, see ISO 15382[10]). Equivalent skin dose, H, is evaluated using Formula 1:

$$H = A_0 \dot{H} \int_{t_1}^{t_2} f(t)\mathrm{d}t \tag{1}$$

where

$\dot{H}$ is the equivalent skin dose rate;

$A_0$ is the initial deposition activity;

$t_1$ is the time after contamination for which the evaluation starts;

$t_2$ is the time the evaluation ends;

$f(t)$ is a function describing the reduction in activity of the radionuclide at the wound site over time.

The time endpoints, $t_1$ and $t_2$, represent the period over which the dose would be compared to an annual limit. The total skin dose is the sum of the doses due to each radionuclide. For contaminated wounds, the dose arises primarily from alpha and beta interactions. The contribution from gamma emission is usually negligible.

## 9.2 Systemic dose assessment

When the wound is being initially evaluated and cared for, a crude upper bound of the internal dose based on the direct measurements of the activity at the wound site can be performed as a quick indication of whether or not decorporation therapies and/or excision therapy should be initiated[3]. For this type of evaluation, it is assumed that all the radioactive material is absorbed into the bloodstream, so dose is calculated by multiplying the activity measured at the wound site by injection dose coefficients. Dose coefficients, whole body retention fractions and wound retention fractions for intakes of radionuclides

via contaminated wounds were tabulated on basis of the NCRP wound model for 38 radionuclides in a report written by Toohey et al. (2014)[11]. NCRP report 156[3] and values from the Toohey et al. paper include injection dose coefficients for selected radionuclides (see Annex F) which can be used for this type of evaluation.

When results of bioassay measurements performed as described in 7.5 become available, systemic dose assessment should be performed if those measurements demonstrate that radioactive material has been absorbed into the systemic circulation from the wound site. This transfer can be determined by measuring radioactivity in urine or faecal samples or by in vivo measurement showing retention in the body outside the wound site. Consideration shall be given to possible activity attributable to earlier intakes or to natural background.

The systemic dose assessment shall always include the determination of committed effective dose. Equivalent dose to specific target organs of the incorporated radionuclides may also be determined if this is of interest for the assessment of the risk to the individual's health.

Formulae (2) and (3) should be used for calculation of intake and committed effective dose $E(50)$ resulting from that intake:

$$I = \frac{M}{m(t)} \tag{2}$$

$$E(50) = I \, x \, e(50) \tag{3}$$

where

$I$ is the intake (in Bq);

$M$ is the measurement (in Bq or Bq·d$^{-1}$);

$m(t)$ is the excretion/retention fraction (in retained/excreted Bq per Bq intake); and

$e(50)$ is committed effective dose coefficient per unit intake (in Sv·Bq$^{-1}$).

Before using excretion and/or retention measurements for the calculation of intake in Formula (2), the values may need to be corrected for:

— radioactivity due to previous intake;

— natural background;

— Influence of treatment on the excretion of the radionuclide. For example, if DTPA is administered, the radioactivity measured in excreta should take into account an "excretion enhancement factor"[12].

The procedure for dose assessment shall be adapted depending upon wound retention. Two scenarios can be distinguished as determined by results of the local measurements:

— if the activity at the wound site rapidly disappears, the intake route may be approximated by an acute injection. Predicted values in urine, faeces or from in vivo measurements following an acute injection intake are given in ICRP publication 78[13] for a selection of radionuclides, and can be used to estimate the uptake to blood. The injection dose coefficients published in NCRP report 156[3] and Toohey et al. (2014)[11] can then be applied to that uptake to assess the corresponding internal doses, see Annex F;

— if local measurements over the first few days post intake demonstrate retention at the wound site, then uptake to the blood should not be determined from early bioassay results as such a determination may underestimate the transfer to the blood in the aftermath of the acute phase of the wound contamination and the corresponding dose received. A dose assessment should be performed using the wound model described in NCRP Report 156[3] or a combination of acute and chronic uptakes. The IDEAS Guidelines[14] provide recommendations for estimation of committed

doses from wound monitoring data (detailed in Annex G). The guidelines provide a three stage approach:

— a simple evaluation using an NCRP wound model category chosen a priori using dose coefficients proposed in Annex F. The choice of category used in the first stage can be based on the known physicochemical form of the contaminant and the wound type (see Clause 7);

— when sufficient monitoring data becomes available, a dose assessment performed using a systematic evaluation of which default wound category best fits the excretion/retention data;

— if the goodness of fit is not acceptable with a single wound category, a dose assessment considering a mixture of two retention categories.

## 9.3 Impact of medical intervention on dose assessment

### 9.3.1 Local chelation therapy and/or the excision of contaminated tissue from the wound

In some cases, thorough irrigation and cleaning of a wound could be sufficient to remove all of the contamination, as adding a chelating agent to an irrigation solution facilitates radionuclide removal from the wound site. The effect of such irrigation may need to be taken into account for the interpretation of bioassay results if chelated material enters the bloodstream.

Wounds containing embedded radioactive fragments pose a unique treatment dilemma. In many of these situations, local treatment with chelating agents is not indicated because of the potential to solubilize excessive amounts of metal from the embedded fragment and distribute it throughout the body. In these cases, it may be necessary to surgically remove the embedded fragment. However, additional considerations such as limitation of exposure of the response staff and medical personnel and proper handling of a surgically removed radioactive fragments should also be taken into account.

Surgically removed fragments should be retained for further analysis. Removed pieces of tissue and the other treatment wastes (e.g. compresses) shall be stored for spectrometric or gross analysis. The facility's health physics staff are essential in providing proper safety measures.

### 9.3.2 Decorporation therapy

If available, decorporation therapy is to be considered depending on the amount of contamination. For wounds contaminated with plutonium, americium, or curium, standard chelation therapy with Ca-DTPA and/or Zn-DTPA is typically considered. The effect of the treatment shall be taken into account when interpreting bioassay results[4][15][16]. For example, if DTPA is used, the radioactivity measured in excreta should take into account an "excretion enhancement factor"[12]. A method for accounting for the enhanced excretion of actinides by DTPA is provided in the European technical recommendations[12].

The measurement laboratory shall be informed that excreta samples could contain DTPA as this may affect the sample analysis methodology.

## 9.4 Software tools for bioassay data interpretation

The following are requirements for inclusion in a software package for interpretation of bioassay data and determination of dose:

a) intake descriptors including:

   1) type of intake such as injection or wound;

   2) pattern of intake, such as acute, chronic or mixed; and

3) date of intake;

b) information on the contaminant such as presence of radionuclides at the workplace, physicochemical characteristics of the compound that conform to retention and absorption parameters in wounds and choice between default and/or specific values;

c) types of measurement (e.g. urine, faeces, whole body, thyroid, lymph node), the possibility of evaluating multiple data types simultaneously, the flexibility of entering, handling and assessing data (type of uncertainties, implemented algorithms for automatic and/or interactive data processing, handling of values close to limit of detection);

d) models available for calculation such as ICRP 78 biokinetic models[13], the NCRP-156 wound model[3] or other models;

e) methods of data fitting and interpretation.

## 9.5 Uncertainties

### 9.5.1 General

An important aspect of quality control in individual monitoring is assessment of the uncertainty of measurement results and computed dose values. This is done for two main reasons:

— the reliability of an assessed dose cannot be judged without at least a qualitative indication of the associated uncertainty;

— information on relative contributions to the overall uncertainty in an assessed dose may indicate where effort should be placed in order to reduce uncertainty.

### 9.5.2 Uncertainties on local dose assessment

General information concerning uncertainties on skin dose assessment is provided in ISO 15382[10]. More generally, uncertainties on local dose assessment should consider assumptions concerning the wound contaminant, the type and characteristics of the wound, radiation measurements, and assumptions used in dose calculation.

### 9.5.3 Uncertainties on internal dose assessment

Distribution of a measured bioassay quantity can be assumed lognormal, with the associated uncertainty quantified by the geometric standard deviation also referred to as the scattering factor ($K_{SF}$). Values for $K_{SF}$ are provided in ISO 27048:2011, Annex B[2], where the general procedure for estimating uncertainties on internal dose assessment is also described.

## 9.6 Quality assurance

The continued effectiveness of any radiation programme relies on the individuals in charge of implementing its various components including the adoption of an effective quality assurance (QA) programme based on ISO 28218, ISO 20553[1], ISO 27048[2] and ISO/IEC 17025[27]. A quality assurance programme includes quality control measures. Such measures evaluate the quality of the specific evaluation or assessment including the use of tools and procedures against established requirements. QA requirements may be determined by national regulations.

# 10 Recording

## 10.1 Recording in vivo measurement results

The results obtained by the service laboratory shall be recorded and shall include the following items as a minimum:

a) subject identification;

b) date and time of measurement;

c) identification of the radionuclides detected;

d) identification of specific measurement procedures and equipment;

e) quantification of the amount of each radionuclide measured at the wound site and other body areas if obtained;

f) estimates of counting uncertainty and the total propagated uncertainty (depending on the client's requirements);

g) values of decision threshold and detection limit;

h) value of the customer-specified or service laboratory action level for prompt notification;

i) identification of the individual responsible for the report.

The service laboratory shall retain, in a retrievable form, records required by ISO 28218. These records shall be retained for a period specified by national regulations.

## 10.2 Recording in vitro radiobioassay and treatment waste results

Results obtained by the service laboratory shall be recorded and shall include the following items as a minimum:

a) sample identification:

   1) subject identification;

   2) assigned sample number;

   3) total volume or mass of sample submitted;

   4) reference date(s) and start and stop times of sample collection and analysis;

   5) identification of any specified radionuclides and other detected radionuclides;

   6) sample type;

   7) sample preservation;

   8) date of sample receipt by service laboratory;

   9) condition of package;

b) quantification of sample activity at the time of measurement, taking account of appropriate blanks and correction factors (e.g. analysis of creatinine);

c) estimates of counting uncertainty and the total propagated uncertainty (depending on the client's requirements);

d) identification of specific procedures for concentrating and extracting analytes;

e) percent or fraction of recovery of added radiotracer or carrier;

f) identification of equipment and specific measurement procedures;

g) values of the decision level and detection limit;

h) identification of the individual responsible for the report.

The service laboratory shall retain, in a retrievable form, records required by ISO 28218. These records shall be retained for a period specified by national regulations.

## 11 Documentation of the dose assessment

Sufficient records shall be kept of the details of all assessments so that the exact conditions of assessment may be reproduced in the future. All reports and records shall be authenticated by responsible entity. Record keeping shall be performed in accordance with national requirements.

Each assessment shall have:

a) a unique identification of dose assessment for each person and for each event;

b) information concerning the type of wound as detailed in 7.3.2;

c) information concerning the type of radioactive contaminant as detailed in 7.3.3. If none is available, the assumptions used;

d) identification of specified radionuclides and other detected radionuclides;

e) date and time of the measurements;

f) quantities measured;

g) the procedure for calculating doses including assumptions made including biokinetic models used, the type of wound, contaminant, temporal pattern of intake, and impact of treatment on assessment;

h) the method of local and systemic dose calculation; whether manually or with a software package;

i) results expressed in terms of equivalent dose to tissue at the wound site and/or equivalent dose to skin target cells. All doses shall be given in units of millisieverts to one decimal place precision;

j) the committed effective dose with the commitment period ($\tau$) being 50 years from intakes of each radionuclide. All doses shall be given in units of millisieverts to one decimal place precision.

## 12 Reporting

Arrangements shall be made to ensure that the results of all assessments are reported to the person's employer and to the client's dose record-keeping service accurately and in reasonable time. Uncertainties should be reported only if explicitly requested by the customer.

# Annex A
(informative)

# Schematic representation of NCRP wound model, default parameters for retention equations and default transfer rates for the wound model for the various categories of radionuclides in wounds (adapted from NCRP report 156 (2007)[3])

## A.1 NCRP wound model

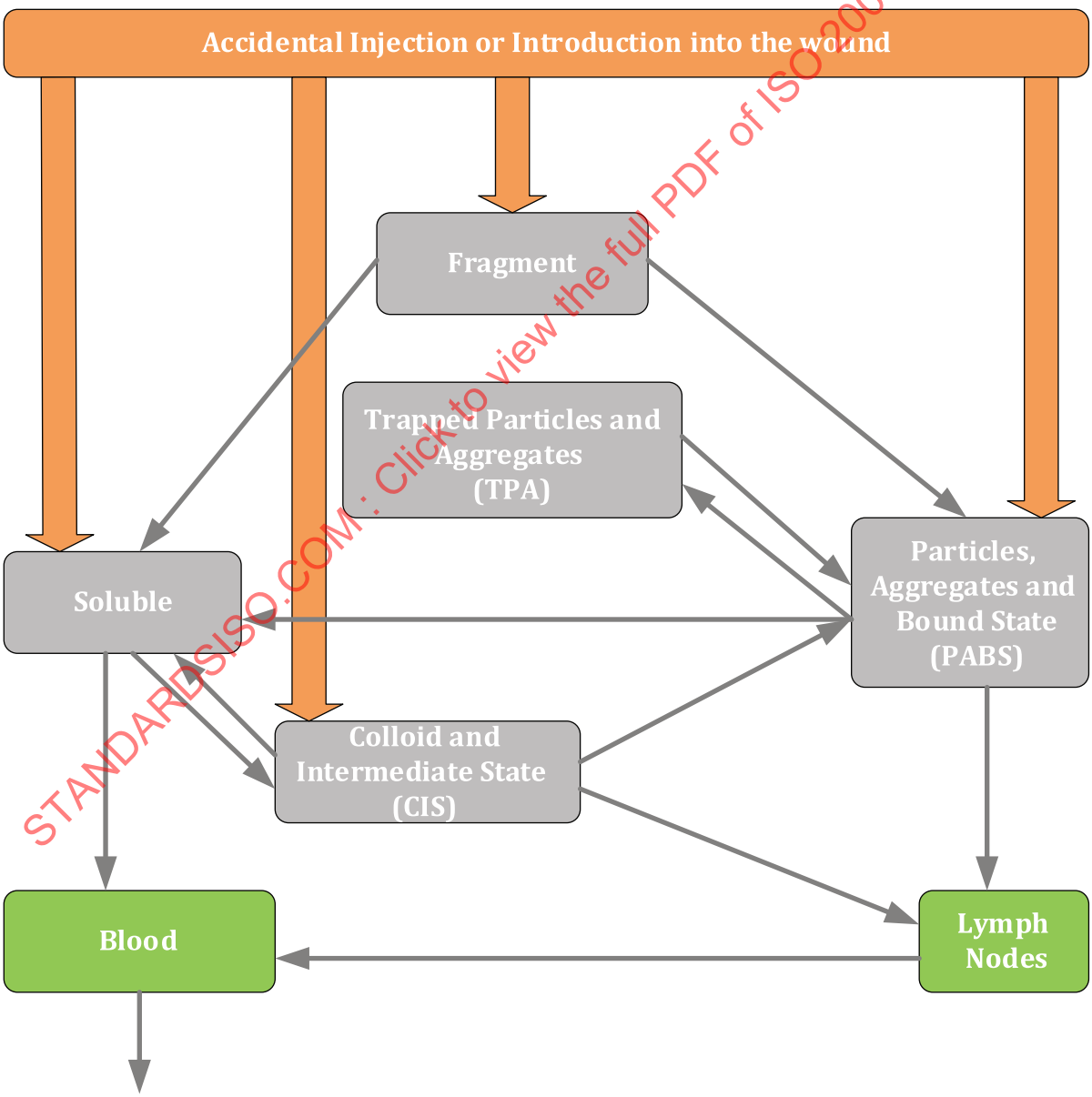





**Figure A.1 — Schematic representation of NCRP wound model[1)]**

1) Adapted from NCRP report 156 with permission of the National Council on Radiation Protection and Measurements, http://NCRPonline.org.

## A.2 Default parameters for retention equations

**Table A.1 — Default parameters for equations describing the retention of various categories of radionuclides in wounds[1)]**

| Wound retention equation parameters[a] | Retention categories of wound contaminant | | | | | | |
|---|---|---|---|---|---|---|---|
| | Radionuclides initially in solution | | | | Radionuclides initially sparingly soluble or insoluble in water | | |
| | Weak | Moderate | Strong | Avid | Colloid | Particle | Fragment |
| $A_1$ (%) | 55 | 55 | 50 | 19 | 15 | 5 | 0,5 |
| $\lambda_1$ ($d^{-1}$) | 55 | 55 | 1,0 | 37 | 3,0 | 0,05 | 0,009 |
| $A_2$ (%) | 40 | 35 | 30 | 81 | 8 | 95 | 99,5 |
| $\lambda_2$ ($d^{-1}$) | 6,0 | 0,5 | 0,03 | 0,001 | 0,055 | $4 \times 10^{-4}$ | $6,5 \times 10^{-6}$ |
| $A_3$ (%) | 5,0 | 10 | 20 | — | 77 | — | — |
| $\lambda_3$ ($d^{-1}$) | 0,1 | 0,02 | 0,001 | — | $7 \times 10^{-4}$ | — | — |

[a] Wound retention equations are expressed as sum of exponentials,

$$R(t)=\sum_i A_i e^{-\lambda_i t}$$

where

$R(t)$ is percent of injected or introduced amount of radionuclides retained at the wound site,

$A_i$ is the partition coefficient (*i.e.*, the percent of the deposited amount retained for retention component $i$),

$\lambda_i$ is the retention rate constant for retention component $i$, and

$t$ is days after injection or introduction.

## A.3 Default transfer rates

**Table A.2 — Default transfer rates for the wound model for the various categories of radionuclides in wounds[2)]**

| Type of transfer | Transfer rate $d^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Radionuclides initially in solution | | | | | Radionuclides initially sparingly soluble or insoluble in water[a] | | |
| | Weak | Moderate | Strong | Avid | | Colloid | Particle | Fragment |
| **Soluble to blood** | 45 | 45 | 0,67 | 7,0 | | 0,5 | 100 | — |
| **Soluble to CIS** | 20 | 30 | 0,6 | 30 | | 2,5 | — | — |
| **CIS to soluble** | 2,8 | 0,4 | $2,4 \times 10^{-2}$ | 0,03 | | $2,5 \times 10^{-2}$ | — | — |
| **CIS to PABS** | 0,25 | $6,5 \times 10^{-2}$ | $1,0 \times 10^{-2}$ | 10 | | $5 \times 10^{-2}$ | — | — |
| **CIS to lymph nodes** | $2 \times 10^{-5}$ | $2 \times 10^{-5}$ | $2 \times 10^{-5}$ | $2 \times 10^{-5}$ | | $2 \times 10^{-3}$ | — | — |
| **PABS to soluble** | $8 \times 10^{-2}$ | $2 \times 10^{-2}$ | $1,2 \times 10^{-3}$ | 0,005 | | $1,5 \times 10^{-3}$ | $2 \times 10^{-4}$ | 0,0 |
| **PABS to lymph nodes** | $2 \times 10^{-5}$ | $2 \times 10^{-5}$ | $2 \times 10^{-5}$ | $2 \times 10^{-5}$ | | $4 \times 10^{-4}$ | $3,6 \times 10^{-3}$ | 0,004 |
| **PABS to TPA** | — | — | — | — | | — | $4 \times 10^{-2}$ | 0,7 |
| **TPA to PABS** | — | — | — | — | | — | $3,6 \times 10^{-3}$ | $5 \times 10^{-4}$ |
| **Lymph nodes to blood** | — | — | — | — | | $3 \times 10^{-2}$ | $6 \times 10^{-4}$ | $3 \times 10^{-2}$ |
| **Fragment to soluble** | — | — | — | — | | — | — | 0,0 |

[a] Radionuclides are injected or introduced directly in the compartment corresponding to their retention category.

2) Adapted from NCRP report 156 with permission of the National Council on Radiation Protection and Measurements, http://NCRPonline.org.

**Table A.2** *(continued)*

| Type of transfer | Transfer rate $d^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Radionuclides initially in solution | | | | | Radionuclides initially sparingly soluble or insoluble in water[a] | | |
| | Weak | Moderate | Strong | Avid | | Colloid | Particle | Fragment |
| **Fragment to PABS** | — | — | — | — | | — | — | $8 \times 10^{-3}$ |
| [a] Radionuclides are injected or introduced directly in the compartment corresponding to their retention category. | | | | | | | | |

# Annex B
(informative)

# Types of wounds and their specific retention of radionuclides

## B.1 Types of wounds and their specific retention of radionuclides

**Table B.1 — Types of wounds and their specific retention of radionuclides**

| Type of contaminated wound | Brief definition | Information to collect if available to characterise the wound | Category of wound radioactive contaminant | Retention of radionuclides[a] |
|---|---|---|---|---|
| Puncture wound | An injury that is caused by a pointed object that pierces or penetrates the skin. It includes subcutaneous and intramuscular injections | Presence of bleeding, localisation, depth and diameter of the puncture | Soluble radionuclide, Colloids, Particles | Puncture wounding covers subcutaneous injection and intramuscular injection. Practically, it is reasonable to assume that in human wound cases radionuclide retention in contaminated muscle and subcutaneous tissue are similar. For deep puncture wounds, the amounts and residence times at the wound site of the radioactive contaminant increase with increasing positive charge on the ion and its tendencies to hydrolyse and/or bind to protein. Soluble radionuclide absorption is slower after subcutaneous injection than after intramuscular injection |
| Lacerated skin or abraded skin | A wound produced by the tearing, rubbing or scraping the skin, as distinguished from a cut or incision. External lacerations or abrasions may be small or large and may be caused in many ways, such as a blow from a blunt instrument, a fall against a rough surface, or an accident with machinery | Presence of bleeding, localisation, depth and surface area of the laceration/ abrasion | Soluble radionuclide | The amounts of the individual radionuclides absorbed from an undisturbed skin abrasion are nearly the same as from a laceration or from a puncture wound. Therefore, the default fractions of early radionuclide absorption from a puncture wound can reasonably be applied to the case of contaminated abraded skin and to contaminated lacerations. Nevertheless, the influence of depth and surface area on wounds resulting from abrasion or laceration shall not be omitted. The early absorption (in 24 h) of radionuclides from an untreated skin laceration or skin abrasion can be approximated as default fractions of the early absorption from a puncture wound of the same or chemically similar radionuclides, as follows: weakly retained, 1,0; moderately retained, 0,5; strongly retained, 0,2; avidly retained, 0,05. If the concentration of the radionuclide plus carrier in the contaminating solution is greater than (10 to 100) $\mu mol \cdot l^{-1}$ solutions, it is expected that for multivalent cationic radionuclides, the fractional absorption is less than the default fractions given above |
| Thermally-burned skin | A burn resulting from contact with fire, hot objects, or fluids | Localisation, grade and surface area of the burn | Soluble radionuclide | In the case of a contamination immediately after infliction of Grade I to III thermal burns, the absorption of the radioactive contaminant is not significantly different from that through intact skin. The absorption of the radionuclide can increased in the case of disruption of the skin barrier |
| Chemical-burned skin | A burn due to a caustic chemical, usually acid or alkali | Type and concentration of the chemical that induced the burn, localisation, grade and surface area of the burn | Soluble radionuclide | Biokinetics of a given physicochemical form of radionuclide incorporated through contaminated chemical-burned skin depends largely on the physiological evolution of the considered wound. Each type of chemical burn, with its corresponding biokinetic of radionuclide species, is a particular case. The absorption of the radionuclide through chemical-burned skin largely depends on the type and concentration of the caustic chemical at the origin of this kind of wound. The absorption of the radioactive contaminant can vary from baseline level below or equivalent to what is observed for intact skin to higher levels |

[a] Data concerning retention of radionuclides at the wound site were collected from literature [3][17][18][19][20][21][22].

**Table B.1** *(continued)*

| Type of contaminated wound | Brief definition | Information to collect if available to characterise the wound | Category of wound radioactive contaminant | Retention of radionuclides[a] |
|---|---|---|---|---|
| Deep wound (excluding intravenous injection and puncture wound) | A wound produced by breaking or tearing the skin and affecting the subcutaneous and/or muscular tissues (e.g. A wound produced by a shrapnel containing depleted uranium.) | Presence of bleeding, localisation and depth | Particles and fragments | In the case of deep wound contaminated with solid radioactive material, beyond dissolution of radioactive particles or fragments, account has also to be taken of the biological processes of transport of some phagocytized oxide particles to local lymph nodes and eventual isolation or entrapment of the residual metal fragments and shed particles within fibrous capsules at the wound site. *In vivo* experimental data show that less than 1 % of the implanted solid actinide is translocated to the tissues at a moderate initial rate (half-time ≈60 d on average) and then actinide absorption dramatically slow down one year after implantation (half-time ≈800 d on average) |

[a] Data concerning retention of radionuclides at the wound site were collected from literature [3][17][18][19][20][21][22].

# Annex C
(informative)

# Example of a summary sheet that should follow the contaminated worker during his initial care

**Radiation Protection Department**

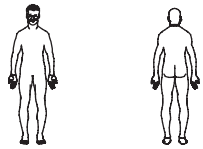
PATIENT
NAME: Surname:
Date of birth:
Department or company:

EVENT LOCATION
BUILDING: ROOM:
Date: Time:

TYPE OF EVENT
❑ BODY CONTAMINATION
Initial measurement (Bq):
❑ RISK OF INHALATION (OR INGESTION):
Assessment of the level of exposure (Bq or Bq.m$^3$):
Duration of the exposure:
❑ WOUND ❑ with contamination
❑ without detectable contamination
Measurement of contaminated object
direct measurement (Bq):
wipe-test sample measurement (Bq):
❑ CLOSED TRAUMA

RADIONUCLIDE:
PHYSICOCHEMICAL FORM:

LOCAL MEASUREMENT OF RESIDUAL CONTAMINATION (Bq)
(show with an arrow or with a hatched area)



TYPE OF CONTAMINATION: ❑ α ❑ β/γ ❑ $^{125}$I ❑ $^{3}$H
Measurement device: Radiation probe:

IMMEDIATE ACTIONS:
❑ Soap Washing ❑ DTPA Washing ❑ NASAL swab ❑ Other:

COMMENTARY:

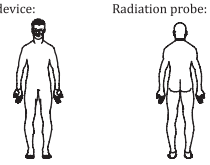
**Name of the Radiation Protection Officer:**

**Date and Signature:**

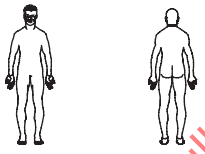
**Medical Department**

Date and time of arrival:

MEASUREMENT OF RESIDUAL CONTAMINATION AT THE ARRIVAL (Bq)
Measurement device: Radiation probe:



MEASUREMENT OF RESIDUAL CONTAMINATION AT THE LEAVING (Bq)
Measurement device: Radiation probe:



| TREATMENTS | | REQUESTED SAMPLES | |
|---|---|---|---|
| External decontamination | ❑ | Nasal swab | ❑ |
| Inhalation of DTPA | ❑ | Urines | ❑ |
| Injection of DTPA | ❑ | Faeces | ❑ |
| DTPA washing | ❑ | Other | ❑ |
| Other | ❑ | | |

REQUESTED IN VIVO COUNTING

| | |
|---|---|
| Whole body | ❑ |
| Thyroid | ❑ |
| Lungs | ❑ |
| Local (X rays) | ❑ |
| Local (Y rays) | ❑ |

COMMENTARY (including information about the wound):

**Name of the Nurse:**

**Date and Signature:**

**Name of the Physician:**

**Date and Signature:**

**Internal Dosimetry Department**

TYPE OF *IN VIVO COUNTING* RADIONUCLIDE/MEASURED ACTIVITY
Whole body counting:

Local counting
(Specify the location or organ counted):

NASAL SWABS

| Emitter | Radiation Protection Department | Medical Department |
|---|---|---|
| α | Energy (keV): | Energy (keV): |
| | Activity (Bq): | Activity (Bq): |
| β | Energy (keV): | Energy (keV): |
| | Activity (Bq): | Activity (Bq): |

COMMENTARY:

**Name of the Internal Dosimetry Department Director:**

**Date and Signature:**

**Figure C.1 — Initial care summary sheet**

# Annex D
(informative)

# Overview of typical methods used for in vitro bioassay measurements

## D.1 In vitro bioassay measurements

In general, the sample matrix has to be removed to avoid significant self-absorption if alpha or beta radiation is measured or to improve detection geometry. In addition, radionuclides that have spectral overlaps with the analyte shall be removed. Typical separation/purification methods include coprecipitation, liquid-liquid extraction, ion exchange chromatography and extraction chromatography. Counting samples for alpha spectrometry are prepared by electrodeposition or microprecipitation.

For radionuclides with long half-lives, ICP-MS can be an alternative to radiometric methods and is much more sensitive for very long-lived nuclides like $^{232}$Th or $^{238}$U or $^{239/240}$Pu.

Table D.1 gives an overview of typical methods used for in vitro bioassay measurements.

**Table D.1 — Overview of typical methods used for in vitro bioassay measurements**

| Type of emission | Sample preparation | Detection method | Examples |
|---|---|---|---|
| Alpha | Radiochemical separation of the sample matrix and from other alpha emitters (if necessary) | Alpha spectrometry with Si detectors | $^{238/239/240}$Pu, $^{241}$Am, $^{210}$Po |
| Beta | Radiochemical separation of the sample matrix and from other beta emitters (if necessary) | Liquid scintillation counting/spectrometry proportional counting | $^{89/90}$Sr, $^{32}$P, $^{55}$Fe |
| Beta (high energy) | Radiochemical separation (if necessary) of the sample matrix and from other high energy beta emitters | Cerenkov counting | $^{89}$Sr, $^{90}$Y, $^{32}$P |
| Beta | None | Liquid scintillation counting/spectrometry | $^{3}$H, $^{14}$C |
| Gamma | None | High or medium resolution gamma ray spectrometry | $^{137}$Cs |
| Nuclides with long half lives | Radiochemical separation of interfering isobars and sample matrix (if necessary) | ICP-MS | $^{232}$Th, $^{238}$U, $^{239/240}$Pu |

# Annex E
(informative)

# Equivalent dose rate in a contaminated wound ($mSv \cdot h^{-1} \cdot kBq^{-1}$) and equivalent dose rate received by the skin ($mSv \cdot h^{-1} \cdot kBq^{-1} \cdot cm^2$) for selected radionuclides

**Table E.1 — Equivalent dose rate in a contaminated wound**

| Radionuclides | Equivalent dose rate in a contaminated wound[a] ($mSv \cdot h^{-1} \cdot kBq^{-1}$) | Equivalent dose rate received by the skin[b] ($mSv \cdot h^{-1} \cdot kBq^{-1} \cdot cm^2$) | | Equivalent dose rate received by the skin[c] ($mSv \cdot h^{-1} \cdot kBq^{-1} \cdot cm^2$) |
|---|---|---|---|---|
| | Deep point source contamination | Surface contamination[d] | Deep contamination | Surface contamination[d] |
| $^{3}H$ | $6,3 \times 10^{-3}$ | 0 | $1,3 \times 10^{-3}$ | |
| $^{14}C$ | $5,4 \times 10^{-2}$ | $3,2 \times 10^{-1}$ | 1,8 | $3,05 \times 10^{-1}$ |
| $^{22}Na$ | | 1,7 | 3,2 | 1,870 |
| $^{32}P$ | $7,7 \times 10^{-1}$ | 1,9 | 4,2 | 2,397 |
| $^{35}S$ | | $3,5 \times 10^{-1}$ | 1,7 | $3,32 \times 10^{-1}$ |
| $^{36}Cl$ | | 1,8 | 3,2 | 2,178 |
| $^{45}Ca$ | | $8,5 \times 10^{-1}$ | 2,2 | $8,84 \times 10^{-1}$ |
| $^{51}Cr$ | $4,8 \times 10^{-3}$ | $1,5 \times 10^{-2}$ | $2,7 \times 10^{-2}$ | |
| $^{54}Mn$ | $1,6 \times 10^{-2}$ | $6,2 \times 10^{-2}$ | $8,1 \times 10^{-2}$ | |
| $^{57}Co$ | $1,4 \times 10^{-2}$ | $1,2 \times 10^{-1}$ | $1,9 \times 10^{-1}$ | $7,8 \times 10^{-2}$ |
| $^{58}Co$ | $5,0 \times 10^{-2}$ | $3,1 \times 10^{-1}$ | $5,6 \times 10^{-1}$ | |
| $^{60}Co$ | $1,5 \times 10^{-1}$ | $7,8 \times 10^{-1}$ | 3,2 | 1,146 |
| $^{59}Fe$ | | $9,6 \times 10^{-1}$ | 3,3 | 1,283 |
| $^{63}Ni$ | | $6,5 \times 10^{-7}$ | $4,5 \times 10^{-1}$ | |
| $^{67}Ga$ | | $3,4 \times 10^{-1}$ | 1,1 | $3,24 \times 10^{-1}$ |
| $^{90}Sr$-$^{90}Y$[e] | 1,2 | 3,6 | 7,9 | 4,272 |
| $^{95}Zr$-$^{95}Nb$[e] | $2,0 \times 10^{-1}$ | 1,6 | 4,3 | |
| $^{99m}Tc$ | $1,5 \times 10^{-2}$ | $2,5 \times 10^{-1}$ | $4,0 \times 10^{-1}$ | $2,43 \times 10^{-1}$ |
| $^{106}Ru$-$^{106}Nb$[e] | 1,6 | 2,2 | 6,5 | |
| $^{110m}Ag$ | $1,2 \times 10^{-1}$ | $6,7 \times 10^{-1}$ | 1,9 | |
| $^{111}In$ | | $3,8 \times 10^{-1}$ | $6,7 \times 10^{-1}$ | $3,76 \times 10^{-1}$ |
| $^{123}I$ | | $3,7 \times 10^{-1}$ | $6,8 \times 10^{-1}$ | $3,65 \times 10^{-1}$ |
| $^{125}I$ | $1,6 \times 10^{-2}$ | $2,1 \times 10^{-2}$ | $3,5 \times 10^{-1}$ | $4,17 \times 10^{-1}$ |

[a] Equivalent dose rate to a 10 mm diameter sphere of tissue-equivalent medium surrounding a point source[23].

[b] Equivalent dose rate to skin target cells located at a depth of 70 µm below the skin surface[24]. Data presented in IAEA publication No. IAEA-TECDOC-869[15] are taken from Chaptinel et al. report (1988)[24].

[c] Data collected from NCRP report No. 111 (1991)[25].

[d] Some contaminated wounds primarily affect the upper layers of the skin (e.g., chemical burns or abrasions). In this case, contamination may be assumed to be due to surface contamination.

[e] Radionuclide is in secular equilibrium with its decay product.

**Table E.1** *(continued)*

| Radionuclides | Equivalent dose rate in a contaminated wound[a] ($mSv \cdot h^{-1} \cdot kBq^{-1}$) | Equivalent dose rate received by the skin[b] ($mSv \cdot h^{-1} \cdot kBq^{-1} \cdot cm^2$) | | Equivalent dose rate received by the skin[c] ($mSv \cdot h^{-1} \cdot kBq^{-1} \cdot cm^2$) |
|---|---|---|---|---|
| | Deep point source contamination | Surface contamination[d] | Deep contamination | Surface contamination[d] |
| $^{131}I$ | $2{,}1 \times 10^{-1}$ | 1,6 | 3,1 | 1,694 |
| $^{137}Cs$-$^{137m}Ba$[e] | $2{,}8 \times 10^{-1}$ | 1,6 | 3,4 | 1,941 |
| $^{144}Ce$-$^{144m, 144}Pr$[e] | $9{,}1 \times 10^{-2}$ | 3,1 | 8,2 | |
| $^{147}Pm$ | | $6{,}0 \times 10^{-1}$ | 2,0 | $6{,}12 \times 10^{-1}$ |
| $^{192}Ir$ | | 1,9 | 3,4 | 1,592 |
| $^{201}Tl$ | $3{,}7 \times 10^{-2}$ | $2{,}8 \times 10^{-1}$ | 1,0 | $3{,}43 \times 10^{-1}$ |
| $^{204}Tl$ | | 1,6 | 3,0 | 1,803 |
| $^{235}U$ | $8{,}4 \times 10^{1}$ | $1{,}8 \times 10^{-1}$ | $3{,}0 \times 10^{3}$ | |
| $^{238}U$ | $9{,}2 \times 10^{1}$ | $2{,}3 \times 10^{-3}$ | $2{,}9 \times 10^{3}$ | |
| $^{238}Pu$ | $1{,}2 \times 10^{2}$ | $3{,}7 \times 10^{-3}$ | $3{,}4 \times 10^{3}$ | |
| $^{239}Pu$ | $1{,}1 \times 10^{2}$ | $1{,}4 \times 10^{-3}$ | $3{,}2 \times 10^{3}$ | |
| $^{241}Pu$ | $5{,}7 \times 10^{-3}$ | $1{,}3 \times 10^{-5}$ | $8{,}0 \times 10^{-2}$ | |
| $^{241}Am$ | $1{,}2 \times 10^{2}$ | $2{,}0 \times 10^{-2}$ | $3{,}4 \times 10^{3}$ | |

[a] Equivalent dose rate to a 10 mm diameter sphere of tissue-equivalent medium surrounding a point source[23].

[b] Equivalent dose rate to skin target cells located at a depth of 70 µm below the skin surface[24]. Data presented in IAEA publication No. IAEA-TECDOC-869[15] are taken from Chaptinel et al. report (1988)[24].

[c] Data collected from NCRP report No. 111 (1991)[25].

[d] Some contaminated wounds primarily affect the upper layers of the skin (e.g., chemical burns or abrasions). In this case, contamination may be assumed to be due to surface contamination.

[e] Radionuclide is in secular equilibrium with its decay product.