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Radiological protection — Radiological monitoring for emergency workers and population following nuclear/radiological incidents — General principles

Radioprotection — Surveillance radiologique des intervenants en situation d'urgence et de la population après des incidents nucléaires/radiologiques — Principes généraux

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Foreword

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

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.

Introduction

Nuclear accidents and major radiological events, referred to herein as nuclear or radiological incidents, can occur and may release large amounts of radioactive materials to the environment and affect large populations. Their consequences may differ across space and time and should be considered both at the emergency exposure situation and during long term recovery within the existing exposure situation. In these circumstances, screening, triage, monitoring and assessing radiation exposures for populations would be a key issue for managing the situation. More precise measurements and associated dose assessments need to be undertaken in support of, and according to, different objectives, including: identification of people potentially subject to internal/external contamination, health assessment, epidemiological follow-up, public information and reassurance and regulatory compliance. Furthermore, not only physical measurements but also biological estimation methods are useful for estimating exposures.

Radiological protection — Radiological monitoring for emergency workers and population following nuclear/radiological incidents — General principles

1 Scope

This document presents general principles for preparedness to conduct individual contamination screening, triage, monitoring and assessing radiation doses received by people exposed during and/or in the aftermath of a nuclear or major radiological incident. The document mainly focuses on the early response phase, which requires rapid actions to be undertaken for achieving the goals in support of, and according to, national or international guidelines on emergency response.

It addresses general requirements for

— members of the public, this includes adults, vulnerable populations (such as children and pregnant women) and people with special needs (such as the elderly and disabled), and

— emergency workers.

This document provides general procedures for screening, triage and monitoring these two categories of people. It deals with individual monitoring for potential external contamination, internal and external exposures and dose assessment. It also gives principles for organizing and managing a population screening centre and for registering and reporting the results of individual monitoring. This document is applicable to most exposure situations following a nuclear or major radiological incident affecting a large number of people, including:

— significant release of radioactive materials (e.g. from a facility or nuclear power plant, during transportation);

— radiological dispersal device (RDD);

— improvised nuclear device (IND);

— nuclear weapon.

Radiological incidents for which there is no release of radioactive material in the environment but only external exposures (e.g. linked to a Radiation Exposure Device (RED)) are outside the scope of this document[1)]. However, some information given by this document may be of interest for this type of event.

The aim of the document is to ensure that the appropriate parties are prepared in advance. This document advises how to obtain and collect data quickly and accurately in order to inform decision makers. It does not specify the parties or individuals who are responsible for undertaking the actions.

This document is intended to give guidance to those in charge of monitoring and assessing doses received by populations in emergency exposure situations involving a large number of people potentially subject to internal/external contamination (and subsequent radiation doses). It can also serve as guidance to regulatory bodies.

1) Incidents resulting from RED exposure are excluded from consideration in this document because they do not result in contamination that would be detected by a portal monitor or handheld device. Identification of victims with only potential external exposure are determined by means such as evaluation of clinical signs and symptoms, biodosimetry, EPR, etc.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

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

3.1
activity
A
quotient of –dN by dt, where dN is the change in the number of radioactive nuclei, at a particular energy state and at a given time, due to spontaneous nuclear transformations in the time interval dt

[SOURCE: ICRU 85, 6.2, October 2011, modified by changing the order of the phrases, by deleting the word "mean", by adding the word "radioactive".]

Note 1 to entry: It is expressed as $A = -dN/dt$. Activity can be calculated as $A = \lambda N$, where λ is the decay constant and N is the number of present radioactive nuclei.

Note 2 to entry: The special name for the unit of activity in the International System of Units is Becquerel (Bq), where 1 Bq = 1 s^{-1}, The use of the former unit Curie (1 Ci = 3,7 × 10^{10} Bq), is also accepted in many countries and in BIPM.

3.2
contamination
radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.3
decontamination
complete or partial removal of *contamination* (3.2) by a deliberate physical, chemical or biological process

Note 1 to entry: This definition is intended to include a wide range of processes for removing contamination from people, equipment and buildings, but to exclude the removal of radionuclides from within the human body or the removal of radionuclides by natural weathering or migration processes, which are not considered to be decontamination.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.4
committed effective dose
$E(\tau)$
quantity $E(\tau)$, defined as:

$$E(\tau) = \sum_{T} w_T . H_T(\tau)$$

where $H_T(\tau)$ is the committed equivalent dose to tissue or organ T over the integration time τ elapsed after an intake of radioactive substances and w_T is the tissue weighting factor for tissue or organ T

Note 1 to entry: Where τ is not specified, it is taken to be 50 years for intakes by adults and the time to the age of 70 years for intakes by children. That is, for intakes by children, 70 years minus the age in years, for example, 60 years for a 10-year old child.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition, modified – by adding the last sentence of definition to Note 1 to entry]

3.5
exposure pathway
route by which radiation or radionuclides can reach humans and cause exposure

Note 1 to entry: An exposure pathway may be very simple, for example the external exposure pathway from airborne radionuclides, or a more complex chain, for example the internal exposure pathway from drinking milk from cows that ate grass contaminated with deposited radionuclides.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.6
absorbed dose
D
differential quotient of $\bar{\varepsilon}$ with respect to m, where $\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter of mass, *m*:

$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}$$

Note 1 to entry: The gray is a special name for joule per kilogram, and is to be used as the coherent SI unit for absorbed dose.

[SOURCE: ISO/IEC 80000-10, 10.81.1]

3.7
equivalent dose
H_T
quantity $H_{T,R}$, defined as:

$$H_{T,R} = w_R \cdot D_{T,R}$$

where $D_{T,R}$ is the *absorbed dose* (3.6) delivered by radiation type R averaged over a tissue or organ T and w_R is the radiation weighting factor for radiation type R

Note 1 to entry: When the radiation field is composed of different radiation types with different values of w_R, the equivalent dose is:

$$H_T = \sum_R w_R \cdot D_{T,R}$$

Note 2 to entry: The SI unit for equivalent dose is joule per kilogram ($J \cdot kg^{-1}$), termed the sievert (Sv).

Note 3 to entry: Equivalent dose is a measure of the dose to a tissue or organ designed to reflect the amount of harm caused.

Note 4 to entry: Equivalent dose cannot be used to quantify higher doses or to make decisions on the need for any medical treatment relating to deterministic effects.

Note 5 to entry: Values of equivalent dose to a specified tissue or organ from any type(s) of radiation can be compared directly.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.8
effective dose
E
quantity *E*, defined as a summation of the tissue or organ *equivalent doses* (3.7), each multiplied by the appropriate tissue weighting factor:

$$E = \sum_{T} w_T \cdot H_T$$

where H_T is the equivalent dose in tissue or organ T and w_T is the tissue weighting factor for tissue or organ T. From the definition of equivalent dose, it follows that:

$$E = \sum_{T} w_T \cdot \sum_{R} w_R \cdot D_{T,R}$$

where w_R is the radiation weighting factor for radiation type R and $D_{T,R}$ is the average *absorbed dose* (3.6) in the tissue or organ T delivered by radiation type R.

Note 1 to entry: The SI unit for effective dose is joule per kilogram ($J \cdot kg^{-1}$), termed the sievert (Sv).

Note 2 to entry: Effective dose is a measure of the dose designed to reflect the amount of radiation detriment likely to result from the dose.

Note 3 to entry: Effective dose cannot be used to quantify higher doses or to make decisions on the need for any medical treatment relating to deterministic effects.

Note 4 to entry: Values of effective dose from exposure for any type(s) of radiation and any mode(s) of exposure can be compared directly.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.9
tissue reaction
deterministic effect
injury in populations of cells, characterised by a threshold dose and an increase in the severity of the reaction as the dose is increased further

Note 1 to entry: In some cases, these effects are modifiable by post irradiation procedures including biological response modifiers.

[SOURCE: ICRP Publication 123]

3.10
erythema
reddening of the skin or mucous membrane

[SOURCE: ISO 10993-10:2021, 3.6]

3.11
tachycardia
increased heart rate due to exercise, pain, anxiety or pathophysiological state

[SOURCE: ISO 16972:2020, 4.42]

3.12
intake
<process> act or process of taking radionuclides into the body by inhalation or ingestion or through the skin

Note 1 to entry: Other exposure pathways by intake are injection (e.g. in nuclear medicine) and intake via a wound, as distinguished from intake through (intact) skin.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.13
intake
<quantity> activity of a radionuclide taken into the body in a given time period or as a result of a given event

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.14
kerma
K
for uncharged ionizing radiation, the differential quotient of E_{tr} with respect to m, where E_{tr} is the mean sum of the initial kinetic energies of all the charged ionizing particles liberated in a mass m of a material:
$K = \frac{dE_{tr}}{dm}$
[SOURCE: ISO 80000-10:2019, 86.1]

Note 1 to entry: The unit is $J \cdot kg^{-1}$. The special name for the unit of kerma is gray (Gy).

[SOURCE: ISO 12749-2:2022, 3.3.16]

3.15
exposure situation
circumstances of the exposure of the individual(s) or the environment to ionizing radiation sources

[SOURCE: ISO 12749-2:2022, 3.3.20]

3.16
planned exposure situation
situation of exposure that arises from the planned operation of a source or from a planned activity that results in an exposure due to a source

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.17
event
any unintended occurrence, including operating error, equipment failure or other mishap, and deliberate action on the part of others, the consequences or potential consequences of which are not negligible from the point of view of protection and safety

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition. modified-By deleting the phrase “by the operator” and “nuclear”.]

3.18
emergency exposure situation
situation of exposure that arises as a result of an accident, a malicious act or other unexpected event, and requires prompt action in order to avoid or to reduce adverse consequences

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.19
existing exposure situation
exposure situation (3.15) which already exists when a decision on the need for control needs to be taken

Note 1 to entry: Exposure to background radiation and exposure to residual radioactive material from a nuclear or radiological emergency after the emergency exposure situation has been declared ended.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.20
reference level
level of dose, risk or activity concentration for an *emergency exposure situation* (3.18) or an *existing exposure situation* (3.19) above which it is not appropriate to plan to allow exposures to occur and below which optimization of protection and safety would continue to be implemented

Note 1 to entry: The value chosen for a reference level depends upon the prevailing circumstances for the exposure under consideration.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.21
dose assessment
assessment of the dose(s) to an individual or group of people

Note 1 to entry: For example, assessment of the dose received or committed by an individual on the basis of results from workplace monitoring or bioassay.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.22
biomarker
traceable substance indicating changes in a cell or an organ caused by environmental actions (e.g. by ionizing radiation)

[SOURCE: ICRP Publication 123]

3.23
biodosimetry
biological dosimetry
assessment of the *absorbed dose* (3.6) of ionizing radiation using indicators found in biological material, particularly peripheral blood

[SOURCE: ISO 12749-2:2022, 3.4.2]

3.24
in vitro measurement
analysis that include measurements of radioactivity present in biological samples taken from an individual

3.25
in vivo measurement
measurement of radioactivity present in the human body carried out using detectors to measure the radiation emitted

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

3.26
direct measurement
equipment for the determination of the body burden activity

3.27
screening
type of analysis aimed at eliminating from further consideration factors that are less significant for protection or safety, in order to concentrate on the more significant factors

3.28
monitoring
measurement of dose, dose rate or activity for reasons relating to the assessment or control of exposure to radiation or exposure due to radioactive substances, and the interpretation of the results

Note 1 to entry: Monitoring may be subdivided in two different ways: 1) according to where the measurements are made, into *individual monitoring* (3.30), workplace monitoring, source monitoring and environmental monitoring, and, 2) according to the purpose of the monitoring, into routine monitoring, task related monitoring and special monitoring.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.29
ambient dose equivalent
$H^*(d)$
dose equivalent that would be produced by the corresponding aligned and expanded field in the ICRU sphere at a depth d on the radius vector opposing the direction of the aligned field

Note 1 to entry: The recommended value of d for strongly penetrating radiation is 10 mm.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.30
individual monitoring
personal monitoring
monitoring (3.28) using measurements by equipment worn by individuals, or measurements of quantities of radioactive substances in or on, or taken into, the bodies of individuals, or measurements of quantities of radioactive substances excreted from the body by individuals

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.31
personal dose equivalent
$H_p(d)$
dose equivalent in soft tissue below a specified point on the body at an appropriate depth d

Note 1 to entry: Quantity used as a directly measurable proxy (i.e. substitute) for equivalent dose in tissues or organs or (with d = 10 mm) for effective dose, in *individual monitoring* (3.30) of external exposure.

Note 2 to entry: The recommended values of d are 10 mm for strongly penetrating radiation and 0,07 mm for weakly penetrating radiation.

Note 3 to entry: $H_p(0,07)$ is used for monitoring for hands and feet for all radiation types.

Note 4 to entry: $H_p(3)$ is used for monitoring exposure of the lens of the eye.

Note 5 to entry: 'Soft tissue' is commonly interpreted as the ICRU sphere.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.32
quality assurance
planned and systematic actions necessary to provide adequate confidence that a process, measurement, or service satisfy given requirements for quality such as those specified in a license

3.33
personal protective equipment
PPE
equipment including clothing or other special equipment that is issued to individual workers to provide protection against actual or potential exposure to radioactive contaminants and ionizing radiations

Note 1 to entry: Includes partial or full-face respirators, face masks, gloves, safety glasses, boots, whole body anti-contamination coveralls, and self-contained breathing apparatus (SCBA), leaded overall, depending on conditions.

3.34
source term
amount and isotopic composition of radioactive material released (or postulated to be released)

Note 1 to entry: Used in modelling releases of radionuclides to the environment, in particular in the context of accidents at nuclear installations.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition, modified-By deleting "from a facility" from the definition and "or releases from radioactive waste in repositories" from Note 1 to entry.]

3.35
incident
any unintended event, including operating errors, equipment failures, initiating events, accident, precursors, near misses or other mishaps, or unauthorized act, malicious or non-malicious, the consequences or potential consequences of which are not negligible from the point of view of protection and safety

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.36
accident
any unintended event, including operating errors, equipment failures and other mishaps, the consequences or potential consequences of which are not negligible from the point of view of protection and safety

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.37
emergency
non-routine situation or *event* (3.17) that necessitates prompt action, primarily to mitigate a hazard or adverse consequences for human life and health, property and the environment

Note 1 to entry: This includes nuclear and radiological emergencies and conventional emergencies such as fires, release of hazardous chemicals, storms or earthquakes.

Note 2 to entry: This includes situations for which prompt action is warranted to mitigate the effects of a perceived hazard.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.38
nuclear or radiological emergency
nuclear or radiological incident *emergency* (3.37) in which there is, or is perceived to be, a hazard due to:

a) the energy resulting from a nuclear chain reaction or from the decay of the products of a chain reaction, or

b) radiation exposure

Note 1 to entry: Points (a) and (b) approximately represent nuclear or radiological emergencies (incidents), respectively. However, this is not an exact distinction.

Note 2 to entry: Radiation emergency is used in some cases when an explicit distinction in the nature of the hazard is immaterial (e.g. national radiation emergency plan), and it has essentially the same meaning.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.39
emergency preparedness
capability to take actions that will effectively mitigate the consequences of an *emergency* (3.37) for human life, health, property and the environment

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.40
precautionary action zone
PAZ
area around a facility for which *emergency* (3.37) arrangements have been made to take urgent protective actions in the event of a *nuclear or radiological emergency* (3.38) to avoid or to minimize severe deterministic effects off the site

Note 1 to entry: Protective actions within this area are taken before or shortly after a release of radioactive material or an exposure, on the basis of prevailing conditions at the facility.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.41
urgent protective action planning zone
UPZ
area around a facility for which arrangements have been made to take urgent protective actions in the event of a *nuclear or radiological emergency* (3.38) to avert doses off the site in accordance with international safety standards

Note 1 to entry: Protective actions within this area are to be taken on the basis of environmental monitoring or, as appropriate, prevailing conditions at the facility.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition, modified – by adding Note 1 to entry.]

3.42
emergency response
performance of actions to mitigate the consequences of an *emergency* (3.37) for human life, health, property and the environment

Note 1 to entry: The emergency response also provides a basis for the resumption of normal social and economic activity.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition]

3.43
emergency worker
person having specified duties as a worker in response to an *emergency* (3.37)

Note 1 to entry: Emergency workers may include workers employed, both directly and indirectly, by registrants and licensees, personnel of response organizations, such as police officers, firefighters, medical personnel, and drivers and crews of vehicles used for evacuation, as well as volunteers.

Note 2 to entry: Emergency workers may or may not be designated as such in advance of an emergency. Emergency workers not designated as such in advance of an emergency are not necessarily workers prior to the emergency, such as volunteers who willingly and voluntarily helps in the response to a nuclear or radiological emergency.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition, modified – by adding ", as well as volunteers." to the end of Note 1 to entry and ", such as volunteers who willingly and voluntarily helps in the response to a nuclear or radiological emergency." to the end of Note 2 to entry.]

3.44
first responder
first members of an emergency service to respond at the site of an *emergency* (3.37)

Note 1 to entry: These may include police, firefighters and rescue brigades, ambulance services, and control teams for hazardous materials.

[SOURCE: IAEA. IAEA Safety Glossary Terminology used in Nuclear Safety and Radiation Protection – 2018 Edition, modified – by adding Note 1 to entry.]

3.45
improvised nuclear device
IND
device incorporating radioactive materials designed to result in the formation of a nuclear-yield reaction

Note 1 to entry: Such devices may be fabricated in a completely improvised manner or may be an improvised modification to a nuclear weapon.

[SOURCE: IAEA. IAEA Nuclear Security Glossary, August 2020]

3.46
radiological dispersal device
RDD
device to spread radioactive material using conventional explosives or other means, thereby exposing people and the environment to radiation

[SOURCE: IAEA. IAEA Nuclear Security Glossary, August 2020, modified- By adding the phrase ", thereby exposing people and the environment to radiation".]

3.47
radiation exposure device
RED
device with radioactive material designed to intentionally expose members of the public to radiation

[SOURCE: IAEA. IAEA Nuclear Security Glossary, August 2020]

3.48
nuclear weapon
state-sponsored, designed, engineered, and tested weapon, tens to hundreds of times more powerful than INDs

4 Symbols and abbreviated terms

4.1 Symbols

A	activity (Bq)
$\langle A \rangle$	measured activities (Bq)
$E(\tau)$	committed effective dose received within τ years after an intake (Sv)
$e(\tau)$	coefficient of the committed effective dose received within τ years after an intake ($Sv \cdot Bq^{-1}$)
$H_T(\tau)$	committed equivalent dose to tissue/organ T received within τ years after an intake (Sv)

$h_T(\tau)$ coefficient of the committed equivalent dose to organ/region T received within τ years after an intake ($Sv \cdot Bq^{-1}$)

I estimated value of a radionuclide intake (Bq)

M measured quantity (Bq)

$m(t)$ bioassay function at a time t after intake ($Bq \cdot Bq^{-1}$)

Q quality of the adjustment for a given mesh vertex

r_T target region

4.2 Abbreviated terms

AMAD activity median aerodynamic diameter

AP antero-posterior

CDC U.S. Centers for Disease Control and Prevention

PSC population screening centre

DTPA diethylenetriaminepentaacetic acid

EPA U.S. Environmental Protection Agency

EPR electron paramagnetic resonance

ESR electron spin resonance

FISH fluorescence in situ hybridization

GM Geiger-Mueller

IAEA International Atomic Energy Agency

ICRP International Commission on Radiological Protection

ICRU International Commission on Radiation Units and Measurements

IND improvised nuclear device

NaI sodium iodide

NCRP National Council on Radiation Protection and Measurements

OSLD optically-stimulated luminescence dosimeter

PAZ precautionary action zone

PPE personal protective equipment

RBE relative biological effectiveness

RED radiological exposure device

RDD radiological dispersal device

ROT rotational

RPLD radio photo-luminescence dosimeter

TLD thermo-luminescence dosimeter

UPZ urgent protective action planning zone

5 Collecting Information about the incident

5.1 General

In order to assist with the identification of individuals that need attention and to determine what type of monitoring, assessment, and mitigation methodologies, such as decontamination and countermeasures[2)], may be required, the responsible authority shall have in place a system for recording the following types of information:

— type of radiation incident;

— source term;

— weather conditions and modelling results;

— timing (duration) and magnitude of release;

— potential exposure pathways;

— affected populations and demographic information.

Each is described in detail.

5.2 Description of the incident

In order to understand the potential radionuclides present, the extent of dispersal and the emergency response actions that may be performed, provision shall be made to record the type of nuclear incident responsible for the emergency.

The types of nuclear or radiological incidents can be grouped into the following categories:

— accidental release of radioactive materials (e.g. from a facility, transportation or nuclear power plant);

— radiological dispersal device (RDD);

— improvised nuclear device (IND);

— strategic nuclear weapon;

— nuclear weapon;

— radiation exposure device (RED).

Information can be obtained from response of active monitors such as continuous air monitors or radiation area monitors, video from passive security cameras or active recording of operations, behaviour of the released radioactivity, interviews of witnesses, and symptoms manifested by individuals as reported by hospitals or other emergency treatment facilities. A timeline of activities and response actions can be helpful in identification of release parameters and exposure cohorts, groups of individuals requiring similar monitoring, assessment, and treatment due to the characteristics of the exposures, as well as add to the accuracy of modelling.

2) See *Radiation Countermeasures for Treatment of Internal Radiation Contamination,* https://remm.hhs.gov/int_contamination.htm#blockingagents.

5.3 Source term identification and magnitude

The most urgent and important data to collect is the identification of the radionuclide and amount released. The first and best source of this information is from the type of radiological dispersal and, in the case of an accidental release, facility and operator from which a release or dispersion has occurred. This should be confirmed by measurement.

If this information is not available, other measurements and observations shall be made. Spectrometric measurements can be made using appropriate instrumentation to determine the radionuclide(s). Depending on the release scenario, types of samples collected could include:

— airborne particulates;

— airborne gas;

— water;

— soil;

— other materials.

Chemical and physical form are more difficult to determine and may require repetitive measurements to determine environmental migration, systemic metabolism, or other behaviour of the source material including the use of scanning electron microscopy, radiochemical methods, or other more accurate or precise measurement technique.

The magnitude of the release shall also be determined. In the case of RDDs, the simplest way of making a determination may be to identify the amount of missing mass or activity. This can be accomplished with prior knowledge either of the mass or radioactivity of the material in question followed by mass or activity measurement of the remaining material and determining the difference.

If prior knowledge of the amount of material is not available, the determination is more difficult. This likely requires an iterative process of modelling the incident with an assumed or estimated amount of radioactivity released and using environmental measurements to adjust the released radioactivity estimate upwards or downwards. Such an analysis certainly has increased uncertainty over the mass-difference methodology described above.

5.4 Weather conditions and modelling results

Soon after a release of radioactive material to the environment, it is desired to obtain an estimate for the extent of any airborne or surface contamination, both for identification of affected individuals and to begin identification of recovery activities. Various computer software codes exist in order to perform this type of analysis at varying levels of complexity and associated computer run times.

Important inputs to such codes are weather conditions including wind direction and rainfall and:

— mean wind speed at pollutant release height, $m \cdot s^{-1}$;

— emission rate, $\mu g\ s^{-1}$ or $Bq\ s^{-1}$;

— standard deviation of lateral concentration distribution;

— standard deviation of vertical concentration distribution;

— pollutant release height (stack height), m;

— crosswind distance from source to receptor, m.

Full soundings that include wind speeds and directions at different elevations can also be used.

5.5 Potential exposure pathways

When the information described is collected, potential exposure pathways may be identified. Such pathways are important for the determination of dosimetry analysis that can be used to estimate risk to exposed individuals. Common initial exposure pathways include:

— inhalation/ingestion of airborne activity from suspended release;

— inhalation/ingestion of airborne activity re-suspended from ground deposition;

— ingestion of contaminated food and drink items

— external dose from suspended release;

— external dose from ground deposition;

— skin contamination from transfer of ground or surface contamination or suspended material;

— intake via wound or absorption through intact skin (iodine and tritium).

As the incident continues, additional pathways become important, such as intake through ingestion of foodstuffs.

5.6 Affected population and demographic information

The size and demographics of the potentially affected population is used in determining the selection of the population screening centre (PSC) site (see Clause 6) and the resources needed for timely screening and decontamination. Special considerations may include:

— number of people, pets, etc. in contaminated area;

— population density;

— zoning (residential, industrial, offices);

— types of buildings (housing units, apartments, multi-level structures);

— populations with special needs (refer to 6.5);

— cultural, religious, language factors.

6 Organizing and managing a population screening centre

6.1 Selecting the site

6.1.1 General considerations

One important benefit of planning in advance for the establishment of population screening centres (sometimes referred to as Community Reception Centres) is that it reduces the potential burden on hospitals by providing a location for non-injured people to be screened for contamination. Another benefit is that it supports the operations of public and special needs shelters that host the displaced population.

The considerations listed in this subclause ensure that the population screening centre is able to meet the needs of the impacted community following a nuclear or radiological incident.

— Identify multiple locations: Planners should consider several locations for conducting population screening and decontamination, due to the uncertainties of where the incident may take place and the likelihood that any of the pre-selected sites would be inaccessible during an emergency.

— Consider collocating with other facilities: To best support shelter operations, planners should consider establishing one or more population screening centres at or near shelters hosting displaced population.

— Allow for flexibility: For large incidents, planners may establish a network of population screening centres that feeds into a larger network of ad-hoc screening locations, shelters, and hospitals, as diagrammed in Figure 1.

Recommendations for identifying and selecting facilities:

a) If possible, establish the population screening centres at locations in areas that ambient dose rate is less than predefined level.

b) Identify facilities based on the anticipated number of affected population and estimated throughput. Consider facilities that are large enough to contain all necessary functions described in this Clause.

c) If possible, select an all-weather facility designed for crowds (with environmental control to prevent temperature extremes).

d) Ensure availability of entrance and exit control.

e) Ensure facility is suitable for accommodating vulnerable populations and people with disabilities.

f) Ensure availability of facilities for decontamination, e.g. sinks/showers, or plan for alternate ways of decontaminating people such as using wet wipes.

g) Ensure adequate parking is available for people arriving in their own vehicles and larger spaces for parking buses.

h) Select locations that are easily accessible.

Examples of suitable facilities include: a covered sports arena or convention centre, schools with gymnasiums, etc. Depending on the circumstances and weather, a tent in a nearby park or large parking lot would also suffice.

NOTE It is important to establish use agreements in advance with facility or site owners and operators.

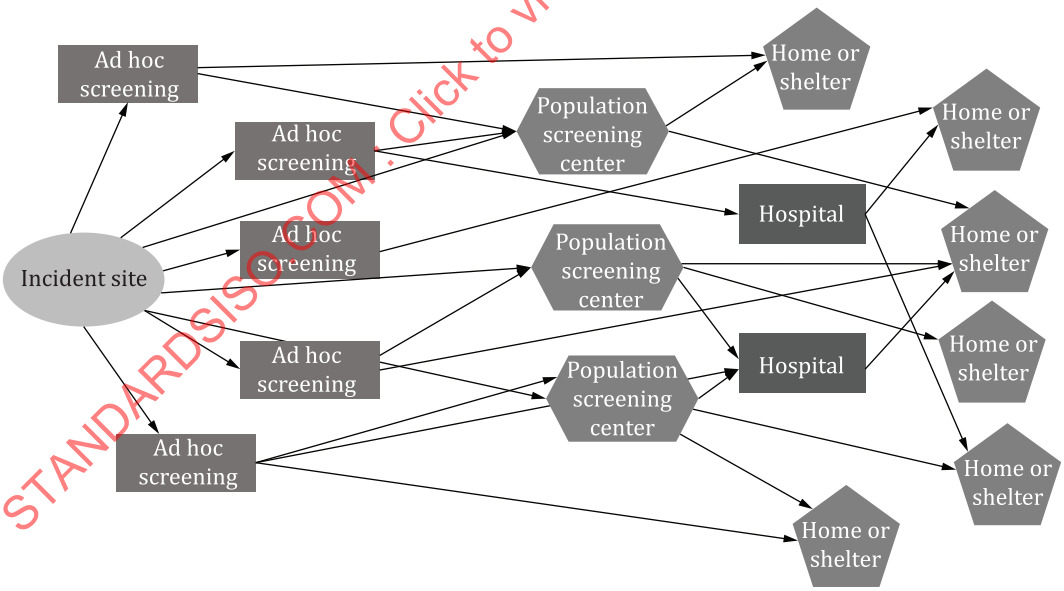


Figure 1 — Schematic of a network of population screening centres including ad hoc screening, hospitals and shelters

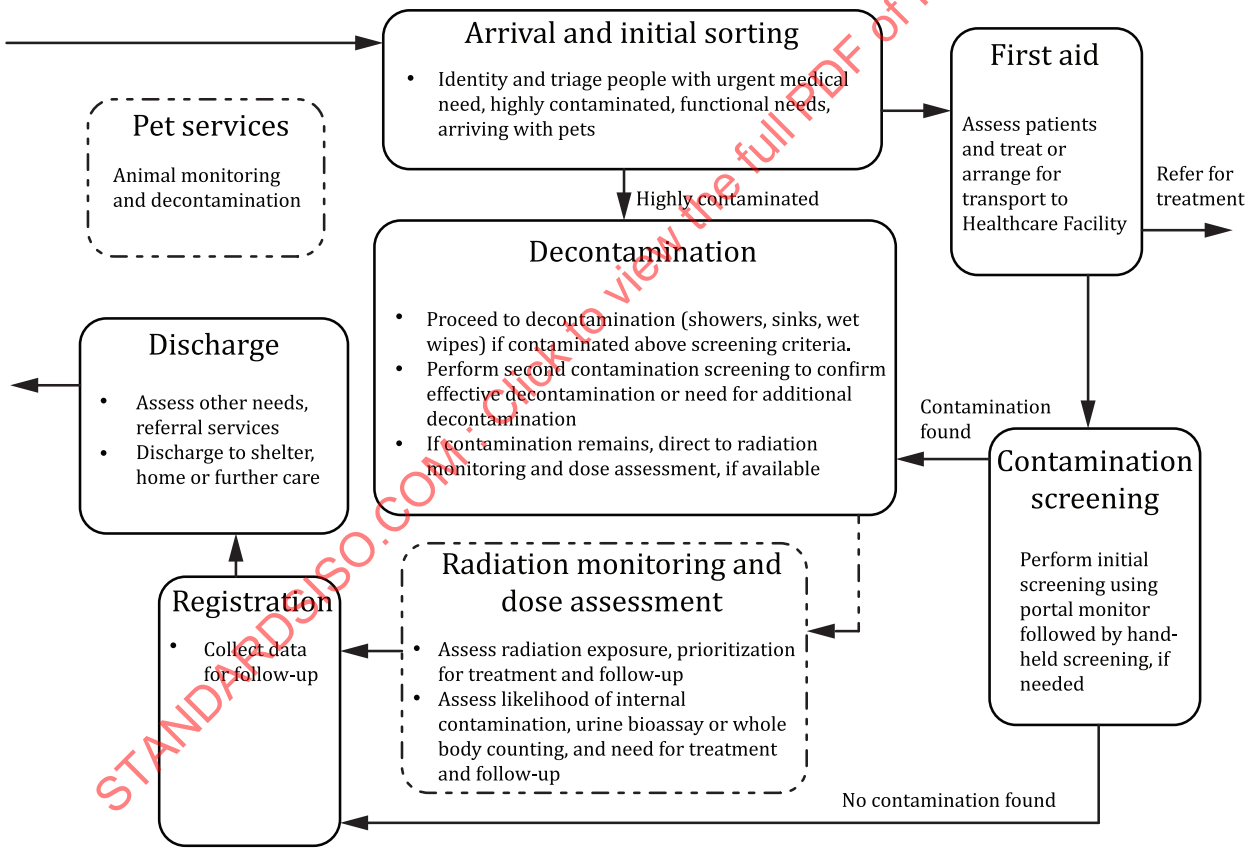
6.2 Staffing and organization

6.2.1 General

The site should have sufficient staff, both technical and non-technical, to operate the various stations and manage the screening centre for up to several days or weeks. A technical staff competent in the use of radiation detection equipment shall be available to support contamination screening. The qualified staff available to operate the facility should include personnel assigned to screen people for contamination, help with decontamination, registration, etc. At least one or more nurses or clinicians shall be readily available to assess and refer people who need medical follow-up. Additional modules may be added to collect spot urine samples for bioassay, accommodate pets, as needed. Plans should exist to bring in additional personnel and assets to allow initial staff to rotate.

A modular population screening centre is shown in Figure 2. It contains eight modules/stations, each described further in this subclause. This modular approach allows for scalability and flexibility according to the demands of the incident and the availability of resources. Additional modules may be added to accommodate pets, bioassay, or other stations, as needed.

A clear demarcation between the contamination control zone and the clean zone shall exist and these two zones should be clearly identified. Table 1 provides an example of where the various stations should be located with respect to the contamination control zone.



Key

- - - - - - optional depending on resources

Figure 2 — Example of a population screening centre modular design

NOTE The type of isotope(s) involved is determined in the field by environmental measurements and that information is available to the population screening centres (for setting up their screening equipment).

Table 1 — Locations of population screening centre stations with respect to the contamination control zone

Station	Zone
Initial sorting First aid Contamination screening Decontamination Pet services (if available)	Contamination control zone
Registration Radiation monitoring and dose assessment Discharge	Clean zone

6.2.2 Modules of a population screening centre

Example stations at the population screening centre illustrated in Figure 2 may include:

— initial sorting;

— first aid;

— contamination screening;

— decontamination;

— pet services (for pet-friendly centres);

— registration;

— radiation monitoring and dose assessment;

— discharge.

Annex A provides a brief description of each station. An example of floor plan depicting the location of the various stations is shown as Figure 3.

In addition to staffing these stations, the screening centre should include a site manager, health and safety officer, and security. It should also consider including additional staff to assist or direct people while they are going from station to station.

Additional staff may be needed to select those individuals waiting in line by questioning when arriving who may have high contamination or need special assistance such as:

— families with small children;

— unaccompanied minors;

— people who might have medical problems;

— women who might be pregnant;

— people who do not speak or understand the language spoken;

— people with cultural or religious considerations.

Provisions to have mental health professionals available, and possibly a station for providing or directing people to counselling resources should also be considered.

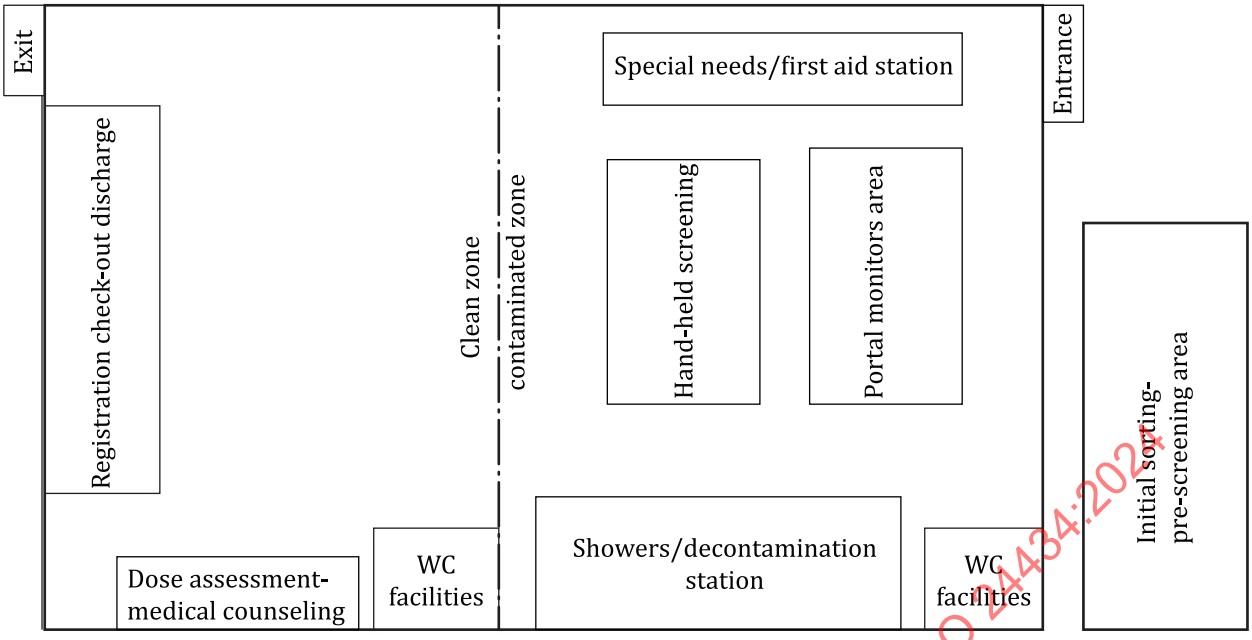


Figure 3 — Example of a population screening centre floorplan

6.3 Scalability and sustainability

The size and nature of the incident are major considerations in planning for population screening. Population screening plans should be scalable based on the timeframe (hours, days, weeks since the incident), the geographical factors (urban, rural, spread of contamination), distance from impacted area, the population affected (size, demographics), available equipment and facilities (for screening and decontamination) and the desired throughput of the screening centre (how many people to process over a given time). If a few hundred people need to be surveyed and decontaminated, emergency workers can probably provide very thorough services at the scene. However, if thousands of people are affected, screening centre operators shall have the flexibility to scale or modify operations as necessary, so that everyone is processed quickly and safely.

6.4 Practical considerations

a) Display a schematic of the *screening centre* to help people navigate the site and include easy-to-read-signs to indicate station name and direction to the next station.

b) Consider including signs and infographics, in particular as people are directed to the decontamination station (this helps people that have limited reading skills or do not speak the language).

c) Consider having translators.

d) Provide a map indicating the affected area so people can point to where they were at the time of the incident. This information is useful for pre-identifying people in higher exposure/contamination areas.

e) Consider including one or two clinicians to assist with medical questions.

f) Consider including mental health professionals.

g) Plan how the data are collected– paper forms, electronic, hybrid.

h) Consider locating population screening centre away from the affected area and near shelter location and other centres that may be assisting, such as family reunification, housing assistance, etc.

6.5 Population with special needs

6.5.1 Main considerations

Public health authorities and emergency planners should identify and prioritize populations in the community that are vulnerable or have special needs during and after a nuclear or radiological incident. These include the following:

— children, as they may be at a higher risk of being contaminated with radioactive materials, receive higher doses per unit intake compared with adults, are more sensitive to radiation health effects and may suffer more significant psychosocial impacts than adults (be cognizant of minor children without custodial adults present, e.g. school children or unaccompanied minors; families should remain together);

— pregnant and nursing mothers;

— elderly people requiring assistance;

— immunocompromised individuals;

— disabled persons requiring the use of wheelchairs or other mobility aids;

— transient or migrant workers;

— commuters;

— homeless people;

— institutionalized individuals who may or may not be able to evacuate or relocate;

— hospitalized patients;

— residents of nursing homes or other institutions;

— prison inmates, guards.

Public health authorities and emergency planners should also address the needs of emergency workers.

6.5.2 Other considerations

a) Determine any cultural or religious factors in the community that would affect the population screening process. For example, changing clothing in a public setting may present a complication for some people.

b) Identify and develop relationships with organizations that are currently assisting special populations in or near the community. They may be able to assist.

c) Ensure that communications and educational materials are available in appropriate languages and literacy level for the community. People who do not speak, as a first language, the official language in the country the incident has taken place could have great difficulty in understanding instructions when under the stress of a nuclear or radiological incident. Consider visuals, universal signage, or videos to communicate vital information.

d) Determine if the screening centre accepts pets and, if so, how they are handled. Be aware that this may affect population screening.

6.6 Services (medical and psychological, security and safety, communication, transportation)

6.6.1 Medical

Even though the main purpose of the population screening centre is to screen ambulatory uninjured people, it is likely that some people present with minor injuries or may have a need for immediate medical care while at the population screening centre. This may be the case for those waiting in line for a long time, have

underlying medical conditions, are elderly, pregnant, etc., or have high levels of anxiety. In this situation, people should be directed to the first aid station where they can have access to a health care provider to treat minor injuries and/or arrange for transporting those requiring immediate medical attention to the hospital.

Other activities that would fall under this station may include:

— examining exposed and potentially contaminated persons for signs of injuries and potential life-threatening problems. This has priority over assessing contamination and decontamination,

— stabilizing life-threatening problems,

— observing for signs of psychological distress,

— examining exposed persons for signs of acute radiation exposure (Table 6.2 of NCRP 161-I describes early effects of whole-body irradiation from external and internal sources).

Dose assessment and reporting is presented in 9.6 and Clause 10.

6.6.2 Mental health (psychosocial)

Psychosocial issues (among the affected population, as well as emergency workers and PSC staff) present significant challenges to public health and medical practitioners both during and after a radiation emergency. The psychosocial consequences of radiation emergencies are unique and serious, and in many ways can be even greater and longer lasting than the physical or economic consequences. People seeking assessment and care are likely to overwhelm public health and medical systems.

Many jurisdictions recognize that preparing to deal with psychosocial issues is critically important for efficiently managing and monitoring the affected population and engaging in other response efforts. Planners should include behavioural health and mental health specialists in emergency planning and response. Psychological first aid is a way to help reduce the initial distress caused by traumatic events. Emergency workers who interact with the public can benefit from training in psychological first aid. Emergency workers should anticipate normal stress reactions and promote the following principles of psychological first aid.

— Safety: provide repeated, simple, and accurate information on how to meet basic needs. This may be especially important for population screening centre staff wearing PPE that hinders communications (such as masks).

— Calm: speak calmly and be compassionate and friendly.

— Connectedness: keep families together.

— Self-efficacy: give practical suggestions to help empower people.

— Help: direct people to available services.

If possible, include behavioural health or mental health professionals on staff at each population screening centre. During the planning process, establish a contact list of credentialed personnel who could provide these services. Plans should also include providing counselling for staff and emergency workers. Adequate rotation of staff members to reduce physical and emotional fatigue is essential.

Public health and emergency preparedness authorities should plan to augment pre-existing behavioural health and mental health services. Such services are in demand both by people acutely affected by the nuclear or radiological incident as well as by members of the public with chronic, long-term mental health needs. The need for such services increases following a nuclear or radiological incident, whether it involves mass casualties or not.

6.6.3 Security and safety

Population screening centres shall include security and safety staff as part of their staffing plan. Security is crucial for running a smooth operation, since these centres will likely handle many people who may be waiting in line for extended periods, are likely anxious, tired, etc., and may become unruly or have malicious

intent. Depending on the size of the population screening centre, having police presence or designated security officer(s) would ensure a secure and safe operation.

Population screening should take place at a location that is free of any known hazards. The area should have no contamination (or have minimal impact from contamination), and no known airborne or respiratory hazards.

Centre's management in coordination with radiation protection professionals shall conduct an assessment to identify any potential hazards (not just radiological) and should coordinate with radiation protection professionals to issue the appropriate PPE and dosimetry to staff members in the contamination control zone. Staff should try to minimize physical contact with people, and gloves should be changed or checked frequently for contamination.

Additional considerations for screening centre roles, equipment, and communication are outlined in Annex A.

7 Screening and monitoring for potential external contamination

7.1 Purpose

Prior to the determination of internal contamination (see Clause 8), external contamination for radioactive material should be monitored and, if necessary, decontamination should be performed. External contamination can be detected using portal monitors or hand-held instruments.

The objectives of monitoring for external contamination and decontamination are given in Reference [3]:

— identify the need for external decontamination to prevent skin damage by radiation and to avoid any subsequent internal contamination by ingestion and/or direct transfer of the radionuclide through the skin;

— give high priority to the measurement of internal contamination to people with external contamination; especially if contamination is detected around the nose, the mouth or any wound, that can imply a risk of entering radioactive material into the body;

— limit the dissemination of contamination and thereby avoid the possible cross-contamination of people or the equipment used for in vivo measurements;

— differentiate between external and internal contamination during in vivo measurement and thus reducing errors in the evaluation of internal contamination;

— recording external screening results for subsequent monitoring and dose assessment (see 10.2.2).

B.1 provides further guidance for high contamination screening.

7.2 Radiation detection equipment

The type of radiation detection equipment used shall be appropriate to the type of radioactive material present, as determined by the health and safety officer.

For beta/gamma emitters, a combination of hand-held instruments (e.g. GM counters) and portal monitors maximizes detection capabilities. For alpha emitters, hand-held instruments with alpha scintillation probes provide the highest detection capability. Hand-held instruments are also necessary to control contamination on screening centre surfaces and to perform other essential radiation control functions (e.g. determining background)[4].

Using headphones in conjunction with hand-held instruments can help to reduce anxiety among people being screened and can improve the operator's ability to recognize elevated radiation levels.

B.2 gives a job aid for portal monitors. B.3 gives a job aid for contamination screening using hand-held instruments.

7.3 Contamination screening during initial sorting

In major incidents, contamination screening can help to identify those who should be prioritized for decontamination. At the onset of an incident a higher throughput may be required. Contamination screening staff may be assigned to the *Initial Sorting* area for immediate segregation and decontamination of people with high levels of contamination. This screening should be quick and non-intrusive. It is often performed using a portal monitor (see B.2) but hand-held instruments can also be used (see B.3).

A partial-body contamination screening, which focuses on the hands, face, shoulders, head and feet, can identify most contaminated people. B.1 gives a job aid for high contamination screening. If contamination is found during initial sorting or partial-body screening, the contaminated person should be conducted to the decontamination station. Immediate decontamination may be necessary to reduce an individual's exposure to radiation from contamination and to help control cross-contamination at the scene.

If resources are available, an express lane may be established for people who have showered or have been decontaminated before arriving at the population screening centre. The express lane allows these individuals to bypass the partial-body contamination screening and proceed directly to the full-body contamination screening. The screening protocol and release criteria for both types of contamination screenings are determined by the health and safety officer.

7.4 Contamination screening station

7.4.1 General

At the contamination screening station people are checked for contamination on their bodies and clothing. If adequate decontamination resources allow, more stringent contamination screening criteria than those used in the early hours after the incident may be considered. Staff should verify that appropriate instruments are available (for beta, gamma and, if suspected, alpha radiation) and that the instruments are calibrated and working properly. All screening results should be consistently documented.

If contamination is detected during the full-body screening, the contaminated person should be conducted to the decontamination station for decontamination. People who are not contaminated proceed to *Registration*.

7.4.2 Contamination screening station location

The contamination screening station should be located near the *initial sorting station*, the *decontamination station*, and *registration*. The layout should accommodate the seamless transfer of people from one station to the next while minimizing the potential for cross-contamination. Everybody without an urgent medical need shall receive a contamination screening prior to registration and discharge.

7.4.3 Contamination screening station staffing

Full-body contamination screening shall be conducted by trained personnel. Staff size varies according to the size of the population screening centre, the desired throughput, and the availability of professionals and trained volunteers. Qualified and trained radiation protection professionals, public health staff, emergency services personnel, and volunteers may be needed.

7.4.4 Contamination screening station personal protective equipment (PPE)

The health and safety officer will determine the appropriate PPE for staff in each area. The health and safety officer will also evaluate the need for—and issue as appropriate—personal dosimetry devices among Population Screening Centre staff.

Typically, population screening centres are not located in contaminated areas. Nevertheless, many people reporting to the population screening centre could be contaminated with radioactive material on their clothes or bodies, presenting a possibility of cross-contamination and a potential inhalation hazard to staff. Universal medical precautions, including gown, gloves, facemask, eye shield, and appropriate respiratory protection — as determined by the health and safety officer — provide adequate protection from cross-contamination.

Staff should try to minimize physical contact with people, and gloves should be changed or checked for contamination frequently. Contamination screenings and PPE exchange are necessary for all staff leaving the area for breaks or at shift change. No food or drink should be consumed in this area.

7.5 Decontamination station

7.5.1 General

External contamination (skin or wound) is rarely life-threatening for patients or medical staff who care for them. Removing outer clothing and footwear generally eliminates about 90 % of external contamination. The objective of the decontamination of people is to remove as much contamination as possible without damaging the skin or creating other adverse effects.

Contaminated people go to the decontamination station. Depending on the situation and resources available, population screening centre managers may decide to use an outdoor decontamination unit, wet wipes or dry wipes. People can also be directed to self-decontaminate using indoor shower facilities or sinks, if available. Decontamination staff should review contamination screening results to determine the best method available for decontamination for each person.

7.5.2 Decontamination station location

Facilities with showers or locker rooms are ideal for incorporating a decontamination station. Alternatively, sinks or mobile decontamination units may be employed to provide decontamination capabilities. Key considerations for establishing the decontamination station include:

— ability to accommodate males and females (if using showers) while maintaining privacy;

— ability to accommodate families and others with special needs;

— direct access from the contamination screening station;

— unimpeded access to registration;

— close proximity to the initial sorting station.

NOTE Water used for decontamination is collected if it can be done without delaying the decontamination.

7.5.3 Decontamination station staffing[5]

Staffing plans shall accommodate the need for gender-specific decontamination locations. Staff size varies according to the size of the population screening centre, the desired throughput, and the availability of professionals and trained volunteers. Qualified and trained radiation protection professionals, public health staff, emergency services personnel, and volunteers may be needed.

7.5.4 Decontamination station personal protective equipment

Decontamination staff work directly with contaminated people and need personal protective equipment to control cross-contamination. This equipment should provide splash protection when working near showers or decontamination units. The health and safety officer should work with radiation protection professionals to conduct a hazard assessment and issue the appropriate personal protective equipment to staff members in this area.

7.5.5 Clothing and personal belongings

Contaminated clothing should be bagged and labelled with the person's name and identification number assigned to them upon entering the screening centre. Contaminated clothing may be required later for epidemiological or law enforcement investigations. If the situation allows, bagged clothes should be stored in a secure, remote location at the screening centre.

If possible, other personal belongings such as mobile phones, wallets, keys, jewellery, and glasses, should be decontaminated, bagged together, labelled with the owner's name and identification number, and returned to the owner when he or she exits the Decontamination Station.

7.5.6 Partial-body decontamination

Some people may need only minimal decontamination, such as removing an article of clothing or washing their hands. Partial-body decontamination stations help to keep showers or decontamination units open for those who need full-body decontamination. They can also be used when few or no showers are available.

7.6 Post-decontamination screening

7.6.1 General

After a person is decontaminated, contamination screening staff perform a full-body screening to ensure the person is decontaminated and can proceed to registration. People who are still contaminated after a second shower may be internally contaminated. Also, if the person initially had high levels of skin contamination and/or if contamination was found on the face or wounds, they may still have internal contamination. These people should be evaluated for internal contamination at the r*adiation dose assessment station* and then proceed to registration.

7.6.2 Factors affecting the criteria for determining if decontamination is warranted

It is important to note that there is no universally accepted level of external activity above which a person is declared to be contaminated and below which they are deemed to be decontaminated to a safe level (i.e. target level). Target levels for adequate decontamination should be in the local and regional emergency plans but may be modified at the time of the response[6][7]. Factors that should be considered are:

— nature and location of the incident;

— where, when and how the survey is conducted;

— number of people who need to be surveyed vs. number of people available and qualified to do radiation surveys and decontamination;

— number of operational, calibrated survey meters;

— type of contamination (alpha, beta, gamma) that needs to be surveyed, and the radionuclide, if identified;

— type of radiation detected by the survey meters available (alpha, beta, gamma) and settings (sensitivity) of the survey equipment;

— physical (e.g. powder, liquid, oily, shrapnel) and chemical (e.g. solvent, acid, base) forms of the contamination, if identified;

— pattern of contamination identified (e.g. loose, fixed, both; generalized/widespread vs. "spot" contamination);

— location of the contamination on the body (face, head, extremities, whole-body).

In general, decontamination efforts are generally stopped when (1) the meter measures less than 2 or 3 times the natural background, or (2) if repeated decontamination cycles (usually 3) do not materially reduce the count rate. If satisfactory decontamination is not achieved following the appropriate external decontamination cycles, the presence of internal contamination should be considered. The target levels for decontamination of people are not identical to criteria for the decontamination of elements such as buildings, vehicles, infrastructure and soil during the long recovery phase of an incident.

8 Assessing and monitoring internal exposure

8.1 Overview

Internal dose cannot be directly measured. It has to be calculated based on the measurements of the activities present in the body or in the excreta (urine, faeces) as described in 8.2 or from the activity concentration in the air. This interpretation is necessary to assess dose received by an individual due to internal exposures in order to address:

— the need for medical treatment to reduce dose which has to be rapidly assessed as drugs aimed to decorporate internal contamination are most effective if given shortly after the intake of the radionuclides. The decision is based on initial dose assessment (8.3.2);

— the need for further measurements which has to be also rapidly decided, ideally before the individual leaves the screening centre;

— the need for subsequent health follow-up based on more detailed internal dose assessment (8.3.3).

For emergency workers, dose assessment allows comparison of the results with the reference levels and guidance values for emergency situations set by national authorities.

Relevant information supporting assessment of internal contamination should be recorded (10.2 and Annex C).

8.2 Sample collection

If a person is indicated as highly contaminated after the initial sorting and when contamination is detected on the face or when the intake of radioactive material is suspected, whenever practicable, swabs from body orifices should be collected as soon as the person's condition permits and before decontaminating the face. For example, if incorporation by inhalation is suspected, separate nasal swabs should be collected, preferably within the first two hours.

Whenever practicable, urine samples should be collected for people indicated as highly contaminated with suspicion of internal contamination, if the incident happened several hours before the screening, and the swabs from body orifices are not reliable. If a case of radiation injury is suspected, collect blood samples for complete blood count (CBC) and differential immediately (follow with absolute lymphocyte counts every 6 h for 48 h when history indicates possibility of total-body irradiation) and consider sending blood samples for biodosimetry whenever practicable.

Date and time of the collection of samples should be documented.

The results from some sample measurements, especially nasal swabs, could be obtained while the person is being decontaminated. Swabs may be measured directly with a survey meter or a contamination smear counter. These results could be quickly assessed and consideration of prompt administration of medical countermeasures could be made. Nevertheless, a negative test (nasal or oral swabs) does not rule out the possibility of internal contamination.

8.3 Monitoring for potential internal contamination

8.3.1 General

A priority for a nuclear or radiological incident is the determination of the radiological hazard that might be imparted on individuals directly involved or in the vicinity of any contamination. Such individuals include exposed public, emergency workers, and individuals assisting, but not part of, the response community. It is therefore important that screening and subsequent monitoring can occur as needed and could include a large population. Such monitoring may differ depending on type of individual but monitoring categories presented here are acceptable for any.

8.3 focuses specifically on the types of monitoring that can be used both for screening and in-depth analysis. Handling the population of interest is discussed in Clause 6 and assessment of results is discussed in this

clause. In addition, environmental parameters such as air sampling or contamination monitoring may be used for estimation of dose to individuals. Those methodologies are not addressed in this clause. Thirdly, neutron activation in individuals from fission activity is not addressed here. Biomarkers that can be used to estimate exposure are discussed in Clause 9.

Monitoring for internal contamination is very dependent on radiation type and energy, as well as chemical compound type and biokinetic behaviour[8]. Penetrating radiation can be monitored using in vivo whole body or organ/partial-body type measurements, whereas non-penetrating radiation requires in vitro measurements of biological samples with increasing detection sensitivity and efficiency.

In addition, monitoring is not limited to what is stated here and additional techniques such as biodosimetry could be considered.

8.3.2 Monitoring for radionuclides emitting predominantly non-penetrating radiation

8.3.2.1 Overview

Non-penetrating radiation includes alpha and beta particles without accompanying penetrating gamma ray (e.g. non-penetrating gamma energies <100 keV, yield >50 %).

8.3.2.2 Screening measurements

Screening can be accomplished using two different categories of sampling – nasal swabs (or similar) and urinalysis. Nasal swabs should be taken as soon as possible post event, but, conversely, urinalysis cannot be performed until some time has passed allowing for the radionuclide in question to metabolize into urine.

Nasal swabs are typically obtained by wrapping gauze or a similar absorbent material around a commercial swab and wiping out the nasal passages. Analysis types used should consider the appropriate minimum detectable dose as compared to the committed effective dose that could be left undetected. This could be proportional counting, if the radionuclide source term is well-known, or liquid scintillation. Either methodology would require some time for the analysis to be completed, so contact information for the sampled individual shall be obtained. Because of the fast clearance of the nasal passage compartments (clearance rate $\sim 100/d$), it is important that these samples be obtained as quickly as possible within the first few hours after the event.

Urine samples require that enough time has elapsed post exposure such that the radionuclide in question is able to pass through the systemic whole body into the urine. For screening purposes, it is suggested that spot samples be obtained. If individuals are identified as higher risk, 24 h samples can be obtained at a later time. To reduce the analysis time, samples can be batched. Batching refers to compositing a small amount of the spot samples into a larger sample and analysing that larger sample. A positive result on a batch would require separate analysis on the samples within that batch. Depending on the knowledge of the source term and detection limit needs, the analysis can be performed using liquid scintillation, radiochemical methods or mass spectrometry methods.

It is important that the methodology be tailored for the specific radionuclide in question and that the detectability of the methodology be fully understood in terms of the detection capability using such methods.

8.3.2.3 Monitoring methods

Once a screened individual has been identified for further analysis, an in-depth methodology should be used to obtain proper data for dose assessment. The methodologies would be those typical for operational monitoring, primarily by obtaining 24 h samples of urine and faeces. Early samples of faeces (1 days to 5 days) are useful in determining that an intake (whether inhalation, ingestion, or otherwise) did in fact occur and its relative magnitude. Uncertainty in this sampling is due to unabsorbed material in a bolus traveling through the gastro-intestinal tract, but the ICRP model assumes exponential translocation from one compartment to the next (see ICRP Publication 100, Human Alimentary Tract Model for Radiological Protection). Urine samples, on the other hand, contain material that has passed through the systemic whole body. This is also true of later faecal samples. These samples are more useful for quantifiable determinations of intake amount and assessment of effective dose. Longer-term (24 h) samples are recommended for

analyses requiring radiochemistry because a larger sample volume reduces the total propagated uncertainty to acceptable amounts.

The duration of analysis should be considered. Some isotopic-specific methodologies can take considerable time, for instance ^{90}Sr can take as long as two weeks or ^{210}Po up to three weeks.

8.3.3 Penetrating radiation

8.3.3.1 Overview

Penetrating radiation can be measured using in vivo methods. This improves the timeliness of individual measurements and mobile systems can be used to assess large numbers of potentially exposed individuals in a relatively short time.

8.3.3.2 Screening methods

As with non-penetrating radiation, screening methods for penetrating radiation are dependent on the specific radionuclides, their metabolism depending on chemical and physical properties of the element itself. When the source term has been identified, and instrumentation available for screening obtained, a quick analysis of the measurement procedure should be developed based on instrument capability and probable location of the radionuclide within the body to determine the analysis parameters necessary to meet required detection limits.

If the energy is high enough, the simplest methodology would be the use of a portable radiation portal monitor. With this type of device, the only variable in analysis would be the time spent in the detectable area of the portal. Positive screened individuals could then be directed to an in vivo counter with increased detection or other analytical capability.

Hand-held instruments can also be used. Such instruments are likely more dependent on geometry based on the radionuclide in question. For instance, testing for iodine isotopes would require the instrument to be placed near the neck/thyroid area. Radionuclides that could distribute quickly throughout the body would be more detectable if the body was arced around the detector.

8.3.3.3 Monitoring methods

As with non-penetrating radiation, monitoring methods for positive screened individuals are performed using operational internal dosimetry-type methods. For penetrating radiation, this typically includes in vivo methods such as whole-body counting for most radionuclides or thyroid counting for radioiodine. Lung counting can also be used if a suspected insoluble radionuclide is expected to be deposited in the lung. For efficiency for large populations, it is recommended that count times be reduced to those which would provide the proper detection limit identified for assessment.

If possible, all instruments should be protected against contamination by covering with a removable thin plastic film or other covering. This may not be possible for those used for measurement of beta contamination. For non-spectrometric instruments, the background should be measured on another body part of the subject (e.g. the thigh, forearm or shoulder).

8.3.4 Radionuclide mixture

If the source term includes a mixture of radionuclides, a particular representative radionuclide or radionuclides should be chosen for measurement based on its ease of measurement as compared to the detection limit required. For instance, a penetrating radiation of moderate to high energy that is a significant part of the source term (e.g. isotopes of Cs for spent nuclear fuel) could be used for detection of the entire source term.

However, if this methodology is used, it is extremely important that the radionuclide composition of the mixture is known. If, for instance, actinide radionuclides are not identified within the source term, the effective dose could be greatly underestimated.

8.4 Method for dose assessment

8.4.1 General

Internal dose assessment based on individual contamination data involves two stages:

a) assessment of intake from the measurements;

b) calculation of dose from the assessed intake.

When a single measurement is made, the intake can be estimated by comparing the result of the measurement with the appropriate value predicted by the corresponding bioassay retention/excretion) $m(t)$ function at time "t" after intake:

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

where

I is the estimated value of a radionuclide intake (Bq);

M is the measured quantity (Bq);

t is the time after intake;

$m(t)$ is the reference (retention/excretion) bioassay function at a time t after intake (Bq.Bq^{-1}).

Bioassay functions and dose coefficients issued from ICRP publications 72, 134, 137, 141 and 151 (including the Occupational Intakes of Radionuclides supplement material OIR Data Viewer, Annex D) should be used to assess internal doses[9][10][11][12][13]. In order to select the appropriate bioassay function and dose coefficients, knowledge of the following aspects is required:

— radionuclide: element, isotope and chemical form;

— route of intake: inhalation, ingestion or wound;

— age of the person measured;

— delay between contamination and in vivo measurement or collection of the excreta.

The committed equivalent doses to target regions and the committed effective dose are evaluated by multiplying the intake by the appropriate dose coefficients:

$$H_T(\tau) = I \cdot h_T(\tau)$$

$$E(\tau) = I \cdot e(\tau)$$

where

$H_T(\tau)$ is the committed equivalent dose to tissue/organ T received within τ years after an intake (Sv);

I is the intake (Bq);

$h_T(\tau)$ is the coefficient of the committed equivalent dose to tissue/organ T received within τ years after an intake (Sv.Bq^{-1});

$E(\tau)$ is the committed effective dose received within τ years after an intake (Sv);

$e(\tau)$ is the coefficient of the committed effective dose received within τ years after an intake (Sv·Bq^{-1}).

If available, other information is of interest for dose assessment:

— particle size in terms of activity median aerodynamic diameter (AMAD) for aerosols;

— isotopic composition of the release.

Concerning the characteristics of the contaminant, when no other information is available, the following AMAD have to be considered:

— 1 µm for the public;

— 5 µm for emergency workers present on the site and 1 µm for those contaminated outside the nuclear facility.

Several technical issue may be encountered when monitoring the population using whole body counters:

— contamination of the body surface,

— accuracy of the WBC measurements of children,

— for the dose assessment, difficulties in defining the contamination scenario.

When the level of internal contamination reaches activities which may lead to adverse tissue reactions, equivalent dose and effective dose should not be used to assess the likelihood and magnitude of these effects on organs or to make decisions on the need for any treatment related to tissue reactions[14]. For such purposes, doses should be evaluated in terms of absorbed dose (in gray, Gy), or, where high-LET radiations (e.g. neutrons or alpha particles) are involved, of absorbed organ dose weighted with an appropriate Relative Biological Effectiveness (RBE)[15]. The RBE for severe deterministic effects depend on the different type of radiation and on the exposed organ. RBE-weighted absorbed doses may include doses to the lungs, the red bone marrow, the colon and the thyroid.

At this high level of contamination individuals should be examined for tissue reaction signs and symptoms (see 9.6.2) even if they would be exceptional after incidental internal exposure. A blood count should also be performed (see 9.6.3). Biological dosimetry may also be performed, particularly when the radionuclides involved are almost homogeneously distributed in the body[15] (see 9.6.5).

8.4.2 Initial dose assessment

Initial evaluation of the dose due to internal contamination should be performed in order to:

— evaluate the need for medical treatment (for example, administration of Prussian Blue to enhance caesium elimination or administration of DTPA to enhance elimination of actinides);

— communicate on health risks with the person contaminated in the event of a positive result;

— inform decisions on the need for additional and/or more accurate monitoring and dose assessments.

This assessment should be performed on the basis of individual monitoring carried out by authorised or approved dosimetry service providers that operate under a quality management system.

Initial dose assessment should be based on conservative hypotheses for the date(s) and periods of contamination, for example by assuming an acute intake at the time of the beginning of the radioactive release.

Depending on the number of persons to be monitored, the complexity of the dose assessment and the type of monitoring equipment, initial dose assessment may be performed using different procedures. Doses may be assessed:

— at the individual level for a limited population;

— using simple tools for dose assessment[17], software tool for the rapid calculation of internal dose from measurements of people in an emergency[18] or tables for interpretation of measured activity for the most encountered radionuclide pre-established for the management of radiological or nuclear emergencies[19].

For the screening of a large population, the activity measured may be directly compared to the value corresponding to the intake level for a radionuclide that, if exceeded, may justify medical treatment to decorporate the radionuclide[20][21].

For emergency workers, initial dose assessment allows to compare with guidance values for restricting further exposure of them. The ISO 27048[22] approach for internal dose assessment may be used to assess doses received by emergency workers.

8.4.3 Detailed internal dose assessment

For the public, a more sophisticated dose assessment should be performed for a second time, taking into account:

— isotopic and physico-chemical composition of the release as evaluated from environmental measurements;

— time-pattern of the exposure based on the scenario of the actual incident;

— place of stay and possibly the post-incident exposure after the passage of the plume.

The dose assessment is dependent on the accuracy of the date and/or period of possible contamination and this issue is a major source of uncertainty in the dose evaluation process.

This assessment allows the estimation of the overall radiation exposure the individual received from external exposure as well as external and internal contamination.

It allows:

— the evaluation of individual health risk for long term medical follow-up;

— providing a quantification of the exposure for epidemiological studies.

In these cases, unbiased dose estimates are needed while overestimation is sometimes accepted in radiation emergency response following initial dose assessment as described above (8.4.2).

For the emergency workers, more accurate dose assessment should also be estimated based on:

— results of individual measurements;

— available data on the characteristics of the contaminant and the exposure conditions specific to the worker; and

— working times and location.

These data should be recorded, if possible, to enable dose reconstruction based on occupancy times of the worker and the activities performed.

9 Assessing and monitoring external exposure

9.1 General

In case of a nuclear emergency or radiological incident, many types of radionuclides are emitted from the nuclear reactors or radiation sources. In terms of nuclear incidents, the radionuclides move as aerosols or as a radioactive plume in the air and emit radiation. Radiation from a radioactive plume is called cloud shine. When radionuclides fall and attach to the ground due to weather conditions, they emit radiation called ground shine. The radionuclides attached on the surface of human bodies are also the cause of external exposures. In radiological incidents, the total amount of radionuclides is not as large as compared to those in nuclear incidents. They are often distributed by humans who find and keep the source without awareness of being contaminated with radioactive materials. In such a case, the external exposures are relatively localized and result in severe harm. Depending on the situation, assessment and monitoring should be performed following appropriate methods and procedures. The persons who are exposed to radiation are classified

here into three categories: workers (radiation workers and others within the facility), public members and emergency workers.

9.2 Assessing external exposure

9.2.1 Subjects

Subjects include radiation workers and other workers who are involved in the incidents in the nuclear or radiation facilities. Basically, radiation workers are assumed to have their own personal dosimeters during their work in the controlled area, and other workers do not have the dosimeters in advance.

9.2.2 Guidance

According to the ICRP Publication 103[23], the limit for occupational effective dose in planned exposure situations is 20 mSv per year, averaged over defined periods of 5 years. Equivalent dose limits for lens of the eye and skin are 150 mSv and 500 mSv per year, respectively. In 2011, for occupational exposures, the equivalent dose limits for the lens of the eyes have been changed to 50 mSv per year and 100 mSv for defined periods of 5 years by ICRP.

In emergency exposure situations, there are no dose limits but reference levels only. In life-saving situations, there are no dose restrictions for helpers if the benefit to others outweighs the rescuer's risk. In any case however efforts shall be taken to reduce the exposure to levels below the reference levels. The reference levels for other urgent rescue operations are 1,000 or 500 mSv, and less than or equal to 100 mSv for other rescue operations. On the other hand, workers other than radiation workers are considered public members. They do not generally have their own dosimeters, so the measurements cannot be directly performed and shall be estimated. Their external exposures can be estimated by measurements in the environment and by indirect calculations. Reference levels for guiding the optimisation of protection of emergency workers and members of the public during the successive phases of a nuclear accident are shown in ICRP Publication 146[24].

9.2.3 Measurement devices

9.2.3.1 General

The external exposures are estimated based on the data measured using the suitable measurement devices and equipment. The measurement devices should be kept where they are easily managed in the facilities and be tested and calibrated periodically.

9.2.3.2 Measurements of ambient dose equivalent rate

The devices or equipment for air dose rate measurements are:

— monitoring station;

— monitoring post (fixed);

— mobile monitoring post;

— survey meter (NaI scintillator, Ionization chamber);

— neutron monitor.

The monitoring station could have multiple types of detectors (for example highly sensitive scintillation detectors for low dose rate measurement and, if applicable, for spectroscopic analysis, gas filled detectors for high dose rate measurements, a gas monitor and a particulate monitor). The monitoring post is simpler compared to the monitoring station, having only dose rate detectors. There are fixed- and mobile-type monitoring posts. The height of the reference point for dose rate measurement should be 1 m from the ground surface.

Each survey meter has its own characteristics with respect to the energy and dose rates responses of radiation. The ionization survey meters are suitable for precise measurements of ambient dose equivalent. However, the sensitivity is not high, normally used at 1 μSv h^{-1} or higher irradiation conditions. Scintillation survey meters have high sensitivity and can detect very low dose rates of radiation; however, high dose rates (several 10 μSv h^{-1}) cannot be measured. Proportional detectors and GM are available in different sizes and sensitivities. Monitoring posts using such detectors typically operate on a series of high and low dose rate detectors and cover very wide measuring ranges. Similarly, highly sensitive detection and wide measuring ranges are provided by modern detector systems based on silicon photo multipliers in combination with scintillators. Neutron monitors detect from thermal to fast neutrons. Electronic ambient dosimeters and/or monitors are also available. They should comply with IEC 60846 1 (for low and medium dose rates) and IEC 60846 2 (for high dose rates and emergency radiation protection purposes).

9.2.3.3 Measurements of cumulative doses

The following devices and equipment can be used for measurements of cumulative doses of external exposure:

— monitoring station;

— monitoring post;

— Thermo-luminescence dosimeter (TLD);

— Radio photo luminescence dosimeter (RPLD);

— Optically-stimulated luminescence dosimeter (OSLD);

— electronic dosimeter.

TLD, RPLD, OSLD and electronic dosimeter are also used as personal dosimeters to measure personal dose equivalents. Both active- and passive-type personal dosimeters have been used for assessing the personal doses. TLD, RPLD and OSLD are passive type dosimeters which can measure cumulative doses. There are many kinds of TLDs, so they can be selected and used for various situations. However, they should be used carefully because the variations among TLD elements are not small, and they have fading effects. On the other hand, RPLD and OSLD have the advantage of high sensitivities, and no measurable fading in working conditions. Passive personal dosimeters should comply with the IEC 62387[25]. The typical active personal dosimeter is the Electronic personal dosimeter with semi-conductor detector. Electronic personal dosimeters should comply with the IEC 61526[26]. The doses can be measured in real-time with high sensitivity. Some types of electronic personal dosimeters have alarm function. However, it should be noted that some kinds of them are affected by microwaves emitted from cellular phones or other electronic devices. All types of personal dosimeters should be used avoiding shock and water.

9.2.3.4 Measurements of radionuclide concentrations in the air

Information on radionuclide concentration and spectra in the air are essential for both external and internal exposures. They are measured using the following devices and equipment:

— air monitor;

— iodine monitor;

— germanium semi-conductor gamma-ray spectrometer;

— NaI scintillator gamma-ray spectrometer.

The measurement of short half-lives radionuclide, e.g. I-131, in the early stage of an incident or accident would be required for later reconstruction of the external and internal exposures. Information of spectra of the radionuclides is also necessary.

9.2.3.5 Measurements of surface contamination

The surface contamination is measured using the following survey meters:

— GM survey meter;

— Zinc sulfide (ZnS) scintillation survey meter;

— Plastic scintillation survey meter.

The GM survey meters have higher sensitivity than the ion-chamber, so they are very useful for contamination surveys. However, their energy response is not good. The survey meter should be selected and used correctly based on the type of radiation being measured. A ZnS scintillation survey meter is used for alpha measurement. The doses from alpha particles are negligible for external exposure measurements because of their very weak penetrating power. Plastic scintillation and GM survey meters are used for beta-ray measurement.

9.3 Assessing external exposure for workers

9.3.1 Subjects

Occupationally exposed workers may be exposed to radiation during the emergency situation at the facilities. If they don't work in a controlled area during the planned exposure situation before the emergency, they would not wear personal dosimeters.

9.3.2 Procedure

Responses to the emergencies differ depending on the situations. In any case, survey meters and personal dosimeters are necessary for environmental and personal monitoring, respectively.

Immediately following the incident, workers may remain in their facility. Depending on the severity of the incident, workers keep working as the initial response to the incident or evacuate the site. For them, personal dose equivalent due to the external exposure to gamma and beta rays are measured by using personal dosimeters or other tools. In addition, if workers are externally contaminated, exposures from the attached radionuclides are measured by using survey meters. Neutrons can be produced in nuclear facilities, so the dosimeters that can detect neutrons should be prepared in advance. In other facilities using radionuclides, suitable dosimeters should be prepared depending on the kinds of radiations.

When radiation workers use active type personal dosimeters, the doses can be directly read in real-time. The measured data should be read and recorded as needed. As passive type dosimeters cannot be read in real-time, the values of exposures are read in the places where the dosimeter can be read. For body surface measurements of workers, suitable survey meters should be selected and used. Note that the measurements could not be performed if background are high.

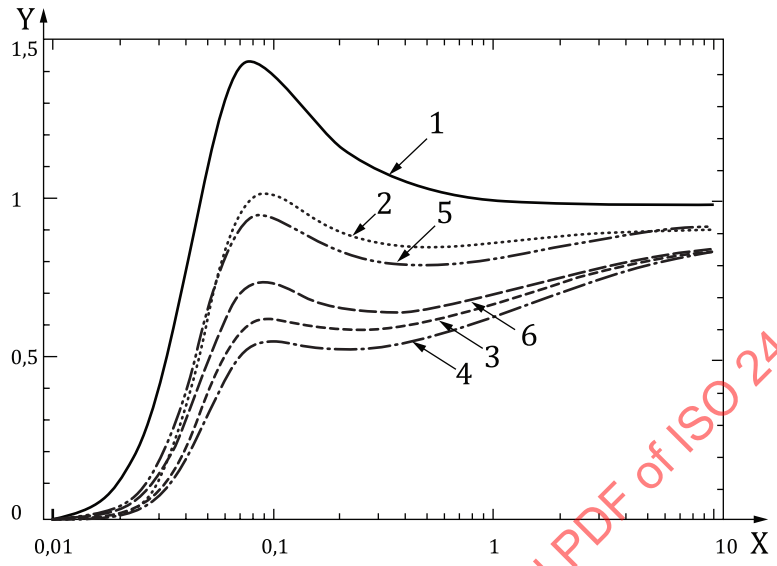
9.3.3 Measurements

In an emergency situation, the number of available dosimeters may be insufficient due to the incident (e.g. the tsunami in Fukushima). In addition, the personal dose control system may lose its functions. As soon as possible after the incident it is important to secure the supply of personal dosimeters for radiation workers and recover the dosimeter control system.

When contamination is suspected, the measurements of surface contamination should be performed using survey meters. The persons who perform the measurements should wear personal protection (e.g. Tyvek suit, cap, gloves, shoes cover and protective mask). The floor where the survey is being conducted should be covered with plastic sheet or similar to avoid contamination. The survey meters should also be covered with plastic or wrap film for packaging food. Do not use plastic coverings for the probe window if surveying for alphas or low energy beta radiations. As an example, the time constant and meter range are set as 3 s and 10 kcpm, respectively. The detector should be moved at a speed of 10 cm/second at 1 cm from the surface of the body.

9.3.4 Calculations

The effective dose depends on the kind, energy and geometry of irradiation. ICRP reports the data[27] based on mathematical phantoms and the revised version[28] is based on the computational phantoms of ICRP. There are differences, but the conversion factors are similar when considering ^{137}Cs radiation energy. Figure 4, taken from ICRP 74 show the conversion coefficients from air kerma to the effective dose in terms of phantom and w_T and w_R values.

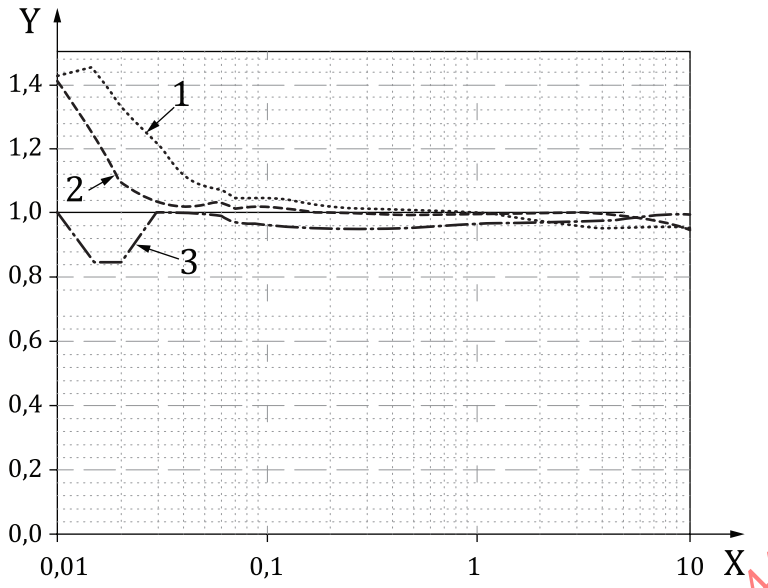


Key

X	photon energy (MeV)	3	LLAT
Y	effective dose per unit air kerma E/K_a (Sv/Gy)	4	RLAT
1	AP	5	ROT
2	PA	6	ISO

Figure 4 — Reference conversion coefficients for effective dose for photons in various irradiation geometries on an adult anthropomorphic computational model (ICRP 74)

Ratios of effective dose per air kerma conversion coefficients for photon, based on the calculation assumptions of ICRP publication 74 (ICRP 1996)[27] and ICRP Publication 116 (ICRP, 2010)[28], are given in Figure 5.



Key

X photo energy (MeV)
Y effective dose/Effective dose (ICRP 74)
1 ratio AP
2 ratio PA
3 ratio ISO

Figure 5 — Ratios of effective dose per air kerma conversion coefficients for photons, based on the calculation assumptions of ICRP publication 74 (ICRP 1996) and ICRP Publication 116 (ICRP, 2010)

The absorbed dose rates of the skin can be calculated based on the skin surface concentration of contamination using ICRU Report 56 (Table 2)[29].

Table 2 — Absorbed dose rates of the skin

Radionuclide	Depth mm	
	0,07	0,4
^{131}I	1 319	303
^{134}Cs	1 000	262
^{137}Cs	1 432	384

NOTE Absorbed dose rates ($nGy \cdot h^{-1} \cdot Bq^{-1} \cdot cm^2$) at various depths in water, on the axis of a 1 $Bq \cdot cm^2$ plane isotropic beta-ray source distributed uniformly over a 1 cm^2 circular area on an air-water boundary. The values also give the absorbed dose rates, averaged over 1 cm^2, from 1 Bq point sources (Cross et al., 1992c)

9.3.5 Assessment

According to IAEA Safety Standard Series No.SF-1[30], Principle 9: Emergency preparedness and response, arrangements shall be made for emergency preparedness and response for nuclear or radiation incidents. In the IAEA GSR Part 3, Requirement 43: Emergency management system, it is said that the government shall ensure that an integrated and coordinated emergency management system is established and maintained based on IAEA Safety Standard Series No.SF-1, Principles 9. The limits for the calculated exposure received by workers shall be established by the government in accordance to IAEA GSR Part 3, Requirement 45, subclause 4.19.

9.4 Assessing external exposure for emergency workers

9.4.1 Subjects

The emergency workers who are exposed to radiation during the incident could be radiation workers, firefighters, police officers, medical staff for emergency medicine and other professions, as well as non-traditional emergency response personnel, such as bus drivers and volunteers.

9.4.2 Guidance

According to ICRP 103, reference levels are applied for occupational and public exposures in emergency situations. ICRP recommended no dose restrictions for informed volunteers in life-saving operations when the benefit to others outweighs the rescuer's risk. The ICRP reference level for other urgent rescue operations is 1 000 mSv (to avoid serious tissue reactions), 500 mSv to avoid other tissue reactions, and less than or equal to 100 mSv in other rescue operations. These effective doses include both external and internal exposures to radiation. Also, according to ICRP 146, the reference level for the protection of responders on-site during the early phase should not generally exceed 100 mSv, while recognising that higher levels, in the range of a few hundred millisieverts, may be permitted in exceptional circumstances to save lives or to prevent further degradation at the facility leading to catastrophic conditions. For the protection of emergency workers off-site, selection of a reference level not exceeding 100 mSv for the early phase and 20 mSv per year for the intermediate phase are recommended. For the long-term phase, the reference level should be selected within the lower half of the recommended band of 1 mSv to 20 mSv per year.

Table 3 — Reference levels for guiding the optimisation of protection of emergency workers and members of the public during the successive phases of a nuclear accident (referred ICRP 146)

	Early phase	Intermediate phase	Long-term phase
Emergency workers on-site	100 mSv or below[a] Could be exceeded in exceptional circumstances[b]	100 mSv or below[a] May evolve with circumstances[abc]	20 mSv per year or below
Emergency workers off-site	100 mSv or below[a] Could be exceeded in exceptional circumstances[b]	20 mSv per year or below[c] May evolve with circumstances	20 mSv per year or below in restricted areas not open to the public Lower half of the 1 to 20 mSv per year band in all other areas[e]
Public	100 mSv or below for the entire duration of both the early and intermediate phases[d]		Lower half of the 1 to 20 mSv per year band with the objective to progressively reduce exposure to levels towards the lower end of the band, or below if possible[e]

[a] Previously, the Commission recommended selection of reference levels in the band of 20–100 mSv for emergency exposure situations. The current recommendations recognise that the most appropriate reference levels may be lower than this band under some circumstances.

[b] The Commission recognises that higher levels in the range of a few hundred millisieverts may be permitted to responders to save lives or to prevent further degradation at the facility leading to catastrophic conditions.

[c] As some responders may be involved in both the early and intermediate phases, the management of exposures should be guided by the objective to keep the total exposure during these phases below 100 mSv.

[d] Previously, the Commission recommended the selection of reference levels in the band of 20–100 mSv for emergency exposure situations. The current recommendation recognises that, in some circumstances, the most appropriate reference level may be below 20 mSv.

[e] This clarifies the expression 'lower part' as used in Publication 111.

IAEA also provides guidance values for restricting the exposure of emergency workers in an emergency response in terms of personal dose equivalent H_p (10) from external exposure to strongly penetrating radiation. See Table 4. The total effective dose and RBE weighted absorbed dose to a tissue or organ need to be estimated as early as possible in a nuclear or radiological emergency (IAEA, 2015)[30]. In practice, physical and operational quantities are measured, and protection quantities are estimated as needed based on the measured data.

Table 4 — Example of a guidance values for restricting exposure of emergency workers (IAEA, 2015)

Tasks	Guidance values		
	$H_p(10)$	E	AD_T
Lifesaving actions [a]	<500 mSv	<500 mSv	$<(1/2)AD_T$
Actions to prevent severe deterministic effects and actions to prevent the development of catastrophic conditions that could significantly affect people and the environment	<500 mSv	<500 mSv	$<(1/2)AD_T$
Actions to avert a large collective dose	<100 mSv	E <100 mSv	$<(1/10)AD_T$

[a] This value may be exceeded under circumstances in which the expected benefits to others clearly outweigh the emergency worker's own health risks, and the emergency worker volunteers to take the action and understands and accepts these health risks.

E: effective dose, AD_T: absorbed dose to a tissue or organ

9.4.3 Measurements

The methods of measurements for emergency workers depend on the kinds of professions and the emergency situations. The public officers dispatched by the government or local governments may have dosimeters prepared in advance. For other professions, dosimeters are not always prepared sufficiently.

If the need is determined by site safety officers, emergency workers should have their own dosimeters as soon as possible before attending the emergency responses, although one emergency workers group with the same duties in the same place might have only one dosimeter due to the shortage of dosimeters. If not possible, the survey meters can be used to monitor the ambient dose equivalent rates around the emergency workers for the estimations of personal doses of the emergency workers afterward based on the monitoring data.

9.4.4 Calculations

A method similar to that used for workers can be used for the dose calculations for emergency workers. However, it should be noted that the dose levels of emergency workers can be higher than other workers or the public. Based on the available data, the kinds of radiation and their energies should be evaluated.

When the personal dosimeters for emergency workers have been suitable, the measured data can be used as estimated personal exposures. If the dosimeters are not suitable for the measurements of the radiation field, the data should be estimated by the responses of the dosimeters.

9.4.5 Assessment

The government shall ensure that an integrated and coordinated emergency management system is established and maintained based on IAEA Safety Standard Series N SF 1, Principles 9. The limited values for the calculated absorbed dose rates received by workers shall be established by the government in accordance to IAEA GSR Part 3, Requirement 45. The doses of all emergency workers should adequately be collected and used for the radiological protection of the emergency workers, and determine the measures for the next step.

9.5 Assessing external exposure for the public

9.5.1 Subjects

The members of the public that need to be assessed for external exposure are residents living in the area affected by the incident and any visitors or tourists who were in the area at the time of the incident. They include newborns, children, adults and elder persons, and their body sizes should be considered in the assessment.

9.5.2 Guidance

In nuclear incidents, the behaviours of the public may differ depending on their locations and the situations at the time of the incident. According to the IAEA Safety standards (IAEA, 2015)[30], the precautionary action zone (PAZ) and urgent protective action planning zone (UPZ) are set in case of emergency due to the nuclear incident. The residents inside the PAZ would be asked to evacuate as a precaution before the release of radionuclides from the reactor. The radii of PAZ and UPZ are about 5 km and 30 km, respectively. In UPZ, shelter-in-place, evacuation, and temporary relocation including preventive protective measures are performed depending on the stage.

In the early phase after the incident (emergency exposure situation):

a) obtain the data of dose rates (and, if possible, energy spectra) in the environment as early, as completely and as precisely as possible in the affected area on a daily basis. The data should include not only dose rates but also energy spectra to get information of the kinds of radionuclides and their activity;

b) check, clean and cover the dosimeters;

c) survey the dose rates in the environment in areas where the data are insufficient;

d) survey the dose rates inside and outside the evacuation areas.

To obtain the dose rates in a wide area, air-borne survey and car-borne survey are useful methods. It is necessary to make fixed point measurements at intervals of a certain distance for development of the dose rate maps.

In the intermediate phase (emergency to existing exposure situation):

— keep obtaining the data of dose rates (and energy spectra) in the environment.

In the long-term phase (existing exposure situation):

— keep obtaining the data of dose rates in the environment.

9.5.3 Measurements

In the early stage, as mentioned, the residents inside the PAZ would be advised to evacuate as a precautionary action before the release of radionuclides. Like non-radiation workers, the public do not have personal dosimeters. It would be important to record their behaviours for external dose calculations to account for doses accrued before, during and after the evacuations.

For the calculations, the measurements of dose rates in the area where the residents evacuated from and their evacuation path are required. If people are able to get screened at monitoring stations or monitoring posts the data would be available. Generally, in the stations or posts, there would be NaI scintillation detectors and ion-chambers able to measure from low to high doses in the environment. Mobile monitoring posts are also useful if available. For estimating dose levels from gamma rays, NaI scintillation survey meters or ion-chambers can be used. In the measurements, the survey meters are kept at 1 m above the ground, starting with a set time-constant of 3 s initially, and adjusting to longer times depending on the dose rates. The measurement data can be used for constructing dose rate maps to estimate external exposures of the public members.

In the middle stage, the local governments might distribute personal dosimeters for the residents. In such cases, external exposures of the public members can be directly measured. It is also important to use personal dosimeters correctly. When obtained the personal doses, the values should be considered as including the uncertainties caused from the measurement geometries, positions and malfunctioning, so corrections should be made if necessary.

9.5.4 Calculations

9.5.4.1 Basic data for assessing

For assessing external exposures for the public, both the behaviours data of the public and the dose rates data in the concerned area are necessary[32]. The behaviour data include information of the locations where the person was, and the length of time in each area as well as the movements each day over the concerned period. Information on the kinds of buildings or houses is necessary for to account for the dose reduction effects due to the construction materials. The dose rate maps should be constructed based on the measured data by monitoring stations or posts, or if available, monitoring data obtained by using survey meters. When measured data cannot be obtained, calculation data are alternatively used in consideration of the topography and climatic condition. Simulation codes and models can be used for both prospective and retrospective calculations.

9.5.4.2 Calculation of external dose

Basically, daily external doses can be calculated by multiplying the staying or moving time in the behaviour data by the dose rates from the dose rate maps. Total external doses are expressed as the sum of the doses over the concerned period. In the calculation, reduction effects resulting from shielding while sheltering in houses and buildings, differences of body size, and conversions for protection quantities are considered.

9.5.4.3 Behaviour data

To keep the data reliable, behaviour data should be obtained by interviewing or via questionnaires sent by official organizations such as municipalities, local or national governments, or organizations commissioned by them to keep the data reliable. When the number of the public members is large, interview cannot be performed for all, so sending questionnaires is effective.

Experience in collecting behaviour data after the Fukushima accident was summarized by Ishikawa[33]. The experience tells us that:

a) behaviour questionnaires shall be easy to fill out but still ensure a certain degree of accuracy in the estimates,

b) the survey should start before memories fade, and,

c) enough staff should be secured to handle the survey.

Because the same problems can arise for behaviour surveys after an accident in the future, these points are worth mentioning.

Considering the reduction curve of dose rates, the concerned period is from the day of the incident to several months later. In the early stage after the incident, the dose rates are high, so detailed information of behaviours are necessary to estimate the doses. For the middle stage, rough information could be sufficient for dose estimations. The questions include time and location, (start and end point if moving), kinds and materials of building or houses.

9.5.4.4 Dose rate maps

To make dose rate maps, measured data of dose rates in the concerned area are necessary. These are usually point data, so they have to be converted to two-dimensional dose distributions by using a mathematical method, e.g. natural neighbour method. The precisions of the map depend on the densities of measured points and the precision of the data. Generally, it is not possible to obtain enough data for each day in the period, so interpolations or extrapolations should be done to construct the maps. To estimate doses conservatively, it is recommended that the dose rates where measured data are not available be interpolated and extrapolated based on the steepest curve in the dose rate graph. In addition to the measured data, calculation data can be used to complement these data.

After making the continuous two-dimensional dose distribution maps, they are divided into small meshes, and the dose distribution in each mesh is averaged mathematically. Background dose rates are subtracted from the dose rate of each mesh for each day, so they should be measured or estimated in advance.

9.5.4.5 Conversion from operational quantities to protection quantities

In general, the dose rates measured at monitoring stations or posts are operational or physical quantities such as ambient dose equivalent, air kerma, and so on. On the other hand, effective dose and equivalent dose are used as protection quantities for the purpose of radiological protection. Hence physical quantities have to be converted to protection quantities and operational quantities have to be taken as estimators of protection quantities in case of external exposures. The conversion coefficients depend on the kinds and energy of the radiation, and the geometry of the irradiation. They can be referred from ICRP Publication 116[28] for protection quantities and ICRU report 57 for operational quantities.

9.5.4.6 Dose reduction effect by houses and buildings

Radiation doses inside buildings or houses are generally lower compared to outside because the materials shield part of the radiation. The reduction rates differ depending on the kinds of materials and radiation, and on the radiation energy. The coefficients can be referred from IAEA TECDOC 225[34] (Table 5).

Table 5 — Coefficients considering shielding by materials of buildings or houses

Building or house	Cloud shine	Ground shine
Outdoor or moving	1	1
Indoor: one or two story wood frame house	0,9	0,4
Indoor: one or two story concrete house or building	0,6	0,2
Indoor: three or more story concrete building	0,2	0,1

If other values based on reasonable scientific evidence are available, they could be used. When the differences between doses inside and outside of the buildings or houses are small (as the absolute values of the dose rates become very low), these coefficients cannot be applied.

9.5.4.7 Dose correction for children

Compared to adults, doses to babies and children are higher under the same radiation exposure conditions due to their small body sizes. Their external doses are modified by multiplying conversion coefficients referred from a previously reported paper[34].

Strictly speaking, effective dose is defined based on the calculation results only for adult male and female computational phantoms according to ICRP Publication 103[23]. However, ICRP published ICRP 143 "Paediatric Computational Reference Phantoms"[36] in which reference paediatric phantoms are described. By using them, effective doses can be calculated for babies and children.

9.5.5 Assessment

Many parameters are used in the calculation of external doses for the public members and have their own uncertainties. Hence the obtained results should be considered as the rough estimation values within 1 or 2 significant digits.

9.6 Clinical and biological dose assessment

9.6.1 Overview

Individual dose assessments can be conducted during a radiological emergency using a variety of methods that measure changes in individuals at the biological level. These can be as simple as observing clinical signs and symptoms or measuring blood counts but also include more involved methods such as cytogenetics or physical measurements on biological material. 9.6 provides an overview of methods for which there are ISO

standards or well -validated methods for emergency response. Annexe D gives information on a grading system for response of neurovascular, gastrointestinal, cutaneous, and hematopoietic systems.

9.6.2 Clinical signs and symptoms

Signs and symptoms are abnormalities that can indicate a potential medical condition. Symptoms are subjective, apparent only to the patient (i.e. nausea). A sign is any objective evidence of a disease that can be observed by others (i.e. erythema, vomiting). Erythema is the superficial reddening of the skin as a result of injury causing dilation of the blood capillaries.

Exposure of the skin to high doses of ionizing radiation leads to accumulation of lymphocytes in the layers of the skin caused by the effects of cell death and eventually to the development of erythematous skin changes. Transient, mild erythema can occur within hours of skin exposure, likely due to capillary dilation shortly after patient exposure to radiation. However, the more conventional, sustained hyperpigmentation or erythema associated with skin exposure typically does not occur until 2 to 4 weeks into treatment. Recording of the fraction of the body exhibiting radiation-induced erythema can contribute to providing evidence of partial-body exposures that can provide diagnostic guidance for development of medical treatment strategies.

Exposure to ionizing radiation induces a constellation of clinical signs and symptoms with dose-dependent features of time of onset, incidence, and severity levels. Incidence and severity levels for radiation-induced clinical signs and symptoms progressively increases with increases in radiation dose and injury. Examples of selected radiation signs and symptoms are shown in Table 6.

Table 6 — Selected list of signs and symptoms of acute radiation exposures

Sign	Symptom
Vomiting	Nausea
Diarrhea	Headache
Fever	Dizziness
Infection	Disorientation
Erythema	Weakness
Hair loss	Fatigue
Bloody vomit and stool from internal bleeding	
Low blood pressure	
Tachycardia	
Note that such signs (apparent to physician) and symptoms (apparent to patient) are not specific to radiation exposure and can be due to a variety of other effects including stress and chronic radiation syndrome[37][38].	

Patients with acute radiation syndrome (ARS) classically go through four clinical phases: prodrome, latency, manifest illness, and either recovery or death. Clinical triage systems, for each of the clinical phases, have been developed based on radiation-induced signs and symptoms to triage individuals into various dose ranges. Suspected exposed individuals should be assessed clinically and triaged on the basis of any prodromal signs and symptoms of overexposure plus information concerning their involvement in the incident[39]. Caution is warranted to not solely rely on a single sign or symptom (i.e. onset of vomiting). At a 3-Gy acute photon exposure only 50 % of individual exposed vomit. It is important to record the clinical signs and symptoms of individuals suspected of over-exposure to ionizing radiation.

9.6.3 Haematology

Radiation causes some well-documented changes in hematologic tissue during the hematopoietic component of acute radiation syndrome that are easily measured[39]. Changes occur in lymphocyte, granulocyte and platelet counts that vary with time after exposure and dose level, typically involving an initial drop that can rebound back to normal levels at sub-lethal levels of radiation. Performing serial blood counts every few hours over the first 12 hours post exposure and continuing at lower frequency over a few days can help identify the level of exposure and injury and predict the health outcome as actions for radiation emergency medical management[40]. (https://remm.hhs.gov/).

9.6.4 Blood chemistry

Exposure to ionizing radiation results in time- and dose-dependent injury to various human organ systems (i.e. salivary glands, liver, bone marrow, small intestine, etc.) that results in corresponding time- and dose-dependent leakage of organ-derived proteins (i.e. α-salivary amylase, C-reactive protein or CRP, Fms-related tyrosine kinase 3 ligand or Flt-3 ligand) and metabolites (i.e. citrulline) into the circulating blood[40] (see Table 7).

Table 7 — Selected list of blood proteomic biomarker following acute radiation exposures[40][41]

Biomarker	Recommended sampling time after exposure
C-reactive protein, serum amyloid A	6 h to 4 d (peak ↑ 1 d)
Salivary α-amylase	12 to 36 h (peak ↑ at 1 d)
Flt-3 ligand	1 to 10 d (peak ↑ 3-4 d)
Citrulline	1 to 6 d (peak ↓ at 3-4 d)

The parotid glands are two salivary glands that sit just in front of the ears on each side of the face. Human parotid glands are exquisitely radiosensitive and following exposure of the head or neck to ionizing radiation results in peak levels of serum α-salivary amylase levels 18-30 hours after exposure to acute photon radiation. The liver is the primary source for the production of radiation-induced C-reactive protein (CRP)[41], a component of the inflammation - acute phase reaction protein system. The initial phase peak dose-dependent blood CRP levels are reported 24 h after exposure to ionizing radiation. Blood Flt-3 ligand levels, derived from the bone marrow after exposure to ionizing radiation, are reported to be a bio-indicator for radiation-induced bone-marrow aplasia and show increases 2 to 5 days post-irradiation. Citrulline is an amino acid metabolite, which is not a component of proteins, but a metabolic product of the urea cycle and nitric oxide formation. Radiation causes time-and dose-dependent decreases in blood citrulline levels, attributed to the loss of epithelial cells of the small intestine. Peak dose-dependent declines are reported at 3 days to 4 days after radiation exposure.

Triage-dose assessment algorithm systems, for each of these blood chemistry biomarkers, have been developed based on human radiation therapy studies and used in various radiation accidents. It is recommended to collect blood samples following radiation exposure and measure these blood chemistry biomarkers to assess radiation injury and dose of individuals suspected of over-exposure to ionizing radiation.

9.6.5 Cytogenetics

9.6.5.1 Dicentric assay

Biological dosimetry based on the study of chromosomal aberrations, and in particular dicentrics, is a well-established component of dose assessment during radiation emergency response, as it allows assessment of the whole- and partial-body dose to the individual. Biodosimetry using the dicentric assay can be used to perform initial cytogenetic dose assessment of mass casualties in radiological or nuclear emergencies, to assist with initial triage of individuals[39], and/or can give a firm dose assessment for individuals to assist with more detailed treatment planning and consideration of the potential long-term consequences of radiation exposure[42]. The estimated whole-body dose is reported with corresponding uncertainties usually expressed as 95 % confidence limits.

A key component of routine or emergency preparedness to apply biodosimetry is the creation of radiation and energy specific calibration curves. The procedures for doing this are fully defined in ISO 19238, however, in brief, blood taken with informed consent from healthy individuals with no prior radiation exposure is exposed to a number of radiation doses between 0 Gy and 5 Gy, and the resulting numbers of aberrations observed per cell at each dose is fitted to a linear or linear quadratic dose response relationship. The numbers of aberrations observed in blood taken from an exposed person or persons can then be linked, with a degree of uncertainty dependent on the exposure circumstances, to a dose[42][43]. For radiation emergencies, the number of aberrations manually scored in as few as 20 cells may be sufficient for rapid dose categorisation to assist with triage[38].

Throughput of analysis can also be improved through alternative rapid scoring techniques (e.g. QuickScan, Flegal et al, 2010, 2012)[44][45] and partial or full automation of some of the image analysis. Metaphase finding, image capturing and image analysis have been implemented in many labs and have been validated for use in emergency response[46] and have been tested during interlaboratory comparisons[47].

There are a number of limitations associated with biological dose estimation, and in particular with the dicentric assay, not least that dose estimation can take several days. Further, as dicentric chromosomes are rare events, their distribution in homogeneously irradiated blood (equivalent to whole body exposure events), corresponds to the Poisson distribution. For external radiation exposures, the degree of divergence from the Poisson distribution can thus be used to estimate the degree of inhomogeneity of exposure[48]. As internalisation of radionuclides is characterized by a spatially inhomogeneous irradiation of the body, which changes over time, biological dosimetry – especially for emergency response purposes - is only really effective in the small number of cases when the radionuclides are almost homogeneously distributed in the body (e.g. tritium, caesium[16]). However, in many of the circumstances considered in this document, there is a combination of external as well as internal exposure, with external exposure representing the larger dose. Hence, the dicentric assay represents an important tool for radiation emergency dosimetry purposes, and its use should be considered by the responsible authority on a case-by-case basis.

9.6.5.2 CBMN assay

It is well known that ionizing radiation induces the formation of acentric chromosomal fragments and, to a lesser extent, the incorrect segregation of whole chromosomes during mitosis, which when not integrated into the daughter nuclei can form small independent nuclei called micronuclei. The micronucleus analysis in peripheral blood lymphocytes with block of cytokinesis using cytochalasin B[49] has been routinely used for more than 40 years to estimate the individual dose after exposure to ionizing radiation.

As with most of the cytogenetics based biological dosimetry assays, the micronucleus (MN) frequency observed in vivo, when analysing an adequate number of binucleated cells (BNCs), is related to the exposure dose by comparison with the calibration curve previously carried out in vitro under identical conditions[50]. The cytokinesis block micronuclei (CBMN) assay is best suited to analysis of acute whole-body irradiation in the range of 0,2 Gy to4 Gy assessed shortly after exposure.

Limitations of the CBMN assay arise since like the DCA assay it can take several days and from background frequencies of MN that are related fundamentally to age and sex. To mitigate this limitation, each laboratory generates its own database of base-line MN frequencies, with at least three age groups for each sex. For dose estimates from the standard calibration curve, the mean value of its age group and sex background is assumed and subtracted from the measured value of MN. The minimum detection level is between 0,18 Gy and 0,26 Gy, depending on age and sex. The estimated whole-body dose is reported with corresponding uncertainties usually expressed as 95 % confidence limits.

For mass casualty events, the CBMN assay in rapid mode can be used to identify individuals exposed to at least 1 Gy of radiation, by scoring 200 BNCs or when MN yield is high, by scoring enough BNCs to observe 200 MN. In special cases where there is a high abundance of MN but few BNCs, the dose can be reported after observing 100 MN.

Automation of any biodosimetry assay could reduce the uncertainties involved in human scoring and increase throughput of the samples. ISO 17099 describes three important CBMN automation systems with different background technologies and procedures including Flow cytometry, Laser scanning cytometers (LSC) and computerized microscopes with advanced image analysis systems. More recently developed automation methods include imaging flow cytometry (IFC) methods have also been developed for CBMN analysis[51], sample processing and image analysis with the RABiTII system[52] and integration of sample preparation on the RABiTII with IFC image analysis[53].

9.6.5.3 Other – PCC for high dose

When high doses of radiation are received during a radiation accident, neither the DCA nor CBMN assays are useful, particularly for doses above 5 Gy due to the delay in or inability to stimulate highly damaged cells into mitosis. In this situation, premature chromosome condensation (PCC) assay can be used as this method forces the chromosomes to condense in any stage of the cell cycle, enabling visualization of the individual chromosomes. PCC can be used to detect chromosome breaks, dicentric chromosomes, rings

and translocations depending on the method used and the staining process. This method is well suited to provide dose estimates for acute exposures within hours of blood sampling and is useful over the dose range of 0 Gy to 30 Gy.

There are two main methods for PCC, cell fusion and chemical induction. Cell fusion involves fusing human lymphocytes with mitotic CHO cells with polyethylene glycol. This can force G_0 chromosomes in the lymphocytes to condense resulting in visible single G_0 phase chromatids within 3 to 4 h. Due to this morphology, typically, the number of excess chromatid fragments are used as a measure of radiation-induced damage. Recently mitotic *Akodon* cells, with fewer chromosomes and weakly staining telomeric sequences, were used instead of mitotic CHO cells in the cell-fusion PCC method coupled with use of centromeric and telomeric DNA hybridization probes to enhance detection of radiation-induced dicentric chromosome aberrations[54]. The chemical induction method, also called the PCC ring assay, uses a chemical such as okadaic acid or calyculin A to induce PCC in lymphocytes stimulated with a mitogen for 48h. With this assay, G_2 phase excess chromosomes, rings, and dicentrics are assessed as markers for radiation-induced damage.

Triage mode PCC has been performed for the PCC ring assay and was shown to be more accurate than the DCA at doses higher than 6 Gy[55]. More recently, the PCC fusion assay was used for triage analysis during a RENEB exercise, demonstrating satisfactory results, even for partial-body exposure[56].

Recently there have been advances in PCC that involve the addition of telomere and centromere probes that make the identification of dicentrics and centric rings more accurate[57] Automated detection of different PCC endpoints using image analysis are also being developed[57][58][59].

The PCC assay as well as additional cytogenetic techniques (i.e. FISH, γH2AX) and molecular (i.e. gene expression, etc.), while showing relevant applications for radiation dose assessment, are not discussed here since at present there are no ISO standards for their use established.

9.6.6 EPR Dosimetry

When there is uncertainty as to whether an individual has received a medically significant dose of ionizing radiation, (e.g. absence of personnel dosimetry, partial-body exposure, high dose exposure suspicion) Electron paramagnetic resonance (EPR) dosimetry with fingernails and teeth can be used for assessment of external radiation dose. The other name of this technique is ESR or electron spin resonance. This technique is able to provide an estimation of the dose absorbed in the individual. The characteristics of EPR dosimetry that may be useful arise from the nature of the technique, which is based on a purely physical interaction that does not require biological processing or is affected by pre-existing physiology or previous or simultaneous pathophysiology in the individual. Currently there are three different approaches of doing EPR biodosimetry: in vitro using samples of teeth or bones or fingernails, in vivo using fingernails and toenails, and in vivo using teeth. The dosimetric changes occur immediately and can be detected with little or no alteration for weeks in nails or thousands of years in teeth. EPR dosimetry provides an indication of dose that is unaffected by dose rate (it can be dependent on the type of radiation). It does not provide information on the biological consequences of the dose. Therefore, it is naturally complementary to biological biodosimetry, which can be affected by previous and coexisting alterations in physiology or pathophysiology but can provide insights into the likely biological (medical) consequences of the dose. For biodosimetry EPR measures a radiation-induced free radical signal in human hard tissues such as tooth enamel, bone, finger- and toenails. While not covered further here EPR is also able to measure doses absorbed in some electronic gadgets and objects carried on the body such as cell phones, watches, sugar-coated drugs and candies. ICRU report 68 “Retrospective Assessment of Exposures to Ionizing Radiation”[60] provides description and examples of application of EPR dosimetry in teeth for epidemiological studies. ICRU REPORT 94 Methods for Initial-Phase Assessment of Individual Doses Following Acute Exposure to Ionizing Radiation[61] provides similar details for use EPR dosimetry in teeth and fingernail for initial dose assessment. There are also two ISO standards devoted to the description of EPR dosimetry[62][63].

The in vitro methods are the most widely available and extensively developed. They usually use conventional EPR spectrometers operating at about 9,5 GHz (“X-band”). X-band EPR spectrometers are commercially produced by several companies and typically available at most universities and research centres. This method requires availability of the extracted or exfoliated teeth or bones or clippings of fingernails. The use of teeth or bones therefore is most suitable for epidemiological studies of populations with a prior history of potential exposure to ionizing radiation, such as populations living downstream from a contaminating source. It is a well-established method[62], which was successfully used in several radiation epidemiological

studies[59]. With this technique experienced laboratories can resolve doses as low as 50 mGy. A similar approach can be used with bone but the intensity of the radiation induced signal is lower. Because of the paucity of circumstances when samples of bone are available, it has only been used after a few accidents with dose due to high radiation exposures; in these instances, it has provided useful data.

Fingernail clippings also can be measured in vitro usually using X-band. The required amount of the sample is about 30 mg. Although initially there was great optimism about the potential value of using nail clippings for dosimetry after a large event, this approach has been stymied by artifacts associated with the clipping process and post-clipping changes in the nails. Consequently, currently the role of EPR dosimetry based on nail clippings has been limited to the management of small incidents[64].

In vitro EPR dosimetry in small biopsy samples of tooth enamel and fingernail clips are feasible at high microwave frequency, usually using Q-band (35 GHz). It would be more feasible to obtain such small samples almost immediately after an exposure and does not require sample preparation. Therefore, it has the potential to be used for acute potentially life-threatening exposures[61].

In vivo EPR biodosimetry measurements of dose in teeth and fingernails now can be made. The obvious benefit of this method is that it does not require sample collection and it can be done on the spot with instrumentation that can be brought to the site of the event if needed and operated by non-expert personnel. Both approaches are in development and not widely available.

In vivo tooth dosimetry using lower frequency EPR (1,2 GHz, L-band) is the furthest advanced with field deployable instruments located in the USA (3 instruments), Japan (1 instrument), and Korea (2 instruments). The in vivo tooth dosimeter uses the two upper central front teeth (incisors) which are readily accessible and less subject to tooth decay. Based on realistic measurements of one front tooth the technique can reliably determine in less than 5 min whether an individual has received more than 2 Gy, the commonly used threshold for triage into the health care system after an acute exposure to ionizing radiation[65]. Lower doses can be detected by extending the measurement time or measuring both incisors. Detectable levels also can be lowered by obtaining background measurements in personnel (e.g. radiation workers, first responders). The instrument can be used by non-expert operators. It has been transported to Fukushima Japan where measurements were made on residents (no detectable doses found due to the accident. However, there is a case of signal detection derived from frequent dental radiological examinations). The resulting estimates of dose are independent of dose rate or when the exposure occurred so these factors need to be taken into account when utilizing the results of the measurements.

In vivo nail dosimetry is at an earlier stage of development. It utilizes the usual higher frequency EPR (X-band, 9,2 GHZ). It requires a special developed resonator to make measurements in vivo at this frequency. These have now been developed and measurements have been made in human volunteers[65]. This technique has the very important potential advantage of enabling measurements to be made to determine the homogeneity of the exposure, which is a critical medical consideration in determining the medical consequences of exposures. It can do this because measurements can be made in each hand and foot. It also has the potential advantage of being able to measure multiple nails on each limb, which would bring the sensitivity for screening lower than the currently projected 2 Gy attainable with current state of the technology. Currently there are only developmental versions of these instruments available[65][66].

9.6.7 Combination of dose assessment methods

Use of a multiple parameter-based biodosimetry and dosimetry assessment is recommended in order to address potential complex radiation exposure scenarios that can involve partial-body vs total-body radiation exposures, combination of low- and high-LET radiation, and radiological mass-casualties events. The radiation dose to cause life-threatening risks is increased by 2 to 3 Gy with partial-shielding of at least 5 % of the bone marrow. Fission neutron exposure reduces the dose to cause 50 % survival at 30 days ($LD50_{30d}$) when compared with exposures to acute photons. Results from triage dose assessment assays can assist to prioritize high-risk individuals in the initial processing of patients from a radiological mass-casualty incident.

To date, it is clear that the dicentric assay and other biodosimetric methods and EPR techniques can only be applied in certain special cases of internalisation of radionuclides[48].

Algorithms using multiple-parameter based biodosimetry and dosimetry assessment have been developed and in general show improved accuracy for prediction of triage radiation dose and injury[68][69]. Biodosimetry worksheets (see Annex C), software tools, and websites to aide in the recording of dose assessment by use of a combination of dose assessment methods (i.e. clinical signs and symptoms, haematology, blood chemistry, cytogenetics, EPR-dosimetry, etc.) have been developed (see section below). Use of a multiple-parameter based biodosimetry approach can contribute to develop appropriate early-phase treatment strategies and definitive radiation exposure assessment.

Resources to assist responders and emergency medical personnel in managing radiation injury and dose assessment are available. These resources include: worksheets, software, and website tool (Annex E). It is advisable to prepare in advance and review/access the relevant resources to assist in the response to a radiological incident.

10 Recording and reporting monitoring and dose assessment results

10.1 Purpose

Upon their arrival at the population screening centre, emergency workers and the public should be informed about the purpose and the need for screening, monitoring and dose assessment, and how such information is used and safeguarded.

In the registration form (see A.2.5), there should be designated spaces for recording results of screening, monitoring and dose assessment, as well as extra spaces for adding notes when necessary. Results from screening, monitoring and dose assessment for both external and internal contamination and exposure shall be recorded, with necessary and available details. One important lesson learned from the Fukushima accident and the Chernobyl accident is that the lack of a pre-planned registration system for the populations monitored became a critical impediment for health surveillance and epidemiology after the accident[69]. Example protocol for establishing a registry of individuals potentially affected by a large incident was reported by Close et al.[70].

Purposes of recording screening, monitoring and dose assessment results are to:

— identify the individuals who need external decontamination;

— identify the individuals whose contamination and/or exposure is of concern;

— identify the individuals who need more detailed dose assessment;

— identify the individuals who need medical or health follow up; and

— keep records for future revisit/verification and potential legal applications.

At the registration station (see A.1.5), the screening, monitoring and dose assessment results if available shall be communicated with the affected individuals. For the ones who need more detailed dose assessment and potential medical or health follow up, their results shall be reported to dose assessment station (see A.1.6).

Purposes of reporting screening, monitoring and dose assessment results to the affected individuals are to:

— relieve the individuals from unnecessary concerns if the external/internal contamination and/or exposure is not a concern; otherwise;

— inform them about external contamination with radionuclides on their surfaces (clothing, skin and hair), health risks, and the need for further decontamination;

— or, inform them about exposure from radiation they received from the environment (air, ground), health risks, and necessary follow up steps;

— or, inform them about internal contamination, health risks, and necessary follow up steps.

Purposes of reporting screening, monitoring and dose assessment results to professionals for detailed dose assessment, medical or health follow up are to:

— provide initial findings/results that inform the plans for more detailed dose assessment from external contamination/exposure and/or internal contamination;

— provide initial findings/results that inform decisions and prescriptions for necessary medical interventions; and

— provide initial findings/results that inform the plans for health follow up.

10.2 Recording monitoring and dose assessment results

10.2.1 General

For contaminated or exposed persons, sufficient details should be recorded for screening, monitoring and dose assessment. It is recognised that during a mass casualty incident, it is difficult to capture a lot of this information. However, as much of the available information should be recorded as possible.

10.2.2 Recording screening and monitoring results

Results of screening and monitoring for emergency workers and members of the public from both external contamination/exposure and internal contamination should be recorded.

For screening:

— for external exposure: demographics, location at time of incident and time spent near the radiation field;

— for external contamination: radionuclides involved, initial screening readings, screening results after decontamination, and potential for internal contamination;

— for internal contamination: radionuclides involved and their physical/chemical properties, time and duration of exposure, and possible intake pathways;

— in addition, health conditions and clinical manifestations for significant exposure scenarios, such as nausea and vomiting, diarrhoea, fever, skin burns, neurological manifestations, if observed, should also be recorded.

For sampling:

— the procedure for taking samples (e.g. urine or nasal samples) shall be described or referenced;

— the procedure shall be designed to ensure that the sample is properly collected, packaged and labelled and is not contaminated;

— each sample shall bear a unique identification and should be handled following chain of custody protocols. This identification shall be used to denote the identity of the individual, the date and time that the sample was taken, and the purpose of sampling;

— the purpose of sampling should be clearly communicated with the individual and the consent should be obtained, if necessary.

For measurements:

— the procedure for making measurements shall be documented;

— the procedure shall be designed to ensure that the equipment used is operating correctly and is properly calibrated;

— each measurement shall be given a unique identification. In the case of measurements on samples, this identification shall be used to denote the identity of the sample measured and the date and time of the measurement. In the case of direct measurements on individuals (e.g. thyroid count, whole body count,

surface contamination screening), this identification shall denote the identity of the individual and the date and time of the measurement;

— the measurement result shall be recorded with an estimated uncertainty if possible, together with conditions of measurement, such as counting time, equipment and method used for the measurement (including calibration), limit of detection and background, if available.

10.2.3 Recording dose assessment results

Results of dose assessment for emergency workers and members of the public from both external contamination/exposure and internal contamination shall be recorded.

For dose assessment:

— the procedures for assessing doses shall be documented, including the assumptions made with respect to dose rates and durations used for external exposure, routes and temporal patterns of intakes for internal contamination, as well as default or specific parameters applied (e.g. values of AMAD and f_1 absorption fraction), chemical and physical nature of the radioactive contaminant and the assumed absorption type);

— if computer software is used to calculate the dose, the identity of the software used shall be recorded together with all parameters used in the calculation;

— assessment result for dose shall be recorded and detailed notes should be provided on information leading to the assumptions and selected parameters as well as anything that requires further verification, if available.

10.3 Reporting screening, monitoring and dose assessment results

10.3.1 General

Screening and decontamination results for external contamination/exposure and possible internal contamination shall be communicated with the affected individuals at the registration station (A.1.5). If such results are not available, contact information for the affected individuals shall be captured for submitting results to them later.

For the individuals whose assessed exposure/contamination warrants more detailed dose assessment and/or medical or health follow-up, their results shall be reported to dose assessment station (A.1.6) for further dose assessment and/or the person shall be directed to medical and health professionals for necessary medical or health follow up.

All results from screening, monitoring, initial dose assessment, detailed dose assessment, medical interventions and health follow ups should be entered into a special registry dedicated to each emergency event.

10.3.2 Reporting results to the individuals being monitored and assessed

At the registration station (see A.1.5), the screening and decontamination results shall be communicated with the affected individuals, if available, including:

— contamination on body surface (clothes, skin, hair), and if it is a concern, the health risks to the individual and his/her family members, as well as instructions for further decontamination at home if necessary;

— the necessity for initial dose assessment for internal contamination.

At the d*ose* assessment station (see A.1.6), the following information shall be communicated with the affected individuals:

— the estimated dose, and if it is of a concern, the health risks to the individual and his/her family members, as well as the next steps including detailed contamination/dose assessment and medical or health follow up.

10.3.3 Reporting results to personnel performing more detailed dose assessment

The screening, monitoring and dose assessment results for the individuals whose surface contamination, external exposure/contamination, or internal contamination, indicates significant exposure and/or large assessment uncertainties, shall be reported to d*ose* assessment station (A.1.6) for more detailed dose assessment, including:

— for external contamination screening, the initial results (e.g. count rates, radionuclides identified), decontamination performed (full, partial), the re-screening results, and instrumental (instrument type, model, serial number) and environmental (background reading) parameters;

— for external exposure from radiation in the environment, the locations and time spent in each location in which the individual has been involved;

— for internal contamination, monitoring performed (thyroid, partial or whole body, nasal swabs or facial swipes) and results, sampling procedures and timing, instrumental and environmental parameters;

— for all of the above, assumptions and uncertainties as well as any potentially useful information related to exposure/contamination and/or screening/monitoring, if available;

— contact information of the persons who performed the screening, monitoring and dose assessment.

10.3.4 Reporting results to professionals for medical or health follow up

For individuals whose monitoring and dose assessments indicate significant contamination or exposure and/or who show symptoms of significant exposures, their screening, monitoring and dose assessment results shall be reported to medical and health professionals for necessary medical interventions and health follow up, including:

— observations on health conditions and clinical manifestations indicating significant exposure (nausea and vomiting, diarrhoea, fever, skin burns, neurological manifestations);

— results of external contamination screening, radionuclides and activity concentrations before and after decontamination, as well as any indication of skin burns;

— results of internal contamination, radionuclides and intake activities, chemical and physical parameters;

— results of assessed exposure and dose from radiation in the environment, exposure from external contamination, and exposure from internal contamination.

11 Supporting processes and quality management

11.1 Purpose

Nuclear crisis response refers to the preparation of measures taken to reduce the severity of the nuclear/radiological incident effects. In this frame emergency management procedures for supporting process such as protection to human life, health, environment and hazard assessment for foreseeable events or incidents should be considered by national authorities.

The goal of preparedness shall be to reduce the impact of incidents on vulnerable populations, prepare an organization for an influx of activity, and design a coordinated emergency plan with a strong quality assurance program that reduces the waste of resources, time for actions, and efforts[31]. Further protocols for preparing for nuclear incidents shall include communication strategies in the event of a crisis on the actual incident in progress as well as on the risks and possible health consequences in the short and long term of the incident. Besides, this planning cannot be designed without strong training of workers and population involved in the incident.

11.2 Preparedness

It is recognized among the organizations responsible for the management of radiological emergencies that good preparation shall considerably improve the response to this emergency including population monitoring.

In addition, one of the most important characteristics of this preparation is to be integrated into the different bodies involved, guaranteeing clear lines of responsibility and authority.

The protocols identified in advance shall facilitate information to decision-makers, the coordination of information from local and national authorities, and which channels are used to communicate this information to the public[31][71].

Objectives are more likely to be achieved in accordance with these principles by implementing a preparedness program for serious emergencies. Emergency preparedness also helps to build confidence in effective management, control and coordination during an emergency response.

In other words, the practical objective of emergency preparedness should be to ensure that arrangements are in place for timely, managed, controlled, coordinated and effective response at the site including population monitoring, as well as at local, regional, national and international levels, for any nuclear or radiological emergency.

Furthermore, it should improve flexibility to adapt to specific situation and help to be prepared for the unexpected. An appropriate emergency preparedness program includes:

— emergency plans and procedures to deal with all the potential dangers linked to the practices considered;

— training and exercise programs for a variety of representative scenarios including providing sufficient theoretical and practical courses for all the key organizations and positions indicated in emergency plans;

— process of audits and evaluation allowing the feedback from lessons learned from real incidents, during training and following exercises in order to improve all of the above.

11.3 Emergency plans and procedures (planning)

Emergency planning is a major part of the preparedness for nuclear/radiological incidents that require population monitoring. It should be at the heart of the civil protection duty of first responders. Responders are required to maintain plans for preventing emergencies; reducing, controlling or mitigating the effects of emergencies in both the response and recovery phases; and taking other actions in the event of emergencies. The regulations require quality assurance plans based on standards containing a procedure for determining whether an emergency has occurred; provisions for training key staff; and provisions for exercising the plan to ensure it is effective (ISO 9001 and ISO 17025)[72][73].

Procedures shall also be put in place to ensure that the plan is reviewed periodically and kept up to date.

Quality assurance emergency plans should take the form of generic plans - which set out the core of a responder's response to, and recovery from, any emergency - or specific plans dealing with particular hazards or sites.

These procedures should be completed in relation with quality assurance emergency plans with specific information or check list to facilitate the realisation of emergency procedures. An example of a check list for facility opening is given in Table 8.

11.4 Training and exercises

Training public health personnel and those involved in emergency response is essential. Training should focus on improving the understanding of the physical principles of radiation protection and its effects. In addition, it should prepare emergency workers to focus on their roles and responsibilities (e.g. proper use of available detection and personal protective equipment, decontamination, communications, collection of samples, methods and laboratory procedures), and identification of resources[74][75].

The training should be provided to allow better awareness of the methods of monitoring the population for the following groups:

— first responders (first members of an emergency service to respond at the scene of an emergency[30]);

— officials and public decision makers;

— clinicians, other health care providers and hospital staff;

— journalists and the media;

— voluntary intervention organizations, such as civil security, firefighters.

Training shall be interactive and understandable. It shall use situational exercises from various scenarios representative of different circumstances/situations (national or local) to test the preparation plans put in place and ensure that all entities that are involved in the response (both emergency response and health care organizations/hospital workers) are included.

In addition, existing training resources, such as satellite broadcasts, webcasts, videos and printed materials, should be used and tailored for specific purposes. An example of a check list for considerations for venue selection is given in Table 9.

Training themes for awareness should address at least:

— the types of radiological risks;

— the principles of radioactivity and radiation protection;

— means of contamination control and how to minimize individual exposure;

— principles of external and internal dosimetric reconstruction.

Regarding the training of public health personnel, this training should cover the following activities:

— medical organisation and management of the population screening centres (PSCs) according to the size of the population to be monitored and the specific needs of the community;

— the establishment of large population management organizations, including the development of triage procedures and the distribution of information during population monitoring;

— the use of on-site equipment to monitor external and internal contamination;

— identification and management of the specific needs of the population, such as knowing how to recognize psychological trauma and practicing psychological first aid.

Staff working at a population screening centre should be trained on and exercise the following:

— emergency and first aid procedures for victims of radiation and internal contamination;

— medical effects of radiation;

— assessment of exposure to external and internal radiation;

— triage and rapid management of contaminated or irradiated patients;

— psychological consequences;

— emergency operations communication systems and procedures.

Additionally, specific documentation should be prepared by and for a wide range of stakeholders (local public health authorities, journalists) to increase knowledge among populations of radiation protection and the effect of radiation. This material could be used to provide quick basic information during an incident.

11.5 Communication

11.5.1 General

Emergency communication plans should be developed in order to clearly define the roles and responsibilities of national and local stakeholders involved in communications[76].

National and international communication requirements should be taken into account in these plans, as well as requirements for different types of information intended for responders, the general public and technical experts. In addition, using multiple routes of communication (news outlets, websites, social media, flyers, etc.) helps in reaching as many people as possible in different sectors/societal groups.

These plans should be maintained and improved by carrying out periodic reviews or exercises and using regular and frequent communications during normal operation of nuclear facilities to build local relationships and trust.

11.5.2 Public communication

The main focus of public communication should be to maintain the bond of trust between the population and those involved in the management of a nuclear/radiological incident (State, experts and operators) in order to get the population to adhere to the measures taken to guarantee the implementation of protection actions[71]:

— ensuring transparency by disseminating information based on the reality of the situation;

— by making information accessible to the general public (thanks to an adapted pedagogy, its credibility and rapid and multi-channel distribution);

— by explaining the organization (actors and responsibilities) and crisis management (actions implemented).

It should also allow the people concerned to take part in their protection:

— by providing information on vigilance and behaviour recommendations (actions to be taken to assist in the application of measures);

— by communicating on the importance of their active investment in the management of the crisis (placing the fellow citizens at the heart of the system, making people understand the importance of their action for the community and for themselves).

It should take into account all populations (even those not impacted) and the international community[73]:

— by adapting certain messages to the national dimension;

— by integrating into the communication strategy, taking into account the specificities of the expectations, observations and reactions of other countries.

The implementation of public communication should be:

— in the continuity of the information of the local populations, the information at the governmental level shall be able to immediately take into account the national dimension. This measure continues throughout the crisis management period;

— as part of the management of a post-incident situation, national communication shall be maintained on certain specific themes (contaminated areas, agricultural activities, medical follow-ups, consumption, etc.).

11.5.3 Emergency operations communication

Communications among responders are critical to effective response operations. Planners are encouraged to consider emergency communications systems that may be utilized in the wake of a nuclear/radiological incident. It is critical to establish communications between each facility having emergency-response

capabilities and with the pertinent emergency coordinators to obtain and transmit information on the status within and outside the population screening centre[31][71].

Communications after a nuclear explosion is expected to be difficult due to local damage to communications infrastructure, and potentially damaging electromagnetic pulse (EMP). Where possible, planners should incorporate EMP resistant equipment and consider redundancy with dissimilar means of communication.

Communications systems within PSC facilities should be redundant, tested regularly, and maintained appropriately. Phone and cellular circuits are frequently overloaded in disasters, possibly rendering them useless. Therefore, 2-way radios and satellite phones should be available as backup communication methods for key PSC personnel.

11.6 Audits and evaluation

Evaluation of preparedness and training is generally carried out by participating in drills or exercises[31].

The organisations in charge of preparedness shall regularly conduct a program of national nuclear/radiological crisis exercises including population monitoring. These exercises should involve at least the operator (if the exercise involves nuclear power plant or other large facility that uses radioactive materials), local and national public authorities, first responders, health personnel, volunteers, and, if possible, the public.

The main objective shall be to test the resources that are anticipated to be available, or planned for, in the event of a radiological emergency in order to:

— ensure that the plans are kept up to date, known to managers and stakeholders at all levels, and that the alert and coordination procedures they contain are effective;

— train people who would be involved in such a situation;

— implement the various aspects of the organization and the procedures provided for: emergency plans, municipal backup plans and various conventions;

— sensitize the population, so that everyone can contribute by their behaviour to civil security;

— capitalize on knowledge and experience in emergency management.

Table 8 — Facility opening checklist

Facility opening checklist				
Facility name:	Facility representative:			
Location:	Date of facility check:			
	Conducted by:			
	Date of last facility check:			
	Conducted by:			
Name of person addressing issue:	Date issues addressed:			
Contact information for person addressing concerns:				
"NA" for the specific areas needing correction. The persons responsible for corrections should be noted in the comments column				
Areas to review	Yes	No	NA	Comments
Are indoor/outdoor walking surfaces free of tripping or falling hazards (uneven sidewalks, unprotected raised walkways/ramps/docks, loose/missing tiles, wires, extension cords, etc.)?				

Table 8 *(continued)*

Are the paths to exits relatively straight and clear of obstructions (blocked, chained, partially blocked, obstructed by garbage cans, etc.)?				
Are all the emergency exits properly identified and secured?				
Are there at least two exits from each floor?				
Are illuminated exit and exit directional signs visible from all aisles?				
Is there an emergency evacuation plan and identified meeting place?				
Are there guidelines for directing occupants to an identified assemble area away from the building once they reach the ground floor?				
Are there any site specific hazards (hazardous chemicals, machinery)? If so describe them.				
Is the facility clean, neat and orderly?				
Are the following building systems in good working order?				
Electrical				
Water				
Sewage System				
HVAC (heating, ventilation and air-conditioning), if necessary				
Are fire extinguishers and smoke detectors present, inspected and properly serviced?				
If power fails, is automatic emergency lighting available for egress routes, stairs and restrooms?				
Are first aid kits readily available and fully stocked? Where?				
Are occupants of the building notified that an emergency evacuation is necessary by PA (personal assistance) or alarm?				
Any damage or additional comments:				
Worker signature:			Date:	
Reviewer signature:			Date:	

Table 9 — Considerations for venue selection for practice drills

If practicable, choose a location in which you would actually set up your population screening centre in an emergency to simulate facility operations in the most realistic setting possible, taking into account the following considerations: — Ensure the location has sufficient additional space to accommodate logistical activities related to the drill. — Make sure that the location has sufficient space to allow for all of the facility equipment, including electrical cords and power sources, without impeding drill participants. — Make sure the maximum occupancy limitations are sufficient for the expected number of participants (including observers and evaluators). — Set aside room(s) or area(s) for registration, briefings, and participant waiting (separate volunteers playing affected individuals, players, and controller/evaluators if possible). — Select a facility with room acoustics that facilitate ease of discussion. — Include tables and chairs in the registration, drill, and waiting areas as appropriate for the expected activities. — Consider accessibility of the facility to all participants, and whether special permission or security screening is needed prior to entry. — Choose a facility in a location that is free from other distractions, such as other concurrent uses of the building or accessibility to the public that could result in unplanned observers. — Use a facility with adequate parking and restrooms for all participants. — If outside observers/media are expected, make sure the venue has sufficient space to allow these individuals to observe without obstructing or affecting play. — If the drill includes live pets and service animals, the drill facility should be suitable for this purpose. — If the drill includes demonstration of decontamination methods (e.g. showering), the drill facility should be suitable for this purpose.

Annex A
(informative)

Screening centre roles, equipment, and communication (see Clause 6)

A.1 Description of activities/roles at each station

A.1.1 Initial sorting station

Staff greet and direct people based on:

— having an urgent medical need;

— being potentially highly contaminated with radioactive material;

— requiring special assistance;

— eligible for expedited handling – person has already showered or been decontaminated before coming to the Centre.

A.1.2 First aid station

Provides basic medical care.

— If the patient needs advanced medical care, first aid staff should request medical transport to a healthcare facility.

— If the patient is contaminated with radioactive material, first aid staff can perform a gross decontamination by carefully removing the patient's outer layer of clothing before transport.

— Lifesaving care should not be delayed due to concerns of cross-contamination.

A.1.3 Contamination screening station

Station where people are monitored for contamination.

— Depending on the resources and staff available, a combination of partial-body and full-body contamination screenings can be used to identify contaminated people.

— An express lane can be established for people who have showered or been decontaminated before coming to the centre.

— A partial-body contamination screening focuses on the hands, face, shoulders, head, and feet and can identify most contaminated people.

— If contamination is detected during this screening, that person is conducted to the decontamination station.

A.1.4 Decontamination station

Staff review contamination screening results to determine the best decontamination method for each contaminated person.

— Soap and warm water are effective in removing external contamination. Decontamination can be conducted using showers, sinks, or wet wipes.

— After a person finishes decontamination, staff should perform a full-body screening to ensure the person is clean and can proceed to Registration.

— Depending on the resources available, centre managers may decide to use existing indoor shower facilities or an outdoor decontamination unit.

— Contaminated clothing should be bagged and labelled with the person's name and ID number assigned upon entering the Centre.

A.1.5 Registration station

Staff collect demographic and incident-specific information from people who have been screened for contamination and cleared to enter the clean zone. This information is used to determine whether someone needs immediate follow-up at the radiation dose assessment station and possibly long-term follow-up.

A.1.6 Radiation monitoring and dose assessment station

Requires specialized staff and equipment to:

— screen people for potential internal contamination;

— assess each person's radiation dose;

— collect samples (e.g. blood, urine, fingernails) for in vitro laboratory analysis;

— assess each person's need for treatment;

— prioritize people for further care.

A.1.7 Discharge station

Staff provide information for people leaving the screening centre, including referrals to hospitals or alternate care sites for additional medical follow-up.

— As possible, mental health professionals at this station assess each person's need for counselling and make themselves available to address psychological needs elsewhere in the screening centre.

People leaving may be:

— referred for additional care;

— discharged to their home, to the home of a friend or family member, or to a public shelter.

A.2 Equipping the centre

A.2.1 General

Initial supplies shall be strategically stored, and sources identified, in advance of anticipated emergencies. Some materials have a limited shelf life and should be inspected and replenished regularly. The following are examples, and not intended to be complete listings of all needed supplies.

A.2.2 Contamination control supplies

— materials for constructing signs or instruction posters;

— barriers (stanchions and rope);

— step-off pads (tacky mats);

— plastic bags (variety of sizes);

— butcher paper (or absorbent floor covering such as disposable painting drop cloths);

— plastic sheeting.

A.2.3 Personal protective equipment (PPE) for screening centre workers

The health and safety officer determines the level of protection needed for workers at each station, noting that respirators and other PPE may cause physical strain on the wearer and might require medical surveillance and training, according to the local jurisdiction. The list below provides examples of types of PPE that may be needed for stations located in the contaminated zone of the screening centre, and specific recommendations depend on several factors including location of screening centre with respect to incident site, anticipated level of contamination in arriving individuals, etc.:

— scrubs or uniforms;

— coveralls (e.g. Tyvek®) with or without attached boots and hood;

— waterproof surgical gowns or aprons;

— plastic (vinyl, nitrile) examination gloves, multiple layers are recommended;

— closed-toe shoes or boots;

— disposable shoe covers;

— respiratory protection;

— surgical masks;

— N-95 masks;

— face shields or safety glasses;

— tape (duct tape, masking tape, barrier tape).

A.2.4 Decontamination equipment and supplies

— moist towels or disposable wipes;

— paper towels or disposable towels;

— duct tape (for dry decontamination);

— large plastic bags (a variety of sizes to hold clothing);

— zipper-type bags for small personal items;

— adhesive labels;

— soap (mild);

— shampoo (without conditioner);

— baby shampoo;

— waterless hand cleaner;

— plastic sponges;

— soft nail brushes;

— towels;

— clothing items, such as coveralls or scrubs for people to wear as they exit showers. (Consider having clothing of various sizes including very large and children's sizes.);

— sanitary garments, such as diapers for children of various ages;

— shoes, sandals, or shoe coverings;

— blankets or heaters for warmth. (Heaters should not blow air across a potentially contaminated area.).

A.2.5 Forms and telecommunications equipment

— informational fact sheets (in several languages) to distribute to people at the population screening centre (brief informational posters can also be positioned along the queues);

— pre-designed forms (paper or electronic) to collect information (demographics, contact information, contamination levels, etc.);

— notebooks;

— telephones, cell phones, radios and fax machines;

— computers (laptops, tablets) and Internet connectivity (if possible);

— photocopiers or scanners (copying driver licenses or other forms of photo identification with current information may expedite the registry process).

A.2.6 Example of equipment and supplies needed for sample collection

— appropriate administrative forms (e.g. consent forms);

— urine sample collection cups;

— blood sample collection kits (unlikely unless population is being checked for exposure, not contamination);

— nasal swabs;

— nail clippers (for in vitro EPR analysis);

— chain-of-custody documentation.

A.2.7 Types of radiation detection and measurement equipment

Identify the type and number of equipment that would be needed for screening population and their availability. Examples of types of instruments needed are provided below.

NOTE These instruments require periodic calibration and maintenance. For specific information on these instruments and their maintenance requirements, consult with health physics experts in your radiation program.

— Geiger-Mueller (GM) pancake survey meters (see B.3);

— handheld alpha contamination monitors (only if alpha contamination is suspected);

— beta/gamma portal monitors (see B.2);

— direct (in vivo) measuring equipment for internal contamination (e.g. thyroid scan, whole body counter), if available;

— personnel dosimetry or area monitors, as determined by the health and safety officer.

More details are provided in Clause 9.

A.2.8 Miscellaneous supplies

— large garbage bags;

— large waste drums capable of holding about 200 l;

— folding chairs (at various places in the facility, folding chairs should be available in temporary waiting areas; some people, particularly the elderly, may find it difficult to stand for an hour or more until cleared through the monitoring process);

— drinking water;

— first aid kits;

— defibrillator;

— portable toilet facilities (outside area only);

— portable sinks or tubs (outside area only).

A.3 Communication

Communicating about radiation and related emergency issues is extremely challenging. Radiation is unfamiliar to, and not well understood by, most people. Increased understanding and effective communication during radiation emergencies can decrease illness, injury, and death; facilitate response and recovery efforts; avoid misallocation of limited resources; reduce rumours; and minimize medically unnecessary self-referrals to hospitals and other critical facilities.

Information primarily revolves around questions to help determine the risk, as well as questions on protective actions to reduce risk. Such questions could include the following:

— Am I in danger from the radiation?

— Am I radioactive?

— Am I still carrying around radioactive material on my body? Skin? Clothes? How do I get it off? What symptoms should I expect? Is my condition contagious? Is it curable?

— Did I eat or breathe in radioactive material? Is it inside my body now? If so, how long will the material stay in my body? Should I be treated?

— Were my children exposed? Were my pets exposed?

— I'm pregnant – will my baby be all right?

For any level or amount of exposure, even miniscule, people want to know what health effects they may have in the future. The communication strategy should meet people's informational needs, bridge the gap between technical facts and risk perception, and promote responsible public actions.

Effective and credible communication strategies are necessary. Most radiation exposures do not result in any measurable health effects, and the U.S. Environmental Protection Agency (EPA) has prepared a useful booklet on this subject[3]. In addition, research conducted by the U.S. Centers for Disease Control and Prevention (CDC)[4] has identified best practices in communication in radiation emergencies, which include the following:

a) create messages that address public concerns;

b) provide prioritized instructions and directions;

c) tailor messages by:

   1) time post-incident;

   2) distance from the incident;

3) https://19january2021snapshot.epa.gov/sites/static/files/2017-07/documents/epa_communicating_radiation_risks.pdf

4) Radiation Risk Communication for Public Health WD4239 | CDC

3) delivery method (television, radio, Internet, social media, etc.);

d) create messages that are urgent and serious in tone yet provide a sense of hope;

e) avoid using messages that contain perceived contradictions;

f) use plain, non-technical language;

g) make messages concise;

h) avoid or define unfamiliar and technical terms and phrases;

i) repeat messages as appropriate.

In a radiation emergency, people seek information using multiple communication channels. Providing a consistent message through television, radio, websites, and social media, along with any other public information methods, maximizes message efficiency and efficacy.

Communication and public information staff should establish a network of qualified public health media contacts, specifically those with radiation expertise. Identify key public health spokespeople and train them in advance for media announcements or interviews and develop plans to communicate with special populations.

Ensure that the public health department is aware of procedures for contacting community and civic organizations, local government and corporate officials, and appropriate federal agencies. Local government and corporate officials need to be aware of their roles in the overall response plan, ideally through participation in training, drills, and exercises.

A.4 References

Population Monitoring in Radiation Emergencies – A Guide for State and Local Public Health Partners. Second Edition. April 2014. Population Monitoring in Radiation Emergencies (cdc.gov) (accessed 28 April 2023).

Annex B
(informative)

Screening external contamination

B.1 High contamination screening job aid

B.1.1 General

Screening for highly contaminated people is an important contamination control measure in the population screening centre. Staff at the initial sorting station can use either alarming dose rate meters or count rate meters (e.g. Geiger-Mueller counters) to perform high contamination screenings. This screening should be quick and non-intrusive, and it should not delay entry into the facility. Contaminated people should be conducted directly to the decontamination station.

B.1.2 High contamination screening technique using an alarming dosimeter

a) Set your dose rate meter to the established screening criteria (dose rates below this level do not set off the alarm).

b) If your meter has an audible alarm, use headphones or an earpiece to help you hear the alarm and reduce anxiety among people in line.

c) Walk slowly along the line, engaging new arrivals as they approach or enter the facility.

d) If your meter alarms, isolate the source, and ask that person to step out of line.

e) Conduct the contaminated person to the decontamination station. Avoid physical contact with the person.

B.1.3 High contamination screening technique using a count rate meter

a) Set your meter to proper settings for the probe you are using and review the screening criteria.

b) If your meter has an audible signal, use headphones or an earpiece to help you hear the counts and reduce anxiety among people in line.

c) Walk slowly along the line, engaging new arrivals as they approach or enter the facility.

d) If your meter registers readings above the screening criteria, isolate the source, and ask that person to step out of line.

e) Conduct the contaminated person to the *decontamination station*. Avoid physical contact with the person.

B.1.4 If the person is not contaminated

a) No action is required.

b) Allow person to continue into the facility.

B.2 Portal monitor job aid

B.2.1 General

Portal monitors provide an efficient means of screening people for external contamination. These monitors can detect gamma and beta radiation, but not alpha radiation. Similar to metal detectors at airports, the portal monitor scans people as they walk through the device. An occupancy sensor (laser sensor) detects when a person is passing through the monitor. If the portal monitor detects radiation above screening levels, an alarm sounds, and a red light comes on.

B.2.2 Positioning the portal monitor

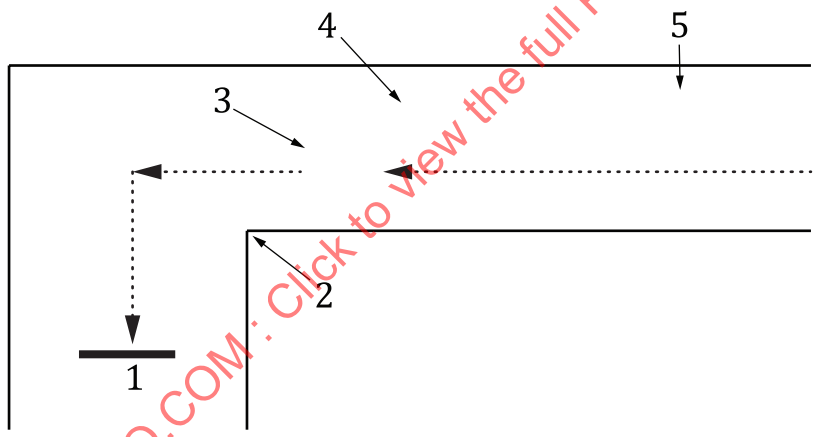
Because portal monitors are highly sensitive to gamma radiation, you need to be careful where you place them in the p*opulation* screening centre. If not positioned properly, a highly contaminated person further back in line could set off the alarm when someone else is walking through the detector.

To avoid false alarms:

a) Provide additional layers of radiation detection before people get to the portal monitor (e.g. high contamination screenings, partial-body contamination screenings).

b) Position portal monitor to take advantage of shielding within the facility (e.g. corners, pillars, doors). See Figure B.1.

c) Otherwise, set a “hold line” at least 2 m to 3 m from the portal monitor (6 m is preferable).



Key

1 portal monitor
2 corner used for shielding
3 line control
4 partial-body screening
5 high contamination screening

Figure B.1 — Portal monitor placement

B.2.3 Setting up the portal monitor

Review the manufacturer’s instructions for assembly:

a) Assemble the unit where you intend to use it.

b) Check cable connections and power source.

c) Turn on monitor and allow it to perform its start-up check.

d) Conduct an operational check using a check source (e.g. button source):

   1) walk through with NO source — monitor should NOT alarm;

   2) walk through with source at head level — monitor should alarm;

   3) walk through with source at waist level — monitor should alarm;

   4) walk through with source at foot level — monitor should alarm;

   5) walk through with source near one detector — monitor should alarm;

   6) walk through with source near other detector — monitor should alarm.

Caution — If any of these checks fail, then the monitor should be considered inoperable. Inform the Health and Safety Officer and take the monitor out of commission.

B.2.4 Operating the portal monitor

a) Operator stands by the display panel;

b) There should be a minimum of 2 m between each individual being monitored;

c) Signal the line control to send a person toward the portal monitor;

d) Ask the person to walk directly to the centre of the portal;

e) When the person enters the portal, ask him/her to pause for 1 s to 2 s;

f) Ensure the occupancy sensor has detected the person;

g) If the alarm sounds or if the alarm light comes on, ask the person to turn around and have a staff member conduct them to the handheld screening station or to the decontamination station;

h) If the green light comes on, the person is not contaminated and can proceed to the registration station;

i) When the path and alarm is cleared, signal line control to send the next person.

Note that operating instructions may differ for other portal models. However, basic concepts of portal positioning and the movement of individuals through the portal remain essentially the same for all models.

B.3 Hand-held detector job aid

B.3.1 Inspect the equipment

a) Attach the meter probe with the cable (if applicable);

b) Inspect the cable that connects the detector to the survey meter (if applicable). Ensure the instrument has batteries and conduct a battery test (see below). With the meter on, wiggle the cable near the connectors. If this causes erratic behaviour of sound or display, the cable is defective;

c) Inspect the meter for obvious signs of damage (e.g. broken detector window; broken glass on meter face);

d) Verify that the instrument is in calibration (usually on a label or log).

e) Initially, periodically, and at the end of each shift, survey the meter and probe (with another meter if available) to determine if they have become contaminated with radioactive materials.

B.3.2 Perform a battery check

Check the batteries, using the "range" switch or "bat" button; the method depends on the type of instrument. The meter needle should move to an area on scale marked "bat" indicating the batteries are good. Replace if necessary.

B.3.3 Conduct a source/operational check

a) Place detector close to a check source;

b) Select appropriate range (e.g. × 10 multiplier/scale setting);

c) Verify meter response;

d) If no source is available, assume the meter is working if the response to background within the expected range (see below).

B.3.4 Conduct a background reading

Before screening for contamination, it is important to determine the ambient signal response displayed by the detector that is independent of the source of contamination (i.e. background). The expected background reading depends on the instrument used and the ambient radiation levels for that location.

B.3.5 Performing the contamination survey

Monitoring of the patient should start at the head and finish at the feet. The entire body should be monitored with special attention to head, hands, feet and skin wounds. Any wounds should be monitored first. Maintain a written record for each individual screened, regardless of the outcome of the survey. Record sequential surveys of the same individual after decontamination on the same survey form or, if required, on additional forms which are serially numbered.

a) The detector “window” or probe should be held as close as possible (within about 1 cm) to the surface being monitored. Use extreme caution to avoid touching surfaces or holding the probe, face-up under potentially contaminated areas;

b) Remove plastic coverings from the detector window if surveying for alphas or low energy radiations;

c) Start on the detector’s lowest scale and move up as necessary;

d) Scan slowly enough to detect low levels of contamination. (See Table B.1).

The recommended probe distance and speed are shown in the table below, but the Health and Safety Officer may recommend other speeds and distances depending upon incident conditions.

Table B.1 — Contamination survey recommendations

Type of contamination	Survey distance cm from surface	Survey rate cm/s
Beta/Gamma[a]	~1 cm to 3 cm from surface	~2 cm/s to 5 cm/s
Alpha	~ ½ cm to 1 cm from surface (avoid contact with surface)	~2 cm/s to 5 cm/s

[a] Typical rates for a GM pancake probe or internal probe instrument. Refer to operational manuals or other technical guidance for other types of instruments/probes.

The following pattern (Figure B.2) of monitoring is not the only technique. The purpose is to monitor the entire body.

a) Instruct the person to stand straight, feet spread slightly, arms extended with palms up and fingers straight out;

b) Starting at the top of the head and face, screen the entire body;