Quick Reference Information
Recommendations of the
National Council on Radiation Protection and Measurements

The information in this document is adapted, with the permission of the National Council on Radiation Protection and Measurements, from its publication *Management of Persons Contaminated with Radionuclides: Handbook, NCRP Report No. 161.* The material includes the publication's Part A: Quick Reference Information, as well as its table of contents to indicate additional information is available.

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Volume I

Part A: Quick Reference Information

3. Compendium of Radiation Facts and Guidance

3.1 Introduction

This section comprises a compendium of information for the medical and radiation-safety personnel who would respond to incidents in which persons may be contaminated with radionuclides. It consists of information, facts and guidance that may be needed quickly by those who are first on the scene of a radionuclide release. The information is deliberately brief for ease of rapid access. The locations of more detailed information are indicated throughout this compendium. The medical and radiation-safety personnel using this Report will likely be familiar with the information relevant to their disciplines, but not necessarily with information relevant to other disciplines, which is important as they work as a team to manage persons contaminated with radionuclides. The information provided also may be helpful to other personnel who might be early responders to contamination incidents.

Incidents that result in contamination of persons with radionuclides can range from small-scale where one or a few individuals are contaminated with small amounts of radionuclides to large-scale incidents where perhaps hundreds of individuals may be contaminated with large quantities of radionuclides. Such incidents can be inadvertent releases in laboratories, hospitals, power plants, industry, and the military or they may be deliberate releases as a result of terrorist activities. Further information can be found in Section 17.

3.1.1 *Organizations Offering Radiological Incident Assistance*

A number of federal and state organizations are available to offer radiological emergency-response assistance in the event of a

radiological or nuclear incident or emergency, at the request of the affected community or facility. Federal organizations include the following:

- Armed Forces Radiobiology Research Institute (AFRRI)
- U.S. Department of Energy (DOE)
  - field offices and national laboratories
  - Radiological Assistance Program
  - Radiation Emergency Assistance Center/Training Site (REAC/TS)
- U.S. Department of Health and Human Services (DHHS)
  - Centers for Disease Control and Prevention (CDC)
  - U.S. Food and Drug Administration (FDA)
  - Radiation Event Medical Management (REMM) Guidance (DHHS, 2009)
- U.S. Environmental Protection Agency
- Federal Radiological Monitoring and Assistance Center

Information on how to contact these and other organizations for assistance and to obtain copies of publications and other related information is provided in Appendix G.

3.1.2 *Terminology*

In the management of persons contaminated or potentially contaminated with radionuclides, communication among the radiation-safety and medical personnel and other responders is important. To minimize misunderstandings and confusion, the terminology used must have clear meanings. To eliminate some of the current ambiguity in the meaning and use of some of this terminology, the following important terms are defined as used throughout this Report. There are some disparities in how these terms are used among government agencies, NCRP and ICRP. The following are generally consistent with NCRP and, in most cases, ICRP usage. These terms also appear in the Glossary along with other terms relevant to the subject of this Report.

- *absorption*: Movement of material to blood regardless of mechanism. Generally applies to the uptake into blood of soluble substances and material dissociated from particles.
- *absorption functions*: Mathematical equations describing the rate of transfer of radionuclides into blood after deposition on skin, in wounds, in the gastrointestinal (GI) tract and in the respiratory tract (equations can be exponential, polynomial or constant relationships).
- *activity median aerodynamic diameter* (AMAD): Median diameter of airborne radioactive particles having the same

aerodynamic properties as unit density spheres. Fifty percent of the activity (aerodynamically classified) in the aerosol is associated with particles greater than the AMAD. A lognormal distribution of particle sizes is assumed.

- *bioassay*: Any procedure used to determine the nature, activity, location or retention of radionuclides in the body by direct (*in vivo*) measurement or by indirect (*in vitro*) analysis of material excreted or otherwise removed from the body.
- *clearance*: The action that results in the movement of radioactive material from the site of deposition in tissues and organs. This action can be natural or induced by therapeutic means.
  - *pathways*: Routes by which material deposited in organ systems can be transported away from the affected organs. For example, materials deposited in the respiratory tract can move out of the respiratory tract by absorption into blood, to the GI tract *via* the pharynx, and to regional lymph nodes *via* lymphatic channels (ICRP, 1994a).
  - *pulmonary*: The removal of material from the respiratory tract by particle transport and by absorption into blood (ICRP, 1994a).
- *contamination*: Radioactive material that is present in any substance, in any area, or on any surface where its presence is unwanted or unexpected.
  - *external*: Unwanted radioactive material deposited on the outside of the body on the clothing, skin, hair, body cavities such as the outer ear and eye.
  - *internal*: Unwanted radioactive material deposited within the body following an intake of the material by absorption through skin, ingestion, inhalation or through wounds.
- *decontamination*: Action taken to remove radionuclides from clothing and the external surfaces of the body, from rooms, building surfaces, equipment, or other items.
- *decorporation*: The therapeutic processes by which radioactive materials are mobilized from tissues and organs and removed from the body by enhanced material excretion.
- *deposition*: Any action resulting in the occurrence of radioactive material on or in external surfaces of the body or on or in internal tissues and organs.
- *deterministic effects*: Harmful tissue reactions that occur in all individuals who receive greater than a threshold dose; the severity of the effect varies with the dose. Examples are radiation-induced cataracts (lens of the eye), radiation-induced erythema (skin), radiation-induced pneumonitis

(lungs), hematopoietic failure (bone marrow), hypothyroidism (thyroid), and GI failure (GI tract).

- *dose*: A general term denoting the quantity of energy from ionizing radiation absorbed in a tissue or organ from either an external source or from radionuclides in the body. When unspecified, dose refers to quantity of absorbed dose, measured in gray (1 Gy = 1 J kg^{-1}) or rad (1 rad = 100 ergs g^{-1}).
- *dose coefficient*: Radiation dose per unit of activity intake.
- *effective dose*: The calculated radiation dose to the entire body, accounting for the distribution of the dose among the organs and tissues of the body, the relative biological effectiveness of the different types of radiations and for the radiation sensitivities of the various organs and tissues that might be irradiated. The term *effective dose*, as used in this Report for internally-deposited radionuclides, always means committed effective dose calculated over a 50 y period beyond the radionuclide intake for adults and from intake to age 70 y for intakes by children.
- *exposure*: In this Report, "exposure is the act or condition of being subject to irradiation" (ICRP, 2005a) (*e.g.*, when a person is near a radiation source) and does not imply that external or internal radionuclide contamination has occurred, only that the potential for contamination has occurred. In the context of airborne radionuclides, exposure is the product of the air concentration of radionuclides to which a person is exposed and the duration of the exposure (ICRP, 2002a). Exposure is often used in a general sense meaning to be irradiated. When used as the specifically defined radiation quantity, exposure is a measure of the ionization produced in air by x or gamma radiation. The unit of exposure is coulomb per kilogram (C kg^{-1}). The special unit for exposure is roentgen (R), where 1 R = 2.58×10^{-4} C kg^{-1}.
- *ingestion*: The process in which radioactive material is taken into the digestive system. Amounts ingested are equivalent to an intake, although only a fraction may be absorbed into the blood system and deposited in tissues and organs and eventually excreted in urine. The ingested activity that is not absorbed to blood is excreted in feces.
- *inhalation*: The process in which air and substances, such as radioactive materials, entrained in the air are taken into the respiratory tract through the nose or mouth. The activity of a radionuclide inhaled may differ from the activity deposited in the respiratory tract since some fraction, depending upon its physical and chemical properties and the physiological state of the individual, may be promptly exhaled.

- *intake*: The amount of radioactive material taken into the body by inhalation, absorption through the skin, ingestion or through wounds. It is distinguished from *uptake*, which is the amount of material that eventually enters the systemic circulation, or *deposition*, which is the amount of the substance that is deposited in organs and tissues.
- *ionizing radiation*: Electromagnetic radiation (x or gamma rays) or particulate radiation (alpha particles, beta particles, electrons, positrons, protons, neutrons, and heavy charged particles) capable of producing ions by direct or secondary processes in passage through matter.
- *irradiation*: The action of incurring radiation by a body, tissue or organ from either external or internal radiation sources.
- *radionuclide*: Naturally-occurring or artificially-produced unstable ion that transforms to a stable or unstable atom and releases radiations in the process.
- *relative biological effectiveness* (RBE): For a specific radiation, the ratio of absorbed dose of a reference radiation required to produce a specific level of a response in a biological system to the absorbed dose of the specific radiation required to produce an equal response. Reference radiation normally is gamma or x rays with a mean linear energy transfer of 3.5 keV μm^{-1} or less. RBE generally depends on dose, dose per fraction if the dose is fractionated, dose rate, and biological endpoint. When calculating RBE-weighted absorbed doses for deterministic effects in this Report, RBE values of two and seven were used for alpha-particle irradiation of the bone marrow and lungs, respectively.
- *retention*: Describes the propensity for radioactive materials to remain at the site of deposition. Retention is frequently described by a rate function.
- *stochastic effects*: Effects, the probability of which, rather than their severity, is assumed to be a function of dose without a threshold. For example, cancer and hereditary effects are regarded as being stochastic
- *translocation*: The redistribution of radionuclides from the initial sites of deposition to other tissues and organs in the body.
- *uptake*: Quantity of a radionuclide taken up by the systemic circulation (*e.g.*, by injection into the blood, by absorption from compartments in the respiratory or GI tracts, or by absorption through the skin or through wounds in the skin) (NCRP, 1987).

3.2 Basic Radiological Facts

3.2.1 *Radiation Types and Recommended Personnel Protection*

- *alpha*: alpha radiation consists of positively charged particles emitted by certain radionuclides with a substantial amount of energy, typically 5 MeV or higher. Alpha radiation of energy less than ~7 MeV will not penetrate beyond 70 μm, the nominal dead-layer of the skin assumed in radiation protection. Alpha particles of ~4 MeV can penetrate the shallow dead-layer over some parts of the body. Alphas with energies of ≥7 MeV are emitted by only a few common radionuclides such as ^{212}Po. Alpha-emitting radionuclides may be a health risk if taken into the body through inhalation, ingestion, or through wounds. However, most alpha emitters are not readily absorbed from the GI tract. Two important exceptions are ^{210}Po and ^{226}Ra, for which 10 % or more of the ingested amount may be absorbed to blood. The maximum range of a 5.3 MeV alpha particle from ^{239}Pu in tissue is ~40 μm; thus it will penetrate on average about five cells in solid lung tissue (NCRP, 1975). (**Protective actions:** *Wear respiratory protection to minimize inhalation or ingestion, cover all open wounds.*)
- *beta*: beta radiation consists of elementary particles emitted from nuclei during radioactive decay and have a single electrical charge. Beta radiation will penetrate protective layers of skin if the maximum beta energies are above ~70 keV, which encompasses the majority of beta-emitting radionuclides. Beta-emitting radionuclides may be a health risk if taken into the body through inhalation, ingestion, or through wounds. [**Protective actions:** *Wear heavy clothing or turnout gear to keep high-activity and physically small beta-emitting particles (hot particles) off of skin; wear respiratory protection to minimize inhalation or ingestion.*]
- *gamma*: gamma rays are short-wave-length electromagnetic radiation. External sources of gamma rays may irradiate the entire body. High doses delivered at a high dose rate can cause an acute radiation syndrome. Gamma-emitting radionuclides taken into the body can irradiate surrounding tissues as well as those in which they are deposited. (**Protective actions:** *Wear gloves and anti-contamination clothing to reduce skin contamination. Wear respiratory protection to minimize inhalation and ingestion. Time, distance and shielding principles can be applied to reduce external exposures from gamma-emitting radionuclides in the surrounding area.*)

3.2.2 *Identifying Radiation Types Using a Pancake or Other Thin End-Window Geiger-Mueller Probe Survey Meter*

- A Geiger-Mueller (GM) detector with a thin window will detect alpha, beta and gamma radiation.
- Each of these types of radiation has different properties which must be understood to interpret meter readings.
- Background radiation (from cosmic sources or naturally-occurring radionuclides in soil or building materials) is always present and will produce counts (and a count rate) even in the absence of radioactive contamination.
- First turn on the meter in an uncontaminated area.
- Subtract the background reading from all subsequent instrument readings.[1]
- The properties of these types of radiation can be used to help differentiate between them and to determine their relative importance.
  - *alpha radiation* will not penetrate paper or thin plastic; to screen for alpha-emitting contamination, cover the probe with paper or a plastic bag; the percent reduction in count rate (if any) is proportional to the level of alpha-emitting contamination.
  - *beta radiation* will not penetrate a hand or heavy gloves; to screen for beta-emitting contamination, cover probe with hand or put inside an empty work glove; the percent reduction in count rate (if any) is proportional to the level of beta-emitting contamination.
  - *gamma radiation* will penetrate all these materials; the count rate penetrating a hand or heavy glove is proportional to the level of gamma-emitting contamination.

Example: If the count rate beneath a probe is 10,000 counts per minute (cpm), the count rate through paper is 5,000 cpm, and the count rate through a glove (probe inside the glove) is 2,000 cpm; then it can be concluded that alpha-, beta- and gamma-emitting contamination is present. In this case, the gamma count rate is 2,000 cpm (the amount that penetrated both paper and glove), the beta count rate is 3,000 cpm (the amount that penetrated the paper, but not the glove), and the alpha count rate is 5,000 cpm (the amount that did not penetrate the paper or the glove).

[1]For example, if background radiation levels are 50 cpm and the count rate in a contaminated area is 150 cpm, the net count rate (attributed to the radiation source measured) is 150 – 50 = 100 cpm.

3.2.3 *Radiation Energy and Radioactive Decay Facts*

The energies required to penetrate protective layer of skin (lower-energy particles will not expose living cells to radiation if the exposure is only from external sources) are:

- alpha: ~7 MeV
- beta: ~70 keV

Average beta and positron energies:

- average beta energy is about one-third the maximum energy
- average positron energy is about one-half of the maximum energy

Beta particle range:

- in air: 3.7 m (12 feet) per million electron volts (MeV) of energy
- in matter: range (g cm^{-2}) ≈ 0.5 E_{max} (MeV)

Range in matter depends upon the density of the matter as well as the energy of the beta particles. Range in density thickness (g cm^{-2}) can be converted to a linear range by dividing it by the mass density of the material. For example, water has a mass density of 1 g cm^{-3} so a 2 MeV beta particle will travel a distance of ~1 cm in water.

- range (g cm^{-2}) ≈ 0.5 × 2 MeV = 1 g cm^{-2}
- range (cm) ≈ range (g cm^{-2}) divided by density (g cm^{-3}) ≈ (1 g cm^{-2})/(1 g cm^{-3}) = 1 cm

Gamma-radiation dose rate (for point sources):

- $\dot{D} = 6\,A\,E\,n$
  where $\dot{D}$ is the dose rate in rad h^{-1} at a distance of *1 foot*, A is the source activity in curies, E is the gamma energy in million electron volts, and n is the number of gammas emitted during each disintegration (*e.g.*, every decay of a ^{60}Co atom emits two gammas).

In a similar manner:

- $\dot{D} = 0.53\,A\,E\,n$
  when $\dot{D}$ is the dose rate in rad h^{-1} at 1 m and A the source activity in curies.

Also:

- $\dot{D} = 0.14\,A\,\mathrm{E}n$
  when $\dot{D}$ is the dose rate in mSv h^{-1} at 1 m and A is the source activity in gigabecquerels.

Radioactive decay:

- after seven half-lives, <1 % of the original activity remains
- after 10 half-lives, <0.1 % of the original activity remains

Unit conversion factors: SI units and previous system:

- 1 Bq = 2.7×10^{-11} Ci = 27 pCi
- 1 Ci = 3.7×10^{10} Bq = 37 GBq
- 1 Sv = 100 rem
- 1 rem = 0.01 Sv
- 1 Gy = 100 rad
- 1 rad = 0.01 Gy
- 1 Sv Bq^{-1} = 3.7×10^{6} rem μCi^{-1}
- 1 rem μCi^{-1} = 2.7×10^{-7} Sv Bq^{-1}
- 1 Gy Bq^{-1} = 3.7×10^{6} rad μCi^{-1}
- 1 rad μCi^{-1} = 2.7×10^{-7} Gy Bq^{-1}

3.3 Incident Response (Section 18)

3.3.1 *Incidents*

3.3.1.1 *Small Scale*. Incidents occurring in laboratories, hospitals, nuclear power plants, etc., involving small amounts of radionuclides with the potential contamination of one or a few individuals are small scale. Radiation-safety and medical professionals are likely to be on the premises or nearby as employees or contract personnel. In nearly all cases, initial responding individuals will be coworkers and supervisors who are responsible for notifying radiation-safety staff/ officers (health physicists) and upper management. The radiological control staff is responsible for initial assessment and, in consultation with management, for determining the course of action for management of the contaminated person or persons, and the steps required to confine the contaminating radionuclides to the location of the incident. Appropriate local, state, or federal regulators may require notification, depending on the nature of the incident (*e.g.*, the theft of radioactive material or the innocent finding of radioactive material).

3.3.1.2 *Large Scale*. Incidents involving relatively-large quantities of radionuclides and the potential contamination of large numbers of people are large scale. Examples of large-scale incidents include terrorist attacks with radiological weapons, nuclear-weapons detonations, and nuclear power plant accidents. Initial responders may be law enforcement, firefighters, and local disaster response teams. Incidents may require designation of several areas, based on levels of contamination and the needs for successfully mediating the incident. The latter includes ensuring the confinement of the radionuclides to the contaminated area while effectively managing contaminated people.

Some of the personnel noted below may be involved in a small-scale incident, and even large-scale incidents may not call for all of these personnel (or they may not all be available). The person(s) in charge of the incident response will be responsible for determining which roles are required and to make the best use of the available personnel and resources.

3.3.2 *Roles and Responsibilities (Section 18)*

Emergency medical responders:

- attend to medical needs of contaminated and/or injured persons;
- take actions needed to stabilize the most badly-injured individuals;
- perform triage as appropriate;
- transfer contaminated and injured persons for medical treatment;
- exercise appropriate radiological controls;
- determine which critically-injured contaminated persons should be permitted to exit without undergoing decontamination;
- help decontaminate less injured persons;
- perform first aid; and
- help stabilize individuals requiring such attention.

Radiation-safety (health-physics) responders:

- establish radiation control and secured areas (Sections 4.3.3 and 18);
- provide radiological coverage for all responding personnel;
- issue dosimeters and record relevant information;

- control the radionuclide decontamination areas; man all control points;
- conduct personal and environmental radiation contamination surveys;
- supervise the use of protective clothing; track exposure of workers;
- assign radiological stay-times;
- supervise contamination control and decontamination efforts;
- take air samples;
- determine the likelihood of radioactive-material intakes;
- estimate potentially-contaminated persons' radionuclide intakes and radiation doses; and
- provide advice and guidance to all nonradiation-safety personnel, including medical professionals, law enforcement, firefighters, public health, and all other responders at the scene.

3.4 Guidance for Professionals at Incident Site

- *Entry into a contaminated area should be made deliberately and cautiously.* Determine radiation levels prior to entry, either in activity count/disintegration rate (counts per minute/disintegrations per minute) or dose rate [mGy h^{-1} (mR h^{-1})]. Wear appropriate protective clothing.
- *Do not attempt to enter areas in which radiation levels are >0.1 Gy h^{-1} (10 rad h^{-1}) without radiation dosimeters and radiation detector OR an accompanying radiation-safety specialist, AND the concurrence of the incident commander or a designated health and safety supervisor.* Radiation levels should be determined by survey with an ion chamber, micro-R meter, or energy-compensated GM detector.
- *Consider critical medical concerns first, followed by serious radiological concerns*.
- *Contaminated or irradiated patients, if clothes are removed, do not pose a health risk to emergency responders unless the patient contains embedded fragments of high-activity radioactive material*. Health-care workers have not been injured by a contaminated patient.
- *Take precautions to minimize the risk of spreading contamination*.

3.4.1 *Radiation Readings and Their Significance (dose-rate meters)*

TABLE 3.1—*Interpretation of dose-rate meter readings.*

Dose Rate[a]	Significance	Actions
20 μGy h^{-1} (2 mR h^{-1})	• Regulatory limit for radiation dose rate in an uncontrolled area	• Evacuate public if practicable • Establish control boundary
50 μGy h^{-1} (5 mR h^{-1})	• Regulations require posting as radiation area	• Entry requires wearing dosimetry
1 mGy h^{-1} (100 mR h^{-1})	• Regulations require posting as high radiation area	• Entry requires double dosimetry • Nonemergency turn-back limit
100 mGy h^{-1} (10 R h^{-1})	• Radiation workers will exceed annual dose limit [50 mSv (5 rem)] in 30 min	• Turn-back limit except for grave emergency or lifesaving
1 Gy h^{-1} (100 R h^{-1})	• May develop radiation sickness with 1 h exposure	• Turn-back limit except for lifesaving, minimize time in these areas
10 Gy h^{-1} (1,000 R h^{-1})	• May develop radiation sickness with 5 – 6 min exposure • Will reach LD_{50} dose (the lethal dose to 50 % of the population) in 30 min • Will receive lethal dose in 1 h	• Do not enter except under the most severe circumstances

[a]NCRP Report No. 138 (NCRP, 2001a) recommends a maximum radiation dose of 500 mSv (50 rem) for those engaged in emergency actions during a radiological emergency.

3.4.2 *Surface Radiation Readings and Their Significance (contamination survey meters)*

TABLE 3.2—*Interpretation of contamination survey readings (adapted from DOE, 1999).*

Contamination (Bq or dpm 100 cm^{-2})[a]	Significance	Actions
0.33 Bq (20 dpm); alpha	Lower limit for alpha emitters	• No control
0.33 Bq (20 dpm); alpha or 16 Bq (1,000 dpm); beta/gamma	Limit for contamination in uncontrolled area	• Establish control boundary • Wear anti-contamination clothing
33 Bq (2,000 dpm); alpha or 1,670 Bq (100,000 dpm); beta/gamma	Resuspended contamination may lead to inhalation or ingestion risk	• High control • Wear anti-contamination clothing • Consider respiratory protection
16.7 kBq (1,000,000 dpm); alpha, beta, gamma	Likely to lead to inhalation of significant amounts of activity	• Very-high control procedures required • Wear anti-contamination clothing and respiratory protection

[a]Instruments that readout in counts per minute or counts per second require calibration to give becquerel or disintegrations per minute. For example:

dpm = counts per minute divided by counting efficiency (in counts per disintegration)
Bq = counts per second divided by counting efficiency (1 Bq = 60 dpm)

3.5 Management of Potentially-Injured and Contaminated Persons

3.5.1 *Priorities for Aiding Contaminated Individuals*

1. life-threatening injuries and medical conditions;
2. high levels of internal contamination (thousands of disintegrations per minute in nasal or oral swabs from ingested or inhaled activity, or thousands of disintegrations per minute from contaminated wounds);
3. evidence of radioiodine or transuranic intakes;
4. serious injuries (not life threatening, but requiring rapid medical attention);
5. high levels of skin contamination (hundreds of thousands of disintegrations per minute or more);
6. moderate injuries (requiring medical attention);
7. moderate levels of internal contamination (hundreds of disintegrations per minute in nasal or oral swabs or from contaminated wounds);
8. moderate levels of skin contamination (thousands to hundreds of thousands of disintegrations per minute);
9. mild injuries with low levels of contamination [<1,000 disintegrations per minute (dpm)]; and
10. contaminated but uninjured persons.

3.5.2 *Stages in Management of Exposed Persons*

REACT/TS (ORAU, 2009) and the Office of the Assistant Secretary for Preparedness and Response, National Library of Medicine, DHHS (2009) have prepared decision-tree charts for medical responses to radiological and nuclear incidents. Drawing largely from these sources, a decision tree (Figure 3.1) is provided to guide medical and radiation safety professionals through nine stages in the management of persons exposed to radionuclides. The first three of nine stages can be accomplished onsite. The subsequent four stages should occur remote from the contaminated area, preferably at a hospital, clinic, or other medical emergency facility. The final two stages will occur post-hospital at a site depending upon the circumstances. The nine stages in managing contaminated persons are not necessarily sequential. Depending upon the nature of the contamination and possible injuries, certain stages may be bypassed. These stages suggest the proper course of action to be taken to achieve a favorable outcome for exposed and contaminated individuals. It is recommended that the activities performed and the information obtained at each stage be documented and that

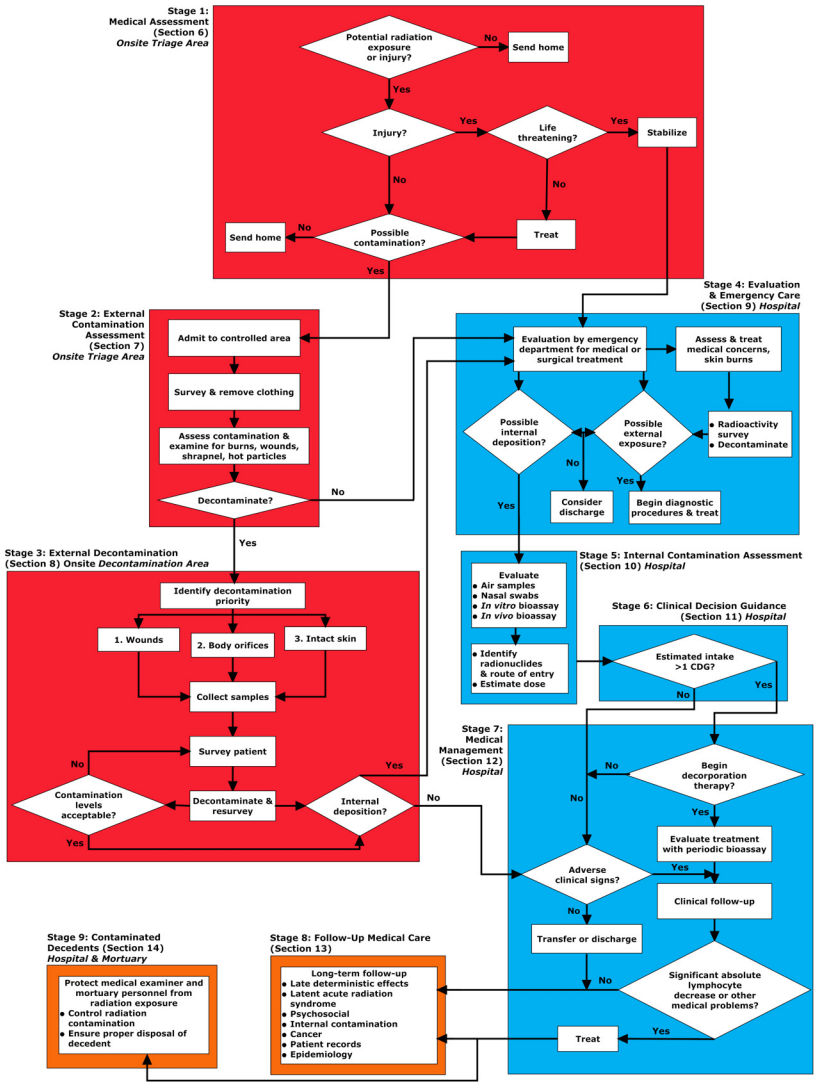

Fig. 3.1. Decision tree for management of persons contaminated with radionuclides (adapted from DHHS, 2009; ORAU, 2009).

copies accompany the patient. These nine stages illustrated in Figure 3.1 are color coded to appropriate parts and sections of the Handbook for specific guidance.

Stage 1. Medical Assessment (Section 6):

Onsite Triage Area

Screen potentially-exposed persons for life-threatening problems and for evidence of exposure and contamination. Depending upon the nature of the contaminating incident, it may be that not all persons at the site will be exposed and contaminated. This assessment should occur at the site of the incident.

- Examine exposed persons for signs of injuries and potential life-threatening problems. This has priority over assessing contamination and decontamination.
- Stabilize life-threatening problems.
- Observe for signs of psychological distress because psychosocial effects can be both widespread and long lasting constituting some of the most significant and challenging consequences of a radiation incident (Becker, 2001) (Sections 9.1.2 and 13.4).
- Examine exposed persons for signs of acute radiation exposure. Table 6.2 describes early effects of whole-body irradiation from external and internal sources.
- Survey the individuals' facial areas and check nasal swabs with a GM, sodium iodide (gamma radiation), or zinc-sulfide (alpha radiation) detector for evidence of inhalation or ingestion. Consider prompt treatment with KI if high intakes of radioiodine are suspected and with DTPA if intakes of transuranics are indicated (Section 12).
- Survey wounds with a GM, sodium iodide (gamma radiation), or zinc-sulfide (alpha radiation) detector for evidence of contamination or shrapnel and flush with sterile saline solution or water if contamination is detected or suspected (Section 9.4.1).
- Attempt to determine the time of intake as accurately as possible.
- Air samples and any other samples such as swabs of contaminated surfaces should be collected for analysis.

Stage 2. External Contamination Assessment (Section 7):

Onsite Triage Area

In a controlled area, perform whole-body surveys and record the levels and locations of the contaminating radionuclides.

- locate contaminated body area, including orifices;
- identify hot particles, shrapnel and contaminated debris;
- identify and quantify radionuclides;
- evaluate potential for skin injury; and
- confirm internally-contaminated individuals.

Stage 3. External Decontamination (Section 8):

Onsite Decontamination Area

In a controlled area, remove clothing and decontaminate all areas showing evidence of contamination until levels are less than twice the background reading (Section 8.1.1) and reduce amounts of radionuclides in wounds.

Stage 4. Patient Evaluation and Emergency Care (Section 9):

Hospital

Evaluation of injuries and emergency care of contaminated persons in hospital; guidance in controlling contamination:

- treat patients with injuries;
- evaluate patients for evidence of radiation sickness and begin treatment;
- evaluate patients with skin burns, contaminated wounds, and radionuclide intakes for emergency treatment;
- consider treatment with KI if intakes of radioiodine are suspected and DTPA if intakes of transuranics are indicated; and
- observe patients for adverse psychosocial reactions.

Stage 5. Internal Contamination Assessment (Section 10):

Hospital

Collection and evaluation of bioassay data such as *in vivo* counting, nasal swabs, and excreta should occur as soon as possible in an emergency facility or hospital. Estimate radionuclide intakes and radiation doses.

Stage 6. Clinical Decision Guidance (Section 11):

Hospital

Evaluate internal contamination and radiation dose with respect to the CDG.

Stage 7. Medical Management (*Section 12):*

Hospital

This will generally occur in hospital if, after evaluation of the intake, the physician recommends treatment.

Stage 8. Follow-Up Medical Care (Section 13):

Location Depends Upon Circumstances

Patients should be followed for evidence of latent development of radiation injuries, monitoring internal contamination, possible epidemiology studies, and negative psychosocial reactions.

Stage 9. Contaminated Decedents (Section 14):

Hospital and Mortuary

Guidance is provided to protect medical examiners and mortuary professionals from radiation exposure and to control radionuclide contamination of individuals and facilities.

3.6 Radiation Exposures from External Sources

3.6.1 *Health Effects from External Radiation*

Table 3.3, adapted from ICRP Publication 96 (ICRP, 2005a), may be useful in assessing the potential health risks of such whole-body doses. This table provides a summary of the health effects that can result from whole-body x- or gamma-radiation doses ranging from background to very-high dose levels.

3.6.2 *Neutron-Radiation Dose from Criticality Accident (based on ^{24}Na activation in body)*

Naturally-occurring ^{23}Na is activated by neutron exposure to produce ^{24}Na, which then emits 1.37 and 2.87 MeV gamma rays. The half-life of ^{24}Na is 15 h.

Estimating neutron dose using the ^{24}Na "quick sort" method (Tables 3.4 and 3.5):

- Place probe of radiation monitoring instrument against the abdomen with the person bent over during the measurement (the armpit may be used if person is unable to bend over or external contamination prohibits such a measurement).
- If the detector (*e.g.*, Cutie-pie type ionization chamber) is used to measure radiation dose rate, the following relationships can be used to determine the neutron dose:

$$D_{\mathrm{Gy}} = \frac{3{,}600\ (\dot{D}_{\mathrm{mGy}})}{\text{body weight (kg)}} \tag{3.1}$$

$$\left[D_{\mathrm{rad}} = \frac{8{,}000\ (\dot{D}_{\mathrm{mrad}})}{\text{body weight (lb)}}\right]$$

TABLE 3.3—*Simplified summary of radiation-induced health effects from whole-body radiation (adapted from ICRP, 2005a).*

Expected Dose	Effects	Outcome
Very-low dose: ~10 mSv (1 rem) effective dose or less.	No acute effect, extremely small additional cancer risk (<0.1 %).	No observable increase in the incidence of cancer, even in large exposed population (~1,000,000 people).
Low dose: towards 100 mSv (10 rem) effective dose.	No acute effects, subsequent additional cancer risk of <1 %.	Possible observable increase in the incidence of cancer, if the exposed group is large (perhaps greater than ~100,000 people).[a]
Moderate dose: towards 1,000 mSv (100 rem) (acute whole-body dose).	Nausea, vomiting possible, mild bone-marrow depression; subsequent additional cancer risk of ~10 %.	Probable observable increase in the incidence of cancer, if the exposed group is more than a few hundred people.
High dose: >1,000 mSv (100 rem) (acute whole-body dose).	Certain nausea, likely bone-marrow syndrome, high risk of death from ~4,000 mSv (400 rem) of acute whole-body dose without medical treatment. Significant additional cancer risk.	Observable increase in the incidence of cancer.

[a]Epidemiological studies do not have the power to reveal cancer risks in the dose range up to ~100 mSv (10 rem) (ICRP, 2007).

TABLE 3.4—*Survey instrument readings on the body after an criticality accident (SI units) (Rathbone, 2007).*

Weight of Subject (kg)	Pancake GM net Reading (cpm) for a 0.1 Gy Neutron Dose			Dose-Rate Instrument Reading (μGy h^{-1}) for a 1 Gy Neutron Dose[a]		
	Time Following Exposure (h)					
	0	4	15	0	4	15
60	600	500	300	17	4	15
70	700	580	350	19	16	10
80	800	660	400	22	18	11
90	900	750	450	25	21	12
100	1,000	830	500	28	23	14
110	1,100	910	550	31	25	15

[a]Air-filled ion chamber.

TABLE 3.5—*Survey instrument readings on the body after an criticality accident (previous system) (Rathbone, 2007).*

Weight of Subject (lb)	Pancake GM net Reading (cpm) for a 10 rad Neutron Dose			Dose-Rate Instrument Reading (mrad h^{-1}) for a 100 rad Neutron Dose[a]		
	Time Following Exposure (h)					
	0	4	15	0	4	15
125	570	470	280	1.6	1.3	0.8
150	680	570	340	1.9	1.6	0.9
175	800	660	400	2.2	1.8	1.1
200	910	760	450	2.5	2.1	1.2
225	1,000	850	510	2.8	2.3	1.4
250	1,100	940	570	3.1	2.6	1.6

[a]Air-filled ion chamber.

where $\dot{D}$ is the radiation dose-rate reading in milligray (millirad) per hour, using a probe calibrated with ^{137}Cs.

- If the detector (*e.g.*, GM pancake-type radiation monitoring instruments) is used to measure radiation count rate (cpm), the following relationships can be used to determine the neutron dose:

$$D_{Gy} = \frac{0.01\ (\text{cpm})}{\text{body weight (kg)}} \tag{3.2}$$

$$\left[D_{rad} = \frac{2.2\ (\text{cpm})}{\text{body weight (lb)}}\right]$$

Notes:

- Decay correction is not necessary if the measurement is made within the first few hours after exposure (IAEA, 1974; Rathbone, 2007).
- The radiation dose calculated by this method only addresses the neutron component. Gamma-to-neutron ratios or personal gamma dosimetry must be used to determine the dose from gamma radiation.

Example 1:

A 75 kg person was exposed to neutron radiation and measures 750 cpm above background using a GM pancake-type detector. The calculated radiation dose is 0.1 Gy (10 rad).

Example 2:

A 200 lb person was exposed to neutron radiation. Using the quick-sort method, a Cutie-pie-type ionization chamber is used to measure radiation dose rate, which is 0.022 mGy h^{-1} (2.2 mrad h^{-1}). The calculated radiation dose is 0.88 Gy (88 rad).

3.6.3 *Exposures from Sealed Radioactive Sources*

In many situations it may be possible to determine the activity of a radioactive source by referring to shipping documents, source documentation, asking the source's owner, contacting the source manufacturer, or by other means such as measurements. If the source activity can be ascertained, the information in Table 3.6 can be used to help determine the risk that the source may pose to bystanders and response personnel.

In some cases, it may not be possible to determine the activity of a radioactive source but potential whole-body radiation doses to

TABLE 3.6—*Activity and significance of sealed radioactive sources.*

Activity	Significance	Actions
10s of kBq (μCi)	Not a significant health risk	• Control as radioactive material
10s of MBq (mCi)	May be a minor health risk	• Control as radioactive material, do not handle directly, use tongs
10s of GBq (Ci)	May be a health risk	• Do not handle directly, use tongs
100s of GBq (a few Ci)	May be a health risk	• Do not approach closely • Do not handle source • Establish 20 μGy h^{-1} (2 mrad h^{-1}) boundary
TBq (10s of Ci)	May be a severe health risk	• Do not approach without radiation dose and dose-rate monitoring equipment • Establish 20 μGy h^{-1} (2 mrad h^{-1}) boundary

bystanders and response personnel may be estimated from measurements of the air-kerma rate (exposure rate) from the source and comparing them with the values in Table 3.7.

3.7 Air Kerma and Skin Doses for Point Sources

3.7.1 *Intervention Levels for Skin Contamination*

Deterministic effects are estimated to occur at skin doses of 2 to 3 Gy (200 to 300 rad), such as from beta emitters deposited on the skin. With respect to "hot particles" on the skin, NCRP concluded that the risk of stochastic effects was negligible compared with deterministic effects. It was recommended that the dose to skin (and the ear) at depth of 70 μm be limited to 0.5 Gy (50 rad) averaged over the most highly exposed 10 cm^2 area of skin. This is a limit per particle, with no overlap. For the eye and respiratory tract (anterior nose) the limits are annual because of the small mass of tissue. For the eye, the recommended limit for hot particles is 5 Gy (500 rad) at 70 μm averaged over the most highly exposed 1 cm^2 of ocular tissue. For hot particles sequestered in the anterior nasal

TABLE 3.7—*Air-kerma rate (1 m from point source) and electron constants (skin dose rate at depth of 70 μm from source on skin surface) for selected radionuclides.*

Radionuclide[b]	Half–Life	Decay Mode[c]	Air-Kerma Rate[d]		Electron Constant[e]	
			[Gy s^{-1} (Bq m^{-2})$^{-1}$]	[rad h^{-1} (μCi m^{-2})$^{-1}$]	[Gy s^{-1} (Bq cm^{-2})$^{-1}$]	[rad h^{-1} (μCi cm^{-2})$^{-1}$]
^{60}Co	5.27 y	β–	8.53×10^{-17}	1.14×10^{-6}	3.09×10^{-10}	4.12×10^{0}
^{90}Sr	28.8 y	β–	—	—	4.98×10^{-10}	6.63×10^{0}
*^{90}Y	64.1 h	β–	1.65×10^{-21}	2.20×10^{-11}	6.65×10^{-10}	8.86×10^{0}
^{131}I	8.0 d	β–	1.45×10^{-17}	1.93×10^{-7}	4.82×10^{-10}	6.42×10^{0}
^{137}Cs	30.2 y	β–	6.11×10^{-23}	8.14×10^{-13}	4.73×10^{-10}	6.30×10^{0}
*^{137m}Ba	2.55 m	IT	2.26×10^{-17}	3.01×10^{-7}	6.88×10^{-11}	9.16×10^{-1}
^{192}Ir	73.8 d	β– EC	3.18×10^{-17}	4.24×10^{-7}	5.46×10^{-10}	7.27×10^{0}
^{210}Po	138. d	α	3.60×10^{-22}	4.80×10^{-12}	8.53×10^{-17}	1.14×10^{-6}
^{235}U	7.04×10^{8} y	α	1.32×10^{-17}	1.76×10^{-7}	4.69×10^{-11}	6.25×10^{-1}
^{238}U	4.47×10^{9} y	α SF	2.04×10^{-18}	2.72×10^{-8}	2.70×10^{-13}	3.60×10^{-3}
*^{226}Ra	1,600 y	α	5.23×10^{-19}	6.97×10^{-9}	1.42×10^{-11}	1.89×10^{-1}
^{238}Pu	87.7 y	α SF	2.64×10^{-18}	3.52×10^{-8}	2.49×10^{-13}	3.32×10^{-3}
^{239}Pu	2.41×10^{4} y	α	1.11×10^{-18}	1.48×10^{-8}	1.29×10^{-13}	1.72×10^{-3}

TABLE 3.7—(*continued*)

Radionuclide[b]	Half–Life	Decay Mode[c]	Air-Kerma Rate[d]		Electron Constant[e]	
			[Gy s^{-1} (Bq m^{-2})$^{-1}$]	[rad h^{-1} (μCi m^{-2})$^{-1}$]	[Gy s^{-1} (Bq cm^{-2})$^{-1}$]	[rad h^{-1} (μCi cm^{-2})$^{-1}$]
*^{241}Am	432 y	α	9.80×10^{-18}	1.31×10^{-7}	7.60×10^{-13}	1.01×10^{-2}
^{252}Cf	2.65 y	α SF	7.54×10^{-17}	1.00×10^{-6}	1.32×10^{-10}	1.76×10^{0}

[a]See Section 7 for additional radionuclides and Section 21.3 for explanation of skin dose calculations.

[b]Names preceded by an asterisk are radioactive progeny that may be present in significant quantities.

[c] EC = electron capture
IT = isomeric transition
SF = spontaneous fission

[d]The air-kerma rates include the contribution of annihilation radiations associated with the emission of positrons and neutrons, prompt gamma, and delayed gamma associated with spontaneous fission.

[e]The electron constant includes the contribution from delayed beta emissions associated with spontaneous fission.

passages, the recommended limit is 5 Gy (500 rad) at 70 μm averaged over the most highly exposed 1 cm^2. With the possible exception of situations where hot particles are continually moving within tissues and irradiating an increasing volume of tissues and numbers of cells, hot particles are a greater risk of causing deterministic effects than stochastic effects such as cancer (NCRP, 1999).

Default operational intervention levels for skin contamination suggested by the International Atomic Energy Agency (IAEA, 2005a) are given in Table 3.8. Appropriate actions for each level are indicated in the fourth column (Section 7).

3.7.2 *Guidance for Decontaminating Skin*

The skin decontamination objective is to reduce the level to less than two times background by washing the skin. The number of washings should be limited to avoid skin injury; two cycles or as long as each washing reduces the level by 50 % (Section 8). When the lack of facilities or equipment or the number of contaminated people make it impracticable to achieve this objective, other guidance may apply as shown in Table 3.9.

3.8 Radiation Exposures from Internal Depositions of Radionuclides

3.8.1 *Health Effects from Internal Radionuclide Contamination*

3.8.1.1 *Deterministic Effects (harmful tissue reactions)*. Table 3.10 summarizes the organs and tissues at risk for deterministic effects if sufficient quantities are taken into the body through the respiratory tract. If these radionuclides are ingested in sufficient quantities (especially the beta/gamma emitters) the GI tract is at risk as well as the other tissues in the body in which the radionuclides may deposit. If taken into the body through wounds in the skin, the tissues at risk from the more soluble radionuclides are those in which the radionuclides tend to deposit, as shown in the table. Ingested insoluble alpha emitters are a minimal risk to the body because little of the alpha radiation penetrates to the sensitive cells in the GI tract. Insoluble material entering wounds tends to be sequestered in lymphatic tissues. In these cases the radiation dose from alpha emitters is localized, while that from beta/gamma emitters may penetrate further into adjacent tissues.

Deterministic effects observed following human intakes of radionuclides are very limited, primarily because the large intakes required to cause deterministic effects have been rare. These include thyroid nodules in Marshall Islanders exposed to radioiodine in the fallout from nuclear-weapon tests in the Pacific (Mettler and Upton,

TABLE 3.8—*Skin contamination intervention levels (adapted from IAEA, 2005b).*

Alpha {Bq cm^{-2} (nCi cm^{-2}) [dpm cm^{-2}]}	Beta/Gamma {Bq cm^{-2} (nCi cm^{-2}) [dpm cm^{-2}]}	Beta/Gamma (low background area)[a] [μSv h^{-1} (μrem h^{-1})]	Actions
<10 (<0.27) [<600]	<100 (<2.7) [<6,000]	Not detectable	*None* • allow release
>10 (>0.27) [>600]	>100 (>2.7) [6,000]	Not detectable	*Intervention optional* • decontaminate or advise to shower and wash clothing • no significant health risk • slow release
>100 (>2.7) [>6,000]	>1,000 (>27) [>60,000]	0.2 – 0.3 (20 – 30)	*Intervention advisable* • prevent inadvertent ingestion and inhalation, limit spread of contamination and decontaminate
>1,000 (>27) [>60,000]	>10,000 (>270) [>600,000]	2 – 3 (200 – 300)	*Intervention required* • prevent inadvertent ingestion and inhalation, limit spread of contamination and decontaminate

[a]Ambient dose equivalent rate measured at 10 cm from skin surface.

TABLE 3.9—*Decontamination guidance; applicable when large numbers of people are contaminated and the goal of less than two times background is impractical.*

Contamination	Spot[a] (0.2 cm^2)	Body Surface	Reference
Alpha[b]	<0.37 kBq (0.01 μCi) 22,000 dpm	17 Bq cm^{-2} (0.45 nCi cm^{-2}) 1,000 dpm cm^{-2}	IAEA (2005b)
Beta/gamma	<3.7 kBq (0.1 μCi) 220,000 dpm	<170 Bq cm^{-2} (4.5 nCi cm^{-2}) 10,000 dpm cm^{-2}	FEMA (2002) NCRP (2005a)

[a]For contamination fixed on skin. Limit is factor of 10 greater for mixed loose and fixed.
[b]The value for alpha radiation is a factor of 10 less than beta/gamma radiations consistent with IAEA skin contamination operational intervention levels.

TABLE 3.10—*Summary of organs or tissues at risk from deterministic effects following inhalation of example radionuclides (Table 16.13).*

Radionuclide and Form	Emissions	Absorption Type[a]	Organs/Tissues at Risk[b]
$^{90}SrCl_2$	β	F (fast)	Bone marrow
^{131}I vapor	β	F (fast)	Thyroid
$^{137}CsCl$	β γ	F (fast)	Bone marrow
$^{144}CeO_2$	β γ	S (slow)	Lungs
^{210}Po	α	F or M (fast or moderate)	Lungs, bone marrow, kidneys, liver, others
$^{238}PuO_2$	α	M (moderate)	Lungs, thoracic lymph nodes, liver, bone
$^{239}PuO_2$	α	S (slow)	Lungs, thoracic lymph nodes

[a]Based on rate of absorption into blood from respiratory tract (ICRP, 1994a).
[b]Organs and tissues at risk are those in which the radionuclides are preferentially deposited and retained, in some cases, for relatively long periods.

1995; NCRP, 2008). Early death occurred in a person following the ingestion of a large quantity of ^{210}Po (Harrison *et al*., 2007). The ingestion of large quantities of ^{137}Cs resulted in the deaths of four persons and serious injuries in a number of others in Goiânia, Brazil (IAEA, 1988; 1998a). Deaths from radiation pneumonitis/pulmonary fibrosis occurred in early plutonium workers at the Mayak Production Association in the former Soviet Union (Claycamp *et al*., 2000).

3.8.1.2 *Stochastic Effects*

3.8.1.2.1 *Cancer.* Tissues at risk for the development of cancer later in life are primarily those in which radionuclides are deposited and retained for extended periods. Examples are the tissues listed in Table 3.11 for several radionuclides taken into the body through the respiratory tract. The same tissues are at risk when the route of entry is through the GI tract or through the skin except for those insoluble forms that are retained in the respiratory tract.

Epidemiology studies have identified statistically significant increases in cancer incidence in only a few populations of the many that have been exposed to natural and man-made radionuclides through the years and extensively studied. Studies of workers at former Soviet Union nuclear weapons facilities and nearby residents are still in progress (UNSCEAR, 2008). Those showing increases include:

- lung cancer in underground hard rock and uranium miners exposed to radon;
- bone cancer in radium dial painters;
- bone and liver cancers in patients treated with ^{232}Th and progeny [Thorotrast® (VanHeyden Company, Dresden-Radebeul, Germany)], lung, bone and liver cancers in plutonium workers at the Mayak Production Association;
- thyroid cancers in individuals exposed as children at the Chernobyl nuclear reactor accident;
- thyroid cancer in patients treated with ^{131}I for thyroid disorders; and
- bone cancers in ankylosing spondylitis patients treated with ^{224}Ra (UNSCEAR, 2000; 2008) (Section 16.7.2.1).

3.8.1.2.2 *Hereditary effects (Section 16.7.2.2)*. Hereditary effects have not been considered a serious risk following intakes of radionuclides.

3.8.1.3 *Developmental Effects (Section 16.7.3)*. The risk of developmental effects occurring as a result of internal contamination is

TABLE 3.11—*Tissues at risk for cancer induction by radionuclides taken into the body through the respiratory tract in a chemical form with the clearance characteristics specified (Sections 17.7.2 and 20 provide references and further information).*[a]

Radionuclide	Emissions	Absorption Type[b]	Tissues at Risk[c]
$^{3}H_2O$	β	F (fast)	Total body
^{60}Co oxides	γ	S (slow)	Lung
$^{90}SrCl_2$	β	M (moderate)	Bone marrow, bone
$^{106}RuO_2$	β	S (slow)	Lung
^{131}I vapor	β	F (fast)	Thyroid
^{137}CsCl	γ	F (fast)	Total body
$^{144}CeO_2$	β	S (slow)	Lung
^{210}Po	α	M (moderate)	Lungs, spleen, kidney, blood cells, liver, bone marrow
^{222}Rn and decay products	α	F (fast)	Lung
^{226}Ra sulfate	α	M (moderate)	Bone
^{232}Th	α	S (slow)	Lung
$^{238}PuO_2$	α	M (moderate)	Lung, bone, liver
$^{239}PuO_2$	α	S (slow)	Lung,
$^{241}AmO_2$	α	M (moderate)	Bone, lung

[a]Natural and depleted uranium are not included because UNSCEAR concludes "… there is little or no epidemiological evidence for an association between uranium and any cancer." (Volume I, Annex A of UNSCEAR, 2008).

[b]Based on rate of absorption into blood from the respiratory tract (ICRP, 1994a).

[c]Organs and tissues at risk are those in which the radionuclide preferentially deposits and is retained.

considered minimal because the exposure of the fetus to at least 0.1 Gy (10 rad) would have to occur three to eight weeks after conception.

3.8.2 *Inhalation Intakes*

Only in very extreme situations can the inhaled amounts approach levels that would cause early health effects (deterministic effects). Relatively-high air concentrations of radionuclides would have to be sustained for many minutes or even hours for such intakes to occur (Section 16).

3.8.2.1 *Air Samples*. Air samples can be useful as indicators of exposures to airborne radionuclides and in estimating inhalation intakes. Personal air samplers are used in many occupational situations where airborne radionuclides are relatively frequent. These are generally accompanied by room or area air samplers. In incidents where large numbers of people may be contaminated, air samples are not likely to be collected, if at all, until sometime after the incident. When air samples are available, they can be used to assess the potential for deterministic effects. Table 3.12 gives estimates of the air concentrations of several radionuclides that would have to be breathed for 10 min to result in intakes that would give radiation doses approximating threshold levels for deterministic effects and effective doses of 0.25 Sv (25 rem) (see Section 16 for further information).

3.8.2.2 *Nasal Swabs*

- Particle-size distribution of the inhaled material is an important factor. For aerosols with an AMAD of 5 μm, ~34 % of the inhaled amount is deposited in the anterior nasal passages of an adult working male, whereas only ~17 % is deposited when the aerosol has an AMAD of 1 μm (ICRP, 1994a). The portion of inhaled activity collected on nasal swabs in the early hours after inhalation of a radionuclide is highly variable, depending upon such factors as aerosol particle size, the extent of nose versus mouth breathing during the exposure, and the amount of nose blowing and wiping of the nostrils since the beginning of the exposure. Based on model predictions and controlled human experiments, it is estimated that the combined activity on swabs of both nostrils represents ~5 % of the amount inhaled. See Section 10.3.1.1 for guidance in taking and interpreting nasal swabs and Section 16.4.1.2 for additional information.

TABLE 3.12—*Estimates of the concentrations in air [MBq m^{-3} (μCi m^{-3})] of several radionuclides that would have to be inhaled for 10 min to achieve intakes sufficient to produce deterministic effects or give effective doses of 0.25 Sv (25 rem) (Section 16.7).*

Radionuclide[a]	Air Concentrations Required to Cause Deterministic Effects[b,c]	Air Concentrations Required to Result in an Intake of 1 CDG Leading to an Effective Dose of 0.25 Sv (25 rem)[c]
$^{90}SrCl_2$ (Type F)	2,600 (70,000) Bone-marrow depression	51 (1,400)
^{131}I (Vapor)	30 (800) Hypothyroidism	76 (2,100)
$^{137}CsCl$ (Type F)	8,000 (220,000) Bone-marrow depression	350 (9,500)
$^{144}CeO_2$ (Type S)	3,700 (100,000) Pneumonitis	52 (1,400)
$^{210}PoCl_2$ or $^{210}PoCl_4$ (Type M)	1,900 (51,000) Bone-marrow depression	0.67 (18)
$^{238}PuO_2$ (Type M)	40 (1,100) Pneumonitis	0.049 (1.3)
$^{239}PuO_2$ (Type S)	40 (1,100) Pneumonitis	0.18 (4.9)
$^{241}AmO_2$ (Type M)	40 (1,100) Pneumonitis	0.57 (1.5)

[a]The radionuclides shown here are used as examples to demonstrate the levels of airborne activity required to cause serious health concerns. Assumed a breathing rate of 1.2 m^3 h^{-1} of unfiltered air for an adult and a lognormal particle-size distribution with AMAD = 5 μm.

[b]Deterministic effects expressed within two to three months are given for the particular radionuclide.

[c]Calculations based on a breathing rate of 1.2 m^3 h^{-1} of unfiltered air by an adult, 5 μm AMAD particles, and a total deposition of 82 % (ICRP, 1994a).

- Other complicating factors include uncertainty about the length of time since inhalation, whether the individual was mouth breathing, and whether the individual has respiratory problems (*e.g.*, sinus restrictions, upper respiratory infections, etc.).
- High activity on a nasal swab does not always imply high penetration to lower regions of the respiratory tract.

3.8.2.3 *Doses Received from Inhaled Radionuclides*. The following table, Table 3.13, is derived from data in Section 20 on absorbed and effective dose[2] coefficients for radionuclides (5 μm AMAD particle-size distribution unless otherwise specified).

3.8.3 *Intakes Through Skin and Ingestion*

Wounds in areas of skin contamination are strong indicators of possible radionuclide intakes. More detailed information on the behavior of radionuclides in wounds and possible treatments is given in NCRP Report No. 156 (NCRP, 2006a). Contamination of skin surfaces suggest possible intakes through absorption, but only in cases of very heavy contamination would absorption result in significant internal contamination, even if the radionuclide is in a soluble form (Section 10). Injuries with contaminated debris and shrapnel are clear evidence of internal contamination.

Discovery of contaminated food and water should be taken as evidence of possible ingestion intakes. Contamination of the mouth and other oral surfaces suggest possible intakes by ingestion, not necessarily in contaminated food, but by touching the face and mouth with contaminated hands.

3.9 Medical Management of Internal Radionuclide Depositions

3.9.1 *Clinical Decision Guides*

The Clinical Decision Guide (CDG), a new operational quantity, is defined in Section 11 to provide a basis that physicians can use when considering the need for medical treatment for internally-deposited radionuclides or as a screening level indicating the need for a more detailed investigation of tissue-specific absorbed doses over different time periods. For radionuclides other than isotopes of iodine, CDG is the maximum, once-in-a lifetime intake of a radionuclide that represents: (1) a stochastic risk, as judged by the calculated effective dose over 50 y for intake by adults and to age 70 y for intake by children that is in the range of risks associated with guidance on dose limits for emergency situations (DOE, 2008a; FEMA, 2008; ICRP, 1991a; NCRP, 1993; 2005a); and (2) avoidance of deterministic effects as judged by the calculated 30 d RBE-weighted

[2]The term effective dose, as used in this Report for internally-deposited radionuclides, always means committed effective dose calculated over a 50 y period beyond the radionuclide intake for adults and from intake to 70 y of age for intakes by children.

TABLE 3.13—*Dose estimates for inhalation intake of radionuclides by adults (Section 20).*

Radionuclide[a]	Half-Life[b]	Emissions[c]	Method of Measurement[d]	Absorption Type[e]	Tissues	Absorbed Dose (30 d)		Effective Dose (50 y)	
						(Gy Bq^{-1})	(rad μCi^{-1})	(Sv Bq^{-1})	(rem μCi^{-1})
^{227}Ac	21.8 y	α β γ	NS, IVC, U, F	Type M	Lung	8.2×10^{-7}	3.0×10^{0}	4.8×10^{-5}	1.8×10^{2}
^{241}Am	432 y	α γ	NS, IVC, U, F	Type M	Lung	6.3×10^{-7}	2.3×10^{0}	2.7×10^{-5}	1.0×10^{2}
^{252}Cf, D	2.65 y	α γ n	NS, BC, U	Type M	Lung	9.7×10^{-7}	3.6×10^{0}	1.1×10^{-5}	4.1×10^{1}
					Red marrow	1.3×10^{-8}	4.8×10^{-2}		
^{144}Ce, D	285 d	β γ	NS, BC, U	Type M	Lung	4.1×10^{-8}	1.5×10^{-1}	2.3×10^{-8}	8.5×10^{-2}
				Type S	Lung	4.9×10^{-8}	1.8×10^{-1}	2.9×10^{-8}	1.1×10^{-1}
^{137}Cs, D	30.2 y	β γ	NS, BC, U	Type F	Red marrow	1.5×10^{-9}	5.6×10^{-3}	4.3×10^{-9}	1.6×10^{-2}
^{60}Co	5.27 y	β γ	NS, BC, U	Type M	Lung	1.5×10^{-8}	5.6×10^{-2}	7.1×10^{-9}	2.6×10^{-2}
				Type S	Lung	1.7×10^{-8}	6.2×10^{-2}	1.7×10^{-8}	6.3×10^{-2}
^{244}Cm	18.1 y	α γ n	NS, IVC, U	Type M	Lung	7.3×10^{-7}	2.7×10^{0}	1.7×10^{-5}	6.3×10^{1}
^{154}Eu	8.59 y	β, EC	NS, IVC, U, F	Type M	Lung	2.5×10^{-8}	9.2×10^{-2}	3.2×10^{-8}	1.2×10^{-1}
				Type S	Lung	2.9×10^{-8}	1.1×10^{-1}	2.4×10^{-8}	8.8×10^{-2}
^{3}H	12.3 y	β	U	HTO	Red marrow	1.5×10^{-11}	5.6×10^{-5}	1.8×10^{-11}	6.7×10^{-5}
^{131}I, D	8.02 d	β γ	IVC, U	Vapor	Thyroid	4.1×10^{-7}	1.5×10^{0}	2.0×10^{-8}	7.4×10^{-2}
^{192}Ir	73.8 d	β γ	NS, BC, U, F	Type M	Lung	1.7×10^{-8}	6.3×10^{-2}	4.1×10^{-9}	1.5×10^{-2}

TABLE 3.13—(*continued*)

Radionuclide[a]	Half-Life[b]	Emissions[c]	Method of Measurement[d]	Absorption Type[e]	Tissues	Absorbed Dose (30 d)		Effective Dose (50 y)	
						(Gy Bq^{-1})	(rad μCi^{-1})	(Sv Bq^{-1})	(rem μCi^{-1})
^{32}P	14.3 d	β	IVC, U	Type M	Lung	1.4×10^{-8}	5.2×10^{-2}	2.9×10^{-9}	1.1×10^{-2}
^{238}Pu	87.7 y	α n	IVC, U, F	Type M	Lung	6.3×10^{-7}	2.3×10^{0}	3.1×10^{-5}	1.1×10^{2}
				Type S	Lung	7.4×10^{-7}	2.7×10^{0}	1.1×10^{-5}	4.1×10^{1}
^{239}Pu	24,110 y	α	IVC, U, F	Type M	Lung	5.4×10^{-7}	2.0×10^{0}	3.3×10^{-5}	1.2×10^{2}
				Type S	Lung	6.4×10^{-7}	2.3×10^{0}	8.4×10^{-6}	3.1×10^{1}
^{210}Po	138 d	α	U	Type M	Lung	5.5×10^{-7}	2.0×10^{0}	2.3×10^{-6}	8.5×10^{0}
					Red marrow	3.2×10^{-9}	1.2×10^{-2}		
					Kidneys	3.5×10^{-8}	1.3×10^{-1}		
^{226}Ra, D	1,600 y	α β γ	NS, IVC, U, F	Type M	Lung	4.7×10^{-7}	1.7×10^{0}	2.2×10^{-6}	8.1×10^{0}
^{103}Ru	39.3 d	β γ	NS, BC, U, F	Type M	Lung	8.9×10^{-9}	3.3×10^{-2}	1.8×10^{-9}	6.6×10^{-3}
			NS, BC, U, F	Type S	Lung	1.0×10^{-8}	3.7×10^{-2}	2.1×10^{-9}	7.7×10^{-3}
^{106}Ru	374 d	β γ	NS, BC, U, F	Type M	Lung	3.3×10^{-8}	1.2×10^{-1}	1.7×10^{-8}	6.3×10^{-2}
				Type S	Lung	3.9×10^{-8}	1.4×10^{-1}	3.4×10^{-8}	1.3×10^{-1}
^{153}Sm	46.5 h	β γ	NS, BC, U	Type M	Lung	3.2×10^{-9}	1.2×10^{-2}	6.8×10^{-10}	2.5×10^{-3}
^{90}Sr, D	28.8 y	β	U, F	Type F	Red marrow	4.6×10^{-9}	1.7×10^{-2}	3.0×10^{-8}	1.1×10^{-1}

^{232}Th, D	1.4×10^{10} y	α β γ	NS, IVC, U, F	Type M	Lung	3.1×10^{-7}	1.1×10^{0}	2.9×10^{-5}	1.1×10^{2}
				Type S	Lung	3.7×10^{-7}	1.4×10^{0}	1.2×10^{-5}	4.4×10^{1}
^{234}U[f], D	2.5×10^{5} y	α β γ	NS, IVC, U, F	Type M	Lung	4.6×10^{-7}	1.7×10^{0}	2.1×10^{-6}	7.8×10^{0}
				Type S	Lung	5.4×10^{-7}	2.0×10^{0}	6.8×10^{-6}	2.5×10^{1}
^{90}Y	64.1 h	B	U	Type M	Lung	4.5×10^{-9}	1.7×10^{-2}	1.6×10^{-9}	5.9×10^{-3}

[a]Radionuclides are listed alphabetically by element. D is the possible presence of daughters with a half-life of <25 y (the radiations of the daughters are not included in the listing).

[b]Radioactive half-life.

[c]The primary radiations are listed. These include radiations emitted by dosimetrically-significant chain members.

β = both positron and electron emission
γ = includes conversion x-ray emissions as well as gamma rays
EC = electron conversion
n = neutrons

[d]The following symbols are used to indicate principal techniques for measuring external contamination or indicating internal exposure. The order of the symbols has no significance in the listing:

BC = whole-body count (standard gamma detection methods)
F = feces sample analyses
IVC = special *in vivo* counting techniques useful for low-energy counting (wound monitoring, thyroid counting), or special low-energy x-ray or gamma detectors for chest counts (*e.g.*, plutonium or americium counting)
NS = nasal swab counted in laboratory if inhalation suspected
U = urine sample analyses

[e]Absorption type in the respiratory tract as defined in ICRP Publication 66 (ICRP, 1994a), Type F (fast), M (moderate), and S (slow.

[f]Uranium always comes as a mixture of the isotopes 238, 234 and 235. Natural uranium is composed of 99.3 % ^{238}U, 0.711 % ^{235}U, and 0.0058 % ^{234}U by weight. In equilibrium, natural uranium has the same activity of ^{238}U and ^{234}U (48.9 %) and 2.2 % ^{235}U. Enriched uranium is obtained when the concentration of ^{235}U is increased to significantly >0.711 % by weight. When the concentration of ^{235}U is decreased from 0.711 % by weight to 0.2 to 0.3 %, the material is called depleted uranium (Section 20.24).

absorbed doses to red marrow and lungs, with allowance for uncertainties typically involved in the dose estimates. CDGs for radioiodine are defined differently from those for other radionuclides because the cumulative dose to the thyroid is the pertinent measure of risk in this case, and FDA (2001) issued specific guidance regarding projected thyroid doses at which treatment for intake of radioiodine is indicated for different risk groups (Section 12).

Based upon the recommendations and limits for emergency situations and knowledge of deterministic effects, the numerical values of dose used as a basis for computing the CDG intake values for different radionuclides, excluding isotopes of iodine, in adults are 0.25 Sv (25 rem) (50 y effective dose) for consideration of stochastic effects [based on the population-averaged nominal cancer fatality risk coefficient of 5 % Sv^{-1} derived from epidemiological data (ICRP, 2007), this represents about a 1.3 % lifetime risk of fatal cancer attributable to the radiation dose]; a 30 d RBE-weighted absorbed-dose (see Terminology, Section 3.1.2) value of 0.25 Gy-Eq (25 rad-Eq) for consideration of deterministic effects to bone marrow (RBE = 2); and a 30 d RBE-weighted absorbed-dose value of 1 Gy-Eq (100 rad-Eq) for consideration of deterministic effects to the lungs (RBE = 7). CDG for an adult is the intake that satisfies the constraints on the effective dose and the 30 d absorbed doses to the red marrow and lungs. Table 3.14 provides a list of CDG values for nine noniodine radionuclides in adults. CDG values for additional noniodine radionuclides are given in Table 11.1.

CDGs for children (0 to 18 y of age) and pregnant women for noniodine radionuclides are defined as one-fifth the adult value, reflecting the increased vulnerabilities during development and maturation (AAP, 2003). Children weighing >70 kg should be considered as adults.

For an intake or expected intake of radioiodine, FDA recommends that KI be administered to adults >40 y of age if the projected dose to thyroid is ≥5 Gy (500 rad), to adults 18 to 40 y of age if the projected dose ≥0.1 Gy (10 rad), and to pregnant or lactating women or persons <18 y of age if the projected dose is ≥0.05 Gy (5 rad). In this Report, CDGs for ^{131}I (the only isotope of iodine considered here) are derived separately for the following subgroups of the population, considering not only FDA dose guidelines for different risk groups but also projected differences with age in dose per unit intake of radioiodine (Section 20): adults of age >40 y; adults 18 to 40 y; pregnant or lactating women; and age groups 12 to 18, 7 to 12, 3 to 7, 0.5 to 3, and <0.5 y. The dose coefficient for thyroid (committed equivalent dose to thyroid per unit intake) for a reference adult is applied to each of the first three subgroups, and the coefficients for intake

TABLE 3.14—*Abbreviated list of model predictions used to assess whether a radionuclide intake exceeds the CDG.*[a,b] *Values are for a reference adult (see Tables 11.1 and 11.2 for a full listing).*[c]

Radionuclide	Intake Mode[d]	Form[d]	Effective Dose		CDG (intake activity)		Early Excretion and Retention (percentage of intake)			Early Excretion and Retention Levels Indicative of Intake of 1 CDG (dpm)[e]			
			Sv Bq^{-1}	mrem μCi^{-1}	Bq	μCi	Urinary Excretion 0 – 24 h	Retention in Chest at 24 h[f]	Total-Body Retention at 24 h	Urinary Excretion 0 – 24 h	Retention in Chest at 24 h[f]	Total-Body Retention at 24 h	Nasal Swab Soon After Inhalation[g]
^{60}Co	Inhalation	Type S	1.7×10^{-8}	6.3×10^{1}	1.5×10^{7}	4.0×10^{2}	—[h]	6.4	49	—[h]	5.6×10^{7}	4.3×10^{8}	4.4×10^{7}
^{90}Sr	Inhalation	Type F	3.0×10^{-8}	1.1×10^{2}	8.3×10^{6}	2.3×10^{2}	6.8	NA[i]	49	3.4×10^{7}	NA	2.5×10^{8}	2.5×10^{7}
^{137}Cs	Inhalation	Type F	4.3×10^{-9}	1.6×10^{1}	5.8×10^{7}	1.6×10^{3}	2.2	NA	58	7.7×10^{7}	NA	2.0×10^{9}	1.7×10^{8}
^{192}Ir	Inhalation	Type M	1.7×10^{-8} [j]	6.3×10^{1} [j]	5.9×10^{7}	1.6×10^{3}	0.31	5.7	49	1.1×10^{7}	2.0×10^{8}	1.7×10^{9}	1.8×10^{8}
^{226}Ra	Inhalation	Type M	2.2×10^{-6}	8.1×10^{3}	1.1×10^{5}	3.1×10^{0}	0.16	5.8	50	1.1×10^{4}	4.0×10^{5}	3.4×10^{6}	3.4×10^{5}
^{238}U [k]	Inhalation	Type S	6.8×10^{-6}	2.5×10^{4}	3.7×10^{4}	9.9×10^{-1}	0.07 [l]	6.4	49	1.5×10^{3} [l]	1.4×10^{5}	1.1×10^{6}	1.1×10^{5}
^{238}Pu	Inhalation	Type M	3.1×10^{-5}	1.1×10^{5}	8.1×10^{3}	2.2×10^{-1}	0.021	5.80	50	1.0×10^{2}	2.8×10^{4}	2.4×10^{5}	2.4×10^{4}
^{239}Pu	Inhalation	Type M	3.3×10^{-5}	1.2×10^{5}	7.6×10^{3}	2.0×10^{-1}	0.021	5.8	50	9.6×10^{1}	2.6×10^{4}	2.3×10^{5}	2.3×10^{4}
^{241}Am	Inhalation	Type M	2.7×10^{-5}	1.0×10^{5}	9.3×10^{3}	2.5×10^{-1}	0.18	5.8	50	1.0×10^{3}	3.2×10^{4}	2.8×10^{5}	2.8×10^{4}

[a]For radionuclides other than isotopes of iodine, the CDG for a specific form of a radionuclide and mode of exposure is the *intake activity* estimated to result in the most restrictive of the following doses to an adult: a 50 y effective dose of 0.25 Sv (25 rem), an RBE-weighted 30 d absorbed dose to red marrow of 0.25 Gy-Eq (25 rad-Eq), or an RBE-weighted 30 d absorbed dose to lung of 1 Gy-Eq (100 rad-Eq). Fivefold lower CDGs are applied to children and pregnant women. The following alpha RBEs are applied: 20 for effective dose, two for 30 d RBE-weighted absorbed dose to red marrow, and seven for 30 d RBE-weighted absorbed dose to lungs. Effective dose is more restrictive than the 30 d RBE-weighted absorbed dose to red marrow or lung in most cases.

TABLE 3.14—(*continued*)

[b]The following example illustrates how this table may be used. A patient enters the emergency room a few hours after an acute inhalation of ^{60}Co, thought to be in the form of a relatively-insoluble oxide. External measurements indicate that total-body activity is $<10^6$ dpm and activity in the chest is $<5 \times 10^5$ dpm. Measurements of urinary ^{60}Co indicate that 24 h excretion is $<10^4$ dpm. These measurements are considerably lower than the reference 24 h retention and excretion values in this table corresponding to inhalation of 1 CDG of a relatively-insoluble form of ^{60}Co (Type S). The measurements are also considerably lower than the reference values for inhalation of ^{60}Co in moderately-soluble form (Type M) shown in Table 11.1. Thus, it appears that the patient has inhaled considerably <1 CDG, even if the inhaled material is somewhat more soluble than suspected.

[c]For application to children and pregnant women the CDG and the activities in urine, chest, total body, and nasal passages that correspond to 1 CDG should be divided by five.

[d]If no information is available regarding the mode of intake or form of the radioactive material taken into the body, and if multiple cases are provided in this table for the radionuclide of concern, then measurement of activity in urine, chest, total body, or nasal swipe should be compared with the smallest listed value for urine, chest, total body, or nasal swipe, respectively, given for that radionuclide.

[e]Divide by 60 to convert to becquerels and by 2.22×10^6 to convert to microcuries.

[f]Retention in the chest refers to activity measured externally over the thoracic portion of the respiratory tract. This is assumed to represent activity in the lungs.

[g]The portion of inhaled activity found in a nasal swab in the early hours after inhalation of a radionuclide is highly variable, depending on such factors as aerosol size, the extent of nose breathing versus mouth breathing during the exposure, and the amount of nose blowing and wiping of the nostrils since the beginning of exposure. The listed activity for nasal swab represents 5 % of the inhaled amount, based upon experimental data and model predictions summarized in Section 10.3.1.1 and in greater detail in Section 16.4.1.2. The presence of radioactivity in a nasal swab is suggestive evidence of an inhalation exposure, particularly if both nares are contaminated. The absence of activity in a nasal swab does not establish that there was no inhalation exposure.

[h]For these cases, calculation of an intake based on urinary excretion data is not recommended because of the high sensitivity of the estimate to the GI absorption fraction, which is not well established. Where feasible, decisions concerning treatment should be based on external measurement of activity in the chest, supplemented with measurement of activity in feces. Fecal excretion data can be interpreted on the basis of tabulations in Section 20.

[i]NA = not applicable. In many cases of inhalation of radionuclides, external counts over the chest are not useful. For example, after inhalation of highly-soluble forms of radionuclides, activity quickly moves from the lungs to blood. Also, radionuclides that emit little if any penetrating radiation (*e.g.*, the beta-emitter ^{3}H or the alpha-emitter ^{210}Po) are not detectable by external measurement.

[j]The indicated dose is the RBE-weighted 30 d absorbed dose to the lungs, which is more restrictive than the effective dose in this case.

[k]Table entries for ^{238}U may also be applied to ^{234}U or ^{235}U. Chemical toxicity of uranium (nephrotoxicity) is generally of greater immediate concern than radiological toxicity following acute inhalation of elevated quantities of natural or depleted uranium.

[l]Measurement of the urinary excretion rate should be supplemented with measurement of fecal excretion rate where feasible. A number of inhalation cases have been reported in which little or no activity was measured in urine for an extended period following significant exposure to an insoluble form of this radionuclide (see case studies for uranium and plutonium in Section 20).

ages 15 y, 10 y, 5 y, 1 y, and 3 months are applied to age groups 12 to 18 y, 7 to 12 y, 3 to 7 y, 0.5 to 3 y, and <0.5 y, respectively. The CDG for radioiodine for a specific subgroup of the population is defined as FDA dose guideline value applicable to that subgroup, divided by the thyroid dose coefficient for that subgroup (Table 20.56). The resulting CDG intake values are given in Table 3.15 and also in Table 11.2.

3.9.2 *Decorporation Therapy*

Comprehensive information on decorporation therapy for internally-deposited radionuclides appears in Section 12. Tables 3.16 and 3.17 provide synopses of this information for quick access.

3.10 Radiation Dose Limitation

The NCRP and ICRP dose limits in Tables 3.18 and 3.19 apply to planned, controllable, routine work, including small-scale and nonemergency contamination incidents. In the event of a major radiation emergency (*e.g.*, a terrorist attack), it may be necessary to exceed these dose limits to perform lifesaving and other emergency-response activities as described in ICRP Publication 96 (ICRP, 2005a) and NCRP Report No. 138 (NCRP, 2001a).

For lifesaving or equivalent purposes: workers may approach or exceed 0.5 Sv (50 rem) equivalent dose, 0.5 Gy (50 rad) absorbed dose for x-ray and gamma radiation to a large portion of the body and 5 Sv (500 rem) or 5 Gy (500 rad) for x and gamma radiation to the skin of the extremities (hands, feet, lower legs, and forearms) (NCRP, 1993). The decisive control for emergency responders working within or near the inner contamination area with personal protection equipment (PPE) is 0.5 Gy (50 rad) to the whole body. These are considered once-in-a-lifetime exposures (NCRP, 2005a). In Table 3.20, the Federal Emergency Management Agency (FEMA) dose limit is 0.25 Sv (25 rem) committed effective dose for lifesaving or protection of large populations when lower doses are not practicable; higher dose limits only on a voluntary basis to persons fully aware of the risks (FEMA, 2008).

TABLE 3.15—*Model predictions used to assess whether an intake of ^{131}I by inhalation as a vapor or ingestion exceeds the CDG.*[a]

Group	Committed Equivalent Dose to Thyroid		CDG (intake activity)		Excretion and Retention During First 24 h (percentage of intake)			Excretion and Retention Levels During First 24 h Indicative of an Intake of 1 CDG (dpm)[b]		
	(Sv Bq^{-1})	(mrem μCi^{-1})	(Bq)	(μCi)	Urinary Excretion 0 – 24 h	Retention in Thyroid at 24 h	Total-Body Retention at 24 h	Urinary Excretion 0 – 24 h	Retention in Thyroid at 24 h	Total-Body Retention at 24 h
Adult >40 y	3.9×10^{-7}	1.4×10^{3}	1.3×10^{7}	3.5×10^{2}	56	23	33	4.3×10^{8}	1.8×10^{8}	2.5×10^{8}
Adult 18 – 40 y	3.9×10^{-7}	1.4×10^{3}	2.6×10^{5}	6.9×10^{0}	56	23	33	8.6×10^{6}	3.5×10^{6}	5.1×10^{6}
Pregnancy or lactation	3.9×10^{-7}	1.4×10^{3}	1.3×10^{5}	3.5×10^{0}	56	23	33	4.3×10^{6}	1.8×10^{6}	2.5×10^{6}
Age 12 – 18 y	6.2×10^{-7}	2.3×10^{3}	8.1×10^{4}	2.2×10^{0}	56	23	33	2.7×10^{6}	1.1×10^{6}	1.6×10^{6}
Age 7 – 12 y	9.5×10^{-7}	3.5×10^{3}	5.3×10^{4}	1.4×10^{0}	56	23	33	1.8×10^{6}	7.3×10^{5}	1.0×10^{6}
Age 3 – 7 y	1.9×10^{-6}	7.0×10^{3}	2.6×10^{4}	7.1×10^{-1}	56	23	33	8.8×10^{5}	3.6×10^{5}	5.2×10^{5}
Age 0.5 – 3 y	3.2×10^{-6}	1.2×10^{4}	1.6×10^{4}	4.2×10^{-1}	56	22	32	5.3×10^{5}	2.1×10^{5}	3.0×10^{5}
Age <0.5 y	3.3×0^{-6}	1.2×10^{4}	1.5×10^{4}	4.1×10^{-1}	56	22	29	5.1×10^{5}	2.0×10^{5}	2.6×10^{5}

[a]The tabulated values are based on threshold doses estimated by FDA (2001) and listed in Table 12.14 for different risk groups, together with age-specific biokinetic and dose estimates for ^{131}I inhaled as a vapor listed in Table 20.56 of this Report.

[b]Divide by 60 to convert to becquerels and by 2.22×10^{6} to convert to microcuries.

TABLE 3.16—*Decorporation therapy recommendations for radionuclides of concern.*[a]

Radionuclides	Treatment	Preferred Prescription
Actinium	Consider DTPA	Consider DTPA
Americium	DTPA	DTPA
Antimony	British Anti-Lewisite (BAL), penicillamine	BAL
Arsenic	BAL, dimercaptosuccinic acid (DMSA)	BAL
Barium	Barium, calcium therapy (Section 12.4.1)	Section 12.4.1
Berkelium	DTPA	DTPA
Bismuth	BAL, Penicillamine, DMSA	DMSA
Cadmium	DMSA, DTPA, Ethylenediaminetetraacetic acid (EDTA)	DMSA
Californium	DTPA	DTPA
Calcium	Barium, calcium therapy (Section 12.4.1)	Section 12.4.1
Carbon	Consider hydration and nonlabeled carbon	Consider hydration and nonlabeled carbon
Cerium	DTPA	DTPA
Cesium	Prussian blue	Prussian blue
Chromium	DTPA, EDTA (antacids are contraindicated)	DTPA
Cobalt	DMSA, DTPA, EDTA, N-acetyl-L-cysteine (NAC)	DTPA
Copper	EDTA, penicillamine, trientine	Penicillamine
Curium	DTPA	DTPA
Einsteinium	DTPA	DTPA
Europium	DTPA	DTPA
Fission products (mixed)	Management depends on predominant isotopes present at time. Early: iodine; late: strontium, cesium, and others	
Fluorine	Aluminum hydroxide	Aluminum hydroxide
Gallium	Consider penicillamine	Penicillamine

TABLE 3.16—(*continued*)

Radionuclides	Treatment	Preferred Prescription
Gold	BAL, penicillamine	BAL
Indium	DTPA	DTPA
Iodine	KI, consider saturated solution of potassium iodide (SSKI), propylthiouracil, methimazole or potassiumiodate	KI
Iridium	Consider DTPA, EDTA	Consider DTPA
Iron	Deferoxamine (DFOA), deferasirox, DTPA, DFOA and DTPA together	DFOA
Lanthanum	DTPA	DTPA
Lead	DMSA, EDTA, EDTA with BAL	DMSA
Manganese	DFOA, DTPA, EDTA	DTPA
Magnesium	Consider strontium therapy (Section 12.4.5)	Consider strontium therapy
Mercury	BAL; EDTA; penicillamine; DMSA	BAL
Molybdenum	Limited clinical experience	
Neptunium	Consider DFOA and/or DTPA	Consider DFOA and/or DTPA
Nickel	BAL, EDTA	BAL
Niobium	DTPA	DTPA
Palladium	Penicillamine, DTPA	Penicillamine
Phosphorus	Phosphorus therapy (Section 12.4.4)	Phosphorus therapy
Plutonium	DTPA, DFOA, EDTA, DTPA and DFOA together	DTPA
Polonium	BAL, DMSA, penicillamine	BAL
Potassium	Diuretics	Diuretics
Promethium	DTPA	DTPA
Radium	Radium, strontium therapy (Section 12.4.5)	Section 12.4.5

Rubidium	Prussian blue	Prussian blue
Ruthenium	DTPA, EDTA	DTPA
Scandium	DTPA	DTPA
Silver	No specific therapy.	
Sodium	Diuretic and isotopic dilution with 0.9 % NaCl	Diuretic and isotopic dilution with 0.9 % NaCl
Strontium	Radium, strontium therapy (Section 12.4.5)	Section 12.4.5
Sulfur	Consider sodium thiosulfate	Consider thiosulfate
Technetium	Potassium perchlorate	Potassium perchlorate
Thallium	Prussian blue	Prussian blue
Thorium	Consider DTPA	Consider DTPA
Tritium (^{3}H)	Force fluids	Water diuresis
Uranium	Bicarbonate to alkalinize the urine. Consider dialysis	Bicarbonate
Yttrium	DTPA, EDTA	DTPA
Zinc	DTPA, EDTA, zinc sulfate as a diluting agent.	DTPA
Zirconium	DTPA, EDTA	DTPA

[a]The majority of these drugs are not approved by FDA for the indications listed in this table (see Section 12 for further information and warnings).

TABLE 3.17—*Dose schedules for drug or treatment modalities.*

Drug or Treatment Modality	Dosage
Acetylcysteine [N-acetyl-L-cysteine (NAC)] (Section 12.4.2)	Consider dosage as for acetaminophen overdosage, start at 140 mg kg^{-1} oral loading dose (RxList, 2009).
Deferoxamine (DFOA) mesylate (Section 12.3.1)	FDA does not specify age: DFOA mesylate injectable; IM is preferred. 1 g IM or IV (2 ampules) slowly (15 mg kg^{-1} h^{-1}); Repeat as indicated as 500 mg IM or IV q4h × 2 doses; then 500 mg IM or IV every 12 h for 3 d.
Dimercaprol [British Anti-Lewisite (BAL)] (Section 12.3.2)	FDA does not specify age: IM: 300 mg per vial for deep IM use, 2.5 mg kg^{-1} (or less) every 4 h for 2 d, then twice daily for 1 d then daily for days 5 to 10.
Diethylenetriaminepentaacetate (DTPA, calcium or zinc) (pentetate calcium trisodium and Pentetate zinc trisodium) (Section 12.3.3)	Adults: IV: 1 g in 5 mL IV push over 3 to 4 min or IV infusion over 30 min diluted in 250 mL of 5 % dextrose in water, Ringers lactate or normal saline. Nebulized inhalation: 1g in 1:1 dilution with sterile water or normal saline. Children under 12 y: 14 mg kg^{-1} IV as above, not to exceed 1 g.
Edetate calcium disodium [Ethylenediaminetetraacetic acid (EDTA)] Section 12.3.4)	FDA does not specify age: Ca-EDTA (edetate calcium disodium); 1,000 mg m^{-2} d^{-1} added to 500 mL 5 % dextrose or 0.9 % sodium chloride infused over 8 to 12 h. This same dosage can be given IM divided into equal doses spaces 8 to 12 h apart.
Penicillamine (Section 12.3.5)	FDA does not specify age: Oral: 250 mg daily between meals and at bedtime. May increase to 4 or 5 g daily in divided doses.
Phosphorus therapy Potassium phosphate, dibasic (Section 12.4.4)	Oral: 250 mg phosphorus per tablet. Adults: 1 – 2 tablets oral four times daily with full glass of water each time, with meals and at bedtime. Children >4 y of age: 1 tab oral four times daily.
Potassium iodide (KI) (Section 12.4.3)	Oral: tablets or liquid. Drug dose varies between 16 and 130 mg daily depending on age, thyroid exposure level, and whether or not pregnant or lactating (Table 12.14).

Propylthiouracil (Section 12.4.3)	Oral: 50 mg tablets, 2 tablets three times daily for 8 d. FDA does not specify age.
Prussian blue (Section 12.3.6)	Oral: Adults and adolescents 3 g three times daily. Children 2 to 12 y of age: 1 g three times daily.
Sodium bicarbonate (for uranium only) (Section 12.4.7)	Oral or IV (Table 12.22).
Radium and strontium therapy (Section 12.4.5)	Section 12.4.5.
Succimer [dimercaptosuccinic acid (DMSA)] [Chemet® (Schwarz Pharma, Monheim, Germany)] (Section 12.3.7)	FDA approved pediatric dosing: Start dosage at 10 mg kg^{-1} or 350 mg m^{-2} oral every 8 h for 5 d. Reduce frequency of administration to 10 mg kg^{-1} or 350 mg m^{-2} every 12 h (two-thirds of initial daily dosage) for an additional two weeks of therapy. A course of treatment lasts 19 d.
Water diuresis (Section 12.4.6)	Oral: Fluids >3 – 4 L d^{-1}.

[a]Unless noted otherwise, the references for these dose schedules are given in the listed sections.

[b]Dosage notations:

IV	=	intravenous injection	bid	=	twice per day
IM	=	intramuscular injection	tid	=	three times per day
mEq	=	milliequivalent	qid	=	four times per day
PO	=	per os or orally	qd	=	every day
q12h	=	every 12 h	q4h	=	every 4 h

TABLE 3.18—*NCRP dose-limit recommendations (NCRP, 1993; 2005a)*.[a]

Population	Dose Limit
Occupational	
Effective dose, annual	50 mSv (5 rem)
Effective dose, cumulative	10 mSv (1 rem) × age
Equivalent dose, annual for tissues and organs; lens of eye	150 mSv (15 rem)
Skin, hands, and feet	500 mSv (50 rem)
Public	
Effective annual (frequent or continuous) (infrequent)	 1 mSv (0.1 rem) 5 mSv (0.5 rem)
Equivalent dose, annual for tissues and organs; lens of eye	15 mSv (1.5 rem)
Skin, hands, and feet	50 mSv (5 rem)

[a]Dose limits, both NCRP and ICRP, apply only to planned exposure situations.

TABLE 3.19—*ICRP individual dose limits (ICRP, 2007)*.[a]

Type	Dose Limit
Public Exposure	
Individual	1 mSv (100 mrem) effective dose in a year
Lens of eye	15 mSv (1.5 rem) annaul equivalent dose
Skin	50 mSv (5 rem) annaul equivalent dose
Occupational Exposure	
Individual worker	20 mSv (2 rem) effective dose average over 5 y
Lens of eye	150 mSv (15 rem) annaul equivalent dose
Skin	500 mSv (50 rem) annaul equivalent dose
Hands and feet	500 mSv (50 rem) annaul equivalent dose

[a]Recommendations of ICRP do not apply directly to persons in the United States, but may apply to those in other nations.

TABLE 3.20—*Emergency worker guidelines in the early phase (FEMA, 2008).*[a]

Total Effective Dose Equivalent[b] Guideline	Activity	Condition
0.05 Sv (5 rem)	All occupational exposures	• All reasonably achievable actions have been taken to minimize dose.
0.1 Sv (10 rem)	Protecting valuable property necessary for public welfare (*e.g.*, a power plant).	• Responders have been fully informed of the risks of exposures they may experience. • Dose >0.05 Sv (5 rem) is on a voluntary basis. • Appropriate respiratory protection and other personal protection is provided and used. • Monitoring available to project or measure dose.
0.25 Sv (25 rem)[c]	Lifesaving or protection of large populations. It is unlikely that doses would reach this level in a radiological dispersal device incident. However, worker doses >0.25 Sv (25 rem) are conceivable in a catastrophic incident such as an improvised nuclear device incident.	• All appropriate actions and controls have been implemented; however, >0.05 Sv (5 rem) is unavoidable. • Responders have been fully informed of the risks of exposures they may experience. • Dose >0.05 Sv (5 rem) is on a voluntary basis. • Appropriate respiratory protection and other personal protection is provided and used. • Monitoring available to project or measure dose.

[a]In the intermediate and late phases, standard worker protections, including the 0.05 Sv (5 rem) occupational dose limit, would normally apply.

[b]The projected sum of the effective dose equivalent from external radiation exposure and committed effective dose equivalent from internal radiation exposure.

[c]EPA (1992) states that "Situations may also rarely occur in which a dose >0.25 Sv (25 rem) for emergency exposure would be unavoidable in order to carry out a lifesaving operation or avoid extensive exposure of large populations." Similarly, NCRP and ICRP raise the possibility that emergency responders might receive an equivalent dose that approaches or >0.5 Sv (50 rem) to a large portion of the body in a short time (NCRP, 1993). If lifesaving emergency-responder doses approach or >0.5 Sv (50 rem), emergency responders must be made fully aware of both the early and the late (cancer) risks of such exposure.

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