Management of RADIOACTIVITY in DRINKING-WATER

World Health Organization

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FOREWORD

Rationale for this document

The World Health Organization *Guidelines for drinking-water quality* (WHO GDWQ) (WHO, 2017a) provide the basis for the development of national regulations and standards and risk management strategies to ensure safe drinking-water.

Although they include guidance related to the radiological aspects of drinking-water in non-emergency situations (see Chapter 9 developed in the 2011 edition and retained in the 2017 edition), practical advice was requested by Member States to support stakeholders in the interpretation and implementation of the GDWQ in order to take appropriate action on these aspects. Accordingly, this guidance on management of radioactivity in drinking-water has been developed, taking into account the experience and knowledge gained with implementation of Chapter 9 of the GDWQ. This guidance will also facilitate the development of relevant national drinking-water standards and support their implementation.

Further, in response to requests from Member States, additional guidance in the event of a nuclear or radiological emergency has been written with the aim of raising awareness on applicable international standards and criteria as well as facilitating the management of drinking-water supplies.

Target audience

The questions and answers (Q&As) in this document are intended for organizations that set or enforce standards related to, or manage risks from, radioactivity in drinking-water at both local and national levels. The document will also be useful to the agencies that may provide support on issues related to radioactivity in drinking-water. Therefore, the document will be useful to water suppliers, drinking-water regulators, radiation protection specialists, and emergency planners.

The guidance is not written as communication material for members of the public, although it may be helpful in developing such materials.

Description of this document

This guidance on radiological aspects of drinking-water quality is written in the format of Q&As. Each question and associated answer is written to be largely stand-alone with links to other Q&As that provide additional relevant information; there is no need to read the document from start to finish.

The document is divided into four sections:

- **Section 1** on **non-emergency situations** provides background information on the GDWQ, explains the approach adopted by WHO to assess the public health risks from radionuclides in drinking-water and aspects to support their management in these situations. Information on radon, including the assessment and management of risks, is provided in a separate section, as the assessment and management approach for radon is distinct compared to the other radionuclides.

- **Section 2** on **emergency situations** provides similar information included in the non-emergency section, but within an emergency context.
- **Section 3** provides **supporting information** that is largely common to both non-emergency and emergency situations, including information on treatment and analytical methods.
- **Section 4** includes **case studies** illustrating how some countries have managed radioactivity in drinking-water.

The document also includes an **Annex** to support calculation of doses and guidance levels for specific non-emergency situations.

For non-emergency situations, it is anticipated that the reader will use this guidance in conjunction with Chapter 9 of the GDWQ (WHO, 2017a); however, some information in the GDWQ is summarized within this guidance for convenience, to support practical implementation.

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ABBREVIATIONS

ALARA	as low as reasonably achievable
Bq	becquerel
BSS	Basic Safety Standards
EC	European Commission
FAO	Food and Agricultural Organization of the United Nations
GDWQ	*Guidelines for drinking-water quality*
IAEA	International Atomic Energy Agency
ICP-MS	inductively-coupled plasma mass spectrometry
ICRP	International Commission on Radiological Protection
IDC	individual dose criterion
ILO	International Labour Organization
LOD	limit of detection
mSv	millisieverts
NaI	sodium iodine
NEA	Nuclear Energy Agency
OECD	Organisation for Economic Co-operation and Development
OIL	Operational Intervention Level
PAHO	Pan American Health Organization
Sv	sieverts
UNEP	United Nations Environment Programme
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization

GLOSSARY

Activity: See "radioactivity".

Activity concentration: Amount of radioactivity expressed by a unit of activity per unit volume, e.g. becquerel/litre or becquerel/kilogram. See also "radioactivity" and "becquerel".

Alpha particles: Two neutrons and two protons bound as a single particle that is emitted from the nucleus of certain radioactive isotopes in the process of decay or disintegration; a positively charged particle indistinguishable from the nucleus of a helium atom. Alpha particles can scarcely penetrate the dead outer layer of human skin so radionuclides that emit them are only hazardous if they are taken into the body, for example via inhalation or ingestion.

Atoms: The smallest particles of a chemical element that retains its chemical properties. They are composed of particles distributed in a dense nucleus of positively-charged protons and electrically-neutral neutrons, surrounded by a cloud of negatively-charged electrons.

Becquerel: The spontaneous disintegration of radioactive atoms is called "radioactivity" or just "activity". The amount of radioactivity is measured as the number of spontaneous disintegrations per second. The becquerel (Bq) is the unit of activity in the International System of Units. It is equal to one disintegration per second.

Beta particles: A negatively charged particle emitted from the nucleus of an atom, with mass equal to those of an electron. Beta particles may penetrate a centimetre or so of tissue, so radionuclides that emit them are hazardous to superficial tissues but not internal organs unless they are taken into the body via inhalation or ingestion.

Conservative: An approach that deliberately chooses an option (e.g. an assumption) that is more likely to overestimate than to underestimate the risk.

Consumption rate: Average quantity of an item consumed during a given time interval and expressed in an appropriate unit of measurement e.g. litres per day for drinking-water.

Dose: In the context of this document, a measure of the energy deposited by radiation in a target. See also "effective dose".

Dose coefficients: Factors used to convert the amount of incorporated radioactive substances (radionuclide intake) to the dose in tissues or organs, or the whole-body dose. These factors (also called "dose conversion factors") may depend on the radionuclide, the incorporation route (e.g. inhalation, ingestion), the chemical compound and the age of the person. Usually expressed as dose per unit intake, e.g. sieverts/becquerel.

Dose conversion factor: See "dose coefficients".

Effective dose: Sum of the products of dose to each organ multiplied by a radiation-weighting factor and a tissue-weighting factor that takes into account the radiosensitivity of tissues and organs. Related term: "dose".

Emergency situation: In the context of this document, a situation which requires prompt action in order to avoid or reduce undesirable consequences from radiation exposure to humans and/or the environment. An emergency exposure situation may arise as a result of an accident, a malicious act or any other unexpected event. Emergency exposures can be to the public and to workers, such as those who may be exposed while taking actions to respond to the emergency.

Exposure: In the context of this document, the state or condition of being subjected to irradiation from a source outside the body (i.e. external exposure) or within the body (i.e. internal exposure).

Exposure pathway: In the context of this document, a route by which radiation or radionuclides can reach humans and cause exposure.

External exposure: See "exposure".

Gamma rays: Short wavelength electromagnetic radiation without mass or charge (i.e. photons) of nuclear origin; they are similar to X-radiation but emitted at very specific energies characteristic of the decaying atoms. Gamma rays can pass through the body, so radionuclides that emit them may be hazardous whether on the outside or the inside of the body.

Gross alpha (activity concentration): Total activity of all alpha particle emitters, expressed in terms of unit of activity per unit of volume (e.g. becquerel /litre). The gross alpha screening measurements do not provide the identity of or activity concentration of specific alpha-emitting radionuclides.

Gross beta (activity concentration): Total activity of all beta particle emitters excluding tritium, although other weak beta emitters are also excluded using most screening measurement techniques; expressed in terms of unit of activity per unit of volume (e.g. becquerel /litre). The gross beta screening measurements do not provide the identity or activity concentration of specific beta-emitting radionuclides.

Groundwater: Water contained beneath the surface of the earth in rocks or subsoil, which may accumulate underground in aquifers.

Guidance level: In the context of this document the activity concentration of a given radionuclide that, if present in drinking-water consumed throughout one year at a consumption rate of 2 litres per day would result in an individual dose of 0.1 millisievert (mSv).

Half-life: The time taken for the quantity of a radionuclide to decrease by half as a result of radioactive decay.

Hazard: A biological, chemical or physical agent that may cause harm to human health.

Health effect: Changes in the health status of an individual or population, identifiable either by diagnostic or epidemiological methods.

Individual dose criterion: In the context of this document, the criterion for assessing health risks from prolonged exposure to radionuclides in drinking-water. The individual dose criterion (IDC) is 0.1 millisievert (mSv) per one year's consumption of drinking-water. In practice, this criterion is translated into two operational quantities: the screening levels and the guidance levels. See also "screening level" and "guidance level".

Ingestion: In the context of this document, the incorporation of a radionuclide into the body through the gastrointestinal tract.

Intake: The activity of a radionuclide taken into the body (by ingestion, inhalation or through the skin) in a given time period or as a result of a given event.

Internal exposure: In the context of this document, a radiation exposure resulting from radioactive material that gets inside the body by ingestion, inhalation or through the skin. Radioactive materials produce radiation exposure during the entire time they are inside the body until the material is no longer radioactive (it decays) or it is naturally removed by the body e.g. by urinary or faecal excretion. See also "exposure".

Ionizing radiation: Radiation that has a high enough energy to remove electrons from atoms and is therefore capable of producing ion pairs in a material/tissue. Examples are alpha particles, beta particles and gamma rays.

Mineral water: Water obtained directly from natural or drilled sources from underground water. In order to be characterized as natural mineral water, the water needs to meet a number of criteria as defined by Codex Standard 108–1981[1].

Natural background radiation: Amount of radiation to which a population is exposed from natural sources, such as terrestrial radiation resulting from naturally occurring radionuclides in the soil, cosmic radiation originating in outer space, and naturally occurring radionuclides deposited in the human body.

Non-emergency situations: In the context of this document, a situation where a planned activity results in a radiation exposure from a source (e.g. radioactive discharges from the normal operation of a nuclear medicine facility or a nuclear power plant) or where an existing exposure already exists when a decision on the need for control needs to be taken (e.g. exposure to natural background radiation and exposure to residual radioactive material from a previous nuclear or radiological emergency after the emergency has been declared ended).

Nuclear emergency: An emergency in which there is, or is perceived to be, a hazard due to radiation exposure in a situation involving atomic fission or fusion. Fission and fusion are associated with the generation of electrical power by nuclear power plants, scientific research and nuclear weapons test/use. See also "emergency situation".

Parametric value: In the context of the Euratom Drinking-Water Directive[2], the value of radioactive substances in water intended for human consumption above which Member States shall assess whether the presence of such radioactive substances poses a risk to human health which requires action and, where necessary, shall take remedial action to improve the quality of water to a level which complies with the requirements for the protection of human health from a radiation protection point of view.

Radiation: Energy that travels through matter. In the context of this document this term is used to refer to ionizing radiation. See also "ionizing radiation".

Radioactive decay: The process of spontaneous transformation of the nucleus of unstable atoms resulting in the release of radiation in the form of alpha particles, beta particles, gamma rays and other particles. See also "atoms", "radiation", "alpha particles", "beta particles" and "gamma rays".

Radioactive material: A substance that contains unstable atoms that give off radiation as they decay. See also "radioactive decay".

Radioactivity (also called "activity"): The property of the nucleus of unstable atoms that causes them to spontaneously release energy in the form of photons (e.g. gamma rays) or subatomic particles (e.g. alpha or beta particles). The amount of radioactivity is defined as the mean number of decays per unit time. See also "becquerel".

Radiological emergency: An emergency in which there is, or is perceived to be, a hazard due to radiation exposure from radiological devices or radioactive materials used in medical, industrial or research applications. See also "emergency situation".

Radionuclide: Radioactive species of an atom characterized by an unstable nucleus which spontaneously transforms, releasing energy in the form of radiation.

1 http://www.fao.org/input/download/standards/223/CXS_108e.pdf
2 http://ec.europa.eu/environment/water/water-drink/legislation_en.html

Reference level: In the context of the system of radiological protection, a level of radiation dose 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.

Remedial action: See "remediation".

Remediation: In the context of this document, any measures carried out to reduce radiation exposure, through actions applied to the contamination itself (the source) or to the exposure pathways to humans.

Risk: The likelihood of an event occurring that exposes populations to a hazard, combined with the severity of its consequences. In the context of this document, the term is used to refer to health risks associated with radiation exposure through drinking-water.

Screening level: In the context of this document, these are levels of radioactivity in drinking-water, expressed as total alpha and total beta activity concentrations, below which no further action is required.

Water safety plan: A comprehensive risk assessment and risk management approach to ensure drinking-water safety that encompasses all steps in the water supply, from catchment to consumer.

Chapter 1

NON-EMERGENCY SITUATIONS

CHAPTER 1 NON-EMERGENCY SITUATIONS

1.1 BACKGROUND

1.1.1

Are radionuclides in drinking-water likely to be a public health risk in non-emergency situations

No. The health risks associated with the presence of radionuclides in drinking-water are generally very low compared to those from microorganisms and chemicals. Any health effects from radionuclides in drinking-water will not be acute or immediate. Except in unusual circumstances, the radiation dose resulting from the ingestion of radionuclides in drinking-water is much lower than that received from other sources of radiation (see Information Box 1.1).

Further, the levels of potassium-40 (^{40}K) do not need to be considered in assessing health risks from radionuclides in drinking-water because potassium is a key element in regulating many body functions and the potassium content of the body (and ^{40}K) is kept constant by a range of physiological processes.

Information Box 1.1: Radiation doses from natural sources of radiation

People typically receive a radiation dose of about 0.3 mSv each year due to radionuclides of natural origin in their diet; of this about 0.01 mSv (about 5%) comes from drinking-water. A dose of 0.3 mSv is typically 10% of the average annual radiation dose from all natural sources of radiation (cosmic rays, soil, radon, diet) received by an individual, which is about 2.4 mSv (UNSCEAR, 2008).

1.1.2

What are the possible sources of radionuclides in drinking-water in non-emergency situations

Radionuclides in drinking-water can arise from natural or human-made (i.e. anthropogenic) sources. Many radionuclides occur in nature, including in rocks and soil, and concentrations of radionuclides in drinking-water are therefore more commonly detected in supplies derived from groundwater sources (IAEA, 2016). Of particular significance for human radiation exposure from drinking-water are the naturally occurring radionuclides that originate from the elements of the thorium and uranium decay series, for example radium-226, radium-228, polonium-210, lead-210 and radon. These radionuclides can arise in water from natural processes in the ground or human activities involving naturally occurring radioactive materials, such as uranium mining and other extractive industries (coal, oil and gas), the fertilizer (phosphate) industry and the building industry. Information Boxes 1.2 and 1.3 provide examples of activity concentrations of naturally occurring radionuclides in drinking-water across the world and an example from Germany showing the contribution they make to radiation exposure from natural background.

Radon is considered separately within this guidance in Section 1.6[3].

Human-made radionuclides may be present in drinking-water from several sources, such as accidental or regular discharges from nuclear facilities, discharges of radionuclides produced for and used in medicine or industry, discharges from military activities and global dispersion of nuclear weapons fallout. The human-made radionuclides that might be found in drinking-water are caesium-134, caesium-137, strontium-90, iodine-131, tritium and carbon-14. The levels of these radionuclides in drinking-water are generally very low and are usually not measurable using standard analytical methods, i.e. they are below the limits of detection (see Information Box 1.4).

Information Box 1.2: Worldwide activity concentrations of naturally occurring radionuclides in drinking-water

Data from across the world on levels of naturally occurring radionuclides in drinking-water have been reviewed (UNSCEAR, 2000; 2008; 2016). The activity concentrations of natural radionuclides can vary widely across a country dependent on the underlying geology. For example, average uranium levels in water sources worldwide used for public water supplies show great variability, notably for groundwater, where activity concentrations range from 0.00001 Bq L^{-1}–200 Bq L^{-1}. However, few drinking-water samples (generally < 3%) exceed the national or international guidelines for uranium (UNSCEAR, 2016). Worldwide typical values of naturally occurring radionuclides in drinking-water derived from the most widely available and representative data compiled by UNSCEAR (UNSCEAR, 2000) indicate that the activity concentrations of naturally occurring radionuclides in drinking-water are typically very low.

Typical activity concentrations in drinking-water, Bq L^{-1}

^{210}Pb	^{210}Po	^{226}Ra	^{228}Ra	^{228}Th	^{230}Th	^{232}Th	^{235}U	^{238}U
0.01	0.005	0.0005	0.0005	0.00005	0.0001	0.00005	0.00004	0.001

Key: lead-210 (^{210}Pb), polonium-210 (^{210}Po), radium-226 (^{226}Ra), radium-228 (^{228}Ra), thorium-228 (^{228}Th), thorium-230 (^{230}Th), thorium-232 (^{232}Th), uranium-235 (^{235}U) and uranium-238 (^{238}U).

[3] Where radon remains dissolved in drinking-water, the radionuclides lead-210 or polonium-210 (radon decay products) may become important contributors to the overall dose from the ingestion of drinking-water.

Information Box 1.3: Contribution of naturally occurring radionuclides in drinking-water to annual natural background radiation exposure in Germany

As part of systematic studies in Germany to obtain representative data on public exposure to radiation from natural radionuclides in German drinking-water (BfS, 2009), 582 samples from public water supplies were analysed between 2003 and 2008. These covered urban areas as well as regions known for elevated concentrations of naturally occurring radionuclides (mainly areas rich in granite and/or gneiss, e.g. Erzgebirge, Bayerischer Wald). The results showed that natural radionuclides in German drinking-water only contribute to a minor extent to the total mean value of annual natural background radiation exposure (2.1 mSv). The mean values of radiation exposure from drinking-water (ingestion dose) obtained from the data were about 0.009 mSv y^{-1} for adults and about 0.05 mSv y^{-1} for infants, assuming an annual ingested volume of drinking-water of 350 litres for adults and 55 litres for infants according to the German Radiation Protection Ordinance (BMU, 2001). However, there is a considerable range in variation of activity concentrations for uranium-238, uranium-234, radium-226, radium-228, radon-222, lead-210 and polonium-210.

Information Box 1.4: Occurrence of anthropogenic radionuclides in drinking-water

National experiences have shown that the vast majority of measurements of human-made individual radionuclides, such as caesium-137 and strontium-90, made as part of monitoring programmes in drinking-water sources around nuclear licensed sites are all usually below limits of detection (e.g. Environment Agency et al., 2016; Canada Nuclear Safety Commission, 2016; BMU, 1986; BMU, 2006).

1.1.3

How do naturally occurring radionuclides enter into drinking-water

All materials in the earth's crust contain naturally occurring radionuclides, mainly from the uranium and thorium decay series as well as potassium-40. These radionuclides, which are dispersed throughout rocks and soils normally in low concentrations, may leach into groundwater (see Information Box 1.5). They are, therefore, more commonly found in drinking-water derived from groundwater sources and springs than surface water and rainfall.

Information Box 1.5: Behaviour of naturally occurring radionuclides in drinking-water

The hydro-chemical behaviour of uranium, thorium and individual members of the uranium and thorium decay series is complex and depends to a great extent on a range of other water quality parameters such as alkalinity, pH, redox and chemical composition. For example, thorium is considered to be relatively immobile and insoluble in the vast majority of natural waters while uranium can be highly mobile especially in water where the pH is near neutral and has high carbonate alkalinity.

1.1.4

When should radionuclides in drinking-water be considered in non-emergency situations

The potential for radionuclides to be present in drinking-water should be considered when a significant source of radionuclides entering drinking-water supplies is expected. This should be anticipated where there are areas with high levels of naturally occurring radionuclides in the underlying rocks and soil.

Activities involving naturally occurring radioactive materials, such as uranium mining and other extractive industries, and the use of human-made radionuclides in industry and medicine may also lead to radionuclides being present in drinking-water (See Question 1.1.2).

There are circumstances, for example some deeper groundwater sources in certain regions, where the health risks from naturally occurring radionuclides may be greater than those from chemicals.

CHAPTER 1 NON-EMERGENCY SITUATIONS

1.2 PURPOSE AND SCOPE OF THE GUIDELINES FOR DRINKING-WATER QUALITY

1.2.1

What is the purpose of the Guidelines for drinking-water quality

The primary purpose of the Guidelines for drinking-water quality (GDWQ) is to protect public health. The GDWQ detail the World Health Organization (WHO) recommendations for managing the health risks from hazards that may compromise the safety of drinking-water, including radionuclides. The recommendations should be considered in the context of managing the risk from other sources of exposure to these hazards, such as air and food.

The GDWQ provide a comprehensive approach to assess and manage risks to drinking-water safety. This holistic approach, the framework for safe drinking-water shown in Figure 1.1, encompasses the development of health-based targets (parameters and associated "limits" in national drinking-water standards), the assessment and management of risks by water suppliers (water safety plans) and independent surveillance to ensure that water safety plans are being implemented effectively and that health-based targets are being met. The water safety plan approach to risk assessment and risk management of drinking-water supplies increases confidence in the safety of the drinking-water by ensuring that the most significant risks are addressed and limited resources are used the most effectively.

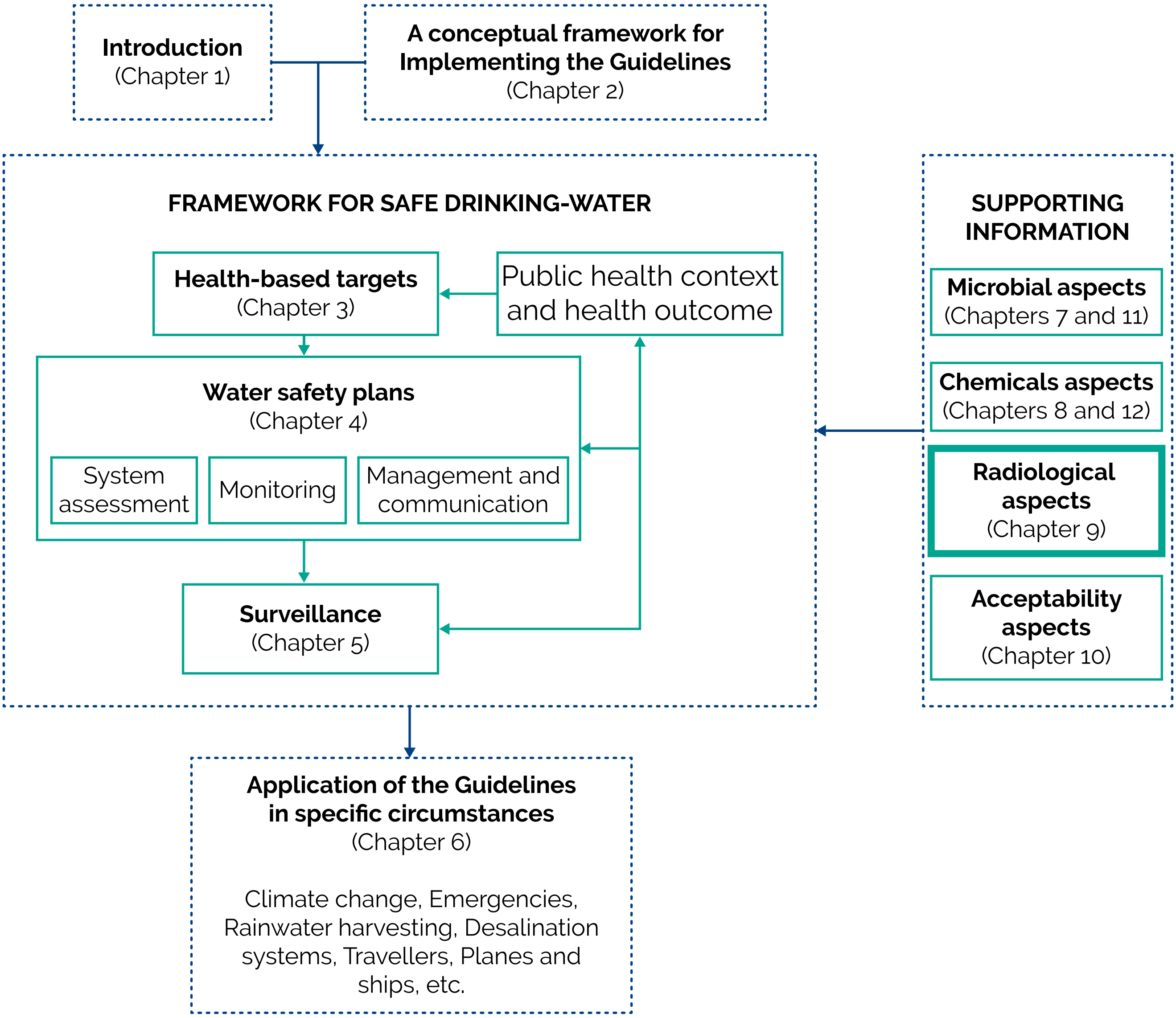
Chapter 9 of the GDWQ provides specific supporting information on the radiological aspects of drinking-water quality, as shown in Figure 1.1.

The assessment and management of health risks from radionuclides need to be considered in the context of other potential health risks from the water supply, namely microbial and chemical risks [4], the availability of other water supplies and available resources.

The GDWQ are addressed primarily to water and health regulators, policy-makers and their advisers, to assist in the development of national standards.

[4] Chapter 8 of the GDWQ provides specific information on the chemical aspects of uranium in drinking-water.

Figure 1.1. Interrelationships among the individual chapters of the Guidelines for drinking-water quality in ensuring drinking-water safety



1.2.2

What guidance does WHO provide on radionuclides in drinking-water

The GDWQ provide guidance on drinking-water quality, including radiological aspects (see Question 1.2.1).

Chapter 9 of the GDWQ provides specific information for assessing and managing health risks from radionuclides in drinking-water.

- Criteria (screening levels and guidance levels; see Question 1.3.1 for more information) are provided which allow for the assessment of the quality of drinking-water with respect to its radionuclide content.

- A methodology is given for interpreting the health criteria to support the assessment and management of health risks from radionuclides in drinking-water, which includes:
  - the identification of the individual radionuclides potentially present
  - measurement of the radionuclide concentrations in drinking-water
  - evaluation of potential radiation doses that could be received.
- Guidance is provided on remedial actions that can be taken to decrease radionuclide concentrations in drinking-water.
- Guidance is provided on radon in drinking-water supplies and the health risks arising from radon in drinking-water.

1.2.3

What situations can the GDWQ be used for

The guidance on radionuclides in the GDWQ is primarily for non-emergency situations where there could be ingestion of drinking-water containing radionuclides over extended periods of time, leading to prolonged radiation exposure of individuals. Exposure could continue for many years or even over a lifetime.

The criteria in the GDWQ for radionuclides are not applicable during radiological and nuclear emergencies. For emergency situations, criteria for taking emergency response actions including those related to drinking-water are issued in other international standards, that is the International Atomic Energy Agency (IAEA) Safety Standard Series (IAEA, 2011; 2015), for which WHO is a sponsoring organization (see Question 2.1.4).

However, there is information in the GDWQ on general planning and management of drinking-water quality in emergencies that might be useful in a nuclear or radiological emergency (see for example Sections 4.4.3 and 6.7 in the GDWQ). Other information in the GDWQ on analytical methods, remedial measures and the effectiveness of water treatment may also be useful in the event of a radiological or nuclear emergency.

1.2.4

Are the radiological criteria in the GDWQ mandatory

No. The GDWQ is international guidance designed to help countries develop customized regulations and standards. Countries should consider their specific situation when adopting the GDWQ, including the criteria to use (i.e. whether to adopt the individual dose criterion (IDC), screening levels and guidance levels without change). Question 1.5.10 covers the considerations for developing national standards.

1.2.5

Why do the criteria provided in the GDWQ not apply during a radiological or nuclear emergency

The criteria for radiological aspects in the GDWQ[5] (i.e. individual dose criterion (IDC), screening levels and guidance levels) do not apply to emergency situations because they have been established for the ingestion of drinking-water over prolonged periods of time (e.g. for many years or even over a lifetime), which is not appropriate for emergency situations. In the latter, exposures from drinking-water usually only occur in the short term, although possibly from higher activity concentrations of radionuclides in drinking-water than would typically be found in non-emergency situations. The dose criteria for use in an emergency situation can therefore be higher than the IDC in the GDWQ and the International Basic Safety Standards (BSS) reference level for drinking-water for non-emergency situations. International standards and criteria that apply for drinking-water quality in emergency situations are described in Section 2, for example Question 2.1.4.

Once the relevant authorities have declared the termination of an emergency, any remaining radionuclides in drinking-water over the longer term should be treated as a non-emergency situation and the GDWQ criteria should be used.

1.2.6

Are there any international criteria for radionuclides in bottled and packaged drinking-water

The Codex Alimentarius Commission has published a Codex General Standard for bottled/packaged drinking-water (other than natural mineral waters), CODEX STAN 227-2001 (CODEX, 2001). This standard states that the water should comply with the health-related requirements of the GDWQ for microbiological, chemical and radiological substances. There is also a Codex Standard for natural mineral waters, CODEX STAN 108-1981 (CODEX, 1981), but this standard does not contain any criteria for radionuclides.

For emergency situations, the international guidance in IAEA Safety Standards Series on preparedness and response for a nuclear or radiological emergency, which includes General Safety Requirements No. GSR Part 7 (IAEA, 2015) and General Safety Guide No. GSG-2 on *Criteria for use in preparedness and response for a nuclear or radiological emergency* (IAEA, 2011) apply to drinking-water in a nuclear or radiological emergency irrespective of whether the drinking-water is packaged or not. These standards are applicable for drinking-water destined for human consumption in affected countries (see Section 2, Question 2.1.4).

[5] Some of the information in Chapter 9 of the GDWQ is applicable during emergency situations, although the criteria included in that chapter (IDC, screening levels and guidance levels) are not applicable to emergencies. Further useful general information on planning for emergencies is given in Sections 4.4.3 and 6.7.

1.2.7

Should naturally occurring radionuclides and human-made radionuclides present in drinking-water be managed differently

No. A radiation dose associated with the intake of a radionuclide into the body from drinking- water does not depend on its source. Accordingly, the GDWQ do not differentiate between radionuclides that occur naturally and those that arise from human activities in terms of the criteria included to assess health risks.

However, in terms of risk management, there is a difference because human-made (i.e. anthropogenic) radionuclides are often controllable at the point at which they enter the water supply. Naturally occurring radionuclides, in contrast, which usually enter the water supply from the surrounding rocks and soil, are often less amenable to control. This may influence the actions that are taken in the event that the criteria in the GDWQ are exceeded.

CHAPTER 1 NON-EMERGENCY SITUATIONS

1.3 APPROACH ADOPTED BY WHO FOR ASSESSING THE PUBLIC HEALTH RISK FROM RADIONUCLIDES IN DRINKING-WATER

1.3.1

What are the criteria used in the GDWQ for assessing health risks from radionuclides in drinking-water

The criteria in the GDWQ for assessing health risks from radionuclides in drinking-water are screening levels, guidance levels and an individual dose criterion (IDC). Radon is not included in these criteria and is considered separately, see Section 1.6.

Each criterion is discussed in more detail in other questions, as indicated below.

- The GDWQ include an IDC of 0.1 mSv y^{-1} for assessing health risks to an individual from prolonged exposure to radionuclides in drinking-water. The IDC provides the basis for the development of the operational criteria that can be measured by water suppliers and regulators (i.e. screening levels and guidance levels).
- The screening levels are total activity concentrations that can be measured as part of drinking-water monitoring to assess if the IDC may be or is exceeded. The screening levels are 0.5 Bq L^{-1} for gross alpha activity and 1 Bq L^{-1} for gross beta activity (see Question 1.3.3). If either of the screening levels is exceeded, the activity concentrations of individual radionuclides should be determined and compared with the guidance levels in order to determine if the IDC is exceeded (see below).

- The guidance levels are specific for individual radionuclides and are the concentration that, if present in the drinking-water consumed throughout a year at a rate of 2 litres per day, would result in an individual dose of 0.1 mSv being received (see Question 1.3.4). Question 1.5.6 explains how to use the guidance levels to determine if the IDC is exceeded for one or several radionuclides present in drinking-water).

National experiences have shown that the vast majority of drinking-water supplies comply with the radiological criteria in the GDWQ.

1.3.2

What is the individual dose criterion of 0.1 mSv y^{-1}

The individual dose criterion (IDC) is a criterion in the GDWQ for assessing health risks from prolonged exposure to radionuclides in drinking-water. The IDC of 0.1 mSv y^{-1} represents a very low level of health risk (see Information Box 1.6). The IDC of 0.1 mSv is for consumption of drinking-water over the course of a year regardless of whether the radionuclides are naturally occurring or human-made. In practice, the IDC is translated in the GDWQ into two operational quantities, screening levels and guidance levels (see Questions 1.3.3 and 1.3.4).

Information Box 1.6: Interpretation of the IDC

The individual dose criterion (IDC) should not be interpreted as a limit above which drinking-water is unsafe for consumption. Drinking-water is a fundamental requirement of life and the risks of not having a drinking-water supply are likely to be much higher than consuming drinking-water that does not meet the IDC.

1.3.3

What purpose do the screening levels serve and how should they be used

The screening levels are operational criteria, expressed as total alpha and beta activity concentrations, below which no further action is required. This is because the individual dose criterion (IDC) of 0.1 mSv y^{-1} would usually not be exceeded.

Screening levels enable water suppliers and regulators to assess the total radioactivity in drinking-water in a resource- and cost-efficient manner. The use of screening levels is recommended because the process of identifying individual radionuclides in drinking-water and determining their concentration is time-consuming, resource intensive and expensive; and further, in most situations activity concentrations in drinking-water are very low and detailed analysis is not normally justified for routine monitoring.

The screening levels are 0.5 Bq L^{-1} for gross alpha activity and 1 Bq L^{-1} for gross beta activity. They are robust values that have been derived to cover the most common radionuclides that would be found in drinking-water and their contributions to the radiation dose from the consumption of drinking-water. These screening measurements do not provide the identity of specific radionuclides. Information Box 1.7 discusses what countries should do if they have a national dose criterion different from the IDC of 0.1 mSv y^{-1} and want to set screening levels.

If either screening level is exceeded, further investigation should be triggered (see Question 1.5.3). The stepwise process for applying the screening (and guidance) levels is shown in Figure 1.2 in Question 1.5.3.

In using the screening levels, it is important to be aware of the following situations.

- The methods for gross alpha and gross beta measurements rely on the detection of emitted alpha or beta particles during the radioactive decay of the radionuclides. They are appropriate for most situations in which radionuclides in drinking-water are likely to be found.
- However, there are a few radionuclides that cannot be measured using these screening methods. Question 1.4.3 provides further information on this and the approach to be adopted if the local situation indicates that these radionuclides may be present.
- There are a few naturally occurring radionuclides (notably radium-228 and polonium-210) where the IDC of 0.1 mSv y^{-1} could be exceeded, even if the screening levels are not exceeded, in the uncommon situation where these radionuclides are the only significant contributors to the total gross activity concentration. If the local geology and hydrology indicate that these radionuclides may be present, the individual radionuclides should be measured and compared with the guidance levels (see Question 1.5.6).

Information Box 1.7: Establishing screening levels based on national dose criterion that is different from the IDC

If a country has established a national dose criterion that is different to the IDC of 0.1 mSv y^{-1} and is using gross alpha and gross beta measurements as a screening approach, different screening levels need to be determined, taking into account the radionuclides in the drinking-water and their contributions to the dose; specialist advice should be sought.

1.3.4

What purpose do the guidance levels for radionuclides serve and how should they be used

The guidance level for a radionuclide is the concentration that, if present in the drinking-water consumed throughout the year at a rate of 2 litres per day, would result in an individual dose of 0.1 mSv. If several radionuclides have been identified, then a sum across the radionuclides present needs to be made to check that together they do not lead to the 0.1 mSv y^{-1} individual dose criterion (IDC) being exceeded. It is likely that drinking-water from a groundwater source containing naturally occurring radionuclides will contain several radionuclides in varying amounts. Further details of assessing if the IDC has been exceeded and summing across radionuclides are given in Question 1.5.6.

Guidance levels are provided in the GDWQ for a comprehensive set of naturally occurring radionuclides most commonly detected in drinking-water supplies as well as for human-made radionuclides potentially relevant for non-emergency situations. The guidance levels for the radionuclides most likely to be identified in drinking-water are given in Table 9.2 in the GDWQ and summarized in Table 1.1 of this document. For other radionuclides, values can be found in Table A6.1 of the GDWQ. The guidance levels are rounded to the nearest order of magnitude to reflect the generic nature of the assumptions made in the calculation of the guidance levels, these being conservative for the majority of cases.

The guidance levels should be used as a trigger for further investigation and not be interpreted as a limit above which drinking-water is unsafe for consumption. The guidance levels are likely to be conservative because they assume that drinking-water is consumed at this activity concentration for the whole year at a rate of 2 litres per day. In practice, activity concentrations often vary throughout the year and the consumption of drinking-water may be from a number of different sources (e.g. at home, a workplace, school, public places, etc.).

A guidance level can be calculated for a specific situation, for example using local or regional drinking-water consumption rates, as explained in Chapter 9 of the GDWQ. Annex 1 provides further information on the calculation of guidance levels, including calculations for children. If a guidance level is exceeded, due to the conservative assumptions made in calculating the guidance levels, it is very important to investigate whether the sample taken is representative of the situation at other times of the year and to understand the drinking-water habits of the population. Question 1.5.9 gives further details of what should be done if a guidance level is exceeded.

The guidance levels in the GDWQ do not apply in emergency situations (see Question 1.2.5).

1.3.5

Do the guidance levels need to be adjusted for children

No. As the guidance levels are not limits above which drinking-water is unsafe for consumption but are used as triggers for further investigation, it is appropriate for them to be based on parameter values for adults. The assumptions made in the calculation of the guidance levels are conservative, reflecting the assessment methodology adopted in the GDWQ.

If a guidance level is exceeded, it is important that there is further investigation; this may include a site-specific assessment for the population affected and can take into account their drinking-water consumption habits. In the case of there being a prolonged period over which a guidance level is exceeded, an assessment of doses to children and babies drinking bottled milk reconstituted with drinking-water may be appropriate. This is because children are more sensitive to exposure from some radionuclides (as reflected in different dose coefficients), although they typically consume smaller quantities of drinking-water than adults (for further details, see Question 1.5.9).

1.3.6

What is the reference level (1 mSv y^{-1}) and how does it relate to the individual dose criterion (0.1 mSv y^{-1}) for drinking-water

The International Basic Safety Standards (BSS[6]) (IAEA, 2014) recommend a reference level for the radiation dose due to consumption of drinking-water of approximately 1 mSv y^{-1}. A reference level represents the level of dose or risk above which it is judged to be inappropriate to plan to allow exposures to occur and below which the optimization of protective actions should be planned in order to keep doses as low as reasonably achievable (ALARA). It should not be regarded as an acceptable dose or as a dose limit, and efforts should be made to reduce any exposures that are above the reference level, to a level that is below, if possible. The International BSS require regulatory authorities to establish reference levels for radiation dose due to radioactivity in drinking-water, an approach that is consistent with the GDWQ.

The individual dose criterion (IDC) of 0.1 mSv y^{-1} represents a very low level of health risk. The majority of water supplies comply with this criterion and establishing a national standard at 0.1 mSv y^{-1} is appropriate for most countries as part of the optimization process (ALARA). However, in cases where this is not achievable, regulatory authorities may establish a specific reference level (or national standard) for radionuclides in drinking-water higher than 0.1 mSv y^{-1} (IDC), but generally less than the International BSS reference level of 1 mSv y^{-1}, depending on the circumstance (see Question 1.5.10).

Situations may arise where it may be appropriate to permit doses higher than 1 mSv y^{-1} for selected population groups, depending on the situation at the time, and considering a balance of the overall risks, including the risk of not having a supply of drinking-water. The consequence of this would be the acceptance of a potential slight increase in radiological risks to health.

6 The International BSS are the international benchmark for radiation safety. Eight organizations sponsor the International BSS: the European Commission, Food and Agricultural Organization of the United Nations (FAO), IAEA, International Labour Organization (ILO), Organisation for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA), Pan American Health Organization (PAHO), United Nations Environment Programme (UNEP) and WHO. The International BSS are used in many countries as the basis for national legislation to protect workers, patients, the public and the environment from the risks of ionizing radiation; they are not legally binding.

CHAPTER 1 NON-EMERGENCY SITUATIONS

1.4 MEASURING RADIONUCLIDES IN DRINKING-WATER

1.4.1

At what points in the water supply chain should measurements of radionuclides in drinking-water be made

It is important that the measurements that are made are representative of the drinking-water being consumed. If water is treated before consumption, the water should be monitored after treatment because treatment can reduce the activity concentrations of many radionuclides. Further information on the likely effectiveness of water treatment is given in Question 3.2. In general, the concentration of radionuclides does not change in the distribution system (except for radon; see Section 1.6), so it is appropriate to measure the water at the treatment works after treatment or at storage reservoirs prior to distribution. For supplies of drinking-water that are not treated, e.g. some small water supplies, the radionuclides can be measured at the source or the point of collection. Ideally, some measurements should be made at the point of consumption, i.e. at the tap or communal point of collection; however, this is usually not practicable.

For a new drinking-water supply, measurements of radionuclides in the water should be made at the source as part of characterizing it and determining its suitability as a source of drinking-water (see Question 1.4.2 for more information). The extent of treatment that will be carried out should also be taken into account (see Question 3.2). This characterization should be carried out along with assessing microbiological and chemical risks as part of developing water safety plans.

1.4.2

With what frequency should measurements of radionuclides in drinking-water be made

The frequency for measuring activity concentrations of radionuclides in drinking-water should be set taking into account the potential for there to be a public health risk from radionuclides in the drinking-water, the available resources and other priorities for providing safe drinking-water, including the analyses of microbiological and chemical contaminants.

In general, new water supplies should be sampled and analysed for radionuclides to determine their suitability for drinking-water before design and construction. It is important that the seasonal variation in radionuclide concentrations are characterized over the first year with the water tested frequently enough to show any seasonal variation, typically at least four times over the year (i.e. once per season). Ideally, measurements of individual radionuclides should be made in addition to measurements of gross alpha and gross beta activity, particularly if the presence of naturally occurring radionuclides is expected.

Due to the possibility of high heterogeneity in radionuclide levels in groundwater, it may be necessary to consider monitoring of new drinking-water supplies (including new abstraction points); this should be done even if there is already information on the groundwater source, or similar groundwater sources in the area and knowledge about the underlying geology (that could lead to high levels of uranium and/or thorium in rocks and the ground).

The sampling frequency of existing water supplies should be linked to several factors: the level of activity concentrations in the water; the source of the supply (i.e. surface water or groundwater) and how likely it is that activity concentrations may vary across the year (e.g. groundwater sources may display less variability than surface water sources); the size of the population supplied; and the quantity and quality of historical monitoring records. In determining the frequency, the following points should also be considered.

- If activity concentrations are below screening levels and stable, the frequency of monitoring can be reduced in agreement with the relevant regulatory agencies and health and water authorities to once every two to five years (or longer), depending on the water source.
- If gross activity concentrations are approaching the screening levels, activity concentrations of individual radionuclides are approaching the guidance levels or, where multiple radionuclides are measured, the sum of the ratios of the observed concentrations of the individual radionuclides to their guidance levels approaches unity (see Question 1.5.6), sampling frequency should be maintained, or even increased.
- Increasing the sampling frequency in the following situations:
  a. if the measurements indicate that there is an increasing trend in the activity concentrations;
  b. in areas with residual radioactive material from past practices that were never subject to regulatory control;
  c. in areas where there are residual levels of radionuclides following a nuclear or radiological emergency;
  d. if sources of potential radionuclide contamination exist nearby or are expected to change rapidly with time (e.g. mining activity or nuclear reactors).
- If activity concentrations consistently exceed the screening levels, then further investigation is needed, including further measurements and a possible increase in sampling frequency (see Question 1.5.3).

An international standard is available on the design of sampling programmes (ISO, 2006). Some examples of drinking-water monitoring programmes are given in Information Box 1.8.

Information Box 1.8: Examples of drinking-water monitoring programmes

Germany

The drinking-water ordinance in Germany (BMG, 2016) contains requirements on monitoring of drinking-water for radionuclides. Initial analysis is required to identify and assess the annual average activity concentrations in public water supplies and comprises

- for existing drinking-water supplies: four analyses in four different quarters within four years;
- for newly-established drinking-water supplies: four analyses in four different quarters within one year;
- regular analyses are necessary if the initial analyses reveal an exceedance of one or more parametric values[1] for radioactive substances.

Japan

After the Fukushima Daiichi nuclear power plant accident in March 2011 in Japan, monitoring of drinking-water for caesium-134 (^{134}Cs) and caesium-137 (^{137}Cs) was carried out and has continued beyond the initial emergency phase of the accident because radioactive caesium was detected in tap water (MHLW, 2011). The recommended monitoring frequency has progressively been reduced from at least daily, to weekly during the emergency phase, and then to at least monthly in April 2012, when the measurement frequency was recommended to be more than once a month for ^{134}Cs and ^{137}Cs (MHLW, 2012a; 2012b). However, there are several water utilities still measuring radioactive caesium more frequently (as of January 2018) for added reassurance to ensure radiation in drinking-water remains at safe levels.

United States of America

In the United States of America, suppliers providing drinking-water to at least 15 service connections or to more than 25 individuals (who consume it for a year) must conduct initial monitoring consisting of quarterly samples over the first year at each entry point to the distribution system after beginning operation, or after beginning to use a new source of water supply. The initial results determine the frequency of future monitoring:

1. if the initial monitoring results are less than the defined detection limit, then monitoring frequency is reduced to one sample every nine years;
2. if the initial monitoring results are greater than the defined detection limit but less than half of the maximum contaminant limit, then monitoring frequency is reduced to one sample every six years;
3. if the initial monitoring results are greater than half of the maximum contaminant limit but less than the maximum contaminant limit, then monitoring frequency is reduced to one sample every three years; and
4. if the initial monitoring results are greater than the maximum contaminant limit, then quarterly samples are required.

Different monitoring frequencies may be established for different contaminants for the same supply, based on the results for that one supply compared to each of four maximum contaminant levels, e.g. one system may be required to sample for gross alpha activity every three years, and uranium every six years, depending on the sample results for gross alpha activity and uranium, respectively.

Source: EPA (2000).

[1] Parametric value for radioactive substances is the term used in the Euratom Drinking-Water Directive (EC, 2013); values equivalent to the screening levels and guidance levels in the GDWQ are given.

Information Box 1.8: Examples of drinking-water monitoring programmes (continued)

Jordan

In Jordan, regular monitoring of radionuclide levels in water at various points of the supply chain between wells and consumer taps are made within the Disi Water Conveyance Project (see case study in Section 4.3 for additional information). The water provider and the health authorities follow a monitoring protocol that entails the following frequencies at each of the agreed upon sampling points.

1. Quarterly grab samples for each of the 55 wells in the Disi Water Conveyance Project well field to assess trends of radionuclide concentrations with time; frequency is reduced to once per year after two years of operation.
2. Monthly grab sample from the combined water of the 55 wells at the header tank in the south of Jordan before the water is admitted to the main 320 km long conveyer pipe.
3. Monthly composite samples for the Disi water before blending at the two delivery points in Amman.
4. Yearly monitoring of the waters containing low activity concentrations used for blending (water taken from Zara-Ma'en and Zai treatment plants whose historical results for gross alpha, gross beta, radium-226 and radium-228, are consistently below the analytical detection limits).
5. Monthly composite samples for the drinking-water after blending, measured at the outlets of the main reservoirs in Amman.
6. Monthly composite samples from public reservoirs to represent the water supplied to consumers in the different distribution zones in Amman.

1.4.3

Are there any radionuclides that are not detected by standard gross alpha and gross beta screening methods

Gross alpha measurement will detect all the alpha-emitting radionuclides that are likely to be found in drinking-water.

Standard gross beta measurement will detect most other radionuclides that emit beta particles that could be found in drinking-water under non-emergency situations. However, there are a few radionuclides that will not be detected by standard gross beta measurement methods or where their concentrations will be underestimated because either they do not emit beta particles or the energy of the beta particle emission is too low to be efficiently detected by the method.

The notable radionuclides that are not detected by gross beta measurement methods are tritium, carbon-14 and sulfur-35 (Information Box 1.9 provides an example of the monitoring requirements for tritium in Europe). Some gaseous or volatile radionuclides, such as isotopes of iodine will also not be detected, as losses of the radionuclides will occur during the analytical procedure. However, routine analysis for these human-made radionuclides is unlikely to be necessary in most situations.

The notable radionuclides for which activity concentrations are likely to be underestimated are naturally occurring lead-210 and radium-228 (^{228}Ra). Due to the low energy of their beta particle emissions, the efficiency of their detection is very poor and accordingly, their contribution to the gross beta activity is underestimated. An example is discussed in Information Box 1.10. In the uncommon situation where these radionuclides are the most significant contributors to the total gross activity concentration, this may lead to the individual dose criterion (IDC) of 0.1 mSv y^{-1} being exceeded even if the screening levels are not. If it is thought that these radionuclides may be present, radionuclide-specific analyses should be made. A review of the geology and hydrology of the area and radionuclide content of rocks, mineralization and soil, as well as historical data can be used to determine the extent of these naturally occurring radionuclides in groundwater.

Information Box 1.9: Requirements for monitoring tritium in the Euratom Drinking-Water Directive

In the Euratom Drinking-Water Directive[1] (EC, 2013), Member States are required to monitor tritium in water intended for human consumption where a human-made source of tritium or other radionuclide is present within the catchment area and it cannot be shown on the basis of other surveillance programmes or investigations that the level of tritium is below the parametric value of 100 Bq L^{-1}. If the concentration of tritium exceeds its parametric value, an investigation of the presence of other human-made radionuclides is required (EC, 2013).

[1] The European Commission (EC) has specific responsibilities in monitoring the implementation of the European Union law on radioactivity in drinking-water. The Euratom Drinking-Water Directive (EC, 2013) provides a framework for controlling radioactivity in drinking-water and the radiation dose received from the consumption of different forms of drinking-water (tap water and bottled water). The Directive does not apply to natural mineral waters and to small private supplies.

Further information on measurement methods is covered in Section 3.5. The measurement of radon in drinking-water is covered in Section 1.6.

Information Box 1.10: Monitoring of ^{228}Ra in Jordan

In Jordan, regular monitoring of radionuclide levels in water at various points of the supply chain between the wells and consumer taps are made within the Disi Water Conveyance Project. Analysis for radium isotopes and dose calculations are conducted since it is known that ^{228}Ra is the dominant radionuclide present and since, as noted above in the main text, gross beta measurements may not adequately detect this radionuclide. In Jordan, there have been a number of measurements where the gross beta activity concentration is less than or about 1 Bq L^{-1} but the measured activity concentrations of ^{228}Ra are higher than the guidance level of 0.2 Bq L^{-1} (unrounded value) and the dose is therefore > 0.1 mSv y^{-1} (using the GDWQ default assumptions on drinking-water consumption rates).

CHAPTER 1 NON-EMERGENCY SITUATIONS

1.5 HOW TO APPLY THE GDWQ METHODOLOGY FOR RADIONUCLIDES IN DRINKING-WATER

1.5.1

If a screening level is exceeded for one or a few drinking-water samples, does this mean that the radiation dose will be greater than the individual dose criterion of 0.1 mSv y^{-1}

No. An exceedance of either the gross alpha or the gross beta screening levels does not necessarily mean that the individual dose criterion (IDC) of 0.1 mSv y^{-1} will be exceeded. The IDC is an annual criterion and so if the gross activity screening levels are exceeded for a short time in an individual drinking-water sample or even a few samples, this does not necessarily imply that the IDC will be exceeded. If either of the screening levels is exceeded, then there is a need to investigate the situation further, e.g. take further samples (see Question 1.5.3).

1.5.2

Is any action required if the screening levels are not exceeded

If both the gross alpha and gross beta screening levels are not exceeded, routine monitoring of drinking-water should continue at the locations and frequency that has been agreed with the water quality regulator. The individual dose criterion (IDC) of 0.1 mSv in a year will not be exceeded in the vast majority of cases; however, there are two uncommon situations that are an exception to this.

- The first is if it is suspected that the water may contain a radionuclide that will not be detected by the screening methods. Question 1.4.3 provides information on the main radionuclides, which are human made, that will not be detected by the gross alpha and gross beta screening methods. Other sources of information may indicate that radionuclides in drinking-water could be present but would not be detected e.g. other environmental monitoring data in the area and the catchment that the water is drawn from, knowledge of sites that could have led to discharges of radionuclides to the catchment and local geology.
- The second is if the most significant contributors to the total activity concentration are radionuclides that are not detected efficiently by the screening methods. As explained in Question 1.4.3, radium-228 (^{228}Ra) and polonium-210 (^{210}Po) are the most notable. See Information Box 1.11 for examples of situations where ^{228}Ra in drinking-water is the highest contributor to the dose.

In these cases, radionuclide-specific measurements should be made and compared with the relevant guidance levels (see Question 1.5.3).

Information Box 1.11: Examples where ^{228}Ra is the most significant contributor to radionuclide concentrations in drinking-water

Jordan: Disi well water measurements between October 2013 and May 2015

^{226}Ra: 0.31–0.47 Bq L^{-1}
^{228}Ra: 1.07–1.41 Bq L^{-1}
Lead-210 (^{210}Pb): 0.02 Bq L^{-1}

Concentrations have remained stable over time.

Queensland, Australia: 110 bore holes reflecting a range of aquifer lithology (area of 1.7 million km^2) (Kleinschmidt, Black & Akber, 2011)

^{226}Ra: mean 0.07 Bq L^{-1} (0.01–0.96 Bq L^{-1})
^{228}Ra: mean 0.14 Bq L^{-1} (0.01–2.8 Bq L^{-1})
Uranium-238 (^{238}U): mean 0.15 Bq L^{-1} (0.04–0.71 Bq L^{-1})

1.5.3

What further action is required if either of the screening levels is exceeded for a drinking-water sample

If the gross beta screening level is exceeded, the contribution from potassium-40 should be subtracted from the measurement(s) following a separate determination of the total potassium in the drinking-water (see Question 1.5.4).

If either of the screening levels is exceeded (after subtracting the contribution from potassium-40 for gross beta measurements), the validity of the result should be confirmed by repeating the measurement. If some of the original drinking-water sample is left, a repeat measurement could be carried out.

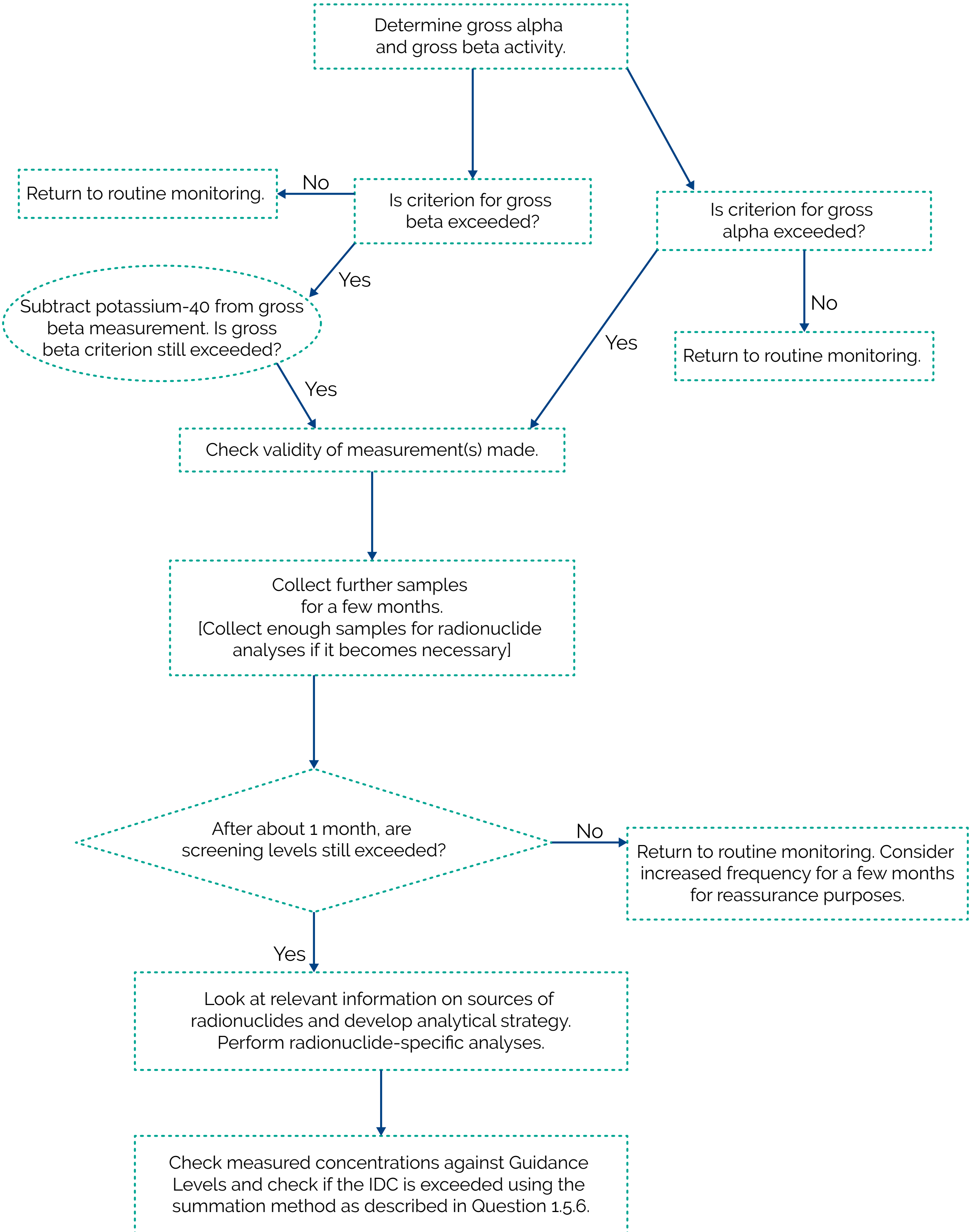
Once the initial measurement has been confirmed, the next step is to carry out further measurements of gross alpha and/or gross beta activity concentrations in the drinking-water. These are needed to assess the situation and whether it is varying with time. Initially, further samples should ideally be taken at least weekly for a few weeks. It is worth collecting enough sample volume so that individual radionuclide analysis can be carried out later, if necessary.

If the measured gross activity concentrations continue to exceed the screening level(s), further samples should be taken over at least a period of a few months. This is needed to understand potential seasonal variations because activity concentrations averaged over an extended period may not exceed the screening level(s). Temporal variability of radionuclides may vary widely unless the water source is very stable and, in most cases, will match the characteristics of the catchment. Large variations may possibly also be seen due to discharges of radionuclides to surface water sources if these are not controlled or if unauthorized discharges occur. The duration of the monitoring period will depend on the characteristics of the water source and the results of the ongoing monitoring.

If further measurements made over an agreed period following the initial measurement that exceeded the screening level, fall below the screening level, then no further intervention is required. Some occasional sampling might be needed in addition to the routine monitoring programme, e.g. at a greater frequency than normal, to provide reassurance that the low levels of radionuclides are being maintained.

If screening level(s) are consistently exceeded, the radionuclides that are present in the water need to be identified. Radionuclide-specific analyses are required to both determine if a radionuclide is present and, if it is, what the activity concentration in the drinking-water is. Potential sources of radionuclides should be studied (see Question 1.5.5 for further information) and a specific analytical strategy developed. The process is illustrated schematically in Figure 1.2.

Figure 1.2. Flowchart for measurement of radionuclides in drinking-water



1.5.4

What is the reason for subtracting the contribution of potassium-40 from gross beta activity when the gross beta activity concentration exceeds the screening level? How can it be performed

Gross beta measurements will include a contribution from potassium-40 (^{40}K), which is a beta emitter that occurs naturally in a fixed ratio to stable potassium. Potassium is a key element in regulating many body functions and the potassium content of the body is kept constant by physiological processes, so the content of ^{40}K in the body is also regulated naturally and does not accumulate in the body whatever the size of the intake. The contribution of ^{40}K to the measured gross beta activity concentration should therefore be subtracted if the gross beta screening level is exceeded.

It is impractical to use a radionuclide measurement technique to determine the concentration of ^{40}K in a drinking-water sample due to its low gamma-ray emission and the difficulty of chemically isolating the radionuclide from solution. Because of the fixed ratio between ^{40}K and stable potassium, chemical analysis can be used to determine total potassium. The beta activity due to ^{40}K can be calculated using a factor of 27.9 Bq per gram of total potassium. The formula is shown in Information Box 1.12.

Information Box 1.12: Calculation of ^{40}K in water

^{40}K in water sample (Bq L^{-1}) = total potassium in water sample (g L^{-1}) × 27.9

1.5.5

How to identify what radionuclides in the drinking-water are contributing to screening levels being exceeded

If either of the gross alpha or gross beta screening levels are exceeded, the validity of the result has been confirmed and additional measurements made have also exceeded the screening levels (having subtracted potassium-40 for gross beta measurements) (see Questions 1.5.3 and 1.5.4 for further details), the individual radionuclides contributing to the activity concentrations in the drinking-water need to be identified. All relevant information should be taken into account when deciding on what radionuclides are likely to be leading to the screening level being exceeded. Sources of information could be environmental monitoring data in the area and the catchment that the water is drawn from, knowledge of sites that could have led to discharges of radionuclides to the catchment and local geology. It is most likely that the source of radionuclides will be of natural origin, for example, radium-226 and radium-228. However, artificial radionuclides may also be present such as cobalt-60, strontium-90 and caesium-137.

1.5.6

How to assess if the individual dose criterion of 0.1 mSv y^{-1} has been exceeded using measurements of individual radionuclides in drinking-water

The guidance level for a radionuclide is the concentration that, if present in drinking-water consumed throughout the year at a rate of 2 litres per day, would result in an individual dose of 0.1 mSv. If only a single radionuclide has been identified in the drinking-water, the activity concentration should be compared with the guidance level for that radionuclide (see Table 9.2 in chapter 9 of GDWQ and summarized in Table 1.1 below, for common radionuclides; guidance levels for other radionuclides are given in Table A6.1 in Annex 6 of the GDWQ). If the guidance level is exceeded, it is very likely that the individual dose criterion (IDC) of 0.1 mSv y^{-1} has been exceeded; further investigation is required (see Question 1.5.9).

Table 1.1. Summary of WHO guidance levels for common radionuclides in drinking-water

Radionuclide	Guidance level (Bq L^{-1})
^{3}H	10 000
^{14}C	100
^{90}Sr, ^{131}I, ^{134}Cs, ^{137}Cs, ^{238}U*	10
^{226}Ra, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}U*, ^{239}Pu, ^{241}Am	1
^{210}Pb, ^{210}Po, ^{228}Ra	0.1

* Uranium is normally controlled on the basis of its chemical toxicity; the WHO guideline value for total content of uranium in drinking-water is 30 µg L^{-1}, which is equivalent to 0.37 Bq L^{-1} of ^{238}U or ^{234}U.
Key: tritium (^{3}H); carbon-14 (^{14}C); strontium-90 (^{90}Sr); iodine-131 (^{131}I); caesium-134 (^{134}Cs); caesium-137 (^{137}Cs); uranium-238 (^{238}U); radium-226 (^{226}Ra); thorium-228 (^{228}Th); thorium-232 (^{232}Th); uranium-234 (^{234}U); plutonium-239 (^{239}Pu); americium-241 (^{241}Am); lead-210 (^{210}Pb); polonium-210 (^{210}Po) and radium-228 (^{228}Ra).

If several radionuclides have been identified, then the sum across radionuclides needs to be considered to check that it does not exceed unity, i.e. to check if the IDC has been exceeded. The equation to use is:

$$\sum_i \frac{C_i}{GL_i} \leq 1$$

Where:

C_i = the measured activity concentration above the respective limit of detection (LOD) of radionuclide i,
GL_i = the guidance level for radionuclide i, calculated using the default assumptions (adult, 2 L d^{-1})

(see the theoretical example in Information Box 1.13).

Information Box 1.13: Theoretical example to illustrate the evaluation of activity concentrations in a drinking-water sample against the IDC

Measured activity concentrations are:

Radium-226 = 0.8 Bq L^{-1}

Radium-228 = < LOD

Lead-210 = 0.05 Bq L^{-1}

Polonium-210 = 0.03 Bq L^{-1}

Summation equation = 0.8/1 + 0.05/0.1 + 0.03/0.1 = 1.6

As the summation is > 1 in this case, the IDC of 0.1 mSv y^{-1} is exceeded

If the summation is ≥ 1, then the IDC is very likely to have been exceeded and further investigation is required (see Question 1.5.9). The guidance levels in the GDWQ are rounded to the nearest order of magnitude, as described in Question 1.3.4. Part of this investigation is to check if using these rounded guidance levels is too conservative (see Question 1.5.9).

Care should be taken if the measurements being used to compare with the guidance levels are reported as less than the LOD (Information Box 1.14 provides an example from Sweden on this topic). These measurements are not actual activity concentrations but are a feature of the detection capability of the equipment used. Using measurements reported as < LOD as actual activity concentrations in the drinking-water sample will be conservative; the radionuclide may be present in the sample but the equipment used is unable to quantify the amount.

Information Box 1.15 presents the approach to identifying an exceedance of the 0.1 mSv y^{-1} dose criterion used in the Euratom Drinking-Water Directive (EC, 2013).

Information Box 1.14: Example of interpreting LODs when comparing with guidance levels

In Sweden, in implementing the Euratom Drinking-Water Directive (EC, 2013) into national standards, the recommendation is to exclude radionuclides from the summation (and dose calculation) if their activity concentrations are below the LOD, given that the required LOD values in the Directive are very low (see Information Box 3.6 in Question 3.5).

Information Box 1.15: Identifying an exceedance of the IDC in the Euratom Drinking-Water Directive

A very similar approach to that used in the GDWQ for identifying an exceedance of the 0.1 mSv y^{-1} dose criterion is used in the Euratom Drinking-Water Directive (EC, 2013). In addition, activity concentrations are given which are 20% of the guidance levels. These values can be regarded as levels above which further investigation is warranted. Provided none of the measured activity concentrations exceed these “trigger levels”, there is no need to carry out the more complex process of summing across radionuclides to check if the IDC has been exceeded.

1.5.7

If the activity concentrations in drinking-water for the radionuclides measured do not exceed the guidance levels, does this mean that no further action is required

Yes, in many cases. If only a single radionuclide has been identified in the drinking-water and the guidance level is not exceeded, the individual dose criterion (IDC) of 0.1 mSv y^{-1} is very unlikely to be exceeded. Monitoring of drinking-water should continue at the locations and at the frequency that are specified in the national drinking-water regulations for radiological parameters.

If several radionuclides have been identified, but individually none of the measured activity concentrations exceed the guidance levels for the radionuclides measured, the sum across radionuclides needs to be considered to check that it does not exceed unity. The equation to determine this is shown in Question 1.5.6. If the summation is ≥ 1, then the IDC is likely to be exceeded and further investigation is required (see Question 1.5.9).

However, there is an uncommon situation that is an exception to this: even if the summation is < 1, if any of the radionuclides uranium-238, radium-226 or strontium-90 have been identified as contributing significantly to the dose, the annual dose may have been underestimated. This is because the guidance levels for these radionuclides, which are rounded to the nearest factor of 10, are higher than the activity concentrations that would lead to a dose of 0.1 mSv y^{-1} by a factor of two or more[7] (see Table 1.2 in Question 1.5.9).

1.5.8

If the 0.1 mSv y^{-1} individual dose criterion is exceeded, does this mean that the drinking-water is unsuitable for consumption

No. Exceeding the individual dose criterion (IDC) is not an indication that the drinking-water is unsafe for consumption. However, if the measurements of radionuclides in drinking-water indicate that the IDC will be exceeded using default assumptions, additional steps are required to further investigate the situation; see Question 1.5.9. A radiation dose of 0.1 mSv y^{-1} represents a very low level of health risk and is typically at least a factor of 20 lower than doses that members of the public receive from all sources of radiation. Further, it is a factor of 10 lower than the reference level for exposure due to radionuclides in drinking-water recommended in the International Basic Safety Standards (BSS) (IAEA, 2014).

Use of a water supply for drinking should not automatically be stopped if the annual dose is around the reference level of 1 mSv y^{-1} recommended in the International BSS (see Question 1.3.6), particularly if no other source is available or alternative sources are not suitable and affordable. In these circumstances, it may be appropriate to permit doses higher than 1 mSv y^{-1} for selected population groups, considering a balance of the overall risks, including the risk of not

[7] Guidance levels are rounded to the nearest order of magnitude according to averaging the log scale values (to 10^n if the calculated value was below 3×10^n and to 10^{n+1} if value is 3×10^n or above).

having a supply of drinking-water. The consequence of this would be the acceptance of a potential slight increase in radiological risks to health.

It is important to note that, even if a water supply is not considered fit for human consumption due to the level of radionuclides, it will still be suitable for use for other purposes such as washing and cleaning.

1.5.9

What is the next step if a guidance level is exceeded or the sum across radionuclides exceeds unity, i.e. the individual dose criterion of 0.1 mSv y^{-1} is exceeded[8]

Consuming water that is calculated to give a radiation dose of between 0.1 and 1 mSv y^{-1} is not considered a radiological health risk (see Questions 1.3.6 and 1.5.8). However, if the individual dose criterion (IDC) of 0.1 mSv y^{-1} is exceeded, a number of steps should be taken and it is still necessary to apply optimization to try and reduce the prolonged exposure to the source of the drinking-water as far as reasonably possible. Although national and local authorities will need to thoroughly investigate the situation, in deciding what action to take, a key consideration is the extent to which the IDC is exceeded. No actions need to be implemented urgently if the assessed dose is below the reference level of 1 mSv y^{-1} specified in the International Basic Safety Standards (BSS).

Step 1 – Use un-rounded values for the guidance levels to calculate the IDC

The guidance levels in the GDWQ are rounded to the nearest order of magnitude to reflect the screening nature of the approach, with the assumptions made in the calculation of the guidance levels being conservative in most cases. Table 1.2 gives the guidance levels in the GDWQ, which are rounded to the nearest order of magnitude, and the actual activity concentrations that would give a dose of 0.1 mSv y^{-1}. The use of the GDWQ guidance levels may lead to a situation where the calculated IDC indicates an exceedance of 0.1 mSv y^{-1} but the radiation dose is actually below 0.1 mSv y^{-1} (Information Box 1.16 provides a theoretical example and Information Box 1.17 provides an example from Brazil).

Table 1.2. Guidance levels for common radionuclides

			Guidance Levels	
Radionuclide		Half-life	Rounded value[a] Bq L^{-1}	Un-rounded values Bq L^{-1}
^{3}H	Tritium	12.5.y	10 000	7 610
^{14}C	Carbon-14	5 730 y	100	240
^{90}Sr	Strontium-90	29.12 y	10	4.9
^{131}I	Iodine-131	8.04 d	10	6.2
^{134}Cs	Caesium-134	2.062 y	10	7.2
^{137}Cs	Caesium-137	30 y	10	11.0
^{210}Pb	Lead-210	22.3 y	0.1	0.2
^{210}Po	Polonium-210	138.38 d	0.1	0.1
^{228}Ra	Radium-228	5.75 y	0.1	0.2

[8] This answer is written on the basis that the IDC criterion in the GDWQ has been exceeded. Countries can set a different drinking-water standard or reference level (see Question 1.5.10); however, the stepwise approach given here would be the same if the country's national standard/reference level were exceeded.

Table 1.2. (Continued)

Radionuclide		Half-life	Guidance Levels: Rounded value[a] Bq L^{-1}	Guidance Levels: Un-rounded values Bq L^{-1}
^{234}U	Uranium-234	244 500 y	1	2.8
^{238}U	Uranium-238	4.468×10^9 y	10	3.0
^{228}Th	Thorium-228	1.913 y	1	0.6
^{230}Th	Thorium-230	7.54×10^4 y	1	0.7
^{232}Th	Thorium-232	1.405×10^{10} y	1	3.0
$^{239}Pu/^{240}Pu$	Plutonium-239/240	2.41×10^4 y/6537 y	1	0.6
^{241}Am	Americium-241	432.2 y	1	0.7

a Guidance levels are rounded to the nearest order of magnitude according to averaging the log scale values (to 10^n if the calculated value was below 3×10^n and to 10^{n+1} if value is 3×10^n or above).

Information Box 1.16: Theoretical example of checking if the sum across radionuclides exceeds unity

Measured activity concentrations are:

Uranium-234 = 0.07 Bq L^{-1}
Radium-228 = 0.05 Bq L^{-1}
Lead-210 = 0.03 Bq L^{-1}
Polonium-210 = 0.03 Bq L^{-1}

Using rounded guidance levels in the GDWQ (shown in Table 1.2):
Summation equation = 0.07/1 + 0.05/0.1 + 0.03/0.1 + 0.03/0.1 = 1.17
In this case the summation is > 1 and the IDC of 0.1 mSv y^{-1} is exceeded

Using un-rounded activity concentrations (see Table 1.2):
Summation equation = 0.07/2.8 + 0.05/0.2 + 0.03/0.2 + 0.03/0.1 = 0.725
In this case the summation is < 1 and the IDC of 0.1 mSv y^{-1} is not exceeded

Information Box 1.17: Radionuclide concentrations in groundwater in Brazil (see also Section 4.1)

Geometric mean radionuclide concentration in groundwater wells in Brazil (N=416 wells)			
Radionuclide	Concentration (Bq L^{-1}) C_i	C^i/GL_i [a,b] Guidance level (GL) rounded	C^i/GL_i [a,b] Guidance level (GL) un-rounded
^{238}U	0.013	0.0013	0.0043
^{234}U	0.045	0.045	**0.016**
^{230}Th	0.007	0.007	0.01
^{226}Ra	0.015	0.015	0.03
^{228}Ra	0.06	0.60	**0.30**
^{232}Th	0.0002	0.0002	**0.00007**
^{210}Po	0.030	0.30	0.30
^{210}Pb	0.04	0.40	**0.20**
Summation		**1.37 (> 1)**	**0.86 (< 1)**

[a] Guidance levels from Table 1.2
[b] A **bold** value indicates where the value for C^i/GL^i is lower using the unrounded guidance levels.

Key: uranium-238 (^{238}U); radium-226 (^{226}Ra); thorium-228 (^{228}Th); thorium-230 (^{230}Th); uranium-232 (^{232}U); lead-210 (^{210}Pb); polonium-210 (^{210}Po) and radium-228 (^{228}Ra).

Step 2 – Conduct a more detailed assessment of doses

A more detailed assessment should consider both the characteristics of the water supply being investigated and the actual population that is consuming the drinking-water. Monitoring of the water supply and the water source will provide information on the stability of the activity concentrations in the water and whether they fluctuate throughout the year due to natural processes or possibly large variations in discharges of radionuclides to surface water sources. Taking further measurements could be considered to identify whether there are fluctuations in the activity concentrations of the radionuclides contributing most to the dose, particularly if this was not done at the screening stage (see Question 1.5.3).

For assessing doses, the average doses over the year should be used.

Where data are available or sufficient capacity exists to undertake such an analysis, national drinking-water consumption estimates can be used in calculating the guidance levels rather than using the guidance levels in the GDWQ, which are based on the default assumption of a consumption of 2 litres a day. The assessment of doses to children and babies drinking bottled milk reconstituted with drinking-water should also be considered, as appropriate (Annex 1 provides information on how to calculate doses to children).

Step 3 – Consider options to reduce activity concentrations in drinking-water, including water treatment (see Question 1.5.11)

For drinking-water supplies where it is confirmed that the IDC of 0.1 mSv y^{-1} is exceeded after undertaking steps 1 and 2, national authorities should consider whether it is a reasonable and practicable option to implement remedial actions to reduce the health risks from consumption of the drinking-water to as low as reasonably possible, depending on the extent of exceedance of the IDC and available resources.

As part of the investigation of an exceedance of the IDC, any water treatment that is in place should be reviewed to see if further reductions could be achieved with additional or changed treatment that is straightforward to implement (see Question 3.2). Implementing new water treatment or making substantial changes to existing water treatment is likely to be a major undertaking, particularly for groundwater which is often untreated or only disinfected; it needs to be done carefully so as not to increase other possible health risks from the drinking-water supply.

Discontinuing the use of the water for drinking purposes must be justified in terms of the overall benefit. Factors to be taken into account in making such a decision include the extent to which the reference level is exceeded, the costs of remediation and the availability of other drinking-water supplies. It is not appropriate to discontinue the use of the water supply without ensuring another safer option is available to consumers.

A summary of the suggested actions for given levels of individual dose is shown in Table 1.3.

Table 1.3. Summary of suggested actions for given levels of individual dose

Individual dose from ingestion of drinking-water, mSv y^{-1}	Intervention/action
< 0.1	No action required.
0.1–1	Investigate exceedance of IDC, national standard or reference level. Actions should be proportionate to exceedance of dose criteria/radiological health risk and available resources. Restrictions on the use of a drinking-water supply are not justified based on the radiological health risks. Reduce doses if possible.
> 1	Investigate exceedance of national standard or reference level. Actions should be taken on a case-by-case basis and proportionate to exceedance of dose criteria/radiological health risk and available resources. Restrictions on the use of a drinking-water supply may be considered based on the radiological health risk but it is important to balance the overall risks, including the risk of not having a supply of drinking-water. Reduce doses if possible.

1.5.10

What are the considerations for establishing national standards based on the GDWQ and the International Basic Safety Standards

For a non-emergency that can be controlled, the protection strategy should be commensurate with the associated radiation risks. The International Basic Safety Standards (BSS) require regulatory authorities to establish a reference level for radiation exposure due to radioactivity in drinking-water based on an effective dose that does not exceed a value of about 1 mSv y^{-1}, as noted in the GDWQ. In setting up a national reference level, the prevailing technical, economic, environmental and societal circumstances need to be taken into account as part of an optimization process. Each situation will be different; and non-radiological factors such as the costs of remediation and the availability of other drinking-water supplies will need to be taken into account in reaching a final decision. Establishing a national standard at 0.1 mSv y^{-1} is appropriate for most countries where groundwater supplies with elevated levels of naturally occurring radionuclides are not present. Where there are elevated levels of naturally occurring radioactivity in groundwater and minimal options for alternative water sources or water treatment, a value higher than 0.1 mSv y^{-1}, but generally less than the BSS reference level of 1 mSv y^{-1}, may be appropriate for the affected population groups.

Situations may arise where it may be appropriate to permit doses higher than 1 mSv y^{-1} for selected population groups, depending on the situation at the time, and considering a balance of the overall risks, including the risk of not having a supply of drinking-water. It is not appropriate to discontinue the use of the water supply without ensuring another safer option is available to consumers.

A framework for setting a national standard or reference level within the recommendations and requirements of the International BSS and the GDWQ is given in Table 1.4.

Table 1.4. Framework for setting a national standard or reference level

Individual dose from ingestion of drinking-water, mSv y^{-1}	National standard/reference level
< 0.1	Set to be the individual dose criterion (IDC) in the GDWQ (0.1 mSv/y^{-1}). (The operational values included in the GDWQ, expressed as screening and guidance levels should be used.)
0.1–1	Set in the range 0.1–1 mSv y-1 in accordance with the GDWQ and International BSS (see Question 1.3.6). (The operational values included in the GDWQ, expressed as screening and guidance levels, would need to be adapted.)
> 1	Set on a case-by-case basis. A level can be set > 1 mSv y^{-1}, depending on the situation at the time, and considering a balance of the overall risks, including the risk of not having a supply of drinking-water. A standard/reference level > 1 mSv y^{-1} is appropriate only for the affected population group. One option is to establish an interim standard/reference level, to allow time to achieve a lower value. (The operational values included in the GDWQ, expressed as screening and guidance levels, would need to be adapted.)

In establishing criteria and/or reference levels to be used in national standards, the following considerations should be made by the competent authorities:

- mapping of areas which have a geology leading to high levels of natural radioactivity in rocks and/or groundwater aquifers where radionuclides are mobile (see Information Box 1.18 for an example);
- performing a population-weighted survey of where groundwater is used for drinking-water supplies;
- determining whether water supplies are treated or amenable to treatment (taking into account that implementing new water treatment or making substantial changes to existing water treatment is likely to be a major undertaking and in many low-resource settings may not be feasible);
- determining whether alternative supplies are available;
- establishing a monitoring programme for radionuclides in drinking-water to identify any health risks, putting these in context with other risks from the water supply (namely microbial and chemical risks) and consideration of available resources;
- establishing programmes to increase awareness of the public and stakeholders of the low health risks from radionuclides in drinking-water, particularly in situations where activity concentrations in excess of the guidance levels and IDC have been identified.

Examples of setting reference levels and national standards for drinking-water are given in Information Box 1.19.

Information Box 1.18: Example of mapping radionuclides in groundwater in Queensland, Australia

A screening programme was developed to provide initial data on the extent of radiological properties of groundwater supplies. The sampling was designed to include as many aquifer systems as possible, particularly those serving a community. Sampling regions were chosen to cover the range of aquifer lithology descriptors provided by the Queensland Water Resources Commission. The area to be covered was approximately 1.7 million km^2 and so a sampling kit was developed and mailed with a questionnaire. Samples were received for 110 boreholes (59% of the 185 kits sent out) and analyses carried out for a range of naturally occurring radionuclides. Further details can be found in Kleinschmidt, Black & Akber (2011).

Information Box 1.19: Examples of setting reference levels and national standards for drinking-water

Japan

After the Fukushima Daiichi nuclear power plant accident in Japan, from March 2011 until March 2012 provisional advisory index values for restrictions on tap water intake (for drinking and cooking purpose) were established for iodine-131 (300 Bq L^{-1} for adults and 100 Bq L^{-1} for infants) and for radioactive caesium (200 Bq L^{-1}) (MHLW, 2011). Since 1 April 2012, a criterion called "the target level for management of radioactive materials in tap water" has been established (MHLW, 2012a). The target value is 10 Bq L^{-1} for radioactive caesium[1], which replaced the previous provisional index levels for an emergency, and is used for the long-term non-emergency exposure situation. This level is derived directly from the guidance levels in the GDWQ. (It was not necessary to set a target value for iodine-131, as this radionuclide was no longer of concern due its very short radioactive half-life, ~eight days.)

Jordan

In Jordan, investigation identified that the average dose of the Ram aquifer (which is blended with available low radioactivity water resources before consumption) was between 0.65–0.75 mSv y^{-1} with radium-228 contributing between 70% and 85% of the overall dose. Subsequently, the Jordanian reference level in the drinking-water standard was raised from 0.1 to 0.5 mSv y^{-1} after consideration of the guidance from WHO in the GDWQ and careful review of the local environmental, social and economic conditions. The new reference level was justified based on the assessment that the potential health risks are tolerable and the net health benefits outweigh the potential health risks.

Brazil

The Brazilian Nuclear Energy Commission, the regulatory authority for drinking-water in Brazil, is adopting the following criteria in its drinking-water regulations.

Reference level (1 mSv y^{-1})	National reference level.
	Total dose from drinking-water should be below the national reference levels of 1 mSv y^{-1}.
Optimization range (0.1–1 mSv y^{-1})	Whenever possible, protective actions should be planned to keep doses as low as reasonably achievable. In situations where the IDC of 0.1 mSv y^{-1} is not a practically achievable standard, no action is expected if total doses are above 0.1 mSv y^{-1} and below the reference level of 1 mSv y^{-1}.
Investigation level (0.1 mSv y^{-1})	This level cannot be interpreted as a limit indicating that the drinking-water is unsafe but a trigger for further investigation.

The Brazilian Nuclear Energy Commission will also establish a specific regulation containing a dose calculation procedure for situations where the gross alpha and gross beta screening levels are exceeded.

[1] The sum of caesium-134 and caesium-137.

1.5.11

What are the possible options for reducing activity concentrations of radionuclides in drinking-water

The options available to reduce the activity concentrations in drinking-water should be examined where the individual dose criterion (IDC), or reference level set within a country, is exceeded. Where remedial measures are contemplated, any strategy should first be justified, in the sense that it achieves a net benefit and overall does more good than harm, and is proportionate to the radiation risks in the context of other risks (e.g. microbiological, chemical).

The main options that could be considered are briefly discussed below. The options chosen will be dependent on the specific situation and the factors to be taken into account in the choice of option include the extent to which the IDC or reference level is exceeded, the costs of the option and the availability of other drinking-water supplies.

The information given here is of a general nature and a full evaluation of the options for a specific situation would need to be made.

- Provide an alternative drinking-water supply. It may be possible to change to alternative sources of water, for example change from a groundwater source to a surface water source. Alternatively, there may be available groundwater sources with an underlying geology that do not lead to such high concentrations of naturally occurring radionuclides. Particular care should be taken to ensure that changes in source water do not lead to the introduction of additional, more significant risks that cannot be controlled or may be difficult to control (e.g. surface water sources which are often more polluted, particularly from microbial contamination).
- Controlled blending of drinking-water supplies. The drinking-water of concern could be mixed with water containing no radionuclides or lower concentrations of radionuclides if more than one supply is available at the point of water treatment or post treatment. This is an effective method of reducing activity concentrations in drinking-water and has the added benefit of not generating radioactive waste products (see examples in Information Box 1.20. Blending is unlikely to be practical for small private or community supplies.
- Implementing water treatment or the modification of existing water treatment. Water treatment plants with a combination of coagulation, sedimentation and sand filtration processes for treating surface water may remove about 30% to 100% of the suspended radionuclides present in the source water. Ion exchange filtration is particularly applicable to groundwater sources and can remove over 70% for naturally occurring radium and uranium. Further information on removal performance for common water treatment processes for some radionuclides can be found in Question 3.2. An example of a general checklist that could be used to assist with determining whether implementing additional water treatment may be the most appropriate and feasible option is given in Section I of USEPA (2005). Implementing new water treatment, or making substantial changes to existing water treatment is likely to be a major undertaking.
  - Water treatment options usually generate waste products that will contain the radionuclides removed from the water (see Question 3.3).
  - There are commercially-available treatment options that can be used in the home or private premises that will reduce radioactive contamination of drinking-water. These are: water filter systems for softening water that use a carbon filter with some ion exchange material (jug filters), and small reverse osmosis units. These products should be certified by an appropriate standards organization. Household water treatment options will generate waste products that will contain the radionuclides removed from the water (see Question 3.3).

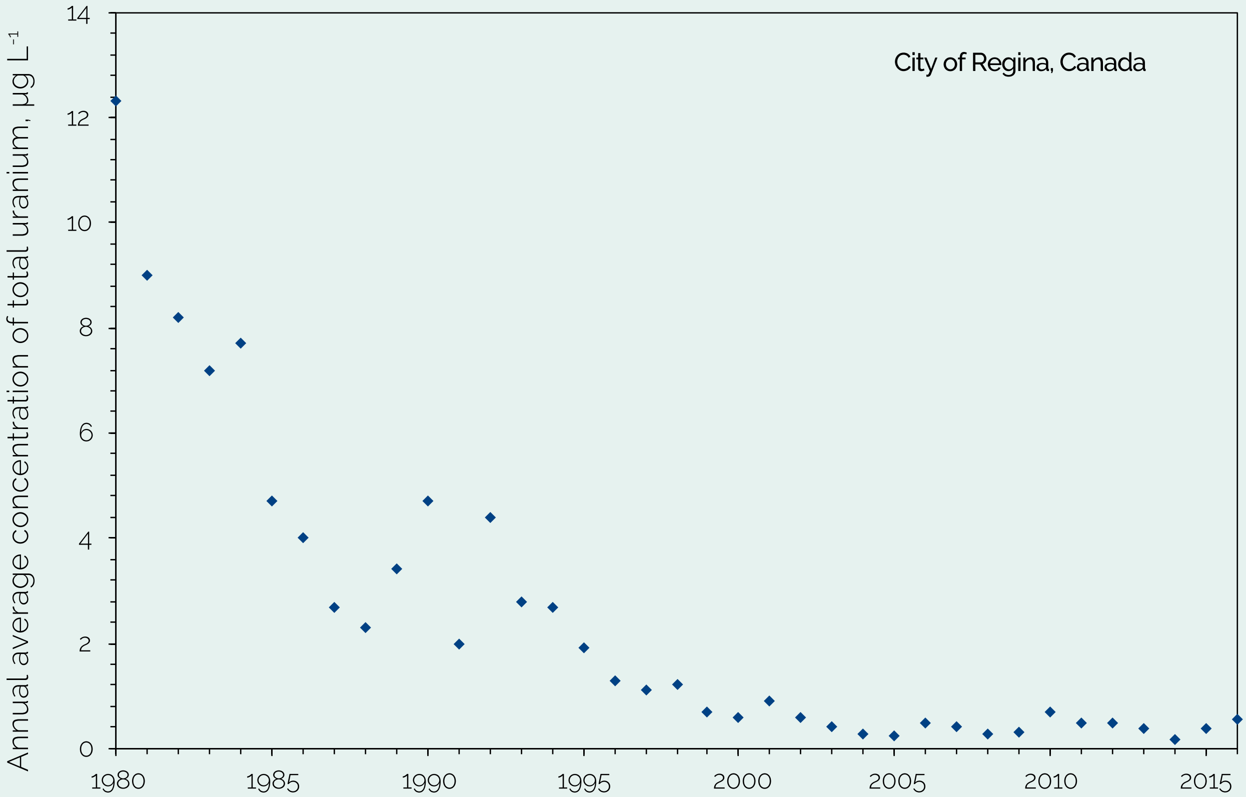
Information Box 1.20: Examples of blending of drinking-water supplies

Jordan

In Jordan, the following remedial options were considered to address the situation of exceeding the national reference level in the Disi Water Conveyance Project supply: blending, reverse osmosis, nano-filtration, lime softening, ion exchange on selective resin and electro-dialysis. For each of the alternatives a feasibility study was performed on a pilot scale design. After considering remediation of the full yield of the Disi Water Conveyance Project supply of 100 million m^3 y^{-1} using an environmental and cost–benefit analysis, it was decided that the most practical and sustainable option for Jordan was blending the Ram aquifer water (Disi) with available low radioactivity water resources (90 million m^3 per year from Zai and 45 million m^3 per year from Zara-Ma'en) (El-Naser et al., 2016). Blending typically reduces the annual doses from about 0.7 mSv y^{-1} (water from well field) to about 0.4 mSv y^{-1} at the point of consumption after blending (see Section 4.3 for further details).

Canada

The drinking-water for the city of Regina, Canada is taken from Buffalo Pound Lake, a shallow reservoir in the Qu'Appelle Valley through the Buffalo Pound Water Treatment Plant. The plant was commissioned in 1955. Before that time, all of the water came from deep wells with elevated levels of uranium concentration, higher than the national average. Since the 1960s, more and more surface water from Buffalo Pound Lake was mixed with well water before it was delivered to customers to reduce the concentrations of uranium in the drinking-water. Since the 1990s, almost 100% of the drinking-water for the city of Regina has been taken from surface water. Water quality monitoring data has shown that uranium concentration in the water decreased exponentially with increased amount of surface water being introduced into the water system (Health Canada, 2009). Available historical records from the database of the Canadian Radiological Monitoring Network showed that the annual average uranium concentration reduced from 12.3 μg L^{-1} in 1980 to 0.5 μg L^{-1} in 2016.



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CHAPTER 1 NON-EMERGENCY SITUATIONS

1.6 RADON IN DRINKING-WATER

1.6.1

How does radon get into drinking-water

Radon is produced from radium isotopes (produced during decay of naturally occurring uranium and thorium) and is present in the ground. As an inert gas, it dissolves readily in water, so if water passes through ground materials it can readily dissolve the radon and transport it over long distances[9]. The longest-lived isotope of radon, and consequently the most abundant in drinking-water supplies, is radon-222 which decays with a radioactive half-life of 3.8 days. Processes that enable the partial degassing of radon, such as water treatment, storage and distribution, usually reduce the radon concentration. However, drinking-water from natural springs, boreholes or wells, where there is a relatively short time between water extraction and its use, are more likely to result in an increased exposure to radon. Levels of radon in surface waters are typically very low because the gas is readily lost into the atmosphere.

1.6.2

Do national standards for radon in drinking-water need to be established

No, not necessarily. The GDWQ does not provide guidance levels for radon because it is considered more appropriate to measure radon concentrations in indoor air rather than in drinking-water. A review of international research data (UNSCEAR, 2000) concluded that, on average, 90% of the dose attributable to radon in drinking-water comes from inhalation rather than ingestion. Radon dissolved in drinking-water can be released into the air when the water is used in activities associated with water being heated or agitated, such as boiling,

[9] Where radon remains dissolved in drinking-water, the radionuclides lead-210 or polonium-210 (radon decay products) may become important contributors to the overall dose from the ingestion of drinking-water.

showering, bathing and toilet flushing. However, the main source of radon in indoor air is likely to come from the rocks and soil underlying the building and not from drinking-water.

WHO recommends a national reference level for indoor air of 100 Bq m^{-3} (WHO, 2009). If compliance with this level cannot be achieved under the prevailing country-specific conditions, the WHO radon handbook notes that the chosen reference level should not exceed 300 Bq m^{-3}. In studies of the exposure from radon released into indoor air from water (Hess et al., 1987; Nazaroff et al., 1987), an overall transfer coefficient of radon from water to air of 10^{-4} was estimated, albeit with considerable variability. Using this transfer coefficient, a level of 1000 Bq L^{-1} of radon in tap water would be required to increase the radon concentration in indoor air by about 100 Bq m^{-3}.

If a country wants to set a national standard for radon in drinking-water, screening levels for radon in drinking-water should be based on the national reference level for radon in indoor air. Some countries have set national standards for radon in drinking-water (see Information Box 1.21).

Information Box 1.21: Setting national standards for radon in drinking-water in the Euratom Drinking-Water Directive

The Euratom Drinking-Water Directive (EC, 2013) sets a parametric value of 100 Bq L^{-1} for radon in drinking-water. Member States may set a level for radon at which it is judged inappropriate for it to be exceeded and below which optimization of protection should be continued, without compromising water supply on a national or regional scale. The level set by a Member State may be higher than 100 Bq L^{-1} but must be lower than 1 000 Bq L^{-1}. Further, remedial action is deemed to be justified on radiological protection grounds, without further consideration, where radon concentrations exceed 1 000 Bq L^{-1} (EC, 2013).

1.6.3

At what points in the water supply chain should measurements of radon in drinking-water be made

Samples should ideally be taken at the point of consumption. This is because radon concentrations can be reduced to very low levels between the water source and the point of consumption due to treatment processes that lead to agitation of the water, which promote degassing of the radon[10], or distribution and storage, which lead to radioactive decay of the radon. Measurements made of radon at the water source may not therefore reflect the concentrations in consumed water and could be much higher. However, taking measurements of radon at the groundwater source are useful to determine the potential for radon in drinking-water to be present and to inform decisions on any remedial actions that may be necessary.

[10] It should also be noted that the degassing of radon is promoted when other naturally occurring dissolved gases such as CO_2 and N_2 degas from groundwater.

1.6.4

What methods can be used for sampling and measuring radon in drinking-water supplies

The precision of sampling and the subsequent measurement of radon in drinking-water is predominantly a function of whether the radon gas is lost from the sample during handling. Extreme care is needed when collecting the sample of water in the field and when handling the sample in the laboratory to prevent radon loss. Highly-trained staff are therefore required.

Samples should be collected in containers made of materials that are impervious to radon, such as aluminium or glass. The water should be poured slowly into the container at a very low flow rate to avoid aeration and degassing of the radon from the sample. The transfer of the water sample to a Lucas Cell (a scintillation chamber for the detection of radon) in the field ensures that transport to the laboratory does not lead to any loss of radon from the sample. Due to the potential for loss of radon during sampling and handling, it is advisable to take multiple samples at the time of collection.

The two main laboratory methods for measuring radon in drinking-water are the widely-used liquid scintillation counting and gamma spectrometry (see Question 3.5). Due to the short half-life of radon, ideally samples should be analysed on the day they are returned to the laboratory.

It is important to note that radon will not be included in gross alpha screening measurements due to its volatility.

Further information on methods for measuring radon in drinking-water can be found in the WHO handbook on indoor radon, Section 2.1.3 (WHO, 2009).

1.6.5

How can radon in drinking-water be managed when radon concentrations in the source water are high

In situations where high radon concentrations have been identified or are suspected in groundwater, exposure from both inhalation and ingestion need to be considered in determining if steps are needed to reduce activity concentrations in drinking-water. Radon exposure from ingesting water is small compared to that from inhalation and the focus in controlling overall exposure is most likely to be on reducing radon concentrations in the indoor air from radon entering buildings from the ground. It is unusual for a building to have high levels of radon in indoor air caused solely by the water supply.

For centralized water supplies with treatment, the most effective treatment option for high levels of radon is often the aeration of the water, which can remove up to 100% of the radon. This can lead to a build-up of radon in the air where people are working on everyday maintenance tasks if the water treatment works are covered. Firstly, measurements of radon in the air should be made to determine the levels in the working environment. If necessary, there are two options for controlling exposures to radon in this situation: ideally ventilation of the buildings or extraction of air to the outdoors should be implemented; however, where this is not possible, the exposure time of people working in environments with high radon concentrations can be controlled.

Water treatment at the point of entry into the home may also reduce activity concentrations of radon in drinking-water. The most effective treatment option is aeration of the water, which can remove up to 100% of the radon; it is very important however, that the radon released from the water is extracted to the outdoors. Filtration with granular activated carbon with or without ion exchange can also be used, which is cheaper than aeration but less effective in reducing levels of radon in water (for example, Annanmaki & Turtianen, 2000).

In situations where multiple dwellings are served by the same water supply, it may be practical and more cost-effective to remove high levels of radon at a point in the network that serves multiple dwellings rather than on an individual property basis.

Where remedial measures are in place to manage radon levels in indoor air, these will also act to reduce the concentrations of radon in air from the use of drinking-water. However, it is advisable to continue to measure radon in drinking-water if the drinking-water supply comes from a nearby groundwater source.

Chapter 2

EMERGENCY SITUATIONS

CHAPTER 2 EMERGENCY SITUATIONS

2.1 BACKGROUND ON EMERGENCY SITUATIONS AND CRITERIA FOR MANAGING DRINKING-WATER QUALITY

2.1.1

What is a radiation emergency situation

A radiation emergency situation arises as a result of an accident, a malicious act or any other unexpected event that requires prompt action in order to avoid or reduce adverse consequences. Once an emergency arises, radiation exposure can be reduced by taking protective actions.

2.1.2

Are radionuclides in drinking-water likely to remain a long-term public health risk after a nuclear or radiological emergency

No. It is very unlikely that radionuclides in drinking-water will remain a long-term public health risk after a nuclear or radiological emergency. Although open surface water sources will be the most vulnerable to contamination after a nuclear or radiological emergency involving releases to the atmosphere or water sources (see Question 2.3.2), activity concentrations in drinking-water from such sources will reduce quickly as they become significantly diluted due to mixing in large water volumes. It should be noted that if initial atmospheric deposition of radionuclides from the emergency occurs onto snow pack or ice-cover, this may lead to a delay in any doses received from drinking-water from surface water sources until the snow/ice thaws. However, as for any initial contamination of surface waters, activity concentrations in drinking-water from such sources will also become significantly diluted very quickly due to mixing in large water volumes. Information Box 2.1 discusses the drinking-water restrictions imposed after the Fukushima Daiichi nuclear power plant accident.

Direct contamination from a release of radionuclides into the environment will not occur to groundwater sources; any significant contamination of these drinking-water sources is very unlikely (see Question 2.3.2).

Deliberate contamination of a drinking-water supply (i.e. a malicious act) could be to a surface or groundwater source or directly into the water supply. In this case, radionuclides will only be present in drinking-water for a very short period of time at high activity concentrations. Radionuclides in drinking-water are therefore very unlikely to remain a long-term health risk in this situation.

Information Box 2.1: Example of restrictions placed on drinking-water after an accident in Japan

After the Fukushima Daiichi nuclear power plant accident in Japan, the restriction of drinking-water intake was implemented in 20 water supply utilities serving a total population of about 14 million. The longest restriction was 12 days, except for one location (population about 4 000), where the restriction on intake for infants lasted 51 days (see Section 4.5 for more details).

2.1.3

When does an emergency situation end and what does this mean with respect to drinking-water quality

The transition from an emergency situation to a non-emergency (existing) situation and subsequent termination of the emergency will be a decision made by the responsible authority, based on the prevailing conditions after relevant and pre-set conditions and other criteria have been met (ICRP, 2009; IAEA, 2015; IAEA 2018). During the transition period, the criteria for drinking-water in emergency situations apply (IAEA, 2015; 2011). Once the relevant authority has declared an end to the emergency situation, any remaining radionuclides in drinking-water and its sources in the longer term resulting from the emergency should be treated as a non-emergency situation (where the criteria for drinking-water in non-emergency situations in the GDWQ apply, see Question 1.3.1). The international Safety Standards Series on preparedness and response for a nuclear or radiological emergency (IAEA, 2011) indicates that as soon as possible, the WHO guidance in the GDWQ should be used to determine if drinking-water is suitable for long-term consumption after the emergency phase of the accident has ended.

2.1.4

Are there any international standards and criteria that apply for drinking-water quality in emergency situations

Yes. There are the IAEA Safety Standards Series on preparedness and response for a nuclear or radiological emergency, which includes General Safety Requirements No. GSR Part 7 (IAEA, 2015) and General Safety Guide No. GSG-2: *Criteria for use in preparedness and response for a nuclear or radiological emergency* (IAEA, 2011). These contain criteria for drinking-water that apply for emergency situations. These standards are co-sponsored by a number of international organizations, including WHO.

According to these international standards, governments are responsible for ensuring that protection strategies are developed, justified and optimized at the preparedness stage for taking effective emergency response actions in a nuclear or radiological emergency. The protection strategy is expected to include criteria for taking emergency response actions including those for drinking-water.

Generic criteria in terms of projected radiation doses for planning purposes and Operational Intervention Levels (OILs) in terms of activity concentrations in emergency situations – which would warrant urgent protective actions such as banning consumption of drinking-water – are included in GSR Part 7 and GSG-2, respectively (IAEA, 2011; 2015).

- GSR Part 7 provides generic criteria for the projected doses at which restrictions on the consumption of drinking-water should generally be implemented. These generic criteria are to be used for developing operational criteria in terms of directly measurable quantities that can be used in an emergency situation to impose these restrictions.
- GSG-2 provides default OILs in terms of gross alpha and gross beta activity concentrations (i.e. OIL5) and in terms of activity concentrations for a large number of radionuclides in drinking-water (OIL6) at which restriction on the consumption of drinking-water should generally be imposed in a nuclear or radiological emergency.

The screening criteria (OIL5)[11] are:

OIL5 – Gross alpha: 5 Bq Kg^{-1}

OIL5 – Gross beta: 100 Bq Kg^{-1}

The OIL5 and OIL6 values for drinking-water are derived on the basis of a generic dose criterion of 10 mSv in the first year after the emergency, assuming that no protective actions are taken, and that all drinking-water is contaminated at the OIL activity concentration throughout the year and using the most restrictive age group and consumption rates. The OIL values are therefore very conservative as activity concentrations in drinking-water after a nuclear or radiological emergency will reduce rapidly after the initial contamination event and will not remain at a constant level for the whole year. Ten mSv is 10% of the generic criterion of 100 mSv in the first year for implementing early protective actions and other response actions during emergency situations (IAEA, 2015). The use of 10 mSv ensures that the dose from all exposure pathways will not exceed the 100 mSv criterion. Further details on the OILs and their use are provided in Question 2.3.1 and 2.4.1.

Based on the above-mentioned international standards, individual countries may develop their own national criteria, taking into account the criteria provided in these international standards as well as local prevailing circumstances (e.g. environmental, demographic, social, political, economic and other factors). The aim of giving consideration to all these various factors is to ensure that the national criteria guide justified and optimized emergency response actions.

Any further restrictions on drinking-water extending into the longer term might be implemented with the aim of eventually achieving a reference level (or national standard) that takes into account the WHO individual IDC of 0.1 mSv y^{-1} and the International Basic Safety Standard (BSS) reference level of 1 mSv y^{-1}, balancing the prevailing technical, economic, environmental and societal circumstances as part of an optimization process.

[11] 1 Bq Kg^{-1} = 1 Bq L^{-1} in water

CHAPTER 2 EMERGENCY SITUATIONS

2.2 HEALTH RISKS FROM DRINKING-WATER IN THE EVENT OF A NUCLEAR OR RADIOLOGICAL EMERGENCY

2.2.1

What radionuclides are likely to be of concern in drinking-water during a nuclear or radiological emergency

The radionuclides likely to be of concern in drinking-water in a nuclear or radiological emergency depend on the type of emergency and types of facilities and activities that might be involved (e.g. accidents at nuclear power plants, accidental releases from industrial or medical facilities using radionuclides and transport accidents) as well as their ability to enter the drinking-water sources for drinking-water supplies (Brown, Watson & Nisbet, 2015; WHO, 2017a).

Table 2.1 gives the radionuclides that are potentially relevant for exposure from drinking-water following a nuclear or radiological emergency, including the incident scenarios and routes to surface water contamination. Although radiological incidents arising from industrial uses of radionuclide sources are common (UNSCEAR, 2016), they are very unlikely to give rise to the contamination of drinking-water and radionuclides specific to these types of incidents are therefore not included in the table. Information Box 2.2 provides an example of the sampling that determined the most critical radionuclides following an accident.

Information Box 2.2: Example of the identification of important radionuclides after an accident

In the case of the Fukushima Daiichi nuclear power plant accident in Japan, the identification of individual radionuclides revealed that caesium-134, caesium-137 and iodine-131 were of importance for drinking-water immediately after the accident. Activity concentrations of other radionuclides measured, including strontium-90 and tritium, were much lower.

Source: WHO (2012).

Table 2.1. Radionuclides potentially relevant for drinking-water following a nuclear or radiological emergency

Radionuclides	Incident scenarios where used and/or produced	Routes to surface water contamination[a]
^{3}H	By-product of nuclear reactor operations	Release to atmosphere Direct contamination of water
^{60}Co	By-product of nuclear reactor operations	Release to atmosphere Direct contamination of water
^{90}Sr / ^{90}Y	By-product of nuclear reactor operations	Release to atmosphere Direct contamination of water
^{95}Zr / ^{95}Nb	By-product of nuclear reactor operations	Release to atmosphere
^{99}Mo / ^{99m}Tc	Medical (nuclear medicine Technetium generators) By-product of nuclear reactor operations	Release to atmosphere Direct contamination of water
^{103}Ru ^{106}Ru	By-product of nuclear reactor operations	Release to atmosphere
^{132}Te	By-product of nuclear reactor operations	Release to atmosphere
^{131}I	Medical (nuclear medicine facilities used for diagnostic and/or therapeutic procedures) By-product of nuclear reactor operations	Release to atmosphere Direct contamination of water
^{134}Cs ^{136}Cs ^{137}Cs / ^{137m}Ba	By-product of nuclear reactor operations	Release to atmosphere Direct contamination of water
^{140}Ba / ^{140}La	By-product of nuclear reactor operations	Release to atmosphere
^{144}Ce	By-product of nuclear reactor operations	Release to atmosphere
^{235}U	Reactors and nuclear weapons	Direct contamination of water
^{238}Pu ^{239}Pu	By-product of nuclear reactor operations Nuclear weapons (^{239}Pu)	Release to atmosphere Direct contamination of water
^{241}Am	Medical diagnostics By-product of nuclear reactor operations	Release to atmosphere Direct contamination of water

Radioactive daughters are mentioned where they are the dominant contributor to the health risk and otherwise are implicitly included in the list.

[a] Releases into the atmosphere can lead to deposition onto water sources and treated water or indirectly into water sources via run-off from catchment areas.

Source: Adapted from Brown J, Hammond D & Wilkins BT (2008b). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking-water and risks to water treatment plant operatives: supporting scientific report. HPA-RPD-041, Chilton, UK. © Crown copyright.
Key: tritium (^{3}H); cobalt-60 (^{60}Co); strontium-90 (^{90}Sr); yttrium-90 (^{90}Y); zirconium-95 (^{95}Zr); niobium-95 (^{95}Nb); molybdenum-99 (^{99}Mo); technetium-99m (^{99m}Tc); ruthenium-103 (^{103}Ru); ruthenium-106 (^{106}Ru); tellurium-132 (^{132}Te); iodine-131(^{131}I); caesium-134 (^{134}Cs); caesium-136 (^{136}Cs); caesium-137 (^{137}Cs); barium-137m (^{137m}Ba); barium-140 (^{140}Ba); lanthanum-140 (^{140}La); cerium-144 (^{144}Ce); uranium-235 (^{235}U); plutonium-238 (^{238}Pu); plutonium-239 (^{239}Pu) and americium-241 (^{241}Am).

2.2.2

Do children require stricter protection than adults when establishing criteria for the consumption of drinking-water after a nuclear or radiological emergency

For emergency situations, the criteria established in international standards (IAEA, 2015; 2011) take into account the members of the public who are the most vulnerable to radiation exposure (i.e. children and pregnant women). These criteria are derived using the most restrictive age dependent dose conversion factors and ingestion rates (i.e. those for infants) to ensure that the most vulnerable members of the population are protected from relatively high short-term doses. The assumptions made in the derivation of the operational criteria are conservative.

Some countries may decide to set different activity concentration criteria for different age groups for specific radionuclides (see Information Box 2.3). This approach may lead to challenges in implementation of different actions for different population groups and difficulties in conveying a clear message to the public why some members of their families can consume the drinking-water while others cannot do so.

Information Box 2.3: Example of setting different criteria for children

In Japan after the Fukushima Daiichi nuclear power plant accident, the provisional regulation values for drinking-water were established considering the most susceptible age groups. For radioactive caesium (^{137}Cs and ^{134}Cs), the provisional regulation value was the same for adults, young children and infants (300 Bq Kg^{-1}) (Iwaoka, 2016). However, for iodine-131, it was considered that the adverse effects on the thyroid are higher for infants than other age groups. A value of 300 Bq Kg^{-1} was set for adults and children and a lower value was set for infants for both drinking-water and water used for making bottled milk (100 Bq Kg^{-1}) taken from the CODEX Standard (CODEX, 2001).

2.2.3

How are health risks from radionuclides in drinking-water likely to compare to those from other exposure pathways in nuclear or radiological emergencies

It is very unlikely that radionuclides in drinking-water will remain a long-term public health risk after a nuclear or radiological emergency, as explained in Question 2.1.2. With the exception of cases of deliberate contamination of a drinking-water supply system, at the time of the emergency, external exposure from radionuclides on the ground and internal exposure from inhalation of radionuclides in the air are expected to be the pathways that are dominant contributors to the dose of the public living in the vicinity of the accident site. With increasing distance from the accident site, internal exposure from the ingestion of radionuclides in food, milk and drinking-water becomes dominant, but the doses will be significantly lower than those received by people closer to the accident site.

Depending on the radionuclides released into the environment, doses over the long term will be dominated by external exposure and/or ingestion of foods and not the ingestion of drinking-water. This was observed after the nuclear accident at the Fukushima Daiichi nuclear power plant (WHO, 2012; WHO, 2013) and is described in Information Box 2.4.

Information Box 2.4: Example of the importance of exposure pathways after an accident

After the Fukushima Daiichi nuclear power plant accident in Japan on 11 March 2011, the Japanese authorities measured radionuclide levels in drinking-water; the first sample of drinking-water was collected in Fukushima Prefecture on 16 March 2011. Levels were only elevated for a limited period in the months following the accident. Within Fukushima Prefecture, doses to people living in each district were estimated for the period March 2011–March 2012. For example, in Iitate village, the radiation dose to 1-year old children from radionuclides in drinking-water was estimated to be less than 5% of the total dose from all external and internal exposures, including ingestion of food.

CHAPTER 2 EMERGENCY SITUATIONS

2.3 MEASURING RADIONUCLIDES IN DRINKING-WATER IN AN EMERGENCY SITUATION

2.3.1

What screening methods can be used in nuclear or radiological emergencies to measure radionuclides in drinking-water

Measurements of gross alpha and gross beta activity concentrations, designed and used for routine monitoring of drinking-water, can also be used in a nuclear or radiological emergency situation. However, these screening techniques do not identify the individual radionuclides present or their activity concentrations. An advantage of using screening methods is that capability may already be in place within water authorities and laboratories in a country, whereas equipment for measuring individual radionuclides may not be available (see Question 3.5). In many circumstances, gross alpha and gross beta screening methods could be used to demonstrate that activity concentrations are below the operational intervention levels (OILs) set for an emergency situation, thus saving time and resources for detailed radionuclide analysis.

The OILs for both gross alpha and gross beta activity concentrations (OIL5) in the IAEA Safety Guide GSG-2 are intended for use as screening criteria in nuclear or radiological emergencies (IAEA, 2011) (see Questions 2.1.4 and 2.4.1). The OIL5 values are not the same as the gross alpha and gross beta screening levels for non-emergency situations (see Question 1.3.3).

Although screening methods are appropriate under most situations, depending on the measurement techniques being used, some radionuclides would not be detected by gross alpha or gross beta activity analysis (such as tritium, selenium-75, niobium-95, ruthenium-103 or ytterbium-169) and therefore not included in the gross measurement. Some gaseous or volatile radionuclides, such as isotopes of iodine will also not be detected as losses of the radionuclides will occur during the analytical procedure. If it is suspected that these radionuclides have been released during an emergency and may be present in drinking-water, it is necessary to also carry out radionuclide-specific measurements.

If the radionuclides released during an emergency are known, particularly in the case of a small-scale emergency or where there are only a limited number of drinking-water supplies that need to be measured, it may be most efficient to measure the individual radionuclides in the first instance and directly compare these with the radionuclide-specific criteria, such as the OIL6 values.

Countries may set their own screening levels for drinking-water based on their own national emergency criteria (see Question 2.1.4). An example of setting screening levels is given in Information Box 2.5.

Information Box 2.5: Example of setting screening levels for emergencies

The Environment Agency of the United Kingdom of Great Britain and Northern Ireland developed guidance on monitoring drinking-water using gross alpha and beta screening methods. Emergency screening levels in terms of gross activity concentrations have been developed (see below) that can be used in the event of a radiation incident to determine if intervention is required to reduce activity concentrations in drinking-water.

Emergency screening levels for gross alpha and gross beta activity concentrations in drinking-water in the United Kingdom

Type of monitoring	Emergency screening level (Bq L^{-1})
Gross alpha activity	5
Gross beta activity	30

(For comparison, screening levels for non-emergency situations are 0.1 Bq L^{-1}) and 1 Bq L^{-1}) for gross alpha and gross beta, respectively.)

Source: Brown, Watson & Nisbet, 2015.

2.3.2

During a nuclear or radiological emergency, what types of water source are likely to be affected

Water sources, such as rivers and reservoirs, are likely to be most vulnerable to radionuclide contamination after a nuclear or radiological emergency involving releases of radionuclides to the atmosphere or water sources. Under such circumstances, in addition to direct deposition to surface water sources, run-off from surrounding land, and thawing of snow pack or ice-cover contaminated with radionuclides can also enter surface waters over the long term. This excludes deliberate contamination of water supplies with radionuclides (e.g. malevolent acts), which may affect the water in reservoirs or at distribution points.

Direct contamination will not occur to underground aquifers immediately and contamination of these drinking-water sources is only likely to occur in the long term if radionuclides percolate down through the soil and rocks. Ingress of radionuclides could also occur through poorly protected wells and bore heads, particularly if flooding is associated with an accident.

Rainwater that is collected in tanks and cisterns for drinking-water on domestic premises could contain radionuclides if rain occurs while the plume is overhead. Exposure from consuming this water would only be for a short period as radionuclides would rapidly become diluted with further rainfall after the plume has passed and consumption of this water will be limited by the size of the storage tank. The IAEA international Safety Standard (GSR Part 7) (IAEA, 2015) suggests considering precautionary actions around nuclear facilities to protect drinking-water supplies that use rainwater or other untreated surface water from direct contamination, as part of emergency planning.

2.3.3

During a nuclear or radiological emergency, which water sources are a priority for monitoring

Priority should initially be given to the monitoring of water supplies taken from surface water sources under the radioactive plume following a release of radionuclides to the atmosphere. These water sources are likely to have the highest levels of radionuclides and become contaminated quickly after the accident. The levels of radionuclides in the water extracted will depend on how far downstream from the accident extraction occurs, as levels will decrease with distance due to dispersion in the atmosphere and dilution in the water.

Run-off from the catchment area of surface waters can lead to a longer-term source of radionuclides in drinking-water supplies and, depending on the nature of the catchment area and the size of the release, additional water sources to those initially contaminated by the radioactive plume could be affected. It is unlikely that the levels of radionuclides would be of public health concern (see Question 2.1.2) but monitoring of water supplies at treatment works or in stored water supplies should be carried out to demonstrate that activity concentrations are low.

In areas where the initial atmospheric deposition of radionuclides is onto snow pack or ice-cover, the planning of monitoring needs to take account of both any initial contamination of surface waters and also contamination of surface water that may occur following the thawing of the snow pack and ice, as noted in Question 2.1.2. This may require monitoring over an extended period depending on the rate of thaw and subsequent release of radionuclides from the top of the ice/snow pack into surface waters.

It is important that measurements are made that are representative of the drinking-water being consumed for comparison with operational criteria, e.g. the operation intervention levels (OILs). If water is treated before consumption, the water should be monitored after treatment because treatment can reduce the activity concentrations of many radionuclides in the water (see Question 3.2).

A long-term drinking-water monitoring programme should include monitoring of groundwater supplies to provide reassurance that activity concentrations in these sources remain low.

CHAPTER 2 EMERGENCY SITUATIONS

2.4 MANAGING EXCEEDANCES OF CRITERIA FOR DRINKING-WATER IN EMERGENCY SITUATIONS

2.4.1

How are operational intervention levels for drinking-water used in the event of a nuclear or radiological emergency

If the gross alpha or gross beta screening criteria established for emergencies (operation intervention levels (OILs), e.g. OIL5 values) are not exceeded after measurements have been made on drinking-water, all members of the public, including infants, children and pregnant women, can drink the water.

If either of the screening criteria is exceeded[12], measurements of activity concentrations of individual radionuclides are required before any judgement is made whether drinking-water consumption should be restricted.

This staged approach (shown in Figure 2.1) is consistent with that recommended in the GDWQ for non-emergency situations, where screening levels and guidance levels are used.

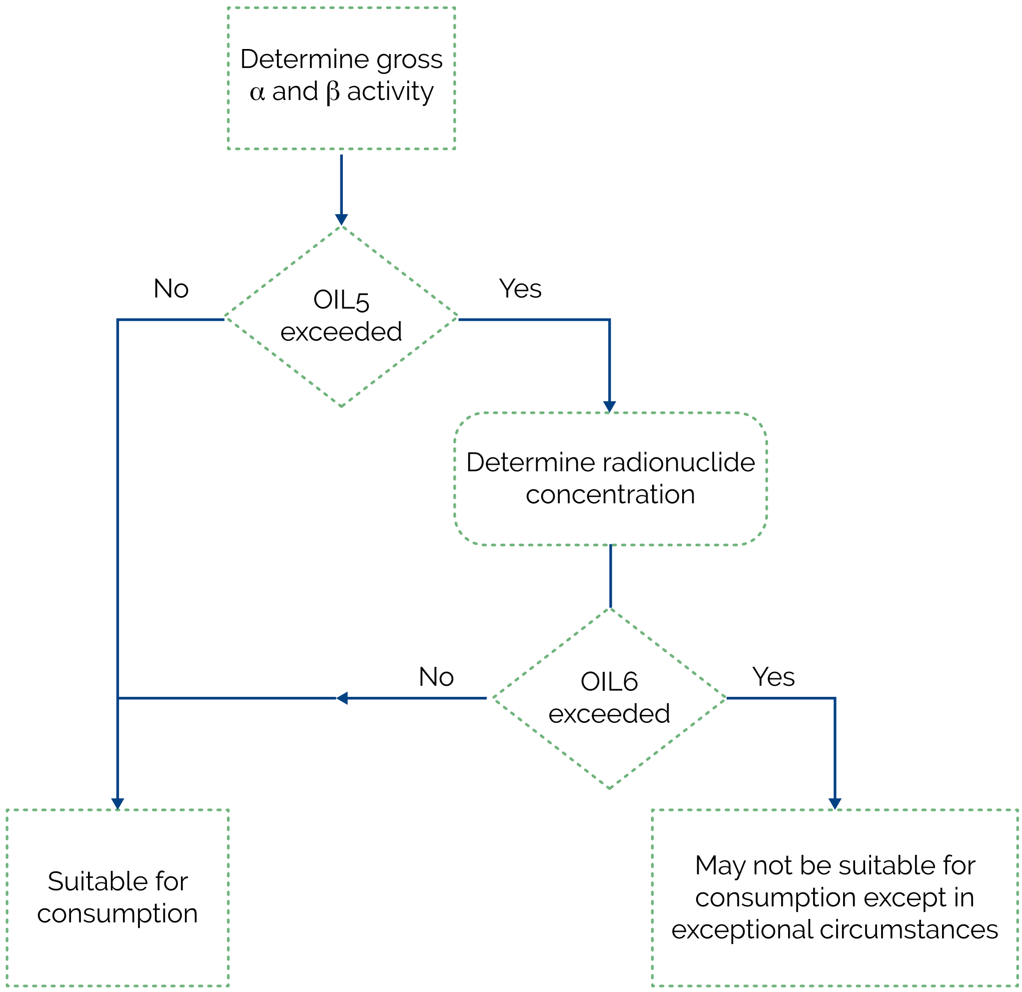
The General Safety Guide No. GSG-2 on *Criteria for use in preparedness and response for a nuclear or radiological emergency* (IAEA, 2011) provides values of activity concentrations (OIL6) for more than 300 radionuclides. The OIL6 values are very conservative as they have been calculated using the assumption that the activity concentrations in drinking-water would remain at this level for a whole year, which is extremely unlikely to be the situation following an emergency situation (see Question 2.1.4). If the activity concentration of any radionuclide exceeds its OIL6 value, it may not be suitable for consumption and actions to reduce activity concentrations in the drinking-water and doses from

[12] If the gross beta screening criteria (OIL5) is exceeded, the contribution from potassium-40 should be subtracted from the measurement(s) following a separate determination of the total potassium in the drinking-water, if this has not already been done.

consumption of drinking-water should be considered (see Question 2.4.2). However, as the determination of OIL6 values considers the most vulnerable members of the public (e.g. infants and pregnant women) and it is assumed that all of the drinking-water is contaminated for a full year, exceeding the criteria does not necessarily mean that the drinking-water is unsuitable for consumption. Further investigation, including consideration of actual consumption rates and additional measurements, would be needed (see Question 2.4.2 for more information).

It is important that information on the radionuclides present in drinking-water are known as quickly as possible in an emergency situation. It is anticipated that screening of drinking-water supplies against the OIL5 and OIL6 values could be implemented within about a week to confirm any precautionary restrictions placed on the consumption of drinking-water immediately after the emergency (IAEA, 2011).

Figure 2.1. Staged approach for applying the OILs in emergency situations



Source: IAEA (2011); pp. 40 (https://www-pub.iaea.org/books/iaeabooks/8506/Criteria-for-Use-in-Preparedness-and-Response-for-a-Nuclear-or-Radiological-Emergency-General-Safety-Guide). Reprinted with permission of the publisher.

2.4.2

What actions can be considered if the criteria for drinking-water in emergency situations are exceeded ? Are there any special actions for small water supplies, including community supplies

If drinking-water supplies become contaminated with radionuclides after a nuclear or radiological emergency, it is likely that some of the contaminated water will be consumed. As explained in Question 2.1.2, it is very unlikely that radionuclides in drinking-water will remain a long-term public health risk and radionuclides are only likely to be present for a very short period of time at relatively high activity concentrations. Effective communication of the risks associated with consuming this drinking-water is therefore important both in the case that drinking-water contains radioactivity at concentrations below the operational intervention levels (OILs) set, and if they are above these levels for a limited period of time (see Question 2.4.1).

If the OILs are exceeded, the international standards recommend that restrictions on the consumption of non-essential drinking-water are implemented as a protective action (IAEA, 2015; 2011). If consumption of the supplied drinking-water is unavoidable because its restriction may lead to dehydration and replacement water is not available, the drinking-water can be consumed until a replacement is available. However, even if the drinking-water is consumed, it is not likely to pose a significant health risk as discussed in Question 2.1.4. While there may be a slight increase in the radiological risk to health, the risk of not having water for consumption is a far more significant risk to health. If radioactive iodine has been released, the international standards recommend that implementation of iodine thyroid blocking is considered (WHO, 2017b). Further information about criteria for iodine thyroid blocking implementation is available elsewhere (IAEA, 2011; WHO, 2017b).

There are different water management and remedial options that could be considered for drinking-water that exceeds the pre-established criteria for emergency situations and these options are briefly discussed below. The options chosen will be dependent on the specific situation; factors to be taken into account in the choice of option include the extent to which the emergency criteria are exceeded, the costs of the option and the availability of other drinking-water supplies. The information given here is of a general nature and a full evaluation of options for a specific situation would need to be made depending on the country context and resources. Further details of possible options can be found in handbooks on recovery after radiation incidents, for example the *UK recovery handbooks for radiation incidents 2015 – Drinking-water supplies handbook* (Brown, Watson & Nisbet, 2015).

- Continue the use of the drinking-water supply supported by a detailed monitoring programme. If the radionuclide has a half-life of less than about a week, it may not be necessary to consider any specific option for reducing activity concentrators in the drinking-water due to the short timescale of the exceedance. Relying on normal water treatment, supported by monitoring and good risk communication to the public, may be the most practicable option, particularly for small community supplies.
- Provide an alternative drinking-water supply that does not contain radionuclides, such as bottled water or water from an unaffected area brought in by tankers. Water from the supply can still be used for sanitation purposes. As part of an emergency response plan, water utilities should have developed plans for providing and distributing emergency supplies of drinking-water. It is important to ensure that the alternative supply does not introduce additional, more significant risks (as described below).
- Change the water source to one that does not contain radionuclides above the criteria (changes to water abstraction point or location of water source). There may be water sources available that are not affected or are much less affected by the consequences of the emergency. It may also be possible to change from a surface water source

to a groundwater source. Particular care should be taken to ensure that changes in source water do not lead to the introduction of additional, more significant risks that cannot be controlled or may be difficult to control (e.g. surface water sources which are often more polluted, particularly from microbial contamination).

- Controlled blending of drinking-water supplies. The drinking-water of concern could be mixed with water not affected by the consequences of the emergency, or with water that was less affected and containing lower concentrations of radionuclides, if more than one supply is available at the point of water treatment or post treatment. This is an effective method of reducing activity concentrations in drinking-water and has the added benefit of not generating radioactive waste products. Blending is unlikely to be practical for small private or community supplies.
- Implementing water treatment or the modification of existing water treatment. Water treatment plants with a combination of coagulation, sedimentation and sand filtration processes for treating surface water may remove between 30% and 100% of radionuclides present in the source water, depending on the radionuclide. Further information on removal performance for common water treatment processes for some radionuclides can be found in Question 3.2. An example of a general checklist that could be used to assist with determining whether implementing additional water treatment may be the most appropriate and feasible option is given in Section I of USEPA (2005). Implementing new water treatment, or making substantial changes to existing water treatment, is likely to be a major undertaking and is very unlikely to be implemented quickly.
  - Water treatment options usually generate waste products that will contain the radionuclides removed from the water (see Question 3.3).
  - There are commercially available treatment options that can be used in the home or private premises that will reduce radioactive contamination of drinking-water. These are: water filter systems for softening water that use a carbon filter with some ion exchange material (jug filters), and small reverse osmosis units. These products should be certified by an appropriate standards organization. Household water treatment options will generate waste products that will contain the radionuclides removed from the water (see Question 3.3). These types of units are more likely to be practical for small communities or where only a small water-supply is affected, as they will not be accessible on a large scale and their use will need to be carefully controlled to ensure they are effective and waste filters are handled appropriately. Information Box 2.6 and Information Box 2.7 discuss remedial activities undertaken in response to the Fukushima Daiichi nuclear power plant accident in 2011.

Information Box 2.6: Covering open storage reservoirs

During a release of radionuclides to the atmosphere, radionuclides can be deposited directly onto source water at the abstraction point and during treatment or onto treated water being stored prior to distribution. In this case, taking actions to protect the drinking-water supply systems such as covering open water storage reservoirs to protect it from direct contamination via dry and wet deposition may be effective if implemented before or shortly after the release. For example, water treatment basins were covered in Japan after the Fukushima Daiichi nuclear power plant accident.

Information Box 2.7: Restricting consumption of drinking-water after an accident

In the case of the Fukushima Daiichi nuclear power plant accident on 11 March 2011 in Japan, restrictions on tap water intake by infants were implemented by 20 water supply utilities in a total of five prefectures because the index value of radioactive iodine (100 Bq Kg^{-1}) was exceeded for infants. Most of the restrictions lasted two to three days in prefectures other than Fukushima Prefecture. All restrictions on the infants' intake were lifted by 10 May 2011. An intake restriction for all age groups was only implemented for a small-scale water supply utility in Fukushima Prefecture on 21 March 2011; this was because the level of radioactive iodine exceeded 300 Bq Kg^{-1} (index value for adults). This restriction was lifted on 1 April 2011. During the period of the restrictions, distribution of bottled water or via tankers was carried out. Further information can be found in Section 4.5.

Chapter 3

SUPPORTING INFORMATION

CHAPTER 3 SUPPORTING INFORMATION

3.1 DOES BOILING WATER REDUCE THE EXPOSURE FROM RADIONUCLIDES IN DRINKING-WATER?

No. Boiling will not reduce concentrations of radionuclides in drinking-water. However excessive (i.e. continuous or extended) boiling may lead to higher concentrations of radionuclides due to the reduction in volume of water from boiling (see Information Box 3.1).

Information Box 3.1: Reducing activity concentrations by boiling drinking-water

Tests in Japan after the Fukushima Daiichi nuclear power plant accident (Tagami & Uchida, 2011) showed no iodine-131 loss from the tap water with either short-term boiling (1–10 minutes) or prolonged boiling (up to 30 minutes). Long-term boiling resulted in increased concentrations of iodine-131 due to a threefold reduction in volume.

CHAPTER 3 SUPPORTING INFORMATION

3.2 HOW EFFECTIVE ARE WATER TREATMENT OPTIONS IN REMOVING RADIONUCLIDES FROM DRINKING-WATER ?

Surface water typically undergoes more treatment than groundwater, particularly water sources with high turbidity (large amounts of suspended particulate matter) and high microbial content (see Table 3.1). Removal of radionuclides is likely to be higher for water undergoing more extensive treatment. For water sources with less treatment (e.g. many groundwater sources), generally there will be less removal of contaminants, including radionuclides.

Table 3.1. Surface and groundwater characteristics

Characteristic	Surface water	Groundwater
Turbidity	High	Low
Dissolved minerals	Low-moderate	High
Microbial content	High	Low
Temporal variability	Very high	Low

In general, treatment that combines coagulation with sedimentation or filtration should be effective at removing suspended radionuclides to some extent, with the effectiveness ranging from about 30% to 100%, and typically about 70% for the main naturally occurring radionuclides (see Table 3.2). Ion exchange filters, which are more commonly used for groundwater, are particularly effective for radium and uranium, removing over 70% of these radionuclides. However, these are often installed to remove nitrates from water and these may compete with radionuclides in terms of their preferential removal. Information Box 3.2 provides an example of filtration activities after the Fukushima Daiichi nuclear power plant accident.

Table 9.4 in Chapter 9 of the GDWQ, adapted below, gives a summary of the removal performance for some common water treatment processes for some elements. For further details, a review of the effectiveness of different water treatment processes and a description of the factors that can influence this can be found in Brown, Hammond & Wilkins (2008b) and USEPA (2005). References for treatment technologies specific to radionuclides are also provided in Annex 6 of the

GDWQ. Further information on techniques for removing uranium, radium, lead and polonium and their likely effectiveness can also be found in Annanmaki & Turtianen (2000). It should be noted that the removal performance will be very specific to the water source and treatment undertaken and the information provided is only indicative of the reductions in concentrations that could be expected.

Table 3.2. Water treatment performance

Element	Coagulation	Sand filtration	Activated carbon	Lime-soda softening	Ion-exchange	Reverse osmosis
Strontium	XX	XX	X	XXXX	XXX	XXXX
Iodine	XX	XX	XXX	X	XXX	XXXX
Caesium	XX	XX	X	XX	XXX	XXXX
Radium	XX	XXX	XX	XXXX	XXXX	XXXX
Uranium	XXXX	X	XX	XXXX	XXXX	XXXX
Plutonium	XXXX	XX	XXX	X	XXXX	XXXX
Americium	XXXX	XX	XXX	X	XXXX	XXXX
Tritium	Not possible to remove					

Key: x = 0–10%; xx = 10–40% removal; xxx = 40–70% removal; xxxx = > 70% removal.

Source: Adapted from Table 9.4, Chapter 9 of WHO (2017a).

Information Box 3.2: Effectiveness of water treatment in removing iodine-131 (^{131}I), caesium-134 (^{134}Cs) and caesium-137 (^{137}Cs)

After the Fukushima Daiichi nuclear power plant accident, measurements were made in some water treatment plants to study the effectiveness of removing ^{131}I and radioactive caesium (^{134}Cs and ^{137}Cs) during water treatment.

Iodine-131

In two water treatment plants it was found that coagulation and sedimentation did not remove ^{131}I (concentrations in raw water:treated water of 2.9 Bq L^{-1}:2.8 Bq L^{-1} and 5.4 Bq L^{-1}:5.7 Bq L^{-1} were observed) (Kosaka et al., 2012; 2014). In these cases, ^{131}I in raw water was considered to be present in a dissolved form and not as particulate.

It was found that the granular activated carbon process did remove ^{131}I. Reductions of 2.8 Bq L^{-1} to 1.9 Bq L^{-1} were observed in a water treatment plant, i.e. a removal of 34%. Powdered activated carbon treatment was also effective at removing ^{131}I. The removal ratio of ^{131}I by granular activated carbon and powdered activated carbon in actual water treatment plants was considered to be around 30% to 40%. In a bench-scale removal test using river water (about 3.5 Bq L^{-1} of ^{131}I), treated with 10, 25 and 50 mg powdered activity carbon per litre with a 30 minute contact time removed 9%, 36% and 71%, respectively. A weak pre-chlorination with a dose of about 0.5 to 1.0 mg L^{-1} before powdered activated carbon treatment could enhance the removal to 41%, 59%, 71% for the same powdered activated carbon doses described above.

Information Box 3.2 (continued)

Radioactive caesium (^{134}Cs and ^{137}Cs)

It was found that if radioactive caesium in the water treatment plant existed mainly as particulate form, it is selectively adsorbed on and into some types of soil particles and subsequently removed by particle separation processes including coagulation and flocculation, sedimentation and sand filtration. About 1.5 months after the Fukushima Daiichi accident, removal of ^{134}Cs and ^{137}Cs in a water treatment plant was examined. Levels of ^{134}Cs and ^{137}Cs in raw water were 5.6 and 6.4 Bq L^{-1} and those after coagulation and sedimentation processes were below the detection limits (which were 0.50 and 0.83 Bq L^{-1}, respectively). These results suggested a reduction in concentration of particulate radioactive caesium of up to a factor of 10. In a bench-scale coagulation test using river water, in which ^{134}Cs and ^{137}Cs concentrations were 5.6 and 6.4 Bq L^{-1} and turbidity was 51 degrees (approximately 35-41 Nephelometric Turbidity Units), the removal of ^{134}Cs and ^{137}Cs was 94% and 95%, respectively, confirming the high removal of the particulate form (Kosaka et al., 2012).

In contrast, radioactive caesium in dissolved ion form cannot be removed. Removal of the ion forms of ^{134}Cs and ^{137}Cs by coagulation, sedimentation and sand filtration in two water treatment plants were measured in October 2012, about 1.5 years after the accident. Levels of ^{137}Cs in dissolved ion form in two raw waters were 0.005 and 0.010 Bq L^{-1} and those in treated water were 0.005 and 0.011 Bq L^{-1} (Ohno et al., 2013). The evidence that conventional coagulation and sand filtration processes are not effective to remove radioactive caesium in ion form was further observed in bench-scale tests using contaminated pond water from the reactor site. Levels of ^{134}Cs and ^{137}Cs in the pond water were 9.8 and 11.0 Bq L^{-1}, respectively, and turbidity was 0.3 degrees (approximately 0.2–0.3 NTU). Removal of ^{134}Cs and ^{137}Cs by this coagulation test was only 5% and 6%, respectively. (Kosaka et al., 2012)

These results suggested the particle separation processes are very effective in removing the particulate form of radioactive caesium but they do not remove radioactive caesium in dissolved ion form.

As a potential effective method for removal of dissolved ion radioactive caesium, addition of soil particle was suggested. In a bench scale test, the addition of 200 mg L^{-1} of local soil of which the diameter was sieved to 25–75 µm to the dechlorinated tap water (0.1 µg L^{-1} of ^{133}Cs was added) and stirred for 30 minutes. Using this method, 50% of ^{133}Cs originally in a dissolved form was removed (Tampo et al., 2016).

CHAPTER 3 SUPPORTING INFORMATION

3.3 IF RADIONUCLIDES ARE REMOVED FROM DRINKING-WATER BY TREATMENT, WHERE DO THEY END UP IN THE TREATMENT PROCESS? COULD THERE BE WASTES FROM WATER TREATMENT PROCESSES THAT NEED TO BE HANDLED AS RADIOACTIVE WASTE ?

If radionuclides are removed from water during its treatment, they will end up in the waste products resulting from the treatment processes. For traditional coagulation, sedimentation and filtrations processes, the main waste products will be sludge (from coagulation) and filter media (e.g. sand) from filtration.

The production of sludge from the coagulation process is a concentration mechanism, as typically the amount of sludge produced is small compared to the throughput of the water being treated. The amount of sludge depends on the quality of the source water and its level of turbidity, higher levels of turbidity leading to more sludge per litre of water treated. Sludge will also be produced from the backwashing of filters. For example, in a study of radiologically-residual wastes from domestic water treatment in southeast Queensland, Australia, the sludge produced per million litres of treated surface water ranged from 0–46 kg with a mean of 14 kg per million litres of water (Kleinschmidt & Akber, 2008). The authors state that this is consistent with reports from other countries and give comparison values for Germany and the USA. For water treatment plants with a high throughput of water, relatively more sludge will be produced. Information Box 3.3 gives an example of measurements made in sludge in a non-emergency situation.

The accumulation of radionuclides in filter beds, for example sand and activated carbon, is also a concentration mechanism, as the filter beds will accumulate radionuclides over the period that water passes through them and the activity concentration per mass of filter material will increase over time. The less frequent the replenishment of filter bed media, the higher the concentrations will become. The radionuclides removed by filtration will be associated with a very large mass of filter media and the activity concentrations of radionuclides per unit mass of filter material are likely to be significantly lower than those in waste sludge. Further information can be found in Brown, Hammond & Wilkins (2008a).

Ion exchange and reverse osmosis will also lead to radionuclides accumulating on the ion exchange resin or reverse osmosis membranes, although these can be removed by regeneration. However, this regeneration will lead to radionuclides being discharged to wastewater, which may need to be controlled.

There are practical issues with the removal of filter media and filters or replacing ion exchange or reverse osmosis membranes that would need to be considered, including their removal, transportation, replacement and re-commissioning prior to resuming water treatment.

It is unlikely, but still possible, that the activity concentrations in the waste materials arising from water treatment will be required to be managed as radioactive waste. However, activity concentrations in waste products, particularly sludge, can be high in the short-term after an emergency (as shown in the examples in Information Box 3.4) and taking measurements in the treatment waste products should be considered if a nuclear or radiological emergency has led to radionuclides entering water sources that are being treated to supply drinking-water. Specialist advice should be sought from the appropriate regulators. Some background information on the management of radioactive waste products from drinking-water treatment can be found in USEPA (2005).

The potential health risks to individuals working in water treatment activities should be considered and may need to be controlled, although it is very unlikely that any exposure to the treatment waste materials would pose any significant health risks to people working on water treatment activities. Further information is given in Question 3.4.

Information Box 3.3: Example of activity concentrations in waste sludge in a non-emergency situation in Australia

At a site in Northern Territory, Australia, groundwater is extracted from boreholes and is stored in tanks prior to distribution leading to settling of sludge (Kleinschmidt Black & Akber, 2011). Average daily water demand from the bore field is 0.35 million litres per day, peaking at 0.63 million litres per day. The concentrations of radium-226 and radium-228 in the groundwater and sludge are as follows:

	Radium-226	Radium-228
Water (borehole)	1 Bq L^{-1}	0.7 Bq L^{-1}
Sludge (tank waste)	2830 Bq Kg^{-1}	2010 Bq Kg^{-1}

Information Box 3.4: Examples of activity concentrations in waste sludge after emergencies

Following the Fukushima Daiichi nuclear power plant accident in Japan

Conventional water treatment processes including coagulation, sedimentation and rapid sand filtration are used in Japan. Therefore, after the Fukushima Daiichi nuclear power plant accident, the radioactive caesium concentrated in the waste sludge. Many water treatment plants had to keep the sludge for the first few months after the accident because the concentration of radioactive caesium was very high (> 8000 Bq Kg^{-1} of sludge). The sludge cannot be disposed of in normal landfill sites and needs to be stored as radioactive waste; a disposal site for the waste sludge was not agreed until about one year after the accident.

Following the Chernobyl nuclear power plant accident in the United Kingdom

In a drinking-water treatment works in the northwest of England, high activity concentrations were measured in sludge after the Chernobyl accident (Jones & Castle, 1987). Measurements showed that the treatment used (coagulation and filtration) removed ruthenium and radioactive caesium which accumulated in the sludge. After five months, due to dilution of radionuclides in the water sources being treated (and radioactive decay for ^{131}I and ^{132}Te), the activity concentrations in the sludge had significantly decreased.

Concentrations in waste sludge (Bg Kg^{-1})		
Radionuclide	May 1986	October 1986
^{103}Ru	1900	24
^{131}I	900	Not detectable
^{134}Cs	350	17
^{137}Cs	600	24
^{132}Te	900	Not detectable

Key: ruthenium-103 (^{103}Ru); iodine-131 (^{131}I); caesium-134 (^{134}Cs); caesium-137 (^{137}Cs), tellurium-132 (^{132}Te)

Following the Chernobyl nuclear power plant accident in Germany

Activity concentrations were also measured in sludge cake in Berlin after the Chernobyl accident (BMU, 1987; SSK, 1988). While these measurements were at a wastewater treatment works and not a drinking-water treatment facility, they illustrate the rapid decrease in activity concentrations with time after an accident. The highest activity concentrations were measured on 11 May 1986 (two weeks after the accident) after heavy rainfall, which washed contamination from the environment into the sewage system. As observed in the example from the United Kingdom, activity concentrations in processed sludge cake decreased rapidly over a few months.

CHAPTER 3 SUPPORTING INFORMATION

3.4 WHAT ARE THE HEALTH RISKS TO PEOPLE WORKING IN WATER TREATMENT ACTIVITIES THAT HAVE PROCESSED WATER CONTAINING RADIONUCLIDES ?

If there are radionuclides in the water being treated in drinking-water treatment plants, people working on water treatment activities could be exposed to them while they are working on day-to-day tasks or undertaking routine maintenance. The main sources of exposure will be from being in close proximity to, or inadvertently ingesting, radionuclides in treatment waste products, particularly sludge resulting from coagulation and backwashing of filters and filter material. However, it is very unlikely that any exposure to these materials would pose any significant health risks to these workers.

Information on the possible exposure pathways from undertaking water treatment activities are described in USEPA (2005) and Brown, Hammond & Wilkins (2008a). Guidance on how to assess the doses to people undertaking treatment activities can also be found in Brown, Hammond & Wilkins (2008a).

If there are concerns about exposure to drinking-water industry workers, specialist advice should be sought.

The water supply industry may want to assess the potential health risks to people working in water treatment facilities from radiation exposures as part of their emergency planning, so that exposures could be controlled in the short term after a nuclear or radiological emergency, in the unlikely situation that this is necessary. Information Box 3.5 discusses measurements that were taken to assess impact on workers in water treatment facilities.

Information Box 3.5 Example of potential doses to people working in water treatment plants after an accident in the United Kingdom

In a treatment works in the northwest of England, high activity concentrations of caesium-137 were measured in sludge after the Chernobyl accident (see Information Box 3.5 in Question 3.3. Measurements showed that the treatment used (coagulation and filtration) removed ruthenium and radioactive caesium. There was concern at the time that workers may be at risk from intakes of radionuclides from carrying out some activities, such as cleaning out sludge tanks. However, monitoring indicated that doses were very small; also sludge was kept wet, reducing dust which minimized inhalation doses. Further measured activity concentrations in sludge in October 1986 (five months later) confirmed water entering the treatment works had become diluted and activity concentrations in sludge were much lower.

Brown, Hammond & Wilkins (2008a) used the measurements made in sludge and default assumptions about working activities and water throughput at the treatment works to estimate conservative doses for a person carrying out all of the day-to-day tasks (doses were not estimated or measured at the time). The estimated doses using the highest measured activity concentrations in sludge were very low (0.03 mSv in a week) and would subsequently have decreased as activity concentrations in sludge became diluted with time (see Information Box 3.4).

CHAPTER 3 SUPPORTING INFORMATION

3.5 WHAT METHODS CAN BE USED FOR MEASURING RADIONUCLIDES IN DRINKING-WATER SUPPLIES?

The process of identifying individual radionuclides in drinking-water and determining their concentrations is time-consuming and expensive. A practical approach, regularly used for routine surveillance measurements in non-emergency situations, is to use a screening method where the total (or gross) radioactivity present in the form of alpha and beta radiation is initially determined. The gross alpha and gross beta screening methods rely on the detection of emitted alpha or beta particles during the radioactive decay of the radionuclides. The methods are appropriate for most situations in which radionuclides are likely to be found in drinking-water.

While gas proportional counters have traditionally been employed for gross alpha and gross beta measurements and continue to be the standard counters used in many laboratories across the world, the use of liquid scintillation counters is increasing. This technique is more suited to undertaking measurements of groundwaters (typically those having high total dissolved solids content) and can be less resource intensive. Liquid scintillation counters are able to measure beta-emitting radionuclides regardless of the energy of their emissions, whereas gas proportional counters are more limited to those with higher beta energies. However, both techniques are suitable for measuring activity concentrations to compare with the gross alpha and gross beta screening levels. Gross beta measurements will include a contribution from potassium-40, which should be subtracted if the gross beta screening level is exceeded (see Questions 1.5.3 and 1.5.4). References for some standard methods for the analysis of gross alpha and gross beta activity concentrations in drinking-water using gas proportional counters are given in Table 9.3 in Chapter 9 of the GDWQ.

Gross alpha and gross beta screening methods only give the total activity present due to alpha and beta activity and radionuclide-specific information cannot be obtained. It should be emphasized that the sum of the activities of the radionuclides contributing to the overall activity concentration in drinking-water is very unlikely to agree with the result from the gross measurements, particularly for gross beta measurements. This is because of the difference in the counting techniques employed, together with the associated uncertainties in the measurements.

Methods for measuring individual radionuclides

When the individual activity concentrations of specific radionuclides are required, the measurement technique depends on the radionuclide and the type of radiation it emits. High-resolution gamma spectrometry is the standard method for quantifying many gamma-emitting natural and artificial radionuclides. It is a non-destructive measurement that can be applied directly to the sample of drinking-water, without any processing of the sample other than putting an aliquot into a suitable container. Hyper Pure Germanium detector systems are the predominant instrumentation for high-resolution gamma spectrometry but may require concentration of samples when dealing with the activity concentrations commonly found in natural waters. High-resolution gamma ray spectrometry is most likely to be the first measurement technique used in the event of a radiological or nuclear emergency.

If gamma ray spectrometry is available, direct measurement of individual gamma-emitting radionuclides could be used as a screening method, as many radionuclides emit gamma rays. The measurements of individual radionuclides using this method should be compared with the guidance levels and not the screening levels. However, gamma-ray spectrometry will not detect all radionuclides that could be in drinking-water for non-emergency situations, particularly naturally occurring radionuclides that would be detected via the gross alpha and gross beta methods.

To identify and determine the radionuclides that are predominantly pure alpha or beta emitters and produce none or very weak gamma photons, analytical techniques like alpha spectrometry, liquid scintillation counting, and/or other beta counting techniques are required. The measurement techniques often need to be preceded by radiochemical methods to extract the radionuclide into a form that can be measured.

Inductively-coupled plasma mass spectrometry (ICP-MS) is a sensitive, efficient and versatile means of elemental analysis for measuring radionuclides in environmental media, including drinking-water. ICP-MS is being increasingly used due to its high sensitivity, as it detects atoms rather than the radioactive emissions associated with radionuclides. This technique is particularly useful for radionuclides with very long radioactive half-lives, for example uranium-234 and uranium-238, as these radionuclides produce a small number of radioactive decays per unit mass of the isotope and are therefore difficult to measure via their radioactive emissions.

The measurement of radon in drinking-water is covered in Section 1.6.

Measurements should be made using accredited analytical methods, ideally under a recognized quality standard, such as ISO/IEC 17025:2005 (ISO, 2010). ISO/IEC 17025:2005[13] is for use by laboratories in developing a management system for quality, administrative and technical operations. As well as quality assurance of the measurements made, the standard puts requirements on a laboratory to undertake proficiency tests (internal and external) to ensure the techniques used are valid and consistent results are obtained.

The limits of detection of the various analytical methods and measurement techniques depend on a number of factors, mainly the method and equipment used and the counting time. Standards adopted by a country may specify the limit of detection that is required in order to ensure that the radionuclide concentration in the sample can be confidently assessed against the guidance level (or national standard), taking into account the uncertainties of the measurement. (see Information Box 3.6 for an example)

The main features of the different measurement methods are summarized in Table 3.3. Some comparative information is expressed in relative terms and not absolute values, which will be situation specific. References for analytical methods for specific radionuclides are provided in Annex 6 of the GDWQ.

[13] ISO17025:2005 specifies the general requirements for the competence of testing and calibration laboratories, including sampling.

Information Box 3.6: Required limits of detection for analytical methods used for measuring radionuclides in the Euratom Drinking-Water Directive

As an example, the Euratom Drinking-Water Directive (EC, 2013) gives limits of detection that should be achieved for the analytical methods used for measuring individual radionuclides. Typically, these are about a factor of 10 lower than the derived concentrations (equivalent to the guidance levels in the GDWQ). For gross alpha and gross beta activity concentrations, the limits of detection required are 40% of the relevant screening values (EC, 2013).

Table 3.3. Main features of the different methods to measure radionuclides in drinking-water

Feature	Analytical technique					Comments
	Gross alpha/beta	ICP-MS	Gamma spectrometry (high resolution)	Beta counting	Alpha counting	
General	Screening method – total alpha emitting- and total beta emitting-radionuclides. Contribution of some radionuclides will not be included (see Question 1.4.3).	Effective for radionuclides with long half-lives. Particularly useful for ^{234}U, ^{238}U.	Use for gamma-emitting radionuclides e.g. ^{134}Cs, ^{137}Cs, ^{131}I, ^{241}Am. Will not detect many naturally occurring radionuclides likely to be found in drinking-water, e.g. ^{234}U, ^{238}U, ^{210}Po. ^{226}Ra and ^{228}Ra can be detected with low-energy detectors and assuming equilibrium with other radionuclides can be established. In the case of ^{226}Ra, it has to be ensured that no radon is lost from the sample. Low-resolution spectrometry e.g. NaI detectors can be used for screening in emergency situations.	Accurate measurement of radionuclides that are predominantly beta emitters, e.g. ^{90}Sr, ^{3}H, ^{14}C.	Accurate measurement of radionuclides that are predominantly alpha emitters, e.g. ^{239}Pu, ^{210}Po, ^{210}Pb (via ^{210}Po).	Low-resolution gamma ray spectrometry can be used as a screening method following an emergency, e.g. using NaI detectors. Provides broad indication of the activity concentration in the sample but not, in general, specific radionuclide information.
Speed (elapsed time)	Hours–few days (depending on sample preparation time).	Hours	Hours	Days–weeks	Days–weeks	Standard methods. Rapid methods may be available but these are likely to affect the limits of detection achievable.

Feature	Analytical technique					Comments
	Gross alpha/beta	ICP-MS	Gamma spectrometry (high resolution)	Beta counting	Alpha counting	
Preparation of sample/ sample size	Sample is evaporated onto a counting disc for gas proportional counters. Concentration of sample for liquid scintillation counters as very small sample size counted (10–15 ml).	Measurement is made directly on sample of drinking-water. This enables further analyses to be carried out on the same sample without any degradation of performance.	Measurement can be made directly on sample of drinking-water. This enables further analyses to be carried out on the same sample without any degradation of performance. However, sensitivity can be a problem especially for the radionuclide concentrations commonly found in drinking-water in non-emergency situations and therefore some pre-concentration of sample may be required.	Complex chemistry to extract radionuclide before measurement.	Complex chemistry to extract radionuclide before measurement.	High salinity of the water sample can adversely affect the gross alpha measurement due to the shielding effect of the total dissolved solids on the emission and counting of the alpha particles.
Limits of detection	High	Low compared to other methods for measuring individual radionuclides.	Higher than gross beta and gross alpha measurement techniques.	Low compared to gamma spectrometry.	Low compared to gamma spectrometry.	
Training level	Medium–high	Medium	Medium–high	High	High	Gamma counting needs medium training for interpretation of results, low training for sample preparation
Likely sample throughput	High	High	High–medium	Low	Low	Duration of overall measurement depends on limit of detection required (based on requirement of low levels of detection for concentrations expected in non-emergency situations).
Cost per sample	Low	Low	Low	High	High	Excludes purchase of equipment.
Relative cost of equipment	Medium	High	High	Medium	High	

Key: uranium-234 (^{234}U); uranium-238 (^{238}U); caesium-134 (^{134}Cs); caesium-137 (^{137}Cs); iodine-131 (^{131}I); americium-241 (^{241}Am); polonium-210 (^{210}Po); radium-226 (^{226}Ra); radium-228 (^{228}Ra); strontium-90 (^{90}Sr); tritium (^{3}H); carbon-14 (^{14}C); plutonium-239 (^{239}Pu);lead-210 (^{210}Pb) and sodium iodine (NaI).

Additional information for emergency situations

In addition to high-resolution gamma ray spectrometry, low-resolution gamma ray spectrometry can be used as a screening method following an emergency, for example using sodium iodine (NaI) detectors. They provide a quick screening measurement that gives a broad indication of the activity concentration in the sample but do not provide specific radionuclide information, unless the gamma-emitting radionuclides are known and can be easily distinguished from each other.

In emergency situations, the activity concentrations in water are likely to be much higher than those in non-emergency situations; and higher limits of detection can be accepted for the analytical techniques used. This means that it may be possible to obtain a measurement result more rapidly by reducing the sample preparation time and the counting time for some radionuclides. These rapid methods need to be practiced as part of emergency preparedness, as they will not be routinely used by laboratories and it will be necessary to adapt standard analytical techniques very quickly to respond rapidly to an emergency situation. Some radionuclides, for example strontium-90, will still require radiochemical methods to extract the radionuclide into a form that can be measured.

If a high-resolution gamma ray spectrometry capability is available within a country following an emergency situation and the radionuclides of importance are measurable by gamma ray spectrometry, for example caesium-137 and caesium-134, it may be preferable to continue to use gamma ray spectrometry when the situation returns to a non-emergency situation, rather than use the gross alpha and gross beta screening methods (see Information Box 3.7 for an example of this).

Information Box 3.7: Example of using gamma spectrometry rather than gross alpha and gross beta screening methods in Japan

Japan developed an extensive gamma ray spectrometry capability after the Fukushima Daiichi nuclear power plant accident and has continued to use this to measure radionuclides in drinking-water. An automatic high-resolution gamma spectrometry and measurement system has been introduced at the treatment works where the evacuation order was lifted in 2015. This instrument can automatically quantify the activity concentration of caesium-134 and caesium-137 in treated drinking-water every hour.

Chapter 4

CASE STUDIES

CHAPTER 4 CASE STUDIES

4.1 BRAZIL

Background

In some Brazilian areas with high levels of naturally occurring radiation, radionuclide activity concentration in groundwater may exceed the WHO guidance levels and the individual dose criterion (IDC) of 0.1 mSv y^{-1} (WHO, 2017a). One example of this situation occurred in the municipality of Caetité, located in the northeast region of Bahia in Brazil. Caetité contains several uranium anomalies (uranium occurrence above background); 36 anomalies have been mapped so far, spread over an area of 1200 km^2. Since 2000, an uranium mining and milling industry has been exploiting one of these radioactive anomalies in the region and environmental monitoring programmes have been conducted since 1989. High uranium concentration in groundwater had been reported for some wells even before the industry started operating in the region. Although Caetité´s population is only about 50 000 inhabitants, 40% of the population lives in rural areas where most of these anomalies occur and groundwater supply is the main source of potable water.

In 2008, nongovernmental organizations blamed the uranium industry for groundwater contamination as measurements of gross alpha and gross beta activity performed in some water wells in the region exceeded the WHO screening level based on an IDC of 0.1 mSv y^{-1}. As a consequence, these wells were closed by the local authority until further investigations were done. This situation became the centre of a debate among nongovernmental organizations, the uranium industry, the Ministry of Health (MoH) and the Brazilian Nuclear Energy Commission. The Brazilian Nuclear Energy Commission argued that: i) interpretation and applicability of WHO GDWQ screening levels was misleading; ii) measurements of individual radionuclide concentrations should be performed before taking any decision; iii) high radionuclide concentrations in groundwater have been reported for these wells even before the uranium industry started operating in the region; and iv) the decision of closing the wells was doing more harm than benefit, since they were the most important source of potable water for this rural population.

Regulatory framework and responsibilities for drinking-water

In Brazil, the Ministry of Health is responsible for the regulation of microbiological, chemical and radiological contaminants in drinking-water supplies through Resolution MS 2914/2011 (Ministry of Health Brazil, 2011). This resolution requires that every water supply must monitor gross alpha and gross beta activity against the screening levels of 0.5 Bq L^{-1} and 1.0 Bq L^{-1}, respectively. If the screening levels are exceeded, the concentration of individual radionuclides should be determined and compared with a maximum allowed value for radium-226 (1.0 Bq L^{-1}) and radium-228 (0.1 Bq L^{-1}). The resolution also states that, under the Brazilian Nuclear Energy Commission's requirement, other radionuclides should be investigated.

In Brazil, there are three types of water supply systems:

1. large water system supplies with a distribution network operated by water concessionaires in each city or region;
2. an alternative collective water supply system, which includes surface or groundwater collection without a distribution network;
3. an individual water supply system, which usually uses groundwater collection to serve only one family and relatives.

While the first two systems are under regulatory control, individual water supply systems are not. The responsible authorities for controlling drinking-water quality in the first two systems submit the monitoring results regarding radionuclides in drinking-water to the public health municipality authority every six months.

Description of the situation and response

After the complaints made in 2008 by non-governmental organizations, six wells were closed. Unfortunately, the government was not able to maintain the drinking-water supply to the affected communities, which had a great social impact on these communities (e.g. population had to walk long distances to obtain water from other sources). Radiation doses were estimated based on measurements of individual radionuclide concentrations by the Brazilian Nuclear Energy Commission. Several water wells from 10 villages were monitored, and estimated mean doses were in the range of 0.07 to 0.5 mSv y^{-1}. Two wells located in one of these villages were closed as the natural uranium concentrations were above the WHO guideline value for uranium toxicity in drinking-water (30 µg L^{-1}). The Brazilian Nuclear Energy Commission jointly with the Municipality Health Office released a public notice providing a comprehensive review of the situation, explaining that although the estimated dose for some water wells exceeded the WHO IDC of 0.1 mSv y^{-1}, the dose was still below the International BSS reference level of 1 mSv y^{-1} (IAEA, 2014) and cannot be seen as unsafe for consumption. The purpose of this public notice was to provide technical support to the Municipality Health Office to enable it to reopen the closed wells where the annual doses were above 0.1 mSv y^{-1} but below the reference level of 1 mSv y^{-1}. Radionuclide monitoring should continue to be carried out and doses should be kept as low as reasonably achievable using a reference level of 1 mSv y^{-1}.

The need to review the Brazilian criteria/standards used for radionuclides in drinking-water became quite evident after these events. In order to discuss these events and propose a revision of the national legislation on radioactivity in drinking-water, the Institute of Radiation Protection and Dosimetry (IRD) from the Brazilian Nuclear Energy Commission organized a symposium on water quality and radioactivity. The purpose of this symposium was to join the national regulators, water supply companies, analytics service companies and research institutes involved in drinking-water quality along with representatives of WHO and IAEA to discuss several aspects of radioactivity in drinking-water regulation including the international recommendations, mainly the role of the WHO IDC of 0.1 mSv y^{-1} and the 1 mSv y^{-1} reference level in the International BSS. The lack of a clear communication programme with the interested parties had led to new stressful events in 2010 and 2015, such as other complaints of water in wells exceeding the gross alpha and gross beta screening levels and the WHO IDC of 0.1 mSv y^{-1}, resulting again in the shutdown of these wells.

Outcome

Based on the discussions during the National Symposium on Water Quality and Radioactivity, a working group from the Brazilian Nuclear Energy Commission was established to revise the radiological section of the Brazilian standards for drinking-water.

This working group proposed that the Ministry of Health adopt the following criteria for radiological aspects of drinking-water.

- Every water supply has to be screened for gross alpha and gross beta activity (screening levels of 0.5 Bq L^{-1} and 1 Bq L^{-1}, respectively).
- If the gross beta activity screening levels are exceeded, the contribution of potassium-40 should be subtracted.
- If gross alpha and gross beta activity screening levels (after potassium-40 subtraction) are exceeded, a new sample should be collected and analysed.
- If the new gross alpha and gross beta activity levels remain above the screening levels, these results should be forwarded to the Brazilian Nuclear Energy Commission with information about the sampling location and type of water supply (surface or groundwater).
- The Brazilian Nuclear Energy Commission should determine which natural or artificial radionuclides have to be investigated in these samples and also request additional information about the water supply.
- Results for radionuclide-specific measurements should be forwarded to the Brazilian Nuclear Energy Commission to estimate the total dose due to water ingestion and evaluate if the water is safe for consumption.
- The outcome of this evaluation may indicate that no action is required if total doses are below the reference level of 1 mSv y^{-1}, especially in situations where the IDC of 0.1 mSv y^{-1} is not a practically achievable standard.

The National Standard for Water Quality (Resolution MS 194/2011) is under revision to incorporate these new criteria proposed by the working group. Nevertheless, as no effective communication programme has been established so far between the government agencies and the affected community as well as with the nongovernmental organizations, this community is still vulnerable to new events of this nature.

Four lessons were learned from these events in Caetité, Brazil.

1. The criteria adopted for managing radioactivity in drinking-water must be consistent among the different regulatory authorities.
2. Exceeding the screening levels or IDC does not necessarily mean that water is unsafe for drinking. It would be useful to provide further guidance/explanations to policy-makers and water suppliers on how to interpret and use the criteria, as these were misinterpreted in this case.
3. Coordination and dialogue among the different regulatory authorities is essential – for example, in this case the Brazilian Nuclear Energy Commission, the Brazilian Institute of Environment and Renewable Natural Resources, Bahia Institute of Water Management and Climate and Bahia Health Department.
4. Risk Communication is a key component of a national plan for management of radionuclides in drinking-water. Both the uranium-mining operator and the regulators need to have a systematic and institutional programme of communication with the community, including public hearings (as specified in the licensing process) to guarantee the involvement of all stakeholders. Having a risk communication programme can reduce this community's vulnerability to further events of this nature.

References

IAEA (2014). Radiation protection and safety of radiation sources: International Basic Safety Standards. IAEA Safety Standards Series No. GSR Part 3. Vienna: International Atomic Energy Agency (http://www-pub.iaea.org/MTCD/publications/PDF/Pub1578_web-57265295.pdf, accessed 17 October 2017).

Ministry of Health Brazil (2011). Resolution 2914, 12 December 2011. Procedimentos de controle e de vigilância da qualidade da água para consumo humano e seu padrão de potabilidade [Procedures for controlling and monitoring water quality for human consumption and potability standard]. Diário Oficial da União; 14 dez.

WHO (2017a). Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Geneva: World Health Organization (http://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/, accessed 27 November 2017).

CHAPTER 4 CASE STUDIES

4.2 CANADA

Background

In the Province of Nova Scotia, about 50% of the population rely on groundwater for drinking-water. The presence of elevated levels of naturally occurring uranium in groundwater was identified in 1978. In response to this finding, a provincial uranium task force was formed. Subsequent investigation tested more than 700 water wells for radionuclides during the 1980s. It has become routine in Nova Scotia to test for uranium in drinking-water monitoring programmes. However, most of the other naturally occurring radionuclides were not commonly tested. Drinking-water systems were routinely tested for gross alpha and gross beta activity.

Regulatory framework and responsibilities for drinking-water

In Canada, the responsibility for making sure drinking-water supplies are safe is shared between the provincial (10 provinces), territorial (three territories), federal and municipal governments. The provincial government is the regulator for all drinking-water supplies. The day-to-day responsibility of providing safe drinking-water to the public generally rests with the authorities in the provinces and territories, while municipalities usually oversee the day-to-day operations of the treatment facilities.

The Federal-Provincial-Territorial Committee on Drinking-Water (comprising members from the authorities responsible for drinking-water quality in each jurisdiction) together with Health Canada established the Guidelines for Canadian drinking-water quality (Health Canada, 2009). These guidelines deal with microbiological, chemical and radiological contaminants. They also address concerns with physical characteristics of water, such as taste and odour. Maximum acceptable concentrations for natural and artificial radionuclides are calculated using a reference dose level of 0.1 mSv for 1 year's consumption of drinking-water, assuming a consumption of 2 litres per day at the maximum acceptable concentrations.

Description of the situation and response

In May 2002, during an environmental assessment in which drinking-water was tested for gross alpha and gross beta activity, the gross alpha activity in well water at a school in Hubley, Nova Scotia, exceeded the Canadian screening level of 0.1 Bq L^{-1} (the screening level effective at that time). Follow-up detailed analysis showed that all naturally occurring radionuclides were below Canadian guideline values, except for lead-210 (^{210}Pb).

The Department of Education took extra precautions to ensure that drinking-water was safe for students and staff surrounding the school in Hubley. In a press release on 29 May 2002, the Education Minister said "We take the health and safety of students very seriously, … While we have no reason to believe there are problems at other schools, testing the water is a responsible and precautionary step. We don't take chances where children are concerned" (Department of Education, 2002). The province's medical officer of health for the region also said at the first press release that there was no public health risk associated with continuing to drink water with the levels of ^{210}Pb found in the preliminary sample at the school in Hubley. He explained clearly that the preliminary result indicated only that further investigation was necessary. It was announced at the press release that tests had started immediately in 13 schools from St. Margaret's Bay to Herring Cove for naturally occurring radionuclides (uranium-234, uranium-235, uranium-238, thorium-228, thorium-230, thorium-232, thorium-234, radium-224, radium-226, radium-228, lead-210, polonium-210, bismuth-210, beryllium-7).

In response to this discovery, an inter-governmental special well water advisory group was promptly formed and led by the Department of Environment and Labour. A province-wide sampling programme was initiated at public schools, municipal water supplies and registered public water supplies in 2002 and 2003 to determine levels of individual radionuclides and identify areas and geological formations in the province where drinking-water supplies were most likely to have elevated radionuclide levels (Drage, Baweja & Wall, 2005a; Drage, Baweja & Wall, 2005b).

The province-wide radiological testing programme took a graded approach. The initial sampling programme of testing drinking-water in 52 schools was conducted in June 2002. Twelve of the schools were found to have levels of ^{210}Pb above Health Canada's guideline for drinking-water (0.2 Bq L^{-1}). In two of these 12 schools, total uranium was also above Health Canada's drinking-water guideline (0.02 mg L^{-1}). The test results initiated an expanded testing programme in September 2002 to cover all provincial schools (184 in total).

Among the 184 schools, 178 schools had groundwater supplies and six had surface water supplies. Radiological tests were only conducted in schools with groundwater supplies. The results confirmed that ^{210}Pb and total uranium levels commonly exceeded drinking-water guidelines: 16 of 178 (9%) school water wells had elevated ^{210}Pb and three (2%) school water wells had elevated total uranium.

Based on the radionuclide levels observed in the province-wide testing programme, it was anticipated that owners of domestic wells and public water supplies would require information on how to treat the drinking-water for ^{210}Pb and uranium. Since water treatment systems for uranium have been commonly used and available, the evaluation of treatment methods for ^{210}Pb was conducted.

A literature review indicated that reverse osmosis and ion-exchange treatment systems were likely to be the most practical treatment options for treating ^{210}Pb. A field evaluation programme was initiated at several schools with elevated levels of ^{210}Pb to confirm ^{210}Pb removal efficiencies of these systems. The results from the field evaluation showed that both treatment methods had ^{210}Pb removal efficiencies of less than 29% and were not able to effectively reduce ^{210}Pb levels. However, once activated carbon or aeration was added, removal efficiencies were greatly improved (Drage, Baweja & Wall, 2005b).

With aeration to remove radon in water, levels of ^{210}Pb were reduced by more than 90%. This suggested that very little ^{210}Pb was present when the water was first drawn from the well for drinking, and most ^{210}Pb was generated by radon decay in the time between when the water was taken from the well and its analysis. The sampling protocol was modified accordingly, i.e. radon was removed from groundwater samples at the time of sampling by boiling for 10 minutes to eliminate the generation of ^{210}Pb arising from radioactive decay of radon in the drinking-water during the laboratory analysis.

All schools originally over the ^{210}Pb guideline were retested with the modified sampling protocol. The final results led to the conclusion that ^{210}Pb was not a significant problem in Nova Scotia, but levels can exceed the guideline value if water containing radon is stored prior to consumption. This new understanding of how to test for ^{210}Pb has provided a valuable lesson for many other jurisdictions in the assessment of ^{210}Pb levels in drinking-water.

The ^{210}Pb project raised the potential issue of radon in drinking-water and the more important question of exposure to radon in indoor air resulting from the use of water containing radon. As a precautionary measure, indoor radon tests were conducted in the summer of 2004 as an extension of the work done to address radionuclides in drinking-water in schools. Results showed levels below the Canadian guidelines for radon in air at schools.

Outcome

The ^{210}Pb project earned credibility by acknowledging challenges proactively, rather than trying to downplay concerns. Communications were incredibly important to the project, especially since the issue was initially discovered in schools. The project team reported frequently, even when results were not yet available; this built trust that the team was being open and honest about the situation. Between 2002 and 2004, there were a total of 10 press releases issued, first by the education ministry then led by the Department of Environment and Labour. In all the press releases, the effective communicator was the medical officer of health for the region. At the last press release on 21 September 2004 (Department of Environment and Labour, 2004), it was announced that the Department of Environment and Labour had set up a toll-free telephone number for information about radionuclides in well water and radon.

References

Department of Education (2002). Province to test school water in Sir John A Vicinity. Press release, 29 May 2002 (http://novascotia.ca/news/release/?id=20020530002, accessed 18 October 2017).

Department of Environment and Labour (2004). Majority of schools come off bottled water. Press release, 21 September 2004 (http://novascotia.ca/news/release/?id=20040921001, accessed 18 October 2017).

Drage J, Baweja A & Wall P (2005a). Naturally occurring radionuclides in ground water in Nova Scotia
• Part 1. Canadian Radiation Protection Association Bulletin. 26(3):15–21.

Drage J, Baweja A & Wall P (2005b). Naturally occurring radionuclides in ground water in Nova Scotia
• Part 2. Canadian Radiation Protection Association Bulletin. 26(4):13–22.

Health Canada (2009). Guidelines for Canadian drinking-water quality. guideline technical document: radiological parameters. Ottawa: Health Canada (http://healthycanadians.gc.ca/publications/healthy-living-vie-saine/water-radiological-radiologique-eau/index-eng.php, accessed 19 October 2017).

CHAPTER 4 CASE STUDIES

4.3 JORDAN

Background

Jordan[14] is a severely water stressed country. Groundwater constitutes 80% of the domestic water supplied, a source that is already exploited by 160% above safe yields. To augment the water supply, especially in high-demand areas, the Disi Water Conveyance Project was developed between 2005 and 2009. The Disi Water Conveyance Project is a "build-operate-transfer" project[15] that extracts 100 million m^3 y^{-1} of fossil groundwater from 55 wells drilled in the Ram Aquifer System in the southern desert of Jordan. This water is conveyed to the capital Amman (4 million inhabitants) via a conveyer pipe that is 1.7 m in diameter and 320 km in length.

In June 2013, The Disi Water Conveyance Project started supplying the capital Amman with 70 million m^3 y^{-1} in an emergency mode due to the high demand following the influx of 1.3 million Syrian refugees. In January 2014, the Disi Water Conveyance Project started supplying Amman with its full capacity of 100 m^3 y^{-1} of water. The Ram aquifer water (Disi) is blended with sufficient amounts of surface water from sustainable sources (Figure 4.1).

An extension is now under implementation during 2017–2018, which will ultimately serve 75% of the total population of Jordan and will fulfil increased demand in the north of the country.

[14] A significant portion of this case study comes from El-Naser et al. (2016).
[15] Build-operate-transfer projects are explained at: https://ppp.worldbank.org/public-private-partnership/agreements/concessions-bots-dbos#overview.

Regulatory framework and responsibilities for drinking-water

In Jordan, the Ministry of Health is the regulator for drinking-water quality. The responsibility for ensuring the safety of drinking-water supplied to the public is shared between the Water Authority of Jordan, which is the water provider and the Ministry of Health. The Ministry of Health is responsible for surveillance activities, from catchment to consumer.

The Higher Committee for Water Quality plays an advisory role on water quality-related issues. This committee is chaired by a representative from academia and includes membership from relevant ministries. It develops water quality management guidelines and manuals and provides recommendations to be considered in the revisions of the water quality standards.

Through a national team of experts from different organizations including the Ministry of Health, the Jordan Standards & Metrology Organization develops and reviews the national Jordanian standards including the drinking-water standard JS286, which specifies the limits, reference levels, sampling frequencies and points along the supply chain for the physical, chemical, radiological and microbiological parameters in drinking-water. It also defines the actions and intervention needed in case of violation or exceedance for any of the listed parameters. The latest edition of the JS286 was issued in 2015 and has been effective since 1 May 2016.

For radiological water quality management, the Disi Water Conveyance Project company developed Part 2 of the Environmental and Social Management Plan (ESMP2), to be implemented by the Water Authority of Jordan. The ESMP2 defines the water quality compliance requirements for monitoring and blending that reflect the GDWQ and the Jordanian Drinking-Water Standard Requirements.

The Water Authority of Jordan and the Ministry of Health jointly developed a protocol containing a detailed monitoring programme and management actions required to ensure that blended water supplied to customers always complies with the JS286 and the ESMP2 requirements.

Description of the situation and response

Water quality investigations on the groundwater of the Ram aquifer between 2001 and 2009 revealed elevated gross alpha and gross beta concentrations above the screening levels. The concentrations were dominated by naturally occurring radium-226 (^{226}Ra) and radium-228 (^{228}Ra). The average dose of the Ram aquifer was between 0.65–0.75 mSv y^{-1} with 70–85% of the dose due to ^{228}Ra.

The Government of Jordan accordingly requested technical and normative guidance from WHO on i) revising the reference level in the Jordanian national standard for radioactivity in drinking-water and ii) the suggested national intervention and management actions in case the reference levels were exceeded.

In 2008, The Jordanian reference level in the drinking-water standard was raised from 0.1 to 0.5 mSv y^{-1} after consideration of the guidance from WHO in the GDWQ and careful review of the local environmental, social and economic conditions. The new reference level was justified based on the assessment that the potential health risks are tolerable and the net health benefits of the provision of adequate water outweigh the potential health risks due to radionuclide content in water.

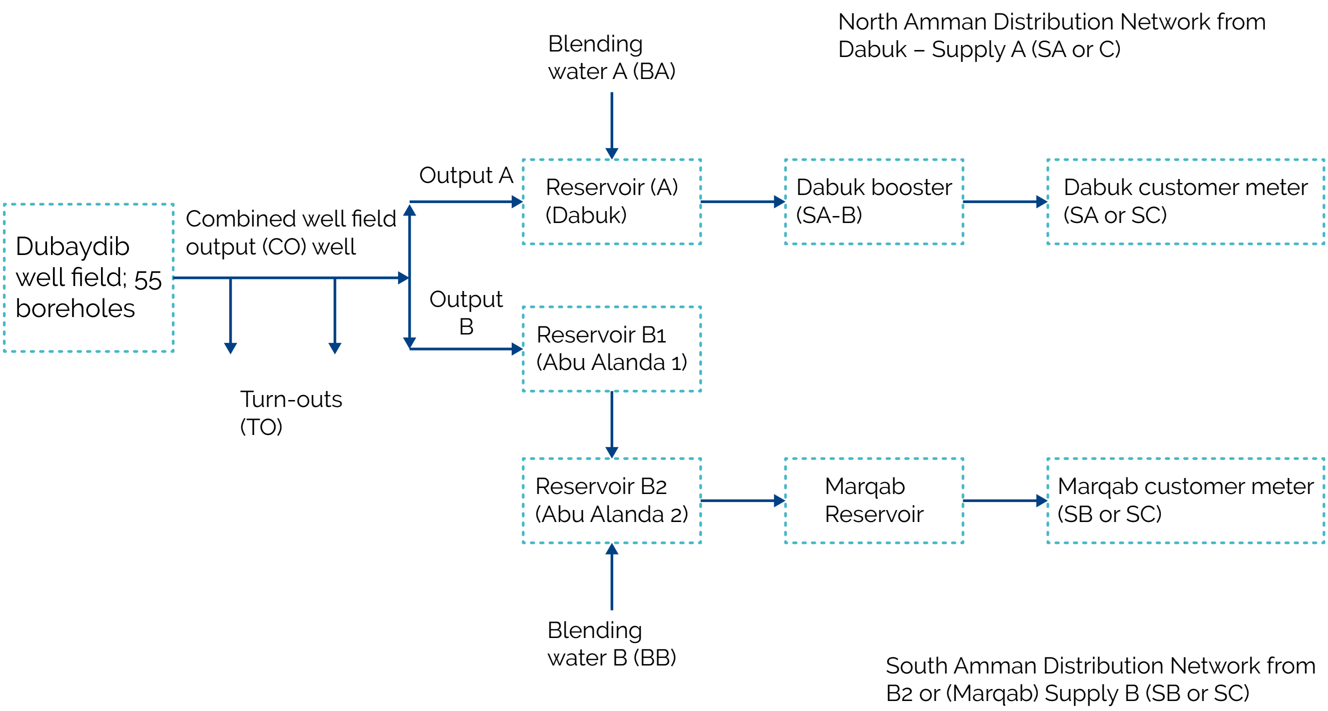
Between 2005 and 2012, the Water Authority of Jordan considered management options to secure safe water that meets the requirements of the revised national drinking-water standards; for each of the alternatives a feasibility study was performed according to a pilot scale design.

After considering remediation of the full yield of the Disi Water Conveyance Project of 100 million $m^3 y^{-1}$, via environmental and cost–benefit analysis, it was decided that the most practical and sustainable option for Jordan was blending the Ram aquifer water (Disi) with available low radioactivity surface water sources that are sustainable in the following amounts: 90 million $m^3 y^{-1}$ from Zai and 45 million $m^3 y^{-1}$ from Zara-Ma'en drinking-water supply systems.

For small communities supplied by single high-radioactivity wells where no water is available for blending, different treatment options at the wellhead are explored after approvals are obtained from the Ministry of Health. The treatment options are reverse osmosis and resin ion exchange, which are both being used in small-scale pilot projects.

Figure 4.1 shows the entire system of sampling points from the source to the point of consumption. The Water Authority of Jordan is requested to provide quarterly progress reports to the Disi Water Conveyance Project company.

Figure 4.1. A simplistic schematic of the Disi-Mudawarra conveyance system to Amman



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The sampling and analysis programme was developed by the Water Authority of Jordan and approved by the Ministry of Health for the radioactive parameters of concern (monthly for gross alpha, gross beta, radon-222 (^{222}Rn), ^{226}Ra, ^{228}Ra, lead-210 (^{210}Pb) and annually for radium-224 (^{224}Ra). This was done to ensure that the JS286 and the ESMP2 for radiological parameters could be met with the following frequencies.

- Quarterly grab samples from each of the 55 wells constituting the Disi Water Conveyance Project well field to assess trends of radioactivity levels over time. The frequency will be reduced to once per year after two years of operation.

- Monthly grab sample from the combined water of the 55 wells at the header tank in the south of Jordan before the water is admitted to the main 320 km conveyer pipe.
- Monthly composite samples of the Disi water before blending at the two delivery points in Amman (Dabuk reservoir in the north of Amman and Abu Alanda reservoir in the south of Amman).
- Yearly monitoring of the blending waters from Zara-Ma'en and Zai treatment plants (historical results for gross alpha, gross beta, ^{226}Ra and ^{228}Ra are consistently below the analytical detection limits).
- Monthly composite samples of the drinking-water after blending measured at the outlets of the main reservoirs in Amman.
- Monthly composite samples from public reservoirs to represent the water supplied to consumers in the different distribution zones in Amman.

The Water Authority of Jordan follows the approach recommended in the GDWQ (Figure 9.2; WHO, 2017), assessing against the screening and guidance levels for radionuclides in drinking-water and sending monthly reports (or whenever an emergency arises) of the results to the Ministry of Health. The interventions taken by the Water Authority of Jordan and the Ministry of Health are in accordance with the approved national protocol and comply with the JS286 and the ESMP2 requirements. The staged approach to intervention is illustrated in Table 4.1.

Table 4.1. Intervention protocol to be followed in Jordan after radionuclide monitoring in drinking-water

Dose unit mSv y^{-1} – 0.5 is the reference level
< 0.45: No action; maintain routine monitoring
≥ 0.45: Red flag value; be vigilant
> 0.5 – < 1.0: Investigate to lower the dose while maintaining use of water supply
≥ 1.0: This is the action limit where water supply is stopped and issue addressed

The Water Authority of Jordan is required to immediately notify (red flag notification) the Ministry of Health and the Disi Water Conveyance Project company in the event that the blended water output exceeds the annual dose of 0.45 mSv. The Water Authority of Jordan must carry out progressive sampling of the boreholes within three months after notification is issued, to identify and mitigate the problem, and inform the Ministry of Health and Disi Water Conveyance Project company when corrective actions are taken. The protocol specifies that the number of days during which blending stops shall not exceed 46 days per calendar year; this is based on historical data and calculations to ensure that the requirements in the JS286 and the ESMP2 are complied with, taking into account that the two surface water sources used for blending are subject to closure during floods.

Outcomes

In managing radioactivity in the water of the Disi Water Conveyance Project, Jordan developed, adopted and implemented a solution compatible with the national conditions after guidance and support from WHO. The outcome of this project is that the water is now more frequently monitored, risk is assessed and the water is managed more effectively overall.

Quarterly results of gross alpha, gross beta, ^{226}Ra, ^{228}Ra, ^{222}Rn and ^{210}Pb from each of the 55 wells constituting the Disi Water Conveyance Project well field have remained constant since the start of operations in 2013. The activity concentrations of ^{210}Pb have been consistently below the detection limit while ^{222}Rn activity concentrations have been fairly low.

The annual radiological dose along the drinking-water supply chain (after blending, distribution and delivery to the point of consumption) is around 0.40 mSv y^{-1}. This dose is below the red flag value of 0.45 mSv y^{-1} and the JS286 reference level of 0.5 mSv y^{-1}.

To gain public trust awareness campaigns were organized and the activities related to the risk assessment, development of the Jordanian drinking-water standard (and reference level) and management of the Disi Water Conveyance Project were conducted in a transparent manner.

Although the Jordanian authorities have assessed that blending is effective and the water supplied to consumers is safe, there are still areas that need to be addressed:

- Assess the long-term health impacts of consuming drinking-water meeting the national standard limit of 0.5 mSv y^{-1} on infants and children.
- Evaluate the health impact of short lived radionuclides like ^{224}Ra, especially when considering small community water supply wells in the south of Jordan where the time between abstraction and consumption is short.

References

El-Naser HK, Smith B, Kilani S, Abdeldin I, Howarth B, Saleh B (2016). Blending as the best compliance option for the management of radioactivity in drinking-water supplied from the deep sandstone aquifer in Southern Jordan. J Water Health. 14(3):528–48.

CHAPTER 4 CASE STUDIES

4.4 SWEDEN

Background

In Sweden, where uranium-rich geology prevails, high concentrations of naturally occurring radionuclides are expected in drinking-water extracted from the ground. This may particularly be an issue in drinking-water coming from bedrock aquifers. Naturally occurring radionuclides from the uranium-238 decay series are of principal interest. Radon is the most studied radionuclide but awareness of uranium in drinking-water is increasing. Regarding the occurrence of other radionuclides in that series, such as polonium-210 (^{210}Po) and lead-210 (^{210}Pb), knowledge is limited. The occurrence of radionuclides from the thorium-232 decay chain in drinking-water have not been studied despite the fact that the concentration of thorium is three times higher than that of uranium in soils and bedrock (SGU, 2016).

There are about 2000–3000 public water works in operation, using groundwater as a source of drinking-water. Public water works supplying large volumes of water are operated principally by municipalities but there exist a large number of private companies supplying drinking-water on smaller scales. Concentrations of radionuclides in public water supplies are generally low.

In addition to public water works, there are about 260 000 drilled wells and 140 000 dug wells that are used on a permanent basis in Sweden. The number of drilled wells increases by approximately 5000 annually. About 1.2 million people obtain their daily water supply from these private wells. Information about the concentration of radionuclides in drinking-water from private wells is insufficient but the few studies that have been performed over the years (Salih, 2003; Skeppström, 2005; Ek et al., 2008) provide insight into the extent of the problem. The concentrations of radionuclides in many private drilled wells are significant and in some cases very high.

Regulatory limits for radioactivity in drinking-water

In Sweden, the National Food Agency issues regulations to ensure safe drinking-water to the population. The regulations include criteria for microbiological, chemical and radiological contaminants in drinking-water and are applicable to public water supplies. The National Food Agency is a central authority and does not perform any supervision over water treatment facilities. This responsibility is instead assumed by municipalities.

Since Sweden is a member state of the European Union, the criteria used for radionuclides in drinking-water are in agreement with the requirements laid down in the Euratom Drinking-Water Directive (EC, 2013). This directive aims to protect the health of the general public with regard to radioactive substances in water intended for human consumption. For public water supplies, Sweden has set a regulatory limit of 100 Bq L^{-1} for radon. Remediation measures are required if radon concentrations in drinking-water exceed that limit. For uranium, a concentration of 30 μg L^{-1} should not be exceeded and this recommendation is principally used to protect against the chemical toxicity of the metal. For drinking-water extracted from groundwater, it has been mandatory since November 2015 to screen for gross alpha and gross beta activities. The screening level is set as 0.1 Bq L^{-1} and 1 Bq L^{-1} for gross alpha and gross beta activity, respectively. Specific radionuclide analyses are required if the screening levels are exceeded. The screening and parametric values (excluding radon and short-lived radon decay products) are based on an indicative dose of 0.1 mSv y^{-1} [16], assuming a consumption of 730 litres per year. The indicative dose is a binding limit in Sweden.

For private wells, there exist two recommendations for radioactivity in drinking-water. Remediation measures are recommended if the concentration of radon exceeds 1000 Bq L^{-1} and for uranium, the concentration should not exceed 30 μg L^{-1}.

Radioactivity in drinking-water from public water works

The only radioactive element that has routinely been analysed since the late 1990s in Sweden is radon. Requirements to control indicative dose as stipulated by the Euratom Drinking-Water Directive (EC, 2013) (which superseded Council Directive 98/83/EC) were enforced in Swedish regulations in 2003 but were poorly abided to, due to lack of guidelines on how the requirements should be implemented. The Swedish Radiation Safety Authority and the National Food Agency initiated a project in 2004 with the aim of getting an overview of the situation in Swedish drinking-water (Falk et al., 2004). The project targeted public water supplies where groundwater (both bedrock aquifers and soil aquifers) was used as a source of drinking-water and 265 municipalities were given the opportunity to provide water samples.

The project led to the collection of 256 samples of treated water from water works supplying large volumes of drinking-water. Gross alpha and gross beta measurements were performed on all water samples as a screening strategy. Radium-226 (^{226}Ra) was also determined in all water samples. For the majority of the water samples (~80%), gross beta concentrations were below the detection limit. The screening level of 1 Bq L^{-1} was exceeded in only 21 water samples but no radionuclide-specific analysis was performed to determine which radionuclides contributed to the gross beta activity. Regarding gross alpha activity, 65% of water samples were below the detection limit; the screening level of 0.1 Bq L^{-1} for gross alpha activity was exceeded in 40 water samples. For the calculation of indicative dose, all alpha activity was assumed to come from uranium when no activity from ^{226}Ra was detected. In samples where ^{226}Ra was found to occur, the activity from uranium was deduced from the difference between the gross alpha activity and activity from ^{226}Ra. The concentration of ^{226}Ra in almost all samples was below the detection limit. Drinking-water from only two water works (barely 1% of the studied water works) had an indicative dose exceeding 0.1 mSv y^{-1}.

The conclusion drawn from that study (Falk et al., 2004) was that the concentrations of radionuclides in drinking-water from public water works did not usually lead to the exceedance of the indicative dose and hence proved no risk to health. It is worth noting that only 256 water works out of a total of approximately 3000 were studied in that project. However, since the implementation of the Euratom Drinking-Water Directive (EC, 2013) in November 2015, all relevant water works are gradually analysing and evaluating the quality of drinking-water with regard to radioactive substances. The National Food Agency has also created a database at the national level to collect all measurement results and other parameters,

[16] Similarly, the screening and guidance levels in the GDWQ are based on an IDC of 0.1 mSv per year, where the gross alpha screening value is 0.5 Bq L^{-1} and the gross beta screening value is 1 Bq L^{-1}. The gross alpha screening value was changed from 0.1 to 0.5 Bq L^{-1} in the third edition of the GDWQ in 2004.

with the aim of evaluating the data. Hence a better picture of the scale of the problem of radioactivity in drinking-water from public water works will be obtained after some years.

The regulations for radioactivity in drinking-water together with the infrastructure to follow up measurement data for drinking-water from public water works will be used to ensure that the public is not exposed to high concentrations of radionuclides in drinking-water. The main challenge is instead for those who are not connected to a public water supply but instead obtain their water supplies from private wells.

Radioactivity in drinking-water from private wells

About 12% of the population in Sweden obtain their drinking-water supply from private wells. In 2001, a mapping project of naturally occurring radionuclides in drinking-water from private wells was launched by the Swedish Radiation Safety Authority in collaboration with the Geological Survey of Sweden. The study, which lasted for five years, had several aims; the main aim was to get an overview of radioactivity in drinking-water in private wells and thereby to make an estimation of the potential radiation dose that certain groups of the population can receive. Two other aims were to study temporal variation and potential correlation that can exist between different radionuclides. Results of temporal variation and correlation are not presented here.

The study included 722 drilled wells. Sampling was conducted by the staff at the Geological Survey of Sweden. The large majority of the wells were chosen at random way and the selection was made county-wide, covering a total of 24 counties. Wells were also chosen in areas known to have high concentration of radioactivity in the geological media. Geogenic maps were used and previous studies were reviewed to identify areas of interest. A special area of interest, the Siljan Ring, located in the municipality of Rättvik was studied. This region has a unique geological formation due to the fall of a meteorite about 360 million years ago. Private wells located in that region have very high concentrations of uranium as well as other metals.

The approach adopted in that study was screening for gross alpha and gross beta activity prior to any specific radionuclide analysis, with the exception of radon. Exceedance of 0.1 Bq L^{-1} for gross alpha activity led to the measurement of activity concentration of ^{226}Ra. Activity concentration from uranium (uranium-238 (^{238}U), uranium-234 (^{234}U) and uranium-235 (^{235}U)) was calculated as the difference between gross alpha activity and activity concentration of ^{226}Ra. The activity concentrations of these radionuclides were required for the calculation of indicative dose. The concentration of uranium expressed in µg L^{-1} was also determined with the aim of comparing the values with the recommendation issued by the authority. Results of mass concentrations of uranium are not presented here. Exceedance of gross beta did not lead to specific analysis of any beta-emitting radionuclide, although concentration of lead-210 (^{210}Pb) was estimated in a few samples, from the beta energy-spectrum. It was assumed that the major contributors to indicative dose were the alpha-emitting radionuclides from the U-238 decay series.

Concentration of ^{226}Ra was generally low in drinking-water with a median value of 0.02 Bq L^{-1} and a maximum of 7.0 Bq L^{-1}. Regarding uranium (^{238}U, ^{234}U, ^{235}U), the median activity concentration was found to be 0.13 Bq L^{-1} and a maximum of 26.7 Bq L^{-1} was recorded. Activity concentrations of uranium exceeding the guidance value of 3 Bq L^{-1} was found in 2% of the studied wells.

Radon concentration exceeding 1000 Bq L^{-1} was measured in 8% of the studied wells, supplying drinking-water to about 60 000 people. The maximum and median concentrations for radon were 66 200 Bq L^{-1} and 220 Bq L^{-1}, respectively.

Calculation of indicative dose based on the activity concentrations of uranium (^{238}U, ^{234}U, ^{235}U) and ^{226}Ra were performed for 620 wells. It was found that 10% of the wells had an indicative dose that exceeded 0.1 mSv y^{-1}. In areas near the Siljan Ring, concentrations of all studied radionuclides in drinking-water were high. Consumption of water from a large majority of wells in that area would give a radiation dose exceeding 0.1 mSv y^{-1}. The highest dose calculated (including dose contribution from ^{210}Pb) in that region was 5 mSv y^{-1}.

One limitation of the project is that neither ^{210}Pb (except in a few samples from areas near the Siljan Ring) nor ^{228}Ra, were analysed in water samples. These elements can potentially be present in drinking-water in Sweden as shown by previous studies (Salih, 2003). This implies that the radiation dose received by the population consuming drinking-water from private wells could be higher than the dose calculated just from uranium and ^{226}Ra. Another limitation of the project is that ^{210}Po which could potentially be present in some samples had not been investigated. Finally, gross alpha activity was assumed to come from ^{226}Ra and the isotopes of uranium, implying that dose contribution from uranium isotopes might have been overestimated in some cases.

Conclusions and response

The studies from public water works and private wells highlighted that some private wells are particularly at risk. Where the results showed extreme concentrations of radionuclides (radon concentrations > 1000 Bq L^{-1} and activity concentration of uranium > 3.0 Bq L^{-1}), the owners of the wells were contacted and informed about the problem. Site visits were also made in the study area near the Siljan Ring, in the municipality of Rättvik, where the highest concentrations of radon and uranium were detected. Health inspectors at the municipality as well as stakeholders at county level were informed about the extent and significance of the problem. This in turn led to further studies and local information campaigns in that region. A follow-up survey showed that many participants who had high concentrations of radon and uranium in their drinking-water took remediation measures after the nationwide mapping project. Aeration techniques for radon and ion exchange filters for uranium were commonly used. The follow-up survey also showed that many private well owners still had limited knowledge on radioactivity in drinking-water despite their participation in the project. This highlighted the need for regular risk communication about radionuclides that occur naturally in the environment.

References

EC (2013). Council Directive 2013/51/EURATOM laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption. Brussels: European Commission (http://eur-lex.europa.eu/, accessed 19 January 2018).

Ek BM, Thunholm B, Östergren I, Falk R, Mjönes M (2008). Naturligt radioaktiva ämnen, arsenik,och andra metaller i dricksvatten från privata brunnar [Naturally occurring radioactive elements, arsenic and other metals in drinking-water from private wells]. SSI-report 2008:15. Stockholm: Swedish Radiation Protection Authority (in Swedish).

Falk R, Mjönes L, Appelblad P, Erlandsson B, Hedenberg G, Svensson K (2004). Kartläggning av naturligt radioaktiva ämnen i dricksvatten [A survey of natural radioactivity in drinking-water]. SSI Report 2004:14. Stockholm: Swedish Radiation Protection Authority (in Swedish).

Salih IM (2003). Radon in natural waters [dissertation]. Linköping: Linköping University.

SGU (2016). Mineralmarknaden, Energimetallerna uran och torium [Market of minerals, fuel facts on uranium and thorium]. Report 2016:2. Uppsala: Geological Survey of Sweden (in Swedish).

Skeppström K (2005). Radon in groundwater - influencing factors and prediction methodology for a Swedish environment [thesis]. Stockholm: KTH Royal Institute of Technology.

CHAPTER 4 CASE STUDIES

4.5 JAPAN

Background

After the 11 March 2011 Great East Japan Earthquake and subsequent tsunami, the Tokyo Electric Power Company's (TEPCO) Fukushima Daiichi nuclear power plant was severely damaged, resulting in the release of a large amount of radionuclides into the environment in Japan. The dispersion and deposition of these radionuclides was influenced by the prevailing meteorological conditions during the passage of the radioactive cloud, particularly the wind direction and the occurrence of precipitation (e.g. rain, snow).

Measures were taken by national authorities to protect people from the consequences of the accident, including the establishment of a 20-km evacuation zone with a 30-km sheltering zone. As the availability of environmental monitoring data increased, other protective actions were implemented to reduce doses in the longer term (WHO, 2012; WHO, 2013). Monitoring of tap water was conducted, both by central and local government and by the water supply utilities. On 16 March 2011, iodine-131 (^{131}I) was first detected in some tap water samples and, beginning on 21 March, restrictions on tap water consumption were applied in a number of villages and cities, including Tokyo (MHLW, 2011a). However, because ^{131}I has a short half-life (~eight days), activity concentrations in drinking-water rapidly decreased; afterwards caesium-134 (^{134}Cs) and caesium-137 (^{137}Cs) were the main radionuclides of concern.

The water supplies affected were mostly public supplies from surface water sources. Generally, private water systems were not affected because they principally rely on groundwater as a source.

Regulatory framework for drinking-water

In Japan, the regulatory authority for drinking-water is the Ministry of Health, Labour and Welfare. The Water Supply Division of the Ministry of Health, Labour and Welfare establishes the drinking-water quality standards and related items. Radioactive substances are not in the category of regulated items, but since the accident, their monitoring in Fukushima and the neighbouring 10 prefectures has been requested by the Ministry of Health, Labour and Welfare. In the case of a severe emergency in the future, the Nuclear Regulation Authority or the Ministry of Health, Labour and Welfare will be responsible for any restrictions placed on drinking-water.

On 17 March 2011, the Department of Food Safety of the Ministry of Health, Labour and Welfare established provisional regulation values, of radionuclide concentration in domestic food by adopting the guidelines from the Nuclear Safety Commission in Japan, which was reformed into the Nuclear Regulation Authority in September 2012 (in accordance with the Food Sanitation Act, Act No. 233 of 24 December 1947) (MHLW, 2011b). Drinking-water (which includes tap water, well water and bottled water) was included as one of the categories for application of the provisional regulation values. Regulation values were provided for ^{131}I, ^{134}Cs, ^{137}Cs, uranium and the alpha-emitting nuclides of plutonium and other transuranic elements. There were no screening levels such as gross alpha and gross beta activity concentrations put in place. On 19 March 2011, the Water Supply Division of the Ministry of Health, Labour and Welfare established provisional index levels for restriction on tap water intake, which were the same levels as provisional regulation values but, which were provided only for ^{131}I, ^{134}Cs and ^{137}Cs (MHLW, 2011c). The Ministry of Health, Labour and Welfare notified local government authorities and regional water suppliers that tap water contaminated above the provisional regulation values should ideally not be consumed but can be consumed even by infants if an alternative water supply could not be obtained (MHLW, 2011c).

The current criterion (for non-emergency situations), which is called "the target level for management of radioactive materials in tap water", was established on 1 April 2012 (MHLW, 2012), about one year after the Fukushima Daiichi nuclear power plant accident.

Description of the situation and response

During the period of emergency exposure, Fukushima Prefecture and the other neighbouring 10 prefectures were designated as the main monitoring areas, from which intensive measurement of ^{131}I, ^{134}Cs and ^{137}Cs in tap water was requested by governmental organizations including the Ministry of Health, Labour and Welfare. The population in the area was about 50 million and accounted for 40% of the total population in Japan (about 126 million). Many governmental organizations, research institutions and water supply utilities started working cooperatively on the measurement of source and tap water on a daily basis or more frequently. Individual radionuclides, primarily ^{131}I, ^{134}Cs and ^{137}Cs, were measured using high-purity germanium semiconductor detectors or sodium iodine scintillation counters. All of the measured concentrations of radionuclides in drinking-water were publicly announced via the websites of the Ministry of Health, Labour and Welfare and each water supplier.

As a response to the to the emergency situation, on 17 March 2011 provisional regulation values for restriction on drinking-water were established by Department of Food Safety of the Ministry of Health, Labour and Welfare. A provisional regulation value of 300 Bq Kg^{-1} was established for ^{131}I and 200 Bq Kg^{-1} for radioactive caesium (the sum of ^{134}Cs and ^{137}Cs). On 19 March 2011, the Water Supply Division of the Ministry of Health, Labour and Welfare announced provisional index levels for restriction on tap water intake, which were the same levels as provisional regulation values but supplied only for ^{131}I and the sum of ^{134}Cs and ^{137}Cs. On 21 March, the Water Supply Division additionally announced that the provisional index level of ^{131}I for infants was 100 Bq Kg^{-1} (MHLW, 2011d).

Restriction on infants' intake of tap water was requested by 20 water supply utilities, which served a population of about 14 million including the Tokyo metropolitan area, starting on 21 March 2011. The restriction in the Tokyo metropolitan area was only for two days (23 and 24 March) and in other areas was lifted by 1 April 2011 in all water supply utilities except one small-scale water supply in Fukushima Prefecture (supplying Iitate village, which served a population of about 4000) (MHLW, 2011a). The restriction on infants' intake of tap water was lifted on 10 May 2011 in the water utility supplying water to Iitate village (although the restriction for all other age groups was lifted on 2 April 2011). No water supply utilities requested a restriction on intake of tap water based on the provisional index level for radioactive caesium (200 Bq Kg^{-1}).

There was increased communication and collaboration between all stakeholders (the Ministry of Health, Labour and Welfare, water supply utilities, health departments of local governments, media, local residents, etc.). Public announcements were also made, especially about tap water restrictions for infants through television, the use of publicity cars for broadcasting by the local government, etc. However, people were still concerned about the health impacts under the emergency situation and were not satisfied with the announcements. As a result, citizens made many telephone calls to the health departments of local governments, water supply utilities and related organizations.

When the restriction on infants' intake of tap water was announced in the Tokyo metropolitan area for two days (23 and 24 March 2011), bottled water sold-out in stores very quickly. In response, the Bureau of Waterworks of the Tokyo Metropolitan Government announced at a press conference at 21:00 on 23 March that they would provide bottled water to homes with infant(s) aged 1 year or younger. Three 550 mL bottles of water were provided to families of about 80 000 nfants who lived in the served area (a total of approximately 240 000 bottles).

Precipitation about 10 days after the nuclear power plant accident led to a very large amount of radioactive material being deposited from the atmosphere onto the land. This was the major cause of contamination of water sources. Therefore, ceasing abstraction of surface water sources after the precipitation reduced the concentration of radionuclides in tap water. In some water purification plants, covering the open-air basins for water treatment processes, including flocculation, clarification and sand filtration, with plastic sheets was performed in order to reduce contamination of the water via dry and wet deposition directly onto the basins. (In Japan, almost all finished water reservoirs are covered to prevent chemical and microbial contamination.) These measures were performed partly because there was not enough evidence of the effectiveness of powdered activated carbon treatment and particle separation in removing radionuclides from water. While some subsequent research has confirmed that the former treatment method was effective for iodine removal (Kosaka et al., 2012) and the latter for caesium removal (Kosaka et al., 2012; Tampo et al., 2016), covering the water treatment basins is still considered a relatively effective and pragmatic approach to prevent radionuclide contamination; the cover prevents the direct dry/wet deposition to the water surface. This is particularly important for iodine, as the effective treatment for removing it, as described above, is carried out before the water is stored in the treatment basins and, unlike radioactive caesium, sand filtration will not remove iodine (Kosaka et al., 2012).

The following are lessons learned/recommendations for managing radionuclides in drinking-water in emergency situations.

- Immediate response to a nuclear accident is of paramount importance. There is a need to establish criteria for drinking-water in an emergency situation and these should be established as part of emergency planning and preparedness.
- Although the measurements of gross alpha and gross beta activity used for routine monitoring of drinking-water can also be used in an emergency situation, in this case those screening methods were inefficient, mainly because ^{131}I may not be measured with the gross beta method as a result of volatilization during pre-treatment.
- Techniques for measuring radionuclides in drinking-water in the event of an emergency should be established as part of emergency planning. Using the compiled information in the GDWQ on measurement techniques for the first time is not practicable during the response to an emergency.
- Effective dialogue and collaboration between all the relevant stakeholders is of paramount importance during an emergency to provide clear messages to the public about the health risks, the developing situation and the measures in place.

Non-emergency situation (existing exposure situation) after April 2012

From April 2012, the situation has been regarded as an existing exposure situation in terms of drinking-water (except for the areas under the evacuation order, which are excluded from this case study). In April 2012 a target level for management of radionuclides in tap water was successively established. This target level replaced the provisional index levels and was derived directly from the guidance levels of the GDWQ (see below). The target value is 10 Bq Kg^{-1} for the sum of ^{134}Cs and ^{137}Cs, which has replaced the previous provisional index level for an emergency. Radioactive caesium is the only substance that has a target level because the impact of ^{131}I from the nuclear power plant accident had disappeared from the general environment owing to its relatively short half-life (~eight days).

Longer-term issues include the following.

- There have been risk communication issues regarding consuming tap water for people returning home after the lifting of evacuation orders. Some people are still concerned about radioactive caesium in tap water because some water purification plants draw water from the dam where the sediment is contaminated with radioactive caesium, although the purified water does not exceed the target level for radioactive caesium.
- There are concerns about the long-term behaviour in the water environment, especially the transfer of the remaining radioactive caesium in forest and mountainous areas to groundwater. This is unlikely to happen based on observation and prediction so far (for example, Tampo et al., 2016).
- Disposal of sludge resulting from water purification processes: the sludge immediately after the nuclear accident contained high levels of ^{134}Cs and ^{137}Cs. In Japan, the sludge containing more than 8000 Bq Kg^{-1} (the sum of ^{134}Cs and ^{137}Cs) cannot be disposed of in normal landfills; it needs to be stored as radioactive waste.
- The WHO guidance levels for ^{134}Cs and ^{137}Cs were directly applied to establish the target levels in drinking-water for the non-emergency (existing exposure) situation in Japan. However, the meaning and concept of the guidance levels are easily misunderstood by the public, and even by regulators and experts in the drinking-water division. They generally regard the guidance values as maximum allowable limits. There is therefore a need to improve communication on interpretation of the guidance levels.

References

Kosaka K, Asami M, Kobashigawa N, Ohkubo K, Terada H, Kishida N et al. (2012). Removal of radioactive iodine and cesium in water purification processes after an explosion at a nuclear power plant due to the Great East Japan Earthquake. Water Research. 46(14):4397–4404.

MHLW (2011a). The survey results of radioactive materials in tap water.
The 10th subcommittee for environmental health and water supply, Health Sciences Council held on April 19, 2011 (http://www.mhlw.go.jp/english/topics/2011eq/dl/Document2.pdf, accessed 2 February 2018).

MHLW (2011b). Handling of food contaminated by radioactivity (relating to the accident at the Fukushima Nuclear Power Plant) (Press release). Tokyo: Department of Food Safety, Ministry of Health, Labour and Welfare, March 17, 2011 (http://www.mhlw.go.jp/english/topics/foodsafety/dl/food-110317.pdf, and http://www.mhlw.go.jp/english/topics/foodsafety/dl/110318-1.pdf, accessed 2 February 2018).

MHLW (2011c). Response to contamination of tap water following accidents at the Fukushima nuclear power plants 1 and 2, 2011 [in Japanese]. Tokyo: Water Supply Division, Health Service Bureau, Ministry of Health, Labour and Welfare, 19 March 2011 (http://www.mhlw.go.jp/stf/houdou/2r98520000014tr1-img/2r98520000015k18.pdf, accessed 7 March 2018).

MHLW (2011d). Handling of the index levels on radioactive materials in tap water, etc. (Press release). Tokyo: Water Supply Division, Health Service Bureau, Ministry of Health, Labour and Welfare, April 4, 2011 (http://www.mhlw.go.jp/english/topics/2011eq/dl/april_8_01.pdf, accessed 31 January 2018).

MHLW (2012). Measures against radioactive materials in tap water. Tokyo: Water Supply Division, Health Service Bureau, Ministry of Health, Labour and Welfare (http://www.mhlw.go.jp/english/topics/2011eq/dl/Document_121011.pdf, accessed 31 January 2018).

Tampo R, Ohno K, Konuma S, Aruga T, Igarashi D, Saito T et al. (2016). A study on adsorptive removal of dissolved cesium using local clay and bentonite clay [in Japanese]. In: Proceedings. The 50th Annual Conference of Japan Society on Water Environment, Tokushima, Japan, 16–18 March. Tokyo: Japan Society on Water Environment; 2016:466.

WHO (2012). Preliminary dose estimation from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami. Geneva: World Health Organization (http://www.who.int/ionizing_radiation/pub_meet/fukushima_dose_assessment/en/, accessed 20 October 2017).

WHO (2013). Health risk assessment from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami based on a preliminary dose estimation. Geneva: World Health Organization (http://www.who.int/ionizing_radiation/pub_meet/fukushima_risk_assessment_2013/en/, accessed 20 October 2017).

REFERENCES

REFERENCES

Annanmaki M & Turtianen T (2000). Treatment technologies for removing natural radionuclides from drinking-water. Final report of the TENAWA project, STUK-A169. Helsinki: Radiation and Nuclear Safety Authority (http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/32/018/32018426.pdf, accessed 28 September 2017).

BfS (2009). Strahlenexposition durch natürliche radionuklide im Trinkwasser in der Bundesrepublik Deutschland. [Radiation exposure by natural radionuclides in drinking-water in the Federal Republic of Germany.] Eds. Beyermann M, Bünger T, Gehrcke K. und Obrikat D. Bundesamt für Strahlenschutz (Hrsg.), BfS SW 06/09, Salzgitter: 129 S (in German) (http://nbn-resolving.de/urn:nbn:de:0221-20100319945, accessed 19 October 2017).

BMG (2016). Trinkwasserverordnung in der Fassung der Bekanntmachung vom 10. März 2016. BGBl, Teil I Nr. 12: S. 459–491 Federal Ministry of Health (BMG) German Drinking-Water Ordinance (in German) https://www.bundesgesundheitsministerium.de/topics/drinking-water-ordinance/?L=0, accessed 20 March 2018).

BMU (1986). Gesetz zum vorsorgenden Schutz der Bevölkerung gegen Strahlenbelastung (Strahlenschutzvorsorgegesetz – StrVG) vom 19. Dezember 1986. BGBL Teil I: S. 2610 (geändert in BGBL Teil I: S. 1474 vom 31. August 2015) Radiation Protection Precautionay Act (in German). Published in the Federal Law Gazette (BGBI Bundesgesetzblat).

BMU (1987). Auswirkungen des Reaktorunfalls in Tschernobyl auf die Bundesrepublik Deutschland. Gemeinsamer Bericht der Leitstellen für das Jahr 1986. Bundesminister für Umwelt, Naturschutz und Reaktorsicherheit (Hrsg.), Bonn (in German).

BMU (2001). Verordnung über die Umsetzung von Euratom-Richtlinien zum Strahlenschutz (Strahlenschutzverordnung – StrlSchV) vom 20. Juli 2001. BGBl., Teil I Nr. 38: S. 1714–1846 Radiation Protection Ordinance (in German) Published in the Federal Law Gazette (BGBI Bundesgesetzblat).

BMU (2006). Allgemeine Verwaltungsvorschrift zum Integrierten Mess- und Informationssystem zur Überwachung der Radioaktivität in der Umwelt (IMIS) nach dem Strahlenschutzvorsorgegesetz (AVV-IMIS) vom 13. Dezember 2006. bundesanzeiger Nr. 244a: S. 4–80 (in German).

Brown J, Hammond D & Wilkins BT (2008a). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking-water and risks to water treatment plant operatives. Chilton: Health Protection Agency (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/340109/HPA-RPD-040_for_website.pdf, accessed 19 October 2017).

Brown J, Hammond D & Wilkins BT (2008b). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking-water and risks to water treatment plant operatives: supporting scientific report. Chilton: Health Protection Agency (http://www.dwi.gov.uk/research/completed-research/reports/DWI70-2-192_supporting.pdf, accessed 19 October 2017).

Brown J, Watson S & Nisbet AF (2015). UK recovery handbooks for radiation incidents 2015. Drinking-water supplies handbook. Version 4. London: Public Health England (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/433689/PHE-CRCE-018_Drinking_Water_Supplies_Handbook_2015.pdf, accessed 17 October 2017).

Canada Nuclear Safety Commission (2016). Independent Environmental Monitoring Program (IEMP) [website]. Ottawa: Canada Nuclear Safety Commission (http://nuclearsafety.gc.ca/eng/resources/maps-of-nuclear-facilities/iemp/index-iemp.cfm, accessed 19 October 2017).

Chen, J, Cooke, MW & Mercier, JF (2017). A review of natural radionuclides in Canadian drinking-water (1975–16). Radiat Prot Dosimetry. 176(1–2):1–11.

CODEX (1981). CODEX standard for natural mineral waters. CXS 108-1981. Rome: Food and Agriculture Organization of the United Nations, Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission (www.fao.org/input/download/standards/223/CXS_108e.pdf, accessed 19 October 2017).

CODEX (2001). CODEX general standard for bottled/packaged drinking-waters (other than natural mineral waters), CXS 227-2001. Rome: Food and Agriculture Organization of the United Nations, Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission (www.fao.org/input/download/standards/369/CXS_227e.pdf, accessed 19 October 2017).

EC (1998). Council Directive 98/83/EC on the quality of water intended for human consumption. Brussels: European Commission (http://eur-lex.europa.eu/, accessed 19 January 2018).

EC (2013). Council Directive 2013/51/EURATOM laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption. Brussels: European Commission (http://eur-lex.europa.eu/, accessed 19 January 2018).

El-Naser HK, Smith B, Kilani S, Abdeldin I, Howarth B, Saleh B (2016). Blending as the best compliance option for the management of radioactivity in drinking-water supplied from the deep sandstone aquifer in Southern Jordan. J Water Health. 14(3):528–48.

Environment Agency et al. (2016). Radioactivity in food and the environment, 2015. Rotherham: Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resource Wales, Northern Ireland Environment Agency and the Scottish Environment Protection Agency (https://www.gov.uk/government/publications/radioactivity-in-food-and-the-environment-rife-reports-2004-to-2016, accessed 19 January 2018).

EPA (2000). Radionuclides Rule under the Safe Drinking-Water Act, 66 Federal Register 76708, December 7, 2000. Washington (DC): United States Environmental Protection Agency (https://www.federalregister.gov/documents/2000/12/07/00-30421/national-primary-drinking-water-regulations-radionuclides-final-rule).

Health Canada (2017). Guidelines for Canadian drinking-water quality—summary table. Ottawa: Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch, Health Canada (https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/water-eau/sum_guide-res_recom/sum_guide-res_recom-eng.pdf, accessed 19 October 2017).

Hess CT, Vietti MA & Mage DT (1987). Radon from drinking-water – evaluation of water-borne transfer into house air. Environ Geochem Health. 9:68–73.IAEA (2011). Criteria for use in preparedness and response for a nuclear or radiological emergency.

IAEA (2011). Criteria for use in preparedness and response for a nuclear or radiological emergency. IAEA Safety Standards Series No. GSG-2. Vienna: International Atomic Energy Agency (http://www-pub.iaea.org/MTCD/publications/PDF/Pub1467_web.pdf, accessed 17 October 2017).

IAEA (2014). Radiation protection and safety of radiation sources: International Basic Safety Standards. IAEA Safety Standards Series No. GSR Part 3. Vienna: International Atomic Energy Agency (http://www-pub.iaea.org/MTCD/publications/PDF/Pub1578_web-57265295.pdf, accessed 17 October 2017).

IAEA (2015). Preparedness and response for a nuclear or radiological emergency. IAEA Safety Standards Series No. GSR Part 7. Vienna: International Atomic Energy Agency (http://www-pub.iaea.org/MTCD/publications/PDF/P_1708_web.pdf, accessed 20 October 2017).

IAEA (2016). Criteria for radionuclide activity concentrations for food and drinking-water. IAEA-TECDOC-1788. Vienna: International Atomic Energy Agency (http://www-pub.iaea.org/MTCD/Publications/PDF/TE-1788_web.pdf, accessed 27 November 2017).

IAEA (2018). A arrangements for the termination of a nuclear or radiological emergency (GSG-11). IAEA-Safety Standards Series No. GSG-11. Vienna: International Atomic Energy Agency (https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1796_web.pdf, accessed 15 May 2018)

ICRP (2009). Application of the Commission's recommendations to the protection of people in emergency exposure situations. Publication 109. Ann ICRP. 39(1)1–110.

ISO (2006). ISO/NP 5667-1: Water quality – Sampling – Part 1: Guidance on the design of sampling programmes and sampling techniques. Geneva: International Organization for Standardization.

ISO (2010). ISO/IEC 17025:2005. General requirements for the competence of testing and calibration laboratories. Geneva: International Organization for Standardization.

Iwaoka K (2016). The current limits for radionuclides in food in Japan. Health Phys. 111(5):471–78.

Jones F & Castle RG (1987). Radioactivity monitoring of the water cycle following the Chernobyl accident. Water Environ J. 1(2):205–217.

Kleinschmidt R & Akber R (2008). Naturally occurring radionuclides in materials derived from urban water treatment plants in southeast Queensland, Australia. J Environ Radioact. 99:607–620.

Kleinschmidt R, Black J & Akber R (2011). Mapping radioactivity in groundwater to identify elevated exposure in remote and rural communities. J Environ Radioact. 102:235–243.

Kosaka K, Asami M, Kobashigawa N, Ohkubo, K, Terada H, Kishida N et al. (2012). Removal of radioactive iodine and cesium in water purification processes after an explosion at a nuclear power plant due to the Great East Japan Earthquake. Water Res. 46:4397–4404.

Kosaka K, Watanabe S, Kobayashi Y, Sasaki M, Asami M, Oikawa T et al. (2014). Removal of radioactive iodine and cesium by powdered activated carbon and coagulation-sedimentation processes [in Japanese]. Journal of Japan Water Works Association. 83(1):7–22.

MHLW (2011). Handling of the index levels on radioactive materials in tap water, etc. (Press release). Tokyo: Water Supply Division, Health Service Bureau, Ministry of Health, Labour and Welfare, April 4, 2011 (http://www.mhlw.go.jp/english/topics/2011eq/dl/april_8_01.pdf, accessed 31 January 2018).

MHLW (2012a). Measures against radioactive materials in tap water. Tokyo: Water Supply Division, Health Service Bureau, Ministry of Health, Labour and Welfare (http://www.mhlw.go.jp/english/topics/2011eq/dl/Document_121011.pdf, accessed 31 January 2018).

MHLW (2012b). Notice on the replacement of provisional index levels for restriction on tap water intake [in Japanese]. Tokyo: Water Supply Division, Health Service Bureau, Ministry of Health, Labour and Welfare (http://www.mhlw.go.jp/stf/houdou/2r98520000018ndf-att/2r98520000024of2.pdf, accessed 31 January 2018).

Nazaroff WW, Doyle SM, Nero AV, Sextro RG (1987). Potable water as a source of airborne Rn-222 in US dwellings: a review and assessment. Health Phys. 52(3):281–289.

Ohno K, Ogata T, Kawamura S, Sato H, Kosaka K, Asami M et al. (2013). Behaviour of low level radioactive caesium ion during conventional water purification processes. Proceedings. The 8th International Water Association Micropol & Ecohazard, Zurich, Switzerland, June 2013:138–139.

SSK (1988). Auswirkungen des Reaktorunfalls in Tschernobyl auf die Bundesrepublik Deutschland Veröffentlichungen der Strahlenschutzkommission – Band 7 [Effects of the reactor accident in Chernobyl on the Federal Republic of Germany. Publications of the Radiation Protection Commission]. Bundesminister für Umwelt, Naturschutz und Reaktorsicherheit (Hrsg.). Stuttgart: Gustav Fischer Verlag (in German).

Tagami K & Uchida S (2011). Can we remove iodine-131 from tap water in Japan by boiling? Experimental testing in response to the Fukushima Daiichi nuclear power plant accident. Technical Note. Chemosphere. 84(9):1282–1284.

UNSCEAR (2000). Sources and effects of ionizing radiation. Volume I: Sources. New York (NY): United Nations Scientific Committee on the Effects of Atomic Radiation (http://www.unscear.org/unscear/en/publications/2000_1.html, accessed 20 October 2017).

UNSCEAR (2008). Sources and effects of ionizing radiation. Volume I: Sources: Report to the General Assembly and Scientific Annexes A and B. New York (NY): United Nations Scientific Committee on the Effects of Atomic Radiation (http://www.unscear.org/unscear/en/publications/2008_1.html, accessed 20 October 2017).

UNSCEAR (2016). Sources, effects and risks of ionizing radiation. Annex D – Biological effects of selected internal emitters—Uranium. New York (NY): United Nations Scientific Committee on the Effects of Atomic Radiation (http://www.unscear.org/docs/publications/2016/UNSCEAR_2016_Annex-D.pdf, accessed 20 October 2017).

USEPA (2005). A regulators' guide to the management of radioactive residuals from drinking-water treatment technologies. Washington (DC): United States Environmental Protection Agency (https://www.epa.gov/sites/production/files/2015-05/documents/816-r-05-004.pdf, accessed 20 October 2017).

WHO (2009). WHO handbook on indoor radon. A public health perspective. Geneva: World Health Organization (http://www.who.int/ionizing_radiation/env/9789241547673/en/, accessed 27 November 2017).

WHO (2012). Preliminary dose estimation from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami. Geneva: World Health Organization (http://www.who.int/ionizing_radiation/pub_meet/fukushima_dose_assessment/en/, accessed 20 October 2017).

WHO (2013). Health risk assessment from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami based on a preliminary dose estimation. Geneva: World Health Organization (http://www.who.int/ionizing_radiation/pub_meet/fukushima_risk_assessment_2013/en/, accessed 20 October 2017).

WHO (2017a). Guidelines for drinking-water qualityfourth edition incorporating the first addendum. Geneva: World Health Organization (http://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/, accessed 27 November 2017).

WHO (2017b). Iodine thyroid blocking: guidelines for use in planning for and responding to radiological and nuclear emergencies. Geneva: World Health Organization; 2017 (http://www.who.int/ionizing_radiation/pub_meet/iodine-thyroid-blocking/en/, accessed 17 January 2018).

Annex 1

CALCULATION OF DOSES AND GUIDANCE LEVELS FOR SPECIFIC NON-EMERGENCY SITUATIONS

A.1

Doses to children from the consumption of drinking-water

If a guidance level is exceeded, it is important that there is further investigation; this may include a site-specific assessment for the population affected and can take into account their drinking-water consumption habits. In the case of there being a prolonged period over which a guidance level is exceeded, an assessment of doses to children and babies drinking bottled milk reconstituted with drinking-water may be appropriate. This is because children are more sensitive to exposure from some radionuclides, although they typically consume smaller quantities of drinking-water than adults.

The calculation of doses for children can be made using age-specific values for consumption of drinking-water and ingestion dose coefficients. The equation is:

$$D = A \times C \times I$$

Where:

D = annual dose (mSv y^{-1})
A = radionuclide activity concentration in drinking-water (Bq L^{-1})
C = consumption rate of drinking-water for relevant age group (L y^{-1}); see Table A.1
I = ingestion dose coefficient for relevant age group (mSv Bq^{-1}); see Table A.2

A.2

Drinking-water consumption rates

Drinking-water consumption rates can vary considerably between countries and age groups, depending on the habits of the population and the climate (Howard & Bartram, 2003). Daily water intake can vary significantly in different parts of the world, seasonally and particularly where consumers are involved in manual labour in hot climates. Therefore, where local drinking-water consumption data exist, it is important this information is used to calculate the doses. In cases where local or national data are not available, information from neighbouring countries within a region is also likely to be more appropriate than worldwide averaged data. It is also important to investigate if tap water is used for making bottled milk for babies.

If country- or region-specific data are not available, the doses to children from the consumption of drinking-water can be assessed using the default values given in Table A.1.

Table A.1. Default consumption rates of drinking-water for children

Age	Litres day^{-1}	Comments	Reference
Infant (< 6 months)	0.75	Bottle-fed babies, feed made with tap water. Based on a body weight of 5 kg	WHO (2017)
Young child	1.0	Based on a body weight of 10 kg, i.e. child aged about 1 year	WHO (2017)
All children	1.0–2.0	Consumption rates variable within this range and depend on habits, body weight and climate	IPCS (1994); Howard & Bartram (2003)

A summary of country-specific average drinking-water consumption data is given in *Quantitative microbial risk assessment: application for water safety management* (WHO, 2016) based on a number of studies. A number of important aspects are identified that can influence the analysis and interpretation of consumption data, which should be taken into account when such surveys are conducted (WHO, 2016; Mons et al., 2007).

A.3

Ingestion dose coefficients for children

Ingestion dose coefficients for all age groups, including children and infants, are provided by the International Commission on Radiological Protection (ICRP, 2012). Values are given in Table A.2 for the common natural and human-made radionuclides listed in Chapter 9 (Table 9.2) of the GDWQ (WHO, 2017). Values for other radionuclides are given in ICRP (2012). It should be noted that the values given for infants are for babies on a milk diet, typically aged less than 6 months. If infants are consuming food, it is more appropriate to use the values for a 1-year-old child.

As can be seen in Table A.2, the difference in the values for children aged 1 year and 10 years is no more than a factor of about two (except for iodine-131) and all children (other than bottle fed babies) could be considered as a single age group, with the range of doses considered using the consumption rate for drinking-water in Table A.1. If drinking-water contains iodine-131, it may be appropriate to carry out a more detailed assessment of doses as a function of age.

Table A.2. Ingestion dose coefficients for different ages

Radionuclide	Dose coefficient (mSv/Bq^{-1})[a,b]			
	Adults	Infants (< than 6 months old)[c]	Children (1-y-old)	Children (10-y-old)
Tritium	1.8×10^{-8}	6.4×10^{-8}	4.8×10^{-8}	2.3×10^{-8}
Carbon-14	5.8×10^{-7}	1.4×10^{-6}	1.6×10^{-6}	8.0×10^{-7}
Strontium-90	2.8×10^{-5}	1.3×10^{-4}	7.3×10^{-4}	6.0×10^{-4}
Iodine-131	2.2×10^{-5}	4.8×10^{-4}	1.8×10^{-4}	5.2×10^{-5}
Caesium-134	1.9×10^{-5}	2.6×10^{-5}	1.6×10^{-5}	1.4×10^{-5}
Caesium-137	1.3×10^{-5}	1.1×10^{-5}	1.2×10^{-5}	1.0×10^{-5}
Lead-210	6.9×10^{-4}	2.4×10^{-3}	3.6×10^{-3}	1.9×10^{-3}
Polonium-210	1.2×10^{-3}	5.6×10^{-2}	8.8×10^{-3}	2.6×10^{-3}
Radium-226	2.8×10^{-4}	5.7×10^{-3}	9.6×10^{-4}	8.0×10^{-4}
Radium-228	6.9×10^{-4}	3.0×10^{-2}	5.7×10^{-3}	3.9×10^{-3}
Uranium-234	4.9×10^{-5}	1.7×10^{-4}	1.3×10^{-4}	7.4×10^{-5}
Uranium-238	4.5×10^{-5}	1.4×10^{-4}	1.2×10^{-4}	6.8×10^{-5}
Thorium-228	7.2×10^{-5}	3.7×10^{-3}	3.7×10^{-4}	1.4×10^{-4}
Thorium-230	2.1×10^{-4}	4.1×10^{-3}	4.1×10^{-4}	2.4×10^{-4}
Thorium-232	2.3×10^{-4}	1.6×10^{-3}	4.5×10^{-4}	2.9×10^{-4}
Plutonium-239/240	2.5×10^{-4}	5.2×10^{-3}	4.2×10^{-4}	2.7×10^{-4}
Americium-241	2.0×10^{-4}	4.7×10^{-3}	3.7×10^{-4}	2.2×10^{-4}

[a] Taken from WHO (2017)

[b] Taken from ICRP (2012)

[c] Values to be used for bottle-fed infants where tap water is used for making bottled milk

A.4

Guidance levels for specific situations

Normally, it will be appropriate to use the guidance levels in the GDWQ. The guidance levels are likely to be conservative because they assume that drinking-water is consumed at this activity concentration for the whole year at a rate of 2 litres per day. If required, guidance levels can be calculated by a country for specific situations, for example drinking-water consumption rates that are country- or site-specific or for potentially more vulnerable population groups, such as children. For these situations, appropriate annual consumption rates of drinking-water and dose coefficients for ingestion are required.

The guidance levels in the GDWQ are calculated in the following way, as described in Section 9.4 of the GDWQ:

$$GL_i = \frac{IDC}{h^{ing} \times q}$$

Where:

GL = guidance level in drinking-water for radionuclide i (Bq L^{-1})
IDC = individual dose criterion (0.1 mSv y^{-1})
q = annual consumption of drinking-water, assumed to be 730 L y^{-1} (2 L d^{-1})
h^{ing} = adult dose coefficient for ingestion (mSv Bq^{-1}).

The equation above can be used, substituting local or regional consumption rates or age-specific consumption rates (parameter q). Default drinking-water consumption rates for children are given in Table A1 and ingestion dose coefficients for different ages for the common natural and human-made radionuclides listed in Chapter 9 (Table 9.2) of the GDWQ are given in Table A2.

References

Howard G & Bartram J (2003). Domestic water quantity, service, level and health. Geneva: World Health Organization (http://www.who.int/water_sanitation_health/publications/wsh0302/en/, accessed 19 October 2017).

ICRP (2012). Compendium of dose coefficients based on ICRP Publication 60. Publication 119. Ann ICRP. 41(Suppl 1).

IPCS (1994). Environmental Health Criteria 170. Assessing human health risk of chemicals: derivation of guideline values for health-based exposure limits. Geneva: International Programme on Chemical Safety (http://www.inchem.org/documents/ehc/ehc/ehc170.htm, accessed 20 October 2017).

Mons MN, van der Wielen JM, Blokker EJ, Sinclair MI, Hulshof KF, Dangendorf F et al. (2007). Estimation of the consumption of cold tap water for microbiological risk assessment: an overview of studies and statistical analysis of data. J Water Health. 5(Suppl 1):151–70.

WHO (2016). Quantitative microbial risk assessment: application for water safety management. Geneva: World Health Organization (http://www.who.int/water_sanitation_health/publications/qmra/en/, accessed 20 October 2017).

WHO (2017). Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Geneva: World Health Organization (http://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/, accessed 27 November 2017).

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