Chapter 7 Radiological quality of drinking water

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7.1 Introduction

This chapter describes the sources of radiation in the environment and in drinking water, the health effects of radiation, how people are exposed to radiation and how radiation exposure is measured. It also explains how the guideline values provided in Chapter 10 are derived.

7.2 Sources of radiation in the environment and in drinking water

Radioactive materials occur naturally in the environment (e.g. uranium, thorium and potassium). Some radioactive compounds arise from human activities (e.g. from medical or industrial uses of radioactivity) and some natural sources of radiation are concentrated by mining and other industrial activities.

By far the largest proportion of human exposure to radiation comes from natural sources – from external sources of radiation, including cosmic radiation, or from ingestion or inhalation of radioactive materials. A very low proportion of the total human exposure comes from drinking water. Radiological contamination of drinking water can result from:

- naturally occurring concentrations of radioactive species (e.g. radionuclides of the thorium and uranium series in drinking water sources)
- technological processes involving naturally radioactive materials (e.g. the mining and processing of mineral sands or phosphate fertiliser production)
- manufactured radionuclides, which might enter drinking water supplies from the medical and industrial use of radioactive materials.

7.3 Health effects of radiation

There is evidence from both human and animal studies that radiation exposure at low to moderate doses may increase the long-term incidence of cancer. There is also evidence from animal studies that the rate of genetic disorders may be increased by radiation exposure.

Acute health effects of radiation, ranging from skin burns to nausea, vomiting, diarrhoea, reduced blood cell counts and death, occur at much higher doses and therefore are not a concern for water supplies except in extreme accident situations.

7.4 Exposure to radiation

Several different forms of radiation can be emitted by radioactive species (alpha particles, beta particles and positrons, gamma rays and x-rays). Each form has different biological effects. Alpha particles have very low penetration of tissue but cause considerable cell damage over a short range. Radionuclides that emit alpha particles are therefore only a hazard if they are taken into the body (internal irradiation). Beta particles are more penetrating than alpha particles but on external exposure do not penetrate to internal organs. Gamma radiation and x-rays, on the other hand, are highly penetrating and radioactive sources of these types of radiation are an external radiation hazard.

Humans are irradiated internally if they ingest radioactive substances in food and water or inhale radioactive components in air. Radionuclides that enter the body in this way can remain in a particular organ or tissue for a long time, resulting in exposure over many months or, in some cases, years. Exposure to radiation from contaminated water comes from internal radiation by ingested radionuclides.

7.5 Units of radioactivity and radiation dose measurement

7.5.1 UNITS OF RADIOACTIVITY AND RADIATION DOSE

The International System of Units (SI) unit of radioactivity is the becquerel, where 1 Bq = 1 disintegration per second.

The radiation dose resulting from ingestion of a radionuclide depends on a number of chemical and biological factors. These include the fraction of the intake that is absorbed from the gut, the organs or tissues to which the radionuclide may be transported and deposited, and the time that the radionuclide might remain in the organ or tissue before excretion. The nature of the radiation emitted on decay and the sensitivity of the irradiated organs or tissues to radiation must also be considered.

The absorbed dose refers to how much energy is deposited in material by the radiation. The SI unit for absorbed dose is the gray (Gy). The equivalent dose is the product of the absorbed dose and a factor related to a particular type of radiation. The equivalent dose of radiation received by a person can be further quantified as the effective dose, which, in simple terms, is the sum of the equivalent doses received by all tissues or organs, weighted to account for the different sensitivities to radiation of different organs and tissues in the human body. The SI unit for effective dose is the sievert (Sv).

To reflect the persistence of radionuclides in the body, once ingested, the 'committed effective dose' is a measure of the total effective dose received over a lifetime (50 years) following intake of a radionuclide (internal exposure).

The term 'dose' is used as a general term to mean either absorbed dose (Gy) or effective dose (Sv), depending on the situation. For monitoring purposes, however, 'doses' are determined from the concentration of the radionuclide, which in the case of water is described in terms of Bq/L. This value is converted to an effective human dose per year using a dose conversion factor and the average annual consumption of water.

7.5.2 DOSE CONVERSION FACTORS

The dose arising from the intake of 1 Bq (by ingestion) of radioisotope in a particular chemical form can be estimated using a dose conversion factor. Data for age-related dose conversion factors for ingestion of radionuclides has been published by the International Commission on Radiological Protection (ICRP 1996). Table 7.1 shows the conversion factors or dose per unit intake (mSv/Bq), for naturally occurring radionuclides or those arising from human activities, that could be found in water supplies.

Table 7.1 *Dose per unit intake by ingestion for adult members of the public (ICRP 1996)*

Category	Radionuclide	Dose per unit intake (mSv/Bq)
Natural uranium series	Uranium-238	4.5×10^{-5}
	Uranium-234	4.9×10^{-5}
	Thorium-230	2.1×10^{-4}
	Radium-226	2.8×10^{-4}
	Lead-210	6.9×10^{-4}
	Polonium-210	1.2×10^{-3}
Natural thorium series	Thorium-232	2.3×10^{-4}
	Radium-228	6.9×10^{-4}
	Thorium-228	7.2×10^{-5}
Fission products	Caesium-134	1.9×10^{-5}
	Caesium-137	1.3×10^{-5}
	Strontium-90	2.8×10^{-5}
	Iodine-131	2.2×10^{-5}
Other radionuclides	Tritium	1.8×10^{-8}
	Carbon-14	5.8×10^{-7}
	Plutonium-239	2.5×10^{-4}
	Americium-241	2.0×10^{-4}
	Potassium-40	6.2×10^{-6}

7.5.3 AVERAGE HUMAN DOSE OF RADIATION

The dose of radiation received varies significantly between individuals and communities, and depends on locality, lifestyle, diet and type of dwelling. The global average for the individual dose of radiation from natural sources has been estimated to be 2.4 mSv per year (UNSCEAR 2000). Of this annual dose, less than 10 per cent comes from ingestion of food and drinking water containing radium and other radionuclides of the natural uranium and thorium series. Australian data suggest that the average annual dose in this country may be slightly lower at approximately 2 mSv per year (Webb *et al* 1999).

7.6 Approach for derivation of guideline values for radionuclides

The *Australian Drinking Water Guidelines* (ADWG) provide:

- a single guideline value for the annual exposure to radioactivity in drinking water
- a method to assess the radiological quality of water
- a simple screening method to assure compliance with the Guideline
- a method for assessing water if screening levels for gross radioactivity are exceeded.

This approach reduces the need for routine costly and time-consuming analyses to identify individual radionuclides present in the water.

7.6.1 PRACTICES AND INTERVENTIONS

The ADWG are based on the recommendations of the ICRP (ICRP 1991, 2000) and the NHMRC (NHMRC 1995). Both organisations distinguish between 'practices' and 'interventions' as follows:

- A 'practice' is a situation where the dose of radiation received is increased by the activities under consideration; for example, the development of a uranium mine or nuclear power station. Radiation dose limits can be imposed on the operation so that compliance with these limits reduces risks from the 'practice' to levels considered 'acceptable'. If the facility cannot be designed or operated to comply with the radiological protection standards, then the facility can be forced to close.
- An 'intervention' may be required when the public are exposed to a radiation source that is already present and incidental to the situation under consideration. Such situations include exposure to natural sources of radiation, or exposure from abandoned radioactive waste from past operations. Frequently, these situations result in prolonged radiation exposures. Action to reduce the radiation dose to the exposed population may therefore be warranted and is called an 'intervention'.

Reducing the radiation exposure from radionuclides in drinking water requires an intervention. For example, the supply may be treated to reduce the levels of radioactive contaminants, an alternative supply may be substituted, or, in the extreme case, the population may be relocated to an area where better quality water is available.

The levels considered acceptable in practice provide a basis for setting levels that require an intervention.

7.6.2 ESTIMATION OF THE DOSE FROM RADIONUCLIDES IN WATER

To estimate the equivalent dose to members of the public from the ingestion of radionuclides in drinking water, the parameters required are the concentration of the radionuclides in water (measured in Bq/L), the daily consumption rate of water (L/day), and the dose conversion factor for the particular radionuclide.

WHO has estimated that adults consume an average of 2 L of water per day, and this figure is believed to be an appropriate average figure for Australia, giving an annual consumption of 730 L for each adult Australian. Therefore, the amount of each radionuclide ingested per year from the water supply is the concentration of that radionuclide in the water (Bq/L) multiplied by 730.

The annual dose from an individual radionuclide consumed in water is calculated using the following equation:

$$\underset{\text{(mSv/year)}}{\text{Annual dose}} = \underset{\text{(mSv/Bq)}}{\text{dose per unit intake}} \times \underset{\text{(litre/year)}}{\text{annual water consumption}} \times \underset{\text{(Bq/L)}}{\text{radionuclide concentration}}$$

Usually, a water supply contains more than one radionuclide; therefore, the doses arising from each individual radionuclide must be summed to give the total dose.

7.6.3 ESTIMATION OF RISK FROM LOW-LEVEL RADIATION

Lifetime

Because of the very low level of exposure resulting from consumption of drinking water containing radionuclides, and the radionuclides involved, it is not possible to distinguish a radiation-induced cancer incidence from the baseline level of cancers in the general population. Therefore, the health risks must be estimated by extrapolation from the effects at higher doses.

The ICRP (1991) estimates the lifetime risk of a fatal cancer resulting from exposure to radiation to be 5×10^{-2} per Sv of radiation dose, that is, five additional fatal cancers for every 100 people exposed per year. On the basis of this estimate, a dose of 1 mSv per year gives an annual risk of 5 x 10^{-5}, that is, about five additional fatal cancers per 100 000 people exposed per year. (Additional fatal cancers are those that occur in addition to those that result from all other causes.)

Any increase in genetic disorders (including birth defects) is expected to be very much less than any increase in the cancer rate and therefore an acceptable dose level for cancer risk will also be protective for genetic risk.

Acceptable dose from drinking water

Both the ICRP (1991) and the NHMRC (1995) recommend that the need for, and the extent of, intervention to reduce radiation exposure should be determined on the basis of a generalised cost-benefit analysis, where the resulting public health benefit should be balanced against the overall costs of achieving a reduction in radiation exposure. The outcome of this type of analysis will almost always be specific to a particular situation because the costs of reducing exposure vary widely depending on the situation. It is thus not possible to set a completely generic level at which intervention must be undertaken to reduce the radiation dose from radionuclides in water supplies.

Guidance can, however, be gained from the recommendations of Lokan (1998) and the ICRP (2000) on the protection of the public in situations of prolonged exposure. The ICRP noted that, on radiological grounds alone, intervention may not be necessary for doses below 10 mSv per year. However, this applies to the total dose from all sources of exposure. The ICRP also recommended that, for commodities that are essential for normal living and are amenable to intervention, an individual dose of approximately 1 mSv per year is an acceptable intervention exemption level (ICRP 2000). This is consistent with the recommendation of the NHMRC (1995) of a public exposure limit for practices of 1 mSv per year from all sources.

Furthermore, Lokan (1998) concluded that a value of 1 mSv per year might be appropriate as a default action level above which some corrective action will be necessary.

7.6.4 GUIDELINE VALUE FOR DRINKING WATER

Based on the above, it is recommended that a guideline dose of 1 mSv per year should be applied for radioactivity in drinking water. When the existing or potential dose from the radionuclide content exceeds this guideline dose, a decision on the need for and the degree of remedial action (intervention) should be based on advice from the relevant state health authorities, and should include a cost-benefit analysis.

There may be some circumstances where there is no practical alternative but to accept a dose that exceeds the guideline dose of 1 mSv, together with a potential slight increase in the risk to health as a consequence. However, if doses from the use of a particular water supply will exceed 10 mSv per year, immediate action must be taken to reduce the existing or potential exposures.

7.6.5 APPLICATION OF GUIDELINE VALUES

This Guideline deals only with situations where the radionuclide concentrations arise either from natural sources, or, more rarely, as the result of past practices (such as abandoned mining operations). It specifically does not apply to situations where the radionuclides arise from current practices under regulatory control, such as an operating uranium mine.

Therefore, the guideline should not be used to support an increase in the radionuclide concentrations of drinking water as a result of an operation, on the grounds that the overall dose levels remain below 1 mSv per year.

7.7 References

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