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In reply please refer to :

Prière de rappeler la référence :

PCS-W8/374/4(A)

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January 18, 1993

Dear Dr Goldberg,

As requested, attached is the draft section on radionuclides in drinking water. The same text will appear in both Volume 1 - Recommendations and Volume 2 - Health Criteria and Other Supporting Information.

The WHO Technical Secretary of the Working Group that developed this information was Dr Peter Waight who recently retired from WHO. Dr Waight is now working in Canada:

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I am very sure that Dr Waight can help with all your questions concerning tritium in drinking water.

Yours sincerely,

Dr H. Galal-Gorchev
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Safety

enc. as stated.

3. RADIOLOGICAL ASPECTS

3.1 Introduction

The guideline levels of radioactivity in drinking-water recommended by WHO in 1984 (1) were based on the data available on the risks of exposure to radiation sources estimated at that time. Since then, additional information has become available on the health consequences of exposure to radiation, risk estimates have been reviewed, and the recommendations of the International Commission on Radiological Protection (ICRP) have been revised. This new information (2) has been taken into account in the preparation of the recommendations in this chapter.

The purpose of these recommendations for radioactive substances in drinking-water is to guide the competent authority in determining whether the water is of an appropriate quality for human consumption.

3.1.1 Environmental radiation exposure

Environmental radiation exposure originates from a number of naturally occurring and man-made sources. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (3) has estimated that exposure to natural sources contributes more than 98% of the radiation dose to the population (excluding medical exposure). There is only a very small contribution from nuclear power production and nuclear weapons testing. The global average human exposure from natural sources is 2.4 mSv/year. There are large local variations in this exposure depending on a number of factors, such as height above sea level, the amount and type of radionuclides in the soil, and the amount taken into the body in air, food, and water. The contribution of drinking-water to the total exposure is very small and is due largely to naturally occurring radionuclides in the uranium and thorium decay series (3).

Levels of natural radionuclides may be enhanced in drinking-water from a number of human activities. Radionuclides from the nuclear fuel cycle and from medical and other uses of radioactive materials may enter drinking-water supplies; the contributions from these sources are normally limited through regulatory control of the source or practice, and it is through this regulatory mechanism that remedial action should be taken in the event that such sources cause concern by contaminating drinking-water.

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3.1.2 Potential health consequences of radiation exposure

Exposure to ionizing radiation, whether natural or man-made, can cause two kinds of health effects. Effects for which the severity of the damage caused is proportional to the dose and for which a threshold exists below which the effect does not occur are called "deterministic" effects. Under normal conditions, the dose received from natural radioactivity and routine exposures from regulated practices is well below these thresholds, and therefore deterministic effects are not relevant to these recommendations.

Effects for which the probability of the occurrence is proportional to dose are known as "stochastic" effects, and it is assumed that there is no threshold below which they do not occur. The main stochastic effect of concern is cancer.

Because different types of radiation have different biological effectiveness and different organs and tissues in the body have different sensitivities to radiation, the ICRP (2) has introduced radiation and tissue weighting factors to provide a measure of equal effect. The sum of the doubly weighted dose received by all the tissues and organs of the body gives a measure of the total harm and is referred to as the effective dose. Moreover, radionuclides taken into the body may persist, and, in some cases, the resulting exposure may extend over many months or years. The committed effective dose is a measure of the total effective dose incurred over a lifetime following the intake of a radionuclide. It is this measure of exposure that is relevant to the present discussion; in what follows, the term "dose" refers to the committed effective dose, which is expressed in units of "sievert" (Sv). The risk of adverse health consequences from radiation exposure is a function of the total dose received from all sources. A revised estimate of the risk (i.e., the mathematical expectation) of a lifetime fatal cancer for the general population has been estimated by the ICRP to be 5×10^{-2} per sievert (2). (This does not include a small additional health risk from non-fatal cancers or hereditary effects.)

3.1.3 Recommendations

- These recommendations apply to routine operational conditions of existing or new water supplies. They do not apply to a water supply contaminated during an emergency involving the release of radionuclides into the environment. Guidelines covering emergencies are published elsewhere (4).
- They do not differentiate between natural and man-made radionuclides.

- The recommended reference level of committed effective dose is 0.1 mSv from 1 year's consumption of drinking-water. This reference level of dose represents less than 5% of the average effective dose attributable annually to natural background radiation.
- Below this reference level of dose, the drinking-water is acceptable for human consumption, and any action to reduce the radioactivity is not necessary.

3.2 Application of the reference level of dose

For practical purposes, the reference level of dose needs to be expressed as an activity concentration of radionuclides in drinking-water.

The dose to a human from radioactivity in drinking-water is dependent not only on intake but also on metabolic and dosimetric considerations. The reference level assumes an intake of total radioactive material from the consumption of 2 litres of water per day for 1 year and is calculated on the basis of the metabolism of an adult. The influence of age on metabolism and variations in consumption of drinking-water do not require modification of the reference level of dose, as it provides an appropriate margin of safety and is based on a lifetime exposure. Metabolic and dosimetric considerations have been included in the development of dose conversion factors, expressed as sieverts per becquerel, which relate a dose expressed in sieverts to the quantity of radioactive material ingested (in becquerels).

Examples of radionuclide concentrations (reference concentrations) corresponding to the reference level of dose, 0.1 mSv/year, are given in Table 1. These concentrations have been calculated using the dose conversion factors of the National Radiological Protection Board (5) from the formula:

$$\begin{aligned} &\text{reference concentration (Bq/litre)} \\ &= \frac{1 \times 10^{-4} \text{ (Sv/year)}}{730 \text{ (litre/year)} \times \text{dose conversion factor (Sv/Bq)}} \\ &= \frac{1.4 \times 10^{-7} \text{ (Sv/litre)}}{\text{dose conversion factor (Sv/Bq)}} \end{aligned}$$

The previous guidelines recommended the use of an average gross alpha and beta activity concentration for routine screening. These were set at 0.1 Bq/litre and 1 Bq/litre, respectively. The doses associated with these levels of gross alpha and gross beta activity are shown in Table 2 for selected radionuclides. For radionuclides such as ^{226}Ra and ^{90}Sr , a dose much less than 0.1 mSv is incurred

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per year on consumption. It can also be seen from this table that if some of the radionuclides, such as ^{232}Th , ^{228}Ra , or ^{210}Pb , are singly responsible for activity concentrations of 0.1 Bq/litre for gross alpha or 1 Bq/litre for gross beta, then the reference level of dose of 0.1 mSv would be exceeded for 1 year's intake. However, these radionuclides will normally represent only a small fraction of the gross activity. In addition, an elevated activity concentration of these radionuclides would normally be associated with high activities from other radionuclides. This would elevate the gross alpha or beta activity concentration above the respective investigation level and provoke specific radionuclide analysis. Therefore, the values of 0.1 Bq/litre for gross alpha activity and 1 Bq/litre for gross beta activity continue to be recommended as screening levels for drinking-water, below which no further action is required.

Radionuclides emitting low-energy beta particles such as ^3H and ^{14}C and some gaseous or volatile radionuclides such as ^{222}Rn and ^{131}I will not be detected if the standard methods of measurement are used. The values for average gross alpha and beta do not include such radionuclides, so that if their presence is suspected, special sampling techniques and measurements should be undertaken to determine their activity concentration and the resulting dose.

Where the gross beta activity concentration approaches or exceeds the level of 1 Bq/litre, it should not necessarily be assumed that the reference level of dose has been exceeded. This situation may well result from the presence of the naturally occurring radionuclide ^{40}K , which makes up about 0.01% of natural potassium. The absorption of the essential element potassium is under homeostatic control and takes place mainly from ingested food. Thus, the contribution to dose from the ingestion of ^{40}K in drinking-water with its relatively low dose conversion factor (5×10^{-9} Sv/Bq) will be much less than that of many other beta-emitting radionuclides. This situation will be clarified by the identification of the specific radionuclides in the sample.

3.2.1 Analytical methods

The International Organization for Standardization (ISO) has published standard methods for determining gross alpha (6) and gross beta (7) activity concentrations in water. Although the detection limits depend on the radionuclides present, the dissolved solids in the sample, and the counting conditions, the recommended levels for gross alpha and gross beta activity concentrations should be above the limits of detection. The ISO detection limit for gross alpha based on ^{239}Pu is 0.04 Bq/litre and between 0.04 and 0.1 Bq/litre for gross beta based on ^{137}Cs .

For analyses of drinking-water for specific radionuclides, there are general compendium sources in addition to specific methods in the technical literature, such as HASL-300 (8), the Eastern Environmental Radiation Facility Radiochemistry Procedures Manual (9), Association of Official Analytical Chemists, Official Methods of Analysis (10), Examination of Water for Pollution Control (11), and Standard Methods for the Examination of Water and Wastewater (12).

3.2.2 Strategy for assessing drinking-water

If the gross alpha activity concentration of 0.1 Bq/litre or the gross beta activity concentration of 1 Bq/litre is exceeded, then the specific radionuclides should be identified and their individual activity concentrations measured. From this data, a dose estimate for each radionuclide should be made and the sum of these doses determined. Where the following additive formula is satisfied, no further action is required.

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

where C_i is the measured activity concentration of radionuclide i and RC_i is the reference activity concentration of radionuclide i that, at an intake of 2 litres per day for 1 year, will result in a committed effective dose of 0.1 mSv (see Table 1).

If alpha-emitting radionuclides with high dose conversion factors are suspected, this additive formula may also be invoked when the gross alpha and beta screening values of 0.1 Bq/litre and 1 Bq/litre are approached. Where the sum exceeds unity for a single sample, the reference level of dose of 0.1 mSv would be exceeded only if the exposure to the same measured concentrations were to continue for a full year. Hence, such a sample does not in itself imply that the water is unsuitable for consumption and should be regarded only as a level at which further investigation, including additional sampling, is needed.

The options available to the competent authority to reduce the dose should then be examined. Where remedial measures are contemplated, any strategy considered should first be justified (in the sense that it achieves a positive net benefit) and then optimized in accordance with the recommendations of ICRP (2,13) in order to produce the maximum net benefit. The application of these recommendations is summarized in Figure 1.

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3.2.3 Radon

There are difficulties in applying the reference level of dose to derive activity concentrations of ^{222}Rn in drinking-water (3). These difficulties arise from the ease with which radon is released from water during handling and the importance of the inhalation pathway. Stirring and transferring water from one container to another will liberate dissolved radon. Water that has been left to stand will have reduced radon activity, and boiling will remove radon completely. As a result, it is important that the form of water consumed is taken into account in assessing the dose from ingestion. Moreover, the use of water supplies for other domestic uses will increase the levels of radon in the air, thus increasing the dose from inhalation. This dose depends markedly on the form of domestic usage and housing construction (14). The form of water intake, the domestic use of water, and the construction of houses vary widely throughout the world. It is therefore not possible to derive an activity concentration for radon in drinking-water that is universally applicable.

The global average dose from inhalation of radon from all sources is about 1 mSv/year, which is roughly half of the total natural radiation exposure (3). In comparison, the global dose from ingestion of radon in drinking-water is relatively low. In a local situation, however, the risk from inhalation and ingestion may be about equal. Because of this and because there may be other sources of radon gas entry to a house, ingestion cannot be considered in isolation from inhalation exposures.

All these factors should be assessed on a regional or national level by the appropriate authorities, in order to determine whether a reference level of dose of 0.1 mSv is appropriate for that region, and to determine an activity concentration that may be used to assess the suitability of the water supply. These judgements should be based not only on the ingestion and inhalation exposures resulting from the supply of water, but also on the inhalation doses from other radon sources in the home. In these circumstances, it would appear necessary to adopt an integrated approach and assess doses from all radon sources, especially to determine what optimal action should be undertaken where some sort of intervention is deemed necessary.

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5. Committed Equivalent Organ Doses and Committed Effective Doses from Intakes of Radionuclides. R.245 1991. A Report of the National Radiological Protection Board of the United Kingdom, Chilton, Didcot, Oxon.
6. International Standards Organization (ISO), Water Quality - Measurement of gross alpha activity in non-saline water - thick source method. International Standard 9696, Geneva. 1990 Draft.
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8. Environmental Monitoring Laboratory (EML), 1990. EML Procedures Manual. HASL-300, US Department of Energy, New York, NY.
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11. Suess MJ, 1982. Examination of Water for Pollution Control. Vols. 1-3. Pergamon Press, Oxford.
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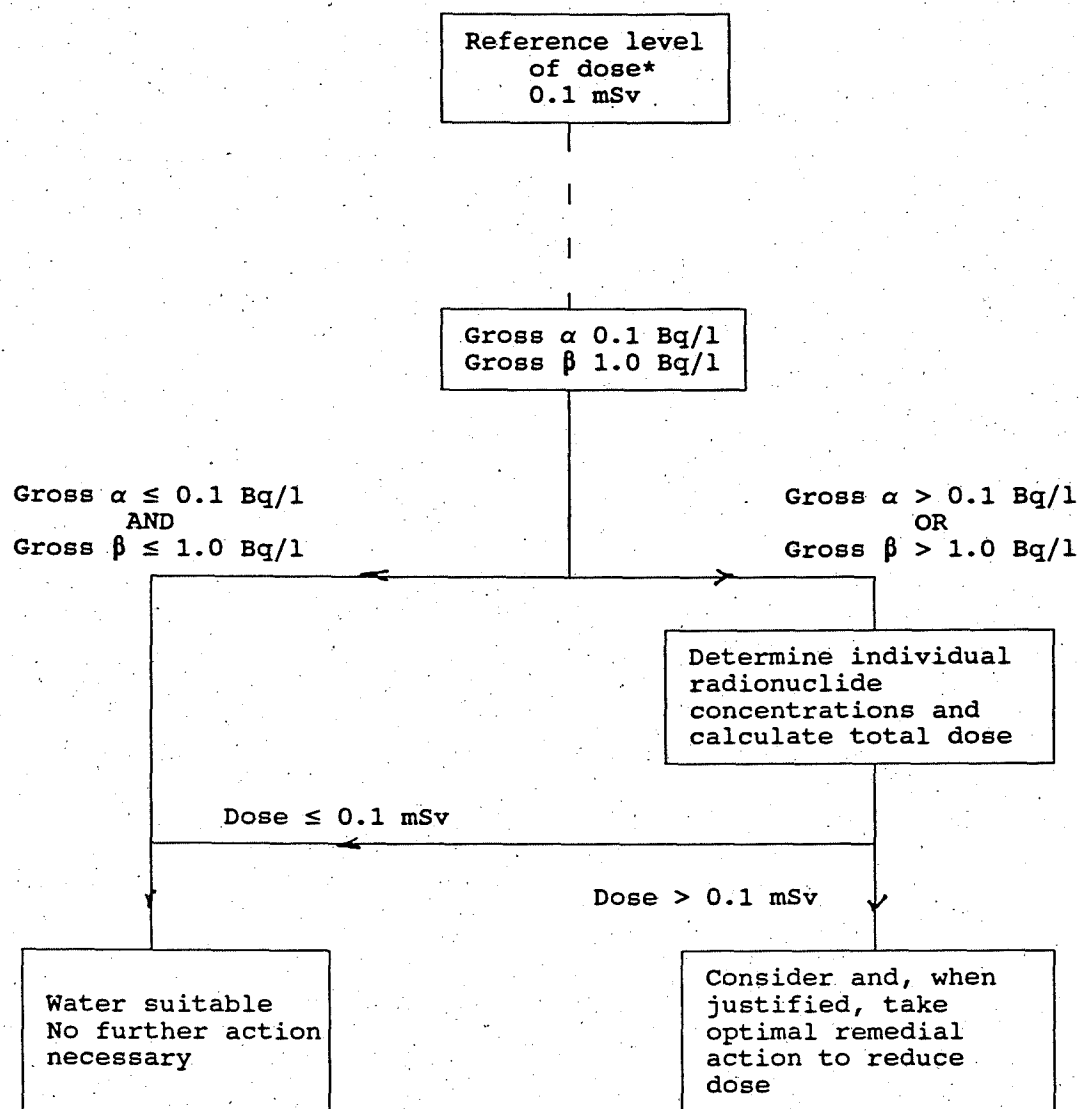
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and Decision-Making in Radiological Protection.

14. NCRP Report No. 103. Control of Radon in Houses. Recommendations of the National Council on Radiation Protection and Measurements. Issued September 1, 1989.

Figure 1: Application of recommendations on radionuclides in drinking-water



* Dose refers to 1 year's intake

Table 1: Activity concentration of various radionuclides in drinking-water corresponding to a dose of 0.1 mSv from 1 year's intake

Radionuclide*	Dose conversion factor (Sv/Bq)+	Calculated rounded value (Bq/litre)
H-3	1.8×10^{-11}	7800 7600
C-14	5.6×10^{-10}	250 240
Co-60	7.2×10^{-9}	20
Sr-89	3.8×10^{-9}	37 36
Sr-90	2.8×10^{-8}	5
I-129	1.1×10^{-7}	1 2
I-131	2.2×10^{-8}	6 7
Cs-134	1.9×10^{-8}	7
Cs-137	1.3×10^{-8}	10
Pb-210	1.3×10^{-6}	0.1
Po-210	6.2×10^{-7}	0.2
Ra-224	8.0×10^{-8}	2 1.7
Ra-226	2.2×10^{-7}	1 0.6
Ra-228	2.7×10^{-7}	1 0.5
Th-232	1.8×10^{-6}	0.1
U-234	3.9×10^{-8}	4 3.5
U-238	3.6×10^{-8}	4 3.8
Pu-239	5.6×10^{-7}	0.3 0.2

* For K-40, see paragraph preceding Section 4.2.1. For Rn-222, see Section 4.2.3.

+ Values taken from the National Radiological Protection Board of the United Kingdom (NRPB-R245) (5).

Table 2: Examples of the doses arising from 1 year's consumption of drinking-water containing any of the given alpha-emitting radionuclides at an activity concentration of 0.1 Bq/litre or of the given beta-emitting radionuclides at an activity concentration of 1 Bq/litre.

Radionuclide	Dose (mSv)
Alpha emitters	(0.1 Bq/litre)
Po-210	0.045
Ra-224	0.006
Ra-226	0.016
Th-232	0.130
U-234	0.003
U-238	0.003
Pu-239	0.04
Beta emitters	(1 Bq/litre)
Co-60	0.005
Sr-89	0.003
Sr-90	0.020
I-129	0.080
I-131	0.016
Cs-134	0.014
Cs-137	0.009
Pb-210	0.95
Ra-228	0.20

Note: Appropriate dose conversion factors taken from the National Radiological Protection Board of the United Kingdom (R245) (5).