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Guidelines for Drinking Water Quality

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RADIOLOGICAL EXAMINATION OF DRINKING WATER

Background information taken from EURO Report 17 and ICRP documentation in support of Draft Document "A".

1. Summary

The section on Radiological Examination in the WHO drinking water standards (1.2) was reviewed by the Working Group (3) to determine what changes, if any, were warranted as a result of the increasing use and generation of radioactive materials for a variety of beneficial purposes and their release to surface waters, and to review the presence of naturally-occurring radionuclides in ground water used as sources of drinking water. The Working Group, having regard to the recommendations of the International Commission on Radiological Protection (ICRP) (4) suggested that the annual dose equivalent attributable to drinking water be limited when practicable to no more than 0.05 mSv (5 mrem). On this basis, "non-action levels" were suggested for gross alpha and gross beta activity, which was not to exceed 0.1 Bq/l and 1 Bq/l respectively. These levels were based upon an adult drinking water intake of 2 l/d. Levels of activity exceeding these values were to be reported to the appropriate competent authorities, who would determine what action was required.

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2. Introduction

Man has always been exposed to radiation from his natural environment.

Radioactive materials are introduced into the environment from a number of sources - naturally-occurring and man-made. The naturally-occurring sources include those substances produced by cosmic rays, which may find their way to water courses with rainfall and runoff, and those present in the rocks and soil, such as uranium-238 and its daughters radium-226 and radon-222. The man-made radionuclides are those resulting from fallout from nuclear tests, nuclear power production, and medical and other beneficial uses of radioactive materials.

The dose of natural radiation that a person receives depends upon a number of factors such as the height above sea level at which he lives,the amount and type of radioactive nucleides in the soil in the neighbourhood and the amount he takes into his body in air, water and food.

Increases in environmental releases resulting from beneficial practices could add to the amount of radioactive substances in surface and ground water and could have a direct effect on radioactivity levels in water sources used for public water supply. These increased discharges thus suggested the need to review the current radioactivity levels included in the WHO drinking water standards. Accordingly, the WHO Regional Office for Europe, in cooperation with the Government of Belgium, convened a Working Group on Examination of Drinking Water for Radioactive Substances at the Institute of Hygiene and Epidemiology in Brussels from 7 to 10 November 1978. The Working Group reviewed the current WHO drinking water standards pertaining to radioactivity in drinking water and recommended appropriate revisions (3). The Group also discussed procedures for sampling and analysis of radon-222 which are incorporated in the manual on Analysis for Water Pollution Control, now in preparation (5).

3. Basic considerations

3.1 Some ICRP principles

In assessing radiation exposure, the recommendations of ICRP were followed by the Group. Earlier ICRP recommendations (6) developed criteria for occupational exposure and, by applying suitable factors, recommended permissible levels of exposure to the individual and the population group based on somatic and genetic considerations. Maximum permissible body burden values were given and, from these, maximum permissible concentrations were calculated for inhalation and ingestion. The ICRP not only recommended that the levels given should not be exceeded, but specifically recommended that radiation exposure should be kept as far below these levels as practicable and possible.

In radiation protection the Commission's recommended dose-equivalent limits have not been regarded as applying to, or including, the "normal" levels of natural radiation, but only as being concerned with those components of natural radiation that result from man-made activities or in special environments.

Clearly however, the ICRP accept and recognize there is no sharp dividing line between levels of natural radiation that can be regarded as "normal" and those that are more elevated owing to human activities or choice of environment.

Subsequently, the ICRP pointed out that in case of uncontrolled exposure, e.g. in the environment, there is a need to balance the risk from radiation against the risk that may arise from particular countermeasures (7). This concept has been developed and now requires that in an endeavour to abide by the system of dose limitation:-

(a) no practice shall be adopted unless its introduction produces a positive net benefit;

(b) all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account (4).

3.2 Dose-response relationships

The relationship between the dose received by an individual and any particular biological effect induced by radiation is a complex matter in need of further exploration.

The deleterious effects of exposure to radiation may be of many kinds. Among the effects on health there may be both stochastic and non-stochastic effects.

Some stochastic effects are somatic and of these carcinogenesis is considered to be the chief risk at low doses and consequently a cause for proctection. The aim of radiation protection should therefore be to prevent detrimental non-stochastic effects and to limit the probability of stochastic effects to a level deemed acceptable.

By setting dose-equivalent limits at sufficiently low values, so that no threshold dose would be reached even for the whole of a life span, one could achieve the prevention of non-stochastic effects. An attempt to limit stochastic effect may be achieved by keeping all exposure to radiation as low as is reasonably achievable.

3.3 Dose-equivalent

To further the aim of protection the ICRP has adopted the concept of 'dose-equivalent' which is a value incorporating the absorbed dose weighted by modifying factors (4). The validity of the relationship between collective dose-equivalent and detriment depends upon the assumed linearity, with no threshold, between risk and dose-equivalent, the reliability of which has not yet been established.

3.4 Dose-equivalent limits

The Commission's recommended dose limits apply to two categories of exposure - occupational and general. The limitation of the dose-equivalent refers to the sum of the annual dose-equivalents contributed by external sources and committed dose-equivalents from radioactivity taken into the body during any year. Dose-equivalent limits have been established for occupational exposure and are regarded as upper limits. Limitation of dose-equivalent for members of the public is a more theoretical concept mainly to ensure that it is unlikely an individual in the public will receive more than the specified dose-equivalent. Usually the effectiveness is checked by assessments through sampling procedures and statistical calculations and by control of sources from which exposure is expected to arise.

3.5 Individual members of the public

For the purposes of radiation protection involving individuals the ICRP (4) concludes that the mortality risk factor for radiation-induced cancers is about 10^{-2} Sv^{-1}, as an average, for both sexes and all ages. The Commission state that a total risk of this order would imply the restriction of the lifetime dose to the individual member of the public to a value that would correspond to 1 mSv per year of life-long whole body exposure. Thus the ICRP's recommended whole body dose-equivalent limit of 5mSv (0.5 rem) in a year - as applied to critical groups[1] has been found to provide this degree of safety. However the application of an annual dose-equivalent limit of 5mSv to individual members of the public is likely to result in average dose-equivalents of less than 0.5 mSv providing that the practices exposing the public are few and cause lttle exposure outside the critical groups. An increase in the average dose to members of the public could result from any large increase in the number of sources of exposure - none individually exceeding the recommended exposure limit.

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[1] The ICRP define 'Critical Groups' as groups of the population with characteristics causing them to be exposed at a higher level than the rest of the exposed population from a given practice. These groups may be used as a measure of the upper limit of the individual doses from a proposed practice.

4. Practical application

In complying with these principles, competent authorities have set authorized levels for radionuclides released into the environment. These levels apply to discharges from nuclear power plants, hospitals, industries, and other users of radioactive materials. To facilitate estimation of radiation exposure levels in respect of populations downwind or downstream, the emissions are evaluated on the basis of specific radionuclides released into the environment.

In general, the releases from particular facilities have been small. However, the levels of radioactive materials may be measurably higher where a water intake is located below the discharge of several facilities releasing small amounts of specific radionuclides or where radioactivity is contributed directly from naturally,occurring sources, man-enhanced natural sources or man-made sources of radionuclides. Where waterworks use waters receiving these radioactive materials, it may be necessary to initiate a programme of monitoring to confirm, if they are not otherwise confirmed, the estimated levels of radionuclides reportedly released into the watercourse. Once confirmation shows that the reported and other sources are below levels of concern, the need for continuous monitoring of normal intake and final water levels at the waterworks may be reduced following review and consultation with the appropriate competent authorities.

Where ground waters constitute the primary source of supply, the radionuclides of interest are generally those present in the geological formations from which the water is drawn.

In the case of new water treatment facilities, measurements of radioactivity levels in the water supply sources would be required, and the levels encountered in the final water as a result of treatment should be calculated in advance. These calculated values should later be confirmed by laboratory analyses. The levels found in water have to be related to the total exposure from other sources to which the population served by the water treatment plant is subjected.

5. Sources of radiation exposure

The basic criterion for estimating the level of exposure to individuals, to which drinking water is generally a relatively minor contributor, is established on the annual dose-equivalent limits recommended by the ICRP (4). Exposure may result from naturally-occurring radionuclides at natural levels or at levels enhanced by man's activities, and from artificial radionuclides introduced into the environment, such as fallout from nuclear tests, releases from nuclear power cycle facilities, and discharges from the use of radionuclides in medicine, industry and research (8).

Exposure from these sources can result from different pathways:

(a) External radiation

Primarily from naturally-occurring gamma radionuclides and from diagnostic and therapeutic radiation.

(b) Internal radiation

Primarily from inhalation and ingestion of naturally-occurring radionuclides, fallout from nuclear weapon tests and man-made radionuclides used for beneficial purposes.

The Working Group, unlike the ICRP, has included exposure from natural sources as well as from man-made sources in its suggested dose-equivalent limit of 0.05 mSv/y for drinking water, thus providing a double guarantee that this pathway will not contribute more than a small percentage of the ICRP average dose-equivalent of 0.5 mSv/y likely to result from applying an annual dose-equivalent limit recommended for individual members of the public.

Exposure levels from natural and man-made radioactivity are, in fact, regularly evaluated on a global basis, in so far as is possible, by the United Nations Scientific Committee on the Effects of Atomic Radiation, whose most recent report was published in 1977 (8). An examination of the data contained therein shows that drinking water is a relatively minor constituent of total radiation exposure.

6. Radionuclides of interest

The radionuclides of interest were identified on the basis of those present in the natural environment as well as those resulting from man's activities. They are identified basically as the alpha emitters, radionuclides with alpha-emitting daughters, and the beta emitters.

6.1 Naturally-occuring radionuclides

The naturally-occurring, alpha-emitting radionuclides of interest include radium-226, polonium-210, radon-220 and 222, and isotopes of uranium and thorium. The beta-emitting radionuclides include radium-228, lead-210 and carbon-14.

6.2 Man-made radionuclides

The man-made radionuclides of interest include tritium, cobalt-58 and 60, strontium-89 and 90, iodine-129 and 131, cesium-134 and 137, plutonium-239 and americium-241.

6.3 Gross radioactivity

In addition to the specific radionuclides identified above, gross alpha and gross beta activity measurements are of interest for routine monitoring purposes. Radionuclides, such as tritium, carbon-14, and other soft-beta emitters, require special instrumentation for their measurement, because they are not usually detected by gross radioactivity measurements.

6.4 Radionuclides, assumption

The concentration levels selected for gross alpha and gross beta activity allow for the sole presence of radium-226 and strontium-90 as the respective indicator radionuclides, each being representative of the most radiotoxic alpha and beta emitter, respectively. Although not a major concern at present, the long-lived beta emitter iodine-129 could eventually control the gross beta and gamma activity levels, and is further considered below since it is of greater toxicity than strontium-90.

6.5 Radon

Data from several countries show radon concentrations up to 800 Bq/l in ground water sources (deep wells) used as drinking water supplies by some large communities (9-11). Radon is a noble gas that is easily removed from the water by aeration or heating. It is not yet possible to make accurate calculations of the dose actually received by a person drinking water containing radon, although rough calculations have been published (12-15).

Subgroup IV concluded that the radon content of water supplies was a problem that merited considerable attention. Further investigations concerning the actual radon concentration in drinking water and the relationship between the concentration in tap water and the resulting doses due to inhalation of the released radon have to be carried out before a "non-action" level can be set.

Procedures for sampling and analysing for radon-222 were prepared by Subgroup II and are incorporated in the chapter Radiological examination in the book Examination of water for pollution control (1)(Annex I).

6.6 Tritium

Where tritium is suspected in the water sampled and found to have been introduced as a result of man's activity, a special examination for the radionuclide should be carried out. If the level found exceeds 40 Bq/l the appropriate authorities should be notified, since such concentrations are unusual and the source of excess tritium in the water should be identified.

7. Calculation of derived levels of alpha and beta activity in drinking water

The Working Group recognized that the presence of current levels of radionuclides in drinking water would, in general, contribute by only a very small percentage to the total exposure of individuals and population groups. It being assumed that the presence of 0.1 Bq/l of radium-226 in the drinking water represented the alpha radioactivity and that 2 l/d of water was consumed by adults, the corresponding annual effective dose-equivalent was calculated as 0.04 mSv (4 mrem).

On the same basis, and assuming an overall annual effective dose equivalent from water of approximately 0.05 mSv (5 mrem), the gross beta activity as represented by the concentration of strontium-90 was calculated to be 1 Bq/l which, for an intake of 2 l/d of water by adults corresponded to an exposure of 0.01 mSv (1 mrem). Thus, the total exposure due to 0.1 Bq/l of alpha activity (represented by radium-226) and 1 Bq/l of beta activity (represented by strontium-90) would be 0.05 mSv (5 mrem), which was believed to be a justifiable annual effective dose-equivalent from drinking water.

The dose corresponding to an intake of tritium at 40 Bq/l is negligible when compared to the above calculated doses for radium and strontium. This calculated total dose of 0.05 mSv (5 mrem) is high compared to doses calculated from normally observed concentrations of radium and strontium in drinking water.

The levels quoted, 0.1 Bq/l gross alpha and Bq/l gross beta activity, would conform as a general criterion, and because of the innate presence of natural radioactivity, to the basic precept of keeping exposure levels as low as reasonably possible. The Working Group considered that a level of 1 Bq/l of beta activity would not present any problems in control; indeed. where the contribution from natural radioactivity gives only a fraction of the gross beta activity, a total value appreciably below 1 Bq/l may well be reasonably achievable, even in the presence of major nuclear power installations, by treating man-made discharges at the source.

The levels of 0.1 Bq/l as gross alpha activity and 1 Bq/l gross beta activity were identified as "non-action" levels, i.e. at or below these concentrations no action would be required by the water supplier.

7.1 Calculated concentrations in water based on annual intake levels

The oral annual limits of intake (ALI) recommended by ICRP are based on the Commission's recommended dose equivalent limits (4). These recommended values, set out in the table below, were used in calculating the concentrations of specific radionuclides which may be found in drinking water and which would not exceed an annual equivalent dose of 0.05 mSv (5 mrem).

Table. Intake values not to exceed 0.05 mSv/y based on 10% average annual dose-equivalent limit of 0.5 mSv/y

Intake of 2 litres of water per day

Nuclide	ALI[z] (Bq)	(Bq/l)
^{3}H	3.10^{9}	4000
^{58}Co	6.10^{7}	80
^{60}Co	2.10^{7}	30
^{89}Sr	2.10^{7}	30
^{90}Sr	1.10^{6}	1
^{129}I	2.10^{5}	0.3
^{131}I[a]	1.10^{6}	1
^{134}Cs	3.10^{6}	4
^{137}Cs	4.10^{6}	6
^{222}Rn	2.10^{8}	300
^{226}Ra	7.10^{4}	0.1
^{228}Ra	9.10^{4}	0.1
^{241}Am	5.10^{4}	0.1

[a] Based on non-stochastic effect to thyroid

[z] Based on data in reference 17

The values tabulated above show that the proposed levels of 0.1 Bq/l for gross alpha emitters and 1 Bq/l for gross beta emitters will not exceed the annual effective dose-equivalent of 0.05 mSv identified as being a reasonable dose contribution from drinking water. Even though the current levels of iodine-129 are very low but will probably increase with time as the beneficial application of nuclear power increases, the calculations show that concentrations of this radionuclide fall below the level of 1 Bq/l.[1] The actual annual equivalent dose resulting from present levels of radionuclides encountered in drinking water, except for a few atypical water supply sources, which may be higher in radium-226 and 228, will be far below the 0.05 mSv (5 mrem) recommended.

If the competent authorities indicate the desirability of reducing the gross alpha concentrations where these exceed 0.1 Bq/l because of the presence of radium-226 and/or radium-228, a number of alternative measures may be available for reducing intake of these radionuclides.

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[1] However, iodine-129 being a low-energy beta emitter, measurements of gross activity would not be satisfactory; further consideration will have to be given to this aspect should future research work show that this radionuclide has become generally significant in drinking water supplies.

These calculations also show that the levels of tritium and radon-222 which will result in an exposure of 0.05 mSv (5 mrem) are far in excess of the other radionuclides shown. With regard to tritium, it has been suggested that the competent authorities be notified as to action to be taken when the tritium level reached 40 Bq/l, which is far below the 4000 Bq/l indicated in the table. Furthermore, using available but not generally accepted dose models a radon-222 concentration corresponding to an annual equivalent dose of 0.05 mSv can be calculated. This calculated value is shown to be considerably less than the levels encountered in some deep wells which show concentrations of radon-222 in water as high as 800 Bq/l. However, as indicated in Section 6.5, there is a need to determine how much of the radon present in water is actually ingested with the water consumed as compared to the amount of radon released and inhaled from the water as it is drawn from the tap. It should also be noted that only a small fraction of the 2 l/d intake assumed is likely to be consumed in the condition as drawn from the tap.

8. Potential problems

The Working Group recognized the need to examine the levels of radon released during treatment of ground waters with a high radon content since these might present an exposure potential through inhalation.

Where treatment is provided for the removal of specific radionuclides, consideration has to be given to protecting treatment plant personnel and determining whether they are occupationally exposed to radioactivity accumulated in treatment units or in the various sludges or other wastes generated during treatment. Safe disposal of these materials must be ensured to minimize the levels of exposure of populations.

The change in the valence state of plutonium following the addition of chlorine or other oxidizing agents in water treatment should be carefully considered (16).

The Working Group considered that information on treatment efficiency in the removal of radionuclides from ground and surface waters should be accumulated to provide more meaningful data than those based on laboratory studies with artificially produced, simulated, or distilled waters.

9. Conclusions

The Working Group concluded that the level for gross alpha activity in drinking water, based on exposure to radium-226, should not be permitted to exceed at 0.1 Bq/l and that the current level for gross beta activity be slightly reduced to 1 Bq/l, the latter level being based on the assumption that all of the beta activity was contributed by strontium-90 in drinking water. These levels are a small fraction of those calculated from the annual effective dose-equivalent recommended by the ICRP for the contribution from man-made practices and are consistent with the basic precept that the level of exposure should be as low as can be reasonably achieved in practice. The 1 Bq/l concentration has as its basis that the sum of the alpha and beta gross activity levels, as calculated from the presence of radium-226 and strontium-90, will not cause a dose that exceeds the fraction of the annual dose-equivalent, considered by the Working Group as reasonable for the drinking water pathway.

10. Working Group recommendations

(1) Data obtained from several countries show that there are large communities supplied with drinking water (from ground water) containing high radon concentrations of up to 7 500 Bq/l at the source. Radon is a noble gas that is easily removed from the water by aeration or heating. However, it is not yet possible to make accurate calculations of the dose actually received by a person drinking water containing radon. Further investigations on actual radon concentrations in drinking water and on the relationship between the concentration in the tap water and the resulting ingestion and inhalation doses should be carried out to aid the evaluation of this hazard.

(2) In some regions, populations have been exposed for many years to exceptionally high levels of natural radioactivity in water. Consideration should therefore be given to undertaking epidemiological enquiries on health effects that are important for the identification and evaluation of potential risks, provided that concurrent factors are properly taken into account.

(3) A thorough knowledge of radioactivity levels in drinking water is a prerequisite for responsible public health decisions. Periodic radiological investigations of water supplies by competent national authorities should therefore be encouraged.

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