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Radiological Examination of Drinking-Water

Report on a WHO Working Group

Brussels
7 – 10 November 1978

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WHO WORKING GROUP ON RADIOLOGICAL EXAMINATION OF DRINKING-WATER

Brussels, 7-10 November 1978

1. SUMMARY

The section on Radiological Examination in the WHO drinking-water standards was reviewed by the Working Group 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), 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 (approximately 3 pCi/l) and 0.8 Bq/l (approximately 20 pCi/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.

2. INTRODUCTION

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 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.

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 (project ICP/RCE 101(8)) at the Institute of Hygiene and Epidemiology in Brussels from 7 to 10 November 1978. The Working Group was to review the current WHO drinking-water standards pertaining to radioactivity in drinking-water and recommend revisions as appropriate. The Group also discussed procedures for sampling and analysis of radon-222 to be incorporated in the manual on Analysis for Water Pollution Control, now in preparation (*1*).

The meeting was opened by Dr J. DeRoy, Director-General, Administration of Hygiene, Ministry of Public Health and Family Welfare, who welcomed the Group on behalf of the Belgian Government. Professor A. Lafontaine greeted the Group for the host Institute. Dr J.C. Nenot was appointed Chairman, Mr J. Bouquiaux Vice-Chairman, and Dr C.P. Straub Rapporteur. Dr M.J. Suess acted as Secretary.

3. DRINKING-WATER DEFINED

For the purposes of the Working Group, drinking or potable water was defined as that water which is derived from either surface or ground water and which is supplied for consumption at the home tap or made available as bottled water for table use. Mineral water used for medicinal or curative purposes was specifically omitted. With regard to control, i.e., determination of radioactivity, water delivered from the tap would be sampled from the distribution system, whereas bottled water for table use would be sampled at the point of bottling.

4. BASIC CONSIDERATIONS

In assessing radiation exposure, the recommendations of ICRP were followed. Earlier recommendations (*2*) 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.

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 (*3*). This concept has been developed and now requires that:

(*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*).

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 in the watercourse reportedly released. Once confirmation shows that the reported and other sources are below levels of concern, the need for continuous monitoring of normal treated 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 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 (*5*).

Exposure from these sources can result from different pathways: external radiation, primarily from naturally-occurring gamma radionuclides and from diagnostic and therapeutic radiation, and 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 ICRP states that its recommendations are "likely to ensure that the average dose equivalent to the population will not exceed 0.5 mSv/y" (*4*). The Working Group 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 value of 0.05 mSv/y indicated above.

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 (*5*). 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-occurring 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 Indicator radionuclides

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 (∿20 000 pCi/l) in ground water sources (deep wells) used as drinking-water supplies by some large communities (*6–8*). 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 acutally received by a person drinking water containing radon, although rough calculations have been published (*9–12*).

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 to be 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 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 (∼1000 pCi/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 (3 pCi/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 0.8 Bq/l (20 pCi/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 (3 pCi/l) of alpha activity (represented by radium-226) and 0.8 Bq/l (20 pCi/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 but is small when compared to the effective dose equivalent of the ICRP average level of 0.5 mSv/y (50 mrem/y) (*4*).

The levels quoted, 0.1 Bq/l (3 pCi/l) gross alpha and 0.8 Bq/l (20 pCi/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 0.8 Bq/l (20 pCi/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 0.8 Bq/l may well be 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 (3 pCi/l) as gross alpha activity and 0.8 Bq/l (20 pCi/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 annual limits of intake (ALI) recommended by ICRP are based on the Commission's recommended dose equivalent limits (*4*). These values have been calculated for a number of radionuclides by Adams et al. (*13*) and were published for guidance in advance of definitive values to be published by the ICRP Committee 2. These recommended values were used in calculating the concentrations of specific radionuclides which can be found in drinking-water and 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 annual limits of intake for 0.05 Sv/y

Nuclide	ALI[a] (Bq)	Intake of 2 litres of water per day (pCi/l)	(Bq/l)
^{3}H[b]	$3 \cdot 10^{9}$	$1 \cdot 10^{5}$	4000
^{58}Co	$5 \cdot 10^{7}$	$2 \cdot 10^{3}$	60
^{60}Co	$7 \cdot 10^{6}$	$3 \cdot 10^{2}$	10
^{89}Sr	$2 \cdot 10^{7}$	$7 \cdot 10^{2}$	30
^{90}Sr	$2 \cdot 10^{6}$	$7 \cdot 10^{1}$	3
^{129}I	$5 \cdot 10^{5}$	$2 \cdot 10^{1}$	0.6
^{131}I[c]	$1 \cdot 10^{6}$	$4 \cdot 10^{1}$	2
^{134}Cs	$3 \cdot 10^{6}$	$1 \cdot 10^{2}$	4
^{137}Cs	$4 \cdot 10^{6}$	$2 \cdot 10^{2}$	6
^{222}Rn[b]	$2 \cdot 10^{8}$	$7 \cdot 10^{3}$	300
^{226}Ra	$1 \cdot 10^{5}$	$4 \cdot 10^{0}$	0.2
^{228}Ra	$7 \cdot 10^{4}$	$3 \cdot 10^{0}$	0.1
^{241}Am[d]	$8 \cdot 10^{4}$	$3 \cdot 10^{0}$	0.1

[a] (*13*) Issued for guidance in advance of definitive ICRP values.

[b] Additional values calculated by N. Adams and made available to the Working Group by Mr Hesketh.

[c] Based on non-stochastic effect to thyroid.

[d] Proposed in forthcoming ICRP publication 30.

The values tabulated above show that the proposed levels of 0.1 Bq/l (3 pCi/l) for gross alpha emitters and 0.8 Bq/l (20 pCi/l) for gross beta emitters will not exceed the annual effective dose equivalent of 0.05 mSv identified as being a reasonable general criterion for the 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 0.8 Bq/l (20 pCi/l).[a] The actual annual equivalent dose resulting from present levels of radionuclides encountered in drinking-water, except for atypical water supply sources which may be higher in radium-226 and 228, will be far below the 0.05 mSv (5 mrem) indicated.

If the competent authorities indicate the desirability of reducing the gross alpha concentrations where these exceed 0.1 Bq/l (∿3 pCi/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.

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 reaches 40 Bq/l (∿1000 pCi/l), which is far below the 4000 Bq/l (∿100 000 pCi/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 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.

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[a] 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.

8. OTHER PROBLEM AREAS

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 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 (*14*) and the matter should be reviewed so as to ascertain whether a change in the ALI of plutonium is warranted.

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 remain at 0.1 Bq/l ($\sim$3 pCi/l), and that the current level for gross beta activity be reduced to 0.8 Bq/l ($\sim$20 pCi/l), the latter level being based on the assumption that all of the beta activity was contributed by strontium-90 in drinking-water. These levels are a small fraction of those calculated from the annual effective dose equivalent recommended by the ICRP for the contribution from man-made practices referred to above and are consistent with the basic precept that the level of exposure should be as low as can be achieved in practice. The 0.8 Bq/l ($\sim$20 pCi/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, 0.05 mSv (5 mrem), recommended by the Working Group and considered reasonable for the drinking-water pathway.

10. 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 20 000 pCi/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.

REFERENCES

1. **Mitchell, N.T.** Radiological examination. *In: Examination of water for pollution control,* Volume 2, Chapter 5 (In preparation. To be published by Pergamon Press, Oxford, on behalf of the WHO Regional Office for Europe).
2. **International Commission on Radiological Protection.** Report of Committee 2 on permissible dose for internal radiation (1959), ICRP publication 2. *Health physics journal,* **3**:1–380, (1960); ICRP publication 2 was modified by ICRP publication 6, Oxford, Pergamon Press, 1964.
3. **International Commission on Radiological Protection.** *Recommendations of the International Commission on Radiological Protection* (as amended 1959 and revised 1962), ICRP Publication No. 6, Oxford, Pergamon Press, 1964.
4. **International Commission on Radiological Protection.** Recommendations of the International Commission on Radiological Protection (adopted 17 January 1977), ICRP publication 26. *Annals of the ICRP,* Sowby, F.D., ed., Oxford, Pergamon Press, 1977.

5. **United Nations Scientific Committee on the Effects of Atomic Radiation.** *Sources and effects of radiation.* 1977 Report to the General Assembly, with annexes. New York, United Nations, 1977.
6. **US Environmental Protection Agency.** *Radon in water sampling program.* Report EPA/EERF-Manual-78-1 (mimeographed). Washington, 1978.
7. **Snihs, J.O.** The content of some natural radioactive elements, especially ^{222}Rn, in some potable waters in Sweden. *Nordic Hydrology,* **4**:256–274 (1973).
8. **Asikainen, M. & Kahlos, J.H.** *Natural radioactivity of ground and surface water in Finland.* Report STL-A24. Helsinki, Institute of Radiation Protection, 1977 (in Finnish).
9. **Kahlos, H. & Suomela, M.** *Studies on the elimination data and the radiation exposure following ingestion of Radon-222 rich water.* Report SFL-A16. Helsinki, Institute of Radiation Physics, December 1970.
10. **Lindell, B.** Ingested radon as a source of human radiation exposure. *Proceedings of the First International Congress of Radiation Protection,* Rome, 5–10 September 1966. New York, Pergamon Press, 1968.
11. **Hursh, J.B. et al.** The fate of radon ingested by man. *Health physics journal,* **11** (6): 465–476 (1965).
12. **von Döbeln, W. & Lindell, B.** Some aspects of radon contamination following ingestion. *Arkiv för fysik,* **27** (32): 531–572 (1964).
13. **Adams, N. et al.** *Annual limits of intake of radionuclides for workers.* Report NRPB-R82, National Radiological Protection Branch, Harwell, United Kingdom, October 1978.
14. **Larsen, R.P. & Oldham, R.D.** Plutonium in drinking-water: effects of chlorination on its maximum permissible concentration. *Science,* **201** (4360): 1008–1009 (1978).

Annex I

PROCEDURES FOR SAMPLING AND ANALYSIS OF RADON-222

Sampling

As radon is a gas, special care has to be taken to prevent losses during the sampling. Generally the following precautions are necessary.

(*a*) Before taking the sample the water should be allowed to flow until a constant temperature is reached.

(*b*) All sampling equipment coming into contact with the sample must be rinsed with the water to be sampled.

(*c*) During the sampling water must flow slowly to prevent aeration. Contact of water with air between the source (water tap) and the sampling bottle must be avoided.

(*d*) The time between sampling and measurement must be kept as short as possible, in view of the decay of radon-222 (half-life about 3.8 days) and the ingrowth of radon out of radium-226 that may be present.

Measurement by the de-emanation method

This method is selective and the most sensitive. Detection limits go down to 1 pCi/l. The special equipment (counting cells and detector) is not very expensive, considering that the same electronics can be used as for gross alpha determination.

The sample should be taken in a bottle that can be used for de-emanation (a gas-washing bottle which can be made airtight). In the laboratory the radon is removed from the sample by passing small bubbles of inert gas (He) through it and letting the gas flow into a transparent chamber (counting cell) which is internally coated with a thin layer of silver activated LnS. The rate of flow can be established using a closed vacuum system or a closed circuit.

The counting cell is placed on a detector consisting of a photomultiplier in a lightproof cover and the alpha-scintillations are counted.

Annex II

REVISION OF THE WHO STANDARDS FOR DRINKING-WATER

5. RADIOLOGICAL EXAMINATION

5.1 Levels of radioactivity in drinking-water

The levels of radioactivity set out below are in accord with the recommendations of the International Commission on Radiological Protection (ICRP), and have been developed to provide guidance to water suppliers and/or competent national authorities on the radioactive content of drinking-water. To determine whether levels in drinking-water meet these specified values, the water supplier or competent authority must have information on the actual levels of radioactivity present in such water. The levels may be determined by direct measurement or may be supplemented or replaced by other data and information available relevant to radioactivity levels in the drinking-water supply, provided that such information is acceptable to the competent authority.

In deriving the specified concentrations, allowance has been made for the fact that drinking-water will not be the sole contributor to the radiation dose received by individuals. The control of total radiation represents the basic method of ensuring public health and safety. Moreover, the presence of radioactivity arising directly from both natural and man-made activities has been taken into account.

The concentration levels have been calculated to correspond at most to the relevant annual effective dose equivalent limitation, which is a small percentage of the limit recommended by the ICRP for life-long whole-body exposure resulting from man's activities (*1*). Where these levels are exceeded, it is recommended that the competent authorities be required to decide what further action, if any, is necessary. The concentration levels conform, in general, to the basic precept of radiological protection that exposure levels should be as low as is reasonably achievable, taking into account economic and social factors, subject to the condition that the appropriate dose equivalent limits are not exceeded (*1*) (para. 10).

Errors caused by non-representative samples and by deviations from the metabolic patterns assumed (*1*), or from the water consumption rate adopted for adults (2 l/d), in general, should be of no importance. However, where the average water consumption rate is known to differ significantly from that cited, the specified concentrations may be weighted accordingly.

The concentrations cited refer to gross alpha activity, gross beta activity, and, where appropriate, tritium activity. Unlike nuclide-specific measurements such as that of tritium, gross activity rarely provides a good indication of the true toxicity, although a pessimistic estimate may be deduced on the basis that only the most toxic radionuclides are present. It is suggested, therefore that an appropriate nuclide analysis be performed occasionally to allow a more exact evaluation of the radiotoxicity. This procedure should also be performed when selecting new sources of water supply.

It should be emphasized that the concentrations given below are intended solely for the purpose of defining the need, or otherwise, for further action by the water supplier.

In the event that dose rates representing a small percentage of the limit recommended by the ICRP are found to result from discharges from nuclear or other installations reaching water supplies, such dose rates may or may not meet the requirement that dose rates should be as low as is reasonably achievable. The same will be true of such dose rates resulting directly from natural radioactivity. In both cases, it will be the responsibility of the competent authority to decide whether or not the dose rates are acceptable in the particular conditions. The competent authorities will be required to give due regard to the ICRP recommendations (*1*) that all exposures require justification of risks against exposure and optimization of the benefits incurred, taking into account the economic and social conditions.

Finally, it must be noted that the monitoring requirements and follow-up actions described below are intended to apply only to routine operational conditions. The competent authorities, on a case-by-case basis and in conjunction with the water suppliers, should prepare individual plans for dealing with emergency situations appropriate to local requirements.

Radioactivity in drinking-water should not only be kept within safe limits; it should also, within those limits, be kept as low as is reasonably achievable. It therefore follows that radioactive wastes should not be admitted indiscriminately to sources that are being used for drinking-water. Where radioactivity originating from man's activities is concerned, this goal may be achieved by discharge control. The radioactivity levels given include both naturally-occurring radioactivity and any radioactivity that may have reached the water sources as a result of man's activities. From a radiological point of view, they represent a "non-action" level below which water can be considered potable without more complex radiological examination.

The following levels are proposed:

gross alpha activity – 0.1 Bq/l (∿3 pCi/l)
gross beta activity – 0.8 Bq/l (∿20 pCi/l)

These levels are applicable to the mean of all radioactivity measurements obtained during a sampling period appropriate to the source water. The frequency of sampling is a matter of judgement, but plainly it should be sufficient to establish confidence in the water quality. When a significant increase or change in radioactive contamination of the water supply is suspected, additional water samples should be collected and investigated without delay.

The non-action levels specified above are based on the assumption that the most toxic radionuclides, namely ^{226}Ra and/or ^{90}Sr, are present in the water.

The methods of analysis of gross alpha and gross beta activity should be selected in the light of local conditions in coordination with the appropriate authorities. Procedures for the sampling and measurement of gross radioactivity levels in water have been published, together with methods for the analysis of some specific radionuclides (*2*).

Where the results of the gross alpha and/or gross beta analysis show concentrations that exceed the values given above, the appropriate competent national authorities should be notified. They should consider what radionuclides are known to be present in the water, and their activity levels, before taking action.

5.1.1 *Alpha activity*

Before starting the analysis for alpha activity, the activity due to ^{222}Rn and ^{220}Rn should be eliminated. Their short-lived daughter-products can be accounted for in a second sample measured after decay of the radon.

If the alpha activity is less than 0.1 Bq/l ($<\sim$3 pCi/l), no further exmination is necessary except for such routine surveillance as may be required by the competent authorities.

If the alpha activity exceeds 0.1 Bq/l ($>\sim$3 pCi/l), further examination of the water is required. Such examination should include ^{226}Ra and such other radionuclides as may be necessary upon recommendations of the appropriate competent authority.

The following radionuclides have been identified as naturally-occurring alpha-emitting radionuclides having high toxicity: ^{226}Ra, ^{224}Ra, ^{210}Po, ^{232}Th, ^{234}U and ^{238}U. In addition, the beta emitters ^{228}Ra and ^{210}Pb, which have alpha-emitting daughters, are sometimes associated with these radionuclides. The need to examine the water for particular radionuclides should be based on knowledge of local hydrogeological and other information. Where necessary, the expertise and equipment to perform the necessary examinations must be sought in regional and national laboratories.

Where examination of the water indicates that the combined radiotoxicity of all the radionuclides present exceeds that of 0.1 Bq/l ($>\sim$3 pCi/l) from ^{226}Ra, the matter should be referred to the appropriate authorities for further examination and for advice.

Radon

Measurements of water drawn from deep wells in certain geological formations show radon levels in excess of 800 Bq/l ($>\sim$20 000 pCi/l) (*3–6*).

Studies show that the health risk resulting from inhaled radon, originating in the home when water is drawn from the tap, is greater than the risk due to ingestion of the water (*3*). Thus these two problems should be considered in context.

5.1.2 *Beta activity*

If the beta activity measured in a sample of water is less than 0.8 Bq/l ($<\sim$20 pCi/l), no further examination is necessary except for such routine surveillance as may be required by the designated authorities.

If the beta activity exceeds 0.8 Bq/l ($>\sim$20 pCi/l), the ^{40}K contribution should be subtracted. If the residual activity still exceeds 0.8 Bq/l ($>\sim$20 pCi/l), it may indicate contamination of the water supply source and further examination of the water is required upon the recommendation of the appropriate competent authority.

The following radionuclides have been identified as beta-emitting radionuclides having high toxicity: ^{90}Sr, ^{89}Sr, ^{134}Cs, ^{137}Cs, ^{131}I, and ^{60}Co. Examination of the water for the particular radionuclides should be based on local knowledge concerning discharges of specific radionuclides from operations in the watershed. Where necessary, the expertise and equipment to perform the necessary examination must be sought in regional and national laboratories.

Tritium

Where it is suspected that ^{3}H may have reached the water as a result of man's activities, a special examination for this radionuclide should be carried out. If the level found exceeds 40 Bq/l ($>\sim$1000 pCi/l), the appropriate competent authorities should be notified and the source of excess tritium in the water identified.

It should be noted that the techniques normally used for the detection and measurement of gross beta activity are not applicable to the measurement of such radionuclides as ^{3}H, ^{14}C, and other soft-beta emitters.

REFERENCES

1. **International Commission on Radiological Protection.** Recommendations of the International Commission on Radiological Protection (adopted 17 January 1977). ICRP Publication 26. *Annals of the ICRP,* Sowby, F.D., ed., Oxford, Pergamon Press, 1977.

2. **Mitchell, N.T.** Radiological examination. *In: Examination of water for pollution control,* Volume 2, Chapter 5 (In preparation. To be published by Pergamon Press, Oxford, on behalf of the WHO Regional Office for Europe).
3. **United Nations Scientific Committee on the Effects of Atomic Radiation.** *Sources and effects of radiation.* 1977 Report to the General Assembly, with annexes. New York, United Nations, 1977.
4. **Snihs, J.O.** The content of some natural radioactive elements, especially ^{222}Rn, in some potable waters in Sweden. *Nordic hydrology,* **4**: 256–274, 1973.
5. **Asikainen, M. & Kahlos, J.H.** *Natural radioactivity of ground and surface water in Finland.* Report STL-A24. Helsinki, Institute of Radiation Protection, 1977 (in Finnish).
6. **Duncan, D.L. et al.** *Radon-222 in potable waters.* Presented at the 10th Mid-year Technical Symposium of the Health Physics Society, 11–13 October 1976, Saratoga Springs, NY. Troy, Rensselaer Polytechnic Institute, 1976.

Annex III

LIST OF SUBGROUP MEMBERS

Subgroup I – Radiation dose levels

Mr Bouquiaux (*Leader*)
Dr Dean (*Rapporteur*)
Dr Gans
Mr Kool
Mrs Salo

The Subgroup was later expanded and included the following members:

Dr Dean (*Leader*)
Dr Gans
Mr Kool
Mrs Salo
Dr Ellett
Mr Fraser
Dr Holmberg
Dr Mastinu
Dr Suess
Dr Straub (*Rapporteur*)

Subgroup II – Methods for sampling and analysis of radon

Mr Cantillon (*Leader*)
Dr Havlik
Dr Mastinu
Mr Mattern (*Rapporteur*)
Mrs Swedjemark

Subgroup III – Specific radionuclides

Dr Nenot (*Leader*)
Dr Elias
Dr Ellett
Mr Fraser
Dr Frantz
Mr Hesketh
Dr Holmberg
Mr Ledich
Dr Straub (*Rapporteur*)
Dr Suess
Dr Taylor

Subgroup IV – Criteria for radon in drinking-water

Mrs Salo (*Leader*)
Dr Havlik
Dr Holmberg (*Rapporteur*)
Dr Mastinu
Mrs Swedjemark

Subgroup V – Introduction to new WHO draft drinking-water standards

Dr Gans
Mr Fraser
Dr Kool

Annex IV

LIST OF PARTICIPANTS

Temporary advisers

Mr J. Bouquiaux, Chief, Department of the Environment, Institute of Hygiene and Epidemiology, Brussels, Belgium (*Vice-Chairman*)

Mr G.E. Cantillon, Chief, Section of Radioactivity, Department of the Environment, Institute of Hygiene and Epidemiology, Brussels, Belgium

Dr R.B. Dean, Consultant, Environmental Science and Technology, Copenhagen, Denmark

Dr P.S. Elias, Project Director, International Project in the Field of Food Irradiation, Institute for Radiation Technology, Karlsruhe, Federal Republic of Germany

Dr William H. Ellett,[a] Chief, Bioeffects Analysis Branch, Criteria and Standards Division, Office of Radiation Programs, US Environmental Protection Agency, Washington, DC, USA

Mr G. Fraser, Health and Safety Directorate, Commission of the European Communities, Luxembourg, Grand Duchy of Luxembourg

Dr Anny Frantz, Head, Department of Radiology, Federal Institute of Water Quality, Vienna, Austria

Dr I. Gans, Head, Department of Radioactivity Investigations, Institute of Water, Soil and Air Hygiene, Berlin (West)

Dr B. Havlik, Head, Water Hygiene Branch, Institute of Hygiene and Epidemiology, Prague, Czechoslovakia

Mr G.E. Hesketh, Radiochemical Inspector, Department of the Environment, London, United Kingdom

Dr L. Holmberg, Chief, Section on Norms and Standards, National Institute of Radiation Protection, Stockholm, Sweden

Mr H.J. Kool, Head, Microbiology and Radiological Laboratory, Chemical Biological Division, National Institute for Water Supply, Leidschendam, Netherlands

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[a] Part-time only

Dr A.R. Lafontaine,[a] Professor and Director, Institute of Hygiene and Epidemiology, Brussels, Belgium

Mr A.F. Ledich,[a] Chief, Radiological Department, Federal Institute of Food Control and Food Research, Vienna, Austria

Dr G. Mastinu, Environmental Geochemistry Laboratory, Radiation Protection Department, Environmental Protection Division, National Commission on Nuclear Energy (CNEN), Rome, Italy

Mr F.C.M. Mattern, Head, Radiochemical Division, Physical Laboratory, National Institute of Public Health, Bilthoven, Netherlands

Dr J.C. Nenot, Deputy Chief, Radiation Protection Department, Atomic Energy Commission, Fontenay-aux-Roses, France (*Chairman*)

Mrs L.A. Salo, Head, Research Department, Institute of Radiation Protection, Helsinki, Finland

Dr C.P. Straub, Professor and Director, Environmental Health Program, School of Public Health, University of Minnesota, Minneapolis, USA (*Rapporteur*)

Mrs G.A. Swedjemark, Head, Environmental Laboratory, National Institute of Radiation Protection, Stockholm, Sweden

Dr N.R.W. Taylor, Senior Medical Officer, Department of Health and Social Security, London, United Kingdom

WHO Regional Office for Europe

Dr M.J. Suess, Regional Officer for Environmental Pollution Control (*Secretary*)

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[a] Part-time only