Radionuclides in drinking water: the approach of the European Union, the World Health Organization and the US Environmental Protection Agency

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In the last years the European Union (EU), the World Health Organisation (WHO) and the US Environmental Protection Agency (EPA) have issued new regulations for limiting population exposure to radionuclides in drinking water. For the first time the EU addressed the issue by adding some requirements to its new regulation on drinking water, whereas WHO and EPA reviewed already existing regulations. The paper describes the regulations, presents a database set up by the ISS and discusses the similarities and differences of the approaches chosen by the different international authorities. In the paper tritium and radon concentrations in drinking water have not been examined: the health significance of tritium is negligible in the European Union, and radon, due to its particularity, requires a separate discussion.

THE EUROPEAN DIRECTIVE ON DRINKING WATER

In December 1998, the Council Directive… on the quality of water intended for human consumption (1) was published in the Official Journal of the European Union. It was a revision of the Council Directive of 1980 (2) on the same issue, and had to be implemented by Member States within two years of its entry into force (i.e., December 2000). It applies to "…all water, either in its original state or after treatment, intended for drinking, cooking, food preparation…whether it is supplied from a distribution network, from a tanker, or in bottles or containers… and all water used in food-production undertaking… unless the competent national authorities are satisfied that the quality of the water cannot affect the wholesomeness of the foodstuff in its finished form".

For the first time, on request of the European Parliament, the 1998 Drinking Water Directive also includes requirements for radioactivity. It was decided not to make these requirements mandatory (putting them in Annex I PART B), but only indicative (as indicator parameters, see Annex I PART C). That is, for tritium concentration an indicator parametric value of 100 Bq/l is reported, and for the total indicative dose (TID) an indicator parametric value of 0.1 mSv/year. TID explicitly excludes tritium, potassium 40[1], radon and radon decay products. It is

[1] This is due to the well-known fact that K-40 does not accumulate in the body, but remains at a constant level independently of intake.

worth noting that other parameters in Annex I PART C are indicators of a potentially broader problem, but do not imply a risk in their own right. Therefore, both tritium concentration and TID should have a similar status, indicating a potential radiological problem when exceeded, and should not be regarded as limit values.

Detailed requirements on monitoring frequencies, methods and locations were to be published within 18 months after the Directive's entry into force. However, these requirements are not yet available.

In 1999, a working party of the Article 31 Group of Experts of the EURATOM Treaty (Article 31 working party on radioactivity in drinking water) was set up and worked in collaboration with a working party of the Article 36 group of experts of the Euratom Treaty in order to draw up a proposal for an environmental monitoring plan that would guarantee the level of protection required by the TID. The former party suggested that a database be prepared with derived activity concentrations for drinking water ingestion (DWC) for all radionuclides listed in Table A of Annex III of the European Basic Safety Standards (3), for different age groups, on the basis of the corresponding ingestion dose coefficients. Under contract from the EU Commission, this Institute performed the work and made the database available in a report (4) for health authorities and environmental radioactivity monitoring laboratories to use.

The DWC were calculated using the following formula:

$$\textit{DWC (Bq/l)} = \frac{1\text{x}10^{-4}\ \text{(Sv/y)}}{\text{Ann. intake value (l/y) x Committed eff. dose per unit intake (Sv/Bq)}}$$

where $1x10^{-4}$ Sv/y = 0.1 mSv/y is the stated TID. The committed effective dose per unit intake via ingestion (Sv/Bq) for different age groups were those of the already cited Table A of Annex III of the Basic Safety Standards (3), and the annual intake values were chosen by the Article 31 working party on radioactivity in drinking water - after an overview of different intake values used by different organisations, including the WHO - in the following way:

≤ 1 y old: 250 l/y
1-10 y old: 350 l/y
> 17 y old: 730 l/y

Therefore, calculations were carried out for the age classes ≤ 1y, (1-2) y, (2-7) y, (7-10) y, and >17 y, but not for the age class 10-17 y, for there was no agreement on the related intake value.

In the report (4), the critical value of concentration (critical concentration, in Bq/l) and the corresponding critical age group are identified for each radionuclide. Some examples of DWC and critical age groups are reported below, specifically in Table 1 for main radionuclides in a nuclear emergency and in Table 2 for main radionuclides of natural origin.

Observing the two tables, it can be noted that, Cs isotopes excluded, the population groups most at risk are infants (≤ 1 year) and small children (1-2 year), notwithstanding the lower annual intakes. Similarly, in the complete database (see ref. 4) except for 5 radionuclides (Zr-93, I-129, Cs-134, Cs-135 and Cs-137), infants (≤ 1 year) and small children (1-2 year) are the population groups most at risk.

In the last column of the two tables the adults/critical age DWC ratio is reported: it ranges from 1 (for the Cs isotopes) to 17.6. In the complete database (see ref. 4) it ranges from 1 to 24.6, mean value 4, standard deviation 2.3. It can be concluded that in case of a prolonged contamination of drinking water – particularly for some radionuclides – the respect of the DWC for adults could expose infants and small children to a dose higher than the TID.

Table 1. DWC for main radionuclides in a nuclear emergency for different age classes, critical age and adult/critical age DWC ratio

Nuclide	Derived activity concentration in drinking water (Bq/l)					Critical age (y)	adult DWC/ critical age DWC
	age ≤ 1 y	1-2 y	2-7 y	7-12 y	>17 y		
Sr-89	1.1E+01	1.6E+01	3.2E+01	4.9E+01	5.3E+01	≤1	4.7
Sr-90	1.7E+00	3.9E+00	6.1E+00	4.8E+00	4.9E+00	≤1	2.8
Zr-95	4.7E+01	5.1E+01	9.5E+01	1.5E+02	1.4E+02	≤1	3.1
Ru-103	5.6E+01	6.2E+01	1.2E+02	1.9E+02	1.9E+02	≤1	3.3
Ru-106	4.8E+00	5.8E+00	1.1E+01	1.9E+01	2.0E+01	≤1	4.1
I-131	2.2E+00	1.6E+00	2.9E+00	5.5E+00	6.2E+00	1-2	3.9
Te-132	8.3E+00	9.5E+00	1.8E+01	3.4E+01	3.6E+01	≤1	4.3
Cs-134	1.5E+01	1.8E+01	2.2E+01	2.0E+01	7.2E+00	>17	1
Cs-137	1.9E+01	2.4E+01	3.0E+01	2.9E+01	1.1E+01	>17	1
Ce-144	6.1E+00	7.3E+00	1.5E+01	2.6E+01	2.6E+01	≤1	4.3
Pu-238	1.0E-01	7.1E-01	9.2E-01	1.2E+00	6.0E-01	≤1	6.0
Pu-239	9.5E-02	6.8E-01	8.7E-01	1.1E+00	5.5E-01	≤1	5.8
Pu-240	9.5E-02	6.8E-01	8.7E-01	1.1E+00	5.5E-01	≤1	5.8
Pu-241	7.1E+00	5.0E+01	5.2E+01	5.6E+01	2.9E+01	≤1	4.0
Am-241	1.1E-01	7.7E-01	1.1E+00	1.3E+00	6.8E-01	≤1	6.3

Table 2. DWC for main radionuclides of natural origin for different age classes, and adult/critical age DWC ratio

Nuclide	Derived activity concentration in drinking water (Bq/l)					Critical age (y)	adult DWC/ critical age DWC
	age ≤ 1 y	1-2 y	2-7 y	7-12 y	>17 y		
Pb-210*	4.8E-02	7.9E-02	1.3E-01	1.5E-01	2.0E-01	≤1	4.2
Po-210*	1.5E-02	3.2E-02	6.5E-02	1.1E-01	1.1E-01	≤1	7.4
Ra-226	8.5E-02	3.0E-01	4.6E-01	3.6E-01	4.9E-01	≤1	5.7
Ra-228	1.3E-02	5.0E-02	8.4E-02	7.3E-02	2.0E-01	≤1	14.9

Th-228	*1.1E-01*	*7.7E-01*	*1.3E+00*	*1.9E+00*	*1.9E+00*	*≤1*	*17.6*
Th-230	*9.8E-02*	*7.0E-01*	*9.2E-01*	*1.2E+00*	*6.5E-01*	*≤1*	*6.7*
Th-232	*8.7E-02*	*6.3E-01*	*8.2E-01*	*9.9E-01*	*6.0E-01*	*≤1*	*6.8*
U-234	*1.1E+00*	*2.2E+00*	*3.2E+00*	*3.9E+00*	*2.8E+00*	*≤1*	*2.6*
U-235	*1.1E+00*	*2.2E+00*	*3.4E+00*	*4.0E+00*	*2.9E+00*	*≤1*	*2.6*
U-238	*1.2E+00*	*2.4E+00*	*3.6E+00*	*4.2E+00*	*3.0E+00*	*≤1*	*2.6*

**the calculations were also carried out for Pb-210 and Po-210, but they are excluded from the Directive application, as specified above.*

THE GUIDELINES FOR DRINKING WATER QUALITY OF THE WORLD HEALTH ORGANIZATION

World Health Organization (WHO) issued in 2004 the third edition of its Guidelines for Drinking -water Quality (5). They apply to routine conditions or new drinking water supplies; they do not apply to a water supply during an emergency, but they do if a nuclear accident occurred more than 1 year before. K-40 is excluded and Rn-222 is discussed separately.

The approach chosen for controlling radiological hazards is said to have two stages: "1) initial screening for gross alpha and gross beta activity to determine whether the activity concentrations are below the levels at which no further action is required; and 2) if these screening levels are exceeded, investigation of the concentration of individual radionuclides and comparison with specific guidance levels".

Screening levels for drinking water, below which no further action is required, are set at: 0.5 Bq/l for gross alpha activity and 1 Bq/l for gross beta activity. The contribution of K-40 to beta activity should be subtracted following a separate determination of total potassium. The gross alpha activity screening level in the previous editions of the guidelines was 0.1 Bq/l and is here increased to 0.5 because they claimed that "…this activity concentration reflects values nearer the radionuclide specific guidance RDL[2]".

Specific guidance levels are based on a recommended reference dose level of the committed effective dose equal to 0.1 mSv/y from 1 year consumption of drinking water, assuming that the annual volume of drinking water ingested by adults is 730 l/y and dose coefficients for adults provided by ICRP (6), which are the same utilised by the EU Basic Safety Standards (3). The similarity of approach is not surprising, because it is the same adopted in the previous edition of the guidelines (7), which were used by the Article 31 working party on radioactivity in drinking water as a basis for the elaboration of the EU proposal for the monitoring. However, in WHO's recent document guidance levels " …are rounded according to averaging the log scale values (to 10^n if the calculated value was below $3x10^n$ and above $3x10^{n-1}$)". In Tables 3 and 4 the results of these calculations are reported for main radionuclides in a nuclear emergency and for main radionuclides of natural origin, respectively.

[2] *Recommended Reference Dose Level (see below)*

Table 3. Guidance levels for main radionuclides in a nuclear emergency

Nuclide	Guidance level (Bq/l)	Nuclide	Guidance level (Bq/l)
Sr-89	100	Cs-137	10
Sr-90	10	Ce-144	10
Zr-95	100	Pu-238	1
Ru-103	100	Pu-239	1
Ru-106	10	Pu-240	1
I-131	10	Pu-241	10
Te-132	100	Am-241	1
Cs-134	10		

Table 4. Guidance levels for main radionuclides of natural origin

Nuclide	Guidance level (Bq/l)	Nuclide	Guidance level (Bq/l)
Pb-210	0.1	Th-230	1
Po-210	0.1	Th-232	1
Ra-226	1	U-234	10
Ra-228	0.1	U-235	1
Th-228	1	U-238*	10

*provisional guideline value for U: 15 µg/l (187 mBq/l), based on its chemical toxicity for the kidney

The guidelines state that "the higher age-dependent dose coefficients calculated for children (accounting for the higher uptake and/or metabolic rates) do not lead to significantly higher doses due to the lower mean volume of drinking water consumed by infants and children". This statement, as shown above, is not that convincing. In order to clarify the point, in Tables 5 and 6 WHO guidance levels are compared with those obtained, rounded according to the same rule, starting from the DWC for the critical age. It can be noticed that for most radionuclides considered the guidance value turned out to be one order of magnitude lower.

Table 5. WHO guidance levels and guidance levels calculated for the critical age for main radionuclides in a nuclear emergency

Nuclide	Guidance level (Bq/l)	Possible guidance level based on children (Bq/l)	Nuclide	Guidance level (Bq/l)	Possible guidance level based on children (Bq/l)
Sr-89	100	10	Cs-137	10	---
Sr-90	10	1	Ce-144	10	10
Zr-95	100	100	Pu-238	1	0.1
Ru-103	100	100	Pu-239	1	0.1
Ru-106	10	10	Pu-240	1	0.1
I-131	10	1	Pu-241	10	10
Te-132	100	10	Am-241	1	0.1
Cs-134	10	--			

Table 6. WHO guidance levels and guidance levels calculated for the critical age for main radionuclides of natural origin

Nuclide	Guidance level (Bq/l)	Possible guidance level based on children (Bq/l)	Nuclide	Guidance level (Bq/l)	Possible guidance level based on children (Bq/l)
Pb-210	0.1	0.1	Th-230	1	0.1
Po-210	0.1	0.01	Th-232	1	0.1
Ra-226	1	0.1	U-234	10	1
Ra-228	0.1	0.01	U-235	1	1
Th-228	1	0.1	U-238*	10	1

*provisional guideline value for U: 15 µg/l (187 mBq/l), based on its chemical toxicity for the kidney

THE NATIONAL PRIMARY DRINKING WATER REGULATIONS OF THE ENVIRONMENTAL PROTECTION AGENCY (EPA)

In December 2000, the Environmental Protection Agency (EPA) issued the National Primary Drinking Water Regulations (8), which became effective in December 2003. The previous rule had been promulgated in 1976, but in 1991 EPA initiated a wide consultation phase regarding a number of proposed changes and additions to the previous rule. The basis for the final regulatory decisions was the new information that became available as from the 1991 proposal, in particular a *new study (9) providing numerical factors used in estimating cancer risks from low-level exposures to radionuclides.*

This regulation is only applicable to community water systems and it "…finalises maximum contaminant level goals (MCLGs), maximum contaminant levels (MCLs), and monitoring, reporting and public notification requirements for radionuclides". As regards the MCLGs, they are defined as "non-enforceable health-based target" and it is stated that "the final MCLGs are zero for all radionuclides, based on the no-threshold cancer risk model for ionizing radiation." The MCLs are defined as "enforceable regulatory limits" and are reported in Table 7 in SI units.

Table 7. EPA maximum contaminant levels

Radionuclide	*Maximum Contaminant Level*
Gross alpha (excluding Rn and U)	*555 mBq/l*
Beta particle and photon radioactivity	*40 µSv/y*
Ra-226 + Ra-228	*185 mBq/l*
Po-210	*Included in gross alpha*
Pb-210	*Explicitly not regulated*
Uranium	*30 µg/l*

Therefore, it can be said that the EPA approach is quite different from those of WHO and EU, because the suggested levels are neither "indicator parameters" aimed at assessing the quality of drinking water (1), nor "guidance levels" that, if exceeded, "…should be regarded as an indication that further investigation… is needed" (5), but actual limits. Taking into account this important difference, it should be noticed that:

- *the gross alpha MCL is almost the same of the value suggested by WHO, but in the latter case it is only a screening level "below which no further action is needed";*
- *the MCL for beta particles and photon radioactivity is less than half the TID (1) or the recommended reference dose level (5);*
- *the MCL for the sum of Ra-226 and Ra-228 is much lower than that of the EU Directive (DWC for adults 0.5 and 0.2, respectively) and presumably than that of WHO (an additive formula of the two concentrations weighted by the two guidance levels, that is 1 and 0.1, respectively);*
- *a specific MCL for Po-210 is not provided for, because Po-210 is included in gross alpha; however, Po-210 is excluded by the EU Directive (but a proposal for its limitation was issued in the 2001 Euratom Recommendation (10)), but included in the WHO guidance levels (with a value of 0.1);*
- *Pb-210 is explicitly not regulated by EPA, excluded by the EU Directive (but a proposal for its limitation was issued in the 2001 Euratom Recommendation (10)), but included in the WHO guidance levels (with a value of 0.1);*

- *the MCL for U is a factor of 2 higher than the one suggested by the WHO guidelines (15 µg/l), whereas in the EU Directive it is not considered for its chemical toxicity, but only for its radioactivity in the TID.*

As regards children exposure, EPA claims that "…the Agency does have reason to believe that radionuclides in drinking water present higher unit risks to children than to adults, since there is evidence that children are more sensitive to radiation than adults. Because of this, we have explicitly considered the risks to children in evaluating the lifetime risks associated with the current MCLs…In summary, today's decision to retain the current more stringent MCLs for radionuclides and to establish an MCL for uranium in drinking water is consistent with the protection of children's health."

May be this is the reason why EPA requirements are generally much stricter than EU and WHO requirements.

CONCLUSIONS

EU, WHO and EPA regulations on the content of radionuclides in drinking water look quite different, even if two of them seem to start from the same goal of limiting the population exposure to less than 0.1 mSv/y.

The practical application of the European Directive calls for the issuing of "… detailed requirements on monitoring frequencies, methods and locations" (see notes to Annex I PART C). As soon as they will be available the comparison and discussion about the approaches chosen by these international authorities could be extended to these aspects.

From the discussion in the paper it is all too clear that infants and small children are the population groups most at risk. In the implementation of the EU Directive in the Member States this aspect might be accounted for, stressing that in case of prolonged contamination in some cases the derived activity concentration in drinking water calculated for adults might not be conservative enough for these age classes. Moreover, the age class 10-17 y, not considered in the database for there was no agreement on the related intake value (see first paragraph), is also critical - even if not the most at risk - for some radionuclides (e.g. Ra-226 and Ra-228). However, it should be kept in mind that the total indicative dose of 0.1 mSv/y is only reached if the contamination lasts for one entire year. Being drinking water a primary need, a thorough risk-benefit analysis should be done before deciding any limitation to its use.

ACKNOWLEDGEMENT

The authors are grateful to Ms. Monica Brocco (Istituto Superiore di Sanità) for the linguistic revision.

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