

The derivation of preliminary reference levels for natural radioactivity in drinking water surrounding nuclear sites

Thato B Molokwe

National Nuclear Regulator: Centre for Nuclear Safety and Security, Pretoria,
Gauteng, 0028, South Africa

E-mail: Tmolokwe@nnr.co.za

Abstract. The mandate of the National Nuclear Regulator (NNR) is to protect the people, property and environment from radiological damage, through the establishment of safety standards and regulatory practices. The NNR aims to establish criteria for drinking water in the vicinity of authorised nuclear facilities and is currently involved with projects to establish the levels of radioactivity in drinking water in the vicinity of authorised nuclear sites. The study seeks to derive preliminary reference levels based on the principles established by the World Health Organisation (WHO). The Annual Limit on Intake (ALI) was calculated for different age groups. The calculations were performed using the dose conversion factors provided by the International Atomic Energy Agency (IAEA) in the General Safety Regulations (GSR Part 3). The calculated ALI results for infant, child and adult age groups are presented. The calculated ALI could be used as preliminary reference levels during the assessment of the radioactivity status of baseline data that is currently being collected.

1. Introduction

The major sources of public exposure to natural radiation are cosmic and terrestrial radiation, inhalation of air/dust containing radionuclides and ingestion of radionuclide contaminated water or food [1]. Therefore, the risk to human health (public) could be presented in numerous pathways, one of which is through the ingestion of water containing radionuclides. The National Nuclear Regulator (NNR) is currently involved with projects to establish the radioactivity of drinking water in the vicinity of authorised nuclear facilities. The objective of conducting these projects is to ultimately establish regulatory criteria for the radioactivity of drinking water in the vicinity of authorised and legacy sites.

The establishment of safety standards and regulatory practices supports the NNR in carrying out its mandate. The mandate of the NNR is to protect the people, property and environment from radiological damage [2]. South Africa is a member state of the International Atomic Energy Agency (IAEA) [3]. The IAEA is an independent intergovernmental organisation that develops nuclear safety standards for the protection of human health and the environment from ionising radiation [4]. Consequently, the NNR considers these standards when establishing its safety standards and regulatory practices. Requirement 51 of the IAEA's General Safety requirements state that "the regulatory body or other relevant authority shall establish reference levels for exposure due to radionuclides in commodities" such as drinking water. In addition, the requirements state that the regulatory body/relevant authority should consider the guideline levels for water containing radionuclides published by the World Health Organisation [3].

Therefore, the principles of the World Health Organization should be used as a basis during the development of national guideline levels for radionuclides in drinking water.

As a way to assist the NNR with establishing regulatory criteria for radioactivity in drinking water, the radiological baseline of drinking water in areas surrounding authorised nuclear sites needs to be established. Before this can be done, it is important to first establish preliminary reference levels, which will be used to assess the radioactivity levels in collected samples later on. The study seeks to derive preliminary reference levels for the infant, child and adult age groups based on the current international best practice. In addition the study aims to, assess the differences of the derived reference levels across the above-mentioned age groups. These reference levels will inform whether the water resource from which the sample was collected could pose a radiological threat to human health if ingested or not.

2. Method

The Annual Limit on Intake (ALI) was calculated for the infant, child and adult age groups based on the principles established by the WHO. The ALI through ingestion is the intake of a given radionuclide by a reference person which would result in a committed dose that is equal to the relevant dose limit [5]. The assumption that is made is that the calculated preliminary radionuclide reference levels are applicable for water under standard conditions for temperature and pressure. ALI was calculated for commonly detected radionuclides in drinking water sources in the vicinity of Naturally Occurring Radioactive Materials (NORM) producing mines and legacy mine sites.

2.1. Determining commonly detected radionuclides in drinking water sources in the vicinity of NORM-producing mines and legacy mine sites.

There are three main decay series in the natural environment, U-238, Th-232 & U-235 [6]. Therefore, all the radionuclides of these decay series have the potential of being present in water resources surrounding regulated nuclear sites (surface water and groundwater). The study also took into consideration the limitations of laboratory measurement techniques in analysing all these radionuclides.

2.2. Drinking water consumption rates.

The daily water consumption rates of the adult (>17 years), children (1-17 years) and infant (<1 year) age groups are presented in table 1 [7]. These were rates converted to annual consumption rates. For the adult age group, the average consumption rate of an adult male and adult female was used.

Table 1. Consumption rates of infant, children and adults adapted from [7].

Category	Daily Consumption Rate (L/d)	Annual Consumption rate (L/yr)
Adult	Male	2.723
	Female	2.129
Children	0.431	157.315
Infant	0.327	119.355

2.3. Calculation of Annual Limit on Intake.

The Annual Limit of Intake is calculated using equation (1) obtained from the WHO drinking water guidelines [8].

$$ALI = \frac{IDC}{(U \times Dc)} \quad (1)$$

Where;

IDC – annual dose to the whole body ($\mu\text{Sv}/\text{yr}$), in this the IDC of 0.0001 (Sv/yr)

ALI – concentration of radionuclide in water, which in this case is the ALI (Bq/L)

U – annual consumption rate (L/yr)

Dc – ingested dose coefficient (Sv/Bq)

3. Results

The calculated ALI for the infant, child and adult age groups are presented in table 2, table 3 and table 4. The differences in calculated ALI for the same radionuclide in the infant, child and adult age groups are within the same order of magnitude. This suggests that the derived radionuclide reference levels for different age groups give rise to a similar dose due to ingestion. However, the WHO recommends that dose assessments may be introduced for infants and children in cases of prolonged contamination of the water source [8].

Table 2. Calculated ALI for an infant.

Infant (<1 yr)				
Radionuclide	Individual Dose Criterion (IDC) - (Sv/yr)	Ingestion Dose Coefficient (Dc) - (Sv/Bq)	Annual Consumption Rate (U) - (L/yr)	Annual Limit on Intake (Bq/L)
U-232	0.0001	2.5E-06	119	0.34
Pb-210	0.0001	8.4E-06	119	0.10
U-235	0.0001	3.5E-07	119	2.39
Th-230	0.0001	4.1E-06	119	0.20
Ra-226	0.0001	4.7E-06	119	0.18
Po-210	0.0001	2.6E-05	119	0.03
Th-227	0.0001	3.0E-07	119	2.79
Ra-223	0.0001	5.3E-06	119	0.16
Ra-224	0.0001	2.7E-06	119	0.31
K-40	0.0001	6.2E-08	119	13.51
Tritium	0.0001	1.2E-10	119	6981.97
I-132	0.0001	3.0E-09	119	279.28
I-133	0.0001	4.9E-08	119	17.10
Cs-134	0.0001	2.6E-08	119	32.22
Cs-136	0.0001	1.5E-08	119	55.86
Co-60	0.0001	5.4E-08	119	15.52
Te-131	0.0001	9.0E-10	119	930.93
U-234	0.0001	3.7E-07	119	2.26
Cs-137	0.0001	2.1E-08	119	39.90
I-131	0.0001	1.8E-07	119	4.65
La-140	0.0001	2.0E-08	119	41.89
I-135	0.0001	1.0E-08	119	83.78
Te-132	0.0001	4.8E-08	119	17.45
Nb-95	0.0001	4.6E-09	119	182.14
U-238	0.0001	3.4E-07	119	2.46
U-235	0.0001	3.5E-07	119	2.39

Table 3. Calculated ALI for a child.

Child (1-17 yr)				
Radionuclide	Individual Dose Criterion (IDC) - (Sv/yr)	Ingestion Dose Coefficient (Dc) - (Sv/Bq)	Annual Consumption Rate (U) - (L/yr)	Annual Limit on Intake (Bq/L)
U-232	0.0001	6.5E-07	157	0.98
Pb-210	0.0001	2.4E-06	157	0.26
U-235	0.0001	8.9E-08	157	7.14
Th-230	0.0001	3.0E-07	157	2.12
Ra-226	0.0001	9.7E-07	157	0.66
Po-210	0.0001	4.4E-06	157	0.14
Th-227	0.0001	3.6E-08	157	17.66
Ra-223	0.0001	6.2E-07	157	1.03
Ra-224	0.0001	3.7E-07	157	1.72
K-40	0.0001	2.0E-08	157	31.78
Tritium	0.0001	7.3E-11	157	8707.77
I-132	0.0001	1.2E-09	157	529.72
I-133	0.0001	2.1E-08	157	30.27
Cs-134	0.0001	1.6E-08	157	39.73
Cs-136	0.0001	5.9E-09	157	107.74
Co-60	0.0001	1.5E-08	157	42.38
Te-131	0.0001	3.3E-10	157	1926.26
U-234	0.0001	9.2E-08	157	6.91
Cs-137	0.0001	1.1E-08	157	57.79
I-131	0.0001	9.2E-08	157	6.91
La-140	0.0001	6.6E-09	157	96.31
I-135	0.0001	4.3E-09	157	147.83
Te-132	0.0001	1.5E-08	157	42.38
Nb-95	0.0001	1.7E-09	157	373.92
U-238	0.0001	8.4E-08	157	7.57
U-235	0.0001	8.9E-08	157	7.14

Table 4. Calculated ALI for an adult.

Adult (>17 yr)				
Radionuclide	Individual Dose Criterion (IDC) - (Sv/yr)	Ingestion Dose Coefficient (Dc) - (Sv/Bq)	Annual Consumption Rate (U) - (L/yr)	Annual Limit on Intake (Bq/L)
U-232	0.0001	3.3E-07	885	0.34
Pb-210	0.0001	6.9E-07	885	0.16
U-235	0.0001	4.7E-08	885	2.40
Th-230	0.0001	2.1E-07	885	0.54
Ra-226	0.0001	2.8E-07	885	0.40
Po-210	0.0001	1.2E-06	885	0.09
Th-227	0.0001	8.8E-09	885	12.84
Ra-223	0.0001	1.0E-07	885	1.13
Ra-224	0.0001	6.5E-08	885	1.74
K-40	0.0001	6.2E-09	885	18.22
Tritium	0.0001	4.2E-11	885	2690.34
I-132	0.0001	2.9E-10	885	389.64
I-133	0.0001	4.3E-09	885	26.28
CS-134	0.0001	1.9E-08	885	5.95
Cs-136	0.0001	3.0E-09	885	37.66
Co-60	0.0001	3.4E-09	885	33.23
Te-131	0.0001	8.7E-11	885	1298.79
U-234	0.0001	4.9E-08	885	2.31
Cs-137	0.0001	1.3E-08	885	8.69
I-131	0.0001	2.2E-08	885	5.14
La-140	0.0001	2.0E-09	885	56.50
I-135	0.0001	9.2E-10	885	122.82
Te-132	0.0001	3.8E-09	885	29.74
Nb-95	0.0001	5.8E-10	885	194.82
U-238	0.0001	4.5E-08	885	2.51
U-235	0.0001	4.7E-08	885	2.40

4. Conclusions

The above results show that the differences in calculated ALI values for individual radionuclides across all ages are insignificant (within the same order of magnitude). Therefore, it is recommended that the NNR use calculated ALI for adults as preliminary reference levels during the assessment of the radioactivity status of baseline data that is currently being collected. However, if the water source undergoes prolonged contamination dose assessments for infants and child age groups may be introduced.

5. References

- [1] Canadian Nuclear Safety Commission 2019 *Introduction to radiation*. Accessed 18 July 2019. <http://nuclearsafety.gc.ca/eng/resources/radiation/index.cfm>
- [2] National Nuclear Regulator 2020 *Our roles and Functions*. Accessed 15 June 2020. <https://nnr.co.za/about-us/our-role-and-functions/>
- [3] International Atomic Energy Agency 2014 *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (GSR Part 3)*
- [4] International Atomic Energy Agency 2021 *The IAEA mission statement*. Accessed 20 August

2021. <https://www.iaea.org/about/mission>
- [5] International Atomic Energy Agency 2019 *IAEA safety glossary : 2018 edition* p 128-129
 - [6] Kim G 2011 Measurement and application of radium and radon in the environment. *Journal of Analytical Science & Technology* **2** p A115-A119
 - [7] Fakhri Y, Oliveri G, Ferrante M, Bay A, Avazpour M, Moradi B, Zamdsalimi Y, Amirhajloo L R, Langarizadeh G and Keramati H 2016 *Assessment of concentration of radon 222 and effective dose; Bandar Abbas city (Iran) citizens exposed through drinking tap water.* *International Journal of Pharmacy & Technology* **8** p 10782-10793
 - [8] World Health Organization 2017 *Guidelines for drinking water-water quality: Fourth edition incorporating the first addendum.* p 203-218