Case Studies on the Regulation and Management of Radioactivity in Drinking Water

Thato Molokwe[1 *], Margaret Mkhosi[1], and Ian Korir[1]

[1]*National Nuclear Regulator, 420 Witch-Hazel Avenue, Eco-Park Estate, Centurion, 0157, Pretoria, Gauteng, South Africa*

*Tmolokwe@nnr.co.za

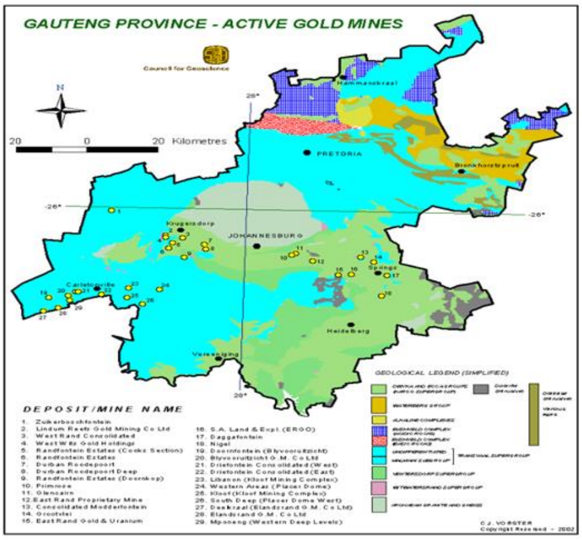
Abstract. In carrying out its mandate of protecting the people, environment and property from radiological damage, the National Nuclear Regulator (NNR) regulates any activity that is capable of causing nuclear damage. This includes damage caused by naturally occurring radioactive material (NORM) arising from mining activities (planned exposure situations) and legacy sites (existing exposure situations). Currently, NNR does not have regulatory criteria for radioactivity in drinking water in the surrounding authorised mines and legacy sites. The study sought to establish the basis for the national radiological standard-setting process from selected countries namely, Canada, United Kingdom, United States of America (USA), Jordan, Morocco and Nigeria. Then make recommendations on how the NNR could establish nuclear safety regulatory criteria for radioactivity of drinking water in the vicinity of authorised mines and legacy sites. The study revealed a trend in how these countries established their national standards. All the of them made use of recommendations of the World Health Organisation (WHO) and the International Commission on Radiological Protection’s (ICRP) recommendations as scientific basis for setting national standards except for the USA. The USA based their standards on experimental results obtained from epidemiological and dosimetric studies as well as experiments conducted on animals.

KEYWORDS: radioactivity, drinking water, regulation

1 INTRODUCTION

The major sources of public exposure to natural radiation are cosmic and terrestrial radiation, inhalation of air/dust and ingestion of water or food contaminated by radionuclides [1]. Qualitatively risk to human health is the product of the probability that contaminated water or food will be ingested and the radiological consequence or damage due to the intake. The mining and processing of uranium-gold bearing deposits of the Witwatersrand basin resulted in the deposition and transportation of NORM in the groundwater and surface water bodies [2]. The majority of mining in the Witwatersrand basin occurs in the Gauteng Province of South Africa (as shown in **Figure 1**). NORM that finds its way into drinking water sources could pose a health risk to the public, if not controlled. The public's radiation exposure through ingestion could be determined by measuring the radioactivity levels in drinking water ingested by the public [1].

Figure 1: Active gold mines in the Gauteng Province [3]



The mandate of the National Nuclear Regulator (NNR) is to regulate any activity that can potentially cause nuclear damage. Typically this can be NORM-producing mines (planned exposure situations) and legacy sites (existing exposure situations). Currently, the NNR does not have regulatory safety criteria for radioactivity in drinking water in the vicinity of authorised NORM mines and legacy sites. To assist the NNR with the development of a national regulatory criteria for radioactivity in drinking water, it is important firstly to establish reference levels. Prior to this, it was important to examine the international best practice as recommended by the World Health Organisation (WHO) and how other countries established reference levels, manage and regulate radioactivity in drinking water.

2 THE SOUTH AFRICAN REGULATORY FRAMEWORK AND DRINKING WATER STANDARDS

In recognition of the challenges that Water Service Authorities (WSAs) in South Africa faces, the then Department of Water Affairs and Forestry (DWAF) currently known as the Department of Water and Sanitation (DWS) identified key stakeholders to form a task team to develop a Drinking Water Quality Framework (DWQF) for the country. The outcome of this initiative was a DWQF for South Africa. This framework allows for the effective management of drinking water quality resulting in one aspect of the protection of public health [4]. The domestic water use guideline for South Africa recommends that gross activity should be used for screening purposes only. Tentative guideline criteria are given for the following radiation emitting radionuclides which are usually found in water which account for the major portion of gross activity in water; Uranium-238, Thorium-232, Radium-226 and Radon-222. **Table 1** are the target water quality ranges for the activities of the above mentioned radionuclides [5].

Table 1: Target water quality ranges for drinking water [5]

Radioactivity	Target Water Quality Range (Bq/l)
Gross Activity	0 – 0.5
U-238	0.89 – 3.6
Th-232	0 – 0.228
Ra-226	0 – 0.24
Rn-222	0 - 11

The drinking water limits set for radioactivity are based on the possible stochastic risk of cancer induction due to long-term exposure to radiation. The lifetime cancer risk of exposure to radiation was estimated to be 5×10^{-2} after receiving and equivalent dose of a Sievert (per Sv). The absorbed tissue dose was calculated from the tissue dose using radioactivity conversion factors for each radionuclide (assuming an average intake of water of 2 l/day). This should apply to adults only however the DWS does not factor in the critical group or representative person approach [5]. A conservative approach is favoured; the approach assumes that 100% of the ingested radionuclide is absorbed. This is not the case in the real world. Under normal circumstances, the drinking water guideline does not consider the radioactivity in the water in terms of its effect on the health of an individual because the natural radioactivity levels in water are usually low [5].

3 THE WORLD HEALTH ORGANISATION

The WHO is concerned with the monitoring and advising of international health and is a support organization of the United Nations (UN). The WHO collaborates with the world's top health experts to provide international reference materials such as the Drinking Water Guidelines [6] and also makes recommendations on how to offer improved health to people across the world. The WHO drinking water quality guidelines are considered "international best practice" and are used by many countries in the world as a scientific reference point for establishing national drinking water standards [7]. The radionuclide in drinking water guidance levels recommended by the WHO applies to radionuclides that originate from natural sources that are discharged into the environment. This is through either current or past activities. The radionuclide levels are in line with the ICRP's recommended Reference Dose Level (RDL) of 0.1 mSv/year [6]. As such, the recommended radionuclide in drinking water guidance levels were calculated using the following equation:

$$GL = \frac{IDC}{\left(h_{ing} \bullet q\right)} \tag{1}$$

where;

GL - guidance level of radionuclide in drinking water (Bq/litre),
IDC -individual dose criterion which is equal to 0.1 mSv/year,
h_{ing} - radiation dose coefficient for ingestion by adults (mSv/Bq)
q - the annual volume of ingested drinking water, assumed to be 730 litres/year.

These recommended guidance levels were calculated for adults because age-dependent dose coefficients for children do not lead to significantly higher doses. This is attributed to an average a lower volume of drinking water ingested by children. Therefore, the recommended RDL of the committed effective dose of 0.1 mSv/year is independent of age [6].

4 CANADA

The Canadian drinking water standards, which include radiological standards were established by the Federal-Provincial-Territorial Committee (FPtrPC) on drinking water and Health Canada (HC). It is the committee working in conjunction with the municipal government that shares the responsibility of ensuring safe drinking water to the public. The established guidelines are applicable during normal routine operational conditions (non-emergencies) [8] NORM is regulated by the provincial and territorial governments. The FPtrPC plays the role of harmonising standards throughout the country and ensures that appropriate control of NORM is applied. This is done with the consultation of provincial regulations [9].

Guidelines for radioactivity in drinking water are based on international radiation protection methodologies, these include recommendations of the ICRP and the WHO. Canadian Nuclear Safety Commission (CNSC) and HC adopted the dose limits recommended by the ICRP (for occupational and public exposures) which must be adhered to under normal conditions. Canada's effective dose limit for the public is 1 mSv for internal and external doses (per year) excluding natural background, medical or therapeutic radiation. Ten percent (10%) of this dose (0.1 mSv) is the recommended effective dose from one year's consumption of drinking water by WHO guidelines for drinking-water quality [10]. Thus, the Maximum Acceptable Concentrations (MACs) also known as Guideline Reference Levels (GLs) for both natural and artificial radionuclides were derived using the reference dose level of 0.1 mSv/yr for 1 year's consumption of drinking water. This is assuming the consumption of 2 litres per day at maximum acceptable concentrations [8]. The derived GLs for radionuclides in drinking water were calculated using the same equation as the WHO. The dose conversion factors for younger age groups have proven not to lead to significantly higher dose criteria due to the small amounts of water being consumed. Therefore, the GLs based on adult parameters are being used for all age groups (conservative assumption) [10].

5 UNITED KINGDOM

The United Kingdom (UK) comprises four nations; England, Scotland, Wales and Northern Ireland. The UK subscribes to the drinking water quality standards set by the European Commission (EC). The drinking water directive of the EC is concerned with the quality of water intended for human consumption. It makes use of the WHO's drinking water guidelines (derived standards) and the opinion of the Scientific Advisory Committee's as a scientific basis for drinking water standards [11]. Member states of the EU may translate the Euratom Derivative (ED) to their national legislature, looking at their socio-economic, geographical, geological factors. They could choose to include additional standards to their legislature. However, member states are not allowed to set lower standards than those specified by the ED. The directive also provides radionuclide specific derived concentration values. The derived concentrations of the Euratom Derivative were calculated based on the Indicative Dose (ID) value of 0.1 mSv at an annual intake of 730 litres (for adults) and Euratom dose coefficients [12].

In the drinking water legislation, the limits of detection for which a method of analysis must at least be able to measure are specified. Limits of detection should be calculated according to the International Organisation for Standardisation (ISO) standard. The legislation also specifies the screening standards for gross alpha (0.1 Bq/l) and gross beta (1.0 Bq/l) activities, which should be conducted first during the monitoring of radioactivity levels. This is before deciding if specific radionuclide analysis is required or not [13].

6 UNITED STATES OF AMERICA

In the USA, the setting of radiation protection standards and the regulation of sources of ionising and non-ionising radiation is not a responsibility of a single federal agency. State regulation control programs may be different when it comes to approach, regulations and legislation. The United States Environmental Protection Agency (US-EPA) is responsible for air emissions, drinking water and waste [14]. The US-EPA sets drinking water quality standards and delegates the responsibility of implementing the standards to the States and Tribes. During the standard-setting process, the US-EPA makes use of the assistance of the National Drinking Water Advisory Council (NDWAC) [15].

USA did not adopt ICRP risk coefficients and dose limit recommendations in deriving its standards. The US-EPA used information gathered from animal experiments, epidemiological studies and dosimetric models (a gastro-intestinal model used for radiation exposure via ingestion) to set standards for humans. The reason for this is that for moral reasons, human beings cannot be deliberately exposed to radiation in order to understand the relationship between radiation dose and the corresponding health effects [16].

The Federal Radiation Council (FRC) set the upper limit for radiation exposure to the public at 170 mrem/yr (100 rem = 1000 mSv). The drinking water limits set by the US-EPA are 5 pCi/l (0.185 Bq/l) of Ra-226, 15 pCi/l (0.555 Bq/l) of gross alpha particle activity (excluding U and Rn) and an equivalent dose rate of 4 mrem/yr = 0.04 mSv/yr. The dose for other alpha particle emitters excluding U and Rn are projected to be not more than one-fifth (1/5) of the value of Ra based on dosimetric models. Should the gross alpha particle activity be greater than 0.185 Bq/l, activity of Ra-226 is to be determined. These levels were set based on health effects and the costs involved in the removal of radionuclides in drinking water. This is also in line with the ALARA principle, which requires keeping the radiation risk as low as practically possible [16].

7 JORDAN

In Jordan the departments responsible for ensuring safe drinking water is the Ministry of Health and the Water Authority of Jordan. The development and review of drinking water standards (JS286) are done through a collaborative effort of different organisations that included the Ministry of Health and Jordan Standards & Meteorology Organisation. The standards specify the limits, reference levels, sampling frequencies and points of physical, chemical, radiological and microbiological parameters found in drinking water [17]. The WHO's drinking water quality standards were used to form the basis for Jordan's drinking water quality standards [18]. The Jordanian Drinking Water Standards JS 289/2001 provides radionuclide-screening values. However, specific radionuclide limits are not given. The assessment of the level of exposure to radioactive materials should be conducted to ensure that the dose received does not exceed 0.1 mSv/yr for each radionuclide [19]. In 2007, Jordan adopted a national dose limit of 0.5mSv/yr (5 times higher than the WHO recommended limit) as a result of the water shortage in the country [20].

8 MOROCCO

The responsibility of regulating and managing public water supply in Morocco is a collaborative effort between different administrations. The National Drinking Water Supply Office is responsible for the control of pollution in drinking water resources, drinking water supply in urban areas and the production of drinking water. The Ministry of Health is the authority responsible for water quality surveillance. National drinking water quality standards were derived from the WHO guidelines and other sources such as the EU, USA and Canadian standards [21]. Morocco makes use of the effective dose limit of 0.1 mSv/yr recommended by the WHO and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Effective doses received through the ingestion of drinking water are calculated using the quantity of water ingested during a year (approx. 730 l/yr for adults) and coefficients of dose per unit intake (DPUI) for both adults and infants. These values of DPUI are also used in the European Directive [22].

9 NIGERIA

The Nigerian water standards are specified in the Federal Environmental Protection Agency's (FEPA); Guidelines and Standards for Environmental Pollution in Nigeria [23]. The Federal Ministry of Water Resources and the Federal Ministry of Health collaborated with the Standards Organisation of Nigeria and a technical committee to establish the Nigerian Standard for Drinking Water Quality. The determination of maximum allowable limits and selection of parameters was conducted taking into account the recommended guidelines of WHO. The maximum permitted level of radionuclides in drinking water is specified to be 0.1 Bq/l [24]. However in studies assessing the radioactivity levels of drinking water, the specified radionuclide limit in drinking water was not considered, instead measured radioactivity was compared to the IRCP and WHO drinking water quality guidelines. This was attributed to unfavourable legislative, technical and operational constraints [25].

10 GAP ANALYSIS

A gap analysis was performed to examine and assess the regulations currently existing in South Africa and NNR and where it should be compared to international practices. **Table 2**: is a gap analysis of South Africa and the NNR compared to international practice:

Objectives	South Africa	NNR	International Practice
To establish regulatory criteria for Radioactivity in drinking water	The Department of Water and Sanitation provided tentative guidelines for uranium, thorium, radium and radon radionuclides in the South African Drinking Water Quality Guidelines	Currently, NNR does not have regulatory criteria specifically for radioactivity levels in drinking water in the vicinity of uranium producing mines and legacy sites	The trend identified internationally is that most countries make use of variations of the WHO’s drinking water quality guidelines to establish national guideline reference levels

11 CONCLUSIONS AND RECOMMENDATIONS

South Africa's Department of Water and Sanitation provides a drinking water quality framework and tentative radiological standards for drinking water. The standards employed were based on the possible stochastic risk of cancer induction due to long-term exposure to radiation. However, the standards do not factor in the critical group or representative person approach. Since there is insufficient data available on the radiological status of water resources in the country, there is no indication whether the drinking water resources in the country comply with these the tentative radiological drinking water standards.

National radionuclide guideline levels for drinking water were established by the countries based on WHO and ICRP's international radiation methodologies and recommendations. The countries made use of the ICRP's dose conversion factors to derive radionuclide maximum contaminant levels, except for the USA. The American drinking water dose limit and standards were established based on epidemiological studies, dosimetric models and experiments performed on animals.

Therefore, on the basis of the information provided above, the following are recommendations made to assist with the establishment of standards for regulating radioactivity in drinking water surrounding the regulated NORM mines and legacy sites:

- Set standards for the maximum permitted level of radionuclides in drinking water for the radionuclides that occur frequently and in significant concentrations in water resources and which have the most impact on human health (standard prioritisation);
- Establish an advisory committee comprising experts from the relevant government departments to play a role in the harmonisation and coordination of radiation protection regulation, guidance and practices among the regulatory body, relevant government departments and institutions;
- Use the WHO Drinking Water Quality Guidelines approach as a reference point for establishing a regulatory criterion for the radioactivity of drinking water in the surroundings of regulated mines. The criterion should consider different age groups;
- Consider establishing a national centralised database of radioactivity levels in drinking water that is accessible to governmental institutions and stakeholders coordinated by the body of experts, to avoid data duplication

12 REFERENCES

[1] Canadian Nuclear Safety Commission. (2012). Introduction to radiation. Available from: www.nuclearsafety.gc.ca.

[2] Sutton M.W and Weirsbye I.M (2008). Land-use after mine closure-risk assessment of gold and uranium mine residue deposits on the Eastern Witwatersrand, South Africa. Mine Close. pp 363-374. ISBN 978-0-984185-6-9

[3] Vorster C.J (2002). Gauteng Province – Active Mines. Council for Geoscience. Retrieved from: https://geoscience.org.za/cgs/

[4] Hodgson K and Manus L (2006). A drinking water quality framework for South Africa. Water SA. Vol 32 (5). pp 673-678. ISSN 0378-4738

[5] Department of Water Affair and Forestry (1996). South African water quality guidelines (second edition) Vol 1: Domestic use. pp 141-148.

[6] World Health Organization (2017). Guidelines for drinking water-water quality: Fourth edition incorporating the first addendum. pp 203-218. ISBN 978 924 154815 1

[7] Lenntech (2019). Drinking water standards. [ONLINE] Retrieved from: https://www.lenntech.com/applications/drinking/standards/drinking-water-standards.htm. [Accessed: 24 May 2019]

[8] Health Canada (2009). Guidelines for Canadian drinking-water quality. Guideline Technical Document: Radiological Parameters. Ottawa: Health Canada. [ONLINE] Retrieved from: http://healthycanadians.gc.ca/publications/healthy-living-vie-saine/water-radiological-radiologique-eau/index-eng.php [Accessed: 14 October 2018]

[9] Canadian Nuclear Safety Commission (2020). Naturally occurring radioactive material. Retrieved from: https://nuclearsafety.gc.ca/eng/resources/fact-sheets/naturally-occurring-radioactive-material.cfm

[10] Canadian Nuclear Safety Commission (2008). Standards and Guidelines for Tritium in Drinking Water. Retrieved from: nuclearsafety.gc.ca ISBN 978-0-662-47497-5

[11] European Commission (2018). Drinking Water – Legislation. [Online] Retrieved from: http://ec/europa.eu/environment/water/water-drink/legislation_en.html [Accessed: 21 February 2019]

[12] European Commission (1998). Council Derivative 98/83/EC of 3 November 1998. Retrieved from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1998:330:0032:0054:EN:PDF
[13] Legislation.gov.uk (2016). The Water Supply (Water Quality) Regulation 2016: Water, England and Wales. pp 43-44. Retrieved from: http://www.legislation.gov.uk/id/uksi/2016/614
[14] McBurney R. E (2019). Development of a regulatory framework for Naturally Occurring Radioactive Material in United States. Webinar: Conference of radiation control program directors
[15] Watts and Crane Associates (2008). Review of England and Wales monitoring data for which a national standard or international standard has been set. Retrieved from: http://dwi.defra.gov.uk/research/completed-research/reports/DWI70_2_215_Monitoring_Data.pdf
[16] United States Environmental Protection Agency (1981). Radioactivity in Drinking Water. Criteria and Standards Division EPA 570/9-81-002
[17] World Health Organization (2018). Management of radioactivity in drinking-water. Geneva. pp 81-85. ISBN 978-92-4-151374-6
[18] Mediterranean Environmental Technical Assistance Program (1995). Water Quality Management: Jordan. [Online] Retrieved from: http://siteresources.worldbank.org/EXTGLOREGPARPROG/Resources/METAP_Eval_Report.pdf [Accessed: 27 February 2019]
[19] Jordan Institute of Standards and Meteorology (2001). Standard No. 286/2001: Technical Regulation. Retrieved from: https://www3.opic.gov/environment/eia/ammanwater/Annex%20C21-Drinking%20Water%20Standards.pdf
[20] Almeer S., Al-Hamarneh I.F., Al-Bed T et al. (2011). Natural radioactivity in tap water and associated age-dependent dose and lifetime risk assessment in Amman, Jordan. Applied radiation and isotopes: including data, instrumentation and methods for use in agriculture, industry and medicine 70(4). pp 692
[21] Abouzaid H and Echihabi (1995). Drinking water quality and monitoring in North Africa: the Moroccan experience. The Science of the Total Environment. pp 29-34
[22] Hakam O.K., Choukri A., Abbad A et al. (2015). Uranium and radium activities measurements and calculation of effective doses in some drinking water samples in Morocco. International Journal of Cancer Therapy and Oncology. DOI: 10.14319/ijtco.33.2
[23] Longe E.O., Omole D.O., Adewumi I.K et al. (2010). Water resources use, abuse and regulations in Nigeria. Journal of Sustainable Development in Africa. pp 35-44 ISSN:1520-5509
[24] Standards Organisation of Nigeria (2015). Nigerian Standard for Drinking Water Quality
[25] Ebiare E and Zejiao L (2010). Water quality monitoring in Nigeria: Case study of Nigeria's industrial cities. Journal of American Science. pp 22-28