

Radon in Drinking Water in Novi Sad

J. Nikolov, N. Todorovic, S. Forkapic, I. Bikit, D. Mrdja

Abstract—Exposure to radon occurs when breathing airborne radon while using water: showering, washing dishes, cooking, and drinking water that contain radon. The results of radon activity measurements in water from public drinking fountain in city of Novi Sad, Serbia is presented in this paper. Radon level in some samples exceeded EPA (Environmental Protection Agency) recommendation for maximum contaminant level (MCL) for radon in drinking water of 11.1 Bq/l.

Keywords—radon, radioactivity dose, public drink fountain.

I. INTRODUCTION

RADON originates from the radioactive decay of naturally occurring uranium and radium deposits. Radon is picked up by groundwater passing through rocks and soil containing such radioactive substances; it enters water supplies when this water is pumped up a well [1]. Some radon stays in the water; drinking water containing radon presents a risk of developing internal organ cancers, primarily stomach cancer. However this risk is smaller than the risk of developing lung cancer from radon released to air from tap water. When water leaves a faucet, dissolved gases are released. This process is increased by mechanical sprays during a shower or by the heating and agitation that occur during laundering, washing, and cooking [2]. Based on a National Academy of Science report, Environmental Protection Agency (EPA) [3] estimates that radon in drinking water causes about 168 cancer deaths per year: 89% from lung cancer caused by breathing radon released to the indoor air from water and 11% from stomach cancer caused by consuming water containing radon. Radon is only a concern if your drinking water comes from underground, such as a well that pumps water from an aquifer, though not all water from underground sources contains radon.

Drinking water is the most important food. Therefore its availability, quality and regulation are delicate and important topics. For this purpose it is fundamental to have regulations about natural radioactivity in drinking water. The European commission recommends for ^{222}Rn , that a reference level should be appointed above an activity concentration of 100 Bq/l [4], and with radon activity concentrations above 1000 Bq/l measures are justified. For the radon progenies ^{210}Pb and ^{210}Po the Commission recommends (European Commission, 2001) that above an activity concentration of 0.2 Bq/l and 0.1 Bq/l respectively, it should be tested whether any measures are necessary.

J. Nikolov is with University of Novi Sad, Faculty of Sciences, Department of Physics, Nuclear Physics Group, Trg Dositeja Obradovica 3, Novi Sad, Serbia (phone: +381459368; fax: +381459367; e-mail: jovana.nikolov@df.uns.ac.rs).

The Safe Drinking Water Act directs the EPA (Environmental Protection Agency) to propose and finalize a maximum contaminant level (MCL) for radon in drinking water, but also to make available an alternative approach: a higher alternative maximum contaminant level (AMCL) accompanied by a multimedia mitigation (MMM) program to address radon risks in indoor air. The proposed MCL is 11.1 Bq/l, and the proposed AMCL is 146 Bq/l [3].

II. ABSORBED DOSE FROM INDOOR RADON

A person in a room will inhale radon decay products that are suspended in air. Some activity can deposit and accumulate in the respiratory airways, depending on breathing patterns and the aerodynamic size of the particles with which the decay products are associated. Because of the short half-lives, the radon decay products that are deposited in the lung will almost certainly decay completely in the lung. The radiations emitted within the lung during these decays can deposit energy in the body. However, this radioactivity is very near the lung epithelium, so alpha particles in particular can transfer copious amounts of energy to vulnerable cells [2].

Radon gas itself is also inhaled. Most of it is exhaled immediately and therefore does not accumulate in the respiratory system, as do radon decay products. Because the radon does not get close to radiosensitive cells, the absorbed dose from alpha particles is small. However, some of the radon that reaches the interior region of the lung is transferred to blood and dispersed throughout the body. Radon and the decay products formed inside the body can deliver a radiation dose to tissues and organs.

On some occasions, water is consumed immediately after leaving the faucet before its radon is released into the air. This water goes directly to the stomach. Before the ingested water leaves the stomach, some of the dissolved radon can diffuse into and through the stomach wall. During that process, the radon passes next to stem or progenitor cells that are radiosensitive. These cells can receive a radiation dose from alpha particles emitted by radon and decay products that are created in the stomach wall. After passing through the wall, radon and decay products are absorbed in blood and transported throughout the body, where they can deliver a dose to other organs [5].

Ingested water eventually passes through the stomach into the small intestine, where the remaining radon and decay products are released from the water and transferred to blood. They then circulate within the body; most are released from the blood into the lung and exhaled, but some remain in the blood and accumulate in organs and tissues, which receive an absorbed dose from alpha, beta, and gamma radiation [2].

Most of the cancer risk from radon in drinking water arises from the transfer of radon into indoor air, and exposure through inhalation, although there is some risk from ingesting water containing radon. The primary health risks from radon in drinking water are lung cancer, from inhaling radon discharged from water used in the home, and stomach cancer, from ingesting radon in drinking water [3].

III. LEGISLATION AND REGULATIONS REGARDING INDOOR RADON

It was recognized that water might also make a substantial contribution to and in some circumstances be the primary source of health risks associated with radon. EPA developed a criteria document that summarized the health effects of radon and its prevalence in drinking water [3]. On the basis of the document and considerations of uncertainties in the analytic procedures for testing for radon in drinking water, a regulation was proposed in 1991 that established a maximum contaminant level (MCL) of 11,1 Bq/l (EPA 1991b). That MCL corresponded to a lifetime individual health risk of 10^{-4} posed largely by an increase in radon in indoor air.

IV. MATERIALS AND METHODS

Only about 1-2 percent of radon in the air comes from drinking water. However, breathing radon release to air from tap water increase the risk of lung cancer over the course of life. In the present research results of radon measurements in 38 bottled drinking water, 6 water samples from public drinking fountain (before the water enters any treatment process) and in 2 tap water samples in the city of Novi Sad, Serbia are presented.

Sampling technique is generally the major source of error in measuring the radon content of water. The water sampled must be representative of the water being tested and such that it has never been in contact with air. In this experiment the samples were collected using the techniques proposed by the manufacturer [6]. In the method a bowl puts up to the faucet so that the water overflowing the bowl prevents the water when leaving the faucet from touching the air and the vial is filled with water at the bottom of the bowl.

The RAD 7 radon detector manufactured by DURRIDGE COMPANY Inc. has been used for radon concentration measurement in the water samples. The RAD H₂O is an accessory to the RAD7 that enables to measure radon in water over a concentration range of from less than 30 pCi/L to greater than 105pCi/L. The lower limit of detection is less than 10 pCi/L. The equipment is portable and battery operated, and the measurement is fast. The RAD H₂O gives results after 30 minutes analysis with a sensitivity that matches or exceeds that of liquid scintillation methods.

The RAD-H₂O method employs a closed loop aeration scheme whereby the air volume and water volume are constant and independent of the flow rate. The air re-circulates through the water and continuously extracts the radon until a state of equilibrium develops. The RAD-H₂O system reaches this state of equilibrium within about 5 minutes, after which no more

radon can be extracted from the water. The extraction efficiency, or percentage of radon removed from the water to the air loop, is very high, 94% for a 250 ml sample. The exact value of the extraction efficiency depends somewhat on ambient temperature, but it is almost always well above 90% [6].

The radon content of the water, at the time of the analysis, is the mean value shown in the printout. This value takes into account the calibration of the RAD7, the size of the sample vial and the total volume of the closed air loop, as set up.

If a sample is taken and analyzed some time latter (rather than immediately), the sample's radon concentration will decline due to the radioactive decay. It is necessary to correct the result for the sample's decay from the time the sample was drawn to the time the sample was counted. Decay correction can be used for samples counted up to 10 days after sampling, though analytical precision will decline as the sample gets weaker and weaker. The decay correction is a simple exponential function with a time constant of 132.4 hours.

V. EVALUATION AND MEAN ANNUAL RADON DOSE

Values reported for the dose to the stomach per unit radon activity ingested (a dose coefficient) vary widely and they are often based on assumptions that are not documented, and very often they are not based on contemporary dosimetric methods [2]. The central issues are: 1) the extent to which radon diffuses into the wall of the stomach, and 2) the behavior of radon and its decay products in the body. Studies of the behavior in the body of inhaled and ingested radon indicate that radon is readily absorbed by blood and is rapidly eliminated from the body in exhaled air [7].

The radon concentration of drinking water is an important issue from the dosimetry aspect, because more attention is paid to the control of public natural radiation exposure. Regarding radiation dose to the public, due to waterborne radon, it is believed that waterborne radon may cause higher risk than all other contaminants in water [8]. Radon enters human body through ingestion and through inhalation as radon is released from water to indoor air. Therefore, radon in water is a source of radiation dose to stomach and lungs. The annual effective doses for ingestion and inhalation were calculated according to parameters introduced by UNSCEAR report [9].

For ingestion, the following parameters were used:

- (i) The effective dose coefficient from ingestion equals 3.5 nSv/(Bq l);
- (ii) Annual intakes by infants, children and adults are found to be about 100, 75 and 50 liters, respectively;
- (iii) The annual effective doses, due to ingestion corresponding to 1 Bq/l, would be equal to 0.35 μ Sv/y for infants, 0.26 μ Sv/y for children and 0.18 μ Sv/y for adults.

For inhalation, the following parameters were used:

- (i) Ratio of radon in air to radon in tap water supply is in the range of 4 to 10;
- (ii) Average indoor occupancy time per person is about 7000 h/y;
- (iii) Equilibrium factor between radon and its progeny is

equal to 0.4;

(iv) Dose conversion factor for radon exposure is $9 \text{ nSv}/(\text{Bq h m}^3)$.

The annual effective dose due to inhalation corresponding to the concentration of 1 Bq/l in tap water is $2.5 \text{ } \mu\text{Sv/y}$. Therefore, waterborne radon concentration of 1 Bq/l causes total effective dose of about $2.68 \text{ } \mu\text{Sv/y}$ for adults. The mean annual effective dose per person for adults caused by different water samples are reported in Tables I and II.

VI. DOSE TO ORGANS OTHER THAN THE LUNG FROM INHALED ^{222}Rn

Any inhaled gas, including radon, is slightly soluble in body tissues. Radon in the lung diffuses to blood and is transported to other organs, where the gas and the decay products that build up in the tissue deliver a radiation dose. The dose per unit exposure for organs other than the lung are shown in Table 3, where it can be seen that the dose to other organs is lower than the dose to the bronchial epithelium, in most cases by a factor of about 100 [2].

TABLE I
THE WEIGHTED EQUIVALENT DOSE TO TISSUES OTHER THAN THE LUNG FOR CONTINUOUS EXPOSURE TO 1 BQ M^{-3} OF ^{222}Rn IN AIR [2]

Tissue	mSv y^{-1} per Bq m^{-3}
Liver	$5.1 \cdot 10^{-3}$
Kidneys	$5.6 \cdot 10^{-3}$
Spleen	$5.2 \cdot 10^{-3}$
Red Bone Marrow	$9.6 \cdot 10^{-3}$
Bone Surfaces	$2.5 \cdot 10^{-3}$
Soft Tissue	$3.0 \cdot 10^{-3}$
Adipose Tissue	$9.0 \cdot 10^{-3}$
Skin	$50 \cdot 10^{-3}$
Normal Marrow	$6.3 \cdot 10^{-3}$
Adipose Tissue Marrow	$16 \cdot 10^{-3}$
Bone Surfaces (Normal Marrow)	$1.5 \cdot 10^{-3}$
Bone Surfaces (Adipose Tissue Marrow)	$3.0 \cdot 10^{-3}$
T Lymphocytes	0.01
Alveolar Capillaries	$20 \cdot 10^{-3}$

VII. RESULTS AND DISCUSSION

A. Radon in Water from Public Drink Fountain in the City of Novi Sad

Not all drinking water contains radon. If drinking water comes from a surface water source, such as a river, lake, or reservoir, most radon that might be in the water will be released into the air before reaching water supplier or home. Radon is only a concern if drinking water comes from underground, such as a well that pumps water from an aquifer, though not all water from underground sources contains radon [3].

Results of radon concentration measurements from 6 public drink fountains in city of Novi Sad are presented. The public drink fountains are placed in the city (one in the park (Limanski park), one on the Danube's river beach (Ribarsko ostrvo), one on the urban boulevard (cesma SPENS), one in the Sremski Karlovci (Lenjinova ulica) and two on the suburban road which connect Novi Sad and Sremski Karlovci.

Residents most commonly used drinking water directly from the tap, poured into bottles and used in households for drinking and cooking. Although tap water chemical, bacteriological and radiological correct, opinion of some people is that water from public drink fountain is much healthier and even healing.

These are the first results of measurements of radon in public fountains. As in the four fountains activity concentrations of radon is above the recommended EPA MCM level of 11.1 Bq/l , a further step is to introduce the City Administration with the results, and take all measures and actions to reduce their radon level before public usage and protect citizens.

The World Health Organization [10] and the EU Council [11] recommend the determination of reference level of the annual effective dose received from drinking water consumption at 0.1 mSv/y from these three radioisotopes: ^{222}Rn , ^3H , ^{40}K .

TABLE II
RESULTS OF RADON MEASUREMENTS IN WATER FROM PUBLIC DRINK FOUNTAINS

No	WATER SAMPLE	Activity Concentrations [Bq/l]	ANNUAL EFFECTIVE DOSE OF ADULTS [$\mu\text{Sv/year}$]	
			Stomach	Lung
1.	Fountain "Limanski park"	18.4 ± 1.7	3.312	46
2.	Fountain "SPENS"	13.9 ± 1.4	2.502	34.75
3.	Fountain entrance to Sremski Karlovci	9.8 ± 1.1	1.764	24.5
4.	Fountain exit from Sremski Karlovci	3.9 ± 1.1	0.702	9.75
5.	Fountain "Lenjinova ulica"	4.6 ± 1.5	0.828	11.5
6.	Fountain "Ribarsko ostrvo"	18.6 ± 1.3	3.348	46.5

B. Radon in bottled drinking water and tap water

Water samples were taken from public transport, where we tried to perform measurements of all bottled drinking water that can be found in the market in Serbia. Some waters are measured several times, with the different date of charging. Also, it was managed that the water be “fresher”, which means that for the time elapsed from the date of bottled as short as possible. The decay corrections were done for every sample, which gives the activity of water on the date of filling. The initial activity of these waters are unknown, because it is not known how much time has elapsed since storage of water until the filling.

From the results it can be concluded that the majority of bottled drinking water is safe to use from the standpoint of concentration of radon in them, (if the EPA adopted the recommendations of the permitted concentration of radon in drinking water from 146 Bq / l). The highest concentration of ^{222}Rn was measured in natural water “AQUA VIVA”. The activity concentrations was 1463 ± 316 Bq / l, which significantly exceeds the recommended level. Source of this water is in the rocks of volcanic origin, which may explain the high radon concentration. Hence, it should be noted that the corrected activity is equal to the radon activity present at the time of charging, and that bottled water is used at least a few days later. In sparkling bottled water radon concentration is negligible, which can be explained by the fact that during the addition of CO_2 radon leaves the water.

TABLE III
RESULTS OF RADON MEASUREMENTS IN BOTTLED DRINKING WATER AND IN TAP WATER

No	WATER SAMPLE	Activity Concentration [Bq/l]	ANNUAL EFFECTIVE DOSE OF ADULTS [$\mu\text{Sv}/\text{year}$]	
			Stomach	Lung
1.	Tap water, Novi Sad	3.9 ± 0.5	0.702	9.750
2.	PI-VODA 1.5l Purified Drinking Water PROLOM	2.5 ± 0.8	0.450	1.125
3.	VODA 1.5l natural water	14.3 ± 3.5	2.574	35.750
4.	Tap water, Novi Sad	3.9 ± 1.1	0.702	9.750
5.	AQUA VIVA 0.5l natural water	1463 ± 316	263.34	3657.5
6.	ROSA 0.5l natural water	18.3 ± 11.7	3.294	45.750
7.	Tap water, Backi Petrovac PROLOM	0.75 ± 0.08	0.135	1.875
8.	VODA 2l sparkling water KNJAZ MILOS	71 ± 33	12.780	177.5
9.	1.5l sparkling water	1.59 ± 0.04	0.286	3.975

The other measured samples of bottled water showed radon activity concentrations under minimum detectible activity and they are not included in the Table III.

The above results show that in view of radon concentration,

having in mind the EPA MCM recommendation for allowed radon level in drinking waters of 11.1 Bq/l, almost all of bottled waters are safe for utilization.

VIII. CONCLUSION

The results of the study well indicate that the radon concentrations in public drinking water samples in Serbia are mostly low enough and below the proposed concentrations limit [4]. Samples number 1, 2 and 6 (Table II) exceed the limitation of 11.1 Bq/l. According to the advice of WHO and EU Council, just one water sample induced the total annual effective dose greater than 0.1 mSv/y (Sample 5, Table III). Unfortunately, up till now, there is no specific national regulation for radioactivity in drinking water in Serbia.

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