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ORIGINAL PAPER

Radon ^{222}Rn in drinking water of West Pomeranian Voivodeship and Kuyavian-Pomeranian Voivodeship, Poland

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Abstract. Radon Rn-222 is a commonly occurring natural radionuclide found in the environment from uranium--radium radioactive series, which is the decay product of radium Ra-226. The presence of radon carries negative health effects. It is, in fact, classified as a carcinogen, and therefore, it is necessary to continuously monitor its concentration. The aim of this study was to determine the level of radon-222 concentration in water intended for human consumption in the two voivodeships of Poland: West Pomeranian and Kuyavian-Pomeranian. Measurements were performed for more than 60 intakes. The level of radon was measured by using the liquid scintillation counting method. The range of measured radon concentration in the water from the West Pomeranian Voivodeship was from 0.90 to 11.41 Bq/dm^3 with an average of 5.01 Bq/dm^3, while that from the Kuyavian-Pomeranian Voivodeship was from 1.22 to 24.20 Bq/dm^3 with an average of 4.67 Bq/dm^3. Only in three water intakes, the concentration of radon-222 exceeded the value of 10 Bq/dm^3. The obtained results allowed to conclude that population exposure associated with radon-222 in water is negligible and there is no need to take further action. In the case of three intakes where a higher concentration of radon was found, the potential exposure was low.

Keywords: drinking water • ionizing radiation • Kuyavian-Pomeranian Voivodeship • preliminary monitoring of radioactivity • radon-222 concentration • West Pomeranian Voivodeship

Introduction

Radon-222 is a commonly occurring radioactive noble gas found in the environment, which is odorless, tasteless and not chemically reactive. It is easily soluble in water. When water is heated to the boiling point, Rn-222 is almost completely removed. Dissolved in water, radon can easily emanate when using a shower for example. Radon decays (with a half-life of 3.8 days) to several radionuclides that are solids. Radon-222 and its short-lived decay products such as polonium-218, lead-214, bismuth-214 and polonium-214 are primarily alpha and beta emitters. The source of the radon-222 in water is its precursor in radioactive uranium series: isotope radium-226. The sources of radon in the lithosphere are primarily rocks containing uranium (radium) or other minerals in which uranium (radium) occurs. The concentration of Rn-222 in groundwater depends on the time water is present in contact with the rock material, the degree of rock fragility, radon emanation coefficient from rocks and the content of radium-226 in rocks. A high level of radium-226 in water usually provides high radon-222 content; however, a high concentration of radon in water does not always correspond to a high concentration of radium-226.

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As a result of consumption of water with increased content of radon-222 by humans, the gastrointestinal tract, particularly the stomach, receives the highest dose of ionizing radiation. Other organs such as liver and lung are also exposed to ionizing radiation but to a lower extent [1–5].

Until recently, there were no official requirements in Poland specifying the acceptable concentration of Rn-222 in water intended for human consumption. The situation changed when the Directive 2013/51/EURATOM [6] was introduced. It enforced the implementation of the regulation in this area. In Poland, the requirements in relation to the content of radionuclides in water were specified in the Regulation of the Minister of the Health of 7 December 2017 on the quality of the water intended for human consumption [7].

Owing to the obligation to carry out the preliminary measurement of radioactive substances and subsequent constants, control monitoring was introduced. This requirement was imposed as part of internal water quality control on water and sewage entities and companies that provide water from individual intakes as part of their business.

The aim of this study was to determine the level of concentration of Rn-222 in water intended for human consumption in Poland in the two voivodeships: West Pomeranian and Kuyavian-Pomeranian.

Material and methods

Samples of raw water for the surveys were taken by the workers of the water and sewage entities and sanitary-epidemiological stations from the West Pomeranian and Kuyavian-Pomeranian voivodeships in years 2016 and 2017. Samples for surveys were taken from wells, water intakes and water treatment plants. These are places from which water is very often taken by people from both voivodeships.

The sampling of water was based on the instruction prepared by the Department of Radiation Hygiene and Radiobiology, National Institute of Public Health – National Institute of Hygiene (NIPH-NIH) [8]. The procedure of examining sampling water was based on releasing water for 15 min from the intake and then gathering the appropriate sample into a glass bottle of volume 0.5 dm^3. Water was poured slowly up to the neck of the bottle. In this way, air did not stay in the bottle. Additionally, the screw of bottle was preserved with a foil in order to minimize the risk of radon from getting out of the container.

After intake, the samples of water together with the collection protocols were sent as soon as possible to the laboratory. In the laboratory, the samples were prepared: 10 cm^3 of water was moved to the Packard vessel (22 cm^3), and then, 10 cm^3 scintillation solution of Opti-Fluor O was added. The samples were shaken for 5 s and then waited for at least 3 h, until the radon, which has a greater affinity to aromatic hydrocarbons, was extracted into the organic phase.

After this procedure, radioactive equilibrium existed between radon-222 and its decay products. Measurements of radon-222 concentrations were performed by using the liquid scintillation counting method. The scintillation counter Tri-Carb 1900 TR (Canberra-Packard Company, USA) was used. Three alpha and two beta particles resulting from the decay of Rn-222 and its derivatives were recorded. The results were achieved using a computer program (PicoRad Radon Analysis Program; Nitron, Inc., ver. 6.06). This program recounted the counting frequency of radon concentration in analysed samples. The control parameters for this program were date and time of water sampling, the date and time of the connection with the scintillation solution, the temperature of water, counting frequency and measurement time. The measurement time was from 20 to 60 min. The extended uncertainty (k = 1.96) of the measurement ranged from 5.6 to 29.1%.

Results and discussion

Radon-222 concentration measurements were carried out in 61 water samples from West Pomeranian

Table 1. Radon-222 concentration in water from the West Pomeranian Voivodeship

Name of intake place	Concentration [Bq/dm^3]	Uncertainty [Bq/dm^3]
Intake area no. I		
well drilled no. 6	6.04	0.78
well drilled no. 9a	11.41	1.05
well drilled no. 12b	6.19	0.79
well drilled no. 13a	7.71	0.43
well drilled no. 14	6.65	0.81
well drilled no. 15a	5.04	0.73
well drilled no. 16	8.16	0.88
well drilled no. 17a	8.54	0.90
well drilled no. 18a	5.05	0.73
well drilled no. 19	4.22	0.70
well drilled no. 20	7.29	0.84
well drilled no. 21	6.00	1.03
Intake area no. II		
well drilled no. 1a	4.54	0.71
well drilled no. 2a	5.73	0.77
well drilled no. 5b	3.87	0.68
well drilled no. 1az	5.04	0.73
well drilled no. 2az'	4.54	0.71
well drilled no. 5bz	3.82	0.68
Intake area no. III		
well drilled no. 6a	3.77	1.05
well drilled no. 15a	3.73	0.79
well drilled no. 16a	4.15	0.43
well drilled no. 17a	2.90	0.81
well drilled no. 18a	2.90	0.73
well drilled no. 22	5.58	0.88
well drilled no. 23	4.57	0.90
well drilled no. 24a	4.76	0.36
well drilled no. 25a	6.27	0.40
Intake area no. IV		
well drilled no. 2	1.99	0.51
well drilled no. 3	2.94	0.65
Kurowski channel	1.03	0.30
Miedwie lake	<0.9	
Average	**5.01**	**0.74**

Table 2. Radon-222 concentration in water from the Kuyavian-Pomeranian Voivodeship

Name of intake place	Concentration [Bq/dm^3]	Uncertainty [Bq/dm^3]
Białkowo	2.54	0.31
Bochlin – water treatment plant	3.34	0.39
Boguszewo – water treatment plant	2.81	0.33
Chełmno	7.84	0.78
Drzycim – water treatment plant	4.34	0.49
Górna Grupa	4.51	0.52
Górzno-Wybudowanie – water treatment plant	2.79	0.33
Gródek – water treatment plant	3.11	0.35
Gruczno	2.38	0.28
Grudziądz – Hallera St.	4.40	0.48
Grudziądz – Parkowa St.	19.91	1.94
Grudziądz – Słowackiego St.	24.20	2.35
Grudziądz – water treatment plant	2.98	0.34
Gruta – water treatment plant	2.46	0.30
Jaszcz	4.59	0.50
Kłódka – water treatment plant	3.68	0.43
Mełno – water treatment plant	1.99	0.24
Mgowo – water treatment plant	3.82	0.43
Morsk	2.51	0.30
Nowe – meat processing plant	1.99	0.25
Nowe – water treatment plant	1.22	0.15
Osie	4.40	0.48
Plemięta – water treatment plant	2.49	0.30
Płużnica – water treatment plant	2.00	0.25
Rogoźno – water treatment plant	2.50	0.30
Szembruk – water treatment plant	2.48	0.30
Terespol Pomorski	6.54	0,66
Tleń	4.88	0.53
Tryl – water treatment plant	3.69	0.43
Zarośle – water treatment plant	3.72	0.44
Average	**4.67**	**0.51**

Voivodeship and Kuyavian-Pomeranian Voivodeship. The obtained results for the West Pomeranian Voivodeship are given in Table 1 and those for the Kuyavian-Pomeranian Voivodeship are given in Table 2.

In water samples taken from the West Pomeranian Voivodeship, the range of measured radon-222 concentration was from 0.9 to 11.41 Bq/dm^3, with an average value of 5.01 Bq/dm^3. In water samples from the Kuyavian-Pomeranian Voivodeship, the range of measured radon concentration was from 1.22 to 24.20 Bq/dm^3, with an average value of 4.67 Bq/dm^3. Based on analysis of the results, one can observe that the concentrations of Rn-222 from both voivodeships are on a similar level (average values). Only in one water sample from the West Pomeranian Voivodeship and in two water samples from the Kuyavian-Pomeranian Voivodeship, the concentration of Rn-222 was found to be higher than the value of 10 Bq/dm^3.

The obtained results indicate that in majority of cases, the concentration of Rn-222 is less than 10 Bq/dm^3. It means that in accordance with the Regulation of the Minister of the Health of 7 December 2017 on the quality of the water intended for human consumption, the exposure to the population is negligible. Water providers do not have to take additional actions to reduce radon level. The next surveys should be carried out after 10 years. With regard to the three intakes where radon concentration was found to be more than 10 Bq/dm^3, the exposure to the population should be considered as low. The concentration of Rn-222 obtained for these three intakes enforced, however, on water suppliers the need for increased control including the renewed measurement of radon after 6 months. Depending on its result, the frequency of further surveys is 5 years (for concentrations lower than 50 Bq/dm^3) or 2 years (for concentrations in the range of 50–100 Bq/dm^3) [7].

A detailed description of the procedure depending on the measured Rn-222 activity concentration and exposure assessment is presented in Table 3 [7].

The valid exposure assessment in Poland, presented in Table 3, specifies the procedure depending on the measured radon-222 activity concentration in water intended for human consumption. In case the concentration of Rn-222 more than 100 Bq/dm^3 is discovered at the point of water intake, it must be assessed whether the presence of radioactive substances in water is threatening to human health. If necessary, a corrective action plan should be undertaken to improve the quality of water to a level corresponding to the requirements for the protection of human health from radiation.

Table 3. Exposure assesment and procedure depending on the activity concentration of radon-222 in drinking water

Activity concentration of Rn-222 in water C_{Rn} [Bq/dm^3]	Exposure assessment	Procedure	Survey
≤10	Lack or marginal	The system under control – no special action required.	Once in 10 years.
$10 < C_{Rn} \leq 100$	Low	Increased control of measurements is needed. Further actions depends on the result of the next survey.	The second survey after 6 months. If the radon concentration does not exceed 50 Bq/dm^3, a test should be carried out with a frequency of once per 5 years. If the activity concentration of the determined parameter is between 50 and 99.9(9) Bq/dm^3, the frequency of survey should be once every 2 years.
$100 < C_{Rn} \leq 999.9(9)$	Medium	It must be assessed whether the presence of radioactive substances in water is threatening to human health. If necessary, the correction action plan should be taken to improve quality of water to a level corresponding to the requirements for the protection of human health from radiation.	The second study after 6 months, and the third test should be carried out after 6 months of the previous study, if the concentration of radon in the preliminary monitoring does not exceed 500 Bq/dm^3, a test is required at a frequency of once per year. If the concentration of radon in the preliminary monitoring is more than 500 Bq/dm^3, a test is required at a frequency of once per 6 months.

Conclusions

1. The average value of Rn-222 concentration in analysed samples of drinking water from the West Pomeranian Voivodeship was 5.01 Bq/dm^3 and that from the Kuyavian-Pomeranian Voivodeship was 4.67 Bq/dm^3.
2. In three water samples, the measured concentration of Rn-222 exceeded 10 Bq/dm^3.
3. The population exposure associated with Rn-222 in water should be described as negligible (concentration less than 10 Bq/dm^3) or low (concentration between 10 and 100 Bq/dm^3).

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