Article

Assessment of Effective Dose from Radioactive Isotopes Contained in Mineral Waters Received by Patients During Hydrotherapy Treatments

Maria Karpińska ^{1,*}, Jacek Kapala ¹, Agnieszka Raciborska ¹ and Stanisław Mnich ²

¹ Department of Biophysics, Medical University of Białystok, Mickiewicza 2A, 15-222 Białystok, Poland; jacek.kapala@umb.edu.pl (J.K.); agnieszka.raciborska@umb.edu.pl (A.R.)

² The State Higher School of Computer Science and Business Administration in Lomza, Akademicka 14, 18-400 Lomza, Poland; mnich@umb.edu.pl

* Correspondence: maria.karpinska@umb.edu.pl

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Abstract: Hydrotherapy is a natural treatment and health protection method. Treatments using natural mineral water are gaining popularity as an alternative to pharmacotherapy or as additional support to pharmacotherapy in many types of diseases. The aim of the study was to determine the effective dose obtained as a result of baths and inhalations using popular mineral water samples. A total of 18 commercially available water samples used in hydrotherapy were tested for their radioactive isotope content. The following isotopes were found: ^{40}K , ^{208}Tl , ^{212}Bi , ^{212}Pb , ^{214}Bi , ^{214}Pb , ^{226}Ra , ^{228}Ac , ^{234}Th . Effective doses received by patients during inhalation and bathing using the tested mineral water samples were determined. The collected sample activity was measured using gamma spectrometry. The effective doses received by patients from a series of inhalation treatments ranged from 170.4 to 22.9 μSv . Infants receive the highest effective dose as a result of inhalation of mineral water. The doses received by patients as a result of bathing in the studied mineral water samples were in the range of from 0.04 to 1.1 μSv and were comparable with doses from ordinary baths in tap water (0.06 μSv). The determined doses are very low; thus, they are unlikely to cause noticeable biological effects.

Keywords: inhalation; hydrotherapy

1. Introduction

In recent years, there has been growing interest in natural treatments and health protection methods. The health-promoting properties of various types of water used in health resorts and spas have been confirmed by long-term observations and clinical studies. Curative water is considered a mineral resource, and its use and protection are regulated by the Polish Geological and Mining Law (2011) [1] and the Polish Act on Pharmaceutical Law (2001) [2]. Pursuant to the Polish Geological and Mining Law, therapeutic water is currently defined as groundwater that is not chemically or microbiologically contaminated, characterized by natural variability of physical and chemical properties with a content of dissolved solid mineral components not less than 1000 mg dm^{-3} or one of the following: ferrous ion—no less than 10 mg dm^{-3} ; fluoride ion—no less than 2 mg dm^{-3} ; iodide ion—no less than 1 mg dm^{-3} ; bivalent sulfur—no less than 1 mg dm^{-3} ; metasilicic acid—no less than 70 mg dm^{-3} ; radon—no less than 74 Bq dm^{-3} ; unbound carbon dioxide—no less than 250 mg dm^{-3} . Hydrotherapy uses brine, sulphide, peat mud, and other types of water in baths, inhalations, mouth rinses, and wet compresses. The suitability of mineral water is assessed on the basis of the microelement content, such as sodium, bromine, iodine, boron, manganese, calcium, as well as bicarbonate and chloride anions, not taking into account radioactive elements widely available in the natural environment.

Naturally occurring radionuclides in water mainly come from three radioactive series (^{235}U , ^{238}U , and ^{232}Th). These radioactive series are the source of 43 radioactive isotopes. In addition, water may contain radioactive potassium ^{40}K , whose activity concentration always remains in a constant ratio (0.012%) to stable potassium ^{39}K . Natural radionuclides and their decay products are transported with water extracted from bore-holes and later used in therapeutic treatments. Bathing can lead to external exposure, while inhalation and mouth rinsing to internal exposure.

There are few estimations of the effective dose received by patients during balneological treatments as a result of ionizing radiation and its impact on the body, and mainly cover radiation caused by radon ^{222}Rn [3–6] or drinking mineral water [5,7–11].

It is important to determine the content of natural and artificial radioactive substances present in water samples used for inhalation and bathing because these treatments have recently been more widely used in outpatient treatment. Inhalations are particularly popular for treating upper respiratory tract infections in children. Introduction of mineral water with increased radioisotope content through inhalation may burden the patients with an additional dose that should be estimated.

The aim of the study was to collect information on the content of natural radioactive isotopes in commercially available therapeutic water samples used in hydrotherapy, and to determine the inhalation and skin dose from the isotopes contained therein received by patients.

2. Materials and Methods

Samples for testing are commercially available. We purchased all the types of mineral water intended for bathing and inhalation available on the Polish market. The sample descriptions are presented in Table 1. Measurement of sample activity was performed by gamma spectrometry, using a CANBERRA spectrometric set with a 34.8% coaxial germanium detector and Genie2000 computer system for spectral collection and analysis. This method ensures lower detection limits, using Marinelli geometry (450 mL), calculated using the method according to Lloyd A. Currie, at a level of 0.1 Bq L^{-1} .

The detector is placed in a lead shielding with a wall thickness of 10 cm, lined with two layers of aluminum and copper sheeting. The same measurement time of 160,000 s was used for all samples.

Table 1. Description of samples.

No.	Sample Name	Description of Sample
1	Zabłocka iodine-bromine brine mist	Source Dębowiec near Skoczów
2	Rabczańska iodine-bromine brine	“Krakus” spring at Rabka Zdrój
3	Zabłocka iodine-bromine thermal salt	Source Dębowiec near Skoczów
4	Rabczańska Thermal Brine	Source “Rabka” IG-2 at Rabka Zdrój
5	Kołobrzeg peat mud water	Kołobrzeg Health Resort
6	Dziedziła water	Source “Dziedziła” at Szczawa
7	Solec Zdrój sulfur water	Solec Zdrój Health Resort
8	Ciechocinek brine water 1	Ciechocinek mineral spring
9	Ciechocinek brine water 2	Ciechocinek mineral spring
10	Szczawa water	Source “Szczawa I” at Szczawa
11	Konstancin therapeutic brine water	Source “Warszawa IG” at Konstancin Zdrój Health Resort
12	Kołobrzeg iodine-mineral brine	Source no. 7 “Warcisław” at Kołobrzeg Health Resort
13	Goczałkowice Zdrój brine for inhalation	Goczałkowice- Zdrój Health Resort
14	Goczałkowice Zdrój bath brine	Goczałkowice- Zdrój Health Resort
15	Półczyńska brine	Source “IG-1” at Półczyn Health Resort
16	Ciechocińska bath brine	Ciechocinek Health Resort
17	Bath brine from Zabłocie	Bore-hole “Korona” at Zabłocie Solanka Health Resort
18	Brine from Zabłocie for inhaling	Bore-hole “Korona” at Zabłocie Solanka Health Resort
19	municipal water	supply in Białystok

3. Results and Discussion

A total of 18 commercially available water samples used for baths, compresses and inhalations were collected. According to classification:

–3 g L^{–1}—poorly mineralized
 3–10 g L^{–1}—average mineralization
 >10 g L^{–1}—highly mineralized [12]

It was found that highly mineralized water predominated in the studied group (14). The radioactive isotope content in 18 mineral water samples used for inhalation and bathing was determined. The following isotopes were found: ⁴⁰K, ²⁰⁸Tl, ²¹²Bi, ²¹²Pb, ²¹⁴Bi, ²¹⁴Pb, ²²⁶Ra, ²²⁸Ac, ²³⁴Th.

The total (of all) isotopes radioactivity content in water and its mineralization are presented in Table 2. The reference level was the total activity and mineralization of water supplied by the municipal water supply system in Białystok (sample number 19).

Table 2. Total activity and mineralization of mineral water samples.

No.	Total Activity (Bq L ^{–1})	Mineralization (g)
1	8	1.44
2	9	24.17
3	6	183.44
4	8	21.0
5	5	60.0
6	7	5.70
7	8	17.07
8	26	5.87
9	52	5.87
10	11	17.13
11	11	71.17
12	13	56.73
13	140	74.5
14	43	71.3
15	11	101.52
16	14	47.38
17	12	42.52
18	9	42.64
19	9	0.9

The largest total activity was demonstrated by the “Goczałkowice Zdrój brine for inhalation” sample (140 Bq L^{–1}); it was highly mineralized. In the tested water samples, four isotopes had the highest specific activity: ⁴⁰K, ²²⁶Ra, ²²⁸Ac, ²³⁴Th. The radioactivity of the isotope content in the tested water samples is shown in Figure 1.

Figure 1. Specific activity of the main isotopes in the tested water samples used in balneology. For comparison, sample number 19 is water from the Białystok water supply system.

3.1. Inhalations

The incidence of respiratory diseases has increased in recent decades. Air pollution plays a significant role in the pathogenesis of chronic respiratory diseases [13]. Inhalation is the unquestioned method of treating respiratory diseases [14]. These treatments are used particularly often in children with upper respiratory tract infections [15].

Inhalation doses received by infants, preschool-aged children, and adults as a result of treatments with mineral water intended for inhalation were determined. The manufacturer informed about the possibility of using a given water for this type of treatment. In total, 20 treatments were assumed, 200 mL of water was used for each treatment. The effective dose was determined using the following equation:

$$E_i = e(g) \times A \quad (1)$$

where: A —absorbed activity, $e(g)$ —effective loading dose from inhalation 1 Bq.

The estimated effective dose values from radioisotopes absorbed by inhalation for adults, children, and infants are presented in Table 3.

The effective dose received by adults as a result of using the aforementioned mineral water samples for inhalation was also estimated. The obtained results are presented in Table 4.

The effective doses received by patients from a series of inhalation treatments ranged from 170.4 to 22.9 μSv . Radium, which was present in the mineral water samples from 76% to 98.8%, had the greatest contribution to the effective dose obtained as a result of inhalation of children, as well as adults. In each age group, the highest value of the effective dose received via inhalation was received by patients using Goczałkowice Zdrój brine for inhalation.

Table 3. Effective doses (in μSv) from all the radioisotopes contained in water samples— E_i and ^{226}Ra contribution to this dose received by infants, children aged 1–2 and 2–7 years as a result of inhalation of mineral water.

Sample Number	≤ 1 year		1–2 years		2–7 years	
	^{226}Ra	E_i	^{226}Ra	E_i	^{226}Ra	E_i
1	8.24	8.50	2.98	3.17	1.74	1.81
2	9.73	10.10	3.52	3.74	2.06	2.13
4	4.68	5.00	1.69	1.91	0.99	1.05
5	2.25	2.50	0.81	0.97	0.48	0.52
6	4.87	5.10	1.76	1.93	1.03	1.08
12	4.93	5.70	1.78	2.32	1.04	1.25
13	168.42	170.40	60.89	62.22	35.63	36.07
14	5.12	6.70	1.85	2.95	1.08	1.44
15	2.81	3.30	1.02	1.31	0.59	0.68
16	5.43	6.10	1.96	2.40	1.15	1.31
18	5.30	5.70	1.92	2.21	1.12	1.25

Table 4. Effective doses from Ra-226 and all isotopes (in μSv) received by adults as a result of inhalation of mineral water samples.

Sample Number	>17 years	
	^{226}Ra	E_i
1	1.11	1.14
2	1.31	1.35
4	0.63	0.67
5	0.30	0.33
6	0.66	0.69
12	0.66	0.76
13	22.67	22.94
14	0.69	0.89
15	0.38	0.45
16	0.73	0.81
18	0.71	0.76

3.2. Baths

Baths and compresses made of balneological raw materials are a fairly common treatment method, especially for adults. Thermal mineral water bathing is a recognized treatment for many diseases. Studies conducted in Turkey and Italy confirmed statistically significant greater improvement in the clinical status of patients treated with thermal mineral baths compared with the control group who used only pharmacotherapy. Some studies indicated a long-term maintained analgesic effect of thermal baths [16,17].

The effective dose from beta and gamma radiation received by adults as a result of mineral water bathing (manufacturer's recommendations) was determined. A cycle of 20 treatments of 30 min each was assumed. We assumed that 90% of the skin is immersed and that the water is not diluted.

The effective dose E_β from the beta emitters was determined from the dependence

$$E_\beta = A \times w \times s \times T \times \beta \quad (2)$$

where: A —surface activity in Bq cm^{-2} , T —exposure time in hours, β —conversion ratio of Sv h^{-1} to Bq cm^{-2} [18], w —skin weighting factor 0.01, s —fraction of immersed skin.

The dose from gamma radiation obtained from compact isotopes in the bath was determined using the following equation:

$$E_\gamma = A \times \text{DCF}_{\text{ef}} \times t \quad (3)$$

where:

DCF_{ef} —conversion factor of $Sv\ s^{-1}$ to $Bq\ m^{-2}$,

T —time in s,

A —surface activity $Bq\ m^{-2}$.

Doses were not determined from alpha emitters received through the skin because alpha particles do not reach the depth at which sensitive basal cells are found in the epidermis 50–100 μm [19]. For practical calculation purposes, the ICRP recommends using a value of 70 μm [19–21]. In the measured water samples, the present isotopes that emit α molecules have too little energy to reach the basal cells.

Table 5 shows the determined doses from gamma and beta radiation obtained as a result of bathing. The last item, which serves as a reference, contains the doses received from analogous treatments with tap water.

Table 5. Doses from beta and gamma radiation received after 20 half-hour baths.

Sample Number	E (μSv)
2	0.05
3	0.04
4	0.05
5	0.04
7	0.06
8	0.24
9	0.49
11	0.09
12	0.1
13	1.1
14	0.37
15	0.091
16	0.12
17	0.1
19	0.06

Doses received by patients as a result of bathing in the tested mineral water samples (intended for this purpose) ranged from 0.04 to 1.1 μSv and were much lower than those received as a result of inhalation, and comparable with the doses received as a result of normal bathing in tap water (0.06 μSv).

Exposure to natural ionizing radiation is one of the therapies used in balneology. The performed treatments include baths, inhalations, and drinking of mineral water. One of the most popular in hydrotherapy is radon water. Patients undergo radon baths (^{222}Rn concentration higher than 74 $Bq\ L^{-1}$) and are treated with radon inhalations. It was found that radon inhalation treatment of patients with arthritis reduced oxidative stress, strengthened immune response, and reduced pain [22]. Patients suffering from rheumatoid arthritis and treated for four weeks with baths containing radon at a concentration of 1.3 $kBq\ L^{-1}$ felt marked improvement. The authors believe that the accompanying radon inhalations had an effect on reduced pain perception [23].

In the Heviz health resort (Hungary), patients received a dose of 81 μSv from ^{222}Rn and its derivatives during a two-week treatment with water baths and accompanying inhalations. Spring water containing radon had a much lower dose, 1.4 μSv [24].

In the 34 tested mineral water sources in the Kłodzko Valley, there were clear differences in the radionuclide content, which resulted in patients receiving significantly different doses during 14 days of treatment. Depending on the source, patients received doses from 0.92 to 28.9 μSv . The lowest value was recorded at the *Pieniawa Józefa II* water source in Polanica Zdrój, and the highest at the *Jerzy* water source in Łądek Zdrój [7]. Exposure to elevated ^{222}Rn concentrations in the Tapolca cave (Hungary) of

patients suffering from lung diseases caused the absorption of doses from 0.18 to 4.22 mSv, depending on therapy duration [4].

The effective dose received by patients during peat mud treatment in Polish health resorts from beta and gamma emitters contained in the mud bath was low, i.e., 0.022 μ Sv [24].

Comparing the dose received during mineral water treatments with the dose received from radon at home by the inhabitants of northeastern Poland (1.8 mSv), we found that the effective dose obtained during bathing or inhalation therapy is at least an order of magnitude smaller [25]. Measurements of isotope activity and dose calculations, both for bathing and inhalation, complete the gap in knowledge about patient exposure during hydrotherapy procedures.

For decades, the matter of assessing the biological effects of low-dose radiation has been the subject of research and controversy. Although the linear dose-effect relationship is still officially accepted, there are papers describing the beneficial health effects of low doses of ionizing radiation, i.e., radiation hormesis [26–30].

In studies investigating radiation hormesis, the radiation doses used ranged from a few to 200 mSv [27–30]. The proposed mechanisms explaining this phenomenon are supposed to be based on stimulating the apoptosis of cells that have slipped from immune surveillance, reducing oxidative stress, and strengthening immune reactions. The papers published thus far in the literature are quite far from comprehensive understanding of this phenomenon [29].

Without commenting on the truth of the radiation hormesis hypothesis, it should be noted that in the majority of studies on this phenomenon doses from 40 to 200 mGy were used, whereby visible effects of the exposures used were observed. The estimated doses received during treatment with mineral water were much smaller.

4. Conclusions

There are few papers determining the effective doses in baths with mineral water. The literature on determining inhalation doses from isotopes contained in mineral water concerns mainly radon. In the study, effective doses obtained from radioactive isotopes present in mineral water samples used in balneological treatments were determined. They ranged from 0.3 to 170.4 μ Sv for inhalations and from 0.04 to 1.1 μ Sv for baths. The determined values are very small doses. The authors studying radiation hormesis obtained relatively small radiobiological effects at doses about two orders of magnitude higher. Generally, the inhalation dose is usually the highest among the doses received during balneological treatments. This is particularly true about the most commonly used radon inhalations. In the case of thermal inhalations, the dose for the lungs can reach over 5 mSv during 14 days of treatment [6]. In light of modern radiobiological knowledge, it is difficult to assume that such small doses that we determined could cause noticeable clinical effects.

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