Mine Water and the Environment (2019) 38:581–589
https://doi.org/10.1007/s10230-019-00626-0

TECHNICAL ARTICLE

Natural Radioactivity in Polish Coal Mines: An Attempt to Assess the Trend of Radium Release into the Environment

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Received: 16 October 2018 / Accepted: 1 August 2019 / Published online: 9 August 2019

Abstract
The highly mineralised formation waters in the coal mines of Poland's Upper Silesian Coal Basin contain natural radioactive nuclides, mostly radium. The ^{226}Ra concentration in the groundwater that flows into the underground mine workings reaches 390 Bq/L, and is sometimes exceeded by the ^{228}Ra concentration. The radium-bearing water sometimes also contain barium ions, which enables coprecipitation of barium-radium sulphate. Another type of radium-bearing water contains sulphate ions instead of barium; in this case, radium is transported to settling ponds and downstream. We have assessed the daily activity of radium in waters flowing into the underground mines and being discharged to the environment. Based on 1995 data, we estimate that the total activity of radium isotopes flowing into the mines was about 1300 MBq/day, while the radium activity in the discharge waters was about 700 MBq/day. A similar assessment performed with 2016 data indicated that the total activity in inflows was roughly 1150 MBq/day, while that discharged to surface waters was about 450 MBq/day.

Keywords Coal mining · Formation waters · Radium inflows · Bottom sediments · Radium balance

Introduction

One of the most serious problems faced by the collieries in Upper Silesia, Poland, are the highly saline waters in the carboniferous strata (Różkowski 1995; Różkowski and Wilk 1982). These formation waters often contain elevated concentrations of natural radionuclides, which are mainly radium isotopes. Upper Silesian radium-bearing waters were first described by Sałdan (1965) and later investigated by Tomza and Lebecka (1981). The predominant radionuclides in these waters are radium ^{226}Ra, a member of the uranium series, and radium ^{228}Ra, a member of the thorium series. The ^{226}Ra concentration in the Upper Silesian brines is usually between 0.1 and 8 Bq/L, while ^{228}Ra concentrations usually range from 0.1 to 10 Bq/L.

Natural waters with similar high radium concentrations have been observed elsewhere (Gucało 1964), especially in oil fields (Alley et al. 2011; Eriksen et al. 2009). Hot springs in Iran contained up to 330 Bq/L of ^{226}Ra (Khademi et al. 1980; Sohrabi 1993). In German coal mines (Centeno et al. 2004; Eggeling et al. 2013; Gans et al. 1981), radium-bearing waters were identified with ^{226}Ra concentrations reaching 63 Bq/L. Galhardi and Bonotto (2017) described radium and uranium measurements upstream and downstream of the discharge from the coal mine, and used the activity ratios of ^{234}U/^{238}U and ^{226}Ra/^{238}U to explain the possible leaching of radionuclides from mine tailings. Although several publications have studied elevated ^{226}Ra concentrations in water, there is little information about radium isotopes from the thorium series (^{228}Ra and ^{224}Ra), as they are more difficult to measure (Eriksen et al. 2009; Dickson 1990; Gans et al. 1981).

Daily ^{226}Ra activity in water flowing into underground galleries and discharging from collieries was first estimated in 1987. Since then, the daily release of radium isotopes has been assessed regularly by monitoring radium concentrations in formation waters flowing into underground workings, and in the waters that then discharge to the natural environment. However, only rough estimates were made for individual or groups of mines (Chałupnik et al. 2017). Detailed analyses of radium concentrations in formation waters at all mine levels have not been conducted.

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More precise analysis of radium in underground waters became necessary in 1995, when approximately half of the mines that were still active were closed. Some of these collieries were allowed to flood, but waters from others are pumped to the surface directly or through active mines' dewatering systems (Bukowski 2015). Furthermore, we expect that more mines will be shut down or combined in the forthcoming years. Some coal mines have already or will begin to exploit deeper levels, up to 1100–1200 m below the surface (Dubiński 2013). We expect that radium will appear in inflows of more saturated brines at deeper levels, although we do not expect significant changes in redox potential (Gzyl et al. 2017).

Brines in the Upper Silesian Coal Basin Collieries

Investigation Site

The Upper Silesian Coal Basin (USCB) is located in the southern part of Poland (Fig. 1). There are currently 31 underground coal mines in this region extracting $\approx 72 \times 10^6$ metric tons (t) of coal per year. In 1995, 66 coal mines operated in the area, extracting $\approx 150 \times 10^6$ t per year. The geological structure of Upper Silesia is very complicated, with numerous faults and other tectonic dislocations (Kotas 1982); see Fig. 2. The geological cross-section of the USCB is shown in Table 1.

There are two hydrological regions in the USCB. The first is located in the southwestern area of the basin, with

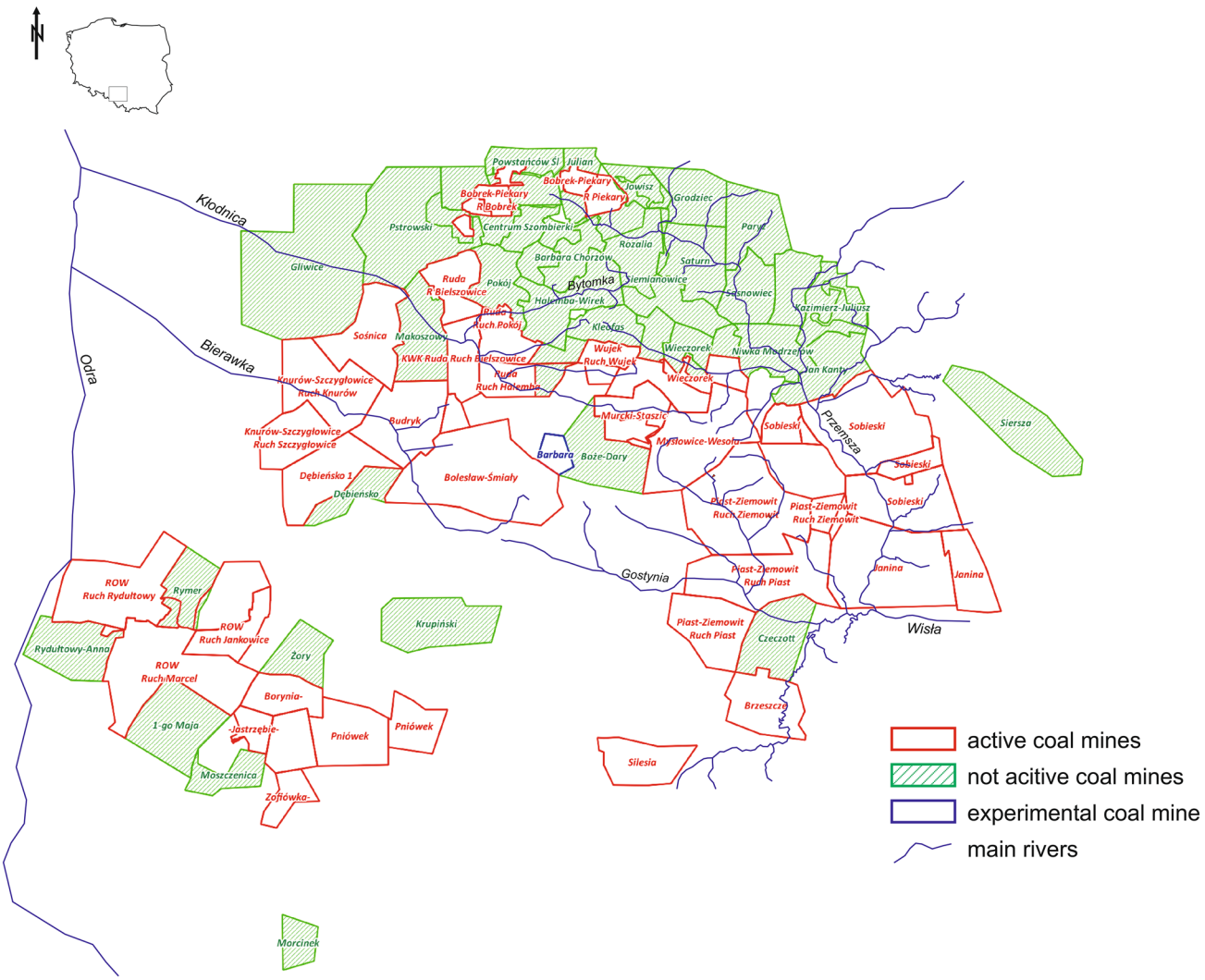

Fig. 1 Abandoned and active coal mines in the Upper Silesian Coal Basin

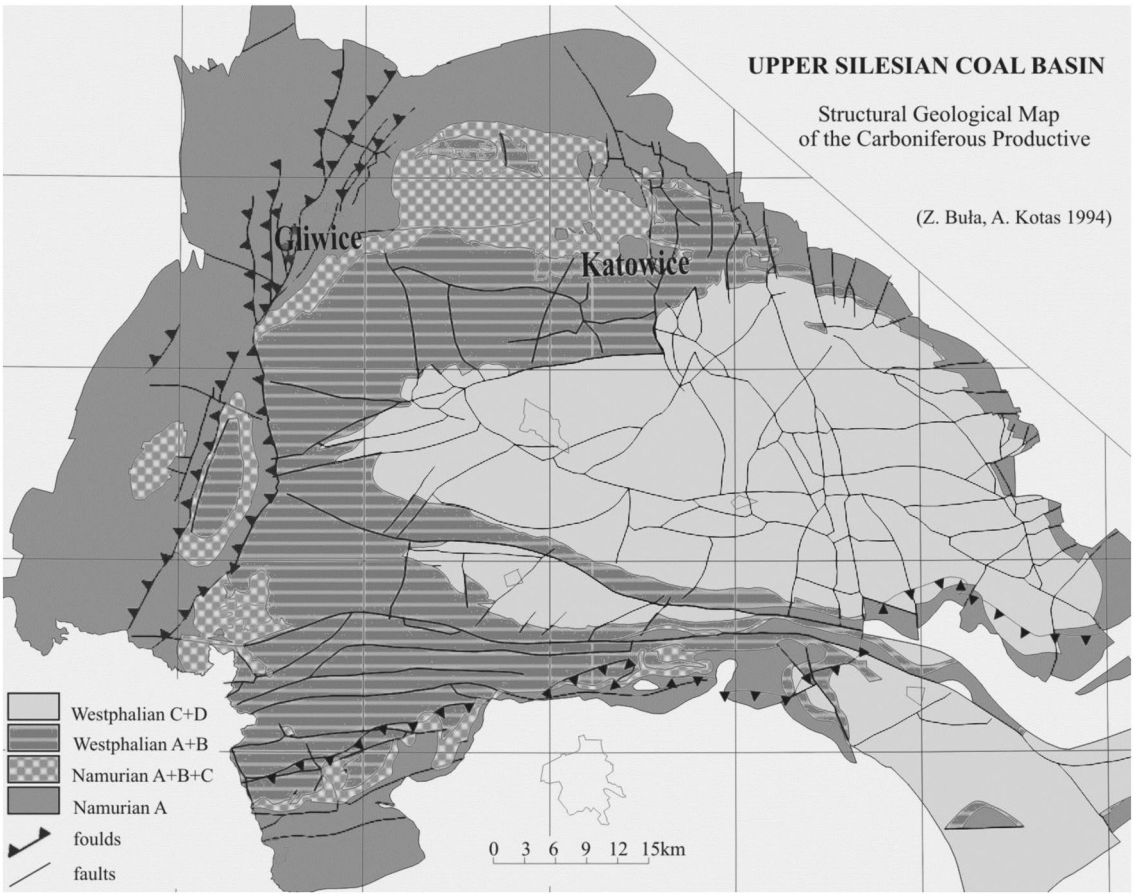

Fig. 2 Tectonic structural map of Carboniferous (based on Buła and Kotas 1994)

Table 1 Stratigraphical classification of the Carboniferous of the Upper Silesian Coal Basin (based on Buła and Kotas 1994)

Namurian			Westphalian			
A	B	C	A	B	C	D
Paralic coal-bearing		**Limnic coal-bearing formation**				
Paralic Series = Marginal Beds		Upper Silesian Sandstone	Mudstone Series		Cracow Sandstone Series	

thick strata of impermeable sediments covering a Carboniferous formation. This overburden (700 m thick) mainly consists of Miocene clays and shales, which render water and gas migration almost impossible.

There are no Miocene clays in the second region. Carboniferous strata are covered by slightly compacted Mesozoic and Quaternary sediments. Meteoric waters, rich in oxygen, can easily reach exploitation zones. Strongly fissured Permian or Triassic limestones are the oldest formations in this area. There are several outcrops of coal seams, enabling easy migration of water and gases. The active and abandoned mines are shown in Fig. 1. Most of the mines in the northern part of the USCB are closed, but due to their interconnectivity, most of them must still be dewatered.

Characteristics of Formation Waters in USCB Collieries

The USCB mine waters contain extremely high concentrations of salts (much higher than oceanic levels), and are

sometimes almost fully saturated. The USCB radium-bearing waters are highly mineralised Cl–Na or Cl–Na–Ca brines. The total dissolved concentration is often ≈ 100,000 mg/L, but may reach ≈ 220,000 mg/L (Różkowski 1995). The dominant anion is Cl^-, which typically does not exceed 100,000 mg/L, while the concentration of HCO_3 reaches 10 mg/L (Bondaruk et al. 2015). Although the dominant cation is Na^+ (up to 50,000 mg/L), there are significant concentrations of Ca^{2+} and Mg^{2+} (up to 10,000 and 7000 mg/L, respectively). Such brines in Silesian collieries contain elevated concentrations of ^{226}Ra and ^{228}Ra, and it has been confirmed that the radium content is correlated with the mine water salinity. We observed ^{226}Ra concentrations in water flowing out from rocks ranging from < 0.002 to 390 Bq/L. While the ^{228}Ra concentrations were sometimes lower, the ^{228}Ra concentrations can exceed that of ^{226}Ra by three times or more (Chałupnik 2007; Wysocka et al. 1998). A similar effect has been observed even in drinking water supplies in Finland, where due to increased salinity near the seashore, radium concentrations were higher there than in inland water supplies (Vesterbacka 2007).

Two types of radium-bearing brine can be distinguished (Tomza et al. 1985)

- Barium-rich water: contains almost no SO_4^{2-} ions, but Ba^{2+} ions are present at relatively high concentrations (up to 6000 mg/L)—not often observed in nature, except in mines;
- Sulphate-rich water: Ba^{2+} ions do not occur in these salty waters, but there are SO_4^{2-} ions at maximum total concentrations of 5000 mg/L.

Although some believe that redox potential is the most important factor affecting radium appearance and behaviour in underground aquifers (Wiegand and Feige 2002) and leaching of radium from rocks, our modelling of radium behaviour (Chałupnik 2008) shows that the only process responsible for radium release into brines is the recoil effect, as was found by others (Dickson 1990; Krishnaswami et al. 1982). Radium activity is further controlled by the salinity of the brines and the presence of barium. Barium can efficiently block the cation exchange centres and prevent radium adsorption. In sulphate-rich brines, sodium (a univalent ion) is not so efficient and there is radium adsorption. This leads to a different activity ratio (^{226}Ra and ^{228}Ra) in barium- and sulphate-rich brines, being 2:1 in the first type of waters, but 1:2 or even 1:3 in the latter one., despite the 1:1 activity ratio of ^{238}U and ^{232}Th in the strata (Krishnaswami and Turekian 1982).

The presence of barium ions greatly influences the behaviour of radium in the environment because it enables the coprecipitation of radium and barium sulphates. Therefore, the radium present in barium-rich water always precipitates, forming radioactive deposits of radio-barite ($BaSO_4 + RaSO_4$) (Martin and Akber 1999; Paschoa and Nobrega 1981; Tomza and Lebecka 1981; Wiegand and Feige 2002). This process can occur due to the spontaneous mixing of natural waters from different aquifers, controlled radium and barium removal, pyrite oxidation and release of sulphate ions, or even underground leaching of fly ash and sulphate from backfilled materials (Chałupnik et al. 2001). Precipitation usually occurs in the underground workings, but sometimes takes place in pipelines transporting water to the surface or in streams, small rivers, or main rivers on the surface (Bondaruk et al. 2015). In the early 1990s, we estimated that 20% of the Polish coal mines (11 collieries) contained barium-rich water. Recent assessments showed that barium-rich waters occur in ≈ 10% of the collieries (only 4 mines). The changes in the chemical composition of the formation waters are due to differing geology as mining depths have increased in the active mines and inflows of barium-rich waters in some of the mines that have closed (Chałupnik et al. 2016).

Radium-rich waters without barium ions are common in the mines in the northern and central areas of the USCB. The hydraulic conductivity of the overburden is relatively high due to the high intergranular and fissure porosity. The permeability of overlying dolomite and limestone is enhanced due to the effects of historical mining and karstic development. Water conditions in the coal measures are determined by the geological structure of the coal basin and anthropogenic factors. The most important factor is the drainage of water through the mine workings (Różkowski 1995; Wagner 1996). Sulphate rich brines are also present in mines with barium and radium-bearing waters. Both types of aquifers are interlaced and mixing of both types of waters leads to spontaneous coprecipitation of sediments with high radium content (Tomza and Lebecka 1981).

The characteristics of Upper Silesian radium-bearing waters are given in Table 2 which is based on the database of the Silesian Centre of Environmental Radioactivity in the Central Mining Institute. The highest radium concentrations are observed in barium and radium-bearing waters, where ^{226}Ra concentrations typically exceed 6.5 Bq/L and sometimes exceed 100 Bq/L. In barium-rich waters, ^{226}Ra concentrations are always higher than ^{228}Ra. In sulphate-rich waters, the predominant radium isotope is the thorium-series ^{228}Ra. However, the concentrations of both radium isotopes in the latter type of waters are significantly lower and have not exceeded 12 Bq/L in recent years, although they previously reached 20 Bq/L (Chałupnik 2007).

The assessment of the daily activity of radium isotopes in waters flowing into underground mine galleries is not very precise due to the reasons described earlier. Water inflows with different salinities, flow rates, chemical compositions, and radium concentrations often enter the same mine. It is

Table 2 Characteristics of typical radium-bearing waters from the Upper Silesian Coal Basin; $K = 1000$

Type of water	Radium concentration [Bq/l]		Chemical compounds [mg/l]										
	^{226}Ra	^{228}Ra	TDS	SO_4^{2-}	Cl	Ba^{2+}	Ca	Mg	Zn	Pb	Cu	Cr	Ni
A (historical data)	0.5–390[a]	0.5–200[a]	30,000–220,000	Traces	Up to 100,000	0.2–3000	Up to 10,000	Up to 7000	Up to 0.60	Up to 1.6	Up to 0.25	Up to 1.00	Up to 1.4
A (data from 2016)	0.002–49.70 ± 1.69	0.06–38.05 ± 3.69	30,000–220,000	Traces	Up to 45,000	0.2–6000	Up to 10,000	Up to 7000	0.01–1.00	0.01–0.06	0.01–0.08	0.02–0.05	0.06–0.15
B (historical data)	0.1–12[a]	0.1–20[a]	500–100,000	Up to 5000	Up to 73,000	Not present	Up to 10,000	Up to 7000	Up to 2.55	Up to 1.6	Up to 0.25	Up to 1.00	Up to 1.4
B (data from 2016)	0.002–6.56 ± 0.28	0.06–11.04 ± 1.05	500–100,000	Up to 3500	Up to 35,000	Not present	Up to 10,000	Up to 7000	0.035–	0.01–0.02	0.01–0.03	<0.02	0.02–0.075

TDS total dissolved solids

[a]The highest values ever measured

especially difficult to assess daily activity in mines where barium-rich and sulphate-rich water flow into the same mine, as spontaneous coprecipitation of radium and barium sulphates occurs immediately after the different waters mix underground. Nonetheless, even a rough approximation provides a better understanding of the scale of the problem.

Methods

Sampling

Water samples were collected by the mining staff during routine underground and surface monitoring, as required by Polish regulations. Chemical and radiological analyses were conducted to measure the concentrations of radium isotopes and other particular ions. Water directly flows into the underground workings from rocks or from boreholes, and the water pumped out from specific mining levels were also sampled in all mines. Radiochemical analyses were conducted by the Central Mining Institute.

Routinely, inflows into the underground workings are sampled once per year, and in mines with radium concentrations above 1 Bq/L, sampling is conducted more frequently. The flow rates are estimated in situ and therefore are not very precise. The level of uncertainty for the flow rate assessment of the inflows from the strata was usually between 15 and 30%, accordingly to data from mines. Assessments of the flow rates from particular horizons in the coal mines were more precise, as the volume of released waters is determined using the flow rate meters of pumps. Therefore, the uncertainty of radium activity in outflowing waters is mostly due to the uncertainty of radium activity concentration measurements (8% for ^{226}Ra and 15% for ^{228}Ra). The surface settling ponds and downgradient brooks and rivers were routinely sampled once a year. Mines with effluent radium concentrations exceeding 1 Bq/L were sampled four times a year. However, assessments of radium activity in surface waters is hampered because flow rates in rivers are usually unstable. The latter values were obtained from the subtraction of radium activity in outflows from the total radium activity in inflows.

Determination of Radium Isotopes

^{226}Ra and ^{228}Ra were determined by liquid scintillation counting after chemical separation of $RaSO_4$ as a barium carrier, following the method developed by Chałupnik and Lebecka (1993). This method allows the simultaneous determination of ^{226}Ra and ^{228}Ra. ^{228}Ra is determined by direct measurements of the low-energy beta particles it emits, while ^{226}Ra is determined by measuring the alpha particles that this radionuclide and its daughter products emit. As the

beta spectrum is continuous, beta particles emitted by ^{226}Ra daughter products are measured in the same energy range as ^{228}Ra. Therefore, this effect must be corrected for. The lower limit of detection (LLD) for ^{226}Ra (0.002 Bq/L) is achieved when a low background liquid scintillation spectrometer QUANTULUS model 1220, Packard Company, is used to analyse the initial 1 L sample, with a counting time of 1 h. The corresponding LLD value for ^{228}Ra is approximately 0.004 Bq/L.

The analyses of natural radionuclides in deposits have been done using low background gamma spectrometry. Sediment samples were dried, pulverized, and homogenized; after that, 0.6 L of the final sample was placed in the Marinelli beaker and measured by high resolution gamma spectrometry. The detection limit for radium isotopes was less than 1 Bq/kg (Michalik 2008).

Results

The main goal of our investigations was to estimate the changes of radium activity in inflows into the USCB collieries as well as in discharges from these mines. To prepare such a balance, two data sets were necessary: the flow rates and radium concentrations. The flow rate(s) of each significant inflow into mine workings and the volumes of water pumped daily to the surface from mines were obtained from every mine, together with water samples. The radium activity balance in the inflows is a sum of products, resulting from multiplication of daily water volumes and radium isotopes concentrations in every investigated inflow. The same procedure was applied for the discharge waters.

As mentioned earlier, the total activity of radium in deposits is the result of subtracting the activity values for the effluents from that of the inflows. Only general water volume data are presented here for the USCB collieries, which changed over time due to the restructuring of the Polish mining industry. For example, in the early 1990s, the total daily inflow of water was ≈ 850,000 m^3. The volume of inflowing water gradually decreased to ≈ 700,000 m^3 per day in 1999. In 2010, the total daily inflow of natural water into mines was 657,500 m^3, of which 35% (almost 230,000 m^3 per day) was pumped from abandoned mines (Bukowski 2015). According to our 2016 assessment, the total daily inflow of water into mines reached ≈ 630,000 m^3. Closing the mines not only caused a decrease in the influent water, but also a change in the water's chemical composition. For example, according to Bukowski and Augustyniak (2013), the total release of chloride and sulphate ions decreased from 8000 t per day in 1991 to 5000 t per day in 2010. We also observed changes in the total activity of radium entering Silesian mines daily in the same period.

The results of the assessment conducted in 1995 showed that the approximate amount of ^{226}Ra in water flowing into the USCB coal mines reached 625 MBq/day (230 GBq per year), while that of the ^{228}Ra was ≈ 700 MBq/day (255 GBq per year). Although radium concentrations in sulphate-rich waters were usually less than in barium-rich waters, the total activity of radium in inflows to mines with sulphate-rich radium-bearing waters was much greater (Skowronek et al. 1998; Wysocka et al. 2017). It should be pointed out that significant concentrations of radium isotopes in waters can only be found in active mines; in closed mines, the mixing of inflows from different aquifers causes the concentration of radium isotopes to not exceed 0,5 Bq/L. Moreover, the daily volume of dewatering is typically much less in abandoned mines than in active mines.

The calculated daily radium activity of mine inflows in 2016 differed from that calculated for 1995; the approximate calculated amount of ^{226}Ra in water flowing into coal mines in the USCB reached 483 MBq/day (176 GBq per year), and 715 MBq/day (260 GBq per year) for ^{228}Ra. Comparing the assessments, the daily activity of ^{226}Ra in inflows was less in 2016 than in 1995, while the activity of ^{228}Ra was comparable. The reasons for the changes in the formation waters are complex. The most important are:

- Several coal mines in which barium-rich waters with elevated concentrations of ^{226}Ra were closed;
- An increase in the inflows of water with higher concentrations of ^{228}Ra than of ^{226}Ra (by a factor of approximately 2) was observed in the three coal mines that are the most important contributors to the daily release of ^{228}Ra;
- Deepening of the exploitation level allowed access to new coal seams where formation waters with elevated radium concentrations occur. The best example is that the radium level in one of the collieries prior to 2010 did not exceed 0.2 Bq/L, but as a result of exploitation at the deeper horizon, the radium activity in inflowing waters increased to 5–7 Bq/L, while the radium content in the discharge waters was 1.5–2.5 Bq/L (Skowronek et al. 1998; Wysocka et al. 2017).
- A reduction in radium removal from underground installation water due to technical and economic problems.

The highest inflow of ^{226}Ra and ^{228}Ra isotopes to collieries with sulphate-rich waters was approximately 245 MBq/day (80 MBq/day of ^{226}Ra and 145 MBq/day of ^{228}Ra). For collieries with barium-rich waters, the corresponding activity was 225 MBq/day (150 MBq/day of ^{226}Ra and 75 MBq/day of ^{228}Ra). The total daily inflow of water into collieries with sulphate-rich waters was ≈ 3.5 times higher than that to collieries with inflows of barium-rich waters.

The daily activity of radium isotopes in inflows and discharge from mines for 1995 and 2016 are compared in Fig. 3.

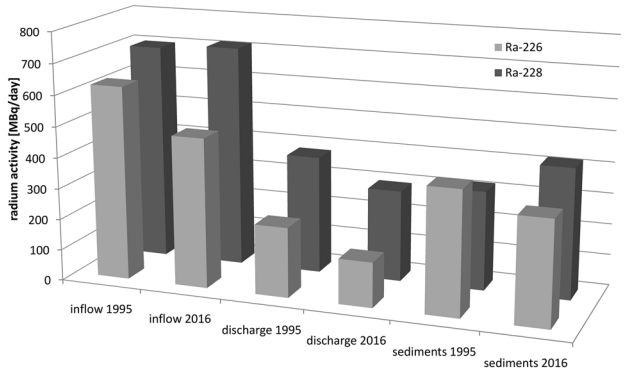

Fig. 3 Comparison of the assessments of the daily activity of radium isotope inflows to coal mines, in discharge waters and sediments in 1995 and 2016 [MBq/day]

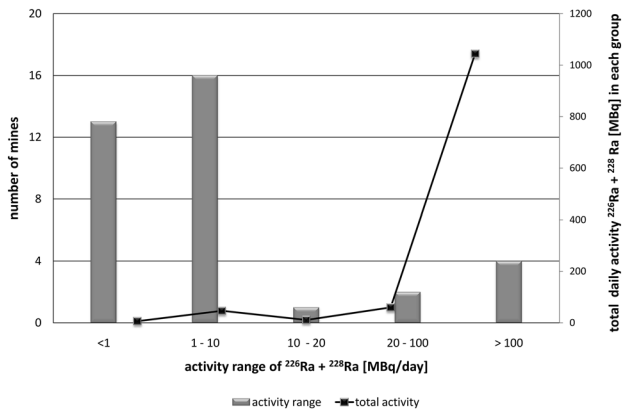

Fig. 4 Distribution of the daily activity of radium $^{226}Ra + ^{228}Ra$ in water flowing into coal mines and total radium activity within each group of coal mine

Additionally, we compared the activities of the radium in water flowing into mines to the activities of radium in water discharged from coal mines to the environment.

Radium accumulates in sediments due to the coprecipitation of barium and radium sulphates and adsorption of radium to bottom sediments. We assumed that the difference between the daily activity of radium in inflows and discharges were a rough estimate of the radium activity in the sediments remaining underground. It is not possible to prove this though, as deposition typically takes place in exploited zones in an uncontrolled way.

The distribution of the ^{226}Ra and ^{228}Ra activities in water flowing into the mines is shown in Fig. 4. In most of the coal mines, the daily radium activity in the inflowing water ranges from 1 to 10 MBq. In the second-largest group of mines, daily radium activity ≤ 1 MBq. However, in four mines, the daily activity of radium in the inflows > 100 MBq. There are thus large differences in the total radium activity within the groups. The lowest total activity for one of the colliery groups equals 6.4 MBq/day, while the highest one exceeds 1000 MBq/day. The contribution of radium activity from these four mines is thus a crucial part of the radium activity in mine waters. Surprisingly, the radium concentrations in the water of those mines is not that high (reaching ≈ 17 Bq/L of ^{226}Ra and ^{228}Ra), but the volume of inflowing formation water is significant, reaching 30,000 m^3/day. This is much higher than that observed in the other coal mines, and the impact of these waters is responsible for approximately 92% of the total daily radium activity release in the entire USCB. However, the highest concentration of radium isotopes in underground inflows (49.70 ± 1.69 Bq/L of ^{226}Ra and 38.05 ± 3.69 Bq/L of ^{228}Ra) was measured as seepage from rocks in 2016.

Environmental pollution caused by the release of radium with the brine from the coal mines is an important issue. The radium (450 MBq/day in 2016) being discharged with mine effluents into surface settling ponds, which are only designed to remove suspended material, is significant, and adsorption of radium to the sediment in these ponds only removes a small portion of the radium activity (5–10%). The remaining activity is released downstream into streams and rivers with the brine, where the radium concentrations gradually decrease due to dilution and slow radium adsorption to the bottom sediments. Elevated radium concentrations, up to 0.05 Bq/L can be seen as far as 100 km downstream from discharge points, as the typical radium concentration in surface and river waters do not exceed 0.008 Bq/L (Koster et al. 1992; Wardaszko et al. 2001). This process leads to the creation of deposits with radium concentrations that often exceed 1 Bq/g.

The typical concentrations of ^{226}Ra and ^{228}Ra in the USCB soils are similar to the world average (25 Bq/kg for both nuclides), while their concentrations in the strata adjacent to the coal seams do not exceed 120 Bq/kg and 100 Bq/kg, respectively (Michalik 2005; Wysocka and Skowronek 1991). This value has been established as the "exemption level" in the Euratom/59/2013 EU Directive (European Council 2014). Therefore, the dewatering of coal mines will require a decision by the National Atomic Energy Agency for a method to solve the problem. Radiation hazards to inhabitants of the Upper Silesia region are another issue. In our experience, the most likely pathway of this hazard is external radiation from the sediments because this water is unsuitable for drinking due to its salinity. However, these sediments are typically covered by water (brooks and rivers) and may sometimes appear on river banks due to floods or the dredging of watercourses. We estimate that additional doses for inhabitants should not exceed 0.1 mSv/year, which is well below the 1 mSv/year threshold (Skubacz et al. 1992; Michalik 2008, 2011). Nonetheless, due to the long half-lives of radium isotopes, particularly ^{226}Ra, the deposition of

radium on the river beds and contamination of adjacent areas by released brines is, in our opinion, an important environmental problem in the USCB (Chałupnik et al. 2017).

Conclusions

The results of long-term monitoring of radium activity in Polish collieries have shown that overall radium activity being discharged from coal mines have decreased during the last two decades. Nonetheless, the release of underground water from the mines with high radium isotope concentrations may lead to considerably increased radioactivity in the environment.

In 1995, the maximum ^{226}Ra concentration was as high as 25 Bq/L, while for ^{228}Ra it was about 13 Bq/L. In 2016, the maximum concentration of ^{226}Ra was up to 7 Bq/L, while for ^{228}Ra it was about 10 Bq/L (maximum total activity 17 Bq/L). The approximate calculated activity of ^{226}Ra in water flowing into the USCB mines in 2016 reached 483 MBq/day (176 GBq/year), while ^{228}Ra was approximately 715 MBq/day (260 GBq/year). A comparison of assessments conducted in 1995 and 2016 shows that the activity of ^{226}Ra in daily inflows was about 30% less in 2016 than in 1995, while the activity of ^{228}Ra was comparable in both years. The reasons for the changes in the ^{226}Ra/^{228}Ra ratio of formation waters are complex, and include changes in the geological conditions at the mine's deeper horizons and technical measures due to the restructuring of the mining industry.

The radium concentrations in the mine water discharges were, and are still, enhanced. Due to dilution, there is a significant decrease in radium concentrations, especially in big rivers like Vistula. On the other hand, during seasons with low precipitation, the enhanced radium activity can be seen few dozens or even 100 km downstream from the mines' discharges.

Radium is gradually removed from river water by adsorption onto bottom sediments. Although the impact of radium-bearing water from the Upper Silesian coal mines on river water and bottom sediments is clear, the radiation doses received by inhabitants were low. Evaluations conducted by scientists from Central Mining Institute showed that annual doses received from wastewater with enhanced radioactivity and the presence of radionuclides in waste rocks released by the mines are well below the 1 mSv threshold.

A comparison of radium activity in inflows and discharges from collieries in 1995 and 2016 showed that even though roughly 50% of the coal mines in the USCB closed over the last two decades, and radium removal techniques have been applied in underground galleries, only a 20% decrease of total radium activity has been observed in colliery inflows and mine effluents. This is because of deeper exploitation in active mines and the fact that water from abandoned mines that are adjacent to active ones, must still be pumped out. Thus, it remains an important environmental problem in the USCB in Poland.

Acknowledgements This work was supported by the Polish Ministry of Science and Higher Education within the statutory activity of the Central Mining Institute, contract 11310255-370. The authors acknowledge the contribution of the 7. PR EURATOM project: Coordination and implementation of a pan-European instrument for radioecology (project 604974, project acronym: COMET).

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