Site no 4 - Bojszowy Reservoir

The second settling pond is the **Bojszowy** Reservoir, into which saline, radium-bearing waters from two mines are released. The inflow from the "Czeczott" Coal Mine is about 15 000 m^3/day whilst from the "Piast" mine, the discharge is even bigger - roughly 20 000 m^3/day. In both cases the type of water is the same (B type – no barium only radium and sulphate ions). The activity ratio between ^{226}Ra: ^{226}Ra is 1:2, the reverse of Rontok. Due to the absence of barium, no precipitation of radium in the pond can be observed. Nevertheless, measurements of the radium content in bottom sediments showed enhanced concentration of radium isotopes up to several hundred Bq/kg as a result of sorption of radium.

The pond was used from 1980 up to 1999, and about 227 million m^3 of waters have been discharged into the reservoir. The pond waters are released into the small river Gostynka, a tributary of the Vistula.

Bojszowy Reservoir - Radium-bearing waters.

Waters, released from two coal mines into the Bojszowy reservoir, are both of type B with ^{228}Ra concentrations higher than ^{226}Ra. The average values of radium concentrations in discharges from the Piast mine were ca. 4.1 kBq/m^3 for ^{226}Ra, while for ^{228}Ra, about 7.2 kBq/m^3. Corresponding values for inflows from the Czeczott Mine were lower,– 3.2 kBq/m^3 for ^{226}Ra and 4.9 kBq/m^3 for ^{228}Ra. These are average values for the last two years.

The assessment of the radium concentrations (^{226}Ra + ^{228}Ra) in inflows to the Bojszowy settling pond gives us an annual activity of about 124 GBq. This is 55% of the total amount of radium carried in waters from all the coal mines of Poland We calculated the average radium concentrations in waters discharged to the pond as 3.6 kBq/m^3 for ^{226}Ra and 6.2 kBq/m^3 for ^{228}Ra.

The reservoir water and bottom sediments were sampled in 1996. The results of analyses of radium concentrations in 42 water samples are shown in table 1.

Table 1. Radium concentration in water samples from Bojszowy

Bojszowy	***Radium concentrations***	
	^{226}Ra	^{228}Ra
	[kBq/m^3]	[kBq/m^3]
Average	**3,45**	**6.95**
Median	**3.34**	**6.76**
Max.	**5.21**	**8.32**
Min	**2.12**	**4.67**

The average radium concentration in outflows from the settling pond were similar to the values at inflow - 3.5 kBq/m^3 for ^{226}Ra and 6.0 kBq/m^3 for ^{228}Ra. This means that only small amounts of radium are deposited at the bottom. Moreover, the total concentration of radium isotopes in waters, released to the Gostynka stream is about 10 kBq/m^3, which is more than 10 times greater than the permitted level for waste water. A significant improvement of the situation was achieved

1998, thanks to the implementation of an underground treatment plant for mine waters in the Piast mine.

By comparing the results of radium analysis of inflows and outflows from the Bojszowy reservoir to the Gostynka river, we calculated that only 2.9 % of the ^{226}Ra and 3.3% of ^{228}Ra activities remain in the pond and are sorbed onto bottom sediments.

More than 95% of the radium is discharged with the saline waters into the Gostynka river. The influence of such discharge is obvious. Upstream from the discharge point the concentration of radium isotopes is very low, below 0.1 kBq/m^3 – which value is typical for groundwater and river waters in Poland. Downstream from the discharge point there is a rapid increase of radium content. Usually during winter and spring, when water levels in the river are higher, the concentration of radium did not exceed 0.7 kBq/m^3. However during summer, the concentrations of ^{226}Ra in Gostynka river vary within the range 0.5 - 0.7 kBq/m^3, whilst for ^{228}Ra the concentrations are higher and range about 1.0 – 1.3 kBq/m^3. The total activity of radium isotopes in Gostynka river can be as high as 1.5 - 2.0 kBq/m^3. Additionally, a proportion of the radium (several relative percent) is adsorbed on bottom sediments, but most of the radium is transported into the Vistula. In this big river the radium concentration in water decreases as a result of dilution and further adsorption.

Bottom sediments.

Bottom sediments were sampled at the same sites that waters were taken. Boreholes were drilled into the bottom of the settling pond and cores of sediments collected and analysed by gamma spectrometry. Sediments from Bojszowy showed radium ^{226}Ra concentrations in the range 95 - 950 Bq/kg, and ^{228}Ra from 124 up to 1705 Bq/kg. It is a characteristic of these samples that in almost all cases the activities of ^{228}Ra and ^{224}Ra were close to equilibrium, and very often the concentration of ^{226}Ra was only slightly lower than the ^{228}Ra content. This implies that the sediments are relatively old, at least a few years. It means also, that the adsorption in such places is very slow. It is only in a very few places, and these far from the banks, that we found “young” deposits. Results are shown in table 2.

Table 2. Radium in bottom sediments from Bojszowy.

Bojszowy	***Radium concentration***	
	^{226}Ra	^{228}Ra
	[Bq/kg]	[Bq/kg]
Average	414	627
Median	406	628
Max.	950	1705
min	95	124

Based upon these measurements, the balance of radium in bottom deposits in the settling pond was calculated (see table 4). We assumed that the distribution of radium isotopes in the bottom sediments was uniform, and so we used the average concentrations of both radium isotopes for our calculations.

The results of these considerations are as follows:

The total activity of ^{226}Ra, accumulated in bottom sediments during the 19 years of operation of the Bojszowy reservoir, is ca. 66 GBq, and the corresponding value for ^{228}Ra – 100 GBq. The annual rate of deposition is about 3.5 GBq for ^{226}Ra and 5.8 GBq/year for ^{228}Ra. This is only 7% of the annual discharge of radium with waters into the settling pond. Earlier calculations gave lower rates of deposition–about 4 % per year, but those assessments were not very accurate, because they did not take into account the large uncertainties in the parameters measured.

Table 3. Assessment of the amount of deposits in Bojszowy and total radium activity in deposits

Area of the pond [m^2]	**Volume of deposits [m^3]**	**Amount of water [m^3]**	**Total activity of ^{226}Ra [Bq]**	**Total activity of ^{228}Ra [Bq]**	**Amount of radium in the pond ^{226}Ra+ ^{228}Ra [Bq]**
160000	240000	262084	66×10^9	100×10^9	166×10^9

The above results can be used to describe the radium behaviour in both settling ponds and rivers and be used to attempt to correlate them with the chemical composition of radium-bearing waters. Comparison of the results is shown in table 4.

In the case of the Bojszowy Reservoir, the rate of deposition of radium is very low, only of about 4 - 7% of the total activity is adsorbed in bottom sediments per year. The distribution of radium in the sediments is rather uniform, therefore calculation of radium balance in sediments was relatively easy. At least 90% of the radium is discharged into the Gostynka river and later to the Vistula. This leads to the contamination of river water a long way from the discharge point.

Table 4. Radium balance in Bojszowy settling ponds

Settling pond	**Area [m^2]**	**Volume of deposits [m^3]**	**Total amount of radium discharged into pond [GBq]**	**Amount of radium deposited in the pond [GBq]**	**Deposition Rate %**
Bojszowy	160 000	240 000	2356	166	7

After the settling pond was dried the natural transgression of flora was observed. During the period 2000-2007 about 80% of the total surface of the settling pond have been overgrown by different plant species. In 2008 the inventory of all plants was done. Above 40 species were identified. Twelve of them were dominating. For three of them the sediment-plant transfer factor (TF) was measured. The relationship between radium activity concentration in sediments and TF was assessed. By the

way of sampling hot spots were the dose rate and radium activity concentration reaches 3 μSv/h and 7 kBq/kg respectively.

In 2010 at the area of the Bojszowy settling pond the process of land reclamation was finished. Sediments have been left at the original place and covered by the layer of the inert material. The first, the waste rock from coal mine was used and the layer about 1 m thick was created. After that the thin layer of sand was put on the top. Finally the top level of settling pond area is still below the banks but 2-3 m above the level of neighbouring land and representing typical wasteland landscape. See pictures below.