Contamination of settling ponds of coal mines caused by natural radionuclides

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ABSTRACT

As a result of a discharge of the radium-bearing waters from coal mines into settlement ponds and later into rivers a significant increase of radium concentration in bottom sediments can be observed. Sometimes also a contamination of river banks, soils and vegetation occurs. Mine waters contain mainly radium isotopes i.e. ^{226}Ra from uranium series and ^{228}Ra from thorium series. Due to chemical properties of such brines, these waters contain usually no uranium, no thorium and rather seldom elevated concentration of other isotopes as lead (^{210}Pb) and polonium (^{210}Po). The deposition or adsorption of radium on bottom sediments may take place on a distance of several kilometres from the discharge points. After a deposition or adsorption of radium isotopes the built-up of the activity of their progeny begins. Therefore concentrations of radium isotopes are higher than the decay products. We are able to measure the disequilibrium in ^{226}Ra decay chain as well as in ^{228}Ra decay chain, which shows the approximate age of the deposit.

The paper describes results of investigation of sediments with enhanced natural radioactivity occurring in settlement ponds, where mine waters have been dumped. The results of measurements show that these deposits contain mainly ^{226}Ra and ^{228}Ra and their progeny. Influence of bottom sediments with enhanced radium concentration on the natural environment in the vicinity of settlement ponds was studied on the example of two different water reservoirs where radium-bearing mine waters type A and B are released. The results show clearly enhanced radioactivity of bottom sediments and water in the settling ponds and in the rivers, but no evident enhancement was found in the adjacent land. Both coal mines are located in the drainage area of Vistula river, and bottom sediments with enhanced radium concentrations were found in Vistula up to 70 km downstream from the discharge point.

INTRODUCTION

Very often human activity, connected with an exploitation of mineral resources, leads to the contamination of the natural environment. Sometimes natural radionuclides are being released or concentrated in a form of waste material. In Poland the main source of waste and by-products with enhanced concentration of natural radionuclides is power industry, based on the coal exploitation and combustion. In hard coal mining industry 50 million tons of different waste materials are produced annually. As a result of coal combustion in power plants, the area of fly ash and sludge piles is increased roughly by several km^2 per year [1].

Additional component of the radiation contamination of the natural environment, different than ordinarily joined with this kind of industry, is caused by underground coal exploitation. In many of coal mines, located in Upper Silesian Coal Basin waters with enhanced radium content occur [2]. Sometimes in radium-bearing brines barium ions are also present, in concentrations up to 2 g/l. Such waters were classified as radium-bearing waters type A. Contrary, in other waters (called B type) no barium can be found but radium and sulphate ions are present.

The presence of barium in waters is the most important factor for the further behaviour of radium isotopes in mine galleries or on the surface. From waters type A radium and barium always co-precipitate as sulphates, when such waters are mixed with any water, containing sulphate ions. As the result of the precipitation of barium sulphate, deposits with highly enhanced radium concentrations, which may sometimes reach 400 kBq/kg, are formed [2,3]. In comparison, average radium content in soil is equal 25 Bq/kg [4].

In case of another type of radium-bearing waters (type B), no precipitation occurs due to the lack of the barium carrier. From such waters radium is removed in a slow process of sorption on bottom sediments in gauntons in underground galleries or on the surface in the settling ponds and rivers. In this case the increase of radium content in sediments is much lower as for waters type A. But we can observe enhanced concentration of radium isotopes in river waters or in bottom sediments on a long distances downstream from the discharge points.

In Laboratory of Radiometry in the Central Mining Institute, routine measurements of radium concentration in mine waters as well as in waters, discharged into the river from settling ponds of coal mines have been performed since several years [5]. Such monitoring is obligatory for all mines in Poland [14]. Therefore, our database consists of several thousands results of radium concentration in water. On this basis the balance of radium in underground mines and in their vicinity was prepared [8]. Results of this assessment are different for two radium isotopes - ^{226}Ra and ^{228}Ra. In case of ^{226}Ra of about 70% out of 625 MBq/day remains in underground galleries, while only 225 MBq per day is released into surface waters. For ^{228}Ra situation is opposite – only 40% out of 700 MBq/day remains underground but 400 MBq is discharged daily into settling ponds and rivers.

Co-precipitation of radium and barium as sulphates and sorption of radium on bottom sediments take places also in small brooks and rivers [7].

Contamination of the natural environment in Upper Silesia

Investigations of the contamination of the natural environment in Upper Silesia region have been started in early 70's. Since 1986 our Laboratory performs routine monitoring of the pollution, caused by mining, on the basis of the Decree of Ministry of Mining and Energy [14]. Due to that act, mine's management are obliged to ensure such monitoring. Possible sources of contamination are radium-bearing waters as a primary source and deposits with enhanced radium content as the secondary source.

As mentioned above, radium behaviour is connected with barium content in brines. If barium ions are present in radium-bearing waters, than deposits of radium and barium sulphates always precipitate out, when such waters have been mixed with waters, containing sulphate ions. Usually such processes occur in underground galleries, only in a very few cases on the surface. Therefore discharge of radium-bearing waters type B leads to severe pollution of settling ponds and river, but on a short distance from the mine. Quite opposite situation can be observed in cases, when waters type B are discharge into settling ponds and later to river. We can observe only slight enhancement of the natural level of radiation but the distance from the source, where contamination happen, is typically quite large, sometimes few tens of kilometres.

As a result of all these processes, of about 70% of ^{226}Ra remains underground in deposits and only 225 MBq per day is discharged with water into natural environment. Corresponding values for ^{228}Ra are as follows: only 40% activity of this isotope remains in underground galleries, but 450 MBq/day is dumped onto surface. It is due to the fact, that the ratio ^{228}Ra: ^{226}Ra is higher in waters type B, without barium. Waters type B occur in mines located in the area in the vicinity of Vistula river, so enhanced radium concentrations can be observed in small tributaries of this biggest Polish river.

Applied methods of measurements

The reliability of the results in measurements of natural and artificial radioactivity is the most important problem. The method to ensure the quality of such measurements is the implementation of the internal quality assurance system in radiometric laboratory. In our case, such system was implemented in early 90's.

Laboratory of Radiometry of the Central Mining Institute has the accreditation granted by Polish Centre of Research and Certification [9]. The scope of certification is as follows:

- Measurements of ^{226}Ra and ^{228}Ra in waters and aqueous solutions
- Measurements of ^{210}Pb in water
- Measurements of gamma radionuclides in solid samples
- Measurements of gamma doses and dose-rates
- Measurements of potential alpha energy concentration (PAEC) of short lived radon progeny
- Calibration of portable instruments for measurements of PAEC.

For the purpose of this work we applied high resolution gamma spectrometry for measurements of natural radionuclides in solid samples (^{226}Ra, ^{228}Ra, ^{224}Ra, ^{40}K) and liquid scintillation counting for measurements of radium isotopes (^{226}Ra and ^{228}Ra) in water.

Monitoring of contamination of settling ponds on the surface

The best example of radium behaviour in correlation with type of radium-bearing waters is the analysis of waters and deposits from different settling ponds, into which waters from coal mines are discharged. The main task of such pond is to settle the mechanical suspension, but additionally deposition of radium takes place there. In this paper results of investigations, performed within the period 1995-1999 are described.

Two big settling ponds were chosen for the comparison. Into the first one, named ***Rontok***, waters type A are discharged. The second reservoir, ***Bojszowy***, is used as a settling pond for waters type B.

1. Rontok Reservoir

The exploitation of that pond has been started in 1977. During this period of about 72 million cubic meters of saline waters were dumped into the reservoir from "SILESIA" Coal Mine. The concentration of the suspension varied from 0.3 to 2.4 g/dcm^3. The total amount of the suspension, deposited in the pond, was calculated as 100 000 m^3 (of about 150 000 tons). Information of the settling pond are presented in table 1.

Waters type A were discharged into the pond during whole period (with radium and barium ions). The activity ratio between two radium isotopes ^{226}Ra: ^{228}Ra was of about 2:1. Previously the daily discharge of water was at the level 10 000 m^3, but since 1998 the amount of water is much smaller, only 5 600 m^3/day. Inflows of groundwater with content of sulphate ions are small but numerous, therefore precipitation of $BaSO_4 + RaSO_4$ occur in the pond. In deposits concentration of radium isotopes is clearly enhanced. From the pond waters are dumped directly into Vistula river.

The process of co-precipitation of radium and barium in the pond is now less intensive, because of the two reasons – lower radium content in waters during recent years in comparison with previous period (now ~ 2.5 kBq/m^3 of ^{226}Ra but up to 15 kBq/m^3 before). Another reason is a decrease of water inflow into pond by factor two. It means, that the total amount of radium in waste water, dumped into pond, is lower several times as for instance 4-5 years ago.

Table 1.
Characteristics of two settling ponds

	Bojszowy	*Rontok*
Type of radium-bearing waters	B	A
Area [ha]	16	36
Volume [m^3]	400	440
Flow rate [m^3/day]	33000 in 1999 - 26000	9200 since 1998 - 5600
^{226}Ra in discharge waters [kBq/m^3]	2.0 - 3.9	2.3
^{228}Ra in discharge waters [kBq/m^3]	3.9 – 7.0	2.4
TDS : Cl ions SO_4^{2-} [kg/m^3]	48 (max 55) 35.9 2.1	40 (max 58) 25 2.5
Total amount of water dumped into the pond: [million m^3]	227	73
Exploitation period	19 years (since 1980)	23 years (since 1976)

1. Bojszowy Reservoir

Second settling pond is **Bojszowy Reservoir**, into which saline, radium-bearing waters from two mines are released. Inflow from "Czeczott" Coal Mine is of about 15 000 m^3/day and from another mine "Piast" 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: ^{228}Ra is 1:2, quite opposite in comparison with Rontok. Due to the lack of barium, no precipitation of radium in the pond can be observed. Nevertheless, measurements of radium content in bottom sediments showed enhanced concentration of radium isotopes up to several hundred Bq/kg as a result of the sorption of radium.

The exploitation of the pond have been started in 1980, and till now of about 227 million m^3 of waters were discharged into reservoir. From the pond waters are released into small river Gostynka, a tributary of Vistula river.

2. Results of investigations

In case of both settling ponds the problem of the contamination is rather a delicate subject. Local communities asked for investigations to check the levels of the pollution.

Another reason was the preparation to the purification of radium-bearing waters in "PIAST" Mine. We wanted to know, how the purification would affect the radium balance in the river waters. Measurements of radium isotopes in waters from settling ponds and rivers were done – upstream and downstream from the discharge points. Monitoring of natural radionuclides in bottom sediments from ponds and rivers was performed, also contamination of soils in the vicinity of both reservoirs have been checked.

Rontok Reservoir **- Radium-bearing waters**

In fall and winter of 1998 radium concentrations were measured in water samples, taken from the inflow to the pond. Average values of radium content were as follows:

- Ra-226 – 2.27 kBq/m^3, Ra-228 – 2.37 kBq/m^3.

The assessment of radium balance in the inflow to ***Rontok*** gave the result approximately 9.5 GBq/year. But before 1998 amount of water, discharged from the mine to the reservoir, was of about two times higher (10 000 m^3/day). Also average radium concentrations were slightly different: for ^{226}Ra – 3.20 kBq/m^3 and for ^{228}Ra – 1.43 kBq/m^3. During the period 1988 to 1999 40 samples taken from the inflow to the settling pond were analysed and results are shown in table 2.

Table 2. Results of radium concentration in inflows to Rontok

Rontok	Radium concentration	
	^{226}Ra [kBq/m^3]	^{228}Ra [kBq/m^3]
Average	3.21	1.43
Median	1.76	1.35
max	**14.20**	**3.38**
min	0.56	0.40

On this basis the assessment of radium balance gives the annual release of radium isotopes at level 10.7 GBq for ^{226}Ra and 4.8 GBq for ^{228}Ra. Taking into consideration the whole period of exploitation of the pond we can calculate the amount of radium, discharged into the pond with saline waters as 240 GBq for isotope ^{226}Ra and 110 GBq for ^{228}Ra.

But analysis of the results of radium concentrations in water samples, taken from the outflow from the pond to Vistula river, leads to a very strange conclusions (see table 3).

Table 3. Results of radium monitoring in outflows from Rontok

Rontok	Radium concentration	
	^{226}Ra [kBq/m^3]	^{228}Ra [kBq/m^3]
Average	**4.77**	**2.03**
median	**4.78**	**1.38**
max	**10.54**	**5.01**
min	**0.89**	**0.55**

It can be seen, that average values of radium concentration in outflows are higher than corresponding values for inflows (table 2). It means that temporal variations of radium content in inflows are very high, while at the outflow radium concentrations are more stable. The results of radium concentrations in waters from the pond (table 4) support that conclusions. For instance, maximum value of ^{226}Ra concentration was found in the reservoir - 20 kBq/m^3. The main reason of such situation is de-watering of deeper horizons (where waters with higher radium concentrations occur) during nights, because the cost of energy is lower.

Table 4. Radium concentration in water samples from Rontok

Rontok	Radium concentrations	
	^{226}Ra [kBq/m^3]	^{228}Ra [kBq/m^3]
Average	6.81	1.65
median	6.88	1.73
max	20.46	2.60
min	0.18	0.23

Release of radium-bearing waters from Rontok leads to the increase of radium concentration in Vistula. In table 5 results of radium analysis of samples from Vistula are shown – for the period between 1988 –1999.

Table 5. Radium concentration in Vistula upstream and downstream from the discharge point from Rontok

Radium content in Vistula	upstream [kBq/m^3]		downstream [kBq/m^3]	
	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra
Average	0.011	0.011	0.246	0.099
median	0.01	0.01	0.207	0.06
max	0.05	0.05	0.787	0.6
min	<0.003	<0.003	0.04	0.01

Bottom sediments in Rontok

Monitoring of the contamination of bottom sediments in Rontok and soil in adjacent area was done. Sampling of scales from the bottom of the pond was done in a grid 50x50 meters. Also the thickness of the layer of sediments was measured in each sampling point. After drying, samples were measured and concentrations of the natural radionuclides have been calculated. The same procedure was applied for soils samples. On this basis a map of the radium isotopes concentrations was prepared. Accordingly to the plans of mine management a restoration of the area, where **Rontok** is located, will be done within few years. Therefore investigations of the pollution is so important

Table 6. Radium in bottom sediments from Rontok

Rontok	Radium in sediments	
	^{226}Ra [Bq/kg]	^{228}Ra [Bq/kg]
Average	5105	1407
median	1191	593
max	49151	6388
min	67	62

We found maximum values of radium content in sediments near the outlet of the pipeline, transporting waters from the mine to the settling pond. The total activity of radium isotopes ($^{226}Ra+^{228}Ra$) reached there 55 kBq/kg. In average, radium content was much lower, and the distribution of radium at the bottom of the pond is very non-uniform. In some places radium concentration in sediments was at level of typical radium concentration in earth crust, as can be seen in table 6.

Table 7. Assessment of the amount of deposits in Rontok and total radium activity in deposits

Area of the pond [m²]	Volume of deposits [m³]	Amount of water [m³]	Total activity of ^{226}Ra [Bq]	Total activity of ^{228}Ra [Bq]	Amount of radium in the pond $^{226}Ra+^{228}Ra$ [Bq]
360000	113107	262084	240×10^9	74×10^9	314×10^9

For of about 35 - 40% of the area of the pond, concentrations of radium isotopes are lower than 350 Bq/kg for Ra-226 and 230 Bq/kg for Ra-228. These levels are our proposal as the maximum permissible concentrations, below which no remedial action is needed [13]. In contrary, in the southern-east part of the pond, near the inlet to the pond, the thickness of deposit's layer is approximately 1.2 m and the maximum concentrations of radium were found. Taking into account all these data, we were able to assess the total amount of deposits in the settling pond and a balance of radium isotopes in deposits – see table 7.

Bojszowy Reservoir

Radium-bearing waters.

Waters, released from two coal mines into Bojszowy reservoir, are type B and ^{228}Ra concentrations are higher than that of ^{226}Ra. Average values of radium concentrations in inflows from Piast Mine were equal for ^{226}Ra ca. 4.1 kBq/m³, while for ^{228}Ra of about 7.2 kBq/m³. Corresponding values for inflows from Czeczott Mine were lower and equal – 3.2 kBq/m³ for ^{226}Ra and 4.9 kBq/m³ for ^{228}Ra. That are average values for the period of last two years.

Assessment of radium balance ($^{226}Ra + ^{228}Ra$) in inflows to Bojszowy settling pond gives us the annual activity of about 124 GBq. It is more than the half of the total amount of radium, released with waters from all coal mines in Poland (55%) [10]. We calculated average radium concentrations in waters discharged to the pond as 3.6 kBq/m³ for ^{226}Ra and respectively 6.2 kBq/m³ for ^{228}Ra.

Sampling of waters from reservoir was done in 1996. The grid was similar as in case of Rontok settling pond – it means 50x50 meters. In the same places samples of bottom sediments were taken. Results of analysis of radium concentrations in water samples are shown in table 8.

Table 8. Radium concentration in water samples from Bojszowy

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

It can be seen, that distribution of radium in water in Bojszowy is more uniform as in Rontok settling pond. The main reasons of such situation seem to be more stable radium content in inflows and type of the water, from which radium is removed only on a way of sorption.

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. It means that only small amount of radium is deposited at the bottom. Moreover, total concentration of radium isotopes in waters, released to Gostynka is of about 10 kBq/m^3, more than 10 times exceeds a permissible level for waste water (0.7 kBq/m^3 [11]). The significant improve of that situation would be seen very soon, due to the implementation of the technology of underground purification of mine's waters from radium in Piast Colliery.

Comparing results of radium analysis of inflows and outflows from the Bojszowy reservoir to Gostynka river, we calculated that only 2.9 % of ^{226}Ra and 3.3% of ^{228}Ra activities remain in the pond and caused the enhancement of radium concentrations in bottom sediments.

More than 95% of radium is dumped with saline waters into Gostynka. Therefore the influence of such discharge is good visible. Upstream the discharge point the concentration of radium isotopes in Gostynka is very low, below 0.1 kBq/m^3 – which value is typical for groundwater and river waters in Poland [12]. Downstream from the discharge point we observed a rapid increase of radium content. Usually during winter and spring, when water flow in the river is higher, concentration of radium didn't exceed value 0.7 kBq/m^3. But during summers concentrations of ^{226}Ra in Gostynce vary in range 0.5 - 0.7 kBq/m^3, and in case of ^{228}Ra concentrations are higher – of about 1.0 – 1.3 kBq/m^3. Total activity of radium isotopes in water in Gostynka reaches even 1.5 - 2.0 kBq/m^3 [8]. Additionally, a portion of radium (several percent) is adsorbed on bottom sediments in Gostynka, but main part of radium is transported with water to Vistula. In this big river radium concentration decreases as a result of dilution and further adsorption [6].

Bottom sediments.

Sampling of bottom sediments have been done in these sites, where water samples were taken. Boreholes were drilled in the bottom of settling pond and cores of sediments were collected and analysed by means of gamma spectrometry. We found in sediments from Bojszowy radium ^{226}Ra concentrations in range 95 - 950 Bq/kg, and respectively for ^{228}Ra from 124 up to 1705 Bq/kg [7]. Characteristic for these samples is the fact, that almost in all cases activities of ^{228}Ra and ^{224}Ra were close to equilibrium and very often concentration of ^{226}Ra was only slightly lower than ^{228}Ra content. It means, that such scales are relatively old ones, at least few years. It means also, that the adsorption in such places is very slow. Only in a very few places, far from the banks, we found "young" deposits. Results of measurements are shown in table 9.

Table 9. Radium in bottom sediments from Bojszowy.

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

On the basis of performed measurements the balance of radium in deposits in the settling pond was done (see table 10). For that assessment the assumption was made, that the distribution of radium isotopes in bottom sediments is uniform. Therefore we used the average concentrations of both radium isotopes for our calculations.

Results of these considerations are as follows. The total activity of ^{226}Ra, accumulated in bottom sediments during 19 years of exploitation of Bojszowy reservoir, is equal ca. 66 GBq, and the corresponding value for ^{228}Ra – 100 GBq. The annual rate of deposition is of about 3.5 GBq for ^{226}Ra and 5.8 GBq/year in case of ^{228}Ra. It is only 7% of the annual discharge of radium with waters into the settling pond. Our earlier calculations gave us lower rate of deposition [7] – of about 4 % per year, but such assessment is not very accurate, accordingly to big uncertainties of all parameters, which have been taken into account.

Table 10. 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 comparison of radium deposition is both settling ponds

Mentioned above results of analyses and assessments can be used to description of radium behaviour in the settling ponds and rivers in correlation with chemical composition of radium-bearing waters. Comparison of the results is shown in table 11.

In case of Bojszowy Reservoir, the rate of deposition of radium is very low, only of about 4 -7% of the total activity is adsorbed at pond's bed per year. The distribution of radium in sediments is rather uniform, therefore calculation of radium balance in sediments was relatively easy. On the other hand at least 90% of radium is dumped into Gostynka river and later to Vistula, leads to the contamination of river's water on the long distance from the discharge point.

Table 11. Radium balance in Bojszowy and Rontok 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]	Ratio Rd %
Bojszowy	160 000	240 000	2356	166	4-7
Rontok	360 000	113107	350 ** 810 ***	314	90** 39***

* → total activity of $^{226}Ra+^{228}Ra$

** → assessment made on a basis of measurements of radium concentration in inflows to the pond

*** → assessment made on a basis of measurements of radium concentration in outflows to Vistula and amount of radium, deposited in the pond.

Rd is a ratio of radium activity deposited in the pond to total amount of radium discharged to the certain pond

In case of Rontok settling pond situation is quite different. The rate of deposition is much higher, because of different type of water – type A with elevated barium content. Also assessment of deposition rate of radium was difficult. Calculations made in two different ways gave different results. Taking into account measurements of radium concentration in inflows we obtained the value of about 350 GBq for whole period of exploitation. Another method of calculations, based on balance of radium in deposits and measurements of radium concentrations in outflows gave result almost three times higher – 810 GBq. It means, that the average concentration of radium isotopes in waters released to the pond during whole period of exploitation was roughly 10 kBq/m^3. In this case the deposition rate is of about 39 %, and this result is more reasonable in comparison with 90%, calculated for the first approach. But for waters type A the deposition rate strongly depends on the amount of groundwater inflow, and the balance of sulphate ions in such inflows.

CONCLUSIONS

- Significant amount of radium, released with mine water into settling ponds on the surface, is transported to rivers. This way of the contamination of the natural environment is very important in the catchment area of Vistula river, the Polish biggest river.
- The behaviour of radium strongly depends on the presence of barium ions in water. Barium acts as a carrier for radium, therefore from radium-bearing waters type A radium co-precipitated out with barium as sulphates. Very often the precipitation takes place in underground galleries and sometimes in settling ponds on the surface. Only small portion of radium is finally dumped into rivers. In case of waters type B, radium is removed in slow process of adsorption on bottom sediments. At least 90% of radium is discharged into rivers with such brines and enhanced radium concentration in water can be found few tens kilometres downstream from the discharge points.
- In particular settling ponds significant amounts of radium isotopes have been accumulated during its exploitation. It leads to the increase of gamma dose rates in the vicinity of such ponds and to the contamination of the banks of such reservoirs.
- Till now regulations concerning mining industry are applied for such reservoirs and dose equivalent limit for miners is much higher than for the general public. Problems may appear

after closing of the mines, because local authorities would have to maintain ground reclamation or removal of deposits with enhanced natural radioactivity. Moreover, much lower dose limit - 1 mSv per year is applicable for inhabitants.

- Very important is also social aspect of that problem. For local societies the contamination of the natural environment in the close vicinity of their homes is treated as a real threat.

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