Environmental pollution and remediation challenges in Upper Silesia Coal Basin, Poland

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Upper Silesia Coal Basin

a post-industrial landscape

- Industrial activity has been carried out since XII century
- 25% of total surface is covered by anthropogenic formation made from different industrial waste
- Approximately the same proportion of surface is deformed due to underground mining
- Different pollution coexists
Upper Silesia Coal Basin

*a post-industrial landscape*

- Coal take-off above 200 millions of tonnes per year (in seventies of XX century) currently about 70 millions of tonnes
- 50 underground hard coal mines still in operation (in 35 administrative units)
- Daily surface discharge of saline water about 100 000 m³
Discharge of radium-bearing waters into surface

- All coal mines have to pump water out of the underground galleries.
- In 40 out of 50 coal mines in Upper Silesia brines with high concentration of radium occur.
- Some proportion of radium remains in underground galleries due to spontaneous precipitation or technical measures but up to 40% of the total inflow is pumped onto surface.
Radium-bearing waters

<table>
<thead>
<tr>
<th>Type of water</th>
<th>Ra-226 [kBq/m³]</th>
<th>Ra-228 [kBq/m³]</th>
<th>Ba$^{2+}$ [g/l]</th>
<th>SO$_4^{2-}$ [g/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.5 - 390</td>
<td>0.3 - 150</td>
<td>Up to 1.5</td>
<td>traces</td>
</tr>
<tr>
<td>B</td>
<td>0.1 - 20</td>
<td>0.1 - 40</td>
<td>no</td>
<td>Up to 15</td>
</tr>
</tbody>
</table>

Behaviour of radium depends mainly on the presence of barium ions in water.
Maximum values of radium activity concentration in formation water, years 1999-2008
Maximum values of radium activity concentration in sediments, years 1999-2008
Mine water destination …

- **From mines at south-west part of USCB:**
  The Oder river through settling/retentive ponds, pumping stations and pipelines.

- **Remaining:**
  The Vistula river, through settling/retentive ponds, streams and small river
The „OLZA” pipeline – mine water collector

- Eight mines are connected
- Each mine discharges about 200 m³/h
- The total length: close to 100 km
- The pipes diameter: 300 up 800 mm
- The total discharge of water to the Oder river: 1500 m³/h (above 13 000 000 m³/year)
- The maximum Radium concentration in water inflow: 11 Bq/l
- **10 settling/retentive ponds**
The „OLZA” pipeline – mine water collector:

**Occupational risk**

Exposure to external gamma radiation in pumps stations and pipeline’s grids/checking points.

Gamma dose rate reaches: \(3.70\pm0.44\ \mu\text{Sv}/\text{h}\)
The „OLZA” pipeline – mine water collector: *environmental effect*

- The maximum radium concentration in water discharged into the Oder river: 0.03 Bq/l – there is’t noticeable effect in the river.

- Contaminated scrap remains underground…..
SETTLING PONDS IN COAL MINING INDUSTRY

- Artificial reservoirs, situated on territory of a colliery, sealed and protected against uncontrolled spread of sediments, periodically cleaned, access is restricted to mine staff.

- Natural lakes or former fish ponds, adapted as settling ponds without any protective layers or barriers, nowadays usually excluded from technological process, accessible for common people and non-human biota.
Sediments originating from mine effluents

the main source of environmental burden

Contain high enough activity concentration of radionuclides to be classified as radioactive waste,

Occur in huge quantities deposited directly in the environment,

Consist of wide variety of chemical compounds and different minerals,

After releasing can start chemical or physical processes leading to the additional radionuclides concentration,

Frequently are associated with other pollutants as heavy metals, sulphates, hydrocarbons.
SETTLING PONDS IN COAL MINING INDUSTRY

There are 25 currently working settling ponds containing sediments with enhanced concentration of radium isotopes (the old ones are not well identified)

Total content: 5 million cubic meters of sediments
### Basic statistics of sampled surface sediments

<table>
<thead>
<tr>
<th></th>
<th>$^{226}\text{Ra}$</th>
<th>$^{228}\text{Ra}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Value</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arithmetic average</td>
<td>4341</td>
<td>1631</td>
</tr>
<tr>
<td>Median</td>
<td>152</td>
<td>104</td>
</tr>
<tr>
<td>Minimum</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Maximum</td>
<td>156,942</td>
<td>83,785</td>
</tr>
<tr>
<td>Number of samples</td>
<td>711</td>
<td>711</td>
</tr>
<tr>
<td><strong>Units</strong></td>
<td>Bq/kg</td>
<td>Bq/kg</td>
</tr>
</tbody>
</table>
Scrap from dewatering systems of mines

Scaling of:
- barium sulphates from formation water discharge systems
- calcium sulphates from coal ash backfilling systems

Shortage of:
- Appropriate regulations
- Means of decontamination
Additional legacy . . .

- contaminated beds of streams, where formation water used to be discharged

- contaminated soils on neighbouring arable lands
Environmental risk characterization

- Natural radionuclides = long lived radionuclides
- Almost all natural radionuclides are alpha emitters
- Risk evolution: increase of concentration of progenies - new elements = different properties (i.e. radium -> polonium)
Environmental effects

an reductionistic approach:

- early mortality
- morbidity
- reduced reproductive success

Reflected in the concept of „reference organism“
Plants, algae, many bacteria (Autotrophs)

Carbon dioxide

Organic compounds

Oxygen

Animals, fungi, many bacteria (Heterotrophs)
Effects on biota

Interaction of contaminants with biota takes place at the cellular level

Cellular response is:
the first manifestation of harmful effects, and
suitable tools for the early detection of the pollution

Genetic test-systems should be used for an early and reliable displaying of the alterations in ecosystems
Environmental risk assessment

Stages of investigation

- Migration of radionuclides in abiotic environment
- Biota exposure to external gamma and alpha radiation
- Biological availability of radionuclides
- Transfer factors of radionuclides’ into biota and committed dose evaluation
- Effects of radiation on biota
SETTLING PONDS UNDER THE INVESTIGATION

- Total area: 16 and 32 hectares
- Specific mass activity of bulk sediments: reaches 45 kBq/kg and 10 kBq of $^{226}\text{Ra}$ and $^{228}\text{Ra}$ respectively (by dry mass).
- Scales inside of pipelines and close to the discharging points: up to 160 kBq/kg both radium isotopes.
- Maximum dose rate above the sediments reaches 0.04 mSv/h
- Associated contamination: barium, cobalt, nickel, zinc, lead and copper are present in dimensions higher than the permitted concentration limits
### Radium concentration in different plants overgrowing the abandoned settling ponds

<table>
<thead>
<tr>
<th>plant</th>
<th>$^{226}\text{Ra}$ Bq/kg (dry mass)</th>
<th>$^{228}\text{Ra}$ Bq/kg (dry mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Calamagrostis australis</em></td>
<td>55±17</td>
<td>91±5</td>
</tr>
<tr>
<td><em>Calamagrostis epigeios</em></td>
<td>43±20</td>
<td>84±7</td>
</tr>
<tr>
<td><em>Calamagrostis epigeios</em></td>
<td>28±18</td>
<td>59±5</td>
</tr>
<tr>
<td><em>Phragmites australis</em></td>
<td>191±22</td>
<td>371±14</td>
</tr>
<tr>
<td><em>Phragmites australis</em></td>
<td>175±30</td>
<td>360±16</td>
</tr>
<tr>
<td><em>Phragmites australis</em></td>
<td>16±0</td>
<td>17±3</td>
</tr>
<tr>
<td><em>Atriplex hastata</em></td>
<td>151±25</td>
<td>286±12</td>
</tr>
<tr>
<td><em>Atriplex hastata</em></td>
<td>580±64</td>
<td>1136±42</td>
</tr>
<tr>
<td><em>Atriplex hastata</em></td>
<td>170±21</td>
<td>324±13</td>
</tr>
<tr>
<td><em>Atriplex hastata</em></td>
<td>69±13</td>
<td>104±5</td>
</tr>
</tbody>
</table>

(samples taken in different parts of the settling pond)
Biota exposition to external \textit{alpha} and \textit{gamma} radiation

- External dose caused by \textit{gamma} radiation
- Exposure to external \textit{alpha} radiation (an approach on base of TLD dosimetry)
- Radon concentration in soil gas
Radionuclides’ transfer factors into biota

- The inventory of plants transgressing into abandoned settling ponds
- Field experiments
- Laboratory tests
Radionuclides transfer factors into biota

The main findings:

- Relationship between transfer factors and radium environmental is non-linear
- Transfer factors (CF) calculated on mobile fraction of radium can be three orders of magnitude higher than calculated on base of total radium concentration in sediments

![Graph showing the relationship between concentration factor and total $^{228}$Ra + $^{226}$Ra activity concentration [Bq kg$^{-1}$]. The equation is $y = 20.577x^{0.9277}$ with $R^2 = 0.9279$.](image)
# Dose rate evaluation

<table>
<thead>
<tr>
<th></th>
<th>Committed dose rate</th>
<th>Total dose rate in root system (μGy d⁻¹)</th>
<th>Total dose rate in upper part system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The first site</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Calamagrostis epigeios</em></td>
<td>63</td>
<td>1659</td>
<td>861</td>
</tr>
<tr>
<td><em>Betula pendula</em></td>
<td>9</td>
<td>84</td>
<td>47</td>
</tr>
<tr>
<td><em>Phragmites australis</em></td>
<td>7</td>
<td>201</td>
<td>104</td>
</tr>
<tr>
<td><em>Quercus robur</em></td>
<td>5</td>
<td>80</td>
<td>43</td>
</tr>
<tr>
<td><strong>The second site</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Phragmites australis</em></td>
<td>5-10</td>
<td>55-570</td>
<td>30-290</td>
</tr>
<tr>
<td><em>Lepidium ruderale</em></td>
<td>7</td>
<td>102</td>
<td>54</td>
</tr>
<tr>
<td><em>Circium vulgare</em></td>
<td>9</td>
<td>46</td>
<td>29</td>
</tr>
<tr>
<td><em>Matricaria perforata</em></td>
<td>14</td>
<td>69</td>
<td>41</td>
</tr>
</tbody>
</table>
Effects on biota

To study cytotoxic and genotoxic potential in sediment from the test-sites the *Allium*-test was applied.

The objective was:

- To reveal key pollutants determining biological effect
- To find relationship between biological effects and levels of key contaminants in water and sediment from test-sites
**Effects on biota**

- high level of genotoxicity has been observed in all samples tested
- only samples with the highest activity concentration showed toxicity estimated from the root proliferation

* Cytotoxicity and genotoxicity of sediments sampled from Upper Silesia post-mining areas.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Total cells</th>
<th>MI, %</th>
<th>AT</th>
<th>AC, %</th>
<th>f1+m1</th>
<th>f2</th>
<th>m2</th>
<th>g</th>
<th>3p</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>1749</td>
<td>32.47 ± 2.30</td>
<td>4063</td>
<td>2.75 ± 0.25</td>
<td>6</td>
<td>6</td>
<td>57</td>
<td>31</td>
<td>12</td>
</tr>
<tr>
<td>B1</td>
<td>1809</td>
<td>31.18 ± 2.34</td>
<td>3693</td>
<td>2.29 ± 0.16</td>
<td>13</td>
<td>2</td>
<td>34</td>
<td>31</td>
<td>10</td>
</tr>
<tr>
<td>B2</td>
<td>1765</td>
<td>34.87 ± 1.31</td>
<td>3860</td>
<td>2.92 ± 0.29</td>
<td>2</td>
<td>3</td>
<td>57</td>
<td>42</td>
<td>12</td>
</tr>
<tr>
<td>control</td>
<td>1810</td>
<td>33.41 ± 1.58</td>
<td>7842</td>
<td>1.27 ± 0.08</td>
<td>16</td>
<td>20</td>
<td>15</td>
<td>26</td>
<td>14</td>
</tr>
</tbody>
</table>

MI – mitotic index; AT – ana-telophases scored; AC - number of aberrant cells; f1, m1 – chromatid (single) fragments and bridges; f2, m2 – chromosome (double) fragments and bridges; g – lagging chromosomes; 3p – multipolar mitoses
The possibilities of contaminated sites land reclamation

- conventional method land reclamation (costs, time and efficiency) 
- versus

- phytostabilisation, phytoextraction, dissolution in environment

But, the gap in relevant regulation in frame of radiation protection as well as in industrial waste treatment results in the lack of any rational approach ....
Summary

in Polish coal mining industry:

- The lack of relevant regulation results in that NORM waste treatment and its environmental impact is left out of regulatory control.

- The frame of proper treatment of NORM waste is already developed

- In the context of economical effectiveness the needs of driving force exists in order to enforce it
Summary

The problems must be solved at the legal level:

- NORM waste = radioactive waste ???
- NORM waste below the level set for radioactive waste – should be regulated?
Thank you for the attention