Prognosis of radioactivity in TENORM

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Industries and materials

TENORM
Technologically enhanced NORM
NORM industries

Raw materials

- Background radioactivity
- Enhanced natural radioactivity

Industrial process

Case A: Dilution by mixing
Case B: Enrichment by separation
Case C: “Case A” and / or “Case B”

Products, Wastes

Case A: Cement production, Waste incineration
Case B: Scales and sludges of oil or gas production, Water treatment, Filter dust of the hot metal production
Case C: Extraction of Rare Earth Minerals, Bauxite processing, Phosphate processing

Examples

R. Gellermann, Nov. 2009
OK, we know we have to deal with radioactivity.

But:

• What happens, if our technology is changed?
• How much NORM-wastes will arise in a certain facility?
• How can the exposure of the employees from NORM-waste be influenced?
The expected changes

NORM shall be considered as planned exposure situation

→ are we able to “plan” NORM amounts arising in a certain facility in advance?
→ How we can make prognosis on NORM wastes? (activity concentrations and masses!!)
There is a lot of experience

We know waste masses and activities of TENORM in industries. We know, that radioactivity may be enriched by technical processes.

![Graph showing the specific activity in Bq/g against mass in t for different materials like Scales, Sludges, Filter dust, Mineral sands, Phosphate, and Bauxite.](image)
But …

we tell us stories about radioactivity

We have examples and explanations on a qualitative level – no theory, no quantifying models, no established terms for characterising the processes of RN enrichment.

What we need is a helpful tool for analysing the processes which may result in TENORM + to communicate about these processes in an easy comparable way.
The general approach

TENORM consists of two components:

• Several radionuclides
• A non-radioactive carrier

The non-radioactive carrier is an inherent part of any TENORM!

Conclusion:
We have to deal with both: radioactivity AND masses!
The problem: complex systems

Real processes: pig-iron plant / steel mill
A phenomenological model of TENORM formation is depicted, illustrating the interactions between raw material (A), additive (Z), process, residue/enriched fraction, and product/depleted fraction.

**Balance equations**

- **Mass balance**: \( M_A + M_Z = M_R + M_P \)
- **Activity balance**: \( A_A + A_Z = A_R + A_P \)

**Process parameters**

1. **Transfer factors**
   - Mass transfer factor (MTF): \( \frac{M_R}{M_A + M_Z} \)
   - Activity transfer factor (ATF): \( \frac{A_R}{A_A + A_Z} \)

2. **Enrichment factor**
   - Additive factor: \( ZF = \frac{1 + A_Z(i)/A_A(i)}{1 + M_Z(i)/M_A(i)} \)
   - Enrichment factor (EF): \( EF_{RA}(i) = \frac{a_{RA}(i)}{a_A(i)} = \left( \frac{ATF(i)}{MTF(i)} \right) \cdot ZF \)

For every RN (Radioactive Nucleus).
# Elementary processes

<table>
<thead>
<tr>
<th>Processes</th>
<th>Type of residue</th>
<th>Parameters and processes affecting the radionuclide enrichment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical processes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal volatilisation</td>
<td>Filter dust (from mineral sintering, blast furnace smelting or other thermal processes)</td>
<td>Temperature (above 1000°C); total mass fraction of dust (!); content of other volatile components</td>
</tr>
<tr>
<td>Solubility of chemical elements in the molten metal</td>
<td>Slag</td>
<td>Grade of ore; volatilisation (Pb-210, Po-210)</td>
</tr>
<tr>
<td>Sorption of dissolved radionuclides on oxide hydrate surfaces</td>
<td>Filter sands in water treatment</td>
<td>Ra-concentration of raw water; chemical composition of raw water; duration of filter use</td>
</tr>
<tr>
<td><strong>Chemical processes (Chemical reactions)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incineration; combustion of carbon</td>
<td>Ashes</td>
<td>Carbon content of fuel</td>
</tr>
<tr>
<td>Precipitation of Ba-Sr-sulfates from water or brines</td>
<td>Scales, sludges (oil or gas production; geothermal plants, etc.)</td>
<td>Concentration of Ba-Sr-Ca in the water or brine</td>
</tr>
<tr>
<td>NaOH treatment of bauxite</td>
<td>Red mud</td>
<td>Grade of ore</td>
</tr>
<tr>
<td>Sulphuric acid treatment of phosphate ore</td>
<td>Phosphogypsum</td>
<td>Grade of ore</td>
</tr>
</tbody>
</table>
Iron smelting

Additives (lime, coke)

Ore: Mass 100 kt
U-238 = Ra-226 = Pb-210 = 1000 MBq

Blast furnace (1500 °C)

Metal: 60 kt
U-238 = Ra-226 = 60 MBq
Pb-210 = 10 MBq

Slag: 39.5 kt
U-238 = Ra-226 = 935 MBq
Pb-210 = 90 MBq

Residue 1: MTF= 0.395
ATF (U-238; Ra-226) = 0.035 \(\rightarrow\) EF = 2.4
ATF(Pb-210) = 0.09 \(\rightarrow\) EF = 0.23

Residue 2: MTF= 0.005
ATF (U-238; Ra-226) = 0.005 \(\rightarrow\) EF = 1
ATF(Pb-210) = 0.90 \(\rightarrow\) EF = 180

Dust: 0.5 kt
U-238 = Ra-226 = 5 MBq
Pb-210 = 900 MBq

Product: MTF= 0.59
ATF (U-238; Ra-226) = 0.06
ATF(Pb-210) = 0.01
Result: large enrichments occur only in processes with small MTF
Conclusion

- The radioactivity of wastes is only partially determined from the radioactivity of raw materials. The transfer of radionuclides into waste may result in an increase of activity concentrations which cannot be disregarded from the radiation protection point of view.

- Because high radionuclide enrichments are attributed to (very) low mass transfer factors, wastes with high activity concentrations occur usually in mass streams of technological processes, which constitute a small fraction of the total mass streams.

- Processes with mass amounts of products and wastes in the same order of magnitude are less sensitive in regard to changes of activity concentrations in the waste. Here the EF are low and the activity of wastes can be well estimated from the activity concentration of raw materials. (e.g. aluminia production from bauxite).

- Activity concentrations in wastes arising from processes with high enrichment factors are very sensitive in regard to any changes of masses in the process. That’s why the activity concentrations of scales in oil and gas production vary in different facilities in a poorly predictable degree.
Real processes

Precipitation, sorption from water

High temperature processes (without combustion)

Metal smelting – Slag

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### Model parameters

<table>
<thead>
<tr>
<th>Physical or chemical elementary process</th>
<th>MTF</th>
<th>Radioelements (-nuclides) r</th>
<th>ATF (r)</th>
<th>ZF (r)</th>
<th>EF (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal volatilisation (blast furnace, pig iron production)</td>
<td>0.005</td>
<td>Pb-210</td>
<td>0.9</td>
<td>1.4</td>
<td>250</td>
</tr>
<tr>
<td>Solubility of chemical elements in the molten metal</td>
<td>0.1-0.3</td>
<td>U, Ra, Th</td>
<td>1</td>
<td></td>
<td>3 – 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pb-210</td>
<td>0.1(b)</td>
<td></td>
<td>0.3 - 1</td>
</tr>
<tr>
<td>Sorption of dissolved radionuclides on oxide hydrate surfaces</td>
<td>&lt; 1E-5</td>
<td>Ra</td>
<td>0.8-0.99</td>
<td>1</td>
<td>&gt;1E+5</td>
</tr>
<tr>
<td>Incineration; combustion of carbon</td>
<td>0.1 – 0.01</td>
<td>U, Ra, Th</td>
<td>1</td>
<td>1</td>
<td>10 - 100</td>
</tr>
<tr>
<td>Precipitation of Ba-Sr-sulfates from water or brines</td>
<td>1E-5</td>
<td>Ra</td>
<td>0.1</td>
<td>1</td>
<td>1E+4</td>
</tr>
<tr>
<td>NaOH treatment of bauxite</td>
<td>0.3</td>
<td>U, Th, Ra, Pb-210</td>
<td>1</td>
<td>0.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Sulphuric acid treatment of phosphate ore</td>
<td>0.72</td>
<td>Th, Ra, Pb-210</td>
<td>0.9</td>
<td>0.44</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>U</td>
<td>0.1(a)</td>
<td></td>
<td>0.06</td>
</tr>
</tbody>
</table>
**Application 1: Combustion of peat**

Data from “Radiological assessment of NORM Industries in Ireland – Radiation doses to workers and members of the public” Catherine Organo and David Fenton December 2008

<table>
<thead>
<tr>
<th></th>
<th>U-238</th>
<th>Ra-226</th>
<th>Pb-210</th>
<th>Th-232</th>
<th>K-40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat Bq/kg</td>
<td>8</td>
<td>4</td>
<td>26</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>fly ash Bq/kg</td>
<td>102</td>
<td>26</td>
<td>414</td>
<td>12</td>
<td>71</td>
</tr>
<tr>
<td>bottom ash Bq/kg</td>
<td>122</td>
<td>30</td>
<td>129</td>
<td>5</td>
<td>109</td>
</tr>
<tr>
<td>EF(Fly ash) EF</td>
<td>12,8</td>
<td>6,5</td>
<td>15,9</td>
<td>12,0</td>
<td>10,1</td>
</tr>
<tr>
<td>EF(Bott. Ash) EF</td>
<td>15,3</td>
<td>7,5</td>
<td>5,0</td>
<td>5</td>
<td>15,6</td>
</tr>
</tbody>
</table>

Why there is a different enrichment of U and Raß
Where the missing Ra has remained?

→ Check of plausibility
Application 2: Mass-activity balance of a sinter facility

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The next step

- Calculate EF from chemical data!
Final remark

This approach was published in

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