Radon and the PFLOTRAN Ingestion Dose Model

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Problem
- Radon-222 (222Rn) and other short-lived isotopes are typically excluded from groundwater flow models.
- However, they can be highly mobile relative to their parents (e.g., 222Rn).
- How do we account for dose from short-lived isotopes?
  - Must account for individual contributions.
  - Must account for emanation and relative adsorption.

Equations
- Dose rate (Sv a⁻¹) [1] for supported isotope i (e.g., 226Ra)
  \[ H_{E,i} = C_{W,i} \cdot \beta \cdot dcf \]
  - Conc. of i in well water (Bq/m³)
  - Ingestion rate (m³/a)
  - Ingestion dose coeff of i (Sv/Bq)
- Aq. Conc. (Bq m⁻³) [2] for unsupported isotope u (e.g., 222Rn)
  \[ C_{W,u} = C_{W,i} \cdot \epsilon_u \cdot \psi_u \]
  - Adsorption enhancement factor
  - Emanation factor
- Adsorption enhancement factor [2]
  \[ \epsilon_u = R_f / R_{fu} \]
  - Retardation factor of i
  - Retardation factor of u

Simulate
- Assume 1 Bq m⁻³ of 226Ra in well water, consumed at 2 L per day.

Results

Table 1. Model inputs/outputs for unsupported descendants of 226Ra.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Adsorption Enhancement Factor ( \epsilon_u )</th>
<th>Emanation Factor ( \psi_u )</th>
<th>Dose Coeff. dc f (Sv Bq⁻¹)</th>
<th>Calculated Aq. Conc. ( C_{W,u} ) (Bq m⁻³)</th>
<th>Calculated Dose Rate ( H_{E,u} ) (Sv a⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>226Ra</td>
<td>NA³</td>
<td>NA³</td>
<td>2.8E-07</td>
<td>1.00⁵</td>
<td>2.0E-07</td>
</tr>
<tr>
<td>222Rn</td>
<td>5000⁶</td>
<td>0.40⁶</td>
<td>3.5E-09</td>
<td>2000</td>
<td>5.1E-06</td>
</tr>
<tr>
<td>214Pb</td>
<td>1.85⁶</td>
<td>1.0⁶</td>
<td>1.4E-10</td>
<td>1.85</td>
<td>1.9E-10</td>
</tr>
<tr>
<td>214Bi</td>
<td>5.0⁶</td>
<td>1.0⁶</td>
<td>1.1E-10</td>
<td>5.0</td>
<td>4.0E-10</td>
</tr>
</tbody>
</table>

a = not applicable; b = [4]; c = [2]; d = assumed; e = [5]; f = [6]; g = input

Conclusions
- Net adsorption enhancement in this example causes ingestion dose from 222Rn to increase by a factor of 2000.
- Open-source PFLOTRAN and GDSA Framework (pa.sandia.gov) [3] include this model.

References

Figure 1. Schematic illustration of affinity of 222Rn for the aqueous phase, relative to 226Ra. This results in enhanced well water concentrations of 222Rn relative to 226Ra and an increased dose rate.

Figure 2. 226Ra and its short-lived descendants.

Figure 3. Effects of adsorption enhancement and emanation factor on dose rates calculated for each isotope. Hollow bars ignore \( \epsilon_u \) and \( \psi_u \).