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]
  \[ H_{E,i} = C_{W,i} * I * dc/f_i \]
  Conc. of i in well water (Bq/m³)  Ingestion rate (m³/a)  Ingestion dose coeff. (Sv/Bq)
• Aq. Conc. (Bq m⁻³) [2] for unsupported isotope u (e.g., 222Rn)
  \[ C_{W,u} = C_{W,i} * \epsilon_u * \psi_u \]
  Adsorption enhancement factor  Emanation factor
• Adsorption enhancement factor [2]
  \[ \epsilon_u = Rf_i / Rf_u \]
  Retardation factor of i  Retardation factor of u

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.

Simulate
• Assume 1 Bq m⁻³ of 226Ra in well water, consumed at 2 L per day.
• Use PFLOTRAN’s biosphere process model with GDSA Framework [3] to calculate dose rates for 226Ra and descendants.

Results

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Adsorption Enhancement Factor</th>
<th>Emanation Factor</th>
<th>Dose Coeff. dc/f (Sv Bq⁻¹)</th>
<th>Calculated Aq. Conc. C_{W,i} (Bq m⁻³)</th>
<th>Calculated Dose Rate H_{E,i} (Sv a⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>226Ra</td>
<td>NA</td>
<td>NA</td>
<td>2.8E-07</td>
<td>1.00</td>
<td>2.0E-07</td>
</tr>
<tr>
<td>222Rn</td>
<td>5000b</td>
<td>0.40c</td>
<td>3.5E-09</td>
<td>2000</td>
<td>5.1E-06</td>
</tr>
<tr>
<td>214Pb</td>
<td>1.85b</td>
<td>1.0d</td>
<td>1.4E-10</td>
<td>1.85</td>
<td>1.9E-10</td>
</tr>
<tr>
<td>214Bi</td>
<td>5.0b</td>
<td>1.0d</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

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 \( \psi_u \).

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