In-Situ Radionuclide Transport Near Nopal I Uranium Deposit At Peña Blanca, Mexico: Constraints From Short-Lived Decay-Series Radionuclides

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Presented by:
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U-series Radioisotopes as a Natural Analog

- **238U series:** $^{238}\text{U} (\alpha, \text{4.5 by}) \rightarrow ^{234}\text{Th} (\beta, \text{24,1 d}) \rightarrow ^{234}\text{U} (\alpha, \text{248 ky}) \rightarrow ^{230}\text{Th} (\alpha, \text{75.4 ky}) \rightarrow ^{226}\text{Ra} (\alpha, \text{1.6 ky}) \rightarrow ^{222}\text{Rn} (\alpha, \text{3.8 d}) \rightarrow ^{210}\text{Pb} (\beta, \text{22.3 y}) \rightarrow ^{210}\text{Po} (\alpha, \text{138.4 d}) \rightarrow ^{206}\text{Pb}$

- **235U series:** $^{235}\text{U} (\alpha, \text{0.71 by}) \rightarrow ^{231}\text{Pa} (\alpha, \text{32.8 ky}) \rightarrow ^{227}\text{Ac} (\beta, \text{22.0 y}) \rightarrow ^{227}\text{Th} (\alpha, \text{18.6 d}) \rightarrow ^{223}\text{Ra} (\alpha, \text{11.1 d}) \rightarrow \ldots \rightarrow ^{207}\text{Pb}$

- **232Th series:** $^{232}\text{Th} (\alpha, \text{14.2 by}) \rightarrow ^{228}\text{Ra} (\beta, \text{5.75 y}) \rightarrow ^{228}\text{Th} (\alpha, \text{1.91 d}) \rightarrow ^{224}\text{Ra} (\alpha, \text{3.64 d}) \rightarrow \ldots \rightarrow ^{208}\text{Pb}$

How fast are the migration rates of radionuclides in groundwater?

U deposit

Vadose zone

Aquifer
Three-pool radionuclide transport model (Ku et al. 1992, Luo et al. 2000)

**In-situ retardation factor:**

\[ R_f = 1 + K = 1 + \frac{\bar{C}}{C} = 1 + \frac{k_1}{k_2 + \lambda} \]

\[
\begin{align*}
    &= \frac{\text{Transport rate of groundwater}}{\text{Transport rate of radionuclide}}
\end{align*}
\]
Mass balance of a radionuclide in the dissolved and sorbed pools:

\[
R_f \left( \frac{\partial C}{\partial t} \right) = P - R_f A - k_p C - Q
\]  \hspace{1cm} (1)

Where \( C \) and \( A \) are concentration and activity of a nuclide in groundwater, \( P \) is supply rates by dissolution (\( P_d \)), alpha recoil (\( P_r \)), and in-situ production (\( R_{f,p} \times A_p \)), \( k_p \) is first-order precipitation rate constant, and \( Q \) is transport by groundwater.

For short-lived radionuclides at steady state, Eq. (1) can be simplified as:

\[
R_f = \frac{P}{A}
\]  \hspace{1cm} (2)
A map of study area showing the sampling wells (red circles) near Nopal I Uranium Deposit at Peña Blanca, Mexico.
Sampling Techniques

- Pre-filter
- Water meter
- Mn-filter A
- Mn-filter B

Vadose zone

Aquifer

U deposit

S. Luo-GSA 10/17/05.
## Ra and Rn Isotope Measurements

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Rn-222 (dpm/L)</th>
<th>Ra-228 (dpm/m³)</th>
<th>Ra-224 (dpm/m³)</th>
<th>Ra-223 (dpm/m³)</th>
<th>Ra-224/Ra-228</th>
<th>Ra-223/Ra-224</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB</td>
<td>1831 ± 80</td>
<td>2614 ± 69</td>
<td>4984 ± 64</td>
<td>96 ± 52</td>
<td>1.907 ± 0.056</td>
<td>0.019 ± 0.010</td>
</tr>
<tr>
<td>Pozos</td>
<td>1421 ± 67</td>
<td>622 ± 19</td>
<td>997 ± 16</td>
<td>29 ± 17</td>
<td>1.604 ± 0.056</td>
<td>0.029 ± 0.017</td>
</tr>
<tr>
<td>PB4</td>
<td>595 ± 37</td>
<td>540 ± 14</td>
<td>589 ± 10</td>
<td>29 ± 20</td>
<td>1.090 ± 0.033</td>
<td>0.050 ± 0.034</td>
</tr>
</tbody>
</table>
# Pb-210 and Po-210 measurements

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Rn-222 (dpm/L)</th>
<th>Pb-210 (dpm/m³)</th>
<th>Po-210 (dpm/m³)</th>
<th>Po-210/Pb-210</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB</td>
<td>1831 ± 80</td>
<td>45.5 ± 1.4</td>
<td>4.9 ± 0.3</td>
<td>0.108 ± 0.007</td>
</tr>
<tr>
<td>Pozos</td>
<td>1421 ± 67</td>
<td>3.2 ± 1.2</td>
<td>0.69 ± 0.07</td>
<td>0.216 ± 0.084</td>
</tr>
<tr>
<td>PB4</td>
<td>595 ± 37</td>
<td>94.1 ± 4.3</td>
<td>95.3 ± 3.7</td>
<td>1.013 ± 0.061</td>
</tr>
</tbody>
</table>
### Estimates of Alpha Recoil Input of Radon in Groundwater

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Pr (Rn-222) (atoms/minute/L)</th>
<th>Pr(Rn)/A(Rn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB</td>
<td>871</td>
<td>0.476</td>
</tr>
<tr>
<td>Pozos</td>
<td>535</td>
<td>0.377</td>
</tr>
<tr>
<td>PB4</td>
<td>49</td>
<td>0.083</td>
</tr>
</tbody>
</table>
## Estimates of In-Situ Retardation Factor for Ra, Pb, and Po

<table>
<thead>
<tr>
<th>Well ID</th>
<th>$R_f$ (Ra) $(10^3)$</th>
<th>$R_f$ (Pb) $(10^5)$</th>
<th>$R_f$ (Po) $(10^6)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB</td>
<td>0.43 ± 0.02</td>
<td>0.59 ± 0.03</td>
<td>5.5 ± 0.4</td>
</tr>
<tr>
<td>Pozos</td>
<td>1.68 ± 0.08</td>
<td>6.1 ± 2.3</td>
<td>28 ± 15</td>
</tr>
<tr>
<td>PB4</td>
<td>1.19 ± 0.08</td>
<td>0.069 ± 0.005</td>
<td>0.068 ± 0.007</td>
</tr>
</tbody>
</table>
## Estimate of Mean Fracture Width

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Pr (Rn-222) (atoms/minute/L)</th>
<th>fracture width (d) (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB</td>
<td>871</td>
<td>0.23</td>
</tr>
<tr>
<td>Pozos</td>
<td>535</td>
<td>0.37</td>
</tr>
<tr>
<td>PB4</td>
<td>49</td>
<td>3.97</td>
</tr>
</tbody>
</table>
Effective Retardation Factor:

\[ R_f^* = 1 + K^* = 1 + \frac{C}{C^*} = 1 + \frac{K}{1 + K_d \{p\}} \]  \hspace{1cm} (3)

where \( C^* = C_{\text{dis}} + C_{\text{col}} \), \( K_d \) is distribution coefficient of a nuclide between colloidal and dissolved pools, and \( \{p\} \) is concentration of colloids in groundwater.

Transport Equation:

\[ \frac{P}{A^*} = R_f^* + \frac{Q}{A^*} = R_f^* + \frac{1}{\lambda \tau_w} \]  \hspace{1cm} (4)

where \( A^* = A_{\text{dis}} + A_{\text{col}} \), \( P \) is supply rates by dissolution \((P_d)\), alpha recoil \((P_r)\), and in-situ production \((R_{f,p}^* \times A_{p^*})\), and \( Q \) is transport in the dissolved and colloidal forms by groundwater.
Transport of radionuclides by colloids become less important with increasing radionuclide decay constant and/or water residence time in the aquifer.

For $1/(\lambda \tau_w) \ll R_f^*$, we have

$$\frac{P}{A^*} = R_f^*$$  \hspace{1cm} (5)

This equation can be applied to short-lived particle-reactive radionuclides, e.g., $^{210}\text{Pb}$ and $^{210}\text{Po}$. 
Conclusions

- No significantly high activities of radionuclides in the groundwater are found to be associated with the nearby uranium ore deposit.

- Migration rates of Ra, Pb and Po isotopes are determined respectively to be about three, three to five, and four to six orders slower than those of groundwater.

- Increased Pb-210 and Po-210 activities or decreased retardation factors of Pb and Po in well PB-4 are most likely attributable to the occurrence of colloids in the groundwater.
Conclusions (continued)

- Enrichment of the sorbed Ra isotopes on the rock fractures provides an important source of radon in groundwater.

- The low alpha recoil input in well PB-4 reflects the large fracture width of rocks in the aquifer.

- Future studies should focus on the behavior of radionuclides in recently drilled wells near the U deposit and the importance of colloids in transporting long-lived radionuclides in groundwater.
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