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

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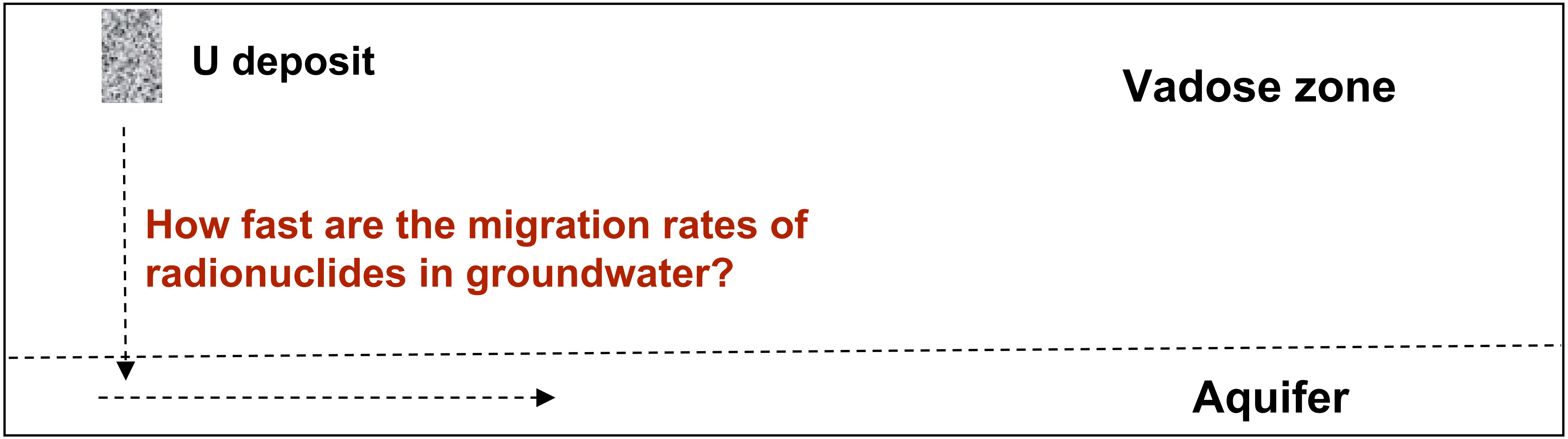
U-series Radioisotopes as a Natural Analog

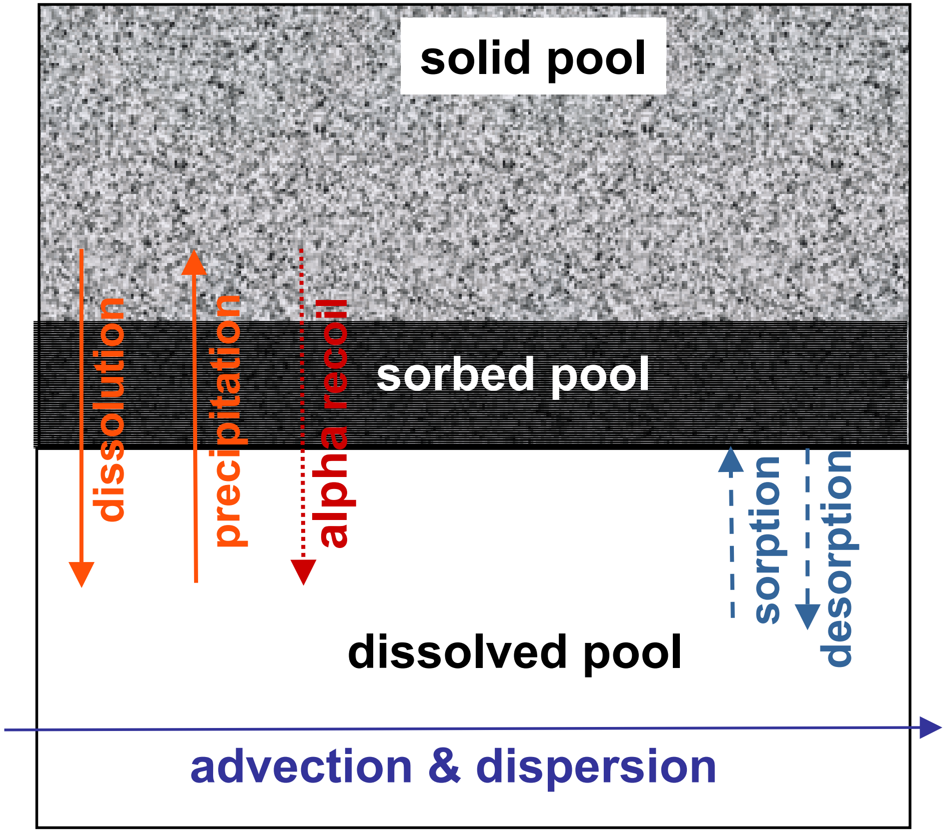
- **^{238}U series:** **^{238}U** (α, 4.5 by) → **^{234}Th** (β, 24,1 d) → **^{234}U** (α, 248 ky) → **^{230}Th** (α, 75.4 ky) → **^{226}Ra** (α, 1.6 ky) → **^{222}Rn** (α, 3.8 d) → **^{210}Pb** (β, 22.3 y) → **^{210}Po** (α, 138.4 d) → **^{206}Pb**
- **^{235}U series:** **^{235}U** (α, 0.71 by) → **^{231}Pa** (α, 32.8 ky) → **^{227}Ac** (β, 22.0 y) → **^{227}Th** (α, 18.6 d) → **^{223}Ra** (α, 11.1 d) → **…**→ **^{207}Pb**
- **^{232}Th series:** **^{232}Th** (α, 14.2 by) → **^{228}Ra** (β, 5.75 y) → **^{228}Th** (α, 1.91 d) → **^{224}Ra** (α, 3.64 d) →**…** → **^{208}Pb**



How fast are the migration rates of radionuclides in groundwater?

Conceptual Model

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



In-situ retardation factor:

$$\boxed{R_f = 1 + K = 1 + \frac{\overline{C}}{C} = 1 + \frac{k_1}{k_2 + \lambda}}$$

$$= \frac{\text{Transport rate of groundwater}}{\text{Transport rate of radionuclide}}$$

U-Series Radionuclide Transport Model

- **Mass balance of a radionuclide in the dissolved and sorbed pools:**

$$R_f\left(\frac{\partial C}{\partial t}\right) = P - R_f A - k_p C - Q \qquad (1)$$

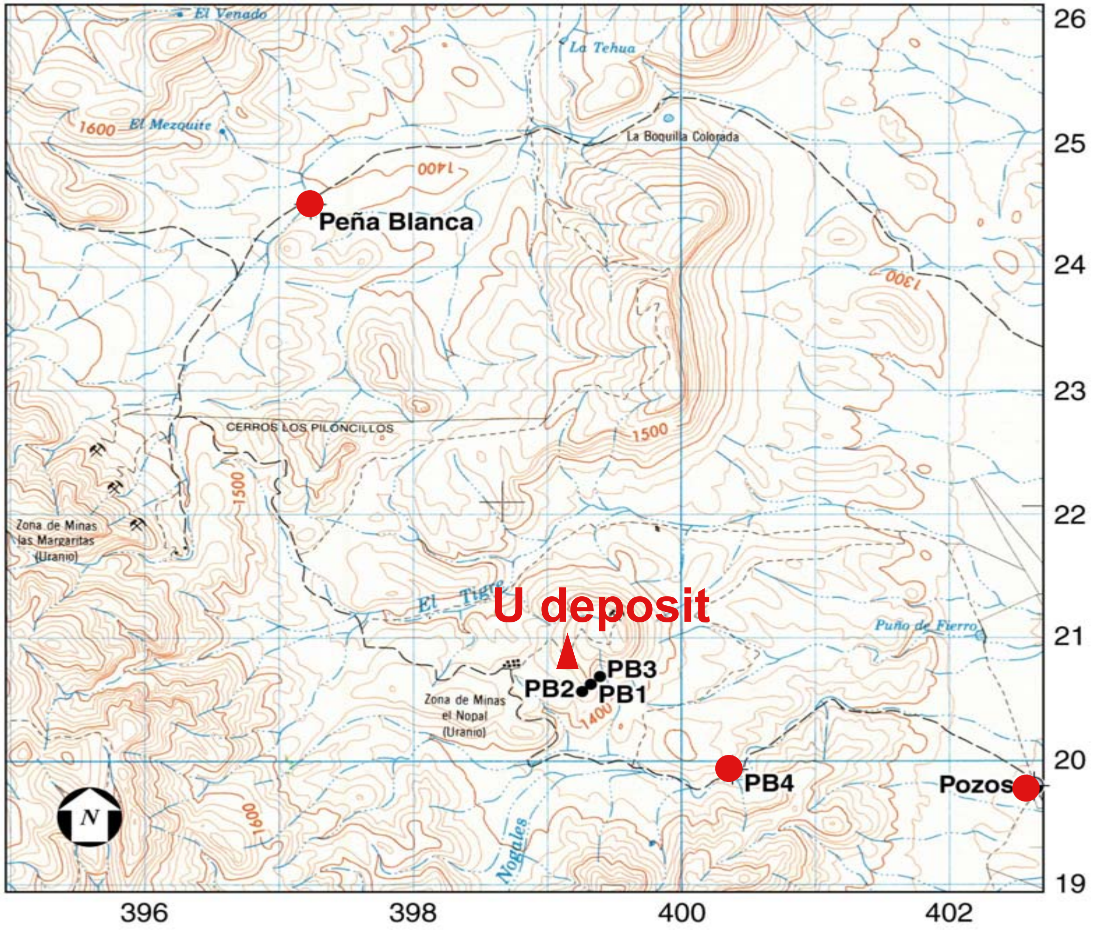
Where *C* and *A* are concentration and activity of a nuclide in groundwater, *P* is supply rates by dissolution (P_d), alpha recoil (P_r), and in-situ production ($R_{f,p}^{*} \times A_p^{*}$), k_p is first-order precipitation rate constant, and *Q* is transport by groundwater.

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

$$R_f = \frac{P}{A} \qquad (2)$$

Location Map

A map of study area showing the sampling wells (red circles) near Nopal I Uranium Deposit at Peña Blanca, Mexico



Legend

- ● Existing Wells
- • New Peña Blanca Boreholes

0 1 Km

Contour Interval = 20 Meters

El Sauz 1:50,000 Topographic Map (H13C46)
North American 1927 datum

NA04-001

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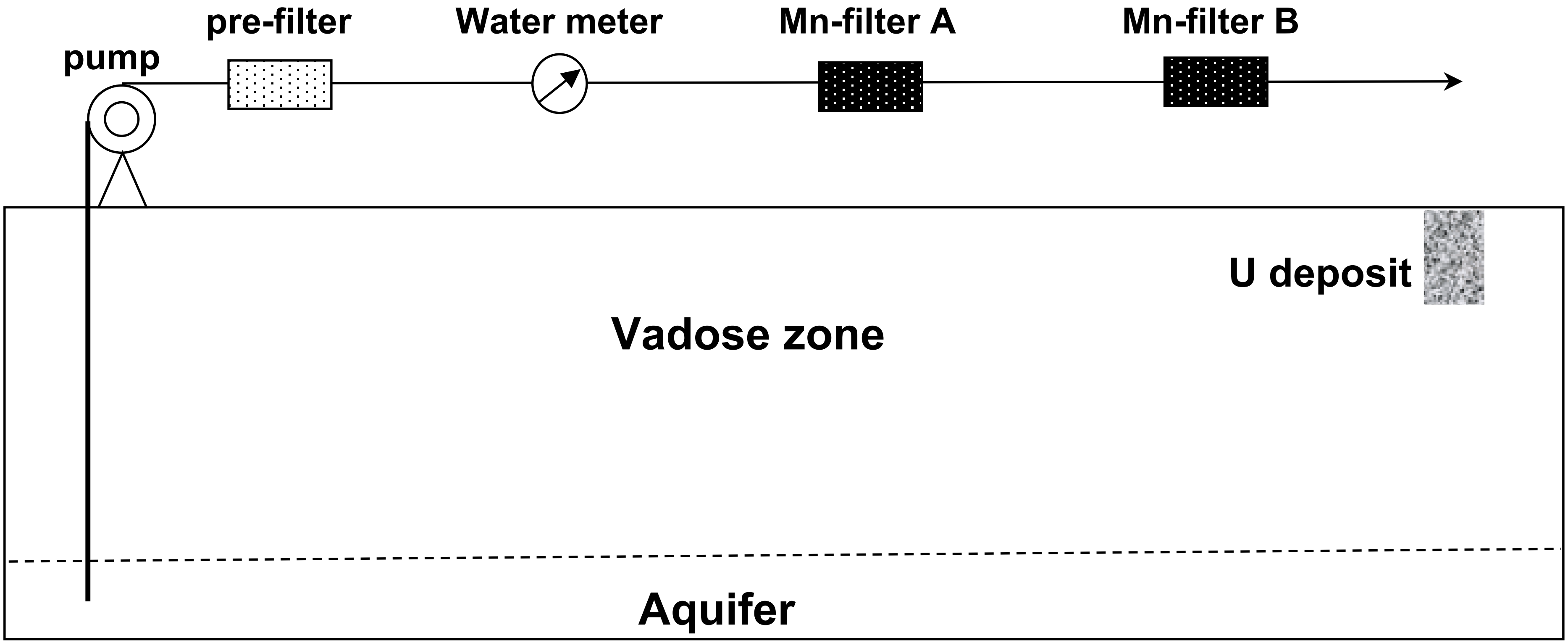
Sampling Techniques



pump

pre-filter

Water meter

Mn-filter A

Mn-filter B

U deposit

Vadose zone

Aquifer

Ra and Rn Isotope Measurements

Well ID	Rn-222			Ra-228			Ra-224			Ra-223			Ra-224/Ra-228			Ra-223/Ra-224		
	(dpm/L)			(dpm/m^3)			(dpm/m^3)			(dpm/m^3)								
PB	1831	±	80	2614	±	69	4984	±	64	96	±	52	1.907	±	0.056	0.019	±	0.010
Pozos	1421	±	67	622	±	19	997	±	16	29	±	17	1.604	±	0.056	0.029	±	0.017
PB4	595	±	37	540	±	14	589	±	10	29	±	20	1.090	±	0.033	0.050	±	0.034

Pb-210 and Po-210 measurements

Well ID	Rn-222			Pb-210			Po-210			Po-210/Pb-210		
	(dpm/L)			(dpm/m^3)			(dpm/m^3)					
PB	1831	±	80	45.5	±	1.4	4.9	±	0.3	0.108	±	0.007
Pozos	1421	±	67	3.2	±	1.2	0.69	±	0.07	0.216	±	0.084
PB4	595	±	37	94.1	±	4.3	95.3	±	3.7	1.013	±	0.061

Estimates of Alpha Recoil Input of Radon in Groundwater

Well ID	Pr (Rn-222) (atoms/minute/L)	Pr(Rn)/A(Rn)
PB	871	0.476
Pozos	535	0.377
PB4	49	0.083

Estimates of In-Situ Retardation Factor for Ra, Pb, and Po

Well ID	R_f (Ra) (10^3)	R_f (Pb) (10^5)	R_f (Po) (10^6)
PB	0.43 ± 0.02	0.59 ± 0.03	5.5 ± 0.4
Pozos	1.68 ± 0.08	6.1 ± 2.3	28 ± 15
PB4	1.19 ± 0.08	0.069 ± 0.005	0.068 ± 0.007

Estimate of Mean Fracture Width

Well ID	Pr (Rn-222) (atoms/minute/L)	fracture width (d) (μm)
PB	871	0.23
Pozos	535	0.37
PB4	49	3.97

Role of Colloids in Transporting Radionuclides in Groundwater

- **Effective Retardation Factor:**

$$R_f^* = 1 + K^* = 1 + \frac{\overline{C}}{C^*} = 1 + \left(\frac{K}{1 + K_d\{p\}} \right) \qquad (3)$$

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

- **Transport Equation:**

$$\frac{P}{A^*} = R_f^* + \frac{Q}{A^*} = R_f^* + \frac{1}{\lambda \tau_w} \qquad (4)$$

where $A^* = A_{dis} + A_{col}$, 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.

Role of Colloids in Transporting Radionuclides in Groundwater (continued)

- **Transport of radionuclides by colloids become less important with increasing radionuclide decay constant and/or water residence time in the aquifer.**
- **For $1/(\lambda\tau_w) << R_f^*$, we have**

$$\frac{P}{A^*} = R_f^* \qquad (5)$$

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

Acknowledgement

- **This work is supported by the U.S. DOE, Office of Civilian Radioactive Waste Management, Office of Science and Technology and International.**