Radon and the PFLOTRAN Ingestion Dose Model

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Problem

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

Conceptual Model

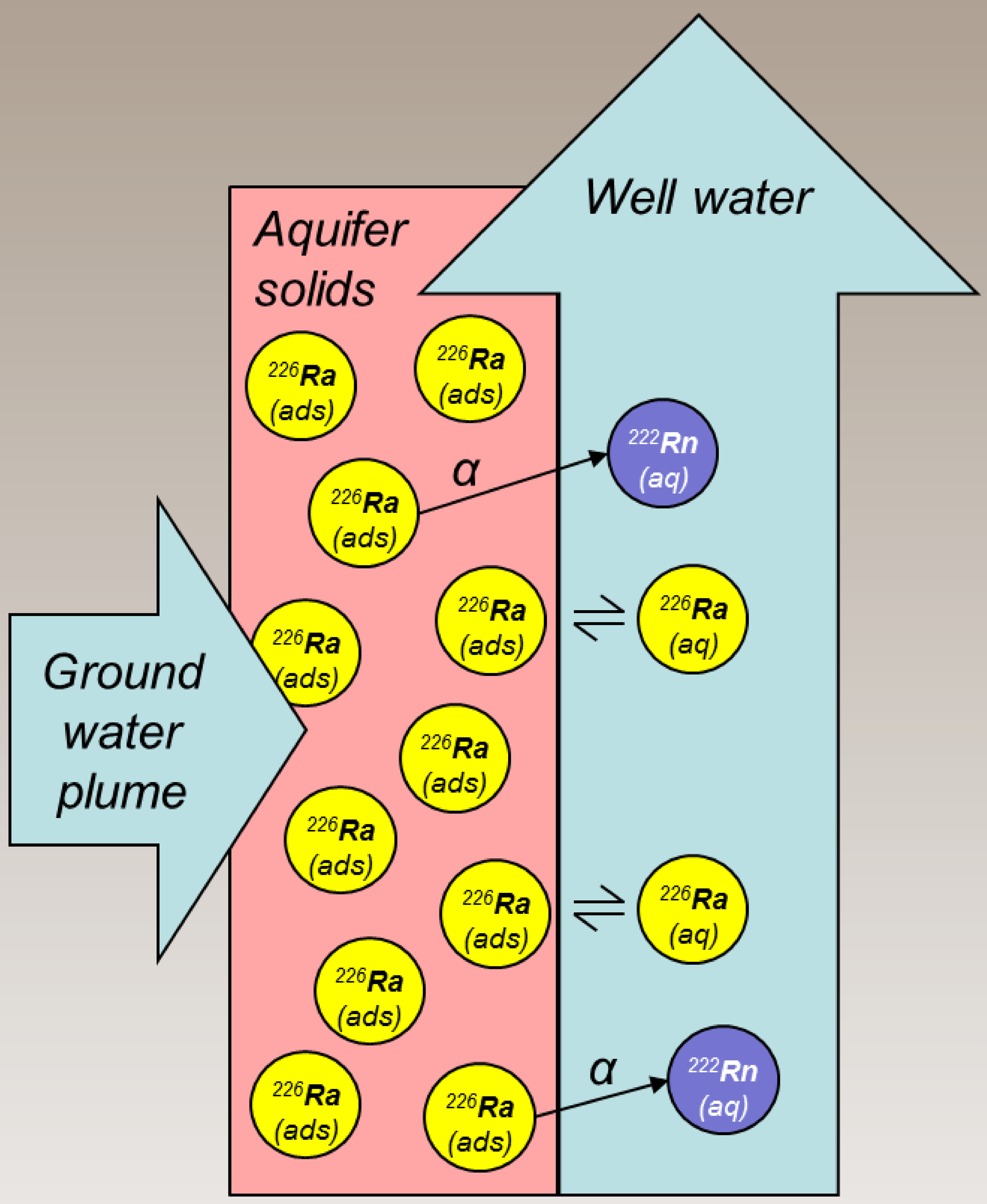

Figure 1. Schematic illustration of affinity of ^{222}Rn for the aqueous phase, relative to ^{226}Ra. This results in enhanced well water concentrations of ^{222}Rn relative to ^{226}Ra and an increased dose rate.

Equations

- Dose rate (Sv a^{-1}) [1] for *supported* isotope i (e.g., ^{226}Ra)

$$H_{E,i} = C_{w,i} * I * dcf_i$$

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., ^{222}Rn)

$$C_{w,\boldsymbol{u}} = C_{w,\boldsymbol{i}} \epsilon_u \varphi_u$$

Adsorption enhancement factor — *Emanation factor*

- Adsorption enhancement factor [2]

$$\epsilon_u = Rf_i / Rf_u$$

Retardation factor of i — *Retardation factor of u*

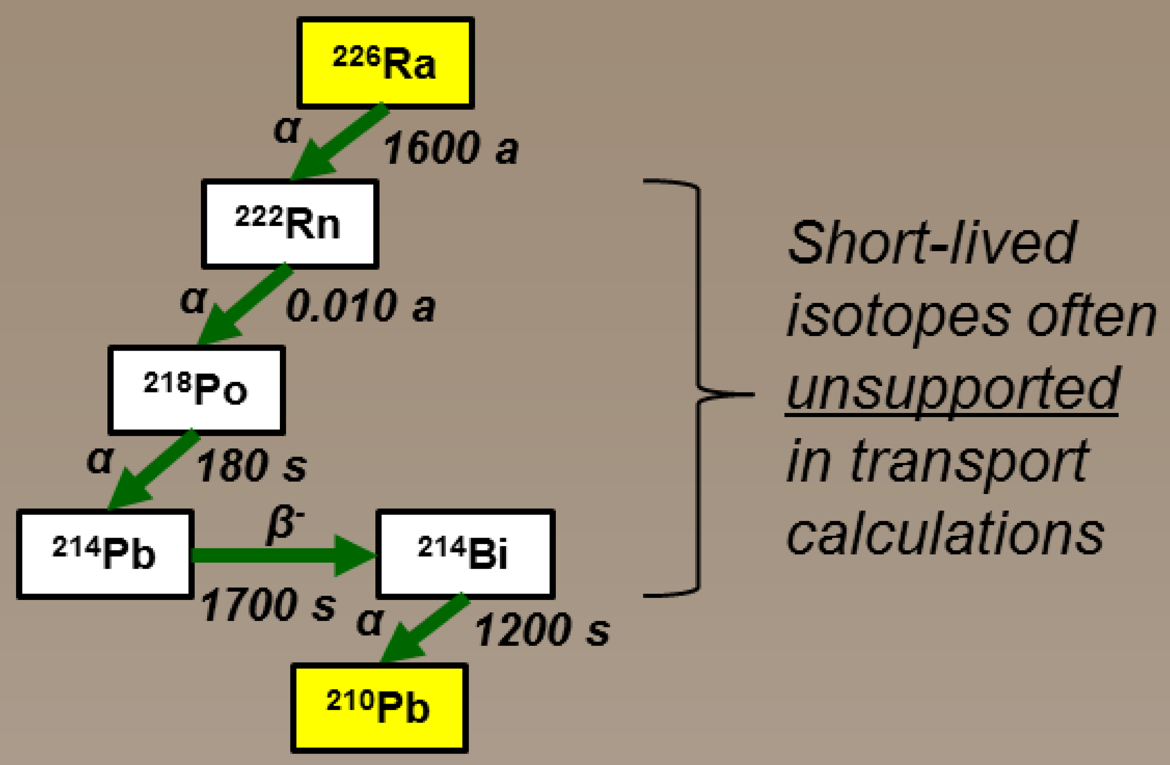

Figure 2. ^{226}Ra and its short-lived descendants.

Simulate

- Assume 1 Bq m^{-3} of ^{226}Ra in well water, consumed at 2 L per day.
- Use PFLOTRAN's biosphere process model with *GDSA Framework* [3] to calculate dose rates for ^{226}Ra and descendants.

Results

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

Isotope	Adsorption Enhancement Factor ϵ_u	Emanation Factor φ_u	Dose Coeff. dcf (Sv Bq^{-1})	Calculated Aq. Conc. $C_{w,u}$ (Bq m^{-3})	Calculated Dose Rate $H_{E,u}$ (Sv a^{-1})
^{226}Ra	NA[a]	NA[a]	2.8E-07[e]	1.00[g]	2.0E-07
^{222}Rn	5000[b]	0.40[c]	3.5E-09[f]	2000	5.1E-06
^{214}Pb	1.85[b]	1.0[d]	1.4E-10[e]	1.85	1.9E-10
^{214}Bi	5.0[b]	1.0[d]	1.1E-10[e]	5.0	4.0E-10

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

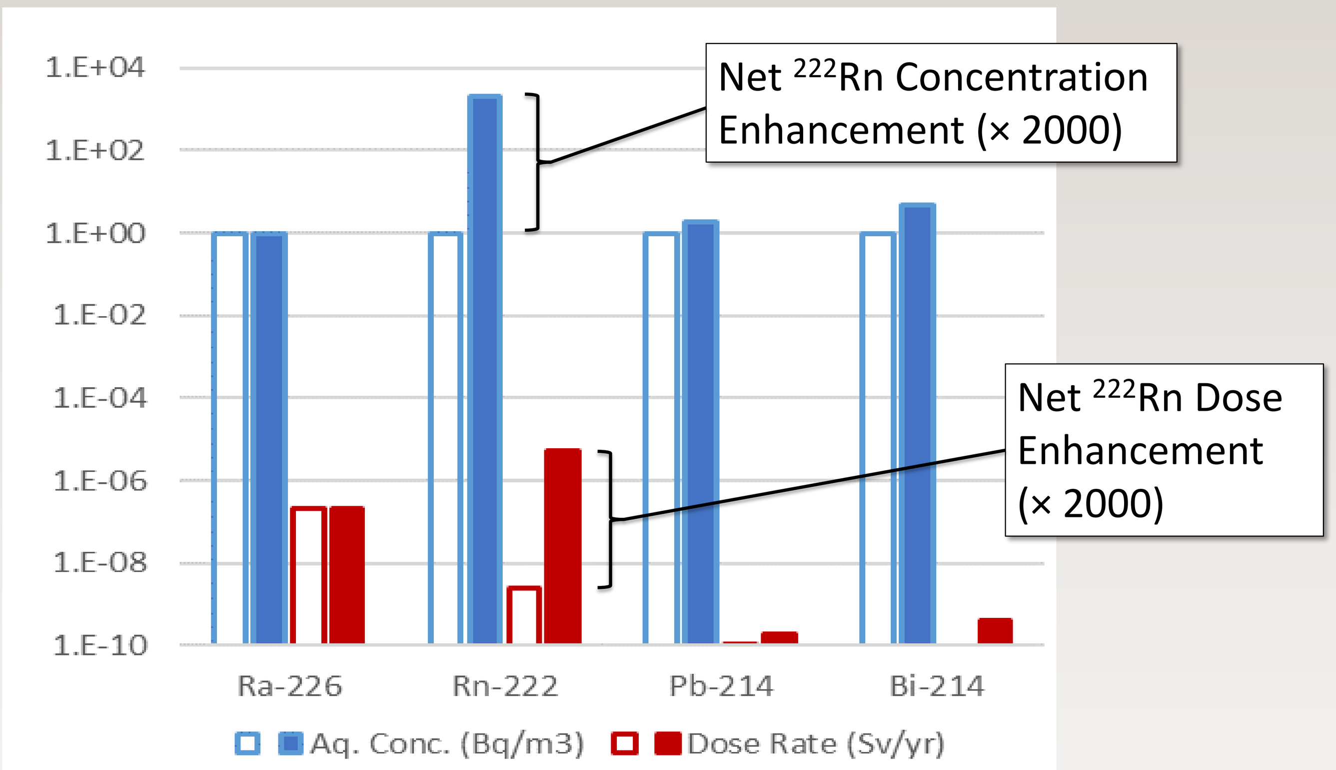

Figure 3. Effects of adsorption enhancement and emanation factor on dose rates calculated for each isotope. Hollow bars ignore ϵ_u and φ_u.

Conclusions

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

References

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2. Olszewska-Wasiolek, M.A. and B.W. Arnold (2011). Radioactive Disequilibria in the Saturated Zone Transport Model and the Biosphere Model for the Yucca Mountain Repository — The Case of Radon-222. International High-Level Radioactive Waste Management Conference 2011. Albuquerque, New Mexico.
3. SNL (2017). *GDSA Framework*: A Geologic Disposal Safety Assessment Modeling Capability. Open Source. Available from: pa.sandia.gov.
4. Sheppard, M.I. and D.H. Thibault (1990). Default soil solid/liquid partition coefficients, Kds, for four major soil types: a compendium. Health Physics 59(4): p. 471-482.
5. ICRP (2012). Compendium of Dose Coefficients based on ICRP Publication 60. ICRP Publication 119. Ann. ICRP 41(Suppl.).
6. UNSCEAR (2000). Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes, United Nations: New York, New York.

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