Uranium Elemental and Isotopic Constraints on Groundwater Flow Beneath the Nopal I Uranium Deposit, Peña Blanca, Mexico

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Groundwater velocity is an important parameter influencing radionuclide transport at Peña Blanca and Yucca Mountain.

Groundwater hydrology at Peña Blanca is poorly understood: speed and direction.

Specifically identified need: conduct artificial tracer studies at Peña Blanca to detect SZ groundwater flow and transport.

This study uses natural U as a tracer of groundwater flow.

SZ groundwater velocity information is directly used by models of radionuclide transport, including TSPA.
Outline

- Saturated Zone Uranium Data
  - Concentrations [U] and isotopes \(^{234}\text{U}/^{238}\text{U}\)
- Modeling
  - One-Dimensional (1-D) Dispersion/Advection
- Conclusions
  - Limited groundwater flow and mixing are apparent
Panoramic View of New PB Wells
U Isotopic Results

The graph shows the 234U/238U (AR) values against the inverse of uranium concentration (1/[U] (1/ppb)) for different locations, including NW Ranch, Spring N Ranch, Pozos Ranch, PB1, PB2, PB3, and PB4. The values are plotted on the x-axis and y-axis, respectively.
Multiple Components for U

- Int. [U], High \(^{234}\text{U}/^{238}\text{U}\)
- Low [U], High \(^{234}\text{U}/^{238}\text{U}\) "Recoil"
- High [U], Int. \(^{234}\text{U}/^{238}\text{U}\)
- Low [U], Low \(^{234}\text{U}/^{238}\text{U}\)

\[1/[U] \text{ (1/ppb)}\]

\[^{234}\text{U}/^{238}\text{U} \text{ (AR)}\]
PB-1 and PB-2 isotopically similar, suggesting interconnectivity.

PB-3 has distinct composition and therefore may be located on a different flow path.

Generally, regional wells have distinct isotopic characteristics indicating limited mixing over larger length scales (km).

Newly drilled wells PB-1, PB-2, and PB-3 have elevated U concentrations which are decreasing over time (next slides).
U Time Series

During Well Conditioning

[\text{U} \text{ (ppb)}] PB1 and PB2

[\text{U} \text{ (ppb)}] PB3

Date

20-Mar-03 9-May-03 28-Jun-03 17-Aug-03 6-Oct-03 25-Nov-03 14-Jan-04

PB-1

PB-2

PB-3

During Well Conditioning
1-D Advection-Dispersion Model

Model Assumptions

- U introduced as a slug at \( t=0, \ x=0 \)
- U is a conservative tracer over short timescales (months-year)
- Analytical solution in Bear (1979)

Relative U concentration (C) controlled by position (x), time (t), groundwater velocity (V), and dispersion (D_h)

At point of U introduction (x=0),

\[
\frac{C_2}{C_1} = (\frac{t_1}{t_2})^{0.5}\exp\{V^2(\frac{t_1-t_2}{4D_h})\}
\]

Knowing \( C_2, C_1, t_2, \) and \( t_1 \), one can obtain a relationship between velocity and dispersion for each of the three wells:

\[
V = \{\ln[(\frac{C_2}{C_1})(\frac{t_2}{t_1})^{0.5}]4D_h/(t_1-t_2)\}^{0.5}
\]
Velocity-Dispersivity Relationship

![Graph showing the relationship between 1-D Flow rate (m/yr) and Hydrodynamic dispersion coeff. (cm²/s). The graph includes two curves labeled PB1 - peak and PB2,3 - peak.](image-url)
Field and laboratory data from Klotz et al. (1980).

Field site (Upper Bavaria, Germany) is composed of gravels with mean grain size of ~5 mm.

- Lines 1-5: Lab tests based on natural mixtures of more homogeneous sands with grain size of 0.1 to 1 mm.
- Lines 6-9: Lab tests based on natural mixtures of gravels from Bavaria
- Line 10: Field tests in Bavaria
Velocity Constraints

1-D U Slug Dispersion/Advection Model

- Velocity Constraints
  - \(V = 20 \text{ m/yr}\)
  - \(D_h = 0.004 \text{ cm}^2/\text{s}\)
  - \(V = 1.2 \text{ m/yr}\)
  - \(D_h = 0.00002 \text{ cm}^2/\text{s}\)

- Graph showing relationship between 1-D flow rate, \(V\), and hydrodynamic dispersion coefficient, \(D_h\), with peak values for PB1, PB2,3, Lab test relationship, and Field test relationship.
Modeling Uncertainties

- Field relationship between velocity and dispersion at Peña Blanca
  - German site is fairly typical of most aquifers (Gelhar et al. 1992).
  - Limestone aquifer data would provide a better approximation.

- Non-conservative behavior for U
  - U removal from solution would lower required flow velocity.
  - U addition to solution from rock-water interaction (aside from U slug) would increase required flow velocity.
Summary

- U isotopic data indicate multiple (4 or more) components for U in saturated zone water over various length scales (50 m to km).
  - Limited subsurface mixing apparent
- Decreasing U concentrations in the wells require limited flow and dispersion.
  - $V \sim 20$ m/yr
  - $D_h \sim 4 \times 10^{-3}$ cm$^2$/s
- Additional work with artificial tracers would better establish flow velocity and direction at this site.
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