Advanced Characterization and Monitoring of Chemical Transport in the Vadose Zone at Hanford

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PPNL Workshop
January 19-20, 2000
Outline

• Types of probes used to collect pore solution
• Limitations of suction lysimeters
• Innovative Field Methods and Instrumentation
  – Suction lysimeters with minimal headspace
  – Water- and concentration-flux meters
  – Radon/Thoron ratio in soil gas
• Uncertainties of measurements using “point”-type probes
  • 3D numerical modeling in spatially heterogeneous soils
  • Box Canyon and Large Scale Infiltration Tests at INEEL
### Suction Sampler Summary (ASTM D 4696-92)

<table>
<thead>
<tr>
<th>Sampler Type</th>
<th>Porous Section Material</th>
<th>Maximum Pore Size (µm)</th>
<th>Air Entry Value (cbar)</th>
<th>Operational Suction Range (cbar)</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vacuum lysimeters</strong></td>
<td>Ceramic PTFE</td>
<td>1.2 to 3.0</td>
<td>&gt;100</td>
<td>&lt;60 to 80</td>
<td>&lt;7.5</td>
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<tr>
<td></td>
<td>Stainless steel</td>
<td>15 to 30</td>
<td>10 to 21</td>
<td>49 to 5</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>NA</td>
<td>&lt;7.5</td>
<td>&lt;7.5</td>
</tr>
<tr>
<td><strong>Pressure-vacuum lysimeters</strong></td>
<td>PTFE</td>
<td>1.2 to 3.0</td>
<td>&gt;100</td>
<td>&lt;60 to 80</td>
<td>&lt;15</td>
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<tr>
<td></td>
<td></td>
<td>15 to 30</td>
<td>10 to 21</td>
<td>49 to 5</td>
<td>15</td>
</tr>
<tr>
<td><strong>High pressure-vacuum lysimeters</strong></td>
<td>PTFE</td>
<td>1.2 to 3.0</td>
<td>&gt;100</td>
<td>&lt;60 to 80</td>
<td>&lt;91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15 to 30</td>
<td>10 to 21</td>
<td>49 to 5</td>
<td>91</td>
</tr>
<tr>
<td><strong>Filter tip samplers</strong></td>
<td>Ceramic</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>None</td>
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<tr>
<td></td>
<td>Polyethylene</td>
<td>2 to 3</td>
<td>&gt;100</td>
<td>&lt;60 to 80</td>
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<tr>
<td></td>
<td>Ceramic</td>
<td>2 to 3</td>
<td>NA</td>
<td>&lt;7.5</td>
<td>&lt;7.5</td>
</tr>
<tr>
<td></td>
<td>Stainless steel</td>
<td>NA</td>
<td>NA</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>Cellulose-acetate hollow-fiber samplers</strong></td>
<td>Cellulose Acetate</td>
<td>&lt;2.8</td>
<td>&gt;100</td>
<td>&lt;60 to 80</td>
<td>&lt;7.5</td>
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<tr>
<td></td>
<td>Non cellulosic Polymer</td>
<td>&lt;2.8</td>
<td>&gt;100</td>
<td>&lt;60 to 80</td>
<td>&lt;7.5</td>
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<tr>
<td><strong>Membrane filter samplers</strong></td>
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<td>&gt;100</td>
<td>&lt;60 to 80</td>
<td>&lt;7.5</td>
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<tr>
<td></td>
<td>Cellulose Acetate PTFE</td>
<td>2 to 5</td>
<td>NA</td>
<td>NA</td>
<td>&lt;7.5</td>
</tr>
</tbody>
</table>
Limitations of Suction Lysimeters

- Pore solution samples under vacuum can be taken only from relatively wet soils
- Evaporation of volatile chemicals in the lysimeter headspace can reduce their concentration in a liquid phase
- The porous membrane can adsorb chemicals and colloids
- Concentration measurements depend on the vacuum applied in a heterogeneous formation
Other Methods

- Electrical Conductivity
- Electromagnetic induction
- Fiber Optics
- TDR Probes
- Pore Water Extraction by Refractometer
- Seamist Absorbent Pads
Effect of vacuum on concentration measurements using suction lysimeters

Dry soils/rocks

Concentration in Matrix

Wet soils/rocks

Concentration in Fracture
Schematic of advanced suction lysimeter - reduces lysimeter’s head-space and has a curved porous element

- Water retrieval tube
- Electrical cable
- Pressure transducer
- Air access tube
- Normally closed valve
- Normally closed valve
- Normally open valve
- Porous tip

Operational module design by B. Freifeld
Schematic of a vadose zone water- and concentration fluxmeter

Porous plate surface-averaged water flux and concentration measurements under natural hydraulic gradient
Soil- Gas Sampling for Radon

- Radon-222 concentration in soil gas depends on (Hutter, 1996):
  - porosity, barometric pressure, precipitation, temperature, soil permeability, moisture content, and temperature
- The ratio of $^{220}\text{Rn}$ (thoron) to $^{222}\text{Rn}$ can be used to assess the near surface weak zones, such as clastic dikes.
Comparison of surface radar and Radon/Thoron methods to determine zones of preferential flow (Chernobyl site data)

Shestopalov et al., 2000
Spatial variability of soil hydraulic properties creates significant spatial variability of water arrival time and concentration.
3-D Permeability Distribution

Correlation scales:
- x-axis = 1 m
- y-axis = 3 m
- z-axis = 5 m
3D Water Saturation Distribution

Time variation of water potential at a 2 m depth to ponded infiltration

Modeling by S. Finsterle
Perspective View of Well Locations at Box Canyon Site
Box Canyon and LSIT tests: Water Arrival Times

Water and tracer arrival (Days) vs. Depth (m)

- BC, Tensiometers
- BC, ER probes
- LSIT, Water arrival
- LSIT, Water arrival, A_B Wells
- LSIT, Tracer arrival

Fast Fracture Flow
Matrix Flow