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Use of Tracers to Interrogate Subsurface Reservoir Properties and Flow/Transport Processes

Paul W. Reimus, Earth Systems Observations

This presentation provides an overview of different types of subsurface tracer tests and the information that can be obtained from these different types of tests. Examples are provided for groundwater contaminant transport applications, geothermal reservoir interrogation, CO_2 sequestration applications, and oil shale reservoir characterization. The importance of well-designed laboratory experiments to evaluate tracer transport properties and to help constrain field test interpretations is discussed. Tracer test interpretive methods are also discussed.

Use of Tracers to Interrogate Subsurface Reservoir Properties and Flow/Transport Processes

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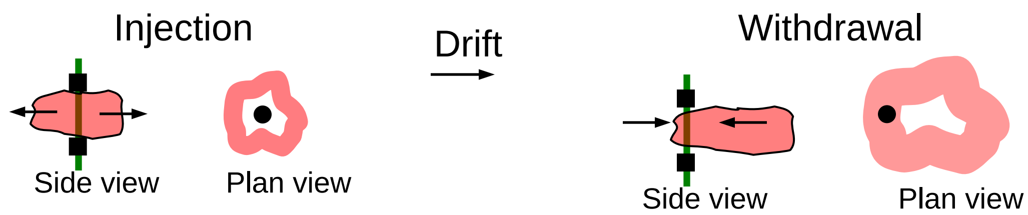
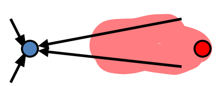
Different Types of Tracer Tests

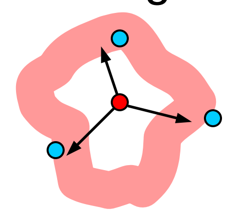
- **Single-Well Injection-Withdrawal**



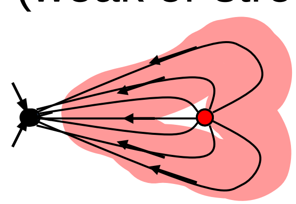
- **Multiple Well**
  - **Forced Gradient**
    - Convergent



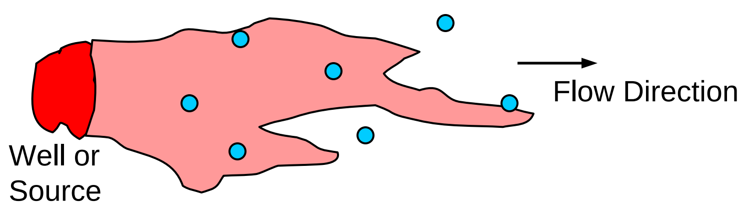
    - Divergent



    - Dipole (weak or strong)



  - **Natural Gradient**



● Injection Well or Source

● Production Well

● Passive Observation Well

Information Obtained from Different Types of Tracer Tests

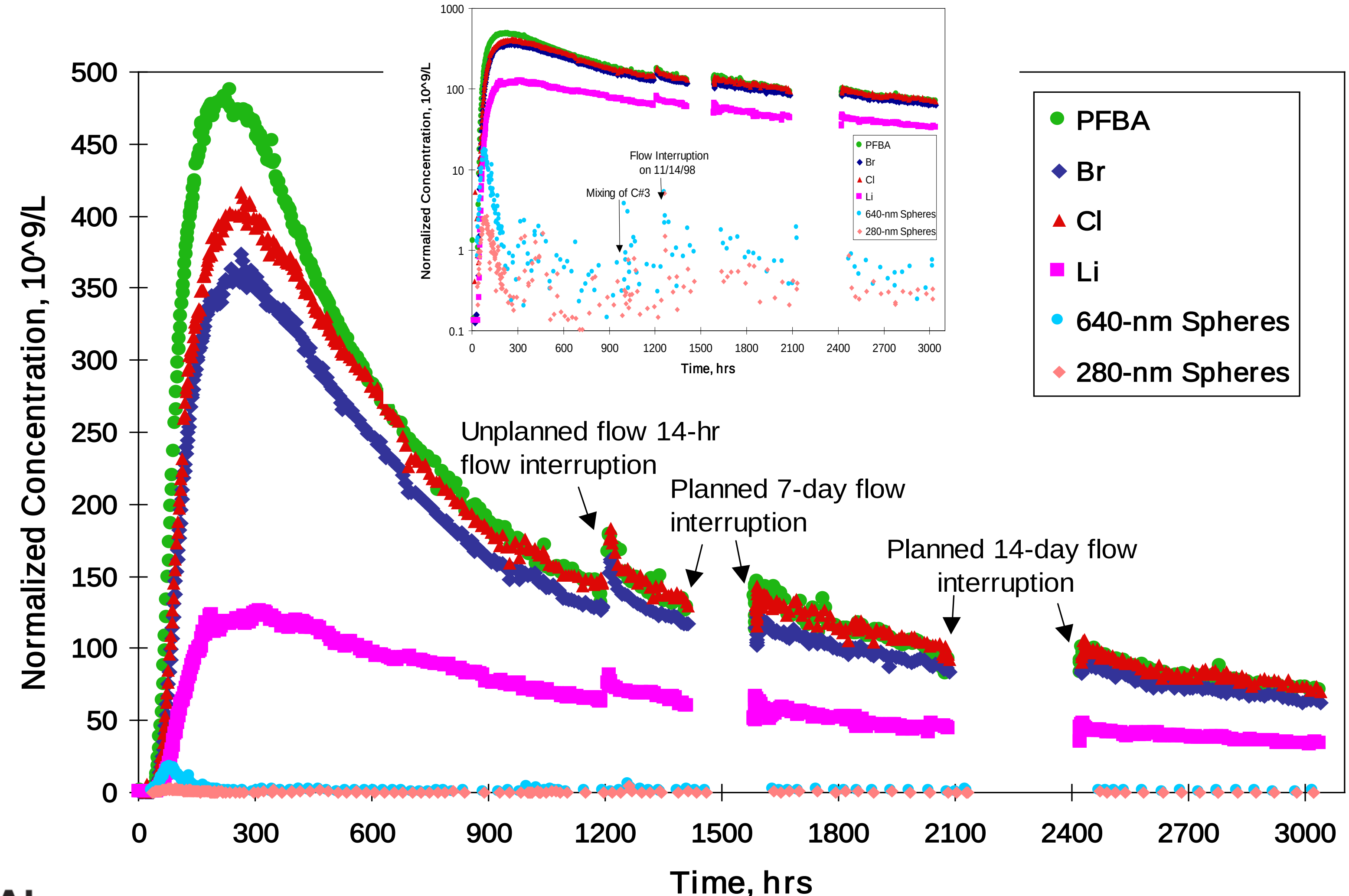
Process/Parameter	Single-Well	Multiple-Forced	Multiple-Natural
Swept Volume		X	
Sweep Efficiency		X	
GW Velocity	X		X
GW Flow Direction			X
Flow Porosity		X	X
Dispersion			X
Matrix Diffusion	X	X	X
Sorption/Partitioning	X	X	X

Information obtained from inert tracers (ideally more than one)

Information obtained from inert and reactive tracers

Can deduce surface area or interfacial area

Multiple Tracer Field Test Example



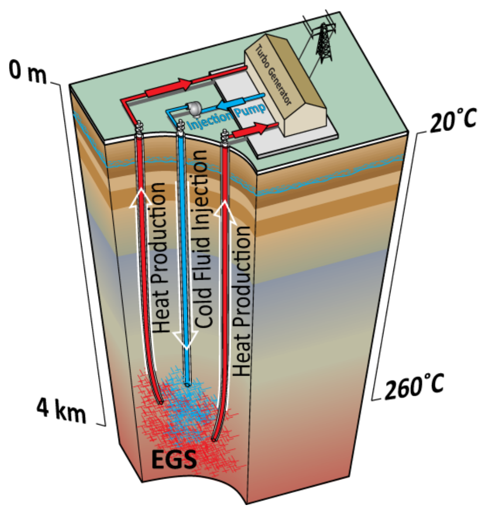
From Yucca Mtn. Field Test in Fractured Tuff

Thermally-Decaying Tracers for Geothermal

- Tracers that decay as a function of temperature/time according to first order Arrhenius kinetics (generally)

$$\frac{dC}{dt} = -kC \;\Rightarrow\; C = C_o e^{-kt} \qquad k = Ae^{-\frac{E_a}{RT}} \;\Rightarrow\; C = C_o e^{-\left(Ae^{-\frac{E_a}{RT}}\right)t}$$

  - Provide information for predicting thermal breakthrough (well before actual thermal breakthrough)
  - Interpretation involves comparison to non-decaying tracer breakthrough curve to extract desired information



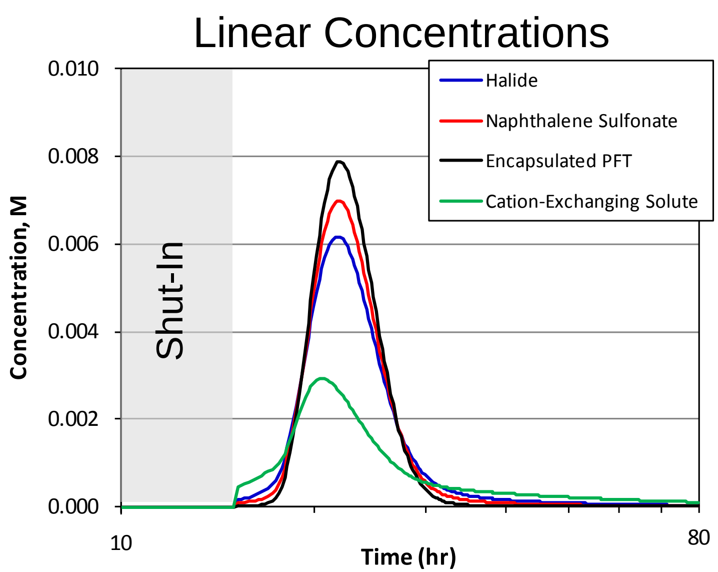
Cool and Hot curves correspond to Fluorescein at 250C and 270C, respectively (Arrhenius parameters from Adams and Davis, 1991)

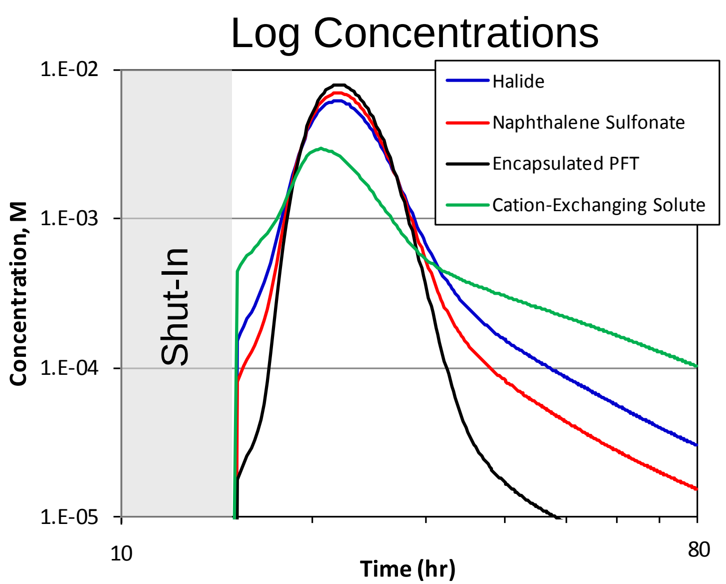
With Recirculation

Diffusing and Sorbing Tracers for Surface Area Interrogation - Single-Well Tests

- Big advantage for applications such as geothermal is that surface area can be interrogated with only one well
  - Evaluate effectiveness of stimulation before drilling second well
  - Great potential to couple with geophysical methods

Tracer injection 0-5 hrs; Water injection 5-10 hrs; “Shut-in” 10-15 hrs; Pumping/flow back starting at 15 hrs



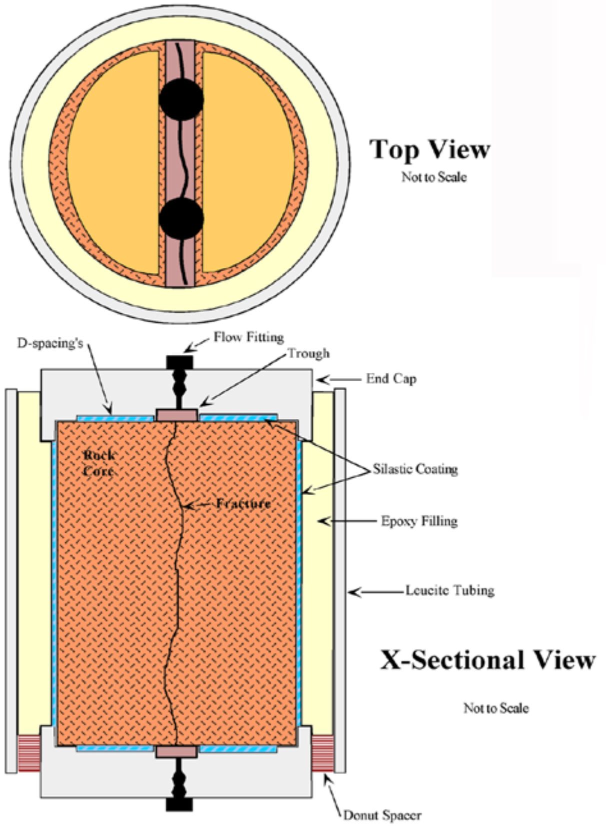


Tracers in Two-Phase Systems

- Examples
  - Perfluorinated hydrocarbons to trace CO_2 and inorganic anions to trace brine in CO_2 sequestration applications
  - Partitioning tracers to determine interfacial areas between aqueous and organic phases or between aqueous and vapor phases
- Careful laboratory testing often needed to refine sampling techniques and to evaluate tracer properties such as stability, partitioning and interactions with rock surfaces at reservoir T and P

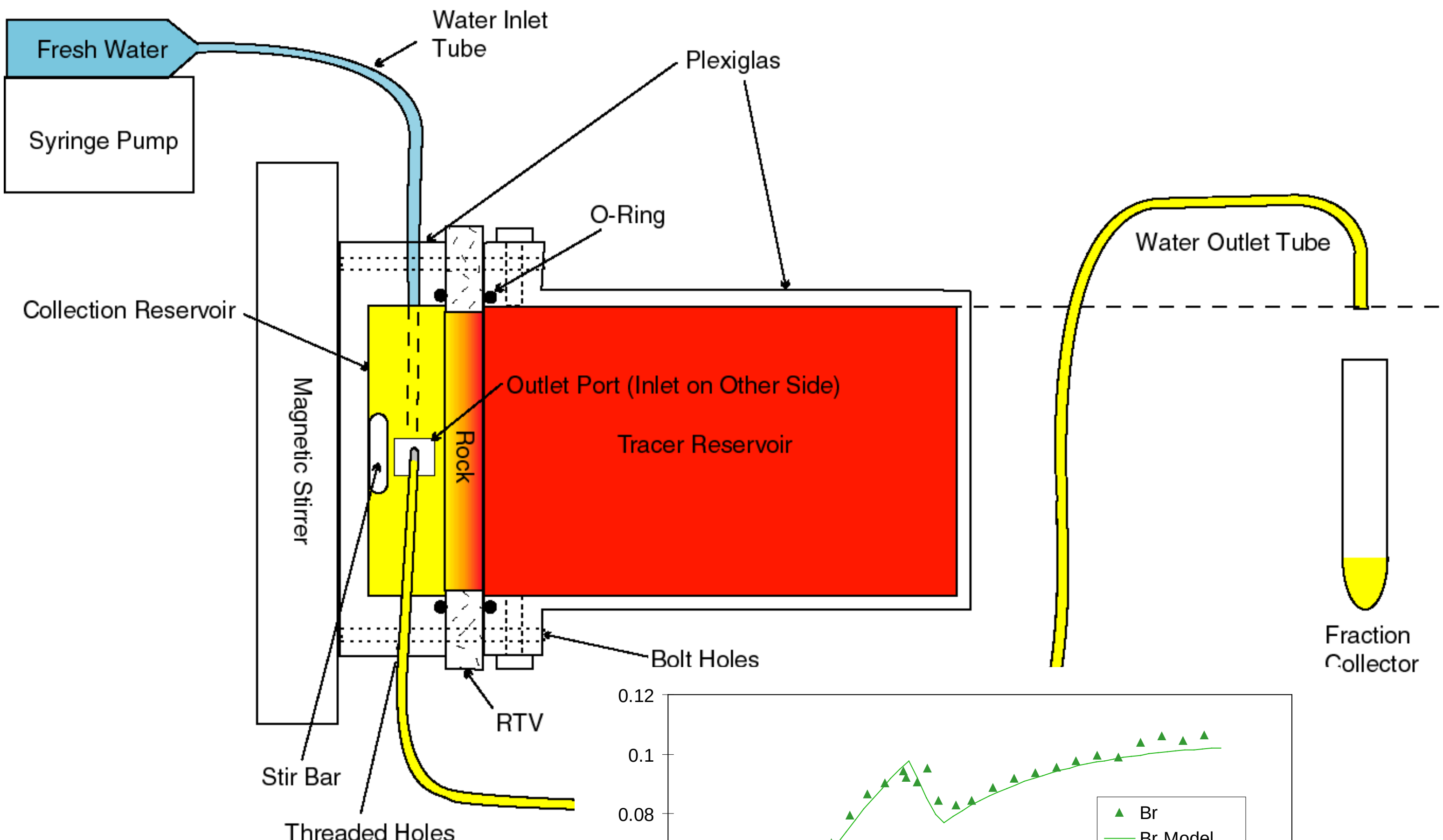
Laboratory-Scale Tracer Experiments

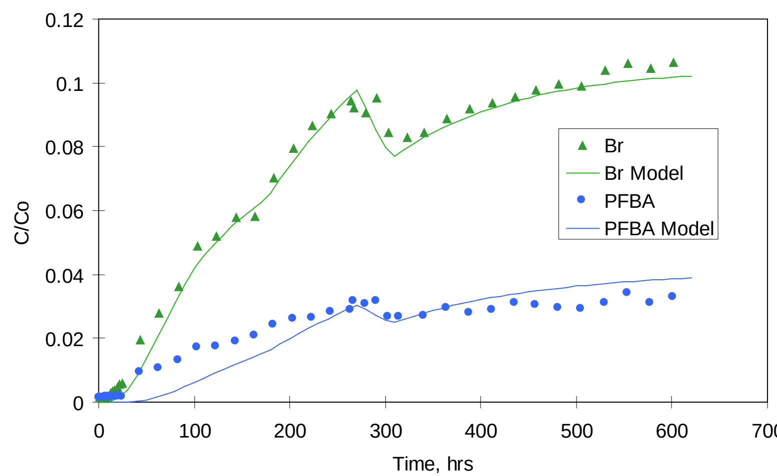
Fracture Column Assembly



Two Fracture Transport Experiments run in Parallel

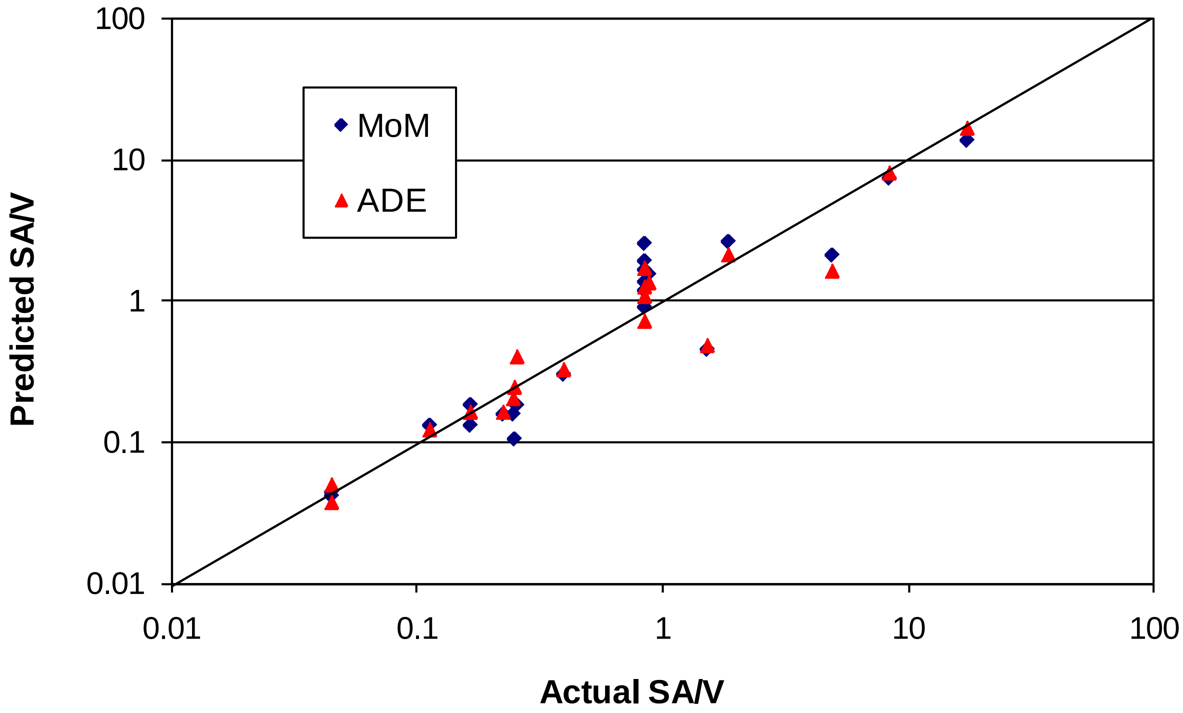
Laboratory Diffusion Measurements





Prediction of Surface Area from Gas-Phase Tracers

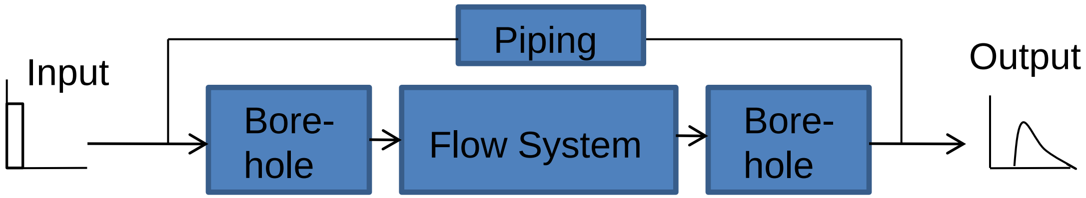
- Fluorinated hydrocarbons as reversibly-sorbing/partitioning tracers
- Correlation of partition coefficients with mineral/organic mass fractions
- Constant plus 3 lumped variables (organics, clays, evaporites) in regression



Developed for Oil Shale Interrogation

Interpretive Tools/Models

- Semi-analytical models (for steady flow)
  - Transfer function approach – convolution by multiplication of Laplace transforms



- Numerical models of varying complexity
  - 1- to 3-D, single vs. multiple interacting components
- Parameter estimation software (e.g., PEST) for:
  - Parameter estimation
  - Sensitivity analysis
  - Uncertainty analysis

Goal: Simplest model that will explain the data while honoring our (usually very limited) knowledge of the system

Summary

- Tracers useful for interrogating many reservoir properties (swept volume, sweep efficiency, flow porosity, surface/interfacial area, ambient flows, thermal drawdown)
  - Lot of opportunity for cross-fertilization with geophysical methods
- Tracers very useful for contaminant transport model discrimination and parameterization of contaminant retardation processes such as matrix diffusion and sorption
- Key opportunity: Development of “smart” tracers