# Use of Tracers to Characterize Fractures in Engineered Geothermal Systems

May 19, 2010

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# Mandatory Overview Slide

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- Timeline
  - Project start date = February 10, 2009
  - Project end date = September 30, 2012
  - Percent complete = 37%
- Budget
  - Total project funding = $1,365,945
  - DOE share = $1,091,039
  - Awardee share = $274,905
  - Funding received in FY09 = $380,472
  - Funding for FY10 = $324,776

# Mandatory Overview Slide (continued)

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- EGS Barriers:
  - Barrier J: Tracers—Inadequate tracers and/or tracer methodology to accurately define the subsurface system of fractures and mapping of fluid flow.
  - limited fracture detection capability
  - lack of high-temperature monitoring tools and sensors
  - limited flow path identification capacity
  - a lack of suitable tracers
- Partners: Lawrence Berkeley National Laboratory under a separate grant

# Relevance/Impact of Research

## Objectives over past year:

- Task 1: Measure Interwell Fracture Surface Area and Fracture Spacing Using Sorbing Tracers
  - 1.1 Design and Fabricate a Laboratory Reactor for Characterizing Tracer Sorption
  - 1.2 Screen Candidate Tracers for Interwell Sorption
  - 1.3 Screen Candidate Interwell-Sorbing Tracers for Thermal Stability
  - 1.4 Develop a Numerical Model of a Representative Geothermal Reservoir for Inverting Sorbing-Tracer Data to Calculate Interwell Fracture Surface Area
- Task 2: Measure Fracture Surface Areas Adjacent to a Single Geothermal Well Using Tracers and Injection/Backflow Techniques
  - 2.1 Screen Candidate Tracers for Single-Well Sorption
  - 2.2 Screen Candidate Single-Well Tracers for Thermal Stability
  - 2.3 Develop a Numerical Model for Calculating Fracture Surface Areas from Tracer Data Obtained from an Injection/Backflow Test
- Task 3: Design, Fabricate and Test a Downhole Instrument for Measuring Fracture Flow Following a Hydraulic Stimulation Experiment
  - 3.1 Design a Downhole Instrument for Measuring Fracture Flow Following a Hydraulic Stimulation Experiment

# Relevance/Impact of Research (continued)

## Innovative Aspects of the Project:

- Allow for the first time the ability of geothermal and EGS operators to characterize the fracture surface area (the heat exchange area) between injectors and producers through interwell tracer testing.
- Allow for the first time the ability of geothermal and EGS operators to characterize the near-wellbore fracture surface area in injection/backflow tracer tests.
- Provide a revolutionary and powerful new high temperature borehole tool that will provide great improvements over current spinner-tool technologies and enable the identification of newly formed fracture sets resulting from hydraulic stimulation procedures.

# Scientific/Technical Approach



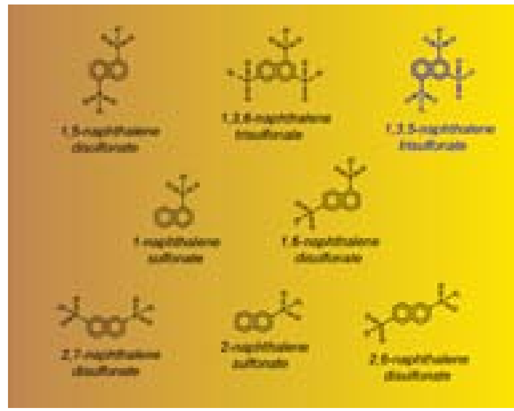
- Conduct laboratory experiments
  - Study the scientific and engineering literature to generate ideas
  - Design and fabricate bench-top reactors
  - Conduct screening tests
  - Perform detailed experiments to determine relevant parameters (rate constants, temperature limits, detection approaches, etc.) under conditions that simulate a geothermal environment
- Develop models of chemical processes
  - Calibrate the model through fitting to laboratory data
  - Develop forward models to predict outcomes of field experiments
- Conduct field tests
  - Compare field data to model predictions and update/correct the model as necessary
- Publish results and disseminate technologies to the geothermal industry

# Scientific/Technical Approach (cont.):

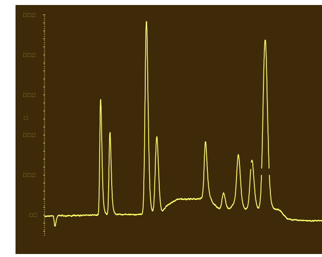
## An Example from the EGI Tracer Development Program

- *Thermally stable or have known decay kinetics under geothermal conditions*
- *Very detectable using conventional methods*
- *Affordable (~ 10-20 $US/kg)*
- *Environmentally benign*
- *Naturally absent in the reservoir (low background)*
- *Non-adsorptive or possess known adsorptivity under geothermal conditions*
- *Have known diffusivities under geothermal conditions*

***Candidate compounds were selected based upon examples from the groundwater literature:***




***The candidate compounds were tested in the lab and models were developed:***



# Scientific/Technical Approach

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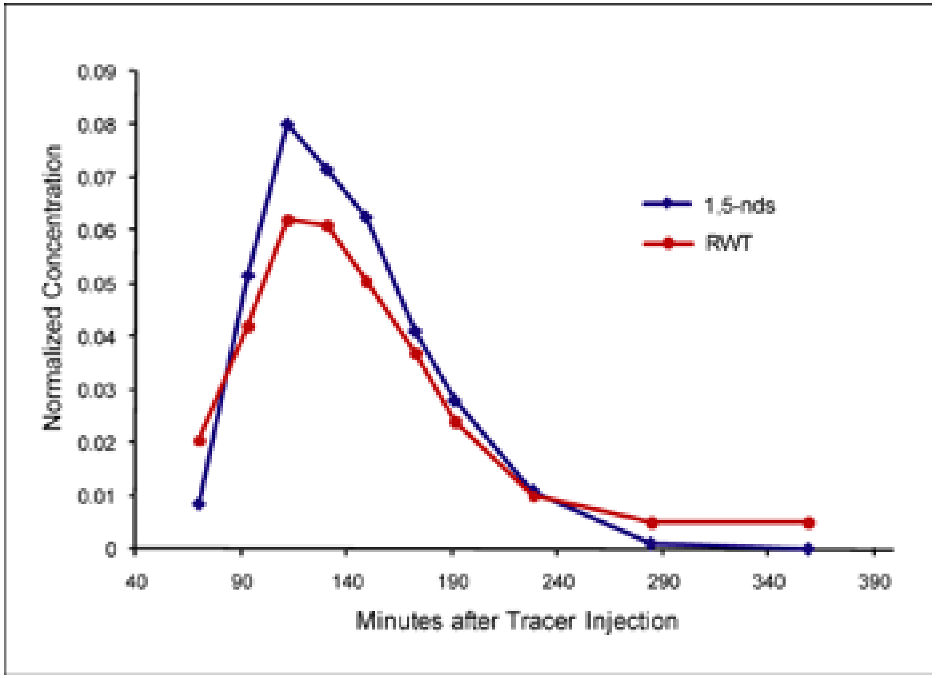
# Accomplishments, Expected Outcomes and Progress

- **The flow reactor:**
  - Temperature capability in excess of 300°C
  - Pressures in excess of 3,000 psi controlled by a back-pressure regulator
  - In-line fluorescence/absorbance detection or off-line HPLC analysis with fluorescence, absorbance, and/or conductance detectors
  - Fraction collector and computer-controlled data acquisition
- **Batch reactors (not shown):**
  - 2 static and one stirred reactor with maximum temperature/pressure of 350°C/5,000 psi.

# Accomplishments, Expected Outcomes and Progress (continued)




**Testing the flow reactor:**

- A pulse of a well established conservative geothermal tracer, 1,5-naphthalene disulfonate, eluting simultaneously with a thermally reactive geothermal tracer, rhodamine WT at 125ºC
- Results comparable to those observed in tracer tests in geothermal reservoirs

# Accomplishments, Expected Outcomes and Progress (continued)

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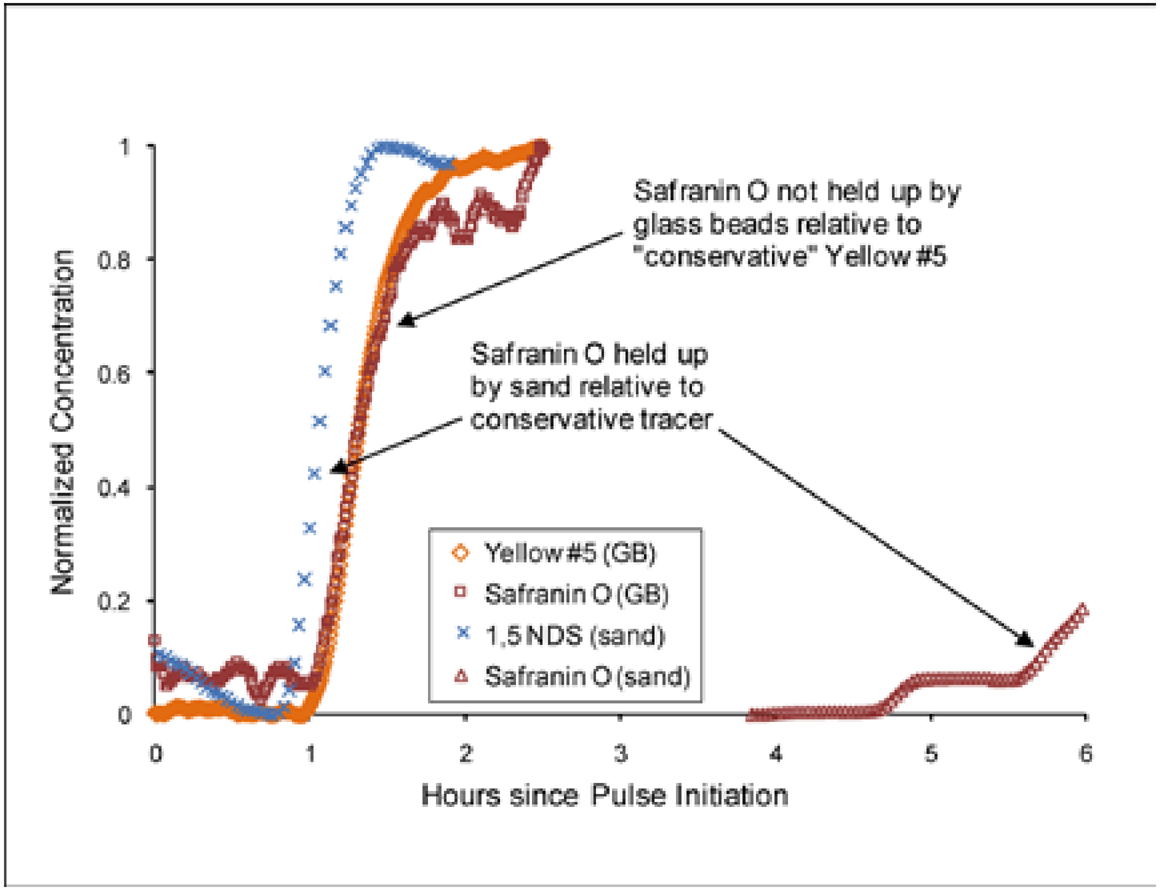
- Aromatics and polyaromatics, sulfonated for solubility, are good candidates due to excellent thermal stability and detectability.
- Cationic groups (usually N) impart some “stickiness”, which provides for reversible sorption.
- Some conventional dyes and food colorings provide these qualities.

Summary of Compounds Screened for Sorption in the Simulated Geothermal Reservoir

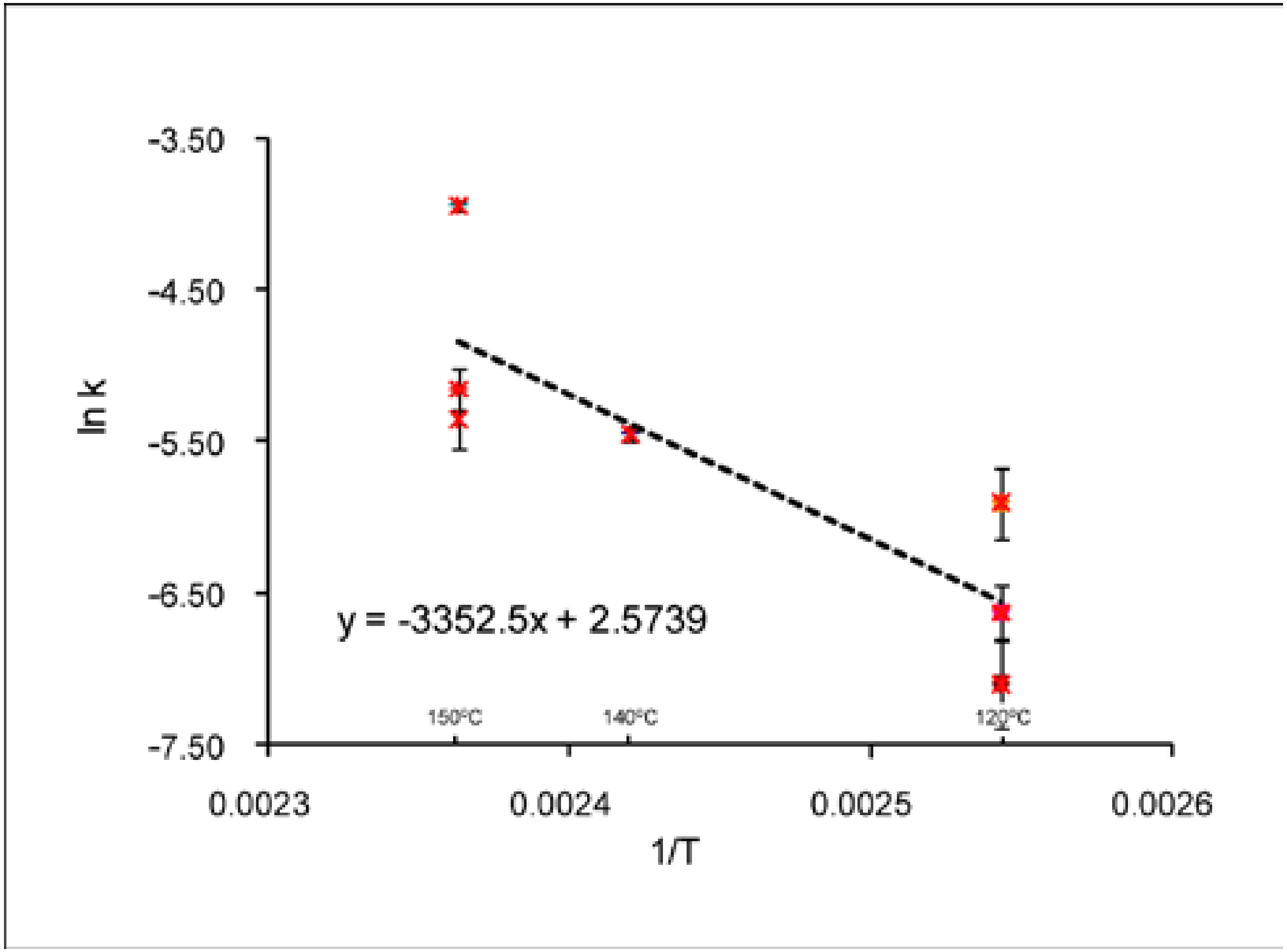
# Accomplishments, Expected Outcomes and Progress (continued)

Plot shows hold-up of safranin O relative to 1,5-nds on sand at 115°C. Safranin O is the leading candidate for an interwell tracer test at the Raft River geothermal field in June, 2010.

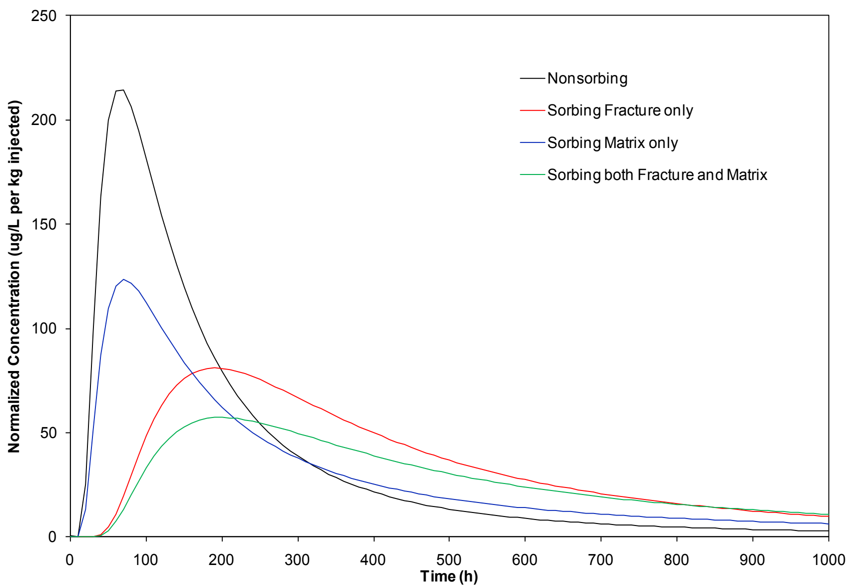


# Accomplishments, Expected Outcomes and Progress (continued)

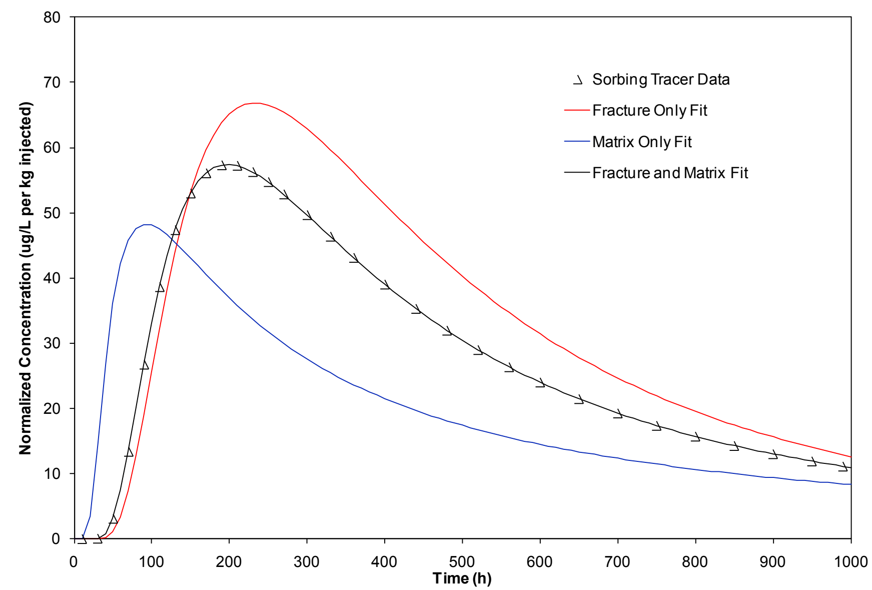
Arrhenius plot for safranin O between 120°C and 150°C. The half-life of safranin O at 140°C is 6-7 days. This qualifies it for testing in an interwell tracer test at the Raft River geothermal field scheduled for June, 2010.



# Accomplishments, Expected Outcomes and Progress (continued)




Breakthrough curve of a nonsorbing tracer and three possible breakthrough curves for a sorbing tracer depending on whether sorption is occurring only in fractures, matrix, or both.



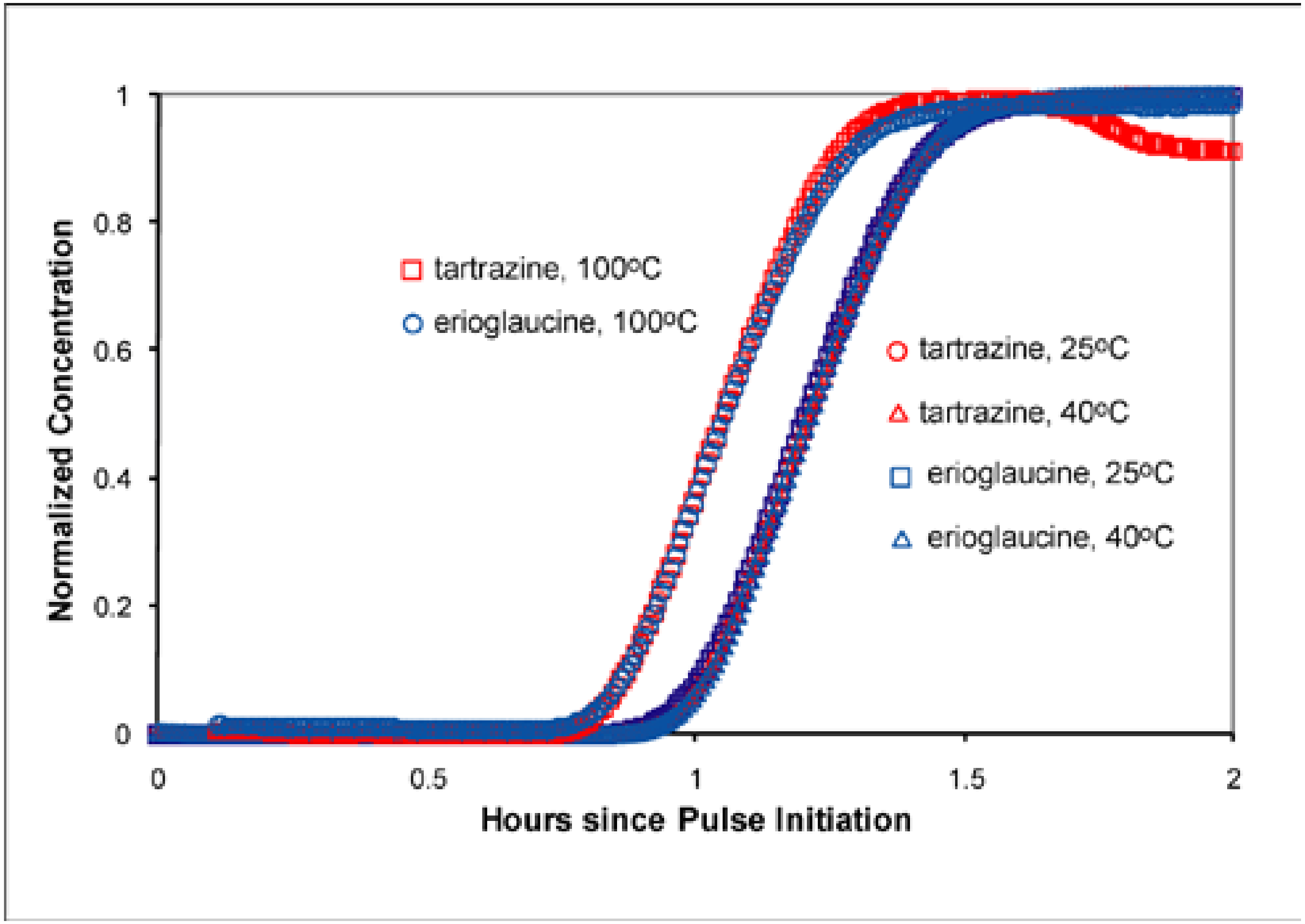

Assuming sorption only in fractures or matrix (red and blue curves) results in much poorer fits to the sorbing tracer breakthrough curve than assuming sorption occurs in both domains. The fracture surface area to volume ratio can be deduced from the best-fitting model parameters for the black curve.


[3]Reimus, P. W., G. Pohll, T. Mihevc, J. Chapman, L. Papelis, B. Lyles, S. Kosinski, R. Niswonger, and P. Sanders. 2003. “Testing and Parameterizing a Conceptual Model for Radionuclide Transport in a Fractured Granite using Multiple Tracers in a Forced-Gradient Test”, Water Resources Research, 39(12), 1350, doi:10.1029/2002WR001597.

# Accomplishments, Expected Outcomes and Progress (continued)



The plots at right show no difference between a sorbing tracer (erioglaucine) and a conservative tracer (tartrazine) at any of the test temperatures.



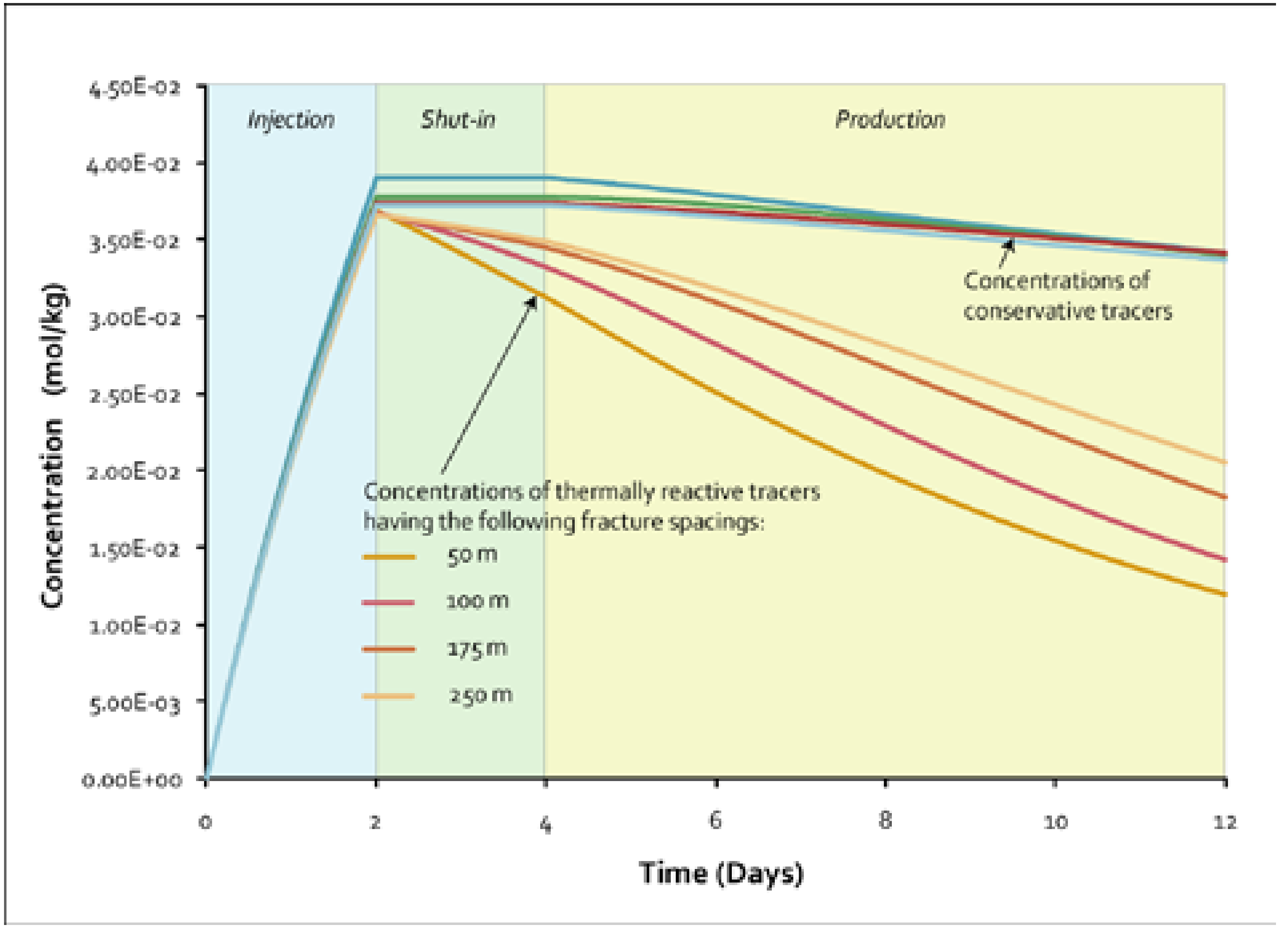
# Accomplishments, Expected Outcomes and Progress (continued)



A qualitative test of the thermal stabilities of tartrazine and erioglaucine shows that tartrazine decays more quickly than erioglaucine. Either may be appropriate for injection/backflow experiments, however, depending on the formation temperature. Quantitative tests to follow.

# Accomplishments, Expected Outcomes and Progress (continued)

Plots of tracer concentration as a function of time during an injection/backflow numerical experiment. The curves show that the extent of thermal decomposition is a function of fracture spacing.



# Accomplishments, Expected Outcomes and Progress (continued)

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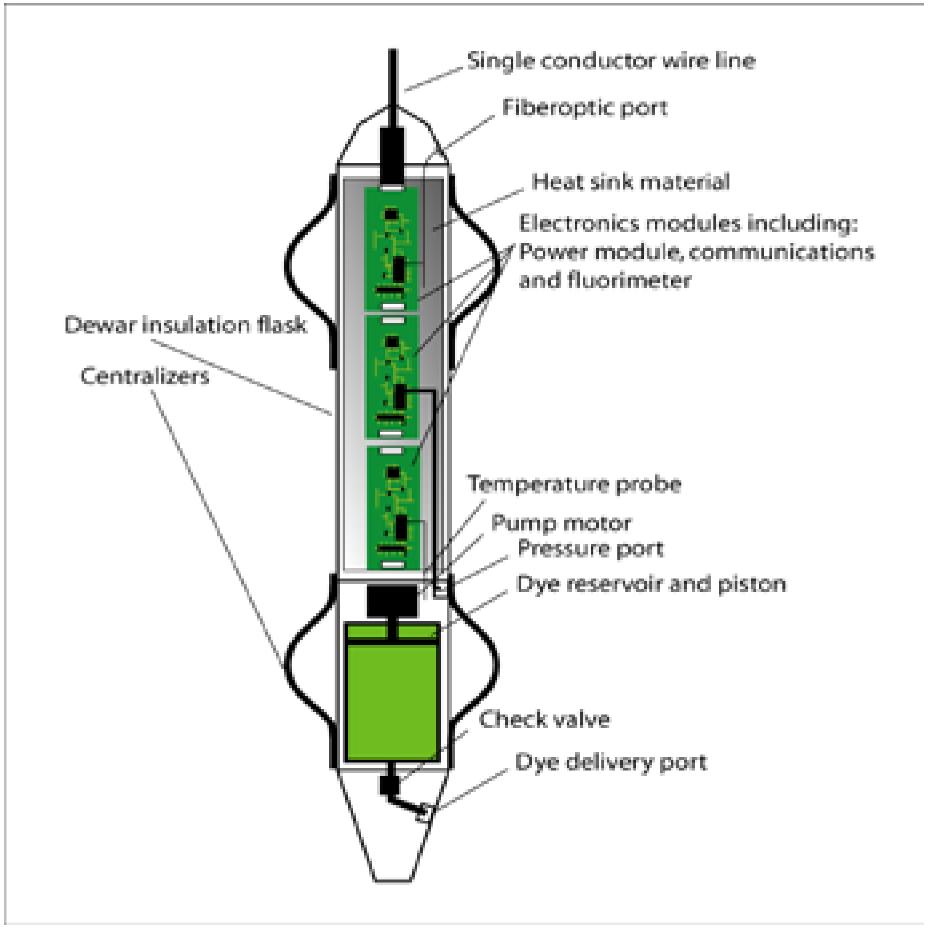
- Use of the tracer dilution method for volumetric flow-rate measurement , thus avoiding accuracy problems resulting from irregular wellbore diameters (washouts).
- Capability to measure flow over a wide range of flows (laminar to turbulent) while avoiding problems with pitch adjustment common to spinner tools.
- A single-conductor wireline for current and signal transmission
- an LED light source
- A robust and sensitive photomultiplier
- A flask and intelligent electronics allowing for operation for 6 hours at 300$^{o}$C.



# Project Management/Coordination

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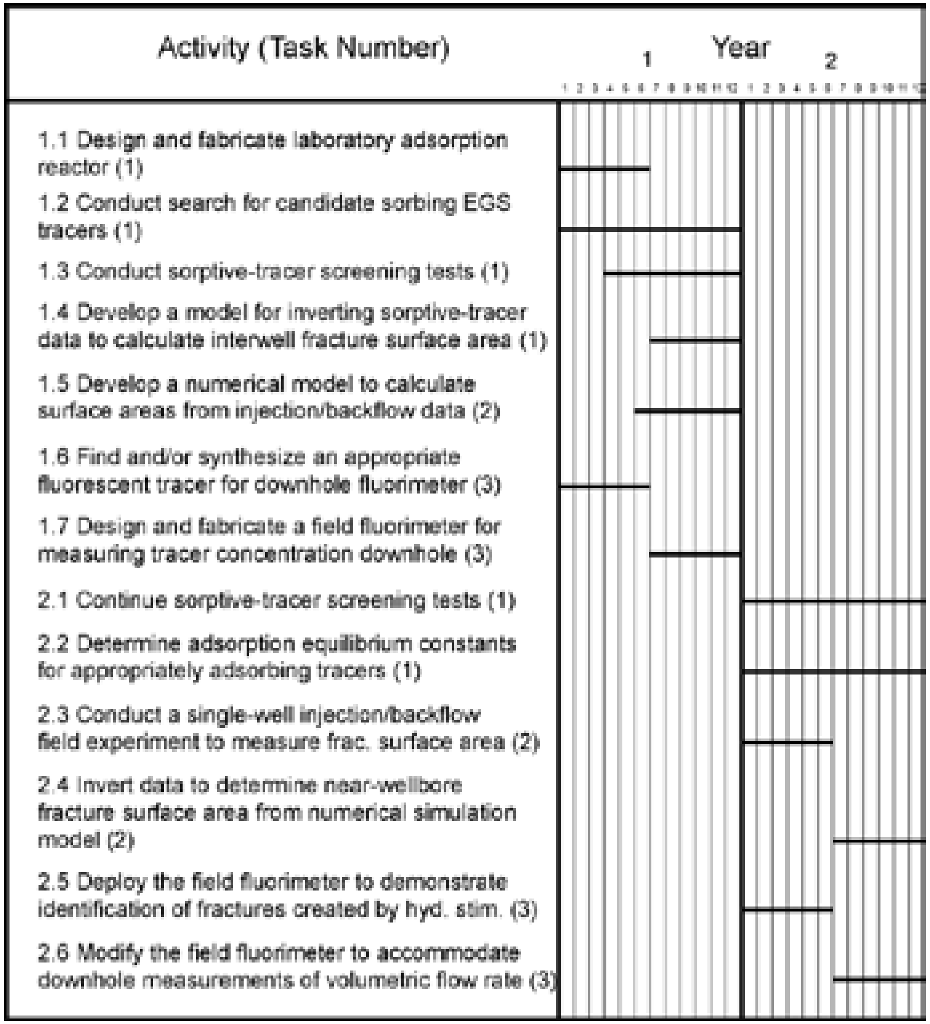
**Key issues:**

- Coordination with LBNL and LANL for interwell-tracer and single-well-tracer modeling
- Interwell and single-well reactive tracer projects on schedule but field demonstration is needed:
  - U.S. Geothermal's Raft River project (coodinated through LBNL, INL, BNL, and PNNL)
  - Ormat's Desert Peak EGS project
  - AltaRock's Newberry Crater EGS project
  - Jemez Pueblo's exploration project
  - Ormat's Brady EGS project
- New borehole fluorimeter-flowmeter design
  - Wireline model provides a significant improvement over the 10,000-ft optical fiber design
  - Design to be reviewed by USGS (Hickman), Sandia (Henfling), PermaWorks (Normann), Welaco (Dan Bebout)
  - Welaco to provide initial field testing

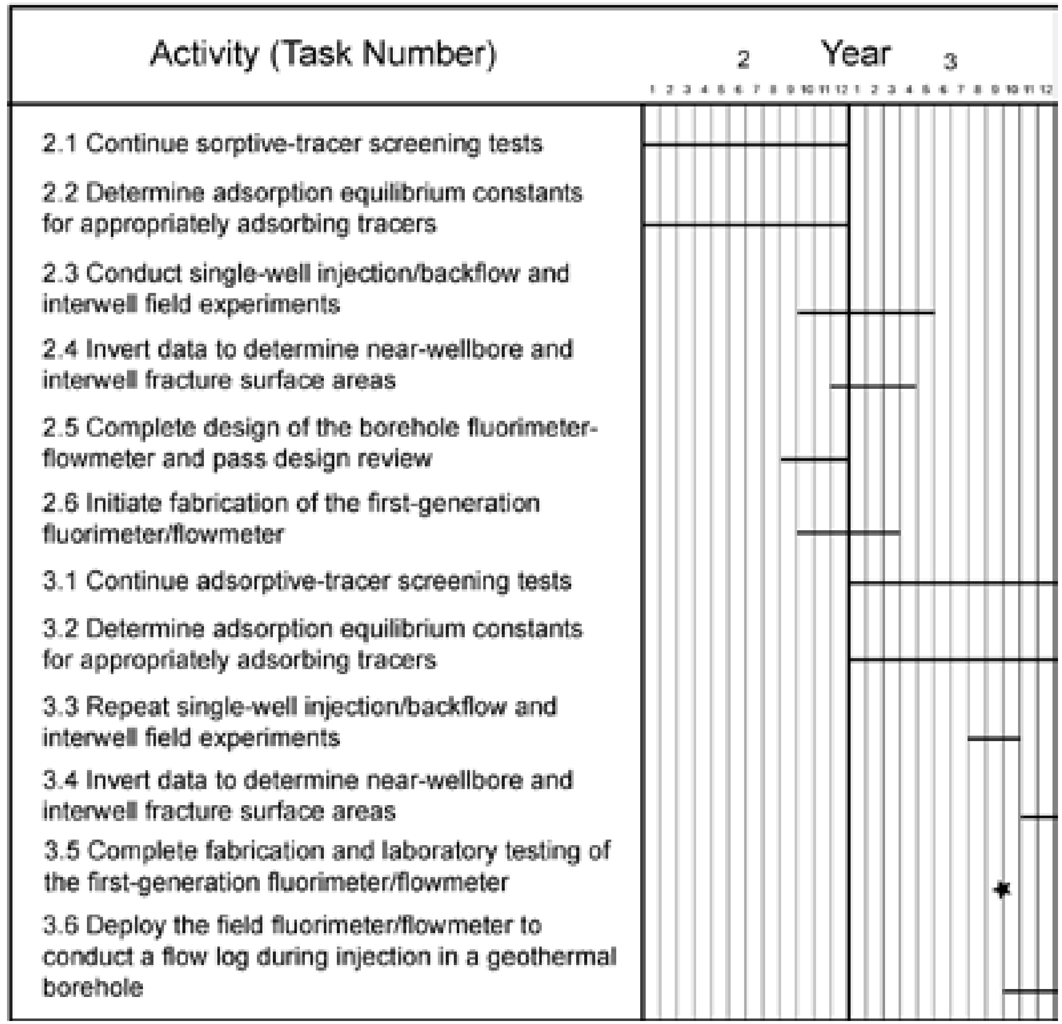
**Schedule for FY2009 and FY2010**



# Future Directions

**Key tasks:**

- Develop a tracer/tracing approach that will work in a single-well injection-backflow experiment
  - Sorption
  - Diffusivity
  - Thermal decay
- Arrange for appropriate sites for the field tests
  - Raft River
  - Desert Peak
  - Newberry Crater
  - Brady
- Complete the fabrication of a 1st generation borehole fluorimeter-flowmeter.



# Mandatory Summary Slide



- We are making good progress in the laboratory towards the development of novel reactive (sorbing and thermally decaying) tracers for characterizing fracture surface areas in interwell and injection/backflow tracer tests.
- In spite of a major change in tool approach and design, we are making good progress towards the design of a fluorimeter/flowmeter that will greatly enhance the measurement of flow processes in geothermal and EGS boreholes.