Tracer Huff-Puff Tests

1. **8-3617 Integrating Tracer Huff-Puff Tests and Geomechanical Analysis to Measure Evolution of the Fracture Network in EGS Reservoirs**
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   - Principal Investigator: Prof. Matthew Becker
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   - Subcontractors and/or Participating Organizations: University of Oklahoma
   - Project Start and End Date: 4/1/2024-3/31/2027

2. **Project Objectives and Purpose**
   - A key economic predictor for EGS projects is the effective heat-exchange surface area created through stimulation. One approach to measuring this area is to perform injection/backflow (huff-puff) tracer experiments. Traditional single solute tracer tests result in non-unique predictions, however, primarily because the interrogation volume is unknown. By combined multiple tests simultaneously (hydraulic, solute, reactive solute, thermal strain) we will provide a more unique estimation of heat-exchange area and, consequently, production life span.

3. **Technical Barriers and Targets**
   - Although huff puff solute tracer tests have been used at geothermal reservoirs, there has not been a rigorous examination of the value of the testing. Neither has there been an evaluation of integration with other methods (hydraulic, thermal transport, reactive solutes etc.). Tests at analog sites have shown that combing hydraulic and tracer methods can constrain production life-time estimates (Figure 1).
   - We revised our testing design and project management plan to account for updated condition of the FORGE reservoir and the available fiber optic sensing in 16B.
   - The effectiveness of parameter estimation and life-time predictions as a function of incremental information will be evaluated using a THMC model developed by Oklahoma University.

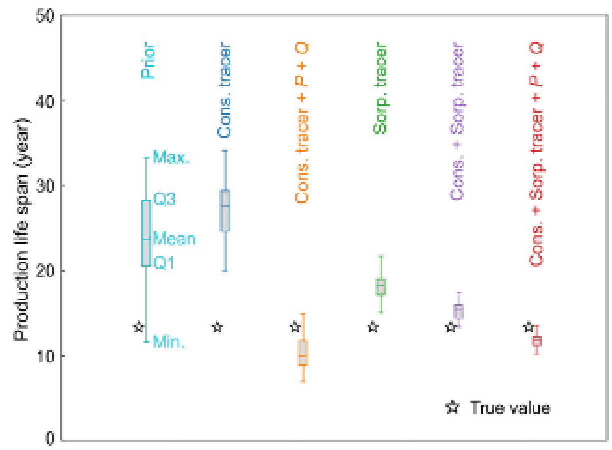


Figure 1. Production life-span estimates in a single fracture using combinations of conservative tracer, sorptive tracer, pressure (P), and flow rate (Q). The estimation of the true value is improved with multiple data streams (after Wu et al, 2021).

4. **Technical Approach**
   - We will overcome the limitations by integrating multiple methods of interrogation: (1) hydraulic, (2) solute tracer, (3) heat tracer, and (4) geomechanical strain
   - Results will be used to calibrate a thermal-hydro-mechanical-chemical (THMC) model of the reservoir
   - Cost-benefit analysis will estimate the relative value of each of the four methods
   - The methodology developed here can be used for periodic monitoring of heat exchange area and predictions of thermal breakthrough through the lifetime of a geothermal reservoir.

5. Project Timeline (list milestones achieved and/or decision points)

Note that Utah FORGE has designated Year 1 to have 5 quarters**.**

- Task 0: **A revised project management plan and a revised budget were approved** based upon realigned project objectives.
- Task 1: This task was accomplished in Year 1. **Milestone reports were submitted** documenting our progress.

	Budget Year	Year 1				
	Actual Qtr.	Q2 24	Q3 24	Q4 24	Q1 25	Q2 25
	Project Qtr.	Q1	Q2	Q3	Q4	Q5
Project Milestones	Deliverable					
Task 0 – Project Management and Planning						
Milestone 0.1 - **SMART** – Revised PMP (CSULB)		•				
Task 1 – Forward Modeling						
Sub Task 1.1 – Collection of existing data (CSULB)			X		•	
Milestone 1.1 Collection of existing data			X		•	
Sub Task 1.2 – **SMART** – Forward modeling of Tracers and DAS (OU)				X		•
Milestone 1.2 Forward modeling of 4Trace Tests	8-3617%20Californi			X		•

Figure 2. Task 0 and Task 1 milestones for Year 1.

- Task 2: A revised deployment plan was approved based upon realigned project objectives. The revised plan resulted in tracer and fiber monitoring being outsourced to vendors in coordination with well-to-well tests conducted by TTU. **Milestone 2.1 was submitted** and our **Go/No-Go Decision #1 was passed** with approval from Utah FORGE. This Go/No-Go Decision #1 was based upon modeling conducted by Oklahoma University with collaboration from CSULB. It demonstrated that we could expect sufficient strain, temperature, and tracer response based upon simulations calibrated to FORGE data.
- Task 3: This task has not been completed but is underway. The THMC model being developed by OU will be augmented to include reactive tracer transport. The task should be completed in the first quarter of Year 2 (Q325).
- Task 4: Experiments are underway at Utah FORGE at the writing of this report. Coiled tubing has been installed, fiber monitoring is functioning, and recirculation tests by TTU are underway.

	Budget Year	Year 1					Year 2			
	Actual Qtr.	Q2 24	Q3 24	Q4 24	Q1 25	Q2 25	Q3 25	Q4 25	Q1 26	Q2 26
	Project Qtr.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Project Milestones	Deliverable									
Task 2 – Design and Procurement	8-3617%20Californi a%20State%20									
Sub Task 2.1 – Design and procurement of tracer injection (CSULB)					•					
Milestone 2.1 Design and procurement of tracer injection equipment					•					
Sub Task 2.2 – Design and procurement of tracer detection (CSULB)					X	•				
Go/No-Go Decision #1: Forward modeling suggests timely testing configurations and sufficient recovery of tracer for analysis: To pass this GNG we must demonstrate through modeling that we have a good expectation of injecting sufficient water volume to interrogate a representative fraction of the reservoir (at least 50 m from injection well), that we can expect sufficient backflow to measure tracer breakthrough (tracer at concentrations 100x greater than detection limit), and that we can expect greater than one nanostrain response at the DAS cable in 16B. This GNG is a joint effort between CSULB (test design) and OU (numerical modeling). This GNG precedes field work. The recipient will provide a report including the deployment plan, NEPA approval and AFE to Utah FORGE for approval prior to mobilization at Utah FORGE. In addition, the recipient will provide a firm quote for return pumping services from Rhino or similar.	8-3617%20Californ ia%20State%2				X	•				
Task 3 – Numerical Model Refinement										
Sub Task 3.1 – THMC enhancement with tracers (OU)					X		o			
Sub Task 3.2 -**SMART**– THMC Benchmarking (OU)						X	o			
Task 4 – Conduct Experiments										
Sub Task 4.1 – Backround monitoring and moblization (CSULB)						X	o			
Milestone 4.1 Background temperature and strain results						X	o			

Figure 3. Task 2 and Task 3 milestones for Year 1 and look ahead to Year 2.

6. Technical Accomplishments

We are on the cusp of field accomplishments at the writing of this report. Here we document activities leading to the field experiments.

- <u>CSULB Design Modeling</u>: We developed COMSOL Multiphysics models to simulate coupled transport of water, geomechanical strain, heat, and non-reactive tracer. These simplified models are not intended to represent FORGE conditions but to answer questions regarding value of datasets (hydraulics, strain, temperature, tracer breakthrough) for determining effective heat transfer area. An example simulation is shown in Figure 4.

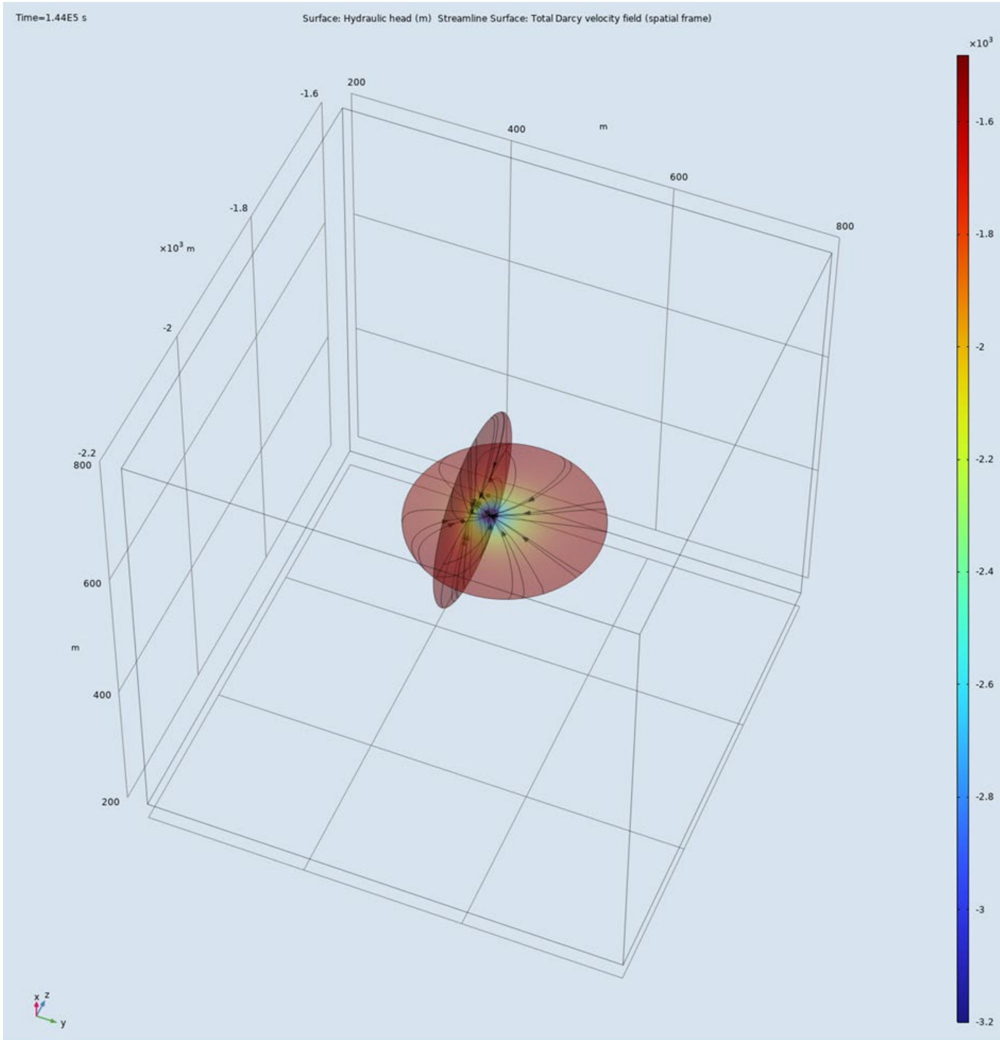
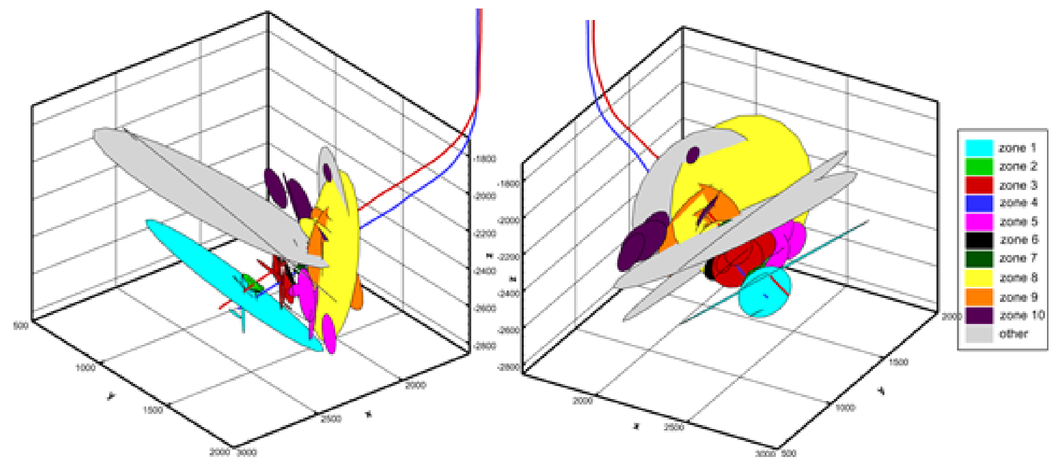
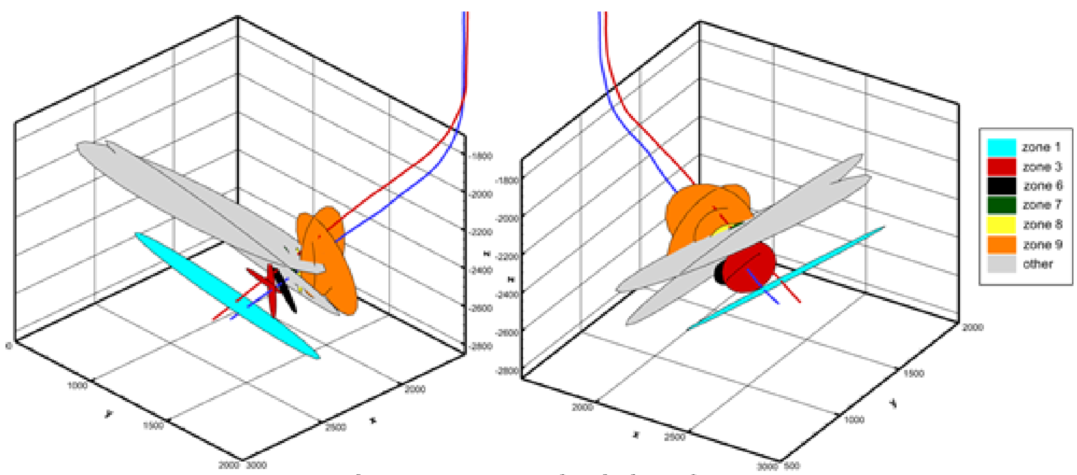


Figure 4. COMSOL Multiphysics simulation of head and streamlines in orthogonal fractures.

<u>Oklahoma University Calibrated Modeling</u>: Oklahoma University Calibrated Modeling: Oklahoma University is developing discrete fracture network models with heat and tracer transport based upon prior information from microseismic epicenters and geological modeling. These models will be calibrated to experimental data but have been used initially to design tests and demonstrate, numerically, that we can expect useful experimental results. The fracture network has been simplified by removing fractures that are hydraulic dead ends (Figure 5). Simulations of water temperature return and tracer concentration were used to design tracer test and anticipate fiber optic monitoring of fluid temperature (Figure 6). Figure 7. Shows the simulated strain rate recorded at the fiber in well 16B. As the fractures open and close, they impart extension and expansion on the fiber.

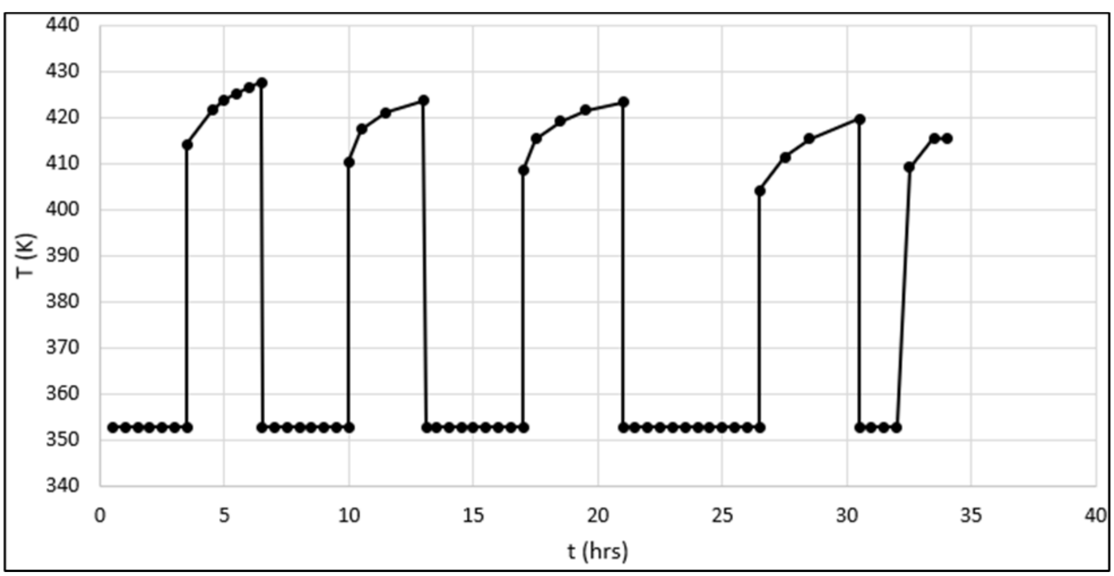


Initial DFN consisting of 49 fractures.



Filtered fractures used in this simulation.

Figure 5. DFN geomechanical model used to design heat and tracer tests.



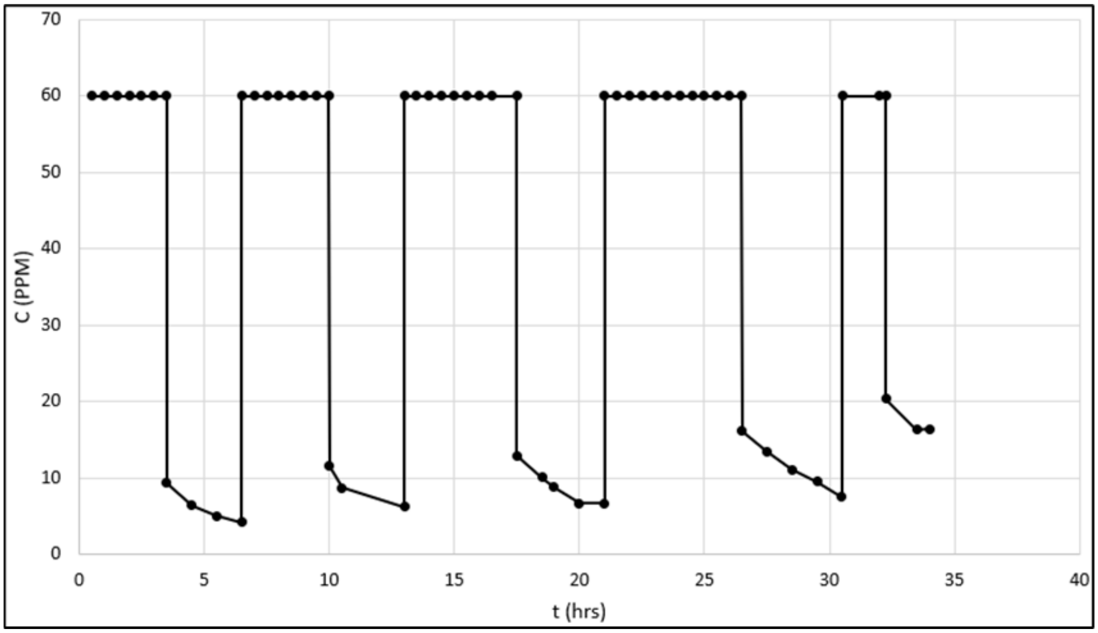


Figure 6. Predictions of temperature and tracer from DFN modeling used to design field tests.

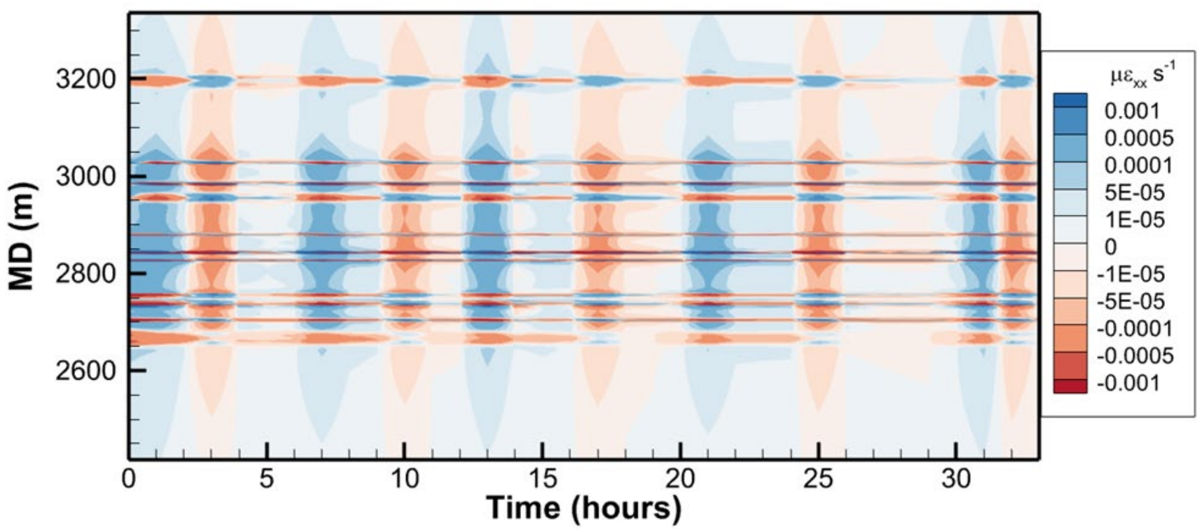


Figure 7. Simulated strain rate recorded at the fiber in well 16B. Red is tension indicating closing of fracs during production.

- <u>Laboratory Experiments for Strain Transfer in Well Casing</u>: Because we have transitioned to using an intervention coiled tubing deployment of fiber in 16B, we have concerns about recording strain in the formation using a fiber laying loosely in the coiled tubing. Formation strain due to fluid pressure must transfer through casing cement, casing, coiled tubing, capillary tubing, and finally fiber cable construction. We anticipate that strain transfer will be frequency dependent with higher frequencies transferred more efficiently due to momentum coupled friction. Our laboratory setup (Figure 8) uses ceramic piezoelectric stacks to induce strain in a pvc casing. Fiber is cemented outside and then laid inside the casing. All fiber is spliced into a single pathway so that DAS can record strain outside the casing and then inside using a variety of cable constructions. The piezoelectric actuators can vary strain in frequency between mHz and Hz. We do not attempt to replicate field conditions but seek to demonstrate the effective of frequency on strain transfer in frictionally coupled fiber.

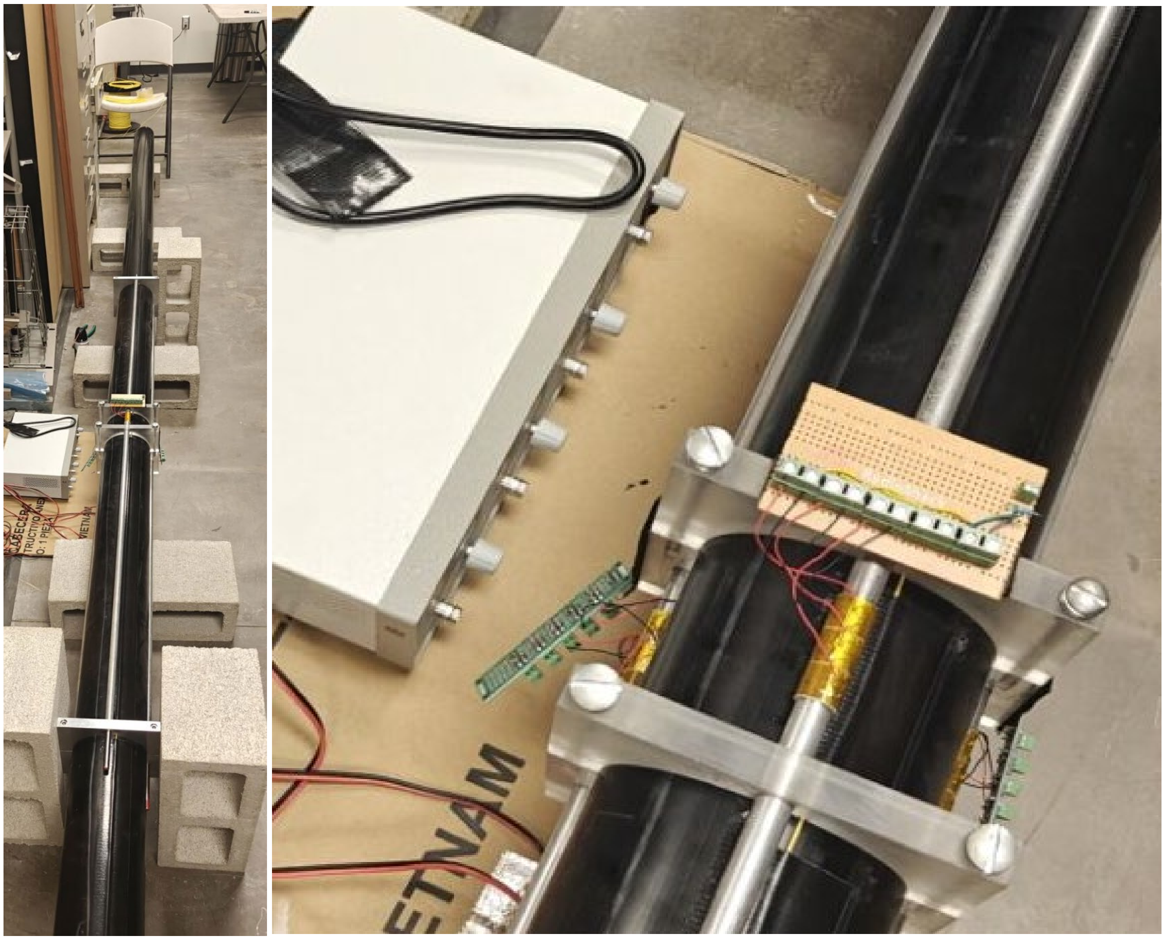


Figure 8. Laboratory stretcher monitored by a cemented fiber externally and loose fiber internally, to determine strain transfer with DAS.

7. Challenges to Date

- After the original proposal was written, the last fiber behind casing failed in 16B. This made it impossible to carry out our primary proposal objectives.
- However, TTU was awarded a similar proposal to ours, involving fiber optic monitoring and tracer testing, but from well-to-well rather than huff puff configuration. This opened an opportunity to combine resources to install a coiled tubing fiber monitoring system which allowed us to carry out both of our proposed objectives. The project realignment required writing essentially new proposals and work plans, rebudgeting the both projects, designing new field deployments, and contracting vendors.
- These challenges were overcome and, to date, the field experiments are running successfully.

8. Conclusion and Plans for the Future

- We have met our Go-No/Go decision and milestone points.
- At time of this writing, field experiments are underway and have so far been operating according to plan except for a partial loss of one of the fibers. We can still collect all the required data on the remaining fibers using multiplexing.
- We completed five huff-puff tracer tests during the last week of August, during the writing of this report.

9. **Geothermal Data Repository**
    - No uploads to date.

10. **Publications and Presentations, Intellectual Property (IP), Licenses, etc.**
    - No publications to date.

11. **Publicity and outreach (Optional)**
    - None to date.