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Geophysical Imaging of Flow and Transport (GIFT):

FY24 Status Report

September 2024

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Summary

The GIFT (Geophysical Imaging of Flow and Transport) system will improve predictive capabilities as a platform for collecting multi-physical (MP) time-lapse datasets from well-controlled laboratory experiments. This will enable more accurate prediction of multi-phase fluid flow during delivery and transport of insitu remedial amendments as important components of the overall Hanford Site cleanup mission. Design and construction of the GIFT system, which consists of a meter-scale test cell and a network of custom gas circulation and analysis systems, was accomplished in fiscal year (FY) 2024, with plans to add liquid circulation to the system and use this new capability for multi-phase deep vadose experiments starting in FY25.

Introduction

This document presents progress on the design and development of the GIFT laboratory system. The GIFT system will build on recent laboratory investments to validate and improve forecasting accuracy of flow and transport models applied to both contaminant transport and remedy application.

The Hanford Central Plateau contains large quantities of mobile contaminants in both existing groundwater plumes and overlying sources in vadose zone sediments. Contaminant fate and transport simulations predict significant challenges with *no action* scenarios, including groundwater plumes that are likely to exist for hundreds of years and groundwater concentrations for multiple contaminants of concern exceeding maximum concentration limits (Ward et al. 2004). Reduced risk and improved decision support can be achieved if controlling transport parameters and their spatial distributions are sufficiently understood (Serne et al. 2010). While substantial progress has been made in recent years, fundamental deficiencies exist regarding conceptual model components that likely dominate the long-term behavior of the system, such as contaminant source distributions, water flux/recharge rates, and the subsurface permeability structure. These parameters not only affect contaminant migration but also the behavior of applied amendments in the subsurface.

For complex sites like Hanford, substantial, long-term groundwater impacts result from large vadose zone contaminant inventories and their migration through the vadose zone to groundwater. Various remedy approaches are proposed for vadose zone remediation, and more information is needed to understand the behavior of amendments in the subsurface.

The GIFT system leverages recent internal investments by Pacific Northwest National Laboratory (PNNL) to improve predictive capabilities by collecting MP time-lapse datasets. Laboratory experiments provide a means for capturing the physical processes that occur in the subsurface during remediation activities but allow for much better control than can otherwise be obtained through field experiments. The GIFT system consists of a 1 × 1 × 2 m test cell instrumented with gas and liquid-phase circulation and tomography capabilities with geophysical (electrical and seismic) imaging and point measurement sensors (moisture content, water potential/capillary pressure, temperature) on each side of the test cell.

Using GIFT, high (centimeter-scale) spatial and temporal resolution MP datasets can be collected during experiments that constrain fluid flow pathways through variably saturated sediments that represent site-specific field conditions. Having a test cell where experiments can be precisely defined enables a more accurate prediction of multi-phase fluid flow resulting from amendment delivery. Therefore, the combined analyses of MP datasets hold promise for improving quantification of model parameters. Novel numerical capabilities recently developed at PNNL within the flow and reactive transport simulation code PFLOTRAN will be used to demonstrate the utility of MP datasets from GIFT experiments. These efforts will provide important information to support the Hanford Site cleanup mission.

FY24 Accomplishments

Test cell assembly

The custom-designed 3.3 × 3.3 × 6.6 ft (1 × 1 × 2 m) test cell was assembled in the laboratory (Figure 1). The cell is an open-top tank with five sides made from 1-inch-thick plexiglass. The tank is held by a steel frame that elevates the base of the cell nominally 24 inches above ground level to provide access to the bottom surface.

Figure 1. The assembled GIFT test cell, consisting of a plexiglass tank on a steel frame.

There are 112 holes of 1-inch-diameter evenly spaced across the five sides of the cell. The holes can be instrumented for different applications, including fluid injection/sampling, point sensors, and geophysical methods. Custom fluid passthroughs for circulating liquid and/or gas also double as electrodes for performing electrical resistivity tomography methods. The surface can also be instrumented with piezoelectric elements for seismic imaging. Finally, the ports can be customized to accommodate a variety of point sensors for monitoring test cell moisture conditions, such as tensiometers, humidity probes, or time-domain reflectometry probes.

Gas circulation controls

Gas circulation and analysis (GCA) control systems were designed and added to the GIFT system in FY24 to allow minimally disruptive gas sampling and basic in situ analysis, including pressure and gas composition. The inner assembly with the instrumentation and wiring fits into a rugged roto-molded polyethylene rack (SKB Corporation, Inc.). Figure 2 shows a completed GCA system.

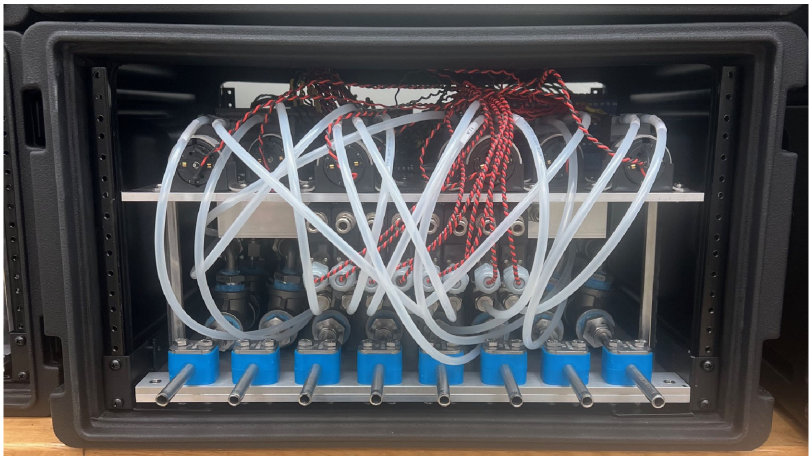

Figure 2. A gas circulation and analysis (GCA) system inside a rugged enclosure.

Gas will enter the system at a controlled flow rate via inlet tubes, then pass through a chamber that measures the gas pressure and oxygen content, then finally return to the cell via outlet tubes (Figure 3).

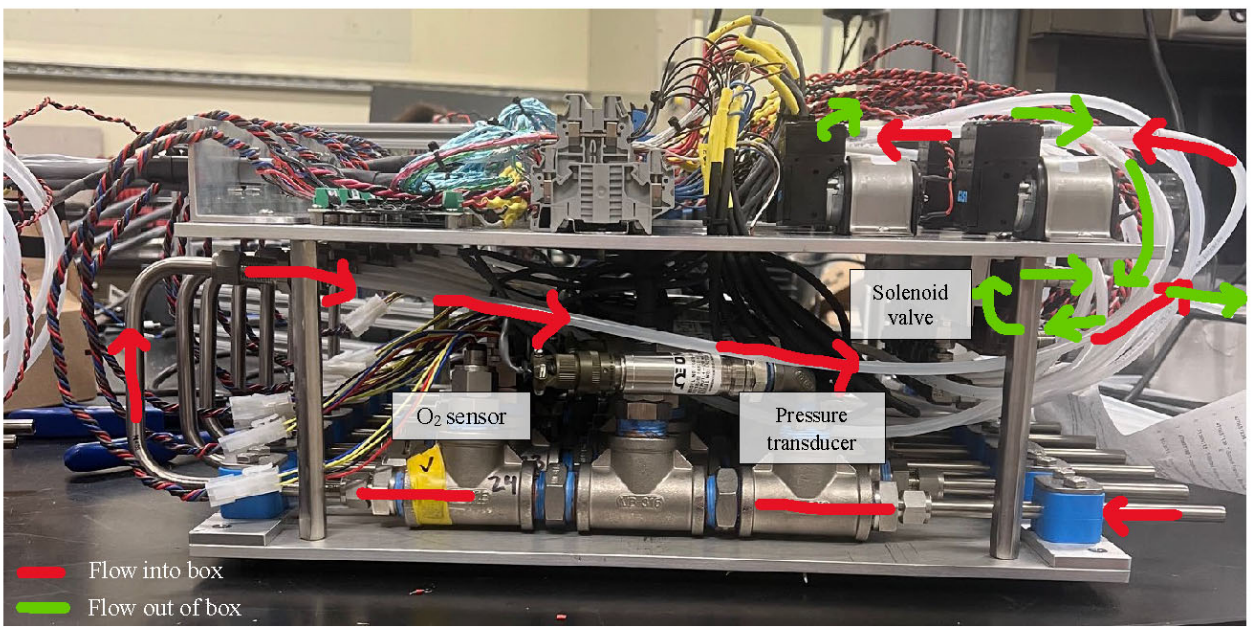

Figure 3. Schematic diagram of gas flow through the GCA system. Gas flows into an inlet tube, through a chamber with a pressure transducer and oxygen sensor, then through the gas pump. It is pumped out through a solenoid valve and finally out the outlet tube back into the test cell.

The initial design uses oxygen gas sensors but could be modified to accommodate sensors for other constituents. There is also an extra port in the chamber for an additional sensor (Figure 4). The sensor configuration can easily be customized to suit the needs of an experiment.

Figure 4. The gas sensing chamber with pressure transducer and oxygen sensor installed. The center port is empty and can be instrumented with an additional sensor per experiment needs.

Each GCA system or "box" can simultaneously circulate/sample gas from eight fluid ports on the test cell. The experimental setup includes eight of these GCA boxes for a total monitoring capability of 64 gas ports. At the time of reporting, seven of the eight GCA systems are built, with plans to finish the eighth before FY24 end.

Liquid circulation controls

The liquid circulation and analysis (LCA) systems will be added in early FY25 and will function nearly identically to the GCA systems. However, they will include liquid pumps rather than gas pumps and an electrical conductivity/liquid temperature sensor rather than an oxygen sensor. As with the GCA, there is a spare sensor port on each leg for experiment-specific sensors. The configuration of liquid controls (fluid injection, sampling, boundary flow, etc.) can be customized based on experimental design. A total of four LCA systems will be added to the GIFT.

Data acquisition systems

Each GCA/LCA box is controlled and powered by a "brain" box. Each brain box contains a National Instruments cRIO controller, ethernet switch, and three power supplies: 24V for the sensors, 12V for the pumps and switch, and a separate 24V power supply for the cRIO (Figure 5). The data acquisition/power assembly is housed in the same model of rugged enclosure as the GCA/LCA systems. The cRIO is controlled by a custom LabView program that operates the whole system and can control/record every valve, pump, and sensor independently. The ethernet switch is used to connect all eight control boxes together into a single network so that all boxes can be controlled in real-time simultaneously.

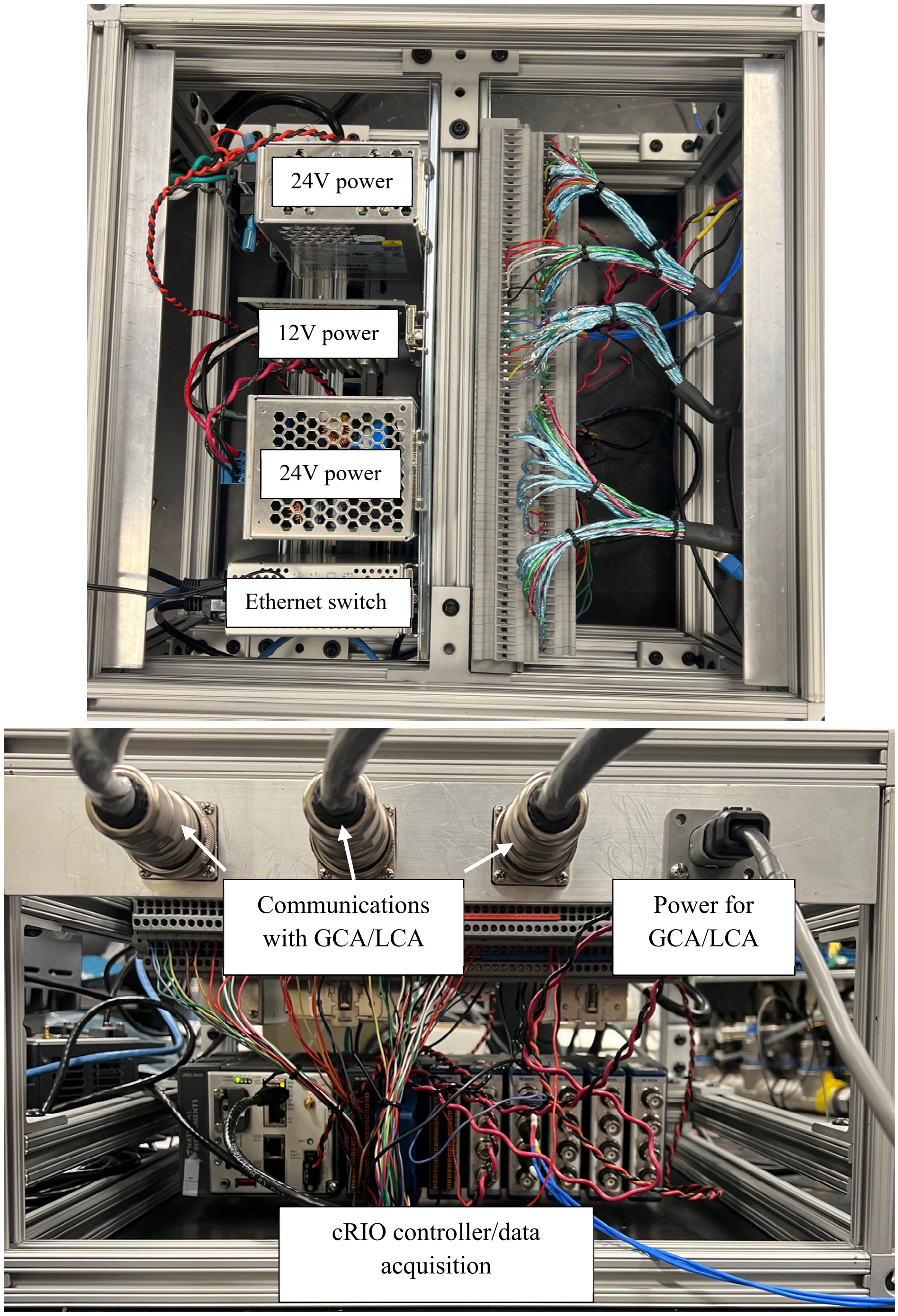

Figure 5. Top: Top view of a “brain” box showing the power supplies and ethernet switch. Bottom: Front view of a brain box showing the cRIO controller and communications cables to the corresponding GCA/LCA box.

Planned FY25 Activities

In Q1 of FY25, the remaining LCA boxes will be constructed and tested, including instrument validation tests to provide confidence in experimental data. Throughout the remainder of the fiscal year, the GIFT system will be used to conduct experiments evaluating delivery challenges and remedial performance of liquid-based amendments related to 200-DV-1 technology treatability testing. Proposed experiments include measuring (1) radial distribution of precipitates from delivery point, (2) impacts of heterogeneity on precipitate distributions, (3) permeability reductions with precipitate formation, and/or (4) effects of repeat injections. The GIFT system will enable a controlled flow experiment with sensor and geophysical data that may be used to compare and validate current flow and transport codes such as PFLOTRAN.

Quality Assurance

This work was performed in accordance with the PNNL Nuclear Quality Assurance Program (NQAP). The NQAP complies with the DOE Order 414.1D, *Quality Assurance*. The NQAP uses NQA-1-2012, *Quality Assurance Requirements for Nuclear Facility Application*, as its consensus standard and NQA-1-2012, Subpart 4.2.1 as the basis for its graded approach to quality. Any data presented in this document is preliminary, For Information Only (FIO), and subject to revision.

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