U.S. DEPARTMENT OF ENERGY

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Subsurface CAPABILITIES

Pacific Northwest NATIONAL LABORATORY

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Environmental Remediation and Stewardship

Pacific Northwest National Laboratory (PNNL) provides continuity of scientific and technical expertise to support environmental remediation and site stewardship decisions. PNNL enables critical cleanup decisions, leveraging research and knowledge from our government sponsors, including the U.S. Department of Energy (DOE) Offices of Science, Environmental Management, Nuclear Energy, and Fossil Energy, and the Department of Defense, industry customers, universities, and our fellow national laboratories. Our strategically focused research, analyses, and technological contributions provide crucial science-based and risk-informed solutions to environmental remediation and stewardship challenges that save the nation millions of dollars and reduce the risks and time frames for cleanup of legacy waste. PNNL is committed to restoring the environment for a cleaner future.

Our support to DOE began by establishing the environmental monitoring programs for the DOE Hanford Site that protect critical water resources today. We also provided the technical foundations for initiating the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) process at Hanford and have developed numerous technologies and approaches for remediation that are being implemented.

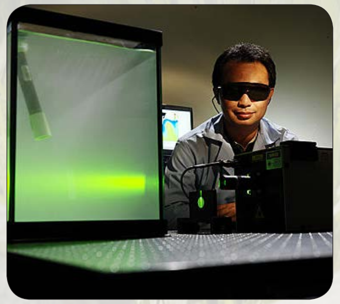
Core Competencies

Today, PNNL stewards the fundamental scientific and engineering underpinnings necessary to enable four core competencies and foundational, multidisciplinary scientific and technical expertise critical to resolving these challenge:

NATURE AND EXTENT OF CONTAMINATION

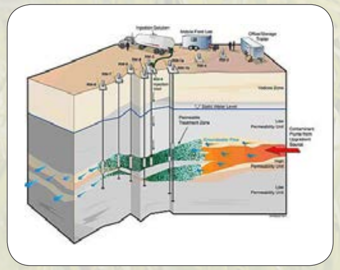
- 1500+ peer-reviewed publications
- 30+ technical experts
  - Subsurface characterization
  - Contaminant behavior
  - Subsurface heterogeneity
  - Microbiology and biological systems
  - Geochemistry and hydrogeology
  - Computational and numerical modeling

REMEDIAL DESIGN



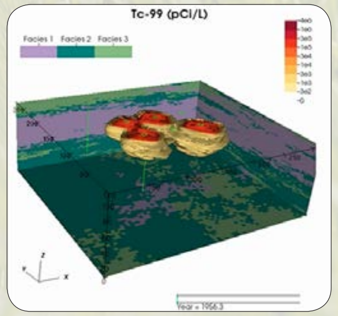
- 1000+ peer-reviewed publications
- 30+ technical experts
  - Fate of inorganic and radionuclide contaminants
  - Moisture and contaminant flux control
  - Technology development and maturation

REMEDIAL ACTION



- 500+ peer-reviewed publications
- 15+ technical experts
  - Remediation systems engineering
  - Biogeochemical stabilization
  - Physical stabilization

END STATES



- 700+ peer-reviewed publications
- 30+ technical experts
  - Risk analysis and decision science
  - Systems-based monitoring
  - Predictive simulation

PILOT SCALE

Integrated Field Research Challenge (IFRC) Site

- Field-scale science investigation
- Evaluation of mass-transport processes
- Geochemistry, microbiology, hydrogeology, and geophysics

Vadose Zone Field Sites

- Recharge measurement and characterization
- Surface barrier design
- Waste form degradation performance assessment
- Simulated tank leaks
- Subsurface heterogeneity characterization
- Remediation treatability development and demonstration
- Geophysics characterization

Institutional Computing

Olympus

- >25K cores
- “Shared User” system

Risk and Decision Sciences

ISB-II

- Web-based analysis and risk-informed decision support software
- Strategic planning
- Lifecycle analysis

Risk Analysis and Performance Assessment

Our experience in risk analysis and performance assessments makes us leaders in evaluating and mitigating potential nuclear safety issues. We currently perform this work for DOE, the Nuclear Regulatory Commission, industry, and international entities. Examples of our risk analysis and performance assessment expertise include:

- Technical approach to define and achieve remediation endpoints
- Exit strategy for pump and treat systems
- Mass flux-based framework for remediation of complex sites
- Framework for monitored natural attenuation for recalcitrant contaminants and complex sites
- Surface barrier and waste form performance assessments
- Systems-based monitoring
- Natural hazard characterization (seismic, ashfall, wildfire, flooding, etc.)

Institutional Microscopy

PNNL has invested over $50M in microscopy instruments that have high-resolution imaging capabilities, including complementary chemical, structural, and phase information, in-situ imaging in native environments, and imaging of dynamic processes with high temporal-resolution. These instruments are available in several PNNL facilities, including the Applied Process Engineering Laboratory (APEL), Radiochemical Processing Laboratory (RPL), and EMSL. Capabilities include:

- Scanning electron microscopes
- Scanning/transmission electron microscopes
- Atomic force microscopes
- Optical

Institutional Spectroscopy

Several members of our staff are interested in various aspects of spectroscopy for studying glasses, ceramics, and other materials. This includes vibrational spectroscopy, mass spectrometry, and ion spectroscopy. Over $100M has been invested in equipment and instruments that are available in several PNNL facilities, including APEL, RPL, EMSL, and the 331 Building. Capabilities include:

- Nuclear magnetic resonance (NMR), Auger, Mossbauer
- Fourier transform infrared spectroscopy (FTIR)
- X-ray diffractometer (XRD), X-ray fluorescence (XRF)
- Alpha, beta, and gamma spectroscopy
- Raman spectroscopy

Radiochemical Analytical Capabilities

Several technical groups within PNNL provide expertise in radiochemical analysis, supporting the Hanford Site cleanup, nuclear materials stewardship, non-proliferation missions, the nuclear fuel cycle, national security missions, and energy production. Capabilities include:

- Analytical support operations
- Radiochemical process engineering
- Radiochemical separation
- Radiological dispersion and interfacial chemistry
- Radiological NMR laboratory
- Radiological surface science laboratory
- Reactor dosimetry
- Shielded facilities operations
- Thermoanalytical capabilities

Subsurface Flow and Transport

PNNL operates nine fully equipped, radiologically controlled wet chemistry and analytical laboratories. These laboratories contain equipment to perform flow-through column experiments under unsaturated moisture conditions, including the pressurized unsaturated flow apparatus. Analytical capabilities are used to safely analyze the most radioactively contaminated sediment and tank waste samples collected on the Hanford Site. Other capabilities include:

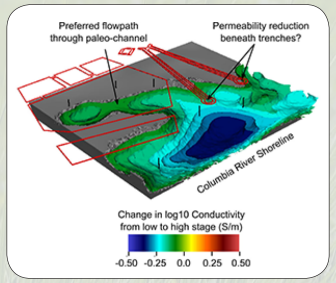
- 1D to meter-scale 3D flow cells and columns
- State-of-the-art dual-energy gamma radiation system for measuring density, water, air, two immiscible non-aqueous phase liquids (NAPLs), salt
- Integrated hydraulic apparatus
- Relative permeability apparatus
- Micromodel fabrication to specification within clean room
- High pressure and temperature micromodels

Environmental Microbiology

PNNL scientists are investigating the genetics, biochemistry, physiology, and ecology of individual microbes and microbial communities. These studies aim to determine the impact microbes have on each other and on biogeochemical processes, particularly those related to the fate and transport of contaminants and to energy production. Capabilities include:

- Microbiology (enrichment/isolation of bacteria)
- Molecular biology (DNA and RNA separations)
- Thermocycler, (quantitative) polymerase chain reaction (qPCR/PCR), bioanalyzer, nanodrop systems, incubators, spectrophotometers, fluorometers, high pressure and temperature bioreactors

Geophysical Tools and Inversion Modeling Development and Testing



Our scientists and engineers develop geophysical tools and inversion models designed for subsurface imaging and monitoring. A critical component of these tools is visualization. Capabilities include:

- Multi-channel field electrical resistivity tomography (ERT), multi-spectrum laboratory ERT
- E4D inversion software (PNNL open source copyright), IMI Software Module for E4D (PNNL copyright), PIC allocations for high performance computing
- Borehole ground penetrating radar
- Surface seismic system, borehole airgun seismic
- Electromagnetic induction geonics 31 and 34
- Distributed temperature sensing system

Environmental Remediation and Stewardship Facilities

Our capabilities are located in facilities across the PNNL campus that enable investigations to be conducted with radiological and non-radiological materials that span molecular-scale investigations through laboratory-, intermediate-, and field-scale demonstrations.

Our suite of experimental facilities and capabilities, coupled with our risk and decision science and institutional computing resources, provide the core competencies necessary to evaluate soil and groundwater remediation at complex sites using a structured, systems-based approach to the regulatory processes established for remediation under CERCLA and the Resource Conservation and Recovery Act. Our systems-based approach facilitates remedy decisions and implementation for complex sites where restoration may be uncertain, require long time frames, or involve use of adaptive management approaches. Evaluation criteria are also used to guide evaluation of data with respect to the ability to reach restoration goals or consideration of alternative goals (e.g., through a waiver process).

MOLECULAR SCALE

Office of Science User Facility (EMSL)

- Chemical kinetics and thermodynamics
- Interfacial sciences
- Subsurface heterogeneity
- Subsurface flow and transport
- Mass contaminant flux
- Conceptual and high performance subsurface modeling

RADIOLOGICAL

331 (Radiological Facility)

- Contaminated sediment characterization
- Metals and radionuclides
- Sediment column flow experiments
- Remediation technology development
- Systems-based monitoring

RPL (Radiological Facility)

- Category 2 Nuclear Facility
- Contaminated sediment characterization
- Metals and radionuclides
- Interfacial sciences

RTL (Radiological Facility)

- Sediment characterization and hydrogeology
- Microbiology/biological system characterization
- Geochemistry
- Remediation technology development
- Biogeochemical and physical stabilization

LSL-II

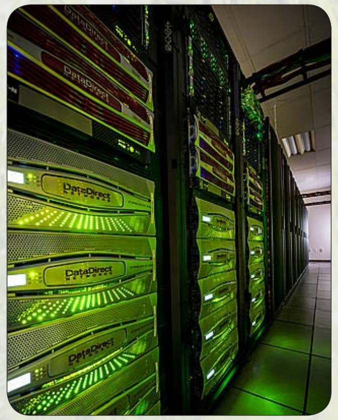
- Environmental Systems Laboratory
- Physical, wet chemistry, and micro-biology laboratory
- Bench top to intermediate-scale testing

Experimental Platforms and Key Capabilities

In addition to our technical experts, PNNL maintains over $225M in experimental and computational platforms central to providing the scientific and engineering knowledge necessary to:

- **Define features, events, and processes controlling contaminant behavior and transport, remedy performance, and exposure pathways**
- **Integrate new knowledge into systems-based conceptual models that provide scientifically defensible bases for long-term decisions**
- **Enable definition of risk-informed remediation endpoints and approaches to achieve them**
- **Provide flexible approaches for adaptive remediation of complex sites**
- **Provide technical support for transitioning from remediation to long-term management and consideration of alternative goals and associated compliance points**

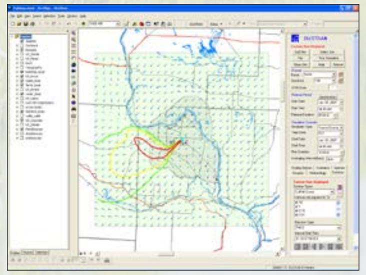
Institutional Computing



The PNNL Institutional Computing (PIC) program is focused on Laboratory needs and DOE missions. It is designed to advance scientific discovery and have impact on PNNL mission areas. PIC is part of PNNL's overall computing strategy that nurtures a culture of computational science. Resources include:

- Environmental Molecular Sciences Laboratory (EMSL) User Facility Super Computer, Olympus (20K + cores)
- PNNL Institutional Computing (7K + cores)

Institutionally Developed Software



PNNL scientists and engineers develop software to address many global challenges, including environmental remediation and stewardship. Examples of internally developed software include:

- Subsurface Transport Over Multiple Phases (STOMP), exscale STOMP (e-STOMP), Akuna, Advanced Simulation Capability for Environmental Management (ASCEM)
- PNNL-Hanford Online ENvironmental Information eXchange (PHOENIX)
- Health physics and atmospheric transport models, including Dust Transport (DUSTRAN), GEN II, and CAP-88