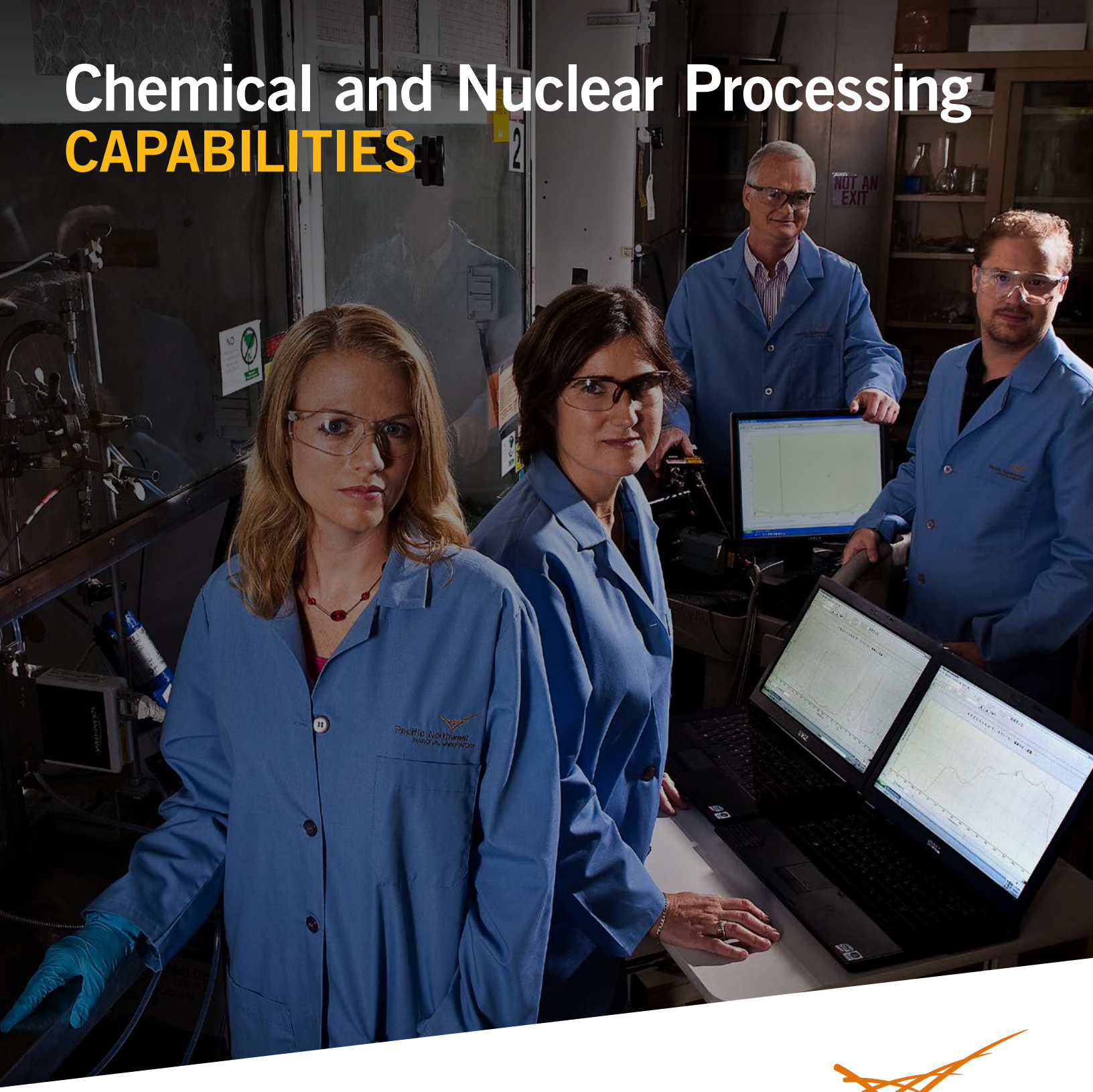
Chemical and Nuclear Processing
CAPABILITIES



Pacific Northwest
NATIONAL LABORATORY

CHEMICAL AND NUCLEAR PROCESSING

Scientists and engineers at Pacific Northwest National Laboratory (PNNL) provide expertise, technical defensibility, and integrated approaches for chemical and nuclear waste processing across the Hanford River Protection Project (RPP) Mission. PNNL enables critical decisions in design, construction, and optimal operation by leveraging research and knowledge from our government sponsors (including the U.S. Department of Energy (DOE) Offices of Science, Environmental Management, and Nuclear Energy), universities, industry, and our fellow national laboratories. PNNL scientists and engineers are developing advanced solutions to the challenges posed by interfacial chemistry, rheology, and fluid dynamics in non-equilibrium chemical systems to allow a predictive understanding for radioactive processing and new treatment options. These solutions improve safety, reduce cost, and reduce the risk of adverse operations. We support development of chemical and engineering processes for tank waste treatment at the Hanford Site, Savannah River Site, and Oak Ridge Site. Our work enabled the efficient and effective treatment of waste at West Valley and we are actively engaged in remediation at Fukushima. Building on this past and current work, PNNL is a critical technology provider contributing to the 1) design and technical defensibility of the RPP integrated flowsheet, 2) development of alternative processes and flowsheets such as Direct Feed Low-Activity Waste, the Tank Waste Characterization and Staging Facility, Direct Feed High-Level Waste, and In-Tank/Near-Tank Pretreatment; (3) waste form development, and (4) waste feed qualification. PNNL is committed to addressing technical issues through systematic approach of formulating research strategies and test methodologies that result in technically defensible solutions.

CORE COMPETENCIES

PNNL stewards the scientific and engineering expertise in four core competencies foundational to the resolution of the national nuclear tank waste remediation challenge.

Tank Waste Chemistry

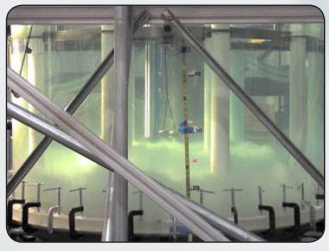
300+ peer-reviewed publications
25+ technical experts

PNNL has performed extensive characterization and process testing on Hanford tank waste samples over the last 25 years. Our experience includes characterization of full core samples, development work that underpins the current treatment and vitrification flowsheets, development of the aluminum leaching process, demonstration of cross-flow filtration, development of the Sr/TRU removal process, identification and validation of cesium removal resin, development of the chromium removal process, as well as detailed understanding of the chemical reactivity and speciation of technetium. This experience includes initial conceptual development, actual waste testing, and pilot scale demonstrations. Capabilities include:

- Hanford tank waste flowsheet development and testing
- Technetium speciation and separation methods
- Mineral and glass-phase stability
- Chemical kinetics and thermodynamics
- Performance-based simulant development
- Simulant and actual waste testing
- Simulant and actual waste facility unit operations testing
- Radiochemical and physical separations
- Interfacial and colloidal science
- Aluminum, chromium, and technetium-99 (^{99}Tc) chemistry
- Actinide chemistry
- Chemical, physical, and radiochemical characterization

Fluid Dynamics and Scaling

200+ peer-reviewed publications
21+ technical experts



For decades, PNNL has developed and stewarded a robust capability in applied engineering and prototypic experimentation in support of process development and commissioning of facilities. Our scientists and engineers have supported waste retrieval and feed

delivery on the Hanford Site since the early production mission. PNNL contributions include developing an understanding and conducting testing for slurry mobilization, mixing, retrieval, and transport of salt cake and sludge in and from waste storage tanks. Equipment assessments have included application of rotary jet pumps, axial mixers, sluicers and scarifiers to evaluate component performance, optimize system integration, and determine impact of equipment on existing infrastructure (e.g., jet forces and wear of in-tank components, dynamics of slurry transport). PNNL has developed advanced and rapid numerical modeling capabilities such as ParaFlow for turbulent jet mixing of chemically reacting, Newtonian and non-Newtonian fluids for mission-critical outcomes. These models also support the technical basis for waste-feed delivery systems at the Hanford Site. Capabilities include:

- Multi-phase flow and transport
- Computational fluid dynamics
- Advanced and rapid numerical modeling
- Non-Newtonian physics and characterization
- Solid/Liquid filtration and separation
- Wear, erosion, corrosion, and erosion/corrosion assessments
- Process assessment
- Scaling basis and relationships for waste feed delivery unit operations
- Process monitoring technologies development and application

Waste forms

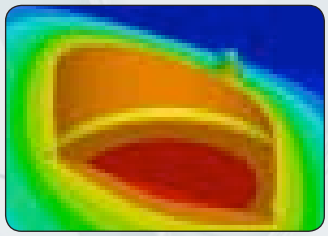
700+ peer-reviewed publications
19+ technical experts

PNNL is a recognized international leader in radioactive waste form development with decades leading the nation in applying glass technologies to waste remediation. Our scientists and engineers developed and applied the joule-heated, slurry-fed ceramic melter that is the basis for vitrification at West Valley, the Savannah River Site, and the Hanford Site. PNNL also has extensive experience in testing and evaluating low-temperature waste forms for solidification of Hanford tank wastes. Our scientists and engineers made critical contributions in process design and waste form development for the Hanford Transportable Grout Facility and the Hanford Grout Disposal program, selection of Cast Stone for solidification of Hanford Tank Waste Treatment and Immobilization Plant (WTP) aqueous secondary waste, and immobilization technologies for separated radionuclides such as ^{99}Tc. Capabilities include:

- Mineral and glass-phase stability and durability
- Simulant and radioactive glass formulation and testing
- Simulant and radioactive low-temperature waste form development and testing
- Physical and chemical property testing
- Waste form performance testing
- Composition-property modeling
- Statistical process control and WTP algorithm deployment
- Waste form qualification
- Integration from laboratory-scale to pilot-scale to deployment
- Cold cap chemistry and melt dynamics testing and modeling
- Scaled melter systems to assess waste processing rates, cold cap dynamics, and off-gas partitioning
- Material science and engineering

Safety Basis

100+ peer-reviewed publications
14+ technical experts



PNNL is a leader in risk assessment, decision science, and associated research and analysis to evaluate and mitigate potential nuclear and chemical safety issues. Our scientists and engineers perform this work for the Nuclear Regulatory Commission, DOE, commercial nuclear power industry, and international community. This capability is rooted in the Hanford mission, including closure of Hanford tank safety issues, gas generation, retention and release in tank waste slurries, flammable gas, and tank vapors. PNNL holds the "Analysis of Record" for all double-shell tanks and single-shell tanks at the Hanford Site, consisting of detailed structural analysis of thermal, seismic, and operating load stresses. Our scientists and engineers have developed several ultrasonic testing detection technologies to assess tank leak integrity and inspection applications to improve detection of wall thinning, pitting, and stress corrosion cracking. Capabilities include:

- Risk and decision science
- Risk and hazards analysis
- Toxicology
- Tank integrity evaluation technologies
- Non-destructive evaluation and analysis
- Ultrasonic instrument design and deployment
- Finite element and structural analysis
- Tank vapor characterization and sensing
- Air dispersion modeling
- Bench- and pilot-scale testing and evaluation of vapor monitoring instrumentation
- Seismic hazard analysis
- Spectroscopy and instrumentation specialists

KEY CAPABILITIES AND EXPERIMENTAL PLATFORMS

To address chemical and nuclear processing, PNNL stewards the following key capabilities including radiological hotcells, gloveboxes, and fumehoods equipped with over $220M in advanced instrumentation, as well as numerous experimental and computational platforms.

Experimental Platforms

- Material mobilization, mixing, retrieval, and transport
  - Multiphase Transport Evaluation Loop (MTEL)
  - Spray release loops
  - Pulse jet mixers
  - Multiscale gas retention and release systems
- RPP Integrated Flowsheet testing
  - Hanford Test Platform (rad and non-rad)
    - Cross-flow filtration
    - Ion exchange
    - Low-activity waste melter
    - Effluent Management Facility evaporator
  - Process Monitoring
    - Inline ultrasonic monitoring for solids deposition, concentration, and viscosity
- Melters
  - Laboratory-scale melter (both rad and non-rad)
  - Research-scale melter (engineering scale, non-rad)
  - Continuous processing laboratory-scale melter (CLSM/RCLSM) (both rad and non-rad, under development)

Institutional Microscopy

PNNL has invested over $50M in microscopy instruments with 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 used to understand and predict the behavior of both radioactive and non-radioactive materials and chemical systems and are located in several PNNL facilities, including the Applied Process Engineering Laboratory (APEL), Radiochemical Processing Laboratory (RPL), and Environmental Molecular Sciences Laboratory (EMSL). Capabilities include:

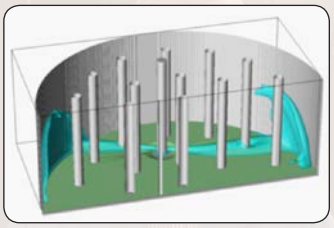
- Scanning and transmission electron microscopes
- Atom probe tomography
- Atomic force microscopes
- Optical microscopes

Institutional Spectroscopy

PNNL researchers are leaders in applying spectroscopy to understand and control important properties in glasses, ceramics, and other materials. For example, scientists at PNNL have used Raman spectroscopy to develop real-time sensors of the characterization and quantification of tank waste in process lines and remote characterization of tank residuals without the need for sample collection. Over $100M has been invested by our sponsors in equipment and instruments that are available in several PNNL facilities, including APEL, RPL, and EMSL. Capabilities include:

- Nuclear magnetic resonance, Auger, Mossbauer
- Fourier transform infrared spectroscopy
- X-ray diffractometer
- X-ray fluorescence
- Alpha, beta, and gamma spectroscopy
- Raman spectroscopy
- X-ray photoelectron spectroscopy
- Thermal ionization mass spectroscopy

Institutionally-Developed Software



PNNL scientists and engineers develop software to address chemical and nuclear processing challenges, release and transport of contaminants from waste forms in the environment, and to solve specific waste-processing issues such as tank waste mobilization and transport. Examples of software include:

- ParaFlow
- Subsurface Transport Over Multiple Phases (STOMP), Exscale STOMP (eSTOMP)

Institutional Computing

PNNL's overall computing strategy nurtures a culture of computational science to support Laboratory needs and DOE missions. The EMSL User Facility Super Computer is used to aid energy, environment, and basic science missions important to DOE. The PNNL Institutional Computing program is designed to advance scientific discovery and advance PNNL mission areas. Specific computational resources are:

- EMSL User Facility Super Computer, Cascade (1440-node computing cluster with 23K cores)
- PNNL Institutional Computer Cluster, Constance (500-node world class cluster with 12K cores)

CHEMICAL AND NUCLEAR PROCESSING FACILITIES

Our capabilities are located in facilities across the PNNL campus that enable investigations with radiological and non-radiological materials that span from the molecular-scale through laboratory-, intermediate-, pilot-, and demonstration-scales.

Our experimental facilities and capabilities, coupled with our institutional computing resources, provide the core competencies necessary to support chemical and nuclear waste processing problems.

MOLECULAR SCALE

Office of Science User Facility (EMSL)

- Chemical kinetics and thermodynamics
- Interfacial sciences
- Materials characterization
- Computational fluid dynamics and speciation modeling


EMSL

RADIOLOGICAL

RPL (Radiochemical Processing Laboratory)

- Hazard Category 2 Nuclear Facility
- Irradiated materials
- Interfacial sciences
- Process testing
- Waste form development
- Tank waste chemistry, characterization, and separations
- Tc chemistry
- Hot cells and gloveboxes


RPL

Material Sciences Laboratory

- Materials synthesis and characterization
- Fuel development
- Structural analysis
- Materials characterization
- Mechanical testing
- Erosion/corrosion testing
- Fabrication and joinery development and testing (e.g., friction stirred welding)


Material Sciences Laboratory

PILOT SCALE

APEL (Advanced Process Engineering Laboratory)

- Waste form development laboratory
- Simulant design and verification
- Interfacial and colloidal science
- Spray/aerosol test stand
- Waste form performance
- Rapid deployment high bay (intermediate to pilot-scale)

Process Development Laboratory

- Prototypic slurry flow pipe loop (MTEL)
- Research-scale melter
- Ion exchange, continuous sludge leaching, and emissions stack platform test skids

MASF (Maintenance and Storage Facility)

- DOE Office of Environmental Management owned
- Full-scale engineering test facility
- Pilot-scale hot cell

INSTITUTIONAL COMPUTING

Cascade and PIC

- EMSL User Facility Super Computer, Cascade (1440-node computing cluster with 23K cores)
- PNNL Institutional Computer Cluster, Constance (452-node world class cluster with 10.8K cores)

RISK AND DECISION SCIENCES

ISB-II

- Modeling and analytics
- Decision support framework for efficiency, quality, and safety
- Cost-effective risk-reduction techniques for complex systems

U.S. DEPARTMENT OF
ENERGY

Pacific Northwest National Laboratory is managed and operated by Battelle for the U.S. Department of Energy.

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