Oak Ridge National Laboratory

Overview of capabilities supporting advanced nuclear technology development and deployment.
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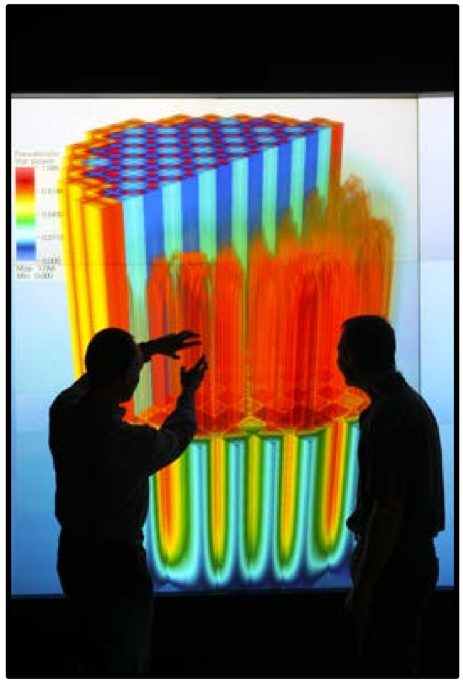
In World War II's Manhattan Project, ORNL helped usher in the nuclear age. Today, ORNL's researchers hold leading roles in using nuclear technologies and systems to improve human health; explore safer, more environmentally friendly power; and support science discoveries that address national challenges. Around the lab, you will find researchers:

- Producing isotopes for medical research, scientific discovery, national security, and industry.
- Leading research in the entire nuclear fuel cycle, from development of advanced reactor technologies to storage of used fuel.
- Using modeling and simulation to improve operations and safely extend the life of existing nuclear reactors.
- Supporting national security through nuclear safeguards and technology, nuclear material detection, and fuel-cycle signature analysis.

ORNL has an unmatched combination of computing, reactor, radiochemical, and materials research facilities that create a rewarding and scientifically stimulating environment for advancing nuclear science and technology.

1. <u>**Modeling and Simulation**</u>



Description

Oak Ridge National Laboratory (ORNL) is a leader in the development of nuclear modeling and simulation software and data, the application of custom-developed and commercial tools to challenging applications scenarios, advanced validation approaches, experiment design, regulatory support, and training, especially in the following areas:

Nuclear Data

ORNL generates and deploys nuclear data evaluation and processing software, fundamental physics evaluations, and nuclear data libraries for a wide range of applications that involve neutron and gamma transport; activation, depletion and decay; and uncertainty analysis. The capabilities and expertise at ORNL span the entire nuclear data life cycle including assessment of nuclear data needs, differential measurement of new data at neutron scattering facilities, evaluation of fundamental data, and processing of data from ENDF and other sources to generate libraries for production use and distribution.

Neutronics

ORNL has a long history of developing robust neutronics analysis tools implementing multigroup and continuous-energy physics with deterministic and Monte Carlo methods. ORNL develops the SCALE Code System, which has served as a key review tool for the US Nuclear Regulatory Commission (NRC) since 1976 and continues to expand with cutting edge capabilities for design and licensing of a wide range of systems. ORNL develops a range of tools for multigroup cross section processing, criticality safety analysis, reactor lattice physics for LWR and advanced systems, reactor depletion, radiation source term characterization, material transmutation and isotope production, and sensitivity and uncertainty analysis.

For liquid fueled molten salt reactors (MSRs), SCALE is being enhanced to include a delayed neutron precursor drift and chemical feed capability that can be coupled to other tools. The Virtual Environment for Reactor Analysis-Core Simulator tool from the Consortium for Advanced Simulation of Light Water Reactors (CASL) is being expanded to provide a fully integrated multiphysics tool capable of three-dimensional analysis of MSRs with feedback effects.

Radiation Transport and Shielding

ORNL provides advanced capabilities in radiation transport and shielding analysis especially through hybrid methodologies that implement deterministic solvers to optimize high-fidelity Monte Carlo calculations for systems that are too challenging to be addressed by conventional means. Application scenarios that require these unique tools for high-fidelity analysis include shielding analysis, site boundary calculations, pressure vessel fluences, activation etc.

Thermal Hydraulics

Thermal hydraulics modeling and simulation at ORNL relies on a combination of custom code development, leveraging of open source software, and the extension of commercial codes.

For high-resolution computational fluid dynamics (CFD), ORNL leverages the DNS/LES capabilities of the open source spectral element code Nek5000 and the open source code PHASTA, a code for Parallel, Hierarchic, Adaptive, Stabilized finite-element Transient Analysis. ORNL supports the integration of Nek5000 with uncertainty quantification and calibration capabilities of the open source Dakota Toolkit, developed by a community led by Sandia National Laboratory. ORNL, in partnership with North Carolina State University (NCSU), supports the continued development of a unique multi-interface multiphase simulation capability within the framework of the PHASTA code, which was initially developed by Rensselaer Polytechnic Institute. ORNL also uses or extends other open source high resolution CFD codes including Hydra-TH, Nalu, and OpenFOAM.

For RANS-based CFD, ORNL partners with commercial code developers to extend the capabilities of commercial products to address our unique simulation needs. Notably ORNL supports the development and validation of innovative multiphase simulation capabilities in the code STAR-CCM+ as part of the CASL thermal hydraulics team and the Nuclear Energy Advanced Modeling and Simulation (NEAMS) Steam Generator High Impact Problem (HIP) team to study flow-induced vibrations. ORNL also maintains a RANS-based analysis capability for HFIR fuel coolant channel analyses constructed within the commercial simulation framework COMSOL.

For subchannel analysis, ORNL supports the development of COBRA-TF code in partnership with NCSU. ORNL focuses on enabling the code to complete multichannel analyses on parallel computing platforms, extension of the code to higher void fraction flow regimes found in boiling water reactors, and integration of the code with neutronic, fuel performance, and coolant chemistry codes and models. ORNL also supports the continued development of the COBRA-SFS code in partnership with Pacific Northwest National Laboratory for assessment of thermal hydraulics in spent fuel storage.

Structural Mechanics

ORNL integrates the capabilities of commercial structural mechanical solvers like ANSYS and Abaqus with other physics codes to solve multiphysics problems. ORNL also maintains a structural mechanics analysis capability in the commercial simulation framework COMSOL for application in multiphysics simulations including flow induced vibration.

Fuel Performance

ORNL provides innovative solutions in integrating and applying tools developed elsewhere and provides unique new features for these tools. Within CASL, the BISON code developed at Idaho National Laboratory for fuel performance analysis and the MAMBA code developed at Los Alamos National Laboratory for the prediction of the buildup of crud are integrated into VERA-CS. This capability is being used to model every fuel rod over multiple cycles of operation and predict the mechanical stresses to estimate the potential for fuel failure through pellet-clad mechanical interaction. It is also being used to predict CRUD growth on the cladding surface to model both CRUD-Induced Power Shift and CRUD-Induced Localized Corrosion.

Through the NEAMS program, ORNL is integrating BISON with the Simulation-based High-efficiency Advanced Reactor Prototyping (SHARP) suite of codes developed at Argonne National Laboratory to create the Warthog multiphysics fuel performance tool for the analysis of advanced reactors and accident tolerant fuels. Additionally, ORNL is integrating the activation and depletion capabilities of SCALE/ORIGEN and the thermodynamic properties of Thermochimica into BISON.

ORNL also supports the High Flux Isotope Reactor (HFIR) low-enriched uranium (LEU) conversion and experiment design using the commercial ANSYS thermo-mechanics software.

Reactor Safety, System Dynamics, Instrumentation and Control

ORNL has recognized expertise in the development, extension, and validation of codes for the assessment of system thermal hydraulics, system dynamics, and reactor safety. ORNL develops TRANSFORM, a unique system analysis code implemented within the Modelica simulation framework. TRANSFORM's implementation provides most of the capabilities of other system codes, but is well suited for system dynamics analysis and instrumentation and control design. ORNL also evaluates and validates the NRC system analysis code TRACE for LWR applications and develops modified branches of the TRACE system analysis code for advanced reactor applications. Similarly, ORNL evaluates and validates the system safety analysis code RELAP5 for LWR and advanced reactor applications. ORNL maintains material property functions for a variety of reactor coolants and structural materials for use in these codes.

Nuclear Security

ORNL creates focused tools and provides detailed analysis and solutions on emerging, difficult radiological questions to DOE, the Department of Defense, the Department of Homeland Security, intelligence agencies, and the national security community using state of the art modeling and simulation. These tools and analyses include material production and detection, nuclear safeguards, forensics, radiation detection modeling, radiation transport applications, detector response modeling, statistical data sampling analysis, and inverse analysis and modeling.

Used Nuclear Fuel

The Used Nuclear Fuel-Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS) comprehensive, integrated data and analysis tool is being developed for the DOE-NE Nuclear Fuels Storage and Transportation Planning Project (NFST). The overarching goal of UNF-ST&DARDS is to provide a comprehensive controlled source of technical data integrated with key analysis capabilities to characterize inputs to the overall US waste management system from reactor power production through ultimate disposition. UNF-ST&DARDS seamlessly integrates a unified spent nuclear fuel (SNF) system relational database and key analysis capabilities to simplify and automate the performance of accurate and efficient SNF related analyses to support numerous DOE waste management and fuel cycle activities.

UNF-ST&DARDS enables decision making relative to design, safety, and licensing of SNF systems and facilities by providing the best information available. Automated analysis sequences have been deployed to characterize the discharge inventory and perform criticality, thermal, and dose analyses using time-dependent data. UNF-ST&DARDS provides cask-specific as-loaded safety analysis including criticality, thermal. and dose evaluations, as well as results visualization, by integrating capabilities from SCALE and COBRA-SFS.

Cross Cutting Capabilities

A number of cross cutting capabilities are available to facilitate the development, testing, deployment, and use of modeling and simulation capabilities, although implementation can vary from team to team to satisfy their sponsor/user base as well as their individualized work practices. Examples of cross cutting capabilities include quality assurance programs, infrastructure to automatically compile and test software on a continuous basis on many platforms with differing compilers, graphical user interfaces, multiphysics coupling, verification and validation, and uncertainty quantification.

As most of the modeling and simulation tools developed at ORNL contain export controlled information, distribution is managed by the Radiation Safety Information Computational Center.

Relevance

ORNL provides comprehensive modeling and simulation tools and expertise for the design, safety analysis, and licensing of current and advanced systems. ORNL tools are an essential component of the NRC's review process and are deployed broadly for use by the community as a whole under a robust quality assurance program for rapid dedication under nuclear quality assurance-1. ORNL experts are ready to assist with development of innovative approaches to analyze your systems.

Point of Contact

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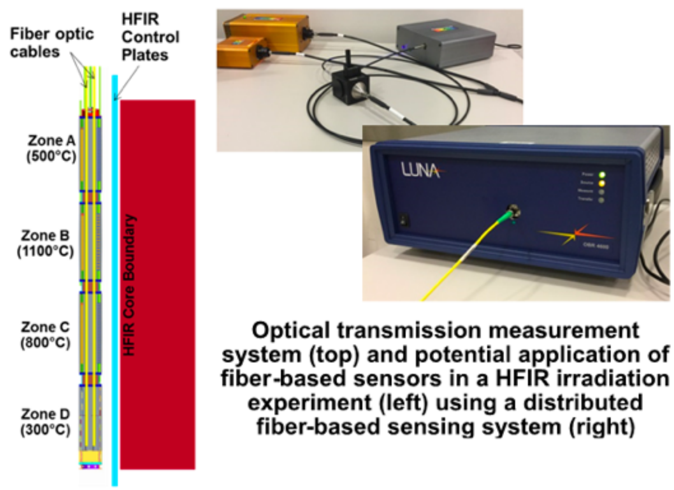
2. <u>Instrumentation and Control</u>



Optical transmission measurement system (top) and potential application of fiber-based sensors in a HFIR irradiation experiment (left) using a distributed fiber-based sensing system (right)

Description
ORNL has extensive expertise and experience in the development, integration, manufacturing, and testing of sensors and instrumentation and control. This is backed up by quality facilities and infrastructure across the laboratory.

- **Sensors**
    - *Development and Integration*
        - Sensors Development Laboratory: a large laboratory space dedicated to sensor and electronics fabrication
        - Access to machine shops with various fabrication capabilities, including
            - alloy design and fabrication
            - precision machining
            - additive manufacturing (a 3D printer in the lab for quick prototyping)
            - surface functionalization
            - lithography
            - various deposition tools, such as physical vapor deposition, chemical vapor deposition, and plasma-enhanced atomic layer deposition
        - Access to a wide range of analytical instruments for characterization
            - Surface profilometry
            - Optical microscopes of various magnification
            - scanning electron microscopes/transmission electron microscopes
        - Embedded sensors technology development and demonstration
        - Radiation-hardened and radiation-tolerant sensors and electronics
    - *Testing*

        - **Sensors and Measurement Systems (SAMS) Laboratory:** state-of-the-art data acquisition and signal processing systems
            - Data acquisition capabilities in various platforms, such as PXIe, VXI
            - High-resolution, high-speed scopes
            - A wide range of electronics capabilities to perform various measurement modes, including ultrasonic and optical measurements
        - **Technical Testing and Analysis Center (TTAC):** TTAC provides quality, standards-based testing and analysis on various instrumentation for government, industry, and ORNL internal customers utilizing National Voluntary Laboratory Accreditation Program (NVLAP)-accredited (NVLAP Lab Code 200861-0) facilities and equipment
            - Perform systematic and comparable testing to ensure equipment under test meets application needs
            - TTAC's capabilities include
                - radiological testing with industrial radionuclides, medical isotopes, or special nuclear material
                - simulating environmental conditions of temperature, humidity, air pressure (altitude), dust, moisture, salt fog, magnetic fields, electromagnetic compatibility/interference, line noise, voltage variation, vibration, and shock
            - The center is accredited by the NVLAP to the American National Standards Institute/Institute of Electrical and Electronics Engineers N42 Homeland Security Standards (NVLAP Lab Code 200861-0
        - Molten salt loop (large-scale forced-cooled loop)
            - Access ports and feedthroughs for testing and demonstration
        - Sodium loop (small-scale loops in glovebox)
        - Thermosiphon facility (high-temperature pressurized water loop)
            - Access ports and feedthroughs for testing and demonstration
- **Controls**
    - Life-cycle functional requirements for control systems
    - Writing technical specifications for complex systems
    - Highly integrated control room designs (distributed controls perspective)
    - Regulatory implications
    - Vast experience in classical control system design
    - Vast experience in modern control, including state-space control, optimal control, and robust control systems design
    - Past work on supervisory control (sometimes called semiautonomous control) funded by DOE (situational analysis, risk-based decision making, supervisory control)
    - Experience on implications on cyber-physical vulnerabilities on the performance of distributed digital control systems

        - Cyber-resilient control system design
- **Communications**
    - Life-cycle functional requirements for communication systems
    - Experience in writing technical specifications for complex communications architectures and bus platforms
    - Experience in highly integrated control room designs (data communications perspective)
    - Experience in various communication platforms and protocols
        - Wired
        - Optical
        - Wireless
    - Dedicated facilities for testing wireless systems
    - Experience in regulatory implications of advanced communication protocols
        - Deterministic vs nondeterministic data communications (BTP 7-21)

Relevance

While there are many types of advanced reactors, a common attribute is chemically more aggressive coolants and high operating temperatures. Technological advances are needed to reduce measurement uncertainties and relax calibration frequency requirements. Furthermore, new measurement modalities may provide information beyond the sensitivity and accuracy limits offered by state-of-the-art technologies. Advanced instrumentation and control methods are considered the enabling technologies to break the barrier in the staffing approach in large light water reactors. This can only be tackled by a multipronged approach through extensive instrumentation; sophisticated and correlated data processing—also called data analytics, diagnostics, and prognostics; and advanced control approaches that implement situation assessment, operator support, and even autonomous control approaches.

The capabilities, history, and experience at ORNL provide a comprehensive set of tools to achieve desired technology maturation objectives, and significantly improve the performance metrics of future nuclear energy systems.

Point of Contact

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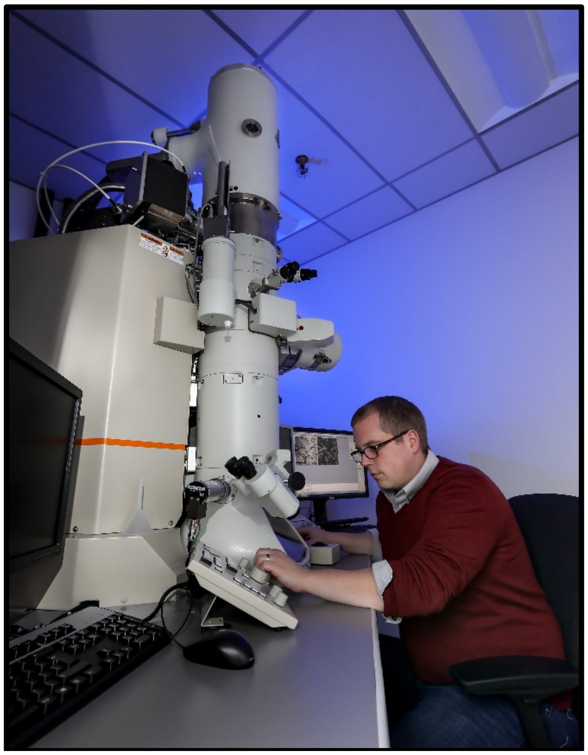
3. Material Development and Testing



Description

ORNL hosts a broad set of capabilities for development and testing of metal, ceramic, and composite structural materials. The 4508 high-bay facility supports systematic studies on metal alloy design and holds the complete set of melting, cold, and hot working (including extrusion), and powder processing capabilities for this purpose. Various high temperature ceramic processing capabilities, including spark plasma sintering and hot isostatic pressing are also available in adjacent facilities.

Materials testing spanning across mechanical, thermo-physical, and microstructural characterization is a core area of strength at ORNL. Mechanical testing includes utilization of digital-image correlation and extends to creep and fatigue testing. In situ mechanical testing (i.e. inside electron microscope, x-ray tomography unit, and neutron beams) is routinely performed. A full suite of thermo-physical and microstructural characterization tools are available. All of these techniques and capabilities are available to be applied on irradiated structural materials.

Irradiation testing of materials in HFIR is ideal for miniature specimens, with a focus on providing scientific understating of material behavior rather than integral effects. Additionally, the building houses a gamma irradiation facility that uses spent fuel assemblies and is capable of providing high gamma doses for studies of the effects of radiation on materials.

Relevance

Materials development and testing capabilities at ORNL are essential to US industry and the mission of DOE to enable the next generation of safe and economic nuclear energy. The performance of current and advanced systems is often limited by the materials that constitute these systems and there exists a strong need to develop and qualify new materials that can push the performance of these systems. ORNL, with nuclear materials science at the core of its expertise, is uniquely positioned to assist US nuclear industry in addressing this need.

Point of Contact

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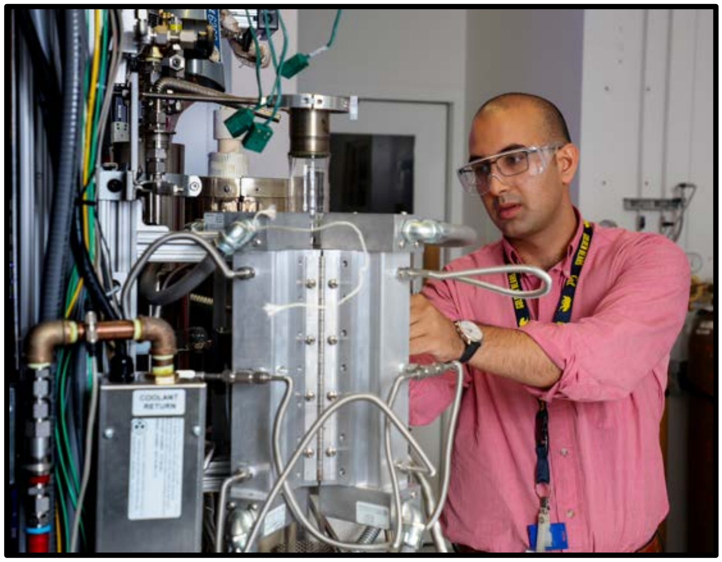
4. Fuel Development and Testing



Description
ORNL holds world class expertise and capabilities in production, characterization, irradiation testing, and post irradiation examination of nuclear fuel. The laboratory leads the national capabilities for production, characterization, and testing of coated fuel particles (TRISO) and ceramic fuels (e.g. light water reactor fuel). Irradiation testing of fuel in HFIR is ideal for miniature specimens, with a focus on providing scientific understating of fuel behavior rather than integral effects. The laboratory's expertise in fuel production—starting from feedstock prepared by solution–gelation—is unique. Application of the latest generation of characterization tools to investigate the microstructure, properties, and behavior of high burnup nuclear fuel is now routinely done at ORNL. All of these unique capabilities and associated expertise are available to the US nuclear industry to design, develop, and qualify the next generation of advanced fuels.

Relevance
ORNL's nuclear fuel development and testing capabilities and expertise are in place to facilitate advance, safe, and efficient nuclear power by applying materials science to design, develop, optimize, and accelerate deployment of advanced nuclear fuels and materials.

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5. Advanced Manufacturing

Description

ORNL hosts the US Department of Energy's first Manufacturing Demonstration Facility. This facility is uniquely positioned to help the US industry adopt new manufacturing technologies to produce materials, components, and systems, facilitating the next generation of higher performance energy generation technologies. This capability, coupled with ORNL's core materials science expertise, is ideal for the development of advanced nuclear energy related materials and components. Some of the advanced manufacturing capabilities are also available to be applied on fuel materials (i.e. U-bearing). These capabilities—coupled with resident experts with a deep knowledge of their optimal application—are ripe for utilization by the US nuclear industry to reduce cost of nuclear electricity, while allowing the next generation of safe and reliable nuclear energy systems.

Relevance

Advanced manufacturing has the potential to reduce life-cycle energy consumption and production costs for existing parts and components in nuclear energy systems. It also can enable new materials and designs that were not previously possible by conventional manufacturing methods. In doing so, advanced manufacturing can play an essential role for reliable, safe, and economic nuclear energy generation.

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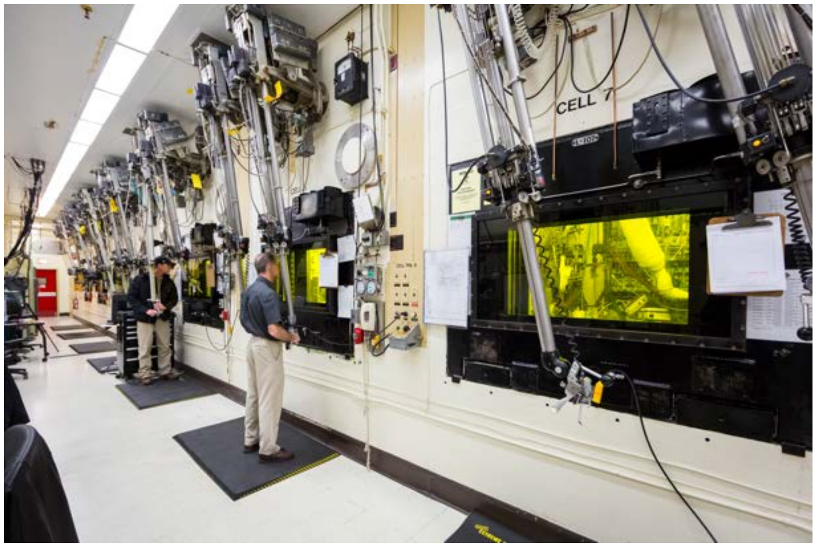
6. Radiochemical Separations and Process Development



Description

ORNL maintains a staff of nuclear chemical engineers, radiochemists, technicians, and robotic operations engineers with expert capabilities for radiochemical separations, process development, and radioactive waste form development.

ORNL operates three radiochemical facilities which contain multiple hot cells and glove box laboratories designed for radiochemical process development and demonstration, as well as special and unique radioisotope production:

- **The Radiochemical Engineering Development Center, Building 7920 (REDC 7920)** was designed to process targets irradiated in the adjacent HFIR, but also has capability and experience in processing irradiated targets and used nuclear fuels (UNF) from the Advanced Test Reactor (ATR) at Idaho National Laboratory, production reactors at the Savannah River Site, the Fast Flux Test Facility at the Hanford Site, and from commercial nuclear power reactors. The current major projects at REDC 7920 are the production of plutonium-238 from irradiated neptunium-237 in HFIR and ATR. In addition, the facility is continuing to produce transuranium elements and isotopes, primarily californium-252 from the irradiation of curium targets in HFIR. The processes used are similar to those used for minor actinide (neptunium, americium, curium) separations from commercial UNF, and the recycle target irradiations and processing are analogous to actinide transmutation process development for the nuclear fuel cycle.
- **The Radiochemical Engineering Development Center, Building 7930 (REDC 7930)** is used for fabrication of californium-252 portable neutron sources and miscellaneous research projects.
- **The Irradiated Fuel Examination Laboratory (IFEL)** was designed for post-irradiation examination on newly designed targets and physical examination of failed reactor fuel elements and other equipment. It is also used for the development and demonstration of dry chemical processes for UNF reprocessing, such as the advanced head-end voloxidation of sheared UNF rods and chlorination of UNF cladding for recovery, purification, and potential recycle of the hafnium-free zirconium.

Relevance

The expert staff and specialized facilities for radiochemical separations, research, and development can enable the evaluation and demonstration of new and improved methods for processing UNF from existing and advanced reactors for the nuclear fuel cycle, and for radioisotope production for medical, research, and industrial applications.

Point of Contact

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7. Safety and Licensing

Description

ORNL has the capability to address technology, safety, and licensing challenges and issues regarding conceptual designs, operation, control, and safety of nuclear systems to support the development and deployment of advanced reactors for power and process heat applications. ORNL's considerable safety and accident analysis capability includes probabilistic risk analysis (PRA) coupled and detailed knowledge of the NRC licensing process and regulatory requirements, including both Part 50 and 52 licensing approaches for power reactors and the equivalent process for test and research reactors. Relevant capabilities and activities include the following:

- Summary document describes ORNL capabilities matching the NRC-identified needs for evaluating and licensing non-LWR advanced reactors as noted in their "Near-Term Implementation Action Plans" published in 2016 focused on the following areas:
  - Computer codes and tools to perform non-LWR regulatory reviews
    - Reactor kinetics and criticality
    - Fuel performance
    - Thermal fluid phenomena
    - Severe-accident phenomena
    - Materials and reactor component integrity

    - Advanced non-LWR regulatory review process
        - PRA and event selection
        - Identify regulatory framework gaps
        - Develop regulatory review roadmap and prototype, research, and test reactor guidance
- Familiarity with key NRC guidance documents including NUREG-0800 (review guidance for power reactors), NUREG-1537 (review guidance for research/test reactors), general design criteria, advanced reactor design criteria, NRC Regulatory Guides, consensus standards, etc.
    - Part of the DOE team that developed the draft set of advanced reactor design criteria as derived from General Design Criteria contained in 10 CFR 50 Appendix A, which are essentially light water reactor centric.
    - NRC interim staff guidance for licensing a liquid homogenous reactor for isotope production.
    - Licensing infrastructure documents to support the licensing of (a) small modular reactors employing integral pressurized water reactors, (i.e. design specific review standards) and (b) Generation III+ light water reactors.
    - Development of a potential licensing framework for establishing the equivalent of fuel qualification process for molten salt reactors (MSRs).
    - Updated guidance in Chapter 7 on I&C systems in NUREG-1537 to support NRC assessments and audits at research/test reactors for implementation of digital systems.
- MSRs including (a) knowledge and expertise derived from the two MSRs that have operated: Aircraft Reactor Experiment and Molten Salt Reactor Experiment and (b) familiarity with new designs under development
    - Fluoride salt-cooled high temperature reactors, both large and small, employing gas-cooled-reactor TRISO fuel using fluoride-based salts as coolant
    - Chloride salt-cooled reactor technologies including salt chemistry measurements, materials, and experimental facilities
- Training programs on MSRs to prepare regulatory agencies for evaluating potential license applications from MSR developers–provided for NRC and the Canadian Nuclear Safety Commission
- Key consensus safety standards for advanced reactors:
    - American Nuclear Society Standard 20.1, “Nuclear Safety Design Criteria for Fluoride Salt-Cooled High-Temperature Reactor Nuclear Power Plants” (lead organization)
    - American Nuclear Society Standard 20.2, “Nuclear Safety Design Criteria and Functional Performance Requirements for Liquid-Fuel Molten Salt Reactor Nuclear Power Plants”
    - American Nuclear Society Standard 54.1, “General Safety Design Criteria for a Liquid Metal. Reactor Nuclear Power Plant”
- Dynamic modeling capability to provide early insights on both design options and identification of licensing basis events.

- Reactor control system and instrumentation issues associated with converting to digital systems from analog systems, including assessment of emerging instrumentation and control technologies and qualification of sensors for harsh operating environments and development of tools for modeling and evaluation of supervisory control systems for plant operations.
- Application and modeling for PRA applications
    - Pioneered the use of PRA techniques to evaluate precursors to potential core damage accidents for NRC.
    - Evaluated the risk attributes of an advanced CANDU reactor (the ACR-700) for NRC.
    - Applying PRA techniques during the design phase for reactor systems using the Risk-Based Design Optimization Tool.
    - Experience with the SAPHIRE and Fault Tree+PRA codes.

Relevance

Given the increased interest and support for the development of advanced reactors in the nuclear industry as possible replacement for the current light water reactor fleet, it is important to have the experience, tools, and understanding of these advanced reactors. In addition, it is necessary to understand the NRC licensing process to: assess the viability of a concept from both an operations and safety standpoint; identify the requisite research and development needed to resolve technology gaps; and identify possible design options to ensure that an advanced reactor meets its design objectives and can be licensed.

Point of Contact

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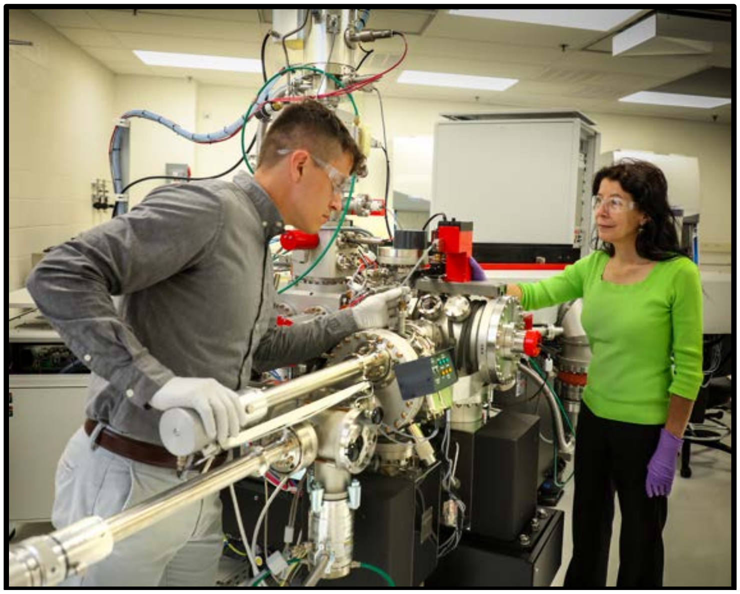
8. **Nuclear Safeguards and Security**



Description

Nuclear Safeguards

The foundation of domestic and international safeguards is nuclear material accountancy supplemented by containment and surveillance methods to provide continuity of knowledge. Nuclear material accountancy includes methods and techniques for measuring nuclear materials reported to national and international authorities and assuring that declared materials are not diverted. Technical measurements include nondestructive assay for measuring material or isotopic concentration without physically changing the item being measured. Additional techniques include destructive assay for measuring item samples to establish content and concentrations. International safeguards can also include unattended and remote monitoring for data collection to confirm operations are as declared. These techniques look for traces of materials that would indicated potential undeclared activities at facilities or related locations.

ORNL has significant depth in:

- **Nondestructive assay/analysis (NDA) capabilities.** ORNL applies their expertise in this area to international nuclear safeguards, domestic safeguards (materials control and accountability), nuclear safety programs, and other emergency response applications—often in areas that can better be categorized under the "security" umbrella (above). Key NDA capabilities at ORNL include research and development and operational applications relating to gamma detection and analysis, neutron detection and analysis, container scanning/imaging, source location and identification, and environmental monitoring. ORNL maintains one of the nation's largest collections of NDA equipment for research and development and testing/evaluation purposes combined with theoretical and operational expertise.
- **Destructive assay capabilities.** ORNL maintains world class analytical chemistry laboratories for measuring nuclear material samples collected from the entire nuclear fuel cycle.
- **Unattended and remote monitoring capabilities.** ORNL has designed, tested, evaluated, and installed instruments used by facility operators for domestic safeguards, US monitors in

support of bilateral agreements, and the International Atomic Energy Agency for international safeguards.

- **Environmental sample analysis capabilities.** ORNL maintains a world class capability for analyzing swipe samples to detect the presence (or confirm the absence) of ultra-trace materials that could indicate undeclared activities.
- **Containment and surveillance methods.** ORNL has developed and applied methods and techniques for ensuring the integrity of items and for monitoring access to strategic areas.

Nuclear Security

For secure operations of nuclear facilities, it is necessary to understand security threats and establish mitigation strategies during the design phase of new installations and to effectively evaluate and retrofit existing facilities, if applicable. ORNL promotes integrating multiple systemic concerns (e.g., security and access control, power/production operations, material control and accounting) to sustain protection levels and reduce impact on operations. In keeping with established regulatory basis, ORNL's experts contribute in four major focus areas.

- **Threat identification and risk assessment** is informed by design basis threat guidance, but also including a focus on regional or local outsider and insider threat identification. ORNL's approach includes the development of programs for monitoring employee's actions and fitness for work and trust building through the evaluation of screening and hiring procedures.
- **Security system design expertise** including access control, alarm and assessment systems, and response and communication systems. Also critical are transportation and supply chain security issues.
- Security readiness assessment using **statistical process control methods** that focus on component level concerns. This includes component effectiveness testing, data analysis, and maintenance programs.
- Organizational assessment to determine existing and developing **security culture** issues.

Relevance

The effectiveness of a facility's or country's nuclear material accountancy system is only as good as its ability to accurately and precisely measure its material in a timely manner. The confidence in an international inspectorate is greatly influenced by its capability to independently verify material declarations and detect undeclared activities. ORNL's experts have years of experience at designing, testing, and deploying technologies and methods for measuring nuclear materials and monitoring operations to meet domestic and international objectives.

Too often the security mission is considered at the operational phase and not, in this integral way, at the design phase where it can be implemented with minimal impact and highest effectiveness. Nuclear power operations are extremely complex and multiple stakeholder's concerns must be considered and balanced. ORNL's experts have experience at operational facilities and can provide consultant services at any phase of the project from design through full operations, working at both the component level and the systems analysis level.

Point of Contact

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9. <u>Enrichment Science and Technology</u>

Description

Enrichment technologies are used to separate isotopes of interest for national security, government research, industrial, and medical applications. The work includes the use of a gas centrifuge—the technology of choice, worldwide, for uranium enrichment for nuclear power plant fuel and stable isotope production. In addition, electromagnetic isotope separation provides small quantities of rare isotopes.

ORNL's current capabilities include:

- Ability to analyze and assess enrichment technologies via refined computer models.
- Perform detailed engineering analysis for development of new centrifuge components and assemblies.
- Dedicated laboratory spaces for research and development of gas centrifuge and electromagnetic separation technologies in
  - uranium enrichment and
  - stable isotope production.
- Proven capability to design, build, and operate gas centrifuges and electromagnetic separation systems.

Relevance

Whether for uranium fuel supply—including high assay LEU—or for specialized salt or fuel additives, there are a number of technical and economic drivers that require the development and use of enrichment technology. With decades of history and experience in developing and operating such technologies, ORNL is ideally placed to further support ongoing industry efforts.

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10. Molten Salt Reactor Science and Technology

Liquid Salt Test Loop and Salt Cleanup System

Description

ORNL has a variety of experimental and computational capabilities to study molten salts and the reactors that use them. ORNL combines the experience and knowledge gained from the Molten Salt Reactor Experiment and its associated salt and materials programs with a team of leading scientists in the fields of physics, chemistry, and material science. ORNL supports salt reactor projects for DOE, NRC, the National Nuclear Security Administration, and several commercial MSR developers.

Laboratory space is available to handle beryllium, uranium, and transuranic salts and other radioactive materials, such as tritium and fission products. ORNL has developed molten salt production, purification, and characterization capabilities and is in the process of expanding with additional facilities, new instruments, and the ability to handle more complex salts. Specialized instrumentation can measure the following major salt properties:

- viscosity,
- density,
- thermal diffusivity/conductivity ,
- heat capacitance, and
- vapor pressure.

Additional post-test surface and microstructural examination of specimens are routinely performed to look at other salt characteristics, such as the corrosion on structural materials. Also, a salt and specimen irradiation capability is under development.

ORNL has operational natural circulation flow loops for corrosion testing, with a larger (~75 l) forced-flow FLiNaK loop that can produce representative flow, temperatures, and pressures for component and technology testing and demonstration. A forced-flow FLiBe salt loop is under development for materials testing under representative flow conditions and for tritium behavior testing.

ORNL is a world leader in reactor analysis and is combining the fields of high performance computing, salt thermodynamics, and dynamic reactor evaluation to understand the behavior of molten salt reactors and the salts that operate within them.

Further details can be found in the related fact sheets.

Relevance

Point of Contact

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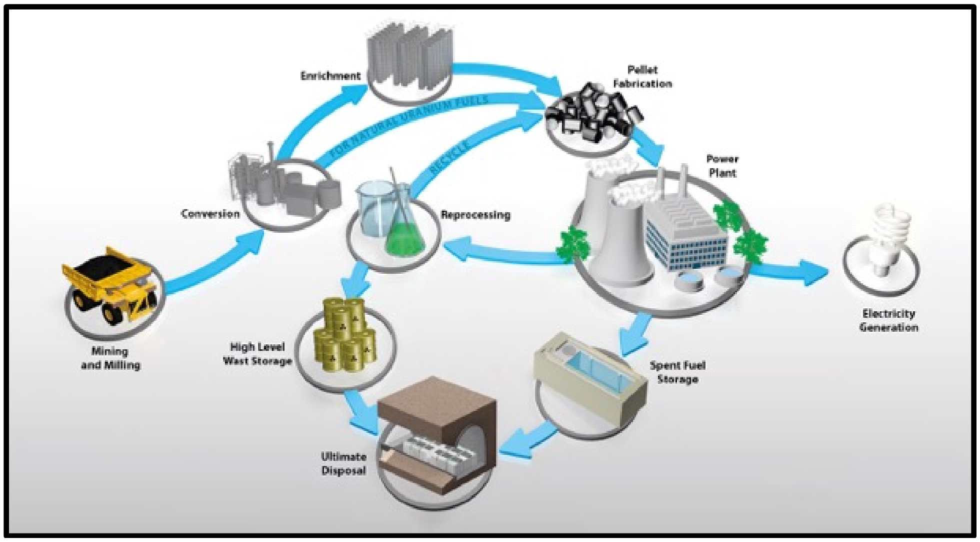
11. Fuel Cycle System Analysis



Description

ORNL has the expertise, experience, and toolset to provide advice, support, and analyses to industry and other stakeholders related to reactors and fuel cycle systems analysis. That includes:

- Economics
  - ORNL is the developers and custodians of the economics tool G4-ECONS, originally developed by the Generation IV Economic Modeling Working Group. The tool provides a lifecycle economics assessment and informs on risk, nuclear technologies, and associated fuel cycles. The integrated tool and capability includes the Capital/Production Cost Model (or Cost Model), Nuclear Fuel Cycle Model (or Fuel Model), Optimal Scale Model, and an Energy Products Model. Together with the guidelines “Cost Estimating Guidelines for Generation IV Nuclear Energy Systems”, G4-ECONS can facilitate consistent, comprehensive cost estimates for evaluation of advanced nuclear energy systems.
- Siting assessment
  - ORNL has developed a siting assessment tool and methodology—OR-SAGE (Oak Ridge Siting Analysis for power Generation Expansion)—which utilizes geographic information system data in addition to ORNL's LandScan, the world's most advanced population database. OR-SAGE examines millions of cells and simultaneously determines their suitability for various types of power generation, fuel cycle facility location, logistical/transportation evaluations, etc.
- Fuel cycle assessment
  - Working with the UK National Nuclear Laboratory, ORNL has coupled ORIGEN (the inventory calculation tool) to ORION, a dynamic fuel cycle simulator. This provides a rapid, accurate evaluation of the performance of any current or future fuel cycle, including the constraints on deployment and transition between fuel cycles and the associated economics. Examples of the application include evaluation of nuclear energy scenarios, investment profiles, evaluation of spent fuel management options, timescales to deployment, facility

throughput needs, material needs and availability constraints, resource requirements, etc.

- Hybrid energy systems
  - ORNL has developed a Modelica-based multiphysics model to simulate and analyze the dynamic integrated system response of tightly-coupled electrical and thermal power production systems.
- Safeguards technology, and concepts and approaches
  - *May not be needed, depending on scope covered above*

Relevance

With the development and pending deployment of advanced reactors and their associated fuel cycles, an evaluation of these fuel cycles economic, technical, non-proliferation, market, logistical, etc.) is needed. In addition, the transition from the current fuel cycle needs to be evaluated to assist in the decision-making process for investment, research priorities, logistics, deployment timescales, etc. The tools, expertise, an experience at ORNL enable a robust evaluation of the constraints and performance of future nuclear energy systems (reactors and/or fuel cycles).

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