Nuclear, Chemical, and Isotopic Science and Technology

Studying reaction pathways of chemical and nuclear systems.

Introduction

Research at Lawrence Livermore National Laboratory (LLNL) spanning nuclei formation to planetary evolution addresses our strategic deterrence and global security missions—including threat detection and diagnostics—and contributes to scientific advances in high explosives research, nuclear and particle physics, environmental radiochemistry, cosmochemistry, and forensic science.

Leveraging unique experimental and computational tools, we study nuclear reactions, the limits of nuclear stability, actinide behavior, chemical reactions of energetic compounds, and heavy-element chemistry. We also explore the evolution of our planet, our solar system, and our universe, from the creation of matter through the formation of the nuclei that comprise the periodic table.

Our leading-edge scientific research efforts provide the foundation for addressing these challenges. Our overarching strategy is to position LLNL at the nexus between fundamental nuclear and chemical science research and nuclear security applications. This approach will support efforts to recruit, train, and retain top-flight scientists and engineers who will play a key role in executing the Laboratory's core nuclear security missions, while also enhancing LLNL's reputation as a center for innovative scientific research.

Applications

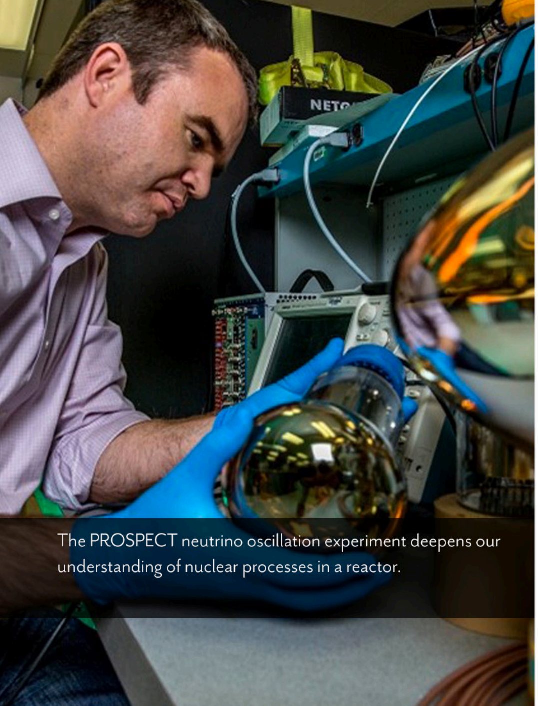
Chemical, nuclear, and isotopic science research directly benefits our national security mission by improving the safety and reliability of our strategic deterrence and enhancing our detection and attribution capabilities for special nuclear materials and nuclear detonations. Our unique isotopic analysis capabilities support LLNL's efforts to develop innovative climate change mitigation approaches.

Applications of nuclear, chemical, and isotopic expertise span the Laboratory:

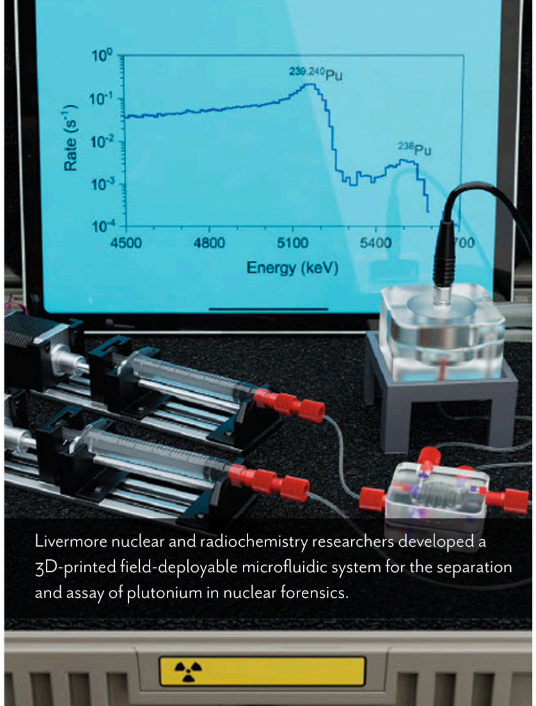
- Researchers are refining new isotopic markers to support carbon-neutral strategies and mitigate the impacts of climate change on water resources.
- Nuclear astrophysicists are developing new machine-learning tools to improve our understanding of nucleosynthesis and reduce uncertainties in nuclear data cross-sections to support strategic deterrence and nonproliferation.
- Particle physicists are launching a new effort for the Office of Science Nuclear Physics program that will unlock the mysteries of the elusive neutrino particle and help scientists better understand the evolution of our universe.
- Experts are creating novel detectors to determine material composition and to detect threats from a distance.
- Experimenters are developing a high intensity, tunable neutron source for radiography to better characterize a larger set of materials.

Examples of the specialized tools and facilities we use to perform our work include:

- The Nuclear Counting Facility, which supports research in stockpile stewardship, nonproliferation, and counter-terrorism by providing high-sensitivity radiation measurements using gamma spectrometers, solid-state detectors, alpha and beta counting systems employing ionization gas chambers, and liquid scintillation techniques.
- The Center for Acceleratory Mass Spectrometry, a signature facility that uses diverse analytical techniques and state-of-the-art instrumentation to develop and apply unique, ultra-sensitive isotope ratio measurement and ion beam analytical techniques to address a broad spectrum of scientific needs.
- LLNL's suite of imaging secondary ion mass spectrometry instruments, including a one-of-a-kind instrument with 10-nanometer spatial resolution, which are used to obtain trace element and isotopic information from solid samples in support of nuclear forensics, nonproliferation, cosmochemistry, and more.



The PROSPECT neutrino oscillation experiment deepens our understanding of nuclear processes in a reactor.



Livermore nuclear and radiochemistry researchers developed a 3D-printed field-deployable microfluidic system for the separation and assay of plutonium in nuclear forensics.

Cosmochemists received a tiny sample of the asteroid Ryugu to study the isotopic composition of stardust, nanometer to micrometer sized particles.

Accomplishments

Nuclear, chemical, and isotopic research at LLNL depends first and foremost on the capabilities of our scientific workforce, including staff, students, and postdoctoral researchers. We also take advantage of a wide array of mass spectrometry instruments for isotopic analysis as well as access to world-class high-performance computing capabilities.

These unique tools enable our scientists to maintain expertise across a wide range of topics, including frontier nuclear and particle physics, nuclear structure and reaction data, radiochemistry, nuclear detection technology and algorithms, nuclear and chemical forensic science, and environmental isotope systems.

Recent accomplishments include:

- Analyzing asteroid and lunar samples in order to understand the evolution of the solar system and support future exploration of the Moon.
- Developing a novel microfluidic platform for rapid radiochemical separations and measurements in a lab or in the field.
- Leading an international effort to develop a modern toolkit for storing and using evaluated nuclear reaction data, enabling higher-fidelity nuclear physics simulations and faster adoption of new data and techniques into nuclear science applications.
- Performing precision measurements of nuclear fission cross-sections for uranium and plutonium using a time projection chamber in the Neutron Induced Fission Fragment Tracking Experiment (NIFFTE) experiment.
- In particle physics, LLNL scientists have set new limits for the axion dark matter candidate with ADMX and for sterile neutrinos with the BeEST and PROSPECT experiments.
- Using findings from Large Hadron Collider experiments to better study the interactions of quarks and gluons in conditions resembling the first microsecond after the Big Bang.
- Reducing uncertainties in the proton capture of beryllium—a new milestone in combining first-principles theory calculations with experimental measurements in a unified treatment of nuclear structure and nuclear reactions.

LLNL-MI-859327
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
January 18, 2024

The Future

Scientists working in nuclear, chemical, and isotopic science and technology are addressing the next big challenges:

- Studying the origin of matter with the nEXO experiment, the nature of the proton at the Electron Ion Collider, and the origin of the nuclear elements at the Facility for Rare Isotope Beams.
- Expanding our knowledge of nuclei by further developing predictive theory for exotic nuclei and their reactions.
- Using artificial intelligence and machine-learning techniques to improve calibration and inference with nuclear data and fundamental nuclear theories.
- Leveraging the fastest high-performance computing architectures (exascale and beyond) to predict nuclear properties and to develop expertise in quantum computing platforms.
- Harnessing the unparalleled high-energy neutron flux at the National Ignition Facility to measure stockpile-relevant nuclear reaction cross-sections and develop a firm theoretical foundation for this research.
- Employing our novel microfluidic chemistry and detection system to perform the first aqueous chemistry experiments with Element 112 at the Lawrence Berkeley National Laboratory cyclotron.