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Nuclear Science & Technology April 2023 Highlights

June 2023

Addison Marie Arave

Changing the World's Energy Future

Idaho National Laboratory

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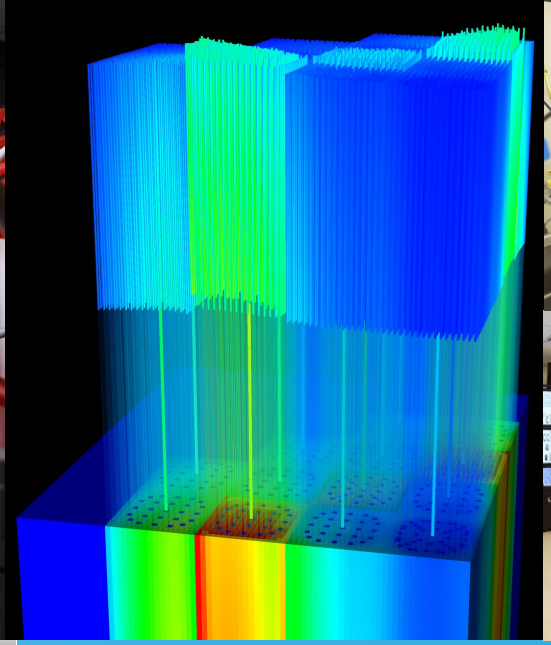

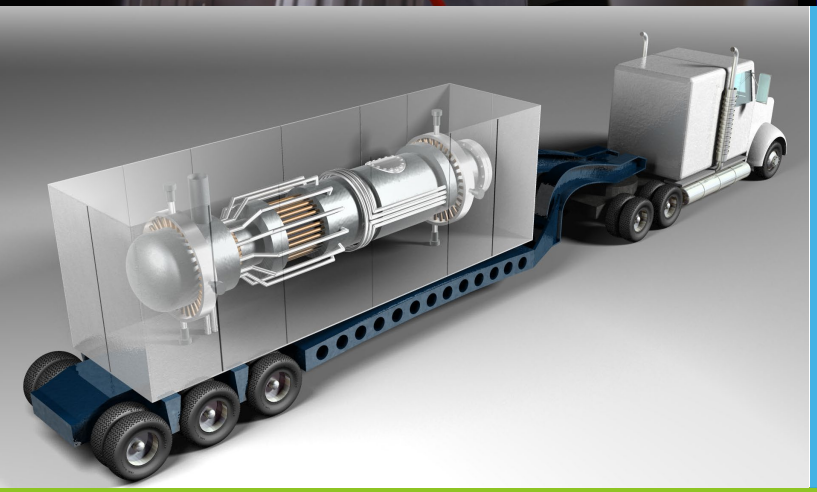

Nuclear Science & Technology

April 2023 Highlights

Idaho National Laboratory

INL Well-Represented at EarthX, Global Event Focused on Addressing Climate Change

- The EarthX Conference and Expo brings together environmentalists, scientists, and politicians to find solutions to climate change.
- Nuclear Science & Technology (NS&T) Associate Laboratory Director Jess Gehin spoke during a panel discussion focused on how advances in nuclear energy will be key to achieving a net-zero future.
- Integrated Energy & Storage Systems Division Director Shannon Bragg-Sitton spoke during a panel discussion about the latest breakthroughs in nuclear energy and barriers and challenges that still need to be addressed.
- INL also had a booth at the EarthX expo. Nuclear Research Communications Team Lead Tiffany Adams and Communications Specialist Alexis David met with a few hundred attendees, including Congressman Bill Foster (Illinois), educating them on the benefits of nuclear energy, research INL is conducting, and opportunities for them to be involved with INL.

Top left: Jess Gehin speaking during a panel discussion focused on advances in nuclear energy.

Top right: Tiffany Adams and Alexis Davis with Congressman Bill Foster.

Bottom: Shannon Bragg-Sittion speaking on a panel discussion about the latest breakthroughs in nuclear energy.

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Nuclear Energy Advanced Modeling and Simulation

Initial Developments Made in Modeling and Simulation of Molten Salt Reactors

- These modeling advances are focused on forming high-fidelity simulation tools for molten salt reactors (MSR) to improve reactor design and perform more accurate safety studies.
- Developed novel computational methods include:
  - Modeling depletion in MSRs with circulating nuclear fuel.
  - Modeling the chemical behavior and stability of fuel salt by coupling multiphysics simulations in MOOSE (Multiphysics Object-Oriented Simulation Environment) with a Gibbs Energy Minimizer (*Thermochimica*).
  - Modeling flow-accelerated corrosion by adding a Poisson-Nernst-Plank corrosion phenomena model to MOOSE.
  - Improving accuracy of thermal-hydraulics models of the reactor core by mapping high-fidelity models into lower-fidelity models.
- Future goals are to:
  - Build an integral modeling and simulation tool for improving the design and safety of MSRs.
  - Create a digital twin for MSRs.

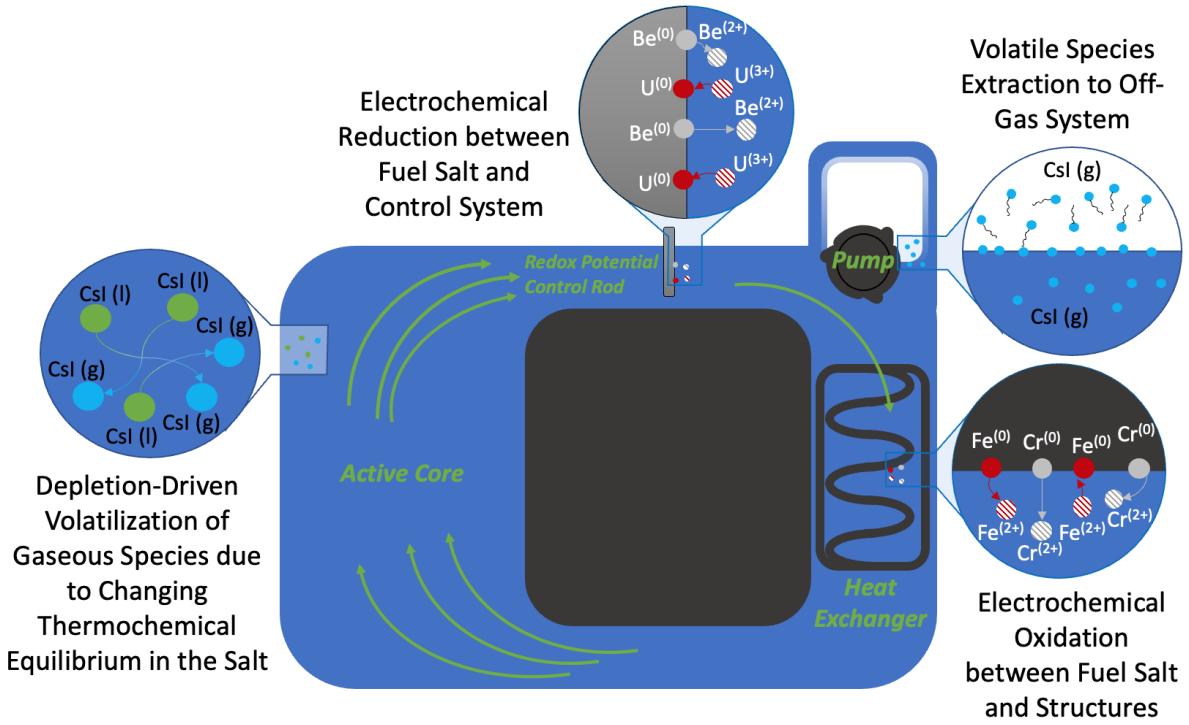

Illustration of the Coupling between the Reactor Physics and Thermochemistry in Molten Salt Reactors.

REACTOR SYSTEMS DESIGN & ANALYSIS | THERMAL FLUIDS SYSTEMS METHODS AND ANALYSES
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REACTOR SYSTEMS DESIGN & ANALYSIS | ADVANCED REACTOR TECHNOLOGY AND DESIGN
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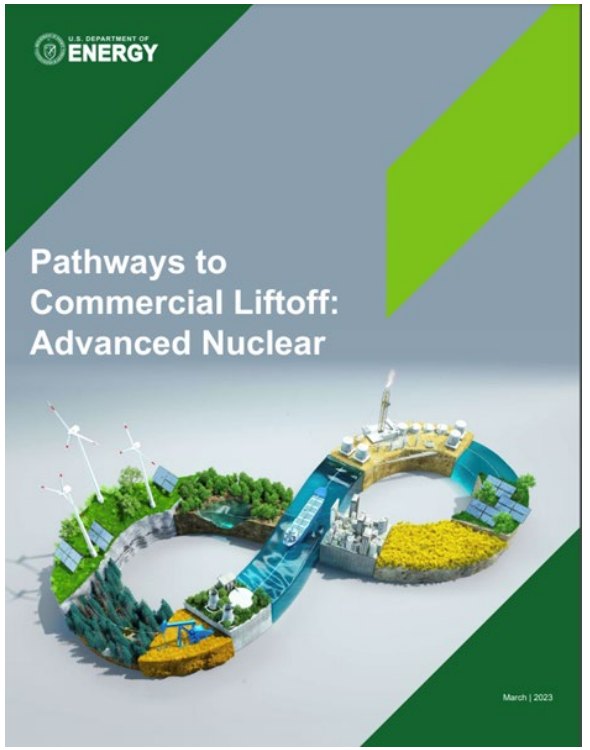
Department of Energy

Department of Energy Report Identifies Commercial Liftoff Paths for Advanced Nuclear

- This report is designed to help industry, investors, and stakeholders make decisions about the emerging technologies that are needed to slash greenhouse gas emissions by highlighting possible solutions to overcome barriers and achieve widespread commercialization.
- Domestic nuclear capacity in the United States has the potential to scale from ~100 GW in 2023 to ~300 GW by 2050—driven by deployment of advanced nuclear technologies.
- Advanced nuclear includes a range of proven and innovative technologies and provides a differentiated value proposition for a decarbonized grid.
  - Nuclear energy generates carbon-free electricity, provides firm power that complements renewables, has low land-use requirements, and has lower transmission requirements than distributed or site-constrained generation sources.
- An initial order book of 5–10 (likely) Generation III and Small Modular Reactors (SMRs) by 2025 would catalyze follow-on growth of the advanced nuclear industry.
- Andrew Foss, on detail assignment from INL to the DOE Office of Policy, worked closely with DOE colleagues to prepare this report.



Title: ***Pathways to Commercial Liftoff: Advanced Nuclear***
Authors: DOE Loan Programs Office, Office of Technology Transfer, Office of Nuclear Energy, Office of Clean Energy Demonstrations, Office of Policy, and Argonne National Laboratory
Link: doi.org/https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Advanced-Nuclear-vPUB.pdf

REACTOR SYSTEMS DESIGN & ANALYSIS | INTEGRATED ENERGY & MARKET ANALYSIS
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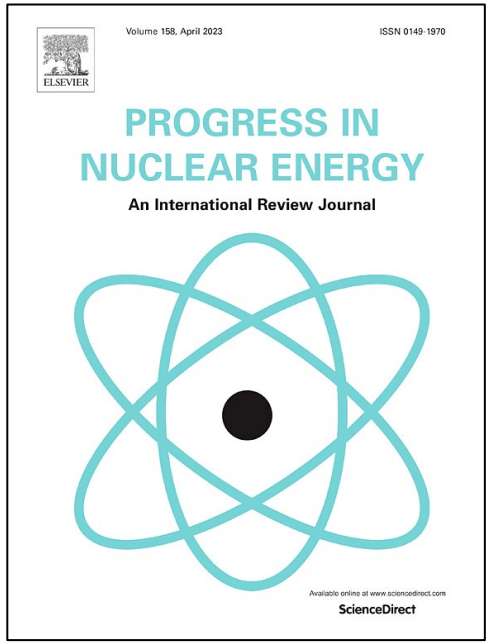
Advanced Reactor Technologies Program

Progress in Nuclear Energy Publishes a Special Issue on the Advanced Experiments for Small Modular Reactors Licensing Progression

- This Progress in Nuclear Energy special issue highlights the current research and development (R&D) experiments for Small Modular Reactors (SMR).
- The scope of the Research Topic of interest focuses on:
  - The integral and separate effects experiments for safety analysis
  - Synergistic approaches to reduce the time and cost of experimental studies
  - Exploring new materials for SMR design and development
  - Innovative methods and advanced manufacturing techniques
  - International joint experiments and shared data for rapid development.
- The special issue is still accepting manuscripts.



Progress in Nuclear Energy.

Title: Progress in Advanced Experiments for Small Modular Reactors Licensing
Link: https://www.sciencedirect.com/journal/progress-in-nuclear-energy/about/call-for-papers#progress-in-advanced-experiments-for-small-modular-reactors-licensing
Guest Editors: Palash K. Bhowmik (INL), Joshua P. Schlegel (Missouri S&T), Hibiki Takashi (City University of Hong Kong)

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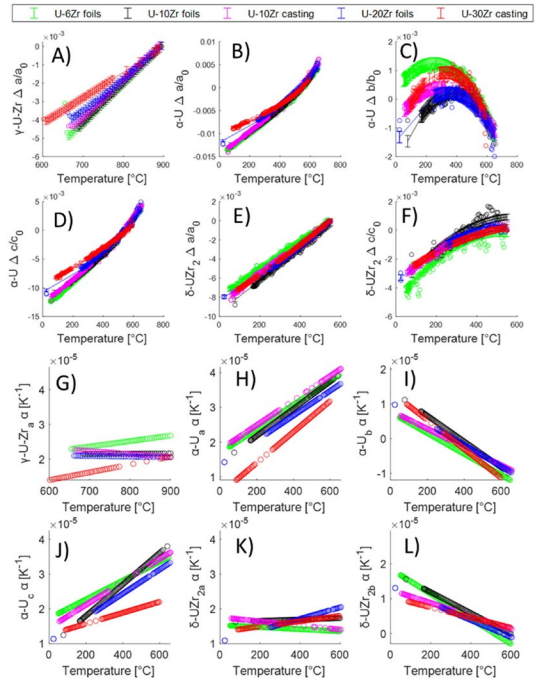
DOE-NE Nuclear Science User Facilities

Researchers Study U-Zr Alloys to Enable More Robust Nuclear Fuel Performance Codes

- The goal of this study was to provide information on the effect of changing temperature on unirradiated Uranium-zirconium (U-Zr) to aid in the characterization of irradiated samples.
- Researchers characterized the crystallographic evolution of U (6, 10, 20, and 30) wt.% Zr alloys during in situ cooling, determining phase transformations, phase fractions, thermal expansion coefficients and site occupancy.
- The samples in this study are excess material from the Nuclear Science User Facilities (NSUF) Disc Irradiation for Separate Effects Testing with Control of Temperature project.
- This research was supported through an NSUF access award and the Advanced Fuels Campaign.



The lattice strain evolution and parameter-specific curves.

Title: Phase transformations and thermal expansion coefficients of unirradiated U-X wt.% Zr (X = 6, 10, 20, 30) measured via neutron diffraction
Authors: W.J. Williams (INL), S.C. Vogel (Los Alamos National Laboratory), M. A. Okuniewski (Purdue University).
Journal: Journal of Nuclear Materials
Link: doi.org/10.1016/j.jnucmat.2023.154380

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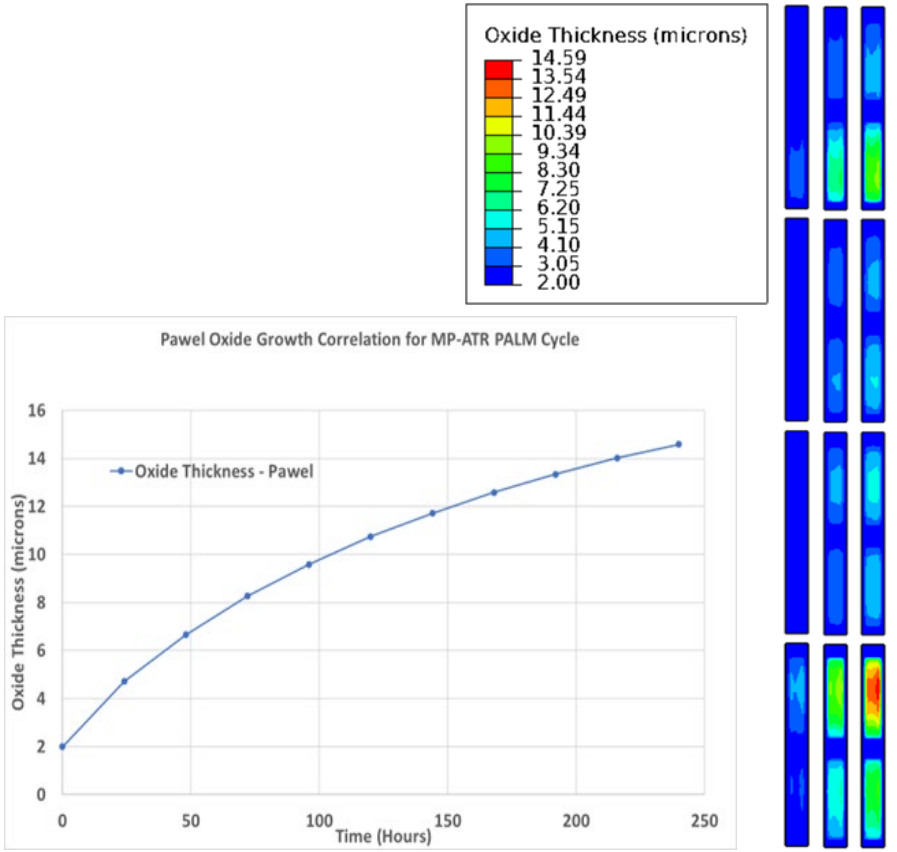
NSUF Nuclear Science User Facilities

Advanced Reactor Technologies Program

Transient Modeled Oxide Growth During an Advanced Test Reactor (ATR) Powered Axial Locator Mechanism (PALM) Cycle

- The Mini-Plate for Advanced Test Reactor (MP-ATR) is a fueled experiment being irradiated during a high-power ATR Powered Axial Locator Mechanism (PALM) cycle.
- A PALM cycle occurs when the irradiation cycle utilizes the PALM to change the axial position of different experiments to simulate different reactor conditions.
- A PALM cycle in ATR is typically run at higher reactor power and increased coolant pressure than normal cycles.
- The MP-ATR high-power experiment required the use of the Pawel correlation, which predicts oxide growth on aluminum-clad fuel plates with high surface heat flux and surface temperature conditions. This is due to it having a built-in sensitivity to heat flux and the ability to accommodate higher heat flux ranges than other correlations.
- This work resulted in increased confidence for using the Pawel correlation for the specific purpose of predicting oxide for aluminum-clad fuel plates during an ATR PALM cycle for the MP-ATR experiment.



Oxide thickness for the MP-ATR experiment at 24 Hours, 120 Hours, and 240 Hours.

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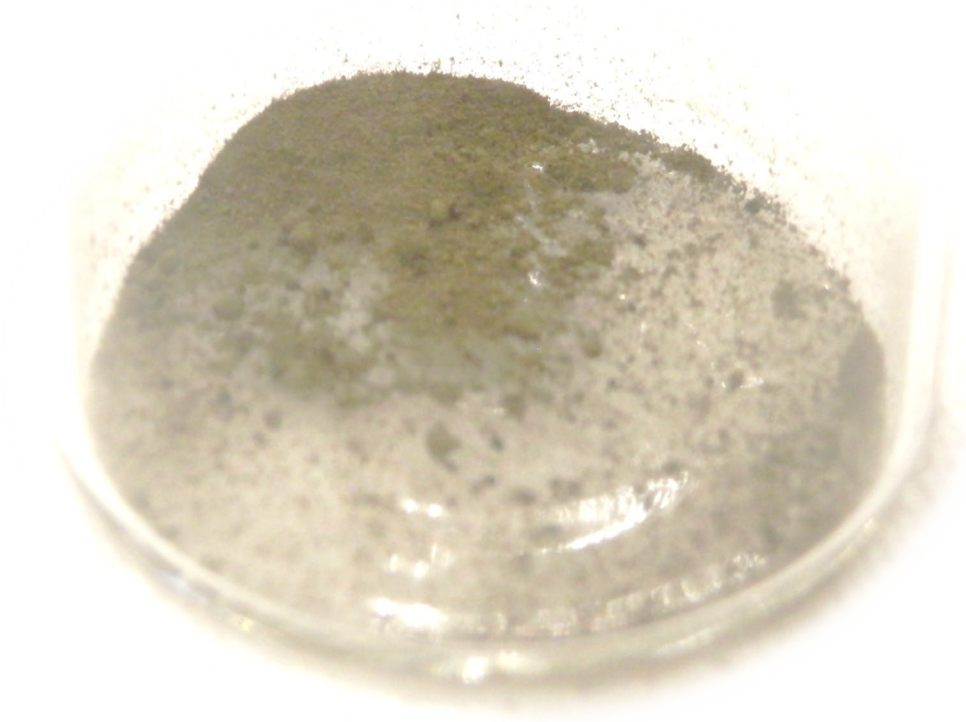
Research Highlight

US-DOE Office of Nuclear Energy Material Recovery and Waste Form Development Campaign

In Situ Down-Blending of Highly Enriched Fuel Demonstrated at the Material Recovery Pilot Plant

- The completion of this first-of-its-kind milestone is an important step in the development of the high assay low enriched uranium (HALEU) supply for advanced reactor programs.
- The Material Recovery Pilot Plant (MRPP) has successfully demonstrated first of a kind in situ down-blending of HEU during the zirconium removal prior to extraction process (ZIRCEX) to produce uranium oxide with a U-235 enrichment in the range 20%–30%.
- A 6 kg piece of HEU fuel was loaded, along with depleted uranium (DU) pellets. These were subjected to hydrochlorination to declad the fuel piece, and subsequent oxidation of the fuel meat and DU pellets.
- Future MRPP operations will focus on continued refinement of this process.



Sample of down-blended UOx product from the MRPP.

Fuel Cycle Science & Technology | Aqueous Separations and Radiochemistry
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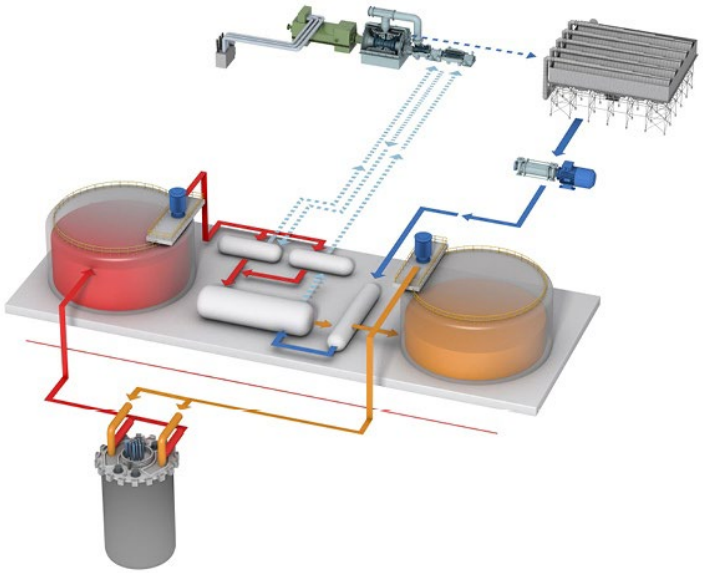
DOE-NE Advanced Reactor Demonstration Program

TerraPower Hosts INL Subject Matter Experts for Natrium Reactor Phase 2 Design Review Meeting

- The March 28–31 TerraPower Natrium Phase 2 Design Review Meeting featured an external review in preparation for their preliminary safety analysis report submittal later this year.
- INL and TerraPower are strategic partners for the Natrium project.
- The meeting included subject matter experts from:
  - Idaho National Laboratory (INL)
  - Argonne National Laboratory (ANL)
  - Pacific Northwest National Laboratory (PNNL)
  - Commercial nuclear industry partners
- Reviewed systems included thermal hydraulics (TH) for the core, reactor vessel auxiliary cooling system, nuclear island, software commercial grade dedication, software validation plan, and product lifecycle management system.
- An INL modeling and simulation engineer and the RELAP5-3D Program Manager participated in the event. They performed the:
  - Core TH review
  - Modeling requirements and software documentation review.



Overview of Natrium Nuclear Power Plant integrated with Molten-Salt Thermal Storage System.

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DOE-NE Light Water Reactor Sustainability Program - Cooperative Research and Development Agreement with Constellation Energy Generation

Preliminary Validation Report Submitted to the Nuclear Regulatory Commission for Limerick Safety-Related Instrumentation and Control Upgrade Human-System Interfaces

- In collaboration with Constellation, Westinghouse and CORYS, INL prepared a near-full scope simulator and coordinated the execution of Preliminary Validation (PV) during the week of February 20, 2023.
  - This included an evaluation of human-system interfaces that support manual operator actions impacted by the safety-related digital instrumentation and control upgrade project scope.
  - Four Nuclear Regulatory Commission (NRC) auditors and the Department of Energy (DOE) program lead for this effort were in attendance.
- INL, working with Constellation, finished the PV report in late March 2023.
  - This enabled Constellation to meet its March 30, 2023 NRC License Amendment Request (LAR) commitment to submit this report.
- All project Human Factors Engineering NRC LAR submittal commitments were met on or before the original schedule dates.

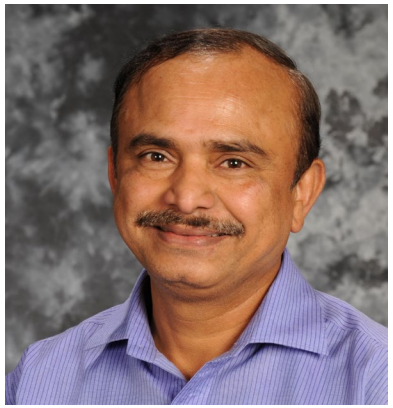
Limerick Generating Station

Human-system interface preliminary validation with Limerick, INL, DOE, and NRC audit personnel at the INL Human-Systems Simulation Laboratory.

Department of Energy Technology Commercialization Fund

Prabhat Tripathy, Michael Shaltry, and David Estrada Awarded Patent for Work in Sensors for Harsh Environments

- The U.S. Patent and Trade Office has awarded a patent to two Nuclear Science & Technology employees and a Boise State University employee under a collaborative effort funded by the Department of Energy Technology Commercialization Fund.
- This invention represents a significant advancement in the ability to manufacture sensors for use in molten salts for advanced reactor environments, as well as other applications.
- The new advanced manufacturing process has shown the ability to fabricate a miniaturized three-electrode (also known as microelectrode) on a suitable substrate.
- The manufacturing process involves printing a three-electrode with an electrically conductive metallic ink on a ceramic material, such as vitreous carbon.
- The printed electrode has been demonstrated experimentally in a eutectic LiCl-KCl to effectively provide electrochemical measurements.



Prabhat Tripathy (INL), Michael Shaltry (INL), and David Estrada (BSU).

Title: METHODS FOR MANUFACTURING ELECTROCHEMICAL SENSORS, AND RELATED ELECTROCHEMICAL SENSORS, US11,635.404B2) on April 25, 2023.
Authors: M.R. Shaltry, P.K. Tripathy and D. Estrada,
Funding: DOE Technology Commercialization Fund

FUEL CYCLE SCIENCE & TECHNOLOGY
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Dr. George Mesina Appointed to Master's Committee at Idaho State University

- In January of this year, George Mesina, Ph.D., was appointed as a member of the advisory committee for a Master's degree candidate in the Nuclear Engineering Department at Idaho State University (ISU).
- ISU is a member of the INL Center for Advanced Energy Studies (CAES) research and education consortium.
- Dr. Mesina is a lead developer and code architect for the INL RELAP5-3D system code.
- This appointment supports modeling and simulation software validation for a Modular High Temperature Gas-cooled Reactor (MHTGR) during the depressurization initiated by a leak in the MHTGR piping.
- Mesina is Vice Chair for the American Society of Mechanical Engineers (ASME) Power Division and previously served as Technical Program Chair for the ASME Power 2020 and 2021 conferences.
- Mesina has a Ph.D. in applied mathematics and extensive experience in computational fluid dynamics, thermal hydraulics and computer science.

INL scientist and newly appointed ISU master's committee member, George Mesina.

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Nuclear Fuels and Materials

Kyle Gamble and Vaibhav Yadav Selected as Lecturers for the 2023 Frédéric Joliot & Otto Hahn Summer School

- The Frédéric Joliot & Otto Hahn (FJOH) summer school is co-organized by the French Alternative Energies and Atomic Energy Commission (France) and the Karlsruhe Institute of Technology (Germany).
- The 2023 school will be held August 23–September 1, 2023, in Karlsruhe, Germany, with a theme of “Digital Twins: New Horizons in Nuclear Reactor Design and Optimization.”
- Gamble is a computational scientist in the Computational Mechanics and Materials department and a developer of the BISON fuel performance code. His lecture will be in the area of “Nuclear Fuel Element Simulations Towards the use of Digital Twins.”
- Yadav is a senior scientist in the department of Instrumentation, Controls, and Data Science. His lecture will be in the area of “Regulatory Aspects of Digital Twin Application in Nuclear.”

Computational Scientist, Kyle Gamble.

Senior Scientist, Vaibhav Yadav.

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Simon Pimblott Elected Vice Chair of American Nuclear Society Division

- Simon Pimblott has been elected Vice Chair of Materials Science & Technology Division of the American Nuclear Society (ANS). He will also be the Chair Elect of the division.
- The ANS is the largest professional society for the nuclear field and boasts more than 10,000 members.
- Pimblott is currently the Nuclear Science User Facilities chief scientist and deputy director of the Energy Frontier Research Center on Molten Salts in Extreme Environments.
- He has over 35 years of scientific and leadership experience in the field of nuclear energy science and engineering supported by the Department of Energy Office of Nuclear Energy and Office of Basic Energy Sciences, as well as the U.K. Nuclear Decommissioning Authority.
- He has an established record of performing world-leading, innovative, and paradigm-shifting research recognized both in the U.S. and internationally.

Newly elected ANS Vice Chair of Materials Science & Technology division, Simon Pimblott.

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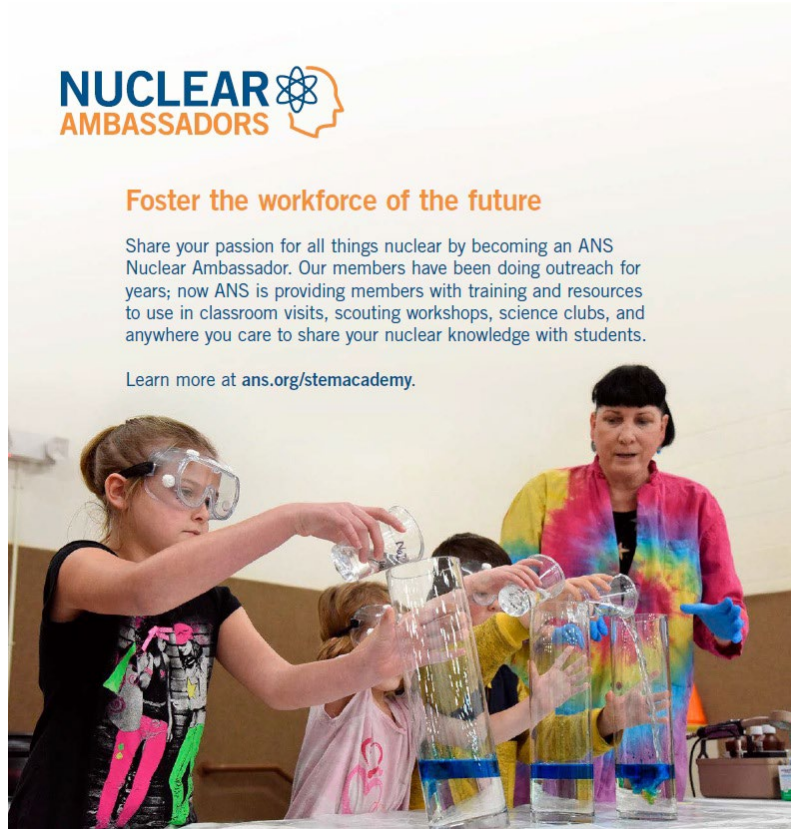
Nuclear Science & Technology STEM Efforts Continue to Garner National Recognition

- The efforts of NS&T employee Catherine Riddle have been recognized recently by the American Nuclear Society in a full-page advertisement in the March issue of *Nuclear News.*
- This ad features Riddle's work with young students in her ongoing mission to engage young minds in the world of science and engineering.
- Riddle is a senior research scientist with expertise in radiochemistry and radiochemical separations. She volunteers her time working with INL's K-12 Education Enrichment Programs.
- Riddle has 14 patents and patents pending for her work in Nuclear Science & Technology and Energy and Environment Science & Technology. Her Colorimetric Detection of Actinides (CoDeAc) technology received an R&D 100 Award and has been commercialized as the new company CoDeAc Solutions, Inc.
- Riddle was recently honored with the INL Director's Award for Inventor of the Year.



Full Page Advertisement in Nuclear News, March 2023.

FUEL CYCLE SCIENCE & TECHNOLOGY
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Dr. Mauricio Tano Appointed Adjunct Professor at North Carolina State University

- In January of this year, Mauricio Tano, Ph.D., was appointed to the position of Adjunct Professor in the Nuclear Engineering Department at North Carolina State University (NCSU).
- NCSU is a member of the INL National University Consortium.
- Dr. Tano is a modeling and simulation developer/analyst for INL multiphysics, computational fluid dynamics and system codes.
- This appointment supports software development that will improve modeling accuracy of the INL's RELAP5-3D and MOOSE Pronghorn computer codes.
- Tano is a committee member for two Ph.D. candidates at Texas A&M University and one Ph.D. candidate at Oregon State University.
- Tano is also co-mentoring a Ph.D. candidate—a 2024 INL Fellow—with NCSU Professor Yousry Azmy.

INL researcher and newly appointed NCSU adjust professor, Mauricio Tano.

Mauricio.TanoRetamales@inl.gov

Publications

- A. Cheniour, E. Davidson, Y. Le Pape, T. Pandya, B. Collins, B. Spencer, A. Godfrey, M. Asgari. 2023. "A structural model of the long-term degradation of the concrete biological shield." NUCLEAR ENGINEERING AND DESIGN. Vol. 405. https://doi.org/10.1016/j.nucengdes.2023.112217.
- A. Weiss, L. Zaidan, M. Bani Ahmad, M. Gomaa Abdoelatef, J. Peterson, A. Lindsay, F. Kong, K. Ahmed, M. Kimber. 2023. "Characterization of the Finite Element Computational Fluid Dynamics Capabilities in the Multiphysics Object Oriented Simulation Environment." JOURNAL OF NUCLEAR ENGINEERING AND RADIATION SCIENCE. Vol. 9. https://doi.org/10.1115/1.4054685.
- C. Smith, J. Jue, T. Trowbridge, D. Keiser, J. Madden, A. Robinson, J. Giglio. 2023. "Possible impacts of Mo chemical banding and second phase impurities on the irradiation behavior of monolithic U-10Mo fuels." JOURNAL OF NUCLEAR MATERIALS. Vol. 576. https://doi.org/10.1016/j.jnucmat.2023.154264.
- E. Eidelpes, J. Jarrell, T. Lister, G. Horne, E. Parker-Quaife, J. Conrad, C. Pilgrim, A. Abboud, P. Winston, R. Smith, A. d'Entremont, B. Randall, R. Sindelar. 2023. "Technical basis for extended dry storage of aluminum-clad spent nuclear fuel." JOURNAL OF NUCLEAR MATERIALS. Vol. 577. https://doi.org/10.1016/j.jnucmat.2023.154299.

Publications

- F. Di Lemma, T. Yao, D. Salvato, L. Capriotti, F. Teng, A. Jokisaari, B. Beeler, Y. Wang, C. Jensen. 2023. "Microstructural and phase changes in alpha uranium investigated via in-situ studies and molecular dynamics." JOURNAL OF NUCLEAR MATERIALS. Vol. 577. https://doi.org/10.1016/j.jnucmat.2023.154341.
- G. Gall, C. Lau, V. Varma, S. Cetiner, D. Ottinger. 2023. "Measurement of a radial flow profile with eddy current flow meters and deep neural networks *." MEASUREMENT SCIENCE AND TECHNOLOGY. Vol. 34. https://doi.org/10.1088/1361-6501/acaf14.
- J. Jiang, J. Stempien, Y. Wu. 2023. "Catalyzed oxidation of nuclear graphite by simulated fission products Sr, Eu, and I." JOURNAL OF NUCLEAR MATERIALS. Vol. 576. https://doi.org/10.1016/j.jnucmat.2023.154255.
- K. Chen, P. Tripathy, K. Mondal, H. Zhang, A. Couet, J. Andrews. 2023. "Solution Processed Schottky Diodes Enabled by Silicon Carbide Nanowires for Harsh Environment Applications." Nano Letters. Vol. 23. https://doi.org/10.1021/acs.nanolett.3c00112.
- P.K. Bhowmik, S. Usman, J.P. Schlegel. “Film condensation with high heat fluxes and scaled experiments using pure steam for reactor containment cooling,” Applied Thermal Engineering, Volume 229, 2023, 120610, ISSN 1359-4311. https://doi.org/10.1016/j.applthermaleng.2023.120610.

Publications

- R. Kile, A. Epiney, N. Brown. 2023. "High Temperature Test Facility sensitivity and calibration studies to inform OECD-NEA benchmark calculations." NUCLEAR ENGINEERING AND DESIGN. Vol. 404. https://doi.org/10.1016/j.nucengdes.2023.112178.
- S. Paul, D. Schwen, M. Short, K. Momeni. 2023. "A Modified Embedded-Atom Method Potential for a Quaternary Fe-Cr-Si-Mo Solid Solution Alloy." Materials. Vol. 16. https://doi.org/10.3390/ma16072825.
- W.J. Williams (INL), S.C. Vogel (Los Alamos National Laboratory), M. A. Okuniewski (Purdue University). “Phase transformations and thermal expansion coefficients of unirradiated U-X wt.% Zr (X = 6, 10, 20, 30) measured via neutron diffraction,” Journal of Nuclear Materials, Vol. 579 https://doi.org/10.1016/j.jnucmat.2023.154380.
- Y. Wang, B. Beeler, A. Jokisaari. 2023. "An atomistic study of fundamental bulk and defect properties in alpha-uranium." JOURNAL OF NUCLEAR MATERIALS. Vol. 576. https://doi.org/10.1016/j.jnucmat.2023.154289.

Patents

- M.R. Shaltry, P.K. Tripathy and D. Estrada, “Methods For Manufacturing Electrochemical Sensors And Related Electrochemical Sensors”, US11,635.404B2, April 25, 2023, https://patentcenter.uspto.gov/applications/16840102.