INL/MIS-22-70629-Revision-0

November 2022 NS&T Highlights

December 2022

Changing the World's Energy Future

Addison Marie Arave

Idaho National Laboratory

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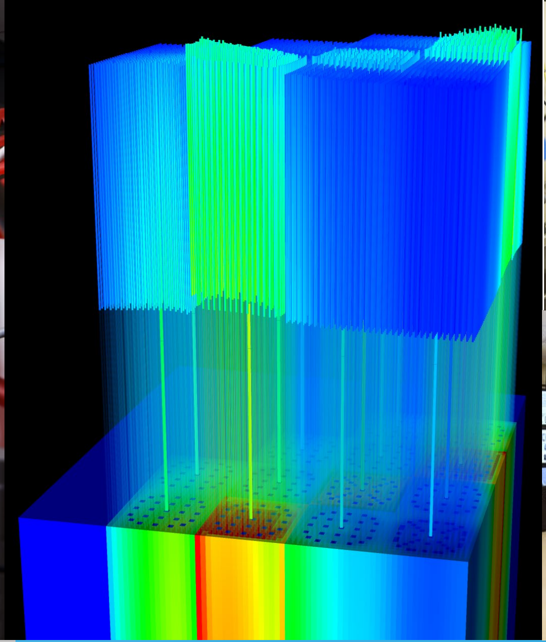
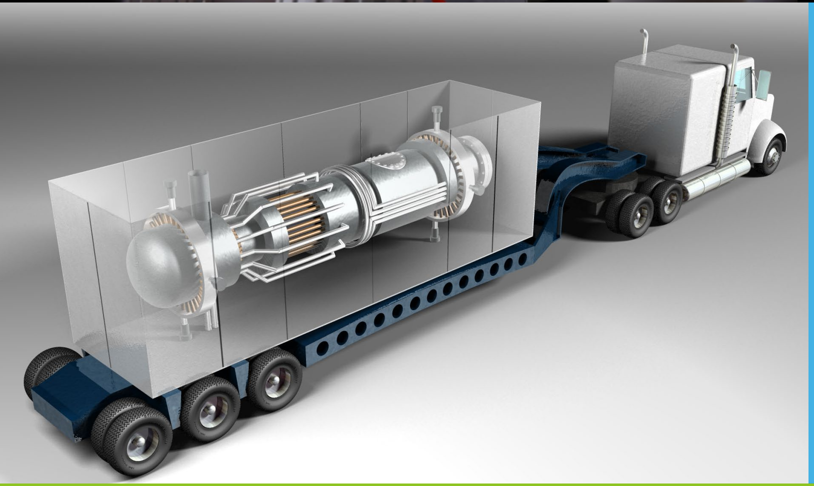
Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517



Nuclear Science & Technology

November 2022 Highlights

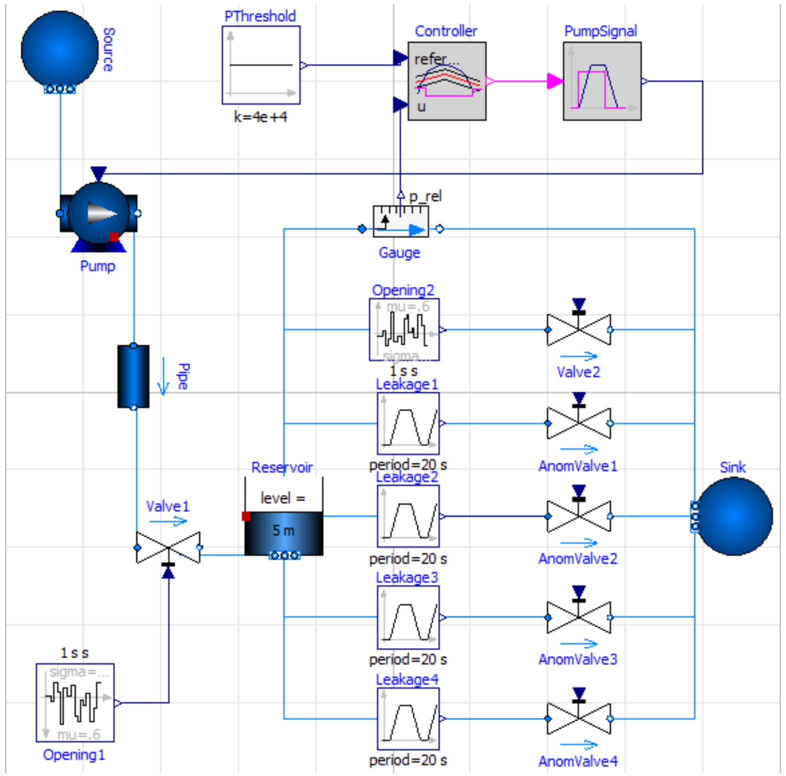
Idaho National Laboratory

Research Highlight

DOE-NE Light Water Reactor Sustainability Program

Data Obfuscation Method For Sharing Nuclear Plant Data Successfully Tested

- One cause of disconnect between nuclear power utilities (that own significant quantities of data) and research organizations (that develop methods based on synthetic data) is data privacy.
- Methods for data-masking exist, such as substitution, shuffling, and encryption, but they impact data characteristics that need to be maintained for the data to be analyzed properly.
- The Light Water Reactor Sustainability Program created a new method called deceptive infusion of data (DIOD), which replaces some of the fundamental physics of the data with generic data to fully hide the data source. This data fusion is performed in a manner that does not impact the data useability in machine learning methods.
- Two use cases were used to evaluate DIOD performance. One targeted a physics-based model, and the other targeted a process model that resembles a nuclear power utility process. Both demonstrated successful achievement of data obfuscation objectives while maintaining the needed features for analysis.



DIOD was used to obfuscate data from a process representing nuclear power plant data by merging them with data from another generic process. The research showed that the original data were not recoverable, and that the fusion did not impact the ability to analyze it because the leakage anomalies were still detectable.

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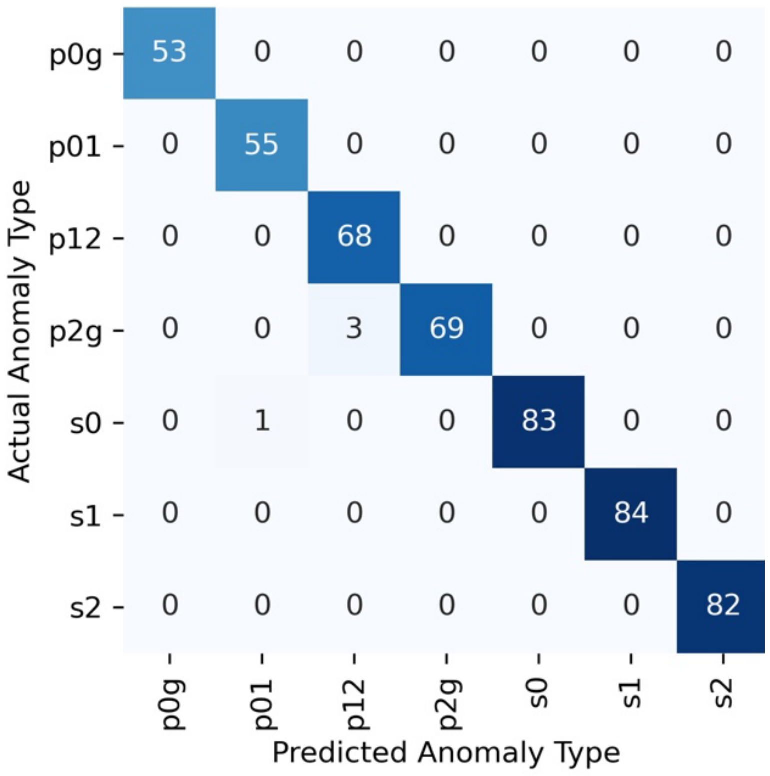
LWRS LIGHT WATER REACTOR SUSTAINABILITY

IDAHO NATIONAL LABORATORY

DOE-NE Light Water Reactor Sustainability Program

Novel Methods Developed to Assist Nuclear Plant Operators in Identifying the Causes of Anomalies

- Since alarms may provide insufficient lead time for nuclear power plant staff to react, anomaly detection methods could help plants prevent them from escalating into unexpected equipment failures.
- To aid operators in analyzing anomalies and preventing unexpected outages, the Light Water Reactor Sustainability Program has been investigating machine learning methods for automated anomaly detection based on time-series data.
- Once anomalies are detected, determining their causes can be a labor-intensive process, made more difficult by the size and complexity of nuclear power plant systems.
- This research used both synthetic data and data from a collaborating nuclear utility to demonstrate two methods of determining the causes of anomalies based on the assumptions that the sensors or processes causing them are usually the largest contributors and that the sensors or processes causing them show abnormal signs before other sensors and processes.



Results from the synthetic data showed that the causes (types) of most events were correctly identified using data-driven methods.

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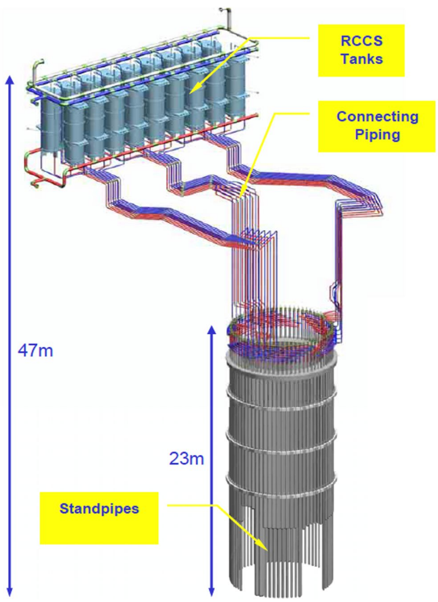
DOE-NE Advanced Reactor Technologies Program

Data Analytics to Inform Advanced Reactor Design and Operation

- INL has been working in collaboration with X-energy and Electric Power Research Institute on the development of data analytics methods designed to inform the design and operation of advance reactor systems that can be highly reliable and cost effective.
- This project targets the establishment of the Reliability and Integrity Management program which establishes how plant systems and components will be monitored and maintained to ensure the plant's safety.
- The developed data analytics methods are designed to identify optimal system designs and lifecycle strategies (e.g., type and frequency of surveillance, testing, and inspection activities; maintenance; expected replacement time). The goal is to balance system availability levels, operation and maintenance costs, and investment protection under regulatory constraints.
- This project employed INL developed codes Risk Analysis Virtual ENvironment and SR2ML. This work was presented at the "November 2022 American Society of Mechanical Engineers Boiler Code Week" in Pittsburgh) and a follow up is set in 2023 in collaboration with Japan Atomic Energy Agency.



Schematic of Reactor Cavity Cooling System (RCCS), a system used as a pilot to demonstrate data analytics methodology for optimization of system monitoring.

Title: Reliability and Integrity Management Program Implementation Approach
Authors: D. Mandelli, T. Anselmi, C. Smith, S. Lawrence, C. Otani
Link: https://www.osti.gov/servlets/purl/1895355

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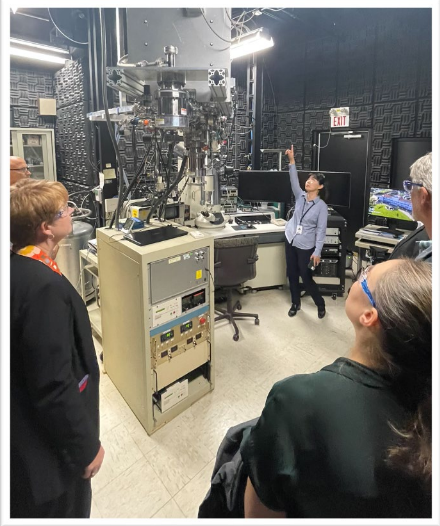
Program Highlight

Gateway for Accelerated Innovation in Nuclear visits Argonne National Laboratory and Scot Forge

- In early November, Gateway for Accelerated Innovation in Nuclear (GAIN) toured Argonne National Laboratory research facilities with advanced reactor industry representatives. GAIN’s Christine King, Hussein Khalil, and Emily Nichols hosted industry partners from Alpha Tech, NuScale, Kinectrics, Framatome, TerraPower, BWXT, and Lightbridge during the visit.
- The GAIN team and industry partners also visited Scot Forge in Spring Grove, Illinois which produces some of the largest forgings in the United States.
  - GAIN toured the 350,000-square-foot production plant and learned about the capabilities for forged materials in the nuclear industry.



Top: Industry & GAIN team at ANL’s Mechanism Engineering Test Loop Lab.
Right: ANL's Meimei Li gives a tour of the Intermediate Voltage Electron Microscope.
Bottom: A ring-rolled forged component glows as it cools in the Scot Forge facility.
Left: Members of the Scot Forge team.

Nuclear Science and Technology

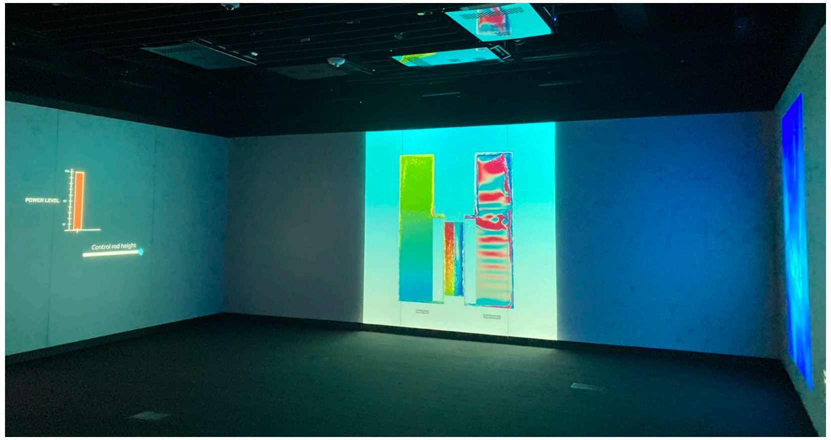
INL has Strong Participation in American Nuclear Society's Expo

- GAIN teamed up with the National Reactor Innovation Center to share an exhibit at the 2022 American Nuclear Society Winter Meeting and Technology Expo November 13–17 in Phoenix, Arizona.
- The annual expo drew close to 1,000 registrants and 29 exhibitors. Sessions included nuclear waste management, digital twin applications in nuclear, and machine learning applications in thermal hydraulics.
- More than 60 INL staff attended, including Associate Lab Director for Nuclear Science and Technology, Jess Gehin, who was invited to participate in the plenary panel. INL staff chaired and presented at more than 30 panel discussions and technical sessions.

Teresa Krynicki, administrative assistant for GAIN, greeted participants at the GAIN and NRIC booth during the 2022 ANS Winter Meeting and Technology Expo.

Advanced Test Reactor, Dry Cask, and Simulation Visualizations Featured at Stein Luminary

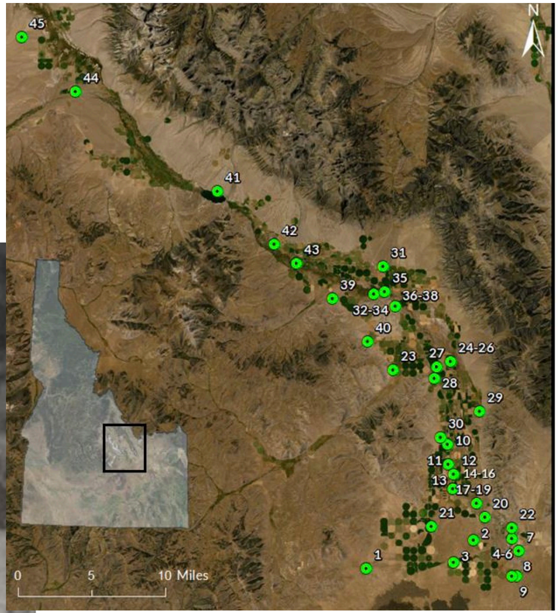
- The Keith and Catherine Stein Luminary at Boise State University is an all-digital museum space with touch-activated glass walls that provide an immersive and interactive experience for visitors.
- On November 17, Stein Luminary hosted an Industry Advisory Board Meeting for the Center for Atomically Thin Multifunctional Coatings.
- INL Visualization Laboratory developed a set of three-dimensional visualizations that highlighted INL capabilities.
- Rajiv Khadka, Nathan Woods, Xingyue Yang, and John Koudelka were involved in creating, assembling, and presenting the content.



The Stein Luminary has three digital walls where INL capabilities were displayed for users to interact with.

Robert Podgorney to Serve on the State of Idaho Modeling Technical Advisory Committee

- Representatives from the Idaho Department of Water Resources requested Chief Computational Scientist Robert Podgorney to serve in an oversight capacity for an upcoming groundwater modeling assessment.
- In this role, Podgorney will guide the development of a groundwater flow model of the Big Lost River Basin by the United States Geological Survey.
- The Big Lost River Basin encompasses an area from the Mackay Reservoir to the town of Arco, Idaho.



A map showing the location for the Big Lost River Basin Groundwater Assessment Model (above) and Robert Podgorney (left) who will assist with its oversight.

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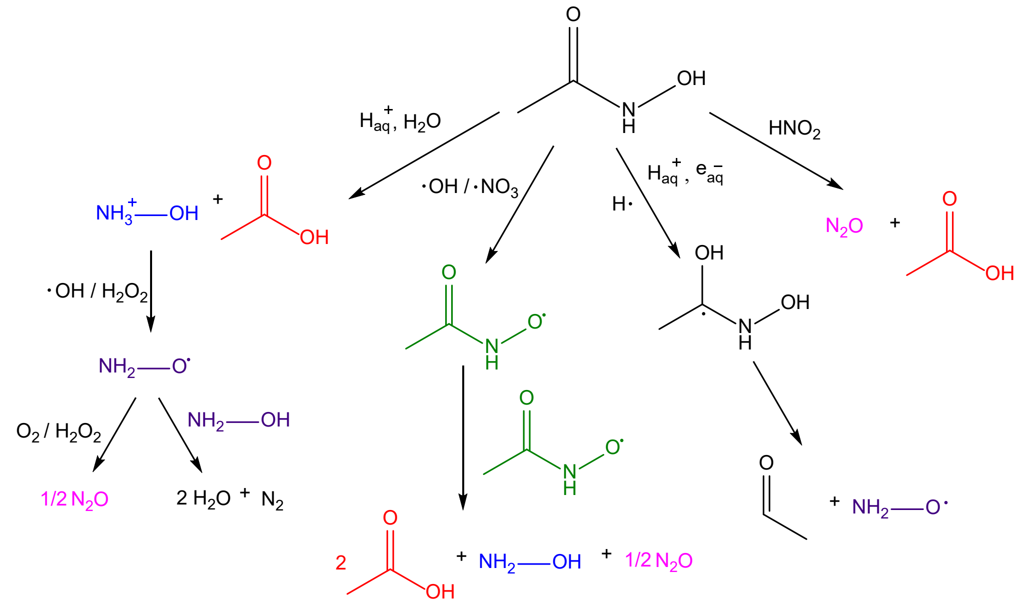
DOE-NE Material Recovery and Waste Form Development Campaign

First Chemical Model to Accurately Describe Acetohydroxamic Acid Degradation Developed

- INL researchers have developed the first multiscale model that accurately predicts acetohydroxamic acid (AHA) chemistry essential to advancing the science of nuclear fuel reprocessing.
- AHA is proposed for use in used nuclear fuel reprocessing cycles for the reduction and complexation of plutonium and neptunium ions for uranium product stream purification.
- This work provides a fundamental framework of degradation pathways essential to understanding AHA chemistry in radiation environments.



Title: Multiscale modelling of the radical-induced chemistry of acetohydroxamic acid in aqueous solution
Authors: Jacy K. Conrad, Corey D. Pilgrim, Simon M. Pimblott, Stephen P. Mezyk, and Gregory P. Horne
Journal: RSC Advances
Link: doi.org/10.1039/D2RA03392E

NUCLEAR SCIENCE & TECHNOLOGY | CENTER FOR RADIATION CHEMISTRY RESEARCH
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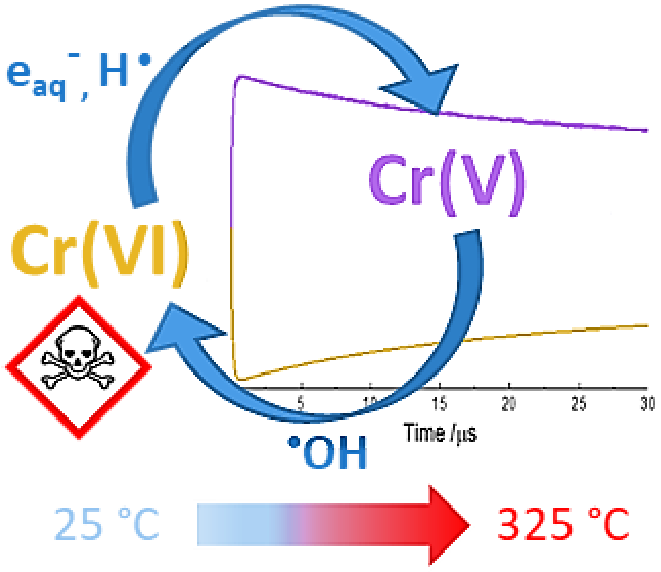
DOE Office of Basic Energy Sciences

New Kinetics Discovered for High Temperature Radiation-Induced Reduction of Chromium in Toxic Solutions

- INL researchers have significantly advanced the understanding of the behavior of highly toxic hexavalent chromium (Cr[VI]) found in industrial wastewaters as a leachate from stainless steels. This development will support advances in the treatment and remediation of industrial wastewaters.
- Electron pulse radiolysis using the Notre Dame Radiation Laboratory Linear Accelerator was employed to measure chemical kinetics for the reactions of Cr(VI) with water radiolysis products up to 325°C.
  - These new findings can be incorporated into models of chromium speciation under these extreme conditions.



NOTRE DAME RADIATION LABORATORY

Title: Pulse Radiolysis and Transient Absorption of Aqueous Cr(VI) Solutions up to 325 °C
Authors: Jacy K. Conrad, Aliaksandra Lisouskaya, David M. Bartels
Journal: ACS Omega
Link: doi.org/10.1021/acsomega.2c04807

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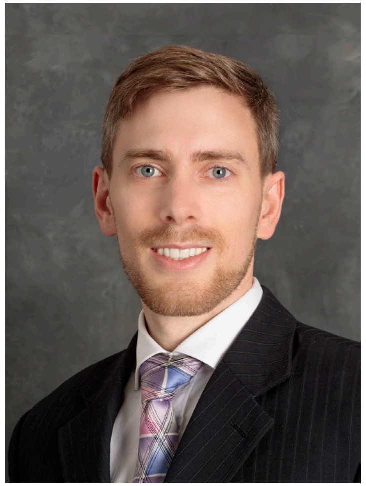
INL Researchers Present Work at the 2022 Molten-Salt Reactor Workshop

- INL is a leading presence in the molten-salt reactor (MSR) community.
  - The MSR Workshop, held on Oct. 11-12, is an annual meeting hosted by Oak Ridge Laboratory, and is one of the largest gatherings for the molten-salt research industry. It is attended by national laboratories, academia, and international colleagues.
- INL researchers presented their work that focused on salt synthesis and purification, corrosion, thermophysical properties, electrochemistry, and design.
  - Dr. William Phillips—“Salt Production and Scale-Up at INL”
  - Dr. Jacob Yingling—“Development of a Thermodynamic Database for Corrosion”
  - Dr. Thomas Fuerst—“Tritium Transport in MSRs”
  - Dr. Toni Karlsson—“Thermophysical Property Measurements & Techniques at INL”

Dr. William Phillips (top, left), Dr. Jacob Yingling (top, right), Dr. Thomas Fuerst (bottom, left), and Dr. Toni Karlsson (bottom right).

INL and Collaborators Develop Inert Anodes for Electrochemical Reduction of Used Nuclear Oxide Fuels

- INL has successfully developed the first monolithic iridium anode for continuous operation at engineering scale for the recovery of transuranics from used uranium oxide fuels.
- Penn State University and University of Nevada-Reno have partnered with INL to develop robust inert anode materials for the electrochemical reduction of used oxide fuels. This work is essential to the recycling of used nuclear fuels and is one of the signature campaigns of the United States Department of Energy.
- Preliminary work performed at INL has also indicated that ruthenium and alloys of platinum group metals have potential application as materials for anode construction.
- The team has recently been awarded with Advanced Research Projects Agency-Energy Optimizing Nuclear Waste and Advanced Reactor Disposal Systems funding to develop new and inexpensive anode materials for electrochemical technologies applied to the production of both nuclear and non-nuclear metallic materials.

Ru anode before (top) and after (bottom) the electrolytic reduction of 200 g of uranium oxide.

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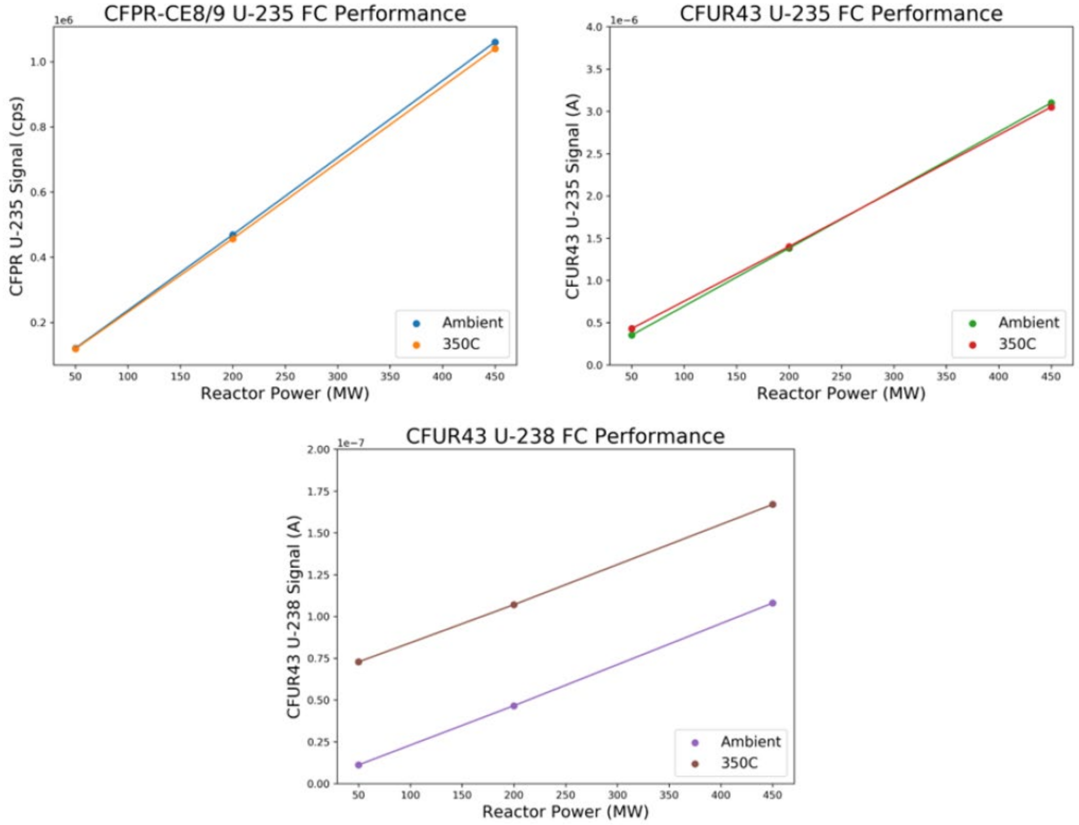
DOE-NE Advanced Sensors and Instrumentation

Neutron Flux measurements Completed with French Alternative Energies and Atomic Energy Commission Researcher

- Three miniature fission chambers were irradiated at the Ohio State University Research Reactor in a movable 6.5-inch dry tube at reactor powers of 50 kW, 200 kW, and 450 kW at ambient temperature and at 350°C.
- Two of the fission chambers are commercial fission chambers—one utilizing highly enriched uranium-235 fissile deposits for thermal neutron detection and the other with highly depleted uranium-238 for fast neutron detection.
- One of the fission chambers was a French Alternative Energies and Atomic Energy Commission (CEA) supplied uranium-235 fission chamber.
- Loic Barbot provided assistance as a visiting researcher from CEA Cadarache during a two-month collaboration at INL.

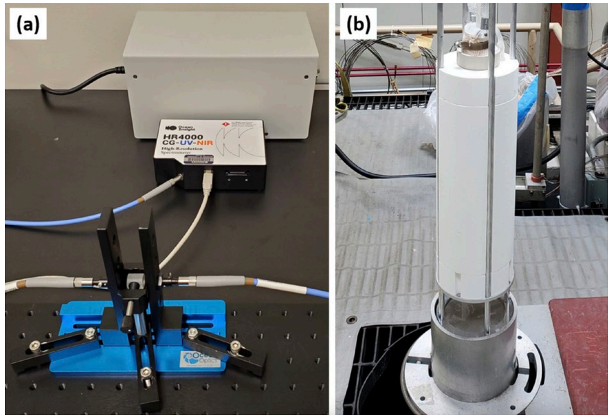


Sensor signals as a function of reactor power for ambient temperature and 350°C.

Nuclear Science User Facilities

Fused Silica and Sapphire Instrumentation Materials Tested for Reactor Safety Enhancements

- Researchers subjected fused silica and sapphire to neutron and gamma irradiation at temperatures from 200–800°C to inform optical material selection. This will help develop fiber optic-based instrumentation in advanced reactor applications.
- The proposed optical instrumentation could detect the degradation of nuclear reactor components, such as the fuel cladding, by analysis of the chemical composition of reactor coolant while the reactor is in operation. Online monitoring of critical reactor components has the potential to reduce the frequency of shutdowns for inspection and significantly enhance the safety and economic performance of power-generating nuclear reactors.
- Three optical material samples (high and low-OH fused silica and sapphire) were tested for transmission degradation in an intense radioactive and thermal environment. The high-OH content fused silica, Heraeus Spectrosil 2000, proved to be the most suitable material at these fluences and temperatures.
- Irradiations and post irradiation examinations (PIE) were performed at the Ohio State University (OSU) Nuclear Reactor Laboratory. PIE of the irradiated samples occurred within an hour of extraction from the OSU pool using a rig specifically constructed for this project. Access to these facilities was provided by a 2019 Consolidated Innovative Nuclear Research award from the Nuclear Science User Facilities.



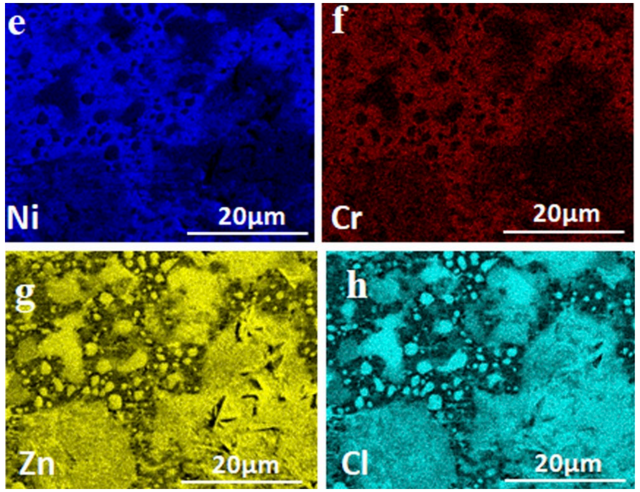
(a) The absorption measurement setup that displays an optical window sample mounted in the holder. (b) The furnace is mounted above the pool dry tube to perform thermal annealing of optical material samples.

Title: Optical Absorption of Fused Silica and Sapphire Exposed to Neutron and Gamma Radiation with Simultaneous Thermal Annealing
Authors: B. W. Morgan, M. Burger, I. Jovanovic (The University of Michigan), M. P. Van Zile (The Ohio State University), C. M. Petrie (Oak Ridge National Laboratory), P. Sabharwall (INL, The University of Michigan)
Journal: Journal of Nuclear Materials
Link: doi.org/ 10.1016/j.jnucmat.2022.153945

Nuclear Science User Facilities

Electrochemical Noise Methodology Enables Molten Salt Evaluations for Energy-Related Industrial Applications

- Molten chloride salts are attractive as heat transfer and energy storage fluids and have been used in concentrating solar power technologies. They have attractive properties such as stability at high operating temperatures, low viscosity and vapor pressure, high heat capacity, and their ability to dissolve many inorganic and organic compounds.
- It is known that nickel-based alloys interact with molten salts at high temperatures, promoting faster corrosion of the structural materials. The corrosion behavior of these materials needs to be understood and monitored before they could be used in a reactor system.
- Researchers studied two model alloy structural materials with the electrochemical noise (ECN) technique in molten chloride salts. This was done at high temperatures utilizing an in-situ monitoring tool to detect localized corrosion. The ECN technique has been proposed for use in nuclear reactors, fuel cycle facilities, and waste storage tanks.
- This study provided more information about the ECN technique and its potential application to molten salt systems. The electrodes were studied using the focused ion beam and scanning electron microscope systems at the Center for Advanced Energy Studies at INL. Facility access was provided through the Nuclear Science User Facilities.



Microscopic images of the elemental mapping for (e) Ni, (f) Cr, (g) Zn, and (h) Cl after study.

Title: Electrochemical noise studies on localized corrosion of Ni and Ni-20Cr in molten $ZnCl_2$
Authors: J. Sure, S. K. Gill, J. F. Wishart, K. Sasaki (Brookhaven National Laboratory), Y. Wang, K. K. Bawane, L. He (INL), P. Halstenberg, D. Shannon (Oak Ridge National Laboratory, University of Tennessee, Knoxville), M. Mahurin (Oak Ridge National Laboratory).
Journal: Electrochimica Acta
Link: doi.org/ 10.1016/j.electacta.2022.141126

Publications

- A. Pikul, M. Szlawska, X. Ding, J. Sznajd, M. Ohashi, D. Kowalska, M. Pasturel, K. Gofryk. 2023. "Competition of magnetocrystalline anisotropy of uranium layers and zigzag chains in UNi0.34Ge2 single crystals." PHYSICAL REVIEW MATERIALS. Vol. 6. https://doi.org/10.1103/PhysRevMaterials.6.104408
- C. Shiau, M. Pena, Y. Li, S. Xiang, C. Sun, M. McMurtrey, L. Shao. 2023. "Micropillar compression of additively manufactured 316L stainless steels after 2 MeV proton irradiation: a comparison study between planar and cross-sectional micropillars." METALS. Vol. 12. https://doi.org/10.3390/met12111843
- E. Worsham, S. Terry. 2023. "Static and dynamic modeling of steam integration for a NuScale small modular reactor and pulp and paper mill coupling for carbon-neutral manufacturing." APPLIED ENERGY. Vol. 325. https://doi.org/10.1016/j.apenergy.2022.119613

Publications, cont.

- G. Beausoleil, L. Capriotti, B. Curnutt, R. Fielding, S. Hayes, D. Wachs. 2023. "FAST irradiations and initial post irradiation examinations-Part I." NUCLEAR ENGINEERING AND TECHNOLOGY. Vol. 54. https://doi.org/10.1016/j.net.2022.07.008
- J. Conrad, A. Lisouskaya, D. Bartels. 2023. "Pulse radiolysis and transient absorption of aqueous Cr(VI) solutions up to 325 degrees C." ACS OMEGA. https://doi.org/10.1021/acsomega.2c04807
- J. Mao, V. Petrov, A. Manera, T. Howard, S. Cetiner. 2023. "On the development of a novel acoustic flowmeter for high-temperature gas-cooled reactors." NUCLEAR TECHNOLOGY. https://doi.org/10.1080/00295450.2022.2133505
- K. Duemmler, M. Woods, T. Karlsson, R. Gakhar, B. Beeler. 2023. "An ab initio molecular dynamics investigation of the thermophysical properties of molten NaCl-MgCl2." JOURNAL OF NUCLEAR MATERIALS. Vol. 570. https://doi.org/10.1016/j.jnucmat.2022.153916

Publications, cont.

- S. Dhulipala, M. Shields, B. Spencer, C. Bolisetti, A. Slaughter, V. Laboure, P. Chakroborty. 2023. "Active learning with multifidelity modeling for efficient rare event simulation." JOURNAL OF COMPUTATIONAL PHYSICS. Vol. 468. https://doi.org/10.48550/arXiv.2106.13790
- T. Yao, D. Murray, X. Liu, D. Salvato, L. Capriotti, T. Pavlov, K. Paaren, F. Xu, M. Benson. 2023. "Transmission electron microscopy study of a high burnup U-10Zr metallic fuel." Journal of Nuclear Materials. Vol. 570. https://doi.org/10.1016/j.jnucmat.2022.153963